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Texas A&M University

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A FRAMEWORK FOR DEDUCTIVE DATABASE DESIGN IN DECISION SUPPORT SYSTEMS

Joobin Choobineh and Arun Sen
Department of Business Analysis and Research
College of Business Administration
Texas A&M University

ABSTRACT

A three-level framework for design and implementation of deductive database management systems is described. The three levels consist of the abstraction, for abstracting the real world semantics, the language, for man-machine communication, and the environment, for specifying the hardware/software environment. This framework is applied to some representative systems. Based on the results, an architecture for a deductive database management system is proposed.

1. INTRODUCTION

The term "decision support" first began to appear in titles of research papers and in conferences in the early 1970s (Bonczek, Holsapple and Whinston 1981). Computers were usually integrated into such systems as a support mechanism; as a whole, these came to be known as Decision Support Systems (DSSs).

A DSS is defined as a collection of several tools: data management, analytical techniques, report writers, and visual displays (Sen 1983). Moreover, these tools need to communicate with one another so that they can collectively support the managerial decision-making process.

The traditional definition and the design considerations of a DSS have gone through a metamorphosis over the past decade, particularly because of users' insistence to make the software more and more "user-friendly." This trend can be seen in works by Donovan (1975), Elam (1979), Bonczek, Holsapple and Whinston (1981), Konsynski (1980), Lee (1985), and others. The trend is more toward building a smart DSS, using the notions of artificial intelligence. As DSS needs a database system, this new impetus in DSS has forced researchers to look into intelligent database systems.

Intelligent database research can be decomposed into three broad categories: (i) deductive database management system, (ii) smart database interface, and (iii) database system enhancement. Deductive Database Management Systems (D-DBMS) are database systems that can also perform deductive operations. These operations are needed for problems that cannot be solved by the traditional database systems. These problems include null value representation (Zaniolo 1981), incomplete data representation (Levesque 1981), representation of complex objects (Zaniolo 1981), virtual data type manipulation (Chang 1981), and heuristics representation (Kellogg 1984, 1986). Smart interfaces include systems that are intelligent and can be interfaced with a traditional database system. For example, a natural language processor acting as a front-end to a database system can act as a smart interface. Database enhancement includes areas such as query optimization (Aho and Ullman 1979) and incremental query formulation (Codd 1978).

The objective of this paper is to study the deductive database systems for decision support. The connection between database and decision support systems has been thoroughly established (Carlson 1977; Donovan 1976; Sen 1983). However, the user-friendliness issue of the DSS is forcing the database research to include "something more" than just data retrieval and update. Some of these extra things are discussed above in connection with the deductive database.

Section 2 describes a framework for the design of D-DBMS. In Section 3, some representative systems are surveyed and presented in a tabular form according to the framework which is developed in Section 2. Section 4 introduces our goals and an architecture for a D-DBMS.
2. A FRAMEWORK FOR DESIGN

In this section, we develop a framework to design a D-DBMS. The framework will first be used to classify various D-DBMS which have been proposed or implemented. Later it will be applied to describe the architecture of DBFLEX. There are three levels in our framework. They are the abstraction level, the language level, and the environment level. The abstraction level includes relevant components to represent the real world. The language level is the user interface to the environment. The environment level depicts the residency of the evaluative and deductive components of a D-DBMS. These three levels roughly correspond to the three levels of knowledge system, language system, and problem processing of Bonczek, Holsapple and Whinston (1981).

2.1. The Abstraction Level

To study the abstraction level of D-DBMS, we first determine the components of the abstraction. In Table 1, the x-axis has the support components, while the y-axis is the problem type. If the D-DBMS is to be designed for decision support, one needs to know the type of support it can provide for various types of decision related problems. These problems can be data oriented, or may need process descriptions and enterprise level information. We think that all organizations will have these three levels of problem complexity. For example, at data level of the inventory management problems, one can ask "how much stock do we have for part number 562?" At process level, one finds that the scope is somewhat broadened. The query at this stage will be "how much should we order next month?" This query recognizes the fact that the ordering process is connected with the inventory management process. At the enterprise level, one finds queries like "should Mr. Jones be allowed to initiate this purchase order?"

To solve these various problems, one needs support tools. These support components are listed in the x-axis. We start with the fact component. This involves only the data types that are of interest to us. The next level is general laws. We define general laws as real world rules which should be followed. These laws are typically common knowledge and are available to everybody. General laws include constraints as well as deductive rules. The final level is expert's knowledge. This is exclusive to those individuals who are experts and is not a common knowledge. In the AI community, it is also known as heuristics. Pearl (1984, page viii) defines heuristics as "...standing..." for strategies using readily accessible though loosely applicable information to control the problem-solving process in human beings and machine[s]." Heuristics are rules of thumb which aid a problem solver in finding satisfiable solutions to the problems, or to reduce the search space so that a solution can be found faster.

The entries in each cell define the abstraction level components of the D-DBMS. Typically, the traditional database systems cover the cells (1,A) and (1,B) at the data level. Semantic data model research (Abrial 1974; Brodie, Mylopoulos and Schnidt 1984; Tsichritzis and Lochovsky 1982) has pushed us to include cells (2,A) and (3,A). We follow Widerhold (1984) to capture the components for the rest of the grid.

We now define these components of each cell in Table 1.

Table 1. The Abstraction Level of Deductive DBMS

<table>
<thead>
<tr>
<th>PROBLEM TYPE</th>
<th>SUPPORT COMPONENTS</th>
<th>expert's knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>data level</td>
<td>1</td>
<td>fact A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>general laws B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>process level</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>enterprise level</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Definition 1. Object type (1,A) is an abstraction of the real-world. It is a Cartesian product of uniquely named attributes, not all necessarily of the same domain. For example, EMPLOYEE is an object type. Its attributes are employee number, name, address, telephone number, salary, etc. The object types can be kept in hierarchies (Smith and Smith 1977).
Definition 2. **Domain Laws** (1,B) are a set of rules that maintains the domain integrity of the object types. Examples of domains are integers, reals, time, etc.

Definition 3. **Structural Laws** (1,B) are defined to be the knowledge we have about dependencies and constraints among the data, restricting ourselves to general and intentional information. An example of a structural knowledge concept is a functional dependency such as employee --> department.

Definition 4. **Operations Laws** (1,B) are the rule set that maintains data integrity upon traditional database operations, such as insert, delete, retrieve, and modify.

Definition 5. **Event Graph** (2,A) is a graph that shows the natural progression of events in a process. A **Form Flow** (2,A) diagram has also been used along with the event graph to abstract process information in business oriented problems (Sen and Kershberg, forthcoming; Tsichritzis 1982).

Definition 6. **Object Graph** (3,A) is a graph of object types that is used to capture the data types at the enterprise level. This has been used by De and Sen (forthcoming) to capture internal control semantics.

The next several definitions do not distinguish between the general laws and expert's knowledge as they can be used in both.

Definition 7. **Procedural Knowledge** (2,B) and (2,C) is the knowledge about appropriate methods and procedures, given some set of data. Many decisions must be made to select and properly invoke the computational procedures which will produce the desired result for a query. Making the wrong choice can lead to processing failures, errors in the result, and wasted resources.

Definition 8. **Application-specific Knowledge** (2,B) and (2,C) is potentially a large body of knowledge that is associated with each application. This is potentially unbounded for an application.

Definition 9. **Derived Knowledge** (2,B), (2,C), (3,B) and (3,C) is the knowledge that is not explicitly stored in the database and is deduced from the explicitly stored information using different rules.

Definition 10. **Enterprise Knowledge** (3,B) and (3,C) is the knowledge at the highest level of abstraction. It involves rules that are typically used by the strategic managers.

There are two other components that are not explicit in Table 1. They are control structure and deduction technique. We define the control structure as a mechanism that actually guides the search process that is inherent in any AI-oriented system. Various kinds of control include forward chaining (starting from the start states), backward chaining (starting from the goal states), bi-directional (forward and backward chaining) and opportunistic (special case of bi-directional). Further elaboration on these techniques can be found in any introductory AI textbook.

Deduction technique defines the method in which the deduction is to be carried out. For example, in predicate logic, one typically uses the resolution principle. In rule-based systems, researchers have used improved search techniques coupled with good pattern-matching. For inexact reasoning, certainty factor and Dempster-Shafer techniques have been used (Shortliffe 1976).

Notice how similar Table 1 is with Gorry and Scott Morton's (1971) framework. Support components are categorized in a hierarchy following Anthony's (1965) classification, with fact and some general laws suitable for operations people. Expert's knowledge follow strategic planners. In the problem type axis, we have exploited Gorry and Scott Morton's classification: data level corresponds to the structured world, and enterprise level corresponds to the unstructured world.

2.2 The Language Level

Various types of languages have been proposed to interface to a deductive database. They range from traditional procedural ones like Pascal, to specification oriented languages like Prolog, and to object oriented languages such as SmallTalk.

Procedural languages do not have deductive capabilities per se. They can be used to arithmetically derive new facts from old, and to reason from premises to goals by if-then-else type statements. They do not, however, have any data modeling capabilities and/or built-in database management system. A good programmer can code any of the deductive capabilities of other languages.
in a conventional programming language, but that is similar to rewriting the interpreter of deductive languages in the source procedural language.

The most popular logic based language is Prolog (Clocksin and Mellish 1981). Prolog is based on horn clauses. A horn clause is of the general form: "IF A & B & C & ... THEN G," in which there are no free and no existentially quantified variables. That is, all the variables are universally quantified. A horn clause is limited to at most one conclusion and must have one or more premises. In Prolog notation, the above statement is represented as: "G := A, B, C, ...."

Lisp based languages for deductions are very popular in artificial intelligence but they have not been as popular for deductive data modeling and language development. Their main thrust has been in the development of natural language interfaces to databases. If deducing user intentions can be considered deduction then the lisp based languages can be included in the language category of our framework.

Frame based languages have gained more popularity recently due to their rich representation mechanism and semantics (Fikes and Kehler 1985). A frame system (Minsky 1975) is a data structure organized as a semantic network in which each node is a frame which represents an object's definitions as well as its behavior. The semantic network is normally organized as a generalization hierarchy. Examples of frame based languages are FRL (Goldstein and Roberts 1977), KRL (Bobrow and Winograd 1977), KEE (Kehler and Clemenson 1984), and UNITS (Stefik 1979).

Object oriented languages are closely related to the frame based languages with the addition of icons and messages passing between objects (Stefik and Bobrow 1986). In this sense, an object oriented language may be considered a richer language processor and user interface than the frame based systems. However, from a modeling standpoint, they are not much stronger than the frame based systems.

Expert system shells, like EMYCIN, M1, OPS5, etc., are very popular in expert systems applications development. Various researchers have envisioned a possible connection between database and expert systems (Kerschberg 1984).

2.3. The Environment Level

Different types of environments can be used to implement the D-DBMS. Issues at this level include selection of hardware, software, and their coupling environments. A D-DBMS can use homogeneous or heterogeneous hardware. Homogenous hardware is a single processor, whereas heterogeneous hardware is a multi-processor.

The software environment can also be homogenous or heterogeneous. If the entire system is written in one language, it is homogenous. Otherwise, the environment is heterogeneous.

Vassiliou, Clifford and Jarke (1985) describe two types of coupling of the evaluative component (traditional DBMS features) and the deductive component. They are loose coupling and tight coupling. Loose coupling is used when a snapshot of data from an existing database which is managed by a DBMS is needed by the deductive component. Such a strategy presents several practical advantages. However, it is not suitable if the portion of the database to be extracted is not known in advance. Tight coupling is used when the deductive component needs to access the database at various points during its operation. In this case, an online communication channel between the two components is required.

3. APPLICATION OF THE FRAMEWORK

In this section, we apply the framework of the previous section to representative Deductive DBMS which are reported in the literature. Tables 2 through 4 show the abstraction, language, and environment levels of the surveyed systems, respectively. The first column of each table contains the system's names or their acronyms. The first column of Table 2 also includes the year of publication and the reference to it. We estimate that there is approximately a one to two year lag between the implementation and publication of the systems. The rest of the columns are the components of each of the categories of our framework.

The first two columns of Table 1 correspond directly to the first two columns of Table 2. The column "Expert's knowledge" of Table 1 is included in the "Heuristic" column of Table 2. Heuristics may include some system related knowledge which is problem specific.
Table 2. Components of the Abstraction Level

<table>
<thead>
<tr>
<th>System</th>
<th>Facts</th>
<th>General Laws</th>
<th>Heuristics</th>
<th>Control</th>
<th>Deduction Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBRM `84</td>
<td>Semantic net as a triple store, entity classes, and meta classes, instance(s)</td>
<td>Domains as entry classes, causal form</td>
<td>Causal form</td>
<td>Not implemented</td>
<td>Inheritance</td>
</tr>
<tr>
<td>DECIDEZ `78</td>
<td>Relations</td>
<td>FOPC, plus numerical quantifiers</td>
<td>Causal form</td>
<td>Not reported</td>
<td>Rewriting rules, a variation of resolution</td>
</tr>
<tr>
<td>MRPPS `78</td>
<td>Semantic net, relations</td>
<td>FOPC</td>
<td>Causal form</td>
<td>Not reported</td>
<td>SL, Resolution</td>
</tr>
<tr>
<td>HOLMES `84</td>
<td>Objects &amp; N-ray, Relationships between them</td>
<td>FOPC close to natural language</td>
<td>FOPC close to natural language</td>
<td>Not reported</td>
<td>Inheritance</td>
</tr>
<tr>
<td>LDL `84</td>
<td>NF2 relations</td>
<td>Extended Horn Clauses</td>
<td>Extended Horn Clauses</td>
<td>Not reported</td>
<td>Resolved</td>
</tr>
<tr>
<td>PROSOL `86</td>
<td>Relations</td>
<td>Horn Clauses</td>
<td>Horn Clauses</td>
<td>Backward Chaining</td>
<td>Resolution</td>
</tr>
<tr>
<td>TAXIS `85</td>
<td>Token, class, Meta Class, Properties, Frames</td>
<td>Pre-requisite, Results, DB Actions, Domain Constraints</td>
<td>Pre-requisite, Results, DB Actions, Domain Constraints</td>
<td>Not reported</td>
<td>Inheritance</td>
</tr>
<tr>
<td>RX `84</td>
<td>Frames, Categories, Domain Contraints, generalization, Statistical knowledge on rules, causal knowledge</td>
<td>Not reported</td>
<td>Not reported</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KM-1 `84</td>
<td>Relations</td>
<td>FOPC</td>
<td>FOPC</td>
<td>Forward chaining, Backward chaining, Mix</td>
<td>Resolution</td>
</tr>
<tr>
<td>ROSE `81</td>
<td>Relations</td>
<td>Rules</td>
<td>Rules</td>
<td>Forward &amp; Backward Chaining, Pattern-matching</td>
<td></td>
</tr>
<tr>
<td>STROBE `86</td>
<td>Frame</td>
<td>Integrity constraint, generalization</td>
<td>Allowed</td>
<td>Not reported</td>
<td>Inheritance</td>
</tr>
<tr>
<td>PROBE `86</td>
<td>DAPLEX environment</td>
<td>Allowed</td>
<td>Allowed</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>SRL `85</td>
<td>Frame</td>
<td>Allowed</td>
<td>Allowed</td>
<td>Constraint satisfaction, multi-level search</td>
<td>Inheritance</td>
</tr>
</tbody>
</table>

3.1 The Abstraction Level

Table 2 shows how each system abstracts the real world. Most of the systems use a relational model for abstracting the object types and relationships between them. This is more so for systems which are based on logic due to the basic underlying mathematical foundations of the relational model and logic. Some more recent systems represent the facts with richer abstractions such as frames or non-normal relations. For instance, MRPPS and SBRM use the semantic network; TAXIS, RX, STROBE, and SRL use frames; and LDL extends logic to handle sets and non-normalized relations. We believe the trend is toward richer representations and away from simple relational models.

Most systems represent general laws as situation-action rules which can easily be formalized in predicate logic. However, some are more restrictive and limit this representation to horn clauses. One reason for this limitation is that most of the logic-based systems are written in Prolog. Similarly, heuristics are represented in causal form in most systems.

The control mechanism, for systems which use unification and pattern matching to deduce new facts, can be forward chaining, backward chaining, or a mix of the two. Most of the systems do not report the control mechanism that they employ. Only KM-1 reports it employs all three mechanisms. Unification and resolution is the main deductive technique used by most. Variations of the resolution is used depending on the extent of the logic formalism. For instance, LDL uses an extended resolution since it has extended logic to handle sets and non-normal form relations. Inheritance is the
next popular method of deduction. Considering the fact that the inheritance can be represented in logic, its importance becomes subordinate to logic formalism. SRL is the exception to the rest since it employs constraint directed deduction.

3.2 The Language Level

Table 3 depicts the language basis of the systems. Out of the thirteen systems, eight use logic or some variation of it, four use Lisp, four use frames, one uses an object oriented approach, and two are shells. We will report not only the language in which the system is written, but also the notions which are supported by that system. For instance, if a system is written in Lisp but it is a frame based system, then both frame and Lisp are marked in the body of the table for it.

<table>
<thead>
<tr>
<th></th>
<th>Procedural</th>
<th>Logic Based</th>
<th>Lisp Based</th>
<th>Frame Based</th>
<th>Object Oriented</th>
<th>ES Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBGM</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEDUCE 2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRTPS</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOLMES</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROSQL</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAXIS</td>
<td>PASCAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>RX</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KM-1</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROSIE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>STROBE</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROBE</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRL</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.3 The Environment Level

Aside from SBGM and PROBE, all systems report some implementation. Most of them, however, do not fully report the implementation environment. Hence, some entries in Table 4 were guesses. All systems reside on a homogeneous hardware except KM-1. We envision the proliferation of multi-processor environments due to the decrease in hardware cost and increase in demand for computing power and inferential applications.

Similar to the hardware environment, most systems are implemented through a single software. If a system resides in a heterogeneous hardware environment, it is likely that its underlying software is also heterogeneous. This is the case for KM-1. PROSQL is an exception to this norm. It is imple-

Table 3. Language Level-Implementation Languages
Table 4. The Environment of Implementation

<table>
<thead>
<tr>
<th>HARDWARE</th>
<th>SOFTWARE</th>
<th>COUPLING</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A Framework for a smart DB machine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Uses theorem proving tech. to resolve virtual rel. against base relations</td>
</tr>
<tr>
<td>MRPP</td>
<td>Univac</td>
<td>SIMPL</td>
<td>Experiment System</td>
</tr>
<tr>
<td></td>
<td>1108</td>
<td></td>
<td>Under Development</td>
</tr>
<tr>
<td>HOLMES</td>
<td>X</td>
<td>X</td>
<td>Prototype; pure Horn clauses</td>
</tr>
<tr>
<td>LDL</td>
<td>X</td>
<td>X</td>
<td>Prototype; pure Horn clauses</td>
</tr>
<tr>
<td>PROSQL</td>
<td>X</td>
<td>Prolog, SQL</td>
<td>Proposed Embeds SQL in PROLOG</td>
</tr>
<tr>
<td>TAXIS</td>
<td>X</td>
<td>X</td>
<td>Extends data oriented semantics such as IS_A to procedures</td>
</tr>
<tr>
<td>RX</td>
<td>X</td>
<td>Interlisp</td>
<td>X Multiple KB Management</td>
</tr>
<tr>
<td>KM-1</td>
<td>Xerox 1100, Britton-Lee IDM-500</td>
<td>Lisp and A Data Mgr</td>
<td>Interfaces a LISP machine to a DB machine</td>
</tr>
<tr>
<td>ROSIE</td>
<td>X</td>
<td>X</td>
<td>A general purpose rule base programming environment</td>
</tr>
<tr>
<td>STROBE</td>
<td>Xerox</td>
<td>Interlisp D</td>
<td>X Extends an object oriented language to include integrity constraint manager</td>
</tr>
<tr>
<td>PROBE</td>
<td>Not implemented</td>
<td></td>
<td>A framework to develop advanced DBMS</td>
</tr>
<tr>
<td>SRL</td>
<td>X</td>
<td>Lisp</td>
<td>A frame based language with &quot;schema&quot; as its primitive</td>
</tr>
</tbody>
</table>

mented in a homogeneous hardware environment as a Prolog system with embedded SQL.

Coupling the database and the deductive component is tight for all systems with a homogeneous software environment. The question of loose versus tight coupling arises when the software is heterogeneous. For instance, the coupling is loose in PROSQL but it is shown how a tight coupling can be implemented. In KM-1 the coupling is also loose due to down loading of the needed data from the global database to a local database.

4. DBFLEX: A DEDUCTIVE DATABASE MANAGEMENT SYSTEM

This section, describes the architecture of DBFLEX, a deductive database management system, which we are presently in the process of designing and implementing. The following criteria are established for the development of DBFLEX:

1. support of inferencing and truth maintenance;
2. efficient processing of recursive queries;
3. support for non-normalized relations;
4. support for plausible reasoning which implies that the facts in the database are no longer 100% true;
5. ability to explain why and how questions, that is, why the system is pursuing this information, and how it arrived at this state;
6. facilities to retrieve, insert, delete, and update facts, and rules.

4.1 The Abstraction in DBFLEX

Facts in DBFLEX are represented as non-normalized relations which can be organized into various abstraction hierarchies. The non-normalized relational structure is chosen due to its natural correspondence to most real world business applications which are hierarchical in nature. The objects, which are represented as non-simple tuples, are further augmented by rules of behavior, which we called general laws and heuristics in our abstraction taxonomy.

Two types of implications are supported in DBFLEX. The situation-action rules are used for their side effects in enforcing integrity constraints and implementing triggers and alerters. The general rules are used for deriving values for virtual fields from the explicitly stored data. General rules are similar to view definition of modern relational DBMS but they can also be used to define recursive relationships.

In answering queries, as in KM-1, the control mechanism of DBFLEX uses forward chaining (what if), backward chaining (find), and bi-directional (given-find) techniques. The deduction techniques are based on resolution and inheritance.

4.2 The Language of DBFLEX

Our preliminary implementation language of DBFLEX is C. The user interface will be a variation of SQL. This includes augmentation of SQL with new data definition and manipulation constructs in order to be able to accommodate the above criteria. SQL is chosen due to its popularity and recognition as a standard database language (ANSI 1986).

4.3 The Environment of DBFLEX

DBFLEX will be implemented on a single SUN 3/160 workstation. Therefore, the hardware environment is homogeneous. The software will also be homogeneous. There will be one language which is used for both deduction and evaluation. A tight coupling will be employed. The system will be tightly integrated; data and rules use each other as the need may arise.

4.4 Architecture of the DBFLEX

Figure 1 depicts the architecture of the DBFLEX. Users interact with the system through a common interface which includes Data Definition, Data Manipulation, Rule Definition and Rule Manipulation. A planning component manages the distribution of user requests through three engines. The evaluative engine can search through various knowledge components for retrieval of explicitly stored knowledge. The deductive engine performs inferential search to satisfy deductive queries which involve derived facts. Upon an insert, delete, or update of any of the knowledge bases, the truth maintenance engine searches knowledge components for violation of constraint rules, conflicts in stored knowledge, and derivability of the new request from the knowledge bases.

Figure 1. Architecture of the DBFLEX

The knowledge base of a system developed through DBFLEX will be composed of four components. The Data Dictionary contains descriptions of data such
as their types, domains, derived or explicit, keys, and indexes. The Database contains the explicitly stored data. The General Laws Base contains the integrity constraint rules, triggers, and alerters as well as the deductive laws for inference of derived facts. The Heuristics Base contains the experts' knowledge about the procedures, application domain, and organization. This knowledge is typically judgmental.

5. CONCLUSION

We have presented a three level framework for the design and implementation of a Deductive Database Management System. Since a Deductive DBMS must support decision making, our framework was based and contrasted to the Gorry and Scott Morton framework. We tested this framework by reviewing the current deductive systems. The framework is used to develop an architecture for DBFLEX, a deductive relational database management system.

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