Essentialized Conceptual Structures in Ontology Modeling

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Psychology and cognitive science show that human concepts possess particular structures (conceptual structures). However, in process of ontology modeling information concerning the structure of human concepts is lost. In ontologies concepts are typically represented as undifferentiated clusters of necessary (and sufficient) conditions. The lack of representation of conceptual structure may cause ontologies to be inadequate and may limit their usability. We present an attempt to bring ontology modeling closer to theories of conceptual structures, in particular to psychological essentialism. A metaontology is developed to support representation of conceptual structure, in particular the distinction between essential and merely necessary conditions.

1 Introduction and Motivation

Ontology modeling (OM) is a process of developing a domain model (an ontology) upon, not formalized or formalized only partially, expert's knowledge. Thus, in order to enable machine processing of ontologies, knowledge must be formalized. However, knowledge, when formalized, may be accidentally changed or deformed; in particular cognitive aspects of knowledge are lost in process of OM.

Much work has been devoted to support ontological/philosophical correctness of knowledge modeling, inter alia Brachman's analysis of *is_a* [4]; Woods' analysis of subsumption [17] and the role of links in semantic networks [16]; Wand's work devoted to the notion of relationship [15]; a metaontology of OntoClean for building ontologically correct taxonomies developed by Guarino and Welty [10].

In contrast to the above our motivation is not to clean ontologies from philosophically incorrect usages of ontological constructs. Instead, we aim to enable cognitive adequacy of ontologies. By a cognitively adequate ontology we mean an ontology, in which the structure of ontological categories resembles the structure of concepts in users/experts heads. Cognitive adequacy is relevant in modeling, since cognitively inadequate ontologies, and models in general, have a limited usability for human users [18]. Moreover an explicit representation of conceptual structures allows identifying subtle differences in meaning of concepts, and thus makes ontologies more precise.

Our second motivation is to make ontological concepts more comprehensive for human users. It seems that formal definitions of ontological concepts are hardly comprehensible for human users. Explicit representation of conceptual structure of essentialized concepts permits to select essential information from the body of concept specification and reveals explanatory dependencies in structure of categories.

Two assumptions underlie our approach. The first is the assumption of psychological essentialism, according to which concepts are represented by humans not as clusters of undifferentiated necessary (and sufficient) conditions, but they have more complex structure, organized around essential properties. The second assumption concerns the notion of *essence*, which is understood not in a modal sense as a necessary property but as an explanation of nonessential characteristics of a category.

To represent conceptual structure we have developed a metaontology introduced in the next section. The metaontology provides means to represent the distinction between *essential* and *peculiar* characteristics and their explanatory interdependence. Those notions are introduced in section 3 and illustrated with an example in section 4. In sections 5 and 6 related works, conclusions and future work are presented.

2 Metaontology

2.1 Scope and Purpose of Metaontology

We introduce a meta-ontological framework for representing conceptual structure in ontologies. The framework is intended to be a metaontology, which can be understood as an ontology devoted to ontologies. Ontology is defined as an explicit specification of a conceptualization [8] or as an explicit, partial account of a conceptualization [9]. Thus, metaontology may be understood as an explicit, partial specification of ontology. Our metaontology is partial, since we do not aim to provide a full specification of ontologies, but only to represent a structure of ontological concepts. Secondly, it is partial, since it does not include all aspects of conceptual structure but it is restricted only to *essence* and related notions.

2.2 Common Ontology Pattern

Typically, ontologies are considered as structures of concepts, relations, functions, axioms and instances [8] where relations, functions and axioms define concepts by necessary (and sufficient) conditions. That general paradigm is adopted by methodologies of ontology development (see for overview [6]) and by ontology representation formalisms. For example, in the Web Ontology Language (OWL) and in the underlying description logics (DL) concepts are defined by use of *inclusions* and *equalities* [2]. An analogous pattern is adopted in modeling paradigms used in software engineering. For example, in the Unified Modeling Language [13] classes, corresponding to ontological concepts, are defined by means of attributes, methods and associations, which can be understood as necessary conditions for class membership.

2.3 Cognitive Ontology Pattern

Since our purpose is to focus on conceptual structures we take a different perspective on ontologies than in the pattern sketched above. We define ontology as follows:

Def. 1. Ontology $O = (Cat, Char, char, cat\text{-}str)$ consists of a set *Cat* of categories, a set *Char* of characteristics, a characterizing relation $char \subset Cat \times Char$, such that *char* assigns to each category *c* a characteristic *ch*, which characterizes it, and a function $cat\text{-}str: Cat \times Char \rightarrow Cat \times Char$, which depicts structure of a category by assigning to its characteristic some other characteristic of that or other category.

In this sense, ontology is a structure of characterized categories, where categories correspond in general to mental concepts, whose meaning is revealed by characteristics. By a category we understand each element of an ontology that is characterized - each that has an explicit specification. In this sense the notion of category is more general than the notion of concept in the pattern discussed in the previous subsection. The set of categories is not disjoint with the set of relations, functions and individuals, since all of them may be characterized by some characteristic and thus all of them are meaningful elements of ontology.

A characteristic is an explicit specification of a category; it is what is said about a category. Characteristics are assigned to categories by a binary characterizing relation, *char(ch,c)* where characteristic *ch*, *Char(ch)*, characterizes category *c*, *Cat(c)*. One characteristic may characterize many categories and each category may be characterized by one or many characteristics.

The assumption taken is that not all characteristics of a category have the same status. Therefore categories are not mere clusters of undifferentiated characteristics, but rather they have an internal structure. To represent a category's structure we use a category structure relation $cat\text{-}str(c_1,ch_1,c_2,ch_2)$, where $Char(ch_1)$ and $Char(ch_2)$ are characteristics of respectively $Cat(c_1)$ and $Cat(c_2)$.

Characteristics ought to be understood as axioms, or meaningful parts of axioms. In UML, attributes, methods and associations, defining UML class should be taken as characteristics. The notion of characteristic is intended to collect under one umbrella various definitional constructs, like UML association and attribute, DL number and value restrictions, subsumption and others.

3 Conceptual Structure: Essential Characteristics

In modeling formalisms categories are represented as clusters of undifferentiated characteristics, which means that all characteristics of a category have equal definitional status. For example none of the characteristics composing DL axioms or none of the constructs defining UML class has a distinguished status. However, humans do not represent all concepts as undifferentiated clusters of mere necessary (or necessary and sufficient) conditions but rather human concepts have intra-structure (see for overview [11]). We consider one of the conceptual structures, namely this postulated by psychological essentialism.

3.1 Psychological Essentialism

According to the psychological essentialism concepts are not represented by humans as undifferentiated clusters of properties. Instead surface properties are considered as caused and constrained by deeper – essential features [1]. Psychological essentialism states that people act as if concepts have some “essential”, deep properties that are both criteria for concept membership and responsible (preferably in a causal sense) for other “surface” features of concepts [12]. We leave aside the argument of the deep character of essence, skipped also in some forms of psychological essentialism [3], and concentrate on the causal and explanatory character of essence.

3.2 Essence as Explanation

Since essence is crucial for category membership, the question arises - “what is essence?”. One possible answer is given by modal essentialism, where as essential are identified necessary characteristics. However this solution seems to be too general since not all necessary characteristics are essential, for example a characteristic of *being a member of a singleton Socrates*, although necessary for *Socrates*, should not be considered as essential [7]. Rather, we say that the set of essential characteristics is a subset of a set of necessary characteristics of a given category. Nonessential necessary characteristics we call *peculiar* characteristics.

We understand essence as such a necessary characteristic of a category that has a prior status in comparison to remaining category’s necessary characteristics. To denote necessary characteristic *ch* of category *c* we use a binary relation *nec-char(c,ch)*, which is a subrelation of relation *char(c,ch)*. Then, we introduce two sub-relations of *nec-char(c,ch)*: essential characterization *ess(c,ch)*, and peculiar characterization *pec(c,ch)*[1]. In the first case *ch* is an essential characteristic of category *c*, in the second *ch* is a peculiar characteristic of *c*. The left-hand side of figure 1 depicts the complete taxonomy of characterizing relations and the right-hand side the complete taxonomy of *cat-str* relations.

The priority of essence over mere necessary characteristics is founded on relation of explanation. In this sense, essence is an explanation of some or all of characteristics of a category:

Def. 2. A necessary characteristic *ch* of a category *c*, *nec-char(c,ch)*, essentially characterizes *c* iff *ch* explains at least one of remaining necessary characteristics of *c*, and is not itself explained by any other necessary characteristics of *c*. A characteristic *ch* essentially characterizing a category *c*, we call an essence of *c* and denote it *ess(c,ch)*.

We introduce explanation relation, *ex(c,ch,c’,ch’)*, as a subrelation of the relation depicting category structure *cat-str(c,ch,c’,ch’)*, with the meaning that a characteristic *ch* of a category *c* explains characteristic *ch’* of category *c’*. A characteristic *ch* is an explanation of *ch’* if *ch* provides an answer for a why-question concerning *ch’*.

Preliminary, we consider two types of explanation: functional explanation *f-ex(c,ch,c’,ch’)* and causal explanation *c-ex(c,ch,c’,ch’)*. Roughly speaking causal explanation of *x* is such that provides a cause of *x*, while functional explanation provides a function or purpose of *x*. Both types of explanation are common in folk theories as well as in science [14].

[1] Not a characteristic as such is necessary, essential or peculiar, but a characteristic in context of a category it characterizes. Thus to be precise one should say that a characteristic characterizes essentially a category, not that a characteristic is essential. However, to simplify the language, in the current paper we use also the second form as an abbreviation of the first.

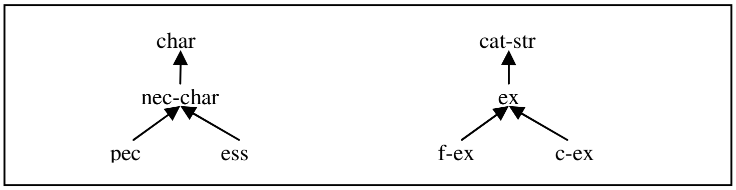

Fig. 1. The left hand-side presents the taxonomy of characterizing relations. The right-hand side illustrates the taxonomy of category structure relations.

4 Example

Let us now illustrate the introduced notions applied to defining categories in ontologies. Consider the following two toy-categories h_1 (`Heart`$_1$) and h_2 (`Heart`$_2$) defined as follows in DL:

`Heart`$_1$ `≡ ∀locatedIn.Chest ⊓ ∀pumps.Blood ⊓ =4hasPart.Cavity`
`Heart`$_2$ `≡ ∀locatedIn.Chest ⊓ ∀pumps.Blood ⊓ =4hasPart.Cavity`

From the above we may conclude that extensionally and intensionally h_1 and h_2 are equal, since they have the same set of referents and share the same characteristics – *is located in chest; pumps blood; has four cavities* respectively denoted by ch_1, ch_2 and $ch_{3.}$ We will now demonstrate that although categories are extensionally and intensionally equal they may nontrivially differ, since their internal structures may differ.

For a functional biologist the function of heart serves as an explanation of its structure and location. For her it is essential for heart that it pumps blood - because of its function heart is located in chest and has a particular structure. Thus on the metalevel the structure of a category h_1 may be represented as follows (see figure 2 for graphical representation): $nec\text{-}char(h_1,ch_1) \wedge nec\text{-}char(h_1,ch_2) \wedge nec\text{-}char(h_1,ch_3) \wedge$
$f\text{-}ex(h_1,ch_1,h_1,ch_2) \wedge f\text{-}ex(h_1,ch_1,h_1,ch_3) \rightarrow ess(h_1,ch_1) \wedge pec(h_1,ch_2) \wedge pec(h_1,ch_3)$.

For a nonfunctional biologist the function is not an explanation of the remaining heart's features. The role of such an explanation is played by, for example, an additional characteristic concerning the structure of organism's DNA, denoted by ch_4 - the structure of DNA could explains why heart has the given characteristics.

Thus, the characteristic ch_4 characterizing *organism o* provides a causal explanation of characteristics ch_1, ch_2 and $ch_{3.}$. The internal structure of category h_2 is as follows: $nec\text{-}char(h_2,ch_1) \wedge nec\text{-}char(h_2,ch_2) \wedge nec\text{-}char(h_2,ch_3) \wedge c\text{-}ex(o,ch_4,h_2,ch_1) \wedge$
$c\text{-}ex(o,ch_4,h_2,ch_2) \wedge ec\text{-}ex(o,ch_4,h_2,ch_3) \rightarrow pec(h_2,ch_1) \wedge pec(h_2,ch_2) \wedge pec(h_2,ch_3)$

Although ch_4 explains all of the characteristics of *heart*$_2$, in accordance with def. 2, it is not considered its essence, since it does not characterize *heart*$_2$ but *organism, char(o,ch*$_4$*)*. Thus, we say that ch_1, ch_2 and ch_3 are peculiar characteristics of *heart*$_2$ and ch_4 provides an external causal explanation of *heart*$_2$.

We see that the structures of the categories h_1 and h_2 are different and the categories, although intensionally and extensionally equal, differ on the metalevel.

The above example shows that representation of conceptual structure can give a deeper understanding of categories. Some of the differences between categories concern not modal facts but essential properties. If essences are not represented in the model, then these subtle differences are lost.

Moreover, representation of explanatory relations within categories makes them more intelligible to human users. If our toy-definitions would be extended to full specifications then finding crucial information turns to be complicated if not impossible for human users. In such cases essential characteristics may serve as a guide-post for grasping the meaning of a whole category.

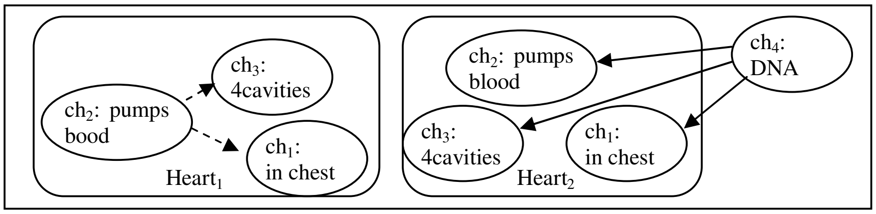

Fig. 2. Categories represented as directed graphs, where nodes represent characteristics, continuous arrow lines - functional explanations, and dashed arrow lines -causal explanations.

5 Related Work

Essence is considered in knowledge modeling generally in modal sense. For example, essence in OntoClean is taken as modal necessity. The exception is Brachman's approach, where definitional properties of concepts are distinguished from incidental properties [5], [2]. That distinction corresponds to our distinction of essential and peculiar characteristics. However, Brachman suggests not including non-essential knowledge in concept's definition. Instead, he suggests modeling it by means of rules in CLASSIC [5], or in the ABox in DL [2]. We do not exclude peculiar characteristics from category specification, since they still remain the necessary conditions of category membership.

6 Conclusion and Future Work

In ontology modeling not only philosophical correctness of ontologies is an issue, but also their cognitive adequacy. If ontologies are intended to represent people's knowledge, then they should preserve structure of human concepts. In particular, in complex domains ontologies should remain maximally similar to source knowledge.

In the current paper a metaontology for representing structure of concepts in ontologies is introduced. The metaontology is founded on psychological essentialism, which gives evidences that humans use essences in mental representation of concepts. Secondly, we refer to non-modal essentialism, according to which essence is not identified with necessary characteristics, but is taken as an explanation.

The approach gives means to represent explanatory structure of categories and to identify and represent their essential characteristics. The identification of essential characteristics has several advantages: (i) it permits to model ontologies more precise in description of human concepts; (ii) it separates essential knowledge form merely necessary, which enables to grasp complex categories; (iii) explicit specification of explanatory dependencies between characteristics of categories makes them more intelligible for human users.

In future the framework will be extended to handle more types of explanation and it will be elaborated in a form ready-to-use for ontology modeling. Moreover it will be incorporated into the current modeling formalisms.

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