CS315: Database Systems
Structured Query Language (SQL)

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  - Specifies what to do, but not how to do
- Is also a data definition language (DDL)
  - Defines database relations and schemas
- SQL has evolved widely after its first inception
  - Supports lots of extra operations that are non-standard

Example Schema

- course (code, title, *ctype*, webpage)
- coursetype (ctype, *dept*)
- faculty (fid, name, *dept*, designation)
- department (deptid, name)
- semester (yr, half)
- offering (*coursecode, yr, half, instructor*)
- student (roll, name, *dept*, cpi)
- program (*roll*, ptype)
- registration (*coursecode, roll, yr, half, gradecode*)
- grade (gradecode, value)

Creating Relation Schemas

- create table: create table
  $r(A_1\ D_1\ C_1, \ldots, A_n\ D_n\ C_n, (IC_1), \ldots, (IC_k))$
  - r is the name of the relation
  - Each A_i is an attribute name whose data type or domain is specified by D_i
  - C_i specifies constraints or settings (if any)
  - IC_j represents integrity constraints (if any)
- Example

```
create table faculty (
    fid integer primary key,
    name varchar(50) not null,
    dept integer,
    designation varchar(3)
);
```

Data Types in SQL

- *char(n)*: fixed-length character string
- *varchar(n)*: variable-length character string, up to *n*
- *integer* or *int*: integer
- *smallint*: short integer
- *numeric(n,d)*: floating-point number with a total of *n* digits of which *d* is after the decimal point
- *real*: single-precision floating-point number
- *double precision*: double-precision floating-point number
- *float(n)*: floating-point number with at least *n* digits

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- *float(n)*: floating-point number with at least *n* digits
- *date*: yyyy-mm-dd format
- *time*: hh:mm:ss format
- *time(i)*: hh:mm:ss:i...i format with additional *i* digits for fraction of a second
- *timestamp*: both date and time
- *interval*: relative value in either year-month or day-time format

Other Data Types

- User-defined data type

```
create type cpi as numeric(3,1);
```

- Large objects such as images, videos, strings can be stored as
  - blob: binary large object
  - clob: character large object
  - A pointer to the object is stored in the relation, and not the object itself

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  - A pointer to the object is stored in the relation, and not the object itself
- User-defined domain

```
create domain name as varchar(50) not null;
```

Constraints

- Can be specified for each attribute as well as separately
  - *not null*: the attribute cannot be null
    - Requires some value while inserting as otherwise null is the default
  - *primary key* $(A_i, \ldots, A_j)$: automatically ensures not null
  - *default n*: defaults to *n* if no value is specified
  - *unique*: specifies that this is a candidate key
  - *foreign key*: specifies as a foreign key and the relation it refers to
  - *check P*: predicate *P* must be satisfied

```
create table faculty (
   fid integer,
   name varchar(50) not null,
   dept integer,
   designation varchar(3) default ''AP'',
   primary key fid,
   foreign key (dept) references department(dept),
   check (fid >= 0)
);
```

Deleting or Modifying a Relation Schema

- drop table: drop table *r* deletes the table from the database
  - Must satisfy other constraints already applied
- Example

```
drop table faculty;
```

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```

- alter table: alter table *r* add *A* *D* *C*
  - Adds attribute *A* with data type *D* at the end
  - *C* specifies constraints on *A* (if any)
  - Must satisfy other constraints already applied
- alter table: alter table *r* drop *A* → attribute
  - Deletes attribute *A* from all tuples
  - Must satisfy other constraints already applied
- Example

```
alter table faculty add room varchar(10);
alter table course drop webpage;
```

Basic Query Structure

- SQL is based on *relational algebra*
- A *basic* SQL query is of the form

  select $A_1, \ldots, A_n$
  from $r_1, \ldots, r_m$
  where P
- Each r_i is a relation
- Each A_j is an attribute from one of $r_1, \ldots, r_m$
- P is a predicate involving attributes and constants
- where can be left out, which then means *true*
- Result is a relation with the schema $(A_1, \ldots, A_n)$

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- Result is a relation with the schema $(A_1, \ldots, A_n)$
- Is equivalent to the relational algebra query
  $\Pi_{A_1,\ldots,A_n}(\sigma_P(r_1 \times \cdots \times r_m))$

Multisets

- SQL relations are multisets or bags of tuples and not sets
- Consequently, there may be two identical tuples
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- Consequently, there may be two identical tuples
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- The set behavior can be enforced by the keyword unique
- In a query, keyword distinct achieves the same effect
- Opposite is keyword all, which is *default*

Select

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```
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from offering
where yr = 2018;
```

- Case-insensitive
- select * chooses all attributes
- To eliminate duplicates, use select distinct . . .
- Otherwise, by default is select all . . .

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- Case-insensitive
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- To eliminate duplicates, use select distinct ...
- Otherwise, by default is select all ...
- Can contain arithmetic expressions

```
select coursecode, yr - 1959
from offering
where yr = 2018;
```

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from course, offering
where course.code = offering.coursecode and yr = 2018;
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- Example: Find name of students in B.Tech. program

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- Example: Find name of students in B.Tech. program

```
select student.name
from student, program
where student.roll = program.roll and program.ptype =
    ''B.Tech.'';
```

↘ Join

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select coursecode
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where yr = 2018 and instructor = 10;
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```

- Unused clause is equivalent to where true

```
select coursecode
from offering;
```

- SQL allows between operator (includes both)

```
select coursecode
from offering
where yr between 2016 and 2018;
```

Rename Operation

- SQL allows renaming of relations and attributes to remove ambiguity
- Keyword as is used
- Example

```
select student.roll as rollnumber
from student, program
where student.roll = program.roll and program.ptype =
    ''B.Tech.'';
```

Rename Operation

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- Example

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select student.roll as rollnumber
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- Example: Find names of students whose cpi is greater than that of "ABC"

```
select T.name
from student as T, student as S
where T.cpi > S.cpi and S.name = ''ABC'';
```

- as can be omitted by simply stating student T

String Operations

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- Uses like to match patterns specified using special characters
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select *
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- Example: Find departments with the name “?E”

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```

matches any character

- Example: Find the department whose name is “_E”

```
select *
from department
where name = ''_E'';
```

matches exactly this

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- Default is ascending order (asc)

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select count(distinct roll)
from student;
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```

- Attributes in select clause outside of aggregate functions *must* appear in group by list

Qualifying Groups

- In order to select certain groups, use having clause
- Only those groups satisfying having clause appear in the result
- Example: Find average grade in each course where number of students is at least 5

avg(grade) count(roll) > 5

registration

```
select coursecode, avg(grade) from student
group by coursecode having count(roll) >= 5
```

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from registration
group by coursecode
having count(roll) >= 5;
```

- The predicate in having is applied *after* forming groups whereas the predicate in where is applied *before* doing so

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group by coursecode
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```

- The predicate in having is applied *after* forming groups whereas the predicate in where is applied *before* doing so
- Example: Find average grade in each course of type 4 where number of students is at least 5

```
select coursecode, avg(grade)
from registration, course
where registration.coursecode = course.code and ctype = 4
group by coursecode
having count(roll) >= 5;
```

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- The predicates is null and is not null can be used to check for null values
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from course
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from course
where webpage is null;
```

- Result of expressions involving null evaluate to null
- Comparison with null returns *unknown*
- Uses same three-valued logic as relational algebra
- Aggregate functions ignore null
  - count(*) does *not* ignore nulls

Nested Subqueries

- A query that occurs in the where or from clause of another query is called a subquery
- Entire query is called outer query while the subquery is called inner query or nested query
- Used in tests for set membership, set cardinality, set comparisons

Set Membership

- Keyword in is used for set membership tests
- Example: Find faculty members who have not offered any course

```
select faculty.fid from faculty where
faculty.fid not in (select instructor
                    from offering)
```

Set Membership

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- Example: Find faculty members who have not offered any course

```
select *
from faculty
where fid not in (
  select instructor
  from offering );
```

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- It is always a good practice to qualify attributes
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- When a nested query refers to an attribute in the outer query, it is called a correlated query
- Example: Find names of all students who have taken course with an instructor with the same name

select name from student ⋈ registrat ⋈ offering ⋈ faculty
where student.name = offering.instructor
= faculty.name .

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- Example: Find names of all students who have taken course with an instructor with the same name

```
select student.name
from registration as R, student as S, faculty as F
where S.roll = R.roll and S.name = F.name and F.fid in (
   select instructor
   from offering
   where offering.coursecode = R.coursecode );
```

- Inner query is evaluated for *each tuple* in the outer query

Correlated Queries

```
select S.name
from registration as R, student as S, faculty as F
where S.roll = R.roll and S.name = F.name and F.fid in (
   select O.instructor
   from offering as O
   where O.coursecode = R.coursecode );
```

student

roll	name
11	AB
12	CD
13	EF

faculty

fid	name
101	AB
102	EF
103	GH

registration

coursecode	roll
1	11
2	12
3	13

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registration	
coursecode	roll
1	11
2	12
3	13

(R.roll = S.roll and S.name = F.name)($R \times S \times F$)

R.coursecode	R.roll	S.roll	S.name	F.fid	F.name
1	11	11	AB	101	AB
3	13	13	EF	102	EF

Evaluation Per Tuple

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select S.name
from registration as R, student as S, faculty as F
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R.roll = S.roll and S.name = F.name			
R.coursecode	roll	name	F.fid
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offering	
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- $\langle 1, 11, AB, 101 \rangle$

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  - With R.coursecode $= 1$, offering chooses only instructor $\{101\}$

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R.roll = S.roll and S.name = F.name			
R.coursecode	roll	name	F.fid
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O.coursecode	instructor
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- $\langle 1, 11, AB, 101 \rangle$
  - With R.coursecode $= 1$, offering chooses only instructor $\{101\}$
  - Now, since *fid* $= 101 \in \{101\}$, tuple is returned

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   where O.coursecode = R.coursecode );
```

R.roll = S.roll and S.name = F.name			
R.coursecode	roll	name	F.fid
1	11	AB	101
3	13	EF	102

offering	
O.coursecode	instructor
1	101
2	102
3	103

- $\langle 1, 11, AB, 101 \rangle$
  - With R.coursecode $= 1$, offering chooses only instructor $\{101\}$
  - Now, since *fid* $= 101 \in \{101\}$, tuple is returned
- $\langle 3, 13, EF, 102 \rangle$

Evaluation Per Tuple

```
select S.name
from registration as R, student as S, faculty as F
where S.roll = R.roll and S.name = F.name and F.fid in (
   select O.instructor
   from offering as O
   where O.coursecode = R.coursecode );
```

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R.coursecode	roll	name	F.fid
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O.coursecode	instructor
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2	102
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- $\langle 1, 11, AB, 101 \rangle$
  - With R.coursecode $=$ 1, offering chooses only instructor $\{101\}$
  - Now, since *fid* $= 101 \in \{101\}$, tuple is returned
- $\langle 3, 13, EF, 102 \rangle$
  - With R.coursecode $=$ 3, offering chooses only instructor $\{103\}$

Evaluation Per Tuple

```
select S.name
from registration as R, student as S, faculty as F
where S.roll = R.roll and S.name = F.name and F.fid in (
   select O.instructor
   from offering as O
   where O.coursecode = R.coursecode );
```

R.roll = S.roll and S.name = F.name			
R.coursecode	roll	name	F.fid
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2	102
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- $\langle 1, 11, AB, 101 \rangle$
  - With R.coursecode $= 1$, offering chooses only instructor $\{101\}$
  - Now, since $fid = 101 \in \{101\}$, tuple is returned
- $\langle 3, 13, EF, 102 \rangle$
  - With R.coursecode $= 3$, offering chooses only instructor $\{103\}$
  - Now, since $fid = 102 \notin \{103\}$, tuple is not returned

Non-Correlated Query

```
select S.name
from registration as R, student as S, faculty as F
where S.roll = R.roll and S.name = F.name and F.fid in (
   select O.instructor
   from offering as O, registration as G
   where O.coursecode = G.coursecode );
```

R.roll = S.roll and S.name = F.name			
R.coursecode	roll	name	F.fid
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Inner query
O.instructor
101
102
103

- $\langle 1, 11, AB, 101 \rangle$

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```

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R.coursecode	roll	name	F.fid
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3	13	EF	102

Inner query
O.instructor
101
102
103

- $\langle 1, 11, AB, 101 \rangle$
  - Since $fid = 101 \in \{101, 102, 103\}$, tuple is returned

Non-Correlated Query

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select S.name
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where S.roll = R.roll and S.name = F.name and F.fid in (
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   from offering as O, registration as G
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O.instructor
101
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  - Since $fid = 101 \in \{101, 102, 103\}$, tuple is returned
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Inner query
O.instructor
101
102
103

- $\langle 1, 11, AB, 101 \rangle$
  - Since $fid = 101 \in \{101, 102, 103\}$, tuple is returned
- $\langle 3, 13, EF, 102 \rangle$
  - Since $fid = 102 \in \{101, 102, 103\}$, tuple is returned

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where S.roll = R.roll and S.name = F.name and F.fid in (
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   from offering as O, registration as G
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Inner query
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- $\langle 1, 11, AB, 101 \rangle$
  - Since $fid = 101 \in \{101, 102, 103\}$, tuple is returned
- $\langle 3, 13, EF, 102 \rangle$
  - Since $fid = 102 \in \{101, 102, 103\}$, tuple is returned
- Thus, non-correlated query results in an error

Set Comparison: some

- $(F\langle \text{comp} \rangle \text{ some } r) \Leftrightarrow (\exists t \in r\ (F\langle \text{comp} \rangle t))$
- Examples:
  - $5 < some\{0, 5, 6\} =$

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- $(= \text{some}) \equiv (\text{in})$
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- $(= \text{some}) \equiv (\text{in})$
- $(\neq \text{some}) \not\equiv (\text{not in})$
- Example: Find roll numbers of students who have CPI greater than some student in "CSE"

```
select roll
from student
where cpi > some (
  select cpi
  from student
  where dept = ''CSE'' );
```

Set Comparison: all

- $(F\langle \text{comp} \rangle \text{ all } r) \Leftrightarrow (\forall t \in r\ (F\langle \text{comp} \rangle t))$
- Examples:
  - $5 < all\{0, 5, 6\} =$

Set Comparison: all

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  - $5 < all\{6, 9\} =$

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- Example: Find roll numbers of students who have CPI greater than all students in "CSE"

```
select roll
from student
where cpi > all (
  select cpi
  from student
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```

Empty Set

- exists tests if the relation is empty
- (exists r) $\Leftrightarrow$ ($r \neq \Phi$)
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- Example: Find faculty members who have offered courses in 2018

```
select fid
from faculty F
where exists (
  select instructor
  from offering O
  where yr = 2018 and O.instructor = F.fid );
```

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- Example: Find faculty members who have offered courses in 2018

```
select fid
from faculty F
where exists (
  select instructor
  from offering O
  where yr = 2018 and O.instructor = F.fid );
```

- Example: Find faculty members who have not offered courses in 2018

Empty Set

- exists tests if the relation is empty
- (exists r) $\Leftrightarrow$ ($r \neq \Phi$)
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- Example: Find faculty members who have offered courses in 2018

```
select fid
from faculty F
where exists (
  select instructor
  from offering O
  where yr = 2018 and O.instructor = F.fid );
```

- Example: Find faculty members who have not offered courses in 2018

```
...
where not exists (
... );
```

Duplication in Sets

- unique tests if the relation contains duplicate tuples
- (unique r) $\Leftrightarrow$ ($\forall t, s \in r$ ($t \neq s$))
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- Example: Find faculty members who have only offered one course

```
select fid
from faculty as F
where unique (
   select coursecode
   from offering O
   where O.instructor = F.fid );
```

- Example: Find faculty members who have offered multiple courses

Duplication in Sets

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- (unique r) $\Leftrightarrow$ ($\forall t, s \in r$ ($t \neq s$))
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- Example: Find faculty members who have only offered one course

```
select fid
from faculty as F
where unique (
   select coursecode
   from offering O
   where O.instructor = F.fid );
```

- Example: Find faculty members who have offered multiple courses

```
...
where not unique (
... );
```

Explicit Sets

- Use set literals specified within brackets
- Example: Find students in “CSE” and “ECO” 33

```
select *
from student
where dept in (''CSE'', ''ECO'');
```

Summary of SQL Query Format

- May contain up to six clauses
- May be nested
- Only the first two, select and from, are mandatory
- Format (in order)
  select ⟨ attribute list ⟩
  from ⟨ relation list ⟩
  where ⟨ predicate or tuple condition ⟩
  group by ⟨ group attribute list ⟩
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  1. from
  2. where
  3. group by
  4. having
  5. select

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order by ⟨ attribute list ⟩

- Execution order

1. from
2. where
3. group by
4. having
5. select
6. order by

Derived Relations

- In the from clause, a derived relation (result of a subquery) can be used

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- Example: Find departments and average CPIs where average CPI is greater than 8.0

```
select dept_id, avg_cpi
from
    ( select deptid, avg(cpi) from
      student group by dept)
    as dept_avg ( depid, avg_cpi)
    where avg_cpi >= 8.
```

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from (
   select dept, avg(cpi)
   from student
   group by dept )
      as dept_avg (deptid, avg_cpi)
where avg_cpi >= 8.0;
```

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select deptid, avg_cpi
from (
   select dept, avg(cpi)
   from student
   group by dept )
     as dept_avg (deptid, avg_cpi)
where avg_cpi >= 8.0;
```

- Avoids using having clause

With

- with clause defines a temporary relation
- This temporary relation is available *only* to the query using the with clause

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- with clause defines a temporary relation
- This temporary relation is available *only* to the query using the with clause
- Example: Find departments and average CPIs where average CPI is greater than 8.0

```
with dept_avg (deptid, avg_cpi) as
   select dept, avg(cpi)
   from student
   group by dept
select deptid, avg_cpi
from dept_avg
where avg_cpi >= 8.0;
```

Insertion

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- insert into . . . values statement

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- Example: Create a new student “ABC” with roll 1897 and department 7

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- Example: Create a new student “ABC” with roll 1897 and department 7

```
insert into student(roll, name, dept, cpi)
values (1897, ''ABC'', 7, 0.0);
```

Insertion

- insert into . . . values statement
- Example: Create a new student “ABC” with roll 1897 and department 7

```
insert into student(roll, name, dept, cpi)
values (1897, ''ABC'', 7, 0.0);
```

- May omit schema

```
insert into student
values (1897, ''ABC'', 7, 0.0);
```

Insertion

- insert into . . . values statement
- Example: Create a new student “ABC” with roll 1897 and department 7

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```

- May omit schema

```
insert into student
values (1897, ''ABC'', 7, 0.0);
```

- If value is not known, specify *null*

```
insert into student
values (1897, ''ABC'', 7, null);
```

Insertion

- insert into . . . values statement
- Example: Create a new student “ABC” with roll 1897 and department 7

```
insert into student(roll, name, dept, cpi)
values (1897, ''ABC'', 7, 0.0);
```

- May omit schema

```
insert into student
values (1897, ''ABC'', 7, 0.0);
```

- If value is not known, specify *null*

```
insert into student
values (1897, ''ABC'', 7, null);
```

- To avoid *null*, specify schema

```
insert into student(roll, name, dept)
values (1897, ''ABC'', 7);
```

Insertion (contd.)

- Example: Create a course of code 9 for every department with the same type

Insertion (contd.)

- Example: Create a course of code 9 for every department with the same type

```
insert into course(code, title, webpage, ctype)
select 9, ''New'', null, type
from course
where type in (
  select deptid
  from department );
```

- Query is evaluated fully before any tuple is inserted

Insertion (contd.)

- Example: Create a course of code 9 for every department with the same type

```
insert into course(code, title, webpage, ctype)
select 9, ''New'', null, type
from course
where type in (
  select deptid
  from department );
```

- Query is evaluated fully before any tuple is inserted 
- Otherwise, infinite insertion happens for queries like

```
insert into r
select * from r;
```

Deletion

- delete from . . . where statement

Deletion

- delete from . . . where statement
- Example: Delete student with roll number 1946

delete from Student where roll = 1946.

Deletion

- delete from . . . where statement
- Example: Delete student with roll number 1946

```
delete from student
where roll = 1946;
```

- where selects tuples that will be deleted

Deletion

- delete from . . . where statement
- Example: Delete student with roll number 1946

```
delete from student
where roll = 1946;
```

- where selects tuples that will be deleted
- If where is empty,

Deletion

- delete from . . . where statement
- Example: Delete student with roll number 1946

```
delete from student
where roll = 1946;
```

- where selects tuples that will be deleted
- If where is empty, all tuples are deleted

Deletion

- delete from . . . where statement
- Example: Delete student with roll number 1946

```
delete from student
where roll = 1946;
```

- where selects tuples that will be deleted
- If where is empty, all tuples are deleted
- Delete all students

```
delete from student;
```

But student table is not deleted.

Deletion (contd.)

- Example: Delete all students whose CPI is less than the average CPI

```
1) (select avg(cpi) from student as X
    avgcpi;)
delete from student with cpi < {avgcpi
as (1)    select avg(cpi) from student.
                }
```

Deletion (contd.)

- Example: Delete all students whose CPI is less than the average CPI

```
delete from student
where cpi < (
   select avg(cpi)
   from student );
```

Deletion (contd.)

- Example: Delete all students whose CPI is less than the average CPI

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delete from student
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- Average is computed before any tuple is deleted
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- Otherwise, average keeps changing
- Ultimately, only the student with the largest CPI remains

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update student set cpi = 105*cpi/100.

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update student set cpi = cpi * 1.05 where cpi >= 6.0;
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```
update student
set cpi =
  case (cpi)
    when cpi < 6.0 then cpi * 1.10
    when cpi < 8.0 then cpi * 1.05
    else cpi * 1.02
  end;
```

Join

- Join types: inner join, left (outer) join, right (outer) join, full (outer) join
- Join conditions: natural, on ⟨ predicate ⟩, using (⟨ attribute list ⟩)
- Examples

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student join program join registration;
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create view student_program as
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- A view can be deleted simply using drop

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drop student_program;
```

- A view has full query capabilities, but limited modification facilities
- A view can be defined using other views, but not itself

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- This allows to capture all updates in the base relations
- If a view is materialized, it is stored physically
- To ensure consistency, database *must* update materialized views once base relations are updated

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- Problems with insert or delete
  - Spurious tuple
  - Null
  - Non-uniqueness

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- It may not allow the full range of modification statements
- It can be called *before* or *after* the modification
- New and old values are referenced using new and old keywords
  - new refers to a inserted or new value of updated tuple
  - old refers to a deleted or old value of updated tuple
- By default, it is for each row (i.e., tuple)

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create trigger update_code
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  for each row
  when ctype = 9
  begin
    update offering set coursecode = new.code where
        coursecode = old.code;
  end;
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- A trigger can be deleted simply using drop

```
drop update_code;
```

Indices in SQL

- create [unique] index name on r (a, b) creates an index *name* on attributes *a, b* of relation *r*
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BST

B-Trees

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- drop index *i* deletes the index

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drop index idx_ctype;
```

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    - System privileges on tables and views: create, alter, drop
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```
grant select on student to xyz;
grant all on course to abc with grant option;
revoke create on student from xyz;
```

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roll	name
1	AB
2	CD

```
set transaction read write;
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commit;
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Savepoint Example

roll	name
1	AB
2	CD
3	EF
4	GH

```
set transaction read write;
savepoint sp1;
delete from student where roll = 1;
savepoint sp2;
delete from student where roll = 2;
rollback to sp2;
```

→ 2 will come back

Savepoint Example

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Variants in SQL

- SQL standards have evolved a lot over the years
- Different vendors provide different flavors and may not implement every feature