CS W186 Spring 2020 Midterm 2 (Online)

Do not share this exam until solutions are released.

Contents:

- The midterm has *6 questions*, each with multiple parts, and worth a total of *85 points*.

Taking the exam:

- You have *150 minutes* to complete the midterm.
- You may print this exam or download it onto an electronic device to work on it.
- For each question, submit only your *final answer* on Gradescope.
- For numerical answers, do not input any suffixes (i.e. if your answer is 5 I/Os, only input 5 and not 5 I/Os or 5 IOs) and do not use LaTeX.
- Questions tagged with **[EXPLANATION]** require you to show work and not doing so will result in **no credit**. You can do this by inputting an explanation in the text field or submitting a file (photo, PDF) of your work. The text field supports LaTeX by using $$insert expression here$$.
- Make sure to submit on Gradescope at the end of the exam.

Aids:

- This exam is open-book, open-calculator, and open-Internet.
- **You must work individually on this exam.**

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 (1 point)

1. (1 point) Please read and sign the Honor Code Statement on Gradescope.

2 Join Zoom Meeting (12 points)

We want to join the `Meetings(zoom_id, class_id, host)` table with the `Classes(cid, dept, course_no, professor)` on the join condition: `class_id = cid`.

- The `Meetings` table has 80 pages with 100 records per page.
- The `Classes` table has 40 pages with 50 records per page.
- We have B = 12 buffer pages.
- We have a clustered Alternative 2, height 3 B+ tree on `Meetings.class_id`. Assume that each class has 4 matches in the `Meetings` table.
- We have no indexes on the `Classes` table.
- For every question, choose the join order that minimizes the I/O cost.

Questions 3-5 walk through doing an unoptimized Sort Merge Join and questions 6-10 walk through doing a Grace Hash Join. All other questions are independent of each other.

1. (2 points) How many I/Os will a Block Nested Loop Join cost?

2. (2 points) [**EXPLANATION**] How many I/Os will an Index Nested Loop Join cost?

3. (1 point) How many I/Os does the merging phase (2nd half) of Sort Merge Join take on average?

4. (1 point) [**EXPLANATION**] How many I/Os does the Sort Merge Join cost in total?

5. (1 point) [**EXPLANATION**] What is the minimum number of buffer pages we could have and not increase the number of I/Os in the previous question?

For the rest of this problem we will go through a Grace Hash Join step-by-step. Assume that we have hash functions that divide the data uniformly into partitions.

6. (1 point) How large are the partitions for the `Meetings` table?

7. (1 point) How large are the partitions for the `Classes` table?

8. (1 point) How many partitioning passes will we need to do in total (consider a pass to be a full pass over each relation, so a and b in total is 1 pass).

9. (1 point) How many I/Os are spent just on the partitioning passes?

10. (1 point) How many I/Os are spent just on the build and probe phase? Recall that (like all joins) the final output is not materialized.

3 Query (O_O) (23 points)

This question will be optimizing the following query:

```
SELECT * FROM R
  INNER JOIN S on S.a = R.a OR S.b > R.b
  INNER JOIN T on T.c = S.c
WHERE R.b > 100 AND S.c != 9
GROUP BY S.c;
```

There are 3 relations R(a,b,c), S(a,b,c), T(a,b,c):

- R - 500 pages with 3 tuples/page
- S - 300 pages with 4 tuples/page
- T - 200 pages with 2 tuples/page

There are 2 indexes:

- Alternative 2 height 3 **unclustered index on S.c** with 35 leaf pages
- Alternative 2 height 4 **clustered index on R.a** with 60 leaf pages

We have the following data (all integers) on table column values:

- R.a ranges from [35-45] inclusive.
- S.a ranges from [40-50] inclusive.
- S.c ranges from [1-50] inclusive.
- T.c ranges from [1-100] inclusive.

To optimize this query, we must first find the best way to access our relations. The table below can be used to compare different access methods.

Relation	Access Method	I/O Cost	Interesting Order	Retained	Output Size
R	File Scan	500	None	Yes	
	Index scan (R.a)				
S	File Scan	300	None	Yes	
	Index scan (S.c)		S.c		
T	File Scan	200	None	Yes	200

1. (2 points) **[EXPLANATION]** What is the I/O cost of performing an index scan on R using the index on R.a?

2. (1 point) Does the index scan on R yield an interesting order?
   A. Yes - R.a
   B. No

3. (1 point) Is the index scan on R retained?
   A. Yes
   B. No

4. (1 point) What is the output size of R in pages?

5. (2 points) **[EXPLANATION]** What is the I/O cost of performing an index scan on S using the index on S.c?

6. (1 point) What is the output size of S in pages?

After finishing the first pass, we use the 2nd pass to find the best way to join sets of 2 tables. The table below can be used to visualize the results of the 2nd pass after answering the questions below.

There are **12 buffer pages** and for the sake of simplicity, assume that there are no duplicates in the join columns. **Disregard the output sizes you computed for the first pass and use R - 60 pages, S - 270 pages for any calculations in the 2nd pass**.

Relations	Best Join	I/O Cost	Interesting Order	Output Size
{S,R}				
{T,S}		1670		

7. (1.5 points) [**EXPLANATION**] What is the best join for the set of tables {S,R}?
   A. BNLJ
   B. INLJ
   C. SMJ
   D. GHJ

8. (1.5 points) What is the I/O cost of the best join for {S,R}?

9. (1 point) Is there an interesting order as a result of joining {S,R}?
    A. Yes - S.a/R.a
    B. Yes - S.b
    C. Yes - R.b
    D. No
10. (1.5 points) What is the output size of the resulting relation after joining {S,R} in pages?

11. (3 points) [**EXPLANATION**] What is the best join for the set of tables {T,S}?
    A. BNLJ
    B. INLJ
    C. SMJ
    D. GHJ

12. (1 point) Is there an interesting order as a result of joining {T,S}?
    A. Yes - S.c/T.c
    B. No
13. (1 point) What is the output size of the resulting relation after joining {T,S} in pages?

Upon finishing the 2nd pass, we've found the best plan for joining any 2 tables together. In the final pass, we will find the best plan for joining any 3 tables together using the estimated costs from the last pass.

Disregard the output sizes you computed for the second pass and use {S, R} - 2900 pages for any calculations in the 3rd pass.

Relations	Best Join	I/O Cost	Interesting Order	Output Size
{{S,R}, T}		15618		5800
{{T,S}, R}	BNLJ	3500	None	5700

14. (3 points) [**EXPLANATION**] What is best join for the set of tables {{S,R},T}?
    A. BNLJ
    B. INLJ
    C. SMJ
    D. GHJ

15. (1.5 points) [**EXPLANATION**] What is the final plan that QO takes?
    A. {{S,R},T}
    B. {{T,S},R}

4 Parallel Patients (13 points)

The hospital want to improve the efficiency of their database, and they hired you to help them query the database in parallel. You have access to 5 machines and the following schemas and sizes of three tables:

`Patients(name, resident_id, level_of_sickness, state, hospital_id)`: 1000 pages
`Doctors(name, resident_id, hospital_id)`: 100 pages
`Hospitals(hospital_id, hname, address)`: 10 pages

`Patients` has a column called `level_of_sickness`, which is an integer between 1 and 10 (inclusive) that indicates how severe the sickness is, 1 being the least severe and 10 being the most severe, and every level of sickness exists in `Patients`. You want to find the more severe patients, so you run the following query:

```
SELECT * FROM Patients WHERE level_of_sickness > 7;
```

1. (1 point) What is the I/O cost of the above query if `Patients` is range partitioned on `level_of_sickness` to the 5 machines, with the following values and sizes for each machine?

Machine	Values	Size (number of pages)
M1	1, 2	270
M2	3	170
M3	4, 5, 6	300
M4	7, 8	60
M5	9, 10	200

2. (1 point) True or False: It is **possible** to achieve a better I/O cost with hash partition.

You want to find all the patients in California, so you run the following query:

```
SELECT * FROM Patients WHERE state = 'CA';
```

3. (1 point) What is the I/O cost of the above query if `Patients` is round-robin partitioned to the 5 machines?

4. (1 point) True or False: It is **guaranteed** to achieve a better I/O cost with hash partition on `state` using any hash function such that none of the partitions are empty.

You want to perform the following join using **Parallel Grace Hash Join**:

```
SELECT * FROM Doctors D, Hospitals H WHERE D.hospital_id = H.hospital_id;
```

Both `Doctors` and `Hospitals` are hash partitioned on `hospital_id` to the 5 machines, with the following numbers of pages:

Machine	Number of pages from `Doctors`	Number of pages from `Hospitals`
M1	40	5
M2	30	2
M3	10	1
M4	10	1
M5	10	1

5. (2 points) [**EXPLANATION**] Each machine has 8 buffer pages, and each I/O takes 1ms. How long does it take the perform the join, in ms?

   Assume the hash partitioning is already done (so don't include that in your answer).

6. (1 point) True or False: It is possible to reduce the time in the previous question by increasing the number of buffer pages.

7. (1 point) True or False: It is possible to reduce the time in the previous question by using a different hash function for the initial hash partitioning.

Unfortunately, some doctors are also sick, and you want to find out the sick doctors. You perform the following join using **parallel un-optimized Sort Merge Join** on the 5 machines (M1, M2, M3, M4, M5):

```
SELECT * FROM Patients P, Doctors D WHERE P.resident_id = D.resident_id;
```

8. (2 points) [**EXPLANATION**] Initially, everything is on M1. Assume we can range partition both `Patients` and `Doctors` on `resident_id` perfectly so that each machine gets the same number of pages. What is the network cost of this initial partitioning in pages?

9. (3 points) [**EXPLANATION**] Each machine has 8 buffer pages, and each I/O takes 1ms. How long does it take to perform this join (in ms) after partitioning evenly data across machines? Assume that the "conquer" phase of sorting is streamed from the network, so that each machine does not incur a read I/O after data is received from the network.

5 New Whip, Who Dis? (17 points)

Ever since you helped Alon Tusk optimize Flux Motors' database of car orders, you've become the go-to Database Engineer in the company! Flux has recently started taking orders for the new car they released, and it's a major hit! Once again, Alon Tusk needs your help making sure the transactions run smoothly.

Alon hands you a snippet of a schedule and asks you to analyze it. Consider the following schedule for all questions:

Transaction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
T1	R(A)				W(C_1)	R(Y)		
T2			W(B)				W(C)	
T3		R(A_1)						W(B_2)
T4				R(B_1)				

For the entirety of this problem, consider a database X with a table Y. Y has pages A, B, and C. Page A has tuples A_1, A_2, page B has tuples B_1, B_2, and page C has tuples C_1, C_2. Additionally, use the multi-granularity locking (with minimum privilege).

1. (3 points) What is the set of edges of the waits-for graph for the schedule? We write (T_i, T_j) if there exists a directed edge from T_i to T_j.
   A. $\{(T_2, T_1), (T_1, T_2), (T_2, T_3), (T_2, T_4)\}$
   B. $\{(T_1, T_2), (T_2, T_1), (T_3, T_2), (T_4, T_2)\}$
   C. $\{(T_1, T_2), (T_2, T_3), (T_2, T_4), (T_4, T_3)\}$
   D. $\{(T_2, T_1), (T_3, T_2), (T_4, T_2), (T_3, T_4)\}$
   E. None of the above
2. (1 point) True or False: This schedule has deadlock.
3. (5 points) [**EXPLANATION**] List all the locks that T1 has after timestep 8 in the order of acquisition with the first lock acquired being on the top left and most recent lock being on the bottom right. If a lock gets promoted, it should stay in the same position (as done in the project). You may or may not need all the boxes. Leave unused boxes blank.

Lock 1	Lock 2	Lock 3	Lock 4	Lock 5
Lock 6	Lock 7	Lock 8	Lock 9	Lock 10

Worried about transactions becoming deadlocked, Alon gives you the task of preventing deadlocks from happening. Having taken CS W186, you remember learning about some deadlock prevention strategies!

For the following four questions, assume that T_1 started first, T_2 started second, T_3 started third, and T_4 started last. If a transaction gets aborted, it will immediately release all locks it has acquired and the wait queue will be processed. Additionally, if a transaction gets placed on a waiting queue (blocked), locks that the transaction acquired up to that point are not released and the actions for that transaction **while it is blocked** do not happen (as if the action was never on the schedule). Additionally, assume promotes are implemented as described on Project 4.

4. (2 points) [**EXPLANATION**] If you use the **wound-wait** approach, which transaction(s) will end up getting aborted? **Select all correct choices. If no transaction gets aborted, select None**
    A. T_1
    B. T_2
    C. T_3
    D. T_4
    E. None

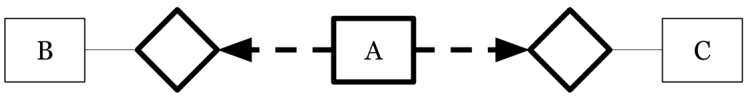
5. (2 points) Which transaction(s) will end up blocked **by the end of timestep 8** if using wound-wait? **Select all correct choices. If no transaction gets blocked, select None**
    A. T_1
    B. T_2
    C. T_3
    D. T_4
    E. None

6. (2 points) If you use the **wait-die** approach, which transaction(s) will end up getting aborted? **Select all correct choices. If no transaction gets aborted, select None**
    A. T_1
    B. T_2
    C. T_3
    D. T_4
    E. None

7. (2 points) [**EXPLANATION**] Which transaction(s) will end up blocked **by the end of timestep 8** if using wait-die? **Select all correct choices. If no transaction gets blocked, select None**
    A. T_1
    B. T_2
    C. T_3
    D. T_4
    E. None

6 A Zoomed Relationship (19 points)

In this problem, you may encounter the concept of a "multi-weak entity" which is a weak entity that can be uniquely identified by an owner entity belonging to one of multiple entity sets. This means that every entity in a multi-weak entity set must participate only once across all its identifying relationship sets. Visually, we will denote the participation of a multi-week entity in an identifying relationship with a **bold dashed arrow**. For example, in the following ER diagram, every entity in A can be uniquely identified by an owner entity that belongs to either B or C.



Also, assume weak and multi-weak entities can participate in non-identifying relationships.

Now onto the problem. With all classes moving online for the rest of the semester, Berkeley is partnering with Zoom Video Communications to develop a new model for tracking online learning. Fill in the ER diagram (attached on page 19) with the series of following constraints. It may be helpful to fill out the entire diagram with all the constraints given on page 19 before answering questions 1-14.

For questions 1-4, what edges should be drawn with the following constraints? Students must take at least 1 course, courses must have at least 1 student taking it and at least 1 professor instructing it, and professors can teach at most 1 course.

1. (1 point) What type of edge should be drawn between **Student** and **Takes**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow
2. (1 point) What type of edge should be drawn between **Course** and **Takes**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow
3. (1 point) What type of edge should be drawn between **Professor** and **Instructs**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

4. (1 point) What type of edge should be drawn between **Course** and **Instructs**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

For questions 5-8, what edges should be drawn with the following constraints? Students can now optionally sign up exactly once as a Zoom User while professors are required to sign up and only once. Each Zoom User account belongs to exactly 1 person (student or professor). Interacting in any form with a Zoom Lecture (attending, lecturing, etc.) can only be done through a Zoom User.

5. (1 point) What type of edge should be drawn between **Student** and **Sign Up (Student)**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow
6. (1 point) What type of edge should be drawn between **Zoom User** and **Sign Up (Student)**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow
7. (1 point) What type of edge should be drawn between **Professor** and **Sign Up (Professor)**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow
8. (1 point) What type of edge should be drawn between **Zoom User** and **Sign Up (Professor)**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

For questions 9-12, what edges should be drawn with the following constraints? To test the online platform, all Zoom Users are required to attend at least 1 Zoom Lecture. A Zoom Lecture must have at least 1 Zoom User lecturing but there is no requirement on the number of Zoom Users attending.

9. (1 point) What type of edge should be drawn between **Zoom User** and **Attends**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

10. (1 point) What type of edge should be drawn between **Zoom Lecture** and **Attends**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

11. (1 point) What type of edge should be drawn between **Zoom User** and **Lectures**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

12. (1 point) What type of edge should be drawn between **Zoom Lecture** and **Lectures**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

For questions 13-14, what edges should be drawn with the following constraints? A Zoom Lecture can optionally be part of at most 1 Course, but a Course must have at least 1 Zoom Lecture be a part of it.

13. (1 point) What type of edge should be drawn between **Zoom Lecture** and **Part of**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

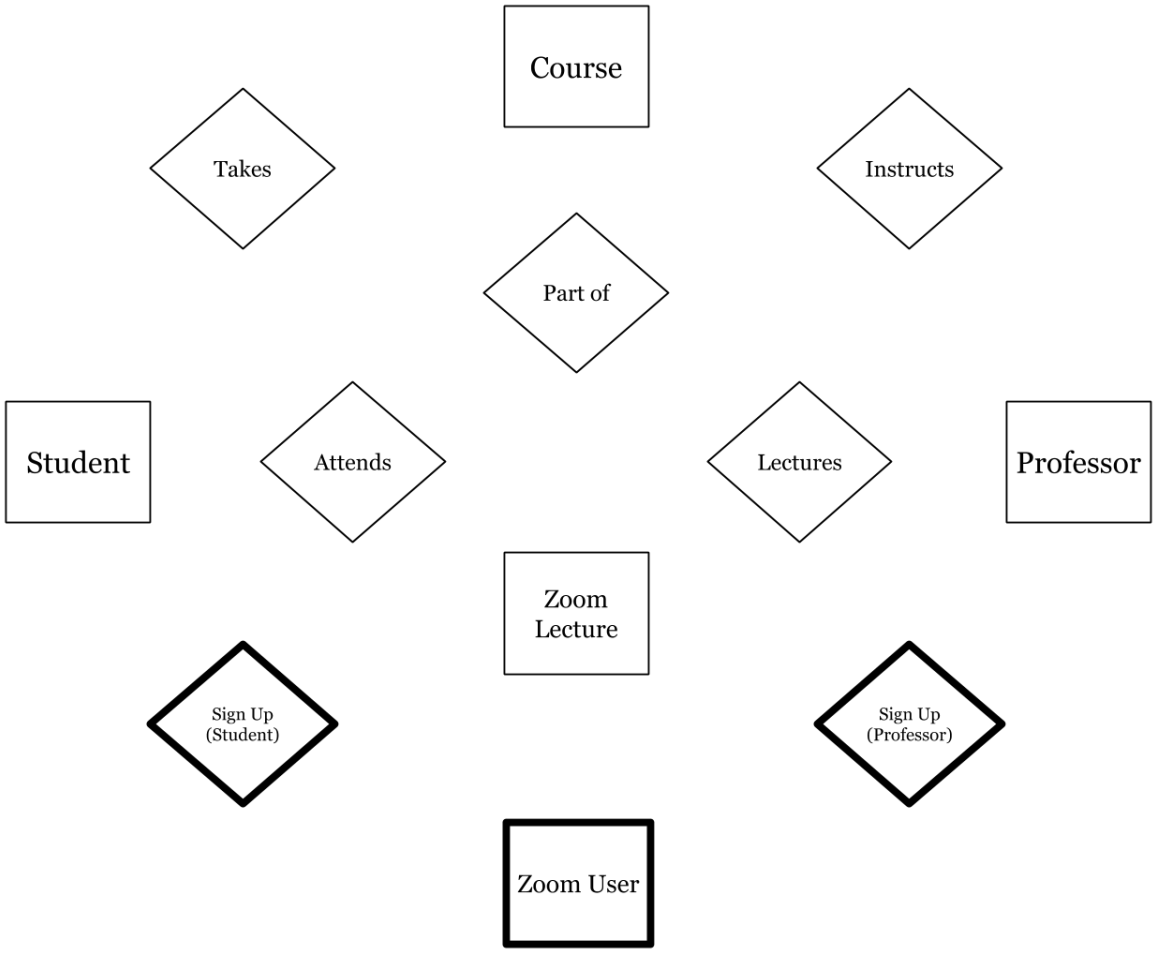
14. (1 point) What type of edge should be drawn between **Course** and **Part of**?
    A. Thin Line
    B. Thin Arrow
    C. Bold Line
    D. Bold Arrow
    E. Bold Dashed Arrow

Consider the following attribute set R = {SOCIALDTNG}

15. (3 points) [**EXPLANATION**] Decompose R into BCNF in the order of the following FDs: S → CLD, D → NG, AO → S, G → IT. Which of the following tables are included in the final decomposition?
    A. SCLD
    B. AOS
    C. DNG
    D. GIT
    E. SOANG
    F. SOIAT

16. (1 point) [**EXPLANATION**] Suppose we decompose R into SOCLDNG and OIATG. Is this decomposition dependency preserving with respect to the FDs in the previous question?
    A. Yes
    B. No

17. (1 point) [**EXPLANATION**] Is the same decomposition lossless with respect to the FDs in the previous question?
    A. Yes
    B. No



All Constraints

1. Students must take at least 1 course, courses must have at least 1 student taking it and at least 1 professor instructing it, and professors can teach at most 1 course.
2. Students can now optionally sign up exactly once as a Zoom User while professors are required to sign up and only once. Each Zoom User account belongs to exactly 1 person (student or professor). Interacting in any form with a Zoom Lecture (attending, lecturing, etc.) can only be done through a Zoom User.
3. To test the online platform, all Zoom Users are required to attend at least 1 Zoom Lecture. A Zoom Lecture must have at least 1 Zoom User lecturing but there is no requirement on the number of Zoom Users attending.
4. A Zoom Lecture can optionally be part of at most 1 Course, but a Course must have at least 1 Zoom Lecture be a part of it.

Scratch Work (0 points)