# Database Concurrency Control

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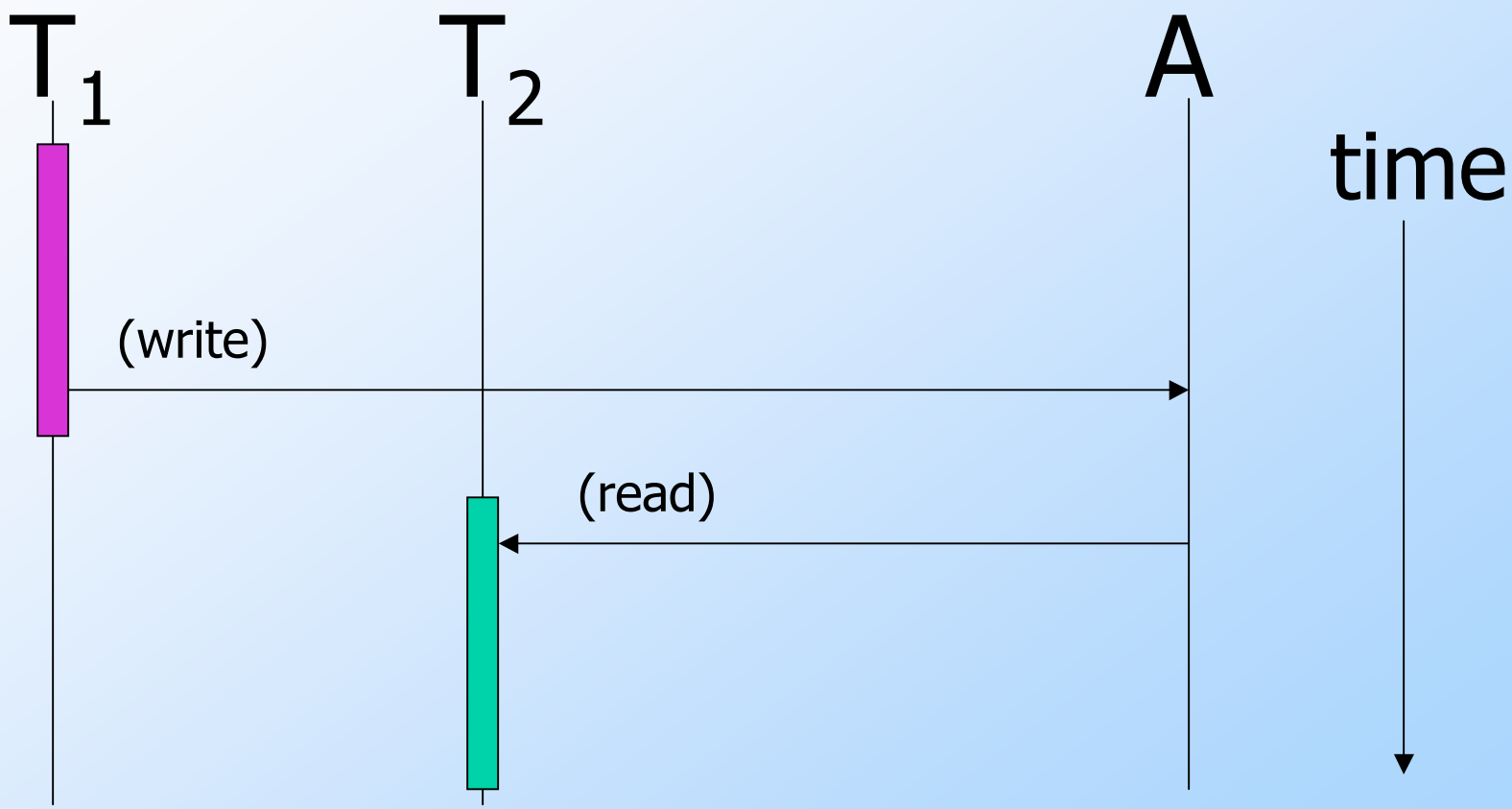
# Modeling with Sequence Diagrams

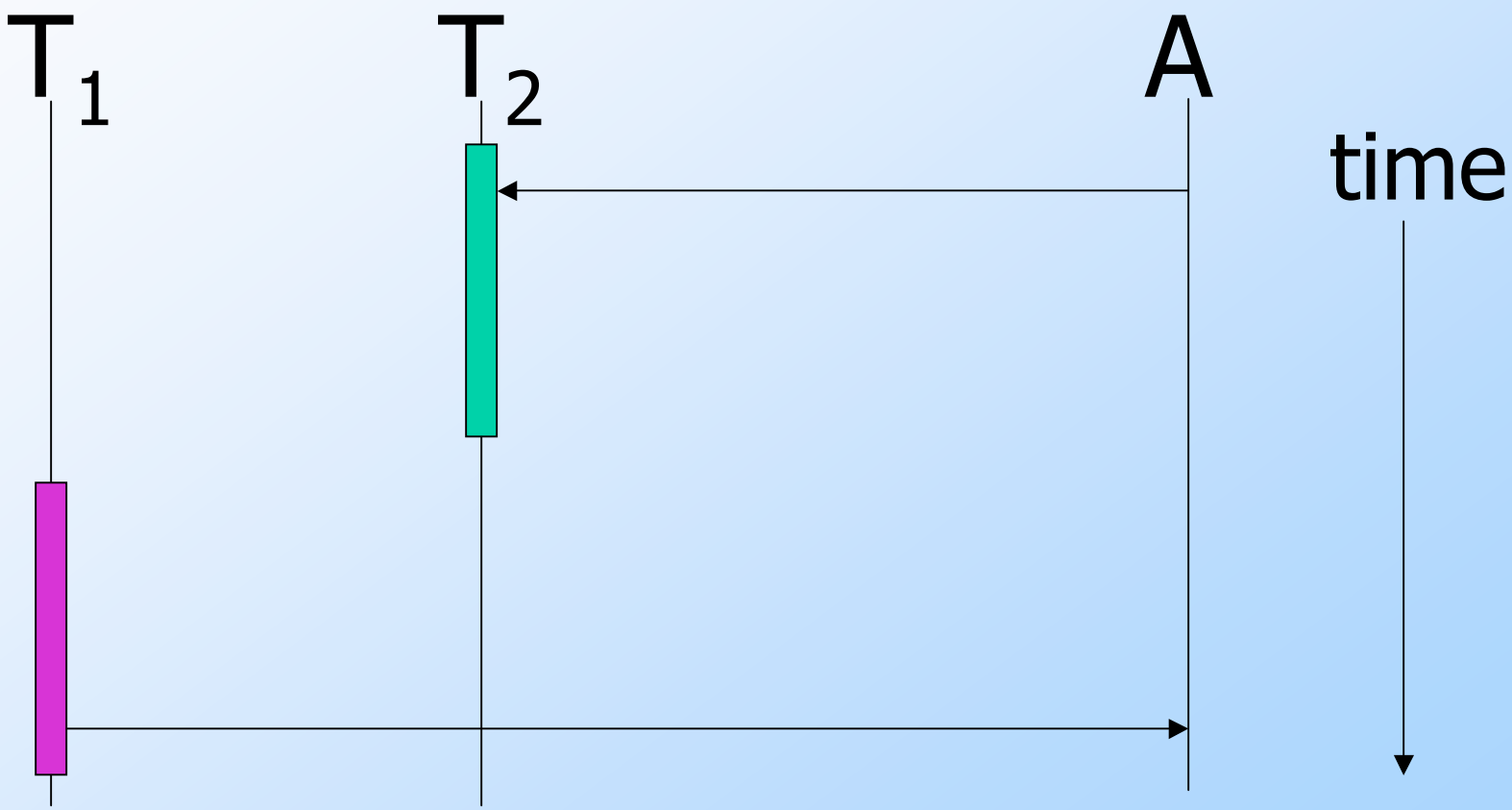
- Sequence diagrams are from UML
- Each line in a diagram corresponds to some object, in our case
  - Database items (relations, tuples, …)
  - Transaction
- We use message direction to show what is being read vs. written, **not** the originator of the message. (All messages originate from transactions.)

# Example 1




$T_1$ writes A, (then) $T_2$ reads A

# Example 2

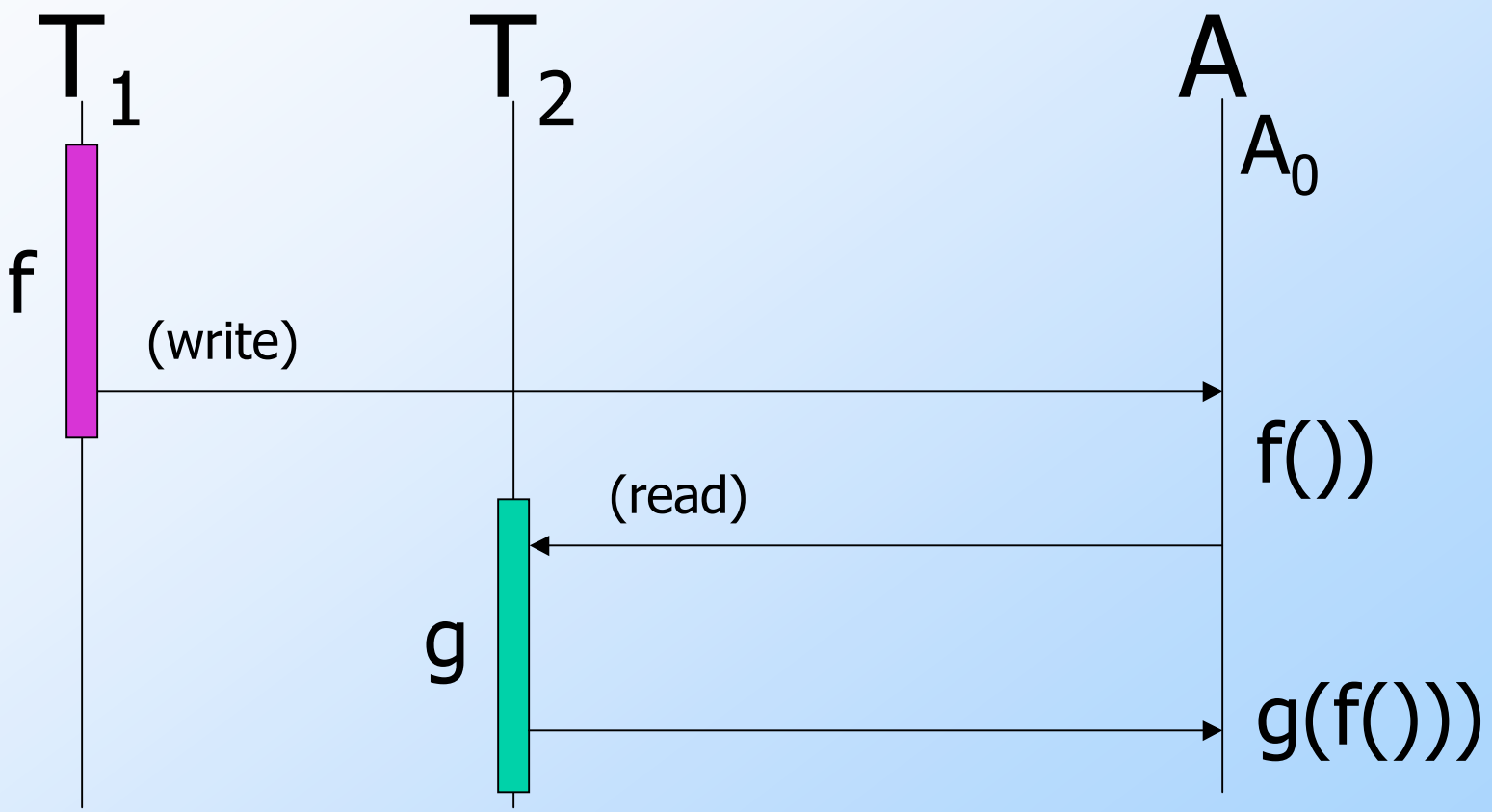



$T_2$ reads A, $T_1$ writes A

# Assumption

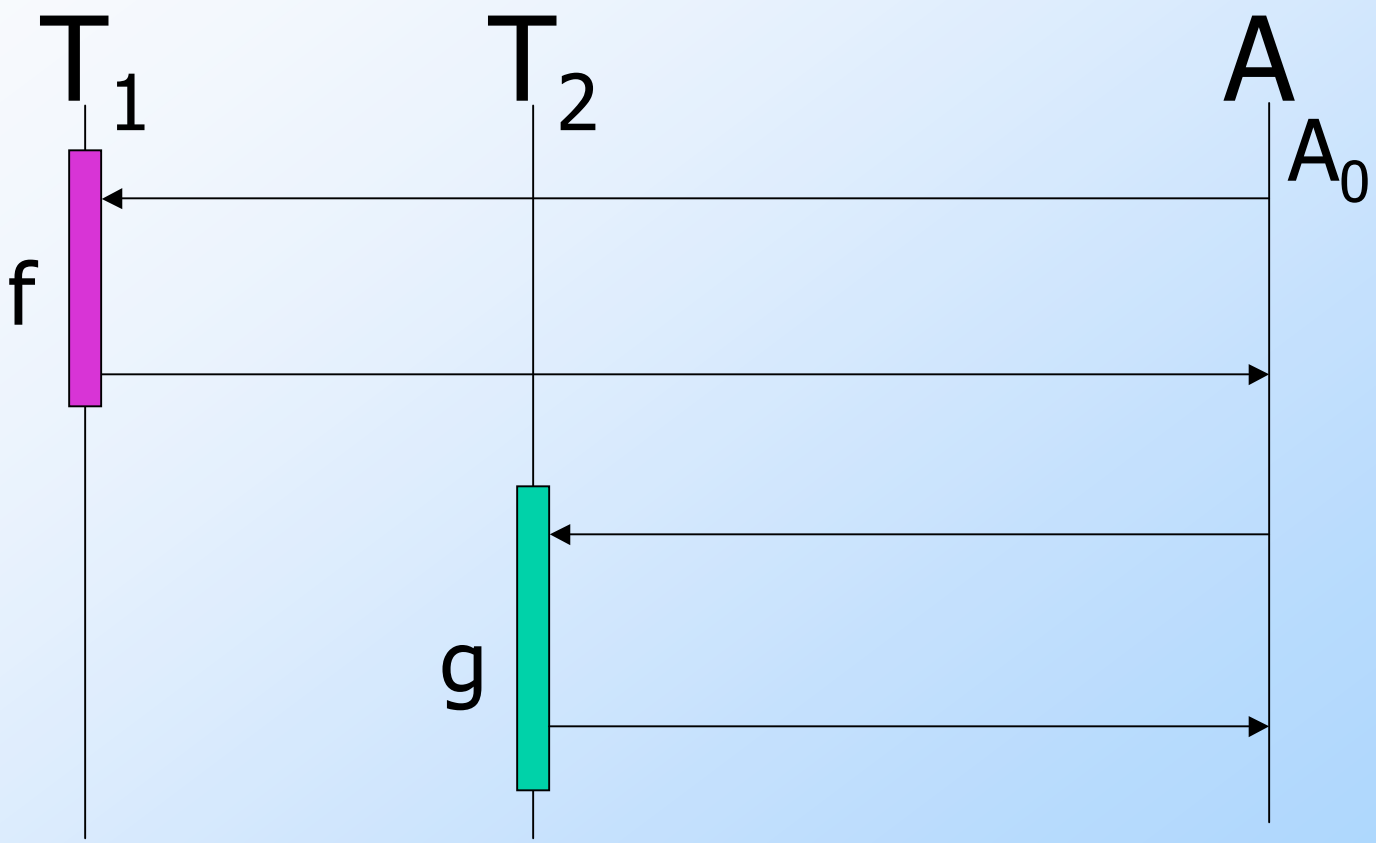
- When a transaction writes, the value it writes is an unknown (but fixed) **function** of the values it has read (and only those).
- In Example 1, $T_1$ writes f() to A, then $T_2$ reads f() as the value of A.
- In Example 2, $T_2$ reads $A_0$ (the initial value) as the value of A, then $T_1$ writes f() to A.

# Example 3




Final value of A is g(f())

# Example 4

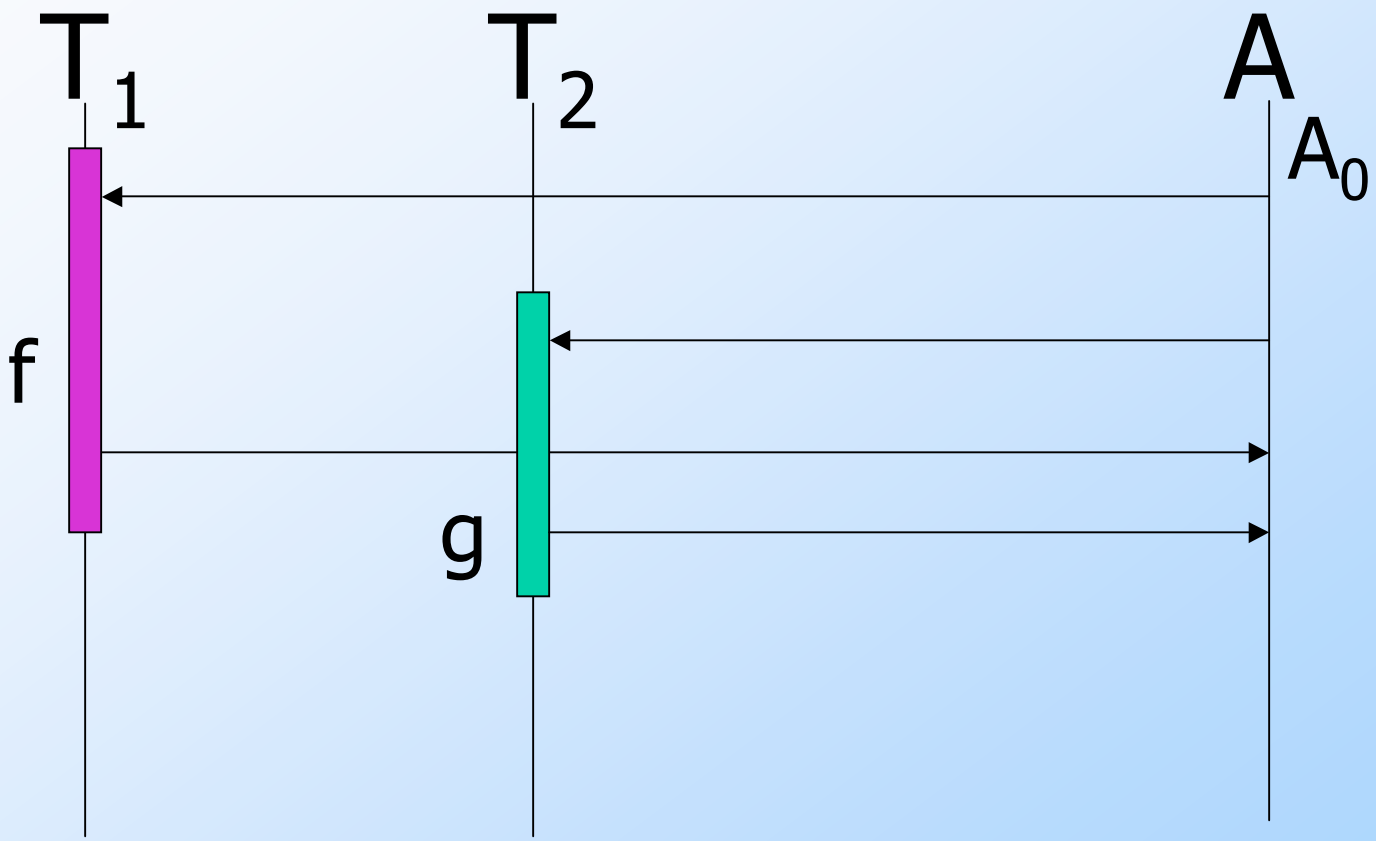



Final value of A is _____

# Possible Phenomena

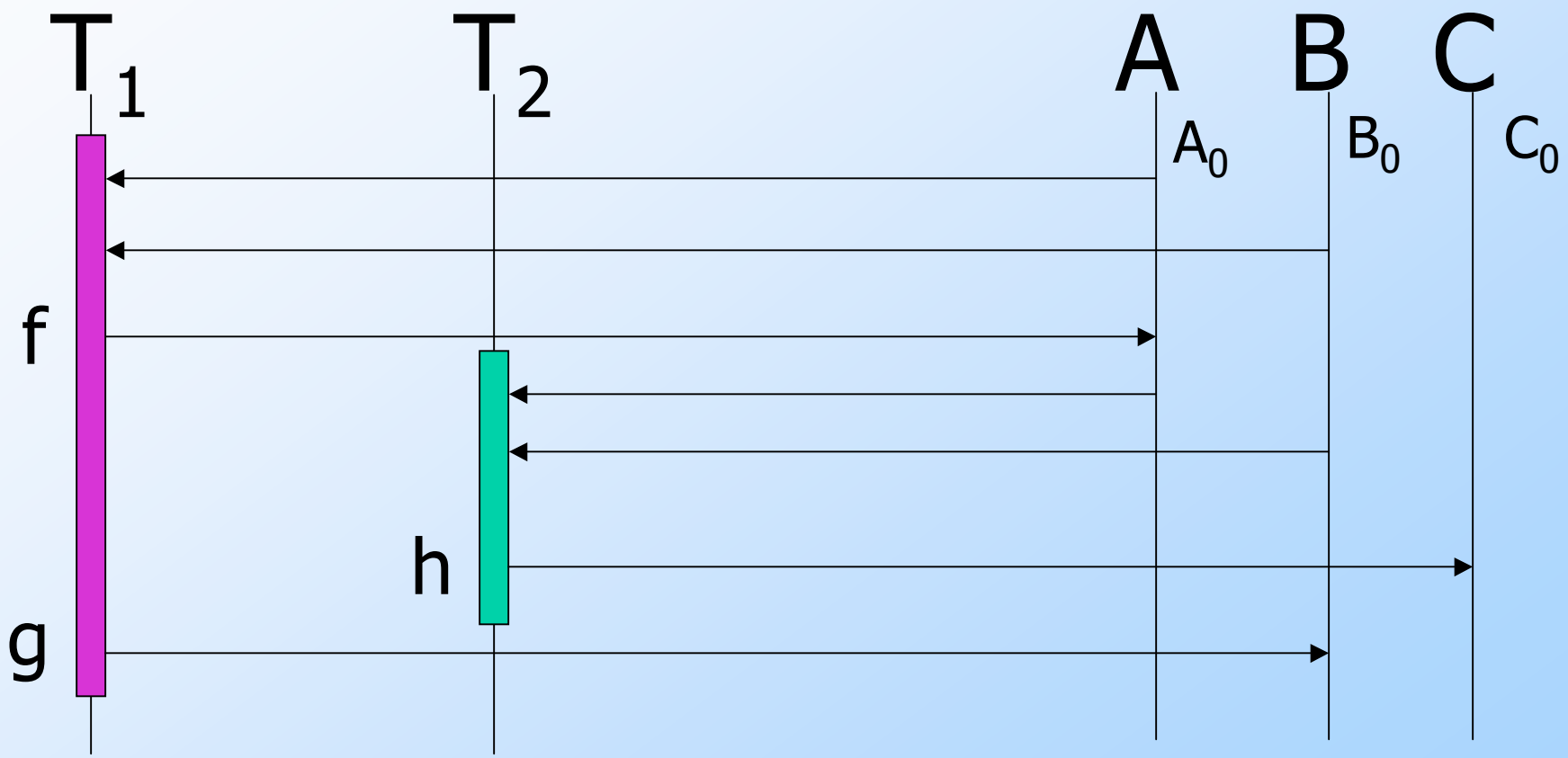
- Lost Update
- Inconsistent Retrieval

# Lost Update Example
(compare Example 3)




Final value of A is _____

# Inconsistent Retrieval Example




Final value of C is _____

# Correctness

- A set of transactions is assumed to operate **correctly** if the net effect is the same as ***some*** **serial** execution.

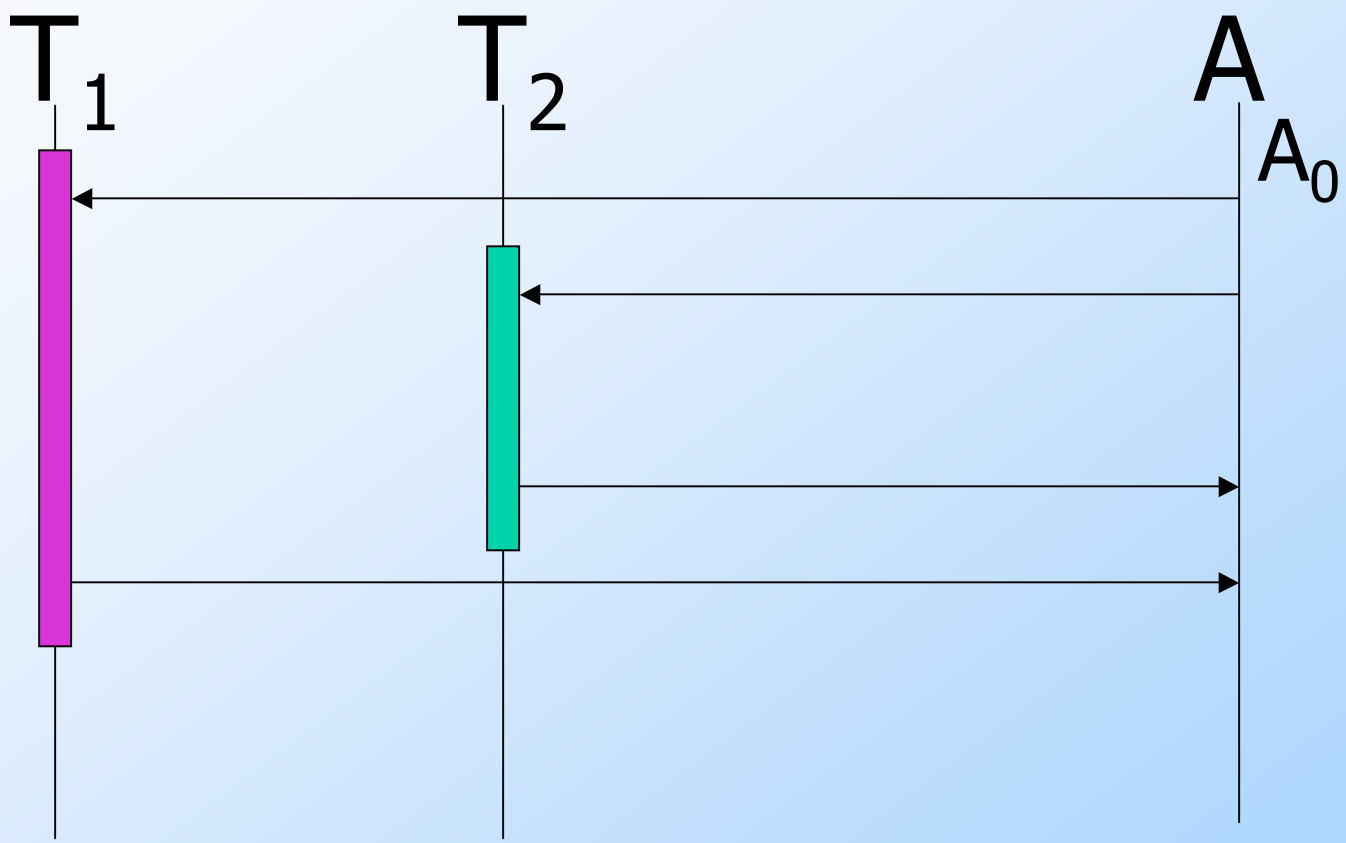
# Interleavings

- An interleaving consists of the steps of all transactions in some order.
- All steps of each transaction must be included.
- Within each transaction, the steps are in the same order as in the serial case.

# Serializable Interleaving

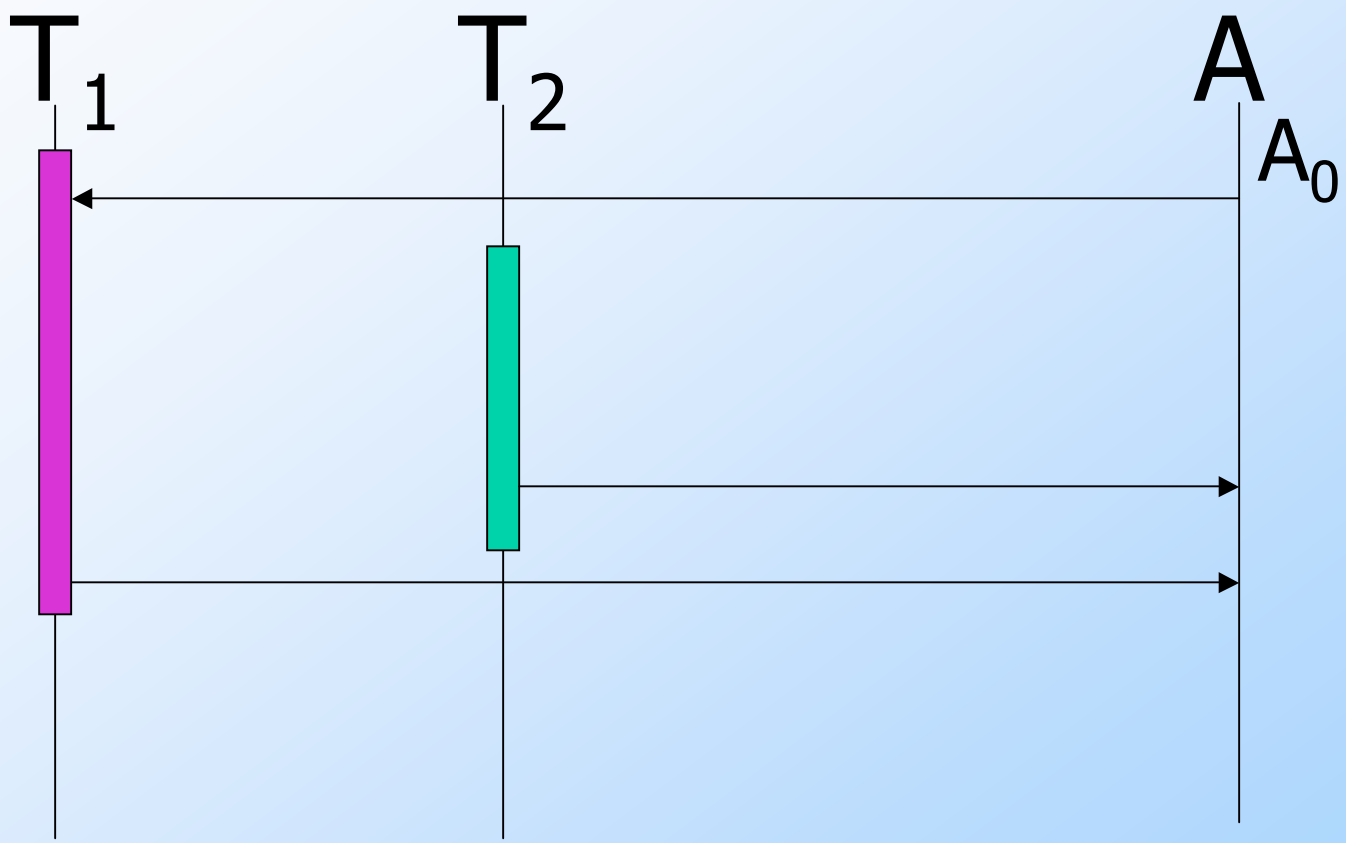
- An interleaving is serializable if the net effect is the same as some serialization of the transactions.

# Is this interleaving serializable?



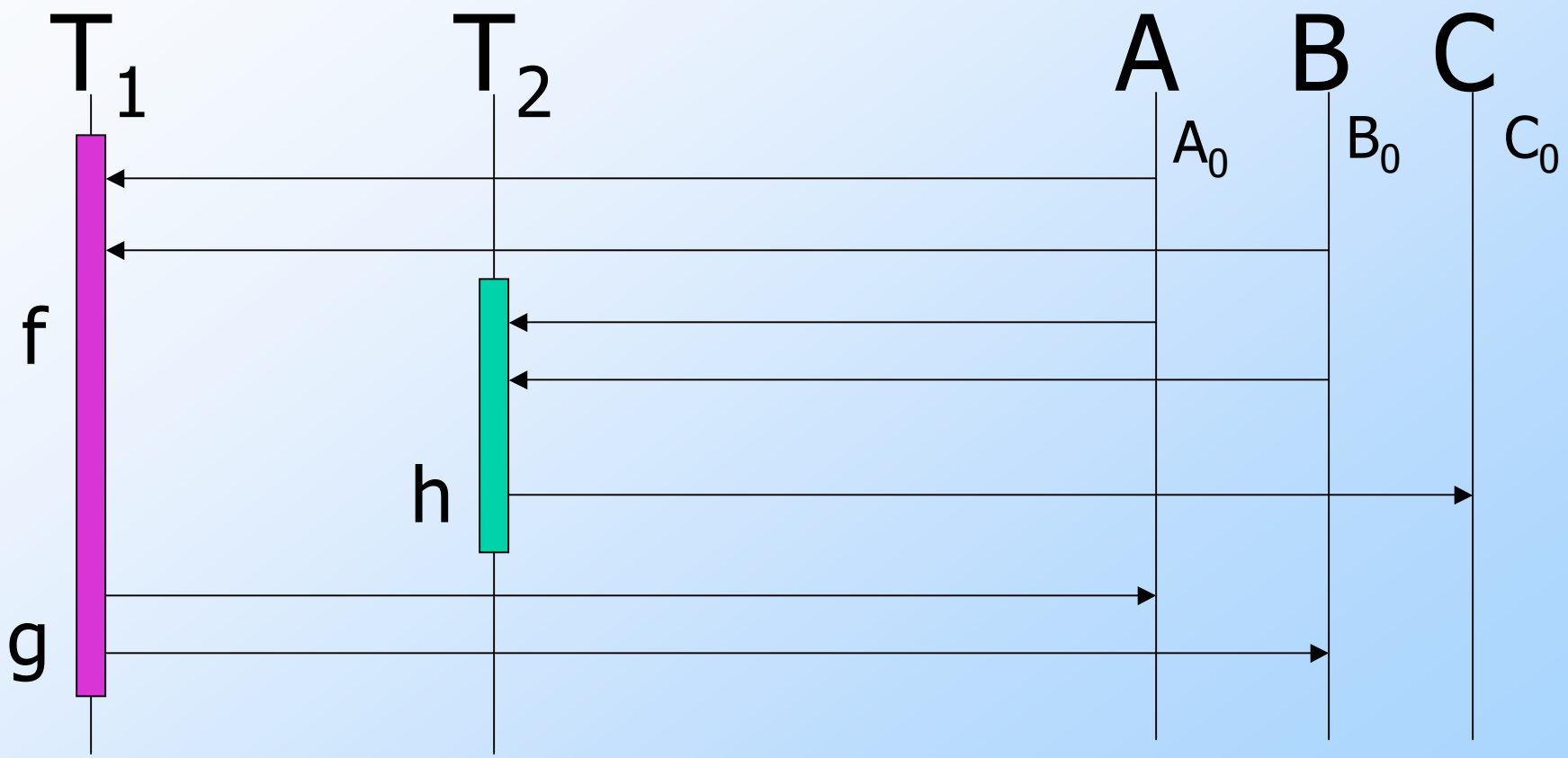

# Equivalent to

# How about this one?




Equivalent to

# And This?

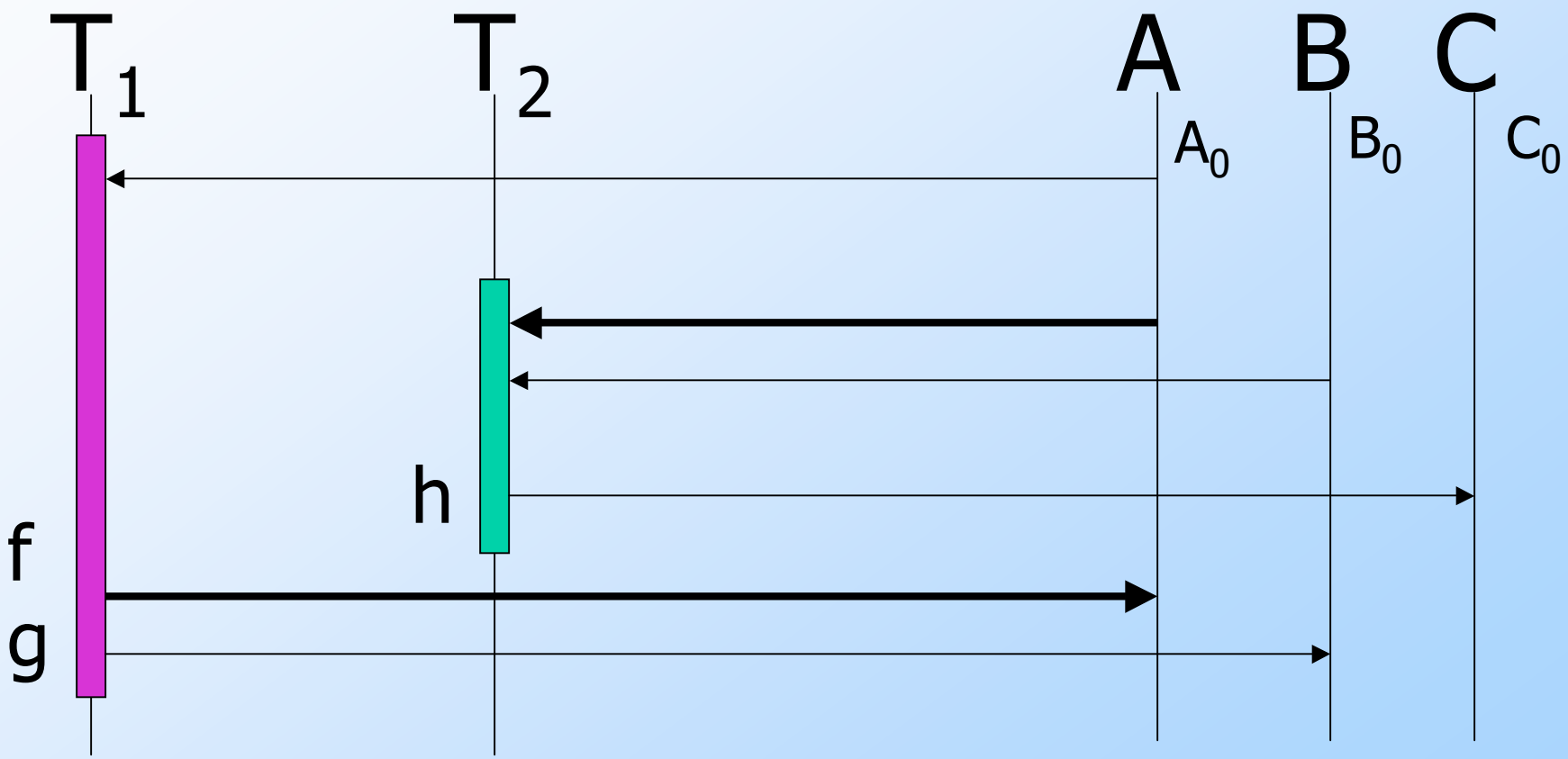



Equivalent to

# Conflicts

- Two operations of different transactions conflict if either:
  - One reads from a data item to which the other reads (R-W conflict)
  - One writes to a data item to which the other writes (W-W conflict)
- If two overlapping transactions have conflicting operations, then there is an order-dependence among the operations.
- We want to preserve such an order in any serialized interleaving.

# Conflict Example




Must preserve the order $T_2T_1$

# Conflict Analysis

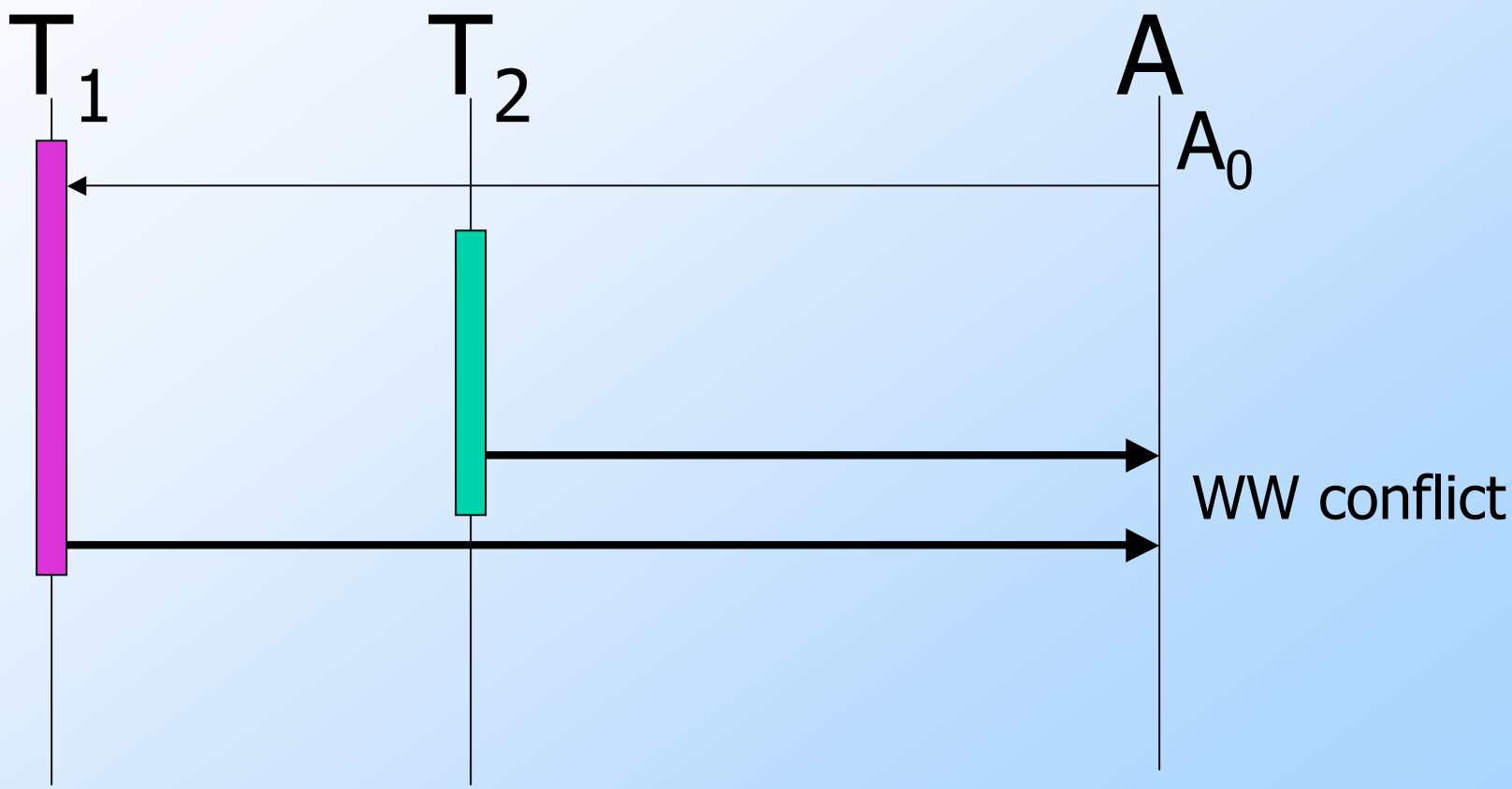
- When two operations in different transactions conflict, the order of those two operations must be **preserved** in any **equivalent** interleaving.

- We may have "conflicting" requirements of this form.

# Visualizing Conflicts

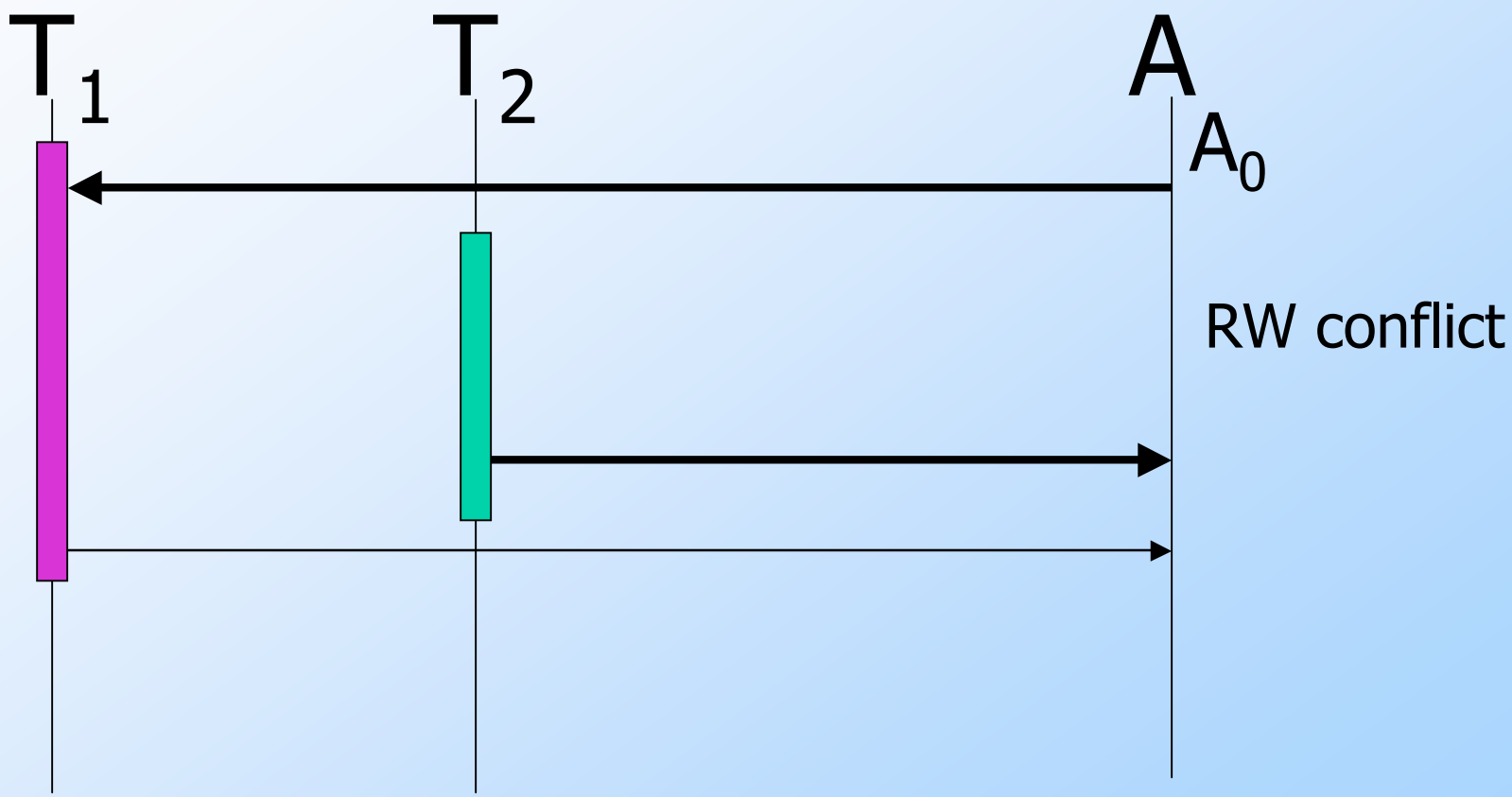
- Scan the read/write sequences for each data item.
- If a write operation to the item is present with other reads or writes in different transactions, then there is a conflict between those transactions.

# Conflict Orders



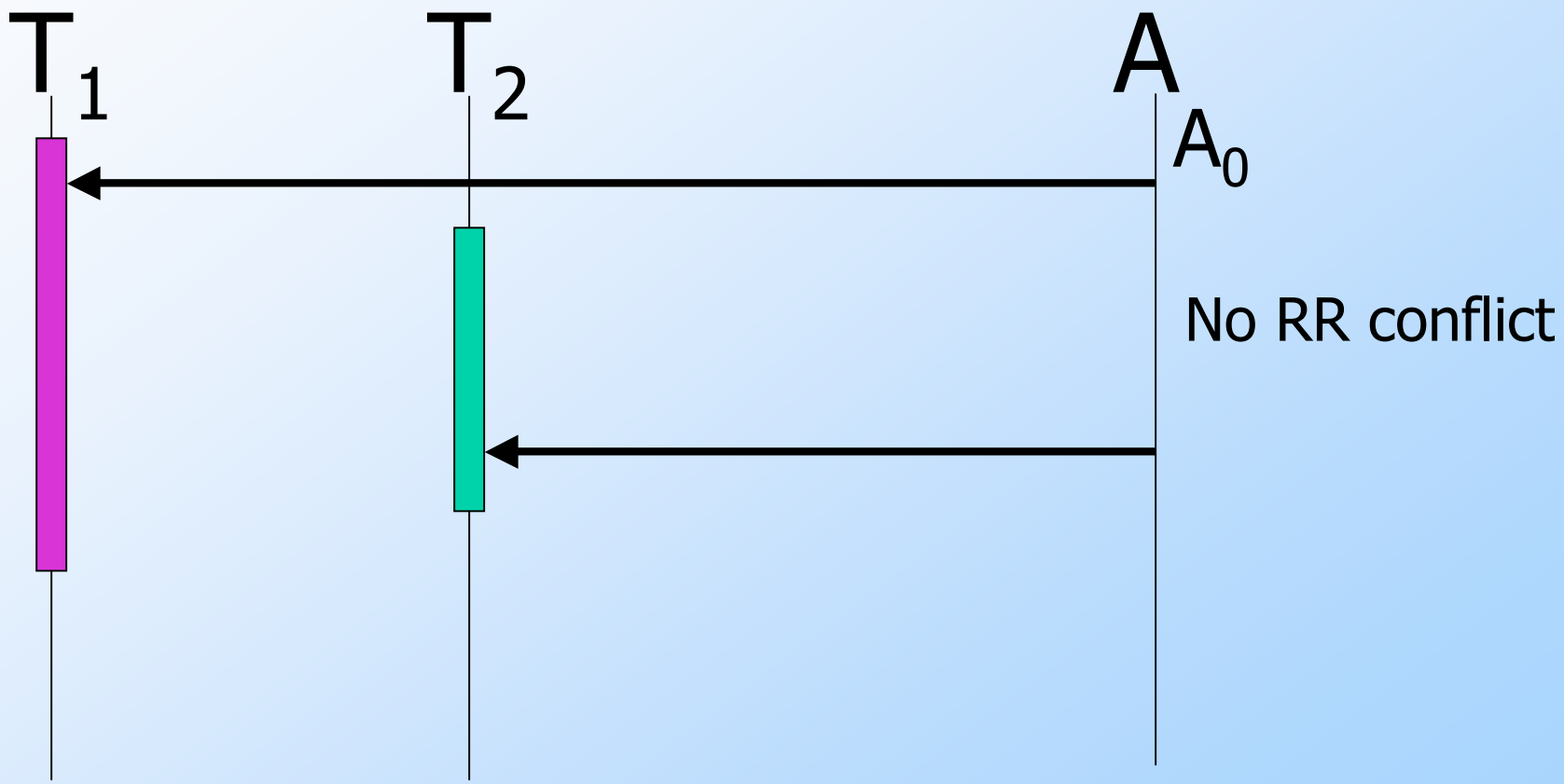

Requires $T_2T_1$.

# Conflicting Conflict Orders




Requires $T_1T_2$; we can't have this and $T_2T_1$.

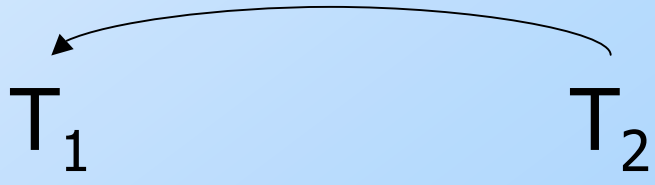
# Non-Conflict Orders



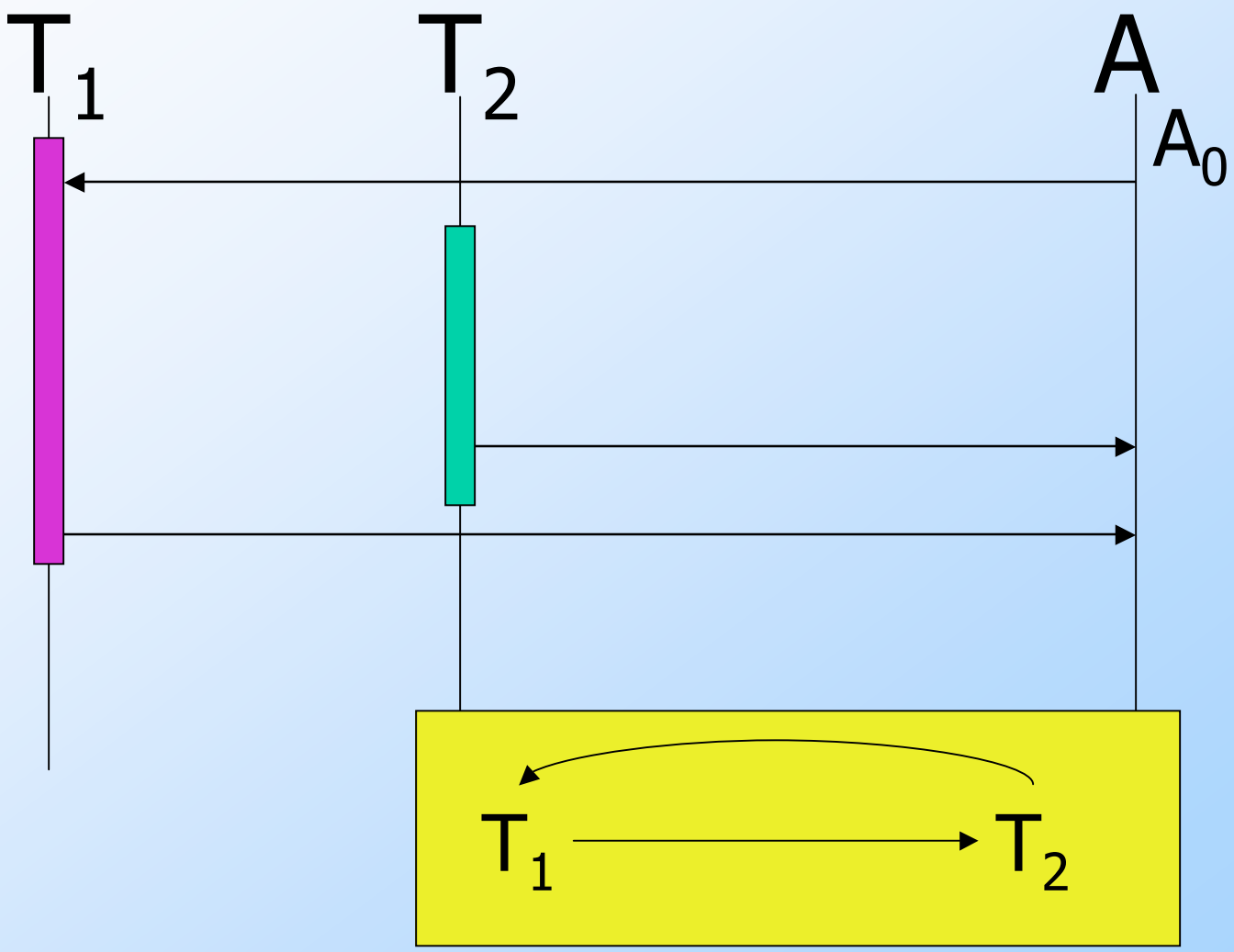

Requires nothing.

# Conflict Graph for an Interleaving

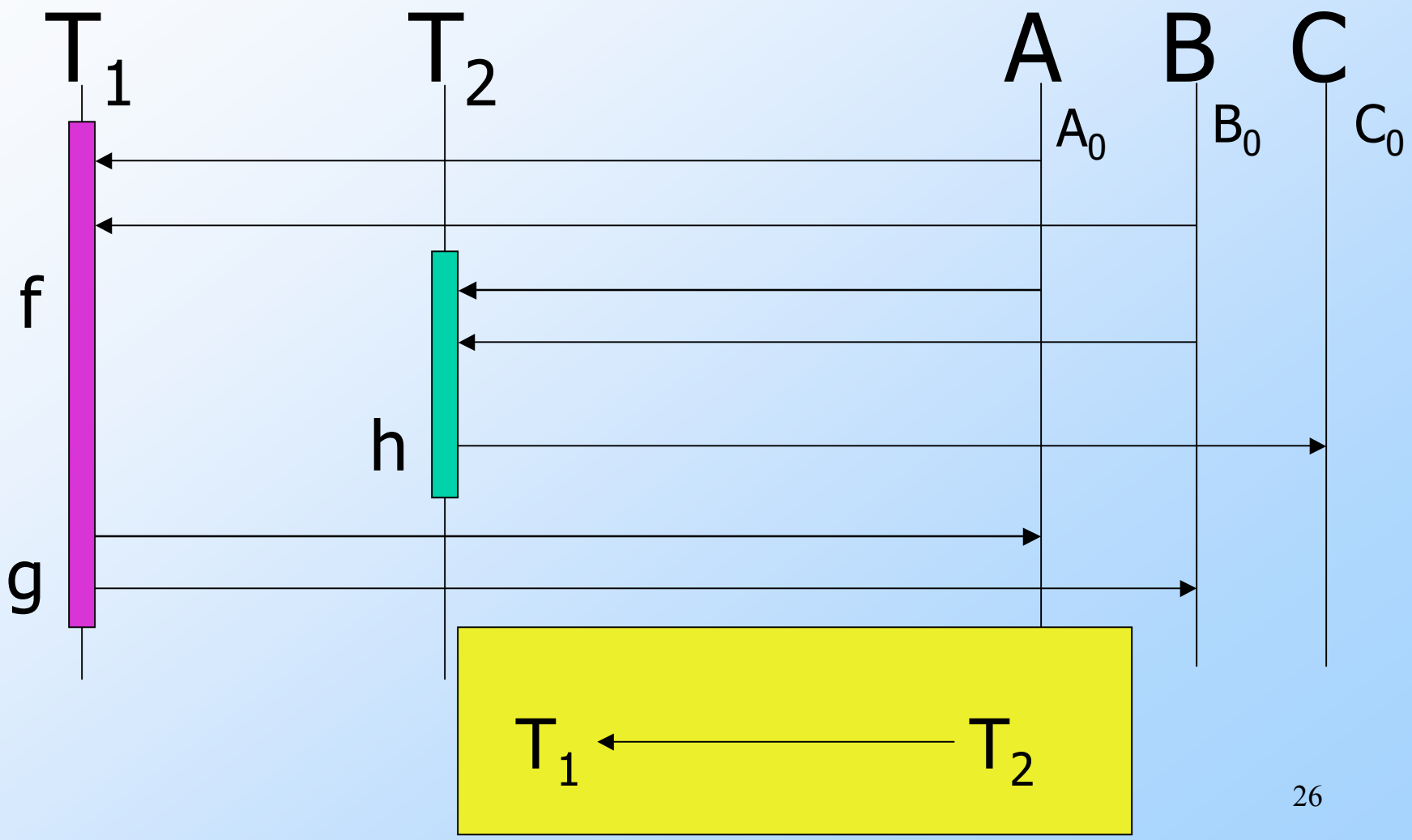
- The conflict requirements can be expressed as a graph:
  - Transactions are nodes
  - There is an arrow if the transactions have conflicting operations, indicating the necessary serial order for equivalence with the interleaving.



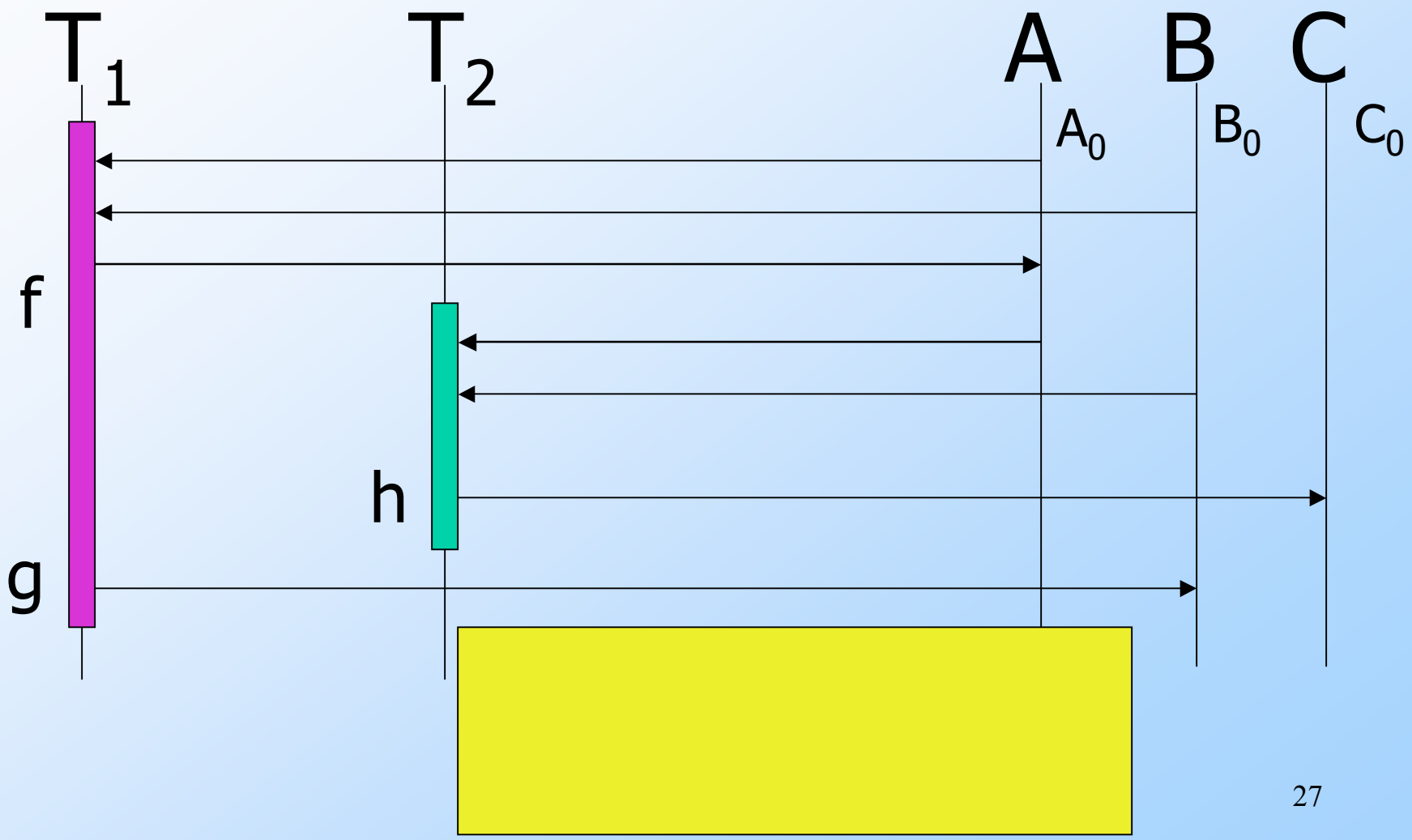
# Conflict Graph Example



# Conflict Graph Example



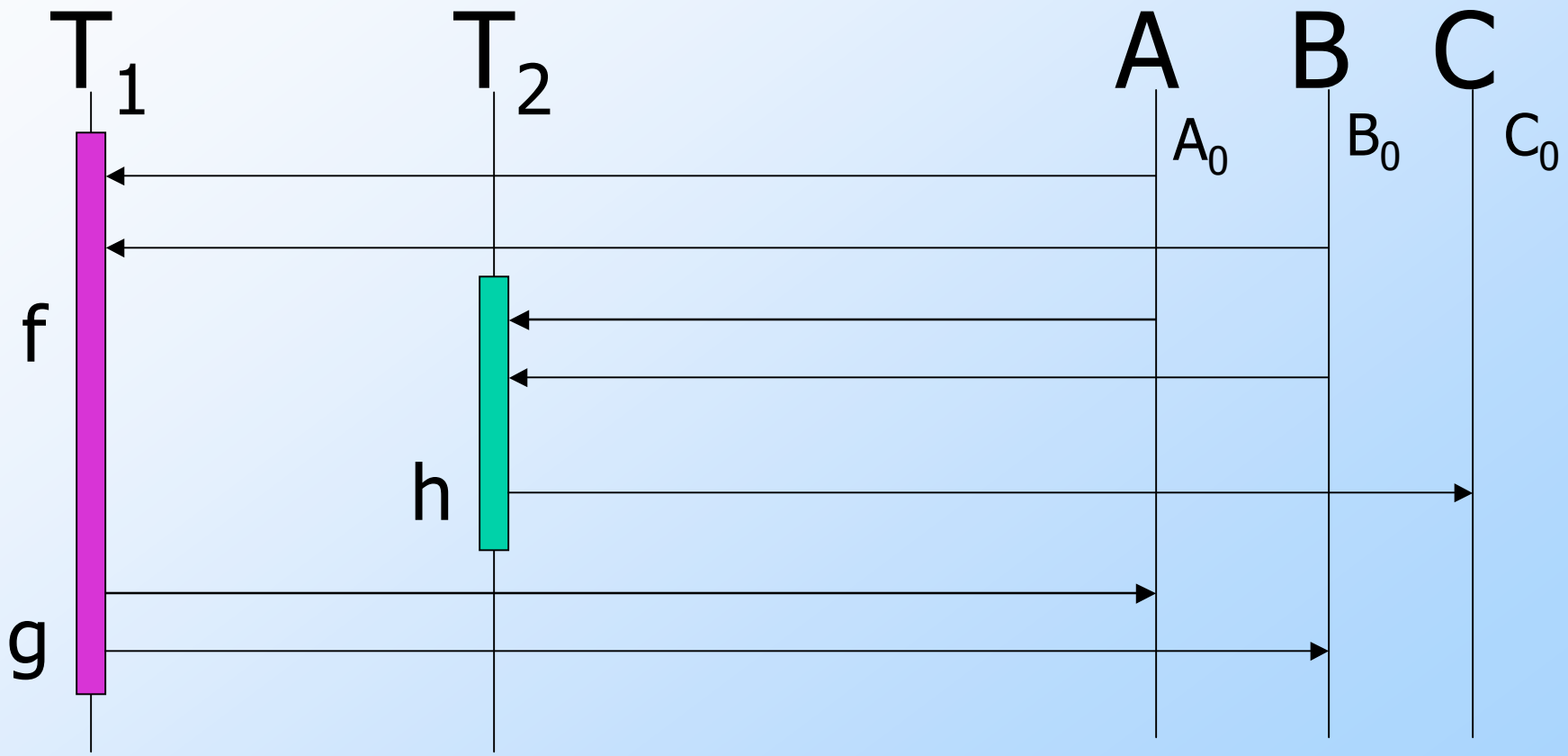
# Conflict Graph Example



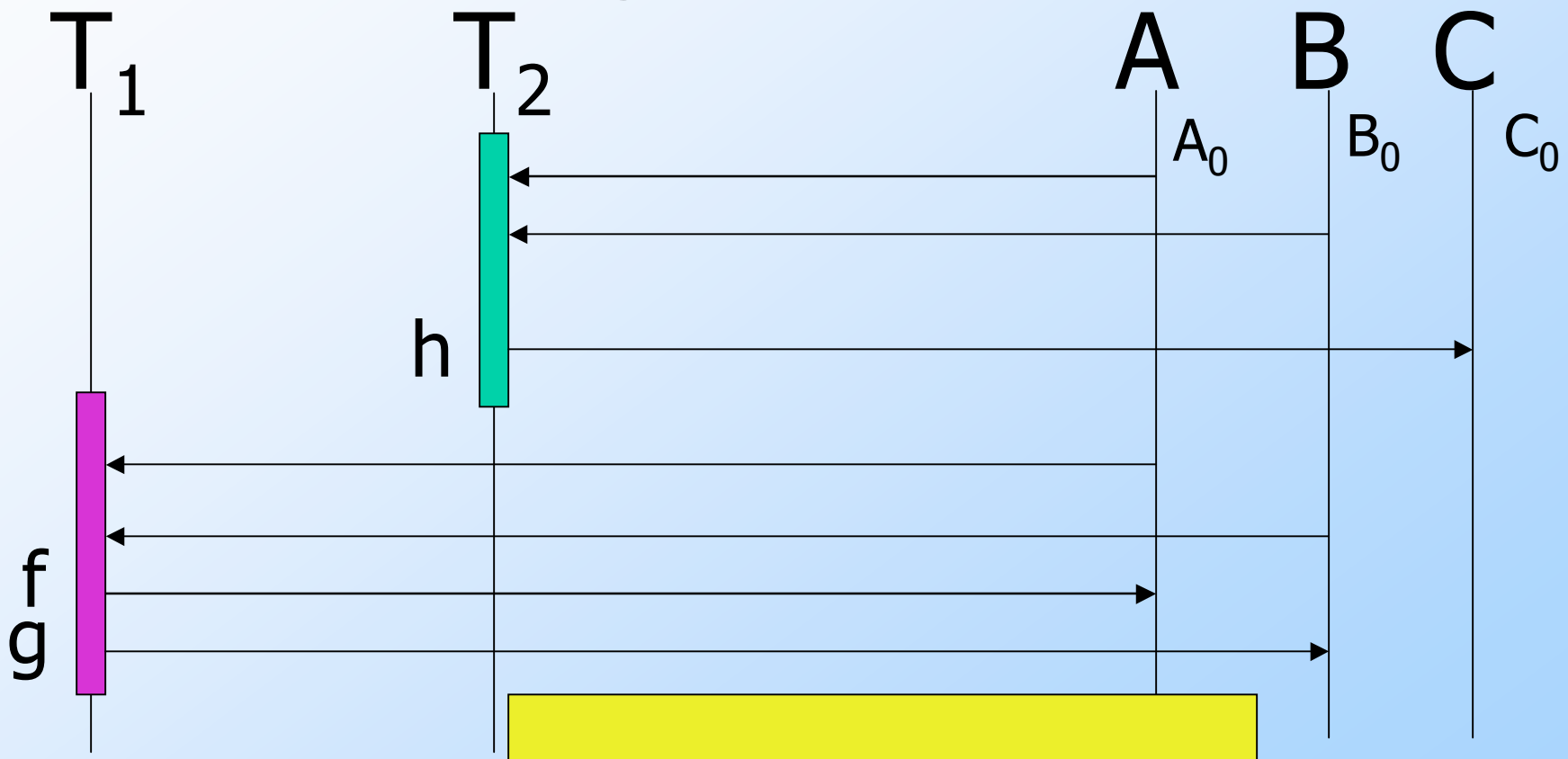
# Result 1

- If there is a serializable interleaving, then the conflict graph is acyclic.
- Proof:
  - Assume that there is a serializable interleaving J.
  - Let K be a *serial* interleaving equivalent to J.
  - If operations in two different transactions conflict in K, then the implied arrows in the conflict graph must all be the same direction, since **one transaction occurs before the other** in K.
  - Therefore, if there is an arrow from $T_i$ to $T_j$ in the conflict graph, it must be the case that $T_i$ **precedes** $T_j$ in K.
  - But K is a *linear* order, so there can be no cycle.

# Example of Result 1: Interleaving J (non-serial):



# Example of Result 1:
# Interleaving K (equiv. serial):

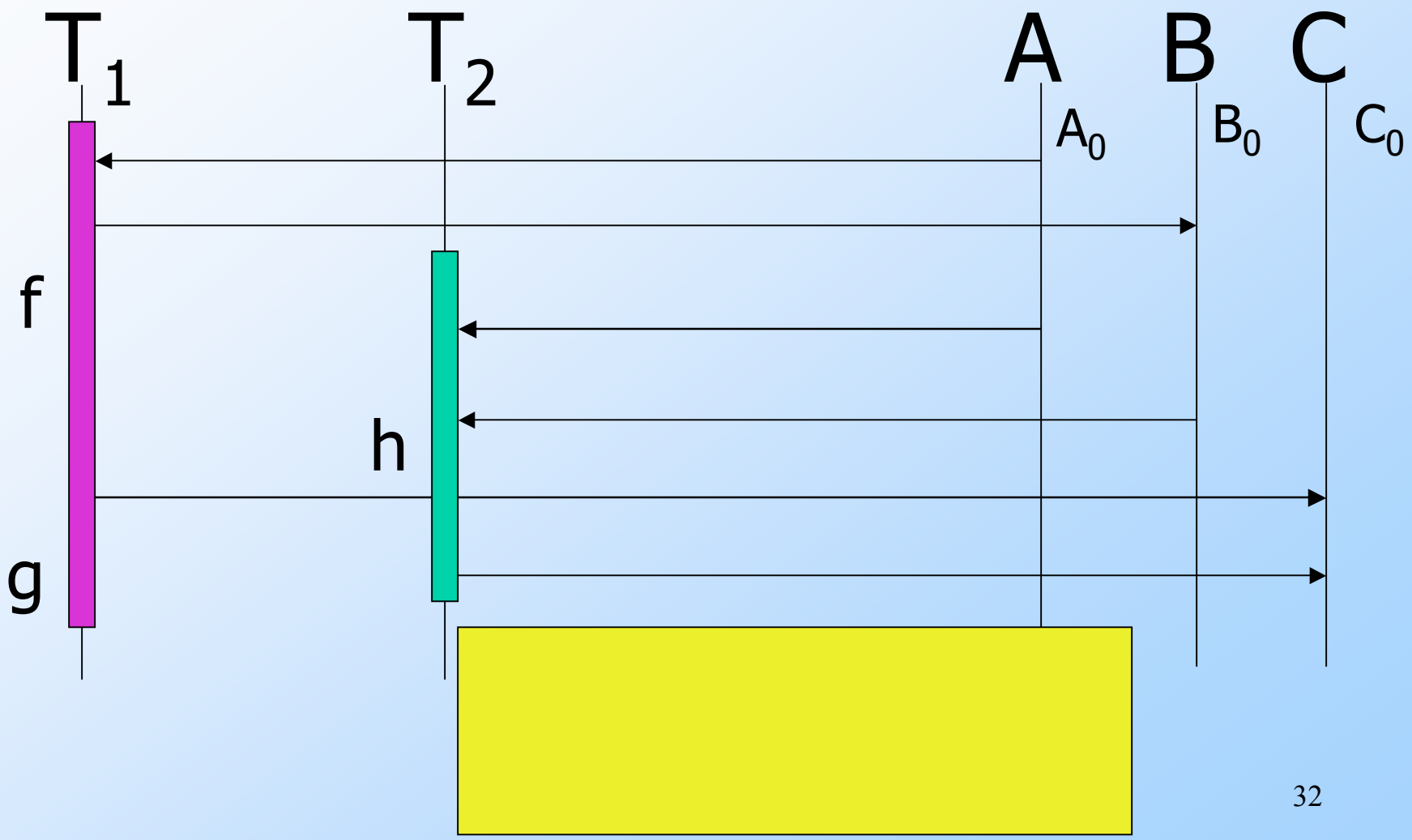



Acylic graph

# Result 2

- If the conflict graph is acyclic, then the interleaving is serializable.
- Proof:

# Example of Result 2:



# Summary of Results 1&2

- An interleaving is serializable iff the conflict graph is acyclic.

# Serializability Requirement

- The execution of a set of transactions must be serializable.

# Alternatives for Ensuring Serializability

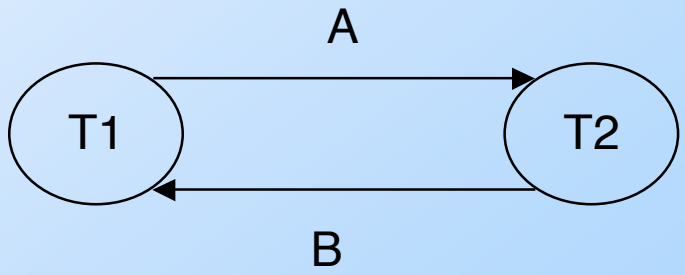
- Allow only one transaction at a time.
- Some more liberal policy that guarantees serializability.
- Analyze transactions statically; only allow compatible transactions to run concurrently.
- Construct conflict graph dynamically; abort (rollback) a transaction if it can create a cycle.
- Use locking.
- Use time stamps.

# Locking

- Simple model:
  - Only one kind of lock
  - Lock data item before any read or write
  - Unlock data item after reads and writes
- By itself, doesn't guarantee serializability:
  - Example?
- Can produce deadlocks if no further protocol imposed.

# Locking Implies Reading or Writing

| **T1** | **T2** |
|---|---|
| LOCK A | |
| UNLOCK A | |
| | LOCK A |
| | UNLOCK A |
| | LOCK B |
| | UNLOCK B |
| LOCK B | |
| UNLOCK B | |



# 2-Phase Locking Policy (2PL)

Every transaction is divided into two phases that occur in sequence:

**Phase I**: All requesting of locks (no releasing)

**Phase II**: All releasing of locks (no further requesting)

[Similar-sounding, but distinct idea: **2-Phase Commit** used in distributed databases.]

# 2PL Theorem

- Under 2-phase locking, every interleaving is serializable.
- Proof:
  - Define the **lock point** of a transaction within an interleaving to be the point at which it acquires the last of the locks it requests.
  - Order the transactions by lock point, earliest to latest.
  - **Claim**: The serial interleaving in which transactions are done in lock point order is equivalent to the original interleaving.

# Proof of Claim

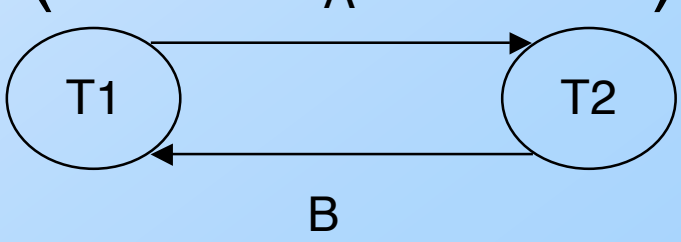
- Claim: The serial interleaving in which transactions are done in lock point order is equivalent to the original interleaving.

- Proof: If $T_i$ is before $T_j$ in the lock point ordering,then $T_j$ cannot read or write an item A until after $T_i$ has released the lock on A.
- Therefore, in the conflict graph there can be no arrow from $T_j$ to $T_i$.
- Hence the conflict graph is a partial order consistent with the linear lock point order. In particular, the conflict graph is acyclic.

# Non-2PL Example

| **T1** | **T2** |
|---|---|
| LOCK A | |
| UNLOCK A | |
| | LOCK A |
| | UNLOCK A |
| | LOCK B |
| | UNLOCK B |
| LOCK B | |
| UNLOCK B | |

conflict graph
(non-serializable)



# 2PL Example

## (lock points underlined)

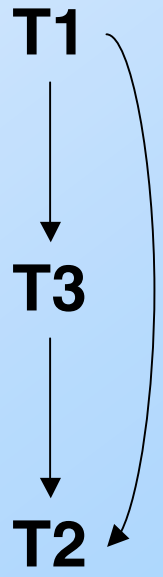
| **T1** | **T2** | **T3** |
|---|---|---|
| Lock A | | |
| Lock B | | |
| | Lock A | Lock B |
| <u>Lock C</u> | (waiting) | (waiting) |
| Unlock A,B,C | I | I |
| | I | (B acquired) |
| | Lock C | <u>Lock C</u> |
| | (waiting) | Unlock B, C |
| | <u>(C acquired)</u> | |
| | Unlock A,C | |

# 2PL Example

## (lock points underlined)

| **T1** | **T2** | **T3** |
|---|---|---|
| Lock A | | |
| Lock B | | |
| | Lock A | Lock B |
| | (waiting) | (waiting) |
| Lock C | I | I |
| Unlock A,B,C | I | (B acquired) |
| | Lock C | Lock C |
| | (waiting) | Unlock B, C |
| | (C acquired) | |
| | Unlock A,C | |

conflict graph




consistent with lockpoint linear order

# Same Transactions, Different Lock Point Order

| **T1** | **T2** | **T3** |
|---|---|---|
| Lock A | Lock A | Lock B |
| (waiting) | Lock C | Lock C |
| I | Unlock A, C | (waiting) |
| (A acquired) | | (C acquired) |
| Lock B | | |
| (waiting) | | Unlock B, C |
| (B acquired) | | |
| Lock C | | |
| Unlock A, B, C | | |

conflict graph

# Deadlock Danger

- 2PL itself does not avoid deadlock
  - Example?
- Need to impose additional mechanism to prevent deadlock

# Serialization with Read- and Write-Locks

- So far, we have assumed all locks are the same (= write-locks).
- This is overly-restrictive:
  inhibits concurrent reads.
- When both types of locks are used, the cycle criterion for serializability can be applied.
- The *conflict graph construction is modified*, however.
- 2PL still works!

# Modified Conflict Graph Construction (for read/write locks)

- If Ti read- or write-locks A, and Tj is the **next** transaction in the interleaving to write-lock A, then there is an arc from Ti to Tj.

- If Ti write-locks A, and Tk read-locks A after Ti unlocks A, but before any other transaction write-locks A, then there is an arc from Ti to Tk.

# Example: Is this serializable?

| T1 | T2 | T3 | T4 |
|---|---|---|---|
| | | Wlock A | |
| | | | Rlock B |
| | | Unlock A | |
| Rlock A | | | |
| | | | Unlock B |
| | | Wlock B | |
| | Rlock A | | |
| | | Unlock B | |
| Wlock B | | | |
| | Unlock A | | |
| Unlock A | | | |
| | | | Wlock A |
| Unlock B | | | |
| | Rlock B | | |
| | | | Unlock A |
| | Unlock B | | |