Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.830 Database Systems: Fall 2016 Quiz I

There are 14 questions and 13 pages in this quiz booklet. To receive credit for a question, answer it according to the instructions given. *You can receive partial credit on questions.* You have **80 minutes** to answer the questions.

Write your name on this cover sheet AND at the bottom of each page of this booklet.

Some questions may be harder than others. Attack them in the order that allows you to make the most progress. If you find a question ambiguous, be sure to write down any assumptions you make. Be neat. If we can't understand your answer, we can't give you credit!

THIS IS AN OPEN BOOK, OPEN NOTES QUIZ.
LAPTOPS MAY BE USED; NO PHONES OR INTERNET ALLOWED.

Do not write in the boxes below

1-3 (xx/26)	4-7 (xx/36)	8-10 (xx/19)	11-14 (xx/19)	Total (xx/100)

Name:

I SQL Query

Consider the following schema for a courses database:

- department(did, dname, location)
- student(sid, sname, did, age)
- course(cid, cname, time, room)
- enrolled(sid, cid)

1. [8 points]: Which of the following SQL queries will count the number of departments with no students taking the course 'Databases'.

(Circle all that apply.)

A.
```
SELECT COUNT(d.did)
FROM department d
WHERE d.did NOT IN (
    SELECT s.did
    FROM student s
    WHERE s.sid IN (
        SELECT e.sid
        FROM enrolled e, course c
        WHERE e.cid = c.cid AND c.cname = 'Databases'
    )
);
```

B.
```
SELECT COUNT(DISTINCT s.did)
FROM student s
WHERE s.sid NOT IN (
    SELECT e.sid
    FROM enrolled e, course c
    WHERE e.cid = c.cid AND c.cname = 'Databases'
);
```

C.
```
SELECT COUNT(DISTINCT d.did)
FROM department d
WHERE d.did NOT IN (
    SELECT s.did
    FROM enrolled e, course c, student s
    WHERE e.cid = c.cid AND c.cname = 'Databases' AND e.sid = s.sid
);
```

D.
```
SELECT COUNT(d.did)
FROM department d, student s, course c, enrolled e
WHERE e.cid = c.cid AND c.cname='Database' AND
      e.sid != s.sid AND d.did = s.did;
```

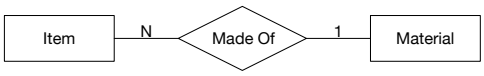
Name:

II Entity and Schema Design

Suppose you are designing a schema to record information about novels (the Internet Novel Database, or INDb). Your database needs to record the following information:

- For each novel, its title, publication date, number of pages, abstract.
- For each writer, his/her name, date of birth, short biography. A writer may write multiple novels. Each novel is written by exactly one writer.
- For each user, his/her username, password, and avatar. A user may rate multiple novels, and an novel may be rated by multiple users. Each rating has a score of 0 to 100.

2. [10 points]: Draw an entity relationship diagram for this database. Please draw entities as squares, attributes as ovals, and denote relationships as diamonds between pairs of entities. Label each edge with a "1" or an "N" to indicate whether the entity on the other side of the relationship connects to 1 or N entities on this side of the relationship. For example, the following would indicate that each item is made of a single material (e.g. wood, metal), and multiple items can be made of the same material:



Give each entity, relationship, and attribute a name.

(Draw your diagram in the space below)

.

Name:

3. [8 points]: Use your ER diagram to determine a relational schema for this database. For each table, use the form:

TablenameN (field1-name, ..., fieldn-name)

to denote its schema. If you wish, you can create an additional field for each table to serve as a unique identifier. Underline the primary keys and use the "... references ..." syntax for foreign keys in your schema.

(Write your answer in the space below.)

III Indexing

4. [6 points]: You are building an index selection tool that measures a numeric benefit for a set of indexes on a query workload W. Larger benefits are better. Suppose that index 1 covers attributes (a,b), and has benefit 10 on W, index 2 covers attributes (a,b,c) and has benefit 12 on W, and index 3 covers attribute (a,c) and has benefit 7 on W.

If you have sufficient storage to create two indexes, which would you recommend, and why?

(Choose one of the following.)

A. 1,2

B. 2,3

C. 1,3

Justify your answer:

IV Joins and Optimization

5. [12 points]:

Consider the problem of joining three tables, A, B, and C via the query:

```
SELECT *
FROM   A,B,C
WHERE  A.a = B.b
AND    C.c = A.b
AND    B.d = C.e
```

Suppose that $|A| > |B| > |C|$, there are no indexes, none of the tables fit in memory, and $|A.a \bowtie B.b| > |A.b \bowtie C.c| > |B.d \bowtie C.e|$ (here $|A|$ refers to number of records in $|A|$, and each record of each table is the same size). Each join is a key-foreign key equality join.

If you know nothing about the size of the final join, which of the following statements about these joins are true? For "bushy" plans like $(A \bowtie C) \bowtie (B \bowtie C)$, assume that the right hand plan is materialized as a table on disk before being used in the top-most join.

(Circle 'T' or 'F' for each choice.)

T F $(A \bowtie B) \bowtie C$ will definitely not be faster than $(B \bowtie C) \bowtie A$

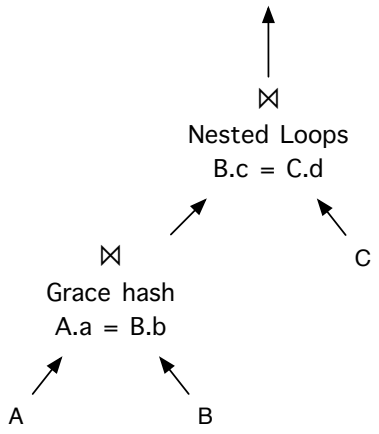
T F $(A \bowtie C) \bowtie B$ will definitely not be faster than $(B \bowtie C) \bowtie A$

T F $(A \bowtie C) \bowtie (B \bowtie C)$ will definitely be faster than $(A \bowtie B) \bowtie C$

T F $(A \bowtie C) \bowtie (B \bowtie C)$ could be faster than $(B \bowtie C) \bowtie A$

Name:

6. [10 points]: Consider the following physical query plan generated by a query optimizer with support for nested loops, index nested loops, grace hash, and blocked hash join.



Given what you know about join algorithms and optimizers, which of the following statements are most likely true, assuming the optimizer is able to accurately estimate statistics (e.g., cardinalities and selectivities of tables and intermediate results.)

(Circle 'T' or 'F' for each choice.)

T F Neither A nor B fits into memory

T F C does not fit into memory

T F The cardinality of (A join B) is equal to or smaller than the cardinality of (B join C)

T F The cardinality of C is very large

T F None of the tables have indexes on them, since index nested loops joins weren't used

Name:

7. [8 points]: Suppose the Selinger optimizer chooses to join four tables A,B,C, and D in the order

```
((A sort-merge B) sort-merge C) sort-merge D)
```

Here the query contains join predicates between all pairs of tables (so that the optimizer might have generated any left-deep ordering of these predicates.) Assume sort-merge can spill to disk (i.e., doesn't require the tables to fit into memory).

You look at the optimizer and find that it estimates that the number of records output by A join B is more than the number of records output by A join C. Give two reasons why it might have produced the plan above:

(Write your answers below.)

Reason 1:

Reason 2:

Name:

V Column-Stores

Consider three tables T1, T2, and T3, each of which has 10 columns (a through j), each of which is 4 bytes wide. T1.a, T2.a, and T3.a are the primary keys of each table, respectively. You are running the query:

```
SELECT AVG(T1.e)
FROM T1, T2, T3
WHERE T1.b = T2.a
AND T1.c = T3.a
AND T2.f > 15
AND T3.g > 50
```

Here attributes T1.e, T2.f, and T3.g are uniformly distributed integers between 0 and 100, foreign keys values (T1.b, T1.c) are selected uniformly and at random, each table is 100 GB on disk (2.5 billion records), and you are running in a row-store with 10 GB of memory.

8. [4 points]: In what order should these joins be run:

(Circle the best ordering)

A. T1.b = T2.a then T1.c = T3.a

B. T1.c = T3.a then T1.b = T2.a

9. [6 points]: For each join, considering your chosen join order, and choosing amongst grace hash, simple hash, in-memory hash, or nested loops, which join algorithm would you recommend for each join:

(Write the join algorithm for each join.)

A. T1.b = T2.a Algorithm: _____

B. T1.c = T3.a Algorithm: _____

10. [9 points]: Now suppose you switch to a column-oriented database like C-Store. If the query on the previous page is the only query being run, and you can choose to sort each table's columns on a set of attributes (e.g., a then b then c), which sort order would you recommend for each table, and why? Assume that system is employing late-materialization, and can compress columns using either Lempel-Ziv (e.g., zip) or run-length encoding.

(Choose a sort order for each table.)

A. Sort order for T1: _____

B. Sort order for T2: _____

C. Sort order for T3: _____

_____

Justification for choice of above orders?

Name:

VI Query Planning

The following tables in Postgres are from TPC-H, a decision support benchmark.

```
               Table "public.lineitem"
     Column      |         Type          | Modifiers
-----------------+-----------------------+-----------
 l_orderkey      | bigint                | not null
 l_partkey       | bigint                | not null
 l_suppkey       | bigint                | not null
 l_linenumber    | integer               | not null
 l_quantity      | numeric               |
 l_extendedprice | numeric               |
 l_discount      | numeric               |
 l_tax           | numeric               |
 l_returnflag    | character(1)          |
 l_linestatus    | character(1)          |
 l_shipdate      | date                  |
 l_commitdate    | date                  |
 l_receiptdate   | date                  |
 l_shipinstruct  | character(25)         |
 l_shipmode      | character(10)         |
 l_comment       | character varying(44) |
Indexes:
    "lineitem_pkey" PRIMARY KEY, btree (l_orderkey, l_linenumber)
    "idx_lineitem_commitdate" btree (l_commitdate)
    "idx_lineitem_partkey" btree (l_partkey)
    "idx_lineitem_receiptdate" btree (l_receiptdate)
    "idx_lineitem_shipdate" btree (l_shipdate)
    "idx_lineitem_suppkey" btree (l_suppkey)

               Table "public.orders"
     Column      |         Type          | Modifiers
-----------------+-----------------------+-----------
 o_orderkey      | integer               | not null
 o_custkey       | bigint                | not null
 o_orderstatus   | character(1)          |
 o_totalprice    | numeric               |
 o_orderdate     | date                  |
 o_orderpriority | character(15)         |
 o_clerk         | character(15)         |
 o_shippriority  | integer               |
 o_comment       | character varying(79) |
Indexes:
    "orders_pkey" PRIMARY KEY, btree (o_orderkey)
    "idx_orders_custkey" btree (o_custkey)
```

We have run VACUUM FULL ANALYZE on all of the tables in the database, which means that all of the statistics used by PostgreSQL server should be up to date.

Name:

Consider the following query and two query plans produced by the EXPLAIN command for it:

```
SELECT l_shipmode,
       SUM(CASE
             WHEN o_orderpriority = '1-URGENT'
                  OR o_orderpriority = '2-HIGH' THEN 1
             ELSE 0
           END) AS high_line_count,
       SUM(CASE
             WHEN o_orderpriority <> '1-URGENT'
                 AND o_orderpriority <> '2-HIGH' THEN 1
             ELSE 0
           END) AS low_line_count
FROM   orders,
       lineitem
WHERE  o_orderkey = l_orderkey
       AND l_shipmode IN ( 'TRUCK', 'AIR' )
       AND l_commitdate < l_receiptdate
       AND l_shipdate < l_commitdate
       AND l_receiptdate >= DATE '1995-01-01'
       AND l_receiptdate < DATE '1995-01-01' + interval '1' month
GROUP  BY l_shipmode
ORDER  BY l_shipmode;
```

```
                                  QUERY PLAN 1
-----------------------------------------------------------------------------------------------
 Sort  (cost=266445.78..266445.78 rows=1 width=27)
   Sort Key: lineitem.l_shipmode
   ->  HashAggregate  (cost=266445.76..266445.77 rows=1 width=27)
         Group Key: lineitem.l_shipmode
         ->  Nested Loop  (cost=0.86..266400.34 rows=2595 width=27)
               ->  Index Scan using idx_lineitem_receiptdate on lineitem
                         (cost=0.43..247401.13 rows=2595 width=19)
                     Index Cond: ((l_receiptdate >= '1995-01-01'::date) AND
                                  (l_receiptdate < '1995-02-01 00:00:00'::timestamp without time zone))
                     Filter: ((l_shipmode = ANY ('{TRUCK,AIR}'::bpchar[])) AND
                              (l_commitdate < l_receiptdate) AND (l_shipdate < l_commitdate))
               ->  Index Scan using orders_pkey on orders
                         (cost=0.43..7.31 rows=1 width=20)
                     Index Cond: (o_orderkey = lineitem.l_orderkey)

                                  QUERY PLAN 2
-----------------------------------------------------------------------------------------------
 Sort  (cost=317988.67..317988.67 rows=1 width=27)
   Sort Key: lineitem.l_shipmode
   ->  HashAggregate  (cost=317988.65..317988.66 rows=1 width=27)
         Group Key: lineitem.l_shipmode
         ->  Hash Join  (cost=61377.00..317943.24 rows=2595 width=27)
               Hash Cond: (lineitem.l_orderkey = orders.o_orderkey)
               ->  Seq Scan on lineitem  (cost=0.00..256514.34 rows=2595 width=19)
                     Filter: ((l_shipmode = ANY ('{TRUCK,AIR}'::bpchar[])) AND
                              (l_commitdate < l_receiptdate) AND
                              (l_shipdate < l_commitdate) AND
                              (l_receiptdate >= '1995-01-01'::date) AND
                              (l_receiptdate < '1995-02-01 00:00:00'::timestamp without time zone))
               ->  Hash  (cost=42627.00..42627.00 rows=1500000 width=20)
                     ->  Seq Scan on orders  (cost=0.00..42627.00 rows=1500000 width=20)
```

Name:

11. [2 points]: Based on the above EXPLAIN output, which of these two plans will Postgres choose, and why?

(Circle the best plan.)

Plan 1 Plan 2
Justification:

12. [2 points]: What type of join is Postgres using in Plan 1?

(Write your answer in the space below.)

13. [5 points]: What is the estimated selectivity of the predicate `l_orderkey = o_orderkey`, in terms of the fraction of the orders table it selects?

(Write your answer in the space below.)

Name:

Now consider the following query and the query plan output from the EXPLAIN command:

```
SELECT l_orderkey,
       SUM(l_extendedprice * ( 1 - l_discount )) AS revenue,
       o_orderdate,
       o_shippriority
FROM   orders,
       lineitem
WHERE
       l_orderkey = o_orderkey
       AND o_orderdate < DATE '1995-02-01'
GROUP  BY l_orderkey,
          o_orderdate,
          o_shippriority;
```

```
                                    QUERY PLAN
-------------------------------------------------------------------------------
 HashAggregate  (cost=358998.96..393962.93 rows=2797118 width=28)
   Group Key: lineitem.l_orderkey, orders.o_orderdate, orders.o_shippriority
   ->  Hash Join  (cost=55061.22..317042.19 rows=2797118 width=28)
         Hash Cond: (lineitem.l_orderkey = orders.o_orderkey)
         ->  Seq Scan on lineitem  (cost=0.00..181499.15 rows=6001215 width=20)
         ->  Hash  (cost=46322.00..46322.00 rows=699138 width=12)
               ->  Seq Scan on orders  (cost=0.00..46322.00 rows=699138 width=12)
                     Filter: (o_orderdate < '1995-02-01'::date)
(8 rows)
```

14. [10 points]: When we create a B+Tree on `orders(o_orderdate)`, we find that Postgres still chooses a sequential scan instead of an index scan on orders. Which of these explains why this might be the case.

(Circle 'T' or 'F' for each choice.)

T F The predicate on `o_orderdate` is not selective enough.

T F The predicate on `o_orderdate` is too selective.

T F Using the index will require using an index nested loops join, resulting in more passes over the lineitem table.

T F Using the index will result in more random I/Os to the order table, which Postgres estimates will be slower than a sequential scan of the orders table.

T F The index on `orders(o_orderdate)` is a clustered index.

End of Quiz I!

Name: