IMPORTANT:

- **Upload this PDF** with your answers to Gradescope by **11:59pm on Monday Dec 3, 2018**.
- **Plagiarism**: Homework may be discussed with other students, but all homework is to be completed **individually**.
- **You have to use this PDF for all of your answers**.

For your information:

- Graded out of **100 points**; **3 questions total**

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Question 1: Two-Phase Commit ................................................. [40 points]

Consider a distributed transaction $T$ operating under the two-phase commit protocol. Let $N_0$ be the coordinator node, and $N_1, N_2, N_3$ be the participant nodes.

The following messages have been sent:

<table>
<thead>
<tr>
<th>time</th>
<th>message</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N_0$ to $N_1$: “Phase1:PREPARE”</td>
</tr>
<tr>
<td>2</td>
<td>$N_0$ to $N_2$: “Phase1:PREPARE”</td>
</tr>
<tr>
<td>3</td>
<td>$N_0$ to $N_3$: “Phase1:PREPARE”</td>
</tr>
<tr>
<td>4</td>
<td>$N_2$ to $N_0$: “OK”</td>
</tr>
<tr>
<td>5</td>
<td>$N_1$ to $N_0$: “OK”</td>
</tr>
</tbody>
</table>

Figure 1: Two-Phase Commit messages for transaction $T$

(a) [10 points] Who should send a message next at time 6 in Figure 1? Select all the possible answers.

- $N_0$
- $N_1$
- $N_2$
- $N_3$
- It is not possible to determine

(b) [10 points] To whom? Again, select all the possible answers.

- $N_0$
- $N_1$
- $N_2$
- $N_3$
- It is not possible to determine

(c) [10 points] Suppose that $N_0$ never received the “OK” response from $N_1$ at time 5 in Figure 1 (the message got dropped due to a hardware failure). Instead, $N_0$ “times out” after waiting a certain amount of time. What should happen under the two-phase commit protocol in this scenario?

- $N_0$ resends “Phase1:PREPARE” to $N_1$
- $N_0$ resends “Phase1:PREPARE” to all of the participant nodes
- $N_0$ sends “ABORT” to $N_1$
- $N_0$ sends “ABORT” all of the participant nodes
- $N_0$ sends “Phase2:COMMIT” all of the participant nodes
- $N_1$ resends “OK” to $N_0$
- It is not possible to determine

Question 1 continues...
(d) [10 points] Suppose that $N_0$ successfully receives all of the “OK” messages from the participants from the first phase (i.e., after time 6 in Figure 1). It then sends the “Phase2: COMMIT” message to all of the participants at time 7 but $N_2$ crashes before it receives this message. What is the status of the transaction $T$ when $N_2$ comes back on-line?

- $T$’s status is committed
- $T$’s status is aborted
- It is not possible to determine
Question 2: Distributed Joins........................................... [25 points]
Answer the following questions about performing joins in a distributed database. You can assume that the DBMS uses a shared-nothing architecture.

(a) Consider the relations \( R(A,B,C) \) and \( S(C,D,E) \) shown in Table 1, where attribute \( S.C \) is a foreign key of attribute \( R.C \).

i. [10 points] What is the output of \( R \bowtie S \)?

- \{ (a4,b5,c3), (a4,b5,c3), (a3,b2,c3) \}
- \{ (a5,b3,c2), (c2,d3,e2), (a1,b2,c3), (c3,d4,e5), (c3,d6,e8) \}
- \{ (c2,b3,a5), (c2,d3,e2), (c3,d4,e5), (c3,d6,e8) \}
- \{ (a1,b2), (a4,b5) \}
- \{ (a5,b3,c2), (a1,b2,c3) \}
- \{ (a5,b2,c3), (a1,b2,c3), (a5,b3,c2) \}

- None of the above

ii. [10 points] What is the output of \( S \bowtie R \)?

- \{ (c3,d6,e8), (c3,d4,e5), (c2,d3,e2) \}
- \{ (c2,d3,e2), (a1,b2,c3), (c3,d6,e8), (c3,d4,e5), (a5,b3,c2) \}
- \{ (c1,d4,e1), (c2,d3,e2), (c1,d2,e3) \}
- \{ (c2,d3,e2), (c1,d4,e1), (c3,d6,e8), (c1,d2,e3), (c3,d4,e5) \}
- \{ (d3,e2), (d6,e8) \}
- \{ (c2,d3,e2), (c3,d6,e8) \}

- None of the above

Table 1: Sample database
(b) [5 points] In general, is the semijoin operation symmetric for every possible database? That is, is the following equation always true for any possible relations $R_1$ and $R_2$?

$$R_1 \bowtie R_2 =? R_2 \bowtie R_1$$

- Yes
- No
- It is not possible to determine
Question 3: Replication .............................................................. [35 points]

Consider a DBMS using active-passive, master-replica replication with multi-versioned concurrency control. All read-write transactions go to the master node (NODE A), while read-only transactions are routed to the replica (NODE B). You can assume that the DBMS has “instant” fail-over and master elections. That is, there is no time gap between when the master goes down and when the replica gets promoted as the new master. For example, if NODE A goes down at timestamp ① then NODE B will be elected the new master at ②. Note that this is not a realistic assumption but we’re using it to simplify the problem setup.

The database has a single table `foo(id, val)` with the following tuples:

<table>
<thead>
<tr>
<th>id</th>
<th>val</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>aaa</td>
</tr>
<tr>
<td>2</td>
<td>bbb</td>
</tr>
</tbody>
</table>

Table 2: `foo(id, val)`

For each question listed below, assume that the following transactions shown in Figure 2 are executing in the DBMS: (1) Transaction #1 on NODE A and (2) Transaction #2 on NODE B. You can assume that the timestamps for each operation is the real physical time of when it was invoked at the DBMS and that the clocks on both nodes are perfectly synchronized (again, this is not a realistic assumption).

<table>
<thead>
<tr>
<th>time</th>
<th>operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>BEGIN;</td>
</tr>
<tr>
<td>②</td>
<td>UPDATE foo SET val = ‘xxx’;</td>
</tr>
<tr>
<td>③</td>
<td>UPDATE foo SET val = ‘yyy’ WHERE id = 1;</td>
</tr>
<tr>
<td>④</td>
<td>UPDATE foo SET val = ‘zzz’ WHERE id = 2;</td>
</tr>
<tr>
<td>⑤</td>
<td>COMMIT;</td>
</tr>
</tbody>
</table>

(a) Transaction #1 – NODE A

<table>
<thead>
<tr>
<th>time</th>
<th>operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>②</td>
<td>BEGIN READ ONLY;</td>
</tr>
<tr>
<td>③</td>
<td>SELECT val FROM foo WHERE id = 1;</td>
</tr>
<tr>
<td>④</td>
<td>SELECT val FROM foo WHERE id = 2;</td>
</tr>
<tr>
<td>⑤</td>
<td>SELECT val FROM foo WHERE id = 2;</td>
</tr>
<tr>
<td>⑥</td>
<td>COMMIT;</td>
</tr>
</tbody>
</table>

(b) Transaction #2 – NODE B

Figure 2: Transactions executing in the DBMS.

(a) Assume that the DBMS is using asynchronous replication with continuous log streaming (i.e., the master node sends log records to the replica in the background after the transaction executes them). Suppose that NODE A crashes at timestamp ④ before it executes the third UPDATE operation.

i. [10 points] If Transaction #2 is running under SNAPSHOT ISOLATION, what is the return result of the `val` attribute for its SELECT query at timestamp ③? Select all that are possible.

- □ aaa
- □ xxx
- □ yyy
- □ None of the above

Question 3 continues...
ii. [10 points] If Transaction #2 is running under the READ UNCOMMITTED isolation level, what is the return result of the val attribute for its SELECT query at timestamp ④? Select all that are possible.

- bbb
- xxx
- zzz
- None of the above

(b) [15 points] Assume that the DBMS is using semi-synchronous replication with continuous log streaming. Suppose that both NODE A and NODE B crash at exactly the same time at timestamp ⑥ after executing Transaction #1’s COMMIT operation. You can assume that the application was notified that the Transaction #1 was committed successfully.

After the crash, you find that NODE A had a major hardware failure and cannot boot. NODE B is able to recover and is elected the new master.

What are the values of the tuples in the database when the system comes back online? Select all that are possible.

- { (1,aaa), (2,bbb) }
- { (1,xxx), (2,bbb) }
- { (1,xxx), (2,xxx) }
- { (1,yyy), (2,bbb) }
- { (1,yyy), (2,xxx) }
- { (1,yyy), (2,zzz) }
- None of the above