CS-245 Database System Principles
Final Exam Winter 2001

This exam is open book and notes. You have 120 minutes to complete it. There are 8 questions.

Serial number: _____
Name: _____

The Honor Code is an undertaking of the students, individually and collectively:

1. that they will not give or receive aid in examinations; that they will not give or receive unpermitted aid in class work, in the preparation of reports, or in any other work that is to be used by the instructor as the basis of grading;
2. that they will do their share and take an active part in seeing to it that others as well as themselves uphold the spirit and letter of the Honor Code.

The faculty on its part manifests its condense in the honor of its students by refraining from proctoring examinations and from taking unusual and unreasonable precautions to prevent the forms of dishonesty mentioned above. The faculty will also avoid, as far as practicable, academic procedures that create temptations to violate the Honor Code.
While the faculty alone has the right and obligation to set academic requirements, the students and faculty will work together to establish optimal conditions for honorable academic work.

I acknowledge and accept the Honor Code.

Signed: _____

Problem	Points	Maximum
1		10
2		10
3		10
4		15
5		15
6		10
7		15
8		15
Total:		100

Problem 1 (10 points)

State if the following statements are **TRUE** or **FALSE**. If a statement is false, please explain why.

False **a)** Any schedule produced by a lock scheduler using shared and exclusive locks is conflict serializable.

Answer: Schedule must be legal, transactions two phase.

True **b)** Multi-key indexes are better than partitioned hash tables for answering range queries on multiple key attributes.

False **c)** Undo logging is suitable for use with archiving, though it's less efficient than redo and undo/redo logging.

Answer: Undo logging is not suitable for archiving.

False **d)** No deadlocks can occur under 2PL.

Answer: Two transactions can both grab a lock on different objects and wait for each other's lock.

True **e)** Consider a disk that has 16 surfaces, each with 1024 tracks. Each track is divided into 36 sectors, and a sector holds 2048 bytes. Blocks consist of 2 consecutive sectors. 20% of the circumference of each track is occupied by gaps between the sectors. The disk rotates at 3840rpm, i.e., one rotation every 15.6 milliseconds. Given these parameters, the transfer time for one block is approximately 0.78ms.

False **f)** Relation R has 4000 records. Suppose a clustered B+ tree index is built on R's key attribute. A block can hold a B+ tree node (interior or leaf node) with 20 keys and 21 pointers. In this case, at least 220 blocks are needed to hold the entire B+ tree index.

Answer: Right answer is 211.

False **g)** Consider an extensible hash table where the hash function generates a 20-bit hash key, but only the high order 8 bits are used. In this case, the hash table can have at most 2^{20-8} data blocks (containing records).

Answer: The table can contain at most 2^8 data blocks.

False **h)** The "containment of value sets property" states that whenever two attributes appear with the same name, the values these attributes can take come from the same set of values.

Answer: Read page 372.

True **i)** In a Zipfian distribution, the frequency of occurrence of the i^{th} most common value is in proportion to 1 over the square root of i.

True **j)** Sequence pointers are used in leaf nodes of B+ trees to speed up range queries.

Common Mistakes: Not explaining why they chose False.

Problem 2 (10 points)

Examine the schedule given below. There are three transactions, T1, T2, and T3. Initially, the salary = 1 and the tax = 2. The assignments happen within the local memory space of the transactions and the effects of these assignments are not reflected in the database until the WRITE operation.

```
     T1                        T2                   T3
-------------------------------------------------------------------
0                                                    start
1                                                    READ tax
2                                                    tax := tax + 1
3     start
4     READ salary
5     salary := salary + 1
6                                                    WRITE tax
7                                                    commit
8                              start
9                              READ tax
10                             READ salary
11                             tax := tax + salary
12                             WRITE tax
13                             commit
14   ------------------- checkpoint start -------------------------
15   READ tax
16   tax := tax + salary
17   WRITE salary
18   ------------------- checkpoint end ---------------------------
19   commit
```

a) Show the undo/redo log file entries that would be generated by this execution. Use the same notation used in class. For each log entry, indicate what line above generates it.

Answer:

<0, T3, start>
<3, T1, start>
<6, T3, tax, 2, 3>
<7, T3, commit>
<8, T2, start>
<12, T2, tax, 3, 4>
<13, T2, commit>
<14, checkpoint start , T1 is still active>
<17, T1, salary, 1, 2>
<18, checkpoint end>
<19, T1, commit>

Common Mistakes and Comments:

1. Writing to log on calculation instead of actual WRITE command
2. Not including START of transactions in log
3. Not including CHECKPOINT start and end in log
4. Logging READs or calculations.
5. Incorrect value of tax for T2 by reading T1's value of salary

b) Assume that the undo/redo recovery algorithm with checkpoints is being used. The database crashes immediately after statement 7. (Assume that all the log records up to this point are on disk.)

b.1) Which transactions would have to be undone?

Answer: T1

Common Mistakes and Comments: Answering NONE since T1 has written nothing to disk, but still need to ABORT transaction regardless of whether on disk.

b.2) Which transactions would have to be redone?

Answer: T3

c) Again assume that the undo/redo recovery algorithm with checkpoints is being used, but now the databases crashes just after statement 18. (Assume that all the log records up to this point are on disk.)

c.1) Which transactions would have to be undone?

Answer: T1

c.2) Which transactions would have to be redone?

Answer: None

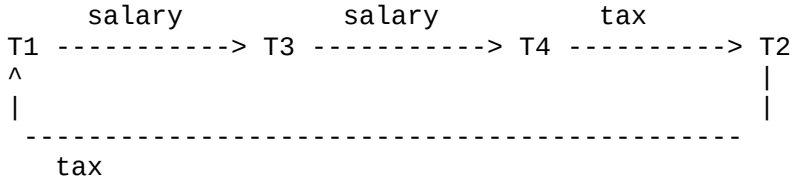
Problem 3 (10 points)

Examine the schedule given below. There are four transactions, T1, T2, T3, and T4.

```
          T1              T2           T3              T4
-------------------------------------------------------------------
1                                                     READ tax
2     READ salary
3                                                     WRITE tax
4                     READ tax
5                     WRITE tax
6     READ tax
7     WRITE salary
8                                   READ salary
9     WRITE tax
10                                  WRITE salary
11                                                    READ salary
12                                                    WRITE salary
```

a) Draw the precedence graph for this schedule.

Answer:



b) What is the equivalent serialization order for this schedule? If no order is possible, then state 'none'.

Answer: None, the conflict graph has a cycle.

c) Assume that transaction T4 did not run at all. What is the precedence graph in this case?

Answer: Same as above with t4 removed.

d) What is the equivalent serialization order for this second schedule? If no order is possible, then state 'none'.

Answer: T2 T1 T3

Common Mistakes and Comments: Not being consistant. if an arc was made from T4->T1, then there should be an arc from T1->T4. Otherwise, if you were reducing the graph, neither edge should be present.

Problem 4 (15 points)

Consider a four-dimensional data cube S(W, X, Y, Z), where the following sum aggregates have been materialized:

Materialized: S(W, X, Y, Z)
S(*, X, Y, Z)
S(W, X, *, *)
S(W, *, Y, *)

For each of the following queries, give the materialized aggregates (or the cube itself) from which the query can most *efficiently* be computed. If the result can be computed from two aggregates S_1 and S_2, but the computation from S_1 is clearly less expensive than the computation from S_2, then only give S_1 in your answer. If with the information given here, you cannot infer that S_1 is better than S_2 or vice versa, then give both S_1 and S_2 in your answer.

Note that lower case variables represent particular values of the attribute (e.g., x is a value for X).

a) S(*, x, y, z)

Answer: S(*, X, Y, Z)

b) S(w, *, *, *)

Answer: S(W, X, *, *) or S(W, *, Y, *)

c) S(*, *, *, *)

Answer: S(W, X, *, *) or S(W, *, Y, *) or S(*, X, Y, Z)

Common Mistakes and Comments: Most of the people didn't put S(*, X, Y, Z) as one of the answers. This is possible if W is infinite or very huge.

d) S(w, *, y, z)

Answer: S(W, X, Y, Z)

Problem 5 (15 points)

Consider a database that uses a validation mechanism for concurrency control. There are only 4 kinds of transactions in the system. The read, write actions of the 4 kinds of transactions are given below.

(i): r(A) r(B) w(A) w(C) w(E)
(ii): r(C) w(F) w(B)
(iii): r(D) r(B) w(B)
(iv): r(c) r(D)

Note that (i) - (iv) are transaction *types* and not transactions. In particular we can have two different transactions of the same type. Two transactions are said to execute *concurrently* if at some point of time, both the transactions have started, but neither has finished.

a) Determine for each pair of transaction types *(m, n)* (including the case $m = n$), if the transaction of type *n* can be aborted due to a transaction of type *m* when executing concurrently (in the absence of any other transaction). Please indicate your answer in the table below by placing a **YES** in column *n* and row *m* if a transaction of type *n* can be aborted due to a transaction of type *m*, and **NO** otherwise.

Answer: First, note that if a transaction T_2 is aborted by a transaction T_1 , then T_1 should have validated first. It is easy to show that if
$WS(T_1) \cap WS(T_2) \neq \emptyset$ **OR** $(WS(T_1) \cap RS(T_2) \neq \emptyset$,
then there exists some sequence of "start", "validation", "end" actions for the two transactions such that T_2 is aborted.

Transaction of this type (*n*)

Can be aborted by type below (*m*)	(i)	(ii)	(iii)	(iv)
(i)	Yes	Yes	No	Yes
(ii)	Yes	Yes	Yes	No
(iii)	Yes	Yes	Yes	No
(iv)	No	No	No	No

b) Determine for each pair of transactions *(m, n)* if the two transactions **can** be run concurrently without either of them aborting (in the absence of any other transaction). Use the notation followed in part (a) to indicate the answer in the table below. In particular, a **YES** in column *n* and row *m* will mean that a transactions of type *m* and *n* can run concurrently (i.e., a transaction of type *m* need not be aborted by a type *n* transaction, and that a transaction of type *n* need not be aborted by a type *m* transaction.)

Answer: Since *concurrent execution* is a symmetric event and we required that neither transaction abort, the table is obviously symmetric. There were two possible interpretations to this question and we gave full credit to solutions assuming any of the two.
The first interpretation was to mark a “Yes" if there existed **some** sequence of execution where the transactions ran concurrently without aborting, and “No" otherwise. Two transactions *can* run concurrently (under favorable circumstances) if the condition given in part (c) is not satisfied. We get the following table for this interpretation.

	(i)	(ii)	(iii)	(iv)
(i)	No	No	Yes	Yes
(ii)	No	Yes	Yes	Yes
(iii)	Yes	Yes	No	Yes
(iv)	Yes	Yes	Yes	Yes

The second interpretation was to mark a “Yes" if the two transactions could *always* run concurrently under any sequence of execution. This can happen only if there are no conflicting actions in the two transactions. The solution for this case is given below.

	(i)	(ii)	(iii)	(iv)
(i)	No	No	No	No
(ii)	No	No	No	Yes
(iii)	No	No	No	Yes
(iv)	No	Yes	Yes	Yes

c) What is the condition under which two transactions can *never* execute concurrently in the validation scheme (without one of them being rolled back)? Express your answer in terms of read-sets ($RS(T_1)$, $RS(T_2)$) and write-sets ($WS(T_1)$, $WS(T_2)$) of the two transactions T_1 and T_2.

Answer:

The condition is:
($RS(T_1) \cap WS(T_2) \neq \emptyset$) AND ($RS(T_2) \cap WS(T_1) \neq \emptyset$)

Common Mistakes and Comments:

1. It is hard to pinpoint the common mistakes for parts (a) and (b) since there were no explanations for the answers. But there were a couple of solutions that managed to get all 16 entries wrong in the above tables but nevertheless got full credit!!
2. The common mistakes for part (c) are as follows:
   - **a)** Using **OR** instead of **AND** , or using no boolean operator on the two conditions.
   - **b)** Using the condition $WS(T1) \cap TWS(T2) \neq \emptyset$. Note that two transactions can execute concurrently even if they write the same database element if the second starts after thefirst validates and validates after the first one finishes.
   - **c)** Reporting the validate rules directly from the text book.

Problem 6 (10 points)

For each of the following statements, indicate if it is TRUE or FALSE. If the statement is false, give a simple counter-example. To construct counter-examples, please only use schedules that use the following two transactions (and only these transactions). It is OK to leave out some actions of these two transactions if you wish. (However, you should not reorder the actions of transactions.)

For this problem, use the definition of recoverable we used in class, not the one used in the textbook.

- T1: w1(A) w1(B) r1(C) c1
- T2: w2(A) r2(B) w2(C) c2

a) All serial schedules are conflict-serializable.

Answer: True

b) All avoids-cascading-rollback schedules are recoverable.

Answer: True

c) All strict schedules are serial.

Answer: False.

$w_1(B)$ w2(A) c_1 $r_2(B)$ c_2

Common Mistakes and Comments: Some students claim they can't construct a schedule as a counter example. In fact we can if we leave out some actions in one or two of the transactions.

d) All recoverable schedules are conflict-serializable.

Answer: False

$w_2(A)$ $w_1(A)$ $w_1(B)$ r1(C) $r_2(B)$ w2(C) c_1 c_2

e) All strict schedules are conflict-serializable.

Answer: True

Problem 7 (15 points)

Consider a legacy source that offers data equivalent to a relation R(X, Y, Z).

For parts (a) through (d) below, assume that the capabilities of this source are described by the following two templates:

- f u b
- o[x_1,x_2] f u

a) Can the following query be *directly* answered by this source?

- R(x_1, Y, z_1)

Answer: Yes

b) Can the following query be *directly* answered by this source?

- R(X, y_1, z_1)

Answer: No

c) Can the following query be *directly* answered by this source?

- R(X, y_1, Z)

Answer: Yes

d) Can the following query be *directly* answered by this source?

- R(x_3, y_1, Z)

Answer: No

For parts (e) and (f) below, assume that the capabilities of this source are described by the following single template:

- b u' c[z_1, z_2]

e) The following query *cannot* be directly supported by the source:

- R(x_1, Y, z_3)

However, can it be answered by submitting a different (and supported) query and then post-processing the results to get the desired answer? If yes, please give the query to submit to the source and explain how its answer is processed. If no, briefly explain why not.

Answer:
No; We have to specify Z value using the listed values.

f) The following query *cannot* be directly supported by the source:

- R(x_1, y_1, Z)

However, can it be answered by submitting a different (and supported) query and then post-processing the results to get the desired answer? If yes, please give the query to submit to the source and explain how its answer is processed. If no, briefly explain why not.

Answer: No; cannot retrieve Y values to evaluate Y condition in query.

Common Mistakes and Comments: For some students use the same reason for (e). While it is true we still can't leave Z unspecified, the key reason is we can't retrieve Y values since the output constraint placed on Y (specified as u').

Problem 8 (15 points)

We would like to sort the tuples of a relation R on a given key. The following information is known about the relation.

- The relation R contains 100000 tuples, i.e., T(R) = 100000.
- The size of a block on disk is 4000 bytes.
- The size of each R tuple is 400 bytes.
- Relation R is clustered, that is each disk block holding R tuples is full of R tuples.
- The size of the sort key is 32 bytes.
- A record pointer is 8 bytes.

Answer the following questions based on the information above.

a) If we use a two pass sorting algorithm, what is the minimum amount of main memory (in number of blocks) required?

Answer: $101 = \sqrt{B(R)} + 1$. Note that we need 1 block for the output buffer. The solution *100* also got nearly full credit.

b) What is the cost of the two pass sorting algorithm in terms of number of disk I/Os? Include the cost of the writing the sorted file to the disk in the end in your calculations.

Answer: *40000 = 4 x B(R).*

c) Consider the following variant of the sorting algorithm. Instead of sorting the entire tuple, we just sort the <key, recordPointer> for each tuple. As in the conventional two pass sorting algorithm, we sort chunks of <key, recordPointer> in main memory and write the chunks to disk. In the merge phase, <key, recordPointer> entries from different chunks are merged. The record pointers to used to recover the rest of the tuple (from the original copy of R) and write the sorted relation to the disk. What is the minimum amount of main memory required for this operation? What is the cost in terms of number of disk I/Os?

Answer:

Memory required = *34*. Note that the solution is not $\sqrt{1000}+1$ as expected. We need an additional block for the random access step in the second phase. It is easy to see that *34* blocks suffices but *33* does not. The solutions *32* and *33* were also given nearly full credit.

The I/Os of the sorting scheme is *122000*. This includes *10000* for initially reading the relation R and constructing < *key; recordPointer* > pairs; *1000* I/Os for writing the sorted < *key; recordPointer* > pair to disk; *1000* for reading the same from disk; *100000* I/Os for random access to retrieve the tuples pointed by the record pointer; and finally *10000* I/Os to write the sorted relation R to disk. The common mistakes for this part were

1) Assuming that the < *key; recordPointer* > is materialized in the disk.
2) Reporting that the cost of random access as *10000*, the number of blocks of R.

d) Keeping all other parameters constant, for what values of tuple size is the variant discussed in (c) better (in the number of IOs)?

Answer:

There are two possible solutions. If we assume that the records are unspanned, then the correct solution is *tuplesize* > 2001. If the records are spanned(ignoring overhead) then the correct solution is *tuplesize* > 2040. Let *t* be the tuplesize. Then *B(R) = 100000 * t/4000 = 25*t*. The cost of the first scheme = *4*B(R)*. The cost of the second scheme is *B(R)+T(R)=100+T(R)/100+T(R)+B(R)* which is 50*t + 102000. The second expression is smaller when *t* >2040.