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Ontology design with a granular approach

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ABSTRACT

Ontology design for complex applications is quite a challenge. The quality of an ontology is highly dependent upon the capabilities of designers, and the collaborative design process is hampered by the difficulty of balancing the viewpoints of different designers. In this paper, we present a granular view of ontology: ontologies are granular, ontologies are granular approximations of conceptualizations and conceptual-relation granules of an ontology are ordered tuples. We then propose a corresponding granular ontology design approach. In our granular ontology design approach, the unified granular cognition level and hierarchies of sub-concepts are initialized before ontological terms are designed in detail, which reduces the subjective effects of the capabilities of designers. Our approach also introduces the idea of optimization to choose an optimal subset, which can best approximate the real concept domain, from the knowledge rule set presented by different domain experts. The optimal subset is chosen on the basis of the principle of granular ontology knowledge structure.

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1. Introduction

Ontology design is an important and essential technique in the creation of knowledge-based applications (Bittner & Smith, 2003; Guarino & Welty, 2002; Liu, Xu, Zhang, & Pan, 2008). Ontology design has been successfully applied in many areas, such as decomposition of information systems (Wand & Weber, 1990), model checking and semantic reasoning (DiPietro, Pagliarecci, & Spalazzi, 2012), and inconsistent detection in complex scene modeling (Liu, Zhang, Jiang, & Zhao, 2012a, 2012b). However, ontology design is still a great challenge for many knowledge-based applications, especially when many complex concepts with fuzzy overlap are involved with the target objects.

Generally speaking, there are two challenges in the designing of an ontology. The first one is the subjective bias in ontology design. It is well known that different designers produce different ontologies for the same target concepts, and the qualities of those ontologies rely greatly on the subjective cognition levels of designers. We call the effect caused by the capabilities of designers *subjective bias*. Currently, few works focus on removing or even reducing subjective bias via objective ontology design approaches. The second challenge is how to enable experts to design an ontology collaboratively. In many cases of collaborative design, the crucial problem becomes how to balance the viewpoints of different experts. Thus a general ontology approach that can highlight experts' conflicts intuitively will simplify the ontology design greatly.

In this paper, we present three granular viewpoints on ontology design: that an ontology is granular, that an ontology is a granular approximation of a conceptualization, and that the conceptual relationship between granules of an ontology are ordered tuples. Based on the three basic granular viewpoints of ontology, we focus on a general design approach for ontology. Our approach can help address the vagueness, fuzzy and overlapped concepts, and potential need for collaboration between different domain experts that make ontology design a challenge.

In our granular ontology design approach, the unified granular cognition level and hierarchies of sub-concepts are initialized before the detailed designing of ontology terms, which reduces the subjective bias in ontology design. Our approach also introduces the idea of optimization to choose an optimal subset, which can best approximate the real concept domain, from the knowledge rule set presented by different domain experts. We present our approach and demonstrate it with an ontology design process for ancient Chinese architecture (Liu, Jiang, & Huang, 2010; Liu et al., 2012a, 2012b), which contains complex sub-concepts and

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also requires the design input of multiple experts working collaboratively.

2. General ontology design process

The use of "ontology" in a design context was originally introduced by Gruber (Gruber, 1993), who described ontology as an explicit specification of a conceptualization—an abstract, simplified view of the "things" in a designer's viewpoints (Sure Staab et al., 2004). A general formal definition of an ontology is a quads $C =< D, W, \Re, V >$, where D is the conceptual domain; V is a set of related entities or sub-concepts involved in the ontology conceptualization C, and W is a set of the conceptual instances. The ontology contains possible states of affairs that correspond to mutual arrangements of the above entities, and $\Re$ is a set of conceptual relations (also called a knowledge set). The conceptual relations are established between the entities and a specific domain's instance in W, the conceptual relations may be referred as a n-ary function $\Re^n : W \to 2^{V^n}$. For example, in our architecture modeling case (Liu et al., 2008), the concept of southeast ancient Chinese architecture C may include four sets:

(1) the hierarchical domain structure set D for the target concept;
(2) the entity set V, which contains the basic architecture components, such as gate, window, and roof;
(3) the instance set W, which contains all the possible instances of the southeast ancient Chinese architecture domain, each instance of which is formed by the components in V, an example is shown in Fig. 1;
(4) the knowledge set $\Re$, which contains all the "correct" combination and topology relations of the basic components.

Thus the design of an ontology can be summarized as the process by which a group of experts clarifies a set of entities V and conceptual relations $\Re$ with respect to a conceptualization C. An obvious way to clarify the set of conceptual relations is to enumerate all the mappings between the set W and V; however, this is impossible when the W is infinite, so designers may introduce a rule system R[1] based on first-order logic (FOL) to represent how the basic components V can constitute the instances in W. A typical example is the grammar used in procedural modeling of architecture (Liu et al., 2008; Müller, Wonka, Haegler, Ulmer, & Van Gool, 2006), for which grammar rules[2] such as the following present the combination sequence of each component in V:

$$r_1(roof ::= roof\_center|roof\_body)$$

$$r_2(window\_wall ::= window\_wall|shop\_wall|column)$$

$$r_3(window\_wall ::= shop\_wall|base|shop\_wall|column)$$

$$r_4(house :: = house|roof|window\_wall|shop\_wall|window\_wall|shop\_wall)$$

Here the terms on the left are internodes and the terms on the right that do not appear on the left are terminal-nodes. An ontology such as this one gives a machine to generate house instances by replacing the internodes with the right parts according to the corresponding rules once or multiple times. For example, with the rules above, a combination sequence for an instance of the house might be:

$$house = roof\_center, roof\_body, shop\_wall, column, shop\_wall, shop\_wall, column, shop\_wall, column, shop\_wall$$

Unfortunately, the refinement of knowledge rules from complex phenomena is a challenge, especially when the conceptual relations of those "things" that need to be conceptualized are hard to describe in a way that is understandable to humans.

Theoretically, the conceptual relations in an ontology should be complete, correct, clear and concise. However, ontologies are created by humans and bias is inevitably introduced, especially when experts from difference domains working on the ontology. The quality of an ontology relies greatly on the experience and skills of the designers, yet to the best of our knowledge, there is not yet a stable data model or objective design pattern for creating an ontology under complex conditions.

In the following article, we present a novel granular ontology design approach, which is based on our three granular views of ontology. In our granular approach, we try to establish a general ontology design framework that is accurate, collaborative, efficient, objective (or at least less subjective than standard ontologies), and appreciable.

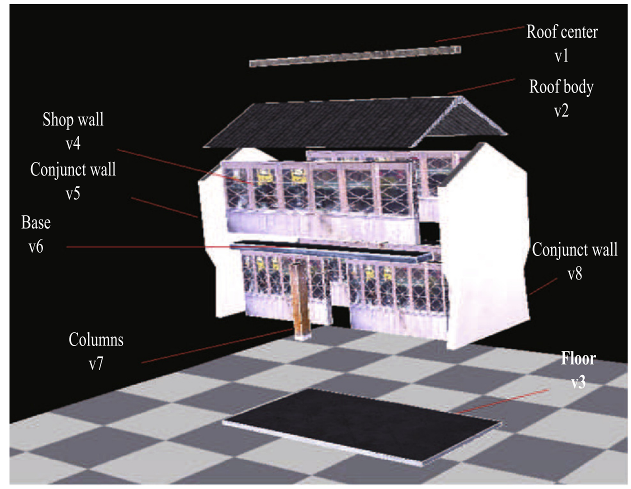

Fig. 1. An example of the architecture instance, formed by many basic components, $v_1, \ldots, v_8$, the instance can be represented as $w = [[v_1]Tv_2]T[[v_5]L[[v_4]Tv_6]T[v_4v_7v_4]D]F[v_8]R[[[v_4]Tv_6]T[v_4v_7v_4]D]B]D$. Here $[v_1]Tv_2$ means v_1 locates top of v_2, similarly, D refers down of, L refers left of, R refers right of, F refers front of, B refers back of, then the house can be regarded as a sequence of the basic components.

3. Granular views on ontology

Our granular views are based on the fact that knowledge tends to be vague and the associated data is often incomplete when trying to find new sub-concepts based on data linked to an ontology (Keet, 2010a, 2010b). Our approach employs a rough methodology that considers the interior, exterior and boundaries of the knowledge in an ontology and is similar to the approach of Calegari (Calegari & Ciucci, 2010). According to our methodology, we construct a specific granular view of an ontology.

3.1. Ontologies are granular

In information science, an ontology can be regarded as an artifact projection (or representation) of a real-world concept based on

[1] The rules are also referred to as the knowledge set R in the ontology, although they are an approximation of $\Re$ in engineering practice.
[2] In a real case, there would also be spatial control terms similar to Fig. 1 among the components.

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