CSE 132C Spring 2022 Final Exam

Full Name:

Student ID:

INSTRUCTIONS

1. You have 3 hours to complete this exam.

2. You can have up to two letter/A4-sized sheet of notes and a calculator or a smartphone with Internet disconnected for its calculator only. Apart from that, the exam is closed books/notes/electronics/peers.

3. Please wait until being told to start reading and working on the exam.

4. If you think a question is ambiguous, write down your assumptions, argue that they are reasonable, and then work on the problem using those assumptions.

5. Please ensure that your writing is clear and legible!

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<tbody>
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<td>Q 1</td>
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<td>Q 2</td>
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AND WE CAN PUT THE CUSTOMER DATA ON THE BLOCKCHAIN.

WHY NOT USE AN IMMUTABLE DATABASE INSTEAD?

WHICH WAY SHOULD WE GO?

ARE EITHER OF THEM MY FAVORITE COLOR?
Q 1. **[40pts]** For each question below, select the right option (only one is correct).

1. Which of the following relational operators can be processed using a regular (unmodified) hash join implementation?
   (a) Union (b) Intersection (c) Set difference (d) Select (e) Project

2. Which of the following SQL aggregates requires a shuffle among worker nodes in a parallel DBMS even when the **GROUP BY** list is empty?
   (a) SUM (b) AVG (c) VARIANCE (d) MEDIAN (e) MAX

3. Which file organization is typically the most efficient for inserting new records?
   (a) Heap file (b) Sorted file (c) B+ tree index with AltRecord

4. We are given this join query: \( R \bowtie S \bowtie T \bowtie U \). Recall that some query optimizers only consider left-deep join trees for join order enumeration. How many different left-deep join trees exist for this query? (Hint: Swapping the left and right input of a \( \bowtie \) in a given tree yields a different tree.)
   (a) 4 (b) 6 (c) 15 (d) 16 (e) 24

5. Which is the dominant parallelism paradigm that is used in parallel DBMSs, MapReduce/Hadoop, and Spark?
   (a) Shared-nothing (b) Shared-memory (c) Shared-Disk

6. Which of the following relational operators does not preserve the schema of (at least one of) their inputs?
   (a) Union (b) Intersection (c) Set difference (d) Select (e) Project
7. In a hard disk, which of the following components of the data access time accounts for the delay caused by the radial movement of the arm?

(a) Seek time  (b) Rotational delay  (c) Transfer time

8. In a B+ tree index, which nodes are allowed to have duplicates of the index key?

(a) Leaf nodes  (b) Root node  (c) Non-root internal nodes

9. Which of the following symbols does not represent a relational operator from the extended relational algebra?

(a) $\gamma$  (b) $\cup$  (c) $\pi$  (d) $\mu$  (e) $\times$

10. Which data system introduced the first major SQL-on-Hadoop dialect?

(a) Pig  (b) Hive  (c) Spark  (d) Polybase  (e) None of the rest

11. Which of the following EMS optimizations cannot raise the I/O cost?

(a) Internal replacement sort  (b) Double buffering  (c) Blocked I/O

12. In an extendible hash index with GD 5, how many pointers from the directory will a bucket with LD 2 have?

(a) 1  (b) 2  (c) 4  (d) 8  (e) None of the rest

13. A primary index is necessarily also the following type of index?

(a) Unique  (b) Secondary  (c) Composite  (d) AltRID  (e) B+ tree

14. Which join order is most amenable to pipelining when using only hash joins?

(a) Left deep tree  (b) Right deep tree  (c) Bushy tree  (d) All of them
15. A given query on a parallel RDBMS takes 20min to finish on a 4-worker cluster. If the RDBMS exhibits linear speedup for this query, what will its runtime be on a 20-worker cluster?

(a) 20min    (b) 10min    (c) 5min    (d) 4min    (e) None of the rest

16. Which of these SQL capabilities does not have a counterpart in extended relational algebra?

(a) SELECT DISTINCT    (b) WHERE    (c) JOIN    (d) GROUP BY    (e) ORDER BY

17. What is the minimum number of distinct hash functions needed for the two-phase improved hash join implementation in a parallel RDBMS?

(a) 1    (b) 2    (c) 3    (d) 4    (e) 5

18. Which page format does not have metadata for each record slot?

(a) Packed    (b) Unpacked    (c) Variable-length    (d) None of the rest

19. Which equi-join implementation’s I/O cost is hard to accurately express in closed analytical form?

(a) BNLJ    (b) INLJ    (c) SMJ    (d) HJ    (e) None of the rest

20. Which of the following machine resources will likely face dramatically higher loads in the serverless and resource-disaggregated design of cloud computing relative to previous generations of cloud designs?

(a) Processor    (b) Memory    (c) Disk    (d) Network    (e) None of the rest
Q 2. [10pts] Hash Join with non-uniform partitioning. You are joining two tables R and S, which have $4BN_R$ and $12BN_S$ pages respectively, using a hash join. The number of available buffer pages is $4B + 1$. The buffer pool is initially empty. You are given that $4BN_R \gg 12BN_S$ and $2FN_S = 4B - 1$, where $F$ is the hash table fudge factor.

The distribution of the join attribute values in R and S are such that after the first hash partitioning phase, we get exactly $4B$ partitions each of R and S. Each partition of R has $N_R$ pages, but the partitions of S have differing sizes. Suppose S gets partitioned as follows: $B$ partitions of size $N_S$ pages each, $2B$ partitions of size $3N_S$ pages each, and $B$ partitions of size $5N_S$ pages each.

What is the I/O cost of the above join using the regular hash join algorithm discussed in class? Exclude the cost of writing the output. Assume that perfect uniform splitting occurs during the recursive repartitioning and that we do not need to recurse more than once. Briefly explain and show all of your calculations clearly.

(Hint: The answer is of the following form: $xBN_R + yBN_S$, where $x \in \{10, 12, 14, 16, 18, 20\}$ and $y \in \{50, 54, 58, 62, 66, 70\}$.)
Q 3. [10pts] Buffer replacement. You are given an initially empty buffer pool with 3 buffer frames. There are 5 pages on disk: A, B, C, D, E. The buffer replacement policy used is LRU. Answer the following questions for the following sequence of page operations being executed. There are no partial credits for each sub-question.


1. (4pts) Circle all the pages (and only the pages) that are present in the buffer pool at the end of the sequence.

   A       B       C       D       E

2. (3pts) How many page flushes take place? Circle only your final answer.

   0       1       2       3       4       5

3. (3pts) What is the total page I/O cost (reads and writes)? Circle only your final answer.

   3       4       5       6       7       8
Q 4. [10pts] MapReduce. Consider this Netflix database table used in class: \textit{Ratings (RID, MovieID, UserID, Stars, RateDate)}. Suppose it is stored as a large distributed CSV file on HDFS hash partitioned on RID. You are asked to answer the following query: \textit{Get the number of five-star ratings for each movie in the table.}

1. (7pts) Write a MapReduce job to answer the query. Clearly explain the Map and Reduce functions separately. Pseudocode or just precise prose suffices.

2. (3pts) Suppose you have Hive or SparkSQL installed. Write a single SQL statement to answer the same query. Your query must be fully correct; \textit{no partial credits}. 
Q 5. [15pts] Logical query optimization. Are you on social media? Given the following simplified relational database schema for social networks.

Person (ID, Name, Age)
Friends (ID1, ID2)

Person.ID is the primary key of that table. Friends.ID1 and Friends.ID2 are foreign keys referring to Person.ID.

For each query given, clearly circle which query listed under it is logically equivalent to it? For each question only one option is correct. No partial credits.

1. (4pts) πName(σAge>20(Person))

   (a) σAge>20(πName(Person))

   (b) πName,ID(σAge>20(Person))

   (c) πName(σAge>20(πName,Age(Person)))

   (d) σAge>20(πName,ID(Person))

   (e) σName(πAge>20(Person))

   (f) πName(πAge(σAge>20(Person)))

   (g) None of the above
2. (5pts) \( \sigma_{(\text{Age}>20) \land (\text{ID}=1234) \land (\text{Name}='\text{Thanos}') \land (\text{ID}=\text{ID1})}(\text{Person} \times \text{Friends}) \)

(a) \( \sigma_{(\text{Age}>20) \land (\text{Name}='\text{Thanos}')}(\text{Person}) \times \sigma_{(\text{ID}=1234) \land (\text{ID}=\text{ID1})}(\text{Friends}) \)

(b) \( \sigma_{\text{ID}=\text{ID1}}(\sigma_{\text{ID}=1234}(\text{Friends})) \times \sigma_{(\text{Name}='\text{Thanos}') \land (\text{Age}>20)}(\text{Person}) \)

(c) \( \sigma_{(\text{Age}>20) \land (\text{Name}='\text{Thanos}')}(\text{Person}) \bowtie_{\text{ID}=\text{ID1}} \sigma_{\text{ID}=1234}(\text{Friends}) \)

(d) \( \sigma_{\text{ID}=1234}(\text{Friends}) \bowtie_{\text{ID}=\text{ID1}} \sigma_{(\text{Age}>20) \land (\text{Name}='\text{Thanos}')}(\text{Person}) \)

(e) None of the above

3. (6pts) \( \pi_{\text{Name,ID}}(\text{Person} \bowtie_{\text{ID}=\text{ID2}} \pi_{\text{ID2}}(\sigma_{\text{Name}='\text{Thanos}'}(\text{Person} \bowtie_{\text{ID}=\text{ID1}} \text{Friends}))) \)

(a) \( \pi_{\text{Name}}(\pi_{\text{ID1,ID2}}(\pi_{\text{ID}}(\sigma_{\text{Name}='\text{Thanos}'}(\text{Person}))) \bowtie_{\text{ID}=\text{ID1}} \text{Friends}) \bowtie \text{Person}) \)

(b) \( \pi_{\text{Name,ID}}(\text{Person}) \bowtie_{\text{ID}=\text{ID2}} \pi_{\text{ID2}}(\sigma_{\text{Name}='\text{Thanos}'}(\text{Person}) \bowtie_{\text{ID}=\text{ID1}} \text{Friends}) \)

(c) \( \pi_{\text{Name,ID}}(\text{Person}) \bowtie_{\text{ID}=\text{ID1}} \pi_{\text{ID1}}(\sigma_{\text{Name}='\text{Thanos}'}(\text{Person}) \bowtie_{\text{ID}=\text{ID1}} \text{Friends}) \)

(d) \( \pi_{\text{Name,ID2}}(\text{Person}) \bowtie_{\text{ID}=\text{ID2}} \pi_{\text{ID2}}(\sigma_{\text{Name}='\text{Thanos}'}(\text{Person}) \bowtie_{\text{ID}=\text{ID2}} \text{Friends} \)

(e) None of the above
Q 6. [15pts] Operator implementation and PQP costing. Do you like shopping? Consider the following simplified relational database schema for shopping.

Products (PID, PName, Vendor, Price)
Customers (CID, CName, Zipcode, Age)
Purchases (CID, PID, Timestamp, Quantity)

Products.PID and Customers.CID are primary keys. In Purchases, CID and PID are foreign keys referring to Customers.CID and Products.PID, respectively. The size of each attribute is 8 bytes, except for PName, Vendor, and CName, which are 40 bytes each.

The tables are stored in a row-store heap file format with the following numbers of pages: 1 million for Products, 10 million for Customers, and 1 billion for Purchases. No indexes are present in the database. Page size is 8 KB. Available buffer memory is 64 GB. The buffer pool is empty to start with. The fudge factor for hash tables is 1.4.

For each query given, what is the lowest possible I/O cost (in pages) using only the physical operator implementations discussed in class? Exclude output write costs. No partial credits for the first two sub-questions. Just circle your final answer.

1. (3pts) Purchases ⊙◁ Customers.

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<th>1010 million</th>
<th>1030 million</th>
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<td>3000 million</td>
<td>3000 million</td>
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<td>3030 million</td>
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<td>5010 million</td>
<td>5010 million</td>
<td>5050 million</td>
<td>None of the rest</td>
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2. (4pts) π_{CID,Age} (Purchases ⊙◁ Customers).

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3. (8pts) *Get the total sales made in each zip code.* (For this one, make sure to explain all steps, starting with the relational algebra query or LQP, any logical rewrites used, the final PQP chosen, any pipelining used, and relevant buffer memory calculations. Partial credits are possible.)
Extra Credit Question. [5pts] Suppose we manage to accomplish full resource disaggregation parallelism for a next generation cloud-native RDBMS. Briefly explain why this can be beneficial for reducing query latency vs. the prior art of shared-nothing parallel execution on a provisioned cluster (e.g., a la Redshift) using a realistic query example on the Netflix database discussed in class. Clearly state the query, show its PQP, and explain what resources are elastically used to accelerate which part of the PQP. Assume that the database is too large to fit entirely in DRAM though.