Ontology Based Semantic Modeling for Chinese Ancient Architectures

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Figure 1: Ancient architectures in southeast China; the top two photos are taken from Hefang Street in Hangzhou, and the other two are taken from Xitang town, Zhejiang Province.

Abstract

Modeling complex architectures is quite challenging. We introduce a novel intelligent system, which can generate semi-style or semi-structure Chinese ancient architectures automatically. By using an ontology based approach to analyze the styles of different architectures, geometry primitives (e.g. point, line, triangle, etc.) are converted into semantic architecture components (e.g. window, gate, roof, etc.) as knowledge. The following modeling process can be performed at different semantic levels, and it is appealing to users having domain knowledge. This intelligent architecture modeling system has been successfully applied in the digital heritage project for ancient architectures in southeast China.

Introduction

Chinese ancient architectures boast a long history and great achievements. As buildings in ancient China are mostly built by wooden material, it is quite difficult to keep them in good condition through long history period. In our digital heritage project for ancient architectures in southeast China, the original goal is to build geometrical models of endangered architectures through the help of existing modeling softwares. Two good examples are Hefang Street, Figure 1, which used to be the downtown area of the capital of South Song dynasty from 1217 to 1279, and Xitang, a beautiful riverside town, consists of several blocks of residential houses. Although the scale of the above two examples looks pretty small, modeling individual houses manually for several street blocks is still a big burden. It is not only time demanding but also requires deep domain knowledge regarding a variety of complex house styles involved. It should be very beneficial if the modeling process can be accomplished semi-automatically at semantical level by using accumulated domain knowledge extracted from those architectures directly.

To achieve this goal, we try to apply an ontology-based approach on the architectures modeling process. By this way, an end user can accomplish modeling process in a much more natural way, paying more attention to the semantic relations among different components instead of focusing on geometrical details.

The rest of the sections are organized as follows. Section 2 gives a brief introduction to related works on architectures modeling. Section 3 presents our ontology based solution. In this method, Chinese ancient architectures modeling is considered as an ontology design process. It consists of multi-level projection ontology design and its implementation in practice etc. Section 4 gives implementation details of the modeling system. Experiment results and a short discussion are presented in section 5.

Related Work

Generally speaking, there are two primary categories of modeling technologies, i.e. manual modeling and automated modeling.

In manual modeling, users usually adopt commercial modeling softwares(e.g. AutoCAD, 3D studio max, Maya etc.), to design and render desired heritage buildings. Although manual modeling can generate the most accurate and complicated models, it is very time-consuming. A typical manual modeling case was given by ChiuShui Chan *et al.* (Chan, Tong, & Dang 2003). It is used to build the model of traditional Chinese architectures.

The automated modeling can generate models with only several input parameters. Yoav I. H. Parish (Parish & Müller 2001) introduced a stochastic, parametric L-system to generate the geometries for buildings. A set of rules are set up to control the transformation, scaling, extrusion and branching of the buildings' geometry. Another approach is to construct new buildings by combining the basic units of houses, such as roof, wall, window, gate etc. (Birch *et al.* 2001).

Text-to-scene technique (Johansson *et al.* 2005; Coyne & Sproat 2001) is another automated modeling approach. It converts the natural language descriptions to the modeling scenes via the ontology analysis. However, the complexity of the natural language processing limits its applications in practice.

As we can see, most of existing modeling techniques aim at professional modeling experts. In order to take advantage of those systems, it is assumed that users are familiar with the common concepts of solid modeling and computer graphics. However, in reality, for most of actual modeling applications, such as movie production, city planning, etc., users typically only have specific domain knowledge while lack of computer science background.

Ontology Based Semantic Approach

Problem Formulation

Our approach aims to implement an architecture modeling system which is capable of distinguishing different elements and styles among varieties of buildings. Besides, the system should be able to generate numerous semi-structure or semi-style architectures based on the semantic knowledge extracted from existing buildings. An ontology based approach is presented here to achieve the goals.

The general definition of ontology was given by Gruber (T.Gruber 1993). Ontology is typically used as the specification of a representational vocabulary for a shared domain of discourse which may include definitions of classes, relations, functions and other objects. The architecture modeling problem based on ontology can be formalized as follows:

Ontology of the Architectures The ontology of the architecture is a four-tuple, $C =< D, W, R, V >$. Here, *D* presents the domain of architectures, e.g. the Chinese southeast architecture domain; *W* is the domain space, it involves all the instants referred by the domain; *V* is the ontology vocabulary set of the architecture domain; and *R* can be viewed as the relation set established on the vocabulary and the domain knowledge.

In the definition, for any w, $w = F_\rho(V)$, *F* is a function of the domain, $\rho \in R$, then $w \in W$. We indicate *F* as the generalized function.

The modeling process can be described as designing an ontology for Chinese ancient architectures. It can then be used to interpret the styles and structures of the architectures. A proper generalized function *F* to generate specific instants in the same domain also can be derived thereafter.

Reusable Knowledge In practice, there are many knowledge overlaps between different domains. For example, two domains, $C_1 =< D_1, W_1, R_1, V_1 >$ and $C_2 =< D_2, W_2, R_2, V_2 >$, $D_1 \neq D_2$, $W_1 \cap W_2 = \phi$,$R_1 \cap R_2 \neq \phi$,$V_1 \cap V_2 \neq \phi$. In knowledge management, these overlapped relations ($R = R_1 \cap R_2$) can be generalized easily and reused in more domains.

Table 1: The Characteristics of three participants in the architectures modeling

Participant	Vocabulary	Relationship
machine	address, operations, RAM etc.	How to operate the devices etc.
programmer	point, line, polygon etc.	logic for the drawing of lines, polygons etc.
designer	house,window, gate etc.	Organization of the components etc.

In the domain of Chinese ancient architectures, it also contains quite much overlapped knowledge with the domain of modern architectures, such as the combination of different building components. Thus, by carefully differing those knowledge and reusing them can simplify the design of modeling system and apply them to other similar modeling systems.

Scalability To reuse the ontology of Chinese ancient architectures and extend it to other types of architectures, it is important to consider the scalability during the design of ontology. We primarily focus on two ontology expanding conditions formalized as follows:

Condition 1. For the ontology $C =< D, W, R, V >$, it can be revised as a new ontology, $C' =< D', W', R', V >$, by changing the knowledge set *R*.

IF $R' = R \cup R_0$, $R_0 \neq \phi$ and $R \neq R_0$, then $W \subset W'$.

IF $R' = R - R_0$, $R_0 \neq \phi$ and $R_0 \subset R$, then $W' \subset W$.

Condition 2. For the ontology $C =< D, W, R, V >$, assume the vocabulary transforming function *G*, $G : V \rightarrow V'$, then the ontology *C* can be revised as a new ontology, $C' =< D', W', R, V' >$.

In the design of the ontology for Chinese ancient architectures, the above two conditions are quite representative. Firstly, since the domain of Chinese ancient architectures can be considered as a specialized domain of normal architectures, we can reuse the knowledge in the normal architectures domain and add specialized knowledge just like in the condition 1. Secondly, since architectures are typically similar in combination and topology, we can use the same knowledge of combination and topology as described in condition 2, while using different vocabularies for different styles.

Ontology Design

Multi-level Projection Ontology Design Approach There are three participants, i.e. machine, programmer, and architecture designer involved in ontology design. Since they have different domain knowledge, they need different ontologies illustrated in Table 1 at different levels. Three participants are all represented with the same domain concepts of architecture models, however, they have their own vocabularies and relationships.

Since ontology used is dependent on the type of participant, it is necessary to have a method unifying their ontology. We adopt a multi-level projection ontology design approach to represent their unified ontology at the semantic level. Here the semantic level processing is different from other natural language based analysis systems, e.g. the semantic translation system (Navigli, Velardi, & Gangemi 2003). In our approach, the vocabulary set is established at the semantic level, same as the architecture designers' ontology, while the control logic of these vocabularies are formal. Why not using natural language just like the text-to-scene systems (Johansson *et al.* 2005; Coyne & Sproat 2001)? Using natural language to describe the complex style and topology of architectures, especially the Chinese ancient styles shown in Figure 1, is really nightmare to the designers and programmers, because of the intricate geometrical shapes and textures in architectures.

The multi-level projection ontology design method, which is similar to the collaborative ontology design approach (Holsapple & Joshi 2002), is implemented as follows:

Step 1: Describe each participant's ontology in the same domain detailedly. At this step, the ontology from machine is easier to represent compared with the other two. It only needs to know where to store the modeling data, and what value the data should be in the storage. While architecture designers' ontology design is more difficult, there are quite many semantic components and temporal/ spatial knowledge about those components. The designers should present their semantic terms (components or vocabularies of the Chinese ancient architectures) as detailedly as possible, including the geometry shape, characteristics, function of the components, and the style of the texture, etc. Then ontology design at programmer's level can focus on the conversion between the other two.

Step 2: Reduce the objections of participants. In this step, the reduction can be applied to find the core concepts and terms about the architectures among all the participants.

Step 3: Find the knowledge overlap of their ontologies by projecting them at the the same level. This step processes the ontology synthesis problem. Although those threes all describe the same Chinese ancient architectures domain, their ontologies lie on different implementation levels. In the problem of Chinese ancient architectures modeling, we project the designers' semantic terms and their control relationships into other two levels, and induce their representations in the programmer's ontology and machine's ontology respectively.

Step 4: Make consensus at the semantic level iteratively. To design a consistent and consolidate Chinese architectures ontology, even though the previous steps try to resolve the inconsistent conditions, there still will be some inconsistent or non-unified terms or relationships, and even the concepts cannot cover all the instants in the domain. So we have to revise the previous ontology iteratively until the consensus reached. As the modeling system is aimed to the semantic terms, once the conflicts occur, the ontology will be revised to fit the ontology of designers, then the consensus is maintained at the semantic level.

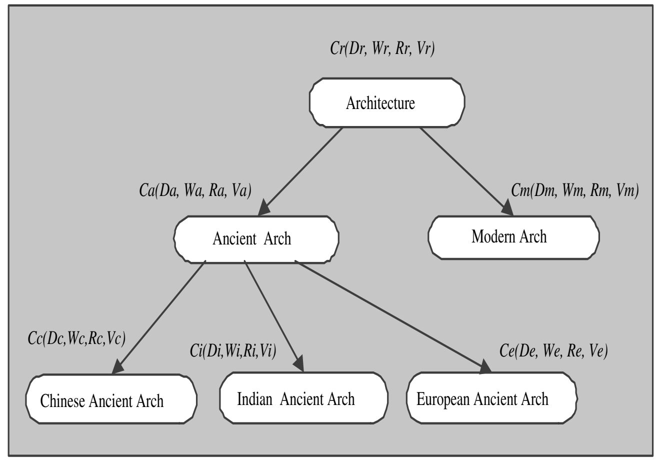

Figure 2: Domain concept tree of the Chinese ancient architectures.

Hierarchical Ontology of the Chinese Ancient Architectures Our ontology based design process for Chinese ancient architectures is carried out according to the hierarchical architectures category as illustrated in Figure 2. As the direct design for the special style of architectures may be quite difficult, we begin from the root of the domain tree. That is, firstly, we only consider the core domain ontology of all the architectures, and expand it to the specific domain ontology. The children specific domain ontologies can be generated by reusing the domain knowledge of the parent node in the tree, and those children with the same parent can transform each other by implementing the scalability of the ontology, as given in condition 1 and condition 2.

For example, the ontology of Chinese ancient architectures ontology $C_c(D_c, W_c, R_c, V_c)$ is a child of root architectures ontology $C_r(D_r, W_r, R_r, V_r)$, then we have $R_r \subset R_c$,$W_r \subset W_c$, and $V_r \subset V_c$. Obviously, Chinese ancient architectures and general architectures have the same vocabularies, such as window, gate, and wall, etc. The combination relationships among those vocabularies are also partly equal. In the domain tree, if we want to design the ontology of Indian ancient architectures or European ancient architectures, we only need to make several revisions from the ontology of Chinese ancient architectures.

Ontology Implementation The ontology implementation means how to apply the defined vocabularies and knowledge to real problems. In the other way, it can be viewed as the process of demonstrating the practical phenomena via integrating vocabularies and knowledge. In our Chinese ancient architecture ontology, the vocabularies almost equate to the natural component categories in the architectonics. And the knowledge relationships in our ontology consist of three parts, the components properties, operations, and spatial relationships. As the vocabularies and relationships are semantic, the programmers will transfer them into the ontology that can be recognized by the machines via the multi-level projection approach.

Generally speaking, any type of the architectures is uni-

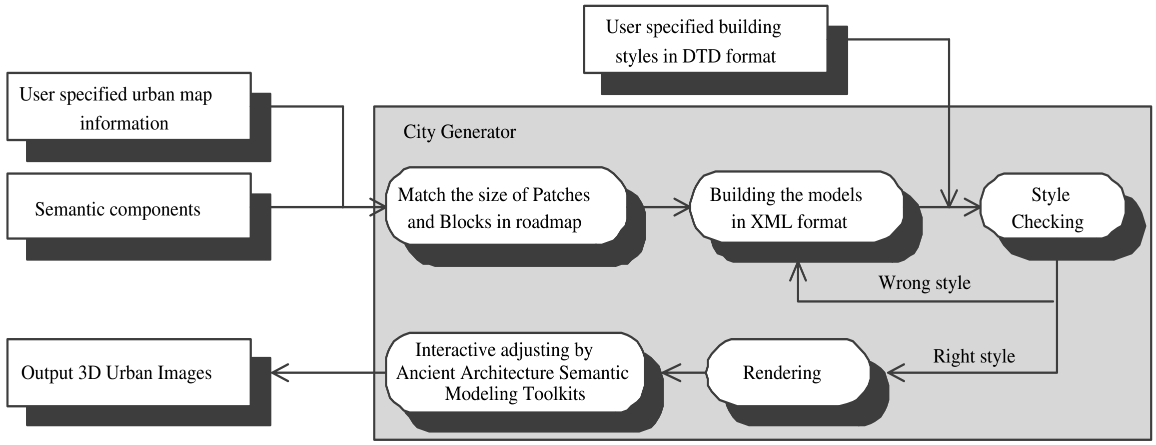

Figure 3: Implementation diagram of the semantic modeling system.

fied by its style and structure. The architecture designers' experiences show that the styles of the architectures are more concerned with the detailed component properties, e.g. the shape of the components, textures, decorations, while the structures of the architectures are relatively consolidated, for example, Chinese ancient architectures in southeast can be induced as six typical combination patterns (Liu *et al.* 2005).

Then the task of modeling the semi-style and semi-structure of Chinese ancient architectures will focus on descriptions of detailed components and their spatial relationships respectively.

Design and Implementation of the Semantic Modeling System

The detailed system diagram of the semantic modeling process is shown in Figure 3. There are three input parameters for the city generator, the urban maps, the semantic components and the descriptions for styles and structures of buildings. That means users can change these input parameters for the specific modeling targets, which results in a better scalability of the overall modeling system.

In the first step, users are supposed to specify the urban map for generation, and the semantic architecture components are also specified as the input data. Then the city generator module will match the roadmap with the buildings' block size and patch size automatically and generate the corresponding models in the description format. The style checking is processed by the city generator with the guidance of user specified building style format (DTD), and only the right style models can be forwarded to the next step for rending. Before outputting the final model images, the city generator also provides an interactive toolkit (AASMT) to adjust the models.

The stage of *Style Checking* in Figure 3 contains a default verifier. The verifier in our modeling system is based on the roadmap and the styles of buildings. The first rule is that those houses should be positioned beside the road and not on the road, so the road could be regarded as the disjunction of the houses. The styles of the houses are decided by their components and the combination of them. And the styles of components can be dealt with easily, because they are relatively finite. In fact, arranging these components is most difficult to ensure the same styles for the whole house. The house is established by the production of the recursive grammar, then each house can be individually written as a sequence of the grammar terms. By this way, the style ensuring work will be considered as the term grammar checking, the verifying system only needs to check the sequences generated by the production engine and to match the sequences with the predefined style term sequences.

Ontology Vocabularies and Semantic Components

The key problem in semantic modeling is the definition of semantic portions. The vernacular houses in southeast China have similar styles in the components, so the houses can be disassembled into several reusable components, each special house could be regarded as the assembly of these components. In our method, these components constitute the terms of the recursive production controller, which controls the houses' generation. While several components of the vernacular houses, such as conjunct walls, roofs and gate-window walls, have complex constructions and different styles compared with the other architectures.

Based on the general classification of architectonics, the ontology vocabularies of Chinese ancient architectures can be described as an object-oriented hierarchical framework: the city (or urban) can be divided into block, street, zone, road etc. The house can be divided into several portions including roof, base and wall etc., and each of these portions can be subdivided into some sub-portions. Each portion is interpreted through a series of attributes, such as its boundary area, sub-portions, basic geometry, texture styles etc.

Domain Knowledge, Topology and Combination of Components

In fact, the representation of the semantic components of vernacular house only finishes the first step of the semantic modeling. Another important step for semantic modeling

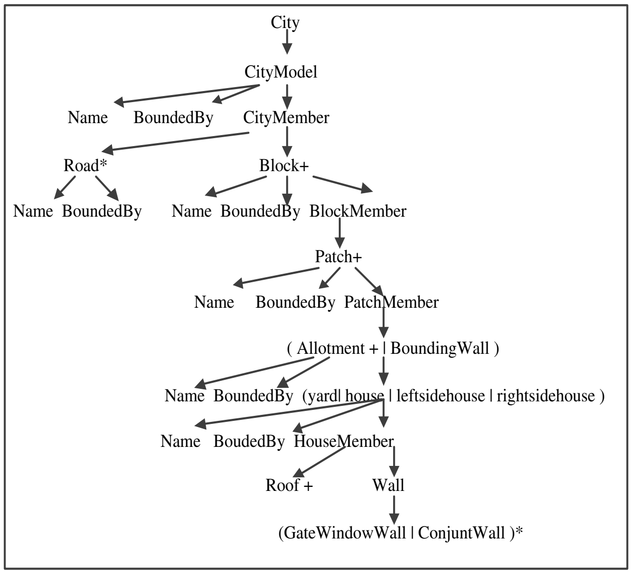

Figure 4: A DTD description for the semantic modeling.

is dealing with the domain knowledge of the architectures. Here we focus on the spatial relationships which include topology control and combination control between those semantic components.

In some sense, the semantic modeling system can be viewed as a kind of language application system. The semantic components are the basic vocabularies. And the semantic controls on topology and combination are the language grammars. The right vocabularies assembling randomly cannot present the right meaning, only those right vocabularies assembling under the grammars can present the right meaning. So the semantic controls on topology and combination are quite important to present and model the vernacular houses' styles and structures correctly.

The topology control mainly concerns the plane position relationships among the houses and walls. And the combination control mainly concerns the compounding relationships among all the semantic components defined in the previous section.

Obviously, the description of grammars is more difficult than the description of vocabularies. In our approach, XML based description and DTD based verifying technique have been adopted (Liu *et al.* 2005).

Topology As the previous section mentioned, the topologies of the Chinese ancient architectures are the two dimensional position problems. In our approach, there are several terms, i.e., road, block, patch, allotment etc. concerning with those topology relationships. We mainly deal with the two dimensional shapes when calculating topology relationships.

As the Figure 3 shows, the topology processing begins with the urban map, however, there is quite little information in it, only the road-lines and wide blank areas are crossed by the road-lines. In the other way, the modeling system is supposed to support area dispatching automatically. Then the modeling system will compare the area of semantic components with the wide blank areas in map, auto-divide the blank areas along the road-lines and fit their sizes with the semantic components of architectures.

When depositing houses in the divided areas, there are several rules regarded as the domain knowledge for the house depositing. For example, there is a default rule that the main gates of the house will face to the south, which is a tradition of Chinese to obtain more sunshine.

Another special component in our semantic modeling system is the road in southeast China. Normally the spare space outside the patches and blocks in the semantic components can all be viewed as the roads. However, this condition is not always true for all the cases, sometimes, there may be some other additional components that lie on the spare space. And the styles of different roads in patches may be varied. So the roads should be distinguished and marked individually.

Combination Normally, other auto-modeling systems (Wonka *et al.* 2003) always focus on how to generate the models fast. While our system tries to resolve the following two problems at the ontology domain knowledge level, i.e., how to combine the semantic components and what kind of combination is desirable?

How to combine the semantic components? In our approach, we present a recursive grammar engine to drive the architecture modeling system. The terms in the production rules are constituted of those components defined at semantic level. In this recursive system, the texture has become one kind of terms that are controlled by the production system. These productions can divide the whole city into basic elements, such as houses, patches, walls, and textures etc, which can increase the modeling efficiency greatly. However, those recursive grammar systems also have their common weakness, that it is hard to control their generation results (Actually we have to design a verifying system to ensure and check the generation results in our previous system). So we improve the rule recursive grammar system by adding the ratio factor to each of these rules. Then the generation system controls the modeling process, it has to obey both the components' ratios and the components' combination relationships, which are controlled by the recursive rules.

What kind of combination is desirable? The grammar based generation approach is difficult to control, it is more suitable for the automated modeling than verifying whether the architecture style is rational. The simple constraint rules cannot describe all the styles of complex ancient architectures. On the other hand, once the artists illustrate the ancient architecture by the rule terms directly, how can we know the style of the architecture obeys the constraint rules in those recursive systems? So a more expressive technology for the semantic modeling is desired.

As the topology and the semantic components are all described by the XML, the DTD has been used as a verifying protocol. Figure 4 gives a DTD verifying grammar for the components' combination. In Figure 4 the "BoundedBy" is the minimal contained box of the components, "+" means the components can be duplicated one or more times, "*"

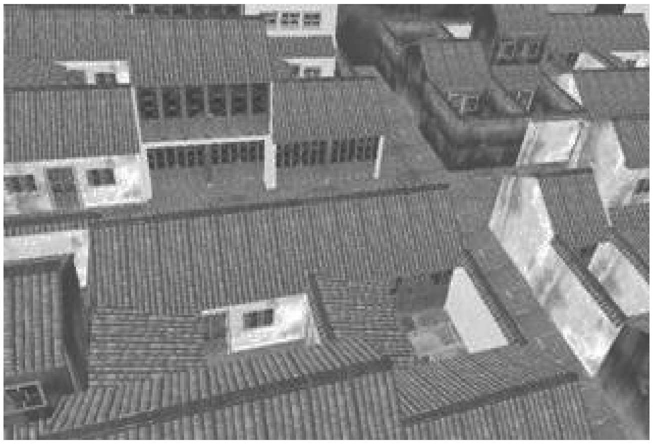

Figure 5: Overview of the Chinese ancient architectures.

means the components can be duplicated zero or multiple times, "?" means the components can be duplicated zero or one time, and "|" means the components are optional. And the arrow means the component at the beginning of the arrow contains those components at its end.

In our modeling system, the control rules can be expressed by XML and DTD as well. The urban models might be multi-instances, but the style of the models is the same one. So the DTD supported by the XML technique can provide a flexible control policy to regulate the whole style and integrity of models.

Experiment Results and Discussions

Given limited space, we can only show a small sample of the results here. Figure 5 shows the visualization results of large numbers of semi-structure and semi-style Chinese ancient architectures. In this Figure, we generate about 120 buildings by our automated modeling system in no less than 10 seconds. Every buildings in Figure 5 are all taken on the similar styles and structures. More examples can be found on our project web site (Liu *et al.* 2005).

This paper has presented an ontology based approach to resolve the problem of modeling semi-structure and semi-style Chinese ancient architectures. Using the multi-level projection ontology design approach, we design a hierarchical architectures ontology, which can reuse the domain knowledge and enable systematic semantic modeling at multiple levels.

There are several possible directions for future work. First, we would focus on the machine auto-generation of more specific styles of the architectures or some modern architectures by expanding or revising the existed Chinese ancient architectures ontology. Second, using the ontology methods to analyze the architectures styles and structures in further step, trying to define the formal concepts of the architectures styles and structures, and implement them in practice. Finally, data mining algorithms can be used to generate modeling data structures and extract useful knowledge to make our system more effective.

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