CS W186 Fall 2019 Midterm 2

Do not turn this page until instructed to start the exam.

Contents:

- You should receive one *single-sided answer sheet* and a 21-page *exam packet*.
- The midterm has *6 questions*, each with multiple parts, and worth a total of *74 points*.

Taking the exam:

- You have *110 minutes* to complete the midterm.
- All answers should be written on the answer sheet. The exam packet will be collected but not graded.
- For each question, place only your *final answer* on the answer sheet; *do not show work*.
- For multiple choice questions, please *fill in the bubble or box completely* as shown on the left below. ***Answers marking the bubble or box with an X or check mark may receive a point penalty***.

- A blank page is provided at the end of the exam packet for use as scratch paper.

Aids:

- You are allowed **one handwritten** 8.5" × 11" double-sided pages of notes.
- *No electronic devices are allowed on this exam.* No calculators, tablets, phones, smartwatches, etc.

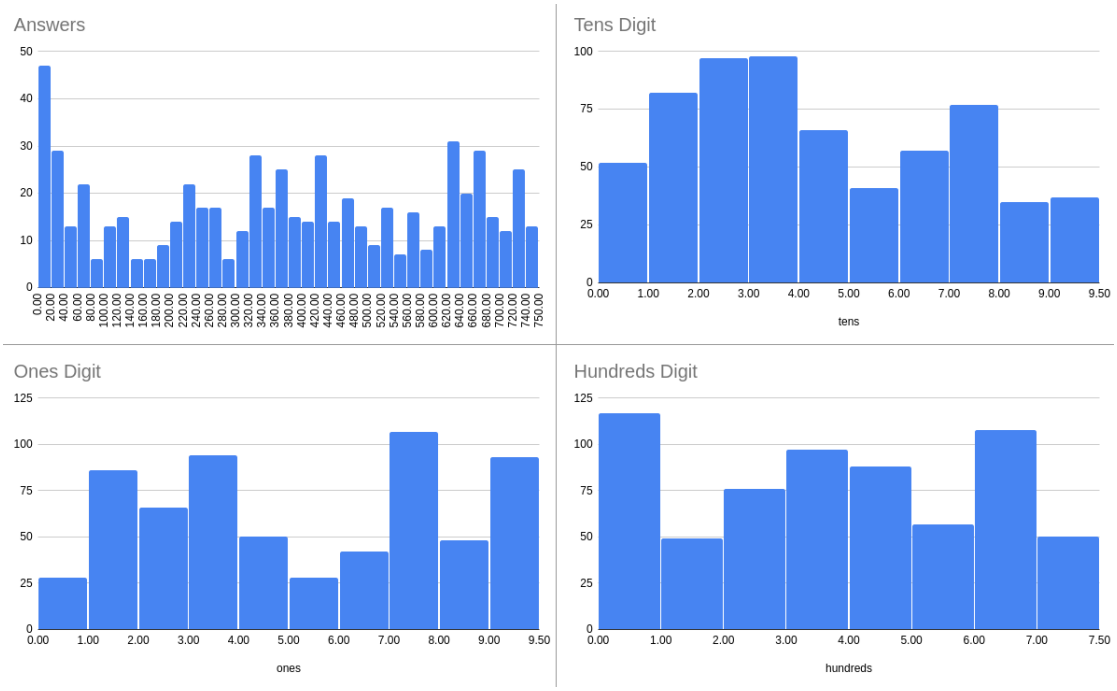
Grading Notes:

- All I/Os must be written as integers. There is no such thing as 1.02 I/Os – that is actually 2 I/Os.
- 1 KB = 1024 bytes. We will be using powers of 2, not powers of 10
- Unsimplified answers, like those left in log format, will receive a point penalty.

1 Pre-Exam Questions (0 points)

1. (0.0001 points) Pick an integer in $[0, 750)$ that no one else taking this exam picked.

Solution: See below for a histogram of the answers:



The most common answer was 333 (10 times), followed by 666 (8 times), 137 (7 times), 0 (6 times), 1 (6 times), 371 (6 times), 420 (6 times), and 721 (6 times).

63.55% of the class answered with an odd number, 4.21% of the class answered with a one-digit number (1.33% of the range), and 18.22% of the class answered with a two-digit number (12% of the range). 30.69% of the class answered with an integer not used by the rest of the class. (All statistics here exclude students that did not follow instructions or left the question blank).

2. (0.0001 points) How many pearls are in a typical 24oz boba drink?

Solution: 170 ± 30! Ask Charles!

2 Grace Hopper Joins (12 points)

You are the organizer for the 2020 Grace Hopper Conference. You are given two tables: Table R, which contains information about all students taking CS W186, and Table S, which contains information about all UC Berkeley students attending the conference. You wanted to know how many students in CS W186 are attending the conference, and whether they have enough slip minutes to put off their project and have a great time in Orlando. You decide to get this information by using Block Nested Loop Join (BNLJ) on both tables. **For the next 2 parts, you may assume that the size of Table R is 100 pages, and the size of Table S is 50 pages. You can also assume that you have 52 pages of buffer space.**

1. (1 point) Calculate the I/O cost of BNLJ, assuming that Table R is the outer relation, and Table S is the inner relation.

   Solution: We have $100 + \lceil \frac{100}{50} \rceil \cdot 50 = 200$.

2. (1 point) Calculate the I/O cost of BNLJ, assuming that Table S is the outer relation, and Table R is the inner relation.

   Solution: We have $50 + \lceil \frac{50}{50} \rceil \cdot 100 = 150$.

3. (1 point) True/False: Using the smaller relation as the outer one in the BNLJ algorithm will always be cheaper than using the larger relation as the outer one in BNLJ.

   Solution: False. Consider a counterexample with [R] = 12, [S] = 11, and B = 6. Then BNLJ with S as the outer relation would result in an IO cost of $\lceil \frac{11}{4} \rceil * 12 + 11 = 47$ I/Os and R as the outer relation would cost $\lceil \frac{12}{4} \rceil * 11 + 12 = 45$ I/Os.

Now, we will perform Grace Hash Join using tables R and S. Operate under the following assumptions:

- $[R] = 60$, $[S] = 20$
- B (number of buffer pages) = 6

4. (2 points) Assuming that we use perfect hash functions and uniformly partition our data at every step of the join process, what is the I/O cost of executing Grace Hash Join?

   Solution: 240 I/Os. Uniform partitioning would mean that at the end of pass 0, you have 5 partitions, each with 12 pages of R and 4 pages of S. This incurs an I/O cost of (60 + 20 + 5 * (12 + 4)) = 160. As you can build a hash table on S now in each partition (as [S] $\leq$ B-2 in each partition), you do not need to recursively hash – just read in each partition for an I/O cost of 5 * (12 + 4) = 80. Our I/O cost is thus 160 + 80 = 240 I/Os. Note that we do not care about the final write cost for the joins, as discussed in lecture.

5. (4 points) Now, assume that the first hash function we use was imperfect. As a result, we end up with partitions after pass 0 that look like this:

   - Partition 1: [R] = 20, [S] = 4
   - Partition 2: [R] = 20, [S] = 7
   - Partition 3: [R] = 10, [S] = 2
   - Partition 4: [R] = 4, [S] = 5
   - Partition 5: [R] = 6, [S] = 2

   Assuming that we use a perfect hash function on each partition following this initial mishap of a partitioning phase, what is the total number of I/Os, from start to finish, needed to execute a Grace Hash Join between R and S?

   Solution: 300 I/Os. Pass 0 will take (60 + 20 + 60 + 20) = 160 I/Os – 1 for reading in every page of R and S, and 1 for writing out every page of R and S (there's no round-up issue here).

   Following this, things get a little more complex. Partitions 1, 3, 4, and 5 require no recursive partitioning, so we can easily calculate the I/Os they'd take: (20 + 4) + (10 + 2) + (4 + 5) + (6 + 2) = 53 I/Os.

   Partition 2 requires (20 + 7) I/Os to do the initial read. Then, we hash it into 5 buckets – using uniform partitioning, this sends 4 pages of R and $\lceil 1.4 \rceil = 2$ pages of S to each bucket. So, 6 pages are sent to each partition in total, meaning we write out 6 * 5 = 30 pages to disk. We then read in those 30 pages to memory for the final probe phase, as at least one of [R] and [S] is now small enough in each partition to fit into memory. This gives 27 + 30 + 30 = 87 I/Os

   Thus, the total number of I/Os is 160 + 53 + 87 = 300 I/Os.

For the next 3 parts, refer to the following pseudo-code for sort merge join:

```
do {
    if (!mark) {
        while (r < s) { advance r }
        while (r > s) { advance s }
        mark = s                          (i)
    }
    if (r == s) {
        result = <r, s>
        advance s
        return result
    } else {
        reset s to mark                   (ii)
        advance r
        mark = NULL                       (iii)
    }
}
```

Everybody makes mistakes, everybody has those days. Whilst implementing SMJ, you may have forgotten some lines of code. For the following questions, indicate the problem you would run into if you were to forget the line of code as indicated by (i), (ii), and (iii). Assume that each question is independent of one another (i.e. you're only minorly flawed -but otherwise you're perfect- and forgot one line of code in each of the questions), also assume that the do loop terminates once one or both iterators, r and s, reach the end of the table.

6. (1 point) What is the problem we run into when we forget to write line (i)?

   A. Error when joining the tables using SMJ

   B. Too many records in the resulting table after running SMJ

   C. Too few records in the resulting table after running SMJ

   D. Nothing wrong

> **Solution:** You get a error when you try to reset s to a mark that you never initialized

7. (1 point) What is the problem we run into when we forget to write line (ii)?

   A. Error when joining the tables using SMJ

   B. Too many records in the resulting table after running SMJ

   C. Too few records in the resulting table after running SMJ

   D. Nothing wrong

> **Solution:** You end up with too few records, consider the case where the left relation (being iterated through by r) has a next record which is the same as the current record.

8. (1 point) What is the problem we run into when we forget to write line (iii)?

   A. Error when joining the tables using SMJ

   B. Too many records in the resulting table after running SMJ

   C. Too few records in the resulting table after running SMJ

   D. Nothing wrong

Solution: You also end up with too few records, we get stuck in the else case and repeatedly iterate r until we reach the end of the left relation.

3 Perpendicular Query Processing (17 points)

1. (1 point) What type of join helps reduce network costs when we have two tables with drastically different sizes?

   Solution: Broadcast Join

2. (1 point) What partitioning scheme is generally best if we only care about ensuring that each machine does an equal amount of work?

   Solution: Round Robin Partitioning

3. (1 point) Which type of parallelism is most likely better if we want to scale up an application with millions of users making simple queries?

   A. Interquery

   B. Intraquery

4. (1 point) Bushy Tree and Pipeline parallelism are subtypes of which class?

   A. Interoperator

   B. Intraoperator

For questions 5-8 we are trying to do a parallel sort on the Students table. The assumptions are:

- $[Students] = 1500$
- We have 5 identical machines (m1, m2, m3, m4, m5) that have B = 10
- All of the pages start on machine 1
- Each page is 1KB
- We are able to partition perfectly so that each machine gets the same number of pages

5. (1 point) What partitioning scheme will we use?

   A. Range

   B. Hash

   C. Round Robin

   D. Other

   Solution: Range. We always range partition when sorting because if each machine sorts independently the data is then fully sorted.

6. (2 points) How many disk I/Os will machine 1 have to do during the initial partitioning?

Solution: 1500. To partition, you must do a full pass over the data.

7. (2 points) What is the network cost of this sorting operation? Remember that we do not need to re-aggregate the data on m1. We can leave data pages on all 5 machines.

Solution: 1200KB. 1/5 of the pages will stay on m1, but 4/5 have to move, so we move 1200 pages.

8. (2 points) How many I/Os will each machine need to do after the initial partitioning phase over the machines? Assume that the "conquer" phase of sorting is streamed from the network, so that each machine does not incur an I/O right after data is received from the network.

Solution: Each machine has 300 data pages to sort independently. With 10 buffer pages, these pages can be sorted in 3 passes (from the standard sorting formula), but the initial read happens before initial range processing. This means we must do (1 + 2 * 2) * 300 = **1500 I/Os**

For questions 9-11 assume that we have hash partitioned the Classes(cid, enrollment) table over three machines on the cid column. The page counts are as follows:

- m1 has 1000 pages
- m2 has 1500 pages
- m3 has 500 pages

Assume 1 I/O takes 1 ms and assume that there is no network or CPU cost.

9. (2 points) How many I/Os will it take to calculate the MAX of the enrollment column?

> **Solution: 3000 I/Os**. We need to look at every page because the max can appear on any page.

10. (2 points) How long will it take to calculate the MAX of the enrollment column?

> **Solution: 1500ms**. Machines operate in parallel and you need to wait for the slowest machine to finish.

11. (2 points) How many I/Os will need to be done in the worst case to find how many students are enrolled in the class with cid=1?

> **Solution: 1500 I/Os**. Worst case is the class occurs on m2 and we need to look at every page to find it. Because the data is hash partitioned on the cid column we know exactly what machine to look for the record on.

4 Query Pessimization (17 points)

1. (1 point) True or False: The lowest-cost order in which to join tables is always a left-deep order.
2. (1 point) True or False: During optimization, the Selinger optimizer will calculate the estimated I/O cost for all possible left-deep orders.
3. (1 point) True or False: In any given pass, the number of subplans that the pass returns is always more than the previous pass.

> **Solution:** All false.
>
> The lowest-cost order is not at all guaranteed to be a left-deep order.
>
> The Selinger optimizer will calculate the estimated I/O cost for a subset of the left-deep orders. It skips over sub-optimal ones due to dynamic programming.
>
> The last pass will always return just one plan (the cheapest plan we found), so the number of plans definitely does not always go up :)

Suppose you are executing the first pass of the Selinger optimizer, and you are currently doing calculations for scanning some table `T` with integer columns `a` and `b`, and 5000 rows over 100 pages.

Suppose the query you are optimizing includes the predicate `T.a > 50`. All predicates will be pushed into the scan when possible.

Suppose we have an unclustered index on column `a` of height 0 (it is just a single node). This index tells us that column `a` has 20 distinct values, the smallest being 1 and the largest being 100.

4. (1 point) What is the cost, in I/Os, of a full table scan on `T`?

> **Solution:** 100 I/Os: it's just the number of pages in `T`.

5. (1 point) What is the cost, in I/Os, of an index scan on `T` over the index for `a`?

> **Solution:** 2501 I/Os. 1 for the index node, and one data page lookup for each row, since the index is unclustered. The selectivity is 0.5, so we will look up 0.5 * 5000 = 2500 rows.

6. (1 point) Now suppose the predicate is `T.a > 50 AND T.b < 40`. There is no index on `b`.

   What is the cost, in I/Os, of an index scan on `T` over the index for `a`?

> **Solution:** 2501 I/Os. The predicate on `b`, while pushed down, does not change our I/O cost for the index scan on `a`.

7. (1 point) Now suppose there is also an index on `b`. It is a height 0 clustered index, and it tells us there are 50 distinct values, the smallest being 30 and the largest being 129.

   What is the cost, in I/Os, of an index scan on `T` over the index for `b`, given the same predicate in the previous problem?

   Solution: 11 I/Os. 1 for the index node. For the predicate on `b`, we will need to look through one-tenth of the index, so we will read the first 0.1 * 100 data pages, or 10 data pages.

8. (1 point) What is the size, in pages, of the output of this scan?

   Solution: 5 pages. Selectivity is 0.5 * 0.1; over 100 pages, this is 5 pages total.

Now suppose you are executing pass 3 of the Selinger optimizer for a different query:

```
SELECT COUNT(*)
FROM A, B, C
WHERE A.x = B.x AND B.y = C.y
GROUP BY A.x;
```

In order to do this, you will need the results from pass 2 of the Selinger optimizer. So, you ask your friend to run the optimizer up to pass 2 and give you the results.

Your friend runs pass 2 and hands you the following list of subplans. It looks funny... Oh no! They forgot to prune the results. That was the whole point of dynamic programming :(

9. (9 points) Not all of the following subplans should have been returned by pass 2 of the Selinger optimizer. For each of the subplans, mark True if it belongs in the result, and False if it does not.

   You will need to look through all the plans before making your selections!

   A. Plan: A ⋈ B (Block Nested Loop Join). Output order: None.
   Cost: 35,000 I/Os. Output size: 1040 pages.

   B. Plan: B ⋈ C (Block Nested Loop Join). Output order: None.
   Cost: 25,000 I/Os. Output size: 550 pages.

   C. Plan: C ⋈ A (Block Nested Loop Join). Output order: None.
   Cost: 7,500 I/Os. Output size: 3850 pages.

   D. Plan: A ⋈ C (Block Nested Loop Join). Output order: None.
   Cost: 6,500 I/Os. Output size: 3850 pages.

   E. Plan: B ⋈ A (Block Nested Loop Join). Output order: None.
   Cost: 40,000 I/Os. Output size: 1040 pages.

   F. Plan: C ⋈ B (Block Nested Loop Join). Output order: None.
   Cost: 20,000 I/Os. Output size: 550 pages.

   G. Plan: A ⋈ B (Sort-Merge Join). Output order: x
   Cost: 50,000 I/Os. Output size: 1040 pages.

   H. Plan: A ⋈ C (Sort-Merge Join). Output order: x
   Cost: 10,000 I/Os. Output size: 3850 pages.

   I. Plan: B ⋈ C (Sort-Merge Join). Output order: y
   Cost: 12,500 I/Os. Output size: 550 pages.

Solution: No A-C plans should be in the result, as they are cartesian products.

Of the A-B plans, we keep the cheapest overall (the BLNJ). There is one interesting order, `x`, since it is in the group-by clause; the cheapest result sorted on `x` is the SMJ, so we keep that too.

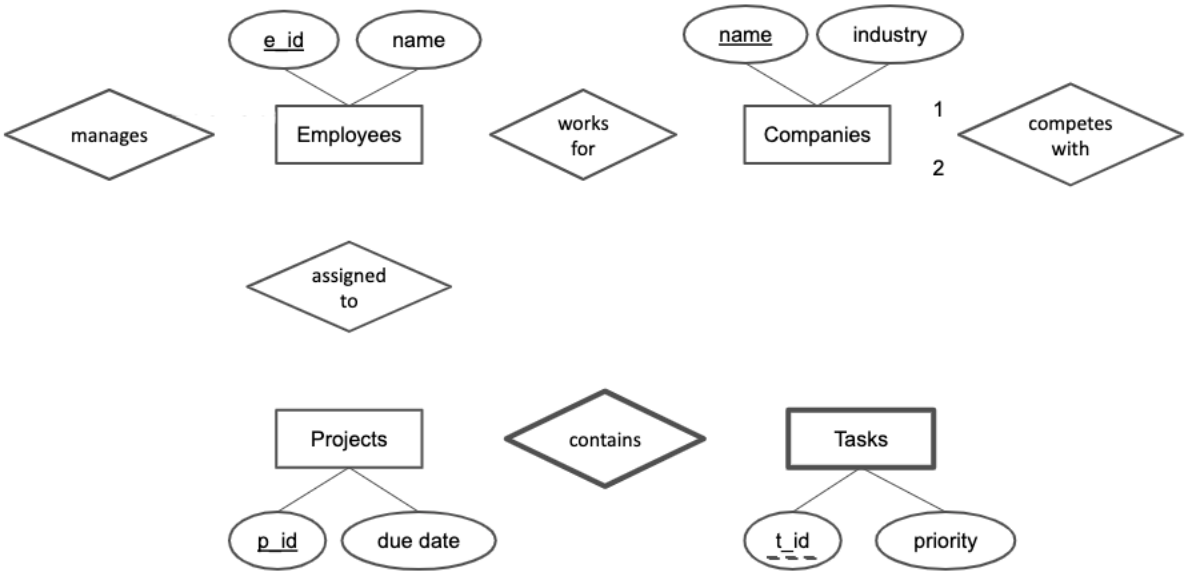
Of the B-C plans, we keep the cheapest overall (the SMJ). There are no interesting orders to additionally keep.

5 DB Design Doc (14 points)

Welcome to Corporate America! Every employee here works as hard as they can every day to complete as many tasks as possible. Total Compensation (TC) is everything in this world and the fastest way to a high TC is to become a 100000x employee.

Assumptions:

- The same entity cannot exist in a relationship with itself when considering recursive relationships.
- A company has to have at least one employee.
- Not all companies have competition but competition that occurs between companies emulates real world competition. That is, a company can have multiple competitors.
- Every employee has one manager and must work for one company.
- Not all employees work on projects but every project must have at least one employee assigned to it.
- All projects contain at least one task that must be finished by the due date.



1. (1 point) What type of edge should be drawn at 1?
   A. thin line
   B. bold line
   C. thin arrow
   D. bold arrow

Solution: Not all companies have competition and a company can compete with many other companies in the same industry so a thin line is used.

2. (1 point) What type of edge should be drawn at 2?
   A. thin line
   B. bold line
   C. thin arrow
   D. bold arrow

Solution: Same as q1.

3. (1 point) What type of edge should be drawn between **Companies** and **works for**?
   A. thin line
   B. bold line
   C. thin arrow
   D. bold arrow

Solution: All companies must have employee(s) so every company must participate in the works for relationship one or more times. A bold line describes this.

4. (1 point) What type of edge should be drawn between **Employees** and **works for**?
   A. thin line
   B. bold line
   C. thin arrow
   D. bold arrow

Solution: All employees must work for one company so every employee must participate in a works for relationship once. A bold arrow describes this.

5. (1 point) What type of edge should be drawn between **Employees** and **manages**?
   A. thin line
   B. bold line
   C. thin arrow
   D. bold arrow

Solution: The thin line represents employees who manage one or more employees. Therefore, the opposite edge represents how every employee must participate in a manages relationship once as all employees have one manager. A bold arrow describes this.

6. (1 point) What type of edge should be drawn between **Employees** and **assigned to**?
   - **A. thin line**
   - B. bold line
   - C. thin arrow
   - D. bold arrow

Solution: Not all employees are assigned to a project and projects can have multiple employees assigned to it so a thin line is used.

7. (1 point) What type of edge should be drawn between **assigned to** and **Projects**?
   - A. thin line
   - **B. bold line**
   - C. thin arrow
   - D. bold arrow

Solution: All projects must be assigned to employee(s) so every project must participate in an assigned to relationship one or more times. A bold line describes this.

8. (1 point) What type of edge should be drawn between **Projects** and **contains**?
   - A. thin line
   - **B. bold line**
   - C. thin arrow
   - D. bold arrow

Solution: All projects contain task(s) so each project must participate in a contains relationship one or more times. A bold line describes this.

9. (1 point) What type of edge should be drawn between **contains** and **Tasks**?
   - A. thin line
   - B. bold line
   - C. thin arrow
   - **D. bold arrow**

Solution: Tasks is a weak entity.

10. (1 point) What is the relationship between **Projects** and **Tasks**?
    - A. one-to-one
    - **B. one-to-many**
    - C. many-to-one
    - D. many-to-many

Solution: Each project can contain many tasks but each task can only be contained within one project due to the relationship expressed in the bold arrow between Tasks and contains.

11. (2 points) Decompose R = SFLADHG into BCNF in the order of the following FDs:
FL → DH, GL → A, S → F, H → GA
Which of the following tables are included in the final decomposition?

A. SLG

B. HGA

C. GLA

D. FLDH

E. HLGA

Solution: FL → DH: SFLADHG decomposes into SLFAG and FLDH
GL → A: SLFAG decomposes into SLFG and GLA
S → F: SLFG decomposes into SLG and SF H → GA: no relation to decompose

12. (1 point) Which of the following could possibly be primary keys of the relation? (There may be zero or more correct answers.)

A. SH

B. SL

C. SG

D. SD

Solution: Primary keys are chosen from candidate keys and candidate keys are minimal keys that determine all other columns in a relation. Therefore, only SL can be chosen as a primary key.

13. (1 point) Is the decomposition dependency preserving?

A. True

B. False

Solution: H → GA does not hold.

14. (0.0001 points) The weekly posts on Piazza have included the phrase "Go Bears" and "Go" what other animal?

Solution: Sharks!

6 The Last Straw (14 points)

1. (5 points) Which of the following statements are true? **There may be zero, one, or more than one correct answer.**

   A. Under strict two-phase locking, once a transaction releases a lock, it must release all other locks.

   B. Holding a SIX lock prevents other transactions from reading or writing at a lower level.

   C. We cannot prevent cascading aborts by using strict two-phase locking.

   D. Two operations are always conflicting if both of them are write.

   E. A waits-for graph is used to figure out if a transaction schedule is serializable.

   Solution: Choice A is true because strict two-phase locking requires a transaction to release all its locks at the same time.
   Choice B is false because holding a SIX lock prevents other transactions from writing at a lower level but does not prevent reading.
   Choice C is false because **strict** two-phase locking **does** prevent cascading aborts (simple two-phase locking does not).
   Choice D is false because they could be writes to different resources and thus would never conflict.
   Choice E is false because a waits-for graph is used for deadlock detection while a conflict dependency graph is used to figure out if a transaction schedule is serializable.

2. (2 points) Mark the transactions involved in the cycle of conflicting operations. If the schedule is conflict serializable, mark none.

T1	R(A)				W(C)	W(D)						
T2		W(B)								R(D)		W(E)
T3			R(A)	W(A)							R(B)	
T4							R(E)	R(C)	R(A)			

   A. T1

   B. T2

   C. T3

   D. T4

   E. None

   Solution: In our conflict dependency graph, we have the following edges:

   - T1 to T3 because T3 wants to write to A which T1 read
   - T1 to T4 because T4 wants to read C which T1 wrote to
   - T3 to T4 because T4 wants to read A which T3 wrote to
   - T1 to T2 because T2 wants to read D which T1 wrote to
   - T2 to T3 because T3 wants to read to B which T2 wrote to
   - T4 to T2 because T2 wants to write to E which T4 read

   The cycle is between T2,T3,T4.

3. (1 point) If we remove the write to E in T2, would this schedule be conflict serializable? If not, mark the transactions involved in the cycle of conflicting operations. Otherwise, mark none.

   A. T1
   B. T2
   C. T3
   D. T4
   E. None

Solution: There is no cycle.

Jenny, Jiayue, Jasmine, and Jeremy want to go try a bunch of different boba drinks together, but they were only able to get one straw per drink. To make sure they don't bump heads while drinking boba with one another, they decide to use locks. Multiple people can pick up a drink at one time, but only one person may drink from a certain drink at a time. In other words, one must obtain a shared lock to pick up the drink. To take a sip, one must obtain an exclusive lock on that drink. Thus, the people are the transactions in this problem (people and transaction are used interchangeably).

Let's say Jenny (J1), Jiayue (J2), Jasmine (J3), and Jeremy (J4) buy a black milk tea (B), a matcha latte (M), jasmine milk tea (J), and a hojicha latte (H).

Person/Time	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
J1	S(H)							X(M)		
J2			S(M)							X(J)
J3		S(J)				X(H)			X(B)	
J4				S(M)	S(H)		X(H)			

4. (1 point) Which people/transactions are in the granted set for M at timestep 4 (including the lock request at this timestep)?

   A. J1

   B. J2

   C. J3

   D. J4

   Solution: Jiayue (J2) and Jeremy (J4) both hold a S lock for the matcha latte (M) so they are both in the granted set.

5. (1 point) Which people/transactions are in the wait queue for H at timestep 7 (including the lock request at this timestep)?

   A. J1

   B. J2

   C. J3

   D. J4

6. (2 points) At timestep 10 (including the lock request at this timestep), we run deadlock detection. Mark the people/transactions involved in the deadlock. If there is no deadlock, mark 'No Deadlock'.

   A. J1

   B. J2

   C. J3

   D. J4

   E. No Deadlock

   Solution: Our waits-for graph has the following edges:

- J1 waits for J2 for resource M
- J1 waits for J4 for resource M
- J2 waits for J3 for resource J
- J3 waits for J1 for resource H
- J3 waits for J4 for resource H
- J4 waits for J1 for resource H

We have a cycle between (J1, J4) and (J1, J2, and J3). Therefore, these are the people in a deadlock.

7. (2 points) If we instead decide to use the wait-die policy for deadlock avoidance, which of the following would be 'aborted' and have to do their boba tasting routine over again based on the order of lock acquisitions? If a transaction is aborted, assume it doesn't restart until after timestep 10. If a transaction is waiting, assume that it doesn't continue to try to acquire other locks.

A. J1

B. J2

C. J3

D. J4

Solution: J3 will abort because of resource H. J4 will abort because of resource H. J1 will wait for J2 on resource M. J2 will be able to acquire resource J because J3 was aborted so it will not be aborted.