CompSci 516: Database Systems

Final

Fall 2018

This booklet has 18 pages (including the cover page and two blank pages at the end).
You can use the reverse sides as additional space for writing your answers.

INSTRUCTIONS

1. No external help (books, notes, laptops, tablets, phones, etc.) or collaboration is allowed.
2. You have **180 minutes** to answer questions that add up to **100 points**. i.e. you have about 9 mins for 5 points, 18 mins for 10 points, and about 36 mins for 20 points.
3. Some questions may need more time, some questions less. Please budget your time accordingly.
4. If you cannot solve a problem fully, write partial solution for partial credit. **Even if explanations are not sought in a question, if you cannot fully solve a problem, writing down your thought process may lead to some partial credit.**
5. Do not spend too much time on a problem that you find difficult to solve - move on to other problems.
6. **The problems are organized in no particular order, easier problems may appear later.**

****Write Your Name Here** (1 bonus point):**

First Name:

Last Name:

All the best!

DO NOT WRITE BELOW THIS LINE

Problem 1	/ 12	Problem 2	/ 32	Problem 3	/ 14
Problem 4	/ 20	Problem 5	/ 5	Problem 6	/ 10
Problem 7	/ 7	bonus point	/ 1	Total	/ 100

Q1. (12 pts) Short Q/A

Q1a. (9 * 1 = 9 pts) Write True or False.

No explanations are needed.

1. If $X \subseteq Y$, then $X^+ \subseteq Y^+$: (**True/False**) (Recall: X^+ is the closure of attributes in X).
   Ans: **True**.

2. $(X^+)^+ = X$: (**True/False**)
   Ans: **False**. It is $(X^+)^+ = X^+$.

3. $(X \cup Y)^+ = X^+ \cup Y^+$: (**True/False**)
   Ans: **False**. Suppose $A \rightarrow B, C \rightarrow D, AB \rightarrow E$. Try $X = \{A\}, Y = \{B\}$.

4. In non-quiescent logs, new transactions can start between START CKPT and END CKPT: (**True/False**)
   Ans: **True**.

5. Nested loop join always returns the same results as hash join: (**True/False**)

   Ans: **True**: they are different implementations of join

6. Given an instance of a relation, we can infer all functional dependencies that HOLD for that relation schema: (**True/False**)

   Ans: **False**: FDs should be true for all instances, we can only infer FDs that do not hold.

7. Static hashing is a better choice than dynamic hashing when there are frequent updates and skew in the data: (**True/False**)

   Ans: **False**: Long overflow chains may develop and rehashing may be needed degrading performance.

8. In frequent itemset mining, an itemset {A, B, C} has larger *support* (no. of transactions containing this itemset) than the itemset {A, B, C, D}: (**True/False**)

   Ans: **True**: A subset always has better support.

9. In two-phase commit protocol, any site can unilaterally decide to commit, but needs consensus to abort: (**True/False**)
   Ans: **False**: any site can unilaterally decide to "abort", but needs consensus to commit.

Q1b. (3 * 1 = 3 pts) Write short answers (one/two sentence(s) should suffice).

1. Consider the following relation instance $R(A,B,C)$. Fill out the table saying: **Yes** (the decomposition is lossless), or **No** (it is not lossless). No explanations are needed.

R

A	B	C
a1	b1	c1
a2	b1	c2

Decomposition	Lossless? (Yes/No)
$R1(A,B)$ and $R2(B,C)$	
$R1(A,C)$ and $R2(A,B)$	

Ans:

Decomposition	Lossless? (Yes/No)
$R1(A,B)$ and $R2(B,C)$	No
$R1(A,C)$ and $R2(A,B)$	Yes

In the first one, spurious tuples $(a1,b1,c2)$ and $(a2,b1,c1)$ will be generated.

.

2. Write **one** key difference between OLAP and OLTP.
   Ans: Several answers are possible: (1) OLTP needs detailed, up-to-date data, whereas summarized historical data is sufficient for OLAP, (2) OLTP queries are structured, repetitive, short, whereas OLAP queries are intensive, ad-hoc, complex, (3) Each transaction in OLTP typically reads/updates only a few tuples, whereas each OLAP query can access many records, and perform many joins, scans, aggregates, (4) Key issues in OLTP are consistency, recoverability, maximizing transaction throughput, whereas in OLAP important issues are query throughput and response times.

3. Write **one** key difference between NOSQL and traditional RDBMS.

   Ans: Several answers are possible: (1) NOSQL systems typically give up on strict ACID conditions and go for eventual consistency. (2) The schema can be relaxed by adding different attributes for different tuples, (3) Efficient for simple operations, not suitable to handle complex queries with joins, distinct etc.

Q2. (32 pts) Miscellaneous

Q2a. (3 + 3 = 6 pts)

Consider three relations $R(A,B), S(B,C), T(C,A)$, each with N (distinct) tuples.

(I) What is the maximum possible number of tuples in the natural join $Q(A,B,C) = R \bowtie S \bowtie T$?

Choose the correct answer from (i) $N/3$, (ii) N, (iii) N^2, (iv) N^3:

Briefly explain your answer.

Ans: (iii) N^2.

Fix any two tuples $R(a,b)$ and $S(b,c)$. It can join with at most one tuple $T(c,a)$ (fixing a,b,c does not give any choice in T). Hence you can only get $\leq N^2$ combinations and not N^3.

(II) Suppose A is key in $R(\underline{A},B)$.

What is the maximum possible number of tuples in the natural join $Q(A,B,C) = R \bowtie S \bowtie T$?

Choose the correct answer from (i) $N/3$, (ii) N, (iii) N^2, (iv) N^3:

Briefly explain your answer.

Ans: (ii) N.

Suppose join from R and T, then S (recall that join is commutative, so the order of join does not affect the result). Fix any tuple $T(c,a)$. It can join with at most one tuple in $R(\underline{a},b)$, since A is key in R. Hence max size of $R \bowtie T$ is N. Then this combination $R(a,b)$, $T(c,a)$ as before can join at most one tuple $S(b,c)$ (no choice for b or c). Hence the final size is at most N.

Q2b. (4 pts)

Consider two relations $R(A,B,C)$ and $S(D,E,F)$ satisfying the following functional dependencies:

$$R : A \rightarrow B$$

$$S : DE \rightarrow F$$

Let $T(A,B,C,D,E,F)$ be the following table:

```
create table T as
   (select R.A, R.B, R.C, S.D, S.E, S.F
     from R, S
    where R.C = S.D and S.E = 5)
```

Find the all the key(s) of T and list below:

Ans: Keys: AC and AD.

Note that A is not determined by anything so must be part of the key. A determines B, so B is not needed. C and D are the same, and are not determined by anything else, so one of them must be present. $E = 5$ is constant, so need not be present. F is determined by DE, so need not be present.

Q2c. (4 pts)

Consider an employee relation $Emp(eid, name, age)$ stored in a heap file, and the following query:

```
SELECT name
FROM Emp
WHERE age > X
```

Suppose the range of the *age* of employees is $21 - 120$, and suppose the employees are uniformly distributed for this entire age range.

Suppose you have the choice to use

- file scan (i.e. no index), or
- a combination of
  - clustered / unclustered
  - B+-tree / hash-based index
  - on any of the attributes *eid* / *name* / age.

Assume that **one index lookup requires 4 I/O and, 1 page can hold about 1% Emp tuples.**

(i) Which index combination (or no index) will you choose when $X = 117$? No explanations are needed.
Ans: Very few tuples satisfy conditions, range query, so choose clustered B+-tree index on *age*.

(ii) Which index combination (or no index) will you choose when $X = 21$? No explanations are needed.
Ans: Almost all tuples satisfy conditions, range query, so don't use an index, just use file scan.
Note that about 1% tuples will be read unnecessarily by a file scan, they fit in one page (so one extra page I/O only), whereas using clustered B+-tree index on *age* will require a lookup for 4 page I/O.

Q2d. (4 pts)

Suppose you have $N = 20$ pages for a relation. Number of buffers in memory $B = 4$. Fill out the following table for the number of sorted runs and I/O cost in each pass of an **external merge sort** algorithm (for pass = 0, 1, 2, $\cdots$).

- DO NOT count the final cost of writing the result to disk.
- No explanations are necessary.
- All rows may not be needed and add more rows if necessary.
- Hint: you do not need to remember any formula to solve this.

Pass	No. of sorted runs after the pass	I/O cost in the pass

Ans: From pass 1 onward, B-1 = 3-way merge will be done.

Pass	No. of sorted runs after the pass	I/O cost in the pass
0	$\lceil \frac{20}{4} \rceil = 5$	$2N = 40$
1	$\lceil \frac{5}{3} \rceil = 2$	$2N = 40$
2	$\lceil \frac{2}{3} \rceil = 1$	$N = 20$ (no write)

Q2e. (3 pts)

Fill out the blanks each with one of the options below:

Under ___(a)_____ *policy,* ***committed*** *transactions need to* ___(b)_____ *in the event of a crash to ensure* ___(c)_____.

- (a) (i) STEAL, (ii) NO FORCE
- (b) (i) REDO, (ii) UNDO
- (c) (i) ATOMICITY, (ii) DURABILITY

Ans: (a) NO FORCE, (b) REDO, (c) DURABILITY.

Not forcing committed transactions to write their updates immediately to disk requires REDOing their actions in the event of a crash to ensure durability.

Q2f. (4 pts)

Consider two relations $R(A,B)$ and $S(B,C)$, and the following query:

```
SELECT *
FROM R, S
WHERE R.B < S.B
```

Consider the following join algorithms:

- Block-nested loop join
- Index-nested loop join with B+-tree index on R
- Index-nested loop join with hash index on R
- Index-nested loop join with B+-tree index on S
- Index-nested loop join with hash index on S
- Sort-merge join
- Hash join

(i) Which join algorithm is likely to perform the best assuming R is outer and S is inner relation? Select one choice – no explanations are needed.

Ans: Inequality in join condition – S is inner – use Index-nested loop join with B+-tree index on S.

(ii) Pick any one option from the above that cannot be used at all.
Ans: Index-nested loop join with hash or tree index on R, INLJ with hash-index on S, or hash-join. The standard sort-merge join does not help as well.

Q2g. (2 pts)

Given a relation $R(A,B)$, write a query to **select "distinct' values** of A **NOT** using the keyword "DISTINCT".

Ans:
SELECT A
FROM R

GROUP BY A

Q2h. (2 pts)

Given two relations $R(A,B)$ and $S(B,C)$, the following VIEW V has been defined. When Alice was asked to compute the average value of B for each value of A from the relation R, she wrote the query Q. Both V and Q are shown below. Is her query correct? Explain your answer.

```
V:
CREATE VIEW V1 AS
SELECT A, C, SUM(B) AS s, COUNT(B) as c
FROM R, S
WHERE R.B = S.B
GROUP BY A, C
```

```
Q:
SELECT A, (SUM(s) * 1.0) / SUM(c)
FROM V1
GROUP BY A
```

Ans: No, it will miss A tuples in R that do not have any matching B values with S.

Q2i. (3 pts)

The table

$$Scores(Team, Day, Opponent, Runs)$$

gives the scores in the Japanese Baseball League for two consecutive days. The Opponent is NULL if the Team did not play on that day. The number of Runs is given as NULL if either the team did not play, or will play on that day but the game is not yet concluded. The data in this table is as follows:

Team	Day	Opponent	Runs
Tigers	Sunday	Bay Stars	9
Carp	Sunday	NULL	NULL
Dragons	Monday	Carp	NULL
Swallows	Monday	Giants	0

What will be the output of the query Q?

```
Q:
SELECT Team, Day
FROM Scores
WHERE Opponent IS NULL
          OR NOT (Runs >= 2)
```

Ans: A row will be selected if the WHERE condition evaluated to true (3-valued logic)

- (Carp, Sunday): "Opponent IS NULL" is true; true $\vee$ unknown = true
- (Swallows, Monday): "Opponent IS NULL" is false; NOT (Runs >= 2) is true, false $\vee$ true = true

The other two evaluate to false and unknown respectively.

Q3. (7 + 7 = 14 pts) RC + SQL

Suppose a university maintains the job interview history of its students as follows.

- `Students(sid, sname, dept)` *(Student id, names, and department of the students).*
- `Employers(eid, ename, location)`
  (Employer id, name, and location of the companies that are recruiting/recruited in the past)
- `Interviews(eid, sid, year)` *(Which company interviewed which student in what year)*
- `Offers(eid, sid, year, salary)` *(Which company made an offer to which student in what year, and the annual salary in the offer)*

Assume that

- A company can interview or make an offer to a student at most once in a year.
- A company can be located in exactly one location (clearly not true in practice), and
- if an (eid, sid) pair appears in the `Offers` table, it also appears in the `Interviews` table, i.e. no students get an offer without an interview (ok, this is mostly true in practice).

Q3a. (7 pts) TRC

Write a **TRC expression** to output "the names (*sname*) of all students who had an interview with **all** companies from $location = `CA'$ that appear in the *Employer* table, but did not get an offer from any of these companies (the student may or may not have interviews with/get offers from companies from other locations).

e.g. If student Y appears in the answer, and if $'G', 'T', 'A', 'F'$ are all the companies in 'CA', then Y had interviews from all four of them, but offers from none of them. Y could have an interview/offer from another company 'M' that is located in $location =' WA'$.
Ans: **solution-1**

$$\{N : \exists S \in Students\ (N.sname = S.sname) \wedge$$
$$[\forall E \in Employers(E.location = `CA') \Rightarrow$$
$$[$$
$$(\exists V \in Interviews[(V.sid = S.sid) \wedge (V.eid = E.eid)])$$
$$\wedge\ \ (\neg\exists O \in Offers[(O.sid = S.sid) \wedge (O.eid = E.eid)])$$
$$]$$
$$]\}$$

solution-2 Equivalent and simpler solution without $\forall, \Rightarrow$ (there does not exist any E tuple such that $E.location = `CA'$ and either the student did not get an interview from E or s/he got an offer from E)

$$\{N : \exists S \in Students\ (N.sname = S.sname) \wedge$$
$$[\neg\exists E \in Employers(E.location = `CA') \wedge$$
$$[$$
$$(\neg\exists V \in Interviews[(V.sid = S.sid) \wedge (V.eid = E.eid)])$$
$$\vee\ \ (\exists O \in Offers[(O.sid = S.sid) \wedge (O.eid = E.eid)])$$
$$]$$
$$]\}$$

You can verify the equivalence between the above two – here is a sketch from sol-1 to sol-2 (omitting some details):

$$
\begin{aligned}
& \exists S \wedge [\forall E(P \Rightarrow ([\exists V(Q \wedge R)] \wedge [\neg \exists O(S \wedge T)])\ ])] \\
= \quad & \exists S \wedge [\neg \exists E \neg (\neg P \vee ([\exists V(Q \wedge R)] \wedge [\neg \exists O(S \wedge T)])\ ])] \\
= \quad & \exists S \wedge [\neg \exists E(P \wedge\ \ \neg([\exists V(Q \wedge R)] \wedge [\neg \exists O(S \wedge T)])\ ])] \\
= \quad & \exists S \wedge [\neg \exists E(P \wedge ([\neg \exists V(Q \wedge R)] \vee [\exists O(S \wedge T)])\ ])]
\end{aligned}
$$

Q3b. (7 pts) SQL

Write a SQL query for the problem in Q3a, i.e.:

Write a **SQL query** to output "the names (*sname*) of all students who had an interview with **all** companies from $location = `CA'$ that appear in the *Employer* table, but did not get an offer from any of these companies).

Only one query is allowed, but it can have nested subqueries, or subqueries using "WITH" clauses.

The schema is repeated below:

- `Students(sid, sname, dept)`
- `Employers(eid, ename, location)`
- `Interviews(eid, sid, year)`
- `Offers(eid, sid, year, salary)`

Ans:

Solution-1:

```
SELECT S.sname
FROM Students S
WHERE NOT EXISTS
  (SELECT *
   FROM Employers E
   WHERE E.location = 'CA'
    AND (NOT EXISTS
        (SELECT *
        FROM Interviews V
        WHERE V.sid = S.sid
          AND V.eid = E.eid)
      OR EXISTS
        (SELECT *
        FROM Offers O
        WHERE O.sid = S.sid
          AND O.eid = E.eid)
    )
  )
```

This can also be answered with multiple subqueries using WITH clause. One such solution:
Solution-2

```
    – Students who had interviews from all companies in CA
WITH SidInterv AS
  (SELECT sid
  FROM (
    SELECT sid, E.eid
    FROM Interviews V, Employers E
    WHERE V.eid = E.eid
    AND E.location='CA'
    GROUP BY sid, E.eid)
  GROUP BY sid
  HAVING COUNT(*) = (
    SELECT COUNT(*)
    FROM Employers
    WHERE location='CA')),

    – Students who had offerns from at least one company in CA
SidOffers AS
  (SELECT sid
  FROM Students S, Employers E, Offers O
  WHERE S.sid = O.sid
  AND E.eid = O.eid
  AND E.location = 'CA'),

    – final output
SELECT sname FROM Students
WHERE sid IN (SELECT sid FROM SidInterv)
AND sid NOT IN (SELECT sid FROM SidOffers)
```

Q4. (20 pts) Transactions

Q4a. (3 pts)

Consider the following transaction schedule of T_1, T_2, T_3:

$$R_1(X),\ R_2(X),\ R_3(X),\ R_1(Y),\ W_2(Z),\ R_3(Y),\ W_1(Z),\ W_1(Y)$$

Find out **all** serial schedules that the above schedule is conflict-equivalent to.
(Hint: you should be able to find the answer(s) without having to go over all possible serial schedules on $T_1, T_2.T_3$).

Ans: Construct the precedence graph: T_2 has to precede T_1 because of the order in which Z is written, and T_3 has to precede T_1 because the latter writes Y before the former reads Y. Thus, the precedence graph looks like $T_2 \rightarrow T_1 \leftarrow T_2$. The only possible serial orders that is conflict-equivalent to the given schedule are

$$T_2, T_3, T_1$$

and

$$T_3, T_2, T_1$$

.

Q4b. (6 pts)

Consider three transactions T_1, T_2, T_3 with the following sequences of operations:

- T_1 : $R_1(A), W_1(B)$
- T_2 : $R_2(B), W_2(D)$
- T_3 : $R_3(C), W_3(A)$

Consider a Timestamp Ordering scheduler named **TO** in which the three transaction T1, T2, and T3 have timestamps 60, 55, and 70 respectively. Assume initially all objects had timestamp 50. **Ignore commit bit (C) for all objects and transactions.**

Consider a Two-Phase Locking scheduler named **2PL**, also operating on the same set of data objects.

Examine the following two schedules:

- S_1 : $R_1(A), R_3(C), W_3(A), R_2(B), W_2(D), W_1(B)$
- S_2 : $R_3(C), R_1(A), W_1(B), R_2(B), W_2(D), W_3(A)$

Determine which of the above schedules can be produced by TO and which can be produced by 2PL by filliing out Yes/No in the following table.
Explanations are not required.

Schedule	Can be produced by TO?	Can be produced by 2PL?
S_1		
S_2		

Ans:

Schedule	Can be produced by TO?	Can be produced by 2PL?
S_1	Yes	No
S_2	No	Yes

- Note that $W_2(D)$ and $R_3(C)$ do not conflict with any of the other operations, so they can appear anywhere in the schedules without issue for TO and 2PL (of course, they should still follow the basic rule of transactions: $W_2(D)$ must appear after $R_2(B)$ and $R_3(C)$ must appear before $W_3(A)$).
- Since the timestamp of T_2 is less than that of T_1, $R_2(B)$ must appear before $W_1(B)$ in any schedule produced by TO. Similarly, $W_3(A)$ must appear after $R_1(A)$ because the timestamp of T_1 is less than that of T_3. Therefore, S_2 cannot be produced by TO, while S_1 can be produced by TO.
- With regard to 2PL, we need to focus on $R_1(A), W_3(A), W_1(B)$ and $R_2(B)$. Specifically, in S_1, T_1 must unlock before $W_3(A)$ and it must obtain the lock on B after $R_2(B)$. Therefore, 2PL cannot produce S_1, while S_2 is producible by 2PL.

Q4c. (3 + 1 + 1 + 2 + 1 + 2 + 1 = 11 pts)

At the time of a system crash, let the log segment (in the **UNDO/REDO** logging scheme) involving four transactions S, T, U, V be as follows. Answer the following questions using this log.

```
 1. (START S)
 2. (S, X, 10, 20)
 3. (COMMIT S)
 4. (START T)
 5. (T, X, 20, 30)
 6. (START CKPT(T))
 7. (T, Y, 10, 20)
 8. (START U)
 9. (COMMIT T)
10. (U, X, 30, 40)
11. (END CKPT)
12. (U, Y, 20, 30)
13. (START V)
14. (START CKPT(U,V))
15. (COMMIT U)
16. (V, Y, 30, 40)
```

(i) (**3 pts**) Fill out the table below by writing **Guaranteed** or **Maybe** or **Impossible** for each updates, which says whether that updated value of the variable was written to disk by the time of the crash:

- **Guaranteed:** this update is guaranteed to be written to disk,
- or, **Maybe:** this update might have been written to disk,
- or, **Impossible:** this update could not be written to disk.

log sequence no.	Variable = value	Status
2	$X = 20$	
5	$X = 30$	
7	$Y = 20$	
10	$X = 40$	
12	$Y = 30$	
16	$Y = 40$	

Ans:

log sequence no.	Variable = value	Status
2	$X = 20$	Guaranteed
5	$X = 30$	Guaranteed
7	$Y = 20$	Maybe
10	$X = 40$	Maybe
12	$Y = 30$	Maybe
13	$Y = 40$	Maybe

Since the second checkpointing did not complete, we only have guarantee on the updates before the first START CKPT. But all other updates might have been written to disk while the second checkpointing was running.

Suppose during the recovery, we first do REDO, and then UNDO.

(ii) (**1 pts**) What is the earliest (smallest) Log Sequence Number that is relevant for recovery in the REDO phase?

Ans: 6 – S committed before the first START CKPT, so it is complete. T, U committed as well at the time of the crash. But all changes made by T prior to the START CKPT are guaranteed to be on disk, so we do not need to go beyond the START CKPT at step 6.

(we also gave points to 7.)

(iii) (**1 pts**) What is the earliest (smallest) Log Sequence Number that is relevant for recovery in the UNDO phase?

Ans: 13 – V is the only uncommitted transaction at the time of crash.

(we also gave points to 16.)

(iv) (**2 pts**) What are the updates (in order) in the recovery for REDO?
Ans: Recovery in the forward direction for T and U:

- Y = 20 (by T)
- X = 40 (by U)
- Y = 30 (by U)

(v) (**1 pts**) What are the updates (in order) in the recovery for UNDO?
Ans: Recovery in the backward direction for V:

- Y= 30 (by V)

(vi) (**2 pts**) What are the final values of variables X, Y after both REDO and UNDO recovery phases are done?

- X =
- Y =

Ans:

- X = 40
- Y = 30

(vii) (**1 pts**) Will we get the same answer if we had done UNDO first and then REDO? (Write yes/no)
Ans: Yes, it does not matter in which order these two steps are executed – we are REDOing committed transactions and UNDOing uncommitted ones – we will get the same solutions $X = 40, Y = 30$.

Q5. (5 pts) Recursion

Recall the standard Datalog program for reachability in a 'directed' graph where the directed edges are stored in the E(U, V) relation (i.e., $E(1,2)$ and $E(2,1)$ are two different edges, and none, either, or both of them can exist) :

- R(x, y) :- E(x, y)
- R(x, y) :- E(x, z), R(z, y)

Write a datalog program to output the pairs of vertices u, v such that there is no path from u to v. Recall that for your query to be correct, it has to be 'safe'. Mention the output relation (in the above example, R is the output).

Ans: Note that if you use $\neg R(u,v)$, both u and v must also belong to a positive atom. Here we only have $E(x,y)$. So it is simpler first to get all the vertices that appear either in the first or in the second position of E.

- V(x) :- E(x, y)
- V(x) :- E(y, x)
- R(x, y) :- E(x, y)
- R(x, y) :- E(x, z), R(z, y)
- NR(u, v) :- V(u), V(v), ¬ R(u, v)

NR is the output.

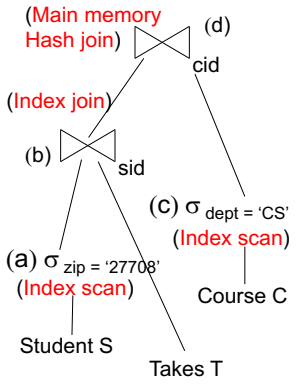
Q6. (10 pts) Query Cost Computation

Consider the relations below (T has foreign keys to C and S.):

- Student: S(sid, name, zip), Takes: T(sid, cid, year), Course: (cid, title, dept)

Recall that $B(R)$ = no. of pages in R, $T(R)$ = no. of tuples in R, $V(R,A)$ = no. of distinct values of $R.A$.

- B(S) = 20. T(S) = 2,000. V(S, zip) = 100.
- B(T) = 10,000, T(T) = 100,000, V(T, sid)=2,000, V(T, cid) = 50.
- B(C) = 10, T(C) = 100, V(C, dept)=1.



Assume the size of the main memory is M = 2000 pages, and all indexes are unclustered and are stored in main memory (hence accessing them requires zero disk I/O's).

Write the (i) the no. of output tuples P and (ii) the I/O cost of each node C in the table below. You can show calculations in terms of B, T, V for partial credit.

Step	**No. of output tuples P**	**I/O cost C**
(a)		
(b)		
(c)		
(d)		
Total	final output size =	total cost =

Ans:

Pass	**No. of output tuples P**	**I/O cost C**
(a)	$P = \frac{T(S)}{V(S,zip)} = 20$	C = 20
(b)	Per S tuple, no. of matching T tuples is $\frac{T(T)}{V(T,sid)} = 50$. Hence $P = 20 \times 50 = 1000$	Cost per S tuple = 50 (unclustered index). Total Cost C = $20 \times 50 = 1000$
(c)	$P = \frac{T(C)}{V(C,dept)} = 100$	C = 100
(d)	Foreign key join. P = no. of tuples on the left = 1000	Cost = 0 (main memory hash join)
Total	final output size = 1000	total cost = 20 + 1000 + 100 = 1120

Q7. (7 pts) Efficient Join Evaluation for Special Queries

You are given k relations $R_1(A_1,A_2), R_2(A_2,A_3), R_3(A_3,A_4), \ldots, R_k(A_k,A_{k+1})$. Each relation has n tuples. The values of each attribute A_i come from an arbitrary domain.

Note that the size of the join $R_1 \bowtie R_2 \bowtie R_3 \bowtie \ldots \bowtie R_k$ can be as large as 2^k or bigger, e.g. if all the relations R_i have the tuples shown in the table below:

R_i

A_i	A_{i+1}
0	a
0	b
1	a
1	b
a	0
a	1
b	0
b	1

i.e. whatever join algorithm you use, to compute the join , you need to spend at least 2^k cost (assume CPU cost for actual computation, ignore pages and disk I/Os). However, suppose your query is

$$\pi_{\{\}}(R_1 \bowtie R_2 \bowtie R_3 \bowtie \ldots \bowtie R_k)$$

The projection is on to empty set, i.e. this query returns true or false. It returns true if there are k tuples in these relations of the form $R_1(a_1,a_2), R_2(a_2,a_3), \ldots, R_k(a_k,a_{k+1})$ that join with each other, and false if no such combination exists.

Task: Briefly describe an $O(kn\log n)$ time algorithm (and explain its time complexity) to compute the above query that checks if there is "path" of tuples that join with each other in these relations (no need to output the paths or combinations). Your algorithm should give $O(kn\log n)$ time even for the above input.

Hint: Recall: (i) sorting n tuples on any attribute takes $O(n\log n)$ time, (ii) The notation $O(N)$ means that there is a constant c such that asymptotically if you increase N, the time is bounded by $\leq cN$. One concept that you have learned in this course in another context would help. **(Use the back of the page too if more space is needed.)**

Ans: Use 'semijoin' (from distributed databases) for consecutive relations!

- Start from R_1.
- Compute R_1'' = Projection of R_1 to A_2 – $O(n\log n)$ time to remove duplicates by sorting.
- Compute R_2' = Join of R_1'' and R_2 – sort both columns on A_2, for each A_2 in R_2, check if there is a match in R_1'' — $O(n\log n)$ time.
- Compute R_2'' = Projection of R_2' to A_3 – $O(n\log n)$ time time to remove duplicates by sorting.
- Repeat the above procedure until R_k is processed.
- If R_k'' is non-empty, the answer is true, otherwise false.
- Overall, the time complexity is $O(kn\log n)$.

More info: The above query is an example of a class of queries called 'acyclic queries'. If you have k relations each with n tuples, the worst case time to compute the join can be n^k. But for (general) acyclic queries, the join can be computed in $O(kn\log n)$ time (poly-time in both n and k and almost linear in n) by a more complex algorithm using join trees.

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