CSE344 Final Exam
Fall 2016
December 12, 2016

- Please read all instructions (including these) carefully.
- **This is a <u>closed-book exam</u>. You are allowed two pages of note sheets.**
- Write your name and UW student number below.
- No electronic devices are allowed, including **cell phones** used merely as watches. Silence your cell phones and place them in your bag.
- Solutions will be graded on correctness and ***clarity***. Each problem has a relatively simple solution. Partial solutions will be graded for partial credit.
- There are 20 pages in this exam, not including this one.
- There are 6 questions, each with multiple parts. If you get stuck on a question move on and come back to it later.
- You have 110 minutes to work on the exam.
- Please write your answers in the space provided on the exam, and clearly mark your solutions. **Do not** use any additional scratch paper.
- Relax. You are here to learn. Good luck!

By writing your name below, you certify that you have not received any unpermitted aid for this exam, and that you will not disclose the contents of the exam to anyone in the class who has not taken it.

Clarifications made during the exam are in RED.

NAME: _________Solutions____________________

STUDENT NUMBER: __________________________________

Problem	**Points**
1	15
2	36
3	32
4	48
5	44
6	25
Total	200

Problem 1: Warm up (15 points total)

Select either True or False for each of the following questions. For each question you get 1 point for answering it correctly, -0.5 point for an incorrect answer, and 0 point for no answer. The minimum you will get for this entire problem is 0.

1. Given `R(A,B)`, `SELECT A+B FROM R` is a monotonic query.

   True False

2. Every superkey is also a key.

   True **False**

3. Spark disallows RDDs to be nested within other RDDs.

   True False

4. A query plan that uses broadcast joins can have lower cost than one that uses partition hash joins for the same query.

   True False

5. BCNF is neither the third nor the fourth normal form.

   True False

6. Setting isolation level to read committed can avoid the phantom problem.

   True **False**

7. MapReduce promotes fault tolerance by writing intermediate files to disk.

   True False

8. All serializable schedules are conflict-serializable.

   True **False**

9. When doing a broadcast join, we typically broadcast the largest relation.

True **False**

10. Serial execution guarantees ACID.

True **False**

11. It is possible to start reducers while some mappers are still running in Hadoop.

True **False**

12. Strict 2PL ensures serializability of transactions.

True **False**

13. The conflict precedence graph can be used to find serial schedules.

True **False**

14. If A and B are sets, then a relation R can be viewed as a subset of A × B.

True False

15. If a transaction is atomic, it either shows all the effects of its operations or none of them.

True False

Problem 2: Writing Queries (36 points total, 6 points each)

Given the following relations on individuals and their friends:

```
Person(id, name, age)
Friends(id1, id2) -- both attributes are foreign keys to Person
```

If A (id: 10) and B (id: 23) are friends, then (10, 23) and (23, 10) are both stored in `Friends.`

a) Write a SQL query that returns the name and the number of friends that each person has.
Return everyone regardless of how many friends they have

```
SELECT p.name, COUNT(f.id2)
FROM Person p LEFT OUTER JOIN Friends f ON p.id = f.id1
GROUP BY p.id, p.name
```

Students need to do both outer join and count on the right attribute to get full points.

b) Write a SQL query that returns the friends distribution. For example, if 2 individuals have 10 friends, 3 have 4 friends, and 5 have 0 friends, then you should return:

friends	count
10	2
4	3
0	5

Note that there are no tuples for 1 friend, 2 friends, etc as the count for those entries are 0.

```
SELECT friends, COUNT(*) AS count
FROM (SELECT COUNT(f.id2) as friends,
      FROM Person p LEFT OUTER JOIN Friends f on p.id = f.id1
      GROUP BY p.id)
GROUP BY friends
```

Students can reuse the query they wrote for a) for this. We don't double penalize if the query in a) was incorrect.

(Problem 2 continued)
Relations duplicated here for your reference:

```
Person(id, name, age)
Friends(id1, id2) -- both attributes are foreign keys to Person
```

c) Write a SQL query that returns the name of the oldest individual(s) in the dataset.

```
SELECT p.name
FROM Person p
WHERE p.age = (SELECT MAX(age) FROM Person)
```

The idea is to use a subquery to find the max age first, and then use the outer query to retrieve the record with the corresponding value.

d) Each pair of friends are currently stored twice in the `Friends` relation, as noted above. Write a Datalog query that returns each pair of friends only once. You can use negation if needed. Return the names of people.

```
Ans(f1, f2) :- Person(i1, f1, _), Person(i2, f2, _), Friends(i1, i2),
               i1 < i2
```

The key is to realize that `i1<i2` can be used to remove duplicates. Other methods are possible.

Many submissions have the following form:

```
F(x, y) :- Friends(x, y), Person(x, _, _), Person(y, _, _)
Ans(n1, n2) :- F(x, y), not F(y, x), Person(x, n1, _), Person(y, n2, _)
```

This is incorrect. Recall the semantics of Datalog. The second rule means:

```
∀x,y . F(x,y) ^ not F(y,x) ^ Person(x, n1, _) ^ Person(y, n2, _) => Ans(n1, n2)
```

If `(x,y)` is in `F`, then `(y,x)` is also in `F`, so no `(x,y)` satisfies the precedent, and `Ans` will be empty as a result.

(Problem 2 continued)
Relations duplicated here for your reference:

```
Person(id, name, age)
Friends(id1, id2) -- both attributes are foreign keys to Person
```

e) Write a SQL query to find friends of friends of Person 1 (id: 10) who Person 1 is not already friends with.
Return all fields.

```
SELECT id, name, age
FROM Person P
AND EXISTS (SELECT f2.id2 AS id
            FROM Friends f1, Friends f2
            WHERE f1.id2 = f2.id1
            AND f1.id1=10
            AND f2.id2<>10)
AND NOT EXISTS (SELECT f.id2 AS id
                FROM Friends f
                WHERE f.id1=10)
```

f) Write a relational calculus query that returns all people who are only friends with those who have one other friend.
Return the ID of those who have AT LEAST ONE other friend

```
Ans(x) = ∃y Friends(x,y) ^ ∀b (Friends(x, b) ⇒ ∃c Friends(b,c) ^ x != c)
```

Problem 3: Transactions (32 points total)

Given the following three transactions:

```
T1: R(A), W(B), I(D), R(C)
T2: R(B), R(D), W(C)
T3: R(D), R(C), R(D), W(A)
```

Assume that `R(X)` reads all tuples in table `X`, `W(X)` updates all tuples in `X`, and `I(X)` inserts one new tuple in `X`. `Co` and `Ab` mean commit and abort, respectively. In the following, indicate the **strongest** isolation level that can generate each schedule, with serializable being the strongest isolation level. If serializable, then also give the serial schedule. (4 points each)

a) `R1(A); W1(B); I1(D); R3(D); R2(B); R3(C); R3(D); R2(D); R1(C); W2(C); W3(A); Co1; Co2; Co3;`

None [✓ Read uncommitted] Read committed Repeatable read Serializable

Serial schedule:

N/A

b) `R2(B); R1(A); R3(D); R3(C); R2(D); W2(C); Co2; R3(D); W3(A); Ab3; W1(B); I1(D); R1(C); Co1;`

None Read uncommitted Read committed Repeatable read [✓ Serializable]

Serial schedule:

`T2; T3; T1; or T2; T1; T3; or T3; T2; T1;`

c) `R1(A); R2(B); R3(D); R3(C); R2(D); I1(D); W2(C); Co2; R3(A); W1(B); W3(D); Co3; R1(C); Ab1;`

[✓ None] Read uncommitted Read committed Repeatable read Serializable

Serial schedule:

N/A
This schedule contains `R3(A)` and `W3(D)` which were not part of `T3`.

(Problem 3 continued)
Transactions copied here for your reference.

```
T1: R(A), W(B), I(D), R(C)
T2: R(B), R(D), W(C)
T3: R(D), R(C), R(D), W(A)
```

d) Does there exist a schedule of the above transactions that would result in a deadlock if executed under strict 2PL with **both shared and exclusive table locks**? If so write such a schedule with lock / unlock ops, and explain why the transactions are deadlocked. Otherwise write "No". Use `L1(A)` to refer to `T1` locking table `A`, and `U1(A)` for unlocking. (5 points)
Use S1(A) for grabbing shared lock, and X1(A) for exclusive lock.

```
S1(A); R1(A); X1(B); W1(B); S3(D); R3(D); S3(C); R3(C); R3(D); X1(D);
I1(D); X3(A); W3(A); <deadlock>
```

T1 and T3 both hold shared locks on A and D but need to grab exclusive locks on the two elements in order to proceed.

e) Does there exist a schedule of the above transactions that would result in a deadlock if executed under strict 2PL with **only exclusive table locks**? If so write such a schedule with lock and unlock operations and indicate why the transactions are deadlocked. Otherwise write "No". Use `L1(A)` to refer to `T1` locking table `A`, and `U1(A)` for unlocking. (5 points)

```
L1(A); R1(A); L2(B); R2(B); L3(D); R3(D); L3(C); R3(C); <deadlock>
```

T1 holds lock on A and is waiting for lock on B, which is held by T2
T2 holds lock on B and is waiting for lock on D, which is held by T3
T3 holds lock on D and is waiting for lock on A, which is held by T1

To get full points, students will need to show both a schedule, explain which transaction holds which lock, and how that leads to a deadlock.

(Problem 3 continued)
Transactions copied here for your reference.

```
T1: R(A), W(B), I(D), R(C)
T2: R(B), R(D), W(C)
T3: R(D), R(C), R(D), W(A)
```

f) Does there exist a schedule of the above transactions that would result in a manifestation of the phantom problem under non-strict 2PL with exclusive table locks? If so write out such a schedule with lock and unlock operations and indicate why there is a phantom problem. Otherwise write "No". (5 points)

No. Phantoms do not appear with table level locking.

g) Suppose we change locking granularity to tuple rather than table level, where we only lock the tuples that are read / written / inserted from the affected table. Is there a schedule of the above transactions that would result in a manifestation of the phantom problem under non-strict 2PL with exclusive tuple locks? If so write out such a schedule with lock and unlock operations and indicate why there is a phantom problem. Otherwise write "No". (5 points)

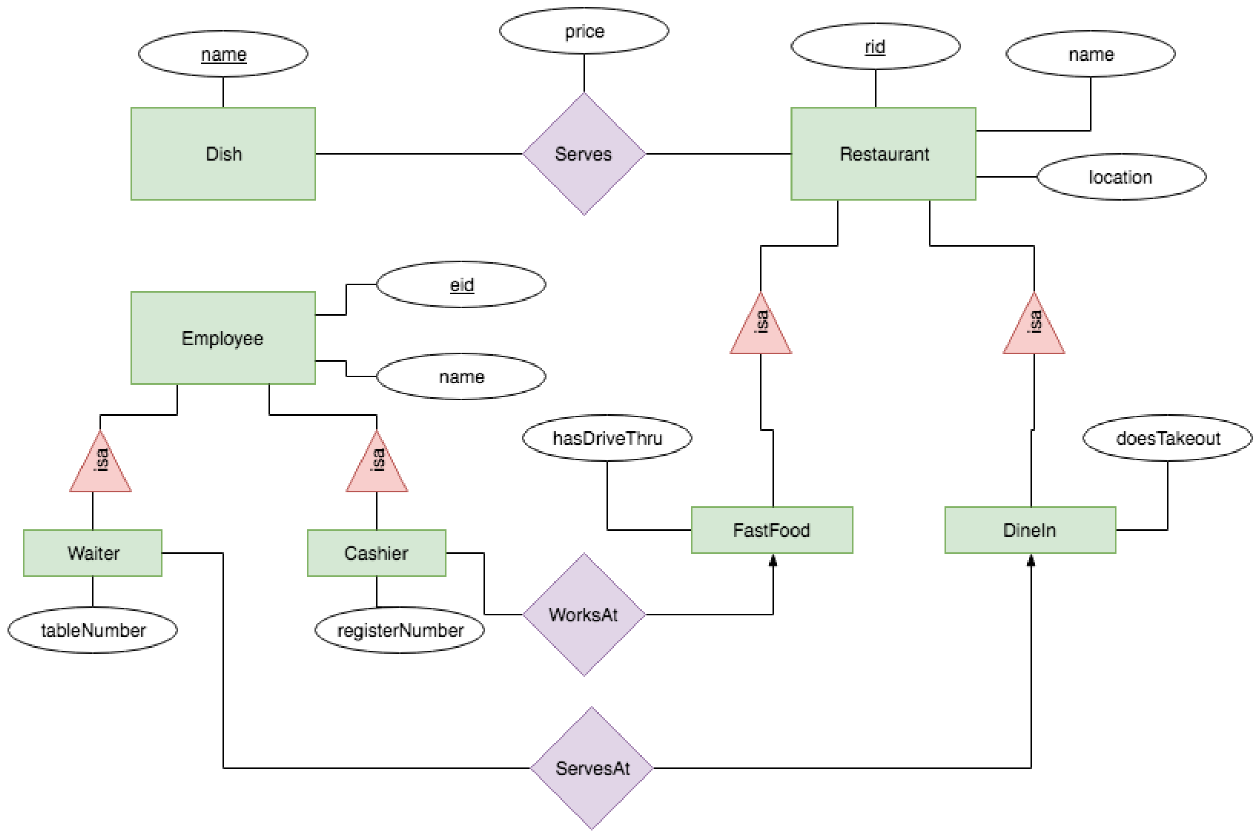
```
L3(D); R3(D); L1(A,B,C,D); R1(A); W1(B); I1(D); L3(C,D); R3(C); R3(D);
```

Here T3 will retrieve a different D in the second read as compared to the first one, due to the insertion by T1.

To get full points, students need to show both a schedule and explain what versions of D will T3 read and why are they different.

Problem 4: Conceptual Design (48 points total)

a)



Convert the above E/R diagram to relations in BCNF form. Include all keys and foreign keys.Use the following notation and explicitly state foreign key relationships. For instance:

```
R(a, b)
S(c, d) -- c is a foreign key to R
```

You can ignore data types for all attributes. (33 points)

(Problem 4 continued)

a)

```
Dish(name)

Restaurant(rid, name, location)

Serves(rid, name, price) rid references Restaurant, name references Dish

FastFood(rid, hasDriveThru) rid references Restaurant

DineIn(rid, doesTakeout) rid references Restaurant

Employee(eid, name)

Waiter(eid, rid, int) eid references Employee, rid references DineIn

Cashier(eid, rid, registerNumber) eid references Employee, rid references
FastFood
```

To get full points, students need to show both relation schemas and PK, FK relationships.

(Problem 4 continued)

b) Consider relation `R(A,B,C,D,E)` with functional dependencies:

`AB → C, C → D, BD → E`

Which of the following attribute sets does not functionally determine `E`? (3 points)

a) `AB`

b) **<u>`AC`</u>**

c) `BC`

d) `ABC`

c) Let relation `R(A,B,C,D)` satisfy the following functional dependencies:

`A → B, B → C, C → A`

Call this set S1. A different set S2 of functional dependencies is *equivalent* to S1 if exactly the same FDs follow from S1 and S2. Which of the following sets of functional dependencies is equivalent to the set above? (3 points)

a) `B → AC, C → AB`

b) `A → B, B → A, C → A`

c) `A → BC, C → AB`

d) **<u>`A → BC, B → AC, C → AB`</u>**

d) Find all non-trivial (i.e., `A → A`, all attributes → all attributes) functional dependencies from the following relation: (6 points)

A	**B**	**C**
a2	b2	c1
a1	b1	c3
a1	b1	c2
a3	b3	c1

```
A → B
B → A
BC → A
AC → B
```

e) Suppose relation `R(A,B,C)` has tuples `(0,0,0)` and `(1,2,0)`, and it satisfies the functional dependencies `A → B` and `B → C`. Which of the following tuples may be inserted into `R` legally? (3 points)

a) `(0,0,1)`

b) `(1,2,1)`

c) `(0,1,1)`

d) `(0,0,2)`

e) **<u>None of the above.</u>**

Problem 5: Parallel Query Processing (44 points total)

Given the following query with relations `R(A,B)` and `S(C)`:

```
SELECT R.A, MAX(R.B)
FROM R, S
WHERE R.A = S.C AND R.B > 10
GROUP BY R.A
```

With the following data statistics:

T(R, a) = 10000
V(R, b) = 100
V(R, a) = 20

Min(R, a) = 10; Max(R, a) = 50, evenly distributed.
Min(R, b) = ~~20~~ 0; Max(R, b) = 100, evenly distributed.

T(S, c) = 5000
V(S, c) = 20

Min(S, c) = 10; Max(S, c) = 50, evenly distributed.

(problem 5, continued)

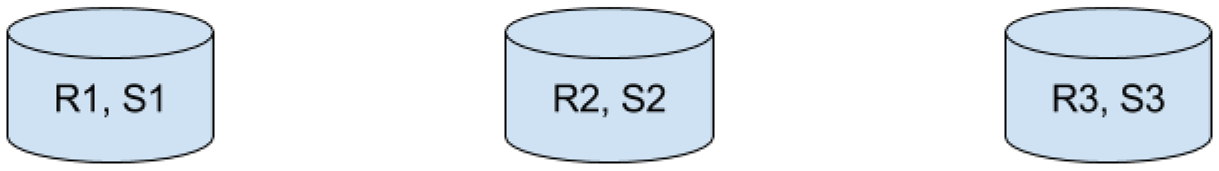
Query copied here for your reference.

```
SELECT R.A, MAX(R.B)
FROM R, S
WHERE R.A = S.C AND R.B > 10
GROUP BY R.A
```

a) Suppose that R and S are partitioned across 3 different machines using random block partitioning, and no indexes are available on any of the machines. Draw the relational algebra plan that you would use to execute the query above. Choose only between broadcast and shuffle for joins. You do not need to indicate how joins are executed locally on each machine. (17 points)

Steps:

1. Scan R and S locally
2. Select on R.b locally
3. Hash on R.a and S.c and shuffle
4. Local join on R.a = S.c
5. Local group by on R.a and compute MAX(R.b) (Each partition is already shuffled by R.a)
6. Project and return final results



(Problem 5, continued)

b) Your friend thinks that random block partitioning is not the best partitioning scheme for this query. Are there better ways to partition `R` and `S` across the machines such that the given query can run faster? If so state how you would partition `R` and `S`, and why would doing so will lead to better performance. If not write "No". (5 points)

Range partition both R and S, and assign each machines with the same range of R and S (e.g., M1 gets R.A = 10 to 20, and S.C = 10 to 20). That way, both the selection and join predicates can be done locally without any shuffling step.

Doing hash partitioning on R.a and S.c would help as well, but not as much as the range partitioning scheme mentioned above (only partial credit is granted).

c) Given a list of pixel values, encoded as `(R,G,B)`, compute a histogram for each of the three color channels, where each pixel value can range from 0 to 255. Return the histogram as key-value pairs, with the key being a string of either "`R`" (red), "`G`", (green), and "`B`" (blue), and value being an array of 255 integers, where each entry indicates the number of pixels in the input pixels that has that value of R/G/B. For instance, given this input of three pixels:

```
(3, 2, 3), (4, 2, 5), (3, 1, 5) // each pixel is of the form (r, g, b)
```

You should output:

```
("R", [0, 0, 0, 2, 1, 0 … 0]) // 255 entries total in array
("G", [0, 1, 2, 0 … 0])
("B", [0, 0, 0, 1, 0, 2, 0 … 0])
```

Note that `R[0] = 0` since none of the input pixels has red value equals to 0, but `R[3] = 2` since two of the input pixels has red value equals to 3.

(Problem 5, continued)

Write a **single stage** map reduce program in Hadoop that computes the output above. You can assume that the input is already parsed and is given to you as a list of `Pixel` objects. You can assume that the Hadoop `emit` method handles object serialization. Use only the Hadoop constructs that we discussed in class.

Do not worry too much about getting Java syntax correct, but make sure you clearly state what key-value pairs are emitted by `map` and how they are reduced. (17 points)

```
void map (Pixel [] pixels) {
// p.r accesses the red value of pixel p as an integer, and similarly for
// p.g and p.b
  for (p in pixels) {
    emitIntermediate("R", p.r);
    emitIntermediate("G", p.g);
    emitIntermediate("B", p.b);
  }
}

// fill in the method signature of reduce
void reduce (String k, List<Integer> vs) {
  int [] histogram = new int[256];
  for (int i = 0; i <= 255; ++i)
    histogram[i] = 0;

  for v in vs:
    ++histogram[v];

  emit(k, histogram);
}
```

(Problem 5, continued)

d) Explain, in a few words, why your solution above performs better than the naive implementation of having the mappers broadcast the entire `pixels` array to all reducers (Obviously you will get no points for c) if that was what you wrote).
(5 points)

We are performing the reduce step in parallel, where each of the 3 reducers computes the histogram for either one of R, G, or B.

Problem 6: Semi-structured Data (25 points total)

Suppose we have a JSON document that encodes individuals and their children, where each individual has a unique "id" field:

```
{ "individuals":
      [ { "id": 1,
        "name": Adam,
        "age": 70,
        "children": [ { "id": 2,
                    "name": John,
                    "age": 49,
                    "children": [ { "id": 24, "name": Liz, "age": 21 } ] } ]
      },
      { "id": 3,
        "name": Beatrice,
        "age": 35,
        "children": [ { "id": 55, "name": Peter, "age": 10 },
                      { "id": 90, "name": Zoe, "age", 14 } ]
      } ]
}
```

Your friend plans to run transactions on this dataset to update existing fields (i.e., individuals cannot be added or removed). She decided to use locks to ensure atomicity. Her locking scheme is as follows:

- Each individual is associated with one exclusive lock.
- To read or write to the children field of individuals, the transaction first releases the lock on the parent individual, and grabs the lock on the child individual. For instance, to change Peter's age, the transaction will first grab the lock on Beatrice, release that lock, and then grab the lock on Peter, using three operations.
- Each lock is released immediately after the corresponding operation on the individual is done.

a) Which isolation level does this locking scheme corresponds to? Explain why. (Hint: not serializable) (5 points)

None. This is not even read uncommitted! Transactions can release write locks before they commit.

(problem 6, continued)

Data duplicated here for your reference.

```
{ “individuals”:
      [ { “id”: 1,
        “name”: Adam,
        “age”: 70,
        “children”: [ { “id”: 2,
                  “name”: John,
                  “age”: 49,
                  “children”: [ { “id”: 24, “name”: Liz, “age”: 21 } ] } ]
      },
      { “id”: 3,
        “name”: Beatrice,
        “age”: 35,
        “children”: [ { “id”: 55, “name”: Peter, “age”: 10 },
                      { “id”: 90, “name”: Zoe, “age”, 14 } ]
      } ]
}
```

b) After realizing the problem, your friend wants to keep locking at the individual level but make her locking scheme fully serializable. How would you change her locking scheme above to do so? (10 points)

One possibility: do not release locks until the transaction is committed / aborted. Note that we don’t need document level locking as inserts and deletes are not allowed (i.e., no phantoms).

(problem 6, continued)
Data duplicated here for your reference.

```
{ “individuals”:
        [ { “id”: 1,
          “name”: Adam,
          “age”: 70,
          “children”: [ { “id”: 2,
                        “name”: John,
                        “age”: 49,
                        “children”: [ { “id”: 24, “name”: Liz, “age”: 21 } ] } ]
        },
        { “id”: 3,
          “name”: Beatrice,
          “age”: 35,
          “children”: [ { “id”: 55, “name”: Peter, “age”: 10 },
                         { “id”: 90, “name”: Zoe, “age”, 14 } ]
        } ]
}
```

c) Convert the data into relations. Show both your relational schemas and how the data above will be encoded. Make sure that your schemas are in BCNF. Don’t worry about data types. Use the notations below: (10 points)

Foo(<u>a</u>, b)

a	b
10	“hello”
20	“world”

```
Individuals(id, name, age)
Children(pid, cid) -- both fields are foreign keys to Individuals

Contents of Individuals:   Contents of Children:
(1, “Adam”, 70)            (1,2)
(2, “John”, 49)            (2,24)
(3, “Beatrice”, 35)        (3,55)
(24, “Liz”, 21)            (3,90)
(55, “Peter”, 10)
(90, “Zoe”, 14)
```

To get full points, students need to state FK and PK relationships in the relations.

-- END OF EXAM --
-- Thank you for taking this class. Happy Holidays! --