Announcements (September 19)

- Homework #1 due today (11:50pm)
  - Submit in class, or slide it underneath my office door
  - Sample solution available Thursday
- Homework #2 assigned today
  - Due next Thursday
- Project milestone #1 due in 23 days
- Tomcat/DB2 combo is working on rack040; see Programming Notes on Web for how to use it for your course project

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 Y2K bug?
    - "00" was used as a missing or invalid year value

Solution 2

- A valid-bit for every column
  - Student (ID, 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;

Solution 3?
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
- $x \text{ AND } y = \min(x, y)$
- $x \text{ OR } y = \max(x, y)$
- $\neg x = 1 - x$

- 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 not enough
Unfortunate consequences

- SELECT AVG(GPA) FROM Student;
- SELECT SUM(GPA)/COUNT(*) FROM Student;

- SELECT * FROM Student;
  SELECT * FROM Student WHERE GPA = GPA;

Be careful: NULL breaks many equivalences

Another problem

- Example: Who has NULL GPA values?
  - SELECT * FROM Student WHERE GPA = NULL;

- 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 ($R \leftmoon S$) includes rows in $R \bowtie S$ plus dangling $R$ rows padded with NULL's
- A right outerjoin ($R \rightmoon S$) includes rows in $R \bowtie S$ plus dangling $S$ rows padded with NULL's

Outerjoin examples

<table>
<thead>
<tr>
<th>CID</th>
<th>Title</th>
<th>SID</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS199</td>
<td>Independent Study</td>
<td>NULL</td>
</tr>
<tr>
<td>CPS196</td>
<td>Analysis of Algorithms</td>
<td>857</td>
</tr>
<tr>
<td>CPS114</td>
<td>Computer Networks</td>
<td>142</td>
</tr>
<tr>
<td>CPS130</td>
<td>Analysis of Algorithms</td>
<td>456</td>
</tr>
<tr>
<td>CPS114</td>
<td>Computer Networks</td>
<td>456</td>
</tr>
<tr>
<td>CPS114</td>
<td>Computer Networks</td>
<td>456</td>
</tr>
</tbody>
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<td>142</td>
</tr>
<tr>
<td>CPS196</td>
<td>Analysis of Algorithms</td>
<td>123</td>
</tr>
<tr>
<td>CPS196</td>
<td>Analysis of Algorithms</td>
<td>857</td>
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<td>Computer Networks</td>
<td>142</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
  - Equivalent to $Course \bowtie_{Course.CID = Enroll.CID} Enroll$, $Course \leftmoon_{Course.CID = Enroll.CID} Enroll$, and $Course \rightmoon_{Course.CID = Enroll.CID} Enroll$

* 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);

  - 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 ⇒ best speedup for queries
- Any number of UNIQUE keys per table
  - Typically implies a secondary index
  - Pointers to rows are stored inside the index ⇒ less speedup for queries

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));

  Doesn’t work on 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”

<table>
<thead>
<tr>
<th>Student</th>
<th>Enroll</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Age</td>
<td>GPA</td>
</tr>
<tr>
<td>Bart</td>
<td>10</td>
<td>2.3</td>
</tr>
<tr>
<td>Milhouse</td>
<td>10</td>
<td>3.1</td>
</tr>
<tr>
<td>Lisa</td>
<td>8</td>
<td>4.3</td>
</tr>
<tr>
<td>Ralph</td>
<td>8</td>
<td>2.3</td>
</tr>
</tbody>
</table>

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 or update an Enroll row so it refers to a non-existent SID
- Delete or update a Student row whose SID is referenced by some Enroll row

- 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));
- 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:
  - CREATE TABLE Enroll
    (SID INTEGER NOT NULL
    CHECK (SID IN (SELECT SID FROM Student)),
    CID ...);
  - Is it a referential integrity constraint?
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