Announcements

- Homework #1 sample solution available
  - In hardcopies only
  - Extra handouts in “handout” box outside D327
- Homework #2 will be assigned Thursday (Sep. 16)
- Project milestone #1 due in 2½ weeks
  - Time to look for partners and ideas
  - Talk to me or TA
- Presentation sign-up today

Incomplete information

- Example: `Student (SID, name, age, GPA)`
- Value unknown
  - We do not know Nelson’s age
- Value not applicable
  - Nelson has not taken any classes yet; what is his GPA?

Solution 1

- A dedicated special value for each domain (type)
  - GPA cannot be –1, so use –1 as a special value to indicate a missing or invalid GPA
  - Leads to incorrect answers if not careful
  - `SELECT AVG(GPA) FROM Student;`
  - Complicates applications
    - `SELECT AVG(GPA) FROM Student WHERE GPA <> -1;`
  - Remember the pre-Y2K bug?
    - 09/09/99 was used as a missing or invalid date value

Solution 2

- A valid-bit for every column
  - `Student (SID, name, name_is_valid, age, age_is_valid, GPA, GPA_is_valid)`
  - Complicates schema and queries
    - `SELECT AVG(GPA) FROM Student WHERE GPA_is_valid;`

SQL’s solution

- A special value `NULL`
  - For every domain
  - Special rules for dealing with `NULL`’s

Example: `Student (SID, name, age, GPA)`

  (789, “Nelson”, NULL, NULL)
Computing with NULL’s

- When we operate on a NULL and another value (including another NULL) using +, -, etc., the result is NULL.
- Aggregate functions ignore NULL, except COUNT(*) (since it counts rows).

Three-valued logic

- TRUE = 1, FALSE = 0, UNKNOWN = 0.5
- \( x \land y = \min(x, y) \)
- \( x \lor y = \max(x, y) \)
- \( \neg x = 1 - x \)
- When we compare a NULL with another value (including another NULL) using =, >, etc., the result is UNKNOWN.
- WHERE and HAVING clauses only select rows for output if the condition evaluates to TRUE.
  - UNKNOWN is insufficient

Unfortunate consequences

- select \( \text{AVG(GPA)} \) FROM Student;
  - select \( \text{SUM(GPA)} / \text{COUNT(*)} \) FROM Student;
    - Not equivalent
    - Although \( \text{AVG(GPA)} = \text{SUM(GPA)} / \text{COUNT(GPA)} \) still
- select * FROM Student;
  - select * FROM Student WHERE GPA = GPA;
    - Not equivalent
    - Be careful: NULL breaks many equivalences

Another problem

- Example: Who has NULL GPA values?
  - select * FROM Student WHERE GPA = NULL;
    - Does not work; never returns anything
  - (select * FROM Student)
    - except all
      - (select * FROM Student WHERE GPA = GPA)
        - Works, but ugly
        - Introduced built-in predicates IS NULL and IS NOT NULL
          - select * FROM Student WHERE GPA IS NULL;

Outerjoin motivation

- Example: a master class list
  - select c.CID, c.title, s.SID, s.name
    - FROM Course c, Enroll e, Student s
      - WHERE c.CID = e.CID AND e.SID = s.SID;
  - What if a class is empty?
  - It may be reasonable for the master class list to include empty classes as well
    - For these classes, SID and name columns would be NULL

Outerjoin flavors and definitions

- A full outerjoin between \( R \) and \( S \) (denoted \( R \bowtie S \)) includes all rows in the result of \( R \bowtie S \), plus
  - “Dangling” \( R \) rows (those that do not join with any \( S \) rows) padded with NULL’s for \( S \)'s columns
  - “Dangling” \( S \) rows (those that do not join with any \( R \) rows) padded with NULL’s for \( R \)'s columns
- A left outerjoin (\( R \bowtie S \)) includes rows in \( R \bowtie S \) plus dangling \( R \) rows padded with NULL’s
- A right outerjoin (\( R \bowtie S \)) includes rows in \( R \bowtie S \) plus dangling \( S \) rows padded with NULL’s
Outerjoin examples

<table>
<thead>
<tr>
<th>Course</th>
<th>Enroll</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS199 Independent Study</td>
<td>NULL</td>
</tr>
<tr>
<td>CPS130 Analysis of Algorithms</td>
<td>857</td>
</tr>
<tr>
<td>CPS114 Computer Networks</td>
<td>142</td>
</tr>
<tr>
<td>CPS196 NULL</td>
<td>142</td>
</tr>
<tr>
<td>CPS196 NULL</td>
<td>857</td>
</tr>
<tr>
<td>CPS130 Analysis of Algorithms</td>
<td>857</td>
</tr>
<tr>
<td>CPS114 Computer Networks</td>
<td>456</td>
</tr>
<tr>
<td>CPS196 NULL</td>
<td>123</td>
</tr>
<tr>
<td>CPS196 NULL</td>
<td>142</td>
</tr>
<tr>
<td>CPS196 NULL</td>
<td>857</td>
</tr>
<tr>
<td>CPS130 Analysis of Algorithms</td>
<td>857</td>
</tr>
<tr>
<td>CPS114 Computer Networks</td>
<td>456</td>
</tr>
</tbody>
</table>

Outerjoin syntax

- SELECT * FROM Course LEFT OUTER JOIN Enroll ON Course.CID = Enroll.CID;
- SELECT * FROM Course RIGHT OUTER JOIN Enroll ON Course.CID = Enroll.CID;
- SELECT * FROM Course FULL OUTER JOIN Enroll ON Course.CID = Enroll.CID;

These are theta joins rather than natural joins
- Return all columns in Course and Enroll
- Not exactly Course→Enroll, Course←Enroll, and Course↔Enroll
- You can write regular (“inner”) joins using this syntax too: SELECT * FROM Course JOIN Enroll ON Course.CID = Enroll.CID;

Summary of SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Table expressions, subqueries
- Aggregation and grouping
- Ordering
- NULL’s and outerjoins

Next: data modification statements, constraints

INSERT

- Insert one row
  - INSERT INTO Enroll VALUES (456, 'CPS116');
  - Student 456 takes CPS116
- Insert the result of a query
  - INSERT INTO Enroll
    (SELECT SID, 'CPS116' FROM Student
     WHERE SID NOT IN (SELECT SID FROM Enroll
     WHERE CID = 'CPS116'));
  - Force everybody to take CPS116

DELETE

- Delete everything
  - DELETE FROM Enroll;
- Delete according to a WHERE condition
  - Example: Student 456 drops CPS116
    - DELETE FROM Enroll
      WHERE SID = 456 AND CID = 'CPS116';
  - Example: Drop students from all CPS classes with GPA lower than 1.0
    - 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”
  - UPDATE Student
    SET name = 'Barney'
    WHERE SID = 142;
- Example: Let’s be “fair”?
  - UPDATE Student
    SET GPA = (SELECT AVG(GPA) FROM Student
    WHERE SID NOT IN (SELECT SID FROM Enroll
    WHERE CID = 'CPS116'));
  - But update of every row causes average GPA to change!
  - Average GPA is computed over the old Student table
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 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));

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”

<table>
<thead>
<tr>
<th>Student</th>
<th>Enroll</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>456</td>
<td>CPS114</td>
</tr>
<tr>
<td>456</td>
<td>857</td>
<td>CPS196</td>
</tr>
<tr>
<td>857</td>
<td>123</td>
<td>CPS114</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

This form is required for multi-attribute keys
Referential integrity in SQL

- Referenced column(s) must be PRIMARY KEY
- Referencing column(s) form a FOREIGN KEY
- Example
  ```sql
  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 or update an Enroll row so it refers to a non-existent SID
  - Reject
- Delete or 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
- All three options can be specified in SQL

Deferred constraint checking

- No-chicken-no-egg problem
- CREATE TABLE Dept
  (name CHAR(20) NOT NULL PRIMARY KEY,
   chair CHAR(30) NOT NULL REFERENCES Prof(name));
  CREATE TABLE Prof
  (name CHAR(30) NOT NULL PRIMARY KEY,
   dept CHAR(20) NOT NULL REFERENCES Dept(name));
- The first INSERT will always violate a constraint
- Deferred constraint checking is necessary
- Check only at the end of a transaction
- Allowed in SQL as an option
- Curious how the schema was created in the first place?
- ALTER TABLE ADD CONSTRAINT (read the manual!)

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 supports 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:
  ```sql
  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

Summary of SQL features covered so far

- Query
  - SELECT-FROM-WHERE statements
  - Set and bag operations
  - Table expressions, subqueries
  - Aggregation and grouping
  - Ordering
  - Outerjoins
- Modification
  - INSERT/DELETE/UPDATE
- Constraints
- Next: triggers, views, indexes