My Name: _____

Final: CS186, Spring 2015

My Course Account: cs186-_____

Prof. J. Hellerstein

You should receive a double-sided answer sheet and a 13-page exam. Mark your name and login on the front of the answer sheet, and in the blanks above. For each question, place ***only your final answer*** *on the answer sheet—do not show work or formulas there. You may use the backs of the questions for scratch paper, but* ***do not tear off any pages****. We will ask you to turn in your question sheets as well as your answers.*

I. Query Processing [16 points]

You and your friends have a brilliant idea for a startup: you decide to build a social-media site, FishBook, which allows users to share their pet fish with the world.

Low on funds, you start building your application on an old ten-year-old computer your friend's parents threw out last year. After much difficulty, you succeed in installing a database management system (DBMS) on this computer, which uses a System R (Selinger) optimizer:

- Page size: 32 KB
- Allocated memory for DBMS: 500 pages (about 16MB)

1. **(2 points)** You decide to test out your shiny new system by running some performance tests on it. What is the maximum amount of data your system can aggregate using external hashing in three passes, in pages, assuming the hash functions partitions data uniformly? **You can write the final answer as an arithmetic expression.**

You start building your web application. Each user can post descriptions of their pet fish to this application. Here's part of your database schema:

```
Users(uid int, username text, ...)
Fish(fid int, ownerid int, age_in_days int, description text, ...)
```

where `uid` and `fid` are primary keys, assigned as sequential integers in ascending order starting from 0. `Fish.ownerid` is a foreign key to `Users`.

Overnight, your application goes viral. Thousands of users have signed up and have posted their pets on your site:

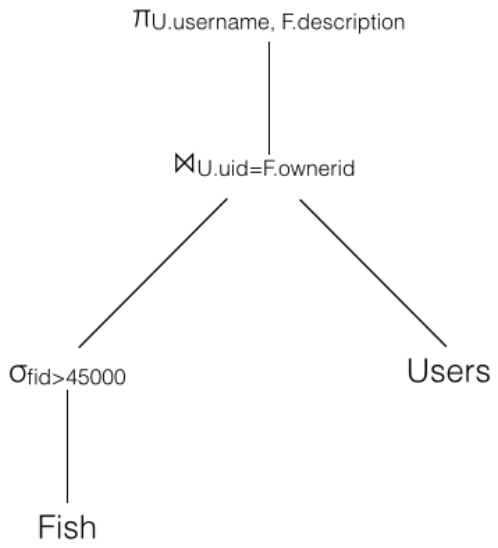
- Users: 10000 tuples, 1000 pages
- Fish: 50000 tuples, 10000 pages

For the following questions, assume the values are distributed uniformly and independently.

I. Query Processing, cont.

Your startup co-founder wants some material for marketing, so you produce some example data from your database:

```
SELECT U.username, F.description
FROM Users U, Fish F
WHERE F.fid > 45000
AND U.uid = F.ownerid;
```



2.

a. **(3 points)** What is the estimated I/O cost of the query plan above, assuming it uses a Sort-Merge join? Use the optimization (described in class) where we merge-join during the final sort pass. Ignore the effects of the buffer pool and disk locality. Do not count the cost of write your final output. Assume that we use quicksort for in-memory sorting.
b. **(2 points)** How many tuples are estimated to be returned by this query?

3. **(2 points)** You decide to speed up your application by adding indexes to your database. Consider two possible indexes:
   - #1: A clustered alternative 1 index on Users.uid, or
   - #2: An unclustered alternative 2 index on Fish.ownerid

   For each of the following queries, which of the above indexes will be more useful in speeding up these queries on expectation? **Answer #1 or #2 for each of the following:**
   a. Given a user ID, compute the average age of his/her fish.
   b. Given a fish ID, look up the username of the user who owns this fish.
   c. Count how many fish some user has.
   d. Find the usernames of the users who own the 100 oldest fish.

I. Query Processing, cont.

Users might find it easier to become acquainted with each others' pet fish if they can also see pictures of them. You add to your database storage for these pictures:

```
Pictures(pid int, fishid int, image blob, ...)
```

where `pid` is a primary key, `Pictures.fishid` is a foreign key to Fish and a `blob` is the image data associated with a picture.

4. **(3 points)** A part of your site needs to display the number of pictures there are of each pet. Which of the following will decrease the I/O cost of this query? **Circle all that apply.**
   i. Sorting Pictures by `fishid` on disk
   ii. Running a compression algorithm on fish image data before inserting the tuples into Pictures
   iii. An unclustered index on `Pictures.pid`

You decide to add a species-recognition feature to your application. Using state-of-the-art machine learning algorithms, you write a classifier for these fish images. You add this to your DBMS as a custom user-defined function (UDF), `classify(blob)`.

5. **(4 points)** Consider the following query:

```
SELECT U.username, count(F.fid)
FROM Users U, Fish F, Pictures P
WHERE U.uid = F.ownerid
AND F.fid = P.fishid
AND classify(P.image) = 'clownfish'
GROUP BY U.uid
ORDER BY count(F.fid) DESC;
```

Assume only heap files are used for storage. **Write down the letters of all joins that produce interesting orders for this query.**

a. Sort-merge(Users, Fish)
b. Sort-merge(Fish, Users)
c. Chunk-Nested-Loops(Users, Fish)
d. Chunk-Nested-Loops(Fish, Users)
e. Sort-merge(Pictures, Fish)
f. Sort-merge(Fish, Pictures)
g. Chunk-Nested-Loops(Pictures, Fish)
h. Chunk-Nested-Loops(Fish, Pictures)

II. Indexing / Storage [17 points]

1. **(5 points)** True/False
    a. The pin count for a buffer pool frame reflects the number of times the page it holds has been referenced since it was last loaded into memory.
    b. If pages are always fully packed, then inserting or deleting a tuple in a sorted file of N pages will require ½ N I/Os on average.
    c. The slotted page format allows tuples to be moved to a different location on the same page without changing the record ID.
    d. For a lookup on a primary key, a clustered B+ tree provides better spatial locality than an unclustered B+ tree.
    e. In a tree-structured index, the fanout is large in order to keep the height of the tree fairly shallow.

You are working as a database administrator (DBA) at ClikClak, an anonymous text message forum app. Their data is stored in a single table with the following schema:

```
Post (postid int, userid int, pdate int, content text)
```

where `postid` is a primary key for `Post`. `Post` takes up N = 10,000 pages on disk.

The `Post` table is partitioned across three servers based on the data's access pattern.

Server ID	Read/Write Ratio	% of N	Access Pattern Details
S1	80/20	20%	sequential scans in chronological order
S2	40/60	60%	posts made by a user, shown on their profile
S3	99/1	20%	queries for random specific posts no temporal locality

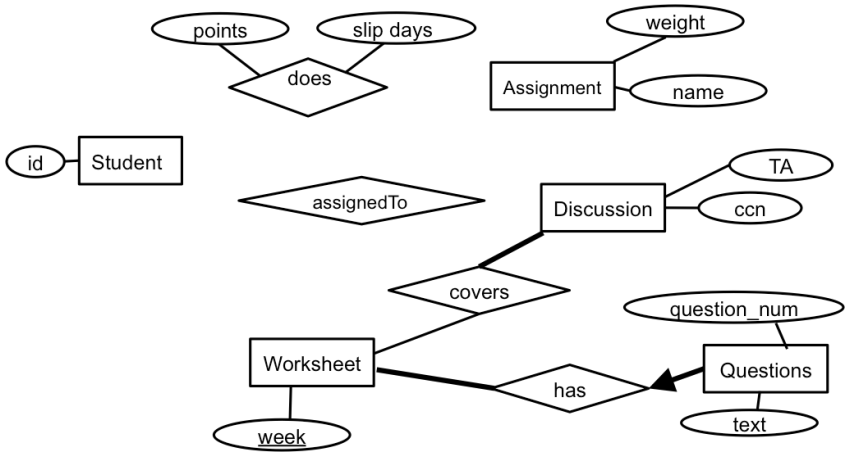
2. **(12 points) For each server**, fill in the blank on your answer sheet to choose parameters that best optimize performance for that server's access pattern. Don't ignore the maintenance cost of insertions/updates when considering performance.

2a. Select a buffer replacement policy:	2b. Select a file layout and index:
A. Least Recently Used B. Most Recently Used C. Random D. Any of the above	A. HeapFile, Unclustered B+ tree on postid B. HeapFile, Clustered B+ tree on userid C. SortedFile on date, Unclustered B+ tree on date D. SortedFile on date, No index E. SortedFile on userid, Unclustered B+ tree on content F. SortedFile on userid, No index

III. Database Design [18 pts]

The CS186 staff is designing a database to store information about students who are currently taking the course.
For each student, the staff wants to keep track of the *one optional* discussion section to which the student is assigned—students may choose to be assigned to no discussion section if they like. The discussion section is composed of a unique course control number (ccn) for that section, and the name of a TA. Students will also do assignments—all of which have differing weights. For each assignment, the staff wants to store the number of points the student earned and the number of slip days they have used on that assignment. If a student does not turn in an assignment, they will be recorded in the database as having done the assignment but will receive zero points. Assume there are many assignments, and all assignments are released to the class to be done.

1. **(3.5 points)** To implement the database, a TA decides to create an ER diagram. Complete the ER diagram on the answer sheet for the **Student**, **Assignment**, and **Discussion** entities by underlining the primary keys and connecting the given entity and relationship sets using the appropriate lines and/or arrows. If bolding a line/arrow, be sure to clearly make it bold.



2. **(1.5 points)** The given ER diagram is missing the proper notation for its weak entity. Complete the notation for the weak entity in the diagram on the answer sheet.

3. **(2 points)** The staff decides the assignments will be difficult, so students should work in teams of two. Each team should have one student who is the "team lead". Make the additions to the ER diagram on the answer sheet to do so. Assume that there are an even number of students. The fewer entities and relationships you use, the better. You should not need to add more than one entity and/or relationship.

4. **(2 points)** For each of the following, select whether the addition would best be included in the ER diagram as an attribute (A), entity (E), or needs more information (NMI).
   a. Student's primary contact email
   b. Student's additional emails
   c. Student's address with city, street, etc.
   d. Student's classes

III. Database Design, Cont.

The staff decides that they need to store more information about each assignment. The TA who redesigns things ignores the ER diagram, and simply designs a relational schema with functional dependencies. Thus, treat the following parts **separately** from the ER diagram above.

Along with the **i**d of the student who did the assignment, the assignment **n**ame, **w**eight, and number of **s**lip days used, they also want to store data for all of the individual **q**uestions. For each question, they want to track the **t**otal number of points it is worth, how many **p**oints the student received on that question, and the student's **r**esponse.

The TA proposes that they should use the relation INWSQTPR, where each attribute is abbreviated by the capitalized version of the underlined, bolded character of the corresponding attribute in the description above.

They imagine the table would look like the one to the right. However, the TA realizes that they can improve their design by finding some functional dependencies (FDs) from the data model, then decomposing the relation into BCNF.

I	N	W	S	Q	T	P	R
1	hw1	25	1	1	5	0	'true'
1	hw1	25	1	2	10	10	'this is...'
1	hw2	10	0	1	5	5	'SELECT * ...'
2	hw1	25	0	1	5	5	'false'

5. **(2 points)** What benefits would the decomposed schema give over using the original relation? Mark all of the following that will **always** apply.
    a. Reduce space required to store the data
    b. Avoid cartesian products
    c. Speed up queries
    d. Avoid update anomalies

6.
    a. **(2 points)** Currently, the FDs that the TA can think of are {N → W, IN → S}. Decompose INWSQTPR into BCNF given these functional dependencies.
    b. **(1 points)** Is the decomposition dependency-preserving based on the FDs above? If not, what relation(s) could you add to make it dependency preserving? Hint: You do not need to compute F+ to answer this question!

7. **(4 points)** The TA needs some help determining the rest of the functional dependencies for this assignment data model. Currently, the FDs he has are {N → W, IN → S}, but he is still missing some useful functional dependencies that will allow him to break the relation into more fundamental components. Write those FDs below. Do *not* include any trivial dependencies or augmentations of the FDs already listed. (Hint: No more than 4 FDs).

IV. Concurrency [19 points]

1. **(5 points)** True/False
   a. SIX locks are compatible with IX locks.
   b. Strict 2PL guarantees conflict serializability but does not prevent cascading aborts.
   c. A schedule is conflict serializable ***if and only if*** its dependency graph is acyclic.
   d. All view serializable schedules avoid cascading aborts.
   e. Wound-wait and wait-die both favor older transactions over newer ones; however, they favor old transactions in different ways.

2. **(2 points)** Consider the follow sequence of transactions:

T1	T2	T3
R(A)		
W(A)		
	R(B)	
R(B)		
W(B)		
		R(C)
W(A)		
T1 COMMIT		
T1 END		
		W(C)
	T2 COMMIT	
	T2 END	
		T3 COMMIT
		T3 END

Does this schedule conform to 2PL?

Does this schedule conform to strict 2PL?

IV. Concurrency

3. **(4 points)** Write the serial schedule that is conflict equivalent to this schedule. If this schedule is not conflict serializable, write “None”.

T1	R(B)							R(F)	W(F)
T2		R(E)							
T3			R(E)	W(E)	R(F)	W(F)			
T4							W(B)		

4. **(8 points)** Under a TO-MVCC scheme, the following actions happen, in the given order. Assume that all objects A-E were originally written at TS0. Write down the letters of the actions that would cause aborts. If no actions would cause abort, write down the letter corresponding to “No writes fail”.

    a. TS10 reads A
    b. TS15 reads B
    c. TS10 reads B
    d. TS20 reads C
    e. TS10 writes A
    f. TS20 writes A
    g. TS15 reads A
    h. TS20 reads B
    i. TS10 writes B
    j. TS15 reads D
    k. TS20 writes D
    l. TS5 writes D
    m. TS1 writes E
    n. TS15 reads E
    o. TS20 writes E

    p. No writes fail

V. Recovery [22 points]

Consider the log below. Some of the information for UPDATE and CLR log records is omitted for brevity. Adjacent log records are spaced exactly 10 LSN's apart.
The system crashes after the last log record is written.

LSN	Record	prevLSN
0	UPDATE: T1 writes P1	null
10	BEGIN_CHECKPOINT	
20	UPDATE: T1 writes P2	0
30	END_CHECKPOINT	
40	UPDATE: T2 writes P3	null
50	UPDATE: T2 writes P4	40
60	ABORT: T1	20
70	CLR: T1 LSN 20	60
80	???	???
90	END: T1	80
100	UPDATE: T3 writes P3	null
110	ABORT: T2	50
120	CLR: T2 LSN 50	110

At checkpoint time, the dirty page table is empty, and **the transaction table is as follows**:

XID	Status	lastLSN
T1	Running	0

1. **(2 points)** What is the missing log record with LSN 80? Please follow the same format as the records above.

The system comes back up after the crash and starts performing recovery.

2. **(4 points)** Fill in the transaction table as it appears at the end of analysis. You may not need to use all rows in the table.

3. **(4 points)** Which pages are in the dirty page table at the end of analysis? You may not need to use all rows in the table.

4. **(4 points)** What actions will occur during the REDO phase? List the LSN's on the answer sheet in the order that they are redone, separated by commas. No new log records will be written during REDO.

5. **(4 points)** What are the records written during the UNDO phase? Start at LSN 200. The difference between the LSN's of two adjacent log records should be 10. You may not need to use all rows in the table.

V. Recovery, cont.

6. **(4 points)** Imagine a version of CS186 where you have to implement ARIES as a class project. Your partner is responsible for the code managing the dirty page table, and his code updates the recLSN in the dirty page table to reflect *each update* to a page, regardless of when the page was brought into the buffer pool. What bugs might you see after recovery? Circle all that apply.
   a. Some writes of committed transactions would be lost.
   b. Some writes of aborted transactions would be visible in the database.
   c. Some transactions that should have been aborted will be committed.
   d. The system tries to commit or abort a transaction that is not in the transaction table.

VI. SQL [15 points]

A group of college dropouts decide that they can take on Uber and start their own ridesharing service called Super.

Super's core business depends on PostgreSQL and primarily relies on 3 tables shown below. Assume that records in the `Trip` table are only created and committed once the actual trip has been completed. Assume the `distance` stored is in miles. The `passenger_rating` of a trip is the rating that the passenger received from the driver, and the `driver_rating` of a trip is the rating that the driver received from the passenger. Assume every driver in the database has completed at least one trip. Ratings are on a scale from 1.0 to 5.0 and can be NULL.

As the Super business grows, they realize the need for analysts with SQL knowledge to help them make better business decisions. They consult you in order to answer their questions regarding their Super business.

VI. SQL, cont.

```
Passenger(pid int, first_name text NOT NULL, last_name text NOT NULL)

Driver(did int, first_name text NOT NULL,last_name text NOT NULL)

Trip( tid int,
      pid int references Passenger(pid) NOT NULL,
      did int references Driver(did) NOT NULL,
      start_time timestamp NOT NULL,
      end_time timestamp NOT NULL,
      distance decimal NOT NULL,
      passenger_rating decimal,
      driver_rating decimal)
```

1. **(3 points)** You hypothesize that some months of the year are more popular than others, perhaps due to weather or special events like holidays. To assess this, you want to know how many trips were taken in each month, independent of year. You and your team define a Trip's `start_time` to indicate which month the trip belongs to.

```
CREATE VIEW num_trips_by_month AS
SELECT EXTRACT(MONTH FROM _____________________) AS month,
       ____________________ AS num_trips
FROM ________________________
GROUP BY month;
```

   Note: `EXTRACT(MONTH FROM _____)` is a PostgreSQL function that extracts the numeric month (e.g. January = 1) out of a timestamp or interval.

2. **(3 points)** You want to prepare your staff next year to improve heavily on the poorest performing month(s), independent of year. Which month(s) had the minimum number of trips? (Use the view created in Q1)

```
SELECT  month
   FROM  num_trips_by_month NTM JOIN
(SELECT _________________ AS min_column
 FROM  _____________________) MIN_TABLE
ON _____________________________;
```

VI. SQL, cont.

3.

a. **(3 points)** Which drivers have a perfect 5.0 average rating from all their trips that received driver ratings? (Return just the unique `did`)

```
SELECT  T1.did
FROM  Trip AS T1
WHERE  _________________(
      SELECT _________________
      FROM  Trip AS T2
      WHERE  ____________________________________________;
);
```

b. **(1.5 points)** When executing this query, you find that this query runs very slowly. What about the structure of this query may cause it to execute so slowly? Circle all statements that could apply.

   A. There are no indices built on the Trip table
   B. The query optimizer optimizes each SELECT block in the query independently
   C. The query will take $O(n^2)$ of work, where n is the size of Trip table and the table is very large

c. **(3 points)** You attempt re-writing this same query with the hope of speeding it up.

```
SELECT  T.did
FROM  Trip as T
GROUP BY  ___________________
HAVING  ____________________ ;
```

4. **(1.5 points)** You hypothesize that drivers and passengers with the same first name get along better (have better ratings) than drivers and passengers that don't share any commonalities.

   You want to eyeball this data yourself. So you have your associate write a query that returns a single row with 2 columns. The first column is the average `driver_rating` of all trips that have driver ratings where the driver and passenger also had the same `first_name`. The second column is the average `driver_rating` of all trips that have driver ratings where the driver and passenger had distinct `first_name`'s.

   Read the following three queries, and circle the ones that yield the desired result on your answer sheet. Notice that the passenger and driver ratings can be NULL, and that SQL aggregate functions (COUNT, SUM, AVG, etc) are defined to ignore NULL values in their calculations.

VI. SQL, cont.

Query A:

```
SELECT SAME_NAME.rating AS same_name,
       DIFF_NAME.rating AS diff_name
FROM (SELECT AVG(driver_rating) AS rating
       FROM  Passenger P, Driver D, Trip T
       WHERE  P.pid = T.pid AND D.did = T.did
              AND P.first_name = D.first_name) AS SAME_NAME,
      (SELECT AVG(driver_rating) AS rating
       FROM  Passenger P, Driver D, Trip T
       WHERE  P.pid = T.pid AND D.did = T.did
             AND P.first_name <> D.first_name) AS DIFF_NAME;
```

Query B:

```
SELECT SAME_NAME.rating AS same_name,
       DIFF_NAME.rating AS diff_name
FROM (SELECT (SUM(driver_rating) / COUNT(*)) AS rating
       FROM  Passenger P, Driver D, Trip T
       WHERE  P.pid = T.pid AND D.did = T.did
              AND P.first_name = D.first_name) AS SAME_NAME,
      (SELECT (SUM(driver_rating) / COUNT(*)) AS rating
       FROM  Passenger P, Driver D, Trip T
       WHERE  P.pid = T.pid AND D.did = T.did
             AND P.first_name <> D.first_name) AS DIFF_NAME;
```

Query C:

```
SELECT  AVG(TS.driver_rating) AS same_name,
        AVG(TD.driver_rating) AS diff_name
FROM  Passenger PS, Driver DS, Trip TS,
      Passenger PD, Driver DD, Trip TD
WHERE PS.pid = TS.pid AND DS.did = TS.did AND
      PD.pid = TD.pid AND DD.did = TD.did AND
      PS.first_name = DS.first_name AND
      PD.first_name <> DD.first_name;
```

Name:_____ Class Login – person on left:_____

Class Login (e.g. -aa): _____ Class Login – person on right:_____

I. Query Processing

1. _____ pages

2a. _____I/Os

2b. _____ tuples

3a. #1 / #2

3b. #1 / #2

3c. #1 / #2

3d. #1 / #2

4. i. / ii. / iii.

5. _____

II. Indexing / Storage

1a. True / False	1d. True / False
1b. True / False	1e. True / False
1c. True / False	

2a. S1 _____ S2 _____ S3 _____

2b. S1 _____ S2 _____ S3 _____

III. Database Design

1-3. Add to the diagram below.

4. a. A / E / NMI
   b. A / E / NMI
   c. A / E / NMI
   d. A / E / NMI

5. a / b / c / d

6a. _____

6b. Yes / No _____

7. _____

_____

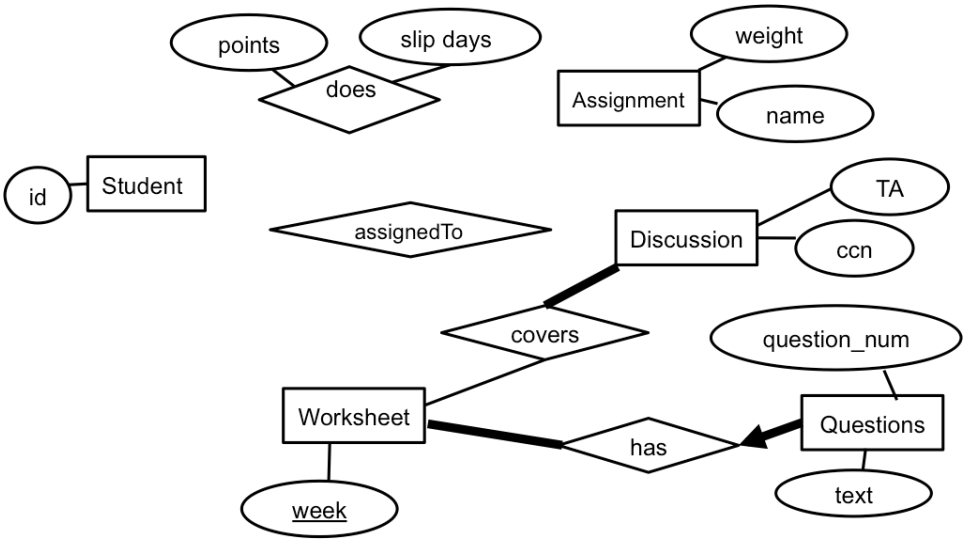
IV. Concurrency

1a. True / False	1d. True / False
1b. True / False	1d. True / False
1c. True / False	

2a. Yes / No	2b. Yes / No

3. _____

4. _____



V. Recovery

1.

LSN	Record	prevLSN

2.

XID	Status	lastLSN

3.

PID	recLSN

4. _____

5.

LSN	Record	prevLSN
200		
210		
220		
230		
240		
250		

6. A / B / C / D

VI. SQL

1.
```
CREATE VIEW num_trips_by_month AS
  SELECT EXTRACT(MONTH FROM
                 _______________) AS month,
  _____________________ AS num_trips
  FROM _____________________
  GROUP BY month;
```

2.
```
SELECT  month
FROM  num_trips_by_month NTM JOIN
  (SELECT _____________ AS min_column
    FROM  ____________________________
  ) MIN_TABLE
ON _____________________________________;
```

3a.
```
SELECT  T1.did
  FROM  Trip AS T1
  WHERE  _____________________________(
    SELECT _____________________________
    FROM  Trip AS T2
    WHERE _____________________________
                 _____________________________);
```

3b. Circle statements that apply:

A / B / C

3c.
```
SELECT  T.did
  FROM  Trip as T
  GROUP BY  _____________________________
  HAVING  _____________________________ ;
```

4. Circle the queries that produce the desired outcome: A B C