The Distributed Interoperable Object Model and Its Application to Large-scale Interoperable Database Systems

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OGI/CSE Technical Report No. 95-003

Abstract

A large-scale interoperable database system operating in a dynamic environment should provide uniform access user interface to its components, scalability to larger networks, evolution of database schema and applications, flexible composibility of client and server components, and preserve component autonomy. To address the research issues presented by such systems, we introduce the Distributed Interoperable Object Model (DIOM). DIOM's main features include the explicit representation of and access to semantics in data sources through the DIOM base interfaces, the use of interface abstraction mechanisms (such as specialization, generalization, aggregation and import) to support incremental design and construction of compound interoperation interfaces, the deferment of conflict resolution to the query submission time instead of at the time of schema integration, and a clean interface between distributed interoperable objects that supports the independent evolution and management of such objects. To make DIOM concrete, we outline the Diorama architecture, which includes important auxiliary services such as domain-specific library functions, object linking databases, and query decomposition and packaging strategies. Several practical examples and application scenarios illustrate the usefulness of DIOM.

Index Terms: *Large scale interoperable database systems, Distributed object management, Dynamic object binding interfaces, Scalability, System evolution, Object-oriented systems*

1 Introduction

Many papers on multidatabase systems or federated database systems [2, 9, 20, 23], focused on the resolution of schematic and semantic incompatibilities among autonomous and heterogeneous component databases in relatively static system configurations. While this assumption was reasonable for the past, recent developments in the Internet show that in the present environment a useful solution can no longer ignore the issues of scalability and evolution. For the upcoming National Information Infrastructure, these issues will become paramount. For example, in an effort to make US government databases easily accessible to the general public, many thousands of federal, state, and local government databases will be interconnected. Even if each participating agency changes slowly, the whole government interoperable database will be a highly dynamic growing and evolving system.

In a modern networking environment as such, we consider *interoperable database systems*, software systems that provide facilities and techniques to interoperate with several individual databases (called *component databases* in this paper), *and* at the same time offer convenient uniform access to a number of remote data sources. We believe that as the number of participating databases in the interoperation increases rapidly, and the interoperable environment evolves dynamically, the issues of system-wide scalability and evolution, as well as component composibility and autonomy become necessarily an integral part of large-scale interoperable database systems. We refer to the properties of Uniform access, Scalability, Evolution, Composibility and Autonomy as USECA properties. In large-scale dynamic interoperable database systems, USECA properties are critical requirements, without which the system becomes much less useful.

Our main contribution in this paper is an approach called *Distributed Interoperable Objects Model* (DIOM), to support the USECA properties of large-scale interoperable database systems. DIOM's main idea is to incorporate system-wide scalability and evolution support as well as component composibility into an interoperation framework. Significant features of the DIOM approach include:

- the explicit representation of and access to semantics in data sources through the DIOM base interfaces,
- the use of interface abstraction mechanisms to support incremental design and construction of compound interoperation interfaces,
- the decoupling of semantic heterogeneity from the representational mismatch, and
- the deferment of conflict resolution to the query submission time rather than at the time of schema integration.

As a result, when the number of databases that participate in the interoperation increases, the existing applications developed earlier may continue to work without source code changes or recompilation. The new applications may define their interoperation interfaces by aggregation or generalization of existing interfaces, or by refinement of pre-defined interfaces, rather than starting from scratch. Autonomy of the component systems is also fully respected such that component systems can evolve without consultation with the interoperable system. Moreover, principled and disciplined evolution of an individual

component schema will cause no or minimal impact on its remote customers. Thus, the rewriting of the application programs developed through interoperable object interfaces can be avoided or minimized in the presence of system evolution.

Before we describe the technical details of DIOM, the USECA properties are discussed in the context of research challenges in large-scale interoperable database systems.

1.1 USECA Properties as Research Challenges

With rapid advances in computer network technology, information systems connected by world-wide high-speed networks provide great opportunities for up-to-date and rapid access to remote information resources. Users and applications can work with remote data sources and request services across networks as if they were working with a single database system. Thus, uniform access to remote data sources becomes increasingly important and critical as the interoperable database evolves dynamically in a distributed environment. Besides uniform access, several challenges arise in the context of large-scale interoperable database systems, including scalability and evolution of the system as a whole and its components, as well as the flexibility in composing components and the autonomy of individual components. Each of the USECA properties (Uniform access, Scalability, Evolution, Composibility, and Autonomy) is important for the usefulness of a large-scale interoperable database system and each presents a serious research challenge.

Consider **Scalability**. A large-scale interoperable database environment (e.g., three hundreds databases as opposed to three databases) presents challenging questions to the viability of both loose-coupling approach to system development (cf. [13, 28]) and the tight-coupling integration framework that concentrates primarily on circumventing schematic and semantic heterogeneity (cf. [12, 24, 25, 26, 29]). As the number of databases participating the interoperable database system increases, the design of an integrated schema involving n different systems requires to reconcile an order of n^2 possibly conflicting representations(i.e., heterogeneity in semantics or in data formats). Such activities are time consuming and can be aggravated when incorporating the system evolution issue with the integration strategies.

Similarly, **system evolution** presents an equally important problem. While the number of data bases available via networks are increasing swiftly, some component databases may also become obsolete or temporarily inaccessible. Furthermore, even when the changes in each individual component database schema are not frequent, the large number of component databases may add up to surprisingly frequent schema change events at the interoperable database system level. Assuming there is only one change in two years for any component database schema, an interoperable system with two hundred databases as such will have to contend with one hundred changes every year, which corresponds to, on average, two changes every week!

Another important challenge is **system composibility**, and more specifically, the need for incremental design and construction of interoperation interfaces. This is simply because an interoperable database system like any other software system is not constructed in "one shot". Besides, multiple data integration efforts to produce multiple kinds of integrated systems that involve overlapping subsets of their component databases become increasingly desirable for those organizations that need to perform multiple forms of integration with overlapping sets of data. Therefore, the interface definition language

of the interoperable database systems should provide interaction abstraction facilities to allow users or applications to define new or complex interfaces in terms of existing or simpler interfaces, for instance, through interface refinement (specialization) or interface composition (aggregation and generalization) mechanisms.

Autonomy and Flexibility. In addition, not only should component systems and their customer set not pay high price on autonomy in order to join the interoperation (or integration), but the remote users should also not have to compromise the way they prefer to understand and represent their application semantics and be forced to surrender to a system-supplied, canonical integration schema. This implies two interesting points. First, to preserve the autonomy of individual systems, it is essential to allow an individual systems to treat the external users and applications and thus the interoperable systems in a similar way as its ordinary clients unless specified otherwise. Thus, the evolution of individual system can be carried out without being interfered by the other parties in the interoperation. Second, to respect the freedom and the flexibility in the use of the interoperable system, it is important to provide data model independent language constructs and facilities in the interoperable object model, which enable users and applications to request services and remote data sources either directly or through the construction of new interfaces that present their own interest and desired representation for accessing interoperable objects.

Of course, our list of critical issues is not exhaustive. For example, efficient query processing is also one of the key concerns in large-scale interoperable database systems. The query optimization strategies that are possible in a small and controlled environment, such as those for "canned" queries to be optimized may not be practical any more, when the environment evolves dynamically, the number of databases increases rapidly, and the autonomy of component systems needs to be fully respected. We believe that these research challenges are non-trivial in large-scale interoperable systems and deserve special attentions in order to provide the cost-effective and robust support for the longer life span of interoperable systems.

1.2 Paper Organization

The rest of the paper proceeds as follows: In order to demonstrate the practical applicability of the DIOM approach, we start with an overview of the Diorama architecture in Section 2. Diorama is an ongoing project that aims at implementing a prototype of the DIOM approach to large scale interoperable database systems with USECA properties. The distributed interoperable object model (DIOM) and the interface abstraction mechanisms are described in Section 3 through a number of illustrative examples. Section 4 explains query compilation in DIOM databases under the Diorama architecture. We compare our approach with related work in Section 5 and conclude the paper in Section 6.

2 The Diorama Architecture

In terms of object-oriented terminology, *interoperability* refers to the ability to exchange requests between objects ad to enable objects to request services of other objects, regardless of the language in which the objects are defined and their physical location (e.g., hardware platforms, operating systems,

DBMS's). *Distributed interoperable objects* are objects that support a level of interoperability beyond the traditional object computing boundaries – the long-standing boundaries imposed by programming languages, data models, process address space, and network interface [1]. The abstraction of distributed interoperable objects is captured in the Distributed Interoperable Object Model (DIOM), explained in Section 3.

Diorama is an interoperable software architecture based on DIOM to support USECA properties. In several ways, Diorama facilitates the construction of applications and database systems from data sources and services provided by different software vendors or application systems. First, it uses DIOM's interface definition language and interface manipulation language to support uniform and transparent access to data sources across Internet. Second, Diorama provides facilities and convenient language constructs to support the explicit representation of and access to disparate data semantics, and encourages to defer the conflict resolution to the time when query is submitted. Third, it offers a number of adaptive software development techniques to support the autonomous evolution of individual components, such as specialization mechanism for interface refinement, aggregation mechanism for interface composition, and adaptive transformation of DIOM interfaces into the skeleton bindings in the intended implementation language. Fourth, Diorama supports composibility with dynamic linking and binding of interoperable objects. Finally, it preserves autonomy through a clean interface between distributed interoperable objects that supports independent evolution and management of such objects.

Figure 1 shows a simplified picture of the Diorama architecture. At the leaf level of Figure 1 we have the data repositories that Diorama integrates. Examples of data repositories include relational database systems, object-oriented database systems, file systems, document managers, image managers, video servers. Above each repository is a repository wrapper. The main task of a *repository wrapper* is to control and facilitate the external access to the data repository, based on the export schema provided by the data repository manager at its integration into the interoperable system.

In the middle right of Figure 1, the DIOM meta object library consists of DIOM interface repository and DIOM implementation repository. The interface repository supports dynamic linking of object interfaces (e.g., which data sources provide relevant information requested by a given application). It could be based on a commercial product, such as OLE or OpenDoc, for distributed dynamic object linking or embedding purpose. The DIOM implementation repository contain information that allows the object request linking subsystem to actually locate and activate objects to fulfill the requests through dynamic loading.

In the middle left of Figure 1, the DIOM object linking database manages the complex relationship objects that most DIOM applications require to glue together the data in multiple repositories in some new or useful ways. For example, in a medical insurance application, the DIOM object linking database could be used as a persistent storage to hold a `ClaimFolder` object for some special medical treatment of a patient, which an insurance agent needs to handle. A `ClaimFolder` object could be formed, for example, by linking the following data that are stored in separate data repositories:

- a patient's X-ray images stored in an image-specific file repository of a radiological lab,
- a doctor's diagnosis report stored in a document management system at doctor's office, and

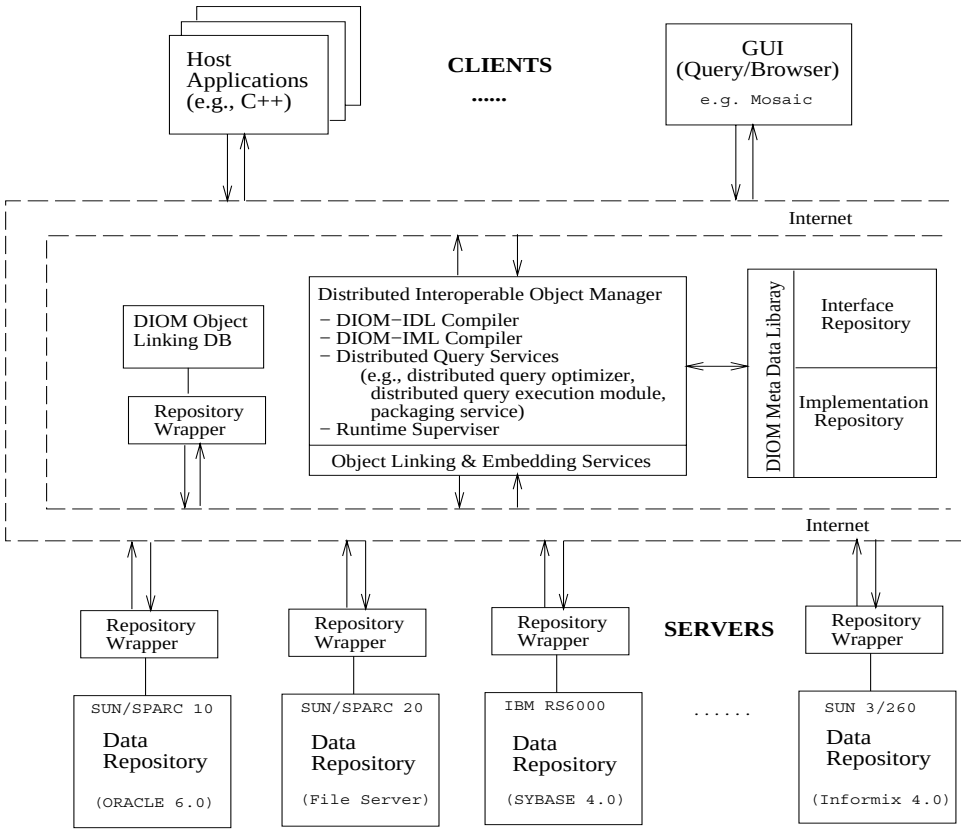


Figure 1: The Diorama system architecture

- a patient's claim and the corresponding insurance agreement records stored in a relational data base of the insurance company.

A DIOM database is a USECA view of clients on the interoperable database system. Diorama is responsible for presenting the applications with a unified object-oriented view of the contents of DIOM databases, and to process users' and applications' requests (e.g., queries, updates on object links, and method invocations) on the content of a DIOM database. The content of a DIOM database is defined using the DIOM interface definition language (IDL). A DIOM database is often composed through dynamically binding data from multiple data repositories provided by the underlying component systems. All queries and request for data and services may be formulated using DIOM interface manipulation language (IML). The DIOM-IDL compiler first check the validity and the type-closure of each import specification in the DIOM interfaces, generates the complete import schema, and then performs mapping of IDL syntax into the DIOM repository implementation language. The DIOM-IML compiler generates the stubs and skeleton bindings in the repository implementation language and performs the actual mapping of DIOM-IML syntax into the implementation skeletons that can be understood by the repository wrappers of the target data repositories. We will illustrate the functionality and the use of DIOM IDL and IML in the later sections.

Diorama's components are designed in the client/server style and dynamically bound to support independent component evolution. On the server side, IDL syntax is mapped into the repository implementation language and generate the implementation skeletons, which will be sent to the corresponding target data repositories. These implementation skeletons can be understood by the data repository wrappers and easily be mapped into a collection of data access functions applicable to the corresponding data repositories. On the client side, DIOM generates the interface stubs that specify the method signatures to invoke methods of target data repositories. For instance, DIOM interfaces to C++ applications may be a set of C++ classes that act as "surrogates" for the corresponding definition of the DIOM interface schema. When a component data repository evolves into a new version, and the changes at the component level need to be reflected at the interoperation interface level, a new DIOM interface library or an interface schema is released as a new interface version that co-exists with the existing versions. Thus, the existing DIOM applications may continue to work without source code changes or recompilation.

The Diorama architecture also includes interactive browsing, navigation, and querying of the content of a DIOM database. The first planned component for the browsing functionality is an HTML-based toolkit.

Generally speaking, the DIOM database interface schemas are *virtual* schemas, since the data contents are actually stored and managed by individual data repository manager (such as the individual DBMSs). The DIOM object linking database is created and maintained only when the DIOM applications need to have frequent access to some linking information that are not provided or cannot be derived automatically through access to the individual data repositories. The DIOM linking database should be considered just as yet another persistent data repository in the DIOM architecture. In the first phase, we intend to implement the link database using an object-oriented database management system such as ObjectStore [7].

We now explain in more detail the basic concepts of DIOM and its mechanisms to further address questions like:

- How does DIOM enable cross-database interoperability?
- What makes DIOM such a useful and unifying model?
- How does DIOM enhance the adaptiveness and robustness of the interoperable systems and their applications in the presence of underlying data repository-based evolution or interoperation-based evolution (such as the future changes to the interoperation interface definitions)?

3 The Distributed Interoperable Object Model

The purpose of DIOM development is to support the construction of a USECA view of data from disparate data sources, rather than inventing yet another object-oriented data model. Recently, a consortium of major OODBMS vendors proposed a candidate for such a model, called ODMG-93 object database standard [21, 11], which was developed by adding database features to the OMG object model standard. Therefore, we adopt the ODMG-93 proposal as a starting point, and add a number of

extensions in order to build integrated views of data across multiple data repositories and to support USECA properties.

3.1 A Quick Look at the Model

As in the ODMG-93 standard, DIOM's basic entity is the *object*. Every object has a unique identity, the object identifier (oid), that can uniquely distinguish the object, thus enabling the sharing of objects by reference. Objects are strongly typed. All objects of a given type exhibit similar behavior and a common range of states. The behavior of objects is defined by a set of *operations* that can be executed on an object of the type. The state of an object is defined by a set of *properties*, which are either *attributes* of the object itself or *relationships* between the object and one or more other objects. Changing the attribute values of an object, or the relationships in which it participates, does not change the identity of the object. It remains the same object.

An object type is described by an interface and one or more implementations. An *interface* can be seen as a strongly typed contract between objects of similar behavior or between objects that need to corporate with each other in order to accomplish a task. It defines properties of a type, properties of the instances of the type, and operations that can be invoked on them. An implementation defines internal data structures, and operations that are applied to those data structures to support the externally visible state and behavior defined in the interface. The combination of the type interface specification and one of the implementations defined for the type is referred to as a *class*. The use of the term class allows a subset of the DIOM model to be consistent with C++.[1] Multiple implementations for a type interface is useful to support databases that span networks which include machines of different architectures, mixed languages and mixed compilers environments.

Consider the `Claim Folder` example mentioned in Section 2. Figure 2 shows the contents of the three data repositories in this example: (1) a patient's insurance agreement and claims for special medical treatments in a relational database, (2) a collection of X-ray images associated with each claim stored in a file-based image repository, and (3) a doctor's diagnosis report stored in a C++ based document repository. Figure 3 shows a sample interface schema for the `Claim Folder` application. This schema contains an interface definitions for each type of data in the underlying data repositories. We assume that each claim may contain more than one X-ray image but involve only one doctor's diagnosis report. There are a number of ways to create `ClaimFolder` objects by linking the patients' claims in the relational database with their associated X-ray images and the corresponding doctors' diagnosis reports. For example, application developers may use the base interface definitions in Figure 3 to design the `ClaimFolder` objects within their programs. It is also possible to either use the DIOM interface specialization abstraction mechanism to establish the links between the underlying data repositories through specialized interfaces, or apply the interface aggregation abstraction mechanism to compose a single compound interface for constructing the `ClaimFolder` objects. In the later case, the type definer of `ClaimFolder` specifies whether the link objects are maintained as persistent objects or transient objects. The `persistent` option will have the `ClaimFolder` objects stored and managed by the link database, whereas the `transient` option implies dynamic binding and composing the objects requested

[1] A C++ class has a single *public part* and a single *private part*. The private part corresponds to the implementation of a class in DIOM.

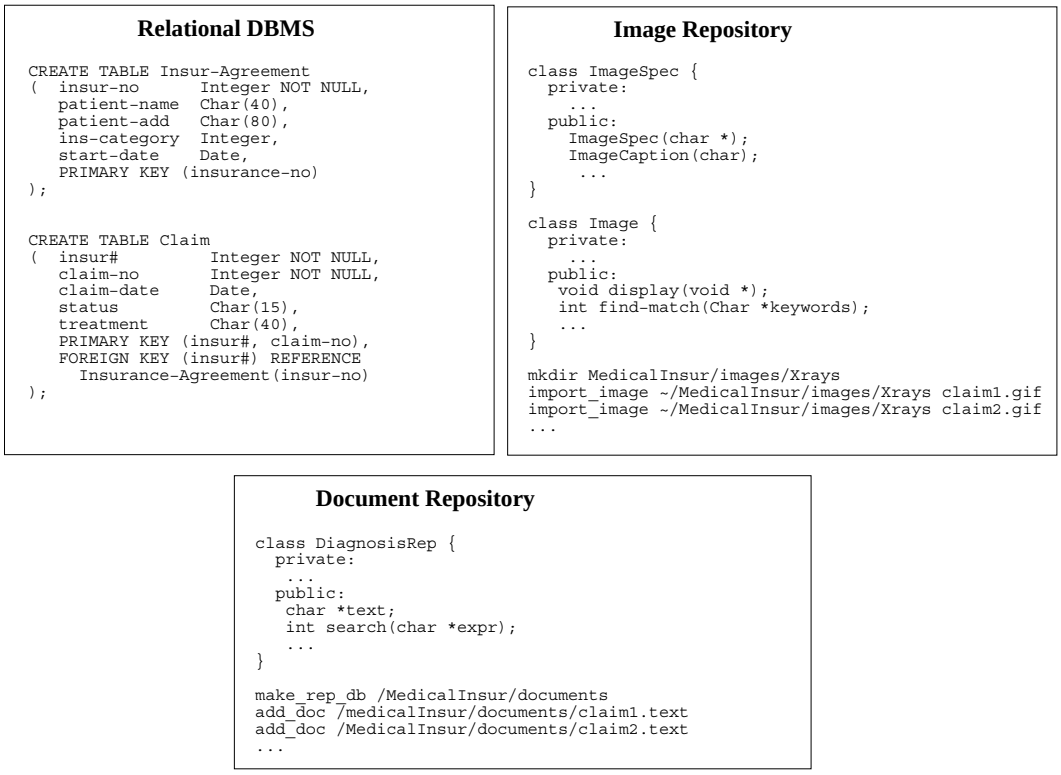


Figure 2: The data repository contents relevant to the medical claim folder scenario

to the target applications. In this example, we also assume that each claim may contain more than one X-ray image but involve only one doctor's diagnosis report.

3.2 Basic Concepts

3.2.1 Types and Type Properties

Types are themselves DIOM objects and may have properties themselves. For instance, each type may have the following three properties:

- *Supertypes.* Object types can be defined by stepwise refinement, which forms a subtype/supertype graph. All attributes, relationships, and methods defined on a supertype are inherited by its subtypes. A subtype may add additional properties and operations to introduce behavior or state unique to instances of the subtype. It may also "override" the properties and operations it inherits to make them specialized to the behavior and range of state values appropriate for instances of the subtype. The formal semantics of inheritance along with subtype/supertype graph is based on the usual notion of subtyping [4]. Figure 4 shows the *subtyping* relationships between types, and the *instance-of* relationship between types and their instances.

```
CREATE INTERFACE Insur-Agreement
(   EXTENT  Insur-Agreement
    KEY     Insur-no): persistent
{
   ATTRIBUTES
     Integer insur-no;
     String  patient-name;
     String  patient-add;
     Integer ins-category;
     Date    start-date;
);

CREATE INTERFACE Claim
(   EXTENT  Claims
    KEY     insur#, claim-no): persistent
{
    ATTRIBUTES
      Integer insur#;
      Integer claim-no;
      Date    claim-date;
      String  status;
      String  treatment;
);

CREATE INTERFACE DiagnosisRep
(   EXTENT DiagnosisReps ): persistent
{
    ATTRIBUTES
      String insur-no;
      String text;
      ...

    OPERATIONS
      int *search(char *expr);
   ...
};
```

```
CREATE INTERFACE ImageSpec
(   EXTENT ImageSpecs ): transient
{
    ATTRIBUTES
     ...

    OPERATIONS
      void *ImageSpec(Char *);
      Char *ImageCaption(Char);
        ...
}

CREATE INTERFACE Image
(   EXTENT Images ): persistent
{
    ATTRIBUTES
      Integer InsurNum;
      ...

    OPERATIONS
      void *display(void *);
      int *find-match(Char *keywords);
       ...
}
```

Figure 3: A sample interface definition in DIOM-IDL

- *Extents.* The extent of a type denotes the set of all instances of the type. By including an extent declaration in the type definition, the type definer instruct the DIOM system to automatically maintain a current index to the members of this set. The actual maintenance of the extent depends on the object binding options specified for the extent: *persistent* or *transient.* The `persistent` option will have the objects stored and managed by the link database, whereas the `transient` option implies dynamic binding, loading, and packaging the objects requested to the target applications. If an object is an instance of type `T`, then it is a member of the extent of `T`. Similarly, if a type `T` is a *subtype* of type `S`, then the extent of `T` is a *subset* of the extent of `S`.

- *keys.* A key of an object type is a property or a set of properties that together uniquely identify the individual instances of the type. An object type may have more than one key. The concept of keys is similar to the concept of candidate keys in the relational data model, and is useful for capturing the key constraints in the underlying relational databases.

3.2.2 Attributes, Relationships and Operations

The interface definition for each DIOM type also contains instance property and instance operation declarations. The instance properties are the properties for which objects of the type carry values. Each property of an object instance is either attribute property or relationship property.

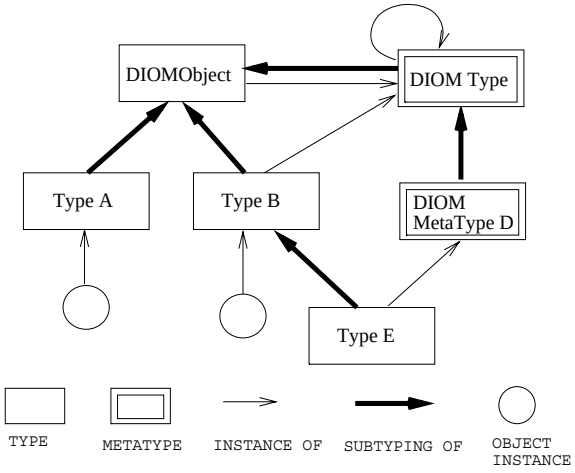


Figure 4: The subtyping relationships between DIOM types

- *Attributes.* The attributes of a given type are specified as a set of *attribute signatures*. Each signature defines the name of the attribute and the type of its legal values (e.g., strings, numbers, etc.). Accessing an attribute returns a value. *Values* can be *atomic values* (values of atomic primitive types), such as integers, characters, floating-point numbers, Boolean values, or values of *structured primitive types*, such as Bit-String, Character-String, Enumeration, Date, Time, Timestamp, Interval. Unlike objects, values cannot be referred by means of references and therefore cannot be shared other than copied.

- *Relationships.* The relationships in which objects of a give type participate are specified as a set of *relationship signatures*. Each relationship signature defines the name of the *traversal function* used to refer to the related object(s), the cardinality of the relationship, and the type of the related object(s). In contrast to attributes that are defined between an object and a value, relationships are binary and are defined between objects. Since the model supports a set of built-in collection types such as sets, lists, bags, arrays, and so on, the cardinality of a relationship (e.g., one-to-one, one-to-many, and many-to-many) can be described by means of the built-in collection types.

- *Operations.* The instance operations of a given type are the operations which objects of the type support. An operation may take zero or more parameters with specified interfaces as arguments, and return a value or an object to the specified interface. Operations are specified as a set of *operation signatures*. Each signature defines the name and the type of any arguments, the type of returned values or objects, and the names of any *exceptions* (or error conditions) the operation may incur. Many of the operations declared in DIOM are actually remote operations. Executions of a remote operation automatically begins a nested transaction so that the calling operation is insulated from network failures.

Due to the space limitation, we omit the discussion on the DIOM built-in type hierarchy in this paper. Readers who are interested in this part may refer to our technical report [16].

3.3 Advanced Concepts for Interface Definitions

3.3.1 Base Interface and Compound Interfaces

As mentioned earlier, a type of distributed interoperable objects is defined by specifying its interface in the DIOM Interface Definition Language (DIOM-IDL). The DIOM interfaces are classified into two categories: *base* interfaces and *compound* interfaces.

A **base interface** refer to the interface in which all the types involved in the definition are from a single data repository. In order to build links and abstract relationships between data from different data repositories, each data type defined in the underlying data repositories and visible to the DIOM system should be declared in terms of a base interface. For example, in the `Claim Folders` application scenario, to build a DIOM database which not only provides users and applications with direct and uniform access to the source data but also creates the `ClaimFolder` link objects based on the data from three disparate data repositories (see Figure 2 and Figure 3), we may define one or more base interfaces for each of the underlying data repositories. The set of base interfaces that correspond to a given source repository can be seen as a *view* over the underlying data repository. The scope of a base interface is the corresponding data repository.

The **compound interfaces** are constructed through repetitive applications of the interface abstraction mechanisms to the existing (either base or compound) interfaces. A compound interface can be seen as a strongly typed contract between interfaces to provide a small but useful collection of semantically related data and operations. Each interface defines certain expected behavior and expected responsibilities of a group of objects. The scope of a compound interface is the number of data repositories to which the interface definition references. Thus, a compound interface can be an external database schema of a given data repository, or an integrated view schema over multiple data repositories. The interface abstraction mechanisms provided by DIOM include specialization abstraction, generalization abstraction, aggregation abstraction and the import mechanism. We will illustrate each of them through examples in the subsequent sections.

There are a number of advantages for distinguishing between base and compound interfaces. For example, by defining a base interface for each type of data in the underlying data repositories, applications of the interoperable systems may have direct access to the data sources residing in any of the underlying repositories through the DIOM interfaces. More importantly, it helps to establish a semantically clean and consistent reference framework for incremental definition of DIOM interfaces. It also facilitates the building of an adaptive and robust implementation architecture that allows independent evolution and management of distributed interoperable objects. For example, queries against compound interfaces can be easily dispatched into a package of subqueries, each against a collections of base interfaces whose interface scope is the same repository. Finally, the distinction allows a better control to the addition of new data types that are not presented in the underlying data repositories and that are unique to the interface schema, because in a distributed interoperable object system, it is important to make sure that the new types will be only those types whose instances can be unambiguously derived from instances of the source types that are defined in the underlying repositories.

3.3.2 Interface Abstraction Mechanism: Specialization

The *specialization* abstraction is a useful mechanism for building a new interface in terms of some existing interfaces through type refinement. This mechanism promotes information localization such that changes in an object type or its implementations can automatically be propagated to the subtypes that are specialized versions of it. In the first phase of DIOM implementation, the specialization abstraction is only supported for construction of a new interface based on one or more base interfaces whose scope is the same data repository.

Recall the `Claim Folder` example. Suppose we are interested in gathering the up-to-date information

```
CREATE INTERFACE S-Claim
(   EXTENT  S-Claims ): transient
{
    SPECIALIZATION OF Claim;
    ...
    RELATIONSHIPS
      Set<S-Image> X-rays
        INVERSE Set<S-Claim> associatedto in S-Image;
      S-DReport has-report
        INVERSE rep-usedfor in S-DReport;
);

CREATE INTERFACE S-Image
(   EXTENT S-Images ): transient
{
    SPECIALIZATION OF Image
    ...
    RELATIONSHIPS
      Set<S-Claim> associatedto
        INVERSE X-rays in S-Claim;
    ...
}

CREATE INTERFACE S-DReport
(   EXTENT  S-DReport ): transient
{
    SPECIALIZATION OF DiagnosisRep;
    ...
    RELATIONSHIPS
      S-Claim rep-usedfor
        INVERSE has-report in S-Claim;
    ...
);
```

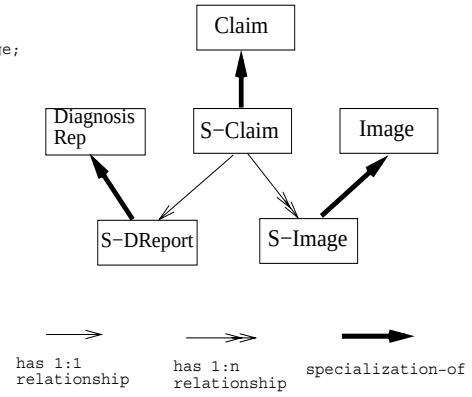


Figure 5: An example for interface specialization abstraction

about a patient's claim and the associated X-ray images as well as the corresponding doctors' diagnosis report. However, we are not interested in maintaining the `ClaimFolder` relationship objects as persistent objects in the link database. One way to do this job is to create a specialized interface that defines the links of the patient's claims with the associated `Image` objects and with the corresponding doctors' diagnosis report objects through the interface refinement mechanism. Figure 5 shows how each of the base interfaces `Claim`, `Image`, and `Document` is specialized by adding the required relationships into its specialized interface definition in DIOM-IDL. Due to the space limit, we omit the the BNF syntax of the DIOM-IDL in this paper. Readers may refer to [16] for detail.

3.3.3 Interface Abstraction Mechanism: Generalization

The *generalization* abstraction provides a convenient facility to merge several semantically similar and yet different interfaces into a more generalized interface. The main idea is based on generalization by abstracting the common properties and operations of some existing (base or compound) interfaces.

As a result, it enables objects that reside on disparate data repositories to be accessed and viewed uniformly through a generalized DIOM interface. Interface generalization mechanism also provides a helpful means to assist the automatic resolution of representational conflicts.

Consider the following example. Suppose we have three stock trade information bases available in the Internet: `NYStockInfo`, `TokyoStockInfo`, and `FfmStockInfo`. For presentation brevity, let us assume that these three repositories are all relational databases maintained separately. Figure 6 shows the relevant portion of the sample export schemas of these three stock trade data repositories. The corresponding base interface definitions in DIOM-IDL are given in Figure 7.

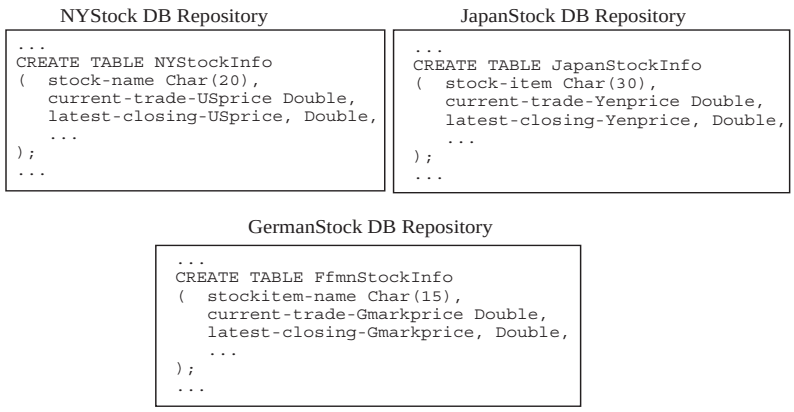


Figure 6: The sample source specifications of `NYStocks, TokyoStocks, FfmStocks`

To query the `latest-closing price` of a stock and return the result in some desired currency (e.g., in US dollar) no matter whether the stock was traded in New York or Tokyo or Frankfurt, it is convenient if we create a new interface `StockTrade` through generalization abstraction of the base interfaces `NYStocks, TokyoStocks, FfmStocks` as shown in Figure 7. The operations `YentoUSD` and `GMtoUSD` in Figure 7 are system-supplied default conversion functions, which are generated based on the *domain-specific* knowledge stored in the DIOM metadata library. For example, we may use the currency exchange rates of the day on which the queries are issued as the default criteria for the currency exchange conversions.

DIOM provides facilities to support *domain-specific library functions* which can be used to resolve large amount of representational heterogeneity and several semantic mismatches. In addition, users may override the system-supplied library functions by defining their own conversion routines as part of their interface definitions. When a function is called, the system first check whether the relevant conversion functions exist in users' interface definitions. If not, the system-supplied library functions will be invoked.

For a particular application whose domain-specific knowledge is not yet recorded completely in the form of DIOM *domain-specific library functions*, it is then the DBA's responsibility to define the necessary conversion functions within the generalization interfaces. For example, assume an application requires information about college marks of a collection of students who come from different countries. Suppose we may gather such information from three disparate data repositories available in the Internet:

```
CREATE INTERFACE NYStocks
(  EXTENT NYStocks ):  persistent
{
   ATTRIBUTES
     String stock-name;
     Double current-trade-USDprice;
     Double latest-closing-USprice;
   ...
);


CREATE INTERFACE TokyoStocks
(  EXTENT TokyoStocks ): persistent
{
   ATTRIBUTES
     String  stock-item;
     Double  current-trade-Yenprice;
     Double  latest-closing-Yenprice;
   ...
);


CREATE INTERFACE FfmnStocks
(  EXTENT FfmStocks ): persistent
{
   ATTRIBUTES
     String  stockitem-name;
     Double  current-trade-GMprice;
     Double  latest-closing-GMprice;
   ...
);
```

```
CREATE INTERFACE StockTrade
(  EXTENT StockTrade ): transient
{
   GENERALIZATION OF NYStocks, FfmStocks, TokyoStocks;

   ATTRIBUTES
     String  stockname;
     Double  current-trade-price;
     Double  Latest-closing-price;
     Enum Currency{USD,Yen,GM,...} currency-preferred;
     ...
   OPERATIONS
     double *get_value(Double current-trade-price,
                       int currency-preferred)
      {
       ...
       switch(x.currency-preferred)
         case x.currency-preferred = 0:
           if (NYStocks(x)
             return x.current-trade-USDprice;
           else
             if (TokyoStccks(x))
                return YentoUSD(x.current-trade-Yenprice);
             else
               if (FfmStocks(x))
                  return GMtoUSD(x.current-trade-GNprice);
               else < exception-handling >
          case x.currency-preferred = 1:
          ...
       };
    ...
};
```

Figure 7: Creating a new interface `StockTrade` based on generalization

`Students-1, Student-2` and `Student-3`. We want the receiving results to be represented in a chosen making scheme uniformly no matter what marking schemes were used in the source data. For example, `Students-1` uses the marking scheme of A to E, called `grade`, whereas `Students-2` uses the `point` scheme of one to ten. The `score` scheme is used by `Students-3` in the third repository in which the highest mark is 100. Suppose the receiver's preferred marking scheme is based on `score` scale, and there is no domain-specific library functions for such marking scheme conversion. Figure 8 shows an example of how a DBA may specify his/her own conversion functions for converting the marking scheme used in each data repository to the receiver's preferred marking scheme.

Alternatively, users may also choose to specify and store these conversion functions as domain-specific knowledge in the DIOM metadata library. The DIOM system will provide standard header files to allow application developers to use the domain-specific library functions in a similar way as the usage of C++ library functions.

3.3.4 Interface Abstraction Mechanism: Aggregation

The *aggregation* abstraction is a mechanism that allows to compose a new interface from a number of existing interfaces such that objects of the container interface may access the objects of component interfaces directly. As a result, the operations defined in the component interfaces can be invoked via the container's interface. The aggregation abstraction mechanism is a useful facility for implementing

```
CREATE INTERFACE Int-Students
(  EXTENT Int-Students ): transient
{
   GENERALIZATION OF Students-1, Students-2, Students-3;

   ATTRIBUTES
     String  sname;
     String  mark;
     Enum Mark {grade, point, score} scheme-preferred;
      ...
   OPERATIONS
     void *get_value(char *mark, int scheme-preferred)
     {
       ...
       if (Students-1(self))
         mark(self) = gradetoscore(grade(self));
       else
         if (Students-2(self))
            mark(self) = pointtoscore(point(self));
          else
            if (Students-3(self))
               mark(self) = score(self);
            else
              < print error message >;
      };
     ...
};
```

Figure 8: An example of user-defined conversion functions in IDL

behavioral composition [14, 15] and ad-hoc polymorphism [5] based on coercion of operations.

Recall the `Claim Folder` example given earlier. We have so far presented two alternative approaches that generate the `ClaimFolder` objects through linking the claims with the relevant images and the corresponding doctors' report. The first approach is to let application developers design the `ClaimFolder` objects within their programs based on the base interface definitions given in Figure 3. The second approach is to use the interface specialization mechanism to establish links between the underlying data repositories. In fact, we may take the third alternative approach by creating link objects of type `ClaimFolder` through interface aggregation abstraction mechanism as shown in Figure 9. As a

```
CREATE INTERFACE ClaimFolder
(   EXTENT  ClaimFolders ): persistent
{
    AGGREGATION OF Claim, Image, DiagnosisRep;

    RELATIONSHIPS
      Claim        claims;
      Set<Image>   X-ray-pictures;
      DiagnosisRep report;
    OPERATIONS
      void *get_value(ClaimFolder);
      void *set_value(ClaimFolder);
       ...
);
```

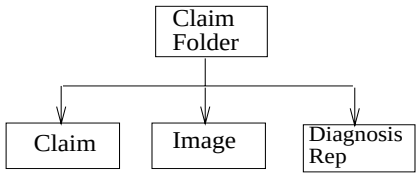


Figure 9: An example of creating a new interface using aggregation abstraction mechanism

result, a compound interface is constructed for processing `ClaimFolder` objects. If the type definer of `ClaimFolder` specifies that the link objects be maintained as `persistent` objects, then once the `ClaimFolder` objects are formed, they will be stored in the link database. When the `transient` option is used, it notifies the system that each subsequent query over the `ClaimFolder` objects will be carried out through the dynamic binding and loading of the objects from the underlying data repositories.

Another benefit of using interface aggregation abstraction is to minimize the impact of component

schema changes over the application programs working with the existing interoperation interfaces. For example, consider the `ClaimFolder`. Suppose a new image repository, called `CAT-Scan` is added into the `Claim Folder` application. After creating a base interface for `CAT-Scan`, we can simply compose a new compound interface `ClaimFolderNew` by aggregation of the original interface schema `ClaimFolder` with the base interface for the `CAT-Scan` image repository, and add the necessary links between `CAT-Scan` and `ClaimFolder`. Thus, the existing programs may continue to work with the original `ClaimFolder` interface schema. No source code modification is necessary. At the same time, the new applications can work with the new interoperation schema.

3.3.5 The Import Mechanism

The *import mechanism* is designed for importing selected portions of the data from a given export schema, instead of importing everything that is available. For a data repository that manages complex objects, the import mechanism performs the automatic checking of type closure property and referential integrity of the imported types/classes. The type closure property refers to the type consistency constraint over subtype/supertype hierarchy such that whenever a type/class is imported, all the properties and operations it inherits from its supertypes have to be imported together. The referential integrity property refers to the type "completeness" rule on object reference relationships, and is used to guarantee that there is no dangling reference within the imported schema.

Using the import mechanism, a number of benefits can be obtained. First, by means of the import mechanism, users may simply specify the key information that are of interest to their intended applications. The system will automatically infer the rest of the types/classes that need to be imported in order to preserve the referential integrity and type closure property. Second, the use of import mechanism allows users to customize the source data during the importing process by hiding irrelevant portions of objects imported. Similarly, users may add derived data as well. Third, when an application is interested in many types of data from a single data repository, using the import mechanism may also relieve the database administrators from the tedious job of specification of base interfaces for each of the source data types. Last but not least, the import mechanism encourages to minimize the impact of component schema changes on the applications of interoperable systems.

Consider the example shown in Figure 10, where the export source database schema `UnivDB1` consists of `Person, Employee, Department, Professor, Staff, Student, TA, RA` and `Course`. We omit the syntactical definition of the source schema in Figure 10 for presentation brevity. Suppose an application want to create a `University` interface by importing only a portion of the data from the source schema `UnivDB1`, which is related to teaching faculty or TAs. We may specify the `University` interface by using the DIOM import facility as shown in Figure 11(a). Three types are explicitly imported from `UnivDB1`. They are `Person, TA` and `Professor`. For the BNF syntax of the IDL import specification, readers may refer to our technical report [16]. According to the referential integrity and type closure property, the type `Course` needs to be imported as well, because the `Course` objects are referenced by the imported types such as `Professor` and `TA` (see Figure 11(b)).

However, there is no need to import the entire type structure of `Address, Department, RA, Staff`, even though they are not explicitly excluded (hidden) from the import list in the `University` specification. The reasons are the following:

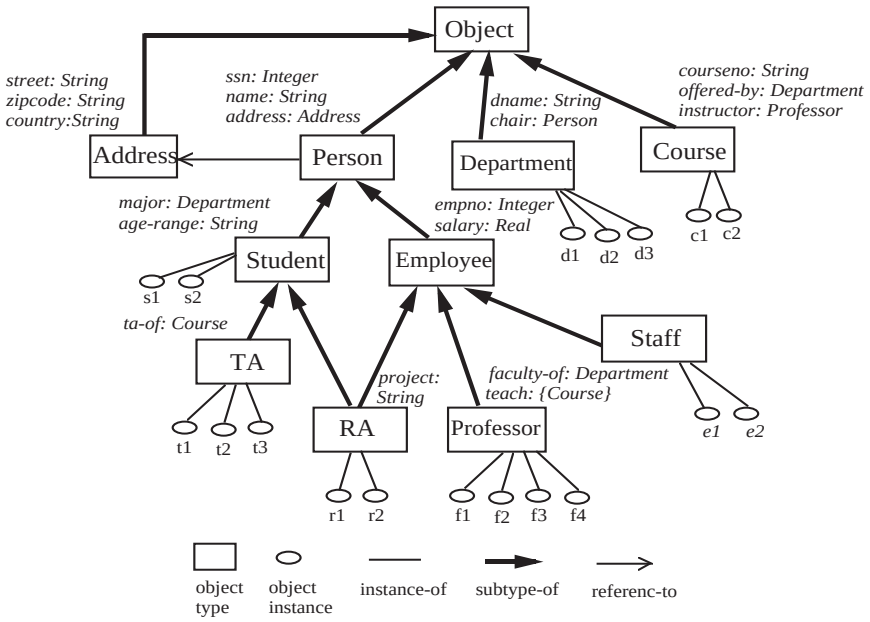


Figure 10: A sample source schema of the source database `UnivDB1`

- The reference to `Address` objects from `Person` is the only reference, and is explicitly excluded in the `University` interface specification through `HIDE` facility associated to the import mechanism. Thus there is no need for importing `Address` into the `University` schema. Similarly, there is no need to import `RA` and `Staff` either.

- In principle, if two types `T` and `S` that have indirect subtyping relationship are imported explicitly, and there are types `T1, T2, ..., Tk` in between `T` and `S` in the subtype/supertype type hierarchy, then all the properties and operations that are locally defined in `T1, ..., Tk` are imported implicitly as the properties and operations of type `S` unless being hidden explicitly. Therefore, although the type `Student` is not in the *import* list, properties of `Student` which are not explicitly hidden, such as `age-range`, are imported as the properties of `TA` objects.

- Since type `Department` is explicitly excluded from the importing list through the `HIDE TYPE` facility associated with the import mechanism, all the references to `Department` objects from the imported objects should be modified accordingly. Hence, attribute `faculty-of` in the `Professor` objects is modified from domain type `Department` to refer to the department name of type `String`.

Now let us discuss how the import mechanism may help to minimize the impact of component schema changes on the applications at interoperable system level. Suppose after the `University` interface is created, the component database `UnivDB1` is changed by the following schema update transactions:

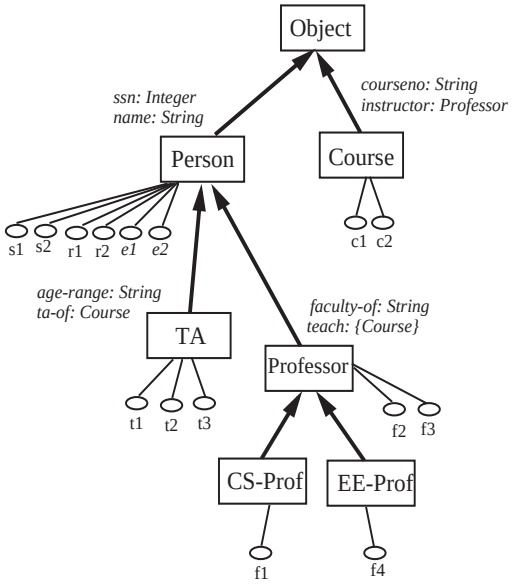
```
T1: adding new attributes such as dept-location, total-num-emp to the Department objects;
T2: modifying the attribute of age-range to a larger scope;
T3: adding a new attribute weekly-wk-hrs to the Employee objects.
```

```
CREATE INTERFACE University
(  EXTENT University ): dynamic
{
   FROM UnivDB1
     IMPORT TYPES Person, TA, Professor;
     HIDE TYPES Deparrtment;

     TYPE Person
       HIDE address;
     TYPE Professor ISA Person
       HIDE empno, salary;
     TYPE TA ISA Person
       HIDE major, empno, salary;

     ADD TYPE CS-Prof ISA Professor
        select * from Professor
        where faculty-of = "CS";
     ADD TYPE EE-Prof ISA Professor
        select * from Professor
        where faculty-of = "EE";
     ...
};
```

(a) Creating interface `University` using the importing mechansim



(b) The resulting interface schema inferred by the facilities that support the importing mechanism

Figure 11: Creating a DIOM interface by importing a portion of the source database `UnivDB1`

Not surprisingly, the updates T1 and T2 require no changes to the source code of the applications which work with the `University` interface schema. Consider T1, since the `University` interface specification in Figure 11 has explicitly excluded `Department` through `HIDE TYPE` facility, any later change to the source data type `Department` will be transparent to the users of the `University` interface schema. Thus the execution of T1 has no change effect on the applications that use the interoperation interface schema `University`. For the schema update T2, since it modifies the domain of attribute `age-range` by augmenting it, thus there is no conflict or illegal data resulted from the programs developed earlier that access the `TA` objects in the `University` schema.

In the case of the component schema update T3, there is no need to rewrite the interoperation interface `University` or to modify the source code of the existing programs that work with the `University` schema. However, a new version of the `University` interface will be generated in order to provide the new applications with up-to-date information. This is simply because in the specification of the compound interface `University`, only two properties `empno, salary` are explicitly hidden from the source type `Employee`. According to the type closure property, this implies that any later extension to type `Employee` in the component repository should be visible through the `Professor` objects in the `University` interface, because of the inheritance relationship between `Employee` and `Professor` in the source repository `UnivDB1`. In order to add the `Employee`'s new attribute `weekly-wk-hrs` to the `Professor` objects, the only action the DIOM system needs to take, after notified of the component update T3, is to recompile the `University` schema, and save the recompilation result into a new version of the `University` interface, called `UniversityNew`. This new interface is seen as a specialized version of the original `University` interface. As a result, the existing programs which use the `Professor` objects via the original `University` interface may continue to work as before, while the new applications can

work with the `UniversityNew` interface.

Generally speaking, by using DIOM interface abstraction mechanisms, as long as the changes in the source data repositories is information-preserving or information-augmenting, the rewriting or recompilation of the source code of the existing programs that have been developed at the interoperable system level can be avoided.

4 Queries in DIOM databases

Even though DIOM is object-oriented, SQL-style query access to DIOM databases should be supported. The DIOM interface manipulation language (IML) is designed as an object-oriented extension of SQL. The design follows a number of assumptions: First, IML by itself is not computationally complete. However, queries can invoke methods, and conversely methods supported in any host language can include queries. Second, IML should provide declarative access to objects and thus can be optimized with known optimization techniques. In this section, we outline the DIOM query model and illustrate the IDL/IML compilation process under the Diorama framework through an example.

Recall the `Claim Folder` application given in Section 3. Suppose the interface schema of `Claim Folder` consists of the base interfaces `Claim, Insur-Agreement, Image, ImageSpec`, `DiagnosisRep` as defined in Figure 3, and the compound interface `ClaimFolder` as specified in Figure 9. The following query is written in DIOM-IML against the `Claim Folder` interface schema.

```
SELECT I.patient-name, I.insur-no, Set(F.X-ray-pictures)
FROM   ClaimFolder F, Insur-Agreement I
WHERE  F.report.search("dental" && "bridge")
AND    I.insur-no == F.claims.insur#
AND    (F.claims.claim-date - I.start-date) < 90;
```

This query asks for the patients who have a claim for insurance of the special "dental bridge" treatment and who have received the insurance premium within three months (90 days). The desired query answer form is the name and the insurance number of the patients and the corresponding set of X-ray images. This query contains a number of path expression (such as `F.claims.claim-date`) for traversal of the relationships defined by `ClaimFolder` link objects. It also includes the method invocation of `search()` associated with `DiagnosisRep`.

Figure 12 illustrates the procedure of how a DIOM query is processed under the Diorama architecture. Suppose this query is embedded in a host program language as shown in the upper left box of Figure 12. First, the program containing the query will be passed to the IDL/IML preprocessor. After syntax analysis, query optimization and decomposition, the IDL/IML preprocessor generates a data access path module for each query embedded in the host program, and returns a modified source file in which all the IML queries are replaced by DIOM system calls to the corresponding access path modules. At the linking stage, the object code is linked with the access path modules. The dynamic binding and linking to the remote data sources and services requested are loaded. The DIOM runtime executable code is produced.

The IDL/IML preprocessor itself consists of four basic modules as shown in Figure 12. They are syntax analyzer, optimization module, query dispatch module and code generation module.

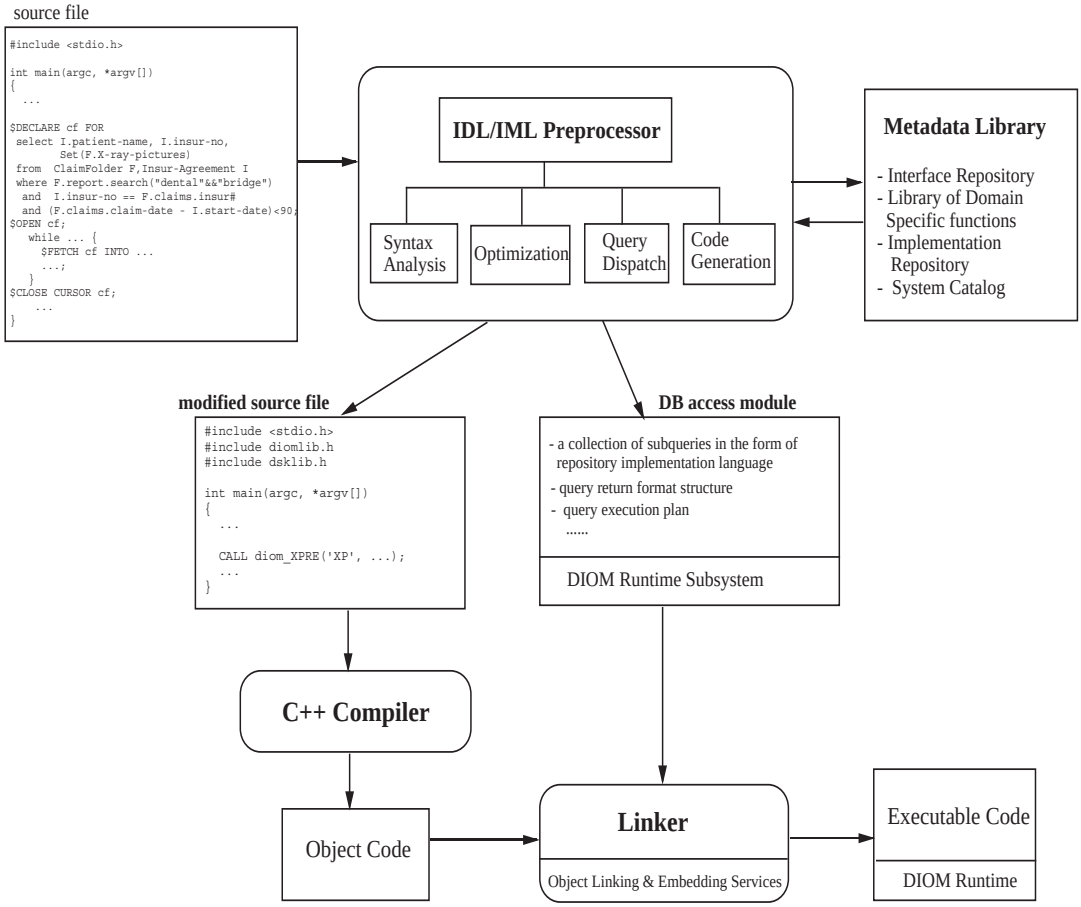


Figure 12: Accessing data from the DIOM database

- **Syntax analysis** module takes an IML query as input, checks its syntax and produce a syntax tree expression of the query.
- **Optimization** module takes the query syntax tree as input, and performs a number of tasks, including:
  - Replace the names used in the query with internal implementation object names according to the DIOM metadata library.
  - Decompose the query into a number of smaller queries, each runnable on an individual repository. Then group those which run on the same repository into one skeleton binding on the server side, and generate a stub for each skeleton binding, including the stub in the header file of the client program.
  - Perform authorization and security checking to verify whether the users may access the collection of objects or the corresponding source data repositories, based on the records in the system catalog. For instance, in the `Claim Folder` query above, the application should have access permission to all the three source data repositories.

– Use the optimization strategies and the statistics available to the DIOM distributed query processor to define the synchronization sequence for remote access among all the subqueries. Prepare the plan for combining results to be returned by the number of smaller queries into the desired query answering form. And then generate an access path module in the repository implementation language.

However, if the statistics required for optimization of a set of subqueries over a particular data repository is not available, which is a common case, then the optimization of the subqueries will be carried out by the individual source repository independently. For instance, suppose the example query be decomposed into three subqueries `subQ1, subQ2`, and `subQ3`. The execution sequence is (`subQ1 || subQ2`) `-> subQ3`. It means the execution of `subQ1` and `subQ2` can be submitted to the corresponding repositories in parallel. Either the result of `subQ1` or `subQ2` will be used as the selection condition of `subQ3` against the image repository. Assume that it is not possible to collect enough statistics for optimization of `subQ1` and `subQ2`, the preprocessor will then choose one from the two subqueries `subQ1` and `subQ2` according to the semantic information implied in the interface schema. In this example, `subQ2` is chosen, because based on the selection condition, only one object will be returned from `subQ2`, whereas each patient may have more than one claim, thus more than one diagnosis report (see Figure 13 for illustration).

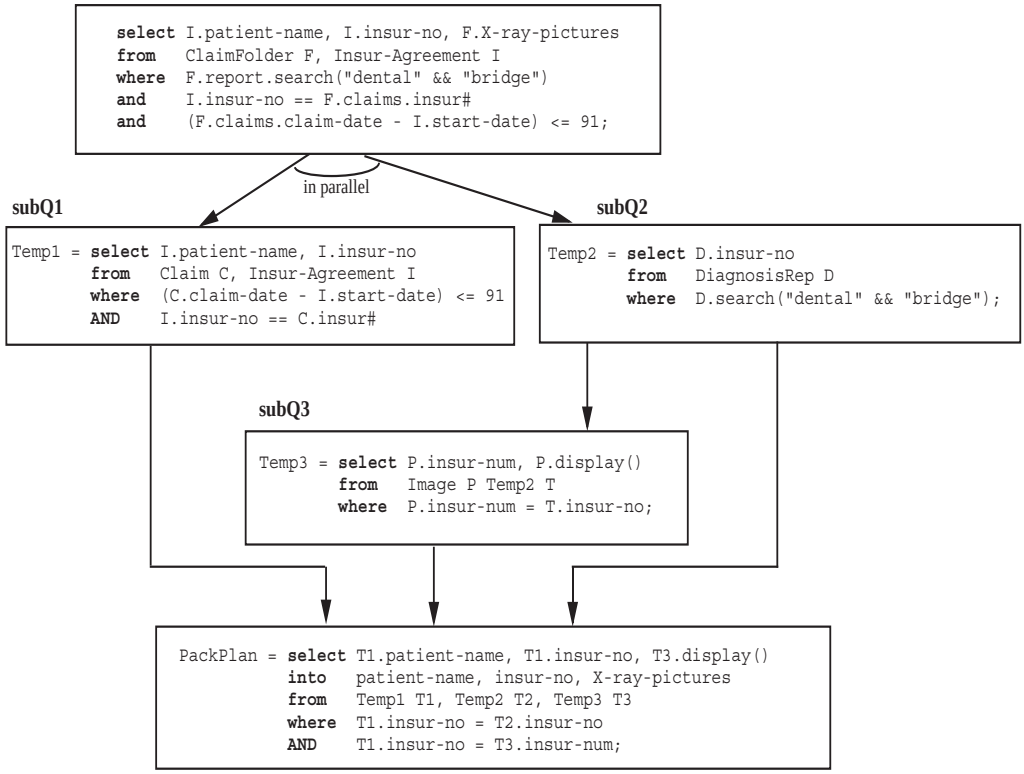


Figure 13: Accessing data from the DIOM database

- **Query dispatch** module will be responsible for invoking the object linking and embedding services

to submit each group of subqueries to the corresponding source repository for execution and collect the subquery result.

- **Code generation** module takes the access path module as input and generate machine language code. This code will be linked together with the object code of the application program written in a host programming language (e.g., C++).

In the first stage of our Diorama prototype implementation, we intend to use the software products such as OLE from Microsoft and DSOM from IBM as tools for dynamic remote object linking purpose.

5 Related Work

Over the last decade, many published results on database interoperability have primarily focused on resolving schematic and semantic incompatibilities arising from autonomy of the underlying databases. They use two integration strategies: *tight-coupling* and *loose-coupling* [25]. Tight-coupling insists on total schema integration. Since the creation and maintenance of such an integrated schema has been recognized as a fundamental roadblock towards system scalability and evolution, tight-coupling is generally considered a small-system strategy. In contrast, loose-coupling goes to another extreme by favoring zero schema integration, for example, by promoting integration and interoperability via a multidatabase query language [28, 13]. It does not require the existence of an integrated schema, leaving many responsibilities, such as resolving semantic mismatch, dealing with multiple representations of data, and coping with dynamic system evolution, to the users.

Recent research in database interoperability has started to pay more attention to interoperation architectures that support both tight-coupling and loose-coupling (cf. [3, 8, 19, 22, 31]). DIOM has been motivated by the mediator architecture [30, 31] and the Context Interchange approach [27, 10]. For example, the idea of using repository wrapper to bridge between the interoperable database system and the individual component repositories is to some extent encouraged by the mediator approach. The intelligent integration of information through query compilation is also supported in the DIOM framework. Comparing with the Context Interchange proposal, both approaches support explicit representation of semantics underlying disparate data sources and heterogeneous receivers. However, in contrast to the shared ontology model used in the Context Interchange proposal, DIOM provides an interface definition language and a semantically rich and clean framework that allows independent evolution and management of distributed interoperable objects. DIOM also includes a number of abstraction mechanisms as well as strategies for incremental design and construction of the interoperation interfaces, for distributed query decomposition and packaging, for generation of optimal data access plan, and for dynamic object linking and embedding.

In addition, a number of proposals have competed as the basic enabling technologies for implementing interoperable objects in distributed and dynamic object computing environments. Examples include Microsoft's Object Linking and Embedding (OLE), IBM's System Object Model (SOM) and its distributed version (DSOM), OMG's Common Object Request Broker Architecture (CORBA), and CI labs OpenDoc. Many of these are available as deployed software packages. The emergence of these technologies also demonstrates that the continued evolution of object-oriented programming and object-oriented

database management systems are converging into language-independent and distributed object computing. Although these proposals are clearly practical and important, they focus primarily on the software interface problem, not the USECA properties in large scale interoperable database systems. DIOM can be seen as a glue that spans and integrates these interface models.

Another related field is the area of Distributed Object Management [18]. A representative effort is the ongoing research at GTE Labs [17] to divide object models into components and then map them into each other. Another example is the BLOOM model [6], which is a semantic data model that includes abstractions such as specialization, generalization, and aggregation. Compared to these more formal models, DIOM is designed to support the USECA properties and it combines abstractions with a practical implementation path.

6 Conclusion

We have introduced the Distributed Interoperable Object Model (DIOM) and described a concrete instance of DIOM in the Diorama project. Diorama and DIOM have been designed to address the research challenges in large scale interoperable database systems: Uniform access, Scalability of network, Evolution of system components, Composibility of component databases, and preservation of Autonomy (USECA properties).

Our main contributions in this paper are the following. First, the use of base interfaces to model data from individual repositories and compound interfaces to model the desired links among remote data sources not only present a useful method for design and construction of interoperable databases from disparate data sources, but also provide a semantically clean framework for allowing independent evolution and management of distributed interoperable objects. Second, the interface abstraction mechanisms provided in DIOM, such as *import* and *hide*, *aggregation, generalization* and *specialization*, allow incremental design and construction of new interfaces in terms of the existing ones. For example, by combining the import facility with the aggregation and generalization abstraction mechanisms, one can easily build a new interface by adding additional properties and operations to the existing interfaces. The composibility as such is very important for the organizations which perform multiple interoperable projects with overlapping sets of data. Third, the design of both the DIOM interfaces and the Diorama architecture have given the full respect to the autonomy of component systems. There is no need for component systems to request an agreement from the interoperable system in the presence of component evolution. Furthermore, all the information-preserving and information-augmenting changes in the component systems will have no impact on the use of the interoperable interfaces. To our knowledge, the DIOM interface abstraction mechanisms are original with respect to the support for USECA properties.

In addition, conflict resolution is considered secondary to the explicit representation of disparate data semantics in DIOM. Thus, the DIOM approach does not require any commitment to a canonical, predefined integration representation of component databases. Conflicts do not have to be resolved once for all in a static integrated schema. Instead, we encourage decoupling the resolution of semantic heterogeneity from representational heterogeneity. Much of conflict resolutions are deferred to the query submission time. More importantly, the conflict resolution is not hard-wired in the interoperation interface schema. Users may define their preferred query answering formats or update the existing conversion functions

whenever necessary. Thus, automatic recognition and resolution of semantic conflicts can be supported. We believe that the framework developed in this paper presents an interesting step towards supporting the USECA properties in large scale interoperable database systems.

Finally, we would like to state that the DIOM approach presented in this paper proposes an adaptive framework and a collection of techniques for incremental design and construction of interoperation interfaces, rather than a new object model. This framework is targeted towards large scale interoperable database systems operating in today's dynamic, growing, and evolving environment, which require the support of USECA properties.

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