CSE 344 Midterm

Wednesday, Oct. 31st, 2018, 1:30-2:20

Name: _____

Question	Points	Score
1	50	
2	25	
3	15	
4	10	
Total:	100	

- This exam is CLOSED book and CLOSED devices.
- You are allowed ONE letter-size page with notes (both sides).
- You have 50 minutes;
- Answer the easy questions before you spend too much time on the more difficult ones.
- Good luck!

1 SQL

1. (50 points)

   A large software company maintains the following database about its projects and developers

   ```
   Project(pid,name,startYear)
   Developer(did,name,hireYear)
   WorksOn(pid,did,year)
   ```

   Each project has a name and a start year. Each developer has a name and the year when she/he was hired. `WorksOn` records whether a developer worked on a project in a given year. Note that a developer may work on the same project in multiple years, and a project may have multiple developers in any given year.

   (a) (5 points) Write the sequence of SQL statements necessary to create the tables above. Assume that `name` is a TEXT type, and all other attributes are integers. Include all keys or foreign keys declarations.

   Solution:

   ```
   DROP TABLE IF EXISTS Workson;
   DROP TABLE IF EXISTS Project;
   DROP TABLE IF EXISTS Developer;

   CREATE TABLE Project(pid INT PRIMARY KEY, name TEXT, startYear INT);
   CREATE TABLE Developer(did INT PRIMARY KEY, name TEXT, hireYear INT);
   CREATE TABLE WorksOn(pid INT REFERENCES Project, did INT REFERENCES Developer, year INT);
   ```

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(b) (5 points) Write a SQL query that returns for each project and for each year the total number of developers who worked on that project in that year. Your query should return the project's ID, name, year, and number of developers, sorted by year in increasing order, and, within each year, sorted in decreasing order of the number of developers. (Years in which no developers worked need not be included as "0 developers.")

Solution:

```
SELECT X.pid, X.name, Y.year, count(Y.pid) AS cnt
FROM Project AS X,  WorksOn AS Y
WHERE X.pid = Y.pid
GROUP BY X.pid, X.name, Y.year
ORDER BY Y.year, cnt desc;
```

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(c) (10 points) A project is called inactive if no developer worked on it since 2010 (including and after 2010). Write a SQL query to find all inactive projects. You should return their IDs and names. (A project is active if a developer worked on it in 2010.)

Solution: Solution 1:

```
SELECT X.pid, X.name
FROM Project AS X
WHERE NOT EXISTS (SELECT *
                  FROM WorksOn AS Y
                  WHERE X.pid = Y.pid and Y.year >= 2010);
```

-1 point for unnecessary joins
-3 points for missing correlation in the subquery `X.pid=Y.pid`

Solution 2:

```
SELECT X.pid, X.name
FROM Project X left outer join WorksOn Y
     ON X.pid = Y.pid and Y.year >= 2010
GROUP BY X.pid, X.name
HAVING count(Y.pid) = 0;
```

Solution 3 (imperfect because it misses projects without any developers):

```
SELECT X.pid, X.name
FROM Project X, WorksOn Y
WHERE X.pid = Y.pid
GROUP BY X.pid, X.name
HAVING 2010 > max(Y.year);
```

-1 point because incomplete answer

Solution 4

```
SELECT X.pid, X.name
FROM Project X
WHERE 2010 > ALL (SELECT Y.year from WorksOn Y WHERE Y.pid = X.pid);
```

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(d) (10 points) For each year since 1990 (including and after 1990), return the project(s) that the most developers worked on during that year. Return the year and project ID. In case of a tie (if multiple projects had the maximum number of developers) return all of them.

Solution:

```
-- Solution 1: Universal Quantifier Approach with ALL
SELECT W.year, W.pid
FROM WorksOn AS W
WHERE W.year >= 1990
GROUP BY W.year, W.pid
HAVING count(*) >= ALL (SELECT count(*)
                        FROM WorksOn AS W2
                        WHERE W2.year = W.year
                        GROUP BY W.pid);

-- Solution 2: Witness Approach
WITH A AS (SELECT W.year AS year, W.pid AS pid, count(*) AS count
           FROM WorksOn AS W
           WHERE W.year >= 1990
           GROUP BY W.year, W.pid),
     B AS (SELECT A.year AS year, max(A.count) AS count
           FROM A
           GROUP BY A.year)
SELECT A.year, A.pid
FROM A, B
WHERE A.year = B.year AND A.count = B.count;

-- Solution 3: variant on the Witness
WITH A ... -- same as above
SELECT x.year, x.pid
FROM A x, A y
WHERE x.year = y.year
GROUP BY x.year, x.pid, x.count
HAVING x.count = max(y.count);
```

-5 points for answers containing the expression `max(count(*))`

-4 points for an expression like `HAVING x.count = max(x.count)` (same x)

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(e) (10 points) 'SystemX' is the oldest project of the company. Write a SQL query that returns all developers who worked every year on 'SystemX', from when it started until 2015. Your query should return the developers' ID and name.

Solution:

```
-- Solution 1
SELECT Z.did, Z.name
FROM Project AS X, WorksOn AS Y, Developer AS Z
WHERE X.pid = Y.pid AND Y.did = Z.did
       AND X.startYear <= Y.year
       AND Y.year <= 2015
       AND X.name = 'SystemX'
GROUP BY Z.did, Z.name, X.startYear
HAVING count(*) = 2015 - X.startYear + 1;

-- Solution 2 (imperfect, but got full credit where present)
SELECT Z.did, Z.name
FROM Developer Z
WHERE NOT EXISTS (  -- find a year where Z didn't work on SystemX
  SELECT *
  FROM WorksOn Y    -- proxy for the set of all years (which we don't have)
  WHERE NOT EXISTS (  -- check if Z worked that year on SystemX
     SELECT * FROM WorksOn Y2, Project X
     WHERE Y.year = Y2.year and Y2.pid = X.pid and X.name = 'SystemX'));
```

A solution without any negation got 2-3 points max.

A solution with only 1 negation got 5 points max.

1 point off for unnecessary join

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(f) For each question below indicate whether the two SQL queries are equivalent. Assume that the database does not contain any NULL values.

i. (1 point) Are Q1 and Q2 equivalent?

```
Q1: SELECT DISTINCT Z.did, Z.name
      FROM Project X1, Project X2, Workson Y1, Workson Y2, Developer Z
     WHERE X1.pid = Y1.pid AND Y1.did = Z.did
       AND X2.pid = Y2.pid AND Y2.did = Z.did
       AND X1.startYear < 2010 AND Y1.year > 2015
       AND X2.startYear < 2012 AND Y2.year > 2018;

Q2: SELECT DISTINCT Z.did, Z.name
      FROM Project X, Workson Y, Developer Z
     WHERE X.pid = Y.pid AND Y.did = Z.did
       AND X.startYear < 2010 AND Y.year > 2018;
```

i. **No**

Yes/No:

ii. (1 point) Are Q3 and Q4 equivalent?

```
Q3: SELECT DISTINCT Z.did, Z.name
      FROM Project X1, Project X2, Workson Y1, Workson Y2, Developer Z
     WHERE X1.pid = Y1.pid AND Y1.did = Z.did
       AND X2.pid = Y2.pid AND Y2.did = Z.did
       AND X1.startYear < 2010 AND Y1.year > 2018
       AND X2.startYear < 2012 AND Y2.year > 2015;

Q4: SELECT DISTINCT Z.did, Z.name
      FROM Project X, Workson Y, Developer Z
     WHERE X.pid = y.pid AND y.did = Z.did
       AND X.startYear < 2010 AND y.year > 2018;
```

ii. **Yes**

Yes/No:

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

iii. (1 point) Are Q5 and Q6 equivalent?

```
Q5: SELECT X.did, count(*)
      FROM WorksOn X
     GROUP BY X.did;

Q6: SELECT X.did, (SELECT count(*)
                     FROM WorksOn Y
                    WHERE X.did = Y.did)
      FROM WorksOn X;
```

iii. **Yes**

Yes/No:

iv. (1 point) Are Q7 and Q8 equivalent?

```
Q7: SELECT X.did, count(*)
      FROM WorksOn X
     WHERE X.year > 2010
     GROUP BY X.did;

Q8: SELECT X.did, (SELECT count(*)
                     FROM WorksOn y
                    WHERE X.did = y.did AND y.year > 2010)
      FROM WorksOn X;
```

iv. **No**

Yes/No:

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

v. (1 point) Are Q9 and Q10 equivalent?

```
Q9: SELECT X.name, Z.name
      FROM Developer X
             LEFT OUTER JOIN
           WorksOn Y ON X.did = Y.did
             LEFT OUTER JOIN
           Project Z ON Y.pid = Z.pid;
```

```
Q10: SELECT X.name, Z.name
       FROM Developer X
              JOIN
            WorksOn Y ON X.did = Y.did
              LEFT OUTER JOIN
            Project Z on Y.pid = Z.pid;
```

v. **No**

Yes/No:

vi. (1 point) Are Q11 and Q12 equivalent?

```
Q11: SELECT X.name, Z.name
       FROM Developer X
              LEFT OUTER JOIN
            WorksOn Y ON X.did = Y.did
              LEFT OUTER JOIN
            Project Z ON Y.pid = Z.pid;
```

```
Q12: SELECT X.name, Z.name
       FROM Developer X
              LEFT OUTER JOIN
            WorksOn Y on X.did = Y.did
              JOIN
            Project Z on Y.pid = Z.pid;
```

vi. **Yes**

Yes/No:

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(g) Consider the following database instance:

Project

pid	name	startYear
10	SystemX	NULL
20	SystemY	2016

WorksOn

pid	did	year
10	1	NULL
20	1	2015
20	2	NULL

Developer

did	name	startYear
1	Alice	2015
2	Bob	NULL

Solution:

```
INSERT INTO Developer VALUES (1, 'Alice', 2015);
INSERT INTO Developer VALUES (2, 'Bob', NULL);
INSERT INTO Project VALUES (10, 'SystemX', NULL);
INSERT INTO Project VALUES (20, 'SystemY', 2016);
INSERT INTO WorksOn VALUES (10, 1, NULL);
INSERT INTO WorksOn VALUES (20, 1, 2015);
INSERT INTO WorksOn VALUES (20, 2, NULL);
```

Indicate for each query below what answers it returns; write "empty" if the answer is the emptyset.

i. (1 point) What does query Q1 return?:

```
SELECT X.name AS proj, Z.name AS dev
  FROM Project X, Workson Y, Developer Z
 WHERE X.pid = Y.pid AND Y.did = Z.did
   AND ((Z.hireyear = 2015 AND Y.year = 2015) OR X.startyear = 2016);
```

Solution:

proj	dev
SystemY	Alice
SystemY	Bob

ii. (1 point) What does query Q2 return?:

```
SELECT X.name AS proj, Z.name AS dev
  FROM Project X, Workson Y, Developer Z
 WHERE X.pid = Y.pid AND Y.did = Z.did
   AND (Z.hireyear = 2015 AND (Y.year = 2015 OR X.startyear = 2016));
```

Solution:

proj	dev
SystemY	Alice

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

iii. (1 point) What does query Q3 return?:

```
SELECT X.name AS proj, Z.name AS dev
  FROM Project X, Workson Y, Developer Z
 WHERE X.pid = Y.pid AND Y.did = Z.did
   AND (Z.hireyear = 2015 OR (Y.year = 2015 AND NOT(X.startyear = 2016)));
```

Solution:

proj	dev
SystemX	Alice
SystemY	Alice

iv. (1 point) What does query Q4 return?:

```
SELECT X.name AS proj, Z.name AS dev
  FROM Project X, Workson Y, Developer Z
 WHERE X.pid = Y.pid AND Y.did = Z.did
   AND (NOT(Z.hireyear = 2015) OR (Y.year = 2015 AND X.startyear = 2016));
```

Solution:

proj	dev
SystemY	Alice

2 Relational Algebra

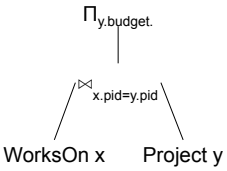
2. (25 points)

Consider the same relational schema as before, including the key/foreign key constraints:

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(a) (5 points) Write a Relational Algebra expression in the form of a logical query plan (i.e., draw a tree) that is equivalent to the SQL query below. Your query plan does not have to be necessarily "optimal": however, points will be taken off for overly complex solutions.

Hint: to avoid renaming, use aliases in the query plan, like this




```
SELECT X.did, X.name, count(*)
FROM Developer X, WorksOn y, Project Z
WHERE X.did = y.did and y.pid = Z.pid
  AND y.year < Z.startYear + 2
GROUP BY X.did, X.name, X.hireYear
HAVING X.hireYear + 10 < max(startYear);
```

Solution:

$$\pi_{(X.did,X.name,C)}($$
$$\sigma_{(X.hireYear+10<M)}($$
$$\gamma_{(X.did,X.name,X.hireYear,count(*)->C,max(Z.startYear)->M)}($$
$$\sigma_{(Y.year<Z.startYear+2)}($$
$$\rho_X(Developer) \bowtie_{(X.did=Y.did)} \rho_Y(WorkOn) \bowtie_{(Y.pid=Z.pid)} \rho_Z(Project)))))$$

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(b) i. (2 points) Which of the following is the most accurate English interpretation of the SQL query below?

```
SELECT X.did
FROM Developer X
WHERE NOT EXISTS
          (SELECT *
           FROM Project Z
           WHERE NOT EXISTS
                   (SELECT *
                    FROM WorksOn Y
                    WHERE X.did = Y.did AND Y.pid = Z.pid
                      AND Y.year = 2015));
```

```
Developers that...
A: in 2015, didn't work on any projects at all
B: in 2015, didn't work on at least one of the projects
C: in 2015, worked on every single project
D: in 2015, worked on at least one project
```

i. **C**

A/B/C/D:

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

ii. (10 points) Write a Relational Algebra expression in the form of a logical query plan (i.e., draw a tree) that is equivalent to the SQL query in the previous question (reproduced below). Your query plan does not have to be necessarily "optimal": however, points will be taken off for overly complex solutions.

```
SELECT X.did
FROM Developer X
WHERE NOT EXISTS
          (SELECT *
           FROM Project Z
           WHERE NOT EXISTS
                   (SELECT *
                    FROM WorksOn Y
                    WHERE X.did = Y.did AND Y.pid = Z.pid
                      AND Y.year = 2015));
```

Solution:

$$\pi_{(X3.did)}(\rho_{X3}(Developer)) - \pi_{(X.did)}(A - B)$$

Where A is

$$\pi_{(Y2.pid,Y2.did)}($$
$$(\rho_{Y2}(WorksOn))$$

Where B is

$$\pi_{(Z.pid,X.did)}($$
$$\sigma_{(Y.year=2015)}($$
$$\rho_X(Developer) \bowtie_{(X.did=Y.did)} \rho_Y(WorksOn) \bowtie_{(Y.pid=z.pid)} \rho_Z(Project)))$$

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(c) Assume the database schema in Question 1 (also shown in the top right corner); assume the key and foreign keys defined there, and that the database instance does not contain NULL's. Answer the questions below, assuming all expressions have set semantics.

i. (2 points) The notation $|S|$ means the cardinality of a set S (number of tuples in S). Does the following always hold?

$$|\texttt{Developer} \bowtie_{\texttt{did=did}} \sigma_{\texttt{year}<2015}(\texttt{WorksOn})| \leq |\texttt{Developer}|$$

i. **No**

Yes/No:

ii. (2 points) Does the following always hold?

$$|\texttt{Developer} \bowtie_{\texttt{did=did}} \sigma_{\texttt{year}<2015}(\texttt{WorksOn})| \leq |\texttt{WorksOn}|$$

ii. **Yes**

Yes/No:

iii. (2 points) Does the following always hold?

$$|\sigma_{\texttt{hireYear}<2015}(\texttt{Developer}) \bowtie_{\texttt{did=did}\wedge\texttt{hireYear=year}} \texttt{WorksOn}| \leq |\sigma_{\texttt{year}<2015}(\texttt{WorksOn})|$$

iii. **Yes**

Yes/No:

iv. (2 points) Does the following always hold?

$$|\texttt{Developer} \bowtie_{\texttt{did=did}\wedge\texttt{hireYear=year}} \sigma_{\texttt{year}<2015}(\texttt{WorksOn})| \leq |\sigma_{\texttt{hireYear}<2015}(\texttt{Developer})|$$

iv. **No**

Yes/No:

3 Datalog

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

3. (15 points)

   Answer the questions below.

   (a) (5 points) Write a datalog program that returns the id and name of all employees who never worked on the project `"SystemX"`.

Solution:

```
nonAnswer(did) :- Developer(did, _, _), WorksOn(pid, did, _),
                  Project(pid, "SystemX", _)
answer(did, name) :- Developer(did, name), ! nonAnswer(did)
```

```
Project(pid,name,startYear)
Developer(did,name,hireYear)
WorksOn(pid,did,year)
```

(b) (10 points) Two developers are "pals" if they worked together on a common project during the same year, or if they have a common pal. Write a datalog program to find the number of common pals of `"Alice"` and `"Bob"`. For the aggregate, use the Souffle syntax.

Solution:

```
pal(x,y) :- WorksOn(z,x,w), WorksOn(z,y,w), x != y
pal(x,y) :- pal(x,z), pal(z,y), x != y
common(x) :- Developer(aid,"Alice",_), Developer(bid,"Bob",_),
             pal(aid,x), pal(bid,x)
answer(c) :- c = count { common(x) }

-- No points removed if 'x != y' is missing.
```

4 Miscellaneous

4. (10 points)

For each statement below, indicate whether it is true or false.

(a) (1 point) *Physical data independence* means that the logical representation of the data is independent of its physical representation in memory and on disk.

(a) **true**

True/False:

(b) (1 point) If the primary key of a relation consists of the attributes A, B, then no record can have $A = B$.

(b) **false**

True/False:

(c) (1 point) If the attribute K of a relation R is a foreign key to some S then every value of that attribute in R must be the value of some key in S.

(c) **true**

True/False:

(d) (1 point) *First normal form* means that all relations in the database are flat.

(d) **true**

True/False:

(e) (1 point) All queries expressible in Relational Algebra are monotone.

(e) **false**

True/False:

(f) (1 point) The following Datalog rule is safe:
Q(name, year) :- Developer(did, name, _), !WorksOn(_, did, year)

(f) **false**

True/False:

(g) (1 point) The following Datalog rule is safe:
Q(name, year) :- Project(_, name, year), year < 2015

(g) **true**

True/False:

(h) (1 point) If two relations have no duplicate tuples (i.e. are sets), then their join (i.e., a relation resulting from joining the two relations with any join condition) does not have duplicate tuples either.

(h) **true**

True/False:

(i) (1 point) The left outer join returns at most as many tuples as the inner join.

(i) **false**

True/False:

(j) (1 point) This relational algebra expression is monotone: $\sigma_{\texttt{not(year=2015)}}(\texttt{WorksOn})$.

(j) **true**

True/False: