Fusionplex: Resolution of Data Inconsistencies in the Integration of Heterogeneous information Sources

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Information Integration and Conflicts

- ✓ **Information Integration**: Given a collection of *heterogeneous* and *autonomous* information sources, provide a system that allows its users to perceive the entire collection as a single source, query it transparently, and receive a *single, unambiguous answer.*
- ✓ **Information conflicts**: The sources may have conflicts of two types:
  - *Intensional (semantic) inconsistencies*: Differences in
    - The data models,
    - The schemas within the same data model,
    - The data is in different languages, or in different measurement systems.
  - *Extensional (data) inconsistencies*: Factual discrepancies among sources that describe the same data objects.
    - Can be observed only after intensional inconsistencies have been resolved.
    - Most information integration systems deal with semantic inconsistencies only.

Fusionplex

- ✓ Resolve extensional inconsistencies by means of *data fusion*.
- ✓ Assumes the Multiplex information integration system.
- ✓ Basic principles of Multiplex:
  - Global schema in the relational model $R_1, \ldots, R_n$.
  - The global schema is *mapped* to a collection of local schemas, by means of *view pairs*.
  - Each pair associates a view of the global schema V_i with a view of the a local schema U_i.
  - The view V_i is materialized by the view U_i.
  - A query Q on the global relations $R_1, \ldots, R_n$ must be translated to a query over the materializable views $V_1, \ldots, V_m$.

Multiplex Advantages

- ✓ Mapping of global schema to local schemas is not *total*:
  - Framework for situations where some local databases to become *unavailable*.
- ✓ Mapping of global schema to local schemas is not *onto*:
  - Framework for *partial* integration of local databases.
- ✓ Mapping of global schema to local schemas is not *single-valued*:
  - Framework for extensional inconsistencies: multiple materializations of the same global view.
- ✓ Local databases need not be relational: *Heterogeneity* .
  - The relational model is only a global description, and a communication protocol.
  - The global database requests and receives information in tables.

How Multiplex Handles Inconsistencies

- ✓ *Inconsistency*: A global query is answered by multiple *sets of records* (tuples).
- ✓ Multiplex provides an approximation for the *true* answer by "sandwiching" it between two answers:
  - The *lower bound* set of records that indicates a *sound* answer: Each tuple in this answer is in the true answer.
  - An *upper bound* set of records that indicates a *complete* answer: All tuples of the true answer are in this answer.
- ✓ These two estimates are obtained in a process similar to *voting*:
  - All tuples in the *union* of answers are sent to the complete upper bound.
  - Tuples showing in *intersection* of answers are sent to the sound lower bound.

Limitations of the Multiplex Approach

- ✓ Inconsistencies are identified at the *record* (tuple) level:
- ✓ When the same real-world object is described slightly differently in two tuples, they are assumed to describe two different objects.
- ✓ Hence, they are both relegated to the upper bound estimate.
- ✓ No attempt at *object identification*.

The Fusionplex Approach

- ✓ Not all data are created equal: The data environment is not *egalitarian*, where all information sources have the same qualifications.
- ✓ Individual sources have their individual advantages and disadvantages.
  - Some data are more *recent*.
  - Some data come from more *authoritative* sources.
  - Some data are more *costly* to obtain.
  - Etc.
- ✓ To resolve conflicts, Fusionplex considers the *qualifications* of the providers.
  - It uses *meta-data* to resolve data conflicts.

Where Does the Meta-data Come from?

- ✓ Some may be provided by the sources themselves.
  - Date of update, cost, …
- ✓ Some may be obtained from Web sites dedicated to the evaluation of the quality of other sites.
  - Usually by summarizing the evaluations of the community of users.
- ✓ In a restricted environment, A *multidatabase administrator* could assign and maintain the meta-data scores of the local sources.

Information Features

- ✓ Our term for meta-data is *features*.
- ✓ Examples include
  - *Timestamp*: The time when information was validated.
  - *Cost*: The time to transmit the information, or the money paid, or both.
  - *Accuracy*: Probabilistic information denoting the accuracy.
  - *Availability*: Probability that at a random moment the source is available.
  - *Clearance*: Security clearance needed to access the information.

Users Control Inconsistency Resolution

✓ Inconsistency resolution requires the following input:
- User provides (in each query)
  - A pruning predicate to remove from the answer non-performing data, and
  - A vector of feature weights expressing their *utility* to the user.
- System provides a *policy* for resolving individual attributes.
  - Policies is part of the global database design.
  - Could be modified by users.
- SQL has been extended to allow users to specify such input.

Formal Framework

- ✓ A global set of features *F* is defined.
- ✓ Each feature is associated with a domain of values. For example,
  - *Availability*: the interval [0,1].
  - *Clearance*: {*top-secret, secret, confidential, unclassified*}.
- ✓ Top facilitate comparisons, all features are *normalized* by mapping them to the interval [0,1].
  - Worst feature value: 0.
  - Best feature value: 1.
  - Source with *timestamp* = 0.7 is more recent than source with *timestamp* = 0.4.
  - Source with *cost* =0.7 is cheaper than source with *cost* = 0.4.
- ✓ Each source is associated with a set of values for the entire feature set *F*.
  - Null values are used, if the source does not have a particular feature.

Homogeneity Assumption

- ✓ Sources are *homogeneous* with respect to every feature.
  - All features values are associated with the *entire* source.
  - Each feature value is *inherited* by each relation, tuple and field.
    - For example, the same *timestamp* is associated with every bit of data.
- ✓ This limitation can be avoided by *splitting* a source into several parts, each with its own features.
- ✓ Small change to Multiplex:
  - Mapping pairs are extended to triplets:
  - The third element of each mapping is the set of source features.
  - Every source provides its meta-data along with the data.

Extended Relational Model and Algebra

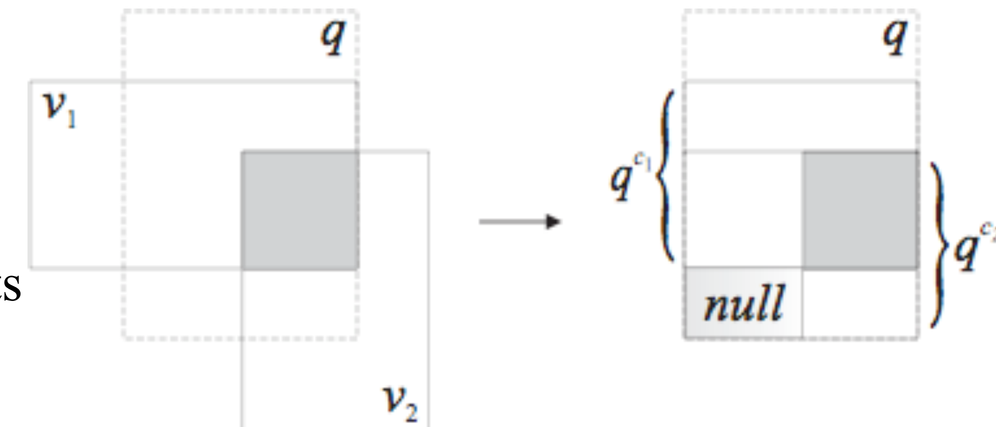
- ✓ Each relation scheme is extended with all the features of *F*, as new attributes.
- ✓ Each tuple is extended correspondingly, with values for these features.
- ✓ The relational algebra operators *selection*, *projection*, and *Cartesian product* are extended to handle these new attributes.
- ✓ The relational algebra operators *union* and *difference* remain unchanged.

Selection, Projection, Cartesian Product

- ✓ *Selection*
  - Uses an additional predicate to select tuples by their feature values.
- ✓ *Cartesian product*
  - Concatenates data values, but *fuses* feature values.
  - Fusion method depends on the feature. For example,
    - *Cost* is the *sum* of the costs of the two components (must be normalized to the interval [0,1]).
    - *Availability* is the *product* of the availabilities of the two components.
    - *Timestamp* is the *minimum* of the timestamps of the two components (reflects worst-case approach).
  - Feature value fusion must consider possible null values. Consider timestamps.
    - Null value indicates any value in the range [0,1].
    - When *null* is merged with specific value x, their minimum is the interval $[0,x]$.
    - While there's more information, it's still a *null*.
- ✓ *Projection*
  - Feature attributes cannot be removed.
  - After removing attributes (as usual), it resolves inconsistencies in the result (next).

Data Collection and Assembly

- ✓ Amalgamate the triplets of different mappings in a single set: $\{(V, URL, f)\}$
- ✓ Each triplet is a *contribution*.
- ✓ Determine the contributions *relevant* to the query (discover overlaps).
- ✓ Convert a relevant contribution to a *query fragment*:
  - Remove tuples and attributes not requested in the query.
  - Add null values for attributes missing from the contribution.



- ✓ The union of all query fragments is called *polyinstance*.
  - Intuitively, all information culled from the data sources in response to the query.
- ✓ *Inconsistency resolution*: Convert the polyinstance to a regular instance.

Inconsistency Detection and Resolution

- ✓ Two phases:
  - Phase one: Inconsistency *detection.*
  - Phase two: Inconsistency *resolution.*
- ✓ Inconsistency detection:
  - Scan the polyinstance and find the tuples that are versions of each other.
  - Resulting clusters are called *polytuples*.
  - Different identification methods can be used.
  - We use the simplest: We assume identification by *keys*.
- ✓ Inconsistency resolution requires 4 inputs:
  - A tuple of feature weights *w* (specified in the query).
  - A feature-based selection predicate (specified in the query).
  - A utility threshold (pre-defined).
  - A resolution policy for every global schema attribute (pre-defined).

Polytuple Resolution: Steps 1 and 2

- ✓ **Step 1**: Selection
  - Remove members that do not satisfy the feature-based selection predicate.
- ✓ **Step 2**: Discard non-performers:
  - The user query provides a vector of weights for the different features: w_i .
  - Each polytuple member has a vector of values for the different features: f_i .
  - Each tuple in a polytuple receives a utility value, by calculating $\sum_i w_i \cdot f_i$.
  - These values are used to rank the members.
  - Using the utility threshold, members with insufficient utility are discarded.

Polytuple Resolution: Steps 3 and 4:

- ✓ **Step 3**: Resolve a polytuple.
  - Within each polytuple, data inconsistency is resolved in each attribute separately:
    - Each column of values is fused in a single value.
    - The resolution policy for that attribute is applied.
- ✓ **Step 4**: Calculate the feature values of each resulting tuple.
  - Similar to how it has been done in the Cartesian product.

Resolution Policy

- ✓ Each resolution policy is a sequence of
  - *Elimination functions*, followed by
  - *Fusion function*.
- ✓ Examples of elimination functions:
  - *max(timestamp)* (feature-based)
  - *max(availability)* (feature-based)
  - *min(cost)* (feature-based)
  - *max(salary)* (content-based)
- ✓ Examples of fusion functions (all content-based):
  - *average*
  - *any*
  - *average-without-extreme-values*

Fusionplex Architecture