# Capability Based Mediation in TSIMMIS

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#### 1 Introduction

The TSIMMIS system [1] integrates data from multiple heterogeneous sources and provides users with seamless integrated views of the data. It translates a user query on the integrated views into a set of source queries and post-processing steps that compute the answer to the user query from the results of the source queries. TSIMMIS uses a mediation architecture [11] to accomplish this (Figure 1).

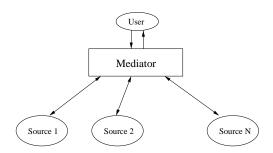


Figure 1: The TSIMMIS Architecture

Many other data integration systems like Garlic [2, 9] and Information Manifold [4] employ a similar architecture. One of the distinguishing features of TSIMMIS is its use of a semi-structured data model (called the *Object Exchange Model* or *OEM* [7]) for dealing with the heterogeneity of the data sources. In particular, it employs source wrappers [3] that provide a uniform OEM interface to the mediator.

In SIGMOD-97, we demonstrated a wrapper toolkit in TSIMMIS that helps in efficient development of wrappers based on declarative specifications [3]. We will show how the same specifications are used by the TSIMMIS mediator to generate feasible query plans in the presence of limited source capabilities.

#### 1.1 Problem Definition

Conventional mediators focus on the contents of the sources and their relationship to the integrated views provided to the users. They do not keep track of the capabilities of sources to answer queries. This may lead them to generate plans involving source queries that cannot be answered by the sources. We illustrate this by the following example.

Suppose we have two sources  $s_1$  and  $s_2$  that supply information about conference papers. Let source  $s_1$  have the title, author and abstract of the papers and let source  $s_2$  store conference and title information. The system provides the integrated view paper, which combines the information from the two sources to provide title, author, abstract and conference information for each paper. Suppose the user wants to know the titles and abstracts of all the papers written by 'Smith' in 'SIGMOD-97'. The mediator may process this user query by sending a source query to  $s_1$ to get the titles and abstracts of papers written by 'Smith', and sending a query to  $s_2$  to get the titles of all papers in 'SIGMOD-97'. The mediator may then join the results of these two source queries to find the answer to the user query. Suppose  $s_1$  can only return the information about papers, given their titles. Then the source query sent by the mediator to  $s_1$  will fail. Consequently, the mediator will be unable to answer the user query.

### 1.2 The TSIMMIS Solution

In the above example, the TSIMMIS mediator notices the limited query capabilities of  $s_1$  and finds a feasible plan that respects these limitations. In particular, it generates the feasible plan that first sends a source query to  $s_2$  to find all the titles of papers in 'SIGMOD-97'. For each of these titles, the plan then sends a separate source query to  $s_1$  to verify that the author is 'Smith' and to get the abstract.

#### 2 The TSIMMIS Mediator and Source Capabilities

In this section, we describe how the TSIMMIS mediator processes user queries. In particular, we show how the mediator translates a user query into a set of relevant source queries in Sections 2.1 and 2.2. We also explain in Section 2.3 how the source capabilities can be described by using query templates.

#### 2.1 Query Translation

The mediator encodes the relationship between the user views and the source views with a set of view definitions. Specifically, it uses the *Mediator Specification Language* (MSL) [6] to define user views. MSL is a logic-based language with object-oriented features. For example, the user view *paper* is defined as follows:

The above rule states that paper is essentially a join of the views exported by  $s_1$  and  $s_2$ , with title being the join attribute. Each rule in MSL has a head and a tail that consist of OEM objects. OEM is a self-describing data model in which each object has a label field and a value field. The value field can be atomic or complex. Complex values accommodate object nesting. For example, in the MSL rule describing the paper view, the head consists of an OEM object with label paper and a list of sub-objects describing the title, author, abstract, and conference of the paper object. Uppercase identifiers (e.g., T, A) are variables that are bound to specific values at run time.

Suppose the user wants to find the title and abstract of each paper written by 'Smith' in 'SIGMOD-97'. The user formulates the following query, based on the user view paper:

When the user query arrives at the mediator, the mediator uses the view definitions to translate the query on the user views into a *logical plan* [6] (i.e., a set of MSL rules which refer to the source views instead of the integrated views). The following is the logical plan for the example user query:

We refer to the parts of the right hand sides of the logical query plan rules as *conditions*. In the logical plan above, there is only one rule with two conditions (there will be multiple rules in the logical plan only if there are multiple rules for the user view *paper*).

### 2.2 Physical Plans

The logical query plans in TSIMMIS do not specify the order in which the conditions are processed. This is done in the physical plans generated in the subsequent stages of the TSIMMIS mediator.

Three possible physical plans for the logical plan of the example user query are:

P<sub>1</sub>: Send query <entry {<title T><author 'Smith'> <abs B>}> to s<sub>1</sub> ¹; send query <entry {<title T> <conf 'SIGMOD-97'>}> to s<sub>2</sub>; join the results of these source queries on the title attribute.

- P<sub>2</sub>: Send query <entry {<title T><author 'Smith'><abs B>}> to s<sub>1</sub>; for each returned title, send query
  <entry {<title T> <conf 'SIGMOD-97'>}> to s<sub>2</sub>, with T bound.
- P<sub>3</sub>: Send <entry {<title T><conf 'SIGMOD-97'>}> to s<sub>2</sub>; for each returned title, send <entry {<title T><author 'Smith'><abs B>}> to s<sub>1</sub>, with T bound.

Some of these physical plans may or may not be feasible depending on the query capabilities of the sources, as discussed in Section 2.3.

# 2.3 Source Capabilities Description: Templates

In order to describe the capabilities of sources, the TSIMMIS system uses templates to represent sets of queries that can be processed by each source [3, 5]. Suppose  $s_1$  and  $s_2$  have the following templates.

```
\begin{array}{lll} T_{11}: & \texttt{X:-X:<} entry \ \{< \texttt{title $T><} author $A>< abs $B>$> @s_1$ \\ T_{21}: & \texttt{X:-X:<} entry \ \{< \texttt{title $T><} conf $C>$> @s_2$ \\ T_{22}: & \texttt{X:-X:<} entry \ \{< \texttt{title $T><} Conf $C>$> @s_2$ \\ \end{array}
```

The first template  $T_{11}$  says that source  $s_1$  can return all the information it has about a paper given its title.  $T_{21}$  says that  $s_2$  can return all the information it has about papers given the conference.  $T_{22}$  says that  $s_2$  can also return the information about a paper given its title. Assume that these are the only templates for  $s_1$  and  $s_2$ . That is,  $s_1$  and  $s_2$  cannot answer any other kinds of queries.

Given these capabilities,  $P_1$  (Section 2.2) is not feasible since  $s_1$  cannot answer the query  $\{$  (Stitle T> $\{$  author 'Smith'> $\{$  abs B> $\{$  >). This is because the title value is not specified.  $P_2$  is also infeasible for the same reason. Only  $P_3$  is feasible as the mediator first gets the title of each paper in 'SIGMOD-97' from  $s_2$  and uses this title value to get the corresponding abstract information from  $s_1$  and check that the author is indeed 'Smith'. Notice that the queries to  $s_1$  are now feasible because they specify the title values.

Other ways to describe source capabilities in mediator systems have been proposed in the literature [4, 8]. For instance, the Information Manifold [4] uses capabilities records for encoding source capabilities. We note that the capability description language used by TSIMMIS is more powerful than the ones proposed in [4] and [8], as shown in [10].

In the next section, we will show how the plan generation process in TSIMMIS takes into account the source capabilities in producing feasible query plans.

#### 3 Capability Based Plan Generation

The architecture of TSIMMIS mediator is shown in Figure 2(a). The logical plan generated by the view expander is passed onto the plan generator module, which computes a feasible physical plan for the query. As shown in Figure 2(b), it accomplishes this in three stages.

### 3.1 Matcher

The first step in the plan generation process is to find all the source queries that can process parts of the logical plan. Some of these queries have requirements indicating the list of variables that need to be bound. To illustrate, consider the logical plan of Section 2.1. Let the two conditions of the logical plan be denoted  $C_1$  and  $C_2$ . There is one query to process  $C_1$ , with the requirement that variable T be bound.

<sup>&</sup>lt;sup>1</sup>Strictly speaking, source queries are MSL rules. For simplicity, we just show the tail of the source query rule.

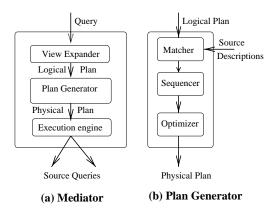


Figure 2: Mediator architecture

Source	Source	Condition	Binding
Query	Template	Processed	Requirement
$M_1$	$T_{11}$	$C_1$	T
$M_2$	$T_{21}$	$C_2$	None
$M_3$	$T_{22}$	$C_2$	T

Table 1: Matcher Result

There are two queries that process  $C_2$ : one with T bound and another without any binding requirements.

Table 1 describes the result of the Matcher. It has a row for each source query that processes some conditions of the logical plan. For instance, the first row  $M_1$  in the table indicates that  $s_1$  can process  $C_1$  by using template  $T_{11}$  with the requirement that variable T be bound.

### 3.2 Sequencer

The second step in the plan generation process is to piece together the source queries for processing the conditions of the logical plan in order to construct feasible plans. Here, what matters is not just the specific source queries chosen to cover all the conditions of the logical plan but also the sequence of processing these queries.

The Sequencer finds the set of feasible sequences of source queries. Each query in a feasible sequence has the property that the variables in its binding requirements are exported by the source queries that appear earlier in the sequence. For instance, in our example logical plan, the Sequencer finds that the only feasible sequence is  $< M_2$ ,  $M_1 >$ , with source query  $M_1$  being parameterized (variables bound) from the result of the source query  $M_2$ . Sequence  $< M_1$ ,  $M_2 >$ , though it can also process all the conditions, is not feasible because  $M_1$ 's binding requirements cannot be satisfied. Other sequences like  $< M_2$ ,  $M_3 >$  cannot process all the conditions of the logical plan.

# 3.3 Optimizer

Having found the feasible sequences of source queries, the third step of the plan generation process is to optimize over the set of corresponding feasible plans and choose the most efficient among these. The Optimizer uses standard optimization techniques to pick the best feasible plan and translates it into a physical plan. In our example case, there is only one feasible sequence of queries  $< M_2$ ,  $M_1 >$  and this leads to the physical plan  $P_3$  of Section 2.2.

# 4 Implementation and Demonstration

We have implemented capability based plan generation in the TSIMMIS mediator as described above. In the demonstration, we show how the mediator constructs feasible plans for user queries in the presence of limited source capabilities.

We employ four information sources in the demonstration. These sources come from two different domains: bibliographic data and financial information. The financial information comes from web-based sources and the bibliographic data comes from legacy systems.

We encode the capabilities of the sources by specifying a set of templates for each source. We demonstrate the ability of the TSIMMIS mediator to generate plans for user queries by taking into consideration these source capabilities. The demonstration is run through a web-based interface to the TSIMMIS mediators.

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