Description Logic Representation for Semantic Concepts of Feature

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Abstract

In order to make the semantic information of feature be shared and understood by computer, this paper discusses and analyzes the semantic information of features, presents a semantic concept of feature. Based on description logic representations for semantic concepts of features and hierarchy structures are given. Based on the description logical reasoning of concept, a solution to realize automatic classification and mapping of concepts is discussed. Description logic representation for semantic concepts of feature creates a basis for ontology representation of feature information.

1. Introduction

Feature is one of the most important information to express design intent. According to Shah’s definitions about the shape feature, feature is an abstract geometry with a specific shape and property, including a lot of design semantic information. Shape information can be explicitly expressed by B-reps. The semantics of feature implicitly represents the engineering meanings about specific application, which mainly include methods of constructing shape structure (involving geometry and topology), engineering applications (relating to function, processing, manufacturing, etc.), parameters and constraints. Because of the diversity of specific applications and understanding, it is difficult for feature semantics to be definitely and formally represented at a standard model so that they can not be understood by computer, even the designers have to need a certain background. So there are three problems as follows to be resolved:

(1) The interoperability of features among heterogeneous CAD systems is still main obstacles. Whether it is based on the STEP standard or XML, it is difficult to realize the automatic semantic mapping between features.

(2) The Semantics of feature is automatically converted to application of CAPP and CAM.

(3) Feature-based part model semantics automatic retrieval and reuse.

In order to make the semantics of feature be understood by computers, the semantic concepts of feature must be set up. Semantic Web technology provides a new solution for computer to understand the semantics of feature. Ontological technology provides formal and explicit representations for domain concepts. Ontology usually is encoded using representation and reasoning mechanisms based on description logic. Description logics (DLs) are knowledge representation languages tailored for expressing knowledge about concepts and concept hierarchies.

2. Related work

At present it should be said that the representations of semantic concept of features are still in the theory initial stage at home and abroad, the current related works are mainly reflected in the following aspects:

Researches on ontology-based product information, design knowledge representation and semantic interoperability of feature have been carried out. In [1], an ontology-based framework to enable semantic interoperability was proposed, which includes a product semantic representation language (PSRL) based on formal description logic (DAML+OIL). In [2] an ontology-based framework for semantic interoperability was also proposed. In [3] a semantic feature model was proposed and developed to represent informative and communicative design intent. Feature semantics is explicitly captured as a RDF trinary relation, which provides good extensibility and prevents semantics loss. Some studies involved in using description logics to directly describe and represent product data. In [4], description logics were used to express the engineering standards. In [5] a finite element analysis model based on description logics was proposed, and the model was used to automatic retrieval.
3. Semantic concepts of feature

3.1 Feature semantics

The meaning of data is semantics. Semantics can be simply regarded as the meaning of the concept on behalf of the data corresponding to the real world of things, as well as the relationships between the data. Semantics also can be regarded as an interpretation and logic representation within specific domain.

Feature is a complex data structure which is identified by terminology string and geometric boundary. In the specific domain, interpretations about feature are the semantics of feature. Semantics of features can be summarized mainly in following aspects:

1) Shape semantics

Shape semantics is the main represented contents for semantics of feature, which include the information that features are how to construct and modify the solid body, reflecting the construction methods and construction process.

2) Engineering semantics

Engineering semantics refers the engineering meaning of feature relating to the manufacture, assembly and so on. For example, a hole feature implicitly expresses the parameters defining the hole, the functional significance and methods of processing.

3) Constraints semantics

Feature is implied rich constraints semantic information, including owned constraints, geometric and topological relations constraints.

4) Parameter semantics

Parameters represent values of quantities that may be regarded as variable for purposes of editing the model. Parameters determine the size of shape, position and structure form of feature. Parameter semantics express the meaning of the parameter.

3.2 Semantic concept of feature

The semantic information of feature has a strong subjective characteristics, there is no a unified and clear explanations. These semantics can not be automatically understood by computers (referring to the formal explanation, reasoning and judgments), only the people with the field knowledge and interpretations can process the works related to the semantics of feature by program coding, such as feature information exchange among the heterogeneous CAD systems.

In order to make computer automatically understand the semantics of features, the specific semantic concept about features must be set up.

Concept is a form thinking of the objective world. On the basis of the perceptual, cognitive and representation concepts are formed to class of entities specified entities, events or the relationship by means of comparison, analysis, synthesis, summary and abstract. Concepts are expressed with words, the express term of concept is called name. A concept can be expressed in different terms, a concept and a word or a term usually be considered equally.

Concept has the scope, the range of concept (extension) is all included in the concept of things, ignores the differences between things, so concept is abstract. The contents (meanings) of concept include all of the properties and relations about concept, which are used to describe the nature of a concept. At the same time, concept is defined by a series of terms (concept must be illustrated its meaning by other concept). A new concept is formed by composing a series of terms, and also a new terminology can be used to give the new concept of naming.

Definition 1: Semantic concept of feature is an abstract class of entities to describe the semantic information of feature.

The semantic concepts of features are set up by following steps:

1) Based on standardization of treatment to terminology of design domain, the public recognized semantic terms of feature within domain are set up.

2) Set up the hierarchy structure of semantic concept of feature, explicitly describe the inheritance (is-a) relationship between concepts.

3) Formally and explicitly describe the semantic concepts of feature by a semantic description language.

3.3 Hierarchy of semantic concept of feature

Semantic concepts of feature are abstract class entities. According to their semantic properties they can be classified into four categories. Fig. 1 shows the hierarchical structure and relationships of semantic concept of feature, and explicitly describes the inheritance (is-a) relationship between concepts.
4. Description logic Representation for semantic concepts of feature

4.1 Atomic concepts and roles

Elementary descriptions are atomic concepts and atomic roles. Complex descriptions can be built from them inductively with concept constructors. Atomic concepts are unary predicates, which express the most basic concepts such as person. Roles denote binary relationships between individuals, which are binary predicates.

In the domain atomic concepts and atomic roles have clear and generally accepted interpretations. Role is a relation concept to describe the semantic relationships between concepts, and provides an interpretation in the interest domain. In order to define the semantic concept of feature, roles are defined as follows:

\[ R = \{ \text{hasChild, hasParent, hasValue, hasSketch, hasConstraints, hasParaDefinition, hasModifies, hasCopy, hasRemovedMaterial} \} \]

4.2 Semantic concept definition of feature

The semantic concept of feature can be formally defined by description logic ALCN language.

Firstly, Feature is defined as the most top-level semantic concepts.

\[ \text{Feature} \equiv T \]

Secondly, sub-concepts such as sketch-based feature, parameter-based feature, modify-based feature and copy-based feature concepts are inherited from feature. As limited short paper space, only a part of definitions of the concepts are given as follows.

4.2.1 Sketch-based Feature. At present the main features based on sketch are extrude, revolve, swept and loft. Their main characteristics are that a sketch is swept in the space according to a certain move path and methods to construct solid body.

(1) Sketch

Sketch is generally defined as a sequence of connected curves set at the base surface. At least there is one geometric curve in a sketch. Sketch also may include dimensional or geometric relationship constraints. Sketch concept can be defined as follows:

\[ \text{Sketch} \equiv \text{Thing} \land ( \exists \text{hasCurve} \land \exists \text{hasConstraint.Surface} ) \]

Sketch and feature are disjointness, namely:

\[ \text{Feature} \land \text{Sketch} \equiv \bot \]

Concept of feature based on sketch can be defined as follows: Sketch-based \( \equiv \text{Feature} \land \exists \text{hasSketch} \)

(2) Extrude

The shape semantics of extrude feature can be considered as that a sketch moves along the normal direction of construct base plane and forms a solid body. Extrude concept can be defined as follows:

\[ \text{Extrude} \equiv \text{Sketch-based} \land ( \exists \text{hasSketch} \land \exists \text{hasValue.Direction} \land \exists \text{hasValue.Length} ) \]

(3) Revolve

The shape semantics of revolve feature can be considered as that a sketch rotates around the central axis of rotation and forms a solid body. Revolve concept can be defined as follows:

\[ \text{Revolve} \equiv \text{Sketch-based} \land ( \exists \text{hasSketch} \land \exists \text{hasRotaAxis} \land \exists \text{hasValue.Angle} ) \]

4.2.2 Parameter-based Feature. Parameter-based feature definition generally refers to those features that are constructed by input a set of parameters with engineering meaning, such as holes, slots, grooves and so on. Feature based on parameter definition concept can be defined as follows:

Parameter-based \( \equiv \text{Feature} \land \exists \text{hasParaDefine} \)

(1) Hole

Hole feature refers to construct rotary shape of removed material. Hole feature can be defined by the center of hole, drilling the base surface and diameter. The shape semantics of hole feature can be classified as rotary characteristics, and the rotation axis intersection with the sketch. Hole feature concept can be defined as follows:

\[ \text{Hole} \equiv \text{Parameter-based} \land ( \exists \text{hasConstraints.(RotaAxis \land Sketch)} \land \exists \text{hasRemovedMaterial} ) \]

Under the hole concept the various types of sub-concepts, such as countersunk hole, pin hole, threaded hole and so on are different in different profile sketches.

(2) Slot

Slot feature has two major categories. One is straight slot, generally refers to remove material by milling process, defined by the width, length and depth parameters. From the shape semantic view, it can be classified as extrude feature. Another is ring groove, generally refers to remove material by turning process, defined by the parameters such as width, inner diameter, outer diameter and so on. From the shape semantic view, it can be classified as revolve feature, and the rotation axis disjoint with the sketch. Slot feature concept can be defined as follows:

\[ \text{Slot} \equiv \text{Parameter-based} \land ( \text{Extrude} \land \text{hasRemovedMaterial} ) \]
5. Reasoning and mapping of concepts

Description Logic provides better logical reasoning of concepts, that is, at TBox layer reasoning. By means of concept reasoning implicit semantic knowledge may be explicit, and realize the classification and mapping of concepts.

5.1 Main forms of reasoning

Reasoning 1, Satisfiability: If there is an interpretation of T model I, makes C is not empty, saying the concept of C on T is satisfied, and said I was a model of C.

Reasoning 2, Subsumption: If for each T model I, there is $C' \subseteq D'$ then the concept of D, said about T model contains C.

Reasoning 3, Equivalence: If for each T model I, there is $C' \equiv D'$ then the concept of C and D, said about T model are equivalent.

Reasoning 4, Disjointness: If for each T model I, there is $C' \cap D' = \emptyset$, then the concept of C and D, said about T model are disjointness.

For example, by making use of the subsumption reasoning of relationship between concepts, the hierarchical structures of concept can be built. By testing whether an individual is an instance of a concept, the consistency of concept can be inferred.

5.2 Classification and mapping of concept

When semantic interoperability of feature is implemented a new introduced concept need to be classified or implemented mapping operations. Steps of its reasoning as follows:

Step 1: to determine whether the new introduced concept is consistent with existing concepts, if it is consistency switch to step 2; otherwise, to Step 3;

Step 2: Inclusive relationships determine, whether the introduced concept is a subset of the other concepts. If it is contained the concept is inserted to suitable hierarchy;

Step 3: Concept mapping, mainly based on the decomposition of concept and role.

For example, the semantic concept of user-defined rectangle spline features can be defined as follows:

\[
\text{Spline} \equiv \text{Parameter-based} \cap (\text{Swept} \cap \text{Circular Array}) \cap \text{hasRemovedMaterial}
\]

By making use of reasoning mapping, spline feature can be decomposed into swept feature and circular array feature. Its structural parameters rely on feature based on parameter definition.

6. Conclusions

Semantic information of feature is very rich, it is difficult to formally and explicitly represent. In order to make the semantic information be shared and be understood by computer, based on the semantic analysis of features this paper presents a semantic concept of feature. Description logic representations for semantic concepts of features and hierarchical structures are given. Based on the description logical reasoning of concept, a solution to realize automatic classification and mapping of concepts is discussed. Description logic representation for semantic concept of feature creates a basis for ontology representation of feature information.

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