Distributed Systems

CS425/ECE428

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Acknowledgements for the materials: Indy Gupta and Nikita Borisov

Logistics

- Midterm 2 in two weeks (April 2-4).
- Same format and duration as Midterm 1.
- Syllabus: Mutual Exclusion, Leader Election, Synchronous Consensus, Paxos, Raft.
- You should be able to make reservations on PrairieTest starting tomorrow (March 21st).
- Some practice questions for Midterm 2 will be released next week.

Agenda for today

- Transaction Processing and Concurrency Control
  - Chapter 16
    - Transaction semantics: ACID
    - Isolation and serial equivalence
    - Conflicting operations
    - Two-phase locking
    - Deadlocks
    - **Timestamped ordering**
- Distributed Transactions (if time)

Transaction Properties: ACID

- **A**tomic: all-or-nothing
  - Transaction either executes completely or not at all
- **C**onsistent: rules maintained
- **I**solation: multiple transactions do not interfere with each other
  - Equivalent to running transactions in isolation
- **D**urability: values preserved even after crashes

Isolation

How to prevent transactions from affecting each other?

- Execute them serially at the server (one at a time).
  - e.g. through a global lock.
  - But this reduces number of concurrent transactions

Goal: increase concurrency and transaction throughput while maintaining correctness (ACID).

Concurrency Control: Two approaches

- Pessimistic: assume the worst, prevent transactions from accessing the same object
  - E.g., Locking
- Optimistic: assume the best, allow transactions to write, but check later
  - E.g., Check at commit time

Pessimistic: Locking

- Grabbing a global lock is wasteful
  - what if no two transactions access the same object?

- Each object has a lock
  - can further improve concurrency.
  - reads on the same object are non-conflicting.

- Per-object read-write locks.
  - Read mode: multiple transactions allowed in
  - Write mode: exclusive lock

Guaranteeing Serial Equivalence with Locks

- Two-phase locking
  - A transaction cannot acquire (or promote) any locks after it has started releasing locks
  - Transaction has two phases
    1. Growing phase: only acquires or promotes locks
    2. Shrinking phase: only releases locks
       - Strict two phase locking: releases locks only at commit point

Can lead to Deadlocks!

Transaction T1

read_lock(x)

x = getSeats(ABC123);

if(x > 1)

x = x – 1;

write_lock(x) *Blocked!*

write(x, ABC123);

commit

Transaction T2

read_lock(x)

x = getSeats(ABC123);

if(x > 1)

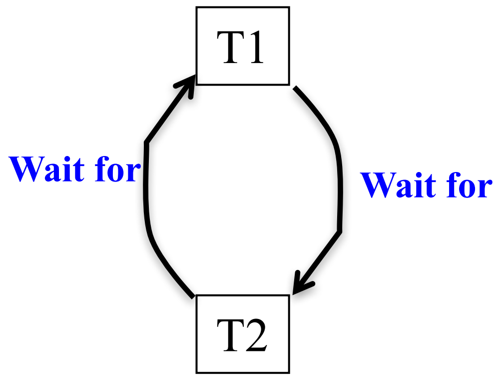
x = x – 1;

write_lock(x) *Blocked!*

write(x, ABC123);

commit

Deadlock!



When do deadlocks occur?

- 3 <u>necessary</u> conditions for a deadlock to occur
    1. Some objects are accessed in exclusive lock modes
    2. Transactions holding locks are not preempted
    3. There is a circular wait (cycle) in the Wait-for graph

- "Necessary" = if there's a deadlock, these conditions are all definitely true

- (Conditions not sufficient: if they're present, it doesn't imply a deadlock is present.)

Combating Deadlocks

1. Lock all objects in the beginning in a single atomic step.
   - no circular wait-for graph created (3rd deadlock condition breaks)
   - may not know of all operations a priori.
2. Lock timeout: abort transaction if lock cannot be acquired within timeout
   - (2nd deadlock condition breaks)
   - Expensive; leads to wasted work
   - How to determine the timeout value?
     - Too large: long delays
     - Too small: false positives.
3. Deadlock Detection:
   - keep track of Wait-for graph, and find cycles in it (e.g., periodically)
   - If find cycle, there's a deadlock

     ⇒Abort one or more transactions to break cycle (2nd deadlock condition breaks)

Concurrency Control: Two approaches

- Pessimistic: assume the worst, prevent transactions from accessing the same object
  - E.g., Locking

- Optimistic: assume the best, allow transactions to write, but check later
  - E.g., Check at commit time

Optimistic Concurrency Control

- Increases concurrency more than pessimistic concurrency control
- Used in Dropbox, Google apps, Wikipedia, key-value stores like Cassandra, Riak, and Amazon's Dynamo
- Preferable than pessimistic when conflicts are *expected to be* rare
    - But still need to ensure conflicts are caught!

First cut approach

- Most basic approach
  - Write and read objects at will
  - Check for serial equivalence at commit time
  - If abort, roll back updates made
  - An abort may result in other transactions that read dirty data, also being aborted
    - Any transactions that read from *those* transactions also now need to be aborted

    ☹ *Cascading aborts*

Timestamped ordering

- Assign each transaction an id
- Transaction id determines its position in serialization order.
- Ensure that for a transaction T, both are true:
  1. T's write to object O allowed only if transactions that have read or written O had lower ids than T.
  2. T's read to object O is allowed only if O was last written by a transaction with a lower id than T.
- Implemented by maintaining read and write timestamps for the object
- If rule violated, abort!
- *Never results in a deadlock! Older transaction never waits on newer ones.*

Timestamped ordering: per-object state

- Committed value.
- Transaction id (timestamp) that wrote the committed value.
- Read timestamps (RTS): List of transaction ids (timestamps) that have read the committed value.
- Tentative writes (TW): List of tentative writes sorted by the corresponding transaction ids (timestamps).
    - Timestamped *versions* of the object.

Timestamped ordering rules

Rule	T_c	T_i	
1.	*write*	*read*	T_c must not *write* an object that has been *read* by any T_i where $T_i > T_c$ This requires that $T_c \geq$ the maximum read timestamp of the object.
2.	*write*	*write*	T_c must not *write* an object that has been *written* by any T_i where $T_i > T_c$ This requires that $T_c >$ write timestamp of the committed object.
3.	*read*	*write*	T_c must not *read* an object that has been *written* by any T_i where $T_i > T_c$ This requires that $T_c >$ write timestamp of the committed object.

Timestamped ordering: write rule

Transaction T_c requests a write operation on object D

if (Tc ≥ max. read timestamp on D

&& Tc > write timestamp on committed version of D)

Perform a tentative write on D:

If T_c already has an entry in the TW list for D, update it.

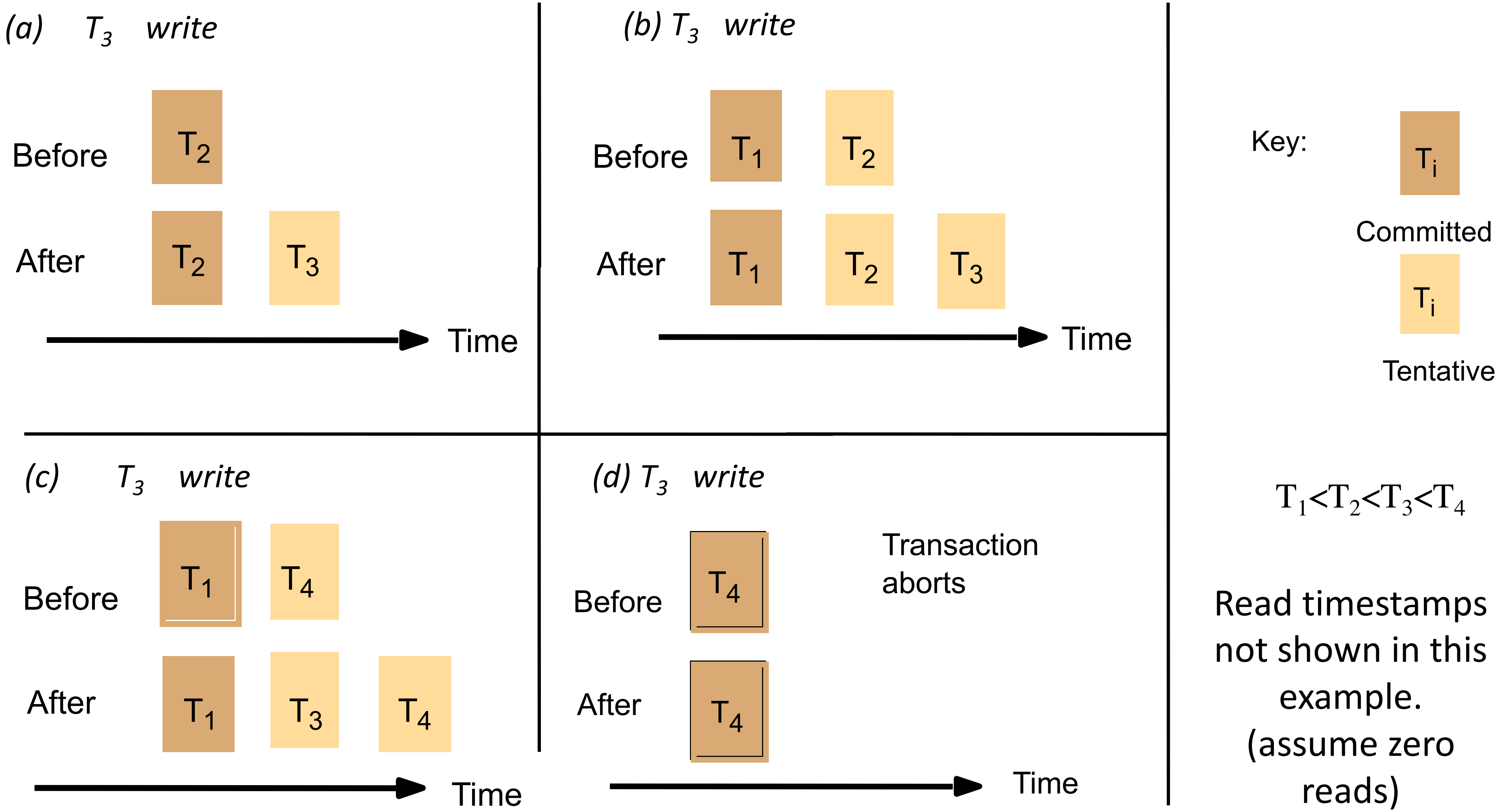
Else, add T_c and its write value to the TW list.

else

abort transaction T_c

//too late; a transaction with later timestamp has already read or written the object.

Timestamped ordering: write rule



$T_1<T_2<T_3<T_4$

Read timestamps not shown in this example. (assume zero reads)

Timestamped ordering: read rule

Transaction T_c requests a read operation on object D

if (T_c > write timestamp on committed version of D) {

D_s = version of D with the maximum write timestamp that is ≤ T_c

//search across the committed timestamp and the TW list for object D.

if (D_s is committed)

read D_s and add T_c to RTS list (if not already added)

else

if D_s was written by T_c, simply read D_s

else

wait until the transaction that wrote D_s is committed or aborted, and reapply the read rule.

// if the transaction is committed, T_c will read its value after the wait.

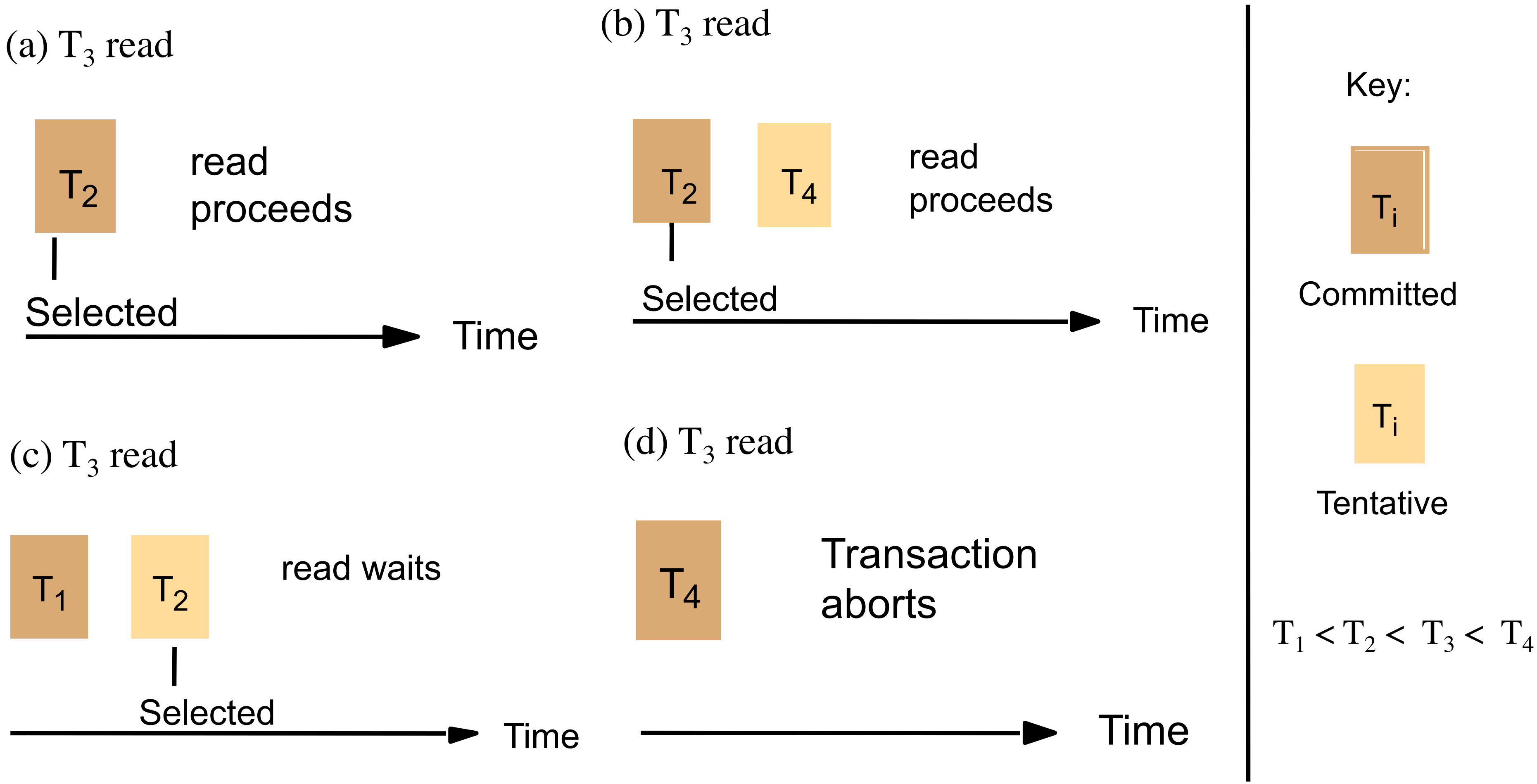
// if the transaction is aborted, T_c will read the value from an older transaction.

} else

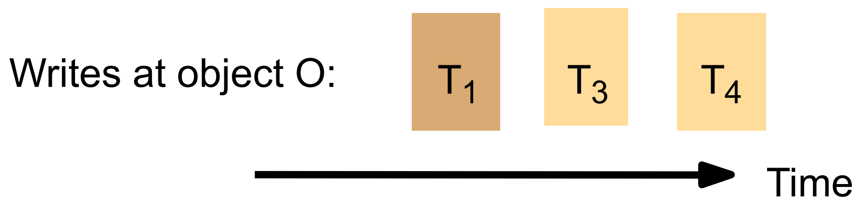
abort transaction T_c

//too late; a transaction with later timestamp has already written the object.

Timestamped ordering: read rule

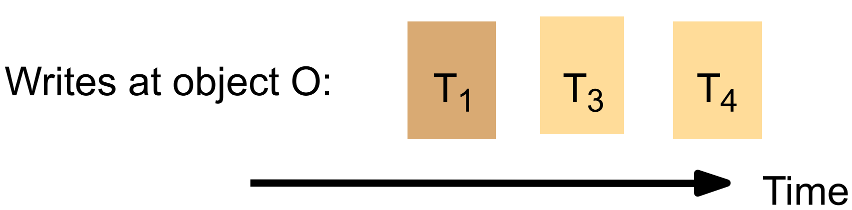


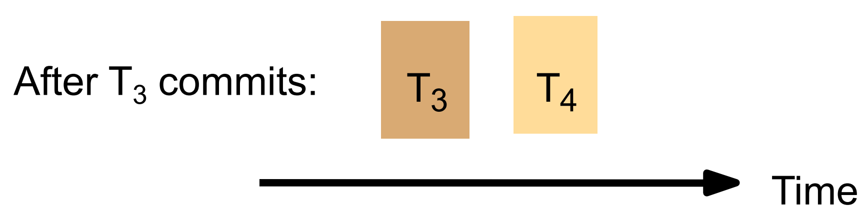
Timestamped ordering: committing



- Suppose T_4 is ready to commit.
- Must wait until T_3 commits or aborts.

- When a transaction is committed, the committed value of the object and associated timestamp are updated, and the corresponding write is removed from TW list.





Lost Update Example with Timestamped Ordering

Transaction T1	**Transaction T2**	ABC123: state committed value = 10 committed timestamp = 0 RTS: TW:
x = getSeats(ABC123);		
	x = getSeats(ABC123);	
if(x > 1)	if(x > 1)	
x = x – 1;		
write(x, ABC123);		
	x = x – 1;	
	write(x, ABC123);	
commit		
	commit	

Lost Update Example with Timestamped Ordering

Transaction T1	**Transaction T2**	ABC123: state
		committed value = 10
		committed timestamp = 0
x = getSeats(ABC123);		RTS: 1
	x = getSeats(ABC123);	TW:
if(x > 1)	if(x > 1)	
x = x – 1;		
write(x, ABC123);		
	x = x – 1;	
	write(x, ABC123);	
commit		
	commit	

Lost Update Example with Timestamped Ordering

ABC123: state
committed value = 10
committed timestamp = 0
RTS: 1
TW:

Transaction T1	**Transaction T2**
x = getSeats(ABC123);	
	x = getSeats(ABC123);
if(x > 1)	if(x > 1)
x = x – 1;	
write(x, ABC123);	
	x = x – 1;
	write(x, ABC123);
commit	
	commit

Lost Update Example with Timestamped Ordering

Transaction T1	**Transaction T2**	ABC123: state
		committed value = 10
		committed timestamp = 0
x = getSeats(ABC123);		RTS: 1, 2
	x = getSeats(ABC123);	TW:
if(x > 1)	if(x > 1)	
x = x – 1;		
write(x, ABC123);		
	x = x – 1;	
	write(x, ABC123);	
commit		
	commit	

Lost Update Example with Timestamped Ordering

Transaction T1	**Transaction T2**	ABC123: state committed value = 10 committed timestamp = 0 RTS: 1, 2 TW:
x = getSeats(ABC123);		
	x = getSeats(ABC123);	
if(x > 1)	if(x > 1)	
x = x – 1;		
write(x, ABC123);		
	x = x – 1;	Abort!
	write(x, ABC123);	
commit		
	commit	

Next Example with Timestamped Ordering

Transaction T1	**Transaction T2**	
		ABC123: state committed value = 10 committed timestamp = 0 RTS: TW:
x = getSeats(ABC123);		
y = getSeats(ABC789);		
write(x-5, ABC123);		
	x = getSeats(ABC123);	
	y = getSeats(ABC789);	
write(y+5, ABC789);		
		ABC789: state committed value = 5 committed timestamp = 0 RTS: TW:
	print("Total:" x+y);	
commit		
	commit	

Try on your own! Will discuss in next class.

Timestamped ordering

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- Transaction id determines its position in serialization order.
- Ensure that for a transaction T, both are true:
    1. T's write to object O allowed only if transactions that have read or written O had lower ids than T.
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- Implemented by maintaining read and write timestamps for the object
- If rule violated, abort!
- *Never results in a deadlock! Older transaction never waits on newer ones.*

Concurrency Control: Summary

- *How to prevent transactions from affecting one another?*
- Goal: increase concurrency and transaction throughput while maintaining correctness (ACID).
- Target *serial equivalence.*
- Two approaches:
  - Pessimistic concurrency control: locking based.
    - read-write locks with two-phase locking and deadlock detection.
  - Optimistic concurrency control: abort if too late.
    - timestamped ordering.