1. Consider a relation R(a, b, c) that may contain duplicate tuples. Which of the following equivalences is/are NOT true? Note that all operations should be assumed to be BAG operations.

   A. $\pi_{a,b}(R) \bowtie \pi_{b,c}(R) = R$
   B. $\pi_{a,b}(\delta(R)) = \delta(\pi_{a,b}(R))$
   C. $R \cap \delta(R) = \delta(R)$
   D. A & B E. A & C F. B & C G. A, B & C.

2. Consider the following statistics for three relations R, S, U.

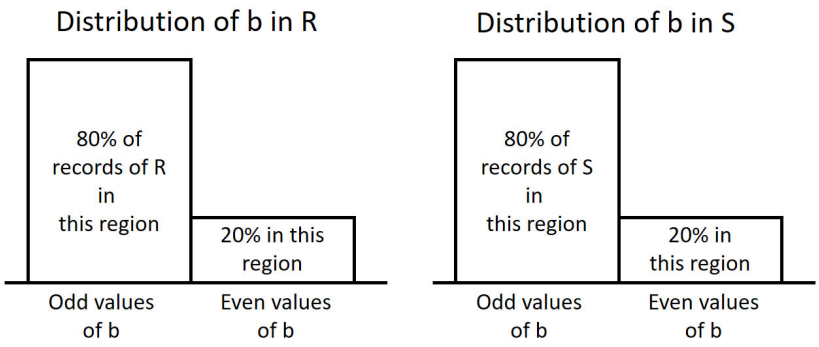
R(a, b, c)	S(b, c, d)	U(b, e)
T(R) = 1000 V(R, a) = 100 V(R, b) = 20 V(R, c) = 200	T(S) = 2000 V(S, b) = 50 V(S, c) = 100 V(S, d) = 400	T(U) = 5000 V(U, b) = 200 V(U, e) = 500

   Moreover, suppose that all attributes are of the same size, and that each page can contain 10 tuples of R. Records do not span across pages. Unless otherwise stated, all attributes should be included in a join output, for example, the join output of R and S (without any projection) should contain 6 attributes (a, b, c, b, c, d). Unless otherwise stated, we also made the standard assumptions that we have introduced in our lecture, e.g., preservation of values, uniform distribution of data, and so on.

   What is the output size (**in number of tuples**) of the following query:

   SELECT DISTINCT b FROM R;

3. Consider the same setting as Question 2. Now, suppose we have the following information on the distribution of the distinct values of b in R and S:



   What is the output size (**in number of tuples**) of the following query:

   SELECT * FROM R, S WHERE R.b = S.b and R.c = S.c;

4. Consider the same setting in Question 3 (**WITH the histogram distribution**). What is the size of the following query (**in number of tuples**)? Assume that U.e are integer values ranging from 1 to 500.

   SELECT R.a, S.d FROM R, S, U WHERE R.b = S.b and R.c = S.c

   and R.b = U.b and U.e > 250;

5. Consider the same setting in Question 2 (i.e,. **WITHOUT the histogram information**). Consider the query

   SELECT R.a, S.d FROM R, S, U WHERE R.b = S.b and R.c = S.c

   and R.b = U.b and U.e > 250;

   Suppose our DBMS employs the Dynamic Programming (System R) optimizer. As covered in the lecture, the optimizer avoids cross products, restricts the space to left-deep trees, and keeps only one optimal plan for a combination of tables. Suppose our DBMS supports only one join algorithm: the **page nested-loops join** (with 3 buffer available for the join). All intermediate results for joins are to be written out to disk. Suppose there are no indexes. For simplicity, you can assume U to be the intermediate table after the selection condition U.e has been applied; the cost to generate this intermediate table is ignored. Assume that U.e are integer values ranging from 1 to 500.

   Which of the following subplans/plans are pruned? Hint: You should only consider subplans/plans that are **explicitly** generated and considered by the algorithm, i.e., you should not consider a plan that is not generated at all, e.g., those involving cross products.

   A. RS B. SR C. RU
   D. (UR)S E. (RS)U F. (SR)U

6. Referring to the setting in Question 5. What is the final optimized plan? Write "(SU)R" if you think the final plan is the join of S and U first with S being the outer table, followed by joining the intermediate result with table R with R being the inner tab

7. Which of the following statement(s) is(are) TRUE?
   A. Randomized algorithms operate on full plans (states). The first state has to be randomly generated.
   B. Greedy algorithms are typically polynomial time complexity because they do not consider plans in the bushy tree space.
   C. The Dynamic Programming algorithm is typically not used for large number of joins (e.g. more than 100) because error propagation may result in sub-optimal plans.
   D. Greedy algorithms typically do not produce optimal solution because they generate the query plan bottom-up (starting from 2 tables, then 3 tables, etc).
   E. A & B F. B & C G. A & D H. None of the above.

8. The cost of a query plan is error prone. Which of the following is not a valid reason?
   A. Cost model does not capture the actual cost (CPU or I/O) accurately.
   B. Error in intermediate result size estimation.
   C. Inaccurate base table size statistics.
   D. Assumptions like preservation of values are used.
   E. None of the above.

9. Which of the following statement(s) is (are) FALSE?
   A. Strict 2PL schedules will not have dirty reads.
   B. Strict 2PL schedules will not result in a deadlock.
   C. Strict 2PL schedules is not always view serializable.
   D. Strict 2PL schedules will not result in unrepeatable reads.
   E. B & C F. B & D G. C & D H. A & D

10. Which of the following statement(s) is/are TRUE?
   A. The validation-based protocol can never have dirty reads.
   B. The validation-based protocol can never have deadlocks.
   C. The validation-based protocol can never have unrepeatable reads.
   D. The validation-based protocol can never have cascading aborts.
   E. The validation-based protocol can never have starvation.
   F. A, B, C G. A, B, C, D H. A, B, D, E I. None of the above.

11. Consider the following two transactions:
   a. T_1: $r_1(X)$, $r_1(Y)$, $w_1(Y)$, $w_1(X)$
   b. T_2: $r_2(Y)$, $w_2(Y)$, $r_2(X)$, $w_2(X)$

   How many conflict-serializable schedules can be created by interleaving these two transactions (including serial schedules)?

12. Which of the following statement(s) is TRUE with regards to this schedule:
   S: $r_1(X)$ $w_2(Y)$ $w_2(Y)$ $w_1(Z)$ $r_2(X)$ c_1 $w_2(Z)$ c_2

   A. S is recoverable.
   B. S is cascadeless.
   C. S is strict.
   D. S is view serializable.
   E. A & B F. A, B & C G. A, B & D
   H. B & D I. B, C & D J. A, B, C & D

13. Consider a DBMS that employs a new lock model for the INCREMENT operation. The INCREMENT operation is "special" because it is commutative, e.g., transactions T_1 and T_2 both increment element A; and the final result of A is the same regardless of which transaction operates on A first. The compatibility matrix now becomes the following:

	S	**X**	**I**
S	T	F	F
X	F	F	F
I	F	F	I

Here, S, X and I denote shared (read), exclusive (write) and increment locks respectively. So, if a transaction holds an I lock, then no other transactions can hold an S or X lock. However, many transactions can hold an I lock concurrently. We are given the following schedule (incr represents an increment action):

$$S = r_1(A); r_2(B); r_3(C); incr_2(C); r_3(B); incr_1(C); incr_2(A);$$

Which of the following statements is TRUE?

A. S is serializable and is equivalent to the serial schedule T1, T2, T3
B. S is serializable and is equivalent to the serial schedule T2, T3, T1
C. S is serializable and is equivalent to the serial schedule T3, T1, T2
D. S is serializable and is equivalent to the serial schedule T1, T3, T2
E. S is serializable and is equivalent to the serial schedule T2, T1, T3
F. S is not serializable

14. Which of the following statement(s) is/are FALSE?

A. For a DBMS that correctly implements the failure recovery mechanisms akin to those discussed in class, the data stored in the relation files on the disk is always in a consistent state.
B. For a DBMS that correctly implements the concurrency control mechanisms akin to those discussed in class, the data stored in the relation files on the disk is always in a consistent state.
C. For a DBMS that correctly implements failure recovery and concurrency control mechanisms akin to those discussed in class, the data stored in the relation files on the disk is always in a consistent state.
D. A & C
E. B & C
F. A & B
G. All of the above.
H. None of the above.

15. Four transactions, T_1, T_2, T_3, T_4. running in a DBMS would have resulted in the following schedule for their actions (based on their time of arrivals if we had ignored locking):

    $r_1(X)$; $w_2(Y)$; $r_1(Y)$; $r_3(Z)$; $w_3(W)$; $w_4(Z)$; $w_3(X)$; $w_2(W)$

    However, for each action, the transaction has to acquire the necessary locks for its action to proceed. In addition, we assume that a transaction never releases a granted lock unless it is aborted, in which case, its locks may be granted to the transaction waiting in the queue. Aborted transactions are not restarted. Suppose the lock manager adopts the Wait-Die policy, and the priority of the transactions are: $T_1 > T_2 > T_3 > T_4$. In other words, T_1 is the oldest transaction while T_4 is the youngest. At the end of the sequence of lock requests, how many transactions are waiting, and how many transactions are aborted?

    A. #waiting = 0; #aborted = 1
    B. #waiting = 1; #aborted = 1
    C. #waiting = 2; #aborted = 1
    D. #waiting = 0; #aborted = 2
    E. #waiting = 1; #aborted = 2
    F. #waiting = 2; #aborted = 2

16. Consider the same setting in Question 15, except the lock manager now adopts the Wound-Wait policy. At the end of the sequence of lock requests, how many transactions are waiting, and how many transactions are aborted?

    A. #waiting = 0; #aborted = 1
    B. #waiting = 1; #aborted = 1
    C. #waiting = 2; #aborted = 1
    D. #waiting = 0; #aborted = 2
    E. #waiting = 1; #aborted = 2
    F. #waiting = 2; #aborted = 2

17. In practice, the NoUndo/NoRedo recovery scheme is not widely used. Which of the following statements is TRUE?

    A. Redo logs are still maintained on disk. However, as soon as a transaction commits, the log records are removed.
    B. Undo logs are still maintained on disks. However, the updated data are not written to the disks until commit time. As such, if there is a crash before a transaction commits, there is no need to perform undo since the data are not updated until commit time.
    C. Redo and Undo logs are still maintained but they are kept in the memory only, which consumes too much memory resource.
    D. No logs need to be maintained. But updates have to be written out to disk to ensure all dirty pages are on disk. This incurs random I/O. But, no recovery is needed since dirty pages are already on disk.
    E. None of the above.

18. Consider a DBMS that uses the Validation-based optimistic concurrency control mechanism (as taught in class). The following table lists two transactions with their read and write sets:

Transaction	Read Set	Write Set
T_1	{X, Y}	{X, W}
T_2	{Z}	{Y, Z}

Based on the Validation-based protocol, the 3 phases – Start-Phase (S), Validate Phase (V), Finish Phase (F) – of the transactions can be interleaved in different ways. For example, one possible interleaving (which we shall refer to as a schedule) is T_1.S, T_2.S, T_1.V, T_2.V, T_1.F, T_2.F. **Suppose T_1 starts first**. Which of the following statements is TRUE:

A. There is exactly one schedule where T_1 validates successfully, but T_2's validation fails.
B. There is exactly one schedule where T_2 validates successfully, but T_1's validation fails.
C. There is exactly one schedule where both transactions validate successfully.
D. There is exactly one schedule where both transactions validate unsuccessfully.

19. Consider the same setting in Question 17. Suppose we are allowed to change the ReadSet of T_1. What is the **minimum** ReadSet(T_1) for both transactions to validate successfully? If ReadSet(T_1) = {X}, then write "X"; if there are multiple possible answers, you only need to write any one of them (e.g., if both X and Y are correct answers, then you only need to write either "X" or "Y").

20. Which of the following statements is TRUE of non-quiescent checkpointing?
    A. In UNDO logging, all the log records before the most recent <START CKPT> log can be discarded.
    B. In REDO logging, all the log records before the most recent pair of <START CKPT> and <END CKPT> log can be discarded.
    C. In UNDO/REDO logging, even if checkpointing is used, it is still possible the recovery process accesses logs at the beginning of the log file.
    D. If a crash happens during checkpointing (i.e., there is a <START CKPT> log but no <END CKPT> log), we only need to examine logs upto the <START CKPT> log of the most recent successful checkpoint.
    E. None of the above.

21. Consider the concurrency control mechanism for B^+-tree (as taught in class). Suppose we have a 3 level tree – root, internal node, leaves. Which of the following sequence(s) is(are) possible sequences of actions on the tree to insert a new entry to a leaf page? Here, L denote Lock, U denote Unlock, M denote modification. L(X) denote locking a node at level X (X = R for root; I for internal node; and L for leaf node). U(X) is similarly defined.
    A. L(R); L(I); L(L); M(L); U(R); U(I); U(L)
    B. L(R); L(I); U(R); L(L); U(I); M(L); U(L)
    C. L(R); L(I); L(L); U(R); U(I); M(L); U(L)
    D. L(R); L(I); U(R); L(L); M(L); U(I); U(L)
    E. A & B
    F. A, B & C G. A, B, C & D H. B & C I. B, C & D.

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