Informatics 1: Data & Analysis

Lecture 7: SQL

Ian Stark

School of Informatics
The University of Edinburgh

Tuesday 6 February 2018
Semester 2 Week 4

Homework from Friday

1. Read This

Either or both of these study guides.

Learning Essentials: Note Making
The University of Manchester
https://is.gd/manchesternotemaking
https://is.gd/manchesternotemakingpdf

How to Take Lecture Notes
wikiHow
http://www.wikihow.com/Take-Lecture-Notes

See also: Note-making styles http://www.sussex.ac.uk/skillshub/?id=305
Taking notes in lectures http://www.sussex.ac.uk/skillshub/?id=306

2. Do This

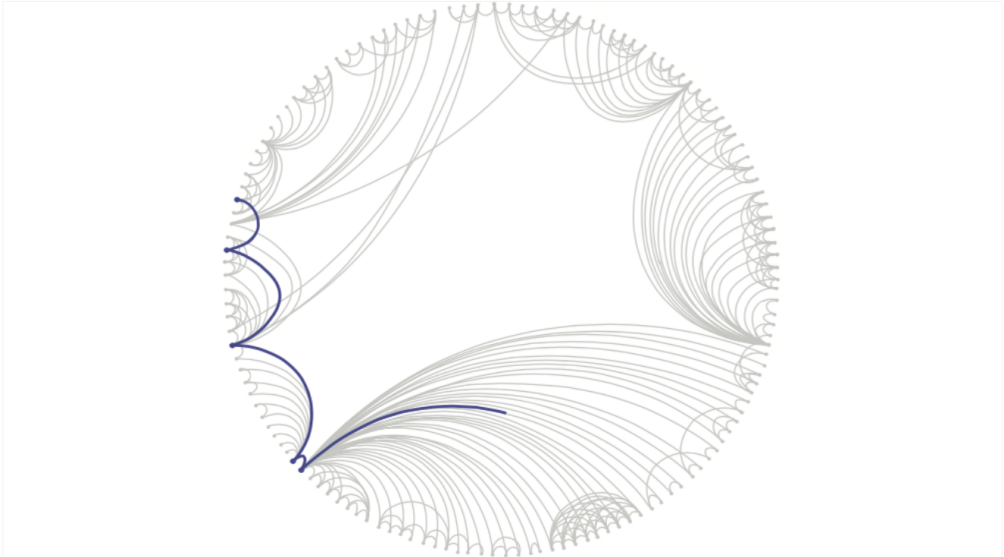
Work through the exercises for *Tutorial 2: Relational Modelling*. For more practice, try some of the additional examples.

Phone Home !

E.T. The Extraterrestrial (Universal Studios)

Three and a half degrees of separation

By: Smriti Bhagat, Moira Burke, Carlos Diuk, Ismail Onur Filiz, Sergey Edunov



Lecture Plan for Weeks 1–4

Data Representation

This first course section starts by presenting two common data representation models.

- The *entity-relationship (ER)* model
- The *relational* model

Data Manipulation

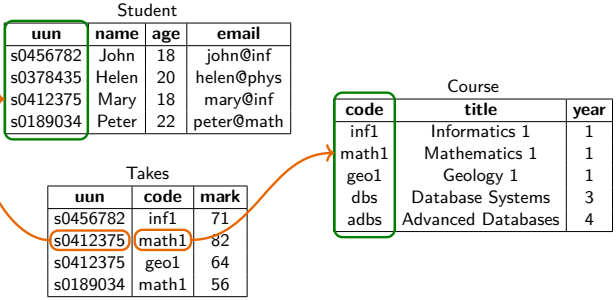
This is followed by some methods for manipulating data in the relational model and using it to extract information.

- *Relational algebra*
- The *tuple relational calculus*
- The query language *SQL*

The State We're In

Relational models

- Relations: Tables matching schemas
- Schema: A set of field names and their domains
- Table: A set of tuples of values for these fields



The State We're In

Relational algebra

A mathematical language of bulk operations on relational tables. Each operation takes one or more tables, and returns another.

selection σ, projection π, renaming ρ, union $\cup$, difference $-$, cross-product $\times$, intersection $\cap$ and different kinds of join $\bowtie$

Tuple relational calculus (TRC)

A declarative mathematical notation for writing queries: specifying information to be drawn from the linked tables of a relational model.

Structured Query Language (SQL)

A mostly-declarative programming language for interacting with relational database management systems (RDBMS): defining tables, changing data, writing queries.

International Standard ISO 9075:2016

SQL: Structured Query Language

- SQL is the standard language for interacting with relational database management systems
- Substantial parts of SQL are declarative: code states what should be done, not necessarily how to do it.
- When actually querying a large database, database systems take advantage of this to plan, rearrange, and optimize the execution of queries.
- Procedural parts of SQL do contain imperative code to make changes to the database.
- While SQL is an international standard (ISO 9075), individual implementations have notable idiosyncrasies and code is not entirely portable.

Oracle : MySQL : Microsoft SQL Server : PostgreSQL : DB2 : Microsoft Access : SQLite

SQL Data Manipulation Language

In an earlier lecture we saw the SQL Data Definition Language (DDL), used to declare the schema of relations and create new tables.

This lecture introduces the Data Manipulation Language (DML) which allows us to:

- Insert, delete and update rows in existing tables;
- Query the database.

Here "query" covers many different scales: from extracting a single statistic or a simple list, to building large tables that combine several others, or creating *views* on existing data.

SQL is a large and complex language. Here we shall only see some of the basic and most important parts. For a much more extensive coverage of the topic, sign up for the *Database Systems* course in Year 3.

Inserting Data into a Table

```
CREATE TABLE Student (
    uun     VARCHAR(8),
    name    VARCHAR(20),
    age     INTEGER,
    email   VARCHAR(25),
    PRIMARY KEY (uun) )
```

The following adds a single record to this table:

```
INSERT
    INTO Student (uun, name, age, email)
    VALUES ('s1428751', 'Bob', 19, 'bob@sms.ed.ac.uk')
```

For multiple records, repeat; or consult your RDBMS manual.

It is possible to omit field names; but if we include them then the compiler will check them against the schema for us.

Update and Delete Rows in a Table

Update

This command changes the name recorded for one student:

```
UPDATE Student
    SET name = 'Bobby'
    WHERE uun = 's1428571'
```

Delete

This deletes from the table all records for students named “Bobby”:

```
DELETE
    FROM Students
    WHERE name = 'Bobby'
```

Simple Query

Extract all records for students older than 19.

SELECT $*$
FROM Student
WHERE age $>$ 19

Returns a new table with the same schema as Student but only some of its rows.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query

Extract all records for students older than 19.

SELECT $*$
FROM Student
WHERE age $>$ 19

Returns a new table with the same schema as Student but only some of its rows.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

uun	name	age	email
s0378435	Helen	20	helen@phys
s0189034	Peter	22	peter@math

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

Tuple Relational Calculus

SQL is similar in form to the comprehensions of tuple relational calculus:

$$\{ S \mid S \in \text{Student} \wedge S.\text{age} > 19 \}$$

Efficiently computing this with relational algebra operations is the job of an SQL compiler.

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

Variations

We can explicitly name the selected fields.

```
SELECT uun, name, age, email
FROM Student
WHERE age > 19
```

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

Variations

We can identify which table the fields are from.

```
SELECT Student.uun, Student.name, Student.age, Student.email
FROM Student
WHERE Student.age > 19
```

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

Variations

We can locally abbreviate the table name with an *alias*.

```
SELECT S.uun, S.name, S.age, S.email
FROM Student AS S
WHERE S.age > 19
```

Simple Query

Extract all records for students older than 19.

```
SELECT *
FROM Student
WHERE age > 19
```

Returns a new table with the same schema as Student but only some of its rows.

Variations

We can save ourselves a very small amount of typing.

```
SELECT S.uun, S.name, S.age, S.email
FROM Student S
WHERE S.age > 19
```

Anatomy of an SQL Query

SELECT *field-list*
FROM *table-list*
[**WHERE** *qualification*]

- The **SELECT** keyword starts the query.
- The list of fields specifies *projection*: what columns should be retained in the result. Using $*$ means all fields.
- The **FROM** clause lists one or more tables from which to take data.
- An optional **WHERE** clause specifies *selection*: which records to pick out and return from those tables.

Anatomy of an SQL Query

SELECT *field-list*
FROM *table-list*
[**WHERE** *qualification*]

The *table-list* in the **FROM** clause is a comma-separated list of tables to be used in the query:

...
FROM Student, Takes, Course
...

Each table can be followed by an alias Course **AS** C, or even just Course C.

Anatomy of an SQL Query

SELECT *field-list*
FROM *table-list*
[**WHERE** *qualification*]

The *field-list* after **SELECT** is a comma-separated list of expressions involving names of fields from the tables in **FROM**.

SELECT name, age
...
...

Field names can be referred to using table names or aliases: such as Student.name or C.title.

Anatomy of an SQL Query

SELECT *field-list*
FROM *table-list*
[**WHERE** *qualification*]

The *qualification* in the **WHERE** clause is a logical expression built from tests involving field names, constants and arithmetic expressions.

...
...
WHERE age $>$ 18 **AND** age $<$ 65

Expressions can involve a range of numeric, string and date operations.

Simple Query with Multiset Result

Extract all recorded student ages.

SELECT age
FROM Student

Returns a new table, similar to Student, but containing only some of its columns.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query with Multiset Result

Extract all recorded student ages.

SELECT age
FROM Student

Returns a new table, similar to Student, but containing only some of its columns.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query with Multiset Result

Extract all recorded student ages.

SELECT age
FROM Student

Returns a new table, similar to Student, but containing only some of its columns.

age
18
20
18
22

Aside: Multisets

The relational model given in earlier lectures has tables as *sets* of rows: so the ordering doesn't matter, and there are no duplicates.

Actual SQL does allow duplicate rows, with a **SELECT DISTINCT** operation to remove duplicates on request.

Thus SQL relations are not sets but *multisets* of rows. A multiset, or *bag*, is like a set but values can appear several times. The number of repetitions of a value is its *multiplicity* in the bag.

The following are distinct multisets:

$$\{\!|2,3,5|\!\} \qquad \{\!|2,3,3,5|\!\} \qquad \{\!|2,3,3,5,5,5|\!\} \qquad \{\!|2,2,2,3,5|\!\}$$

Ordering still doesn't matter, so these are all the same multiset:

$$\{\!|2,2,3,5|\!\} \qquad \{\!|2,3,2,5|\!\} \qquad \{\!|5,2,3,2|\!\} \qquad \{\!|3,2,2,5|\!\}$$

Simple Query with Set Result

Extract the set of student ages in the table.

SELECT DISTINCT age
FROM Student

Returns a new table, similar to Student, but containing only some elements from some of its columns.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query with Set Result

Extract the set of student ages in the table.

SELECT DISTINCT age
FROM Student

Returns a new table, similar to Student, but containing only some elements from some of its columns.

Student

uun	name	age	email
s0456782	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Simple Query with Set Result

Extract the set of student ages in the table.

SELECT DISTINCT age
FROM Student

Returns a new table, similar to Student, but containing only some elements from some of its columns.

age
18
20
22

Quotation Marks in SQL Syntax

SQL uses alphanumeric tokens of three kinds:

- Keywords: **SELECT**, **FROM**, **UPDATE**, ...
- Identifiers: Student, uun, age, S, ...
- Strings: 'Bobby', 'Informatics 1', ...

Each of these kinds of token has different rules about case sensitivity, the use of quotation marks, and whether they can contain spaces.

While programmers can use a variety of formats, and SQL compilers should accept them, programs that *generate* SQL code are often rather cautious in what they emit and may use quotation everywhere possible.

Most SQL is written by machines, for machines.

Know Your Syntax

		Case sensitive?	Spaces allowed?	Quotation character?	Quotation Required?
Keywords	**FROM**	No	Never	None	No
Identifiers	Student	Maybe	If quoted	"Double"	If spaces
Strings	'Bob'	It depends	Yes	'Single'	Always

For example:

```
select uun
from Student as "Student Table"
where "Student Table".age > 19 and "name" = 'Bobby Tables'
```

It's always safe to use only uppercase keywords and put quotation marks around all identifiers. Some tools will do this automatically.

Tutorial Attendance and Participation !

Bring your solutions, or your attempts at them. You will need to be able to show these to your tutor and exchange them with other students.

Come to tutorials prepared. Students who have not even attempted the exercises will be sent away to do them elsewhere and return later.

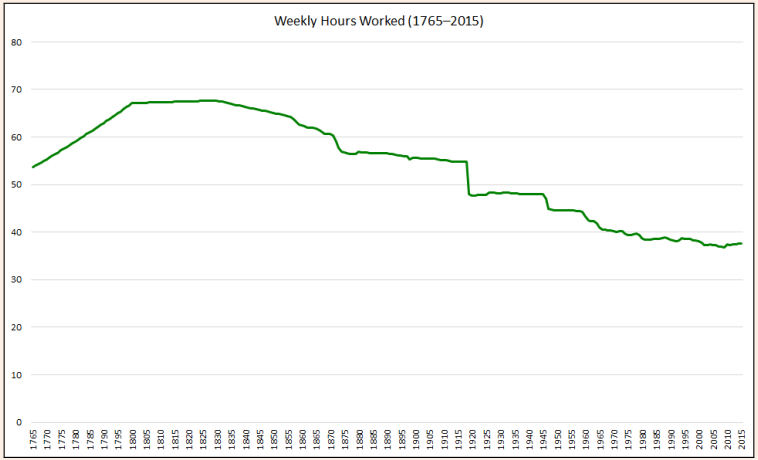
Even so, if you feel you are falling behind and cannot complete the work **do not skip the tutorial.** Instead, do what you can and then explain at the tutorial where you could make no more progress. Tutors are there to help you at whatever level you have reached.

You can also ask for help on Piazza at any time: there are ten tutors and over 170 students there to give advice.

Most important: start early!

Working Hours

!



Bank of England “Three Centuries of Macroeconomic Data”

Working Hours !

- Full-time study is a full-time job. During all weeks of semester, plan to spend at least 40 hours each week across your courses.
- Within each week, balance time between courses according to their relative credit point weights out of 60.
- For a 10-point course like Inf1-DA, that suggests at least 6–7 hours of study per week.
- Inf1-DA has three contact hours per week, which means spending at least the same again in independent study.
- This rule of thumb applies to many courses: for every directly taught hour (lecture, tutorial, lab), add at least one hour for self-study. In later years, this may become two, or three, or ...

Some activities are very different, such as field trips or research projects

Outside Employment !

Some students also undertake paid or voluntary work outside their studies. This can certainly be beneficial, and not just for the money: it widens your experience and is a chance get outside the university bubble.

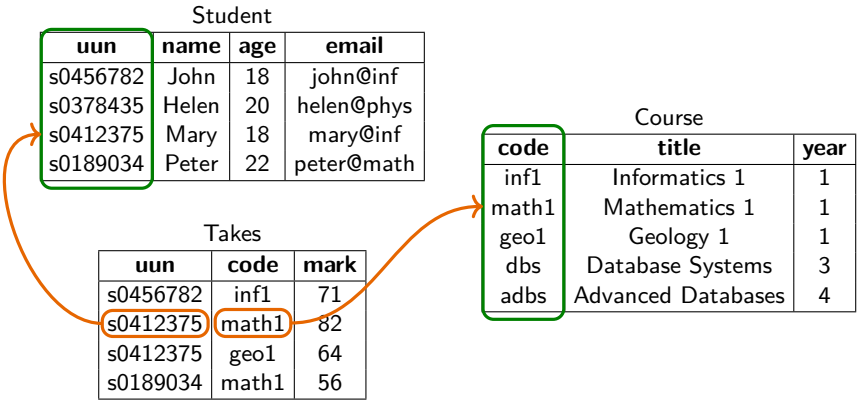
However, too much outside work will affect your study and limit your achievement. I recommend these guidelines:

- Never take on work that clashes with any timetabled class.
- Up to six hours a week is like an additional taught course: it's possible, but only if you are confident about your studies and committed to managing your time strictly.
- Beyond this begins to risk damaging your degree work. I suggest an absolute maximum of 12 hours a week during teaching times.

The University states a limit of 15 outside hours each week: giving a baseline of 55 hours working each week, which I think is unsustainable.

http://www.ed.ac.uk/careers/looking-for-work/part-time-vacation/combining-work-study

Students and Courses



Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
    AND Takes.code = Course.code
    AND Course.title = 'Mathematics 1'
```

Take rows from all three tables at once,

Student

uun	name	age	email
s0456780	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Takes

uun	code	mark
s0456780	inf1	71
s0412375	math1	82
s0412375	geo1	64
s0189034	math1	56

Course

code	title	year
inf1	Informatics 1	1
math1	Mathematics 1	1
geo1	Geology 1	1
dbs	Database Systems	3
adbs	Advanced Databases	4

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
    AND Takes.code = Course.code
    AND Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test,

Student

uun	name	age	email
s0456780	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Takes

uun	code	mark
s0456780	inf1	71
s0412375	math1	82
s0412375	geo1	64
s0189034	math1	56

Course

code	title	year
inf1	Informatics 1	1
math1	Mathematics 1	1
geo1	Geology 1	1
dbs	Database Systems	3
adbs	Advanced Databases	4

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
    AND Takes.code = Course.code
    AND Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test,

Student

uun	name	age	email
s0456780	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Takes

uun	code	mark
s0456780	inf1	71
s0412375	math1	82
s0412375	geo1	64
s0189034	math1	56

Course

code	title	year
inf1	Informatics 1	1
math1	Mathematics 1	1
geo1	Geology 1	1
dbs	Database Systems	3
adbs	Advanced Databases	4

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
    AND Takes.code = Course.code
    AND Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test, and return the named columns.

Student

uun	name	age	email
s0456780	John	18	john@inf
s0378435	Helen	20	helen@phys
s0412375	Mary	18	mary@inf
s0189034	Peter	22	peter@math

Takes

uun	code	mark
s0456780	inf1	71
s0412375	math1	82
s0412375	geo1	64
s0189034	math1	56

Course

code	title	year
inf1	Informatics 1	1
math1	Mathematics 1	1
geo1	Geology 1	1
dbs	Database Systems	3
adbs	Advanced Databases	4

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE  Student.uun = Takes.uun
    AND  Takes.code = Course.code
    AND  Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test, and return the named columns.

name	email
Mary	mary@inf
Peter	peter@math

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
    AND Takes.code = Course.code
    AND Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test, and return the named columns.

Expressed in tuple relational calculus:

$$\{\, R \mid \exists S \in \text{Student}, T \in \text{Takes}, C \in \text{Course} \,.\; R.\text{name} = S.\text{name} \wedge R.\text{email} = S.\text{email} \wedge S.\text{uun} = T.\text{uun} \wedge T.\text{code} = C.\text{code} \wedge C.\text{title} = \text{"Mathematics 1"} \,\}$$

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE  Student.uun = Takes.uun
   AND  Takes.code = Course.code
   AND  Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test, and return the named columns.

Implemented in relational algebra,

$$\pi_{\text{name,email}}(\sigma_{\begin{pmatrix}\text{Student.uun} = \text{Takes.uun} \\ \wedge\, \text{Takes.code} = \text{Course.code} \\ \wedge\, \text{Course.name} = \text{"Mathematics 1"}\end{pmatrix}}(\text{Student} \times \text{Takes} \times \text{Course}))$$

Example Query

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE  Student.uun = Takes.uun
   AND  Takes.code = Course.code
   AND  Course.title = 'Mathematics 1'
```

Take rows from all three tables at once, pick out only those row combinations which match the test, and return the named columns.

Implemented in relational algebra, in several possible ways:

$$\pi_{\text{name,email}}(\sigma_{\text{title}=\text{"Mathematics 1"}}(\text{Student} \bowtie \text{Takes} \bowtie \text{Course}))$$

$$\pi_{\text{name,email}}(\text{Student} \bowtie (\text{Takes} \bowtie (\sigma_{\text{title}=\text{"Mathematics 1"}}(\text{Course}))))$$

Query Evaluation

SQL **SELECT** queries are very close to a programming-language form for the expressions of the tuple relational calculus, describing the information desired but not dictating how it should be computed.

To do that computation, we need something more like relational algebra. A single **SELECT** statement combines the operations of join, selection and projection. This immediately suggests one possible strategy:

- Compute the complete cross product of all the **FROM** tables;
- Select all the rows which match the **WHERE** condition;
- Project out only the columns named on the **SELECT** line.

Real database engines don't do that. Instead, they use relational algebra to rewrite that procedure into a range of different possible *query plans*, estimate the cost of each — looking at indexes, table sizes, selectivity, potential parallelism — and then execute one of them.

Explicit Join in SQL

Find the names and email addresses of all students taking Mathematics 1.

```
SELECT Student.name, Student.email
FROM Student JOIN Takes ON Student.uun=Takes.uun
             JOIN Course ON Takes.code = Course.code
WHERE Course.title = 'Mathematics 1'
```

This is explicit **JOIN** syntax.

It has exactly the same effect as implicit **JOIN** syntax:

```
SELECT Student.name, Student.email
FROM Student, Takes, Course
WHERE Student.uun = Takes.uun
  AND Takes.code = Course.code
  AND Course.title = 'Mathematics 1'
```

Homework (1/2): Do This

A *transaction* is a single coherent operation on a database. This might involve substantial amounts of data, or take considerable computation; but is meant to be an all-or-nothing action.

The features that characterise a reliable implementation of transactions are standardly initialized as the *ACID* properties.

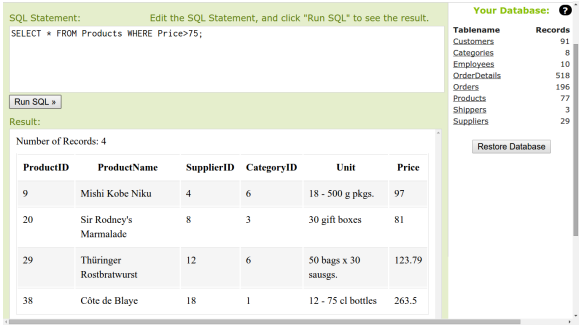
Task

Find out what each letter A C I D stands for here, and what those four terms mean.

Homework (2/2): Try This

Try writing some SQL by hand using one of these web demonstrators.

Basic	w3schools.com	https://tinyurl.com/try-sql
Includes a tutorial	SQL Bolt	http://sqlbolt.com
Advanced	SQL Fiddle	http://sqlfiddle.com



Summary

SQL: Structured Query Language

A declarative language for interacting with relational databases. SQL provides facilities to define tables; to add, update, and remove tuples; and to query tables in complex ways.

Writing Queries

Queries can be used to extract individual items of data or simple lists; to build large tables combining several others; and to generate *views* on these.

SQL queries take a standard form: **SELECT** ... **FROM** ... **WHERE** ... to identify the fields returned, the tables used, and which records to pick.

Executing Queries

Database engines prepare multiple *query plans* and estimate their cost (in memory space, disk I/O, time) before choosing one to execute.