Using Answer Set Programs to Specify Virtual Data Integration Systems:

Obtaining Consistent Query Answers

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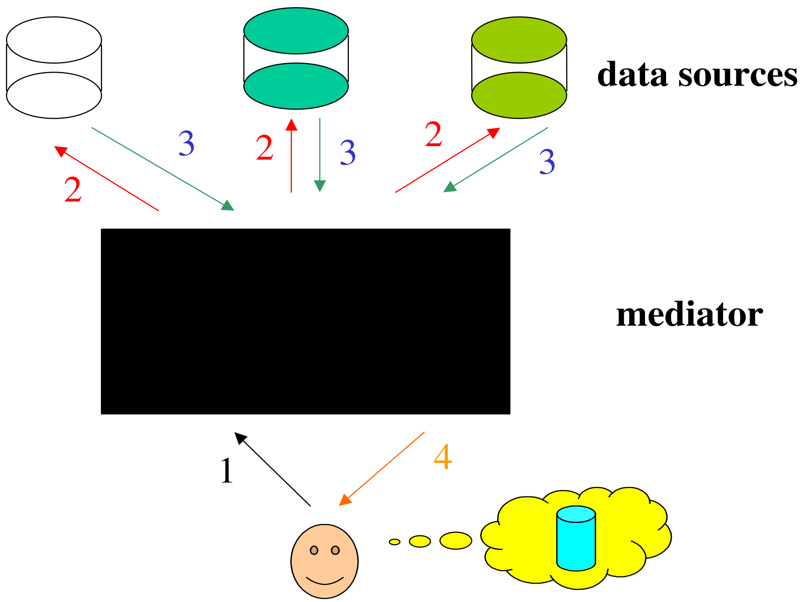
Virtual Data Integration



We consider a mediated approach to data integration: data stay at the sources, and a virtual integration system is created

Mediator: A software system that offers a common query interface to a set of data sources (assume all schemas are relational)

- Data sources are heterogeneous and mutually independent
- Data kept at the local sources

Data extracted at the mediator's request, at query time

Interaction with the mediator is through queries and answers

- Individual data sources are updated independently

Updates on data sources via the mediator not allowed

- System should allow sources to get in and out

Class of participating sources should be flexible and open

- Data sources have their own schema

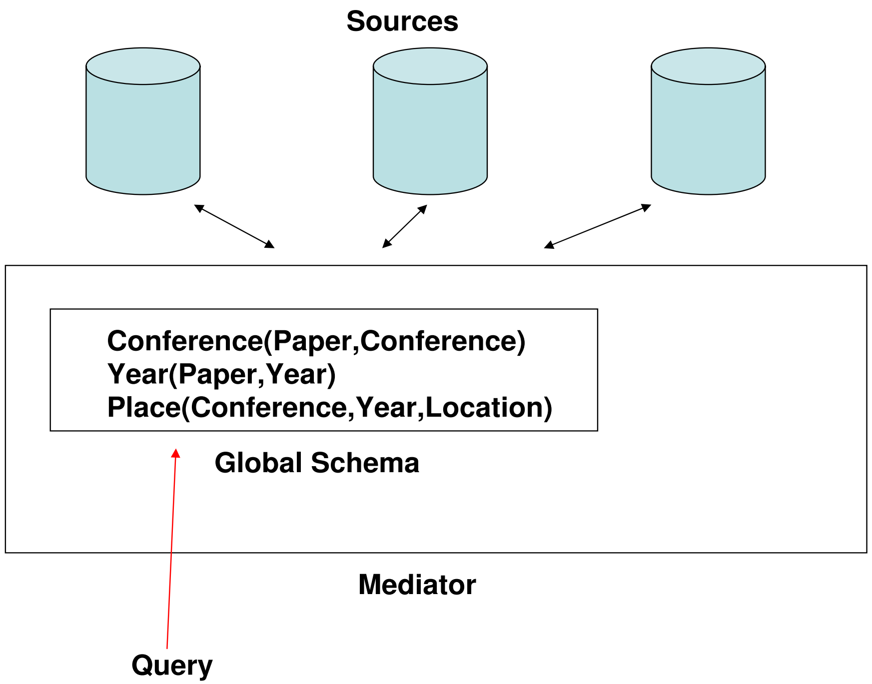
Virtual database has its own global, unifying presentation schema

- Mediator has to know what kind of data is offered by the sources and how they relate to the global schema

A problem of describing data and specifying mappings between data schemas

A form metadata management

Example: Global schema for a DB "containing" information about scientific publications:



$Conference(Paper, Conference), \quad Year(Paper, Year),$
$Place(Conference, Year, Location)$

User poses queries in terms of the relations in the global schema

Query about where conference PODS'89 was held:

$$Ans(x) \longleftarrow Place(pods, 1989, x)$$

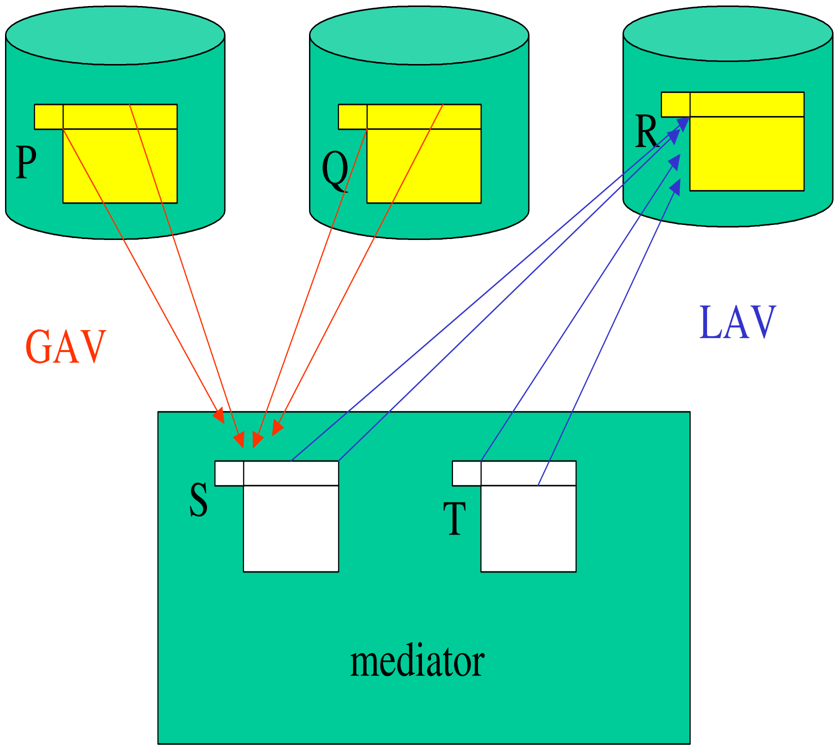
Relationships between the global schema and local sources are specified at the mediator level

This metadata determines how query plans are computed

The sources are described by means of database views

- Global-as-View (GAV): Relations in the global schema are described as views over the tables in the local schemas
- Local-as-View (LAV): Relations in the local, source schemas are described as views over the global schema

  Each source relation is "put in correspondence" with a query (view) over the global relations


P
Q
R
GAV
LAV
S
T
mediator

Example: Global system $\mathcal{G}$ with global predicates P, R, and sources V_1, V_2 defined according to LAV by:

$$V_1(x,y) \leftarrow P(x,z), R(z,y); \qquad v_1 = \{(a,b)\}$$
$$V_2(x,y) \leftarrow P(x,y); \qquad v_2 = \{(a,c)\}$$

From the perspective of V_2, there could be other sources contributing with data of the same kind to P, actually so does V_1

In this sense, information in V_2 is incomplete wrt what $\mathcal{G}$ "contains" (or might contain)

As usual, we assumed sources are incomplete (open)

Provisionally assume: There are no global integrity constraints, i.e. constraints on (the combination of) P, R

When we pose queries to a VDIS, we expect to receive answers

What answers? What are the correct answers?

It depends on the semantics of the system

So, what are the semantically correct answers?

There is no global instance and no answer to a global query in the classical sense

We have to indicate what are the intended global instances of $\mathcal{G}$

The set of admissible, legal global instances will give a meaning to the system

What global instances D if we decided to materialize global instances using the data at v_1, v_2? (usually we won't)

At this point the openness of the sources is taken into account

$$Legal(\mathcal{G}) := \{\text{ global } D \mid v_i \subseteq V_i(D), \quad i = 1, 2\}$$

$V_i(D)$: Contents of view V_i evaluated on global instance D

Example: (cont.)

$$V_1(x,y) \;\leftarrow\; P(x,z), R(z,y); \qquad v_1 = \{(a,b)\}$$
$$V_2(x,y) \;\leftarrow\; P(x,y); \qquad v_2 = \{(a,c)\}$$

The legal instances of $\mathcal{G}$ are all the supersets of instances of the form: $\{P(a,c), P(a,z), R(z,b) \mid z \in Dom\}$

1. $\{P(a,c), R(c,b)\} \;\in\; Legal(\mathcal{G})$
   A minimal legal instance: It is legal and any proper subset is not legal
2. $\{P(a,c), P(a,e), R(e,b)\} \;\in\; Legal(\mathcal{G})$
   Also a minimal legal instance
3. $\{P(a,c), R(c,b), P(e,e), R(e,a), R(d,d), R(a,c)\} \in\; Legal(\mathcal{G})$
   Legal, but not minimal

4. $\{P(a,c), R(e,b)\} \notin Legal(\mathcal{G})$

We have minimal legal instances that are incomparable under set inclusion: 1. $\not\subseteq$ 2. and 2. $\not\subseteq$ 1.

$MinLegal(\mathcal{G})$ denotes the class of minimal legal instances

$$MinLegal(\mathcal{G}) \subsetneqq Legal(\mathcal{G})$$

Global query: $\mathcal{Q}_1: \ Ans(x, y) \leftarrow P(x, y)$

What are the semantically correct answers?

The certain answers to a global query are those that can be obtained from every legal global instance

$$Certain(\mathcal{Q}) \ := \ \bigcap \{\mathcal{Q}(D) \mid D \in Legal(\mathcal{G})\}$$

Global $\mathcal{Q}_1: \ Ans(x, y) \leftarrow P(x, y)$ $\quad Certain(\mathcal{Q}_1) = \{(a, c)\}$

Global $\mathcal{Q}_2: \ Ans(x) \leftarrow R(x, y)$ $\quad Certain(\mathcal{Q}_2) = \{\}$

Global $\mathcal{Q}_3: \ Ans(y) \leftarrow R(x, y)$ $\quad Certain(\mathcal{Q}_3) = \{(b)\}$

We did not use any query plan to get them, only the semantics

Algorithms for computing certain answers?

Algorithms to produce query plans that eventually access the sources?

Some Remarks:

- Monotone queries: $D_1 \subseteq D_2 \quad \Rightarrow \quad \mathcal{Q}(D_1) \subseteq \mathcal{Q}(D_2)$

- Conjunctive queries with built-ins, and disjunctions thereof are monotone

  Negation spoils monotonicity

- Notion of certain answer (as defined above) is not adequate for non-monotone queries

- Monotone queries $\mathcal{Q}$ can be correctly answered by restriction to the minimal legal instances

$$Certain(\mathcal{Q}) \;=\; \bigcap\{\mathcal{Q}(D) \mid D \in MinLegal(\mathcal{G})\}$$

- We will provide an algorithm for computing the certain answers to monotone queries

It is based on a specification of the minimal legal instances of $\mathcal{G}$ (we'll see another use of specification of minimal legal instances)

Specifying Minimal Legal Instances

Example: Global system $\mathcal{G}$ $\qquad Dom = \{a, b, c, \ldots\}$

$$V_1(x,y) \leftarrow P(x,z), R(z,y) \qquad v_1 = \{(a,b)\}$$

$$V_2(x,y) \leftarrow P(x,y) \qquad v_2 = \{(a,c)\}$$

$$MinLegal(\mathcal{G}) = \{\ \{P(a,c), P(a,z), R(z,b)\}\ \mid z \in Dom\}$$

Specification of minimal instances: logic program $\Pi(\mathcal{G})$

$$P(x,z) \leftarrow V_1(x,y), F_1(x,y,z) \qquad (*)$$

$$P(x,y) \leftarrow V_2(x,y)$$

$$R(z,y) \leftarrow V_1(x,y), F_1(x,y,z) \qquad (**)$$

$$F_1(x,y,z) \leftarrow V_1(x,y), dom(z), choice((x,y),z) \qquad (***)$$

$$dom(a).,\quad dom(b).,\quad dom(c).,\quad \ldots, V_1(a,b).,\quad V_2(a,c).$$

Specifies global predicates in terms of source relations!

Inspired by inverse rules algorithm for computing certain answers

$choice((x, y)), z)$: non-deterministically chooses a unique value for z for each combination of values for x, y

Programs with $choice$ operator can be transformed into (usual) programs with stable models semantics

1-1 correspondence between stable models of $\Pi(\mathcal{G})$ and minimal instances

Rules (*) and (**) come from the same view definition, and the functional predicate F_1 is used instead of symbolic functions

Instead of using a function symbol $f(x, y)$ for z, we make z to take values according to the functional predicate F_1

Rule (***) defines the functional predicate: picking values from V_1, Dom makes the rule safe

F_1 is a functional predicate, whose functionality on the second argument is imposed by the choice operator

(Giannotti, Pedreschi, Sacca, Zaniolo; DOOD 91)

The choice operator has to be defined, with something like this:

$$\begin{aligned} ... &\longleftarrow V_1(x, y), dom(z), chosenv1z(x, y, z) \\ chosenv1z(x, y, z) &\longleftarrow V_1(x, y), dom(z),\ not\ \ diffchoicev1z(x, y, z) \\ diffchoicev1z(x, y, z) &\longleftarrow chosenv1z(x, y, U), dom(z), U \neq z \end{aligned}$$

Normal program with recursion via negation, not stratified; several stable models, due to the different possible choices:

$$M_b = \{dom(a), \ldots, V_1(a,b), V_2(a,c), \underline{P(a,c)}, \mathit{diffChoice}_1(a,b,a), chosen_1(a,b,b), \mathit{diffChoice}_1(a,b,c), F_1(a,b,b), \underline{R(b,b)}, \underline{P(a,b)}\}$$

$$M_a = \{dom(a), \ldots, V_1(a,b), V_2(a,c), \underline{P(a,c)}, chosen_1(a,b,a), \mathit{diffChoice}_1(a,b,b), \mathit{diffChoice}_1(a,b,c), F_1(a,b,a), \underline{R(a,b)}, \underline{P(a,a)}\}$$

$$M_c = \{dom(a), \ldots, V_1(a,b), V_2(a,c), \underline{P(a,c)}, \mathit{diffChoice}_1(a,b,a), \mathit{diffChoice}_1(a,b,b), chosen_1(a,b,c), F_1(a,b,c), \underline{R(c,b)}\} \quad \cdots$$

1-1 correspondence between stable models and minimal instances

Remarks:

- In the general case, it holds:

$$MinLegal(\mathcal{G}) \subseteq StableMod(\Pi(\mathcal{G})) \subseteq Legal(\mathcal{G})$$

- In consequence, the program can be used to compute the certain answers to monotone queries

More general than any other algorithm for LAV and open sources

- The program can be refined to compute all and only the minimal legal instances

Refinement not relevant to compute certain answers to monotone queries

- The program can be adapted in order to deal with combinations of open, closed and clopen sources

Cf. Bertossi, L. and Bravo, L. "Consistent Query Answers in Virtual Data Integration Systems". Springer LNCS 3300, 2004, pp. 42-83.

Now, if we have a global query, say $\mathcal{Q}_2\!: \ Ans(x) \leftarrow R(x,y)$

- Combined program $\Pi' \ := \ \Pi(\mathcal{G}) \cup \{Ans(x) \leftarrow R(x,y)\}$
- Evaluate Π' under the skeptical stable model semantics
  It makes true what is true of all stable models
- That is, the certain answers are those in the intersection of the extensions of the Ans predicate on all stable models

$$Certain(\mathcal{Q}_2) = \bigcap \{Ans(M) \mid M \text{ is a stable model of } \Pi'\}$$

The same program $\Pi(\mathcal{G})$ can be used with all the queries

Systems like DLV can be used for program evaluation

For a query only the portion of program $\Pi(\mathcal{G})$ that is relevant can be built and used

Data Integration and Consistency

Still many scientific and technical issues in virtual data integration (among others):

- Uncertain data
- Quality data, preferences, provenance, etc.
- Inconsistent data

Consistency: Two sources may be individually consistent, but taken together, possibly not

E.g. Same ID number may be assigned to different people in different sources

Existing mediated integration systems (MISs) offer almost no support for consistency handling

(Even commercial DBMSs for stand alone databases offer limited general purpose support)

Mediated systems have no global IC maintenance mechanism

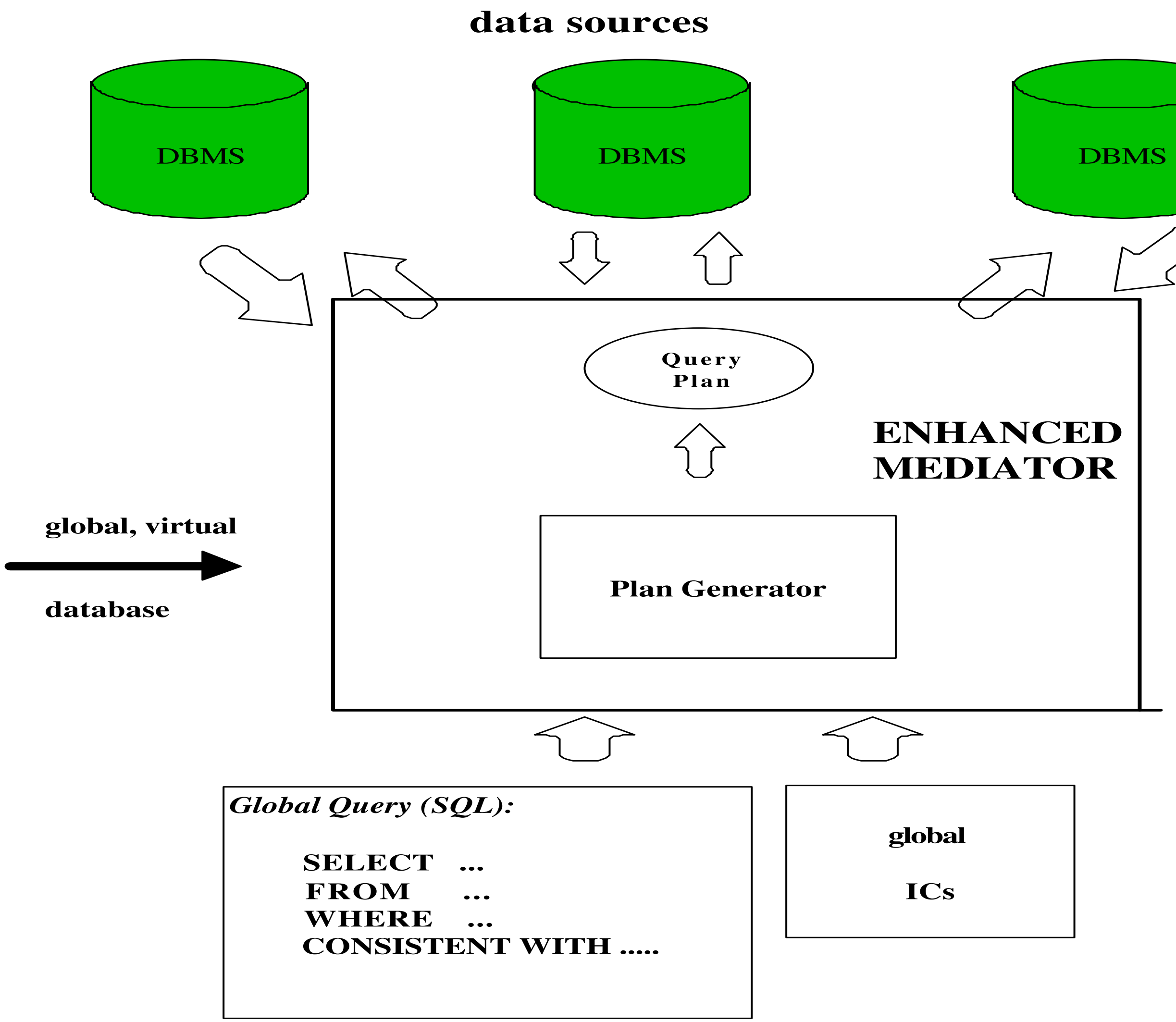
No guarantee that global ICs hold

In the virtual approach to data integration, one usually assumes that certain ICs hold at the global level

A possible approach: Consistent Query Answering!

- Do not try to enforce the consistency of the data "contained" in the integration system
- Better deal with the problem at query time
- When a query is are posed to the system, retrieve only those answers from the global database that are "consistent with" the global ICs
- Obtain semantically correct answers on-the-fly!

Cf. Bertossi, L. "Consistent Query Answering in Databases". ACM Sigmod Record, June 2006, 35(2):68-76.


data sources
DBMS
DBMS
DBMS
Query
Plan
ENHANCED
MEDIATOR
global, virtual
database
Plan Generator
Global Query (SQL):
SELECT ...
FROM ...
WHERE ...
CONSISTENT WITH .....
global
ICs

Obviously, this requires some precisions and formalizations

- What is a consistent answer to a query?
- Consistency or IC satisfaction applies to the whole DB

  However, most likely most of the data in DB is still "consistent"
- When DB is queried, we want only the "consistent answers", a local notion ...
- We need a precise definition of consistent answer to a query in an inconsistent DB
- We need to develop mechanisms for computing consistent answers, hopefully querying the only available, possibly inconsistent DB

Example: System $\mathcal{G}_1$ with sources

$$V_1(x,y) \leftarrow R(x,y), \qquad v_1 = \{(a,b),(c,d)\}$$
$$V_2(x,y) \leftarrow R(x,y), \qquad v_2 = \{(c,a),(e,d)\}$$

$D = \{R(a,b), R(c,d), R(c,a), R(e,d)\}$ and its supersets are the legal instances

Global query $\mathcal{Q}$: $R(x,y)$?

$$Certain(\mathcal{Q}) = \{(a,b),(c,d),(c,a),(e,d)\}$$

What if we had a global functional dependency $R\colon X \rightarrow Y$?

Global FD not satisfied by D, nor by its supersets

Only $(a,b),(e,d)$ should be consistent answers

A Formalization of- and An Algorithm for Consistent Answers:

- Specify the minimal legal instances of the system
  For that use the refined program mentioned above
- Why?: Minimal legal instances do not contain unnecessary information; that could, unnecessarily, violate global ICs
- Minimal instances could violate the global ICs
- Specify the "repairs" of the minimal instances
  Logic programs can be used to specify them
- A repair of an instance D wrt a set IC of ICs is an instance D' that satisfies IC and minimally differs from D (under set inclusion)
- The consistent answers to a global query wrt IC are those obtained from all the repairs wrt IC of all the minimal legal instances

Example: (cont.) For $\mathcal{G}_1$:

- The only minimal legal instance violates the FD $R\colon X \rightarrow Y$

$$D = \{R(a,b), R(c,d), R(c,a), R(e,d)\}$$

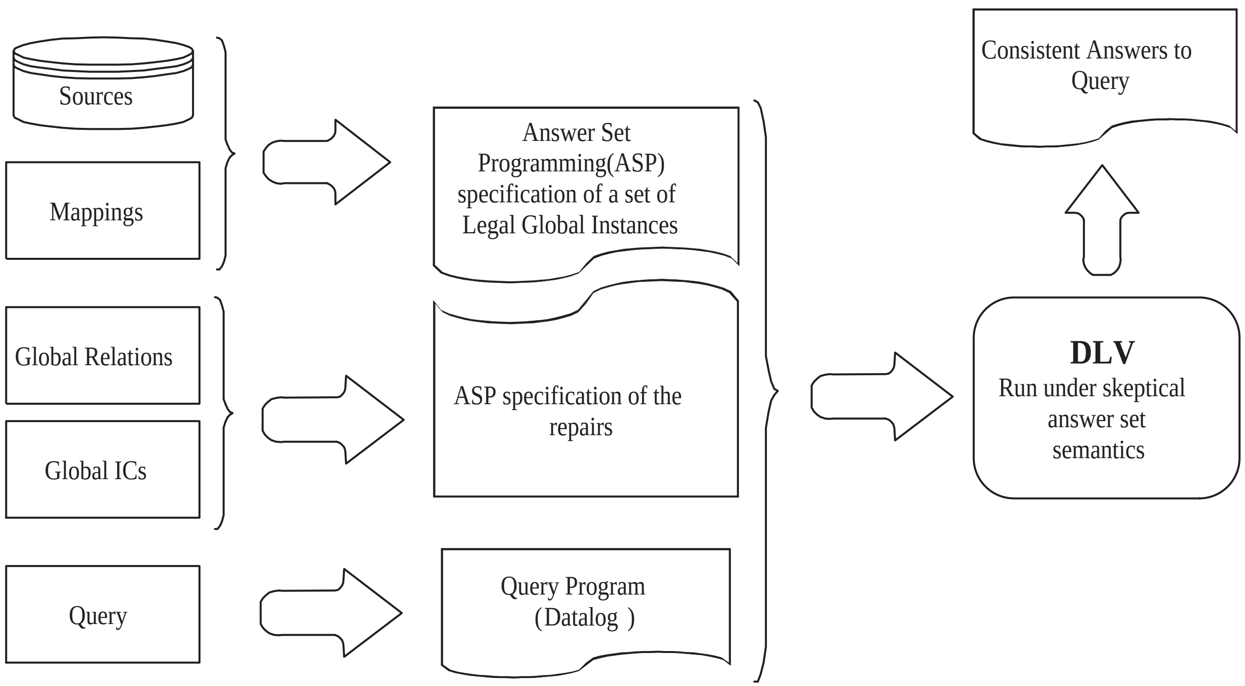
- Two repairs wrt FD:

$$D^1 = \{R(a,b), R(c,d), R(e,d)\}$$
$$D^2 = \{R(a,b), R(c,a), R(e,d)\}$$

- Consistent answers to query $\mathcal{Q}$: $R(x,y)$?
  Only $\{(a,b), (e,d)\}$
  Those that are answers to original query in every repair!

Here we proceeded semantically ...

Computation?



Combine in one single program the programs that specify:

- The minimal legal instances
- The repairs of minimal legal instances wrt the global ICs
- The global query to be consistently answered (as before)

Example: (cont.) $\mathcal{G}_1$

$V_1(x,y) \leftarrow R(x,y)$, $\quad v_1 = \{(a,b),(c,d)\}$

$V_2(x,y) \leftarrow R(x,y)$, $\quad v_2 = \{(c,a),(e,d)\}$

And global FD $R:\ X \rightarrow Y$

Query: $Ans(x,y) \leftarrow R(x,y)$

The three layers of the combined program follow

First Layer: Spec. minimal legal instances

Facts: $V_1(a,b).\quad V_1(c,d).\quad V_2(c,a).\quad V_2(e,d).$

$$R(x,y) \longleftarrow V_1(x,y)$$
$$R(x,y) \longleftarrow V_2(x,y)$$

Second Layer: Spec. Repairs of Minimal Instances

$$R(x,y,\mathbf{f}) \vee R(x,z,\mathbf{f}) \longleftarrow R(x,y), R(x,z), y \neq z$$
$$R(x,y,\mathbf{s}) \longleftarrow R(x,y),\ not\ R(x,y,\mathbf{f})$$

Intended semantics of annotations:

- $\mathbf{f}$: Made false, deleted from database
- $\mathbf{s}$: Stays in the stable model (repair)

We have disjunctive programs with stable model semantics

Third Layer: Spec. of Global Query

$$Ans(x,y) \longleftarrow R(x,y,\mathbf{s})$$

The program composed by the three layers is run under the skeptical stable model semantics of disjunctive programs

Example: System $\mathcal{G}_3$ with

$$\begin{array}{rclcl} V_1(x) & \longleftarrow & P(x,y) & \qquad & v_1 = \{(a)\} \\ V_2(x,y) & \longleftarrow & P(x,y) & \qquad & v_2 = \{(a,c)\} \end{array}$$

$IC: \quad \forall x \forall y (P(x,y) \rightarrow P(y,x))$

Only minimal instance: $\{P(a,c)\}$ (inconsistent)

First Layer: The refined program for minimal instances

$$
\begin{array}{rcl}
dom(a).\ \ dom(c).\ \ \ldots & & V_1(a).\ \ V_2(a,c). \\
P(x,y) & \longleftarrow & P(x,y,v_1) \\
P(x,y) & \longleftarrow & P(x,y,t_o) \\
P(x,y,nv_1) & \longleftarrow & P(x,y,t_o) \\
addV_1(x) & \longleftarrow & V_1(x),\ \ not\ \ auxV_1(x) \\
auxV_1(x) & \longleftarrow & P(x,z,nv_1) \\
fz(x,z) & \longleftarrow & addV_1(x), dom(z), chosenv1z(x,z) \\
chosenv1z(x,z) & \longleftarrow & addV_1(x), dom(z),\ \ not\ \ diffchoicev1z(x,z) \\
diffchoicev1z(x,z) & \longleftarrow & chosenv1z(x,U), dom(z), U \neq z \\
P(x,z,v_1) & \longleftarrow & addV_1(x), fz(x,z) \\
P(x,y,t_o) & \longleftarrow & V_2(x,y)
\end{array}
$$

(atoms in red are the input for next layer)

Second Layer: The program that specifies the repairs

$$P(x, y, \mathbf{f}) \quad \vee \quad P(y, x, \mathbf{t}) \longleftarrow P(x, y),\ not\ P(y, x)$$
$$P(x, y, \mathbf{s}) \longleftarrow P(x, y, \mathbf{t})$$
$$P(x, y, \mathbf{s}) \longleftarrow P(x, y),\ not\ P(x, y, \mathbf{f})$$

Disjunctive rules capture repair process (the head) given an IC violation (the body)

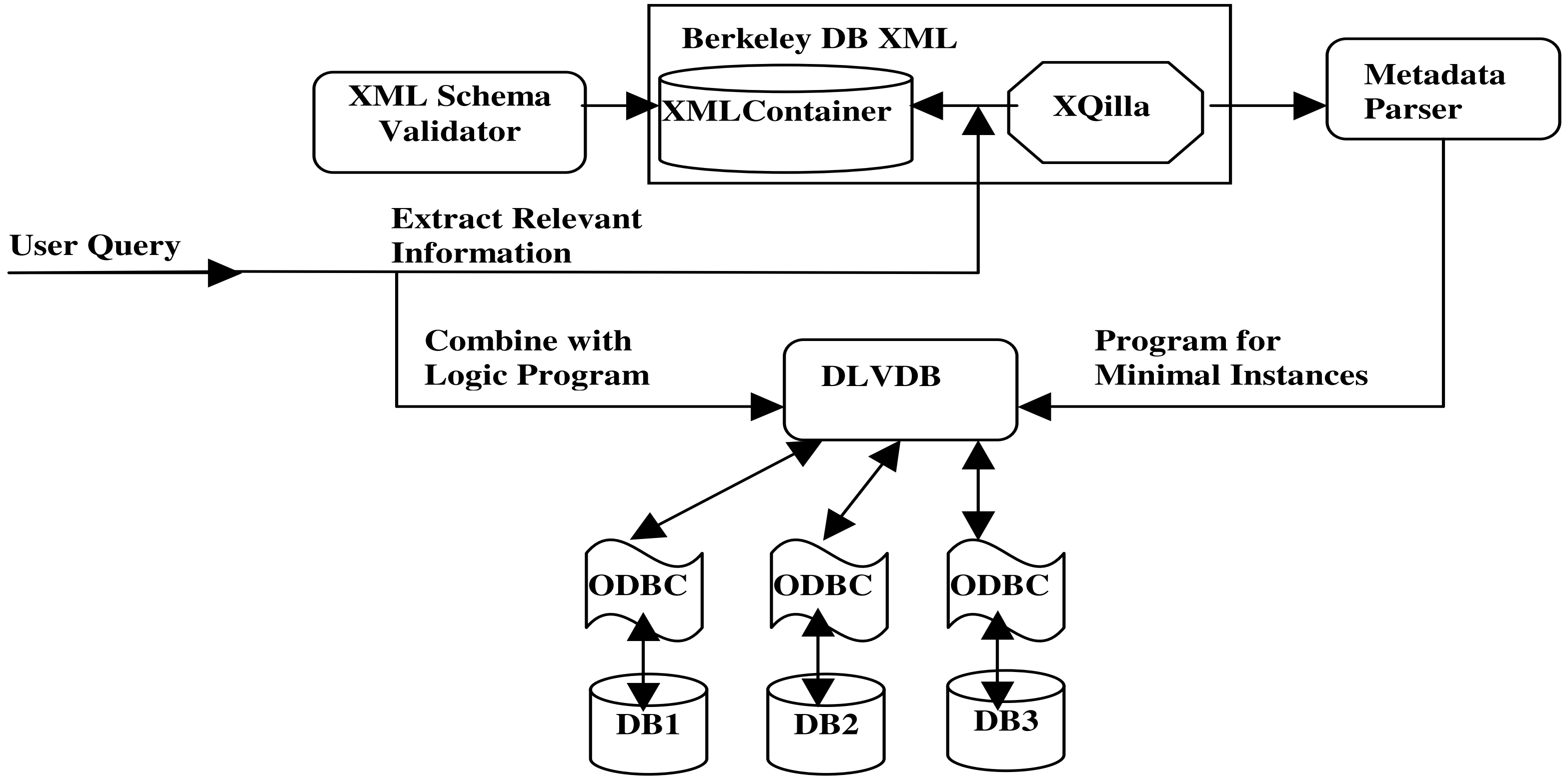
Annotation $\mathbf{t}$ used for tuple insertion

Atoms $P(x, y, \mathbf{s})$ feed the next layer

Third Layer: A query, e.g.

$$Ans(x) \longleftarrow P(x, y, \mathbf{s})$$

Specifying Metadata for a LAV MIS



Architecture of VISS

The mediator requires information about:

- Participating sources, their schemas, and
- How they relate to the global schema

This metadata has to be represented at the mediator level, considering the following issues:

- Sources have possibly very different schemas

  They will differ in terms of predicate names, names and number of attributes, data types, etc.

  As a whole, this is unstructured (meta)data
- Mediators might want to easily and seamlessly share metadata

- We may want a vendor-independent representation

  So that the metadata can be easily processed by any DBMS that the mediator may want to use (if any)

  Commercial DBMSs differ in the way the capture, store, and provide access to metadata

- Mappings are also metadata, that has to be represented

  Keeping track of their syntactic structure and subformulas is crucial (e.g. to build inverse rules)

  Particularly important under LAV

On this basis, we use a combination of

- XML (in native form)
- RuleML, actually also a standardized XML representation
- XQuery, to query the former

Example: Two sources, *AnimalKingdom* and *AnimalHabitat*, with the following relations, resp.

V1	*Name*	*Class*	*Food*
	dolphin	mammal	fish
	camel	mammal	plant
	shark	fish	fish
	frog	amphibian	insect
	nightingale	bird	insect

V2	*Name*	*Habitat*
	dolphin	ocean
	camel	desert
	frog	wetlands

Global schema $\mathcal{G}$: *Animal(Name, Class, Food), Vertebrate(Name), Habitat(Name, Habitat)*

V1 and *V2* are defined as a views over $\mathcal{G}$:

$$V1(Name, Class, Food) \leftarrow Animal(Name, Class, Food), Vertebrate(Name)$$

$$V2(Name, Habitat) \leftarrow Animal(Name, Class, Food), Habitat(Name, Habitat)$$

In an XML document we represent database schemas:

- Source names
- DBMS at each source
- Database names at each source
- Access information for each DB
- Relation names and their schemas at each source
- Global predicates and their schemas

```
<VirInt>
<Schema>
    <Local>
        <Source name="animalkingdom">
            <Type>sqlexpress</Type>
            <Hostname>animalkingdom</Hostname>
            <Databasename>animalkingdom</Databasename>
            <Userid>test</Userid>
            <Password>test</Password>
            <Atom>
                <Rel>V1</Rel> <Var>Name</Var> <Var>Class</Var> <Var>Food</Var>
            </Atom>
        </Source>
        <Source name="animalhabitat">
            <Type>mysql</Type>
            <Hostname>animalhabitat</Hostname>
            <Databasename>animalhabitat</Databasename>
            <Userid>test1</Userid>
            <Password>test1</Password>
            <Atom>
                <Rel>V2</Rel> <Var>Name</Var> <Var>Habitat</Var>
            </Atom>
        </Source>
    </Local>
    <Global>
        <Atom>
            <Rel>Animal</Rel> <Var>Name</Var> <Var>Class</Var> <Var>Food</Var>
        </Atom>
        <Atom>
            <Rel>Habitat</Rel> <Var>Name</Var> <Var>Habitat</Var>
        </Atom>
        <Atom>
            <Rel>Vertebrate</Rel> <Var>Name</Var>
        </Atom>
    </Global>
</Schema>
</VirInt>
```

Next we have to represent the mappings

- We use RuleML
- It was developed for rule representation and exchange in the context of the semantic web
- It is based on XML
- The right XML schemas have to be invoked
- We partially used it in the specification of schemas above
- We are able to specify the syntactic components of the mapping, for further processing
- They are represented as implications of heads by bodies, etc.

```xml
<RuleML xmlns:rule="http://www.ruleml.org/0.91/xsd"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="http://www.ruleml.org/0.91/xsd
 file:///C:/thesis/VDI/datalog.xsd">
<Assert>
  <Implies>
    <head>
      <Atom>
        <Rel>V1</Rel> <Var>Name</Var> <Var>Class</Var> <Var>Food</Var>
      </Atom>
    </head>
    <body>
       <And>
      <Atom>
        <Rel>Animal</Rel> <Var>Name</Var> <Var>Class</Var> <Var>Food</Var>
      </Atom>
      <Atom>
        <Rel>Vertebrate</Rel> <Var>Name</Var>
      </Atom>
       </And>
    </body>
  </Implies>
  <Implies>
    <head>
      <Atom>
        <Rel>V2</Rel> <Var>Name</Var> <Var>Habitat</Var>
      </Atom>
    </head>
    <body>
       <And>
      <Atom>
        <Rel>Animal</Rel> <Var>Name</Var> <Var>Class</Var> <Var>Food</Var>
      </Atom>
      <Atom>
        <Rel>Habitat</Rel> <Var>Name</Var> <Var>Habitat</Var>
      </Atom>
       </And>
    </body>
  </Implies>
</Assert>
</RuleML>
```

In order to compute the certain answers to a global monotone query $\mathcal{Q}$, e.g.

$$Ans(Name, Habitat) \leftarrow Animal(Name, Class, Food), Habitat(Name, Habitat)$$

- The right fragment of the specification $\Pi(\mathcal{G})$ of minimal legal instances has to be built
  The one relative to global predicates $Animal, Habitat$
- Query the XML and RuleML representations of metadata to obtain the pieces needed
- In order to identify the sources and the relations therein that are relevant to $\mathcal{Q}$
- Those are the source predicates that are defined in terms of global relations that are mentioned by $\mathcal{Q}$
- This is good enough: No global ICs (cf. later)
- XQuery is used

```
for $n in collection('mappingAlias')/VirInt return
<rules>
    {for $x in $n/RuleML/Assert/Implies
    where distinct-values($x/body/And/Atom/Rel) =
    ("Animal", "Habitat")
    return
    <rule>
    {for $d in $x return
        <head r1='{$d/head/Atom/Rel}'>
        { for $v in $x/head
        where $v/Atom/Rel=$d/head/Atom/Rel
        return
            concat($d/head/Atom/Rel,'(',
            string-join($v/Atom/Var,','),')')
        }
        </head>
    }
    {for $b in distinct-values($x/body/And/Atom/Rel)
    return
        <body r1='{$b}'>
        { for $m in $n/Schema/Global/Atom
        where $m/Rel=$b
        return concat($b,'(',
        string-join($m/Rel/following-sibling::Var,','),')')
        }
        </body>
    }
    <body r1=''>
{ for $q in distinct-values($x/body/And/Atom/Ind)
let $l as xs:integer := index-of($x/body/And/Atom/*,$q)-1
let $r := $x/body/And/Atom/Ind/preceding-sibling::Rel/text()
let $s := $n/Schema/Global/Atom/Rel[text()=$r]/../Var[$l]
return
if ($q != '') then
(concat('(',$s,'=',$q,')',','))
else ()
}
    </body>
    </rule>
    }
</rules>
```

The query first identifies the source predicates that are defined in terms of global relations *Animal*, *Habitat* that appear in the query

For each of them, it identifies the parts of the bodies of their definitions, including built-ins (the last part)

The following view definitions are used later to built $\Pi(\mathcal{G})$

```
<rules xmlns:xsi='http://www.w3.org/2001/XMLSchema-instance'
xsi:noNamespaceSchemaLocation='mappingrule.xsd'>
    <rule>
        <head r1="V1">V1(Name, Class, Food)</head>
        <body r1="Animal">Animal(Name, Class, Food)</body>
        <body r1="Vertebrate">Vertebrate(Name)</body>
    </rule>
    <rule>
        <head r1="V2">V2(Name, Habitat)</head>
        <body r1="Animal">Animal(Name, Class, Food)</body>
        <body r1="Habitat">Habitat(Name, Habitat)</body>
    </rule>
</rules>
```

This result is used to:

- Build $\Pi(\mathcal{G})$ as required by DLV
- Identify via XQuery sources that are relevant to the query
- For the later appropriate data import commands are generated and added to $\Pi(\mathcal{G})$
- DLV uses them to retrieve the facts directly from the data sources via ODBC

```
#import(animalkingdom, "test", "test", "SELECT * FROM V1", V1,
                       type : Q_CONST,  Q_CONST, Q_CONST).
#import(animalhabitat, "root", "root", "SELECT * FROM V2", V2,
                       type : Q_CONST, Q_CONST).

Animal(Name, Class, Food) :- V1(Name, Class, Food).
Animal(Name, Class, Food) :-  V2(Name,Habitat),
                              f1(Name,Habitat,Class), f2(Name,Habitat,Food).
f1(Name, Habitat, Class) :- V2(Name, Habitat), dom(Class),
                            chosen1(Name, Habitat, Class).
chosen1(Name,Habitat,Class) :- V2(Name,Habitat), dom(Class),
                               not diffchoice1(Name,Habitat,Class).
diffchoice1(Name, Habitat, Class) :- chosen1(Name, Habitat, U),
                                     dom(Class), U != Class.
f2(Name, Habitat, Food) :- V2(Name, Habitat), dom(Food),
                           chosen2(Name, Habitat, Food).
chosen2(Name, Habitat, Food) :- V2(Name,Habitat), dom(Food),
                                not diffchoice2(Name,Habitat,Food).
diffchoice2(Name, Habitat, Food) :- chosen2(Name, Habitat, U),
                                    dom(Food), U != Food.

Habitat(Name, Habitat) :- V2(Name, Habitat).
```

Run with DLV:

```
dl.exe -silent -cautious test2.dlv
dolphin, ocean
camel, desert
frog, wetlands
```

With Global ICs

If there are global ICs:

- Global ICs can also be represented with RuleML
- Dependencies between global predicates may appear
- This may add new relevant sources for a global query
  Those that become indirectly relevant to the query
- Inconsistencies may arise
- In this case a relevant fragment of the refined version of $\Pi(\mathcal{G})$ has to be used (as a first layer)
- Repair programs have to be built on top
- Everything is run with DLV as before

Conclusions

- We have presented a general methodology for computing certain answers to monotone relational queries from a virtual data integration system under the LAV approach
- It is based on a declarative specification in answer set programming of the (minimal) legal instances of the system
- Programs like this can be evaluated using, e.g. DLV
- In order to enforce -at query answering time- global ICs, the repairs of the minimal legal instances are specified by means of answer set programs
- The combined program is queried
- Evaluation can be highly optimized by means of "magic sets" for ASP cf. (Caniupan & Bertossi; SUM 07)
- XML and RuleML techniques can be used to represent, collect and compose the integration system's metainformation; to provide an input to DLV