Knowledge Representation and Semantic Inference of Process Based on Ontology and Semantic Web Rule Language

Zhu Haihua *, *Li Jing*, *Wang Yingcong*

College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P. R. China

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Abstract: The process inference cannot be achieved effectively by the traditional expert system, while the ontology and semantic technology could provide better solution to the knowledge acquisition and intelligent inference of expert system. The application mode of ontology and semantic technology on the process parameters recommendation are mainly investigated. Firstly, the content about ontology, semantic web rule language (SWRL) rules and the relative inference engine are introduced. Then, the inference method about process based on ontology technology and the SWRL rule is proposed. The construction method of process ontology base and the writing criterion of SWRL rule are described later. Finally, the results of inference are obtained. The mode raised could offer the reference to the construction of process knowledge base as well as the expert system's reusable process rule library.

Key words: ontology; semantic web rule language (SWRL); process plan knowledge; semantic inference

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0 Introduction

Traditional process design includes developing mechanical processing route, determining the tooling equipment which could meet the requirements of each process, and determining the machining allowance and cutting parameters[1], etc. Among them, the selection of tooling equipment and the determination of cutting parameters rely on the experience and knowledge accumulated by the technical staff. There will also be differences in a same process when different staffs develop it, which would not only lead to the low efficiency of the process design, but also cause the inadaptability when applying the developed process plan on the new process tasks.

The emergence of the process auxiliary decision-making system has solved the problem of low efficiency of the traditional process design. With the help of such systems, the process design personnel could develop the process more efficiently. Up to now, some large auxiliary decision-making systems have been put into use in foreign countries, for example, the General Aviation Manufacturers Association (GAMA) system of the Kennametal Company in America, the Electron Microscopy Data Bank (EMDB) recommendation system in Singapore, the cutting information center (INFOS) turning database software in Germany, and the intelligent tool selection system developed by the Dundee University in England. In China, there are also many researches about the expert systems for process parameters recommendation, for instance, the blade slot type selection recommendation system developed by Harbin University of Science and Technology, the expert system for high speed milling process by the Nanjing University of Aeronautics and Astronautics, and the expert system for high performance cutting process by the Tongji University.

However, to represent the process knowledge and concepts, these systems only rely on re-

* Corresponding author, E-mail address: zhuhh@nuaa.edu.cn.

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lational database, and the establishment of process rules is related to the integrated database. The relationship between the rules in the database is not obvious, which would cause the retardation of the inference, low efficiency and the mess of the process knowledge and concepts as a whole. Meanwhile, if the rule base is huge, the combination explosion between different rules would exist[2]. The research on the ontology and semantic inference technology could offer effective solutions to the problems and disadvantages of the systems above in the area of knowledge acquisition, retrieval and intelligent inference[3]. They not only offer the complete knowledge definition method and the logical constructed measures, but also realize the intelligent inference based on semantic, which could strengthen the ability of the systems, meet the requirements of customers about raising the efficiency, and broaden the application domain of the systems.

So far, owing to the characteristics of reusability, ontology technology has brought a lot of convenience to the message retrieval and design reuse. As a result, the ontology technology is mainly used in the areas of concurrent product design[4] and process information retrieval[5]. But in the area of process knowledge inference, the ontology technology is seldom used. This article would introduces the ontology technology to the process inference, and uses the SWRL rules as the process inference rules to combines the Jess inference engine to raise a process knowledge representation and semantic reasoning method. Such method could offer some reference resources for the construction of intelligent process knowledge base and reuse of the process inference knowledge.

1 Process Ontology Construction

In the field of mechanical processing, the determination of process parameters will be influenced by many factors. Due to the variety of process knowledge, this study would introduce the concept of ontology technology to represent the knowledge involved in the process design. Ontology could be derived from the concept of philosophy. In philosophy, ontology studies the essence and origin of object[6]. Since the ontology uses the precise formal language, syntax and the determination of the meaning, framing the relationship between the concepts in the field which needs to be described more accurate, thus reducing the misunderstanding among the concepts to a large extent[7]. Ontology could support the representation and treatment of process knowledge. Meanwhile, using ontology to handle the process knowledge could unitize the term expression about the process knowledge in different concept hierarchy[8]. Terms about the process knowledge could also be connected by using ontology. Ontology is also used to address the semantic shortcomings and matchmaking difficulties associated with semantic Web technology. Considering the construction of process ontology knowledge base is complex, to construct the process ontology knowledge base rationally would strongly influence the efficiency and accuracy of the process inference result. In this research, process ontology is developed by a Web-based ontological mark-up language—web ontology language (OWL). OWL is a language for defining and instantiating Web ontology, which can be used to describe the classes and relationships between them that are inherent in Web documents and application. Compared to other languages and standards like standard for the exchange of product model data (STEP), extensible markup language (XML), resource description framework (RDF) and RDF schema (RDF-S), OWL has more facilities for expressing meaning and semantic. Therefore, OWL goes beyond these languages in its ability to represent machine interpretable contents on the Web.

1.1 Basis of process ontology construction

The key point in the construction of ontology is to describe the relationship between the different concepts by defining the class, attribute and instance[9]. To build the ontology knowledge base, the concepts and knowledge about the process should be extracted firstly. Through the inspection of the process manual, the accumula-

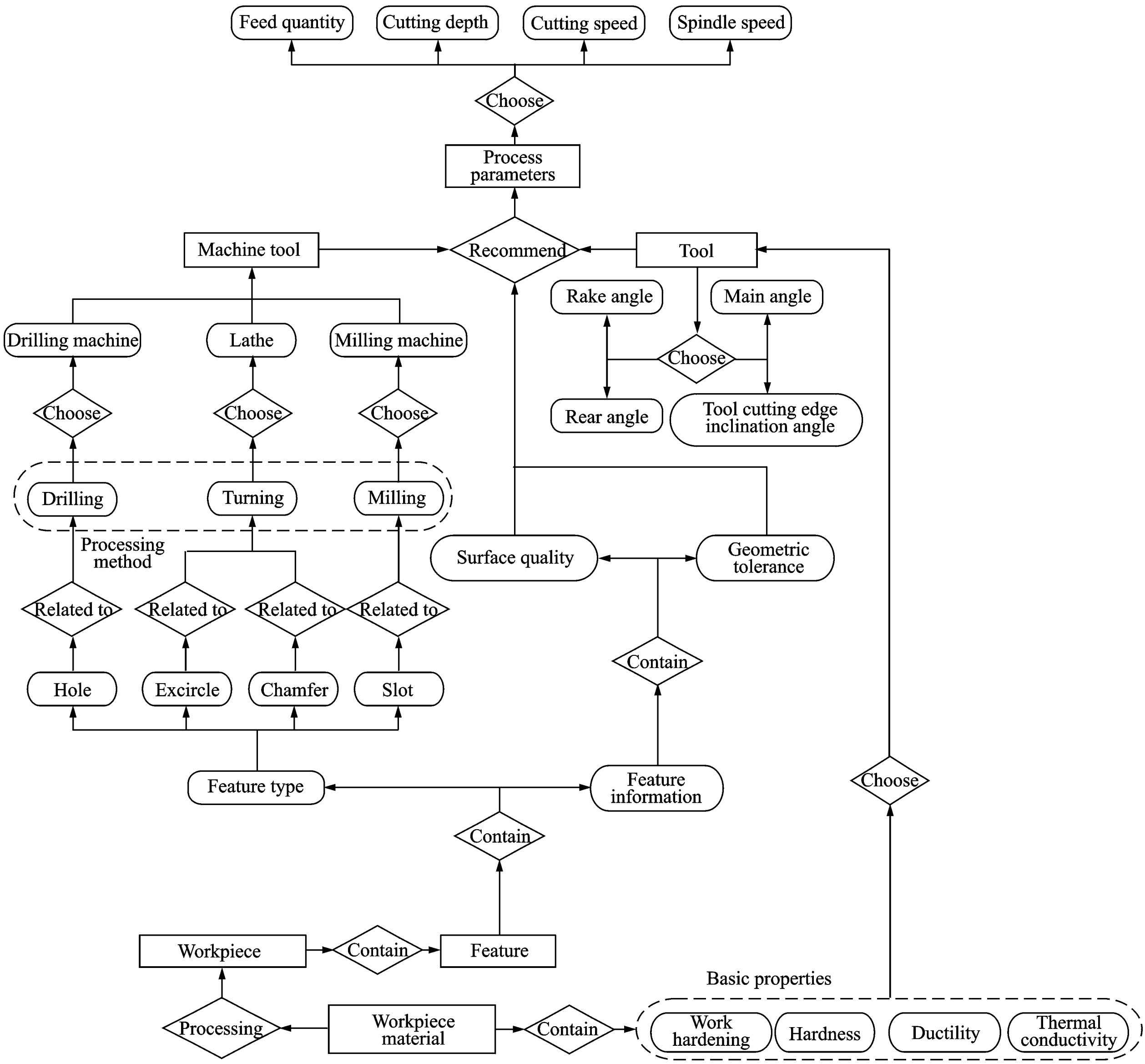

Fig. 1 Logical relationship of process terms

ted experience and the extraction of the information from the process card, the concepts which has significant connections with process ontology could be summarized. For example, the related concepts about the process parameters are as follows:

Feed quantity refers to the displacement of the tool relative to the workpiece in the direction of feed motion.

Feed rate refers to the speed of the reference point on the cutting tool moving along the tool path relative to the speed of the workpiece.

Spindle speed refers to the rotation speed of machine tool spindle.

Because of the limited space, the remaining terms would not be explained in detail. They are the concepts about parts feature, like hole, excircle and slot, and the concepts about processing method, like turning, milling and drilling. The concepts about material properties are also included, like hardness, work hardening, ductility and thermal conductivity, etc. The logical relationship of various terms in the process ontology is expressed in Fig. 1. In Fig. 1, the workpiece material contains the attributes of work hardening, which could help decide the cutting tool material, tool rake angle and rear angle, etc. The feature types contained in the parts dictate the processing method and the type of machine tool. The properties information contained in the parts feature and the selected tool and machine jointly determine the choice of the process parameters.

1.2 Detailed description of process ontology

According to the relationship of the process terms above, the process ontology could be constructed by Protégé. Protégé, developed by Stanford University, is a software which could edit the ontology and acquire knowledge based on JAVA. As the platform for constructing the class, relationship and property of ontology, Protégé is the core development tool for the ontology construction. Among the concepts and terms mentioned before, some are classes, others are instances and properties. Class, which includes subclasses and has a strict hierarchy relationship with subclasses, represents the basic concept in ontology.

Fig. 2 shows that the tree-structure classes could be divided into three levels, i. e., "Top Level", "Middle Level" and "Bottom Level". Generally, classes in the Top Level have great differences with each other. For example, "Tool" and "WorkpieceMaterial" belong to two different classes. The Middle Level is the detailed classification of the Top Level. For instance, class "Tool" could be divided into class "ToolMaterial" and class "GeometricalParameters". The Bottom Level is quite specific that it could be enumerated by instances.

Fig. 2 Hierarchical relation of classes

As the individual of class, instance could indicate the specific examples of the class. Fig. 3 shows exactly the instances of the class "Used_for_Alloy", where the numbers in bracket represent the amount of instances, and the specific examples are listed on the right. Fig. 4 expresses the inclusion relationship of classes and instances intuitively, and the class in the head of the arrow has a super hierarchy relation than the end. It is easy to infer that class "HardAlloy" has superclass "Used_for_Alloy" and twelve instances in Fig. 4. Property could be classified into object property and data property. The object property describes the relationship between classes and instances, while the data property could combine the data value with the instances.

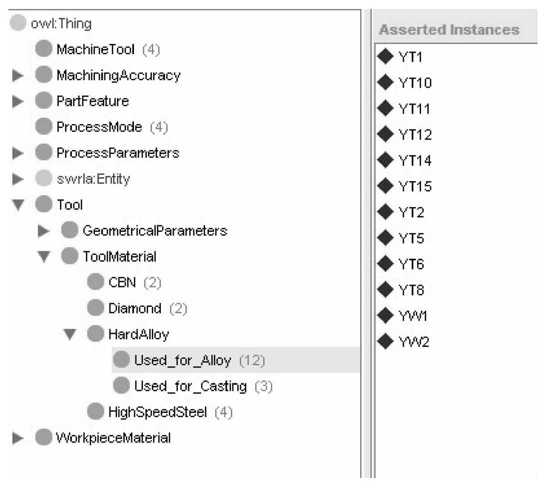

Fig. 3 Construction of instances

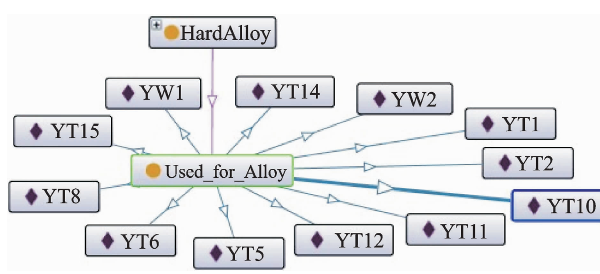

Fig. 4 Inclusion relationship of classes and instances

Fig. 5 is part of the process ontology. It could express the relationship between classes in ontology clearly. For example, the class "PartFeatures" represents the part feature, which includes two subclasses: "FeatureType" and "FeatureInformation". While the class "FeatureInformation" contains some important information like "Rough_ness" and "GeometricTolerance". The ontology constructed by Protégé could be saved as the format of OWL.

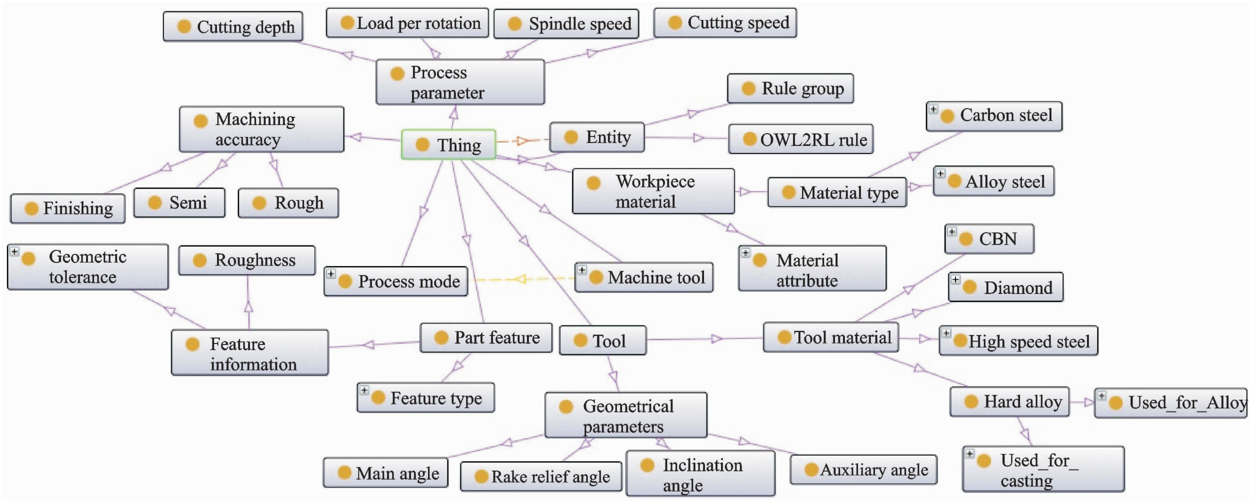

Fig. 5 Part of the sample of constructed process ontology

2 SWRL Process Rule Construction

After the construction of the process ontology, the rule base should be established according to the above. As a language to describe the rules by using semantic method, semantic web rule language (SWRL) could combine the rules with the terms described by OWL-format ontology, which could make up the deficiency of OWL in the field of rule description and inference. By invoking the established ontology and user-defined SWRL rules, SWRL could define more detailed logical relationship for the terms in ontology until the rule base could be used for inference, achieving further optimization for process ontology[10].

2.1 SWRL rule

SWRL rule is composed of two parts: one is the antecedent and the other is the consequent. Antecedent and consequent are connected by an arrow, which means that if the antecedent is satisfied, then the consequent would be satisfied[11]. For example, the relationship Uncle could be defined like this:

$$\text{hasParent}(x,y) \wedge \text{hasBrother}(y,z) \rightarrow \text{hasUncle}(x,z)$$

In this rule, hasParent(x,y) ∧ hasBrother(y,z) is antecedent. The x,y,z are all variables, instances or data value. Then antecedent shows that y is the parent of x, while z is the brother of y. HasUncle(x,z) is the consequent of this rule, which means that z is the uncle of x. The relationship of Parent and Uncle has existed in OWL-format ontology. SWRL could get the inferred result from the defined relationship between different terms.

Generally speaking, the basic terms in SWRL rule could be assembled by $P(x,y)$, $C(x)$, Same As(x,y) and Different(x,y). C could be the classes of OWL, x represents the instance of classes, and P represents property. If P stands for object property, then $P(x,y)$ means that variable x could be related to variable y by P; while if P stands for data property, then $P(x,y)$ means that individuals belong to x could be related to the data value represented by y. If x and y are described as the same object, Same As(x,y) could be used to represent such relationship. Conversely, Different(x,y) could be used.

2.2 Detailed process of construction of SWRL rule

On the basis of the constructed process ontology, the specific inference elements related to the process inference could be extracted, and the inference rules could also be established by the practical experience in processing and basic principles of developing process. The inference results of the process could realize the connection between the feature of the workpiece and the process parameters. Some rules are listed in the following:

Rule 1 The higher the hardness and ductility of the workpiece material is, the higher the hardness and the strength of the cutting tools should be.

Rule 2 The higher the hardness of the workpiece material, the smaller the tool orthogonal rake and clearance, and the larger the main angle and tool cutting edge inclination angle. The deeper the cold hardening of the workpiece material, the smaller the main angle, as well as tool orthogonal rake and the tool clearance. The higher the thermal conductivity, the larger the tool orthogonal rake and clearance, as well as the main angle and the tool cutting edge inclination angle.

Rule 3 The part feature identified is excircle. The workpiece is made of steel 45. Then the processing method should be turning and the machine tool should be lathe. If there is no special requirement, the mode of the lathe should be determined by the size of the workpiece. The cutting depth should be less than 1 mm, and the load could be chosen from 0.1 mm/r to 0.15 mm/r. The cutting speed could be determined from 80 m/min to 100 m/min. The spindle speed could be confirmed by $n=1\,000\ V_c/(\pi d)$, where V_c is the cutting speed, n the spindle speed, and d the identified diameter of the workpiece,

Taking Rule 3 as an example, if in SWRL format, the antecedent should contain the part feature type, feature geometry and workpiece material. And the processing method, machine tool type and the cutting depth are included in the consequent. Then Rule 3 should be expressed as:

45 Steel ∧ excircle ∧ Diameter 50mm ∧

Roughness *Ra*6.3→

Turning ∧ Depth of Cutting 1 mm ∧ Load 0.01 mm ∧ Cutting Speed 80 m/min

The Rule 3 could be described in SWRL like:

CarbonSteel (Steel 45) ∧ FeatureType (Excircle) ∧

Diameter_Excircle(*x*, 50) ∧

Roughness(*y*, 6.3) ∧ Choose_ProcessMode(*z*,*a*) ∧ Cutting_Depth(*b*,*c*) ∧

Feed_per_Revolution_mm(*d*,*e*) ∧

Cutting_Speed_m_per_min(*f*,*g*) →

Choose_ProcessMode(*z*,Turning) ∧

Cutting_Depth(*b*,1) ∧

Feed_per_Revolution_mm(*d*,1) ∧

Cutting_Speed_m_per_min(*f*,80)

In SWRL rule, the variables existed in consequent must emerge in the antecedent, or the error would appears. For example, the Choose_ProcessMode(*z*, Turning) exists in the consequent. Then in the antecedent, Choose_ProcessMode(*z*, *a*) must be mentioned. And in the antecedent, the variable *a* is the unknown quantity, and "Turning" in the consequent represents the variable *a*.

In Protégé3.5, preliminary constructed process inference rule is demonstrated in Fig. 6.

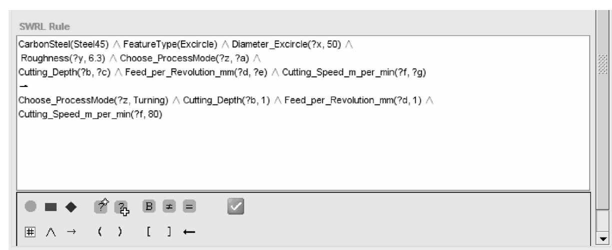

Fig. 6 Rule 3 in SWRL format

3 Inference Implementation Based on Ontology and SWRL Rules

Here the process knowledge base and rule base are built by adapting the ontology technology and SWRL rules. Then the Jess inference engine would be used to infer the process knowledge. The concrete process is shown in Fig. 7. The CATIA secondary development technology would firstly be used to extract the information of the feature of the three-dimensional model (Fig. 8). The extracted information, which contains the feature type, the basic parameters and the properties of the workpiece, would be saved as XML files. The XML files would be pretreated to match the constructed process ontology. If success, the OWL-format data and the SWRL rules related to the part feature would be extracted and transformed as the content which could be identified by Java Expert System Shell JESS inference engine. Finally, the inference results are obtained. If failed, the process ontology and the SWRL rule base should be modified according to the new part feature information. After alteration, the XML files should be pretreated again to match the new process ontology. JESS is the rule engine developed by Ernest Fridman-Hill of Sandia National Laboratory on the platform of JAVA in 1995. It could offer logic programming for the automated expert system. JESS could be fast and small. As one of the fastest inference engine currently, JESS could be compatible with all JAVA API. Based on the established ontology knowledge database and SWRL rule base, the JESS inference engine is used to infer the process parameters. After the SWRL rule and the instance of the OWL ontology are transformed into the terms that could be identified by Jess through SwrlJessTab.

Inference engine would be applied to infer the process parameters[12]. The construction of the ontology, the preparation of SWRL rules and the conduction of the Jess inference engine could all be carried on in Protégé with the help of OWL Plugin. The inference result is shown in Fig. 9. Rule 3 is loaded, the time for conversion of OWL and SWRL (OWL+SWRL→JESS) is 187 milliseconds. After the inference (Run Jess), the results could be transformed into the analyzable OWL-format files (Jess→OWL). The classes,

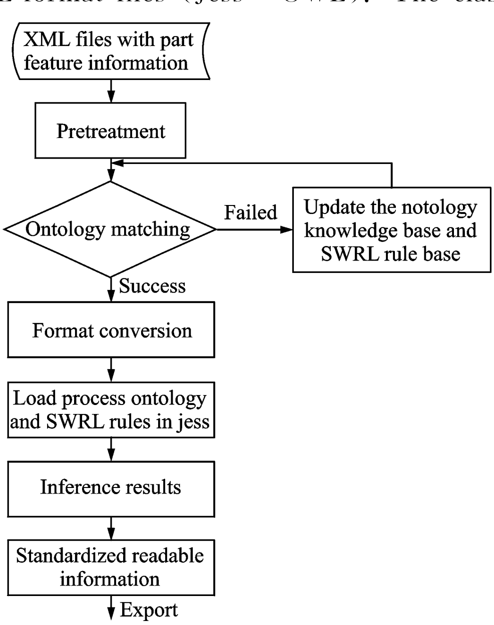

Fig. 7 Procedure of process inference

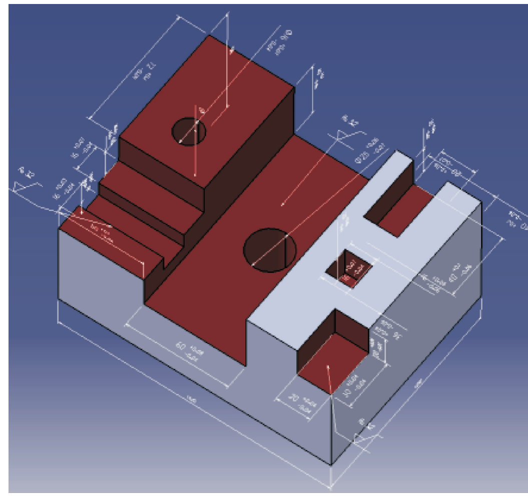

Fig. 8 Extraction of feature information

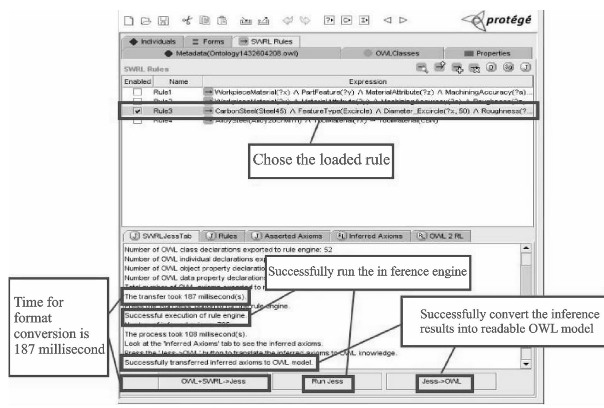

Fig. 9 Inference results of Rule 3

properties and instances in OWL files could all be extracted.

4 Conclusions

Inference about the judgement of machining parameters and tool selection process is a very complex process, in which many factors are often needed to be considered. Therefore, it is necessary to express process knowledge specifically and achieve its intelligence inference. Based on the disadvantages of traditional expert system, ontology and semantic technology are adapted in this paper constructively. This paper introduced ontology and semantic technology to (1) Achieve the process knowledge inference based on the semantic, making the inference more intelligent; (2) Provide a kind of knowledge acquisition mode, which could represent the concepts and relations between them specifically; (3) Achieve the consistency of process knowledge formally by its describe language OWL, and it guarantees the sharing of knowledge base; (4) Relate the established process knowledge base and process rules, solving the problem of combination explosion between different rules. Meanwhile, SWRL rule construction method is used to construct the process rule base, and combined with the JESS engine, the process inference could be achieved. On the one hand, SWRL rule could extract the terms in ontology directly. On the other hand, the light of JESS makes process inference more effective.

Furthermore, the technology adapted this paper is based on the three-dimensional model, which could be applied to three-dimensional computer auxiliary process system. In conclusion, the introduction of ontology and semantic technology in this paper makes process inference much more intelligent, effective, and applicable.

As an ongoing project, there are still a lot of issues need to be done in the future studies. First, the effectiveness and efficiency of the proposed models need to be further verified and improved. Second, more previous process design cases will be adopted to ensure the diversity of knowledge. Last but not least, the next step of this research will focus on the process design of complex structural components.

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References:

[1] RAO P N. Manufacturing Technology: Metal cutting and machine tools[M]. 2nd Edition. New York: Tata McGraw-Hill Education, 2013:257-239.

[2] WILT K V D. Knowledge systems and prolog: A logical approach to expert systems and natural language processing[J]. Machine Translation, 1990, 4(4):329-331.

[3] BRANDT S C, MORBACH J, MIATIDIS M, et al. An ontology-based approach to knowledge management in design processes[J]. Computers & Chemical Engineering, 2008, 32(S 1/2):320-342.

[4] CHEN Y J. Knowledge integration and sharing for collaborative molding product design and process development[J]. Computers in Industry, 2010, 61(7): 659-675.

[5] CAI J, MICHAEL W, ULRICH B. Ontological machining process data modelling for powertrain production in extended enterprise[J]. Journal of Advanced Manufacturing Systems, 2011, 4(4): 69-82.

[6] RODRGUEZ M A, EGENHOFER M J. Determining semantic similarity among entity classes from different ontologies[J]. Knowledge & Data Engineering IEEE Transactions on, 2003, 15(2): 442-456.

[7] HORROCKS I, PATEL-SCHNEIDER P. Reducing OWL entailment to description logic satisfiability [M]// The Semantic Web - ISWC 2003. [S. l.]: Springer Berlin Heidelberg, 2003:17-29.

[8] GONCALVES R J, SARRAIPA J, SILVA J M D. Methodology for the development of sustainable reference ontology in the mechanical engineering domain [C]// ASME 2010 International Mechanical Engineering Congress and Exposition. [S. l.]: American Society of Mechanical Engineers, 2010:39-46.

[9] HE Q, LING T W. An ontology based approach to the integration of entity - relationship schemas[J]. Data & Knowledge Engineering, 2006, 58(3): 299-326.

[10] BENER A B, OZADALI V, ILHAN E S. Semantic matchmaker with precondition and effect matching using SWRL[J]. Expert Systems with Applications, 2009, 36(5):9371-9377.

[11] LEZCANO L, SICILIA M A, RODRÍGUEZ-SOLANO C. Integrating reasoning and clinical archetypes using OWL ontologies and SWRL rules[J]. Journal of Biomedical Informatics, 2011, 44(2):343-353.

[12] LEE K C, LEE J H. Integration of OWL and SWRL Inference using Jess[J]. Journal of Korean Institute of Intelligent Systems, 2005, 15(7):875-880.

Dr. **Zhu Haihua** received the B. S. and Ph. D. degrees in Mechanical Engineering and Automation from the Nanjing University of Science and Technology, Nanjing, China, in 2008 and 2013, respectively. He joined in Nanjing University of Aeronautics and Astronautics in July 2013, where he is a lecturer of College of mechanical and electrical engineering. His research is focused on knowledge manage-

ment, advanced manufacturing technology, product integrated maintenance and service management.

Ms. **Li Jing** received the B. S. degree in Mechanical Engineering and Automation from Hohai University in 2015. She joined in Nanjing University of Aeronautics and Astronautics in 2016, where she is a postgraduate of College of mechanical and electrical engineering. Her research is focused on knowledge management and process design.

Mr. **Wang Yingcong** received the B. S. degree in Mechanics from Nanjing Institute of Technology in 2016. He joined in Nanjing University of Aeronautics and Astronautics in 2016, where he is a postgraduate of College of mechanical and electrical engineering. His research is focused on intelligent maintenance and diagnosis.

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