Concurrency Control

Rong Chen

Institute of Parallel and Distributed Systems

Shanghai Jiao Tong University

http://ipads.se.sjtu.edu.cn/rong_chen

Credits: some slides from Jinyang Li (NYU)

Transaction so far

All-or-nothing atomicity in transactions

- Failures do not result in (undesirable) intermediate state

How to realize all-or-nothing atomicity?

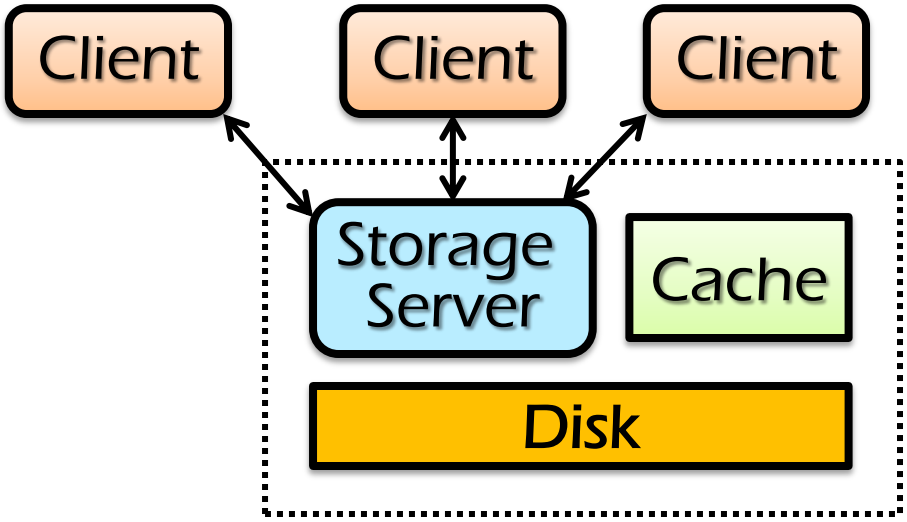
- Logging and recovery
- **DO-REDO-UNDO** protocol
- **REDO/UNDO** vs. **REDO-only**

How about concurrent transactions?

Concurrency Control

Concurrent transactions

- **Multiple** application clients are **concurrently** accessing a storage system
- Transactions might **interfere**
- Similar to **data race** in parallel programs



Example

Client Transactions1

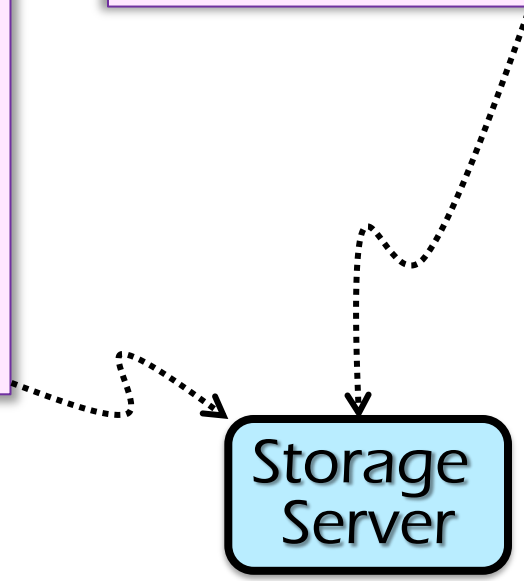
Transfer $1000 from A to B

```
A_bal = READ(A)
if (A_bal > 1000) {
    B_bal = READ(B)
    B_bal += 1000
    A_bal -= 1000
    WRITE(A, A_bal)
    WRITE(B, B_bal)
}
```

Client Transactions2

Report SUM of A and B

```
A_bal = READ(A)
B_bal = READ(B)
Print(A_bal + B_bal)
```



Example

Client Transactions1

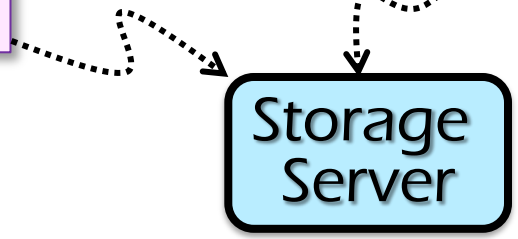
Transfer $1000 from A to B

```
A_bal = READ(A)
if (A_bal > 1000) {
    B_bal = READ(B)
    B_bal += 1000
    A_bal -= 1000
    WRITE(A, A_bal)
    WRITE(B, B_bal)
}
```

Client Transactions2

Withdraw $500 from A

```
A_bal = READ(A)
If (A_bal > 500) {
    A_bal -= 500
    WRITE(A_bal)
    dispense $500 to user
}
```



Potential Solutions

Leave it to **application** programmers

- Application programmers are **responsible** for **protecting** (e.g., lock) data items

Storage system performs automatic concurrency control

- Concurrent transactions execute as if **serially**

ACID Transactions

A (Atomicity)	**All-or-nothing** with respect to failures
C (Consistency)	Transactions maintain any internal state **invariants**
I (Isolation)	Concurrently executing transactions don't **interfere**
D (Durability)	Effect to transactions **survive** failures

ACID Transactions

A (Atomicity)	**All-or-nothing** with respect to failures
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D (Durability)	Effect to transactions **survive** failures

What is ACID ?

T1 Transfer $1000 from A to B

T2 Transfer $500 from B to A

A T1 **completes** or **nothing** (ditto for T2)

C Preserves **invariants**, e.g. account balance > 0

I No **race**, as if T1 happens either before or after T2

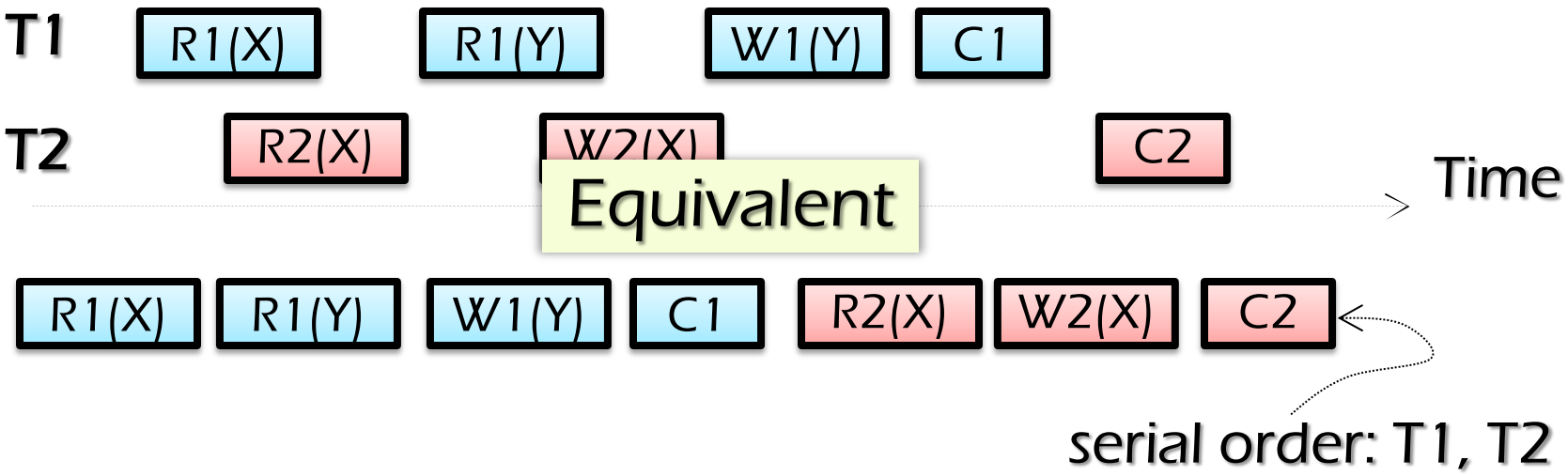
D Once T1/T2 commits, stays done, no updates **lost**

Ideal Semantics: Serializability

Definition: execution of a set of transactions is equivalent to some **serial** order

- Two executions are equivalent

  → if they have the same effect on database and produce same output



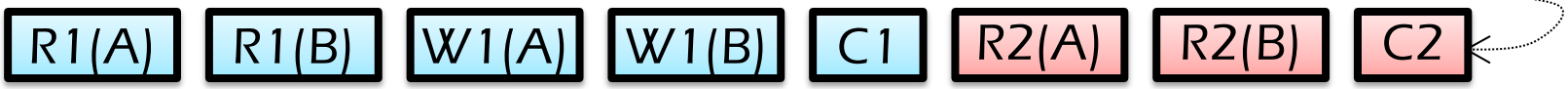
Execution Schedule

An execution schedule is the ordering of **READ/WRITE/COMMIT/ABORT** ops

```
A_bal = READ(A)
B_bal = READ(B)
B_bal += 1000
A_bal -= 1000
WRITE(A, A_bal)
WRITE(B, B_bal)
Commit
```

```
A_bal = READ(A)
B_bal = READ(B)
Print(A_bal + B_bal)
Commit
```

A (serial) schedule



Conflict Serializability

Two schedules are equivalent →

1. Contain **same** operations
2. Order **conflicting** operations the same way

Two operations **conflict** → *they access the same data item and at least one is a* **write**

A schedule is **serializable** if it's **equivalent** to **some** **serial** schedule

Examples

```
A_bal = READ(A)
B_bal = READ(B)
B_bal += 1000
A_bal -= 1000
WRITE(A, A_bal)
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Commit
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```
A_bal = READ(A)
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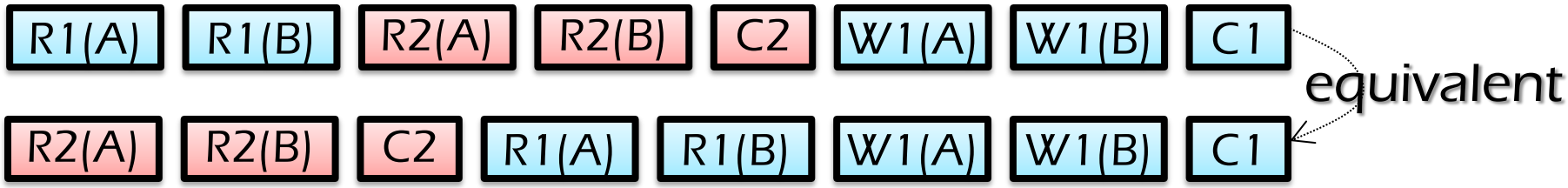
Print(A_bal + B_bal)
Commit
```

Serializable?



Examples

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```
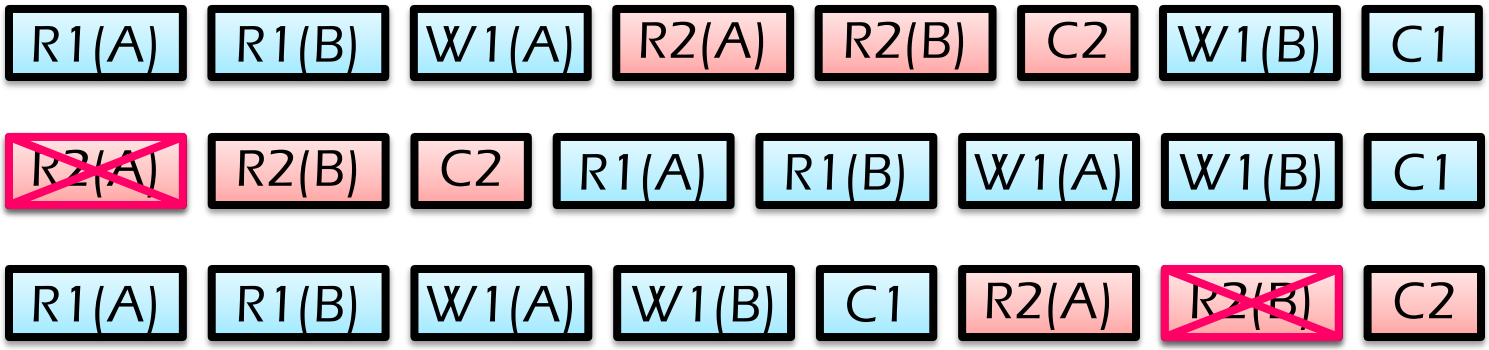

Serializable?



Serializable Schedule

Locking based approach

Strawman solution 1:

- Grab global lock before transaction **START**
- Release global lock after transaction **COMMIT**

A **serial** schedule → Too Slow!!

Strawman solution 2:

Serializable or not ?

- Grab lock on item X before **READ/WRITE** X
- Release lock on X after **READ/WRITE** X

Strawman 2's Example

```
A_bal = READ(A)
B_bal = READ(B)
B_bal += 1000
A_bal -= 1000
WRITE(A, A_bal)
WRITE(B, B_bal)
Commit
```

```
A_bal = READ(A)
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Print(A_bal + B_bal)
Commit
```
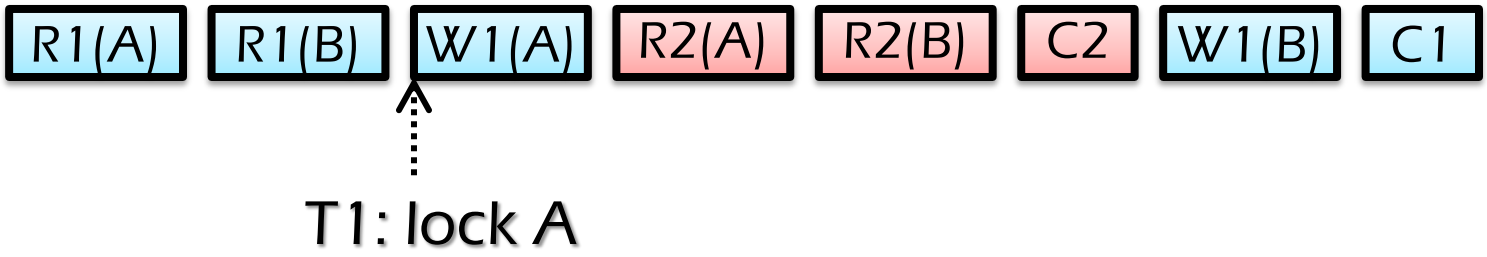

Is it possible?



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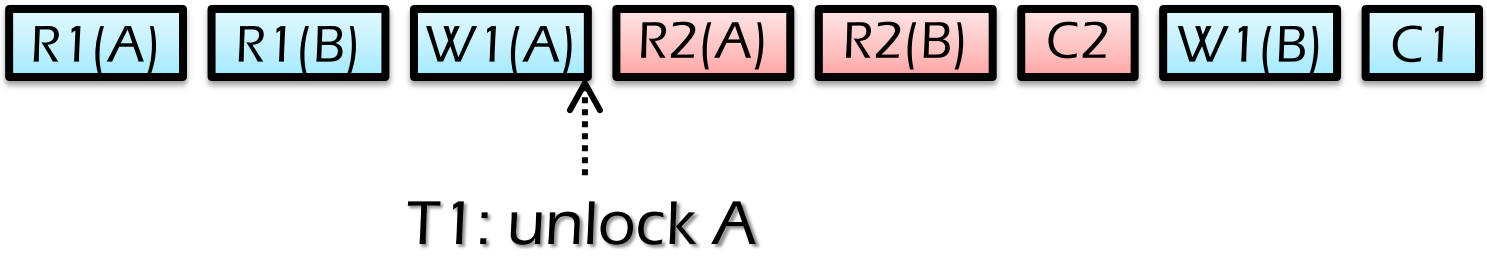
Short-duration locks on **WRITE**s



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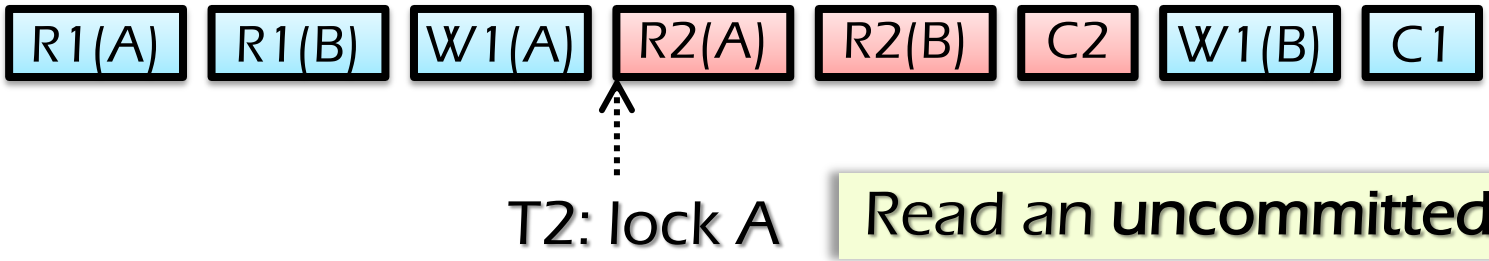
Short-duration locks on **WRITE**s



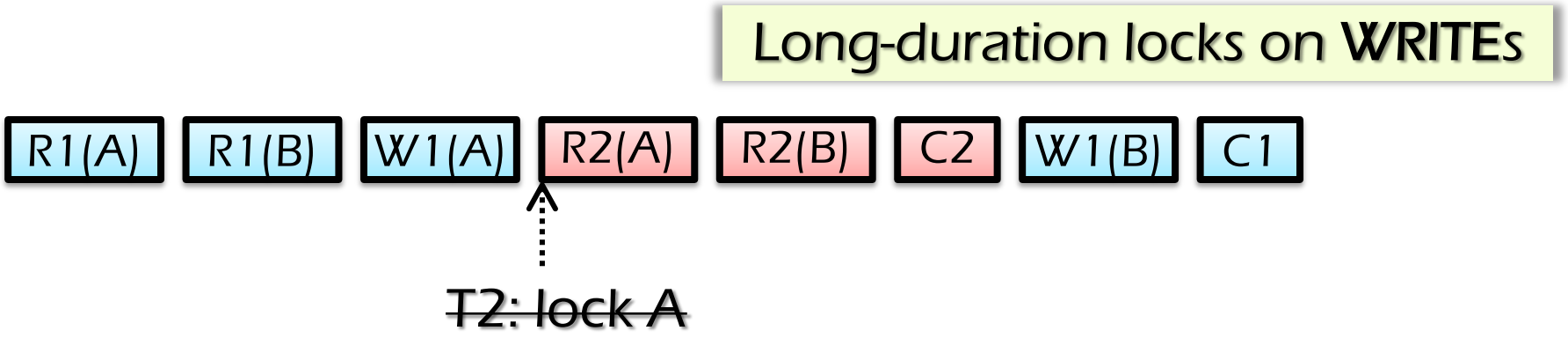
Read an **uncommitted** value?

Locks on **WRITE**s should be held till end of transaction

Serializable Schedule

Strawman solution 3:

- Grab write lock on item X before **WRITE**
- Release write lock after transaction **COMMIT**
- Grab read lock on item X before **READ**
- Release read lock on X immediately **READ**



Serializable Schedule

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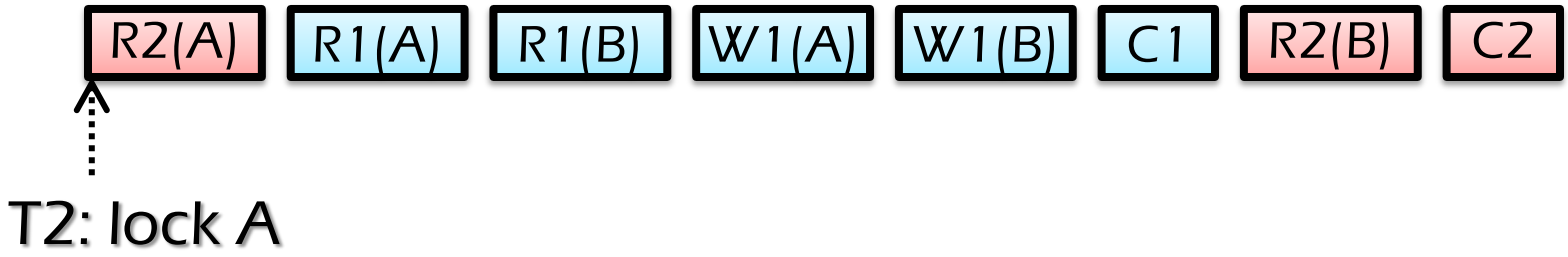

Serializable Schedule

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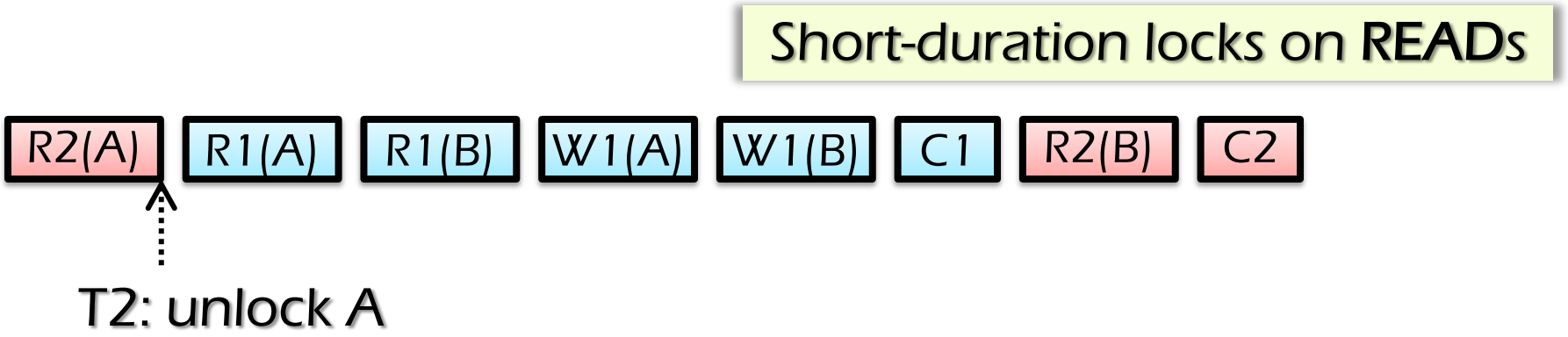

Serializable Schedule

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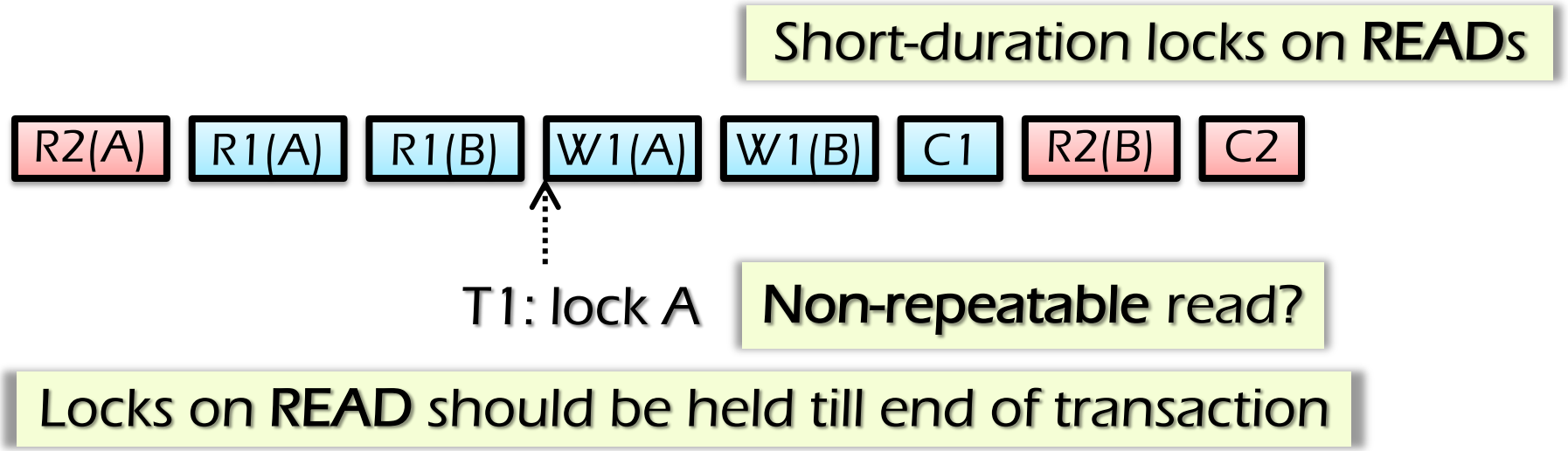


Serializable Schedule

Two-phase locking (**2PL**)

- A growing phase in which the transaction is acquiring locks
- A shrinking phase in which locks are released

In practice

- The growing phase is the entire transaction
- The shrinking phase is at the **COMMIT** time

Optimization

- Use read/write locks instead of exclusive locks

Two-phase Locking's Example

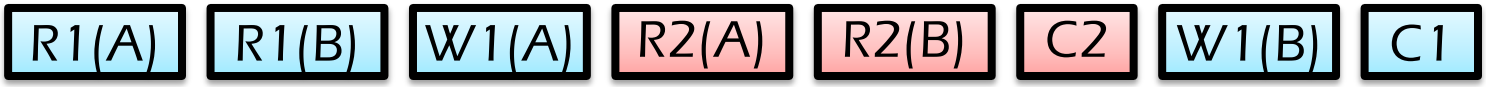
growing

shrinking

```
R_lock(A)
A_bal = READ(A)
R_lock(B)
B_bal = READ(B)
B_bal += 1000
A_bal -= 1000
W_lock(A)
WRITE(A, A_bal)
W_lock(B)
WRITE(B, B_bal)
W_unlock(A)
W_unlock(B)
```

```
R_lock(A)
A_bal = READ(A)
R_lock(B)
B_bal = READ(B)
Print(A_bal + B_bal)
R_unlock(A)
R_unlock(B)
```

Is it possible?



Two-phase Locking

Q1: What if a lock is unavailable?

Q2: Deadlocks possible?

How to cope with deadlock?

- **Avoidance** → grab locks in order

  Not always possible

- **Detection** → detects deadlock cycles (timeout) and aborts affected transactions (self)

  Crash recovery mechanism (e.g., UNDO) to clean up

Phantom Problem

T1 Update **emp** (set salary=1.1*salary) where dept='SS'

T2 Update **emp** (set dept='SS') where emp.name='Rong' or "Zhaoguo"

Update Binyu
Update Haibo
Update Xvjia
Update Yubin
Commit

Move Rong
Move Zhaoguo
Commit (release all locks)

R1(P) | W1(S.B) | W1(S.H) | W2(P.R) | W2(P.X) | C2 | W1(S.S) | W1(S.Y) | C1

Phantom Problem

Issue: only lock things you touch

- But must guarantee non-existence of any new ones!

Two operations conflict → they access the same data item and at least one is a write

e.g., object, row, list, entire table, …

Solutions

- Predicate locking
- Range locks in a B-tree index (e.g., assumes an index on **dept**), or lock entire table
- Often ignore in practice

Why less than Serializability?

Performance

- Long-duration locks on all **READ**/**WRITE**
- Scenarios:

run analytics on a companion data, while update a piece of data

long running read-only transaction

Disadvantages of locking-based approach

- Need distributed deadlock detection
- Read-only transactions (e.g., *data mining*) can block update transactions

Multi-version Concurrency Control

No locking during transaction execution

Each data item has multiple versions

Multi-version transactions:

- Buffer **WRITE**s during execution
- **READ**s choose the appropriate version
- At **COMMIT** time, system validates if OK to make writes visible (generating **new** versions)

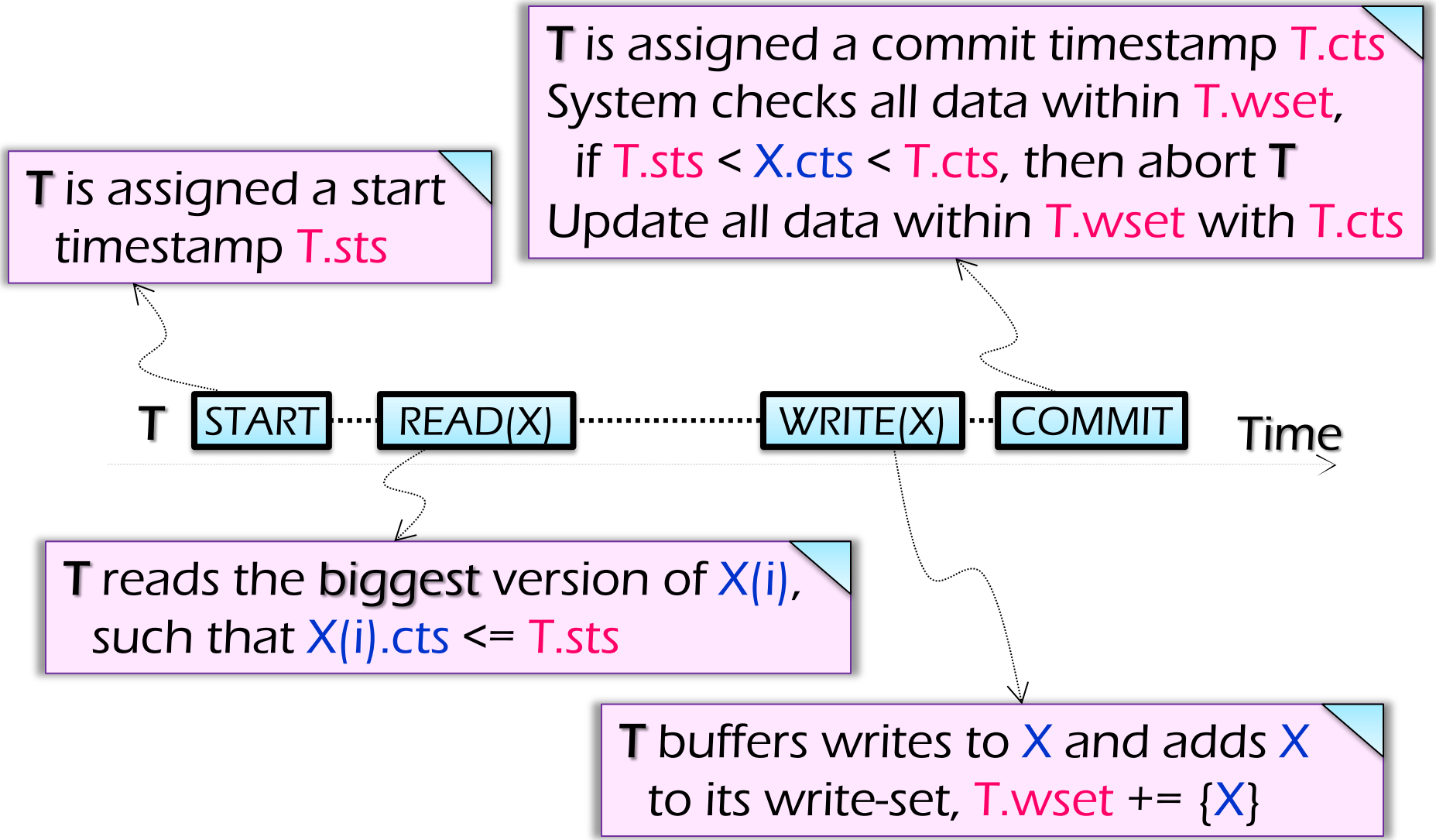
Snapshot Isolation

A popular multi-version concurrency control (MVCC) scheme

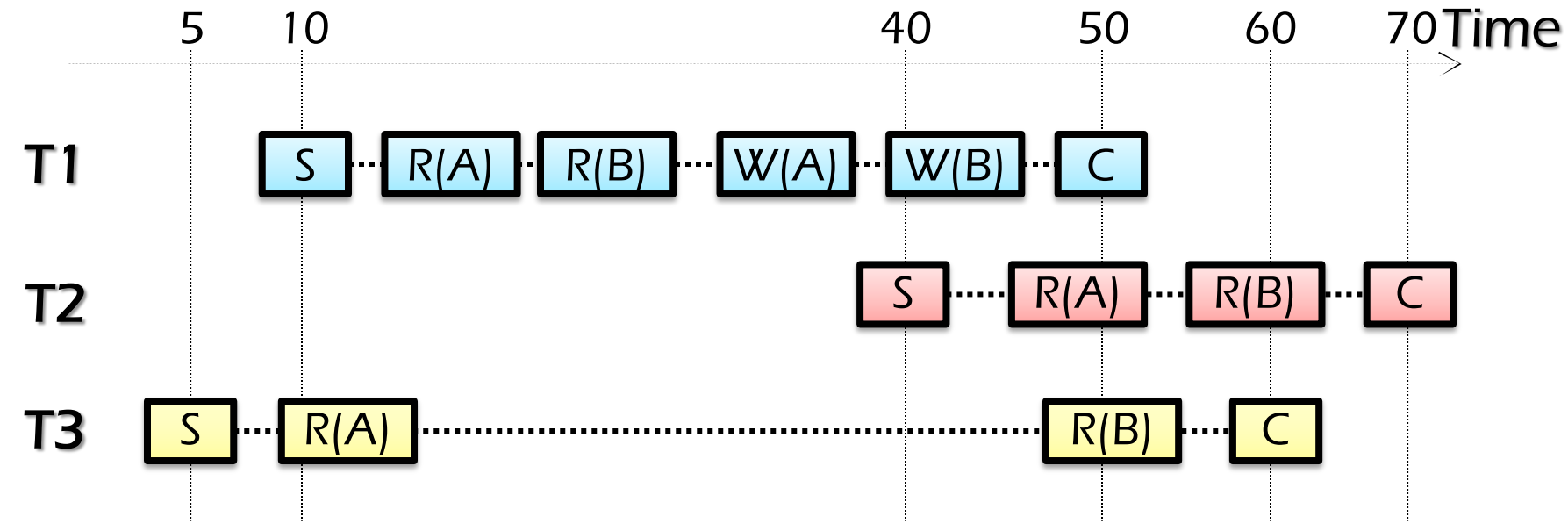
Transactions:

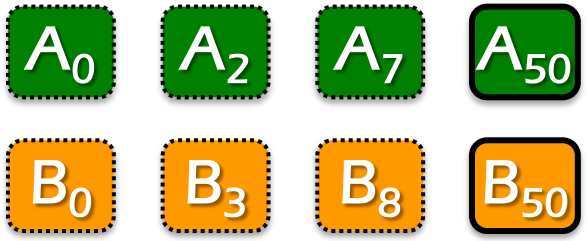
- **WRITE**s a local buffer
- **READ**s a "snapshot" of entire data image
- **COMMIT** only if no write-write conflict

Implementation



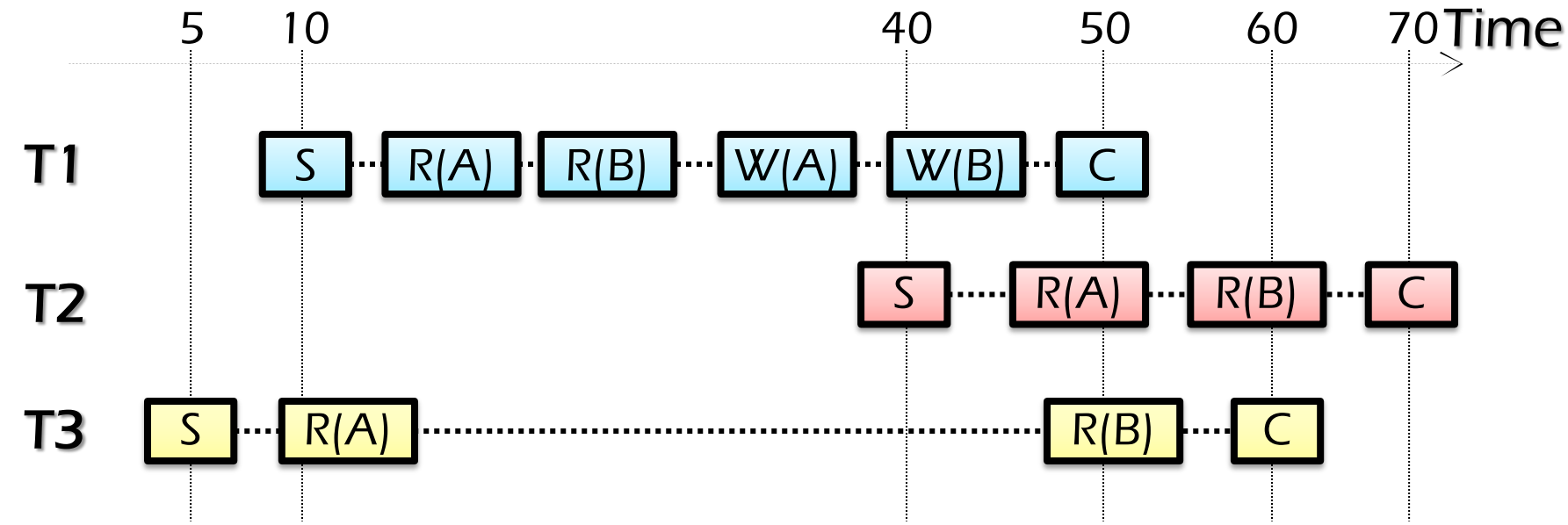
Example

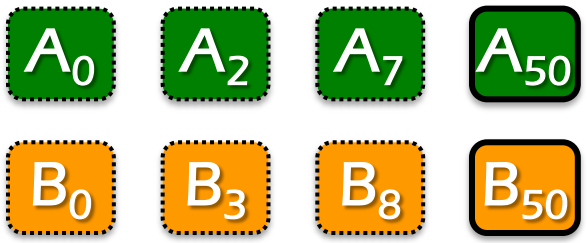




T.sts = 10
R(A) = A_7
R(B) = B_8
T.cts = 50
W(A) = A_{50}
W(B) = B_{50}

Example



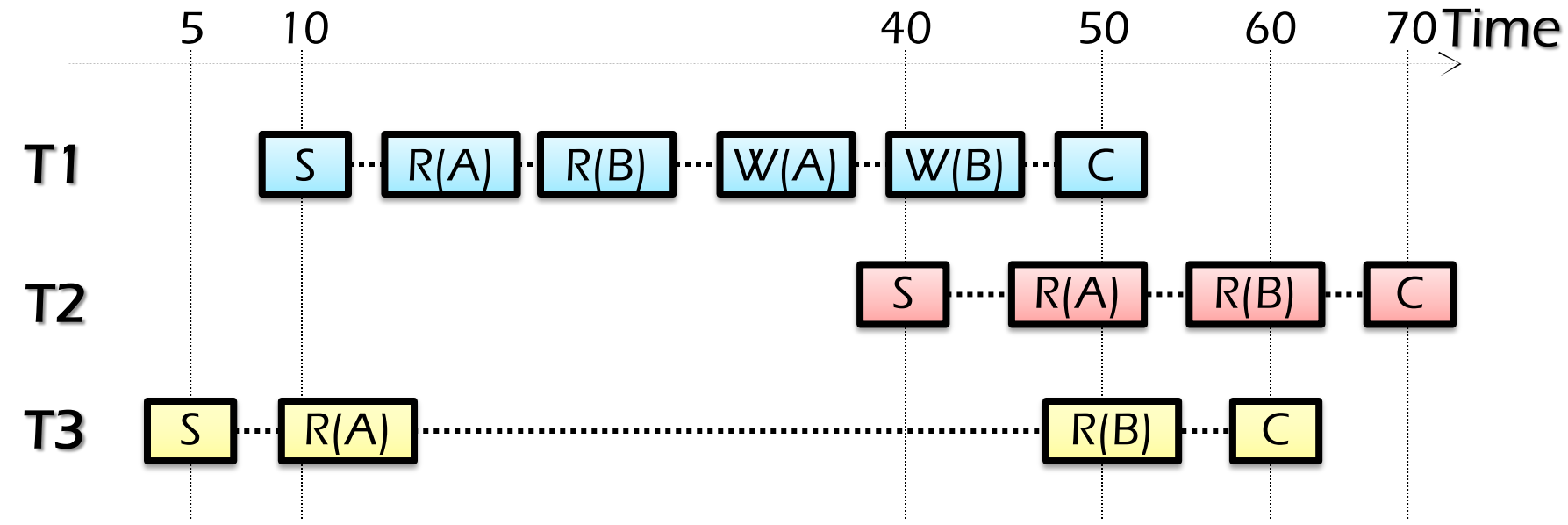


T.sts = 10
R(A) = A_7
R(B) = B_8
T.cts = 50
W(A) = A_{50}
W(B) = B_{50}

T.sts = 40
R(A) = A_7
R(B) = B_8
T.cts = 70

No **read-uncommitted**

Example



A_0 A_2 A_7 A_{50}

B_0 B_3 B_8 B_{50}

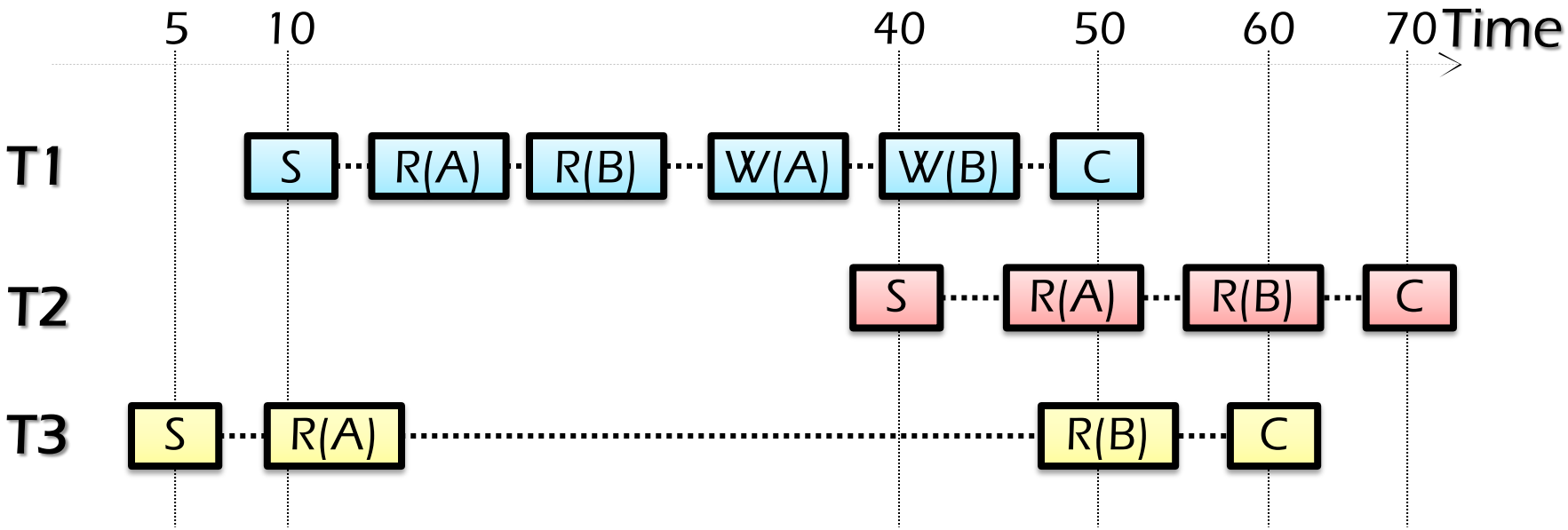
T.sts = 10
R(A) = A_7
R(B) = B_8
T.cts = 50
W(A) = A_{50}
W(B) = B_{50}

T.sts = 40
R(A) = A_7
R(B) = B_8
T.cts = 70

T.sts = 5
R(A) = A_2
R(B) = B_3
T.cts = 60

No **unrepeatable-read**

Example



A_0 A_2 A_7 A_{50}

B_0 B_3 B_8 B_{50}

Equivalent Serial Order

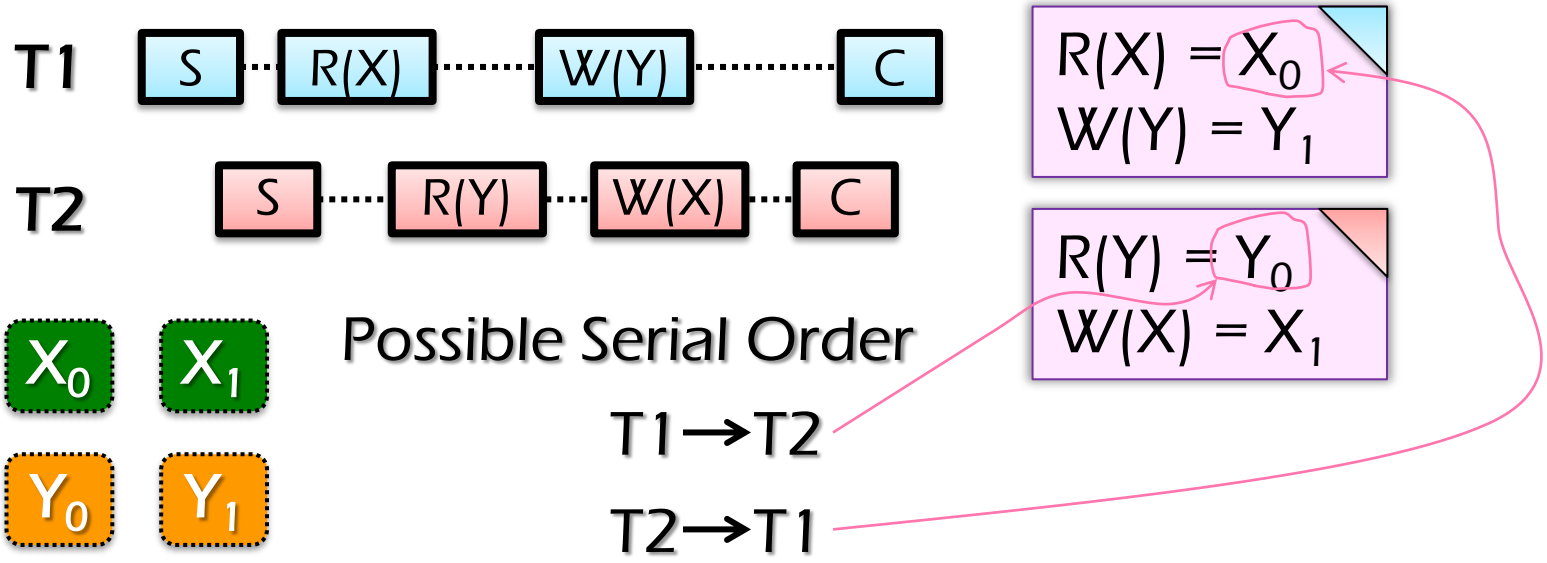
T3 → A_7 → B_8 → T2 → T1

Snapshot Isolation is serializable or not ?

Question

Snapshot isolation (SI) differs from **serializability** due to one **anomaly** that is possible under **SI** but not under **serializability**.

Describe the anomaly and also give a concrete application for which the anomaly is undesirable.



Next Lecture

Topic: Two-phase Commit (2PC)

THANKS