SQL:
Data Manipulation Language

Author: Diane Horton

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Basics

This section is covered by your prep work

Introduction

- So far, we have defined database schemas and queries mathematically.

- SQL is a formal language for doing so with a DBMS.

- "Structured Query Language", but it's for more than writing queries.

- Two sub-parts:
    - DDL (Data Definition Language), for defining schemas.
    - DML (Data Manipulation Language), for writing queries and modifying the database.

PostgreSQL

- We'll be working in PostgreSQL, an open-source relational DBMS.

- Learn your way around the documentation; it will be very helpful.

- Standards?

  - There are several, the most recent being SQL:2008.

  - The standards are not freely available. Must purchase from the International Standards Organization (ISO).

  - PostgreSQL supports most of it SQL:2008.

  - DBMSs vary in the details around the edges, making portability difficult.

Heads up: SELECT vs σ

- In SQL,
  - "SELECT" is for choosing columns, *i.e.*, π.
  - Example:
    ```
    SELECT surName
    FROM Student
    WHERE campus = 'StG';
    ```
- In relational algebra,
  - "select" means choosing rows, *i.e.*, σ.

A high-level language

- SQL is a very high-level language.
  - Say "what" rather than "how."
- You write queries without manipulating data. Contrast languages like Java or C++.
- Provides physical "data independence:"
  - Details of how the data is stored can change with no impact on your queries.
- You can focus on readability.
  - But because the DMBS optimizes your query, you get efficiency.

Meaning of a query with one relation

```
SELECT name
FROM Course
WHERE dept = 'CSC';
```

$\pi_{name} (\sigma_{dept="csc"} (Course))$

… and with multiple relations

```
SELECT name
FROM Offering, Took
WHERE Offering.id = Took.oid and
       dept = 'CSC';
```

$\pi_{name} (\sigma_{Offering.id=Took.id \wedge dept='csc'} (Offering \times Took))$

Temporarily renaming a table

- You can rename tables (just for the duration of the statement):
  ```
  SELECT e.name, d.name
  FROM employee e, department d
  WHERE d.name = 'marketing'
  AND e.name = 'Horton';
  ```

- Can be convenient vs the longer full names:
  ```
  SELECT employee.name, department.name
  FROM employee, department
  WHERE department.name = 'marketing'
  AND employee.name = 'Horton';
  ```

- This is like ρ in relational algebra.

Self-joins

- As we know, renaming is *required* for self-joins.

- Example:
  ```
  SELECT e1.name, e2.name
  FROM employee e1, employee e2
  WHERE e1.salary < e2.salary;
  ```

* In SELECT clauses

- A * in the SELECT clause means "all attributes of this relation."
- Example:
```
SELECT *
FROM Course
WHERE dept = 'CSC';
```

Renaming attributes

- Use `AS «new name»` to rename an attribute in the result.

- Example:
  ```
  SELECT name AS title, dept
  FROM Course
  WHERE breadth;
  ```

Complex Conditions in a WHERE

- We can build boolean expressions with operators that produce boolean results.
  - comparison operators: `=, <>, <, >, <=, >=`
  - and many other operators:
    see section 6.1.2 of the text and chapter 9 of the postgreSQL documentation.
- Note that "not equals" is unusual: `<>`
- We can combine boolean expressions with:
  - Boolean operators: `AND, OR, NOT`.

Example: Compound condition

- Find 3rd- and 4th-year CSC courses:

```
SELECT *
FROM Offering
WHERE dept = 'CSC' AND cnum >= 300;
```

ORDER BY

- To put the tuples in order, add this as the final clause:
  `ORDER BY «attribute list» [DESC]`

- The default is ascending order; DESC overrides it to force descending order.

- The attribute list can include expressions: e.g.,
  `ORDER BY sales+rentals`

- The ordering is the last thing done before the SELECT, so all attributes are still available.

Case-sensitivity and whitespace

- Example query:
  ```
  SELECT surName
  FROM Student
  WHERE campus = 'StG';
  ```

- Keywords, like `SELECT`, are not case-sensitive.

  - One convention is to use uppercase for keywords.

- Identifiers, like `Student` are not case-sensitive either.

  - One convention is to use lowercase for attributes, and a leading capital letter followed by lowercase for relations.

- Literal strings, like `'StG'`, are case-sensitive, and require single quotes.

- Whitespace (other than inside quotes) is ignored.

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Expressions in SELECT clauses

- Instead of a simple attribute name, you can use an expression in a SELECT clause.

- Operands: attributes, constants
  Operators: arithmetic ops, string ops

- Examples:
  ```
  SELECT sid, grade+10 AS adjusted
  FROM Took;


  SELECT dept||cnum
  FROM course;
  ```

Expressions that are a constant

- Sometimes it makes sense for the whole expression to be a constant (something that doesn't involve any attributes!).

- Example:
```
SELECT dept, cNum,
    'satisfies' AS breadthRequirement
FROM Course
WHERE breadth;
```

Pattern operators

- Two ways to compare a string to a pattern by:
  - *«attribute» LIKE «pattern»*
  - *«attribute» NOT LIKE «pattern»*

- Pattern is a quoted string
  - % means: any string
  - _ means: any single character

- Example:
```
SELECT *
FROM Course
WHERE name LIKE '%Comp%';
```

Computing on a column

- We often want to compute something across the values in a column.

- `SUM`, `AVG`, `COUNT`, `MIN`, and `MAX` can be applied to a column in a SELECT clause.

- Also, `COUNT(*)` counts the number of tuples.

- We call this aggregation.

- Note: To stop duplicates from contributing to the aggregation, use `DISTINCT` inside the brackets. (Does not affect `MIN` or `MAX`.)

- Example: aggregation.txt

Aggregation

Grouping

- Example: group-by.txt

- If we follow a SELECT-FROM-WHERE expression with GROUP BY <attributes>

  - The tuples are grouped according to the values of those attributes, and

  - any aggregation gives us a single value per group.

Restrictions on aggregation

- If any aggregation is used, then each element of the SELECT list must be either:
  - aggregated, or
  - an attribute on the GROUP BY list.
- Otherwise, it doesn't even make sense to include the attribute.

HAVING Clauses

- Example: having.txt

- WHERE let's you decide which tuples to keep.

- Similarly, you can decide which *groups* to keep.

- Syntax:

  ```
  . . .
  GROUP BY «attributes»
  HAVING «condition»
  ```

- Semantics:
  Only groups satisfying the condition are kept.

Restrictions on HAVING clauses

- Outside subqueries, HAVING may refer to attributes only if they are either:
    - aggregated, or
    - an attribute on the GROUP BY list.
- (Same requirement as for SELECT clauses with aggregation)

Set operations

Tables can have duplicates in SQL

- A table can hold duplicate rows, unless this would violate an integrity constraint.

- SELECT-FROM-WHERE statements
  - can create new duplicates
  - leave any duplicates in unless you say not to.

- Why?
  - Getting rid of duplicates is expensive!
  - We may want the duplicates because they tell us how many times something occurred.

Bags

- SQL treats tables as "bags" (or "multisets") rather than sets.

- Just like sets, but duplicates are allowed.

- {6, 2, 7, 1, 9}   is a set (and a bag)
  {6, 2, 2, 7, 1, 9}   is not a set, but is a bag.

- As with sets, order doesn't matter.
  {6, 2, 7, 1, 9} = {1, 2, 6, 7, 9}

- Example: Tables with duplicates

Example

```
CREATE TABLE Keyless (x int, y int);
INSERT INTO Keyless VALUES
        (1, 3), (2, 4), (7, 9), (8, 9);
SELECT * FROM Keyless;
 x | y
---+-----
 1 |   3
 2 |   4
 7 |   9
 8 |   9
 1 |  88
 (4 rows)
```

Union, Intersection, and Difference

- These are expressed as:

  (*«subquery»*) UNION (*«subquery»*)

  (*«subquery»*) INTERSECT (*«subquery»*)

  (*«subquery»*) EXCEPT (*«subquery»*)

- The brackets are mandatory.

- The operands must be queries; you can't simply use a relation name.

Example

```
(SELECT sid
 FROM Took
 WHERE grade > 95)
          UNION
(SELECT sid
 FROM Took
 WHERE grade < 50);
```

Operations ∪, ∩, and − with Bags

- For ∪, ∩, and − the number of occurrences of a tuple in the result requires some thought.
- (But it makes total sense.)

1. {1, 1, 1, 3, 7, 7, 8} ∪ {1, 5, 7, 7, 8, 8}
2. {1, 1, 1, 3, 7, 7, 8} ∩ {1, 5, 7, 7, 8, 8}
3. {1, 1, 1, 3, 7, 7, 8} − {1, 5, 7, 7, 8, 8}

Bag vs Set Semantics: which is used

- We saw that a SELECT-FROM-WHERE statement uses bag semantics by default.
  - Duplicates are kept in the result.
- The set operations use set semantics by default.
  - Duplicates are *eliminated* from the result.

Motivation: Efficiency

- When doing projection, it is easier not to eliminate duplicates.

  - Just work one tuple at a time.

- For intersection or difference, it is most efficient to sort the relations first.

  - At that point you may as well eliminate the duplicates anyway.

Controlling Duplicate Elimination

- We can force the result of a SFW query to be a set by using `SELECT DISTINCT ...`

- We can force the result of a set operation to be a bag by using `ALL`, e.g.,

```
(SELECT sid
 FROM Took
 WHERE grade > 95)
            UNION ALL
(SELECT sid
 FROM Took
 WHERE grade < 50);
```

- Examples: controlling-dups.txt, except-all.txt

Views

The idea

- A view is a relation defined in terms of stored tables (called base tables) and other views.

- Access a view like any base table.

- Two kinds of view:

  - Virtual: no tuples are stored; view is just a query for constructing the relation when needed.

  - Materialized: actually constructed and stored. Expensive to maintain!

- We'll use only virtual views.

  - PostgreSQL did not support materialized views until version 9.3 (which we are not running).

Example: defining a virtual view

- A view for students who earned an 80 or higher in a CSC course.

```
CREATE VIEW topresults AS
SELECT firstname, surname, cnum
FROM Student, Took, Offering
WHERE
    Student.sid = Took.sid AND
    Took.oid = Offering.oid AND
    grade >= 80 AND dept = 'CSC';
```

Uses for views

- Break down a large query.
- Provide another way of looking at the same data, e.g., for one category of user.

Outer Joins

The joins you know from RA

These can go in a FROM clause:

Expression	Meaning
R, S	R × S
R cross join S	
R natural join S	R ⋈ S
R join S on Condition	R ⋈*condition* S

Let's break something

- A working query:
  ```
  SELECT sID, instructor
  FROM Student NATURAL JOIN Took
                NATURAL JOIN Offering;
  ```

- Can you break it simply by changing the schema?

Student(<u>sID</u>, surName, firstName, campus, email, cgpa)

Course(<u>dept, cNum</u>, name, breadth)

Offering(<u>oID</u>, dept, cNum, term, instructor)

Took(<u>sID, oID</u>, grade)

```sql
SELECT sID, instructor
FROM Student NATURAL JOIN Took
             NATURAL JOIN Offering
WHERE grade >= 90;
```

Natural join is brittle

- The worst part: we get no syntax or run-time error!
  - The code just starts doing the wrong thing.
- We say that natural join is "brittle".
- Also, having implicit comparisons impairs readability.
- Best practise: Don't use natural join.

A nice practice

Use theta-join (JOIN ON) for sensible combos.
Use WHERE for real filtering.

```
SELECT Student.sID, instructor
FROM Student
    JOIN Took ON Student.sID = Took.sID
    JOIN Offering ON Took.oID = Offering.OID
WHERE grade >= 90;
```

Dangling tuples

- With joins that require some attributes to match, tuples lacking a match are left out of the results.

- We say that they are "dangling".

- An outer join preserves dangling tuples by padding them with `NULL` in the other relation.

- A join that doesn't pad with `NULL` is called an inner join.

Three kinds of outer join

- LEFT OUTER JOIN
  - Preserves dangling tuples from the relation on the LHS by padding with nulls on the RHS.
- RIGHT OUTER JOIN
  - The reverse.
- FULL OUTER JOIN
  - Does both.

Example: joining R and S various ways

R

A	B
1	2
4	5

S

B	C
2	3
6	7

R NATURAL JOIN S

A	B	C
1	2	3

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Example

R

A	B
1	2
4	5

S

B	C
2	3
6	7

R NATURAL FULL JOIN S

A	B	C
1	2	3
4	5	NULL
NULL	6	7

Example

R

A	B
1	2
4	5

S

B	C
2	3
6	7

R NATURAL LEFT JOIN S

A	B	C
1	2	3
4	5	NULL

Example

R

A	B
1	2
4	5

S

B	C
2	3
6	7

R NATURAL RIGHT JOIN S

A	B	C
1	2	3
NULL	6	7

Summary of join expressions

Cartesian product

`A CROSS JOIN B`   same as `A,B`

Theta-join

`A JOIN B ON C`

✓`A {LEFT|RIGHT|FULL} JOIN B ON C`

Natural join

`A NATURAL JOIN B`

✓`A NATURAL {LEFT|RIGHT|FULL} JOIN B`

✓ indicates that tuples are padded when needed.

Keywords INNER and OUTER

- There are keywords `INNER` and `OUTER`, but you never need to use them.

- Your intentions are clear anyway:
  - You get an outer join iff you use the keywords `LEFT`, `RIGHT`, or `FULL`.
  - If you don't use the keywords `LEFT`, `RIGHT`, or `FULL` you get an inner join.

Impact of having null values

Missing Information

- Two common scenarios:
  - Missing value.
    E.g., we know a student has some email address, but we don't know what it is.

  - Inapplicable attribute.
    E.g., the value of attribute spouse is inapplicable for an unmarried person.

Representing missing information

- One possibility: use a special value as a placeholder. E.g.,
  - If age unknown, use 0.
  - If StNum unknown, use 999999999.
- Implications?
- Better solution: use a value not in any domain. We call this a null value.
- Tuples in SQL relations can have `NULL` as a value for one or more components.

Checking for null values

- You can compare an attribute value to `NULL` with
  - `IS NULL`
  - `IS NOT NULL`

- Example:
  ```
  SELECT *
  FROM Course
  WHERE breadth IS NULL;
  ```

In SQL we have 3 truth-values

- Because of `NULL`, we need three truth-values:

  - If one or both operands to a comparison is `NULL`, the comparison *always* evaluates to `UNKNOWN`.

  - Otherwise, comparisons evaluate to `TRUE` or `FALSE`.

Combining truth values

- We need to know how the three truth-values combine with AND, OR and NOT.

- Can think of it in terms of the truth table.

- Or can think in terms of numbers:
  - TRUE = 1, FALSE = 0, UNKNOWN = 0.5
  - AND is min, OR is max,
  - NOT x is (1-x), i.e., it "flips" the value

The three-valued truth table

A	B	A and B	A or B
T	T	T	T
TF or FT		F	T
F	F	F	F
TU or UT		U	T
FU or UF		F	U
U	U	U	U

A	not A
T	F
F	T
U	U

Thinking of the truth-values as numbers

A	B	as nums	A **and** B	min	A **or** B	max
T	T	1, 1	T	1	T	1
TF or FT		1, 0	F	0	T	1
F	F	0, 0	F	0	F	0
TU or UT		1, 0.5	U	0.5	T	1
FU or UF		0, 0.5	F	0	U	0.5
U	U	0.5, 0.5	U	0.5	U	0.5

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Thinking of the truth-values as numbers

A	as a num, x	not A	1 - x
T	1	F	0
F	0	T	1
U	0.5	U	0.5

Surprises from 3-valued logic

- Some laws you are used to still hold in three-valued logic. For example,
  - `AND` is commutative.

- But others don't. For example,
  - The law of the excluded middle breaks:
    `(p or (NOT p))` might not be `TRUE`!
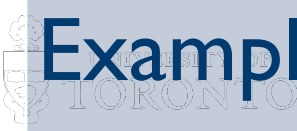 - `(0*x)` might not be `0`.

Impact of null values on WHERE

- A tuple is in a query result iff the WHERE clause is TRUE.

- UNKNOWN is not good enough.

- "WHERE is picky."

- Example: where-null

Impact of null values on aggregation

- Summary: Aggregation ignores `NULL`.
  - `NULL` never contributes to a sum, average, or count, and
  - Can never be the minimum or maximum of a column (unless *every* value is `NULL`).
- If there are no *non*-`NULL` values in a column, then the result of the aggregation is `NULL`.
  - Exception: `COUNT` of an empty set is 0.

Aggregation ignores nulls

	some nulls in A	All nulls in A
`min(A)`		
`max(A)`		null
`sum(A)`		
`avg(A)`		

Example: aggregation-nulls

More about the impact of null values

- Other corner cases to think about:
    - `SELECT DISTINCT`: are 2 `NULL` values equal?
    - natural join: are 2 `NULL` values equal?
    - set operations: are 2 `NULL` values equal?
- And later, when we learn about constraints:
    - `UNIQUE` constraint: do 2 `NULL` values violate?

- This behaviour may vary across DBMSs.

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Summary re NULL

- Any comparison with `NULL` yields `UNKNOWN`.

- `WHERE` is picky: it only accepts `TRUE`.

- Therefore `NATURAL JOIN` is picky too.

- Aggregation ignores `NULL`.

- In other situations where `NULL`s matter

  - when a truth-value may be `NULL`

  - when it matters whether two `NULL` are considered the same

Don't assume. Behaviour may vary by DBMS.

Subqueries

Where can a subquery go?

- Relational algebra syntax is so elegant that it's easy to see where subqueries can go.

- In SQL, a bit more thought is required . . .

Subqueries in a FROM clause

- In place of a relation name in the FROM clause, we can use a subquery.

- The subquery must be parenthesized.

- Must name the result, so you can refer to it in the outer query.

Worksheet, Q1:

```
SELECT sid, dept||cnum as course, grade
FROM Took,
    (SELECT *
     FROM Offering
     WHERE instructor='Horton') Hoffering
WHERE Took.oid = Hoffering.oid;
```

- This FROM is analogous to:

    Took × ρ*Hoffering* (*«subquery»*)

- Can you suggest another version?

Subquery as a value in a WHERE

- If a subquery is guaranteed to produce exactly one tuple, then the subquery can be used as a value.

- Simplest situation: that one tuple has only one component.

Worksheet, Q2:

```
SELECT sid, surname
FROM Student
WHERE cgpa >
    (SELECT cgpa
     FROM Student
     WHERE sid = 99999);
```

- We can't do the analogous thing in RA:

$$\pi_{\text{sid, surname}} \; \sigma_{\text{cgpa} > (\text{«subquery»})} \text{Student}$$

Special cases

- What if the subquery returns `NULL`?

- What if the subquery could return more than one value?

Quantifying over multiple results

- When a subquery can return multiple values, we can make comparisons using a quantifier.

- Example:
```
SELECT sid, surname
FROM Student
WHERE cgpa >
    (SELECT cgpa
     FROM Student
     WHERE campus = 'StG');
```

- We can require that

  - cgpa > **all** of them, or
  - cgpa > **at least one** of them.

The Operator ANY

- Syntax:

  x *«comparison»* ANY (*«subquery»*)

  or equivalently

  x *«comparison»* SOME (*«subquery»*)

- Semantics:

  Its value is true iff the comparison holds for at least one tuple in the subquery result, i.e.,

  $\exists$ y $\in$ *«subquery results»* | x *«comparison»* y

- x can be a *list* of attributes, but this feature is not supported by psql.

The Operator ALL

- Syntax:

  x *«comparison»* ALL (*«subquery»*)

- Semantics:

  Its value is true iff the comparison holds for every tuple in the subquery result, i.e.,

  ∀ y ∈ *«subquery results»* | x *«comparison»* y

- x can be a list of attributes, but this feature is not supported by psql.

- Example: any-all

The Operator IN

- Syntax:

  x IN (*«subquery»*)

- Semantics:

  Its value is true iff x is in the set of rows generated by the subquery.

- x can be a list of attributes, and psql does support this feature.

Worksheet, Q3:

```
SELECT sid, dept||cnum AS course, grade
FROM Took NATURAL JOIN Offering
WHERE
   grade >= 80 AND
   (cnum, dept) IN (
        SELECT cnum, dept
        FROM Took NATURAL JOIN Offering
                  NATURAL JOIN Student
        WHERE surname = 'Lakemeyer');
```

Worksheet, Q4:

Suppose we have tables R(a, b) and S(b, c).

1. What does this query do?

```
SELECT a
FROM R
WHERE b IN (SELECT b FROM S);
```

2. Can we express this query without using IN?

The Operator EXISTS

- Syntax:
  EXISTS (*«subquery»*)

- Semantics:
  Its value is true iff the subquery has at least one tuple.

- Read it as "exists a row in the subquery result"

Example: EXISTS

```
SELECT surname, cgpa
FROM Student
WHERE EXISTS (
    SELECT *
    FROM Took
    WHERE Student.sid = Took.sid and
        grade > 85 );
```

Worksheet, Q5:

```
SELECT instructor
FROM Offering Off1
WHERE NOT EXISTS (
    SELECT *
    FROM Offering
    WHERE
        oid <> Off1.oid AND
        instructor = Off1.instructor );
```

Worksheet, Q6:

```
SELECT DISTINCT oid
FROM Took
WHERE EXISTS (
    SELECT *
    FROM Took t, Offering o
    WHERE
        t.oid = o.oid AND
        t.oid <> Took.oid AND
        o.dept = 'CSC' AND
        took.sid = t.sid );
```

x *«comparison»* ALL (*«subquery»*)

$\forall$ y $\in$ *«subquery results»* | x *«comparison»* y

x *«comparison»* SOME (*«subquery»*)

$\exists$ y $\in$ *«subquery results»* | x *«comparison»* y

x IN (*«subquery»*)

Same as x = SOME (*«subquery»*)

x NOT IN (*«subquery»*)

Same as x <> ALL (*«subquery»*)

just for convenience

EXISTS (*«subquery»*)

$\exists$ y $\in$ *«subquery results»*

Scope

- If a name might refer to more than one thing, use the most closely nested one.

- If a subquery refers only to names defined inside it, it can be evaluated once and used repeatedly in the outer query.

- If it refers to any name defined outside of itself, it must be evaluated once for each tuple in the outer query.
  These are called correlated subqueries.

Renaming can make scope explicit

```
 SELECT instructor
FROM Offering Off1
WHERE NOT EXISTS (
    SELECT *
    FROM Offering Off2
    WHERE
        Off2.oid <> Off1.oid AND
        Off2.instructor = Off1.instructor );
```

Summary: where subqueries can go

- As a relation in a FROM clause.
- As a value in a WHERE clause.
- With ANY, ALL, IN or EXISTS in a WHERE clause.
- As operands to UNION, INTERSECT or EXCEPT.
- Reference: textbook, section 6.3.

Modifying a Database

Database Modifications

- Queries return a relation.

- A modification command does not; it changes the database in some way.

- Three kinds of modifications:
  - Insert a tuple or tuples.
  - Delete a tuple or tuples.
  - Update the value(s) of an existing tuple or tuples.

Two ways to insert

- We've already seen two ways to insert rows into an empty table:

  INSERT INTO *«table»* VALUES *«list of rows»;*

  INSERT INTO *«table»* (*«subquery»*);

- These can also be used to add rows to a non-empty table.

Naming attributes in INSERT

- Sometimes we want to insert tuples, but we don't have values for all attributes.
- If we name the attributes we *are* providing values for, the system will use `NULL` or a default for the rest.
- Convenient!

Example

```
CREATE TABLE Invite (
    name TEXT,
    campus TEXT DEFAULT 'StG',
    email TEXT,
    age INT);

INSERT INTO Invite(name, email)
(   SELECT firstname, email
    FROM Student
    WHERE cgpa > 3.4  );
```

Here, name and email get values from the query, campus gets the default value, and age gets NULL.

Deletion

- Delete tuples satisfying a condition:
  ```
  DELETE FROM «relation»
  WHERE «condition»;
  ```

- Delete all tuples:
  ```
  DELETE FROM «relation»;
  ```

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Example 1: Delete Some Tuples

```sql
DELETE FROM Course
WHERE NOT EXISTS (
    SELECT *
    FROM Took JOIN Offering
            ON Took.oid = Offering.oid
    WHERE
        grade > 50 AND
        Offering.dept = Course.dept AND
        Offering.cnum = Course.cnum
);
```

Updates

- To change the value of certain attributes in certain tuples to given values:

  UPDATE *«relation»*
  SET *«list of attribute assignments»*
  WHERE *«condition on tuples»*;

Example: update one tuple

- Updating one tuple:
  ```
  UPDATE Student
  SET campus = 'UTM'
  WHERE sid = 99999;
  ```

- Updating several tuples:
  ```
  UPDATE Took
  SET grade = 50
  WHERE grade >= 47 and grade < 50;
  ```