Database Management Systems

Triggers

Triggers

- Active Database Systems
- Oracle Triggers
- DB2 Triggers
- Differences between Oracle and DB2
- Trigger Design

Active Database Systems

Active database systems

- Traditional DBMS operation is *passive*
  - Queries and updates are explicitly requested by users
  - The knowledge of processes operating on data is typically embedded into applications
- *Active* database systems
  - Reactivity is a service provided by a normal DBMS
  - Reactivity *monitors* specific database events and *triggers* actions in response

Active database systems

- Reactivity is provided by automatically executing rules
- Rules are in the form
  - Event
  - Condition
  - Action
- Also called active or ECA rules

Active rules

- Event
  - Database modification operation
- Condition
  - Predicate on the database state
  - If the condition is true, the action is executed
- Action
  - Sequence of SQL instructions or application procedure

Rule engine

- Component of the DBMS, in charge of
  - Tracking events
  - Executing rules when appropriate
    - based on the execution strategy of the DBMS
- Rule execution is interleaved with traditional transaction execution

Example

- The active rule manages reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- Event
  - Update of the quantity on hand for product x
  - Insert of a new product x

Example

- The active rule manages reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- Condition
  - The quantity on hand is below a given threshold *and* there are no pending orders for product x
- Action
  - Issue an order with given reorder quantity for product x

Applications of active rules

- Internal applications
  - maintenance of complex integrity constraints
  - replication management
  - materialized view maintenance
- Business Rules
  - Incorporate into the DBMS application knowledge
    - E.g., reorder rule
- Alerters
  - widely used for notification

Triggers

- Commercial products implement active rules by means of *triggers*
- SQL provides instructions for defining triggers
  - Triggers are defined by means of the DDL instruction CREATE TRIGGER
- Trigger syntax and semantics are covered in the SQL3 standard
  - Some commercial products implement different features with respect to the standard

Trigger structure

- Event
  - Insert, delete, update of a table
  - Each trigger can only monitor events on a *single* table
- Condition
  - SQL predicate (it is optional)
- Action
  - Sequence of SQL instructions
  - Proprietary programming language blocks
    - e.g. Oracle PL/SQL
  - Java block

Execution process

When the events take place	[triggering]
If the condition is true	[evaluation]
Then the action is executed	[execution]

- Seems very simple but…
  - Execution modes
  - Execution granularity

Execution mode

- Immediate
  - The trigger is executed *immediately before* or *after* the triggering statement
- Deferred
  - The trigger is executed immediately *before commit*
- Only the immediate option is available in commercial systems

Execution granularity

- Tuple (or row level)
  - One separate execution of the trigger *for each tuple* affected by the triggering statement
- Statement
  - One single trigger execution *for all tuples* affected by the triggering statement

Granularity example

- Table T

A	B
1	5
2	9
8	20

- Transaction statement

```
UPDATE T
SET A=A+1
WHERE B<10;
```

- Trigger execution
  - A row level trigger executes twice
  - A statement level trigger executes once

Database Management Systems

Oracle Triggers

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- *Mode* is BEFORE or AFTER
  - Also INSTEAD OF but should be avoided

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- *Event* ON *TargetTable* is
  - INSERT
  - DELETE
  - UPDATE [OF *ColumnName*]

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- FOR EACH ROW specifies row level execution semantics
  - If omitted, the execution semantics is statement level

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- The old and new states of the row triggering a *row level* trigger may be accessed by means of the
  - OLD.*ColumnName* variable
  - NEW.*ColumnName* variable

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Trigger syntax

```
CREATE TRIGGER TriggerName
Mode Event {OR Event }
ON TargetTable
[[ REFERENCING ReferenceName]
FOR EACH ROW
[WHEN Predicate]]
PL/SQL Block
```

- To rename the state variables
  - REFERENCING OLD AS *OldVariableName*
    - similarly for NEW

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- *Only* for row level execution semantics (i.e., FOR EACH ROW)
  - A condition may be optionally specified
  - The old and new state variables may be accessed

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event {OR *Event* }
ON *TargetTable*
[[REFERENCING *ReferenceName*]
FOR EACH ROW
[WHEN *Predicate*]]
PL/SQL Block

- The action is
  - a sequence of SQL instructions
  - a PL/SQL block
- *No* transactional and DDL instructions

Trigger semantics

- Execution modes
  - immediate before
  - immediate after
- Granularity is
  - row (tuple)
  - statement
- Execution is triggered by insert, delete, or update statements in a transaction

Execution algorithm

1. Before statement triggers are executed
2. For each tuple in *TargetTable* affected by the triggering statement
   a) Before row triggers are executed
   b) The triggering statement is executed
      + integrity constraints are checked on tuples
   c) After row triggers are executed
3. Integrity constraints on tables are checked
4. After statement triggers are executed

Trigger semantics

- The execution order for triggers with the same event, mode and granularity is not specified
  - it is a source of non determinism
- When an error occurs
  - rollback of all operations performed by the triggers
  - rollback of the triggering statement in the triggering transaction

Non termination

- Trigger execution may activate other triggers
  - Cascaded trigger activation may lead to non termination of trigger execution
- A maximum length for the cascading trigger execution may be set
  - default = 32 triggers
- If the maximum is exceeded
  - an execution error is returned

Mutating tables

- A *mutating table* is the table modified by the statement (i.e., event) triggering the trigger
- The mutating table
  - *cannot* be accessed in row level triggers
  - may *only* be accessed in statement triggers
- Limited access on mutating tables only characterizes Oracle applications
  - accessing mutating tables is *always* allowed in SQL3

Example

- Trigger to manage reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- The following database schema is given

  Inventory (<u>Part#</u>, QtyOnHand, ThresholdQty, ReorderQty)

  PendingOrders(<u>Part#</u>, OrderDate, OrderedQty)

Example

- Trigger to manage reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- Event
  - Update of the quantity on hand for product x
  - Insert of a new product x
- Execution semantics
  - After the modification event
  - Separate execution for each row of the Inventory table

Trigger example

```
CREATE TRIGGER Reorder
AFTER UPDATE OF QtyOnHand OR INSERT ON Inventory
FOR EACH ROW
```

Example

- Trigger to manage reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- Condition
  - The quantity on hand is below a given threshold

Trigger example

```
CREATE TRIGGER Reorder
AFTER UPDATE OF QtyOnHand OR INSERT ON Inventory
FOR EACH ROW
WHEN (NEW.QtyOnHand < NEW.ThresholdQty)
```

Example

- Trigger to manage reorder in an inventory stock
  - when the stocked quantity of a product goes below a given threshold
  - a new order for the product should be issued
- Condition
  - The quantity on hand is below a given threshold

    and there are no pending orders for product x
    - This part cannot be introduced into the WHEN clause
- Action
  - Issue an order with given reorder quantity for product x

Example: Trigger body

```
DECLARE
 N number;
BEGIN
 select count(*) into N
 from PendingOrders
 where Part# = :NEW.Part#;
 If (N=0) then
    insert into PendingOrders(Part#,OrderedQty,OrderDate)
    values (:NEW.Part#, :NEW.ReorderQty, SYSDATE);
 end if;
END;
```

Complete trigger example

```
CREATE TRIGGER Reorder
AFTER UPDATE OF QtyOnHand OR INSERT ON Inventory
FOR EACH ROW
WHEN (NEW.QtyOnHand < NEW. ThresholdQty)
DECLARE
 N number;
BEGIN
 select count(*) into N
 from PendingOrders
 where Part# = :NEW.Part#;
 If (N=0) then
    insert into PendingOrders(Part#,OrderedQty,OrderDate)
    values (:NEW.Part#, :NEW.ReorderQty, SYSDATE);
 end if;
END;
```

DB2 Triggers

Trigger syntax

```
CREATE TRIGGER TriggerName
Mode Event
ON TargetTable
[ REFERENCING ReferenceName ]
FOR EACH Level
WHEN Predicate
Procedural SQL Statements
```

- *Mode* is BEFORE or AFTER
- *Event* is INSERT or DELETE or UPDATE
  - *Only one event* is allowed for a single trigger
- *Level* is ROW or STATEMENT

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event
ON *TargetTable*
[REFERENCING *ReferenceName*]
FOR EACH *Level*
WHEN *Predicate*
Procedural SQL Statements

- The condition may be specified for *both* row and statement triggers

Trigger syntax

CREATE TRIGGER *TriggerName*
Mode Event
ON *TargetTable*
[REFERENCING *ReferenceName*]
FOR EACH *Level*
WHEN *Predicate*
Procedural SQL Statements

- State variables are available for *both* row and statement triggers
  - OLD and NEW tuple variables for row triggers
  - OLD_TABLE and NEW_TABLE set variables for statement triggers

Trigger semantics

- Execution modes
  - immediate before
  - immediate after
- Granularity is
  - row (tuple)
  - statement
- Execution is triggered by insert, delete, or update statements in a transaction

Trigger semantics

- Before triggers cannot modify the database
  - apart from the tuples affected by the triggering statement
    - tuple variables are used
  - cannot trigger other triggers
- The execution of row and statement triggers with the same mode is in arbitrary order
- When more triggers are activated on the same event and mode
  - they are executed in *creation order*
- Trigger execution is *deterministic*

Trigger semantics

- Cascading trigger execution is allowed up to a maximum number of triggers in the execution chain
- When an error occurs
  - rollback of all operations performed by the triggers
  - rollback of the *entire transaction*

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Execution algorithm

- Transaction T contains a statement S which generates event E

1. T's execution is suspended and its state is saved into a stack
2. Old and new values of E are computed
3. Before triggers on E are executed
4. New values are applied to the DB (the modification due to E is actually performed)
    - Constraints are checked
        - compensative actions may trigger other triggers, hence cause a recursive invocation of the same execution procedure

Execution algorithm

5. After triggers triggered by E are executed
   - If any trigger contains an action A which triggers other triggers
     - the same execution procedure is recursively invoked on A
6. The execution state of T is extracted from the stack and T is resumed

Example

- The trigger
  - monitors the Inventory table
  - inserts into an audit table the information on
    - the user performing updates on the table
    - the update date and number of updated tuples
- The following table is given

  InventoryAudit (<u>UserName</u>, <u>Date</u>, Update#)

Example

- Event
  - Update of the Inventory table
- Execution semantics
  - After the modification event
  - Separate execution for each update instruction
    - Statement semantics
- No condition for execution

Trigger example

```
CREATE TRIGGER UpdateAudit
AFTER UPDATE ON Inventory
FOR EACH STATEMENT
  insert into InventoryAudit (UserName, Date, Update#)
  values (USER, SYSDATE,
            (select count(*) from OLD_TABLE));
```

Comparing Oracle and DB2 Triggers

Differences between Oracle and DB2

	Oracle	DB2
Reference to Old_Table and New_Table in statement triggers	No	Yes
When clause in statement triggers	No	Yes
Execution order between row and statement triggers with same mode	Specified	Arbitrary
Execution order between triggers with same event, mode and granularity	Unspecified	Creation Order
More than one triggering event allowed	Yes	No
Forbidden access to the mutating table	Yes for row triggers	No
Availability of the instead semantics	Yes	No
Database modifications allowed in before triggers	Yes	Only NEW variables

Trigger Design

Trigger design

- The design of a single trigger is usually simple
  - Identify
    - execution semantics
    - event
    - condition (optional)
    - action

Trigger design

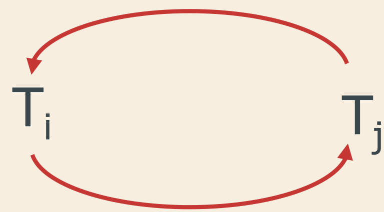
- Understanding *mutual* interactions among triggers is more complex
  - The action of one trigger may be the event of a different trigger
    - Cascaded execution
- If mutual triggering occurs
  - Infinite execution is possible

Trigger execution properties

- Termination
  - For an arbitrary database state and user transaction, trigger execution *terminates* in a final state (also after an abort)
- Confluence
  - For an arbitrary database state and user transaction, trigger execution *terminates in a unique final state*, independently of the execution order of triggers
- Termination is the most important property
- Confluence is enforced by deterministic trigger execution

Guaranteeing termination

- Termination is guaranteed at run time by aborting trigger execution after a given cascading length
- Termination may be verified at design time by means of the triggering graph
  - a node for each trigger
  - a directed edge $T_i \rightarrow T_j$ if trigger T_i is performing an action triggering trigger T_j
- A cycle in the graph shows potential non terminating executions



Example

- Trigger managing salary amounts
  - When a given average salary value is exceeded, a salary reduction is automatically enforced
- The following table is given

  Employee (<u>Emp#</u>, Ename, ..., Salary)
- Event
  - Update of the Salary attribute in Employee
  - Insert into Employee
    - Will write only trigger for update

Example

- Trigger managing salary amounts
  - When a given average salary value is exceeded, a salary reduction is automatically enforced
- The following table is given

  Employee (<u>Emp#</u>, Ename, ..., Salary)
- Execution semantics
  - After the modification events
  - Separate execution for each update instruction
- No condition for execution

Example

```
CREATE TRIGGER SalaryMonitor
AFTER UPDATE OF Salary ON Employee
FOR EACH STATEMENT
BEGIN
  update Employee
  set Salary = Salary * K
  where 2500 < (select AVG (Salary) from Employee);
END;
```

The value of K may be

- K = 0.9 $\longrightarrow$ execution terminates
- K = 1.1 $\longrightarrow$ infinite execution

SalaryMonitor

Trigger applications

- Internal applications
  - maintenance of complex integrity constraints
  - replication management
  - materialized view maintenance
- Business Rules
  - Incorporate into the DBMS application knowledge
    - E.g., reorder rule
- Alerters
  - widely used for notification

Triggers for constraint management

- Triggers are exploited to enforce complex integrity constraints
- Design procedure
  1. Write the constraint as a SQL predicate
     - It provides a condition for the trigger execution
  2. Identify the events which may violate the constraint
     - i.e. the condition
  3. Define the constraint management technique in the action

Design example (1)

- The following tables are given
  - Supplier S (S#, SName, …)
  - Part P (P#, PName, …)
  - Supply SP (S#, P#, Qty)
- Constraint to be enforced
  - A part may be supplied by at most 10 different suppliers

Design example (1)

- Constraint predicate

```
select P#
from SP
group by P#
having count(*) > 10
```

  - set of parts violating the constraint
- Events
  - insert on SP
  - update of P# on SP
- Action
  - reject the violating transaction

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Design example (1)

- Execution semantics
  - *after* the modification
  - *statement level*
    - to capture the effect of the entire modification
    - (Oracle) to allow access to the mutating table
- (Oracle) No condition
  - The condition cannot be specified in the WHEN clause
  - It is checked in the trigger body
- Design for Oracle trigger semantics

Design example (1)

```
CREATE TRIGGER TooManySuppliers
AFTER UPDATE OF P# OR INSERT ON SP
DECLARE
 N number;
BEGIN
 select count(*) into N
 from SP
 where P# IN (select P# from SP
                    group by P#
                    having count(*) > 10);
 if (N <> 0) then
   raise_application_error (xxx, ‘constraint violated’);
 end if;
END;
```

Design example (2)

- The following tables are given
  - Supplier S (<u>S#</u>, SName, …)
  - Part P (<u>P#</u>, PName, …)
  - Supply SP (<u>S#</u>, <u>P#</u>, Qty)
- Constraint to be enforced
  - The quantity of a product supply cannot be larger than 1000. If it is larger, trim it to 1000.
- Check constraints do not allow compensating actions
  - Implement with a trigger

Design example (2)

- Constraint predicate
  - Qty > 1000
  - It is also the trigger condition
- Events
  - insert on SP
  - update of Qty on SP
- Action
  - Qty = 1000

Design example (2)

- Execution semantics
  - *before* the modification takes place
    - its effect can be changed before the constraint is checked
  - *row level*
    - each tuple is modified separately

Design example (2)

```
CREATE TRIGGER ExcessiveQty
BEFORE UPDATE OF Qty OR INSERT ON SP
FOR EACH ROW
WHEN (NEW.Qty > 1000)
BEGIN
 :NEW.Qty := 1000;
END;
```

Triggers for materialized view maintenance

- Materialized views are queries persistently stored in the database
  - provide increased performance
  - contain redundant information
    - e.g., aggregate computations
- Triggers are exploited to maintain redundant data
  - Propagate data modifications on tables to materialized view

Design example (3)

- Tables
  - Student S (SId, SName, DCId)
  - Degree course DC (DCId, DCName)
- Materialized view
  - Enrolled students ES (DCId, TotalStudents)
    - For each degree course, TotalStudents counts the total number of enrolled students
    - Defined by query

```
SELECT DCId, COUNT(*)
FROM S
GROUP BY DCId;
```

Design example (3)

- Tables
  - Student S (<u>SId</u>, SName, DCId)
  - Degree course DC (<u>DCId</u>, DCName)
- Materialized view
  - Enrolled students ES (<u>DCId</u>, TotalStudents)
    - For each degree course, TotalStudents counts the total number of enrolled students
  - A new degree course is inserted in materialized view ES when the first student is enrolled in it
  - A degree course is deleted from ES when the last student quits it

Design example (3)

- Database schema

  S (<u>SId</u>, SName, DCId)

  DC (<u>DCId</u>, DCName)

  ES (<u>DCId</u>, TotalStudents)

- Propagate modifications on table S to materialized view (table) ES
  - Inserting new tuples into S
  - Deleting tuples from S
  - Updating the DCId attribute in one or more tuples of S

Design example (3)

- Design three triggers to manage separately each data modification
  - Insert trigger, delete trigger, update trigger
  - All triggers share the same execution semantics
- Execution semantics
  - *after* the modification takes place
    - Table ES is updated after table S has been modified
  - *row level*
    - Separate execution for each tuple of table S
      - significantly simpler to implement

Insert trigger (3)

- Event
  - insert on S
- No condition
  - It is always executed
- Action
  - if table ES contains the DCId in which the student is enrolled
    - increment TotalStudents
  - otherwise
    - add a new tuple in table ES for the degree course, with TotalStudents set to 1

Insert trigger (3)

```
CREATE TRIGGER InsertNewStudent
AFTER INSERT ON S
FOR EACH ROW
DECLARE
 N number;
BEGIN
 --- check if table ES contains the tuple for the degree
 --- course NEW.DCId in which the student enrolls
 select count(*) into N
 from ES
 where DCId = :NEW. DCId;
```

Insert trigger (3)

```
if (N <> 0) then
    --- the tuple for the NEW.DCId degree course is
    --- available in ES
    update ES
    set TotalStudents = TotalStudents +1
    where DCId = :NEW.DCId;
else
    --- no tuple for the NEW.DCId degree course is
    --- available in ES
    insert into ES (DCId, TotalStudents)
    values (:NEW.DCId, 1);
end if;
END;
```

Delete trigger (3)

- Event
  - delete from S
- No condition
  - It is always executed
- Action
  - if the student was the only student enrolled in the degree course
    - delete the corresponding tuple from ES
  - otherwise
    - decrement TotalStudents

Delete trigger (3)

```
CREATE TRIGGER DeleteStudent
AFTER DELETE ON S
FOR EACH ROW
DECLARE
 N number;
BEGIN
 --- read the number of students enrolled on
 --- the degree course OLD.DCId
 select TotalStudents into N
 from ES
 where DCId = :OLD.DCId;
```

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Delete trigger (3)

```
 if (N > 1) then
      --- there are many enrolled students
      update ES
      set TotalStudents = TotalStudents – 1
      where DCId = :OLD.DCId;
else
      --- there is a single enrolled student
      delete from ES
      where DCId = :OLD.DCId;
end if;
END;
```

Update trigger (3)

- Event
  - Update of DCId on S
- No condition
  - It is always executed
- Action
  - update table ES for the degree course where the student *was* enrolled
    - decrement TotalStudents, or delete tuple if last student
  - update table ES for the degree course where the student *is currently* enrolled
    - increment TotalStudents, or insert new tuple if first student

Update trigger (3)

```
CREATE TRIGGER UpdateDegreeCourse
AFTER UPDATE OF DCId ON S
FOR EACH ROW
DECLARE
 N number;
BEGIN
--- read the number of students enrolled in
--- degree course OLD.DCId
 select TotalStudents into N
 from ES
 where DCId = :OLD.DCId;
```

Update trigger (3)

```
if (N > 1) then
    --- there are many enrolled students
    update ES
    set TotalStudents = TotalStudents – 1
    where DCId = :OLD.DCId;
else
    --- there is a single enrolled student
    delete from ES
    where DCId = :OLD.DCId;
end if;
```

Update trigger (3)

```
--- check if table ES contains the tuple for the degree
--- course NEW.DCId in which the student is enrolled
 select count(*) into N
 from ES
 where DCId = :NEW. DCId;
```

Update trigger (3)

```
if (N <> 0) then
 --- the tuple for the NEW.DCId degree course is available in ES
        update ES
        set TotalStudents = TotalStudents +1
        where DCId = :NEW.DCId;
else
 --- no tuple for the NEW.DCId degree course is available in ES
        insert into ES (DCId, TotalStudents)
        values (:NEW.DCId, 1);
end if;
END;
```