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;
  - Ever heard of the Y2K bug?
    - “00” was used as a missing or invalid year 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;

Solution 3?

- Decompose the table; missing row = missing value
  - StudentName (SID, name)
  - StudentAge (SID, age)
  - StudentGPA (SID, GPA)
  - StudentID (SID)
  - Conceptually the cleanest solution
  - Still complicates schema and queries
    - How to get all information about a student in a table?
    - Natural join doesn’t work!
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 AND y = min(x, y)
- x OR y = max(x, y)
- NOT 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;
  - Not equivalent
  - Although AVG(GPA) = SUM(GPA)/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 ($R \bowtie L S$) includes rows in $R \bowtie S$ plus dangling $R$ rows padded with NULL’s
- A right outerjoin ($R \bowtie R S$) includes rows in $R \bowtie S$ plus dangling $S$ rows padded with NULL’s

### 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, $Course \bowtie_{Course.CID=}Enroll.CID$, and $Course \bowtie_{Course.CID=}Enroll.CID$ Enroll

You can write regular (“inner”) joins using this syntax too:
- SELECT * FROM Course JOIN Enroll ON Course.CID = Enroll.CID;

### Outerjoin examples

<table>
<thead>
<tr>
<th>CID</th>
<th>Title</th>
<th>CID</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS199</td>
<td>Independent Study</td>
<td>CPS116</td>
<td>Intro to Database Systems</td>
</tr>
<tr>
<td>CPS116</td>
<td>Analysis of Algorithms</td>
<td>CPS114</td>
<td>Max</td>
</tr>
<tr>
<td>CPS115</td>
<td>Intro to Database Systems</td>
<td>CPS111</td>
<td>Optional</td>
</tr>
<tr>
<td>CPS116</td>
<td>Intro to Database Systems</td>
<td>CPS110</td>
<td>Max</td>
</tr>
</tbody>
</table>

### 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 won’t update of every row causes average GPA to change?
    - Subquery is always computed over the old 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));
  - 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 example](image)

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));
  - 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?

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

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 CHAR(10) NOT NULL, PRIMARY KEY(SID, CID), FOREIGN KEY CID REFERENCES Course(CID));
- Is it a referential integrity constraint?
- Not quite; not checked when `Student` is modified

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));
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: recursion

“SQL programming & transactions will be covered after we take a detour with XML.”