SQL: Part III

CPS 116
Introduction to Database Systems

Announcements (September 21)

- Homework #2 due next Thursday
- Homework #1 sample solution available today
  - Hardcopies only
  - Check the handout box outside my office if you did not pick one up during the lecture
- Project milestone #1 due in 3 weeks
  - Come to my office hours if you want to chat about project ideas

"Active" data

- Constraint enforcement: When an operation violates a constraint, abort the operation, or try to "fix" data
  - Example: enforcing referential integrity constraints
  - Generalize to arbitrary constraints?
- Data monitoring: When something happens to the data, automatically execute some action
  - Example: When price rises above $20 per share, sell
  - Example: When enrollment is at the limit and more students try to register, email the instructor

Triggers

- A trigger is an event-condition-action (ECA) rule
  - When event occurs, test condition; if condition is satisfied, execute action
- Example:
  - Event: whenever there comes a new student…
  - Condition: with GPA higher than 3.0…
  - Action: then make him/her take CPS116!

Trigger example

```
CREATE TRIGGER CPS116AutoRecruit
  AFTER INSERT ON Student            → Event
  REFERENCING NEW ROW AS newStudent
  FOR EACH ROW
  WHEN (newStudent.GPA > 3.0)        → Condition
  INSERT INTO Enroll
      VALUES(newStudent.SID, 'CPS116');
                                     ↓ Action
```


Trigger options

- Possible events include:
  - `INSERT ON` *table*
  - `DELETE ON` *table*
  - `UPDATE [OF` *column*`] ON` *table*
- Granularity—trigger can be activated:
  - `FOR EACH ROW` modified
  - `FOR EACH STATEMENT` that performs modification
- Timing—action can be executed:
  - `AFTER` or `BEFORE` the triggering event

Transition variables

- `OLD ROW`: the modified row before the triggering event
- `NEW ROW`: the modified row after the triggering event
- `OLD TABLE`: a hypothetical read-only table containing all modified rows before the triggering event
- `NEW TABLE`: a hypothetical table containing all modified rows after the triggering event
- Not all of them make sense all the time, e.g.
  - `AFTER INSERT` statement-level triggers
    - Can use only `NEW TABLE`
  - `BEFORE DELETE` row-level triggers
    - Can use only `OLD ROW`
  - etc.

Statement-level trigger example


```
CREATE TRIGGER CPS116AutoRecruit
  AFTER INSERT ON Student
  REFERENCING NEW TABLE AS newStudents
  FOR EACH STATEMENT
  INSERT INTO Enroll
  (SELECT SID, 'CPS116'
   FROM newStudents
   WHERE GPA > 3.0);
```

BEFORE trigger example

- Never give faculty more than 50% raise in one update

```
CREATE TRIGGER NotTooGreedy
BEFORE UPDATE OF salary ON Faculty
REFERENCING OLD ROW AS o, NEW ROW AS n
FOR EACH ROW
WHEN (n.salary > 1.5 * o.salary)
SET n.salary = 1.5 * o.salary;
```

- `BEFORE` triggers are often used to "condition" data
- Another option is to raise an error in the trigger body to abort the transaction that caused the trigger to fire

Statement- vs. row-level triggers

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Why are both needed?

- Certain triggers are only possible at statement level
  - If the average GPA of students inserted by this statement exceeds 3.0, do …
- Simple row-level triggers are easier to implement and may be more efficient
  - Statement-level triggers require significant amount of state to be maintained in `OLD TABLE` and `NEW TABLE`
  - However, a row-level trigger does get fired for each row, so complex row-level triggers may be inefficient for statements that generate lots of modifications

Another statement-level trigger

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- Give faculty a raise if GPA's in one update statement are all increasing

```
CREATE TRIGGER AutoRaise
AFTER UPDATE OF GPA ON Student
REFERENCING OLD TABLE AS o, NEW TABLE AS n
FOR EACH STATEMENT
WHEN (NOT EXISTS(SELECT * FROM o, n
                 WHERE o.SID = n.SID
                 AND o.GPA >= n.GPA))
UPDATE Faculty SET salary = salary + 1000;
```

☞ A row-level trigger would be difficult to write in this case

System issues

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- Recursive firing of triggers
  - Action of one trigger causes another trigger to fire
  - Can get into an infinite loop
    - Some DBMS restrict trigger actions
    - Most DBMS set a maximum level of recursion (16 in DB2)
- Interaction with constraints (very tricky to get right!)
  - When do we check if a triggering event violates constraints?
    - After a `BEFORE` trigger (so the trigger can fix a potential violation)
    - Before an `AFTER` trigger
  - `AFTER` triggers also see the effects of, say, cascaded deletes caused by referential integrity constraint violations

(Based on DB2; other DBMS may implement a different policy)

Views

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- A view is like a "virtual" table
  - Defined by a query, which describes how to compute the view contents on the fly
  - DBMS stores the view definition query instead of view contents
  - Can be used in queries just like a regular table

Creating and dropping views

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- Example: CPS116 roster
  - ```
    CREATE VIEW CPS116Roster AS
    SELECT SID, name, age, GPA
    FROM Student
    WHERE SID IN (SELECT SID FROM Enroll
                  WHERE CID = 'CPS116');
    ```
    Called "base tables" (arrows point to Student and Enroll)
- To drop a view
  - `DROP VIEW` *view_name*;

Using views in queries

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- Example: find the average GPA of CPS116 students
  - `SELECT AVG(GPA) FROM CPS116Roster;`
  - To process the query, replace the reference to the view by its definition
  - ```
    SELECT AVG(GPA)
    FROM (SELECT SID, name, age, GPA
          FROM Student
          WHERE SID IN (SELECT SID
                        FROM Enroll
                        WHERE CID = 'CPS116'));
    ```

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Why use views?

- To hide data from users
- To hide complexity from users
- Logical data independence
  - If applications deal with views, we can change the underlying schema without affecting applications
  - Recall physical data independence: change the physical organization of data without affecting applications
- To provide a uniform interface for different implementations or sources
- ☞ Real database applications use tons of views

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Modifying views

- Does not seem to make sense since views are virtual
- But does make sense if that is how users see the database
- Goal: modify the base tables such that the modification would appear to have been accomplished on the view

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A simple case

```
CREATE VIEW StudentGPA AS
  SELECT SID, GPA FROM Student;
```

```
DELETE FROM StudentGPA WHERE SID = 123;
```

translates to:

```
DELETE FROM Student WHERE SID = 123;
```

An impossible case


```
CREATE VIEW HighGPAStudent AS
  SELECT SID, GPA FROM Student
  WHERE GPA > 3.7;
INSERT INTO HighGPAStudent
  VALUES(987, 2.5);
```

A case with too many possibilities


```
CREATE VIEW AverageGPA(GPA) AS
  SELECT AVG(GPA) FROM Student;
```

- Note that you can rename columns in view definition

```
UPDATE AverageGPA SET GPA = 2.5;
```

- Set everybody's GPA to 2.5?
- Adjust everybody's GPA by the same amount?
- Just lower Lisa's GPA?

SQL92 updateable views

- More or less just single-table selection queries
  - No join
  - No aggregation
  - No subqueries
- Arguably somewhat restrictive
- Still might get it wrong in some cases
  - See the slide titled "An impossible case"
  - Adding `WITH CHECK OPTION` to the end of the view definition will make DBMS reject such modifications

Indexes

- An index is an auxiliary persistent data structure
  - Search tree (e.g., B^+-tree), lookup table (e.g., hash table), etc.
- ☞ More on indexes in the second half of this course!
- An index on $R.A$ can speed up accesses of the form
  - $R.A = value$
  - $R.A > value$ (sometimes; depending on the index type)
- An index on ($R.A_1, \ldots, R.A_n$) can speed up
  - $R.A_1 = value_1 \land \ldots \land R.A_n = value_n$
  - $(R.A_1, \ldots R.A_n) > (value_1, \ldots, value_n)$ (again depends)
- ☞ Is an index on ($R.A$, $R.B$) equivalent to one on ($R.B$, $R.A$)?
- ☞ How about an index on $R.A$ plus another index on $R.B$?

Examples of using indexes

- `SELECT * FROM Student WHERE name = 'Bart'`
  - Without an index on Student.name: must scan the entire table if we store Student as a flat file of unordered rows
  - With index: go "directly" to rows with `name = 'Bart'`
- `SELECT * FROM Student, Enroll`
  `WHERE Student.SID = Enroll.SID;`
  - Without any index: for each *Student* row, scan the entire *Enroll* table for matching SID
    - Sorting could help
  - With an index on *Enroll.SID*: for each *Student* row, directly look up *Enroll* rows with matching SID

Creating and dropping indexes in SQL

- `CREATE {UNIQUE} INDEX` *index_name* `ON` *table_name*(*column_name*$_1$, …, *column_name*$_n$);
  - With `UNIQUE`, the DBMS will also enforce that {*column_name*$_1$, …, *column_name*$_n$} is a key of *table_name*
- `DROP INDEX` *index_name*;
- Typically, the DBMS will automatically create indexes for `PRIMARY KEY` and `UNIQUE` constraint declarations

Choosing indexes to create

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More indexes = better performance?

- Optimal index selection depends on both query and update workload and the size of tables
  - Automatic index selection is still an area of active research

Summary of SQL features covered so far

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- Query
- Modification
- Constraints
- Triggers
- Views
- Indexes

- Next: transactions