“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

Announcements (October 30)

- Homework #2 due next Thursday
- Project milestone #2 due in 1½ weeks
**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**

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

**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:
- **BEFORE DELETE** row-level triggers
  - Can use only:
  - etc.

Statement-level trigger example

```sql
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

```sql
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

Why are both needed?

- Certain triggers are only possible at statement level
- Simple row-level triggers are easier to implement
  - 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

- 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 (UPDATE Faculty SET salary = salary + 1000;

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

System issues

- 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

- 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: CPS116 roster
  - CREATE VIEW CPS116Roster AS
    SELECT SID, name, age, GPA
    FROM Student
    WHERE SID IN (SELECT SID FROM Enroll
      WHERE CID = 'CPS116');
  - To drop a view
    - DROP VIEW view_name;

Using views in queries

- 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'));
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

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

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);
★ No matter what you do on Student, the inserted row will not be in HighGPAStudent

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 later in 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
  - \( R.A_1 = value_1 \wedge \ldots \wedge R.A_n = value_n \)
  - \((R.A_1, \ldots, R.A_n) > (value_1, \ldots, value_n)\) (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
    \( \{column_name_1, \ldots, column_name_n\} \) 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

More indexes = better performance?
- Indexes take space
- Indexes need to be maintained when data is updated
- Indexes have one more level of indirection

- 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

- Query
- Modification
- Constraints
- Transactions
- API
- Triggers
- Views
- Indexes