EECS 339: Introduction to Database Systems

Final Exam Solution
March 18, 2015

Name:

I Short Answers

1. **(6 points)**: Consider the distributed data management systems below:

   (a) Main memory (NewSQL)
   (b) Dynamo (NoSQL)
   (c) Conventional, disk-based database.

   For the following use cases, select the system that is best for the job.

   1.1. An online game where people earn points by tending to a virtual farm with cows and goats.

   A [✓ **B**] **C**

   1.2. A bank's large database with many transfers between accounts.

   A **B** [✓ **C**]

   1.3. An order entry system for a massive widget store. The seller needs to maintain precise figures for the stock levels in many warehouses.

   [✓ **A**] **B** **C**

   1.4. An online advertising firm specializing in personalized matching between a user's browsing history and their marketing.

   A [✓ **B**] **C**

   1.5. An online auction site where users rapidly bid on one or more items. For fairness, the auctioneer requires serializability on all bidding.

   A **B** [✓ **C**]

   1.6. A social media site for microblogging and sharing links with friends.

   A [✓ **B**] **C**

I.1 Database Design

2. **(6 points):** Consider the following schema for a delivery company:

```
package (p_id, start_address, end_address, priority, sent_timestamp, delivered_timestamp);
driver (d_id, name, address, gender, dob, hire_date);
delivered_by (d_id, p_id);
```

It has the workload:

(a)
```
SELECT name, hire_date
FROM driver
WHERE dob > DATETIME('April 12, 1975');
AND datediff(NOW() - hire_date, 'year') > 10;
```

(b)
```
SELECT d_id, name, p_id
FROM driver, package, delivered_by
WHERE datediff(delivered_time - sent_time, 'day') > 6
AND p_id.priority = 'high'
AND delivered_by.d_id = driver.d_id AND package.p_id = delivered_by.p_id;
```

2.1. What are the indexable columns for Query A?
(dob, hire_date)

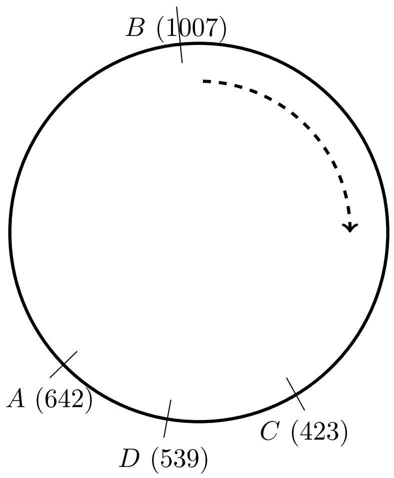
2.2. Given unlimited space, how would you index the data for Query B?
package: (p_id)
driver: (d_id, received_time, delivered_time)
delivered_by: (d_id, p_id)

2.3. How would you create a materialized view for Query B?

```
CREATE VIEW SELECT d_id, name, p_id
FROM driver, package, delivered_by
WHERE datediff(delivered_time - sent_time, 'day') > 6
AND p_id.priority = 'high'
AND delivered_by.d_id = driver.d_id AND package.p_id = delivered_by.p_id;
```

I.2 Consistent Hashing

3. **(4 points)**: Construct a consistent hash table for your DynamoDB deployment. You use the hash function $i \, mod \, 1024$.



Place the following nodes in the hash table:

- Node A: key 37506
- Node B: key 80879
- Node C: key 33191
- Node D: key 23067

Be sure to label each of them with their hashed position on the circle.

4. **(4 points)**: Name the node to which each of the following keys is assigned on your table:

   - Key 238: C
   - Key 269: C
   - Key 946: B
   - Key 33: C
   - Key 332: C
   - Key 74: C
   - Key 108: C

5. **(4 points:)**You may notice a marked imbalance in how much data is assigned to each node. How does DynamoDB address this issue?

   It balances the load by using virtual nodes to hash each host to many positions on the circle's edge. This makes it so that the range of hash values that may be assigned to a given node are distributed throughout the hash table rather than being in one (potentially short) clustered range.

   Note: the node and key numbers were all created using a random number generator. So, skew of this kind is a very real and common problem.

I.3 CAP Theorem

6. **(8 points):** Recall that the CAP theorem states that a distributed system cannot simultaneously provide the following guarantees:

   - **C**onsistency–all nodes see the same data at the same time
   - **A**vailability–a guarantee that every request receives a response about whether it succeeded or failed
   - **P**artition tolerance–the system continues to operate despite arbitrary message loss or failure of part of the system

   For the following scenarios, state which parts of CAP each implements.

   - A column store using two-phase locking wherein if a query waits for a lock for too long it times out.

     CA: 2PL guarantees that consistency is maintained, but addressing deadlocks with time out has the possibility of compromising the system's ability to remain functional in the presence of network failures. It remains available because it notifies users in the event of a failure.
   - Dynamo's eventual consistency model.

     AP: Dynamo's replication will make it such that the system resists network partitions, at the same time providing high availability because subsets of nodes can operate autonomously under eventual consistency.
   - A storage engine with weak consistency but many replicas.

     AP: The same logic for Dynamo applies here. Both sacrifice consistency.
   - A shared-nothing database that maintains ACID properties using optimistic concurrency control.

     CA: The database will abort transactions when it fails to validate them. Therefore, it maintains consistency with ACID and availability by aborting when validation fails and reporting it to the user.

II Concurrency Control

7. **8 points**: For the following transaction schedules, determine whether they are conflict serializable by swapping non-conflicting operations. If they are serializable, specify their order and the swaps needed to get that schedule. If not, identify two pairs of operations that are not swappable making it unserializable.

3.1. Schedule:

Transaction 1	Transaction 2
1. RA	
2. WA	
	3. RB
	4. RA
	5. **commit**
6. WB	
7. WA	
8. **commit**	

Serializable? **Yes** [✓ **No**]

Explanation: It not serializable because of (2,4) and ((3, 6) or (4,7)) conflict.

3.2. Schedule:

Transaction 1	Transaction 2
1. RA	
	2. RB
3. WA	
	4. WB
5. RB	
	6. RA
7. WB	
8. **commit**	
	9. WA
	10. **commit**

Serializable? **Yes** [✓ **No**]

Explanation: It is not serializable, and the conflicting pairs should include one of the following: (1, 9) (3, 6) (3,9)
and one of:
(2.7) (4, 5) (4, 7).

3.3. Schedule:

Transaction 1	Transaction 2
1. RA	
2. WA	
	3. RB
	4. RC
	5. WA
6. RB	
7. RC	
8. **commit**	
	9. WC
	10. **commit**

Serializable? [✓ **Yes**] **No**

Explanation: This schedule is serializable to T1, T2 if we swap (6,7,8) with (3, 4, 5). It is not serializable to T2, T1 because steps 2 and 5 conflict.

3.4. Schedule:

Transaction 1	Transaction 2
	1. RA
	2. WA
3. RB	
4. WB	
	5. RC
	6. WC
	7. **commit**
8. RD	
9. WD	
10. **commit**	

Serializable? [✓ **Yes**] **No**

Explanation: This schedule is serializable to T1 T2 by swapping (3, 4) with (1, 2) and (8. 9, 10) with (1, 2, 5, 6, 7). It is also serializable to T2 T1 by swapping (3, 4) with (5, 6, 7)

8. **(9 points):** Consider the following queries executing under optimistic concurrency control using two-pass validation. Determine whether one or both transactions succeed. If a transaction aborts, state whether it stopped when the failed query was holding the lock or not. Presume that no additional queries overlap with the ones described here.

   (a) T_1 receives its transaction id before T_2 begins validation. They have the following read and write sets:
   T_1: read set: B C, write set: A
   T_2: read set: A, write set: B, C

   T_2 fails before acquiring the lock owing to the overlap of write an read sets on A. T_1 succeeds.

   (b) T_1 enters its validation phase before T_2, but does not have a transaction id before T_2 begins validation. They have the following read and write sets:
   T_1: read set A, B, write set: C
   T_2: read set B, C, write set: A

   T_2 enters its validation and sees an empty queue of transactions before it because T_1 has not received its transaction id yet. Meanwhile, T_1 started first and acquired the lock, hence it succeeds. Once T_1 gives up the lock, T_2 goes into its critical section. It identifies the conflict on C and aborts.

   (c) T_1 receives its transaction id before T_2 begins validation. They have the following read and write sets:
   T_1: read set: A, B C, write set: D
   T_2: read set: A, write set: B, C

   Both transactions succeed because there is no overlap in the write set of T_1 with the read set of T_2.

III Phantom Tuples

For the following transactions, state whether they are subject to the phantom problem and justify your answer.

9. **(2 points):**

```
 Transaction 1                     Transaction 2
SELECT * FROM employees;
                                  INSERT into employees VALUES ('JR', 'Art Dept');
SELECT count(*) FROM employees;
```

Phantom possible: [✓ **YES**] **NO**

Why? The count may increase with the addition of a new employee.

10. **(3 points):**

```
 Transaction 1                          Transaction 2
SELECT room_number
FROM classrooms, buildings
WHERE building.b_name = 'Tech'
AND building.b_id = classrooms.b_id;
                                       INSERT into classrooms VALUES (1, 'Tech', 414);
SELECT max(room_number)
FROM classrooms, buildings
WHERE building.b_name = 'Tech'
AND building.b_id = classrooms.b_id;
```

Phantom possible: [✓ **YES**] **NO**

Why? The first query accesses all room numbers in Tech, and the second part of Transaction 1 may access a larger set of tuples than the one returned in the earlier query.

11. **(3 points):**

```
Transaction 1                              Transaction 2
SELECT borrower, sum(amt_owed) as debt
FROM car_loans
GROUP BY borrower
HAVING debt > 10,000;
                                           DELETE FROM car_loans
                                           WHERE amt_owed = 0;

SELECT distinct borrower
FROM car_loans;
```

Phantom possible: **YES** [✓ **NO**]

Why? The deleted amt_owed entries will not effect the sum. Therefore both queries in Transaction 1 produce consistent results.

12. **(3 points):**

```
Transaction 1                   Transaction 2
SELECT min(sign_out_date)
FROM library_books
WHERE status = 'borrowed';
                                UPDATE library_books
                                SET status = 'missing'
                                WHERE sign_out_date < DATETIME(NOW() - 3 months);

SELECT distinct borrower
FROM library_books
WHERE status='missing';
```

Phantom possible: **YES** [✓ **NO**]

Why? Updates will not involve inserting or deleting tuples. Therefore standard concurrency control (e.g., OCC or 2PL) will work here.

III.1 Hierarchical Locking

For the following transactions, specify the lock(s) needed to complete them. Consider both intention and conventional locks.

13. **(4 points):**

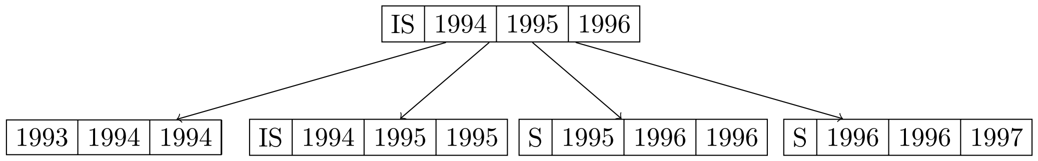
```
SELECT count(*)
FROM students;
```

Acquire a shared lock on table A.

14. **(4 points):**

```
SELECT avg(age)
FROM students
WHERE birth_year >= 1995;
```

If the students table has the following B+ Tree index on birth_year, label the tree pages that would be locked to prevent phantoms. Consider only page-level locking, not record-level. Be sure to note each lock type.



15. **(4 points):**

```
UPDATE students
SET status='enrolled'
WHERE class_year=2019;
```

Presume that students has a B+ Tree index on class_year. Describe the locks needed on the index and database, including record-level locking. Locks needed:

- IX on student table
- IX on all B+ Tree nodes and database pages where their range includes 2019 in addition to other values.
- X lock on pages that entirely match the predicate.
- X lock on records in pages that match the predicate.
- X all B+ Tree nodes and database pages that refer only to 2019.

IV Recovery

Consider the following log for a database implementing ARIES recovery:

LSN	TID	Type	Object
Checkpoint 1			
1	T1	SOT	
2	T2	SOT	
3	T2	UP	A
4	T1	UP	B
5	T3	SOT	
6	T3	UP	A
Checkpoint 2			
7	T1	UP	C
8	T3	UP	B
9	T2	EOT	
10	T1	UP	A
11	T1	EOT	
12	T3	UP	C

Two checkpoints are taken at the indicated times. At the time of Checkpoint 1, the dirty page table and the transaction table are both empty. The system crashes immediately following when LSN 12 was written to disk.

16. **(4 points):** Draw a timeline for this log.

```
CP1                        CP2
 | T1 |--------B------------|---C--------A---|
 | T2   |--A----------------|----------|
 | T3             |---A----|------B-------------C---
```

17. **(4 points):** Presuming there are no flushes, draw a transaction table and a dirty page table for this log after the ARIES analysis phase.

TID	LastLSN
T3	12

PageId	RecLSN
A	3
B	4
C	7

18. **(4 points):** If Checkpoint 2 has the dirty page table below, was there a flush or not? If so, what is the earliest point the flush could have happened?

PageId	RecLSN
A	6

The earliest a flush may have happened between LSNs 4 and 5.

19. **(4 points):** Fill in the dirty page table just before the crash, reflecting the dirty page table above:

PageId	RecLSN
A	6
B	8
C	7

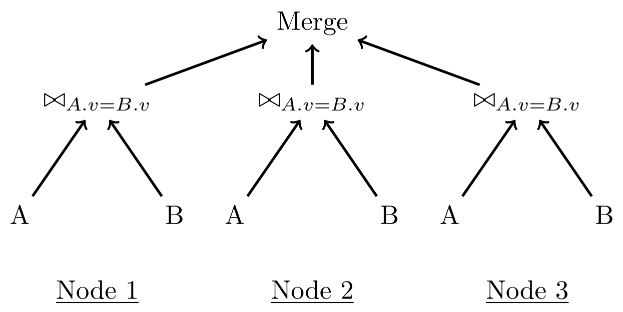
V Distributed Query Processing

For the following queries, draw a distributed query execution plan over three nodes. Be sure to insert the split and merge operators to properly align the data for comparison and for streaming the output to the user.

20. **(4 points):**

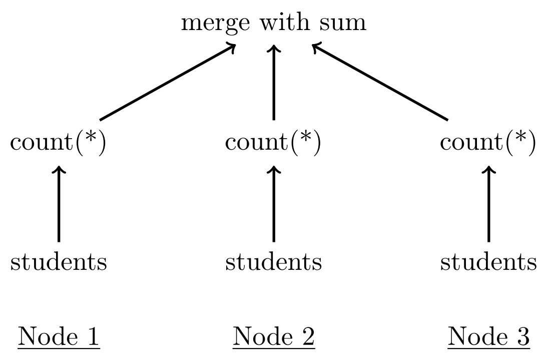
```
SELECT *
FROM A, B
WHERE A.v = B.v;
```

Presume that A and B are both partitioned on v.



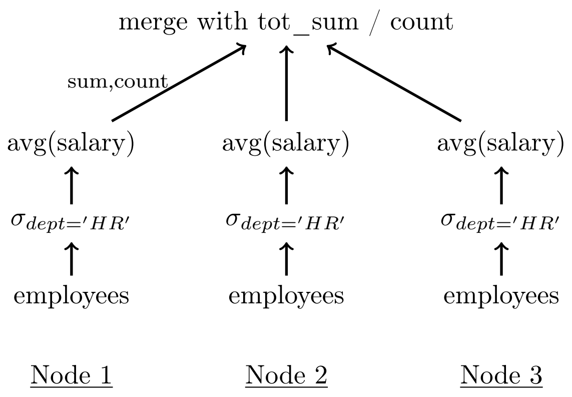
21. **(4 points):**

```
SELECT count(*)
FROM students;
```



22. **(4 points):**

```
SELECT avg(salary)
FROM employees
WHERE dept='Human Resources';
```


merge with tot_sum / count
sum,count
avg(salary)
avg(salary)
avg(salary)
$\sigma_{dept='HR'}$
$\sigma_{dept='HR'}$
$\sigma_{dept='HR'}$
employees
employees
employees
Node 1
Node 2
Node 3