MetaCube-X: An XML Metadata Foundation for Interoperability Search among Web Warehouses

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Abstract

OLAP (Online Analysis Processing) applications have very special requirements to the underlying multidimensional data that differs significantly from other areas of application (e.g. the existence of highly structured dimensions). In addition, providing access and search among multiple, heterogeneous, distributed and autonomous data warehouses, especially web warehouses, has become one of the leading issues in data warehouse research and industry. This paper proposes MetaCube-X to provide interoperability search among Web data warehouses.

1 Introduction

The concept of On-Line Analytical Processing (OLAP), first introduced by [Cod93] to enable business decision makers to work with data warehouses, supports dynamic synthesis, analysis, and consolidation of large volumes of multidimensional data. OLAP tools are frequently used as front-end in data warehouse environments. They allow the interactive analysis of multidimensional data. Independent from the different possible architectures concerning data storage and query processing, they all present the data to the user in a multidimensional data model and queries are formulated using the multidimensional paradigm. The research community for different areas of applications has proposed several formal multidimensional metadata models and corresponding query languages [Agr95], [Bla98], [Cab98], [Cha97], [Eck00], [Gra96], [Gys97], [Leh98], [Li96], [Man99], [Ngu00], [Ola97], [Vas98], [Wan97]. However, each approach presents its own view of multidimensional analysis requirements, terminology and formalism. Consequently, there is no commonly accepted formal multidimensional data model established. Such a model is necessary to serve as a foundation for standardization and future research. This has been the main motivation for us to invest and focus on a new multidimensional data model that is suitable for OLAP applications. Since these applications have very special requirements to the underlying multidimensional data that differ significantly from other areas of application (e.g. the existence of highly structured dimensions). In this context, the concepts of MetaCube have been introduced in [Ngu00].

On the other hand, the World Wide Web is a distributed global information resource that contains a large amount of information placed on the web independently by different organizations. Therefore, related information may appear across different web sites. Furthermore, Web warehousing is a novel and very active research area, which combines two rapidly developing technologies, i.e. data warehousing and Web technology depicted in figure 1 [Mat99] and provides a suitable approach to systematically discover and acquire strategic information from the Web. This information may be identified, cataloged, managed and then accessed by the end users [Mat99], via search engines or some Web information management system.

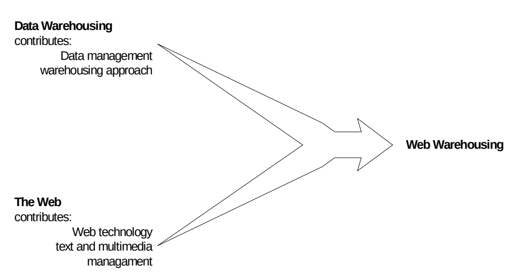

Figure 1: The hybrid of Web warehousing systems.

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To provide the user with a powerful and friendly query mechanism for accessing information on the web, the critical problem is to find an effective way to build web data models. The key objective of our approach is to design and implement a web warehousing system based on MetaCube-X protocol given in Figure 2, which provides access and search capability among multiple, heterogeneous, distributed and autonomous web warehouses. The MetaCube-X is an XML (eXtensible Markup Language) instance of the MetaCube concept [Ngu00] for supporting data warehouses federation. As a result, the MetaCube-X provides a neutral syntax for interoperability among different Web warehousing systems. In this concept, we define a global MetaCube-X stored in a server and local MetaCube-Xs stored in local Web warehouses.

The remainder of this paper is organized as follows. In section 2, we discuss about related works. Then in section 3, we introduce MetaCube-X: from conceptual data model to the XML implementation. The paper concludes with section 4, which presents our current and future works.

2 Related works

Our work is related to research within the area of metadata for multidimensional databases, federated database systems, mediation between multiple information systems, especially distributed data warehousing systems.

The concept of multidimensionality (or n-dimensionality) of these datasets, and in particular, of aggregate data, as well as the concepts of dimension (often called category attribute, descriptive variable, character, etc.) and of measure (often called summary attribute, quantitative data, variable, etc.) has been already discussed [Agr95], [Bla98], [Cab98], [Cha97], [Eck00], [Gra96], [Gys97], [Leh98], [Li96], [Man99], [Ngu00], [Ola97], [Vas98], [Wan97]. Recently, in literature, many authors proposed multidimensional data models and query languages. Gray et al. in [Gra96] proposed the data cube operator as extension to SQL, which generalized the histogram, cross-tabulation, roll-up, drill-down, and sub-total constructs found in most report writers. In [Li96] the authors formalized a multidimensional data model for OLAP, and developed an algebra query language called Grouping Algebra. The relative multidimensional cube algebra is proposed in order to facilitate the data derivation. Gyssens et al. in [Gys97] presented a tabular database model and discussed a tabular algebra as a language for querying and restructuring tabular data. Lehner in [Leh98] discussed the design problem that arose when the OLAP scenarios became very large and they proposed a nested multidimensional data model useful during schema designing and multidimensional data analysis phases. In this context, we proposed a multidimensional data model namely MetaCube in [Ngu00], the concept of which is a generalization of other former multidimensional data models, i.e. relational and multidimensional OLAP models. First, the MetaCube model is able to represent and capture natural hierarchical relationships among members within a dimension as well as the relationships between dimension members and measure data values. Hereafter, dimensions and data cubes with their operators are formally introduced. Each MetaCube is associated with a set of groups each of which contains a subset of the MetaCube domain, which is a poset of data cells. Furthermore, MetaCube operators (e.g. *jumping*, *rollingUp* and *drillingDown*) are defined in a very elegant manner.

[Gmo99] presents distributed and parallel computing issues in data warehousing. [Alb98a], [Alb98b], [Bau97], [Hüm00], [Leh98] present the prototypical distributed OLAP system developed in the context of the CUBE-STAR project. [Hüm00] presents distributed data warehousing based on the *Common Object Request Broker Architecture* (CORBA).

A variety of approaches for interoperability have been proposed, aiming at different levels of integration in related to federated database management systems [She98]. According to [Gar99], data federations will be very important and XML will support for communicating databases, and integrating data over the Internet. The concept of mediator introduced by [Wie92].

In this paper we propose MetaCube-X that is an XML instance of MetaCube concepts to provide a framework for supporting data warehouses federation.

3 The Concept of MetaCube-X

3.1 MetaCube-X Protocol

Figure 2 shows the architecture of MetaCube-X to provide abilities for interoperability search among web-data warehouses. The architecture of MetaCube-X systems consists of clients, server protocol, i.e. MetaCube-X repository, local MetaCube-X, and local data warehouses. Thus, the MetaCube–X protocol is to provide services and to manage accessing to local DWHs corresponding to local MetaCube-X and to global MetaCube-X. Local MetaCube-X is a metadata to describe multidimensional data model for each local data warehouse and it is stored in the local data warehouse. Global MetaCube-X is a global metadata that provides information integration of local MetaCube-X's from local data warehouses and it is stored in the server. Both local MetaCube-X and global MetaCube-X are represented using XML documents to support search facility to the local data warehouse.

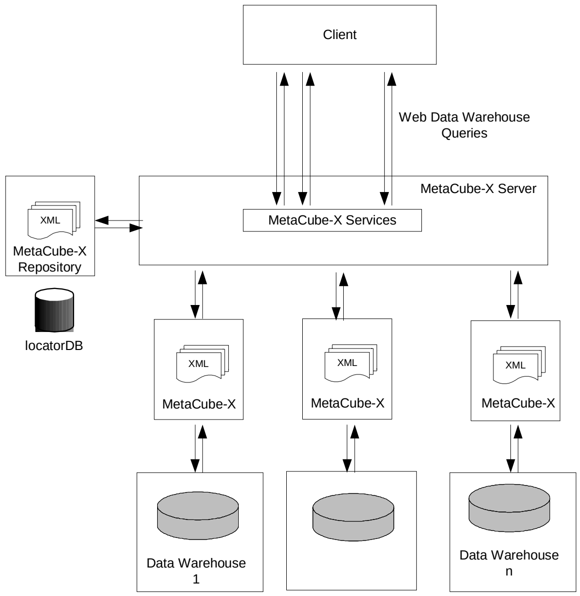

Figure 2: MetaCube-X architecture

3.2 MetaCube Conceptual Data Model

In [Ngu00], a conceptual multidimensional data model that facilitates a precise rigorous conceptualization for OLAP has been introduced and presented. First, our approach has strong relation with mathematics by applying some mathematic concepts, i.e. partial order, partially ordered set (*poset*). The mathematic soundness provides a foundation to handle natural hierarchical relationships among data elements along dimensions with many levels of complexity in their structures. Afterwards, the multidimensional data model organizes data in the form of MetaCubes. Instead of containing a set of data cells, each MetaCube is associated with a set of groups each of which contains a subset of the data cell set. Furthermore, MetaCube operators (e.g. jumping, rollingUp and drillingDown) are defined in a very elegant manner. Formally, the multidimensional data model is constructed based on a set of dimensions $D = \{D_1,..,D_x\}, x \in \mathbf{N}$, a set of measures $M = \{M_1,..,M_y\}, y \in \mathbf{N}$ and a set of MetaCubes $C = \{C_1,..,C_z\}, z \in \mathbf{N}$, each of which is associated with a set of groups $Groups(C_i) = \{G_1,..,G_p\}, p, i \in \mathbf{N}, 1 \le i \le z$.

3.2.1 The Concepts of Dimension

First, hierarchical relationships among dimension members have been introduced by means of one hierarchical domain per dimension [Ngu00]. A hierarchical domain is a poset of dimension elements, organized in hierarchy of levels, corresponding to different levels of granularity. It also allows us to consider a dimension schema as a poset of levels. In this concept, a dimension hierarchy is a *path* along the dimension schema, beginning at the root level and ending at a leaf level. Moreover, the definitions of two dimension operators, namely $O^{ancestor}$ and $O^{descendant}$, provide abilities to navigate along a dimension structure. In a consequence, dimensions with any complexity in their structures can be captured with our data model.

3.2.2 The Concepts of Measures

The concepts of measures, which are the objects of analysis in the context of multidimensional data model, have been also introduced in [Ngu00]. First, the notion of measure schema is a tuple $MSchema(M) = \langle Fname, O \rangle$. In that case that O is "NONE", then the measure stands for a fact, otherwise it stands for an aggregation.

3.2.3 The Concepts of MetaCubes

In [Ngu00], a MetaCube schema is defined by a triple of a MetaCube name, an *x* tuple of dimension schemas, and a *y* tuple of measure schemas. Afterwards, each data cell is an intersection among a set of dimension members and measure data values, each of which belongs to one dimension or one measure. Furthermore, data cells of within a MetaCube domain are grouped into a set of associated granular groups, each of which expresses a mapping from the domains of *x*-tuple of dimension levels (independent variables) to *y*-numerical domains of *y*-tuple of numeric measures (dependent variables). Hereafter, a MetaCube is constructed based on a set of dimensions, and consists of a MetaCube schema, and is associated with a set of groups.

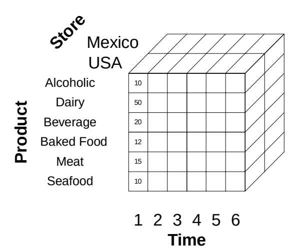

Figure 3: *Sales* MetaCube is constructed from three dimensions: *Store*, *Product* and *Time* and one measure: *TotalSale*.

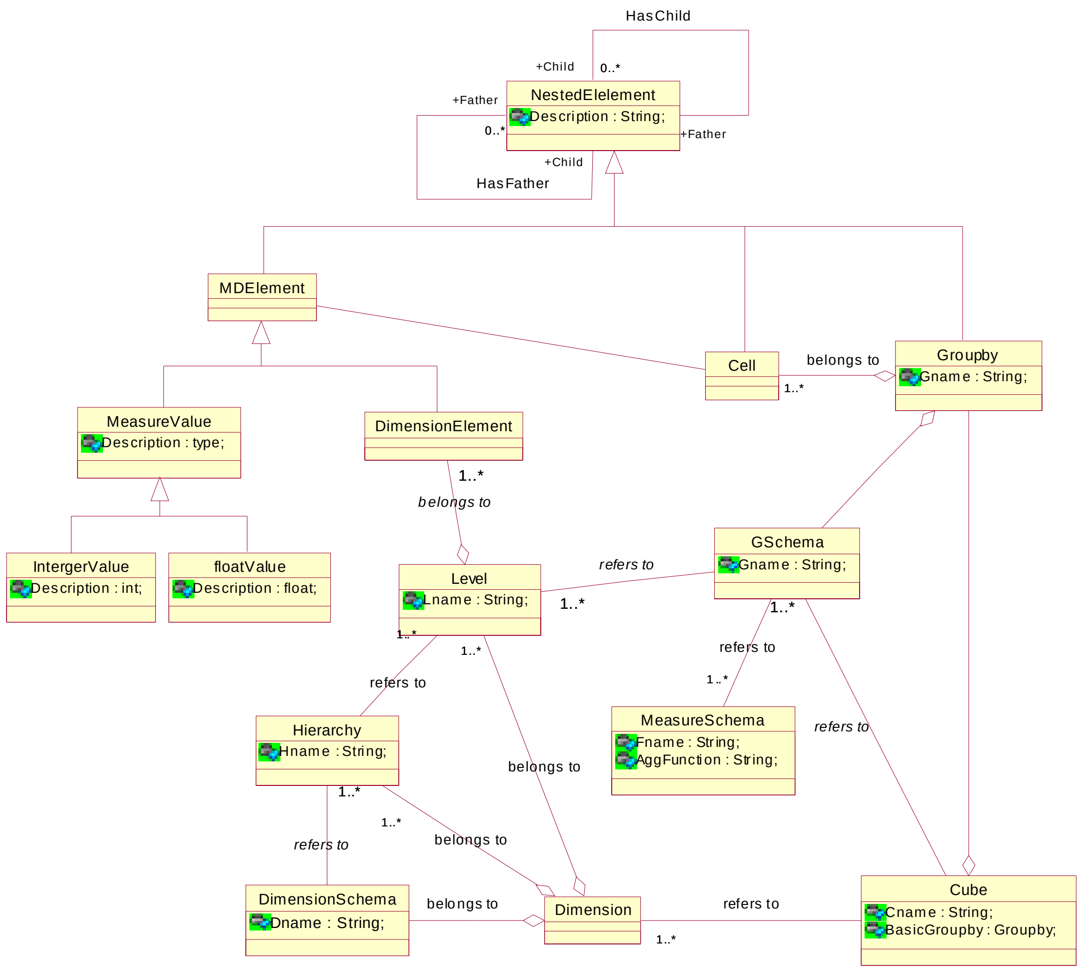

Figure 4: The MetaCube-X model with UML

3.3 Modeling MetaCube-X with UML

The common or *MetaCube-X* is a model used for expressing all schema objects available in the different local data warehouses. The MetaCube-X(s) in a data warehouse federation allow handling the design, integration, and maintenance of heterogeneous schemas of the local data warehouses. It serves for describing each local schema including dimensions, dimension hierarchies, dimension levels, cubes, and measures and it should be possible to describe any schema represented by any multidimensional data model, such as star schema model, snow-flake model, and the like.

To model the MetaCube-X, UML is used to model dimensions, measures and data cubes in context of MetaCube data model (figure 4). We introduce a class, namely NestedElement that provides a framework for defining other classes, i.e. DimensionElement, Level, GSchema, Groupby. In addition, other classes, such as: DimensionSchema, Hierachy, Dimension, MSchema, MValue, Groupby, Cube classes are defined in order to represent dimension schema, dimension hierarchy, dimension, measure schema, measure values, groupby, and cube schema. The modeling will be implemented into XML schema based on the *Meta Data Interchange Specification* (MDIS) [Met99a], and the *Open Information Model* (OIM) [Met97] of the *Meta Data Coalition* (MDC).

3.4 Implementation with XML

The MetaCube-X is an XML instance of MetaCube concept for supporting interoperability of different multidimensional data models. It covers heterogeneity problems, such as syntactical, data model, semantic, schematic, and structural heterogeneities.

The use of XML for representing MetaCube concept is to model data to any level of complexity, to check data for structural correctness, to define new tags as needed corresponding to a new dimension, and to show hierarchical information corresponding to dimension hierarchies. These requirements are completely required for data warehouse schema and OLAP application. In addition, XML can make easy it for extensibility, offers promise for applying data management technology to documents, for providing a neutral syntax for interoperability among different systems, and is very useful for exchanging data.

3.3.1 Mediation

Mediation resolves problems of semantic interoperation. It recognizes the autonomy and diversity of data warehouses. Therefore, in this architecture we need one mediator for each local data warehouse. A mediator is an independent module located in each local data warehouse and it supports flexible application interfaces, reusability, share ability, and simple to increase maintainability.

In this concept, each local data warehouse has a local MetaCube-X and a local mediator. The mediator receives the sub-query from the server managed by MetaCube-X protocol.

3.3.2 Schema Integration

For supporting interoperability in the MetaCube-X protocol, local MetaCube-Xs must be integrated into the global MetaCube-X. The global MetaCube-X provides global views for clients. In addition, because of the integration of local MetaCube-Xs into the global MetaCube-X, we need mapping information. The following section discusses issues concerning local MetaCube-X(s), the global MetaCube-X, and the mapping information.

Local MetaCube-X

The concept of MetaCube-X is to provide a common multidimensional data model for Web warehouses in term of XML docoments. This local MetaCube-X is stored in a local Web warehouse. Furthermore, a local MetaCube-X provides schema of each local Web warehouse. With reference to the MetaCube design, depicted in UML given in figure 4, local MetaCube-X is represented in XML document supports multidimensional data model, such as cube, dimension, dimension schema, hierarchy, measures for each data warehouse. An example of the MetaCube-X of local Web warehouse is given as follows.

```
<?xml version="1.0" encoding="UTF-8"?>
<MetaCube Cname="String">
 <Dimension>
  <DimensionSchema Dname = "String">
   <Hierarchy HName = "String">
    <Level Lname="String">
      <DimensionElement>
         <MDElement>
            <NestedElement Description="String">
                 <Father>Number</Father>
                 <HasChild>Number</HasChild>
                 <Child>Number</Child>
                 <HasFather>Number</HasFather>
            </NestedElement>
           </MDElement>
          </DimensionElement>
         </Level>
   </Hierarchy>

   <Hierarchy>
         <Level>
         ..........
         </Level>
   </Hierarchy>
  </DimensionSchema>
 </Dimension>

 <GroupBy Gname="String">
  <NestedElement Description="String">
   <Father>Number</Father>
   <HasChild>Number</HasChild>
   <Child>Number</Child>
   <HasFather>Number</HasFather>
  </NestedElement>

  <GSchema Gname="String">
   <MeasureSchema Fname="String">
         <AggFunction>String</AggFunction>
           </MeasureSchema>
         </GSchema>
 </GroupBy>
</MetaCube>
```

Figure 5: An Example of local MetaCube-X

Global MetaCube-X

Global MetaCube-X is the integration of local MetaCube-Xs. The global MetaCube-X provides the logic to reconcile differences, and drive Web warehousing systems conforming to the global schema. The global MetaCube-X is a metadata for query processing. If there is a query posted by users, the MetaCube-X service receives the query from the user, parses, checks, and compares it with the global MetaCube-X, and distributes it to selected local Web warehouses. Therefore, the global MetaCube-X must be able to represent heterogeneity of local data warehouse schema including dimensions and measures. In addition, to simplify the integration of local MetaCube-X(s) from local Web warehouses into global MetaCube-X, we use XML. An example of global MetaCube-X is given in the following figure.

```
<?xml version="1.0" encoding="UTF-8"?>
<GlobalMetaCube>
<GlobalDimension>
 <Dimension>
 <DimensionSchema Dname1 = "String">
 <Hierarchy HName = "String">
 <Level Lname="String">
 <DimensionElement>
 <MDElement>
 <NestedElement Description="String">
  <Father>Number</Father>
  <HasChild>Number</HasChild>
  <Child>Number</Child>
  <HasFather>Number</HasFather>
 </NestedElement>
 </MDElement>
 </DimensionElement>
 </Level>
 </Hierarchy>
 <Hierarchy>
 <Level>
 ..........
 </Level>
 </Hierarchy>
 </DimensionSchema>
 </Dimension>
 <Dimension>
 <DimensionSchema Dname2 = "String">
 <Hierarchy HName = "String">
 <Level Lname="String">
 <DimensionElement>
 <MDElement>
  ..........
 </MDElement>
 </DimensionElement>
 </Level>
 </Hierarchy>
 <Hierarchy>
 <Level>

  ..........

</Level>
 </Hierarchy>
 </DimensionSchema>
 </Dimension>
 </GlobalDimension>
 <GlobalGroupBy>
  <MeasureSchema Fname1="String">
  <AggFunction>String</AggFunction>
  <Dimension>
     <DimensionSchema>Dname1</DimensionSchema>
     <DimensionSchema>Dname2</DimensionSchema>
     <DimensionSchema>Dname3</DimensionSchema>
  </Dimension>
  </MeasureSchema>
  <MeasureSchema Fname2="String">
  <AggFunction>String</AggFunction>
  <Dimension>
      <DimensionSchema>Dname1</DimensionSchema>
      <DimensionSchema>Dname2</DimensionSchema>
      <DimensionSchema>Dname4</DimensionSchema>
  </Dimension>
  </MeasureSchema>
 </GlobalGroupBy>
</GlobalMetaCube>
```

Figure 6: An Example of global MetaCube-X

Mapping Information

Mapping information is to provide information of mapping between local MetaCube-X(s) and the global MetaCube-X, when they are integrated. This information is responsible for supporting translation information of global queries into local queries in query processing. It is parsed by search service of the MetaCube-X protocol and compared with the global MetaCube-X, if there is a query posted from the user. An example of mapping information is given as follows.

```
<?xml version="1.0" encoding="UTF-8"?>
<Mapping>
<Cube CubeName1 = "String">
   <Dimension>
     <DimensionSchema>Dname1</DimensionSchema>
     <DimensionSchema>Dname2</DimensionSchema>
     <DimensionSchema>Dname3</DimensionSchema>
   </Dimension>
 </Cube>
 <Cube CubeName2 = "String">
   <Dimension>
<DimensionSchema>Dname1</DimensionSchema>
<DimensionSchema>Dname2</DimensionSchema>
<DimensionSchema>Dname4</DimensionSchema>
   </Dimension>
 </Cube>
</Mapping>
```

Figure 7: An example of mapping information

4. Conclusion and future works

In this paper we have presented the concept of MetaCube-X for supporting data warehouses federation. The MetaCube-X is an XML instance of the MetaCube, the extended MetaCube concepts introduced in [Ngu00], as a conceptual multidimensional data model that facilitates a precise rigorous conceptualization for OLAP. The MetaCube-X metadata based on object-oriented model is a semantically rich for interoperability among different data warehouse systems.

We focus on metadata for data warehouses federation, especially Web warehousing system. Thus, we address query processing for Web warehouses by exploring the use of XML and MetaCube-X protocol. They are designed and implemented for federated queries as well as data exchange for retrieving the results from local Web warehousing islands and offering them to federated users. Currently, we implement incremental prototypes demonstrating the feasibility of our approach to data warehouse federation.

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