An Ontology-Based Approach for Semantic Conflict# Resolution in Database Integration#

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Abstract:# #An#important task in database#integration is to resolve data conflicts,#both# on schema-level and#on#semantic-level. Especially difficult the latter is.#Some existing# approaches#to semantic interoperability#have been criticized for their lack of#semantic# richness#and domain generality.#To overcome these limitations, this paper introduces a# novel#approach#to#detect and resolve#various#semantic conflicts in heterogeneous# databases.# Our approach# includes two important parts: a semantic conflict# representation model based on our classification framework of semantic conflicts, and# a method for detecting and resolving semantic conflicts based on this model.#The# system has been developed, experimental#evaluations on which indicate that this# approach can resolve the semantic conflicts effectively,# without learning about# domains#and integration patterns.#

Introduction#

With the constantly increasing reliance on database systems to store#and#process# data,#comes the additional problem of ensuring interoperability between these# systems.#The fundamental problem#in interoperability is that of identifying objects# in different databases that are semantically related, and then resolving the data# conflicts both on schema-level and on semantic-level. Another important problem# is how to construct an integrated#view over many heterogeneous data sources[1].# According to#Alon Halevy[2],achieving#semantic#interoperability has been the first# challenge facing information integration. In this paper, we are interested in#the# former question, and#focus#on the solutions to#relational databases#(RDBs).#
Previous researches#in interoperability#can resolve#data conflicts on#schema-level# effectively#by#schema translation and intermediary mechanisms.#For example, the# federated schema approach attempts to construct a global schema and establish# mappings between the global schema and the participating local schemas.# However, because#it#is#lack#of semantic richness and flexibility,#it#provides#little or# no support for semantic conflict resolution.##
It is becoming increasingly clear that the emerging technology concerned with the# development and application of ontologies will play a#central role in overcoming# the problems of semantic heterogeneity.# An ontology is a formal, explicit# specification of a shared conceptualization[3]. Compared with database schemas,# ontologies#allow#more complete#and more precise domain models[4].##
Recently,#some#ontology-based approaches to semantic integration have been# developed.#They#can be#classified#into two#categories: domain-ontology-based# approach and ontology-mapping-based approach. The former approach attempts to# construct ontologies for specific#domains, which#express#the#shared knowledge#of# concepts, attributes, and rules. Local schemas participated in integration#are#built# using the concepts defined in domain ontologies, so# that# mappings between#
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semantic related information sources#can be constructed.#Even though such an# approach may be theoretically valid, the application of it is practically infeasible# due to the complexities of the domain knowledge.#Hence, it is lack of domain# generality.#The latter approach attempts to transform the problem#of schema# matching to ontology mapping after the explicit expression#of local schemas.# Ontology mappings can be created semi-automatically#using#heuristic-based#and# machine-learning algorithms, which utilize#lexical and structural#characteristics#to# find correspondences. Although many techniques have produced good results,# automatic mapping between ontologies is#still#beyond our grasp at the moment.#
The design of an ontology-based semantically interoperable system environment# that manages various semantic conflicts is a daunting task.#Semantic conflicts# should be expressed#explicitly#and#resolved effectively.#At the same time, the# approach should be flexible enough to keep independent of domains and# integration patterns. The work described in this paper provides a solution to this# challenge. We introduce a semantic conflict representation model (SCM) based on# our classification framework of semantic conflicts, which includes two important# parts, an ontology (SCO) describing the classification of semantic conflicts and an# abstract semantic model (ESM) extending RDB schema. They are described by RDF# graph[5] and OWL language[6] respectively. Also we propose the method based on# this model to detect and resolve semantic conflicts, which is accomplished by some# semantic mediators. The system has been developed, experimental#evaluations on# which indicate that this approach can resolve the semantic conflicts effectively.#
The rest of this paper is organized as follows. Section 2 discusses the relevant# researches in ontology-based semantic interoperability. Section 3 and section 4# present our semantic conflict representation model. In section 5, we introduce the# methodology for the detection and resolution of semantic conflicts.#Section 6# discusses a case study to give a#proof of the proposed framework and algorithms.# Section#7#shows the system implementation and the results#of experimental# evaluations. Section# 8# summarizes this work and discusses# some# possible# extensions.#

Related Work#

The domain-ontology-based semantic integration researches are mostly domain# specific, such as Gene Ontology[7]#and Unified Medical Language System[8]#in#the# life science community. In these systems, ontologies can be used to define a# common controlled vocabulary, similarly to applying XML to#industry specifications.# These ontologies often have thousands of concepts, and need to be developed# iteratively.#In practical applications, we don't have this "luxury" using#domain# ontologies,#because#there are no absolute semantics that are valid for all potential# users.#
On the contrary, ontology-mapping-based approaches are domain independent.# Some representative works# include# InfoSleuth[9][10],# OBSERVER[11]# and# ONION[12].#InfoSleuth is an agent-based system, which supports construction of# complex ontologies from smaller component ontologies so that tools tailored for# one component ontology can be used in many application domains.#Mappings are# explicitly specified among these ontologies as relationships between terms in one# ontology and related terms in#other ontologies.#OBSERVER uses a component-based#

approach to ontology mapping. It provides brokering capabilities across domain# ontologies to enhance distributed ontology querying, thus avoiding the need to# have a global schema.#ONION is an architecture based on a sound formalism to# support a scalable framework for ontology integration that uses a graph-oriented# model for the representation of the ontologies. Articulation rules are established# between ontologies to enable knowledge inter-operability.# These# systems# substitute ontology mapping for schema matching# by virtue of the explicit# expression# ability of ontologies. Types of mappings include class mappings,# property mappings, axioms/rules mappings, and conditional mappings, the number# of which that is supported determines the#number of semantic conflicts that can be# resolved. Although heuristic-based and machine-learning# algorithms# can help# automate#this process, they are far from being applied.#

Our SCM model differs from existing researches# on# ontology-based semantic# integration in the following ways.#

1. Domain ontologies often have large size, and are difficult to#be#maintained#due# to#the#complexity of domain knowledge. While the#SCO ontology we proposed# has# the# moderate scale. During# iterative development, it tends to be# stabilization.#
2. Ontologies in ontology-mapping-based approaches are equivalent to local# schemas, and# ontologies in domain-ontology-based approaches# express# the# shared domain#knowledge. While#the SCO ontology has the characteristics of# semantic richness and domain generality.#
3. The domain-ontology-based#approach can be#viewed#as#global-as-view, and#the# ontology-mapping-based approach#is similar to#local-as-view. While#the#SCM# model can be used in both integration patterns.#

The most related research to our work is SCROL[13]. It is developed to encode# extensible knowledge on commonly found semantic conflicts, which#provides a# systematic way of detecting and resolving#various semantic conflicts found in# heterogeneous databases. In addition, all schema components captured by a# common semantic data model, called USM, are mapped to this ontology.#On the# basis of#this model, the software environment called CREAM[14]#is#implemented. It# can be used to access heterogeneous databases via a graphical user interface.#

Compared with SCROL, our approach has some distinct characteristics as follows.#

1. SCROL is designed mainly for the resolution of conflicts among heterogeneous# geographic data sources, so the classification framework of conflicts is based on# geographic database systems. However, our work concerns relational databases.#
2. SCROL arranges the ontology hierarchically, like a#kind of#taxonomy. Therefore,# it can't describe the horizontal relationships among the "tree nodes" and#the# conversion relationships#among#conflict instances. While#our SCO ontology is# defined#by RDF#graph, which can#easily express these relationships and#be# processed by many ontology editors.#
3. In order to resolve semantic conflicts, SCROL stores mapping information# between the classification ontology and# underlying schema components.# Consequently different applications need different conflict classification# ontologies. However,# our SCO ontology# do# not# need# store this mapping# knowledge.#Concepts defined in the#SCO ontology#are used#when we extend RDB# schemas, through#which the correspondences#are built#impliedly.#

Among the researches of traditional database integration, there are also many# works related to resolving semantic conflicts, such as X-Specs[15]#and COIN[16].#

#

They often use lexical#systems or global dictionaries to define the global schema,# and use some extensible metadata models (such as#the#deductive object-oriented# data model) to express#data semantics. But in our opinion, they are primary# explorations#in the approach of#ontology-based semantic integration.#

The Ontology for Semantic Conflict Classification in# Database Integration#

In this section, we firstly present our classification framework of semantic# conflicts, which is the foundation of our research. Then this classification# framework is defined as an ontology, which is represented as a RDF graph. So it can# be clearly comprehended and easily processed.#

The Classification Framework of Semantic Conflicts#

According to Won Kim[17], since a database is defined by its schema and data, one# can classify conflicts at the highest level as either schema or data conflicts.# Schema conflicts result from the use of different schema definitions in different# databases.#While#data conflicts are due to inconsistent data in the absence of# schema conflicts.##

Here we develop a complete framework for enumerating and classifying those# conflict types which can't be resolved in#the#RDB#model. So it is only a subset of# data#conflicts#that are classified in [16],#[17],#and#[18].#The RDB schema#can deal# with "weak semantics", such as data scale and data length. They can't represent# the implied data semantics. Therefore, we can't detect these "deep level"# conflicts, to say nothing of resolving them according to some predefined# transformation rules.##

The classification framework we proposed#is as follows.#

1. **Data#Type#Conflicts.** These conflicts occur when two attributes have different# data types. For example, "Student.id" can be defined as an 8 character string# or an 8 digit integer.#Some kinds#of data type conflicts can be#resolved#by# database itself, while most of them rely on the explicit expression# of# transformation rules.#
2. **Data Format# Conflicts**. These conflicts occur when two attributes have# identical data type but different data formats. For instance,#the#"date" type# can be represented as "DD/MM/YY"#and#"YYYY/MM/DD"#two different formats.# There is a one-to-one mapping relationship between them.##
3. **Data#Unit#Conflicts.**#These conflicts occur when two attributes are represented# using different units or#measures. For#example, the "length unit" might be# "meter", "kilometer", and "feet" etc. There are one-to-one mapping# relationships between them, and these relationships are#transitive.#
4. **Data# Precision# Conflicts.** These conflicts occur when two attributes have# identical data type but different data precisions. The mapping relationships# between them might be one-to-one or many-to-one. For example,#the#"area"# field#can be#represented#using 10^{5}#and 10^{7}#two different scales. It is a one-to-one mapping. Considering the representation of#"exam grade", one can use#

digits from 0 to 100 or characters from “A” to “E”.#There exists#a many-to-one# mapping between them.#

5. **Default#Value#Conflicts.** This type of conflict depends#on the definition of the# domain of concerned attributes. The default value of an attribute is that value# defined in the absence of more information about the real world. For instance,# the default value for “age” of an adult might be defined as 18 in one database# or#21 in another.#
6. **Attribute# Integrity# Constraint# Conflicts**. These conflicts occur when two# attributes are restricted by different constraints. Some of them might be# consistent with each other. For example, the constraint for “age” of#an adult# might be defined as “≥16” or “≥18”. Because there is intersection between# them, it can be resolved by a filter. While other conflicts may not be resolved.#

This#classification framework is#based on#previous researches and#our#analysis of# data from practical#database#integration#applications. It is the foundation of#the# following ontology definition.#

The Definition of the SCO Ontology#

Firstly we define the SCO ontology for the classification framework of semantic# conflicts introduced above. Then we use RDF graph to represent it.#This is mostly# because that#RDF is intended for situations in which#the#information needs to be# processed by applications, rather than being only displayed to people, and there# exist many RDF parsers and processing tools.##

The formal definition#of#the#SCO#ontology#is as follows.#

Definition 1#An ontology for#the#classification of semantic conflicts is a tuple#∧#=# (*h*,#*CV*,#*CI*,#*RC*)，it is a set of many#*concepts*,#*instances*#and their#*interrelationships*,# where#*h*,#*CV*,#*CI*#and#*RC*#are defined as below. The RDF#graph#of#the#SCO#ontology#is# depicted in Fig.1.#

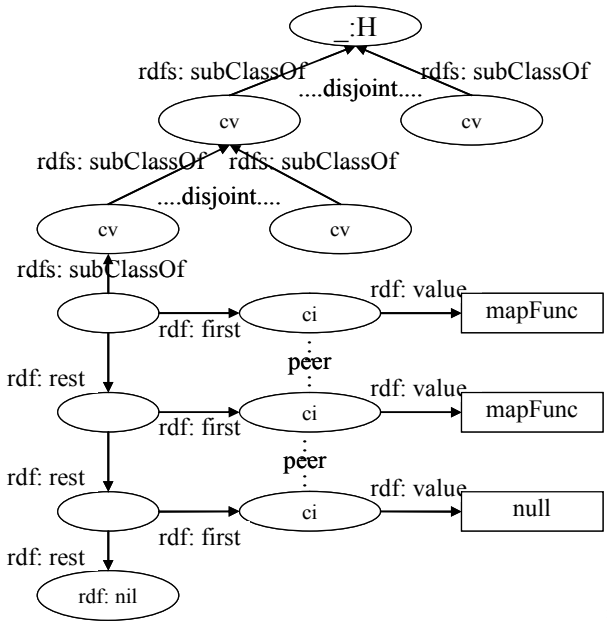

Fig.1 RDF graph of the SCO ontology#

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Definition 2#There is exactly one#*h*#in#∧. It can be considered as the home vertex# in a graph.#It#has no#*superconcept*#or#*instances*, but it is allowed to have# *subconcepts*. According to#the#RDF specification, a blank node can be assigned an# identifier prefixed with "_:". Therefore, we use "_:H" to represent#*h*#in#Fig.1.#

Definition 3#*CV*#is a distinct set of "*virtual#concepts*". Each element of#*CV*#is called# a#*virtual#concept*#in#∧.#It has#*subconcepts*#and#a#*superconcept*, but#is#not allowed# to have#*instances*. In RDF graph depicted in Fig.1,#*cv*#represents#an#element of#*CV*.# Some properties of#*virtual concepts*#are defined as follows.#

1. *Name*#is a term that represents a#*virtual#concept*.#
2. *SubClassOf*#is mandatory property of all#*concepts*#except#*h*. It contains its# *superconcept*.#*Concepts*#can have exactly one#*superconcept*,#that is to say,# multiple inheritance is not allowed.#
3. *SubClass*#is the property contains a list of#*subconcepts*#belonging to#it.#

Definition 4#*CI*#is#a#distinct set of "*instanceable#concepts*". Each element of#*CI*#is# called an#*instanceable#concept*#in#∧.#It has#a#*superconcept*#and#some#*instances*, but# is#not allowed to have#*subconcepts*. In RDF graph depicted in Fig.1,#*ci*#represents an# element of#*CI*.#The#properties of#*instanceable concepts*#are defined as follows.#

1. *Name*#is a term that represents an#*instanceable concept*.#
2. *SubClassOf*#is property#that#denotes its#*superconcept*.##
3. *SeqNo*#is property that represents the sequence number of a#*ci*#element among# its#*siblings*. That is to say, elements in#*CI*#that#are inherited from#the same# *superconcept*#are orderly organized.#
4. *MapFunc*#is property that represents a mapping#function's name. This function is# used to transform between#*objects*#of#*ci*#and#those of#*ci*'s#subsequent#*sibling*. It# is only a character string, not a function or a class.#The#*mapFunc*#value of the# last element among#*ci's#siblings*#is "null".#

According to these#definitions, only elements in#*CI*#represent the#*concepts*#of# semantic conflicts. So we discuss#*CI*#further. In the classification framework of# semantic conflicts described in section 3.1, we#noted that mapping relationships# between conflict instances are various.#What makes this problem even more# complex is that conflict instances are peer to peer,#which#have no sequences. For# the sake of simplicity and clarity, we put some assumptions on the elements of#*CI*.#

1. ***Many-to-many mappings can be converted to one-to-one mappings.***#Suppose## we can achieve this goal by#virtue of "concept generalization". For example,# "exam grade"#can be represented by digits from 0 to 100 or characters from# "A" to "E".#It#is#a many-to-one#mapping between them when we consider 101# digits and 5 characters as#conflict instances. From a different point of view, if# only two conflict instances of "centesimal grade" and "five ranks#system" are# taken into account, one-to-one#mapping#can be#built to#shield#users from# understanding complex relationships.#
2. ***Elements in CI are orderly arranged. Objects of one element can only be# converted to the objects#of its subsequent element.***#Under this assumption,# objects#of#two arbitrary#elements#should be converted using a list of mapping# functions. For instance,#*f1*,#*f2*, and#*f3*#are the mapping#functions of#*object a*,# *object b*, and#*object c*,#respectively. One can convert#*object a*#to#*object b*#by# executing# *f1(a)*.# Similarly, the# compound function# *f2(f1(a))*# denotes the# conversion from#*object#a*#to#*object#c*.#
3. ***Elements in CI can be arranged#to#ensure#the "information lossless" during# conversion***. For example,#the#"date"#format can be represented as follows: 1#

"YYYY-MM-DD", 2 "MM-DD-YY", 3 "DD-MM-YYYY". According to assumption 2,# the conversion processes are#executed#orderly. If we arrange them as 123, the# information about "year"#in 3 will#lose.#

We illustrate the difference between#*CV*#and#*CI*#with examples. "Length" is an# element in#*CV*, it is a#*virtual concept*. Some of its#*subconcepts*#are "meter",# "kilometer", and "feet", which directly express the length unit. So they are# *instanceable concepts*. Conversions#can only#occur between#*objects*#of#these# elements.#

In#the#RDF graph, we use RDF collections to denote the sequence relationships# between elements of#*CI*. The#*instance*#of#*ci*#is#the#mapping#function's#name. For# example, "meterToKilo", "kiloToFeet", and "null" are the mapping#function#names# of element "meter", "kilometer", and "feet" respectively, which can be seen#from# Fig.2.# To convert the objects of "meter" to those of "kilometer", the# "meterToKilo" function should be executed.#

Definition 5#*RC*#refers to the#*sibling relationships*#on#*CV*#and#*CI*. The relationship# among#elements of#*CV*#is#*disjoint*.#It means#elements of#*CV*#which inherit from#the# identical#*superconcept*#have different data semantics.#However, elements of#*CI*# have#*peer*#relationships. They have similar data semantics, so#that equivalent# conversion can be performed among them. For instance, "unit" and "precision" are# elements of#*CV*. "Centigrade" and "Fahrenheit" are elements of#*CI*. They have# different#*sibling relationships*.##

Fig.2 depicts a fragment of#the#SCO#ontology.#We#take "sco" as the QName of those# concepts in the classification framework.#Another two well known QNames "rdf"# and "rdfs" are#also used.#In#the following section, concepts defined in#the#SCO# ontology#(e.g.#"unit" and "length") are used to#define the abstract model which# extends#RDB schema#semantically.#In this#way, mapping relationships between#the# SCO#ontology#and#RDB data sources that participate in integration can be built# impliedly.#

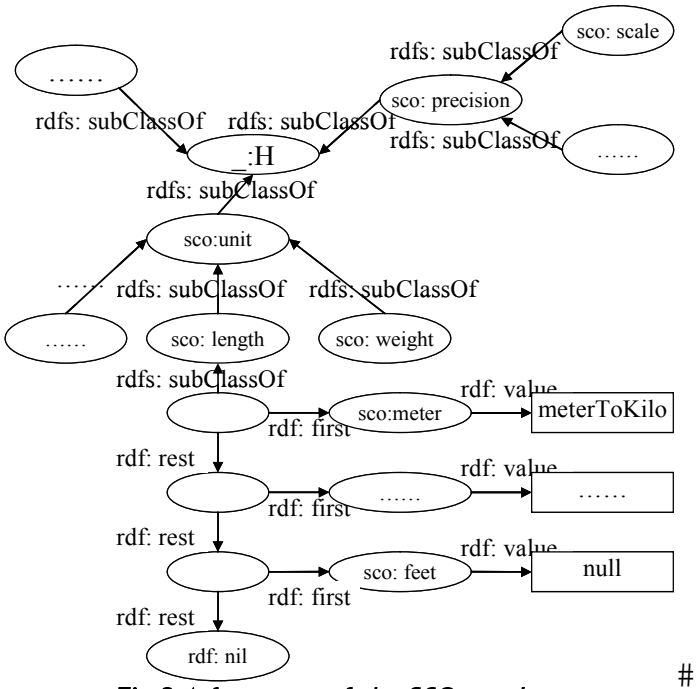

Fig.2 A fragment of the SCO ontology#

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Extending RDB Schema Semantically Using the SCO Ontology#

We aim to use ontologies, which express data semantics explicitly,#to#resolve# those conflicts that the RDB model#can't handle. In section 3, the ontology for the# classification of semantic conflicts is introduced. But where are those conflict# concepts in#the#SCO#ontology from? We don't expect to find them in RDB schemas,# because they can only present "weak semantics". In order to resolve the semantic# conflicts in RDBs, we must extend RDB schema semantically.#

According to Tim Berners-Lee[19], RDF model is great as a basis for ER-modeling.#It# is very directly connected with the#RDB schema#and can be easily mapped onto.# The#OWL language#is designed to facilitate greater machine interpretability of Web# content than that supported by XML, RDF, and RDF Schema (RDF-S) by providing# additional vocabulary along with a formal semantics. What's more, there exist# many editors and process tools for both of them. Thus, we#propose the abstract# model ESM which extends#RDB schema with OWL#language.#

Due to space limitation, we only present the most important parts of ESM in Fig.3.# In#this#OWL ontology, we describe the#RDB schema#abstractly, which includes# classes like#*Table*,#*Column*, and#*Primary Key*. Additionally we specify possible# relationships among#them by#*OWL:ObjectProperty*#classes.#*Columns*#of#*table*#are# defined with#*OWL:DatatypeProperty*#classes, where all the properties required are# specified.#Note#that#the#SCO#ontology#is imported (see row 3).#By using#concepts# defined in#the#SCO#ontology, we can easily extend properties of#*Column*#explicitly# (e.g., Properties of#"unit"#and#"precision"#are defined in row13 and row 14).# Compared with SCROL, we#do#not#need#store the mapping knowledge in#the#SCO# ontology, which ensures generality of our approach.#

```
1 <rdf:RDF xmlns:rdf="&rdf;"
           xmlns:rdfs="&rdfs;"
           xmlns:owl="&owl;">
2 <owl:Ontology rdf:about="">
3     <owl:imports rdf:resource="&sco"/>
 </owl:Ontology>

4 <owl:Classrdf:ID="Database">
      <rdfs:subClassOf rdf:resource="&rdf;Bag"/>
  </owl:Class>
5 <owl:Class rdf:ID="Table">
      <rdfs:subClassOf rdf:resource="&rdf;Seq"/>
  </owl:Class>
6<owl:Class df:ID="Column">
      <rdfs:subClassOf rdf:resource="&rdfs;Resource"/>
  </owl:Class>
7<owl:Class rdf:ID="PrimaryKey">
      <rdfs:subClassOf rdf:resource="&rdf;Bag"/>
  </owl:Class>
8<owl:ObjectProperty rdf:ID="hasTable">
      ……</owl:ObjectProperty>
9<owl:ObjectProperty rdf:ID="hasColumn">
      ……</owl:ObjectProperty>
10<owl:ObjectProperty rdf:ID="isIdentifiedBy">
      <rdf:type rdf:resource="&owl;FunctionalProperty" />
      <rdfs:domain rdf:resource="#Table" />
      <rdfs:range rdf:resource="#PrimaryKey" />
  </owl:ObjectProperty>
11<owl:ObjectProperty rdf:ID="references">
      <rdf:type rdf:resource="&owl;FunctionalProperty" />
      <rdfs:domain rdf:resource="#Column"/>
      <rdfs:range rdf:resource="#Column" />
  </owl:ObjectProperty>
12<owl:DatatypeProperty rdf:ID="scale">
      <rdfs:domain rdf:resource="#Column"/>
      <rdfs:range rdf:resource="&xsd;nonNegativeInteger"/>
  </owl:DatatypeProperty>
13<owl:DatatypeProperty rdf:ID="unit">
      <rdfs:domain rdf:resource="#Column"/>
      <rdfs:range rdf:resource="&sco;unit"/>
  </owl:DatatypeProperty>
14<owl:DatatypeProperty rdf:ID="precision">
      <rdfs:domain rdf:resource="#Column"/>
      <rdfs:range rdf:resource="&sco;precision"/>
  </owl:DatatypeProperty>
  ……
  </rdf:RDF>
```

#

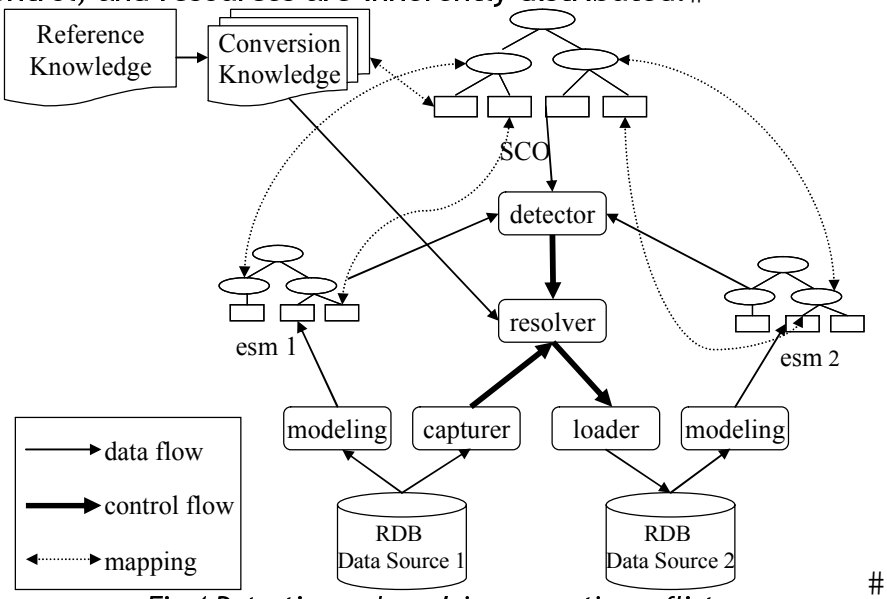
Fig.3 The ESM abstract model described with OWL language#

#
#
#

#

Detecting and Resolving Semantic Conflicts Based on SCM#

Our# conflict detection and resolution method is based on the concept of# "mediator" proposed by#[20]. Fig.4 illustrates the software environment,#in which# the#data, control, and resources are inherently distributed.#



#

Fig.4#Detecting and resolving semantic conflicts#

#

The#*data components*#in Fig.4 are as follows.#

1. **RDB Data Source**,#which denotes the resource that participates#in integration.# According#to the data flow#direction,#it#can be distinguished as "original data# source" and "destined data source".#
2. **esm**, which#is#a concrete ontology defined following the ESM abstract model. It# is built by an equivalent transformation of#the#RDB#schema#and then an# extension of some possible conflict attributes. An esm only describes the# schema of#a#RDB data source,#in which#no data instances#are stored.#
3. **SCO**, which is the ontology defined in section 3.#
4. **Conversion Knowledge**, which denotes the concrete knowledge for the# conversion of conflict concepts.#In#the definition 4 of#the#SCO#ontology,#the# *mapFunc*#property#refers to this knowledge.#
5. **Reference Knowledge**, which denotes dynamic knowledge compared to#the# conversion knowledge. Static knowledge is based on current human#knowledge# or strong belief that has been true for a long period of time. Examples are# "length conversion ratio" and# "time range conversion ratio". Dynamic# knowledge, on the other hand, changes regularly. An example is#the#"currency# exchange rate".##

Note that there are mapping#relationships#between esms#and#the#SCO#ontology,# because esms use some conflict concepts in the SCO ontology when we extend RDB# data sources. There are also#mapping relationships#between#the#SCO#ontology#and# the#conversion Knowledge,#which are built by the#*mapFunc*#property in the SCO# ontology.#

On#the basis of#these semantic mediators, the semantic integration process can be# accomplished in the following six steps.##

1. Design#the#SCO#ontology#manually or using ontology editors;#

#

#

2. Build#the#conversion knowledge and#the#reference knowledge;#
3. Use#the#modeling component to extend#RDB data sources to esms#based on the# ESM#abstract model#and#the#SCO#ontology;#
4. According to the possible semantic conflict concepts that RDB data sources# brought, extend#the#SCO#ontology,#the#conversion#knowledge, and#the#reference# knowledge#incrementally;#
5. Use#the detector component to detect#semantic conflicts#when integration# process occurs;#
6. Use#the resolver component to resolve#the semantic conflicts detected, and# load#transformed data to destined data sources.#

Because the#detection and resolution#of semantic conflicts#are two complex# processes,#we describe the algorithms in Fig.5#and Fig.6.#

```
Algorithm DetectConflicts(IntegrateStatement, ConflictSet)
{
  Input: IntegrateStatament   // e.g. "Select ColumnA From TableA, Insert into TableB(ColumnB) values(ValueOfColumnA)"
                              // We call ColumnA and ColumnB a ColumnPair that has the mapping relationship
                              // ColumnA is the column of original data source□ ColumnB is the column of destined data source
  Output: ConflictSet         // a set of conflict objects

  ColumnPairs = Parse(IntegrateStatement);   // parse the integration statement to get ColumnPairs
  For (each pair<ColumnA, ColumnB> of ColumnPairs){
    OrigianlDataAttributeSet = GetDataAttributes(ColumnA);   //get data attributes of ColumnA from esm1
    DestinedDataAttributeSet = GetDataAttributes(ColumnB);  //get data attributes of ColumnB from esm2
                                                            //data attributes includes type, length, unit, and precision etc.
    For (each OriginalDataAttribute in OriginalDataAttributeSet){      //for each data attribute of ColumnA
      For (each DestinedDataAttribute in DestinedDataAttributeSet){  //compare with the data attribute of ColumnB
        If (OriginalDataAttribute and DestinedDataAttribute have same name but different ranges){
          co = New ConflictObject(ColumnA, ColumnB, OriginalDataAttribute.Name,
                                  OriginalDataAttribute.Range, DestinedDataAttribute.Range);
          //create a new ConflictObject, each conflict object contains column of original data source,
          //column of destined data source, data attribute name and their different ranges
          Add(ConflictSet, co);       //add the new ConflictObject to ConflictSet
          break;                      //exit inner loop for next data attribute of original data source
        }
      }
    }
  }
}
```

#

Fig. 5 The algorithm for conflicts detection#

#

```
Algorithm ResolveConflicts(ConflictSet)
{
  Input: ConflictSet
  For (each ConflictObject in ConflictSet){
    MapFunctionSet = GetMapFunctions(ConflictObject.DataAttributeName, ConflictObject.OriginalDataAttributeRange,
                                     ConflictObject.DestinedDataAttributeRange);
    //according to the name and different ranges of the data attribute, find MapFunctions in the SCO ontology

    ColumnValues = CaptureDataSets(ConflictObject.OriginalColumnName);  //capture data from original data source
    For(each MapFunction in MapFunctionSet){    //execute a series of map functions to transform data
      Update(ColumnValues, MapFunction);
    }
    Load(ConflictObject.DestinedColumnName, ColumnValues);    //load transformed data to destined data source
  }
}
```

#

Fig.6 The algorithm for conflicts resolution#

#

#

Case#Study#

To clarify how to detect and resolve semantic conlicts based on our framework and# algorithms, we discussed a case study in this section.#

The case study comprises#an original data source and a destined data source.#We# aim to add#data from the former to the latter.#The main parts of two#schemas#and# some#example data are illustrated in Fig.7.#

Name	Type
ChannelID	integer
ShowTime	datetime
Duration	integer

Program --Original Schema

Name	Type
ChannelID	string
PlayTime	date
ContinueTime	integer

TVShow--Destined Schema

ChannelID	ShowTime	Duration
322	03:05:01_08:05:00	30
323	03:05:01_08:35:00	45
324	03:05:01_09:20:00	78

Original Data

ChannelID	PlayTime	ContinueTime
"196"	2003/04/25 03:00:00#	900
"197"	2003/04/25 03:15:00	2700
"198"	2003/04/25 04:00:00	480

Destined Data

#

Fig.7 The original source and destined source#

From the schemas of two data sources, we can easily find two type conflicts:#the# type of "ChannelID" in "Program" is integer, while#the#type of same field in# "TVShow" is string;#"ShowTime" in "Program" and "PlayTime" in "TVShow" also# have different#"date"#types.#But these kinds of#conflicts can be resolved by DBMS# itself. The semantic conflicts we#intend to resolve are format conflicts#of the# second field and unit conflicts#of the third field.#As can be seen from the example# data,#the different#"date"#formats are "YY:MM:DD_HH:MM:SS" and "YYYY/MM/DD# HH:MM:SS",#while#the different units#of#"time length"#are "minute" and "second".# To express the semantic conflicts and their transformation relationships explicitly,# we extend the SCO ontology and Conversion Knowledge as Fig.8.#

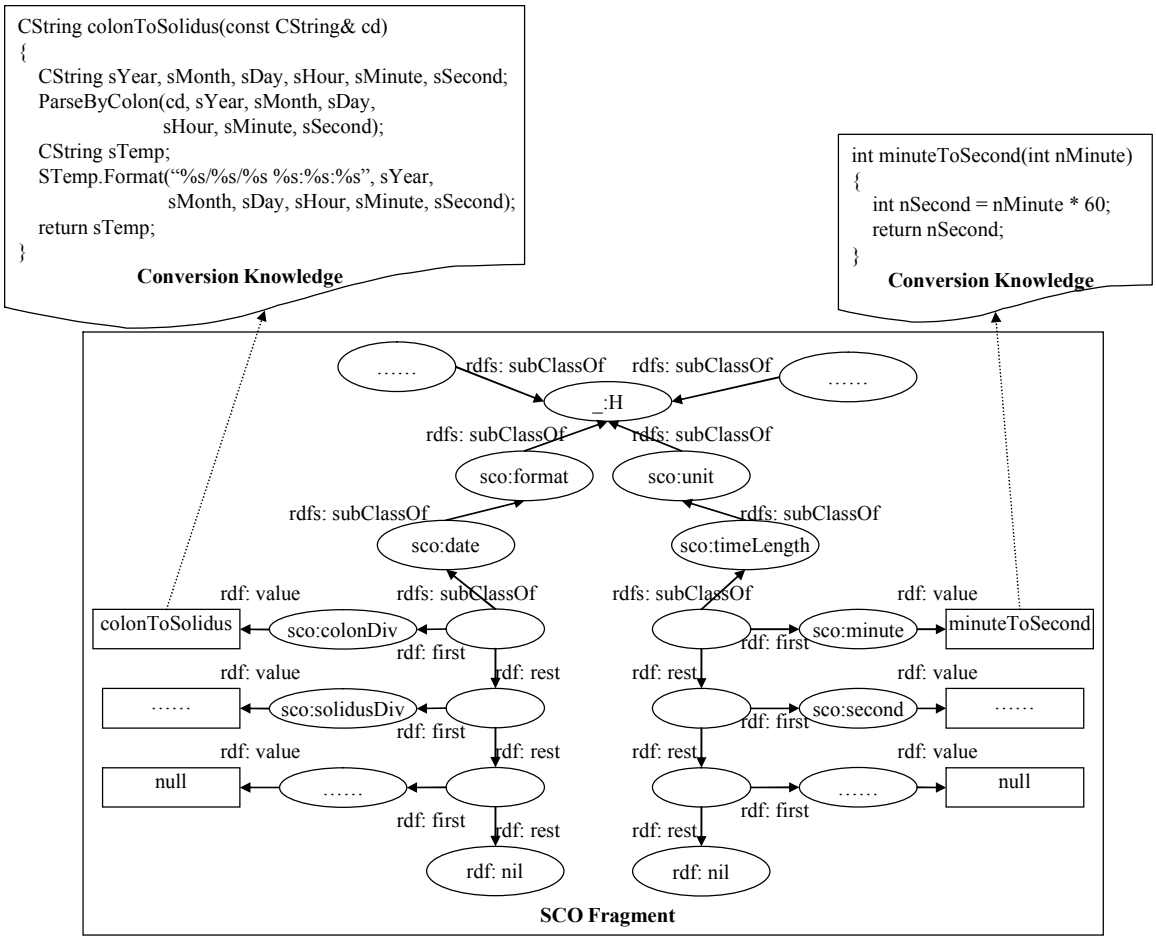


Fig.8#The#related SCO fragment and Conversion Knowledge#

We also extend the#two#schemas to esms according to the SCO ontology, so that# the detection of semantic conflicts can be done automatically.# Two# esms'# fragments#are shown in Fig.9,#among which#the boldfaced parts emphasize the# semantic conflicts involved.#

#

```
<rdf:Description rdf:about="PROGRAM.CHANNELID">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#PROGRAM"/>
   <rdfs:range rdf:resource=
      "http://www.w3.org/2001/XMLSchema#integer"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>10</dbs:length>
</rdf:Description>
 ……
 <rdf:Description rdf:about="PROGRAM. SHOWTIME">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#PROGRAM"/>
   <rdfs:range rdf:resource=
       "http://www.w3.org/2001/XMLSchema#string"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>17</dbs:length>
   <dbs:format>colonDiv</dbs:format>
</rdf:Description>
……
<rdf:Description rdf:about="PROGRAM. DURATION">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#PROGRAM"/>
   <rdfs:range rdf:resource=
       "http://www.w3.org/2001/XMLSchema#integer"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>8</dbs:length>
   <dbs:unit>minute</dbs:unit>
</rdf:Description>
```

esm of original source

```
<rdf:Description rdf:about="TVSHOW.CHANNELID">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#TVSHOW"/>
   <rdfs:range rdf:resource=
       "http://www.w3.org/2001/XMLSchema#string"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>10</dbs:length>
</rdf:Description>
 ……
 <rdf:Description rdf:about="TVSHOW. PLAYTIME">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#TVSHOW"/>
   <rdfs:range rdf:resource=
       "http://www.w3.org/2001/XMLSchema#string"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>19</dbs:length>
   <dbs:format>solidusDiv</dbs:format>
</rdf:Description>
 ……
<rdf:Description rdf:about="TVSHOW. CONTINUETIME">
   <rdf:type rdf:resource=
       "http://localhost/ExtendedRDBSchema.owl#Column"/>
   <rdfs:domain rdf:resource="#TVSHOW"/>
   <rdfs:range rdf:resource=
       "http://www.w3.org/2001/XMLSchema#integer"/>
   <dbs:scale>0</dbs:scale>
   <dbs:length>8</dbs:length>
   <dbs:unit>second</dbs:unit>
</rdf:Description>
```

esm of destined source

#

Fig.9# The# esm# fragments# of two data sources#

#

When the algorithms of conflicts detection and resolution are performed, we can# get the following results as Fig.10.#

ConflictSet =

{ (ShowTime, PlayTime, format, colonDiv, solidusDiv),

(Duration, ContinueTime, unit, minute, second)

}

ChannelID	ShowTime	Duration
322	03:05:01_08:05:00	30
323	03:05:01_08:35:00	45
324	03:05:01_09:20:00	78

Original Data

ChannelID	PlayTime	Continue Time
"196"	2003/04/25 03:00:00#	900
"197"	2003/04/25 03:15:00	2700
"198"	2003/04/25 04:00:00	480
…	…	…
"322"	2003/05/01 08:05:00	1800
"323"	2003/05/01 08:35:00	2700
"324"	2003/05/01 09:20:00	4680

Destined Data

#

Fig.10# The# results of conflicts detection and resolution#

#

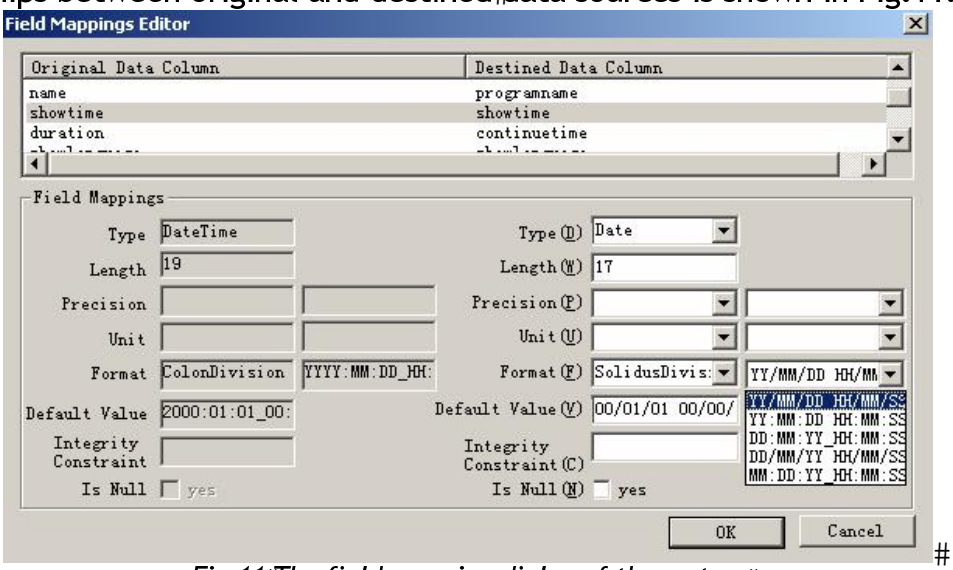
#

#

Implementation and Evaluation#

System Implementation#

We have implemented this#software environment#in OnceDI[21],#which is a data# integration middleware we have developed in last several years.#
We use Protege[22]#to edit#the#SCO#ontology#and#esms, which is a free, open# source ontology editor, and its ontologies can be exported into a variety of# formats. The conflicts detection process can be executed immediately after the# definition of data integration, while the conflicts resolution process are executed# before loading data to destined data#sources. In both#processes, the algorithms of# searching in esm and#the#SCO#ontology affect directly#the system#performance.#
There exist a set of open APIs for the secondary development# by users.# Additionally, we have developed a series of managers that can be directly used to# accomplish any applications.#A typical manager that#is used to build mapping# relationships between original and destined#data sources is shown in Fig.11.#



#

Fig.11#The field mapping dialog of the system#

Experimental Evaluations#

To evaluate#this#approach, we tested#it#with#databases in a practical application.# Additionally, we tested the CREAM platform with same cases as a comparison to# the similar system.#Note#that although OnceDI is designed to transform data# between#heterogeneous databases, while CREAM aims to provide uniform and# integrated access to multiple heterogeneous databases, both#of them#need the# ability of resolving semantic conflicts.#
To examine how well it can handle different types of semantic conflcits and to gain# from the test results insights to guide our future research, we selected data from# the#ChinaEPG system, which is a data exchange#system running in CCTV. In this# system, a data center is built, which is responsible for data exchanges#between# program providers (e.g. ShanDong TV) and EPG# (electronic program guide)# customers. We selected data exchange#scenario among two program providers and# two EPG customers#through the data center, so that data exchanges#occurred#six#
#

times between these five nodes. Because some types of semantic conflicts rarely# happen (e.g. data precision conflicts), we#added#some cases to contain all the# different types of semantic conflicts described in section 3.#
Summary of semantic conflicts resulting from#the#test cases are shown in table 1.#

#

Conflict Type	Number of# Conflicts	Number of Conflicts Found		Number of Conflicts Resolved	
		OnceDI	CREAM	OnceDI	CREAM
Data Type Conflicts	36	36	36	36	36
Data Format Conflicts	19	14	8	14	8
Data Unit Conflicts	6	6	6	6	6
Data Precision Conflicts	2	2	2	2	1
Default Value Conflicts	4	4	0	4	0
Attribute Integrity# Constraint Conflicts	1	1	1	0	1

#

Table 1. Summary#of semantic conflicts resulting from the test cases#

#

From#this test#we can conclude that:#

1. After#the#SCO#ontology#is built and#the#RDB#data sources are extended to esms,# all kinds of#semantic conflicts can be automatically detected and resolved by# the system without further human intervention. Building#the#SCO#ontology#is a# one-time task that should be performed by human experts.#
2. The ability# to# detect and resolve# semantic conflicts depends on# the# completeness of#the#SCO#ontology#and esms. When we use same knowledge to# build ontologies in OnceDI and#CREAM, their#abilities#are#equivalent.#But the# scale of ontologies is different,#the size of#our#SCO#ontology is about#4/5 that of# SCROL.#The reason is#that#SCROL stores the mapping relationships with data# sources#additionally.#
3. CREAM can't resolve some#of the data precision conflicts, because#SCROL don't# support many-to-many mapping# relationships# between conflict concepts.# Furthermore, CREAM can't#detect and resolve#the#default value conflicts.#While# our approach can overcome these shortcomings.#
4. Some of the data format conflicts can't be detected, because the SCO#ontology# isn't complete.#Additionally, due to some schema conflicts exist, OnceDI can't# resolve some of the#attribute#integrity#constraint#conflicts, while#CREAM has# this ability.#

Conclusion and Future Research#

In#this#paper, we present a#novel#approach#to detect and#resolve#semantic conflicts# in database integration.#This#approach is#based on a shared ontology for the# classification of semantic conflicts and an abstract model extending RDB schema# that#can be used to express data semantics explicitly.#Additionally, the#software# environment composed of# semantic mediators# based on this framework is# implemented in our middleware system OnceDI.#Results of our#experimental# evaluation have shown that this approach can resolve much of the semantic# conflicts effectively, and keep independent of domains#and integration patterns.#

#

There are a number of interesting extensions for our future research. One area is to improve automation of the whole process. Currently the SCO ontology and esms are built manually. Developing algorithms to automatically generate the primary esms by virtual of database reverse engineering approach may be a solution. Another problem we have to solve is that errors occur when the SCO ontology isn't complete enough to resolve all kinds of conflicts. This needs friendly wizards to guide users solving this problem smoothly. The third area is to integrate approaches for the resolution of semantic conflicts and schema conflicts effectively, so that all kinds of conflicts can be resolved in one solution.

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