SQL: Part II

CPS 216

Advanced Database Systems

Announcements (February 1)

- Reading assignment for this week
  - System R paper and Lomet's B^+-tree tricks
  - Due Thursday night
- Homework #1 due in 7 days
- No class next Thursday (February 10)
  - Instructor out of town for a program committee meeting

Summary of SQL features covered so far

- Basic modeling features
  - Bags, NULL's
- Schema features
  - CREATE/DROP TABLE
- Query features
  - SELECT-FROM-WHERE statements, set and bag operations, table expressions, aggregation and grouping
  - ☞Next: subqueries

Scalar subqueries

- A query that returns a single row can be used as a value in WHERE, SELECT, etc.
- Example: students at the same age as Bart

```
SELECT *                    What's Bart's age?
FROM Student
WHERE age = (SELECT age
             FROM Student
             WHERE name = 'Bart');
```

- Runtime error if subquery returns more than one row
- Under what condition will this runtime error never occur?
  - *name* is a key of *Student*
- What if subquery returns no rows?
  - Return NULL

IN subqueries

- *x* IN (*subquery*) checks if *x* is in the result of *subquery*
- Example: students at the same age as (some) Bart

```
SELECT *                    What's Bart's age?
FROM Student
WHERE age IN (SELECT age
              FROM Student
              WHERE name = 'Bart');
```


EXISTS subqueries

- EXISTS (*subquery*) checks if the result of *subquery* is non-empty
- Example: students at the same age as (some) Bart

```
SELECT *
FROM Student AS s
WHERE EXISTS (SELECT * FROM Student
              WHERE name = 'Bart'
              AND age = s.age);
```

  - It is a correlated subquery—a subquery that references tuple variables in surrounding queries

Operational semantics of subqueries


- ```
  SELECT *
  FROM Student AS s
  WHERE EXISTS (SELECT * FROM Student
                WHERE name = 'Bart'
                AND age = s.age);
  ```
- For each row `s` in `Student`
  - Evaluate the subquery with the appropriate value of `s.age`
  - If the result of the subquery is not empty, output `s.*`
- The DBMS query optimizer may choose to process the query in an equivalent, but more efficient way (example?)

Scoping rule of subqueries

- To find out which table a column belongs to
  - Start with the immediately surrounding query
  - If not found, look in the one surrounding that; repeat if necessary
- Use *table_name*`.`*column_name* notation and `AS` (renaming) to avoid confusion

Another example


```
SELECT * FROM Student s
WHERE EXISTS
    (SELECT * FROM Enroll e
     WHERE SID = s.SID
     AND EXISTS
         (SELECT * FROM Enroll
          WHERE SID = s.SID
          AND CID <> e.CID));
```

Students who are taking at least two courses

Quantified subqueries

- A quantified subquery can be used as a value in a `WHERE` condition
- Universal quantification (for all):
  … `WHERE` *x op* `ALL` (*subquery*) …
  - True iff for all *t* in the result of *subquery*, *x op t*
- Existential quantification (exists):
  … `WHERE` *x op* `ANY` (*subquery*) …
  - True iff there exists some *t* in the result of *subquery* such that *x op t*
  - ☞Beware
    - In common parlance, "any" and "all" seem to be synonyms
    - In SQL, `ANY` really means "some"

Examples of quantified subqueries

- Which students have the highest GPA?
  - ```
    SELECT *
    FROM Student
    WHERE GPA >= ALL
        (SELECT GPA FROM Student);
    ```
  - ```
    SELECT *
    FROM Student
    WHERE NOT
        (GPA < ANY (SELECT GPA FROM Student));
    ```
  - ☞Use `NOT` to negate a condition

More ways of getting the highest GPA

- Which students have the highest GPA?
  - ```
    SELECT *
    FROM Student AS s
    WHERE NOT EXISTS
        (SELECT * FROM Student
         WHERE GPA > s.GPA);
    ```
  - ```
    SELECT * FROM Student
    WHERE SID NOT IN
        (SELECT s1.SID
         FROM Student AS s1, Student AS s2
         WHERE s1.GPA < s2.GPA);
    ```
    ```

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- Query features
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  - Subqueries: not much more expressive power added

☞ Next: modifications

INSERT

- Insert one row
  - `INSERT INTO Enroll VALUES (456, 'CPS216');`
    - Student 456 takes CPS216
- Insert the result of a query
  - ```
    INSERT INTO Enroll
    (SELECT SID, 'CPS216' FROM Student
     WHERE SID NOT IN (SELECT SID FROM Enroll
                       WHERE CID = 'CPS216'));
    ```
    - Force everybody to take CPS216

DELETE

- Delete everything
  - `DELETE FROM Enroll;`
- Delete according to a WHERE condition

  Example: Student 456 drops CPS216
  - ```
    DELETE FROM Enroll
    WHERE SID = 456 AND CID = 'CPS216';
    ```

  Example: Drop students with GPA lower than 1.0 from all CPS classes
  - ```
    DELETE FROM Enroll
    WHERE SID IN (SELECT SID FROM Student
                  WHERE GPA < 1.0)
    AND CID LIKE 'CPS%';
    ```

UPDATE

- Example: Student 142 changes name to "Barney" and GPA to 3.0
  - ```
    UPDATE Student
    SET name = 'Barney', GPA = 3.0
    WHERE SID = 142;
    ```
- Example: Let's be "fair"?
  - ```
    UPDATE Student
    SET GPA = (SELECT AVG(GPA) FROM Student);
    ```
    - But update of every row causes average GPA to change!
    - Average GPA is computed over the old Student table

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Constraints

- Restrictions on allowable data in a database
  - In addition to the simple structure and type restrictions imposed by the table definitions
  - Declared as part of the schema
  - Enforced automatically by the DBMS
- Why use constraints?
  - Protect data integrity (catch errors)
  - Tell the DBMS about the data (so it can optimize better)
    ```

Types of SQL constraints

- NOT NULL
- Key
- Referential integrity (foreign key)
- General assertion
- Tuple- and attribute-based CHECK's

NOT NULL constraint examples


```
CREATE TABLE Student
  (SID INTEGER NOT NULL,
   name VARCHAR(30) NOT NULL,
   email VARCHAR(30),
   age INTEGER,
   GPA FLOAT);
CREATE TABLE Course
  (CID CHAR(10) NOT NULL,
   title VARCHAR(100) NOT NULL);
CREATE TABLE Enroll
  (SID INTEGER NOT NULL,
   CID CHAR(10) NOT NULL);
```

Key declaration

- At most one PRIMARY KEY per table
  - Typically implies a primary index
  - Rows are stored inside the index, typically sorted by the primary key value
- Any number of UNIQUE keys per table
  - Typically implies a secondary index
  - Pointers to rows are stored inside the index

Key declaration examples

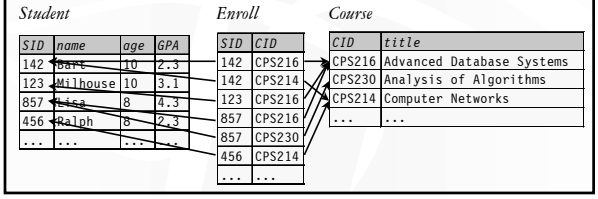

```
CREATE TABLE Student
  (SID INTEGER NOT NULL PRIMARY KEY,
   name VARCHAR(30) NOT NULL,
   email VARCHAR(30) UNIQUE,
   age INTEGER,
   GPA FLOAT);
CREATE TABLE Course
  (CID CHAR(10) NOT NULL PRIMARY KEY,
   title VARCHAR(100) NOT NULL);
CREATE TABLE Enroll
  (SID INTEGER NOT NULL,
   CID CHAR(10) NOT NULL,
   PRIMARY KEY(SID, CID));
```

Works on Oracle but not DB2: DB2 requires UNIQUE key columns to be NOT NULL

This form is required for multi-attribute keys

Referential integrity example

- *Enroll.SID* references *Student.SID*
  - If an SID appears in *Enroll*, it must appear in *Student*
- *Enroll.CID* references *Course.CID*
  - If a CID appears in *Enroll*, it must appear in *Course*
- ☞ That is, no "dangling pointers"



Referential integrity in SQL

- Referenced column(s) must be PRIMARY KEY
- Referencing column(s) form a FOREIGN KEY
- Example
  - CREATE TABLE Enroll
    (SID INTEGER NOT NULL
      REFERENCES Student(SID),
     CID CHAR(10) NOT NULL,
     PRIMARY KEY(SID, CID),
     FOREIGN KEY CID REFERENCES Course(CID));

Enforcing referential integrity

Example: *Enroll.SID* references *Student.SID*

- Insert/update an *Enroll* row so it refers to a non-existent SID
  - Reject
- Delete/update a *Student* row whose SID is referenced by some *Enroll* row
  - Reject
  - Cascade: ripple changes to all referring rows
  - Set NULL: set all references to NULL
- Deferred constraint checking (e.g., only at the end of a transaction)
  - Good for performance (e.g., during bulk loading)
  - Required when creating cycles of references

General assertion

- `CREATE ASSERTION` *assertion_name* `CHECK` *assertion_condition*`;`
- *assertion_condition* is checked for each modification that could potentially violate it
- Example: *Enroll.SID* references *Student.SID*

```
CREATE ASSERTION EnrollStudentRefIntegrity
CHECK (NOT EXISTS
       (SELECT * FROM Enroll
        WHERE SID NOT IN
        (SELECT SID FROM Student)));
```

☞ In SQL3, but not all (perhaps no) DBMS support it

Tuple- and attribute-based CHECK's

- Associated with a single table
- Only checked when a tuple or an attribute is inserted or updated
- Example:

```
CREATE TABLE Enroll
(SID INTEGER NOT NULL
     CHECK (SID IN (SELECT SID FROM Student)),
 CID ...);
```

  - Is it a referential integrity constraint?
  - Not quite; not checked when *Student* is modified

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  - ☞Next: views
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Views

- 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

- Example: CPS216 roster

```
CREATE VIEW CPS216Roster AS
SELECT SID, name, age, GPA
FROM Student
WHERE SID IN (SELECT SID FROM Enroll
              WHERE CID = 'CPS216');
```

Called "base tables"

- To drop a view
  - `DROP VIEW` *view_name*`;`

Using views in queries

- Example: find the average GPA of CPS216 students
  - `SELECT AVG(GPA) FROM CPS216Roster;`
  - 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 = 'CPS216'));
    ```

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
- ☞ Real database applications use tons of views

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☞ Next: indexes

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 following weeks!
- An index on $R.A$ can speed up accesses of the form
  - $R.A = value$
  - $R.A > value$ (depending on the index type)
- An index on $(R.A_1, \ldots, R.A_n)$ can speed up
  - $R.A_1 = value_1 \wedge \ldots \wedge R.A_n = value_n$
  - Multidimensional range searches (depending on the index type)
- ☞ Is an index on $(R.A, R.B)$ equivalent to one on $(R.B, R.A)$? Or 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 INDEX` *index_name* `ON` *table_name*`(`*column_name*$_1$`, ..., `*column_name*$_n$`);`
- `DROP INDEX` *index_name*`;`

- Typically, the DBMS will automatically create indexes for `PRIMARY KEY` and `UNIQUE` constraint declarations

Choosing indexes to create

More indexes = better performance?

- Indexes take space
- Indexes need to be maintained when data is updated
- Indexes have one more level of indirection
  - Perhaps not a problem for main memory, but can be really bad on disk

☞ 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

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- Query features
  - `SELECT-FROM-WHERE` statements, set and bag operations, table expressions, aggregation and grouping, subqueries
- Modifications
- Performance tuning features
  - Indexes

What else?

- Output ordering (`ORDER BY`)
- Triggers
- SQL transactions and isolation levels
- Application programming interface
- Recursion