An inductive database prototype based on virtual mining views

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ABSTRACT
We present a prototype of an inductive database. Our system enables the user to query not only the data stored in the database but also generalizations (e.g., rules or trees) over these data through the use of virtual mining views. The mining views are relational tables that virtually contain the complete output of data mining algorithms executed over a given dataset. The prototype implemented into PostgreSQL currently integrates frequent itemset, association rule and decision tree mining. We illustrate the interactive and iterative capabilities of our system with a description of a complete data mining scenario.

Categories and Subject Descriptors: H.2.4 [Database Management]: System.
Keywords: Data Mining, Inductive Databases.

1. INTRODUCTION
Data mining is not a one-shot activity, but rather an iterative and interactive process. During the whole discovery process, typically, many different data mining tasks are performed, their results are combined, and possibly used as input for other data mining tasks. To support this knowledge discovery process, there is a need for integrating data mining with data storage and management. The concept of inductive databases (IDBs) has been proposed as a means of achieving such integration [7]. In [3, 4, 5, 6], we describe how such a inductive database can be designed in practice, by using virtual mining views.

In an IDB, one can not only query the data stored in the database, but also the patterns that are implicitly present in these data. One of the main advantages of our system is the flexibility of ad-hoc querying, that is, the user can specify new types of constraints and query the patterns and models in combination with the data itself and so forth. In this paper, we illustrate this feature with a data mining scenario in which we first learn a classifier over a given dataset and, afterwards, we look for correct association rules, which describes the misclassified examples w.r.t this classifier. Notice that the functionality of an inductive database goes far beyond that of data mining suites such as, Weka [10] and Yale [8]. These systems have the advantage of imposing one uniform data format for a group of algorithms. On the other hand, they do not allow ad-hoc queries.

The rest of the paper is organized as follows. Section 2 addresses the idea behind the development of our prototype. Section 3 presents the virtual mining views framework. In Section 4, we describe how the system is implemented. Finally, Section 5 describes a complete database scenario, which illustrates the interactive and iterative capabilities of our system.

2. DESCRIPTION OF THE SYSTEM
The system presented in this paper builds upon our preliminary work in [3, 5, 6]. In contrast to the numerous proposals for data mining query languages, we propose to integrate data mining into database systems without extending the query language. Instead, we extend the database schema with new tables containing, for instance, association rules, decision trees, or other descriptive or predictive models. As far as the user is concerned, these tables contain all possible patterns, trees, and models that can be learned over the data. Of course, such tables would in most cases be huge. Therefore, they are in fact implemented as views, called virtual mining views.

Whenever a query is formulated, selecting for instance association rules from these tables, a run of a data mining algorithm is triggered (e.g., Apriori [1]) to compute the result of the query, in exactly the same way that normal views in databases are only computed at query time, and only to the extent necessary for answering the query.

When the user formulates his or her mining query, the parser is invoked by the DBMS, creating an equivalent relational algebra expression. At this point, the expression is processed by the Mining Extension, which extracts from the query the constraints that can be pushed into the data mining algorithms. The output of these algorithms is then materialized in the virtual mining views. After the material-
3. THE VIRTUAL MINING VIEWS

The virtual mining views framework consists of a set of relational tables that virtually contain the complete output of data mining algorithms executed over a given dataset. Every time a dataset D is created in the system, all virtual mining views associated with D are automatically created. Figure 1 illustrates the virtual mining views for the dataset PlayTennis [9]. They are the following:

- **Concepts**: Virtually contains all conjunctive concepts with conditions of the form “Attribute=value” that exist in the domain of the dataset. We represent them as tuples, using '?' as the wildcard value and assume it does not exist in the domain of any attribute. The attribute cid identifies every concept.

- **Sets**: As itemsets in a relational database are conjunctions of the form “Attribute=value”, they can be represented as concepts. Thus, Sets represents all itemsets that can be mined over the dataset along with their characteristics, such as support (supp) and size (sz).

- **Rules**: Represents all association rules that can be mined over the dataset. The attribute rid is the rule identifier, cida and cidc are identifiers of the concepts representing, respectively, the antecedent and consequent of the rule, cid is their union, and conf is the confidence of the corresponding rule.

- **Trees-Attr**: Represents all decision trees that can be learned for one specific target attribute Attr. A unique identifier treecid is associated to every decision tree and each of the decision trees is described as a set of concepts. Each concept represents one path from the root to a leaf of the tree.

- **Treescharac-Attr**: Represents the characteristics of all decision trees that can be learned for the target attribute Attr. For every decision tree, there is a tuple with the decision tree identifier treecid, acc its accuracy and sz its size (in number of nodes).

In Section 5, we give some concrete examples of common data mining tasks and well-known constraints (such as minimum confidence and minimum accuracy) that can be expressed quite naturally with SQL queries over the mining views. For more examples, we refer the reader to [3, 4].
5. AN ILLUSTRATIVE SCENARIO

In this section, we describe an extended scenario that explores the interactive and iterative capabilities of our system. The scenario consists of mining decision trees over the mushroom dataset [2] and also association rules over intermediate query results. We assume that table mushroom is already stored in our system. It contains 8,124 tuples and 23 categorical attributes. The attribute class discriminates mushrooms from being poisonous or edible, while the other attributes describe features of the mushrooms, such as the color of the cap and odor.

Step 1: Pre-processing.
To illustrate how it is possible to preprocess data using our system, we create a new table called simple_mushroom selecting only a subset of the attributes of the original table mushroom.

Figure 2: Pre-processing.

```
create table simple_mushroom
as select cap_color, odor, gill_size,
gill_color, spore_print_color, class
from mushroom;
```

Figure 3: Mining views for table simple_mushroom.

Step 2: Mining over decision trees.
In this step, we look for decision trees over table simple_mushroom, targeting the attribute class and with maximum accuracy among those trees of size \( \leq 5 \).

The query is shown in Figure 4. The subquery selects the maximum accuracy achieved by the trees with size \( \leq 5 \) and accuracy \( \geq 90\% \) (the latter constraint is added in order to prune the search space of possible trees). The main query creates a table containing the trees with the characteristics mentioned above, having the pre-selected maximum accuracy. We use views Concepts and Treescharac in order to retrieve the concepts of the trees along with their characteristics. In the end, 3 trees are stored in table best_tree. All of them have an accuracy of 95% and 5 nodes.

Step 3: Post-processing 1.
Having learned the trees with maximum accuracy in the previous step, we now want to explore the predictive capacity of these trees. Since all trees have the same accuracy, we choose the most balanced one, presented in Figure 5. This tree has treeid equal to 6.

```
create table best_tree
as select t.treeid, c.*, d.acc, d.sz
from simple_mushroom_treescaracter_class t,
simple_mushroom_concepts c
where t.cid = c.cid
and t.treeid = d.treeid
and d.sz <= 5
and d.acc >= 90
and d.acc = ( select max(acc)
from simple_mushroom_treescharac_class
where sz <= 5 and acc >= 90)
order by t.treeid, c.cid
```

Figure 4: Query selecting trees with maximum accuracy.

```
Figure 5: Decision tree (~ foul = {spicy, pungent, none, musty, fishy, creosote, anise, almond})
```

Step 4: Post-processing 2.
Next, we want to store in the database the examples in simple_mushroom that are misclassified w.r.t. the selected tree. To classify a new example using that tree, one simply looks up the concept that covers the new example. More generally, if we have a test set \( S \), all predictions of the examples in \( S \) are obtained by equi-joining \( S \) with the semantic representation of the tree given in the view Concepts. We join \( S \) to Concepts using a variant of the equi-join that requires that either the values are equal or there is a wildcard value ‘?’.

Figure 6 shows the corresponding query. To suit our purposes, the equi-join is made between tables simple_mushroom and best_tree, from which the tree with treeid = 6 is selected. The misclassified examples are those for which the prediction is different from the real class (stated in the last line of the query).

Step 5: Post-processing 3.
In this final step, we are interested in describing the mis-
create table misclassified_{mushroom} as select test.* from simple_{mushroom} test, best_{tree} tree where (test.cap color = tree.cap color or tree.cap color = '?') and (test.odor = tree.odor or tree.odor = '?') and (test.gill size = tree.gill size or tree.gill size = '?') and (test.gill color = tree.gill color or tree.gill color = '?') and (test.spore print color = tree.spore print color or tree.spore print color = '?') and tree.treeid = 6 and test.class <> tree.class

create table mushroom_status as select s.*, '0' as 'status' from simple_{mushroom} s where exists (select * from misclassified_{mushroom} m where s.id = m.id)
union
select s.*, '1' as 'status' from simple_{mushroom} s where not exists (select * from misclassified_{mushroom} m where s.id = m.id)

select S.supp, S.sz, R.conf,
C1.spore_print_color, C1.cap_color,
C1.gill_size, C1.odor,
'=' as ='>','C2.status
from mushroom_status{sets S,
mushroom_status{sets S1,
mushroom_status{rules R,
mushroom_status{concepts C1,
mushroom_status{concepts C2
where R.cid = S.cid
and R.cid = C1.cid
and C2.cid = R.cide
and S.supp >= 15
and R.conf >= 100
and S.sz = 2 //total size of the rules
and S1.sz = 1 //size of the consequent
and C2.status <> '?'
order by C1.status

Figure 6: Query selecting the misclassified mushrooms.

Second, we mine table mushroom_status for correct (100% confidence) class association rules (the class is the attribute status), having one attribute-value pair in the antecedent, i.e. the most general rules. The query is shown in Figure 8.

Figure 7: Query labeling the examples w.r.t. the selected decision tree.

Figure 8: Query over association rules.

Figure 9: Association rules describing the well classified and misclassified mushrooms.

6. REFERENCES