Reverse engineering XML documents into DTD Graph with SAX

HERBERT SHIU	JOSEPH FONG	ROBERT P. BIUK-AGHAI
Department of Computer Science	Department of Computer Science	Department of Computer and Information Science
City University of Hong Kong	City University of Hong Kong	University of Macau
83 Tat Chee Av., Kowloon	83 Tat Chee Av., Kowloon	Av. Padre Tomás Pereira, S.J.
HONG KONG	HONG KONG	MACAU
hcshiu@cityu.edu.hk	csjfong@cityu.edu.hk	robertb@umac.mo
http://www.cs.cityu.edu.hk	http://www.cs.cityu.edu.hk	http://www.fst.umac.mo

Abstract: - We propose a systematic approach to reverse engineer arbitrary XML documents to their conceptual schema, DTD Graphs. The necessity for doing so is due to the fact that XML documents are frequently used for storing structured data and their schemas, such as in Document Type Definition (DTD) format, are missing, especially for those existing historical XML documents. As such, it is difficult for software developers or end users to make use of them. Even the schemas exist, they are difficult to read and undetermined of the underlying relationships among the elements in the documents. In view of this, it is necessary to determine the data semantics from the XML documents. If the DTDs of the XML documents exist with the identifications of the ID/IDREF(S) type attributes, then more data semantics can be derived. Another application of the determined data semantics is to verify the linkages implemented by ID/IDREF(S). If the element is referring to an incorrect XML element type, an extra data semantic will be determined as a result, and such findings can be used for verification purposes. Furthermore, the approaches proposed in this paper use Simple API for XML (SAX) so that the algorithms are applicable to small to huge sized XML documents.

Key-Words: - XML document, DTD Graph, reverse engineering, data semantics, ID/IDREF(S), cardinality, SAX

1 Introduction

As Extensible Markup Language (XML) [1] has become the standard document format on the Internet, software developers have to deal with XML documents in different formats. According to the usages of the XML documents, their document sizes vary from several kilobytes to several gigabytes. For small XML documents, it is feasible to study their structures with either usual text editors or XML enabled viewers, such as a web browser like Microsoft Internet Explorer. However, for medium to huge sized XML documents, what people can do at best is to read the XML document contents just by scrolling up and scrolling down. If the schema of the XML documents, such as in DTD [2] or XSD format, are given or are derived from the XML documents right away, it is easier to study the contents of the XML documents but the formats of these schema are hard to read, not to mention their lack of user-friendliness.

In this paper, a methodology is proposed so that arbitrary data-centric XML document structure can be analyzed and reverse engineered to their conceptual schema, which are DTD Graphs, including cardinalities among entities implemented by parent-child relationship and ID/IDREF type attributes. There are mainly two categories of XML documents, which are data-centric and narrative. As the contents of narrative XML documents, such as *DocBook* [3] documents, are mainly unstructured and their vocabularies are basically static, the necessity of handling them as structured contents and reverse engineering them into conceptual models is far less than that of handling data-centric ones. Therefore, this paper will concentrate on data centric XML documents.

2 Related Work

Accompanying the widespread adoption of XML for representing many different kinds of information in organizations world-wide, there has been considerable interest in more fully integrating these documents into existing systems and organizational information infrastructures. Some XML documents may have been created in an ad-hoc fashion, but subsequently need to be integrated with other documents or databases. To address this need, these existing XML documents can be reverse engineered to recover their semantics, then re-engineered, before being forward engineered into the desired new structure. This process is illustrated in Fig. 1. Different approaches have been proposed for individual steps shown in this process: the recovery of data semantics from XML documents in the form

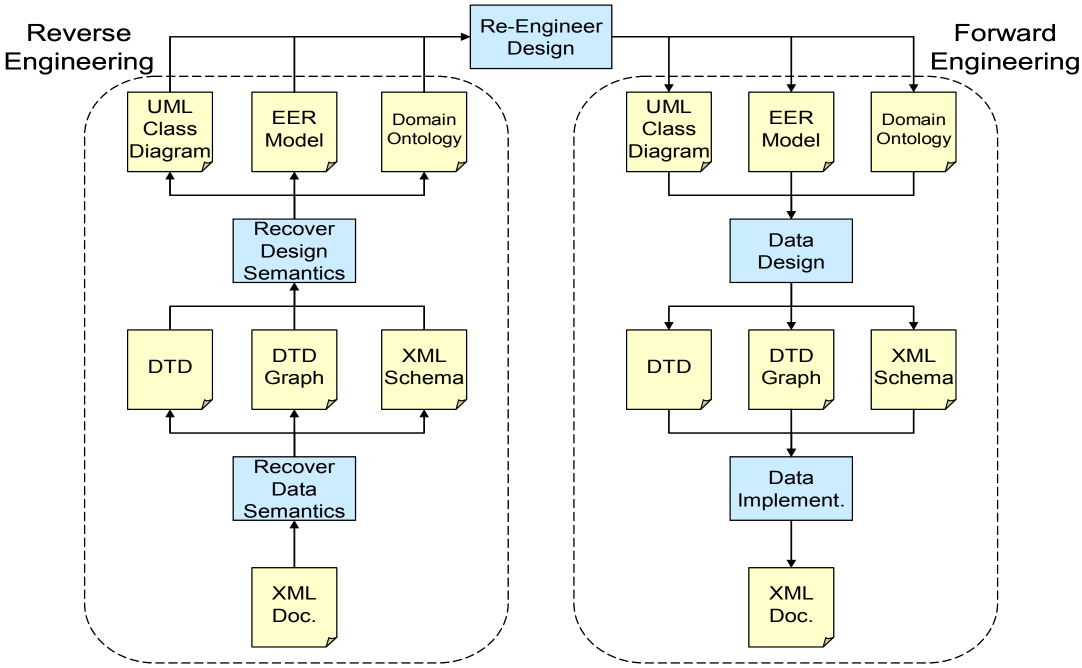

Fig. 1 XML Reverse-Forward Engineering Cycle

of DTDs has been described in [12], while [9,13] describe the extraction of XML schemas. The subsequent step of recovering design semantics has been addressed by [14,15] for deriving UML class diagrams, by [16] for deriving EER models, and by [17] for deriving domain ontologies. However, the majority of research work to date has been concerned with the task of recovering design semantics, whereas little research exists that tackles the extraction of data semantics.

Although there is an approach that can reverse engineer data semantics from XML documents [7], the algorithm maps some predefined templates of document structures to data semantics, and the algorithm can only be implemented with DOM, which needs to read the entire XML document to the memory that is inapplicable to huge sized XML document. On the other hand, the methodology presented in this paper determines all candidate data semantics from arbitrary XML documents with SAX that is applicable to XML document of any size. As such, some of the determined data semantics may not be the intentions of the original writer and it therefore needs user supervision for verification.

Besides, some existing works concern the extraction of schema, such as DTD, from XML document [9] [10] whereas the algorithms proposed in this paper concern the determination of data semantics among the XML element instances rather than simply schema among XML elements. Besides, compared with the approach proposed by Goldman and Widom [11] that directly manipulates semi-structured databases, such as a XML documents, the algorithm proposed here enables the user to have a clear picture of the data semantics among the XML element instances before further manipulating them.

3 Approaches of Implementing Various Data Semantics

3.1 Cardinalities – one-to-many/one-to-one

One-to-many cardinalities within an XML document can be realized by both explicit and implicit referential linkages [6][7]. By implicit referential linkages, a parent element can have child elements of the same type, such as:

```
<PURCHASE_ORDER>
  <PURCHASE_ORDER_LINE .../>
  <PURCHASE_ORDER_LINE .../>
</PURCHASE_ORDER>
```

The parent element `PURCHASE_ORDER` and the child elements `PURCHASE_ORDER_LINE` are implicitly in a one-to-many relationship. If the occurrences of child element `PURCHASE_ORDER_LINE` are at most one for all `PURCHASE_ORDER` elements, they are in a one-to-one relationship instead.

If the schema of the XML document is given, it can specify the `ID`/`IDREF`(S) type attributes. If an XML element defines an `IDREF` attribute and all such elements refer to the same element type, there is a one-to-many relationship between the referred and referring XML elements. For example, sample DTD and XML documents are shown in Fig. 2.

```
<!ATTLIST PURCHASE_ORDER
   PO_ID ID #REQUIRED
   ...
>
<!ATTLIST PURCHASE_ORDER_LINE
   PO_ID IDREF #REQUIRED
   ...
>
```

```
<PURCHASE_ORDER PO_ID="PO001" ... />
...
<PURCHASE_ORDER_LINE
    PO_ID="PO001"
    ... />
<PURCHASE_ORDER_LINE
    PO_ID="PO001"
    ... />
```

Fig. 2 A many-to-one cardinality implemented by an IDREF type attribute

In Fig. 2, a `PURCHASE_ORDER` element is referred by one or more `PURCHASE_ORDER_LINE` elements, and then there is a one-to-many relationship between these two element types. If the attribute definition of the `PO_ID` attribute of `PURCHASE_ORDER_LINE` is `#IMPLIED` instead of `#REQUIRED`, it is optional for a `PURCHASE_ORDER_LINE` element to refer a `PURCHASE_ORDER` element or not, and they can be considered to be partial participation. In the above example, as the `PO_ID` attribute definition of the `PURCHASE_ORDER_LINE` is `#REQUIRED`, they are considered to be total participation.

Besides `IDREF`, element with `IDREFS` type attribute can be used to implement one-to-many cardinality. As `IDREFS` type attribute can refer more than one XML element in the document, if the referred elements are of the same type and each referred element is referred once, the referring element and the referred elements can be considered to be in a one-to-many relationship. For example, consider the sample DTD and XML documents shown in Fig. 3.

In Fig. 3, the `PURCHASE_ORDER` is referring to two `PURCHASE_ORDER_LINE` elements with its `IDREFS` type `POL_IDS` attribute. If each `PURCHASE_ORDER_LINE` element is referred by one `PURCHASE_ORDER` element only, the `PURCHASE_ORDER` and the `PURCHASE_ORDER_LINE` can be considered to be in a one-to-many relationship. For explicit referential linkages, to determine the cardinality is one-to-one or one-to-many, it is necessary to scan the entire XML document to determine the maximum count of referring elements referring of that type referring to the same referred XML element.

3.2 Cardinality – many-to-many

An XML element type may be involved in more than one one-to-many relationship. In other words, all elements of such XML element type define more than one linkage. For example, if an XML element type defines an `IDREF(S)` type attribute, all elements of such XML element type actually defines two linkages, one implicit linkage by the nested structure and one explicit linkage by `IDREF(S)` type attribute. If the two linkages are both one-to-many relationships, the two referred element types by such referring element type can be considered to be in a many-to-many relationship. For example, the XML document in 3 illustrates a many-to-many relationship.

```
<!ATTLIST PURCHASE_ORDER
   POL_IDS IDREFS #REQUIRED
   ...
>
<!ATTLIST PURCHASE_ORDER_LINE
   POL_ID ID #REQUIRED
   ...
>
```

```
<PURCHASE_ORDER
POL_IDS="POL001,POL002" ... />
...
<PURCHASE_ORDER_LINE
     POL_ID="POL001"
     ... />
<PURCHASE_ORDER_LINE
    POL_ID="POL002"
    ... />
```

Fig. 3 A one-to-many cardinality implemented by an IDREFS type attribute

For an XML element type that defines two linkages and hence two one-to-many relationships, the two referred XML element types can be considered to be in a many-to-many relationship that is consistent with existing approach of exporting XML elements for many-to-many relationships [4]. Take a step further. If the XML element type defines three or more linkages and it is therefore involved in more than two one-to-many relationships, the referred XML element types are considered to be in an n-ary relationship.

Many-to-many relationship can be implemented with `IDREFS` type attribute as well, since an `IDREFS` type attribute can refer to more than one instance of the same XML element types. For example, consider the DTD and XML documents as shown in Fig. 4.

Such co-existence relationship specified in the schema can be extended to more than one nested level. For example, if the existence of a `course` element must be accompanied by a `lecturer` element and a `tutor` element, that is:

```
<!ELEMENT course (lecturer, tutor)>
```

the elements, `enrollment`, `student`, `course`, `lecturer` and `tutor`, must exist as a whole. Then, we can consider all these elements are in an aggregation relationship.

4 Algorithms for Determining Cardinality Relationships

The data structure of the algorithms are:

1. MNG: The maximum number of elements of the same element type that are referred by a single referring element with the same linkage type. The value must be one for IDREF type attribute and implicit linkages, and can be greater than one for IDREFS type attribute.

```
<!ATTLIST KEYWORD
KEYWORD_ID ID #REQUIRED
  ...
>
<!ATTLIST TOPIC
TOPIC_ID ID #REQUIRED
  ...
>
<!ATTLIST MESSAGE
MSG_ID ID #REQUIRED
TOPIC_ID IDREF #REQUIRED
KEYWORD_ID IDREF #REQUIRED
  ...
>
```

```
<KEYWORD KEYWORD_ID="KW001"
NAME="..."/>
<KEYWORD KEYWORD_ID="KW002"
NAME="..."/>
...
<TOPIC TOPIC_ID="TP001" NAME="..."/>
<TOPIC TOPIC_ID="TP002" NAME="..."/>
...
<MESSAGE MSG_ID="MG001"
    TOPIC_ID="TP001"
    KEYWORD_ID="KW001"
    .../>
<MESSAGE MSG_ID="MG002"
    TOPIC_ID="TP002"
    KEYWORD_ID="KW002"
.../>
```

Fig. 4 A many-to-many cardinality implemented by an element type with two IDREF type attributes

2. MND: The maximum number of the referring elements of the same element type that are referring to the same referred element with the same linkage type.
3. NL: The number of referring elements that possess the linkage.

Besides the above information, it is necessary to obtain the counts of all referring elements (NE) in the XML document.

According to the combination of the values of the four attribute, it is possible to determine the cardinality data semantics for the involved elements. The rules are shown in Table 1.

The algorithm is composed of a two passes of parsing of the same XML document. The first pass assigns a synthetic element identity to each XML element in the document and determines all `ID` type attribute values and their corresponding element types. For the second pass, the XML document is traversed again and the linkages of each XML element are investigated and their attributes are stored. Finally, the stored linkage attributes are consolidated to give the four linkage attributes mentioned above and in Table 1. The complete algorithm is presented in Fig. 5.

Table 1 Matrix for determining cardinality & participation based on the determined linkage attributes

Cardinality	Participation	
	Total	Partial
One-to-one	MNG = 1 MND = 1 NL = NE	MNG = 1 MND = 1 NL < NE
One-to-many	MNG = 1 MND > 1 NL = NE	MNG = 1 MND > 1 NL < NE
Many-to-one	MNG > 1 MND = 1 NL = NE	MNG > 1 MND = 1 NL < NE
Many-to-many	MNG > 1 MND > 1 NL = NE	MNG > 1 MND > 1 NL < NE

Given Relation ElementIDName (ID, RDE)
Relation ElementNameCount (RGE, NE)
Relation RawReferedInfo (RGE, RDE, LINK_NAME, LINK_VALUE, ND)
Relation ReferringInfo (RGE, RDE, LINK_NAME, **MNG**, **NL**)
Relation ReferredInfo (RGE, RDE, LINK_NAME, **MND**)

Pass One:
Let element ID (*EID*) = 1
Traverse the XML document with SAX
Whenever the start element *E* is encountered
  Select the record from *ElementNameCount* for the element name of E
  If the record exists
    Increment *NE* by 1 and update the record to the table *ElementNameCount*
  Else
    Insert a new record (element name, 1) to the *ElementNameCount* table
  Insert a new record (*EID*, element name) to the *ElementIDName* table
  If E defines an ID type attribute A
    Insert a new record (Value of A, element name of *E*) to the *ElementIDName* table
  End If
  Increase the value of *EID* by 1

Pass Two:
Traverse the XML document with SAX
Whenever the start element (the referring element, *RGE*) is encountered
  For each linkage, *L*, of *RGE*
    For each linkage value, L_{value}
      Get referred element (*RDE*) from *ElementIdName* table by attribute value of *L*, L_{value}
      Select record from the *RawReferredInfo* table for primary key (*RGE*, *RDE*, *L*,

```
            Lvalue)
        If the record exists
            Increase ND by 1 and update the
              record to the table
        Else
            Insert a record (RGE, RDE, L,
              Lvalue, 1) to the table
              RawReferredInfo
    For each referred element type, RDE
        Let NG be the number of RDE referred
            by this linkage, L
        Select the record from the table
          ReferringInfo for (RGE, RDE, L)
        If the record exists
            Update MNG with maximum of
              (MNG, NG) and increment NL
              by 1
            Update the record to the table
              ReferringInfo
        Else
            Insert a new record (RGE, RDE,
              L, NG, 1) to the table
              ReferringInfo

Upon the completion of traversing the XML:
Consolidate the records with the same combination of
  (RGE, RDE, L) in the table RawReferredInfo
    let MND to be the maximum of the ND values of all
      records
    insert a record (RGE, RDE, L, MND) to the table
      ReferredInfo
```

Fig. 5 The table structures and algorithm for determining linkage information by traversing the XML document with SAX

5 Case Study and Prototype

To illustrate the applicability and correctness of the algorithms mentioned in this paper, a prototype was built that implements the algorithms that are proposed in this paper. With such prototype, a sample XML document with DTD file as shown in Fig. 6 are provided to the prototype and the data semantics are determined as shown in Fig. 4- Fig. 6.

```
<?xml version="1.0"?>

<test>
  <element1 id="id1"/>
  <element1 id="id2"/>
  <element2 id="id3"/>
  <element2 id="id4"/>
  <element3 id="id5" idref1="id1" idref2="id3"/>
  <element3 id="id6" idref1="id2" idref2="id4"/>
  <element3 id="id7" idref1="id1" idref2="id4"/>
  <element3 id="id8" idref1="id2" idref2="id3"/>
</test>
```

```
<!ELEMENT test (element1*,element2*,element3*)>
<!ELEMENT element1 EMPTY>
<!ELEMENT element2 EMPTY>
<!ELEMENT element3 EMPTY>

<!ATTLIST element1
      id ID #REQUIRED>
<!ATTLIST element2
      id ID #REQUIRED>
<!ATTLIST element3
      id ID #REQUIRED
      idref1 IDREF #REQUIRED
      idref2 IDREF #REQUIRED>
```

Fig. 6 test.xml and test.dtd

The sample XML and DTD file, test.xml and test.dtd, are supplied to the prototype software and the determined findings are shown in Fig. 7-Fig. 9.

6 Conclusion

This paper provides algorithms to help the users to understand the relationships among the elements by reverse engineering data semantics from the document. Furthermore, the algorithms apply SAX for processing the XML documents so that even huge XML documents can be processed without reading the documents entirely into the computer memory. Moreover, the data structures to be used can be supported by most programming language, or tables in a relational database, and it is therefore feasible to apply the algorithms to XML documents of any size.

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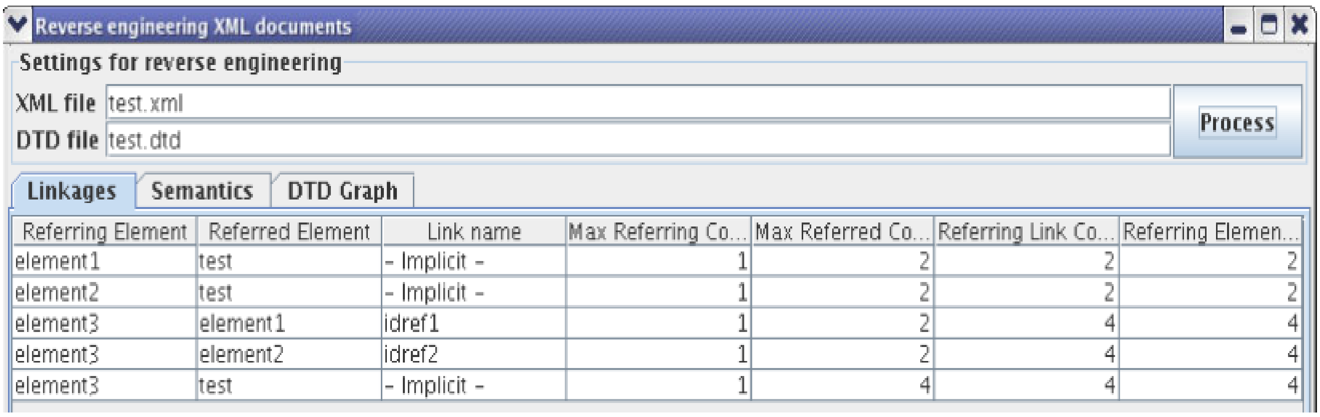

Referring Element	Referred Element	Link name	Max Referring Co...	Max Referred Co...	Referring Link Co...	Referring Elemen...
element1	test	- Implicit -	1	2	2	2
element2	test	- Implicit -	1	2	2	2
element3	element1	idref1	1	2	4	4
element3	element2	idref2	1	2	4	4
element3	test	- Implicit -	1	4	4	4

Fig. 7 The determined linkage information

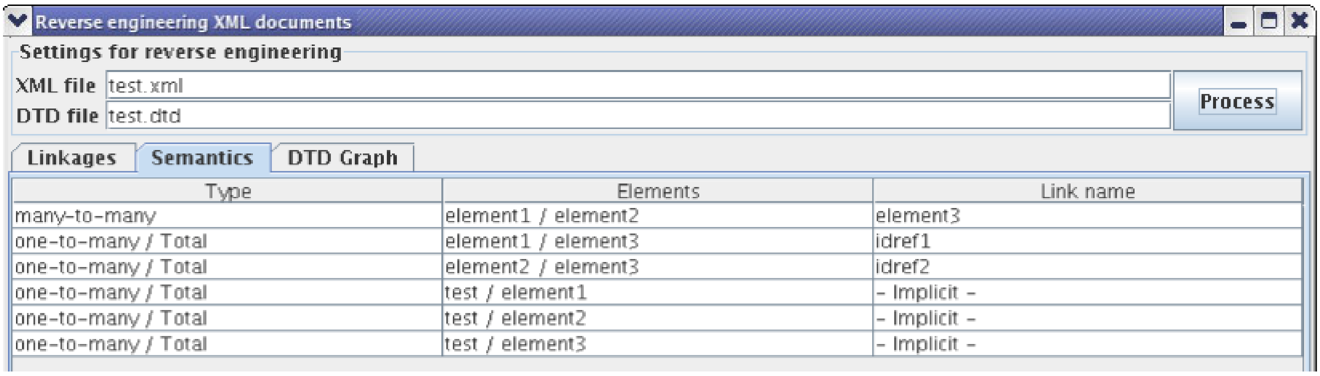

Fig. 8 The determined data semantics

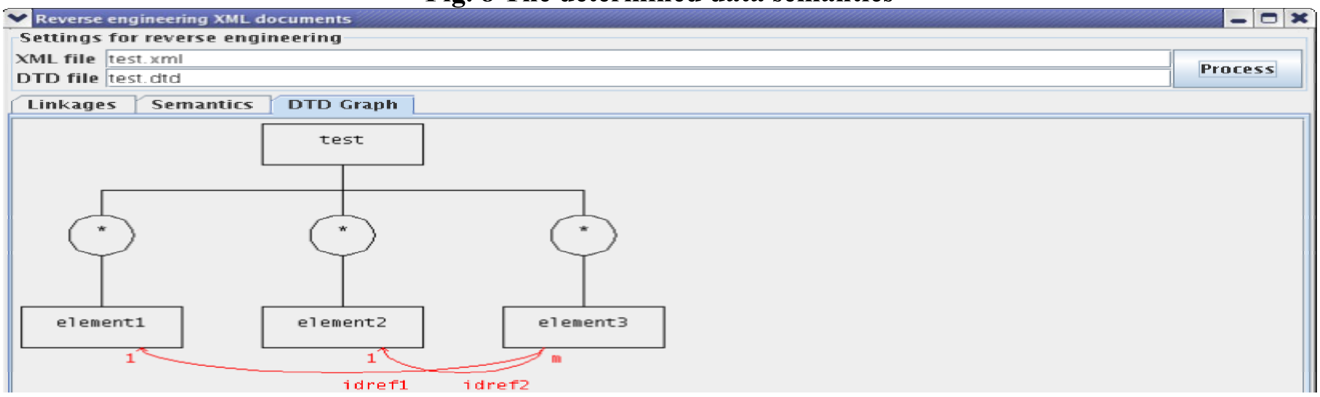

Fig. 9 DTD Graph based on DTD with two one-to-many cardinalities (one many-to-many cardinality)

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