Supporting deductive and active rules on top of a relational DBMS

Jerry Kiernan, Christophe de Maindreville, Eric Simon

UNITÉ DE RECHERCHE
INRIA-ROCQUENCOURT

Institut National
de Recherche
en Informatique
et en Automatique

Domaine de Voluceau
Rocquencourt
B.P.105
78153 Le Chesnay Cedex
France
Tél.:(1) 39 63 55 11

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Jerry KIERNAN
Christophe de MAINDREVILLE
Eric SIMON

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J. Kiernan[1], C. de Maindreville, E. Simon

INRIA Rocquencourt,
78153 Le Chesnay,
France
kiernan@almaden.ibm.com, {maindrev, simon}@madonna.inria.fr

Abstract: Active database systems have rules consisting of an event that causes a condition to be evaluated, and if true, results in the execution of a predefined action. These rules, usually called *triggers*, are useful to express static and dynamic integrity constraints. However, existing trigger languages have a few drawbacks. First, the proposed semantics do not take advantage of well known and accepted formalisms developed for rule-based systems, and thereby do not capitalize on existing rule-based technology (optimization, algorithms, programming environment). Second, trigger languages are low-level languages. These languages require that the user provides all triggering conditions associated with rules. This makes the specification of triggers and their maintenance eager. Our first contribution in this paper is to present an extension of a deductive database language, namely RDL1, towards *active* rules. By actives, me mean rules that react to external events. Rules are expressed at a high level: triggering conditions are derived from rules by the system. The semantics of our rule language is formally described by means of a partial fixpoint operator which encompasses the deductive database and active database paradigms. Our second main contribution is to propose an architecture in which the system responsible for detecting events issued by application programs and triggering rules, is front-ended to a relational DBMS. This approach has the advantage of being easily portable over various kinds of DBMS. We relate our approach to systems like Hipac, Postgres, Starburst and Alert.

1. Introduction

Integrating rules with a DBMS has been the focus of research on active database systems [Han89, SJGP90, WCL91, CBB+89]. Rules generally consist of an event that causes a condition to be evaluated, and if true, results in the execution of a predefined action. Events are usually modifications of the database, conditions correspond to database queries, and actions perform changes to the database. Sometimes the condition is omitted. Rules of this kind are often called *triggers* or *Event Condition Action* rules. They enable to

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[1] Author's present address: IBM Almaden Research center, 650 Harry Road, San Jose, CA 95120, USA.

express static and dynamic integrity constraints like: "the salary of an employee can only increase", or "only departments who have no employee can be deleted".

Existing trigger languages suffer from two main drawbacks. First, the semantics of an active database rule system is not well understood. Different rule system semantics have been proposed [WCL91, SJGP90, McD89, Han89] using descriptions ranging from natural language to pseudo-code procedures. A Petri-net model is used in [ZB90] to formally compare the semantics of active database systems, but the model essentially concentrates on couplings between events and conditions and actions of rules. More recently, an imperative database programming language has been used in [HJ91] to describe the semantics of rules in active database systems (e.g., Starburst). Nevertheless, the proposed semantics do not take advantage of well known and well accepted formalisms developed for rule-based systems such as production systems in AI (e.g., OPS5 or KEE), logic programming languages (e.g., Prolog), or deductive databases (Datalog-like languages). Hence, active database systems do not capitalize on existing rule-based technology (optimization techniques, algorithms, programming environments and methodologies) and important issues like: when rules should be fired ?, how they should be fired ?, how their effects should be combined ?, are not given a uniform and formal treatment.

A second weakness of existing active database rule languages is that triggers are very similar to daemons or database procedures, as specified for instance in [Cod73], i.e., trigger languages are low-level languages. This makes the specification of triggers and their maintenance eager. It is difficult to have a global view of what tasks are performing a set of triggers, because a user-level "management rule" (e.g., an integrity constraint) is translated into many triggers. For instance, consider the two relations:

Emp (name, salary, dept_no, emp_no)

Dept (dept_no, mgr_no)

The referential integrity constraint saying that: "every employee works in a department" will be generally specified by several rules respectively triggered by insertions into *Emp*, updates to *Emp* or *Dept*, and deletions from *Dept*.

Our starting point is that deductive database languages provide a good basis for defining an active database rule language. Deduction rules are declarative statements expressed in a Datalog language, which enable to derive intensional data from existing (stored) data [Ull89]. These languages have a simple and fairly well understood semantics, formally defined using fixpoint operators [Ull89]. Efficient implementation techniques have been developed, including optimization algorithms [Ull89]. Finally, various extensions of Datalog have been proposed to obtain powerful (sometimes complete) languages [NT89, AV89]. These languages provide a formal basis to many rule-based languages like OPS5 or Prolog. Examples of deductive database systems are described in [NT89, PDR91, KMS90, BF89].

Deduction rules can always be translated into triggers. One solution, described in [W91], is to materialize all intensional data defined by deduction rules, and specify triggers for

maintaining these data whenever extensional data are updated[2]. On the other hand, triggers cannot always be mapped into deduction rules. A major reason is that deductive database systems are not designed to manage events (like delete or update operations), and deduction rules cannot refer to the event's effects.

Our first contribution in this paper, is to extend a deductive database rule language, namely RDL1 [KMS90], towards an active database rule language, thereby capitalizing on deductive database technology. As a result, our language offers three main features compared to existing trigger languages. First, rules are expressed at a higher level. For instance, a static integrity constraint does not need to be decomposed into as many triggers as the number of events that can violate it[3]. Second, the meaning of a set of rules is formally described by two distinct aspects: (i) the coupling between rules and events (including transaction boundaries), and (ii) the semantics of rules, (on which database state are rule executed ?, how are they executed ?). The second aspect is common to both deductive and active database rule languages. Therefore, we take advantage of the well understood formalisms developed within the framework of deductive databases to formally characterize rule application semantics. Finally, our rule language facilitates the integration of deduction rules with *active rules*. By active rules, we mean rules that react to events. We provide a single uniform notion of rule and our rule semantics covers both the deductive database and active database paradigms. In particular, a module of rules whose evaluation is triggered by some events may use rules that deduce data in order to perform intermediate computations. Also, active rules can be associated with changes on deduced data.

The second contribution of this paper is to propose an architecture in which the system responsible for detecting events and triggering rules is tightly coupled with a relational DBMS. Most existing architectures for active database systems integrate a rule-based system within a DBMS (e.g., Postgres, Starburst, Alert). Our approach does not require any change to an existing DBMS. Rules, or more generally modules of rules, can be dynamically defined. A newly defined module is first compiled into an executable C/SQL procedure. It also yields an incremental compilation of an environment initialization procedure. These two procedure codes are then assembled together within a specific Toolbox. The resulting system, called Trigger Monitor, is activated whenever an application program is connecting to the database system. It analyzes the successive database commands issued by the application program and automatically triggers the evaluation of rules. This coupling approach has the advantage of being flexible, maintainable, and portable on various kinds of DBMSs. However, this approach can be less efficient than the integrated one because it cannot take advantage of low-level system features provided by the DBMS.

The paper is organized as follows. Sections 2 and 3 respectively present the syntax and semantics of our rule language. In Section 4, we describe the process and functional architectures of the Trigger monitor. The Toolbox we have implemented at INRIA is then

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[2] Practically, this simulation entails a clear space-time tradeoff.

[3] A notable exception is Ariel [Han89], which also has this feature.

described in Section 5. Comparisons with related work are reported in Section 6. The last section concludes.

2. A Language for Active rules

In this section, we describe how we extended a deductive database language, namely RDL1 [KMS90], towards a language that supports *active* rules[4]. The extension is simple: the syntax of rules has been augmented so that rules can refer to events, and couplings between rules and events can be specified. We first specify our meaning of events and introduce the notion of delta relations. Then, the couplings between rules and events is defined. Finally, the general syntax of rules is given and illustrated by means of examples.

2.1 Events and Delta Relations.

Throughout this paper, we shall consider that rule processing is part of the execution of a given transaction which can either be embedded into an application program or interactively produced by a user. That is, rules are activated and executed as a result of operations issued by a transaction. We view a transaction as a stream of operations consisting of SQL commands (like select, insert, delete, commit, ...) and non SQL database commands (e.g., C procedure calls).

Currently, we restricted non database events to assignments of global variables within an application program[5]. The statement "LET <variable name> = <value>", used in an application program, assigns a value to a main memory variable occuring in some rules. For instance, a variable *upper_limit* might record the sum of all salaries in a department. This variable may occur in some rules that are expected to react whenever the variable is modified.

Most existing trigger languages require that rules are explicitely attached to events to which they are susceptible to react, using a specific statement (e.g., "WHEN <events> ...") preceding the specification of the rule. In our language, triggering events do not have to be specified by the user when he defines rules. Instead, they are implicit in rule definitions and will be derived by the system at the time rules are compiled. We simply provide system-defined relations, called *delta relations*, that enable to refer to the effect of database events within rules's conditions. These relations record the net effects of database changes performed by SQL commands: insert, update, delete. Similar kind of relations are used in [WF90, HJ91, RCBB89]. We follow a syntax close to [WCL91] to denote our delta relations.

• *Delta relations*: If T (A1,...,An) is a relation schema, then the delta relations associated with T have the following schemas:

inserted_T (A1,...,An)

---

[4] We shall use the words *active rule* instead of the word *trigger* to denote a rule in our active database system. In our mind, triggers correspond to low-level (i.e., more operational) rules.

[5] The reason is that our current implementation is limited to handle this type of events. More complex events require additional implementation mechanisms, as noted in [SPAM91].

deleted_T (A1,...,An)

updated_T (oldA1, ..., oldAn, A1,...,An)

Intuitively, *inserted_T* (A1,...,An) refers to the tuples currently inserted into T, *deleted_T* (A1,...,An) refers to the tuples currently deleted from T, and *updated_T* (oldA1, ..., oldAn, A1,...,An) refers to the tuples currently updated in T with their new value.

- *Properties of Delta relations*: We impose that delta relations satisfy the following:

  1. inserted_T $\cap$ deleted_T = $\emptyset$;
  2. deleted_T $\cap$ $\Pi_{oldA1, ..., oldAn}$ (updated_T) = $\emptyset$, and

     deleted_T $\cap$ $\Pi_{A1, ..., An}$ (updated_T) = $\emptyset$;
  3. inserted_T $\cap$ $\Pi_{A1, ..., An}$ (updated_T) = $\emptyset$, and

     inserted_T $\cap$ $\Pi_{oldA1, ..., oldAn}$ (updated_T) = $\emptyset$;
  4. The *current value* of T is defined to be:

     T – [deleted_T $\cup$ $\Pi_{oldA1,...,oldAn}$ (updated_T)]

     $\cup$ [inserted_T $\cup$ $\Pi_{A1,...,An}$ (updated_T)]

∎

2.2 Coupling Rules with Events and Transaction Boundaries

As noted in [ZB90], a crucial point in the specification of triggers, is to express how rule execution relates to events, including those that mark the transaction boundaries. Different coupling modes can be envisaged, like stating when the condition (or the action) of a rule is evaluated relative to the transaction in which the triggering event is signaled.

A single coupling mode is defined in our rule system. It specifies if a rule must be evaluated either when the triggering event occurs or when the transaction reaches a commit point. In the former case, we say that the evaluation is *immediate* relative to the event that triggered it, otherwise we say that the evaluation of the rule is *deferred* until the end of the transaction. We do not provide means to specify a coupling mode in which rule evaluation is decoupled from the triggering transaction as in Hipac (see [ZB90]).

Both immediate and deferred rules are useful. Immediate rules enable to detect an inconsistent intermediate database state as soon as it occurs. An immediate decision can be taken, like aborting the transaction, or issuing some compensating actions in order to restablish database consistency. For instance, the constraint saying that: "the salary of an employee cannot decrease" can be checked immediately. Other rules need to be checked at the end of the transaction because they are interested in the final database state reached by the transaction (intermediate inconsistent states w.r.t the rule are allowed). The referential integrity constraint between EMP and DEPT mentioned before is an example of deferred rule. Deferred rules can also be checked before the end of the transaction at *integrity checkpoints* [Ast76, SV87] (also called assertion points in [ANSI]). We introduce a "CHECKPOINT" command that can be used within a transaction to trigger the evaluation of all deferred rules.

2.3 General Syntax of Rules

The syntax of our rules is based on the syntax of RDL1 [KMS90], and incorporates procedural extensions described in [KM91]. A rule consists of an if-then statement, where the if-part (also called condition) is an extended tuple relational calculus expression. The then-part (also called action) of the rule is a set of elementary actions, each of which being either a database update or a variable assignment or a procedural call (that does not involve any database update).

Rules are encapsulated into rule modules. A *module* contains a relation declaration section which defines input, output, base, and deduced relations. *Base* relations correspond to relations that are physically stored in the database. *Input* relations can be passed as arguments to a module, which computes as a result a set of *Ouput* relations. Input and output relations are always extensional. *Deduced* relations are temporary (i.e., intensional) relations computed by a module which do not persist after execution. We refer to [KMS90] and [KM91] for a more detailed presentation of the rule language[6].

To support the declaration of active rules, the RDL1 syntax is enriched in two ways. First, the coupling mode, immediate or deferred, can be specified at the module level or at the individual rule level. Two key words, IMMEDIATE and DEFERRED, can be used just after the key word RULES, or the key-word IS, as shown in the examples below. Second, system-defined relations can be referenced in the condition part of rules.

We now present examples of rule modules and give their intuitive semantics.

Example 2.1: The first module defines a referential integrity constraint between the employee and department relations.

```
module ref_constraint_emp_dept;
base EMP (name string, emp_no integer, dept_no integer, salary integer);
     DEPT (mgr_no integer, dept_no integer);
rules
r is DEFERRED
if  EMP (x) and not exists y in DEPT (x.dept_no = y.dept_no)
then - EMP (x);
end module
```

Intuitively, this module defines an active rule that is activated whenever the EMP or DEPT relations are modified. Here, EMP and DEPT always refer to the *current* values of the employee and department relations. Thus, if an employee with no department is inserted it will be rejected (i.e., deleted from the set of employees to be inserted). If a department that has employees working in it is deleted then all its employees will be deleted. As said before, triggering events are *not* specified by the user but are rather implicit. A crucial point is to determine how triggering events (e.g., insert to EMP, delete

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[6] An abstract of the RDL1 syntax is given in Appendix .

to DEPT) can be derived from rule conditions. We claim that this must be the role of an optimizer and discuss it in Section 5.3.

Example 2.2: This example is borrowed from [WCL91]. We test if any inserted or updated employee has a salary greater than 100. If true, the action sets the salaries of all inserted employees to 50 and reduces each existing employee's salary by 10% if its is greater than 100.

```
module salary_control;
var integer change;
base EMP (name string, emp_no integer, dept_no integer, salary integer);
rules DEFERRED
r1 is  if (exists z in Inserted_EMP (z.salary > 100))
   or (exists z in updated_EMP (z. salary > 100))
thenonce change = 1;

r2 is  if  inserted_EMP (x) (change = 1)  then -/+ EMP (x; salary = 50);

r3 is  if EMP (x) (change = 1 and  and x.salary > 100)
then  -/+ EMP (x; salary = .9 * x.salary);

control  block (r1, r2, r3)
init  {change = 0;}
end module
```

We use a global variable, *change*, to enable and disable the changes to EMP performed by r2 and r3. The variable is initialized in the "init" section, and then updated in the action part of rule r1. In fact, this variable simulates a rule r1 saying: "if <r1's condition> then execute r2; execute r3;". Anticipating the description of our procedural control language in Section 3.3, the control string "block(r1, r2, r3)" indicates that the three rules must be executed sequentially in their specified order. If the module executes, rule r1 is fired once and then disabled because of the use of the "thenonce" key-word. Rule r2 is also fired once because after firing, relation *inserted_EMP* becomes empty (as we shall see, rules are set-oriented). Thus, the only recursive rule is r3. Notice that here again, triggering events are not specified by the user.

A single Starburst rule is used in [WCL91] to express this module. Their rule has a condition equivalent to our first rule. The action part of their rule consists of two SQL update statements that correspond to our two rules r2 and r3. Note that the single Starburst rule is recursive and a priori requires the evaluation of its condition at each firing (i.e., the equivalent of our first rule).

The last example combines both deduction and reaction to database events.

Example 2.3 : We wish to ensure that an employee cannot earn more than the average salary of all his managers. A deduced relation *Manages* (sup, sub) is defined to contain the management hierarchy of the company using the rules r1 and r2 (transitive closure of a

relation obtained by joining relations EMP and DEPT). Then, rule r3 rollbacks any transaction which yields an inconsistency using the key-word *rollback*.

```
module recursive_constraint ;
base  EMP (name string, emp_no integer, dept_no integer, salary integer);
      DEPT (mgr_no integer, dept_no integer);
deduced  MANAGES (sup integer, sub integer) ;
rules DEFERRED
r1 is  if DEPT (x)  and EMP (y) (x.dept_no = y.dept_no)
   then + MANAGES (sup = x.mgr_no, sub = y.emp_no) ;
r2 is if MANAGES (x) and MANAGES (y)  (x.sub = y.sup)
   then + MANAGES (sup = x.sup, sub = y.sub) ;
r3 is  if MANAGES (x) and EMP(y) and EMP (z) (x.sub = y.emp_no and x.sup =
z.emp_no and avg (z.sal) < y.sal)
   then rollback ;
end module
```

A change (insertion, deletion, update) to EMP or DEPT may activate the execution of this module at the end of the transaction (rules are declared DEFERRED). The correct execution ordering is inferred by the system: the deduced relation is first computed using rules r1 and r2, and then used in the third rule. On the other hand, like in RDL1 [KMS90], an SQL select operation on MANAGES will *immediately* activate the two first rules. This example shows that there is a single notion of rule covering both the deductive database and active database paradigms.

3. Semantics of Rules

As mentioned before, rules are activated and executed as a result of events issued by a transaction. The semantics of our rule system is described in three steps. First, in Section 3.1, we describe when rules are activated with respect to the events of the transaction. Second, in Section 3.2, we define how a given set of activated rules is executed using a partial fixpoint operator. Finally, the notion of procedural control over a set of rules is introduced in Section 3.3 and a control language is presented.

3.1 Activation of rules

The way rules are activated with respect to the events of a transaction is described by a recursive function *evaluate*, which takes as parameters a stream of events and a database state. The *execute_imm* function computes the partial fixpoint[7] of a database instance using some immediate rules. Finally, the *execute_diff* function computes the fixpoint of a database instance using some deferred rules. In the following, we use the abbreviations: T_r for a transaction, R for a rule base, and I for a database instance (including delta relations). Also, we denote e(I) the database instance where delta relations in I have been updated

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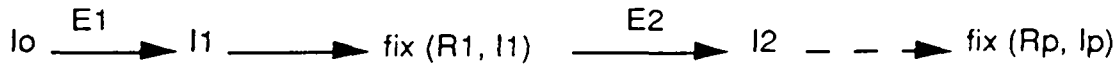
[7] Indeed, this is a partial fixpoint because neither the termination of the execution nor the unicity of the result can be guaranteed for general rule programs [AS91]. For simplicity, we shall abusively use the word fixpoint instead of partial fixpoint.

accordingly to event e, the notation x.S, means that x is the first element of a stream S, and [] denotes the empty stream.

evaluate ([], I) = execute_diff (R, I)
evaluate ($e.T_r$, I) = evaluate (T_r, execute_imm (R, e(I)))

```
% at each invokation of the recursive function:
%    event e is processed
%    immediate rules are evaluated
```

The evaluation process can be depicted using a graphical notation close to the one of [WF90]. Let I_0 stand for the initial database state, we denote E_i the i^{th} event of transaction T_r, and fix (R, I_j), a fixpoint of I_j using rules in R (if rule execution terminates). We assume that T_r contains p events and that R_i denotes the set of rules actually activated by event E_i. If E_p is the event associated with the "commit" action of T_r, then R_p is the set of deferred rules. If $i \neq p$ then R_i is the set of immediate rules.



On this diagram, event E_1 maps the initial state into a new state I_1 in which delta relations, initially empty, may contain some tuples (if the event is an SQL select then $I_0 = I_1$). Then, all immediate rules are used to compute the fixpoint of I_1. Next event is then processed, and so on so forth, until the end of the transaction is reached.

3.2 Partial Fixpoint Semantics of rules

In this section, we concentrate on the meaning of a set of rule modules. We first define the notion of immediate consequence of a database state using a rule instantiation. Let I be a database state, and r be a rule. An *instantiation* of r, henceforth r', is a rule in which every free variable ranging over a relation T has been substituted by a tuple in the "current value" of T in the state I. If T is not a delta relation, then the "curent value" of T, denoted *current_T*, in I is: $(T - \Delta T-) \cup \Delta T+$ where $\Delta T-$ refers to all tuples currently deleted from T, $\Delta T+$ refers to all tuples currently inserted into T. Delta relations $\Delta T+$ and $\Delta T-$ are required to satisfy the properties given in Section 2.1, in particular: $\Delta T- \cap \Delta T+ = \varnothing$. Formally[8], we shall treat an update to a relation T as a deletion from T followed by an insertion into T.

If r' is such that its condition part is true in the state I, then the action part of r' is called an *immediate consequence* of I using r'. Given a rule r, Imm_Cons (r,I) is defined to be the set of all the immediate consequences of I using instantiations of r.

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[8] In practice, the rule system implements the relation *updated_T*, as we mentionned before.

Note that there is a very simple way of constructing Imm_Cons (r,I). Suppose that r's condition has q free variables ranging over relations T1, ..., Tq (not necessarily pairwise distincts). The set of all tuples in the product T1 X T2 X ... X Tq that satisfy the condition part of r, is first retrieved using a relational query. This returns the set of all instantiations of r that satisfy its condition part. Imm_Cons (r, I) is then obtained by projecting these instantiations on the attributes of the relations that appear in the action part of r.

• *Set-oriented semantics*. A set of rules R defines[9] a *relation* among database instances as follows. For each state I, J = R(I) if for some rule r in R, J is such that[10]:

1. If current_T(t) is in I, and + T(t), - T(t) are both in Imm_Cons (r, I), then current_T(t) is in J.

2. If + T(t) is in Imm_Cons (r,I) and - T(t) is not in Imm_Cons (r,I), then:
   if $\Delta T^-(t)$ is not in I and current_T(t) is not in I, then $\Delta T^+(t)$ is in J.
   if $\Delta T^-(t)$ is in I, then $\Delta T^-(t)$ is not in J.

3. If - T(t) is in Imm_Cons (r,I) and + T(t) is not in Imm_Cons (r,I), then:
   if $\Delta T^+(t)$ is not in I and current_T(t) is in I, then $\Delta T^-(t)$ is in J.
   if $\Delta T^+(t)$ is in I, then $\Delta T^+(t)$ is not in J.

4. If T(t) is in I then T(t) is also in J

If the sequence R(I), $R^2(I)$, ... has a limit, it is denoted *fix (R,I)*. []

Intuitively, this definition reflects the facts that: (i) every relation T in the condition part of a rule refers to the current value of T, (ii) if both a fact and its negation are produced by some rule, the effect w.r.t. this fact is null, and (iii) the delta relations are always pairwise disjoint sets for every relation T. Every rule is fired deterministically, but the order of firing rules is left unspecified, thereby introducing non-determinism in the computation. This semantics is a variant of the deterministic and non-deterministic semantics of Datalog extensions studied in [AV89, AS91]. It also captures the semantics of *set-oriented* deduction rules in RDL1 [KMS90].

From the above definition one can see that our notion of immediate rule differs from the one used in Postgres [SJGP90]. In PRSII, immediate rules are evaluated concurrently at a tuple level. In our semantics, immediate rules are evaluated sequentially in a set-oriented fashion.

• *Semantics of modules*. A module is composed from a set of rules R. A set of modules M = $\{R_1, ..., R_n\}$ defines a relation among database instances as follows. For each state I, J = M(I) if there exists j, $1 \leq j \leq n$, such that J = fix (R_j,I). []

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[9] We assume that all rules in R belong to a same module.

[10] We denote "t" a tuple in relation T.

Thus, modules are computed sequentially and each module is computed up to saturation before executing the next one.

3.3 Controlling the Execution of Rules

A procedural control language, derived from [MS88], specifies the execution order of rules that belong to a triggered module. The control language includes basic symbols that are rule names and three primitives: sequence, saturation, and disjunction. The control language is used to declare a control string in the "CONTROL" section of a rule module. The syntax of the control language is now given.

<exp> := <rule_name> | <sequence> | <saturation> | <disjunct>

<sequence> := seq (<exp_1>, ..., <exp_2>)

<saturation> := [<exp_1>, ..., <exp_n>]

<disjunct> := <exp_1> + <exp_2>

The *sequence* primitive means that argument expressions are evaluated in their specified order. The *saturation* primitive means that argument expressions are evaluated up to saturation in any order. Finally, the *disjunct* primitive specifies an exclusive "or" between argument expressions. More formally, the semantics of these primitives is given by the *eval* function below.

eval (r) = fire r if r is firable and returns r, nil otherwise

eval (seq (<exp_1>, ..., <exp_n>)) = eval (<exp_1>); ... ; eval (<exp_n>); ...

eval ([<exp_1> ..., <exp_n>]) = repeat eval (<exp_i>), $i \in \{1, ..., n\}$
until all <exp_i> evaluate to nil

eval (<exp_1> + <exp_2>) = eval (<exp_1>) or eval (<exp_2>)

<exp>; nil = <exp>

Example 3.1: Consider the control string: s = seq (r1 + r2, r3). This is interpreted as: r1 or r2 is first evaluated and then r3 is evaluated.

Consider now the control string: s = [seq ([r1], r2)]. This is interpreted as repeating the following up to saturation: r1 is evaluated up to saturation, then r2 is evaluated once. Thus, the meaning of s is that r1 has always priority on r2. []

Because *priorities* between rules are often useful, we introduced a special key-word *block* such that block (<exp_1>, ..., <exp_n>) expresses that <exp_1> has priority on <exp_2> which has priority on ... on <exp_n>. Formally, block (<exp_1>, ..., <exp_n>) is defined by:

[seq ([seq ([seq ... ([seq ([<exp_1>], <exp_2>)], ..., <exp_n>)]
<---- (n - 1) times ---->

Example 3.2: The control string: s = [block (r1, r3), block (r1, r2)], expresses that r1 has priority on both r2 and r3, but no priority exists between r2 and r3.

It is important to observe that: s = block (r1, r2, r3) is equivalent to: [seq (block (r1, r2), r3)] and cannot be expressed in terms of block (r1, r2) and block (r2, r3). []

Two kinds of *default priorities* between rules are allowed. First, if no control string is specified in a rule module, rules are evaluated in their specification order and every rule is executed up to saturation. Now, suppose that a control string s only contains some of the rules composing the module and that rules r1 ... rk do not occur in s. The *partial_eval* function is defined to evaluate such a control string. Formally, we have:

partial _eval (s) = eval (block (s, [r1] + [r2] + ... + [rk]))

Essentially, the *partial_eval* function enforces that the control string always has priority on the other rules. Suppose that s is evaluated up to saturation (i.e., eval (s) returns nil), then one of the rules r1 to rk can be executed up to saturation. After that, s will be evaluated again.

Finally, a *default ordering* relationship is defined between modules triggered at the same time. This ordering expresses that the least recently created module is executed first[11].

Our control language is more powerful than a priority system as proposed in Starburst [ACL91, WCL91]. For instance, a simple ordering like: "fire r1 once, fire r2 once, fire r3 once, and repeat this up to saturation", is not expressible with priorities as soon as recursive rules are allowed. In fact, our language enables to describe any sequential computation of a set of rules (this is shown by an easy simulation of the context-free grammar presented in [MS88]).

A limited control language can be compensated by expressing control within rules (e.g., using temporary relations that play the role of control predicates). Our desire to have control separated from rules as much as possible influenced the design of a powerful control language. Note that in Example 2.3, we use both control within rules and control string.

4. Implementation of The Rule System

This section presents the functionality and the architecture of the active database system resulting from the specification of a set of rule modules. We first present the main design decisions that guided the implementation of our system.

4.1 Basic Assumptions and Design Decisions

A number of important decisions underlies the architecture of our active database system: (i) a rule base is *compiled* into an executable system called Trigger Monitor that automatically activates and executes rules depending on the actions taken by an application program, and (ii) the Trigger Monitor is *coupled* with a relational database system.

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[11] A more sophisticated mechanism would enable the user to specify priorities between modules.

Most current implementations of active database systems integrate rule processing within an existing DBMS (e.g., Postgres and Starburst rule systems). This has the a priori advantage of efficiency because the implementation of rule processing can take advantage of low level system capabilities like attachments in Starburst [WCL91], or tuple markers in Postgres [Ston90].

However, based on our previous experience in developing an integrated deductive rule system [KMS90], we think that the integrated approach suffers from two drawbacks. First, the integrated system is hard to maintain and to change because its implementation is specific to the extended DBMS. Active database rule languages differ significantly in their semantics, and no sufficient experience has been gained in order to agree on a common semantics[12]. Existing rule languages are then evolving and changing their semantics may require considerable changes in the implementation if it is made too dependent on the usage of low level system features. A second point is heterogeneity. The integrated approach has the drawback of being not portable. On the contrary, the coupled approach facilitates the implementation of a rule system on different DBMSs that accept a common interface protocol like SQL (which is the case of relational DBMSs and some object-oriented DBMSs). This way, one may envisage to use this rule system to define and enforce integrity of interconnected databases supported by different (e.g., relational) DBMS's.

We assume a client-server architecture where an application program is linked with a library of communication procedures to interface a DBMS server. We consider a typical library including procedures like *SqlConnect*, *SqlDisconnect*, *SqlRead*, and *SqlExec*. The *SqlConnect* and *SqlDisconnect* procedures respectively open and close a connection between the application process and a DBMS process. The *SqlExec* procedure takes an SQL command as input and transmits it to the corresponding DBMS process. Such communication procedures may vary from one DBMS to the other. However, our library can be easily simulated on existing DBMS.

Our active database system essentially results from the compilation of a rule base. The choice of a compiled approach is due to efficiency. A strong advantage is that rules do not need to be accessed dynamically which save a significant overhead (about 20% of the average execution time of simple modules in the RDL1 system [KMS90]). On the other hand, an advantage of the interpreted approach, where rules would be kept into a storage structure and accessed when needed, is flexibility (e.g., to support incremental changes).

Incremental compilation is required to efficiently perform changes to the rule base (add, delete, or change rules in a rule module) without having to recompile the entire rule base. This decision has some consequences on the kind of rule processing optimization that can be performed. Essentially, optimization must be performed at the module level.

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[12] we may even expect that a given semantics will be appropriate for some applications and not for other.

4.2 Process Architecture of The Trigger Monitor

The Trigger Monitor is an executable program that automatically activates and executes rule modules according to the operations performed by an application program. This program results from the compilation of a rule base as explained in Section 5. In this section, we describe the process architecture.

Since we assume no change on the underlying DBMS, the communication between an application process and a DBMS process must be intercepted by the Trigger Monitor. This is achieved by using renamed communication procedures to establish and relax the connection between the application and the DBMS. The *SqlConnect* procedure call is replaced by an *SqlConnect** procedure call that creates a Trigger Monitor process instead of a DBMS process, at application start-up time. Communication with a local or remote DBMS process is then established by the Trigger Monitor. Thereafter, the Trigger Monitor intercepts all commands issued by the application to the DBMS. A Trigger Monitor process is then created for every application process and interfaced with the DBMS process to which the application process should communicate.

The Trigger Monitor and the application processes reside on the same client workstation. To fix ideas, assuming a UNIX environment, the communication between the two processes is achieved using a standard pipe mechanism, whereas interprocess communication with the DBMS is achieved by sockets. Figure 4.1 depicts the run-time process architecture.

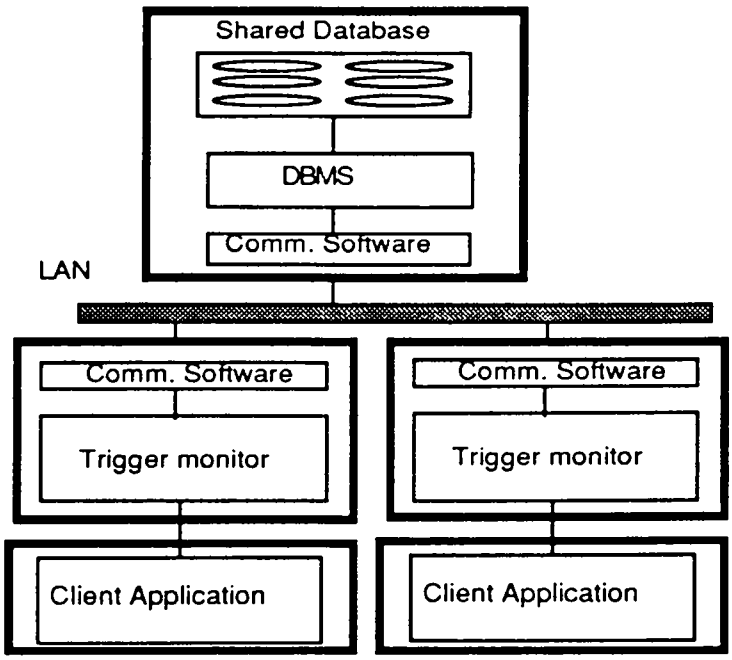

Figure 4.1 : Run-time Process Architecture.

4.3 Functional Architecture of the Trigger Monitor

4.3.1 General Structure

The Trigger Monitor is functionnally decomposed into three main components: the environment initialization, the event handler, and the rule evaluator. The pseudo-code procedure below describes the logical structure of the Trigger Monitor.

```
Trigger Monitor
begin
 create_DBMS_process();
 init_Environment();
 while (an SQL EXIT command is not issued by the application) do
        event = read_Client_Event();
        Handle_Event();
        send_Result_to_Client();
 endwhile
end
```

Figure 4.2: Structure of the Trigger Monitor

The *Init_environment* procedure performs two tasks. First, it builds a data structure describing all the delta relations that should be managed for executing rules in the rule base. For instance, if there is a rule referencing the inserted_EMP relation, this delta relation must be managed whenever an insertion into EMP occurs. On the other hand, if no deleted_EMP relation is used in the rules, no delta relation needs to be managed when deletions to EMP occur. The second task is to build a data structure containing the names of all the rule modules that make the rule base.

The *read_Client_Event* procedure is a (simplified) SQL parser that analyzes incoming database statements (e.g., Sql_Exec). The parser isolates the SQL command. If the command updates the database, it determines which relation is updated and which relations participate in the command.

4.3.2 The Event Handler

The Event Handler performs a case analysis of the SQL commands read by the *read_client_Event* procedure. If the command is a SELECT involving deduced relations, then all modules participating in the definition of the deduced relations are executed. A modified SELECT statement in which deduced relations are replaced by the temporary relations containing their extensions, is send to the DBMS. If the SELECT only involves base relations, it is issued to the DBMS and the result is returned to the client application. If the command is an UPDATE, it is sent to the DBMS. We assume that the result of an SQL data manipulation command can be stored as a temporary relation; a special command "NAME" assigns a relation name to the last query result. In the case of an UPDATE command, the temporary relation returned by the system only contains the updated tuples. A specific treatment is then necessary to build the delta relation associated with updates. When the command "NAME" is used, a specific variable indicates the number of tuples in the temporary relation created by the command. This number indicates if an update has changed the database state. If so, the *Manage_Update* procedure

updates the corresponding delta relations, if any, according to the set-oriented semantics described in Section 3.2. Then, the Rule Evaluator executes immediate rules.

If the command issued by the application program is a COMMIT or a CHECKPOINT, deferred rules are evaluated and then the query is sent to the DBMS (only in the case of a COMMIT).

Non-database events are also allowed. If a command LET is received by the Event Handler, it first updates a data structure containing the value of all variables known to the Trigger Monitor, and determines if the value has changed. Then, all modules containing references to the modified variable are executed. Below, we give a pseudo-code description of the analysis performed by the Event Handler.

```
Handle_Event(event) {
switch (event.type)
      case UPDATE:
            send_Query_to_DBMS();
            receive_Result_From_DBMS();
            if (event.result.tupleCount > 0) {
                  manage_Update(event.updatedRelation, UPDATE);
                  evaluate_rules(event);
            }
      case DELETE:
            /* similar to UPDATE */
      case INSERT:
            /* similar to UPDATE */
      case SELECT:
            if (query involves deduced relations) {
                  evaluate_rules(event);modify_query;}
            send_Query_to_DBMS();
            receive_Result_From_DBMS();
      case LET:
            update_variable_table(event.var_name);
            evaluate_rules(event);
      case COMMIT:
            execute_deferred_rules;
            send_Query_to_DBMS();
            receive_Result_From_DBMS();
            reset_All_Events();
      case CHECKPOINT:
            /* similar to COMMIT */
      case ROLLBACK:
            send_Query_To_DBMS();
            receive_Result_From_DBMS();
            reset_All_Events();
      case EXIT:
            send_Query_To_DBMS();
            receive_Result_From_DBMS();
            mark the end of the DBMS session;
      default:
            send_Query_To_DBMS();
            receive_Result_From_DBMS();
      }
```

Figure 4.3 : Structure of the Event Handler

4.3.3 Evaluation of Rules

The evaluation of rules is part of the *evaluate_rules* and *execute_deferred_rules* procedures. We essentially describe the former procedure since evaluation of rules is done similarly in the second procedure. The *evaluate_rules* procedure cycles over the set of compiled rule modules and successively invokes the program resulting from the compilation of each rule module (by the Rule Compiler) until the database does not change. Below is a pseudo-code description of the *evaluate_rules* procedure.

```
evaluate_rules (E: event);
/* E is represented by the delta relations */
while the database changes {
    execute_module[i] (E), for all modules i;
    }
```

We now detail the execution of a module. Three phases are distinguished. First, the sensitivity of the module with respect to the current cumulated event is tested. This event is represented by the state of the delta relations, and the state of the variable assignment table. For instance, if there is a non empty delta relation associated with relation T and T occurs in a rule r, then the module is sensitive to the event. Notice that T may either occur in the condition or action part of r. This test is produced by inspection of the rules in the module at the time the module is compiled by the Rule Compiler.

If a module is pertinent, then the second phase consists of building a specific data structure, called Production Compilation Network (PCN) in main memory. This structure, derived from Predicate Transition Nets and introduced in [MS88], describes the relationships between relations, main memory variables, and rule's conditions.

The third phase is the execution of rules using the PCN structure. A rule is selected according to the control strategy specified in the module (or the default strategy if no strategy has been specified) and evaluated. If the rule is fired then delta relations, temporary relations, and main memory variables assigned in the rule are updated. A next rule is then selected and fired until no more rule is firable. Contextual data structures (temporary relations, PCN) are updated, and procedural C code associated with the module (specified in the WRAPUP section of the rule module) is executed (if any).

This processing is summarized below.

```
execute_module[i] (E: event); {
    test_module_relevance (E);
    init_PCN ();
    init_Control ();
    select_firable_rule ();
    while there exists a firable (immediate or deferred) rule
    /* the choice between immediate and deferred depends */
    /* on the event E */
       {fire_rule ();
       update_delta_relations ();
       monitor changes to main memory variables;
       select_firable_rule ();
       }
```

```
        free temporary relations no longer needed;
        maintain_PCN ();
        execute_wrapup_code ();
    }
```

Suppose that a module which has already been executed is considered again for execution. The system (in the evaluate_rules procedure) checks whether the database state over which the module executes has changed since its last execution. If not, the system considers the next module.

5. The Toolbox

5.1 Functional Architecture

The Toolbox consists of several software components. Two levels of compilation are used to generate a Trigger Monitor from a set of rule modules. At the first level, a Rule Compiler compiles each source module into a C/SQL procedure, and an Environment Compiler generates the Init_Environment procedure mentioned before. The second level of compilation then follows. A standard makefile facility is used to generate a Trigger Monitor from the outputs of the first compilation phase, the Event Handler, the Interface Procedures (like SqlConnect* described before), and user-supplied procedures invoked in rule modules.

Changes to a rule requires to rebuild the Trigger Monitor. Since rules are organized into modules, only those modules which have been updated need to be recompiled. The initialization procedure has also to be recompiled. The Trigger Monitor is then reassembled from linking together the set of compiled modules.

The functional architecture of the Toolbox is depicted on Figure 5.1. Square boxes represent the compilers and the makefile facility. Bold circle boxes represent the input components.

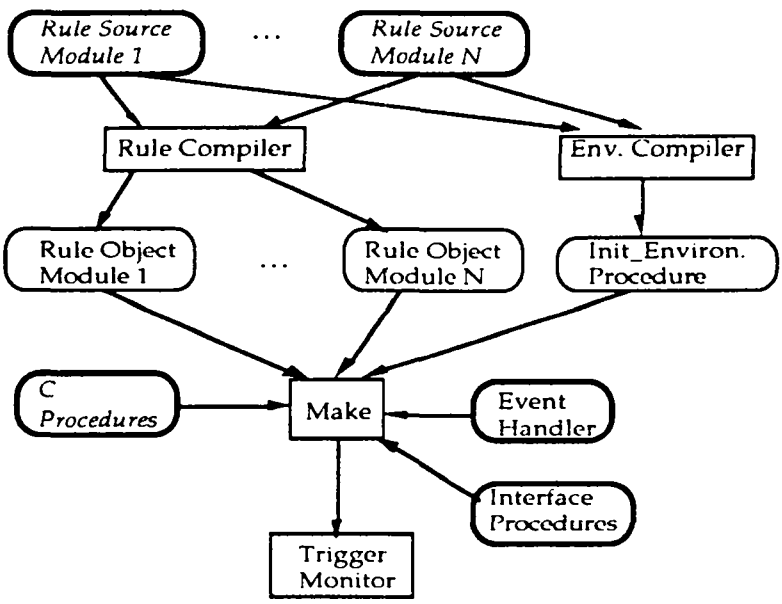

Figure 5.1: Functional Architecture of the Toolbox.

5.2 The Rule Compiler

This compiler translates a rule module into a C procedure containing SQL statements embedded into *SqlExec* procedure calls. It is derived from the RDL compiler presented in [KM91].

Each code produced by the Rule Compiler contains the following elements: a sensitivity test containing triggereing conditions, a skeleton version of each rule; main memory rule program variables, a set of initialization procedures for meta-control, links between rules and relations, links between rules and main memory variables, run-time validation of base relation schemas, run-time validation of virtual relation schemas, and the rule evaluator.

A rule is compiled into a procedure which calculates a set of tuples for each relation involved in the action part of the rule. The name of the procedure is the name of the rule. First, an SQL SELECT statement whose FROM and WHERE clauses are obtained from the condition part of the rule is generated. This query returns a relation having all attributes involved in the action part of the rule. Then one SQL SELECT statement is generated for every relation occuring in the action part of the rule. Actually, the SQL statements are skeletons because relation names (corresponding to temporary relations) and attribute names may change during program execution (e.g., in the case of recursion). Hence, these names appear as variables that are instantiated before each *SqlExec* invocation. Also, variable expressions are replaced by their values at this time.

5.3 Optimization Using Program Rewriting Techniques

Optimization of rule modules is concerned with (i) deriving triggering events from rules, and (ii) optimizing the execution of rules. Database query optimization typically distinguishes rewriting from optimization. Rewriting is heuristic-based and proceeds by applying transformations to the initial query. No selection among alternatives is involved because the heuristics are always considered worth applying. On the contrary, optimization proceeds by applying actions whose effect is measured by a cost function in order to select an optimal solution. This requires to have an accurate cost model of the underlying DBMS. Because, our system is designed to be front-ended to various kinds of DBMS, we only intend to use rewriting techniques.

Several techniques have been proposed in the field of integrity constraint simplification methods to derive triggering events from the syntactic analysis of constraints [Sto75, Nic82, SV87, BDM90]. The heuristics relies on the assumption that delta relations are always much smaller than stored database relations. These techniques can be quite directly applied to our framework. A precedent for this approach is described in [WC90]. We give below a simple example of program rewriting.

Example 5.1: Consider the module given in Example 2.1. The optimizer would rewrite rule r1 as:

r11 is if inserted_EMP (x) and not exists y in DEPT (x.dept_no = y.dept_no)
  then - EMP (x);
r12 is if EMP (x) and deleted_DEPT (y) (x.dept_no = y.dept_no)

then - EMP (x);

r13 is if updated_EMP (x) and not exists y in DEPT (x.dept_no = y.dept_no)
then - updated_EMP (x);

r14 is if EMP (x) and updated_DEPT (y) (x.dept_no = y.olddept_no and not exists z in updated_DEPT (x.dept_no = z.dept_no))
then - EMP (x);

Rewriting techniques like Magic Set and other have also been proposed to optimize the execution of a set of rules using the heuristic that only relevant data should be produced during program computation (see [Ull89] for a panorama). Finally, differential techniques have been proposed in [WCL91] to avoid doing duplicate work during rule processing. Here again, these techniques apply to our framework.

With a similar argument that pushing selections through recursion should not be the responsibility of the programmer, we believe that associating explicitely triggering events with rules should be done by the system. We plan to implement an optimizer based on this strategy.

6. Comparisons With Related Work

This section briefly surveys previous work on active database systems and relates our work.

Alert is an extension architecture designed for transforming a passive SQL DBMS into an active DBMS [SPAM91]. Alert rules are SQL queries (called active queries) which are defined over active tables. Active tables are append-only tables created by the user in order to record events. Therefore, events can be general and are not limited to built-in operations like SQL insert, ... Active queries differ from usual SQL queries in their cursor behaviour. When a cursor is opened for an active query, tuples added to the underlying active table after the cursor was opened contribute to the query. Thus, rules wait for tuples to be appended to the active table and are instantiated with each new tuple (i.e., a rule is executed in a tuple-oriented fashion). Unlike our system, format of events must be declared by the user (in active tables) and rules are explicitely attached to these events. Alert provides several coupling modes between events and rules. Rules can run in the same or in separate transactions as the triggering transaction. The triggering transaction can be halted for the execution of triggered transaction or it can be run in parallel. Finally, a rule can be immediate or deferred. Coupling modes are specified separately from the rules using a command activate. Thus, a rule can be activated with different coupling modes. Changes made to the active tables are detected by a Monitor which selects triggered rules. Selected rules are passed to a conflict resolver which is responsible for managing the execution of rules according to the coupling modes associated with the rules. Unlike our system, rules are executed in a tuple-oriented fashion. however, the semantics of a set of rules is not formally defined and interaction between rules is not clear. Therefore it is not easy to see how an arbitrary rule system could be supported by the Alert architecture.

Triggers in Starburst [WCL91] are expressed using set-oriented production rules where conditions are relational expressions and actions consist of sequences of SQL commands. Triggering events are associated with the built-in operations: update, insert, delete, and they are explicitely attached to each rule. Unlike our language, all rules are deferred and

evaluated at the end and as part of the triggering transaction. Events are implemented using transition tables that are similar to our delta relations. A rule is executed with respect to the net effects of the transaction (including the effects of rules already executed). However, unlike Hipac and our system, the net effects are computed separately for each rule according to the last time the rule was executed. The idea is to prevent a rule from being fired twice with the same tuples in transition tables. This semantics is very similar to the notion of *refraction* used in OPS5 [BFMK85]. Our language enables to simulate this behaviour using the special key-word "thenonce". Finally, control between rules is expressed using a priority mechanism [ACL91].

In Hipac [DBB+88, CBB+89], triggers are specified as event-condition-action statements. Events can be built-in (including timing events, hardware signals), or user-defined. Events can be composed using a specific event language. Changes made by database operations in a transaction are kept into delta relations similar to ours. Like in our system, delta relations record the net effects of database changes. Hipac also offers a rich variety of coupling modes (including those of Alert) [ZB90]. Howewer, as noted in [SPAM91], it is not clear to see which coupling modes are essential and which ones simulate some form of control over rules. Hipac's execution model consists of a nested transaction model, and an assignment of condition evaluation and action execution to transactions based on coupling modes. As a result, there is no conflict resolution policy that chooses a single rule to fire, or a serial order to fire the rules. Instead, all the rules fire concurrently as subtransactions [ZB90]. This semantics makes the expression of control between rules difficult to express.

The Postgres rule language PRSII has a syntax quite close to that of Starburst [SJGP90]. Like in Hipac, rules consist of event-condition-action triples and are low-level statements. Like in Starburst, events correspond to built-in database operations: select, insert, delete, ... PRSII allows a single coupling mode between rules and events: rules are immediate and they are executed within the triggering transaction. Unlike Starburst and Hipac, but like Alert, rules are tuple-oriented. When an individual tuple is accessed, updated, inserted or deleted in a transaction, then the transaction appropriately instantiate the triggered rules and execute them concurrently. A special algorithm uses special locks to mark tuples or table columns whose changes or retrievals would trigger one or more rules. Thus, there is no notion of delta relations. Unlike our system, PRSII does not provide a control language over rules, or a priority system like in Starburst. PRSII enables to define a rule as an exception to another rule.

7. Conclusions

We have presented an extension of a deductive database language, namely RDL1, towards rules that react to external events. Events consist of built-in database operations (select, insert, delete, update), and global variable assignments in application programs. The net effects of database operations are recorded into delta relations. These relations can be used in rule's conditions. Our language has the following features. First, unlike Hipac, Alert, Starburst and PRSII, our rules are expressed at a high level. Triggering events are not provided by the user but are instead derived from rules by the system. High level rules can then be translated into lower level triggers by a compiler/optimizer using rule rewriting techniques. Second, our rule system is formally described by means of a partial fixpoint operator, which encompasses both the deductive database and active database

paradigms. Hence, a rule module may consist of rules that deduce data and rules that modify the database by reaction to external events. In this formal framework, existing work on rule-based systems can be reused (language properties, optimization algorithms, programming environment and methodology). Finally, we presented a control language that enables to specify a rich variety of rule execution orderings.

In this paper, we also presented a system architecture in which the system responsible for detecting events issued by application programs and triggering rules is front-ended to an existing relational database system. This approach can be used over any relational DBMS which supports run-time interpretation of SQL commands. No rule base needs to be managed by the DBMS. A compiler translates rule modules into C procedures which are then linked with an Event Handler which contains all the code necessary to trap events and trigger rules. The resulting system, called Trigger Monitor, runs as a separate process between a client and a server..

Three major future research topics are envisioned. One is the development of an optimizer integrated within our Rule Compiler. We wish to adapt existing techniques proposed for rule optimization and integrity constraint compilation. Second, we would like to extend the language to support object-oriented modeling concepts. Eventually, our objective is to compile rule modules into several Trigger Monitors interfaced with relational and object-oriented DBMS.

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Appendix : Syntax of the RDL Language

The general syntax of a rule module is :

```
module module_name ;
base  base_relation_declaration ;
[ deduced deduced_relation_declaration ;]
[ input input_relation_declaration ;]
[ output output_relation_declaration ;]
[ var  variable_declaration] ;
rules [event coupling mode]
rule_name is [event coupling mode]
if condition then action { c_code; };
...
[ control control_string ;]
[ init c_code;]
[ wrapup c_code;]
end module
```

Below, we give a simplified version of the BNF of a rule condition :

```
Condition       : range_condition and sub_formula ;
range_condition : range_predicate
                | NOT range_predicate
                | range_condition AND range_condition ;
sub_formula     : expression
                | NOT expression
                | sub_formula AND sub_formula ;
expression      : quant_formula
                | comparaison_expression ;
quant_formula   : QUANT var IN relation_name quant_formula
                | QUANT var IN relation_name comparaison expression ;
```

Following is the BNF for the action part of a rule :

```
actions         : action
                | actions action ;
action          : insertion
                | deletion
                | update
                | variable_assignement ;
                | side_effect
insertion       : + relation_name '(' projection_liste')' ;
deletion        : - relation_name '(' projection_liste')' ;
update          : -/+ relation_name '(' tuple_var; projection_liste')' ;
variable_assignement  : var = proc_name (var1, ..., varn)
                | var = const ;
side effect     : proc name (projection liste) ;
```

Le Support de Triggers et de Règles de Déduction au dessus d'un SGBD Relationnel

Jerry Kiernan, Christophe de Maindreville, Eric Simon
INRIA Rocquencourt, 78153 Le Chesnay,France

Résumé: Les systèmes de bases de données actives supportent des règles qui consistent en un événement, une condition à évaluer et une action à exécuter en cas d'évaluation positive de la condition. Ces règles appelées triggers, peuvent être utilisées pour exprimer des contraintes d'intégrité statiques et dynamiques. La sémantique des langages de triggers qui ont été proposés dans la littérature n'a pas été définie formellement à l'aide des formalismes classiques qui ont été développés pour les langages de bases de données déductives. Ces langages de triggers sont fortement procéduraux. Par exemple, ils requièrent des utilisateurs la spécification complète des événements qui sont associés aux règles. La première contribution de ce rapport est de proposer une extension du langage déductif RDL1 afin de supporter des triggers. Cette extension permet de spécifier des triggers dans un langage déclaratif de haut niveau. La sémantique du langage est donnée en terme de point fixe partiel qui étend la sémantique définie pour le langage RDL1. La deuxième contribution du rapport est de détailler une architecture qui a été utilisée pour implémenter ce langage de triggers. Cette approche permet de rendre le langage portable au dessus de divers systèmes relationnels. Notre langage et notre système sont comparés à des approches étudiées dans des projets tels que Hipac, Postgres, Starburst et Alert.

Supporting Deductive and Active Rules on Top of a Relational DBMS

Jerry Kiernan, Christophe de Maindreville, Eric Simon

Abstract: Active database systems have rules consisting of an event that causes a condition to be evaluated, and if true, results in the execution of a predefined action. These rules, usually called *triggers*, are useful to express static and dynamic integrity constraints. However, existing trigger languages have a few drawbacks. First, the proposed semantics do not take advantage of well known and accepted formalisms developed for rule-based systems, and thereby do not capitalize on existing rule-based technology. Second, trigger languages are low-level languages. This makes the specification of triggers and their maintenance eager. Our first contribution in this paper is to present an extension of a deductive database language, namely RDL1, towards *active* rules. Rules are expressed at a high level: triggering conditions are derived from rules by the system. The semantics of our rule language is formally described by means of a partial fixpoint operator which encompasses the deductive database and active database paradigms. Our second main contribution is to propose an architecture in which the system responsible for detecting events issued by application programs and triggering rules, is front-ended to a relational DBMS. This approach has the advantage of being easily portable over various kinds of DBMS. We relate our approach to systems like Hipac, Postgres, Starburst and Alert.

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