



# Knowledge Management of Web Financial Reporting in Human-Computer Interactive Perspective

Dong Wang

Guangzhou University, CHINA

Yujing Chen

Guangdong University of Finance, CHINA  
Guangdong University of Technology, CHINA

Jing Xu

Guangdong University of Finance, CHINA

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## ABSTRACT

Handling and analyzing to web financial data is becoming a challenge issue in knowledge management and education to accounting practitioners. eXtensible Business Reporting Language (XBRL), which is a type of web financial reporting, describes and recognizes financial items by tagging metadata. The goal is to make it possible for financial reports to be handled accurately and to be analyzed automatically via human-computer interactive approach. To solve the issues that analyzing financial data might create, (1) a decidable Tableau algorithm for description logic DLRBR is proposed; (2) a formalization approach about part-whole relationship in XBRL is proposed; (3) consistency checking and logical reasoning of XBRL metadata is discussed; (4) then a human-computer interactive prototype system is developed to verify the proposed method. The results can help prompting the ability of knowledge management and education in accountings.

**Keywords:** XBRL, tableau algorithm, checking, knowledge management, human-computer interactive

## INTRODUCTION

Extensible Business Reporting Language (XBRL), which is an open platform-independent international financial standard, can assist storage, processing and communication of financial reports and business data, allowing these to be timely, accurate and efficient. Since the framework of XBRL was announced in 1998, its characteristics of versatility and easy extension have led to XBRL being widely and rapidly applied all over the world. The U.S. Securities and Exchange Commission has a mandatory requirement for all listed companies to disclose financial information in XBRL. Moreover, in December 2012, the Ministry of Finance of China clearly pointed out that any accounting software should be able to generate XBRL financial reports in line with national standards.

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**Correspondence:** Yujing Chen, *School of Insurance, Guangdong University of Finance, Guangzhou, P.R. China. Address to No527 Yingfu Road, Tianhe District, Guangzhou 510520, China.*

✉ [chenyujingcici@163.com](mailto:chenyujingcici@163.com)

### **State of the literature**

- Studies on handling and analyzing to web financial reports have gained impetus over the past 15 years. The main aims of these studies is achieving an intelligence application through computer aided schema.
- Ontology, which is viewed as an important way in capturing and disseminating the real-world knowledge for effective human computer interactions, have taken into consideration. However, there are no unique web financial report ontology.
- Metadata and ontology are one possible solution to the processing of data in local domain and education to systems users, the systems have ability for users to interactive with computer in business processing.

### **Contribution of this paper to the literature**

- The significance of the present study lies in its contribution to the propose a logical method to propose a ontology-based and reasoning-supporting human-computer interaction approach of handling and analyzing to web financial reports.
- According to the study, in ontology based and reasoning-supporting human-computer interaction approach, the properties of results such as response time, processing efficiency, accuracy and capacity are better than proposed algorithms and approaches.
- The results of this study shows one more possible way to manage knowledge of web financial report depending on human-computer interactive perspective.

Human-computer interaction is focusing on the information interchange between human and computer. The main consideration of human-computer interaction is to determine and develop the communication function and a human machine interface between human and computer. Ontology, which is built from the user's personalized and customized demand, and must have information interchange between user and computer, and the critical successful factor of an ontology is the participation of user, plays an important role in capturing and disseminating the real-world knowledge for effective human computer interactions.

Handling and analyzing to web financial reporting should be in accordance with human-computer interaction approach. Since the financial reports are generated by accountants by hand in the early time. Although in modern times, these reports are exported by computer, but they are still need to be verified by accountants. According to XBRL international association, every country can extend the taxonomy besides the 2845 core financial elements in accordance with XBRL regulations. This would lead an incomparability of the web financial reporting from computer perspective. XBRL recognizes and describes financial items using tagging metadata. The XBRL international association has proposed relevant technical documents such as XBRL specifications, taxonomy and instance, etc., so as to specify the semantics of tagging metadata through natural languages and figures. However, the comparability of the financial information is lost due to the use of inconsistent tagging metadata, which is where the differences between the cognitive concept and the actual business come from. Besides, it is more difficult to distinguish the fundamental concept due

to the numerous characteristics, attributes, relationships and taxonomic extending types in the XBRL taxonomy (Pinsker & Li, 2008). This causes a need for complete hand-checking in the business layer to achieve data quality control of XBRL financial reports. This is unacceptable to the Ministry of Finance of China (Li Ji-mei, 2011). To achieve global comparability of financial documents, ontology can be one possible solution to knowledge management of financial data and the incomparability. Thus, a human-computer interaction approach to develop an XBRL ontology, as well as reasoning and checking from the coordination between human and computer should be taken into consideration.

As a result, two major problems need to be solved to prompt the ability of knowledge management and education in accounting field: (1) To determine how to support the intelligent logical reasoning and consistency checking of metadata via the semantic formalization of XBRL tagging metadata, and (2) To determine how to ensure the comparability of financial information. In accordance with the XBRL initiative, XBRL metadata and its relationships are formalized in description logic, and an intelligent logical reasoning and consistency checking method is proposed in this paper. This is a new attempt to promote the analysis of financial reports and support enterprises' high-efficiency decisions using logic theory and metadata.

## LITERATURE REVIEW

Scholars have carried out many researches in knowledge management and human-computer interaction in processing XBRL financial reports. Extensibility is the most important characteristic of XBRL. Cohen (2004) pointed out that extending the taxonomy can solve the mentioned problem of personalized financial information reporting, but such extension may lead to the loss of information comparability. Liu, Wang, & Yao (2014) proposed an XBRL theoretical framework with all of the 2845 financial elements. To maintain the consistency during XBRL taxonomy extending, Yang, Zhu & Liu (2010) constructed a certification methodology system for the XBRL taxonomy. Debreceeny, Farewell, & Piechocki (2010) discussed the promotion and dissemination analysis of financial information supply chains, and the impact of enterprise information systems in XBRL format. Cohen (2015) found out that in a new development stage, related researches are focusing on XBRL extensible taxonomy through extending formulation to meet the needs of enterprises to give more personalized voluntary information disclosure. Problems and benefits arise at the same time. In the problem field, the improper extension might cause the loss of financial information accuracy Wagenhofer (2003), and lower financial information comparability among different entities Boritz (2005). In the benefits field, XBRL financial reports give the opportunity to list all the contents in a PDF report with the help of a taxonomy extensible Cohen (2015), and solve accounting questions to a certain extent Shen (2004). However, there are few comparative studies of ways to extend the taxonomy, as well as little research on suitability and conversion evaluation of the existing taxonomy extensible functions. Compared with XML, XBRL has a higher semantic explicit expression ability, but it is still inconvenient for automated logical reasoning, analysis and utilization. In addition, formal semantics which are convenient for

computer processing are required, in accordance with the requirement of XBRL initiatives (Yoon, Zo, & Ciganek, 2011). Relevant literature review on formalization of XBRL can be divided into the following four parts.

### **Knowledge management and human-computer interactive**

Human-computer interaction has been developing for thirty years. While human-computer interaction is focusing on the information interchange between human and computer, it has twelve core knowledge domains: system capability, user interface design, task of the human-computer interaction system, evaluation of interaction, user acceptance of technology, personalized system design, interface analysis, performance measurement and improvement, development of interaction, human reaction to technology, facial expression, and effective interaction (Shiau, Yan, & Kuo, 2016). The main consideration of human-computer interaction is determining and develop the communication function and a human machine interface between human and computer. Human-computer interaction has been formed from three stages: language command interaction, graphic human interface and a harmony human-computer interaction. To achieve a harmony human-computer interaction, the information systems should have strong ability in information communication and reasoning. Ontology, which is viewed as an useful approach to describe and provide management ability to concepts and knowledge, plays an important role in capturing and disseminating the real world knowledge for effective human computer interactions (Senthilnayaki, Venkatalakshmi, & Kannan, 2015). Ontology is built from the user's personalized and customized demand, and must have information interchange between user and computer, and the critical successful factor of an ontology is the participation of user. Jiang (2015) put forward an intelligent monitoring system with good human-computer interaction which has the function of abnormal automatic moving object recognition based on data mining technology in finance industry. Mahmadi, Zaaba, & Osman (2015) suggested that most of the end-users are continually experiencing significant difficulties especially in relation to the technical terminologies, security features and other technical issues from a human-computer interaction perspective

### **Knowledge management in semantic promotion by ontology building.**

In the research of early enterprises and institutions, semantic formalization to XBRL were mainly developed through converting XBRL language into semantic description language, in order to increase the formalized semantics. A major research effort was to establish a clear model, resulting in OWL ontology.

P. Castells (2014) discussed the possibility of management level promotion of economic and financial information by using Web technology, and an ontology model with limited semantics is thus put forward. This model can be applied to the basis of the economic and financial information management, including XBRL. In order to collect, integrate and analyze the heterogeneously distributed investment funds information, Chen (2012) advanced a classification taxonomy for XBRL investment funds, and transformed this taxonomy into OWL

ontology. Taking the semantic properties implied by the XBRL taxonomy into account, a step-by-step conversion mode was used in XBRL investment fund classification standards as well as an OWL ontology conversion process. Such a method only resolved the transformation of the XBRL taxonomy's latent semantics, but did not result in a clear formal semantics. Declerck (2006) studied the way to directly convert XBRL taxonomy into the description logic and ultimately obtained the ontological classification taxonomy of XBRL by Protégé. Zhang (2006) defined the semantic features of financial elements and proposed an XBRL theory system based on a financial items structure. Li (2010) established an environment of financial data analysis by Protégé and Jena, but applications in such environment were basically developed on the basis of the traditional priority expansion way, and deductive queries cannot be supported because of lack of the SPARQL. Núñez & Suarez (2008) used a semantics web and theory-aware computing to put forward a proposed framework and methodology to generate a short report from the financial data summarized. This brief report contains several natural statements, which are helpful to define the generated ontology. The famous MUSING of the European Union suggested establishing XBRL ontology from metadata in order to increase the formal semantics, so as to develop a new intelligent systems analysis. The core of the new application of MUSING delivery is XBRL in which management knowledge; advanced predictive analytic sand intelligent third-party data access was combined by integration of semantic technologies, for the purpose of providing a backbone for the integration of knowledge. The project's results are formalized in the ontology, and the body itself is a model for the MUSING knowledge base of library services. This includes mapping data from common type to the XBRL standard. The German Research Center for Artificial Intelligence, a collaborator of MUSING, developed a method which is similar to XBRL ontologies and used it as a backbone model in the process of PDF2XBRL interpretation. Under this method, balance sheet information was classified into the XBRL taxonomy by using natural language processing, thus data was interpreted into a form for machine-readable processing and reusable information. On the other hand, all the knowledge in MUSING is conceptualized in the ontology Plumlee & Plumlee (2008). Combining the semantic web with XBRL technical standards, Liu proposed the XBRL technical model XTMSW Liu (2012). Description logic has become an important formalization method in knowledge expression and management.

### **Knowledge management in semantic improvement by model conversion**

On one hand, ontology is used to increase the formal semantics. On the other hand, lots of conversion technologies and methods in semantic web are used to improve formalized semantics. As a result, with the aim of seeking a best solution for the semantic representation, researches of increasing formalized semantics by a process of transformation among different semantic web technologies have been done.

Taking the needs of deductive query brought by the development of Web technologies into account, Melnik (2010) proposed a method to transform documents in XML format such as XML and XBRL into RDF and RDF Schema with the help of ontology presentation and

inference language. This is not only useful to keep the semantic consistency before and after transformation, but also to support reasoning. Ian Horrocks (2003) showed a formalized description of the transformation process from RDF to OWL by building constructors, data types, frame types and the rules of grammar respectively, and proposed the inference algorithm under description logic. Dragan Gašević (2004) mentioned a method of transforming UML model into OWL ontology in the meta-model level, relying on XSLT technology and on the ontology UML documents. Méndez Núñez (2007) developed a XBRL transformation system by using the semantic web technology for the purpose of showing, passing and analyzing XBRL. The developed XBRL transformation system transformed the concept of XBRL OWL class or property, achieved the semantic transformation in RDF documents by XSLT, established the knowledge of XBRL OWL class or property, and supported SPARQL deductive query. Locke & Lowe (2007) proposed an approach to obtain transformed elements from classes, relationships, mapping, etc, by using XSLT. However, the value of semantics after transformation is not considered. Auer (2008) proposed a mapping data model from XML to OWL by combining XSLT technology and traditional technology. Based on XBRL semantic model in OWL, Bao (2010) proved that little semantic equivalence might be lost in transformation from XML to OWL, and that the semantic model can help reducing the redundancy of financial information. Wang (2011) announced that XBRL meta-model is the delivery product of taxonomy in design stage, while in development stage the latter is the definition of the former.

### **Solutions to semantic inconsistency in financial knowledge management**

There might be heterogeneous problems in XBRL taxonomy, for instance documents and financial data in a distributed environment. For the purpose of integration, analysis and interoperability of XBRL data, it is required to integrate the semantics of different taxonomies. Moreover, recognition and tolerance are required in handling inconsistency. One way to solve this problem is to create a formalized semantic in uniform standards and regulations with full interaction between user and information systems.

After summarizing the requirements of the operations to obtain cross-ontology information, Melnik (2004) mentioned that the core question of cross-ontology information operations was to determine how to handle the metadata. It would be useful to propose a generic model management approach, which includes advanced operators, in order to solve the semantic difference problem in cross-ontology. In order to construct an appropriate XBRL ontology, Spies (2010) did a deep analysis of XBRL data classification standard principles and subdivision systems, and proposed an ontology-building approach by using OWL as GAAP XBRL taxonomy. This approach is compatible with ODM of OMG. In an intermediary technology situation, Troshani & Lymer (2010) proposed an approach of intelligent information integration, and pointed out that this approach was also applicable to the intelligent integration of financial information, query and matching. Zhu & Wu (2011) improved the approach proposed by Troshani & Lymer (2010) and advocated using pattern matching and context intermediaries' technologies to solve the semantic ambiguity in the

XBRL financial reporting taxonomy and instance. This improved approach would enhance the efficiency of the business data supply chain Zhu & Wu (2011). Williams (2014) discussed web financial reports from the perspective of information management and gave the solution to heterogeneous data, heterogeneous ontologies and shared semantics. Nunez and Trivino (2013) suggested to construct an abstract XBRL ontology to achieve comparability under cross-classification standards in a collaborative network environment. Hodge (2014) discussed the possibility of adding perceptivity to the network financial data by setting up query facilities in an open environment. Henderson, Sheetz, & Trinkle (2012) attempted to constitute a system which could manage security data and identify suspect illegal trading by using ontology-driven approach. First, they built a security domain ontology which showed the item characteristics and its relationships based on extensive cases studies and industry-standards, and then data were imported in various systems to avoid semantic inconsistencies. O'Riain, Curry, & Harth (2012) developed an ontology library and knowledge base for the integration of heterogeneous semantic in the XBRL ontology.

#### KNOWLEDGE FORMALIZATION AND MANAGEMENT OF XBRL METADATA

Before we develop a XBRL ontology to provide a human-computer interactive applications in retrieving, checking and reasoning, we here introduce a knowledge management approach of XBRL metadata first. Based on the XBRL technical standards and taxonomy, Pan & Wang (2012) transformed graphical taxonomy into XBRL meta-model, proposed a description logic DLRBR which can be the theory of formalization to XBRL metadata and meta-model, and proved that decidability and satisfiability could be transformed mutually. However, Pan did not propose a decidability algorithm of DLRBR. In this Paper, we here introduce a tableau algorithm for DLRBR to verify the decidability.

#### Tableau algorithm for DLRBR

##### *Operators and their semantics of DLRBR*

We shall interpret the operators and their semantics before we introduce the tableau algorithm. The basic elements in DLRBR are concepts and roles, which describe the object type and relationships among these objects. Suppose we set  $A$  and  $P$  as atom concept and atom relationship respectively, any concept  $C$  and any relationship  $R$  can be described as:

$$C ::= \top_1 | A | \neg C | C_1 \sqcap C_2 | C_1 \sqcup C_2 | (\leq k[i]R);$$

$$R ::= \top_2 | P(i/2:C) | \neg R | R_1 \sqcap R_2 | R_1 \sqcup R_2;$$

where  $i$  is the  $i$ -th element of relationship  $R$  with the value of 1 or 2;  $k$  is an integer;  $(i/2:C)$  shows the  $i$ -th concept related to relationship  $R$  is  $C$ ;  $\leq k[i]R$  shows the  $i$ -th element's multiplicity constraint of relationship  $R$ ;  $(i/2:C)$  and  $\leq k[i]R$  can be viewed as the transformation from  $\exists nR$  and  $\exists nR.C$  but with the same semantic presentation.

The semantic rule of each operator in DLRBR is listed as follows, where  $C$  and  $D$  are terminology,  $R$  and  $S$  are attributes.

$$\begin{array}{ll}
 \top_1 = \Delta^I & \top_2^I = (\Delta^I)^2 \\
 A^I \subseteq \Delta^I & P^I \subseteq (\Delta^I)^2 \\
 \neg C^I = \Delta^I \setminus C^I & (i/2: C)^I = \{t \in \top_2^I \mid t[i] \in C^I\} \\
 (C_1 \sqcap C_2)^I = C_1^I \cap C_2^I & \neg R^I = \top_2^I \setminus R^I \\
 (R_1 \sqcap R_2)^I = R_1^I \cap R_2^I & \\
 (\leq k[i]R)^I = \{a \in \Delta^I \mid \{t \in R^I \mid t[i] = a\} \mid \leq k\} & \\
 (eq \ C[i_1]R_1, \dots, [i_j]R_j)^I = \{\forall a, b \in C^I, \forall t_1, s_1 \in R_1^I, \dots, t_j, & \\
 s_j \in R_j^I : \{a = t_1[i_1] = \dots = t_j[i_j]\} \wedge \{b = s_1[i_1] = \dots = s_j[i_j]\} \wedge & \\
 \{t_h[i_h] = s_h[i_h]\}, h \in \{1, 2, \dots, j\}, i \neq j\} \rightarrow \{a = b\} & 
 \end{array}$$

### Tableau algorithm for DLRBR

Tableau algorithm for description logic DLRBR can be viewed as the extending of ALCN by the reason of  $\theta nR.C$  and  $\theta nR$  in DLRBR. We hence proposed the tableau algorithm for DLRBR based on the tableau algorithm for ALCN. For any instance or element  $X_0$  of an interpretation  $C_0^I$  in concept  $C_0$  in NNF, based on the transformation regulation of decidability algorithm, tableau algorithm for DLRBR can be shown as follows:

Initial input:  $A_0 = \{C_0(X_0)\}$ ;

Root node:  $X_0$ ;

Tree building process:

(1) Determine whether there is existence constraint of concept  $C_0$ . If the answer is yes, increase the corresponding nodes according to the number of existence constraints, and mark them with  $A(x)$ . It turns out that  $A(x)$  is a collection of some concepts, so that there will be an  $x$  to satisfy  $A(x)$ . What is more, there might be many  $x$  which can satisfy  $A(x)$  in the interpretation domain. But the root node has  $A(x) = \{C_0\}$ . If there is no existence constraint in concept  $C_0$ , then stop the algorithm;

(2) Go to step (1) for all the concepts which have existence constraint, then extend the tree;

(3) In the procedure of extending and constructing a new node, if there is no conflict such as  $\{C, \neg C\} \subseteq A(x)$  in  $A(x)$  and no more regulation for any concept  $C$  and its instance  $x$ , a complete tree with no conflicts is finally built.

Result output: Non-empty individual  $C_0^I$ .

We have DLRBR tableau algorithm regulations in [Table 1](#).

**Table 1.** DLRBR tableau algorithm regulations

Name	Rules
Rul. $\sqcap$	If $C_1 \sqcap C_2 \in A(x)$ , and $\{C_1, C_2\} \notin A(x)$ ; Then $A'(x) = A(x) \cup \{C_1, C_2\}$
Rul. $\sqcup$	If $C_1 \sqcup C_2 \in A(x)$ , and $\{C_1, C_2\} \cap A(x) = \emptyset$ ; Then $A'(x) = A(x) \cup \{C_1\}$ , $A''(x) = A(x) \cup \{C_2\}$
Rul. $\exists$	If $\exists R.C \in A(x)$ , and there is no individual $y$ in nodes marking collection $A(x)$ to let $C \in A(y)$ , $(x, y) \in R$ ; then there can be a new individual $z$ , increase a new nodes $z$ , let $A'(x) = A(x) \cup \{A(x, z) = R, A(z) = \{C\}\}$
Rul. $\forall$	If $\forall R.C \in A(x)$ , and there is an individual $y$ in nodes marking collection $A(x)$ to let $(x, y) \in R$ , but $C \notin A(y)$ ; then $A'(x) = A(x) \cup \{C\}$
Rul. $\geq$	If $(\geq nR) \in A(x)$ , there is no individual $y_1, \dots, y_n$ in nodes marking collection $A(x)$ to let $(x, z_i) \in R$ , $z_i \neq z_j (1 \leq i < j \leq n)$ ; then there can be new individual $y_1, \dots, y_n$ , let $A'(x) = A(x) \cup \{R(x, y_i) \mid 1 \leq i \leq n\} \cup \{y_i \neq y_j \mid 1 \leq i < j \leq n\}$
Rul. $\leq$	If $(\leq nR) \in A(x)$ , there is different individual $y_1, \dots, y_n$ in nodes marking collection $A(x)$ to let $(x, y_1), \dots, (x, y_{n+1}) \in R$ , and for $i \neq j$ has $(x, y_i) \neq (x, y_j) \notin R$ ; then for paired $y_i, y_j, i > j, (x, y_i) \neq (x, y_j) \notin R, A_{i,j} = [y_i / y_j]$ can alternative $y_j$ with $y_i$

### Algorithmic properties of DLRBR

#### (1) Soundness

Suppose  $S'$  is a new limited collection transformed from limited collection  $S = \{A_1, \dots, A_k\}$  in *ABox* in applying tableau algorithm regulations,  $S = \{A_1, \dots, A_k\}$  is consistent (Satisfiable) if and only if  $S'$  is consistent (Satisfiable).

#### Proof:

Firstly, all reasoning problems in DLRBR can be transferred to the judgment for the inclusion relationship. For any two concepts  $C$  and  $D$  in collection  $S$  and  $S'$ ,  $C$  is unsatisfiable equivalent to  $C$  is included in  $\perp$ ;  $C$  and  $D$  are equal equivalent to  $C$  is included in  $D$  and  $D$  is included in  $C$ ;  $C$  and  $D$  are disjoint equivalent to  $C \sqcap D$  is included in  $\perp$ .

Secondly, all reasoning problems in DLRBR can be transferred to the judgment for the satisfiability.  $C$  is included in  $D$  are equivalent to  $C \sqcap \neg D$  is unsatisfiable;  $C$  and  $D$  are equal equivalent to  $C \sqcap \neg D$  and  $\neg C \sqcap D$  are both unsatisfiable;  $C$  is disjoint with  $D$  are equivalent to  $C \sqcap D$  is unsatisfiable.

Hence, the new limited collection  $S'$ , which is transformed from limited collection  $S = \{A_1, \dots, A_k\}$  in applying tableau algorithm regulations, have the same satisfiable condition.

## (2) Termination

For any concept  $C_0$  in accordance with NNF in DLRBR, there is not an unlimited times transformation collection  $\{\{C_0(x_0)\}\} \rightarrow S_1 \rightarrow S_2 \rightarrow \dots$  in applying Tableau algorithm regulations, the Tableau algorithm has termination property.

### Proof:

First, the Tableau algorithm is operated in the aspect of tree extension, without deleting any node or concept in the complete tree.

Second, the concept length of DLRBR with the mark  $|C|$  is defined as the number of concept expression, and the sub concept collection is defined as:

$$Sub(C) = \begin{cases} \{C\} \cup Sub(C_1), & \text{if } C = \neg C_1, \text{ or } C = \exists RC_1, \text{ or } C = \forall RC_1 \\ \{C\} \cup Sub(C_1) \cup Sub(C_2), & \text{if } C = C_1 \sqcap C_2, \text{ or } C = C_1 \sqcup C_2, \\ \emptyset, & \text{other} \end{cases}$$

we have  $|Sub(C)| \leq |C|$ . The tableau algorithm will extend a new node with its object only when  $\exists$  regulation is applied, the branch number of the built complete tree is determined by existence limited operator  $\exists$  in concept  $C_0$ . In the algorithm initiation stage, we have  $A_0 = \{C_0(x_0)\} \in Sub(C_0)$ , we will have  $|Sub(C_0)| \leq |C_0|$  and  $|A(x_0)| \leq |C_0|$  after applying regulations. So, the extension of nodes is limited with the maximum length of  $|C_0|$ ;

Third, the concept depth of DLRBR with the mark  $role - depth(C)$  is defined as the number of existence constraint and full name constraint. In the tree extending procedure, the number of concepts is diminishing, we have  $role - depth(C_0) \leq |C_0|$ . if there are existence constraints  $\exists R.C \in A(x)$  in the nodes collection marked by  $A(x)$ , we will extend a new node  $z$  according to existence constraint, where  $A'(x) = A(x) \cup \{A(x, z) = R, A(z) = \{C\}\}$ . Thus, we have  $A(z) \in A(x)$ ,  $role - depth(z) < role - depth(x) \leq |C_0|$ . So, the depth is limited.

Hence tableau algorithm is limited, and it can be terminated.

## (3) Completeness

For any concept  $C_0$  in accordance with NNF in DLRBR, it can produce a complete tree without conflicts after applying Tableau algorithm regulations, and  $C_0$  is satisfiable.

### Proof:

Suppose concept  $C_0$  is satisfiable, there are a model and one element  $x_0$  in the interpret domain  $C_0^I$  of  $C_0$ , where  $C_0^I \neq \emptyset$ ,  $x_0 \in C_0^I$ . All transformation according to the Tableau algorithm regulations are implemented based on consistency, so satisfiability will be the same in the limited times transformation.

### Knowledge formalization to XBRL metadata relationships

When a financial report is produced, not only financial subjects and items but also all the relationships among these subjects and items are needed. These relationships include sum-up relationships, inheritance relationships and generalization relationships, etc. The formalization of these mentioned relationships is called semantic expression. The report regulations and requirements are satisfied only when the relationships are formalized and the computer-reasoning is achieved. Furthermore, it is possible for computers to do the relevant intelligent processes such as reading, analyzing and reasoning in XBRL. Ding Pan (2012) analyzed the XBRL linkbases which contain metadata relationships. He also summarized that XBRL metadata relationships can mainly include hierarchical relationships, ordinary-special relationships, part-whole relationships and sum-up relationships. To avoid the undecidability of description logic reasoning and to decrease the complexity, hierarchical relationships, ordinary-special relationships and sum-up relationships are formalized in the paper.

Obviously, part-whole relationships (PW relationships) are viewed as the most important semantic relationships. Relevant researchers have analyzed the PW relationship, but they did not discuss its applicability in XBRL. Based on the predecessors' research, this paper proposes a formalization method of PW relationships. PW relationships are used to describe the combination of the relationships between various objects in the system. In XBRL, the PW relationship is used to define linkbases. Domain-member relationships can be viewed as a kind of part-whole relationships. Generally speaking, a PW relationship can be divided into the generalized PW and the specialized PW according to how the specific semantic constraints are considered. A PW relationship contains several sub-types which are called PW parent-child relationships. PW parent-child relationships can be viewed as a PW relationship which is specific, concrete and has semantic meanings and characteristics.

According to XBRL, it is usually approbated that financial elements have the following characteristics: (1) Homogeneity, which means that the financial subjects in the same and lower levels are similar to each other; (2) Separability, which means that the lower financial subjects can exist without the higher ones; (3) Functionality, which means that the lower level subjects can reveal or has some of the attributes and values of the superior subjects in a certain degree. (4) Constructively, the lower level subjects can have some specific functions and structures of the superior subjects. However, in financial report elements are not invariant, that is to say, the lower subjects can be separated from the higher ones. In such a situation, the classification for PW relationships proposed by Winston (1986) is more applicable in the following formalizations than Odell (1998). In UML, PW relationships are described as association and combination. Both association and combination can describe a PW

relationship, and the difference between them is that the ability to express a PW relationship of the former is weaker than the latter one's. In terms of association, the lifetime between the object representing the part and the object representing the aggregation is irrelevant. Even though the aggregate object is deleted, it does not mean that the object representing the part is deleted too. In combination, the component part and the integral part have the same lifetime. If the integral part does not exist, so does the component. Elements in XBRL financial report can exist independently, and they do not have unique lifetimes, it is more appropriate to represent generalized PW relationships by associating them in formalization process. According to the formalization of association relationships, generalized PW relationships can be formalized as  $Agg_{x-y}(x, y)$ . This means that if the relationship between X and Y is a PW relationship, then x is a part of y.

PW relationships can be divided into two sub-types: Component-Integral relationships and Member-Collection relationships, which are formed by adding semantic conditional operators to generalized PW relationships. According to the characteristics of the PW sub-relationship and in order to establish semantic conditional operators, the main features are:

(1) Relying conditional operators

Component and integral of a PW relationship have the relying conditional relationship, which is brought about by the separability of the PW relationship. If it satisfies the requirements of separability, which means that components can be separated from integral and each of them does not has dependencies, it can be formalized as  $Indenp(x, y)$ . Otherwise, if it does not satisfy the separability, which means that components cannot be separated from the integral and each of them has dependencies, since the integral cannot exist if separated from components, it can be formalized as  $Denp(x, y)$ .

(2) Homogeneous conditional operator

Component and integral of a PW relationship have a homogeneous conditional relationship which comes from the homogeneity of PW relationships. If unary predicate  $Ess(x)$  is used to represent the essential attributes of entity x, when component x and integral y satisfy homogeneity, they can be formalized as  $Ess(x) \subseteq Ess(y)$ .

(3) Functional conditional operator

The relationship between the component and integral of PW is functional conditional, and it is generated from functionality of PW relationship. If a unary predicate  $Func(x)$  is used to represent the function of entity x, when component x has the same function with integral y, it can be formalized as  $Func(x) = Func(y)$ . When partial x undertakes the expression, but only a part of the whole y function, it can be formalized as  $Func(x) \subset Func(y)$ . When x and y have no functionality, it can be formalized as  $Func(x) \neq Func(y)$ .

(4) Membership conditional operator

Component and integral of a PW relationship have Membership conditional operator, which is used to make clear that component  $x$  is one of the elements of integral  $y$  and integral  $y$  is a sum of component  $x$ . There are similarities among the members, collection exists thanks to some common features. Binary predicate  $Mem(x, y)$  is used to formalize  $x$  as a member of  $y$ .

According to the PW relationship and semantic conditional operator, the two kinds of PW sub-types about XBRL financial report can be formalized as follows:

(1) Component-Integral Object Composition Sub PW relationships

This relationship is also called CIO relationship, which is the most common sub-type of PW relationship. The CIO relationship defines the level of the components presenting and expressing the integral. CIO relationships also define the relationship between components and integral, and meet the requirements of functionality and separability, which means components can be isolated from the integral and undertake some specific functions of the integral. Component and Integral can be not only physical objects but also abstract objects. Because there is no homogeneity between component and integral in representing abstract objects, the homogeneity in CIO relationships is not satisfied. The CIO relationship can be considered as PW relationships with extra functions. Particularly because the elements of accounting subjects have the same attributes, elements in XBRL satisfy the homogeneity as well. This can be formalized as:

$$CIO(x, y) = Agg_{x-y}(x, y) \wedge Indenp(x, y) \wedge (Func(x) \subset Func(y)) \wedge (Ess(x) = Ess(y))$$

(2) Member-Collection Sub PW relationships

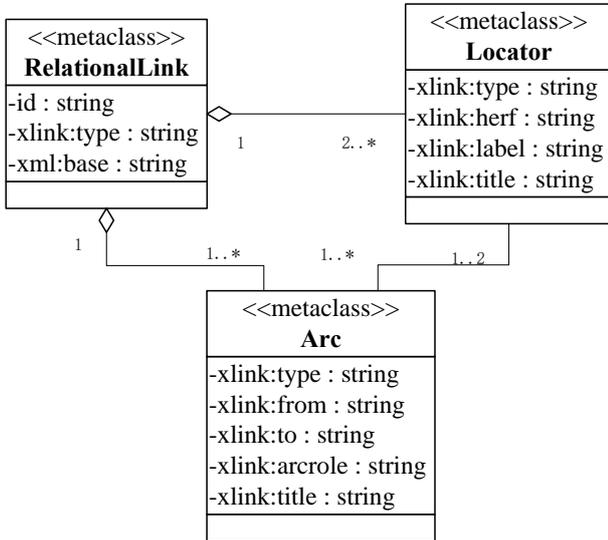
This can be shortly called MC relationship, which is one of the most important sub-types of PW relationships. MC relationships define the collection of relationships between component and integral, which means that components are elements that consist of integral, while integral is the collection of components. Members may exist independently in XBRL, because they have the same essential attributes and some of them can undertake or represent certain functions of integral. Thus, MC relationships can be viewed as the combination of CIO relationships and membership conditional operator. It can be formalized as:

$$\begin{aligned} MC(x, y) &= CIO(x, y) \wedge Mem(x, y) \\ &= Agg_{x-y}(x, y) \wedge Indenp(x, y) \wedge (Func(x) \subset Func(y)) \wedge (Ess(x) = Ess(y)) \wedge Mem(x, y) \end{aligned}$$

Example of XBRL knowledge management via metadata formalization

### Formalization to XBRL meta-model

Based on the XBRL taxonomy meta-model proposed by Pan, Wang & Zhang (2012) and Huang (2011), we will formalize the XBRL relational linkbase meta-model in **Figure 1**. Relationships between financial concepts are defined and documents are linked to interpret these concepts by XBRL relational linkbases.



**Figure 1.** XBRL relational linkbase meta-model

According to DLRBR, metaclass *RelationalLink*, *Locator* and *Arc* can be formalized as follows:

(1) Metaclass *Locator*

$$\begin{aligned}
 Locator &\sqsubseteq \forall[1](xlink: type \rightarrow (2: String)), \\
 Locator &\sqsubseteq \forall[1](xlink: href \rightarrow (2: String)), \\
 Locator &\sqsubseteq \forall[1](xlink: label \rightarrow (2: String)), \\
 Locator &\sqsubseteq \forall[1](xlink: title \rightarrow (2: String)),
 \end{aligned}$$

(2) Metaclass *Arc*

$$\begin{aligned}
 Arc &\sqsubseteq \forall[1](xlink: type \rightarrow (2: String)), \\
 Arc &\sqsubseteq \forall[1](xlink: from \rightarrow (2: String)), \\
 Arc &\sqsubseteq \forall[1](xlink: to \rightarrow (2: String)), \\
 Arc &\sqsubseteq \forall[1](xlink: arcrole \rightarrow (2: String)), \\
 Arc &\sqsubseteq \forall[1](xlink: title \rightarrow (2: String));
 \end{aligned}$$

(3) Metaclass *RelationalLink*

$$\begin{aligned}
 RelationalLink &\sqsubseteq \forall[1](id \rightarrow (2: String)), \\
 RelationalLink &\sqsubseteq \forall[1](xlink: type \rightarrow (2: String)), \\
 RelationalLink &\sqsubseteq \forall[1](xlink: base \rightarrow (2: String));
 \end{aligned}$$

(4) Metaclass *RelationalLink* and *Locator* are aggregation associations, the linchpin of *RelationalLink* and *Locator* are 1 and 2...\* respectively, we have:

$$\begin{aligned}
 Agg_{RelationalLink-Locator} &\sqsubseteq (1: RelationalLink) \sqcap (2: Locator), \\
 Locator &\sqsubseteq (\geq 1[2] Agg_{RelationalLink-Locator}) \sqcap (\leq 1[2] Agg_{RelationalLink-Locator});
 \end{aligned}$$

**Table 2.** Assets and Liability Statement (part)

Assets
CurrentAssets
BankBalancesAndCash
FinancialAssetsHeldForTrading

(5) Metaclass *RelationalLink* and *Arc* are aggregation associations, the linchpin of *RelationalLink* and *Arc* are 1 and 1...\* respectively, we have:

$$Agg_{RelationalLink-Arc} \sqsubseteq (1: RelationalLink) \sqcap (2: Arc),$$

$$Arc \sqsubseteq (\geq 1[2]Agg_{RelationalLink-Arc}) \sqcap (\leq 1[2]Agg_{RelationalLink-Arc});$$

(6) Metaclass *Locator* and *Arc* is association, the linchpin of *Locator* and *Arc* are 1 and 1...\*, respectively. Association can be formalized as a concept  $Ass_{Locator-Arc}$  and its two relevant associated roles  $r_{Locator-Arc}$ ,  $r_{Arc-Locator}$ , we have:

$$Ass_{Locator-Arc} \sqsubseteq \exists[1]r_{Locator-Arc} \sqcap (= 2[1]r_{Locator-Arc}) \sqcap,$$

$$\forall[1](r_{Locator-Arc} \rightarrow 2: Locator) \sqcap \exists[1]r_{Arc-Locator} \sqcap$$

$$\forall[1](r_{Arc-Locator} \rightarrow 2: Arc)$$

$$(eq\ Ass_{Locator-Arc}\ [1]r_{Locator-Arc},\ [1]r_{Arc-Locator});$$

### Formalization to XBRL metadata

The aim of formalization to XBRL metadata is to find out the content to be formalized, formalize these classified contents based on the formalization theory, and make it possible for computers to reason and check it.

We take part of the assets from an ‘assets and liabilities’ statement as an example, with the financial elements being listed in **Table 2**.

The XBRL PW relationships can be formalized as follows:

$$CIO(CurrentAssets, Assets) =$$

$$Agg_{CurrentAssets-Assets}(CurrentAssets, Assets) \wedge$$

$$Indenp(CurrentAssets, Assets) \wedge$$

$$(Func(CurrentAssets) \subset Func(Assets)) \wedge$$

$$(Ess(CurrentAssets) = Ess(Assets))$$

$$\begin{aligned} &CIO(\text{BankBalancesAndCash}, \text{CurrentAssets}) = \\ &Agg_{\text{BankBalancesAndCash}-\text{CurrentAssets}}(\text{BankBalancesAndCash}, \\ &\text{CurrentAssets}) \wedge \\ &Indenp(\text{BankBalancesAndCash}, \text{CurrentAssets}) \wedge \\ &(\text{Func}(\text{BankBalancesAndCash}) \subset \\ &\text{Func}(\text{CurrentAssets})) \wedge \\ &(\text{Ess}(\text{BankBalancesAndCash}) = \text{Ess}(\text{CurrentAssets})) \end{aligned}$$

$$\begin{aligned} &CIO(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) = \\ &Agg_{\text{FinancialAssetsHeldForTrading}-\text{CurrentAssets}} \\ &(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) \wedge \\ &Indenp(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) \wedge \\ &(\text{Func}(\text{FinancialAssetsHeldForTrading}) \subset \\ &\text{Func}(\text{CurrentAssets})) \wedge \\ &(\text{Ess}(\text{FinancialAssetsHeldForTrading}) = \\ &\text{Ess}(\text{CurrentAssets})) \end{aligned}$$

$$\begin{aligned} &MC(\text{CurrentAssets}, \text{Assets}) = \\ &CIO(\text{CurrentAssets}, \text{Assets}) \wedge \\ &Mem(\text{CurrentAssets}, \text{Assets}) = \\ &Agg_{\text{CurrentAssets}-\text{Assets}}(\text{CurrentAssets}, \text{Assets}) \wedge \\ &Indenp(\text{CurrentAssets}, \text{Assets}) \wedge \\ &(\text{Func}(\text{CurrentAssets}) \subset \text{Func}(\text{Assets})) \wedge \\ &(\text{Ess}(\text{CurrentAssets}) = \text{Ess}(\text{Assets})) \wedge \\ &Mem(\text{CurrentAssets}, \text{Assets}) \end{aligned}$$

$$\begin{aligned}
&MC(\text{BankBalancesAndCash}, \text{CurrentAssets}) = \\
&CIO(\text{BankBalancesAndCash}, \text{CurrentAssets}) \wedge \\
&Mem(\text{BankBalancesAndCash}, \text{CurrentAssets}) = \\
&Agg_{\text{BankBalancesAndCash}-\text{CurrentAssets}} \\
&(\text{BankBalancesAndCash}, \text{CurrentAssets}) \wedge \\
&Indenp(\text{BankBalancesAndCash}, \text{CurrentAssets}) \wedge \\
&(\text{Func}(\text{BankBalancesAndCash}) \subset \text{Func}(\text{CurrentAssets})) \wedge \\
&(\text{Ess}(\text{BankBalancesAndCash}) = \text{Ess}(\text{CurrentAssets})) \wedge \\
&Mem(\text{BankBalancesAndCash}, \text{CurrentAssets})
\end{aligned}$$

$$\begin{aligned}
&MC(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) = \\
&CIO(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) \wedge \\
&Mem(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) = \\
&Agg_{\text{FinancialAssetsHeldForTrading}-\text{CurrentAssets}} \\
&(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) \wedge \\
&Indenp(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets}) \wedge \\
&(\text{Func}(\text{FinancialAssetsHeldForTrading}) \subset \text{Func}(\text{CurrentAssets})) \wedge \\
&(\text{Ess}(\text{FinancialAssetsHeldForTrading}) = \text{Ess}(\text{CurrentAssets})) \wedge \\
&Mem(\text{FinancialAssetsHeldForTrading}, \text{CurrentAssets})
\end{aligned}$$

Given that all of the financial elements and the relationships have now been formalized, we can go on to implement the reasoning on the XBRL metadata.

#### HUMAN-COMUTER INTERACTIVE REASONING AND CHECKING TO XBRL ONTOLOGY

For better verifying the intelligent reasoning method in description logic in a human-computer interaction perspective, we first should develop a metadata repository to store, integrate and manage XBRL metadata, and accordingly construct an XBRL ontology; secondly, we have to design an application API for reasoners such as Jena, RacerPro, etc., to access the data in this repository. In the end, we have to give reasoning rules, which can be customized and personalized proposed by different accountant users to do reasoning and consistency checking.



Figure 2. XBRL taxonomy metadata in metadata repository

### XBRL metadata repository

In data analysis and application, metadata repository is usually viewed as metadata management system, which can describe all the terminologies, concepts and their relationships precisely. We develop the XBRL metadata repository in the following steps: sequentially construction of the metadata of XBRL taxonomy elements, definition of the linkbase, labelling of the linkbase, presentation of the linkbase, calculation of the linkbase and the attributes. The repository information system provide a graphic user interface for accounting users to input all the financial metadata humanly, and the finish developing XBRL taxonomy metadata are shown in Figure 2.

### XBRL taxonomy ontology

For the reasoning and result verification in consistency checking of XBRL meta-model and metadata in repository, we built an XBRL taxonomy ontology from the demand of accounting users (in Figure 3) with the name “createtest14.owl”, whose content is in accordance with the developed metadata repository, in Protégé 3.4.8.

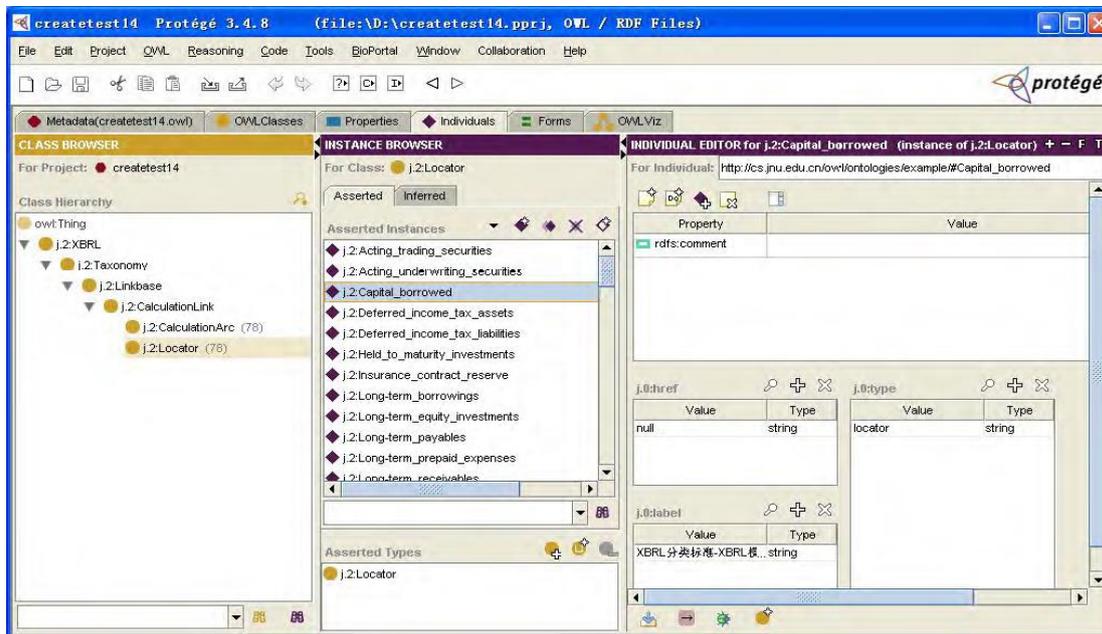


Figure 3. XBRL taxonomy ontology

## Reasoning and checking

In this stage, based on the human-computer interaction ability, the system allows the users to define reasoning rules personally. Consistency checking is the typical use in intelligent logical reasoning for computers. We would verify the proposed formalization theory in equivalence checking and disjoint checking, which are common consistency checking methods.

### (1) Equivalence checking

In DLRBR we have equivalence constraint. That is to say, if two instances have the same attributes and relationship mapping, then these two instances are equivalent or are the same instance. When building XBRL taxonomy ontology, we check the equivalence by setting six attributes for each financial element with the following Jena rules:

Rule: (?C hasinstance ?a) (?C hasinstance ?b) (?R hasproperty ?t1) (?R hasproperty ?t2) (?R hasproperty ?t3) (?R hasproperty ?t4) (?R hasproperty ?t5) (?R hasproperty ?t6) (?S hasproperty ?s1) (?S hasproperty ?s2) (?S hasproperty ?s3) (?S hasproperty ?s4) (?S hasproperty ?s5) (?S hasproperty ?s6) (t1notEqual t2) (t2 notEqual t3) (t3 notEqual t4) (t4 notEqual t5) (t5 notEqual t6) (s1 notEqual s2) (s2notEqual s3) (s3 notEqual s4) (s4 notEqual s5) (s5 notEqual s6) (t1 Equal s1) (t2 Equal s2) (t3 Equal s3)(t4 Equal s4) (t5 Equal s5) (t6 Equal s6) -> (a Equal b)

Results checking can be displayed graphically in Protégé based on the above XBRL taxonomy ontology after we input the reasoning rule. In calculation linkbase, we set two metadata Asset to Current Assets and Assert to Current Assets with the same attributes in

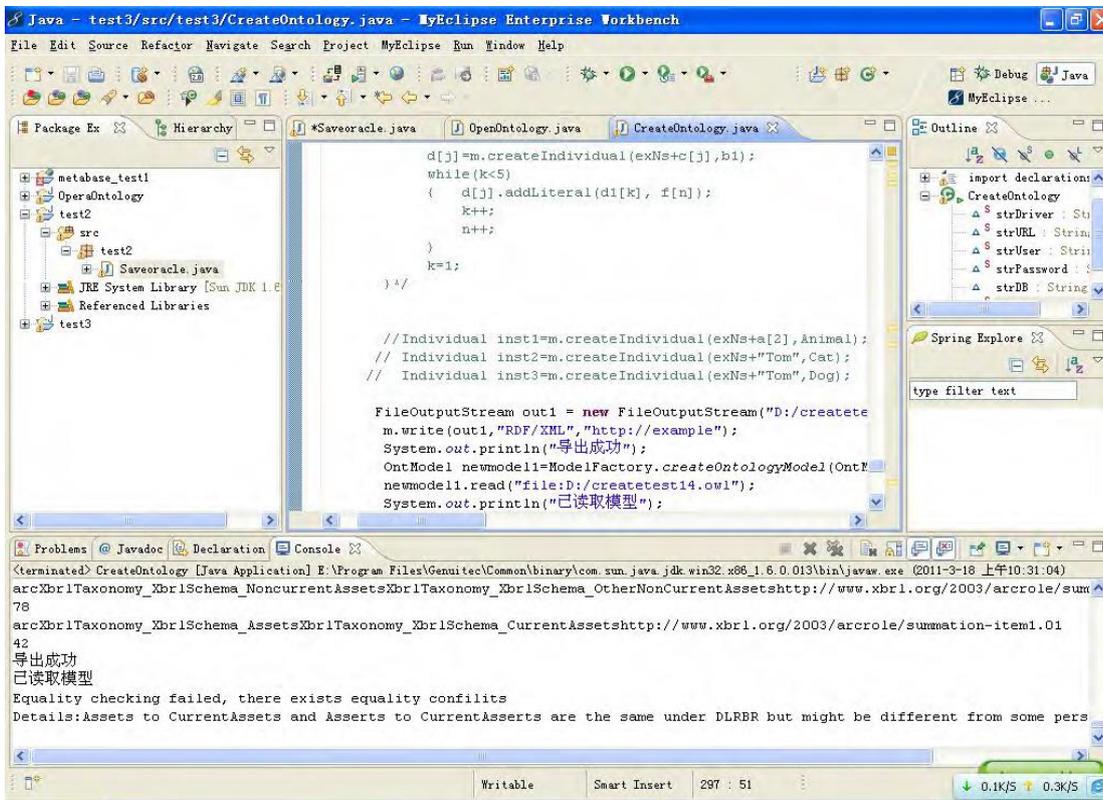


Figure 4. Result of equivalence checking

xlink:type, xlink:href and xlink:label. Reasoning in Jena, we have the warning result in Figure 4: “Equality checking failed, there is equality conflicts, Details: Asset to Current Assets and Assert to Current Assets are the same under DLRBR but might be different from some perspectives”. This can be the verification process in equivalence checking.

(2) Disjoint checking

We set the checking example in calculation linkbase and label linkbase in the meta-model and metadata verification layer in Jena Rule 2 and Rule3 as follows:

Rule 2: (?Chasinstance ?c) (?D hasinstance ?c) (?C disjointwith ?D) ->confilits

Rule 3: (?Rhasproperty ?r) (?S hasproperty ?r) (?C disjointwith ?D) ->confilits

According to XBRL technical standard and China Accounting Standard, calculation linkbase and label linkbase are disjoint. We create a class dif which appertains to both calculation linkbase and label linkbase. In addition, we create an instance Asset\_to\_CurrA for class dif. As we know, class dif and its instance can only be a part of calculation linkbase or label linkbase. The disjoint checking can be implemented in Jena, with the results in Figure 5.

```

<terminated> CreateOntology [Java Application] E:\Program Files\Genuitec\Common\binary\com.sun.java.jdk.win32.x86_1.6.0.013\bin\javaw.exe (2011-3-18 上午11:57:57)

- Error ("conflict"): "Individual a member of Nothing"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA

- Error ("conflict"): "Individual a member of disjoint classes"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Locator
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#CalculationArc

- Error ("conflict"): "Two individuals both same and different, may be due to disjoint classes or functional property"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA

- Error ("conflict"): "Individual a member of disjoint classes"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#Asset_to_CurrA
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#CalculationArc
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Locator

- Warning ("Inconsistent class"): "subclass of two disjoint classes"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#dif
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Locator
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#CalculationArc

Warning ("Inconsistent class"): "subclass of two disjoint classes"
Culprit = http://cs.jnu.edu.cn/owl/ontologies/example/#dif
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#CalculationArc
Implicated node: http://cs.jnu.edu.cn/owl/ontologies/example/#Locator

```

**Figure 5.** Results of disjoint checking

From the above reasoning and checking samples, we have prospective as follows:

- (1) Metabase repository and its application API are the basis of an XBRL quality control system;
- (2) After comparing the metadata repository with XBRL taxonomy ontology built by Protégé, we find that the repository could support the XBRL ontology;
- (3) Rules built by Jena under description logic DLRBR provide the reasoning engine and consistency checking for XBRL report quality promotion.

## DISCUSSION AND CONCLUSION

Based on the comprehensive research of the literature related to finance and human-computer interaction, researchers have reported a variety of methods for ontology building, reasoning and inconsistency handling, with a purpose of making computer can read, understand and analyze to data automatically with the help and interaction of different users. However, they have not proposed an approach based on logical theory in human-computer interactive perspective. Moreover, the logical theory is used in some certain and limited research field.

In the previous study, researchers have pointed out logical theory can be applied into accounting knowledge management. While XBRL provides this opportunity with its XML format. We are here extending the description logic into financial field, with the proposed logical method DLRBR. This is in accordance with the requirement of the XBRL initiatives.

When a new method is proposed, algorithm and properties should be proved. We introduce the Tableau algorithm for DLRBR and prove the algorithm properties accordingly. The proved algorithm is consistency with the research frameworks proposed by Spies, M. (2010). and MUSING. The knowledge management procedures to web financial reports are the following research of Pan et al., and provide a compensative step. The repository developing, ontology building and reasoning rules showing are carried out in human-computer interactive perspective and provide the way of accounting users to use and participate in. These functions also provide the opportunity for the users to learn, communicate and use with each other, as well as with computer. Moreover, the enterprises can educate the employees to improve their professional ability in daily work. Students can be educated to handle a human-computer interactive jobs in campus life. In the future, we should try to solve the conflict automatically by logical theory and consummate the human-computer interactive mechanism in web financial reporting handling, analyzing and other application.

In the environment of web 2.0, huge internet financial data bring challenge to knowledge management stages in information transformation, analysis and process, etc. In this paper, the decidability and infer theorems of DLRBR are proved, reasoning and consistency checking are carried out for XBRL meta-model and metadata in the human-computer interactive perspective. This work, which is consistent with XBRL initiatives, is helpful for prompting the ability of knowledge management and education in accounting users.

#### COMPETING INTERESTS

The authors declare that they have no competing interests.

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