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.)

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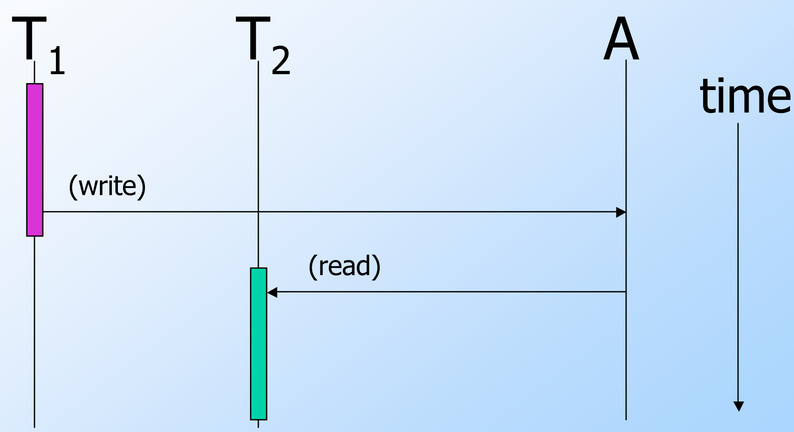
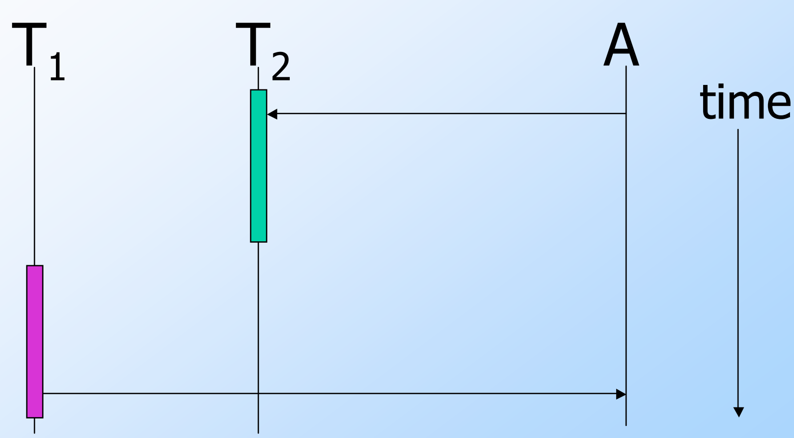
Example 1



T_1 writes A, (then) T_2 reads A

Example 2

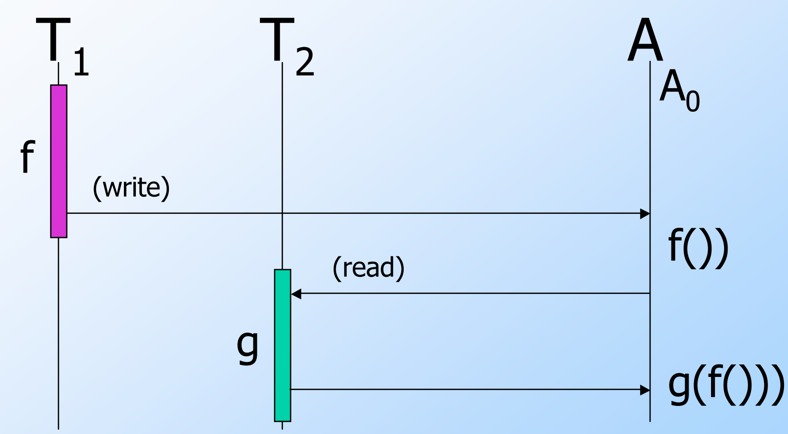


T_2 reads A, T_1 writes A

Assumption

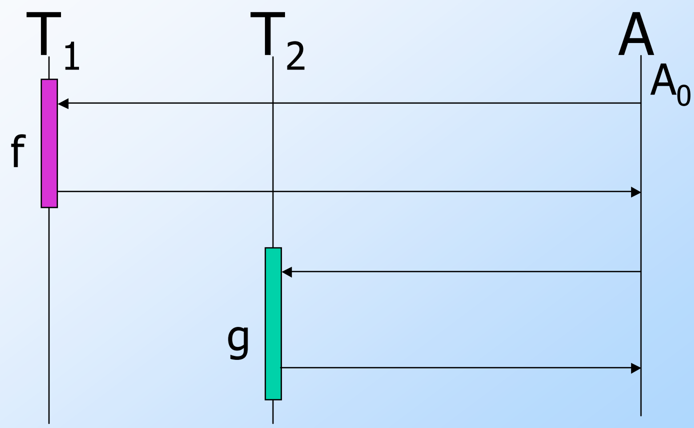
- When a transaction writes, the value it writes is an unknown (but fixed) **function** of the values it has read (and only those).
- In Example 1, T_1 writes f() to A, then T_2 reads f() as the value of A.
- In Example 2, T_2 reads A_0 (the initial value) as the value of A, then T_1 writes f() to A.

Example 3



Final value of A is g(f())

Example 4



Final value of A is _______

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Possible Phenomena

- Lost Update
- Inconsistent Retrieval

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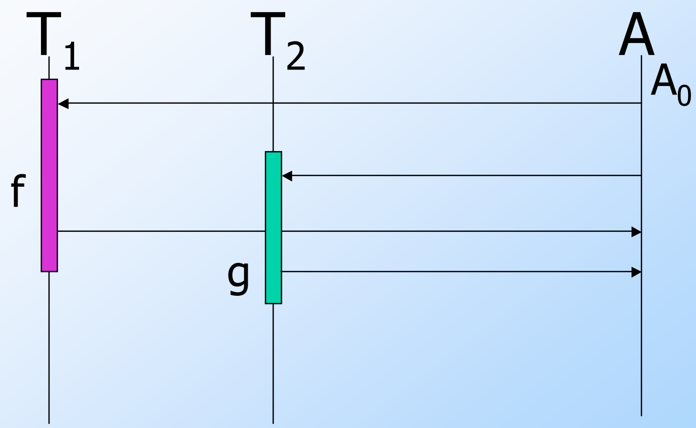
Lost Update Example

(compare Example 3)



Final value of A is ______

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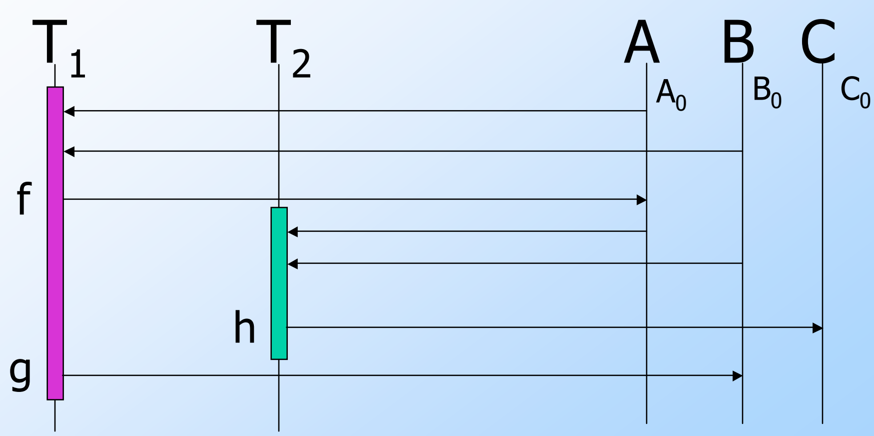
Inconsistent Retrieval Example



Final value of C is ______

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Correctness

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

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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.

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Serializable Interleaving

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

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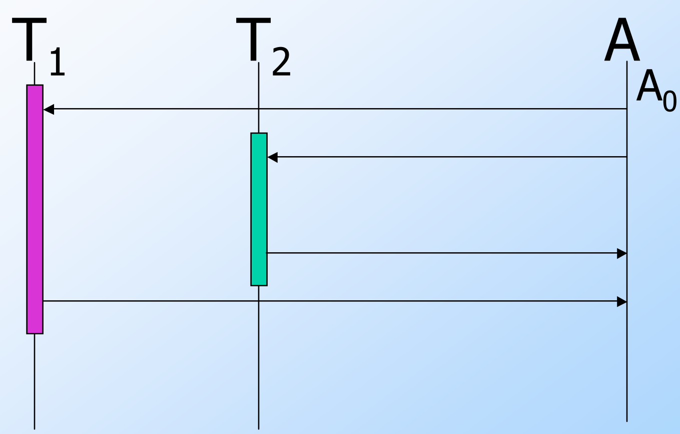
Is this interleaving serializable?



Equivalent to

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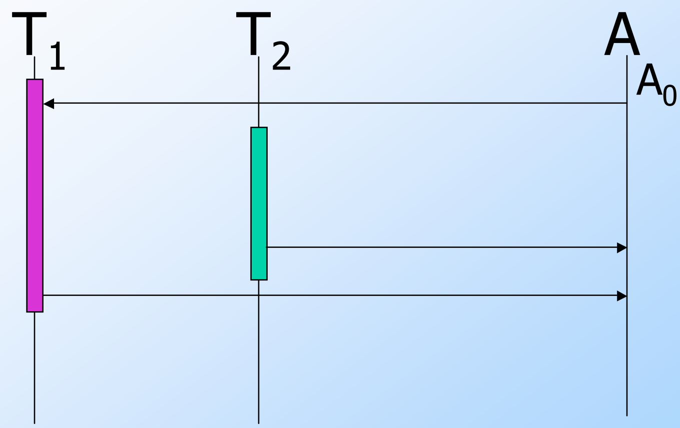
How about this one?



Equivalent to

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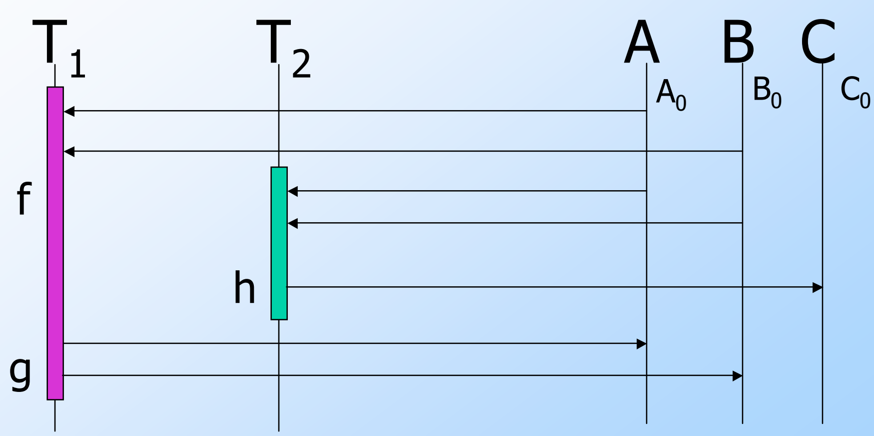
And This?



Equivalent to

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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.

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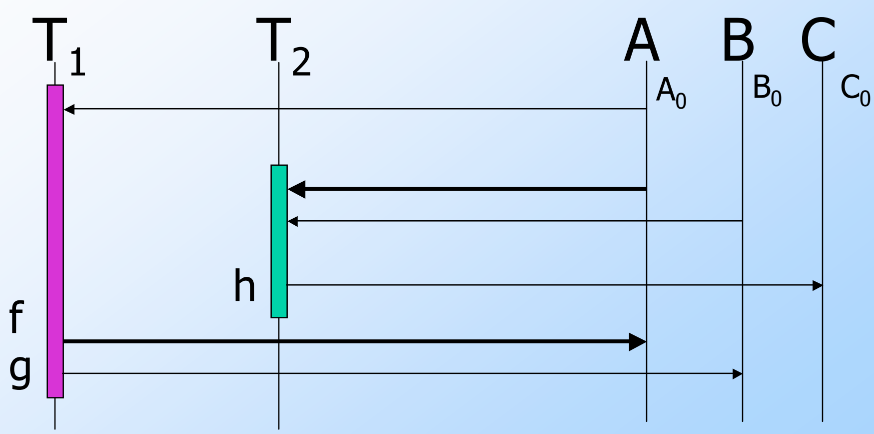
Conflict Example



Must preserve the order T_2T_1

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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.

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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.

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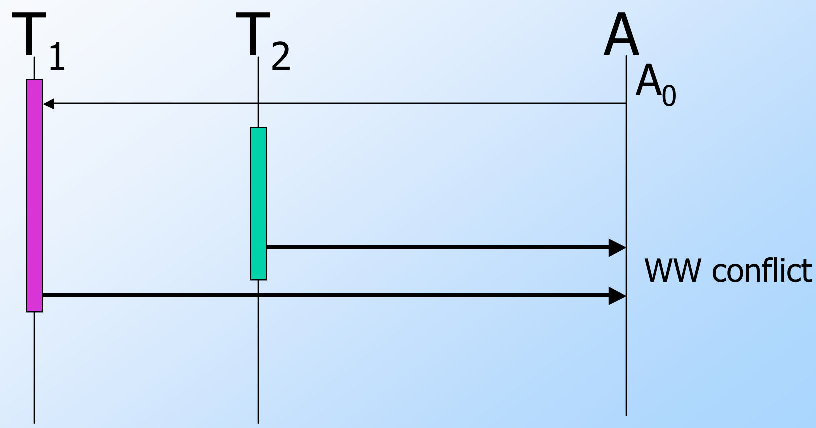
Conflict Orders



Requires T_2T_1.

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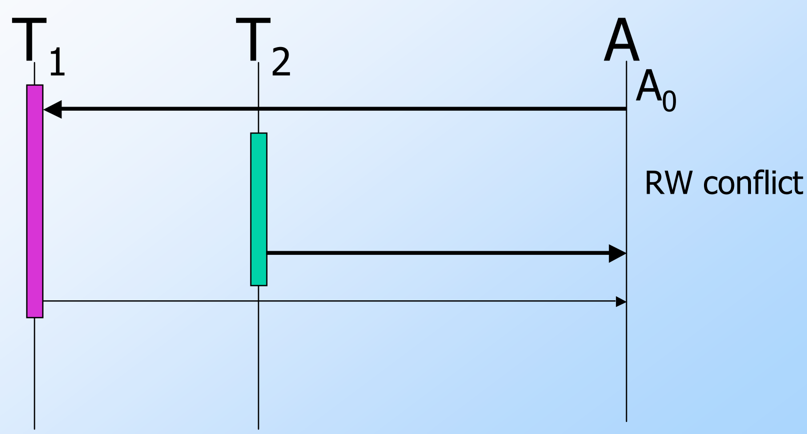
Conflicting Conflict Orders



Requires T_1T_2 ; we can’t have this and T_2T_1.

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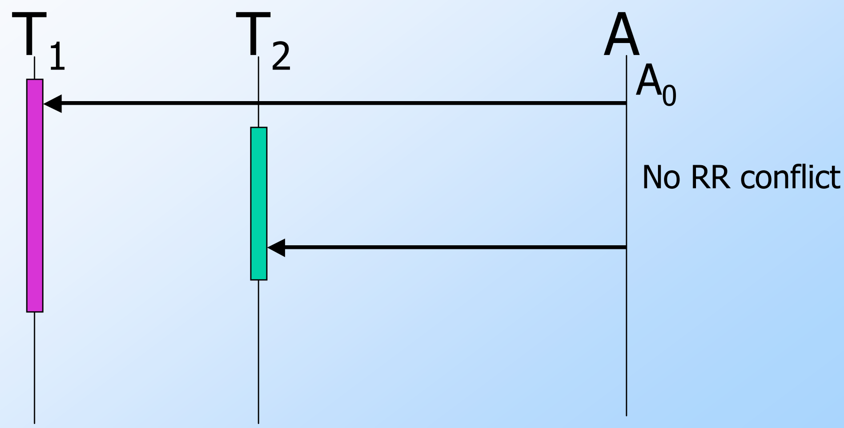
Non-Conflict Orders



Requires nothing.

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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.

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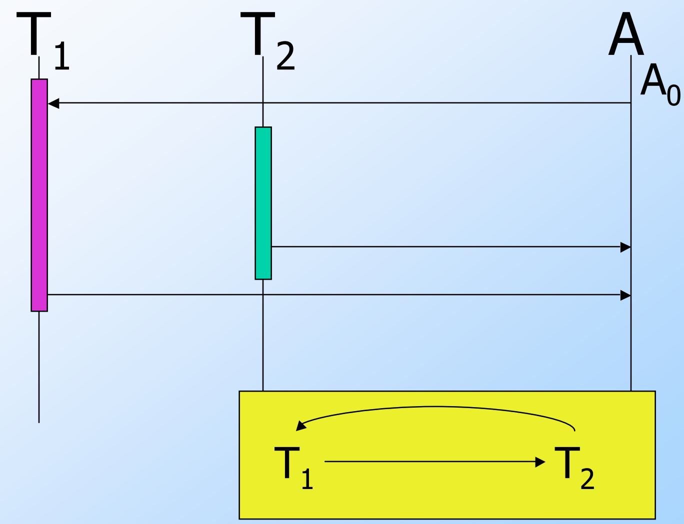
Conflict Graph Example



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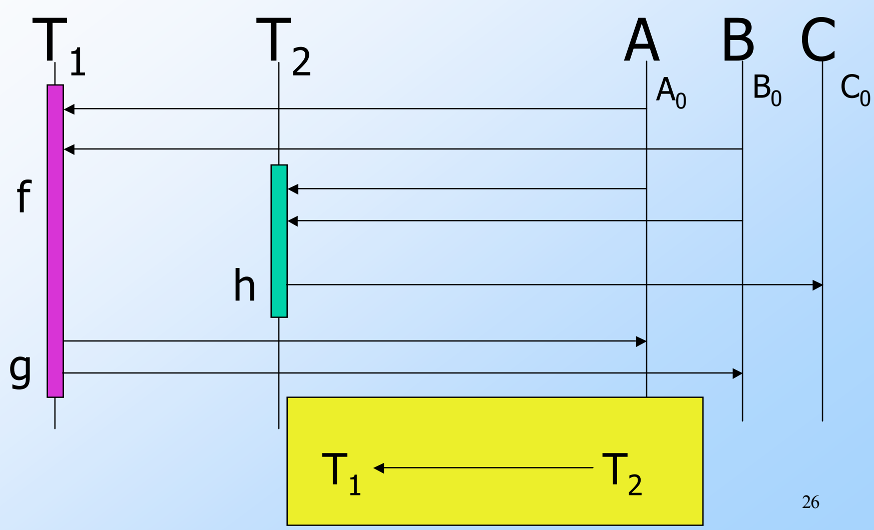
Conflict Graph Example



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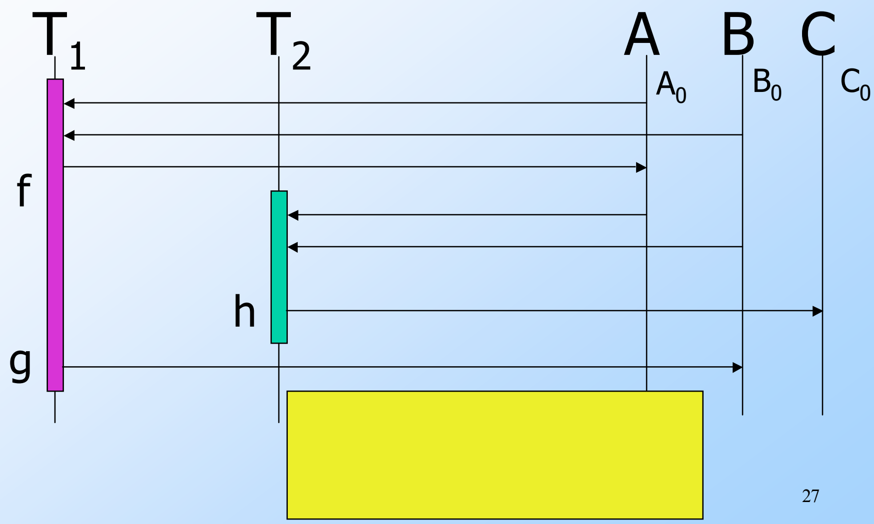
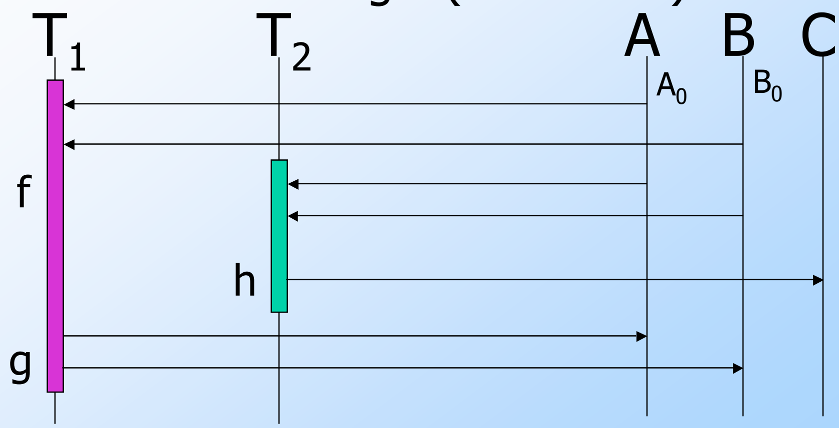
Conflict Graph Example



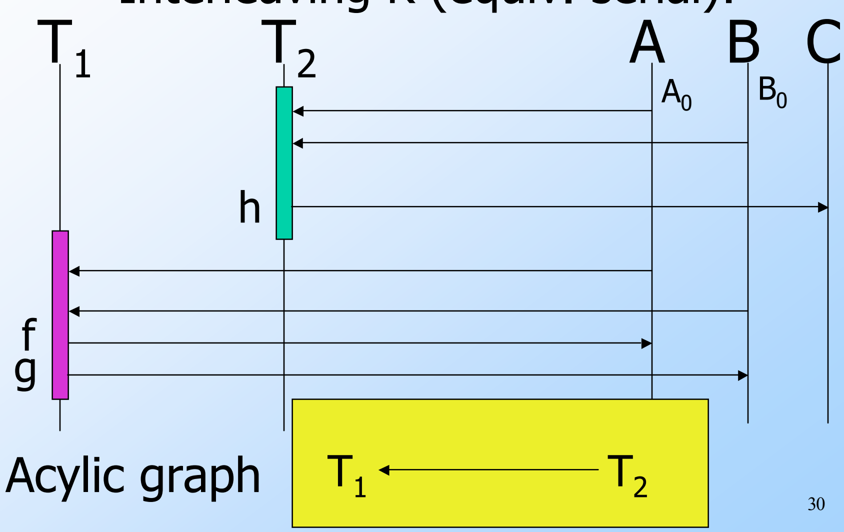
Result 1

- 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):



Result 2

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

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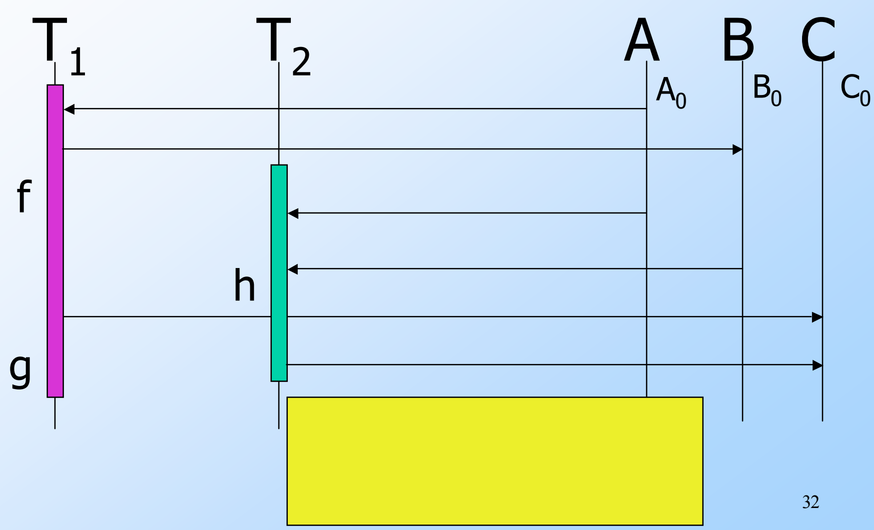
Example of Result 2:



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Summary of Results 1&2

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

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Serializability Requirement

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

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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.

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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.

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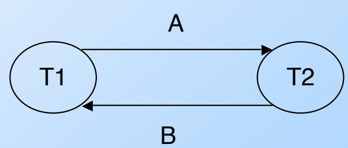
Locking Implies Reading or Writing

T1	**T2**
LOCK A	
UNLOCK A	
	LOCK A
	UNLOCK A
	LOCK B
	UNLOCK B
LOCK B	
UNLOCK B	



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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.]

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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.

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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.

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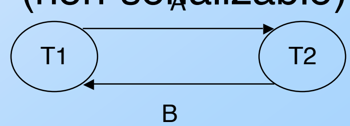
Non-2PL Example

T1	T2
LOCK A	
UNLOCK A	
	LOCK A
	UNLOCK A
	LOCK B
	UNLOCK B
LOCK B	
UNLOCK B	

conflict graph
(non-serializable)



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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	|	|
	|	(B acquired)
	Lock C	<u>Lock C</u>
	(waiting)	Unlock B, C
	<u>(C acquired)</u>	
	Unlock A,C	

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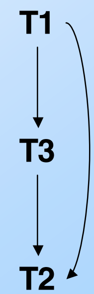
2PL Example

(lock points underlined)

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

conflict graph



consistent
with lockpoint
linear order

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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

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Deadlock Danger

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

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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!

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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		