Chapter 15: Transactions
Chapter 15: Transactions

- Transaction Concept
- Transaction State
- Concurrent Executions
- Serializability
- Recoverability
- Implementation of Isolation
- Transaction Definition in SQL
- Testing for Serializability.
Transaction Concept

- A transaction is a unit of program execution that accesses and possibly updates various data items.

- E.g. transaction to transfer $50 from account A to account B:
  1. read(A)
  2. A := A – 50
  3. write(A)
  4. read(B)
  5. B := B + 50
  6. write(B)

- Two main issues to deal with:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions
Example of Fund Transfer

Transaction to transfer $50 from account A to account B:
1. read(A)
2. A := A – 50
3. write(A)
4. read(B)
5. B := B + 50
6. write(B)

Atomicity requirement
- if the transaction fails after step 3 and before step 6, money will be “lost” leading to an inconsistent database state
  - Failure could be due to software or hardware
- the system should ensure that updates of a partially executed transaction are not reflected in the database

Durability requirement — once the user has been notified that the transaction has completed (i.e., the transfer of the $50 has taken place), the updates to the database by the transaction must persist even if there are software or hardware failures.
Example of Fund Transfer (Cont.)

- Transaction to transfer $50 from account A to account B:
  1. \texttt{read}(A)
  2. \( A := A - 50 \)
  3. \texttt{write}(A)
  4. \texttt{read}(B)
  5. \( B := B + 50 \)
  6. \texttt{write}(B)

- **Consistency requirement** in above example: the sum of A and B is unchanged by the execution of the transaction.

- **In general, consistency requirements include**:
  - Explicitly specified integrity constraints such as primary keys and foreign keys
  - Implicit integrity constraints
    - e.g. sum of balances of all accounts, minus sum of loan amounts must equal value of cash-in-hand
  - A transaction must see a consistent database.
  - During transaction execution the database may be temporarily inconsistent.
  - When the transaction completes successfully the database must be consistent
    - Erroneous transaction logic can lead to inconsistency
Example of Fund Transfer (Cont.)

- **Isolation requirement** — if between steps 3 and 6, another transaction T2 is allowed to access the partially updated database, it will see an inconsistent database (the sum $A + B$ will be less than it should be).

  T1
  1. read($A$)
  2. $A := A - 50$
  3. write($A$)

  read($A$), read($B$), print($A+B$)

  T2
  4. read($B$)
  5. $B := B + 50$
  6. write($B$)

- Isolation can be ensured trivially by running transactions **serially**
  - that is, one after the other.

- However, executing multiple transactions concurrently has significant benefits, as we will see later.
A transaction is a unit of program execution that accesses and possibly updates various data items. To preserve the integrity of data the database system must ensure:

- **Atomicity.** Either all operations of the transaction are properly reflected in the database or none are.

- **Consistency.** Execution of a transaction in isolation preserves the consistency of the database.

- **Isolation.** Although multiple transactions may execute concurrently, each transaction must be unaware of other concurrently executing transactions. Intermediate transaction results must be hidden from other concurrently executed transactions.

  - That is, for every pair of transactions $T_i$ and $T_j$, it appears to $T_i$ that either $T_j$ finished execution before $T_i$ started, or $T_j$ started execution after $T_i$ finished.

- **Durability.** After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures.
## Transaction State

- **Active** – the initial state; the transaction stays in this state while it is executing.
- **Partially committed** – after the final statement has been executed.
- **Failed** – after the discovery that normal execution can no longer proceed.
- **Aborted** – after the transaction has been rolled back and the database restored to its state prior to the start of the transaction. Two options after it has been aborted:
  - restart the transaction
    - can be done only if no internal logical error
  - kill the transaction
- **Committed** – after successful completion.
Transaction State (Cont.)

Transaction states:
- Active
- Partially committed
- Committed
- Failed
- Aborted
The recovery-management component of a database system implements the support for atomicity and durability.

E.g. the **shadow-database** scheme:

- All updates are made on a *shadow copy* of the database
  - `db_pointer` is made to point to the updated shadow copy after
    - the transaction reaches partial commit and
    - all updated pages have been flushed to disk.

![Diagram showing the shadow-database scheme](image)
Implementation of Atomicity and Durability
(Cont.)

- db_pointer always points to the current consistent copy of the database.
  - In case transaction fails, old consistent copy pointed to by db_pointer can be used, and the shadow copy can be deleted.

- The shadow-database scheme:
  - Assumes that only one transaction is active at a time.
  - Assumes disks do not fail.
  - Useful for text editors, but
    - extremely inefficient for large databases (why?)
      - Variant called shadow paging reduces copying of data, but is still not practical for large databases.
  - Does not handle concurrent transactions.

- Will study better schemes in Chapter 17.
Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **increased processor and disk utilization**, leading to better transaction **throughput**
    - E.g. one transaction can be using the CPU while another is reading from or writing to the disk
  - **reduced average response time** for transactions: short transactions need not wait behind long ones.

- **Concurrency control schemes** – mechanisms to achieve isolation
  - that is, to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database
    - Will study in Chapter 16, after studying notion of correctness of concurrent executions.
Schedules

- **Schedule** – a sequence of instructions that specify the chronological order in which instructions of concurrent transactions are executed.
  - A schedule for a set of transactions must consist of all instructions of those transactions.
  - Must preserve the order in which the instructions appear in each individual transaction.

- A transaction that successfully completes its execution will have a commit instructions as the last statement.
  - By default, the transaction is assumed to execute the commit instruction as its last step.

- A transaction that fails to successfully complete its execution will have an abort instruction as the last statement.
## Schedule 1

- Let $T_1$ transfer $50$ from $A$ to $B$, and $T_2$ transfer 10% of the balance from $A$ to $B$.

- A **serial** schedule in which $T_1$ is followed by $T_2$:

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>$A := A - 50$</td>
<td>$temp := A \times 0.1$</td>
</tr>
<tr>
<td>write($A$)</td>
<td>$A := A - temp$</td>
</tr>
<tr>
<td>read($B$)</td>
<td>write($A$)</td>
</tr>
<tr>
<td>$B := B + 50$</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($B$)</td>
<td>$B := B + temp$</td>
</tr>
</tbody>
</table>


Schedule 2

- A serial schedule where \( T_2 \) is followed by \( T_1 \)

<table>
<thead>
<tr>
<th>( T_1 )</th>
<th>( T_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>read(( A ))&lt;br&gt;( A := A - 50 )&lt;br&gt;write(( A ))&lt;br&gt;read(( B ))&lt;br&gt;( B := B + 50 )&lt;br&gt;write(( B ))</td>
<td>read(( A ))&lt;br&gt;( temp := A * 0.1 )&lt;br&gt;( A := A - \ temp )&lt;br&gt;write(( A ))&lt;br&gt;read(( B ))&lt;br&gt;( B := B + \ temp )&lt;br&gt;write(( B ))</td>
</tr>
</tbody>
</table>
Schedule 3

Let $T_1$ and $T_2$ be the transactions defined previously. The following schedule is not a serial schedule, but it is equivalent to Schedule 1.

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>$A := A - 50$</td>
<td>$temp := A * 0.1$</td>
</tr>
<tr>
<td>write($A$)</td>
<td>$A := A - temp$</td>
</tr>
<tr>
<td></td>
<td>write($A$)</td>
</tr>
<tr>
<td>read($B$)</td>
<td>read($B$)</td>
</tr>
<tr>
<td>$B := B + 50$</td>
<td>$B := B + temp$</td>
</tr>
<tr>
<td>write($B$)</td>
<td>write($B$)</td>
</tr>
</tbody>
</table>

In Schedules 1, 2 and 3, the sum $A + B$ is preserved.
Schedule 4

The following concurrent schedule does not preserve the value of \((A + B)\).

<table>
<thead>
<tr>
<th>(T_1)</th>
<th>(T_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>read((A)) (A := A - 50)</td>
<td>read((A)) (temp := A * 0.1)</td>
</tr>
<tr>
<td>write((A)) (B := B + 50)</td>
<td>(A := A - temp) (write(A)) (read(B))</td>
</tr>
<tr>
<td>write((B)) (read(B))</td>
<td>(B := B + temp) (write(B))</td>
</tr>
</tbody>
</table>
Serializability

- **Basic Assumption** – Each transaction preserves database consistency.
- Thus serial execution of a set of transactions preserves database consistency.
- A (possibly concurrent) schedule is serializable if it is equivalent to a serial schedule. Different forms of schedule equivalence give rise to the notions of:
  1. **conflict serializability**
  2. **view serializability**
- **Simplified view of transactions**
  - We ignore operations other than **read** and **write** instructions
  - We assume that transactions may perform arbitrary computations on data in local buffers in between reads and writes.
  - Our simplified schedules consist of only **read** and **write** instructions.
Conflicting Instructions

- Instructions $l_i$ and $l_j$ of transactions $T_i$ and $T_j$ respectively, **conflict** if and only if there exists some item $Q$ accessed by both $l_i$ and $l_j$, and at least one of these instructions wrote $Q$.

  1. $l_i = \text{read}(Q), l_j = \text{read}(Q)$. $l_i$ and $l_j$ don’t conflict.
  2. $l_i = \text{read}(Q), l_j = \text{write}(Q)$. They conflict.
  3. $l_i = \text{write}(Q), l_j = \text{read}(Q)$. They conflict
  4. $l_i = \text{write}(Q), l_j = \text{write}(Q)$. They conflict

- Intuitively, a conflict between $l_i$ and $l_j$ forces a (logical) temporal order between them.
  - If $l_i$ and $l_j$ are consecutive in a schedule and they do not conflict, their results would remain the same even if they had been interchanged in the schedule.
Conflict Serializability

- If a schedule $S$ can be transformed into a schedule $S´$ by a series of swaps of non-conflicting instructions, we say that $S$ and $S´$ are conflict equivalent.

- We say that a schedule $S$ is conflict serializable if it is conflict equivalent to a serial schedule.
Conflict Serializability (Cont.)

- Schedule 3 can be transformed into Schedule 6, a serial schedule where $T_2$ follows $T_1$, by series of swaps of non-conflicting instructions.

  - Therefore Schedule 3 is conflict serializable.

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>write($A$)</td>
<td>write($A$)</td>
</tr>
<tr>
<td>read($B$)</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($B$)</td>
<td>write($B$)</td>
</tr>
</tbody>
</table>

Schedule 3

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>write($A$)</td>
<td>write($A$)</td>
</tr>
<tr>
<td>read($B$)</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($B$)</td>
<td>write($B$)</td>
</tr>
</tbody>
</table>

Schedule 6
Example of a schedule that is not conflict serializable:

<table>
<thead>
<tr>
<th>$T_3$</th>
<th>$T_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($Q$)</td>
<td>write($Q$)</td>
</tr>
<tr>
<td>write($Q$)</td>
<td></td>
</tr>
</tbody>
</table>

We are unable to swap instructions in the above schedule to obtain either the serial schedule $< T_3, T_4 >$, or the serial schedule $< T_4, T_3 >$. 
View Serializability

Let $S$ and $S'$ be two schedules with the same set of transactions. $S$ and $S'$ are view equivalent if the following three conditions are met, for each data item $Q$,

1. If in schedule $S$, transaction $T_i$ reads the initial value of $Q$, then in schedule $S'$ also transaction $T_i$ must read the initial value of $Q$.

2. If in schedule $S$ transaction $T_i$ executes $\text{read}(Q)$, and that value was produced by transaction $T_j$ (if any), then in schedule $S'$ also transaction $T_i$ must read the value of $Q$ that was produced by the same $\text{write}(Q)$ operation of transaction $T_j$.

3. The transaction (if any) that performs the final $\text{write}(Q)$ operation in schedule $S$ must also perform the final $\text{write}(Q)$ operation in schedule $S'$.

As can be seen, view equivalence is also based purely on reads and writes alone.
A schedule $S$ is **view serializable** if it is view equivalent to a serial schedule.

Every conflict serializable schedule is also view serializable.

Below is a schedule which is view-serializable but *not* conflict serializable.

<table>
<thead>
<tr>
<th></th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>read($Q$)</td>
<td>write($Q$)</td>
<td>write($Q$)</td>
</tr>
<tr>
<td></td>
<td>write($Q$)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

What serial schedule is above equivalent to?

Every view serializable schedule that is not conflict serializable has **blind writes**.
Other Notions of Serializability

- The schedule below produces the same outcome as the serial schedule \(< T_1, T_5 >\), yet is not conflict equivalent or view equivalent to it.

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>$A := A - 50$</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($A$)</td>
<td></td>
<td>$B := B - 10$</td>
</tr>
<tr>
<td></td>
<td>read($B$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td></td>
<td>$B := B + 50$</td>
<td>$A := A + 10$</td>
</tr>
<tr>
<td></td>
<td>write($B$)</td>
<td>write($A$)</td>
</tr>
</tbody>
</table>

- Determining such equivalence requires analysis of operations other than read and write.
Testing for Serializability

- Consider some schedule of a set of transactions $T_1, T_2, \ldots, T_n$
- **Precedence graph** — a direct graph where the vertices are the transactions (names).
- We draw an arc from $T_i$ to $T_j$ if the two transaction conflict, and $T_i$ accessed the data item on which the conflict arose earlier.
- We may label the arc by the item that was accessed.
- **Example 1**
### Example Schedule (Schedule A) + Precedence Graph

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>read(Y)</td>
<td>read(X)</td>
<td></td>
<td></td>
<td>read(V)</td>
</tr>
<tr>
<td></td>
<td>read(Z)</td>
<td></td>
<td></td>
<td></td>
<td>read(W)</td>
</tr>
<tr>
<td>read(U)</td>
<td></td>
<td>read(Y)</td>
<td>write(Y)</td>
<td></td>
<td>read(Y)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>write(Z)</td>
<td></td>
<td></td>
<td>write(Y)</td>
</tr>
<tr>
<td>read(U)</td>
<td></td>
<td></td>
<td></td>
<td>read(Z)</td>
<td>write(Z)</td>
</tr>
<tr>
<td>write(U)</td>
<td></td>
<td></td>
<td></td>
<td>write(U)</td>
<td></td>
</tr>
</tbody>
</table>

The precedence graph shows the dependencies among the transactions:

- $T_1$ precedes $T_2$.
- $T_2$ precedes $T_3$.
- $T_3$ precedes $T_4$.
- $T_4$ precedes $T_5$.
- $T_5$ precedes $T_1$.
Test for Conflict Serializability

- A schedule is conflict serializable if and only if its precedence graph is acyclic.
- Cycle-detection algorithms exist which take order \( n^2 \) time, where \( n \) is the number of vertices in the graph.
  - (Better algorithms take order \( n + e \) where \( e \) is the number of edges.)
- If precedence graph is acyclic, the serializability order can be obtained by a topological sorting of the graph.
  - This is a linear order consistent with the partial order of the graph.
  - For example, a serializability order for Schedule A would be 
    \( T_5 \rightarrow T_1 \rightarrow T_3 \rightarrow T_2 \rightarrow T_4 \)
    - Are there others?
Test for View Serializability

- The precedence graph test for conflict serializability cannot be used directly to test for view serializability.
  - Extension to test for view serializability has cost exponential in the size of the precedence graph.
- The problem of checking if a schedule is view serializable falls in the class of $NP$-complete problems.
  - Thus existence of an efficient algorithm is extremely unlikely.
- However practical algorithms that just check some sufficient conditions for view serializability can still be used.
Recoverable Schedules

Need to address the effect of transaction failures on concurrently running transactions.

- **Recoverable schedule** — if a transaction $T_j$ reads a data item previously written by a transaction $T_i$, then the commit operation of $T_i$ appears before the commit operation of $T_j$.

- The following schedule (Schedule 11) is not recoverable if $T_9$ commits immediately after the read:

<table>
<thead>
<tr>
<th>$T_8$</th>
<th>$T_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td></td>
</tr>
<tr>
<td>write($A$)</td>
<td></td>
</tr>
<tr>
<td>read($B$)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>read($A$)</td>
</tr>
</tbody>
</table>

- If $T_8$ should abort, $T_9$ would have read (and possibly shown to the user) an inconsistent database state. Hence, database must ensure that schedules are recoverable.
Cascading Rollbacks

- **Cascading rollback** – a single transaction failure leads to a series of transaction rollbacks. Consider the following schedule where none of the transactions has yet committed (so the schedule is recoverable)

<table>
<thead>
<tr>
<th></th>
<th>$T_{10}$</th>
<th>$T_{11}$</th>
<th>$T_{12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>read($A$)</td>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td></td>
<td>read($B$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>write($A$)</td>
<td>write($A$)</td>
<td></td>
</tr>
</tbody>
</table>

If $T_{10}$ fails, $T_{11}$ and $T_{12}$ must also be rolled back.

- Can lead to the undoing of a significant amount of work
Cascadeless Schedules

- **Cascadeless schedules** — cascading rollbacks cannot occur; for each pair of transactions \( T_i \) and \( T_j \) such that \( T_j \) reads a data item previously written by \( T_i \), the commit operation of \( T_i \) appears before the read operation of \( T_j \).

- Every cascadeless schedule is also recoverable

- It is desirable to restrict the schedules to those that are cascadeless
Concurrency Control

- A database must provide a mechanism that will ensure that all possible schedules are
  - either conflict or view serializable, and
  - are recoverable and preferably cascadeless

- A policy in which only one transaction can execute at a time generates serial schedules, but provides a poor degree of concurrency
  - Are serial schedules recoverable/cascadeless?

- Testing a schedule for serializability \textit{after} it has executed is a little too late!

- \textbf{Goal} – to develop concurrency control protocols that will assure serializability.
Concurrency Control vs. Serializability Tests

- Concurrency-control protocols allow concurrent schedules, but ensure that the schedules are conflict/view serializable, and are recoverable and cascadeless.

- Concurrency control protocols generally do not examine the precedence graph as it is being created.
  - Instead a protocol imposes a discipline that avoids nonserializable schedules.
  - We study such protocols in Chapter 16.

- Different concurrency control protocols provide different tradeoffs between the amount of concurrency they allow and the amount of overhead that they incur.

- Tests for serializability help us understand why a concurrency control protocol is correct.
Some applications are willing to live with weak levels of consistency, allowing schedules that are not serializable

- E.g. a read-only transaction that wants to get an approximate total balance of all accounts
- E.g. database statistics computed for query optimization can be approximate (why?)
- Such transactions need not be serializable with respect to other transactions

Tradeoff accuracy for performance
Levels of Consistency in SQL-92

- **Serializable** — default
- **Repeatable read** — only committed records to be read, repeated reads of same record must return same value. However, a transaction may not be serializable – it may find some records inserted by a transaction but not find others.
- **Read committed** — only committed records can be read, but successive reads of record may return different (but committed) values.
- **Read uncommitted** — even uncommitted records may be read.

- Lower degrees of consistency useful for gathering approximate information about the database
- **Warning:** some database systems do not ensure serializable schedules by default
  - E.g. Oracle and PostgreSQL by default support a level of consistency called snapshot isolation (not part of the SQL standard)
Transaction Definition in SQL

- Data manipulation language must include a construct for specifying the set of actions that comprise a transaction.
- In SQL, a transaction begins implicitly.
- A transaction in SQL ends by:
  - **Commit work** commits current transaction and begins a new one.
  - **Rollback work** causes current transaction to abort.
- In almost all database systems, by default, every SQL statement also commits implicitly if it executes successfully
  - Implicit commit can be turned off by a database directive
    - E.g. in JDBC, `connection.setAutoCommit(false);`
End of Chapter
<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>write($A$)</td>
<td>write($A$)</td>
</tr>
<tr>
<td>read($B$)</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($B$)</td>
<td>write($B$)</td>
</tr>
<tr>
<td></td>
<td>$T_1$</td>
</tr>
<tr>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>read</td>
<td>$A$</td>
</tr>
<tr>
<td>write</td>
<td>$A$</td>
</tr>
<tr>
<td></td>
<td>$B$</td>
</tr>
<tr>
<td>write</td>
<td>$B$</td>
</tr>
<tr>
<td>$T_3$</td>
<td>$T_4$</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
</tr>
<tr>
<td>read($Q$)</td>
<td>write($Q$)</td>
</tr>
<tr>
<td>write($Q$)</td>
<td></td>
</tr>
</tbody>
</table>
Precedence Graph for
(a) Schedule 1 and (b) Schedule 2

(a)

(b)
Precedence Graph
<table>
<thead>
<tr>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($Q$)</td>
<td>write($Q$)</td>
<td>read($Q$)</td>
</tr>
<tr>
<td>write($Q$)</td>
<td></td>
<td>write($Q$)</td>
</tr>
</tbody>
</table>
Implementation of Isolation

- Schedules must be conflict or view serializable, and recoverable, for the sake of database consistency, and preferably cascadeless.
- A policy in which only one transaction can execute at a time generates serial schedules, but provides a poor degree of concurrency.
- Concurrency-control schemes tradeoff between the amount of concurrency they allow and the amount of overhead that they incur.
- Some schemes allow only conflict-serializable schedules to be generated, while others allow view-serializable schedules that are not conflict-serializable.
<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>read($A$)</td>
<td>read($A$)</td>
</tr>
<tr>
<td>$A := A - 50$</td>
<td>$temp := A * 0.1$</td>
</tr>
<tr>
<td>write($A$)</td>
<td>$A := A - temp$</td>
</tr>
<tr>
<td>read($B$)</td>
<td>write($A$)</td>
</tr>
<tr>
<td>$B := B + 50$</td>
<td>read($B$)</td>
</tr>
<tr>
<td>write($B$)</td>
<td>$B := B + temp$</td>
</tr>
<tr>
<td></td>
<td>write($B$)</td>
</tr>
</tbody>
</table>