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Wang Hongwei
Shanghai Jiao Tong University

Jiang Fu
Shanghai Jiao Tong University

Wu Jiachun
Shanghai Jiao Tong University

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A STUDY ON A FORMAL ONTOLOGY MODEL: CONSTRUCTING A CONSUMER ONTOLOGY IN A CRM CONTEXT

Wang Hongwei

Research Center for Intelligent Management
and Computer Simulation Applications
Shanghai Jiao Tong University
Kingdavid@citiz.net

Jiang Fu

Research Center for Intelligent Management
and Computer Simulation Applications
Shanghai Jiao Tong University
Fjiang@mail.sjtu.edu.cn

Wu Jiachun

Research Center for Intelligent Management and Computer Simulation Applications
Shanghai Jiao Tong University
wjiachun@guomai.sh.cn

Abstract

Ontology is defined as an explicit specification of a conceptualization. The customer ontology is a specific application of ontology to customer domain, which can provide a unified view to customers for better sharing customer knowledge. In this paper, an formal ontology model is constructed using Description Logic, which is a 6-tuples including Term Set, Individual Set, Term Definition Set, Instantiation Assertion Set, Term Restriction Set, Term Comment Set. Based on the model, the issue on ontology validation is studied with the conclusion that the four kinds of term validation, including term satisfiability validation, term subsumption validation, term equivalence validation and term disjointness validation, can be reduced to the satisfiability validation, and satisfiability validation can be transformed into instantiation consistence validation, which can be decided by Tableau Algorithm. At last, the issue on the construction of customer ontology in the CRM context is discussed.

Introduction

Good customer relationships are at the heart of business success in today's customer-centered market. Customer relationship management (CRM) is a new business strategy used to analyze the patterns of users in order to develop stronger relationships with them. With the fierce market competition and the rapid IT development, more and more companies have been concerned about CRM to capture and preserve customers for maximizing their profits.

However, CRM systems are facing with several problems now. One of them is a lack of unified views to customers within the whole company. To improve the competitiveness, a company needs to recognize customers in multiple perspectives. Therefore, customer knowledge stored in various departments is required to be shared consistently. For customers, they certainly expect the best product or service, so they hope every department can fully know all the interactions they ever did with the company before. The other problem is the uncertainty of information while interacting with customers. Customers are not seen directly in the e-commerce environment. The information about customers is coming from their own utterances, their histories, and general market analysis, most of which is implicit and need to be made explicit for use. Moreover, some interactions are a series of questionnaires asking information about customers such as personal backgrounds, preferences and so on. Not only questionnaires itself but also users' replies are represented as natural language, which makes customer knowledge even more ambiguous and difficult to be recognized.

The term *ontology* has been originally used in philosophy sphere, where it indicates the systematic explanation of *Existence*. Now it is gaining a specific role in Artificial Intelligence as an explicit specification of a conceptualization (Guarino 1998). Nowadays, the importance of ontology is being recognized in research fields as diverse as knowledge engineering (Gaines 1998), knowledge representation (Guarino 1995), qualitative modeling (Borgo et al. 1997), database design (Van de Riet 1998), information modeling (Ashenurst 1996), information integration (Mena 1998), semantic-based information retrieval (Wang 2003), semantic web, and knowledge management.

Construction of terms about customer (including concepts and relationships among them) is a promising way to a successful CRM in customer knowledge acquisition, retrieval and integration. Customer ontology is a specific application of ontology to the customer management domain. With customer ontology, all the departments of a company can make an agreement with customer knowledge consistently. Unfortunately, up to now, there is still not such a report about deep studies on customer ontology, especially in the Chinese CRM context. Some projects, such as Edinburgh Enterprise Ontology (EO) (Uschold et al. 1998) and Toronto Virtual Enterprise (TOVE) (Fox and Gruninger 1998), explored enterprise concept modeling. In these projects, customer concepts have been presented, but they are too general to satisfy the need of customer management in CRM. So an elaborate ontological model of customer with proper granularities is required.

The research on customer ontology depends on two key issues: the formal model of ontology and the domain knowledge of CRM. In section 2, a formal ontology model is proposed. In section 3, the ontology validation is studied. In section 4, the construction of customer ontology is discussed.

Formal Ontology Model

Ontology and Ontology Interpretation

Most of ontology models are based on first order logic (FOL), e.g. Ontolingua (Gruber 1993), CycL (Gruber 1990), and LOOM (MacGregor 1991). Although FOL has an expressive power, its reasoning processes are more complex and most of them are even undecidable, which is hard to validate ontology model. In this paper, we build an ontology model using Description Logics (DL) (Baader et al. 2002). DL is the name for a family of knowledge representation formalisms that represent the knowledge of an application domain by first defining the relevant concepts of the domain, and then using these concepts to specify properties of objects and individuals occurring in the domain. DL is equipped with a formal and logic-based semantics allowing inferring implicitly represented knowledge from the knowledge that is explicitly contained in the knowledge base. Although DL has a less expressive power than FOL, its inference procedures are more efficient, which is suitable for ontology validation (Wang 2003).

Def. 1: Given a term description language L , an *ontology model* (or *ontology*, for short) is a 6-tuple, written as

$$O = \langle T, X, TD, XD, TR, TC \rangle$$

where T is a *Term Set*, X is an *Individual Set*, TD is a *Term Definition Set*, XD is an *Instantiation Assertion Set*, TR is a *Term Restriction Set* and TC is a *Term Comment Set*. Elements in T are also called *atomic term*, which falls into two categories: *atomic class term* (or *atomic class*, for short) and *atomic property term* (or *atomic property*, for short).

Def. 2: Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, an *ontology interpretation* is a 2-tuple, written as

$$I = \langle \Delta^I, -^I \rangle$$

where $\Delta^I \neq \emptyset$ is the domain of the interpretation, and $-^I$ is an interpretation function, which assigns to every atomic class C in T a set $C^I \subseteq \Delta^I$, and to every atomic property P in T a binary relation $P^I \subseteq \Delta^I \times \Delta^I$, and to every individual a in X an element $a^I \in \Delta^I$.

Figure 1 gives an example of a family ontology using the model defined in Def.1.

O-Family=<{Person, Female, Male, Woman, Man, Mother, Father, Parent, hasChild, hasHusband, Wife, Grandmother, MotherWithoutSon, MotherWithManyChildren}, {Alice, Tom, Mary}, {Woman=Person \sqcap Female, Man=Person \sqcap Male, Mother=Woman \sqcap \exists hasChild.Person, Father=Man \sqcap \exists hasChild.Person, Parent= Father \sqcup Mother, Wife=Woman \sqcap \exists hasHusband.Man, Grandmother= Mother \sqcap \exists hasChild.Parent, MotherWithoutSon= Mother \sqcap \forall hasChild. \emptyset Man, MotherWithManyChildren=Mother \sqcap ≥ 3 ,hasChild}, {Man(Tom), Woman(Alice), hasHusband(Alice, Tom), hasChild(Alice, Mary)}, {Female \sqcap Male}, \emptyset >

Figure 1. A Family Ontology Model

Term Set, Term Definition Set and Term Comment Set

Term Set comprises a group of atomic terms, denoted as $T=\{t_1, t_2, \dots, t_n\}$, where $t_i \in T$ ($i=1, 2, \dots, n$) is an atomic term.

Term Comment Set is to describe the meaning of atomic terms in the natural language, denoted as $TC=\{tc(t_1), tc(t_2), \dots, tc(t_n)\}$, where $t_i \in T$ is an atomic term in T , and $tc(t_i)$ is a description of t_i in the natural language.

However, atomic terms can only express very limited and simple contents, because of their less expressive powers. So we adopt the *term constructors* here from DL to build term formulae for representing more complex contents.

Given a term description language L , the expression satisfying the following syntax is called an L -based term formula.

$$D, E \rightarrow C \mid \top \mid \perp \mid \neg C \mid D \sqcap E \mid \forall P.D \mid \exists P.T \quad (1)$$

where C is an atomic class, D and E are two L -based formula, and P is an atomic property. Tab.1 gives the ontology interpretations to term constructors.

Table 1. Basic Term Constructors and Their Ontology Interpretations

Constructors Name	Term Constructors Syntax	Ontology Interpretation
Universal Class	\top	$\top^I = \Delta^I$
Empty Class	\perp	$\perp^I = \emptyset$
Atomic Class Negation	$\neg C$	$(\neg C)^I = \Delta^I \setminus C^I$
Intersection	$D \sqcap E$	$(D \sqcap E)^I = D^I \cap E^I$
Property Value Restriction	$\forall P.D$	$(\forall P.D)^I = \{a \in \Delta^I \mid \forall b. (a, b) \in P^I \rightarrow b \in D^I\}$
Limited Existential Quantification	$\exists P.T$	$(\exists P.T)^I = \{a \in \Delta^I \mid \exists b. (a, b) \in P^I\}$

Table 1 shows that the expressive power of term formulas depends on the types of term constructors the language L supports. In Formula (1), L only supports six basic constructors listed in Tab.1, so L is also called *basic term description language*, written as L_B , and the corresponding term formulas built by L_B is called L_B -based term formulas.

Obviously, to obtain more expressive languages, we should add term constructors to L_B . Tab.2 gives another set of term constructors, called *extension term constructors*, where P is an atomic property, and D and E are two term formulas.

Table 2. Extension Term Constructors and Their Ontology Interpretations

Constructors Name	Term Constructors Syntax	Ontology Interpretation
Union	$D \sqcup E$	$(D \sqcup E)^I = D^I \cup E^I$
Non-atomic negation	$\neg D$	$(\neg D)^I = \Delta \setminus D^I$
Full Existential Quantification	$\exists P.D$	$(\exists P.C)^I = \{a \in \Delta^I \mid \exists b. (a, b) \in P^I \wedge b \in C^I\}$
At-least number restriction	$\geq n, P$	$(\geq n, P)^I = \{a \in \Delta^I \mid \{b \mid (a, b) \in P^I\} \geq n\}$
At-most number restriction	$\leq n, P$	$(\leq n, P)^I = \{a \in \Delta^I \mid \{b \mid (a, b) \in P^I\} \leq n\}$

There are three kinds of relationships between terms, i.e. subsumption, equivalence, and disjointness.

Def. 3 (Subsumption): Given term description language L and an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, D and E are two L -based term formulas. We say D is *subsumed* by E , if $D^I \subseteq E^I$ holds for any ontology interpretation I , denoted as DME .

Def. 4 (Equivalence): Given term description language L and an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, D and E are two L -based term formulas. We say D and E are *equivalent*, if $D^I = E^I$ holds for any ontology interpretation I , denoted as $D \equiv E$.

Def. 5 (Disjointness): Given term description language L and an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, D and E are two L -based term formulas. We say D and E are *disjoint*, if $D^I \cap E^I = \emptyset$ holds for any ontology interpretation I , denoted as $D \not\sim E$.

Property 1: Let D and E be two term formulas, P be a property. Then we have the following equivalence relationships:

- (i) $D \sqcap \neg D \equiv \perp$; (ii) $D \sqcup \neg D \equiv \top$; (iii) $D \sqcup E \equiv \neg(\neg D \sqcap \neg E)$;
 (iv) $\neg(\exists P.D) \equiv \forall P.\neg D$; (v) $\neg(\forall P.D) \equiv \exists P.\neg D$; (vi) $\neg(\geq(n+1), P) \equiv \leq n, P$
 (vii) $\neg(\leq n, P) \equiv \geq(n+1), P$

Property 2: Let D and E be two term formulas, P be a property. Then the following subsumption relationships hold:

- (i) $D \sqcap EMD$; $D \sqcap EME$; (ii) $DMD \sqcup E$; $EMD \sqcup E$; (iii) $\forall P.DM \sqsupset P.E$, iff DME ;
 (iv) $\exists P.DM \sqsupset P.E$, iff DME ; (v) $\geq n, PM \geq m, P$, if $n \geq m$; (vi) $\leq n, PM \leq m, P$, if $n \leq m$

Def. 6 (Term Definition Item): A term definition item actually is an equivalence relationship between two terms, written as $C \equiv D$, where C is an atomic class term called *definiendum*, and D is a term formula called *definiens*.

A term definition item $C \equiv D$ means C is defined in term of D . Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, *Term Definition Set* TD is such a set that consists of term definition items subject to the following restrictions, written as $TD = \{C_1 \equiv D_1, C_2 \equiv D_2, \dots, C_n \equiv D_n\}$. Where $C_i \in T$, D_i is a term formula, and every term in D_i is from T .

- (i) for any i, j ($i \neq j, 1 \leq i \leq n, 1 \leq j \leq n$), $C_i \neq C_j$ holds.
 (ii) if there exist $C_1' \equiv D_1', C_2' \equiv D_2', \dots, C_m' \equiv D_m'$ in TD , and C_i' occurs in D_{i-1}' ($1 < i \leq m, m \leq n$), then C_1' must not occur in D_m' .

Restriction (i) guarantees that each term in T can be defined at most once to avoid the logical conflict caused by defining a term in multiple times; Restriction (ii) is intended to avoid cyclic definitions.

Def. 7 (Model of Term Definition Item): Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, if there exists an ontology interpretation I satisfying a term definition item A of TD , then I is called a *model* of A . If I is a model of all term definition item of TD , then we say I is a *model* of TD .

Def. 8 (Defined Term & Primitive Term): Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, atomic terms of T can be divided into two sets: the *defined terms* occurring in the *definiendum* of term definition item of TD , written as T_d , and the *primitive terms* occurring only in the *definiens*, written as T_p .

In Figure 1, $T_d = \{\text{Woman, Man, Male, Mother, Father, Parent, Wife, MotherWithManyChildren, MotherWithoutSon, Grandmother}\}$, $T_p = \{\text{Person, Female, hasChild, hasHusband}\}$.

Def. 9 (Expansion of term definition item): Let $TD = \{C_1 \equiv D_1, C_2 \equiv D_2, \dots, C_n \equiv D_n\}$ be a Term Definition Set, we expand each term definition item in TD through an iterative process by replacing each occurrence of a defined term in the *definiense* with the primitive terms it stands for. Since no cycle term definition is allowed in TD (done by Restriction () above), the process eventually stops and we end up with a Term Set $T' = \{C_1 \equiv D_1', C_2 \equiv D_2', \dots, C_n \equiv D_n'\}$, where D_i' contains only primitive terms and no defined terms. We say that D_i' is the *expansion* of D_i with respect to TD , written as $Exp(D_i)$, and $C_i \equiv D_i'$ is the *expansion* of $C_i \equiv D_i$ with respect to TD , and T' is the *expansion* of T with respect to TD , written as $Exp(T)$.

Proposition 1: Suppose that $O = \langle T, X, TD, XD, TR, TC \rangle$ is an ontology, where $TD = \{C_1 \equiv D_1, C_2 \equiv D_2, \dots, C_n \equiv D_n\}$, and E is a term formula. If I is a model of TD , then $E^I = Exp(E)^I$ holds.

Proof: Since I is a model of TD , we can conclude $C_i^I = D_i^I$, for any term definition item $C_i \equiv D_i$ in TD . Then replace one of defined term C_j occurring in E with D_j and obtain a new term formula E' . We have $E^I = E'^I$ since $C_j^I = D_j^I$. Moreover, $Exp(E)$ can be obtained through the above replacing process in finite times until all defined terms are replaced with primitive terms, so $E^I = Exp(E)^I$ holds.

Proposition 2: Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, where $TD = \{C_1 \equiv D_1, C_2 \equiv D_2, \dots, C_n \equiv D_n\}$, and S is a term formula. If I is a model of $Exp(TD)$, then there must exists a model of TD I' , such that $S^I = Exp(S)^{I'}$.

Proof: Let $T_p = \{B_1, B_2, \dots, B_m\}$ be the Primitive Term Set. Since $TD = \{C_1 \equiv D_1, C_2 \equiv D_2, \dots, C_n \equiv D_n\}$, we have the Defined Term Set $T_d = \{C_1, C_2, \dots, C_n\}$. Suppose $Exp(TD) = \{C_1 \equiv D_1', C_2 \equiv D_2', \dots, C_n \equiv D_n'\}$, i.e. $D_i' = Exp(D_i)$. If I is a model of $Exp(TD)$, then $C_i^I = D_i'^I$ holds for any term definition item in $Exp(TD)$. Then we use I to build a new ontology interpretation I' , such that $B_i^{I'} = B_i^I$ for any primitive term B_i ; $C_i^{I'} = D_i'^I$, for any defined term C_i . With the new interpretation I' , we have $S^I = Exp(S)^{I'}$ for any term formula S , which result in $D_i^I = Exp(D_i)^{I'}$. Moreover, since $C_i^I = D_i'^I = Exp(D_i)^{I'}$, we can conclude $C_i^{I'} = D_i^{I'}$, i.e. I' is a model of TD .

Individual Set and Instantiation Assertion Set

Individual Set is a set of individuals. *Instantiation Assertion Set* consists of class instantiation assertions, property instantiation assertions and individual inequality assertions.

A class instantiation assertion, written as $C(a)$, states that individual a belongs to class C . a property instantiation assertion, written as $P(a, b)$, states that there exists a relation P between a and b , and b is called the value of a about property P . Individual inequality assertion, written as $a \neq b$, means that the two objects denoted by a and b are distinct.

Given an ontology interpretation I , if a class instantiation assertion $C(a)$ holds, then $a^I \in C^I$. If a property instantiation assertion (a, b) holds, then $(a^I, b^I) \in P^I$. If an individual inequality assertion $a \neq b$ holds, then $a^I \neq b^I$.

Def. 10 (Model of Instantiation Assertion): Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, if there exists an ontology interpretation I making an instantiation assertion α holds, then I is said to be a model of α . If I is a model of all the instantiation assertions in XD , then I is called a model of XD .

Def. 11 (Expansion of Instantiation Assertion): Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$. $C(a)$ is a class instantiation assertion in XD , and $Exp(C)$ is an expansion of C with respect to TD . $Exp(C)(a)$ is said to be the expansion of $C(a)$ with respect to TD . Through transforming each class instantiation assertion into the form of expansion, we can get a new Instantiation Assertion Set XD' . The new set XD' is called the expansion of XD with respect to TD , denoted as $Exp(XD)$.

Term Restriction Set

Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$, the Term Restriction Set TR is a set of term relationships in the form of subsumption, equivalence or disjointness, which is intended to restrict the logical relationship between terms in T . Let D and E be two term formulas, then the meaning of the three kinds of relationship are as follows:

- (i) DME states that every instance of the class denoted by D is also an instance of the class denoted by E .
- (ii) $D \equiv E$ states that every instance of the class denoted by D is also the instance of the class denoted by E , and vice versa.

(iii) $D \sqcap E$ states that the two classes denoted by D and E respectively do not have any instance in common.

$Exp(D)MExp(E)$, $Exp(D)\equiv Exp(E)$ and $Exp(D) \overset{\frown}{\sqcap} Exp(E)$ are called the expansion of DME , $D\equiv E$ and $D \sqcap E$ respectively.

Def. 12 (Model of Term Restriction): Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$, if there exists an ontology interpretation I satisfying a term relation R in TR , then we say I is a model of R . If I is a model of all the term relation in TR , then I is called a model of TR .

Def. 13 (Expansion of Term Restriction Set): Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$. For convenience, we here assume $TR=\{D_1ME_1, D_2\equiv E_2, D_3 \sqcap E_3\}$. If each term relation in TR has been transformed into the expansion form, a new Term Restriction Set $TR'=\{Exp(D_1)MExp(E_1), Exp(D_2)\equiv Exp(E_2), Exp(D_3) \sqcap Exp(E_3)\}$ is obtained. TR' is said to be the expansion of TR , written as $Exp(TR)$.

Def. 14 (Model of Expansion of Term Restriction Set): Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$, if there exists an ontology interpretation I satisfying all the term interpretations in $Exp(TR)$, then we call I a model of $Exp(TR)$.

Proposition 3: Let $O=\langle T, X, TD, XD, TR, TC \rangle$ be an ontology. If TD and TR have a model I in common, then I is also a model of $Exp(TR)$.

Proof: Let TR be $\{D_1ME_1, D_2\equiv E_2, D_3 \sqcap E_3\}$ for the sake of simplicity, then we have $Exp(TR)=\{Exp(D_1)MExp(E_1), Exp(D_2)\equiv Exp(E_2), Exp(D_3) \sqcap Exp(E_3)\}$. If TD and TR have a common model I , then $D_1^I \subseteq E_1^I$, $D_2^I = E_2^I$ and $D_3^I \cap E_3^I = \emptyset$ hold since I is a model of TR . Moreover, I is also a model of TD , so we can conclude that $C^I = Exp(C)^I$ holds for any term formula C according to Proposition 1. With the above conclusion, we can further obtain that $Exp(D_1)^I \subseteq Exp(E_1)^I$, $Exp(D_2)^I = Exp(E_2)^I$, $Exp(D_3)^I \cap Exp(E_3)^I = \emptyset$. So I is a model of $Exp(TR)$.

Proposition 4: Let $O=\langle T, X, TD, XD, TR, TC \rangle$ be an ontology, where $TD=\{C_1\equiv D_1, C_2\equiv D_2, \dots, C_n\equiv D_n\}$. $T_p=\{B_1, B_2, \dots, B_m\}$ is the set of primitive terms in TD , and S is a term formula. If I is a model of $Exp(TR)$, then there must exist a common model I' of both TD and TR , such that $S^I = Exp(S)^{I'}$.

Proof: Since $TD=\{C_1\equiv D_1, C_2\equiv D_2, \dots, C_n\equiv D_n\}$, the set of defined terms in TD is $T_d=\{C_1, C_2, \dots, C_n\}$. Suppose that $Exp(TD)=\{C_1\equiv D_1', C_2\equiv D_2', \dots, C_n\equiv D_n'\}=\{C_1\equiv Exp(D_1), C_2\equiv Exp(D_2), \dots, C_n\equiv Exp(D_n)\}$ and $TR=\{D_1ME_1, D_2\equiv E_2, D_3 \sqcap E_3\}$, we can get $Exp(TR)=\{Exp(D_1)MExp(E_1), Exp(D_2)\equiv Exp(E_2), Exp(D_3) \sqcap Exp(E_3)\}$. If I is a model of $Exp(TR)$, then $Exp(D_1)^I \subseteq Exp(E_1)^I$, $Exp(D_2)^I = Exp(E_2)^I$, $Exp(D_3)^I \cap Exp(E_3)^I = \emptyset$. Then we use I to construct a new ontology interpretation I' , such that $B_i^{I'} = B_i^I$, for any primitive term B_i ; $C_i^{I'} = D_i^I$, for any defined term C_i ; $a^{I'} = a^I$, for any individual a . With the new constructed interpretation I' , we can conclude $S^I = Exp(S)^{I'}$ for any term formula S , which result in $D_i^I = Exp(D_i)^{I'}$. Moreover, since $C_i^{I'} = D_i^I = Exp(D_i)^{I'}$, we can conclude $C_i^{I'} = D_i^{I'}$, i.e. I' is a model of TD . Furthermore, according to the above conclusion: $Exp(D_1)^I \subseteq Exp(E_1)^I$, $Exp(D_2)^I = Exp(E_2)^I$, and $Exp(D_3)^I \cap Exp(E_3)^I = \emptyset$, we can obtain that $D_1^{I'} \subseteq E_1^{I'}$, $D_2^{I'} = E_2^{I'}$ and $D_3^{I'} \cap E_3^{I'} = \emptyset$, i.e. I' is a model of TR .

Ontology Validation

Term Validation

Ontology Validation includes term validation and instantiation validation. Term validating includes: term satisfiability validation, term subsumption validation term equivalence validation and term disjointness validation.

Term Satisfiability Validation

Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$ and a term formula D , if there exists an ontology interpretation I , such that $D^I \neq \emptyset$, then D is said to be *satisfiable* and *unsatisfiable* otherwise. If there exists a model of TR , such that $D^I \neq \emptyset$, then D is *satisfiable* with respect to TR and *unsatisfiable* otherwise. If there exists a common model of both TR and TD , such that $D^I \neq \emptyset$, then D is said to be *satisfiable* with respect to TR and TD , or else *unsatisfiable* with respect to TR and TD .

In the development of domain ontology, a new term is constructed, possibly in term of others that have been defined before. During this process, it is necessary to find out whether the newly defined term makes sense or whether it is contradictory. From a logical point of view, a term makes sense for us if there is some interpretation that satisfies both TD and TR (that is, a model of TD and TR in common) such that the term denotes a nonempty set in that interpretation.

Term Subsumption Validation

Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$ and two term formulas D and E , if $D' \subseteq E'$ holds for all the ontology interpretation I , then D is said to be *subsumed* by E , or E subsumes D , denoted as $\vdash DME$. If in all the models I of TR , $D' \subseteq E'$ holds, then we say TR entails that D is *subsumed* by E , denoted as $TR \vdash DME$. If $D' \subseteq E'$ holds in all the common models I of both TR and TD , then we say TR and TD jointly entails that D is *subsumed* by E , denoted as $(TR+TD) \vdash DME$.

Term Equivalence Validation

Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$ and two term formulas D and E , if $D'=E'$ holds for all the ontology interpretation I , then we say D and E are *equivalent*, written as $\vdash D \equiv E$. If $D'=E'$ holds in all the models I of TR , then we say TR entails that D and E are *equivalent*, written as $TR \vdash D \equiv E$. If in all the common models I for both TR and TD , $D'=E'$ holds, then we say TR and TD jointly entails that D and E are *equivalent*, written as $(TR+TD) \vdash D \equiv E$.

Term Disjointness Validation

Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$ and two term formulas D and E , if $D' \cap E' = \emptyset$ holds for all the ontology interpretation I , then we call D and E are *disjoint*, written as $\vdash D \dot{\cap} E$. If in all the models I of TR , $D' \cap E' = \emptyset$ holds, then we call TR entails that D and E are *disjoint*, written as $TR \vdash D \dot{\cap} E$. If $D' \cap E' = \emptyset$ holds in all the common models I for both TR and TD , then we call TR and TD jointly entails that D and E are *disjoint*, written as $(TR+TD) \vdash D \dot{\cap} E$.

Proposition 5 (Reduction to Subsumption): Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$, for any two term formulas D, E , we have

- (i) D is unsatisfiable with respect to TR and TD , iff $(TR+TD) \vdash DM \perp$;
- (ii) $(TR+TD) \vdash D \equiv E$, iff $(TR+TD) \vdash DME$ and $(TR+TD) \vdash EMD$;
- (iii) $(TR+TD) \vdash D \dot{\cap} E$, iff $(TR+TD) \vdash (D \sqcap E)M \wedge$.

Proposition 6 (Reduction to Unsatisfiability): Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$, for term formulas D, E , we have:

- (i) $(TR+TD) \vdash DME$, iff $D \sqcap \neg E$ is unsatisfiable with respect to TR and TD ;
- (ii) $(TR+TD) \vdash D \equiv E$, iff both $D \sqcap \neg E$ and $\neg D \sqcap E$ are unsatisfiable with respect to TR and TD ;
- (iii) $(TR+TD) \vdash D \dot{\cap} E$, iff $D \sqcap E$ is unsatisfiable with respect to TR and TD .

Proposition 5 and 6 can be proved easily, so proofs are omitted here. These two propositions imply that all the four kinds of term validation can be reduced to the (un)satisfiability or subsumption.

Proposition 7: Given an ontology $O=\langle T, X, TD, XD, TR, TC \rangle$. D and E are two term formulas. $Exp(D)$ is the expansion of D with respect to TD , and $Exp(E)$ is the expansion of E with respect to TD . We have:

- (i) D is satisfiable with respect to TR and TD , iff $Exp(D)$ is satisfiable with respect to $Exp(TR)$;
- (ii) $(TR+TD) \vdash DME$, iff $Exp(TR) \vdash Exp(D)MExp(E)$;
- (iii) $(TR+TD) \vdash D \equiv E$, iff $Exp(TR) \vdash Exp(D) \equiv Exp(E)$;
- (iv) $(TR+TD) \vdash D \dot{\cap} E$, iff $Exp(TR) \vdash Exp(D) \dot{\cap} Exp(E)$.

Proof:

- (i) **Sufficient Condition:** If $Exp(D)$ is satisfiable with respect to $Exp(TR)$, then there must exist such a model I of $Exp(TR)$ that satisfies $Exp(D) \neq \emptyset$. According to Proposition 4, if I is a model of $Exp(TR)$, then there must exist a common model I' of both

TD and TR , such that $D^I = \text{Exp}(D)^I$. So we can get $D^I \neq \emptyset$ from $\text{Exp}(D)^I \neq \emptyset$ and $D^I = \text{Exp}(D)^I$. That is D is satisfiable with respect to TR and TD .

- (i) **Necessary Condition:** If D is satisfiable with respect to TR and TD , then there must exist a common model I of both TR and TD , such that $D^I \neq \emptyset$. Since I is a model of TD , $D^I = \text{Exp}(D)^I$ holds based on Proposition 1. Therefore we have $\text{Exp}(D)^I \neq \emptyset$. Moreover, according to Proposition 4, we can conclude that I is also a model of $\text{Exp}(TR)$. So $\text{Exp}(D)$ is satisfiable with respect to $\text{Exp}(TR)$.
- (ii) **Sufficient Condition:** Let I be a common model of both TD and TR , then according to Proposition 3, it is also a model of $\text{Exp}(TR)$ such that $D^I = \text{Exp}(D)^I$ and $E^I = \text{Exp}(E)^I$. Since $\text{Exp}(TR) \models \text{Exp}(D)M\text{Exp}(E)$ and I is a model of $\text{Exp}(TR)$, we can conclude $D^I \subseteq E^I$. That is for any common model I of both TD and TR , we have $D^I \subseteq E^I$, therefore $(TR+TD) \models DME$.
- (ii) **Necessary Condition:** First, let I be a model of $\text{Exp}(TR)$, then according to Proposition 4, there must exist a common model I' of both TD and TR such that $D^{I'} = \text{Exp}(D)^{I'}$ and $E^{I'} = \text{Exp}(E)^{I'}$. Then, since $(TR+TD) \models DME$ and I' is a common model of both TD and TR , we can conclude $D^{I'} \subseteq E^{I'}$. That is for any model I of $\text{Exp}(TR)$, we have $\text{Exp}(D)^I \subseteq \text{Exp}(E)^I$, therefore $\text{Exp}(TR) \models \text{Exp}(D)M\text{Exp}(E)$.
- (iii) According to Proposition 5(ii), $(TR+TD) \models D \equiv E$ is equivalent to both $(TR+TD) \models DME$ and $(TR+TD) \models EMD$. According to Proposition 7(ii), $(TR+TD) \models DME$ is equivalent to $\text{Exp}(TR) \models \text{Exp}(D)M\text{Exp}(E)$ and $(TR+TD) \models EMD$ is equivalent to $\text{Exp}(TR) \models \text{Exp}(E)M\text{Exp}(D)$. Therefore, $(TR+TD) \models D \equiv E$ is equivalent to both $\text{Exp}(TR) \models \text{Exp}(D)M\text{Exp}(E)$ and $\text{Exp}(TR) \models \text{Exp}(E)M\text{Exp}(D)$. That is $\text{Exp}(TR) \models \text{Exp}(D) \equiv \text{Exp}(E)$.
- (iv) According to Proposition 5(iii), $(TR+TD) \models D \not\equiv E$ is equivalent to both $(TR+TD) \models DM \neg E$ and $(TR+TD) \models EM \neg D$. According to Proposition 7(ii), $(TR+TD) \models DM \neg E$ is equivalent to $\text{Exp}(TR) \models \text{Exp}(D)M \neg \text{Exp}(E)$, and $(TR+TD) \models EM \neg D$ is equivalent to $\text{Exp}(TR) \models \text{Exp}(E)M \neg \text{Exp}(D)$. Therefore, $(TR+TD) \models D \not\equiv E$ is equivalent to both $\text{Exp}(TR) \models \text{Exp}(D)M \neg \text{Exp}(E)$ and $\text{Exp}(TR) \models \text{Exp}(E)M \neg \text{Exp}(D)$. That is $\text{Exp}(TR) \models \text{Exp}(D) \not\equiv \text{Exp}(E)$.

Proposition 7 states that the term validation can be decided by validating the expansion of the term.

Instantiation Validation

Def. 15 (Consistence of Instantiation Assertion): Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$ and an instantiation assertion α . If there exists such an ontology interpretation I that is a model of α , then we say α is consistent, and inconsistent otherwise. If I is not only a model of α , but also a common model of both TD and TR , then we say α is consistent with respect to TD and TR . If I is a model of XD , then we say XD is consistent. If I is not only a model of XD , but also a common model of both TD and TR , then we say XD is consistent with respect to TD and TR .

Proposition 8: Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$ and a class instantiation assertion $C(a)$, we have:

- (i) $C(a)$ is consistent with respect to TD and TR , iff $\text{Exp}(C)(a)$ is consistent with respect to $\text{Exp}(TR)$.
- (ii) XD is consistent with respect to TD and TR , iff $\text{Exp}(XD)$ is consistent with respect to $\text{Exp}(TR)$.

Proof:

Sufficient Condition: If $\text{Exp}(C)(a)$ is consistent with respect to $\text{Exp}(TR)$, then there exists a model I of $\text{Exp}(TR)$ satisfying $a^I \in \text{Exp}(C)^I$. Since I is a model of $\text{Exp}(TR)$, there must exist a common model I' of both TD and TR such that $a^{I'} \in a^I$ and $C^{I'} = \text{Exp}(C)^I$ according to Proposition 4. So we can obtain $a^{I'} \in C^{I'}$, i.e. $C(a)$ is consistent with respect to TD and TR .

Necessary Condition: If $C(a)$ is consistent with respect to TD and TR , then there exists a common model I of both TD and TR such that $a^I \in C^I$. Since I is a model of TD , we have $C^I = \text{Exp}(C)^I$ according to Proposition 2.2.1, which imply that $a^I \in \text{Exp}(C)^I$. Moreover Proposition 3 states that I is also a model of $\text{Exp}(TR)$. So we can conclude that $\text{Exp}(C)(a)$ is consistent with respect to $\text{Exp}(TR)$.

Proposition 8 states that the consistence of an instantiation assertion is equivalent to that of the expansion of the instantiation assertion.

Proposition 9: Given an ontology $O = \langle T, X, TD, XD, TR, TC \rangle$ and a term formula C , we have: C is satisfiable with respect to TD and TR , iff $C(a)$ is consistent with respect to TD and TR , where a is an arbitrarily chosen individual name.

Proof:

Sufficient Condition: If $C(a)$ is consistent with respect to TD and TR , then there exists a common model I of both TD and TR , such that $a^I \in C^I$, that is $C^I \neq \emptyset$, so C is satisfiable with respect to TD and TR .

Necessary Condition: If C is satisfiable with respect to TD and TR , then there exists a common model I of both TD and TR , such that $C^I \neq \emptyset$. It means that there exists at least one individual in Individual Set, which belongs to the class denoted by C . Let a be the name of the individual, we have $a^I \in C^I$, so $C(a)$ is consistent with respect to TD and TR .

Proposition 9 states that the consistence of an instantiation assertion can be determined through checking the satisfiability of the term.

Primary Study on Customer Ontology in CRM

The customer ontology is a specific application of ontology to the customer management domain. In the e-commerce, customers are not seen directly. The information about customers is coming from customers' own utterances, customers' histories, and general market analysis, etc. much of that is implicit and has to be made explicit for use. With the customer ontology, all the departments can make an agreement with customer information consistently and unambiguously within a company. The customer ontology can be regarded as a part of the enterprise ontology (Usschold 1998).

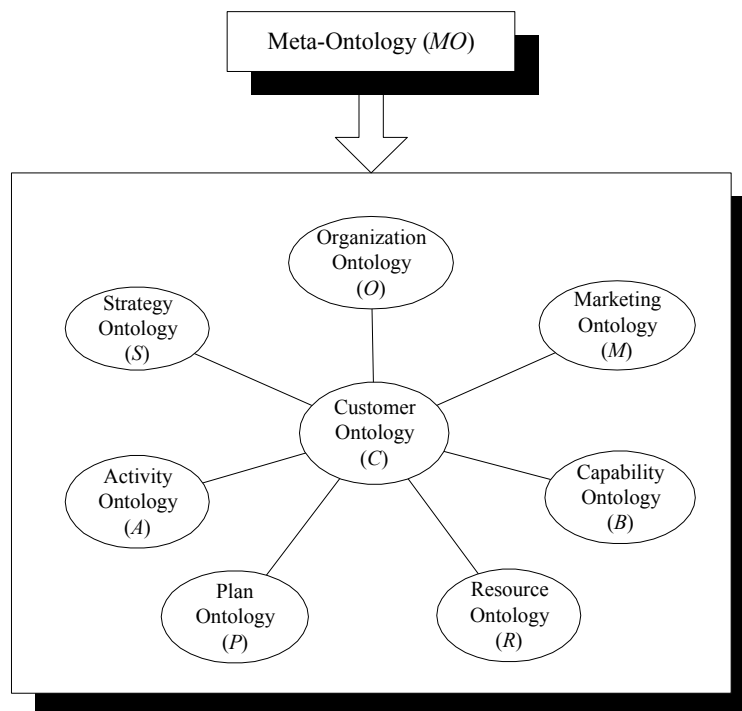


Figure 2. The Hierarchy of the Enterprise Ontology

Figure 2 shows the hierarchy of the enterprise ontology, where the customer ontology is on the center of the other six ontologies (the strategy ontology, the organization ontology, the marketing ontology, the activity ontology, the capability ontology, the resource ontology, and the plan ontology). All these ontologies are below the level of the meta-ontology, which provides basic terms / primitives (e.g. Entity, Relationship, Role) for defining the terms in other ontologies. Figure 3 gives enterprise meta-ontology based on the model presented above.

O-Meta=<{Entity, Relationship, Role, Attribute, State Of Affairs, Achieve, Actor Role, Actor, Potential Actor, Time Point, Time Line, Time Interval}, \emptyset , \emptyset , \emptyset , {RelationshipMEntity, RoleMEntity, Actor RoleMRole, AttributeMRelationship, ActorMEntity, Potential ActorMEntity, TimeMEntity}, {*tc*(Entity)=”a fundamental thing in the domain being modeled”, *tc*(Relationship)=”the way that two or more ENTITIES can be associated with each other”, *tc*(Role)=”the way in which an Entity participates in a Relationship”, *tc*(Attribute)=”a Relationship between two Entities with the property: within the scope of interest of the model, for any particular attributed Entity the Relationship may exist with only one value Entity”, *tc*(State Of Affairs)=”a situation; it consists of a set of Relationships between particular Entities; it can be said to hold, or be true”, *tc*(Achieve)=”the realization of a State Of Affairs”, *tc*(Actor Role)=”a kind of Role in a Relationship whereby the playing of the Role entails some notion of doing or cognition”, *tc*(Actor)=”an Entity that actually plays an Actor Role in a Relationship”, *tc*(Potential Actor)=”an Entity that can play an Actor Role in a Relationship”, *tc*(Time Point)=”a particular, instantaneous point in time”, *tc*(Time Line)=”an ordered, continuous, infinite sequence of Time Points”, *tc*(Time Interval)=”an interval of time specified as two Time Points and bounds on the distance between the two time points”}>

Figure 3. Enterprise Meta-Ontology

Recently, we are engaged in the work, *Construction of Customer Ontology in CRM*, which just begins with many ideas yet to be tested and many issues yet to be resolved. Up to now, a conceptual framework of customer domain has been primarily constructed. Figure 4 gives the model of customer ontology, in which the namespace mechanism is adopted for referring terms from other ontologies. For example, *MO* denotes the namespace for the meta-ontology. So, we can introduce terms defined in the meta-ontology, e.g. Entity, to the customer ontology in the form of *MO: Entity*. In the customer ontology, some terms are from the meta-ontology or the other six ontologies using namespaces. WordNet (Miller et al. 2003) is also a helpful tool in the process of term definitions. Now, we have designed a metadata set (called ONT) using RDF Schema, which provides necessary primitives for modeling domain-specific ontology (Wang 2003). With ONT, the customer ontology has been expressed in RDF syntax.

O-Customer=<{Customer, Relationship, Sale, Potential Sale, For Sale, Sale Offer, Vendor, Actual Customer, Potential Customer, High Profit Customer, Low Profit Customer, Reseller, Product, Asking Price, Sale Price, Market, Segmentation Variable, Market Segment, Market Research, Brand, Image, Feature, Need, Market Need, Promotion, Competitor, Field Sales, Mobile Sales, Inside Sales, Telesales, Loyalty, Satisfaction, Customer Description, Emotional Description, Physical Description, Corresponding Description, Purchase Behavior}, {Customer \equiv M:Customer, Vendor \equiv M:Vendor, Sale \equiv M:Sale, Product \equiv M:Product, Market \equiv M:Market, Segmentation Variable \equiv M: Segmentation Variable, Price \equiv M:Price, Mobile Sales \equiv Field Sales, Telesales \equiv Inside Sales}, \emptyset , \emptyset , {Customer \equiv Actual Customer \sqcup Potential Customer, RelationshipMMO:Relationship, SaleMMO:Relationship, VendorMMO:Role, Actual CustomerMMO:Role, Potential CustomerMMO:Role, ResellerMCustomer, High Profit CustomerMCustomer, Low Profit CustomerMCustomer, ProductMMO:Role, Asking PriceMMO:Role, Sale PriceMMO:Role, Segmentation VariableMMO:Attribute, NeedMMO:Entitiy, Market NeedMNeed, PromotionMA:Activity, CompetitorMMO:Role, Field SalesMA:Activity, Inside SalesMA:Activity, LoyaltyMRelationship, SatisfactionMRelationship, Customer Description \equiv Emotional Description \sqcup Physical Description \sqcup Corresponding Description}, {*tc*(Customer)=”a *Person* who pays for products or services”, *tc*(Relationship)=”a state of connectedness between *Customers* and *Vendors* (especially in emotional connection)”, *tc*(Sale)=”an agreement between two *Legal Entities* to exchange one goods, services or quantity of money for another good, service or quantity of money”, *tc*(Potential Sale)=”a possible future *Sale*”, *tc*(For Sale)=”a situation whereby one *Legal Entity* offers to enter into a *Sale*”, *tc*(Sale Offer)=”a *For Sale* situation where a particular *Legal Entity* is being offered the *Product*”, *tc*(Vendor)=”the *Role* of the *Legal Entity* who offers a *Product*, *For Sale* for an *Asking Price* or agrees to exchange a *Product* for a *Sale Price* in a *Sale*”, *tc*(Actual Customer)=”the *Role* of the *Legal Entity* agreeing to exchange a *Sale Price* for a *Product* in a *Sale*”, *tc*(Potential Customer)=”any *Legal Entity* who may become an *Actual Customer*”, *tc*(Product)=”the *Role* of the good, service, or quantity of money, that is offered *For Sale* by a *Vendor* or agreed to be exchanged by the *Vendor* with the *Actual Customer* in a *Sale*”, *tc*(Market)=”all *Sales* and *Potential Sales* within a scope of interest”, *tc*(Segmentation Variable)=”any *Attribute* determinable from a *Sale* or *Potential Sale* in a *Market*”, *tc*(Market Segment)=”all *Sales* and *Potential Sales* in a *Market* having defined values of one or more *Segmentation Variables*”, *tc*(Need)=”a physical, psychological or sociological requirement of a *Customer*”, *tc*(Promotion)=”an *Activity* whose primary *Purpose* is to improve the *Image* of a *Product*, *Brand* and/or *Vendor*”, *tc*(Competitor)=” a *Role* of a *Vendor* in a *Relationship* with another *Vendor* whereby one offers one or more *Products For Sale* that could limit the *Sales* of one or more *Products* of the other *Vendor*”>

Figure 4. Customer Ontology

The relationship between a company and its customers involves continuous bi-directional communication and interaction. The relationship can be short-term or long-term, continuous or discrete, repeating or one-time, and attitudinal or behavioral. Even though customers have a positive attitude towards the company and its products, their buying behaviors are highly situational and vary with different background, e.g. national culture. So, in our study, such factor as customers' emotion is considered. We plan to conduct some investigations into China's companies in different business fields, such as insurance, telecom, retail, IT and so on. We will design a series of questionnaires for various customers to better learn their behaviors. We expect to find more key issues concerned by both companies and customers and get distinct features of China from other countries. Based on the empirical research finding, the customer ontology will be revised and refined into a deeper level.

Conclusions and Future Work

In this paper, an ontology model is constructed using Description Logics. Based on this model, problems of ontology validation are studied. Finally, a model of customer ontology in CRM is discussed. There are still several issues required to be further done in the future, including refining the customer ontology into a deeper level, establishing the ontology-driven customer management system, and exploring how to improve efficiency of CRM using the customer ontology, in particular in Chinese contexts.

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