**CSCI 4333.2**

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**Introduction to SQL and MySQL**

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**1. Introduction**

* SQL (Structured Query Language): defacto standard for relational databases.
* SQL-like languages are also used in non-relational DBMS.
* Contains core specifications and extensions. Latest SQL standard: 2016.
* Not using a *pure* relational model: e.g.
	1. Use the terms row, column, and table instead of tuple, attribute, and relation.
	2. The results may not be a set.
* Mostly based on Tuple Relational Calculus (TRC) and a little on Relational Algebra (RA).
* SQL is mostly declarative.
* DBMS vendor-specific extensions are common.
* SQL Contains:
	1. Data Definition Language (DDL): define the relation schema (structure)
	2. Data Manipulation Language (DML): manipulate data; CRUD:
		1. Create: Insert
		2. Read
		3. Update
		4. Delete
	3. Data Administration Language: for DB administration such as user and security management.

**2. MySQL**

BNF (Backus–Naur form) for CFG (Context-Free Grammar)

1. Rules: Non-terminal (left hand side, LHS) expands (::= ) to the RHS. E.g. <**postal-address**> ::= <**name-part**> <**street-address**> <**zip-part**>
2. Terminals: ".", “,”, "Sr."
3. Non-terminals: <**postal-address**> , <**name-part**> <**street-address**> <**zip-part**>
4. |: or
5. []: optional
6. Root terminal e.g. <**postal-address**> -> expand to all terminals. It matches the current statement, it is syntactically correct.

E.g.

<**postal-address**> ::= <**name-part**> <**street-address**> <**zip-part**>

 <**name-part**> ::= <**personal-part**> <**last-name**> <**opt-suffix-part**> <**EOL**> | <**personal-part**> <**name-part**>

 <**personal-part**> ::= <**first-name**> | <**initial**> "."

 <**street-address**> ::= <**house-num**> <**street-name**> <**opt-apt-num**> <**EOL**>

 <**zip-part**> ::= <**town-name**> "," <**state-code**> <**ZIP-code**> <**EOL**>

<**opt-suffix-part**> ::= "Sr." | "Jr." | <**roman-numeral**> | ""

 <**opt-apt-num**> ::= "Apt" <**apt-num**> | ""

MySQL: root terminal for the select statement: select\_statement can be expanded.

1. Non-terminals: *elect\_expr, table\_references, where\_condition*
2. Terminals: capital letters: SELECT, ALL, DISTINCT, …
3. … 0 or more

SELECT DISTINCT f.facId, f.lname

FROM faculty AS f

WHERE rank = 'Professor';

*select\_statement* ::= SELECT

 [ALL | DISTINCT | DISTINCTROW ]

 [HIGH\_PRIORITY]

 [STRAIGHT\_JOIN]

 [SQL\_SMALL\_RESULT] [SQL\_BIG\_RESULT] [SQL\_BUFFER\_RESULT]

 [SQL\_NO\_CACHE] [SQL\_CALC\_FOUND\_ROWS]

 *select\_expr* [, *select\_expr*] ...

 [*into\_option*]

 [FROM *table\_references*

 [PARTITION *partition\_list*]]

 [WHERE *where\_condition*]

 [GROUP BY {*col\_name* | *expr* | *position*}, ... [WITH ROLLUP]]

 [HAVING *where\_condition*]

 [WINDOW *window\_name* AS (*window\_spec*)

 [, *window\_name* AS (*window\_spec*)] ...]

 [ORDER BY {*col\_name* | *expr* | *position*}

 [ASC | DESC], ... [WITH ROLLUP]]

 [LIMIT {[*offset*,] *row\_count* | *row\_count* OFFSET *offset*}]

 [*into\_option*]
…

Use [toyu](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/toyu/toyu.html), a drastically simplified university, as examples.

**2.1 DDL:**

* Make sure that you are familiar with the core SQL Data Definition Language (DDL) commands. Refer to, for example: <http://www.w3schools.com/sql/default.asp>.
* MariaDB DDL: <https://mariadb.com/kb/en/sql-statements/>
* MySQL DDL manual: <https://dev.mysql.com/doc/refman/8.1/en/sql-statements.html>.
* Basic DDL: some examples
	1. CREATE TABLE
	2. CREATE DATABASE: a database contains a collection of related tables for an application.
	3. CREATE VIEW: a view is a virtual table for users to access a subset of a database.
	4. CREATE INDEX: an index is a data structure to enhance access performance of specific queries.
	5. CREATE PROCEDURE
	6. CREATE FUNCTION
	7. CREATE TRIGGER: a trigger is event-driven procedural code activated by events.
	8. ALTER (No ALTER TRIGGER and ALTER INDEX)
	9. DROP
* Note that in MySQL, DATABASE and SCHEMA having the same meaning. Hierarchy:
	1. MySQL: Database = Schema: contains a collection of tables.
	2. Postgres:
		1. A database contains a collection of schema.
		2. A schema contains a collection of tables.
* Constraints: to implement certain constraints in your data model.
	1. NOT NULL: attributes cannot have an null value.
	2. UNIQUE: KEY; the set of attributes must be unique for each row:
	3. PRIMARY KEY: unique, not null, and used for the physical structure of the relation.
	4. FOREIGN KEY
	5. CHECK: for a Boolean condition on the columns.
	6. DEFAULT: define a default value.
* Some other options:
	1. AUTO INCREMENT: automatic increment an integer if a value is not specified. Used for id.

***Example:***

Experimenting with the CREATE TABLE command. Execute the following code and ensure that you understand the result. For example,

* A temporary table is not persistent. It is created for a SQL client session. Its scope is the client session.

DROP SCHEMA IF EXISTS tinker;
CREATE SCHEMA tinker;
USE tinker;

CREATE [TEMPORARY] TABLE [IF NOT EXISTS] *tbl\_name*

 [(*create\_definition*,...)]

 [*table\_options*]

 [*partition\_options*]

 [IGNORE | REPLACE]

 [AS] *query\_expression*

CREATE TABLE s2
SELECT \* FROM toyu.student;

SELECT \*
FROM s2;

CREATE TEMPORARY TABLE s3
SELECT \* FROM toyu.student;

SELECT \*
FROM s3;

CREATE TABLE s4 LIKE toyu.student;

SELECT \*
FROM s4;

INSERT INTO s4
SELECT \* FROM toyu.student;

SELECT \*
FROM s4;

SHOW TABLES;

-- Note that keys and constraints of student are missing in s2 and S3.
DESC student;
DESC s2;
DESC s3;
DESC s4;

DROP TABLE s2;
DROP TABLE s3;
DROP TABLE s4;

SHOW TABLES;

DROP SCHEMA IF EXISTS tinker;

Column names may include special characters. For example, you cannot use the name 'first name' directly as column name, as spaces are interpreted as separator. You will need special syntax. For example:

1. In MySQL, use back-quote: `first name`
2. In MS SQL Server, use []: [first name]
* For each column, there is a data type and optional specifiers (such as NULL, NOT NULL, default values, etc.)
* Additional constraints and indexes can be defined.
* In general, some important considerations in creating tables:
	1. What are the columns?
	2. What are the data types of the columns?
		+ The right domain: be restrictive.
		+ Performance consideration.
	3. Nullability of columns
	4. Primary key
	5. Candidate keys
	6. Foreign keys: can they be enforced by the selected storage engine?
	7. Indexes: performance tuning.
	8. Additional constraints: check whether they are enforced by the storage engine.

***Example:***

* MySQL only supports foreign key constraint in the InnoDB database engine.
* Older versions of MySQL ignore the 'check' clause.

**2.2 Data types**

* Data types in MySQL are rich: <https://dev.mysql.com/doc/refman/8.1/en/data-types.html>
* Beside simple data types, other noticeable data types:
	1. JSON: JavaScript Object Notation
	2. Spatial: support OpenGIS Geometry Model
	3. BLOB: Binary large object
	4. TEXT: long character strings (VARCHAR is limited to 255, extensible to 64K).

**3. DML**

* Basically declarative.

**3.1 Writing to the DB**

* Basic *update* commands (write):
	1. INSERT
	2. UPDATE
	3. DELETE

INSERT INTO <<table>> [<<columns>>]
VALUES <<expression>>

* If column names are missing, the proper column order during table creation will be used.
* Column names using default values or auto-increment values should not be included in the INSERT statement if they are used.
* NULL and DEFAULT can be used as values in INSERT.
* One may also insert values from a select statement. E.g.

INSERT INTO <<table>> [<<columns>>]
<<select statement>>

* The DELETE statement includes a condition for selecting the rows for deletion.

DELETE FROM <<table>>
WHERE <<condition>>

* The update statement is used to update rows and may have an update condition to identify the rows to be updated.

UPDATE <<table>>
SET <<update assignments>>
[WHERE <<update condition>>]

***Example:***

UPDATE Student
SET major = 'ITEC'
WHERE StuId = 100000;

* The update and delete statements can be used to affect multiple rows so be very careful.

***Example:***

-- All students will be majoring in CSCI
UPDATE Student
SET major = 'CSCI';

* Once changed, the effect is permanent. There is no 'undo' command.

***Example:***

Note the order of the insertions in createtoyu.sql below.

INSERT INTO Grade(grade, gradePoint) VALUES
    ('A',4),('A-',3.6667),('B+',3.3333),('B',3),('B-',2.6667),
    ('C+',2.3333),('C',2),('C-',1.6667),
    ('D+',1.3333),('D',1),('D-',0.6667),('F',0),
   ('P', NULL), ('IP', NULL), ('WX', NULL);

INSERT INTO School(schoolCode, schoolName) VALUES
    ('BUS','Business'),
   ('EDU','Education'),
    ('HSH','Human Sciences and Humanities'),
    ('CSE','Science and Engineering');

INSERT INTO Department(deptCode, deptName, schoolCode, numStaff) VALUES
    ('ACCT','Accounting','BUS',10),
    ('ARTS','Arts','HSH',5),
    ('CINF','Computer Information Systems','CSE',5),
    ('CSCI','Computer Science','CSE',12),
    ('ENGL','English','HSH',12),
    ('ITEC','Information Technology','CSE',4),
    ('MATH','Mathematics','CSE',7);

INSERT INTO Faculty(facId, fname, lname, deptCode, `rank`) VALUES
    (1011,'Paul','Smith','CSCI','Professor'),
    (1012,'Mary','Tran','CSCI','Associate Professor'),
    (1013,'David','Love','CSCI',NULL),
    (1014,'Sharon','Mannes','CSCI','Assistant Professor'),
    (1015,'Daniel','Kim','CINF','Professor'),
    (1016,'Andrew','Byre','CINF','Associate Professor'),
    (1017,'Deborah','Gump','ITEC','Professor'),
    (1018,'Art','Allister','ARTS','Assistant Professor'),
    (1019,'Benjamin','Yu','ITEC','Lecturer'),
    (1020,'Katrina','Bajaj','ENGL','Lecturer'),
    (1021,'Jorginlo','Neymar','ACCT','Assistant Professor');

INSERT INTO Course(courseId, rubric, number, title, credits) VALUES
    (2000,'CSCI',3333,'Data Structures',3),
    (2001,'CSCI',4333,'Design of Database Systems',3),
    (2002,'CSCI',5333,'DBMS',3),
    (2020,'CINF',3321,'Introduction to Information Systems',3),
    (2021,'CINF',4320,'Web Application Development',3),
    (2040,'ITEC',3335,'Database Development',3),
    (2041,'ITEC',3312,'Introduction to Scripting',3),
    (2060,'ENGL',1410,'English I',4),
    (2061,'ENGL',1311,'English II',3),
    (2080,'ARTS',3311,'Hindu Arts',3),
    (2090,'ACCT',3333,'Managerial Accounting',3);

INSERT INTO Class(classId, courseId, semester, year, facId, room) VALUES
    (10000,2000,'Fall',2019,1011,'D241'),
    (10001,2001,'Fall',2019,1011,'D242'),
    (10002,2002,'Fall',2019,1012,'D136'),
    (10003,2020,'Fall',2019,1014,'D241'),
    (10004,2021,'Fall',2019,1014,'D241'),
    (10005,2040,'Fall',2019,1015,'D237'),
    (10006,2041,'Fall',2019,1019,'D217'),
    (10007,2060,'Fall',2019,1020,'B101'),
    (10008,2080,'Fall',2019,1018,'D241'),
    (11000,2000,'Spring',2020,1011,'D241'),
    (11001,2001,'Spring',2020,1012,'D242'),
    (11002,2002,'Spring',2020,1013,'D136'),
    (11003,2020,'Spring',2020,1016,'D217'),
    (11004,2061,'Spring',2020,1018,'B101');

INSERT INTO Student(stuId, fname, lname, major, minor, ach, advisor) VALUES
    (100000,'Tony','Hawk','CSCI','CINF',40,1011),
    (100001,'Mary','Hawk','CSCI','CINF',35,1011),
    (100002,'David','Hawk','CSCI','ITEC',66,1012),
    (100003,'Catherine','Lim','ITEC','CINF',20,NULL),
    (100004,'Larry','Johnson','ITEC',NULL,66,1017),
    (100005,'Linda','Johnson','CINF','ENGL',13,1015),
    (100006,'Lillian','Johnson','CINF','ITEC',18,1016),
    (100007,'Ben','Zico',NULL,NULL,16,NULL),
    (100008,'Bill','Ching','ARTS',NULL,90,NULL),
    (100009,'Linda','King','ARTS','CSCI',125,1018),
   (100111,'Cathy','Johanson',NULL,NULL,0,1018);

INSERT INTO Enroll(stuId, classId, grade, n\_alerts) VALUES
    (100000,10000,'A',0),
    (100001,10000,NULL,NULL),
    (100002,10000,'B-',3),
    (100000,10001,'A',2),
    (100001,10001,'A-',0),
    (100000,10002,'B+',1),
    (100002,10002,'B+',2),
    (100000,10003,'C',0),
    (100002,10003,'D',4),
    (100004,10003,'A',0),
    (100005,10003,NULL,NULL),
    (100000,10004,'A-',1),
    (100004,10004,'B+',NULL),
    (100005,10004,'A-',0),
    (100006,10004,'C+',NULL),
    (100005,10005,'A-',0),
    (100006,10005,'A',NULL),
    (100005,10006,'B+',NULL),
    (100007,10007,'F',4),
    (100008,10007,'C-',0),
    (100007,10008,'A-',0),
    (100000,11001,'D',4);

Note the explicit use of NULL, which is a keyword in SQL.

***Example:***

Execute the following code and ensure that you understand the result.

INSERT INTO student VALUES
   (100010,'Bun','Yue',null,null,50,null),
   (100011,'Paul','Harris','CSCI','ITEC',23,1015);

SELECT \* FROM student;

INSERT INTO student VALUES
   (100010,'Bun','Yue',null,null,50,null),
   (100011,'Paul','Harris','CSCI','ITEC',23,1015);

INSERT INTO student VALUES
   (100020,'Bunno','Yue','GEOG',null,50,null);
INSERT INTO student VALUES
   (100021,'Bunna','Yue',null,'GEOG',50,null);
INSERT INTO student VALUES
   (100022,'Bunno','Yue',null,null,50,8888);

-- Remove the two new rows.
DELETE FROM Student
WHERE stuId = 100010 OR stuId = 100011;

SELECT \* FROM student;

**3.2 Querying with the SELECT Statement**

* SELECT is the basic data retrieval statement in SQL
* Not to be confused with the select statement in Relational Algebra (RA).
* Basic format, with*conceptual* steps.

SELECT DISTINCT <<result\_columns>> -- [3] construct result columns
FROM <<source\_tables>> -- [1] conceptually join sources to form a large table
WHERE <<conditions\_for\_inclusion>> -- [2] Filter rows from [1]

1. <<source\_tables>>: the source tables to gather the result data
2. <<conditions\_for\_inclusion>>: the conditions to be satisfied for results to be included and possibly the conditions how the tables should be joined together.
3. <<result\_columns>>: the result columns or expressions desired to be displayed.
* Built-in functions and operators: <https://dev.mysql.com/doc/refman/8.1/en/built-in-function-reference.html>
* Some examples of common functions:
	1. BETWEEN lower\_range AND upper\_range
	2. IN: membership test for a set/table (binary operation)
	3. EXISTS: not an empty set (unary operation)
	4. IF: a ternary operation
	5. LIKE: inexact string matching.
		+ wild cards:
			- % match any and all following characters.
			- \_: match any one character.

***Example:***

Execute the following code and ensure that you understand the result.

-- operators:
-- student with credits in a range.
SELECT DISTINCT \*
FROM Student
WHERE credits BETWEEN 30 AND 70;

-- student in selected majors
SELECT DISTINCT \*
FROM Student
WHERE major IN ('CSCI', 'CINF', 'ITEC');

-- student enrolled in some classes.
SELECT DISTINCT \*
FROM Student AS s
WHERE EXISTS
(SELECT \*  -- a subquery
FROM Enroll AS e
WHERE e.stuId = s.stuId);
-- or
SELECT DISTINCT s.\*
FROM Student AS s INNER JOIN Enroll AS e USING (stuId);

-- students not enrolled in any class.
SELECT DISTINCT \*
FROM student AS s
WHERE s.stuId NOT IN (SELECT DISTINCT e.stuID FROM enroll AS e);

-- students wiht a 'k' in their last name.
SELECT DISTINCT s.\*
FROM student AS s
WHERE s.lname LIKE '%k%';

-- case sensitive version.
SELECT DISTINCT s.\*
FROM student AS s
WHERE s.lname LIKE BINARY '%k%';

-- case sensitive version: a more complicated take.
-- The mysql client sends the query using cp850.
-- The default character set of MySQL server is utf8mb4.
-- It is thus necessary to set the @@character\_set\_connection
-- in order to use collate if MySQL client is used.
-- If HeidiSQL is used, it is not necessary.
SET @@character\_set\_connection=utf8mb4;

SELECT DISTINCT s.\*
FROM student AS s
WHERE s.lname LIKE '%k%' COLLATE utf8mb4\_bin;

-- LIKE compares the whole string.
SELECT DISTINCT s.\*
FROM student AS s
WHERE s.lname LIKE 'ng';

-- student with last name of four characters, with ng the last two.
SELECT DISTINCT s.\*
FROM student AS s
WHERE s.lname LIKE '\_\_ng';

**3.3 Joins**

* When multiple tables are needed for a query, it is common that foreign keys are used to connect the tables.
* It is thus necessary to ensure that the equality of the foreign key with the referenced key of the parent table.
* A popular style is shown in the example below.

***Example:*** one popular SQL style

SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
FROM student AS s, enroll AS e, class AS c
WHERE s.stuId = e.stuId -- Join condition
AND e.classId = c.classId -- Join condition
AND c.semester = 'Fall' -- problem condition
AND c.year = 2019; -- problem condition

Result:

mysql> SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
    -> FROM student s, enroll e, class c
    -> WHERE s.stuId = e.stuId   -- Join condition
    -> AND e.classId = c.classId -- Join condition
    -> AND c.semester = 'Fall'   -- problem condition
    -> AND c.year = 2019;        -- problem condition
+---------+---------+---------+-------+
| fname   | lname   | classId | grade |
+---------+---------+---------+-------+
| Tony    | Hawk    |   10000 | A     |
| Mary    | Hawk    |   10000 | NULL  |
| David   | Hawk    |   10000 | B-    |
| Tony    | Hawk    |   10001 | A     |
| Mary    | Hawk    |   10001 | A-    |
| Tony    | Hawk    |   10002 | B+    |
| David   | Hawk    |   10002 | B+    |
| Tony    | Hawk    |   10003 | C     |
| David   | Hawk    |   10003 | D     |
| Larry   | Johnson |   10003 | A     |
| Linda   | Johnson |   10003 | NULL  |
| Tony    | Hawk    |   10004 | A-    |
| Larry   | Johnson |   10004 | B+    |
| Linda   | Johnson |   10004 | A-    |
| Lillian | Johnson |   10004 | C+    |
| Linda   | Johnson |   10005 | A-    |
| Lillian | Johnson |   10005 | A     |
| Linda   | Johnson |   10006 | B+    |
| Ben     | Zico    |   10007 | F     |
| Bill    | Ching   |   10007 | C-    |
| Ben     | Zico    |   10008 | A-    |
+---------+---------+---------+-------+
21 rows in set (0.00 sec)

**3.3.1 Inner Join**

* In the SELECT statement, the FROM clause allows the results of JOIN statements in the table references.
* Using the JOIN operations in the FROM clause is the preferred technique:
	1. Potentially faster performance: better optimization by DB engines, especially when using indexes.
	2. Better style: separation of join conditions and query semantic conditions.
	3. Easier changes between different joins.
* There are many kind of joins, as discussed below.
* You may use the Explain statement in MySQL to find out the execution plan.

***Example:***

Execute the following code and ensure that you understand the result.

SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
FROM student AS s, enroll AS e, class AS c
WHERE s.stuId = e.stuId -- Join condition
AND e.classId = c.classId -- Join condition
AND c.semester = 'Fall' -- problem condition
AND c.year = 2019; -- problem condition

SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
FROM student AS s INNER JOIN enroll e ON (s.stuId = e.stuId) -- Join condition
    INNER JOIN class AS c ON (e.classId = c.classId) -- Join condition
WHERE c.semester = 'Fall' -- Problem condition
AND c.year = 2019; -- Problem condition

-- alternative: using the USING clause.
SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
FROM student AS s INNER JOIN enroll e USING (stuId) -- Join condition
    INNER JOIN class AS c USING (classId) -- Join condition
WHERE c.semester = 'Fall' -- Problem condition
AND c.year = 2019; -- Problem condition

-- the ON clause is more general and can be more effective.
SELECT DISTINCT s.fname, s.lname, c.classId, e.grade
FROM student AS s INNER JOIN enroll e ON (s.stuId = e.stuId) -- Join condition
    INNER JOIN class AS c
   ON (e.classId = c.classId -- Join condition
      AND c.semester = 'Fall' -- Problem condition
      AND c.year = 2019); -- Problem condition

**3.3.2 Left and Right Join**

* Left joins are the most popular joins besides (inner) joins.
* R1 LEFT JOIN R2: same as INNER JOIN, except that for a tuple t1 in R1 without a matching tuple in R2, t1 will be kept in the result with attributes from R2 being null.
	+ All rows in the left table will be in the result at least once.
* A right join is the mirror image of a left join.

***Example***

Execute the following code and ensure that you understand the result.

-- List the names of the students with their minors (in full name).
-- Student with no department not listed.
SELECT DISTINCT CONCAT(s.fname, ' ', s.lname) AS student,
    d.deptName AS `minor department`
FROM student AS s INNER JOIN department AS d ON (s.minor = d.deptCode);

-- List the names of the students with their minors (in full name).
SELECT DISTINCT CONCAT(s.fname, ' ', s.lname) AS student,
    d.deptName AS `minor department`
FROM student AS s LEFT JOIN department AS d ON (s.minor = d.deptCode);

-- List the names of the students with their minors (in full name).
-- more readable form.
SELECT DISTINCT CONCAT(s.fname, ' ', s.lname) AS student,
    IFNULL (d.deptName, 'N/A') AS `minor department`
FROM student s LEFT JOIN department d ON (s.minor = d.deptCode);

* Joins are procedural. Join orders can be important. Use parenthesis to enforce the desired order.

***Example:***

(R1 LEFT JOIN R2) RIGHT JOIN R3
-- may give different result than
R1 LEFT JOIN (R2 RIGHT JOIN R3)

***Example:***

Problem: List student information and the CSCI class information. Include all students, leaving blanks when appropriate
(i.e., no CSCI courses enrolled by the student).

+--------+-----------------+---------+-------------+-------+
| stuId  | student         | classId | CSCI course | grade |
+--------+-----------------+---------+-------------+-------+
| 100000 | Tony Hawk       | 10000   | CSCI 3333   | A     |
| 100000 | Tony Hawk       | 10001   | CSCI 4333   | A     |
| 100000 | Tony Hawk       | 10002   | CSCI 5333   | B+    |
| 100000 | Tony Hawk       | 11001   | CSCI 4333   | D     |
| 100001 | Mary Hawk       | 10000   | CSCI 3333   |       |
| 100001 | Mary Hawk       | 10001   | CSCI 4333   | A-    |
| 100002 | David Hawk      | 10000   | CSCI 3333   | B-    |
| 100002 | David Hawk      | 10002   | CSCI 5333   | B+    |
| 100003 | Catherine Lim   |         |             |       |
| 100004 | Larry Johnson   |         |             |       |
| 100005 | Linda Johnson   |         |             |       |
| 100006 | Lillian Johnson |         |             |       |
| 100007 | Ben Zico        |         |             |       |
| 100008 | Bill Ching      |         |             |       |
| 100009 | Linda King      |         |             |       |
| 100111 | Cathy Johanson  |         |             |       |
+--------+-----------------+---------+-------------+-------+
16 rows in set (0.001 sec)

***Example:*** (advanced)

Execute the following code and ensure that you understand the result.

-- List student information and the CSCI class information.
SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   e.classId,
   CONCAT(co.rubric, ' ', co.number) AS `CSCI course`,
   e.grade
FROM student AS s INNER JOIN enroll AS e USING (stuId)
   INNER JOIN class AS c USING (classId)
   INNER JOIN course AS co USING (courseId)
WHERE co.rubric = 'CSCI';

-- List student information and the CSCI class information.
-- Include all students, leaving blanks when appropriate
-- (i.e. no CSCI courses enrolled by the student).

-- These do not do the job. Why?
SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   IFNULL(e.classId, '') AS classId,
   IFNULL(CONCAT(co.rubric, ' ', co.number), '') AS `CSCI course`,
   IFNULL(e.grade, '') AS grade
FROM student AS s LEFT JOIN enroll AS e USING (stuId)
   LEFT JOIN class AS c USING (classId)
   LEFT JOIN course AS co USING (courseId)
WHERE co.rubric = 'CSCI';

SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   IFNULL(e.classId, '') AS classId,
   IFNULL(CONCAT(co.rubric, ' ', co.number), '') AS `CSCI course`,
   IFNULL(e.grade, '') AS grade
FROM student AS s LEFT JOIN enroll AS e USING (stuId)
   LEFT JOIN class AS c USING (classId)
   LEFT JOIN course AS co ON (c.courseId = co.courseId AND co.rubric = 'CSCI' );

-- This works. Note the LEFT JOIN and RIGHT JOIN.
SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   IFNULL(e.classId, '') AS classId,
   IFNULL(CONCAT(co.rubric, ' ', co.number), '') AS `CSCI course`,
   IFNULL(e.grade, '') AS grade
FROM enroll AS e INNER JOIN class AS c USING (classId)
   INNER JOIN course AS co ON (c.courseId = co.courseId AND co.rubric = 'CSCI' )
   RIGHT JOIN student AS s USING (stuId);

* Note:
	+ The inclusion of the condition co.rubric = 'CSCI' in the INNER JOIN condition.
	+ The student table should be joined the last using RIGHT JOIN.

**3.4 Subqueries**

* A SQL subquery is a nested/inner subquery within a SQL statement or another query (for SELECT, INSERT, UPDATE or, DELETE).
* Subqueries usually appear in the FROM clause (as derived tables) and the WHERE clause.

***Example***

Execute the following code and ensure that you understand the result.

-- subqueries in the WHERE course
-- students not enrolled in any class.
SELECT DISTINCT \*
FROM student AS s
WHERE s.stuId NOT IN (SELECT DISTINCT e.stuID FROM enroll AS e);

-- student with the maximum number of ach.
SELECT DISTINCT MAX(ach)
FROM student;

-- student within 60 credits of the maximum number of ach any student may have.
SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   s.ach AS credits
FROM student AS s
WHERE s.ach + 60 >=
   (SELECT DISTINCT MAX(ach) FROM student);

-- subqueries as derived tables.
SELECT DISTINCT s.stuId,
   CONCAT(s.fname, ' ', s.lname) AS student,
   s.ach AS credits
FROM student AS s INNER JOIN
   (SELECT DISTINCT MAX(ach) AS max FROM student) AS m -- an alias is required.
WHERE s.ach + 60 >= m.max;

**3.5 Common Table Expressions (CTE)**

* Supported by MySQL 8.0 and forward.
* Allow the definition of temporary common tables in a sequence before the body of a SELECT statement.
	+ WITH t1 AS (definition of t1, a query...), t2 AS (...), ..., tn AS () SELECT ...
* A table defined in CTE can be used immediately until the end of the SELECT statement.
* Support a more natural way to implement *algorithmic solutions*, an (n+1) step solutions.
	+ step 1 to n: constructions of the common tables t1, t2, ..., tn
	+ step (n+1): the body of the SELECT statement.
* Allow recursion.
* May degrade performance.
* It is generally better than subqueries in the FROM clauses.
	+ Tables in CTE can be used immediately after their definitions.
	+ More natural order.
	+ Can use recursion.

***Example:***

-- CTE
WITH  t1 AS
   (SELECT MAX(ach) AS max FROM student)
SELECT s.stuId,
   s.ach AS `ach credits`,
   t1.max - s.ach AS `diff from max credits of all`
FROM student AS s, t1
ORDER BY `ach credits` DESC;

-- multiple common tables (not efficient; used as demonstration.)
WITH t1 AS
   (SELECT MAX(ach) AS max FROM student),
t2 AS
   (SELECT s.stuId,
      s.ach AS `ach credits`,
      t1.max - s.ach AS diff,
      s.major
    FROM student AS s, t1)
SELECT t2.stuId, t2.`ach credits`,
   t2.diff AS `diff from max credits of all`,
   d.deptName AS department
FROM t2 LEFT JOIN department d ON (t2.major = d.deptCode)
ORDER BY t2.`ach credits` DESC;

For those interesting in recursive CTE, here is an example. Recursive CTE will not be in the examinations.

Create and populate a simple relation that stores EmpId of an employee and the EmpId of the immediate supervisor.

CREATE SCHEMA CTETinker;
USE SCHEMA CTEtinker;
CREATE OR REPLACE TABLE Employee (
    EmpId CHAR(7) NOT NULL,
    SupervisorEmpId CHAR(7) NULL,
    CONSTRAINT Emp\_EmpId\_pk PRIMARY KEY (EmpId),
    CONSTRAINT Emp\_SupervisorEmpId\_fk FOREIGN KEY (SupervisorEmpId)
        REFERENCES Employee(EmpId)
);

INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E3', null);
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E15', 'E3');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E50', 'E15');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E75', 'E50');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E100', 'E75');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E102', 'E75');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E70', 'E50');
INSERT INTO Employee(EmpId, SupervisorEmpId) VALUES
   ('E103', 'E70');

SELECT \* FROM Employee;

Result:

MariaDB [temp]> SELECT \* FROM Employee;
+-------+-----------------+
| EmpId | SupervisorEmpId |
+-------+-----------------+
| E3    | NULL            |
| E50   | E15             |
| E15   | E3              |
| E70   | E50             |
| E75   | E50             |
| E103  | E70             |
| E100  | E75             |
| E102  | E75             |
+-------+-----------------+
8 rows in set (0.002 sec)

A recursive CTE SQL to get all supervisors of employee 'E100':

WITH RECURSIVE Super(SEId) AS
(  SELECT SupervisorEmpId AS SEId FROM Employee AS e WHERE e.EmpId = 'E100' -- initial condition/action
   UNION ALL -- union all: add rows created by the recursive action to the result, table Super.
   SELECT e.SupervisorEmpId AS SEId -- recursive action
      FROM Employee AS e INNER JOIN Super
      WHERE e.EmpId = Super.SEId
      AND e.SupervisorEmpId IS NOT NULL
      -- exit condition: when the recursive action returns an empty table.
)
SELECT \*
FROM Super;

Result:

+------+
| SEId |
+------+
| E75  |
| E50  |
| E15  |
| E3   |
+------+

DROP SCHEMA IF EXISTS CTEtinker;

**3.6 GROUP BY and HAVING**

* Useful for group reports: one result row per group, not per row as in the regular SELECT statement without GROUP BY.
* Allow aggregate functions (also known as *group functions* and column functions) to be performed by the groups defined.
* Output one row per *group*.
* A group is defined by an unique value of the columns in the group by clause.
* Example aggregate functions: MAX, MIN, AVG, COUNT, SUM, GROUP\_CONCAT, etc. See: <https://dev.mysql.com/doc/refman/8.0/en/aggregate-functions.html>
* The HAVING clause allows using group functions in the condition. The WHERE clause does not allow using group functions.
* Using GROUP BY, the columns of the SELECT clause can only have:
	1. Columns named in GROUP BY.
	2. Aggregate functions on other columns in the tables.
	3. Constant expressions.
* A number can be used in the GROUP BY and the ORDER BY clauses to refer to the positions of the result columns in the select clauses.

Thus, the conceptual steps and framework for the SELECT statement become

SELECT DISTINCT <<result\_columns>> -- [5] construct result columns: based on the groups, and not the initial row.
FROM <<source\_tables>> -- [1] conceptually join tables to form a large table to produce initial rows
WHERE <<conditions\_for\_inclusion>> -- [2] Filter initial rows
GROUP BY <<group\_by\_columns>>
         --[3] group initial rows into groups by values of the group\_by\_column. A group becomes a new row.
HAVING <<conditions for filtering group>> -- [4] filter groups
ORDER BY <<columns>>; -- [6] Order the result of [5].

***Example:***

-- Student names and number of classes enrolled.
-- More than 2 classes to be included in the result.
SELECT CONCAT(s.fname, ' ', s.lname) AS student,
   COUNT(e.classId) AS `Enrolled classes`
FROM student AS s INNER JOIN enroll e ON (s.stuId = e.stuId)
GROUP BY student
HAVING `Enrolled classes` > 2
ORDER BY `Enrolled classes` DESC;

***Exercises***:

[1] Write a query to generate the student names and number of courses enrolled, including those not enrolled?

+-----------------+------------------+
| name            | Enrolled classes |
+-----------------+------------------+
| Tony Hawk       |                6 |
| Linda Johnson   |                4 |
| David Hawk      |                3 |
| Ben Zico        |                2 |
| Larry Johnson   |                2 |
| Mary Hawk       |                2 |
| Lillian Johnson |                2 |
| Bill Ching      |                1 |
| Catherine Lim   |                0 |
| Linda King      |                0 |
+-----------------+------------------+
10 rows in set (0.00 sec)

Solution:

SELECT CONCAT(s.fname, ' ', s.lname) AS student,
    COUNT(e.classId) AS `Enrolled classes`
FROM student AS s LEFT JOIN enroll e ON (s.stuId = e.stuId)
GROUP BY student
ORDER BY `Enrolled classes` DESC;

[2] Can you write a query to generate the following output?

+----------+------------------------------+------------+----------+----------+
| deptCode | deptName                     | numFaculty | numMajor | numMinor |
+----------+------------------------------+------------+----------+----------+
| ACCT     | Accounting                   |          1 |        0 |        0 |
| ARTS     | Arts                         |          1 |        2 |        0 |
| CINF     | Computer Information Systems |          2 |        2 |        3 |
| CSCI     | Computer Science             |          4 |        3 |        1 |
| ENGL     | English                      |          1 |        0 |        2 |
| ITEC     | Information Technology       |          2 |        2 |        2 |
| MATH     | Mathematics                  |          0 |        0 |        0 |
+----------+------------------------------+------------+----------+----------+
7 rows in set (0.00 sec)

Solution:

WITH ma AS
   (SELECT s.major AS deptCode, COUNT(s.stuId) AS numMajor
    FROM student AS s
    GROUP BY s.major),
mi AS
   (SELECT s.minor AS deptCode, COUNT(s.stuId) AS numMinor
    FROM student AS s
    GROUP BY s.minor),
f AS
   (SELECT f.deptCode, COUNT(f.facId) AS numFaculty
    FROM faculty AS f
    GROUP BY f.deptCode)
SELECT d.deptCode,
   d.deptName,
   IFNULL(f.numFaculty, 0) AS numFaculty,
   IFNULL(ma.numMajor, 0) AS numMajor,
   IFNULL(mi.numMinor, 0) AS numMinor
FROM department AS d LEFT JOIN ma USING (deptCode)
   LEFT JOIN mi USING (deptCode)
   LEFT JOIN f USING (deptCode);

**3.7 Window Functions**

* MySQL 8.x supports Window functions.
* A window function performs a computation on a set of rows (a window frame) in which the current row is in the window frame.
* It is not a clause.
* Unlike the GROUP BY clause, it does*not* form groups.
* The OVER clause is used to define the window frame.
* OVER(): all rows are in the window frame.
* OVER(PARTITION BY X): each X value defines a window frame.
* Many aggregate functions can be used by Window functions.
* Modern DBMS support a rich set of Window functions.

***Example:***

WITH temp AS
(SELECT DISTINCT sc.schoolName AS college, d.deptName AS department,
   COUNT(s.stuId) As deptMajor
FROM school AS sc INNER JOIN department AS d ON (sc.schoolCode = d.schoolCode)
   LEFT JOIN student AS s ON (s.major = d.deptCode)
GROUP BY college, department)
SELECT temp.college, temp.department,
   temp.deptMajor AS `major in department`,
   SUM(deptMajor) OVER(PARTITION BY college) AS `major in college`,
   SUM(deptMajor) OVER() AS `major in university`
FROM temp;

Please execute to see the output.

Adding row number and rank:

WITH ma AS
(SELECT s.major AS deptCode, COUNT(s.stuId) AS numMajor
FROM student AS s
GROUP BY s.major),
mi AS
(SELECT s.minor AS deptCode, COUNT(s.stuId) AS numMinor
FROM student AS s
GROUP BY s.minor),
f AS
(SELECT f.deptCode, COUNT(f.facId) AS numFaculty
FROM faculty AS f
GROUP BY f.deptCode)
SELECT ROW\_NUMBER() OVER () AS `#`,
   RANK() OVER (ORDER BY f.numFaculty DESC) AS `# in descending number of faculty`,
   d.deptCode,
   d.deptName,
   IFNULL(f.numFaculty, 0) AS numFaculty,
   IFNULL(ma.numMajor, 0) AS numMajor,
   IFNULL(mi.numMinor, 0) AS numMinor
FROM department AS d LEFT JOIN ma USING (deptCode)
   LEFT JOIN mi USING (deptCode)
   LEFT JOIN f USING (deptCode);

**Introduction to Relational Algebra and Relational Calculus**

by K. Yue

**1. Introduction**

* More theoretical query languages of the relational model:
	1. Relational Algebra (RA): a simple functional language; function calls (LISP)
	2. Relational Calculus (RC): a simple declarative language

Programming paradigms:

* Procedural: steps by steps; how?
* Declarative: what?
* Provide theoretical foundation for the relational model.
* Not used in practical DBMS.
* Some symbols in RA/RC: [RA\_RC\_Symbols.docx](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/RA_RC_Symbols.docx)

**2. Introduction to Relational algebra**

* Include a set of *basic* and *derived* set-theoretic operations.
* Procedural: specify a sequence of operations.
	+ performance optimization is important.
* Operations can be unary or binary.
* The result is also a relation: *closure* property => chained operations.
* RA solutions are algorithmic.

***Example:***

See [toyu\_Ex.pdf](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/toyu_Ex.pdf) and [toyu\_RA\_sol\_even.pdf](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/toyu_RA_sol_even.pdf)

**3. Introduction to Relational Calculus**

* Non-procedural, *declarative*, and high level.
* Two kinds:
	1. Domain Relational Calculus (DRC)
	2. Tuple Relational Calculus (TRC)
* Results specified by the *set builder form*: {s | cond(s)}
* cond(s) is known as a *formula*.
* Constructs:
	1. Variables:
		1. TRC: tuples (bound to tuples): e.g,. s, t, student, class, etc.
		2. DRC: Attributes (bound to domain value): e.g., a, b, c, stuId, fname, etc.
		3. RC's variables are sometime known as 'dummy variables'.
	2. Constants: string, int, etc. E.g., 12, 'csci', 3.7.
	3. Comparison operators: <, <, =, etc.
	4. Boolean operators: and (conjunction, ∧ or just ,), or (disjunction ∨), not (¬), implies (⇒), etc.
	5. Membership functions: belongs to, ∈, not belongs to, ∉, etc.
	6. Quantifiers: there exists (existential, ∃), for all (universal ∀).

***Example:***

See [toyu\_Ex.pdf](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/toyu_Ex.pdf) and [toyu\_RC\_sol\_odd.pdf](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/toyu_RC_sol_odd.pdf)

**4. Relational Algebra**

**4.1 Basic Operations**

**4.1.1 Select**

1. Unary operation.
2. Select tuples (with the same schema) based on a Boolean condition.
3. Conditions may include attributes in the relational schema.
4. The Boolean expression of the condition can be composite (containing Boolean expressions joining by logical operators).
5. *'Horizontal' subset*.
6. Not to be confused with the Select statement in SQL.



σcond(R) = {t | t ∈ R and cond}, or simply

σcond(R) = {t | t ∈ R, cond}

**Example:** All information of students majoring in CSCI.

σmajor='CSCI'(Student)

+--------+-------+-------+-------+-------+---------+---------+
| stuId  | fname | lname | major | minor | credits | advisor |
+--------+-------+-------+-------+-------+---------+---------+
| 100000 | Tony  | Hawk  | CSCI  | CINF  |      40 |    1011 |
| 100001 | Mary  | Hawk  | CSCI  | CINF  |      35 |    1011 |
| 100002 | David | Hawk  | CSCI  | ITEC  |      66 |    1011 |
+--------+-------+-------+-------+-------+---------+---------+
3 rows

In SQL, this is just:

SELECT \*
FROM Student
WHERE major = 'CSCI';

**4.1.2 Project**

1. Unary operation
2. Select attributes from tuples.
3. Duplicate results removed (because a relation is a set).
4. 'Vertical' subset.

πc1, .., cm(R) = {s | ∃t ∈ R (t(ci) = s(ci), for 1 <= i <= m)},

or simply

πc1, .., cm(R) = {s | t ∈ R (t(ci) = s(ci), for 1 <= i <= m)}



**Example:** Names and majors of students

πLName, FName, Major(Student):

+-----------+---------+-------+
| FName     | LName   | Major |
+-----------+---------+-------+
| Tony      | Hawk    | CSCI  |
| Mary      | Hawk    | CSCI  |
| David     | Hawk    | CSCI  |
| Catherine | Lim     | ITEC  |
| Larry     | Johnson | ITEC  |
| Linda     | Johnson | CINF  |
| Lillian   | Johnson | CINF  |
| Ben       | Zico    | NULL  |
| Bill      | Ching   | ARTS  |
| Linda     | King    | ARTS  |
+-----------+---------+-------+
10 rows

**4.1.3.Cartesian Product**

1. Same as the usual definition of the Cartesian Product of two sets.
	1. Remember that a relation is a set.
2. Merge all possible information from two relations.
3. Also called Cross Product or Cross Join.
4. Name ambiguity may be resolved by using full names.
5. The cardinality of a set S is |S|, the number of elements in the set.
6. |RxS|= |R| \* |S|
7. Not very useful in practice as the result can be large and constructing the result can be time consuming.



***Example:***

R(A,B,C) has three tuples. S(A,D) has four tuples.

The result of R \* S always has 12 tuples with the schema (R.A, B, C, S.A, D).

**Example:** in toyu

student:
+--------+-----------+---------+-------+-------+---------+---------+
| stuId  | fname     | lname   | major | minor | credits | advisor |
+--------+-----------+---------+-------+-------+---------+---------+
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 |
+--------+-----------+---------+-------+-------+---------+---------+
10 rows in set

enroll:
+--------+---------+-------+----------+
| stuId  | classId | grade | n\_alerts |
+--------+---------+-------+----------+
| 100000 |   10000 | A     |        0 |
| 100001 |   10000 | NULL  |     NULL |
| 100002 |   10000 | B-    |        3 |
| 100000 |   10001 | A     |        2 |
| 100001 |   10001 | A-    |        0 |
| 100000 |   10002 | B+    |        1 |
| 100002 |   10002 | B+    |        2 |
| 100000 |   10003 | C     |        0 |
| 100002 |   10003 | D     |        4 |
| 100004 |   10003 | A     |        0 |
| 100005 |   10003 | NULL  |     NULL |
| 100000 |   10004 | A-    |        1 |
| 100004 |   10004 | B+    |     NULL |
| 100005 |   10004 | A-    |        0 |
| 100006 |   10004 | C+    |     NULL |
| 100005 |   10005 | A-    |        0 |
| 100006 |   10005 | A     |     NULL |
| 100005 |   10006 | B+    |     NULL |
| 100007 |   10007 | F     |        4 |
| 100008 |   10007 | C-    |        0 |
| 100007 |   10008 | A-    |        0 |
| 100000 |   11001 | D     |        4 |
+--------+---------+-------+----------+
22 rows

student \* enroll:
+--------+-----------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
| stuId  | fname     | lname   | major | minor | credits | advisor | stuId  | classId | grade | n\_alerts |
+--------+-----------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10000 | A     |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   10000 | A     |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   10000 | A     |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   10000 | A     |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   10000 | A     |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   10000 | A     |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   10000 | A     |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   10000 | A     |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   10000 | A     |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   10000 | A     |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100001 |   10000 | NULL  |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100001 |   10000 | NULL  |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100001 |   10000 | NULL  |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100001 |   10000 | NULL  |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100001 |   10000 | NULL  |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100001 |   10000 | NULL  |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100001 |   10000 | NULL  |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100001 |   10000 | NULL  |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100001 |   10000 | NULL  |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100001 |   10000 | NULL  |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100002 |   10000 | B-    |        3 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100002 |   10000 | B-    |        3 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10000 | B-    |        3 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100002 |   10000 | B-    |        3 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100002 |   10000 | B-    |        3 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100002 |   10000 | B-    |        3 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100002 |   10000 | B-    |        3 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100002 |   10000 | B-    |        3 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100002 |   10000 | B-    |        3 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100002 |   10000 | B-    |        3 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10001 | A     |        2 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   10001 | A     |        2 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   10001 | A     |        2 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   10001 | A     |        2 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   10001 | A     |        2 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   10001 | A     |        2 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   10001 | A     |        2 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   10001 | A     |        2 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   10001 | A     |        2 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   10001 | A     |        2 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100001 |   10001 | A-    |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100001 |   10001 | A-    |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100001 |   10001 | A-    |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100001 |   10001 | A-    |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100001 |   10001 | A-    |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100001 |   10001 | A-    |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100001 |   10001 | A-    |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100001 |   10001 | A-    |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100001 |   10001 | A-    |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100001 |   10001 | A-    |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10002 | B+    |        1 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   10002 | B+    |        1 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   10002 | B+    |        1 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   10002 | B+    |        1 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   10002 | B+    |        1 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   10002 | B+    |        1 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   10002 | B+    |        1 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   10002 | B+    |        1 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   10002 | B+    |        1 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   10002 | B+    |        1 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100002 |   10002 | B+    |        2 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100002 |   10002 | B+    |        2 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10002 | B+    |        2 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100002 |   10002 | B+    |        2 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100002 |   10002 | B+    |        2 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100002 |   10002 | B+    |        2 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100002 |   10002 | B+    |        2 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100002 |   10002 | B+    |        2 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100002 |   10002 | B+    |        2 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100002 |   10002 | B+    |        2 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10003 | C     |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   10003 | C     |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   10003 | C     |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   10003 | C     |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   10003 | C     |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   10003 | C     |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   10003 | C     |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   10003 | C     |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   10003 | C     |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   10003 | C     |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100002 |   10003 | D     |        4 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100002 |   10003 | D     |        4 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10003 | D     |        4 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100002 |   10003 | D     |        4 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100002 |   10003 | D     |        4 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100002 |   10003 | D     |        4 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100002 |   10003 | D     |        4 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100002 |   10003 | D     |        4 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100002 |   10003 | D     |        4 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100002 |   10003 | D     |        4 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100004 |   10003 | A     |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100004 |   10003 | A     |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100004 |   10003 | A     |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100004 |   10003 | A     |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100004 |   10003 | A     |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100004 |   10003 | A     |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100004 |   10003 | A     |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100004 |   10003 | A     |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100004 |   10003 | A     |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100004 |   10003 | A     |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100005 |   10003 | NULL  |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100005 |   10003 | NULL  |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100005 |   10003 | NULL  |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100005 |   10003 | NULL  |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100005 |   10003 | NULL  |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10003 | NULL  |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100005 |   10003 | NULL  |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100005 |   10003 | NULL  |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100005 |   10003 | NULL  |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100005 |   10003 | NULL  |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10004 | A-    |        1 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   10004 | A-    |        1 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   10004 | A-    |        1 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   10004 | A-    |        1 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   10004 | A-    |        1 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   10004 | A-    |        1 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   10004 | A-    |        1 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   10004 | A-    |        1 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   10004 | A-    |        1 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   10004 | A-    |        1 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100004 |   10004 | B+    |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100004 |   10004 | B+    |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100004 |   10004 | B+    |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100004 |   10004 | B+    |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100004 |   10004 | B+    |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100004 |   10004 | B+    |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100004 |   10004 | B+    |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100004 |   10004 | B+    |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100004 |   10004 | B+    |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100004 |   10004 | B+    |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100005 |   10004 | A-    |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100005 |   10004 | A-    |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100005 |   10004 | A-    |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100005 |   10004 | A-    |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100005 |   10004 | A-    |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10004 | A-    |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100005 |   10004 | A-    |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100005 |   10004 | A-    |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100005 |   10004 | A-    |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100005 |   10004 | A-    |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100006 |   10004 | C+    |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100006 |   10004 | C+    |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100006 |   10004 | C+    |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100006 |   10004 | C+    |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100006 |   10004 | C+    |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100006 |   10004 | C+    |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100006 |   10004 | C+    |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100006 |   10004 | C+    |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100006 |   10004 | C+    |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100006 |   10004 | C+    |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100005 |   10005 | A-    |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100005 |   10005 | A-    |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100005 |   10005 | A-    |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100005 |   10005 | A-    |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100005 |   10005 | A-    |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10005 | A-    |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100005 |   10005 | A-    |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100005 |   10005 | A-    |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100005 |   10005 | A-    |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100005 |   10005 | A-    |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100006 |   10005 | A     |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100006 |   10005 | A     |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100006 |   10005 | A     |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100006 |   10005 | A     |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100006 |   10005 | A     |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100006 |   10005 | A     |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100006 |   10005 | A     |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100006 |   10005 | A     |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100006 |   10005 | A     |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100006 |   10005 | A     |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100005 |   10006 | B+    |     NULL |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100005 |   10006 | B+    |     NULL |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100005 |   10006 | B+    |     NULL |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100005 |   10006 | B+    |     NULL |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100005 |   10006 | B+    |     NULL |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10006 | B+    |     NULL |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100005 |   10006 | B+    |     NULL |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100005 |   10006 | B+    |     NULL |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100005 |   10006 | B+    |     NULL |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100005 |   10006 | B+    |     NULL |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100007 |   10007 | F     |        4 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100007 |   10007 | F     |        4 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100007 |   10007 | F     |        4 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100007 |   10007 | F     |        4 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100007 |   10007 | F     |        4 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100007 |   10007 | F     |        4 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100007 |   10007 | F     |        4 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100007 |   10007 | F     |        4 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100007 |   10007 | F     |        4 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100007 |   10007 | F     |        4 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100008 |   10007 | C-    |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100008 |   10007 | C-    |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100008 |   10007 | C-    |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100008 |   10007 | C-    |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100008 |   10007 | C-    |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100008 |   10007 | C-    |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100008 |   10007 | C-    |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100008 |   10007 | C-    |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100008 |   10007 | C-    |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100008 |   10007 | C-    |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100007 |   10008 | A-    |        0 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100007 |   10008 | A-    |        0 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100007 |   10008 | A-    |        0 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100007 |   10008 | A-    |        0 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100007 |   10008 | A-    |        0 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100007 |   10008 | A-    |        0 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100007 |   10008 | A-    |        0 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100007 |   10008 | A-    |        0 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100007 |   10008 | A-    |        0 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100007 |   10008 | A-    |        0 |
| 100000 | Tony      | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   11001 | D     |        4 |
| 100001 | Mary      | Hawk    | CSCI  | CINF  |      35 |    1011 | 100000 |   11001 | D     |        4 |
| 100002 | David     | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100000 |   11001 | D     |        4 |
| 100003 | Catherine | Lim     | ITEC  | CINF  |      20 |    1017 | 100000 |   11001 | D     |        4 |
| 100004 | Larry     | Johnson | ITEC  | NULL  |      66 |    1017 | 100000 |   11001 | D     |        4 |
| 100005 | Linda     | Johnson | CINF  | ENGL  |      13 |    1015 | 100000 |   11001 | D     |        4 |
| 100006 | Lillian   | Johnson | CINF  | ITEC  |      18 |    1015 | 100000 |   11001 | D     |        4 |
| 100007 | Ben       | Zico    | NULL  | NULL  |      16 |    NULL | 100000 |   11001 | D     |        4 |
| 100008 | Bill      | Ching   | ARTS  | ENGL  |      90 |    1018 | 100000 |   11001 | D     |        4 |
| 100009 | Linda     | King    | ARTS  | CSCI  |     125 |    1018 | 100000 |   11001 | D     |        4 |
+--------+-----------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
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R \* S in SQL:

SELECT R.\*, S.\*
FROM R, S; -- note that there is no join condition.

**4.1.4 Union**

1. The set union operator.
2. Condition for R U S: R and S must be *union compatible*. Their relation schema must have compatible schema with the same structures. Each corresponding attribute must have the same types (domains).

R U S = {t | t ∈ R V t ∈ S}

**Example:**

Suppose StaffID and FacultyID are union compatible.

 πStaffID(Staff) U πFacultyID(Faculty)

**Example:** All information of students majoring in CSCI or ARTS.

σ(major='CSCI') (Student) U σ(major='ARTS') (Student)

or

σ(major='CSCI') V (major='ARTS') (Student)

+--------+-------+-------+-------+-------+---------+---------+
| stuId  | fname | lname | major | minor | credits | advisor |
+--------+-------+-------+-------+-------+---------+---------+
| 100008 | Bill  | Ching | ARTS  | ENGL  |      90 |    1018 |
| 100009 | Linda | King  | ARTS  | CSCI  |     125 |    1018 |
| 100000 | Tony  | Hawk  | CSCI  | CINF  |      40 |    1011 |
| 100001 | Mary  | Hawk  | CSCI  | CINF  |      35 |    1011 |
| 100002 | David | Hawk  | CSCI  | ITEC  |      66 |    1011 |
+--------+-------+-------+-------+-------+---------+---------+
5 rows

**4.1.4 Difference (Minus)**

1. The set difference operator.
2. R - S: R and S must be *union compatible*.

R - S = {t | t ∈ R and not (t ∈ S)}

or

R - S = {t | t ∈ R, t ∉ S}

**Example:** Information of all students majoring in CSCI but not those taken credits less than 40.

σmajor='CSCI'(Student) - σcredit <40 (Student)

+--------+-------+-------+-------+-------+---------+---------+
| stuId  | fname | lname | major | minor | credits | advisor |
+--------+-------+-------+-------+-------+---------+---------+
| 100000 | Tony  | Hawk  | CSCI  | CINF  |      40 |    1011 |
| 100002 | David | Hawk  | CSCI  | ITEC  |      66 |    1011 |
+--------+-------+-------+-------+-------+---------+---------+
2 rows

Note that this is the same as:

σmajor='CSCI' and credit >=40(Student)

**4.1.6 Rename**

1. Rename the names of selected attributes in a relation.
2. Maybe used to rename attributes before a set operation.
3. Notation in Elmarsi (a popular db textbook):



* A better notation includes the original name and the new name.

Example:

ρ(FacultyId, department <- FacId, deptCode) (Faculty)

+-----------+----------+----------+------------+---------------------+
| facultyId | fname    | lname    | department | rank                |
+-----------+----------+----------+------------+---------------------+
|      1011 | Paul     | Smith    | CSCI       | Professor           |
|      1012 | Mary     | Tran     | CSCI       | Associate Professor |
|      1013 | David    | Love     | CSCI       | NULL                |
|      1014 | Sharon   | Mannes   | CSCI       | Assistant Professor |
|      1015 | Daniel   | Kim      | CINF       | Professor           |
|      1016 | Andrew   | Byre     | CINF       | Associate Professor |
|      1017 | Deborah  | Gump     | ITEC       | Professor           |
|      1018 | Art      | Allister | ARTS       | Assistant Professor |
|      1019 | Benjamin | Yu       | ITEC       | Lecturer            |
|      1020 | Katrina  | Bajaj    | ENGL       | Lecturer            |
|      1021 | Jorginlo | Neymar   | ACCT       | Assistant Professor |
+-----------+----------+----------+------------+---------------------+
11 rows

* The basic set of operations is *complete*. Other relational algebra operations can be derived from them.

**4.2. Derived Operations**

**4.2.1 Theta-join**

1. Allow the application of condition on Cartesian product.
2. There are still redundant data on common attributes.
3. Allow the query engine to throw away tuples not in the result immediately.
4. Conceptually, a Cartesian Product followed by a selection Θ.
5. Not usually used.

R1 ⋈ΘR2 = σΘ(R1 \* R2)

**Example:** All related information of students with 70 or more credits and a grade A or better in some courses.

Student ⋈(credits >= 70 and grade = 'A') Enroll

+--------+-------+-------+-------+-------+---------+---------+--------+---------+-------+----------+
| stuId  | fname | lname | major | minor | credits | advisor | stuId  | classId | grade | n\_alerts |
+--------+-------+-------+-------+-------+---------+---------+--------+---------+-------+----------+
| 100008 | Bill  | Ching | ARTS  | ENGL  |      90 |    1018 | 100000 |   10000 | A     |        0 |
| 100008 | Bill  | Ching | ARTS  | ENGL  |      90 |    1018 | 100000 |   10001 | A     |        2 |
| 100008 | Bill  | Ching | ARTS  | ENGL  |      90 |    1018 | 100004 |   10003 | A     |        0 |
| 100008 | Bill  | Ching | ARTS  | ENGL  |      90 |    1018 | 100006 |   10005 | A     |     NULL |
| 100009 | Linda | King  | ARTS  | CSCI  |     125 |    1018 | 100000 |   10000 | A     |        0 |
| 100009 | Linda | King  | ARTS  | CSCI  |     125 |    1018 | 100000 |   10001 | A     |        2 |
| 100009 | Linda | King  | ARTS  | CSCI  |     125 |    1018 | 100004 |   10003 | A     |        0 |
| 100009 | Linda | King  | ARTS  | CSCI  |     125 |    1018 | 100006 |   10005 | A     |     NULL |
+--------+-------+-------+-------+-------+---------+---------+--------+---------+-------+----------+
8 rows in set (0.01 sec)

 **4.2.2 Equi-join**

1. Theta-join where the condition involves only equality comparisons.
2. There are still redundant data on *common attributes*.
3. Common attributes are attributes that have the same *names*. The attributes may not have the same meaning.
4. Not usually used.

**Example:**

Student |x| (Student.StuId = Enrol.StuId) Enroll

+--------+---------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
| stuId  | fname   | lname   | major | minor | credits | advisor | stuId  | classId | grade | n\_alerts |
+--------+---------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10000 | A     |        0 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10001 | A     |        2 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10002 | B+    |        1 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10003 | C     |        0 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   10004 | A-    |        1 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 | 100000 |   11001 | D     |        4 |
| 100001 | Mary    | Hawk    | CSCI  | CINF  |      35 |    1011 | 100001 |   10000 | NULL  |     NULL |
| 100001 | Mary    | Hawk    | CSCI  | CINF  |      35 |    1011 | 100001 |   10001 | A-    |        0 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10000 | B-    |        3 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10002 | B+    |        2 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 | 100002 |   10003 | D     |        4 |
| 100004 | Larry   | Johnson | ITEC  | NULL  |      66 |    1017 | 100004 |   10003 | A     |        0 |
| 100004 | Larry   | Johnson | ITEC  | NULL  |      66 |    1017 | 100004 |   10004 | B+    |     NULL |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10003 | NULL  |     NULL |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10004 | A-    |        0 |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10005 | A-    |        0 |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 | 100005 |   10006 | B+    |     NULL |
| 100006 | Lillian | Johnson | CINF  | ITEC  |      18 |    1015 | 100006 |   10004 | C+    |     NULL |
| 100006 | Lillian | Johnson | CINF  | ITEC  |      18 |    1015 | 100006 |   10005 | A     |     NULL |
| 100007 | Ben     | Zico    | NULL  | NULL  |      16 |    NULL | 100007 |   10007 | F     |        4 |
| 100007 | Ben     | Zico    | NULL  | NULL  |      16 |    NULL | 100007 |   10008 | A-    |        0 |
| 100008 | Bill    | Ching   | ARTS  | ENGL  |      90 |    1018 | 100008 |   10007 | C-    |        0 |
+--------+---------+---------+-------+-------+---------+---------+--------+---------+-------+----------+
22 rows

It is important to note the difference between names and meanings. Consider

student(stuId, ... advisorFacId, ..., createTime) and

faculty(facId, ..., createTime)

1. The attributes createTime in student and faculty have the same name, but different meaning.
	1. Student(createTime) is the time the student row is inserted into the student table.
	2. Faculty(createTime) is the time the faculty row is inserted into the faculty table
2. student(advisorFacId) and faculty(facId) have different names but the same meaning. In fact, student(advisorFacId) is a foreign key that references faculty(facId).

**4.2.3 Natural Join**

1. Remove redundant common attributes from equi-joins
	1. Equi-join on all common attributes.
	2. Projection to remove redundant common attributes.
2. Used very frequently to combine two tables.
3. If two relations do not share any common attributes, their natural join is the same as their Cartesian Product.

Let C1, C2, ... Cm be the common attributes of R and S.

R |x| S = πA1, A2, .. Al(σR.C1=S.C1,.., R.Cm=S.Cm(R\*S))

where A1, A2, ... Al is the list of attributes in R\*S except S.C1, S.C2,.. S.Cm.

**Example:**

The schema of R(A,B) |x| S(A,C) is ABC. The schema of R(A,B) \* S(A,C) is {R.A, B, S.A, C}.

**Example:**

Student |x| Enroll:

+--------+---------+---------+-------+-------+---------+---------+---------+-------+----------+
| stuId  | fname   | lname   | major | minor | credits | advisor | classId | grade | n\_alerts |
+--------+---------+---------+-------+-------+---------+---------+---------+-------+----------+
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   10000 | A     |        0 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   10001 | A     |        2 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   10002 | B+    |        1 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   10003 | C     |        0 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   10004 | A-    |        1 |
| 100000 | Tony    | Hawk    | CSCI  | CINF  |      40 |    1011 |   11001 | D     |        4 |
| 100001 | Mary    | Hawk    | CSCI  | CINF  |      35 |    1011 |   10000 | NULL  |     NULL |
| 100001 | Mary    | Hawk    | CSCI  | CINF  |      35 |    1011 |   10001 | A-    |        0 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 |   10000 | B-    |        3 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 |   10002 | B+    |        2 |
| 100002 | David   | Hawk    | CSCI  | ITEC  |      66 |    1011 |   10003 | D     |        4 |
| 100004 | Larry   | Johnson | ITEC  | NULL  |      66 |    1017 |   10003 | A     |        0 |
| 100004 | Larry   | Johnson | ITEC  | NULL  |      66 |    1017 |   10004 | B+    |     NULL |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 |   10003 | NULL  |     NULL |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 |   10004 | A-    |        0 |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 |   10005 | A-    |        0 |
| 100005 | Linda   | Johnson | CINF  | ENGL  |      13 |    1015 |   10006 | B+    |     NULL |
| 100006 | Lillian | Johnson | CINF  | ITEC  |      18 |    1015 |   10004 | C+    |     NULL |
| 100006 | Lillian | Johnson | CINF  | ITEC  |      18 |    1015 |   10005 | A     |     NULL |
| 100007 | Ben     | Zico    | NULL  | NULL  |      16 |    NULL |   10007 | F     |        4 |
| 100007 | Ben     | Zico    | NULL  | NULL  |      16 |    NULL |   10008 | A-    |        0 |
| 100008 | Bill    | Ching   | ARTS  | ENGL  |      90 |    1018 |   10007 | C-    |        0 |
+--------+---------+---------+-------+-------+---------+---------+---------+-------+----------+
22 rows

**Exercise:**

Let the cardinality of R(A,B) be 5 and the cardinality of S(A,C) be 6. What is the range of the cardinality of R(A,B) |x| S(A,C)?

**4.2.4 Other Joins** (Additional Materials)

1. Some other joins are left join, right join, outer join, inner join and semi-join.
2. They can be defined through relational algebra expressions based on the basic operations.
3. Look them up when needs arise. For example: <https://en.wikipedia.org/wiki/Relational_algebra>

**4.2.5 Division** (Additional Materials)

1. R / S or R ÷ S.
2. Condition: the domain of S is a proper subset of R.
3. Let the schemes of R, S and T be dom(R), dom(S) and dom(T) = dom(R) - dom(S) respectively.
4. R / S = {t | t ∈ dom(T), ꓯs ∈ S (ꓱr ∈ R (r = st))}.
5. In term of basic RA operations, R / S = πR-S(R) - πR-S((πR-S(R) \* S) - R)

**Example:**

Find the student id of all students who enrolled in all courses offered by the faculty '1014':

Stuid and classNumber information (who is enrolled in which class):

π(stuId, classId) (Enroll): rows added to Class.

+--------+---------+
| stuId  | classId |
+--------+---------+
| 100000 |   10000 |
| 100000 |   10001 |
| 100000 |   10002 |
| 100000 |   10003 |
| 100000 |   10004 |
| 100000 |   11001 |
| 100001 |   10000 |
| 100001 |   10001 |
| 100002 |   10000 |
| 100002 |   10002 |
| 100002 |   10003 |
| 100004 |   10003 |
| 100004 |   10004 |
| 100005 |   10003 |
| 100005 |   10004 |
| 100005 |   10005 |
| 100005 |   10006 |
| 100006 |   10004 |
| 100006 |   10005 |
| 100007 |   10007 |
| 100007 |   10008 |
| 100008 |   10007 |
+--------+---------+
22 rows

Classes offered by faculty '1014':

π(classId) (σ(facId='1014) (Class)):

+---------+
| classId |
+---------+
|   10003 |
|   10004 |
+---------+
2 rows

Solution:

π(stuId, classId) (Enroll) / π(stuId, classId) (Enroll):

+--------+
| stuId  |
+--------+
| 100000 |
| 100004 |
| 100005 |
+--------+
3 rows

**4.3 Query Optimization**

* Since RA is operational and thus algorithmic, there are multiple solutions with varying performance.
* Some heuristics for constructing effective RA solutions:
	1. Minimize the number of RA operations.
	2. Minimize the sizes of the intermediate results.
* In SQL:
	1. A SQL query execution plan breaks down a query into basic execution steps (based on RA).
	2. A SQL optimizer selects one from a list of execution plans.
	3. In MySQL, use the EXPLAIN statement to obtain information about the execution plan: <https://dev.mysql.com/doc/refman/8.1/en/explain-output.html>.

**4.4 Epilog**

Some shortcomings of Relational Algebra:

1. Cannot navigate tuples.
2. Cannot deal with recursion.
	1. e.g., for the relation Employee(SSN, Supervisor\_SSN, ...), find all supervisors (direct or indirect).
	2. May extend to logical databases, e.g. Datalog.
3. No group functions.
	1. e.g., Show the available total quantities of all parts.
4. Operations are too simple, resulting in long sequences.

**5. Relational Calculus

5.1 Review**

* Non-procedural, *declarative*, and high level.
* Two kinds:
	1. Domain Relational Calculus (DRC)
	2. Tuple Relational Calculus (TRC)
* Results specified by the *set builder form*: {s | cond(s)}
* cond(s) is known as a *formula*.
* Constructs:
	1. Variables:
		1. TRC: tuples (bound to tuples): e.g,. s, t, student, class, etc.
		2. DRC: Attributes (bound to domain value): e.g., a, b, c, stuId, fname, etc.
		3. RC's variable is sometime known as 'dummy variable'.
	2. Constants: string, int, etc., E.g., 12, 'csci', 3.7.
	3. Comparison operators: <, <, =, etc.
	4. Boolean operators: and (conjunction, ∧ or just ,), or (disjunction ∨), not (¬), implies (⇒), etc.
	5. Membership functions: belongs to, ∈, not belongs to, ∉, etc.
	6. Quantifiers: there exists (existential, ∃), for all (universal ∀).

**5.2 More RC**

* An *atom* can be thought of as a simple Boolean expression:
	+ e ∈ R, or
	+ x op y where x and y are attributes or constants, and op is a comparison operation.
* A *formula* is either an atom or formula connected by Boolean operator or qualifiers.
* A formula that is not an atom can be thought of a compound Boolean expression.
* A variable is *bound* if it appears in qualifier expressions. Otherwise, it is a *free* variable.
* Free variables can only appear in the LHS of |.
* All RA expressions can be expressed in RC.
* RA and RC have the same expressive power.
* Any query language that can express all RA is known to be relational complete.
* Relational Calculus expressions need to be *safe*: results should be a*finite* set of tuples.
* Care should be taken especially for the negation operation. E.g. {s |¬ (s ∈ Student) } is unsafe.
* For a given implementation of relational calculus:
	+ There may be restrictions in supported constructs.
	+ There may be certain *canonical* requirements: e.g. *conjunction* (joined by the and operator) of *disjunction* (joined by the or operator).

**Example:**

{i | i ∈ I ∧ i % 2 =0}
{i | i ∈ I, i % 2 =0} -- set builder form.

{t | ∃r ∈R, r.firstname = t.firstname, r.lastname = t.lastname}

* t is a *free* variable.
* It will have two attributes: t.firstname and t.lastname.

Alternatively, we can use the set builder form in the LHS before |:

{(r.firstname, r.lastname) | r ∈ R}

R(A,B,C,D) / S(C,D)

{(a,b) | (∀(c,d) ∈ S) (a,b,c,d) ∈ R)}

***Exercises:***

How do you use RC to implement RA operations?

**5.3 TRC**

* The variables in TRC are tuples.
* SQL is based on TRC.

**5.4. DRC**

* The variables in DRC are attributes (domain values).
* Query By Example (QBE) is based on DRC.

**Exercise:**

Work on some of the query questions listed in the [toyu Query Exercise](https://dcm.uhcl.edu/yue/courses/joinDB/Fall2024/notes/rarc/toyu_Ex.pdf) in DRC and TRC.