Student ID: **First Name:** **Last Name:**

School of Engineering and Computer Science

SWEN 304 **Database System Engineering**

Assignment 2

Due: 23:59, Friday, 6 May 2022

The objective of this assignment is to test your understanding of Relational Algebra and Query Processing and Optimization. It is worth **10%** of your final grade. The Assignment is marked out of 100.

In Appendix 1, you will find short recapitulation of formulae needed for cost-based optimization. Appendix 2 contains an abbreviated instruction for using PostgreSQL.

Submission Instructions:

- Please submit your project in **pdf** with your **student ID** and **Name** via the submission system.
- Submissions not in **pdf** will incur **3 marks** deduction from the total marks.

Question 1. Relational Algebra [40 marks]

Consider the Suppliers database schema given below.

Set of relation schemas:

Products ({*PId*, *Description, Category*}, {*PId*}),
Company ({*CId*, *Name*, *Phone, Location*}, {*CId*})
Supplied_By ({*PId*, *CId, Amount, Year, Price*}, {*PId* + *CId* + *Year*})

```
group by pid count >=2 join produc pid
```

Set of referential integrity constraints:
Supplied_By [*PId*] ⊆ *Products* [*PId*],
Supplied_By [*CId*] ⊆ *Company* [*CId*]

In this question, you will be given queries on the Suppliers database above in two ways. Firstly, queries are given in plain English and you must answer them in Relational Algebra. Secondly, queries are given in Relational Algebra and you must answer them in plain English and in SQL. Submit all your answers in printed form.

a) [25 marks] Translate the following query into Relational Algebra:

1) [5 marks] For all products of category 'meat' list their descriptions and the names of their supplying companies.

$$\pi_{Description,\ Name}(Company * (\sigma_{Category='meat'}(Products) * Supplied\_By))$$

2) [5 marks] Retrieve the names of all companies who *always* supply products of category 'fruit'.

$$\pi_{Name}(Company * (\sigma_{Category='fruit'}(Products) * Supplied\_By)) -$$

$$\pi_{Name}(Company * (\sigma_{Category \neq 'fruit'}(Products) * Supplied\_By))$$

3) [5 marks] Retrieve the descriptions of all products that are supplied by *two or more* companies.

$$\pi_{Description}(\pi_{PId}(\sigma_{CId>=2}(PId\ g\ count\ (CId)(Supplied\_By))) * Products)$$

4) [5 marks] Retrieve the names of companies who have *not* supplied any product in 2022.

$$\pi_{Name}(\pi_{CId}(Company) - \pi_{CId}(Company * (\sigma_{Year='2022'}(Supplied\_By))))$$

5) [5 marks] Retrieve the description of products that have been supplied by companies in Wellington who *always* supply products with price lower than $100.00.

$$\pi_{Description}(Products * ((\sigma_{Location='Wellington'}(Company)) * (\sigma_{Price<100}(Supplied\_By)))) -$$

$$\pi_{Description}(Products * ((\sigma_{Location='Wellington'}(Company)) * (\sigma_{Price>=100}(Supplied\_By))))$$

b) [15 marks] Translate the following queries into plain English and into SQL:

1) $\pi_{Name,Phone}(Products * (\sigma_{Amount>1000}(Supplied\_By) * Company))$

Retrieve the names and phone numbers of companies that supplied more than 1000 products.

SELECT Name, Phone FROM Products NATURAL JOIN Supplied_By NATURAL JOIN Company WHERE Amount > 1000;

2) $\pi_{name,\ Description}(\sigma_{price<10}(Products * (Supplied\_By * Company)))$

Retrieve the names of companies and descriptions of products that supplied products which price less than 10.

SELECT Name, Description FROM Products NATURAL JOIN Supplied_By NATURAL JOIN Company WHERE Price < 10;

3) $\pi_{CId}(\sigma_{Amount>1000}(Supplied\_By)) \cap \pi_{CId}(Supplied\_By * (\sigma_{Description='Cake'}(Products)))$

Retrieve the CId of companies who supplied more than 1000 cakes.

SELECT CId FROM Products NATURAL JOIN Supplied_By WHERE Amount > 1000 AND Description = 'Cake';

Question 2. Heuristic and Cost-Based Query Optimization [40 marks]

The DDL description of a part of the University database schema is given below.

```
CREATE DOMAIN StudIdDomain AS int NOT NULL CHECK (VALUE >= 30000000 AND
VALUE <= 300099999);

CREATE DOMAIN CharDomain AS char(15) NOT NULL;

CREATE DOMAIN NumDomain AS smallint NOT NULL CHECK (VALUE BETWEEN 0 AND
10000);

CREATE TABLE Student (
StudentId StudIdDomain PRIMARY KEY,
Name CharDomain,
NoOfPts NumDomain CHECK (NoOfPts < 1000),
Tutor StudIdDomain REFERENCES Student(StudentId)
);

CREATE TABLE Course (
CourseId CharDomain PRIMARY KEY,
CourName CharDomain,
ClassRep StudIdDomain REFERENCES Student(StudentId)
);

CREATE TABLE Enrolled (
StudentId StudentIdDomain REFERENCES Student,
CourseId CharDomain REFERENCES Course,
Term NumDomain CHECK(Term BETWEEN 2000 AND 2100),
Grade CharDomain CHECK (Grade IN ('A+', 'A', 'A-', 'B+', 'B', 'B-',
'C+', 'C')),
PRIMARY KEY (StudentId, CourseId, Term)
);
```

a) [20 marks] Heuristic query optimization

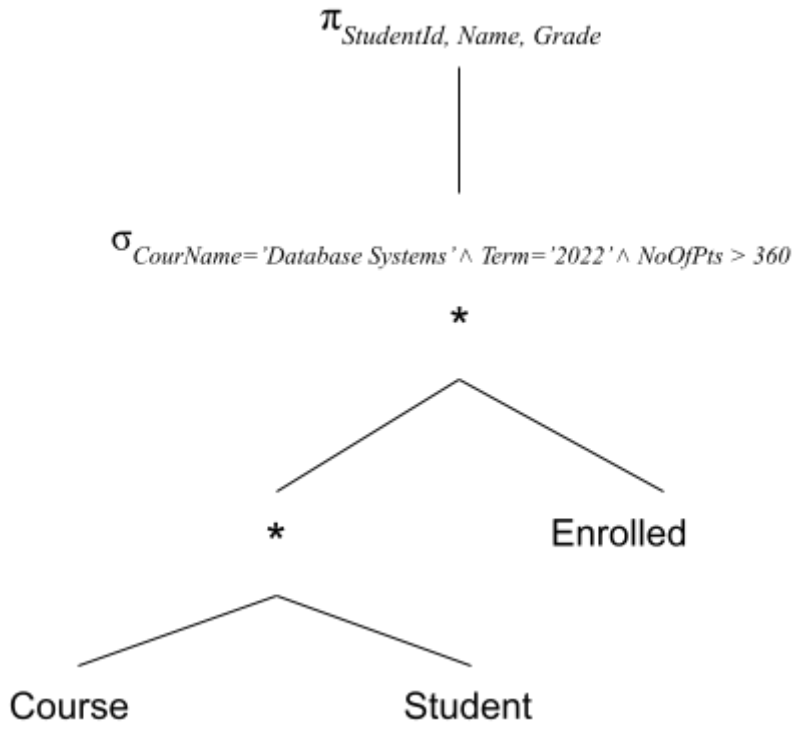
1)[5 marks] Transfer the following query into Relational Algebra.

```
SELECT StudentId, Name, Grade

FROM Student NATURAL JOIN Enrolled NATURAL JOIN Course

WHERE CourName = 'Database Systems' AND Term = 2022
                AND NoOfPts > 360;
```

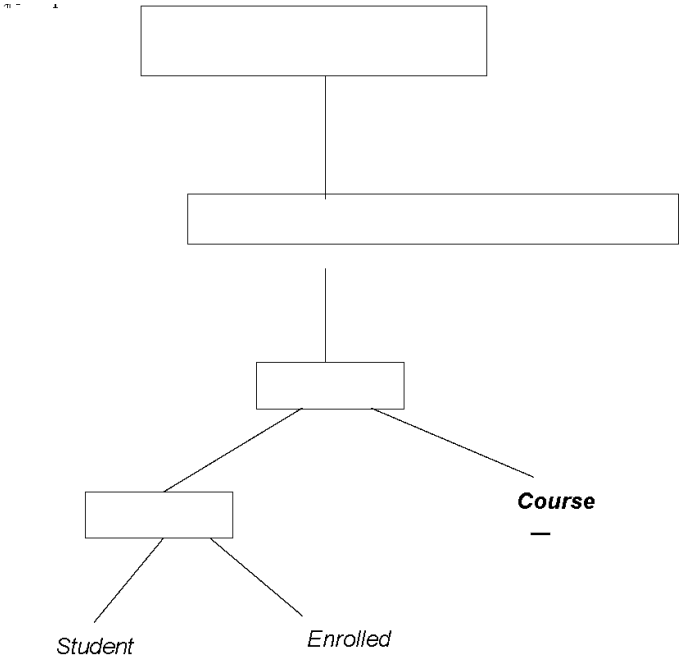
$$\pi_{StudentId,\ Name,\ Grade}\ (\sigma_{CourName='Database\ Systems' \wedge Term='2022' \wedge NoOfPts > 360}((Course * Student) * Enrolled))$$

[3 marks] Draw a query tree for the relational algebra query from **1**).

ANSWER

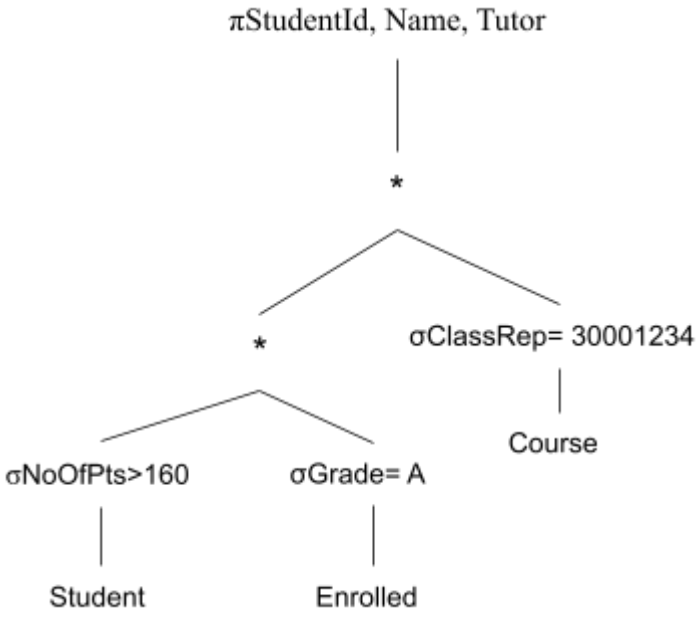


2)[12 marks] Transfer the following query tree into an optimized query tree using the query optimization heuristics.

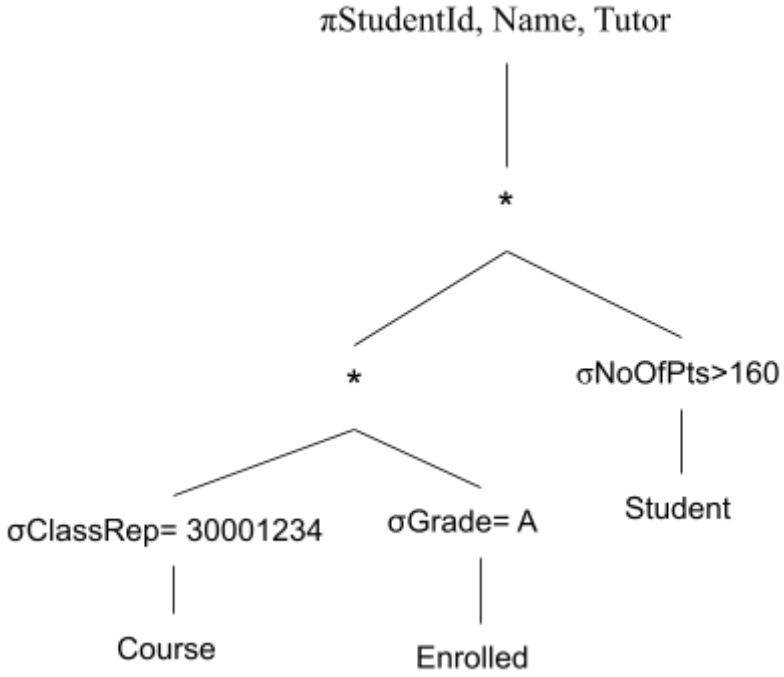


ANSWER

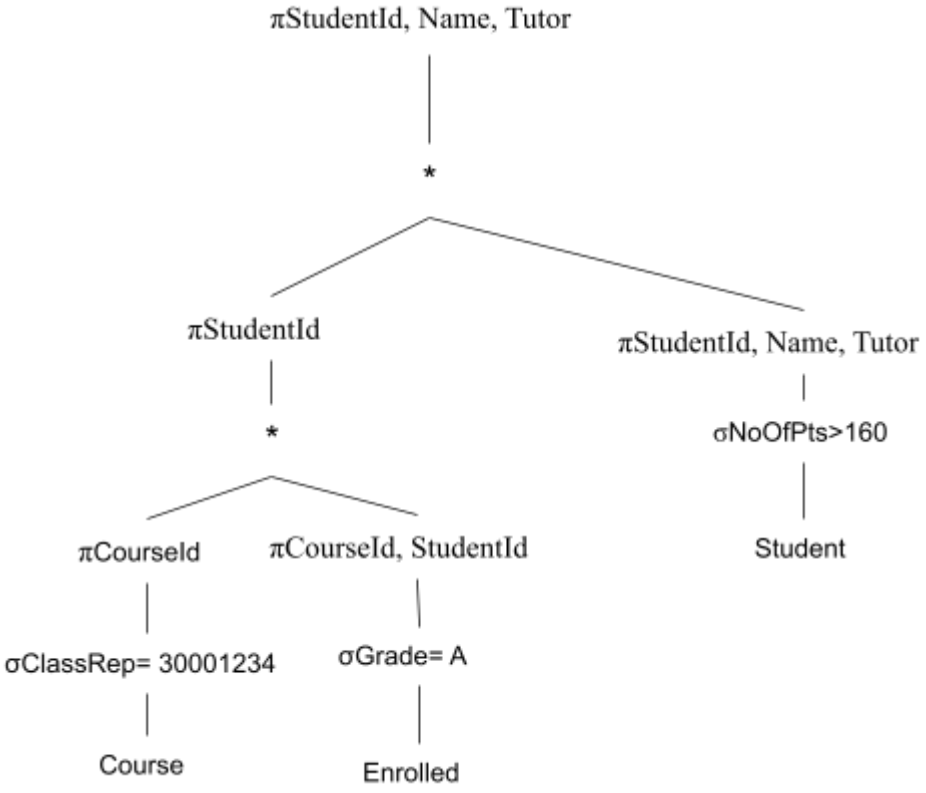
Move select operations down the tree (Rule 6)



Assume there are less ClassRep = 30001234 courses than NoOfPts > 160 students. Switching Course and Student so that the very restrictive select operation could be applied as early as possible (Rule 9)



keeping in intermediate relations only the attributes needed by subsequent operations by applying project (p) operations as early as possible (Rule 7)



b) [20 marks] Query cost calculation

Suppose the following:

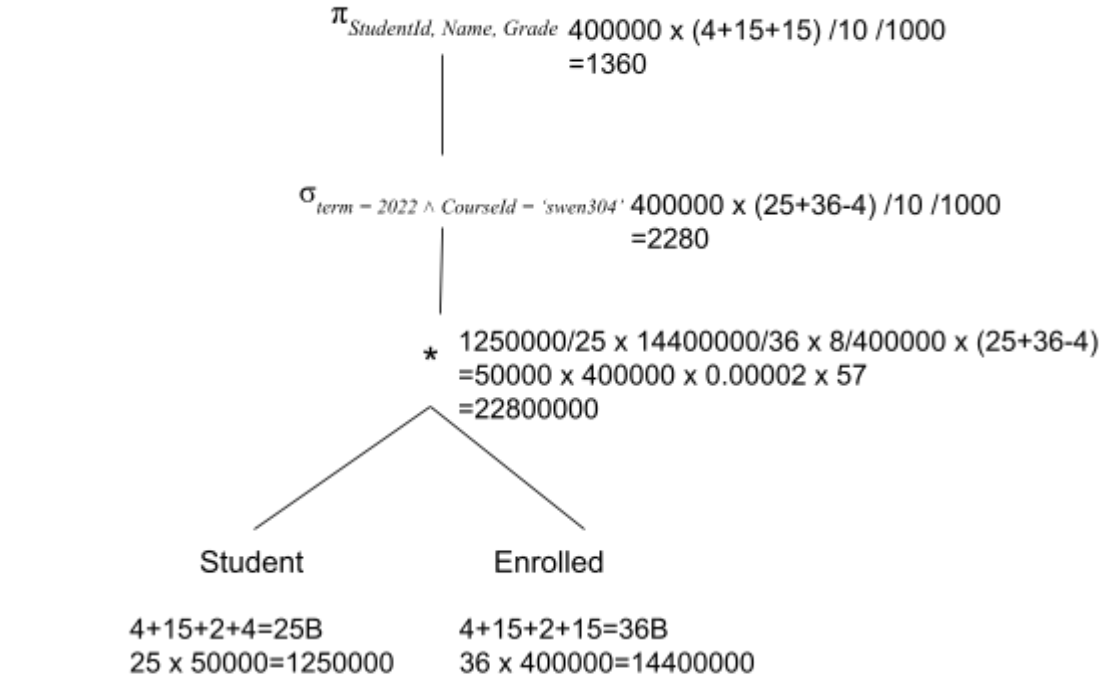
- The *Student* relation contains data about $n_s = 50000$ students (enrolled during the past *10* years),
- The *Course* relation contains data about $n_c = 1000$ courses,
- *The Enrolled relation contains data about* $n_e = 400{,}000$ *enrollments,*
- *All data distributions are uniform (i.e. each year approximately the same number of students enrolls into each course),*
- *The intermediate results of the query evaluation are materialized,*
- *The final result of the query is materialized.*

Note: If you feel that some information is missing, please make a reasonable assumption and make you assumption explicit in your answer.

For each of the given two queries below draw a query tree and calculate the cost of executing query.

(i) $\pi_{\text{StudentId, Name, Grade}}$ ($\sigma_{\text{term = 2022} \wedge \text{CourseId = 'SWEN304'}}$ (Student * Enrolled))

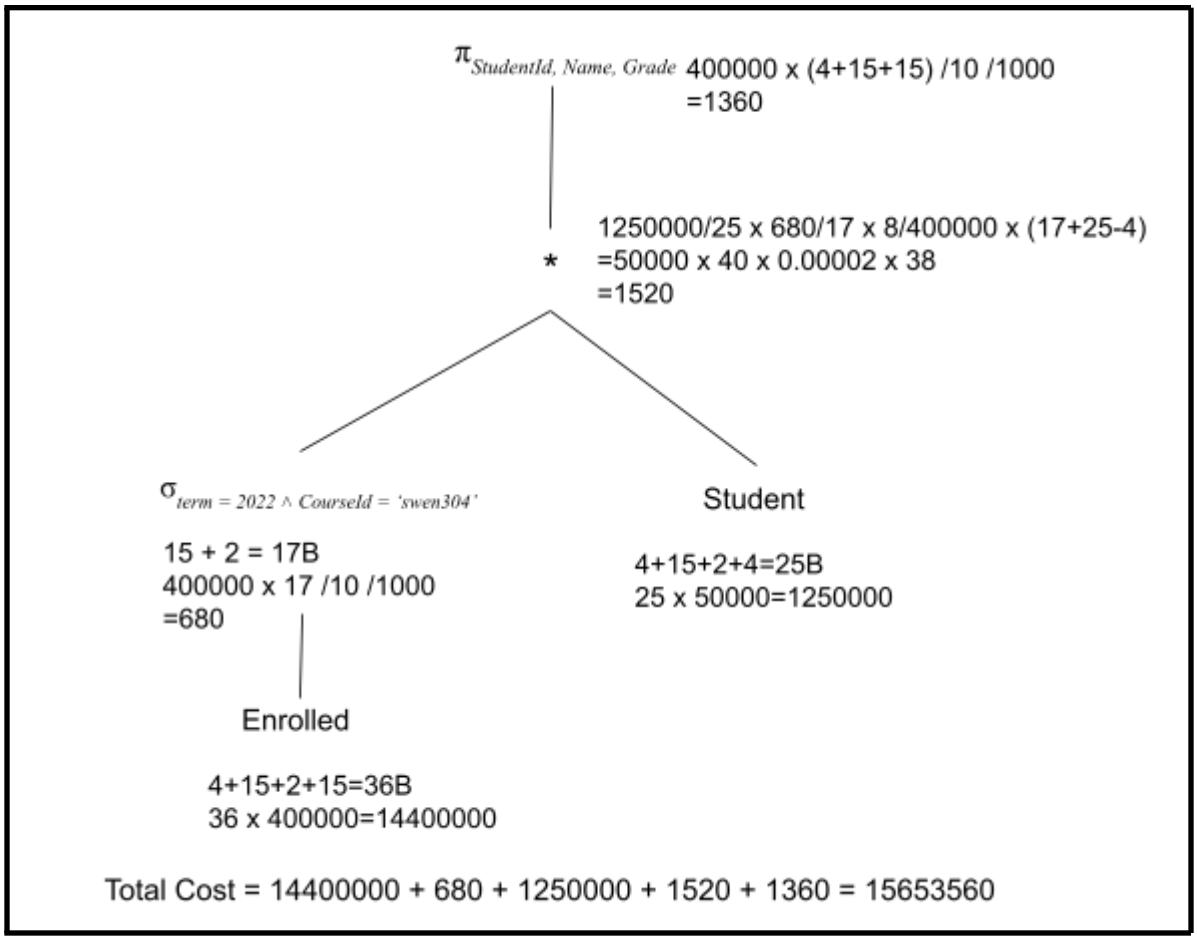
ANSWER



Total cost: 1250000 + 14400000 + 22800000 + 2280 + 1360 = 38453640

(ii) $\pi_{StudentId,\ Name,\ Grade}$ (Student * $\sigma_{term = 2022 \wedge CourseId = \text{'SWEN304'}}$ (Enrolled))

ANSWER



iii) Which of the above two trees has a smaller query cost and why?

ANSWER

Because 38453640 > 15653560. Therefore the second one has a smaller query cost. Because the second query tree does the selection in Enrolled relation first which can get less StudentId from it to join the Student relation. It will reduce lots of costs.

Hint: *To find out about the sizes of attributes in PostgreSQL please consult the documentation (www.postgresql.org/docs/9.2/static/datatype.html) or check this tutorial (www.tutorialspoint.com/postgresql/postgresql_data_types.htm).*

Note: *Use the formulae introduced in the lecture notes (also in Appendix) to compute the estimated query costs. Total query cost of a query tree is the sum of the costs of all leaves, the intermediate notes and the root of a query tree.*

Question 3. PostgreSQL and Query Optimization [20 marks]

You are asked here to improve efficiency of two database queries. The only condition is that after making improvements your queries produce the same results as the original ones, and your databases contain the same information as before.

For the optimization purposes, you will use two databases. A database that was dumped into the file

`GiantCustomer.data`

And the other database that was dumped into the file

`Library.data`

Both files are accessible from the course Assignments web page. Copy both files into your private directory. You are to:

i. Use PostgreSQL in order to create a database and to execute the command

`psql –d <database_name> -f ~/<file_name>`

This command will execute the `CREATE TABLE` and `INSERT` commands stored in the file `<file_name>`, and make a database for you.

ii. Execute the following commands:

- `VACUUM ANALYZE customer;`

on the database containing `GiantCustomer.data` file, and

- `VACUUM ANALYZE customer;`
- `VACUUM ANALYZE loaned_book;`

on database containing `Library.data` file.
These commands will initialize the catalog statistics of your database `<database_name_x>`, and allow the query optimizer to calculate costs of query execution plans.

iii. Read the PostgreSQL Manual and learn about `EXPLAIN` command, since you will need it when optimizing queries. Note that a PostgreSQL answer to `EXPLAIN <query>` command looks like:

```
NOTICE:  QUERY PLAN:

Merge Join  (cost=6.79..7.10 rows=1 width=24)
  ->  Sort  (cost=1.75..1.75 rows=23 width=12)
        ->  Seq Scan on cust_order o  (cost=0.00..1.23 rows=23 width=12)
  ->  Sort  (cost=5.04..5.04 rows=2 width=12)
        ->  Seq Scan on order_detail d  (cost=0.00..5.03 rows=2 width=12)
```

Here, PosgreSQL is informing you that it decided to apply Sort Merge Join algorithm and that this join algorithm requires Sequential Scan and Sort of both relations. The shaded number `7.10` is an estimate of the query execution cost made by PostgreSQL. When making an

improved query, you will compare your achievement to this figure, and compute the relative improvement using the following formula

(original_cost – new_cost) / original_cost.

You may also want to use `EXPLAIN ANALYZE <query>` command that will give you additional information about the actual query execution time. Please note, the query execution time figures are not quiet reliable. They can vary from one execution to the other, since they strongly depend on the workload imposed on the database server by users. ***To get a more reliable query time measurement, you should run your query a number of times and then calculate the average***.

a) [6 marks] Improve the cost estimate of the following query:

```
select count(*) from customer where no_borrowed = 4;
```

issued against the database containing `GiantCustomer.data`. Make such changes to your database or to the query that will allow you to produce the same result as the original query, but in a more efficient way. Of course, your changes have to be fair. Analyze the output from the PostgreSQL query optimizer and make a plan on how to improve the efficiency of the query. *Show what you have done by copying appropriate messages from the PostgreSQL prompt and explain why you have done it, calculate the improvement*. Each time you want to quit with that database, please drop it, since it occupies a lot of memory space.

Marking schedule:
You will receive:

- 5 marks if your query cost estimate is at least 64% better than the original one.
- between 2 and 4 marks if your query cost estimate is between 20% and 60% better than the original one and your marks will be calculated proportionally.
- up to 1 additional marks if you give reasonable explanations of what you have done.

ANSWER

```
postgres=# EXPLAIN select count(*) from customer where no_borrowed = 4;
                            QUERY PLAN
-------------------------------------------------------------------
 Aggregate  (cost=115.36..115.37 rows=1 width=8)
   ->  Seq Scan on customer  (cost=0.00..114.25 rows=443 width=0)
         Filter: (no_borrowed = 4)
```

```
postgres=# CREATE INDEX IX_No_borrowed ON Customer(no_borrowed);
CREATE INDEX
postgres=#  EXPLAIN select count(*) from customer where no_borrowed = 4;
                                      QUERY PLAN
---------------------------------------------------------------------------------------
 Aggregate  (cost=13.14..13.15 rows=1 width=8)
   ->  Index Only Scan using ix_no_borrowed on customer  (cost=0.28..12.04 rows=443 width=0)
         Index Cond: (no_borrowed = 4)
```

```
(115.36 - 13.14)/115.36 = 0.886 = 88.6%
(115.37 - 13.15)/115.37 = 0.886 = 88.6%
```

I created an index on no_borrowed of the Customer table. Check out the number of no_borrowed in each index versus its size. When SQL Server needs to count the number of rows in the table, it's smart enough to look at which object is the smallest, and then use that one for the count.

b) [4 marks] Improve the efficiency of the following query:

```
select * from customer where customerid = 4567;
```

issued against the database containing `GiantCustomer.data`. Make such changes to your database or to the query that will allow you to produce the same result as the original query, but in a more efficient way. Analyze the output from the PostgreSQL query optimizer and make a plan how to improve the efficiency of the query.
Show what you have done by copying appropriate messages from the PostgreSQL prompt and explain why you have done it, calculate the improvement. Each time you want to quit with that database, please drop it, since it occupies a lot of memory space.

Marking schedule:
You will receive

- 3 marks if your query cost estimate is 93% (or more) better than the original one.
- between 1 and 3 marks if your query cost estimate is better between 20% and 93% than the original one and your marks will be calculated proportionally to the improvement achieved.
- up to 1 additional marks if you give reasonable explanations of what you have done.

```
postgres=# EXPLAIN select * from customer where customerid = 4567;
                        QUERY PLAN
-----------------------------------------------------------
 Seq Scan on customer  (cost=0.00..114.25 rows=1 width=56)
   Filter: (customerid = 4567)
```

```
postgres=# CREATE INDEX IX_Customerid ON Customer(customerid);
CREATE INDEX
postgres=# EXPLAIN select * from customer where customerid = 4567;
                                QUERY PLAN
--------------------------------------------------------------------------
 Index Scan using ix_customerid on customer  (cost=0.28..8.30 rows=1 width=56)
   Index Cond: (customerid = 4567)
```

```
(114.25 - 8.3)/114.25 = 0.927 = 92.7%
```

I created an index on customerid of the Customer table. The index allows the database server to find and retrieve the specific row which customerid = 4567 much faster than it could do without an index.

c) [10 marks] The following query is issued against the database containing the data from `Library.data`. It retrieves information about every customer for whom there exist less than three other customers borrowing more books than she/he did:

```
select clb.f_name, clb.l_name, noofbooks
from (select f_name, l_name, count(*) as noofbooks
     from customer natural join loaned_book
     group by f_name, l_name) as clb
     where 3 > (select count(*)
                from (select f_name, l_name, count(*) as noofbooks
                      from customer natural join loaned_book
                      group by f_name, l_name) as clb1
                      where clb.noofbooks<clb1.noofbooks)
                      order by noofbooks desc;
```

Unfortunately, the efficiency of the given query is very poor. Make such changes to your database or to the query that will allow you to produce the same result as the original query, but in a more efficient way.
Show what you have done by copying appropriate messages from the PostgreSQL prompt, calculate the improvement, and briefly explain why the query given is inefficient and why your query is better.

Marking schedule:

You will receive:

- 3 marks if you explain in English how the query computes the answer,
- 5 marks if your query has a cost estimate 70% (or more) better than the original one (otherwise, your marks will be calculated proportionally to the improvement achieved),
- An additional 2 marks if you give reasonable explanations of why the query given is inefficient and why is your query better.

ANSWER

At first, it counts loaned book by customerid by join customer and loaned_book as clb. Then it counts loaned book by customerid by join customer and loaned_book again as clb1. And count a customer the noofbooks in clb is less than clb1 is less than 3 other customer to find the top 3 customers who borrowed more books than others.

```
postgres=# EXPLAIN select clb.f_name, clb.l_name, noofbooks
postgres-# from (select f_name, l_name, count(*) as noofbooks
postgres(#       from customer natural join loaned_book
postgres(#       group by f_name, l_name) as clb
postgres-#       where 3 > (select count(*)
postgres(#                  from (select f_name, l_name, count(*) as noofbooks
postgres(#                        from customer natural join loaned_book
postgres(#                        group by f_name, l_name) as clb1
postgres(#                        where clb.noofbooks<clb1.noofbooks)
postgres-#                        order by noofbooks desc;
                                        QUERY PLAN
-------------------------------------------------------------------------------------------------------------------------
 Sort  (cost=83.02..83.04 rows=8 width=40)
   Sort Key: clb.noofbooks DESC
   ->  Subquery Scan on clb  (cost=3.05..82.90 rows=8 width=40)
         Filter: (3 > (SubPlan 1))
         ->  HashAggregate  (cost=3.05..3.28 rows=23 width=40)
               Group Key: customer.f_name, customer.l_name
               ->  Hash Join  (cost=1.52..2.86 rows=26 width=32)
                     Hash Cond: (loaned_book.customerid = customer.customerid)
                     ->  Seq Scan on loaned_book  (cost=0.00..1.26 rows=26 width=4)
                     ->  Hash  (cost=1.23..1.23 rows=23 width=36)
                           ->  Seq Scan on customer  (cost=0.00..1.23 rows=23 width=36)
         SubPlan 1
           ->  Aggregate  (cost=3.44..3.45 rows=1 width=8)
                 ->  HashAggregate  (cost=3.05..3.34 rows=8 width=40)
                       Group Key: customer_1.f_name, customer_1.l_name
                       Filter: (clb.noofbooks < count(*))
                       ->  Hash Join  (cost=1.52..2.86 rows=26 width=32)
                             Hash Cond: (loaned_book_1.customerid = customer_1.customerid)
                             ->  Seq Scan on loaned_book loaned_book_1  (cost=0.00..1.26 rows=26 width=4)
                             ->  Hash  (cost=1.23..1.23 rows=23 width=36)
                                   ->  Seq Scan on customer customer_1  (cost=0.00..1.23 rows=23 width=36)
```

```
postgres=# select clb.f_name, clb.l_name, noofbooks
postgres-# from (select f_name, l_name, count(*) as noofbooks
postgres(#       from customer natural join loaned_book
postgres(#       group by f_name, l_name) as clb
postgres-#       where 3 > (select count(*)
postgres(#                  from (select f_name, l_name, count(*) as noofbooks
postgres(#                        from customer natural join loaned_book
postgres(#                        group by f_name, l_name) as clb1
postgres(#                        where clb.noofbooks<clb1.noofbooks)
postgres-#                        order by noofbooks desc;
     f_name      |     l_name      | noofbooks
-----------------+-----------------+-----------
 Thomson         | Wayne           |         5
 May-N           | Leow            |         4
 Peter           | Andreae         |         3
(3 行记录)
```

```
postgres=# select f_name, l_name, count(*)
postgres-# from customer natural join loaned_book
postgres-#      group by f_name, l_name
postgres-# order by count desc
postgres-# fetch first 3 rows only
postgres-# ;
     f_name      |     l_name      | count
-----------------+-----------------+-------
 Thomson         | Wayne           |     5
 May-N           | Leow            |     4
 Peter           | Andreae         |     3
(3 行记录)
```

```
postgres=# EXPLAIN select f_name, l_name, count(*)
postgres-# from customer natural join loaned_book
postgres-#      group by f_name, l_name
postgres-# order by count desc
postgres-# fetch first 3 rows only
postgres-# ;
                                    QUERY PLAN
-----------------------------------------------------------------------------------------
 Limit  (cost=3.58..3.59 rows=3 width=40)
   ->  Sort  (cost=3.58..3.64 rows=23 width=40)
         Sort Key: (count(*)) DESC
         ->  HashAggregate  (cost=3.05..3.28 rows=23 width=40)
               Group Key: customer.f_name, customer.l_name
               ->  Hash Join  (cost=1.52..2.86 rows=26 width=32)
                     Hash Cond: (loaned_book.customerid = customer.customerid)
                     ->  Seq Scan on loaned_book  (cost=0.00..1.26 rows=26 width=4)
                     ->  Hash  (cost=1.23..1.23 rows=23 width=36)
                           ->  Seq Scan on customer  (cost=0.00..1.23 rows=23 width=36)
```

(83.04 - 3.59)/83.04 = 0.957 = 95.7%

Because the old query uses too many subqueries to find the result. It would slow down it. My query only uses count and group by as the old one but only once and uses ‘fetch first 3 rows only’ to find the results which is much shorter and faster.

```
                    ++++++++++++++++++++++++++++++++++
select f_name, l_name, count(*)
from customer natural join loaned_book
     group by f_name, l_name
order by count desc
fetch first 3 rows only
```

Appendix 1: Formulae for Computing a Query Cost Estimate

For a relation with schema $R = \{A_1,...,A_k\}$, the average size of a tuple is: $r = \sum_{j=1}^{k} l_j$

The size of relation is $s = n \cdot r$, with n as the average number of tuples in the relation,

Select: for a selection node σ_C the assigned size is $a_C \cdot s$, where s is the size assigned to the successor and $100 \cdot a_C$ is the average percentage of tuples satisfying C

Project: for a projection node π_{Ri} the assigned size is $(1 - C_i) \cdot s \cdot r_i / r$, where r_i (r) is the average size of a tuple in a relation over R_i (R), s is the size assigned to the successor and C_i is the probability that two tuples coincide on R_i

Join: for a join node the assigned size is $s_1/r_1 \cdot p \cdot s_2/r_2 \cdot (r_1 + r_2 - r)$, where s_i are the sizes of the successors, r_i are the corresponding tuple sizes, r is the size of a tuple over the common attributes and p is the matching probability

Union: for a union node the assigned size is $s_1 + s_2 - p \cdot s_1$ with the probability p for tuple of R_1 to coincide with a tuple over R_2

Difference: for a difference node the assigned size is $s_1 \cdot (1 - p)$, where $(1 - p)$ is probability that tuple from R_1-relation does not occur as tuple in R_2-relation

Appendix 2: Using PostgreSQL on the workstations

We have a command line interface to PostgreSQL server from ECS, so you need to run it from a terminal.

To connect to the servers of ECS, such as **greta-pt.ecs.vuw.ac.nz** or **barretts.ecs.vuw.ac.nz**, remotely, you can access PostgreSQL server at home via SSH as below:

> **ssh** [username]**@greta-pt.ecs.vuw.ac.nz**

- If you are not asked to enter your password, type "kinit [username]" at the shell prompt and enter your password.

To enable the various applications required, type either

> need comp302tools

or

> need postgresql

You may wish to add either "`need comp302tools`", or the "`need postgresql`" command to your `.cshrc` file so that it is run automatically. Add this command after the command `need SYSfirst`, which has to be the first `need` command in your `.cshrc` file.

There are several commands you can type at the unix prompt:

> createdb ⟨database_name⟩

Creates an empty database. The database is stored in the same PostgreSQL server used by all the students in the class. Your database may have an arbitrary name, but we recommend to name it either `userid` or `userid_x`, where `userid` is your ECS user name and `x` is a number from 0 to 9. To ensure security, you must issue the following command as soon as you log-in into your database for the first time:

```
REVOKE CONNECT ON DATABASE <database_name> FROM PUBLIC;
```

You only need to do this once (unless you get rid of your database to start again). **Note**, your markers may check whether you have issued this command and if they find you didn't, you may be **penalized**.

> **psql** [**–d** ⟨db name⟩]

Starts an interactive SQL session with PostgreSQL to create, update, and query tables in the database. The db name is optional (unless you have multiple databases)

> dropdb ⟨databas_name⟩

Gets rid of a database. (In order to start again, you will need to create a database again)

> pg_dump -i ⟨databas_name⟩ > ⟨file_name⟩

Dumps your database into a file in a form consisting of a set of SQL commands that would reconstruct the database if you loaded that file.

> **psql –d** <database_name> **-f** <file_name>

Copies the file <file_name> into your database <database_name>.

Inside and interactive SQL session, you can type SQL commands. You can type the command on multiple lines (note how the prompt changes on a continuation line). End commands with a ';'

There are also many single line PostgreSQL commands starting with '\' . No ';' is required. The most useful are

\? to list the commands,

\i 〈file_name〉
loads the commands from a file (e.g., a file of your table definitions or the file of data we provide).

\dt to list your tables.

\d〈table_name〉to describe a table.

\q to quit the interpreter

copy <table_name> **to** <file_name>
Copy your table_name data into the file file_name.

copy <table_name> **from** <file_name>
Copy data from the file file_name into your table table_name.

Note also that the PostgreSQL interpreter has some line editing facilities, including up and down arrow to repeat previous commands.
For longer commands, it is safer (and faster) to type your commands in an editor, then paste them into the interpreter!