KOÇ UNIVERSITY

Database Management Systems

Concurrency Control

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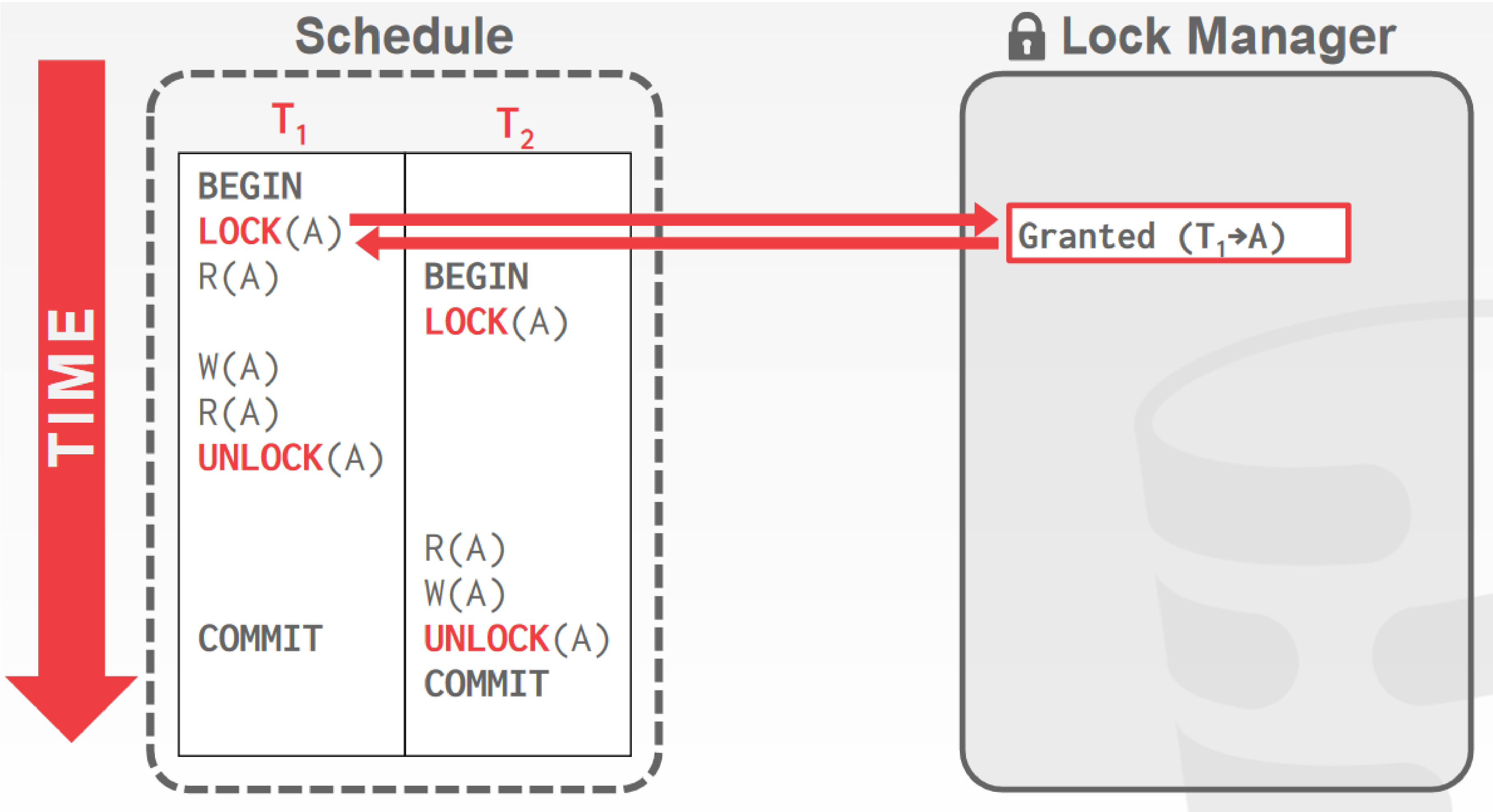
Introduction

- We have been talking about:
  - "Good" schedules versus "bad" schedules (e.g., conflict serializability)
  - How to check if a schedule is "good" or "bad"

- But our previous methods have two shortcomings:
  - They require us to know all transactions and all actions ahead of time (all Rs and Ws)
  - They don't tell us how to create a “good” schedule

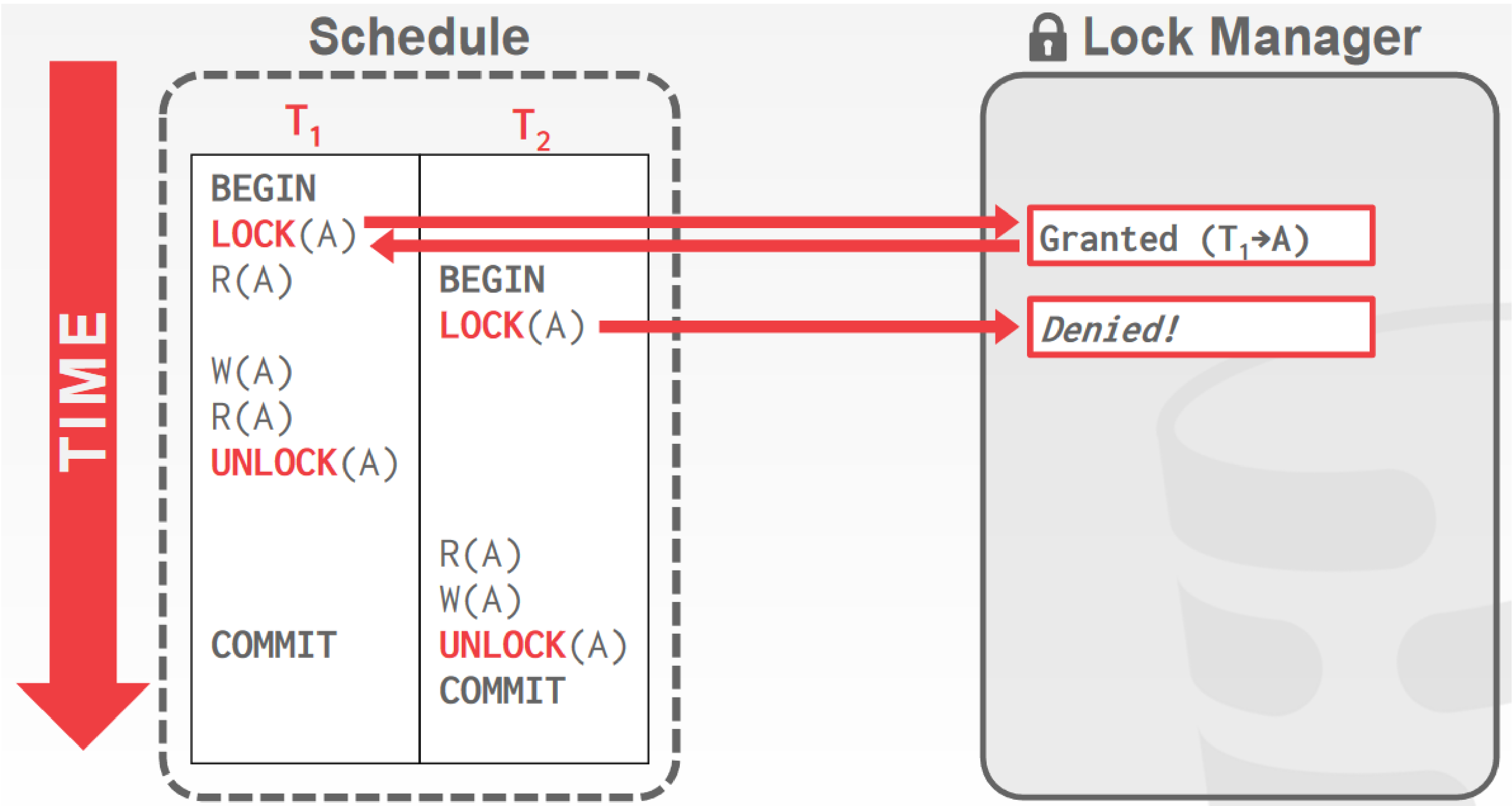
- Now we'll learn about **locking** for **concurrency control**

Intuition



Schedule
Lock Manager
TIME
T_1
T_2
BEGIN
LOCK(A)
R(A)
W(A)
R(A)
UNLOCK(A)
COMMIT
BEGIN
LOCK(A)
R(A)
W(A)
UNLOCK(A)
COMMIT
Granted (T_1→A)

Intuition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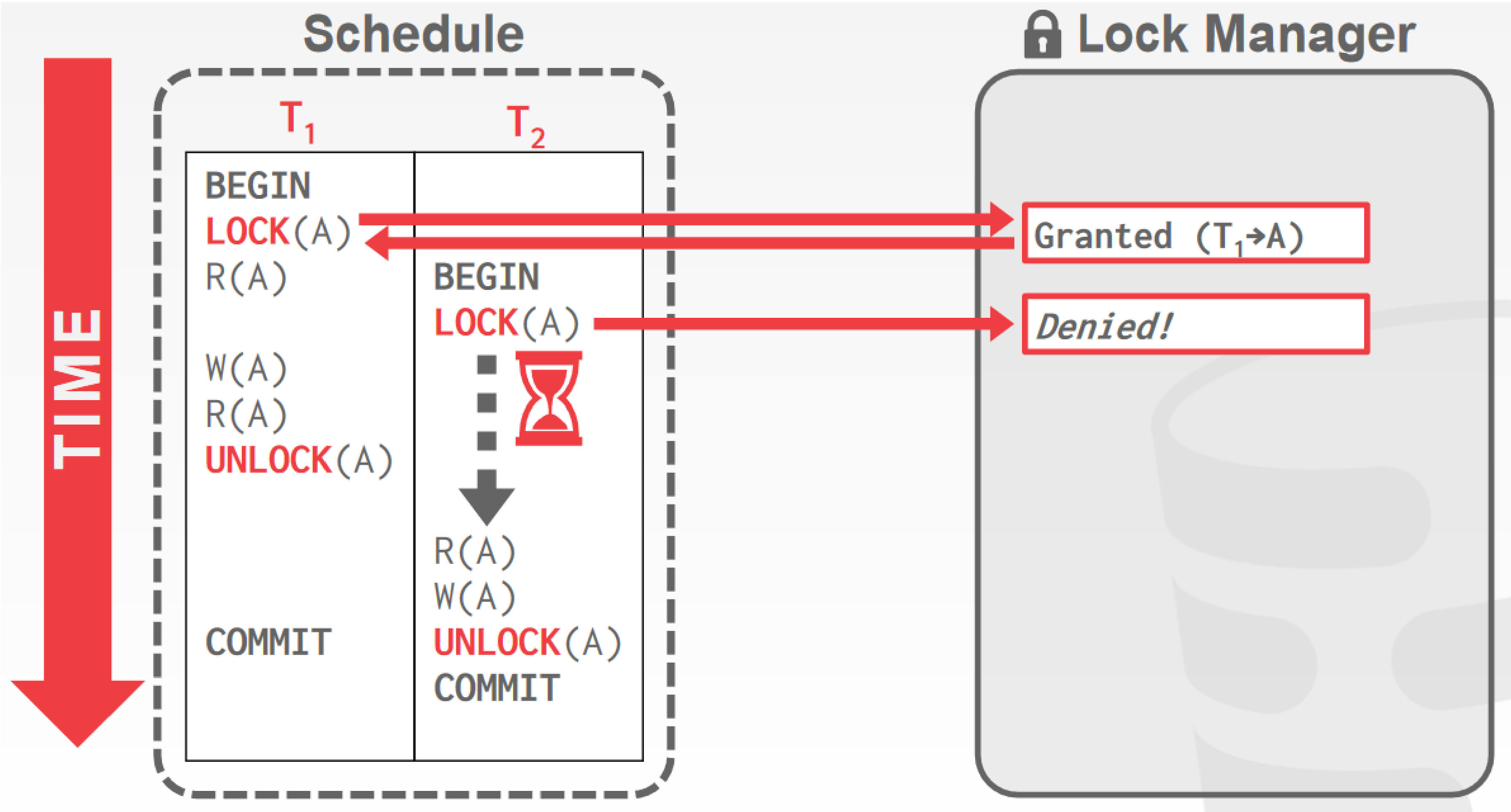
LOCK(A)
R(A)
BEGIN
LOCK(A)
W(A)
R(A)
UNLOCK(A)
R(A)
W(A)
COMMIT
UNLOCK(A)
COMMIT
Granted (T_1→A)
Denied!

Intuition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T_1
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R(A)
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R(A)
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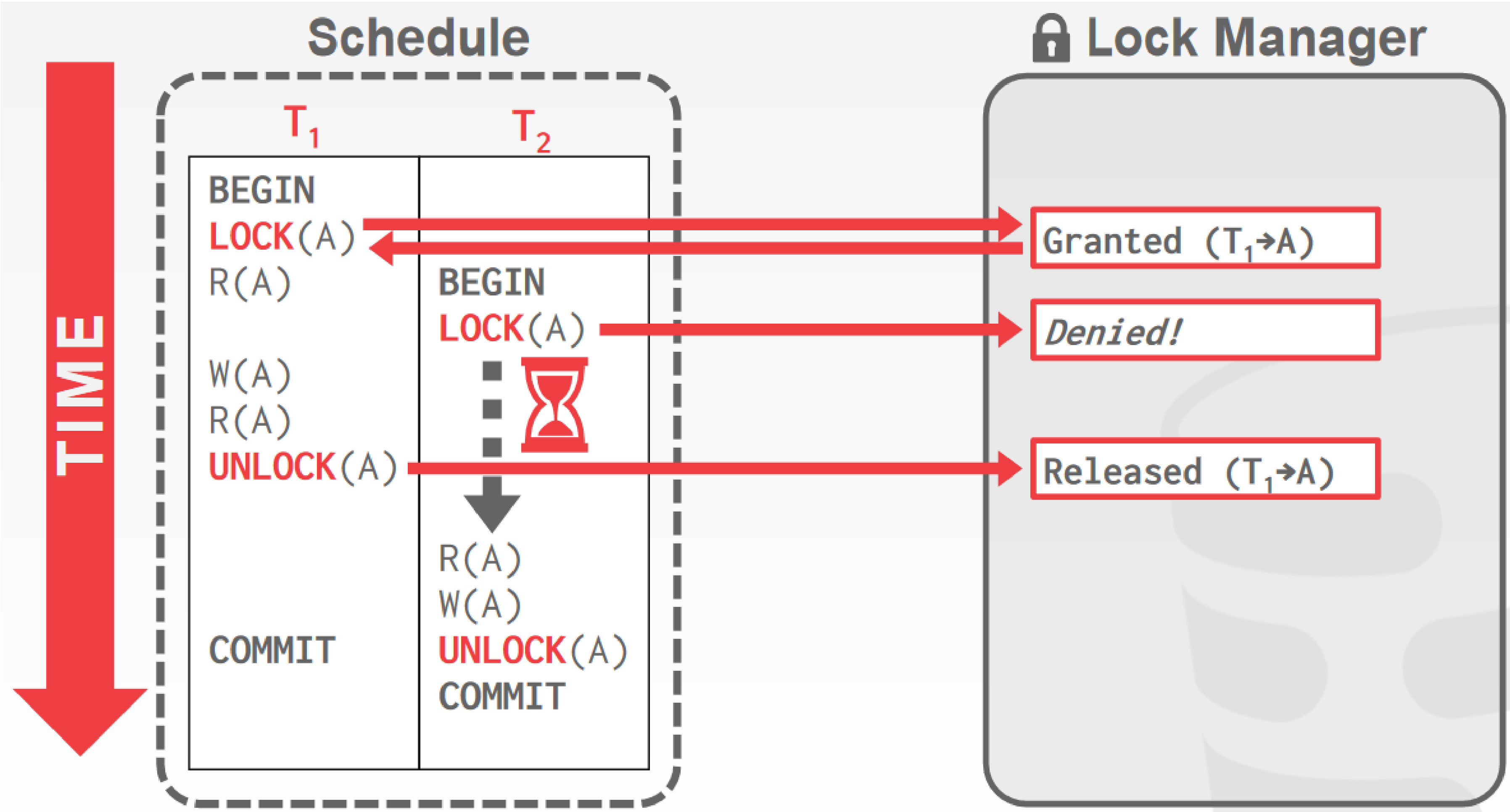
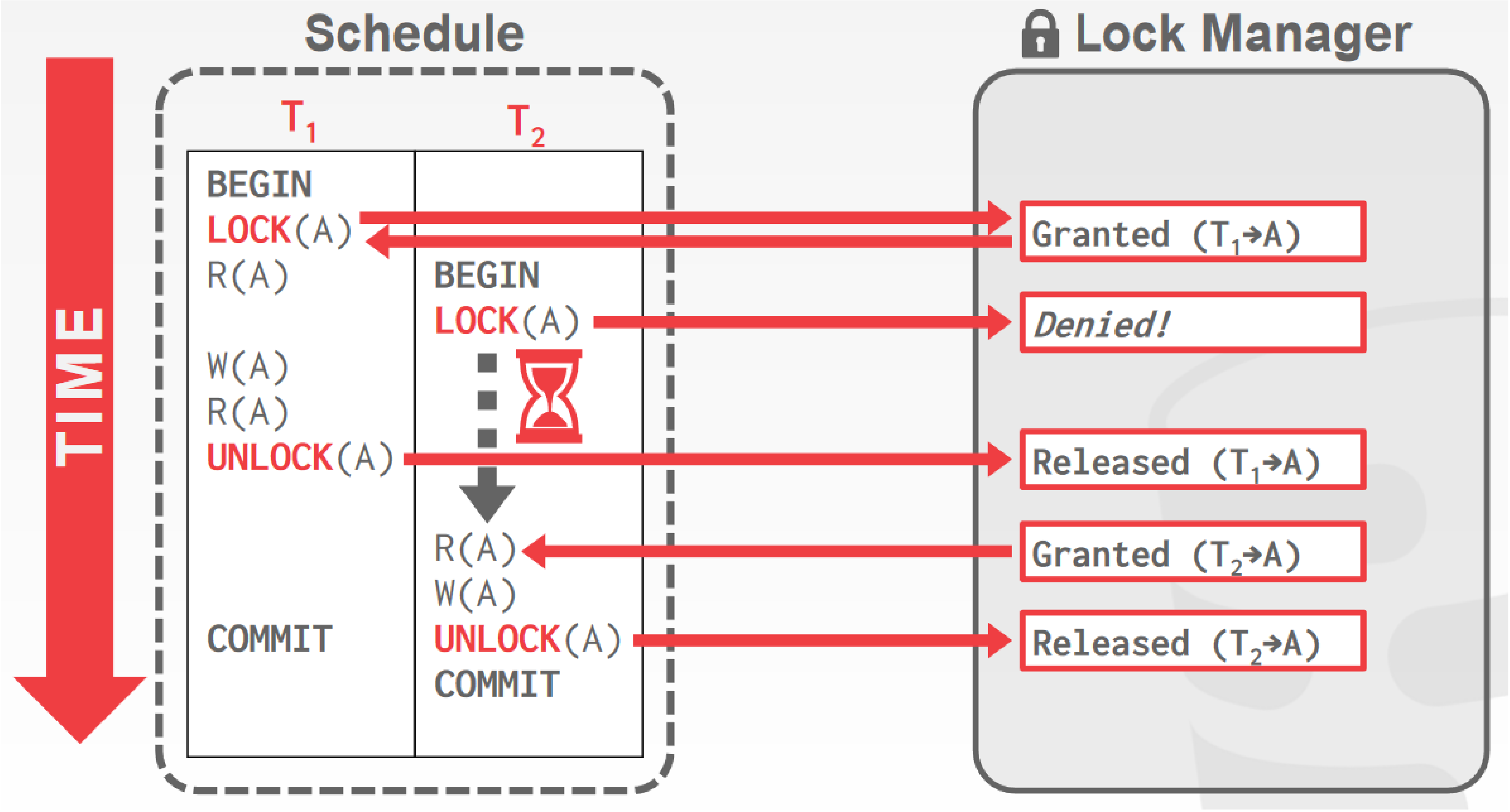
COMMIT
BEGIN
LOCK(A)
R(A)
W(A)
UNLOCK(A)
COMMIT
Granted (T_1→A)
Denied!

Intuition



Schedule
Lock Manager
TIME
T_1
T_2
BEGIN
LOCK(A)
R(A)
BEGIN
LOCK(A)
W(A)
R(A)
UNLOCK(A)
R(A)
W(A)
COMMIT
UNLOCK(A)
COMMIT
Granted (T_1→A)
Denied!
Released (T_1→A)

Intuition



Schedule
Lock Manager
TIME
T1
T2
BEGIN
LOCK(A)
R(A)
W(A)
R(A)
UNLOCK(A)
COMMIT
BEGIN
LOCK(A)
R(A)
W(A)
UNLOCK(A)
COMMIT
Granted (T1→A)
Denied!
Released (T1→A)
Granted (T2→A)
Released (T2→A)

Lock Types

- Two types of locks:
  - **Shared locks (S-lock):** for reads
  - **Exclusive locks (X-lock):** for writes

- Why not use shared locks for writes?
- Why not use exclusive locks for reads?

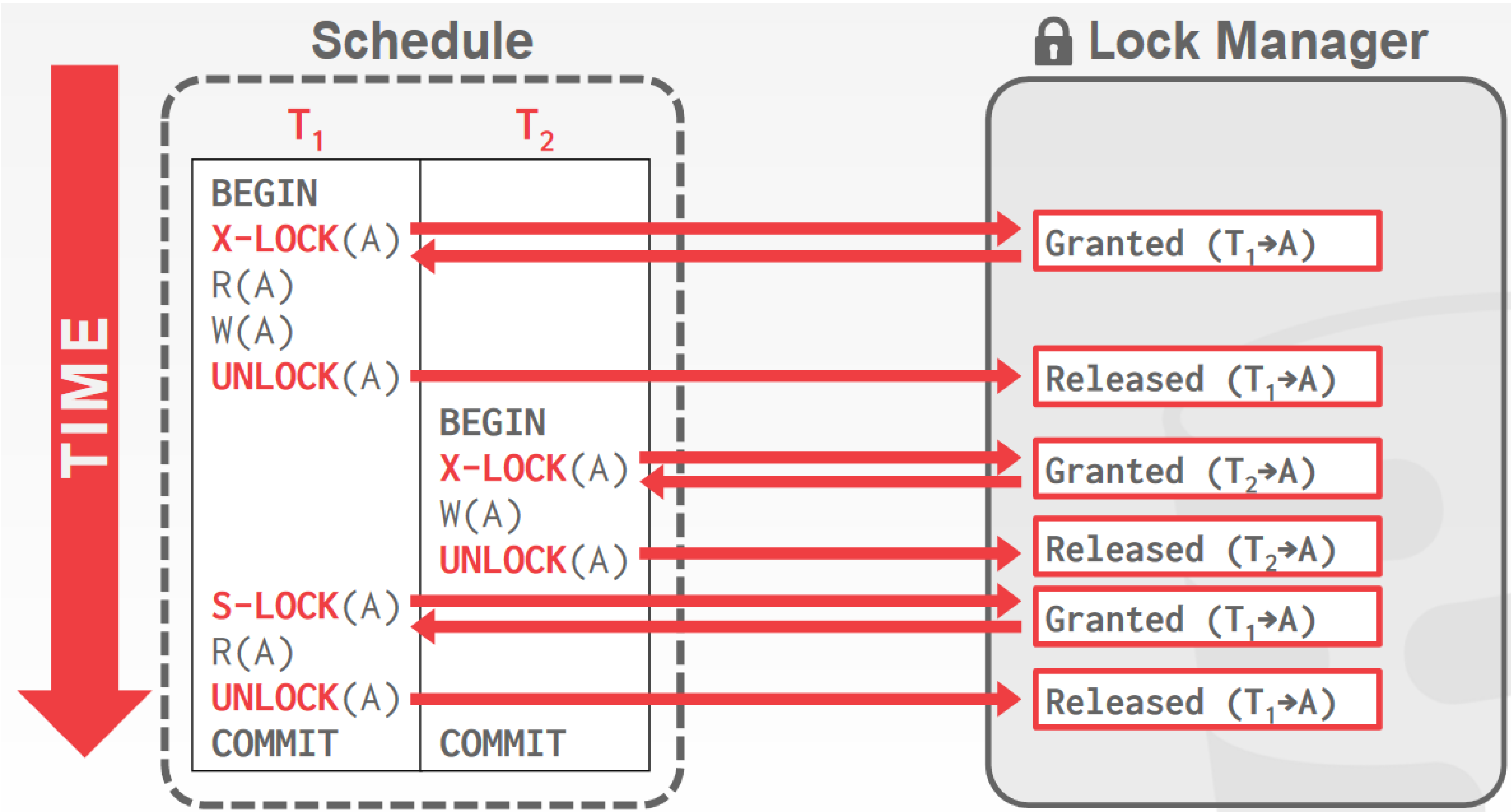
Compatibility Matrix

	Shared	Exclusive
Shared	✓	X
Exclusive	X	X

Executing with Locks

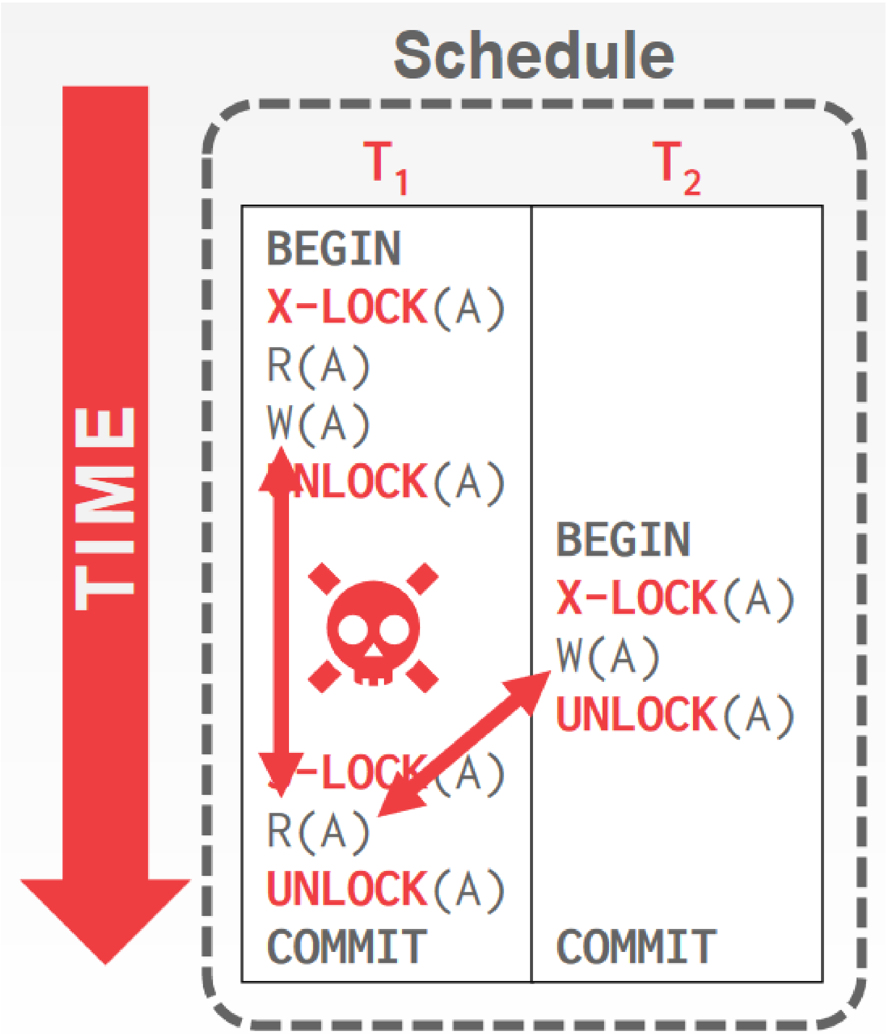
- Execution using locks:
  - Transactions request locks.
  - Lock manager grants or denies requests.
  - Once transactions are done with the DB object, they release their locks (unlock).
  - Lock manager keeps track of:
    - which transactions hold which locks on which objects
    - which transactions are waiting to acquire locks

Executing with Locks



Do you see a problem here?

Executing with Locks

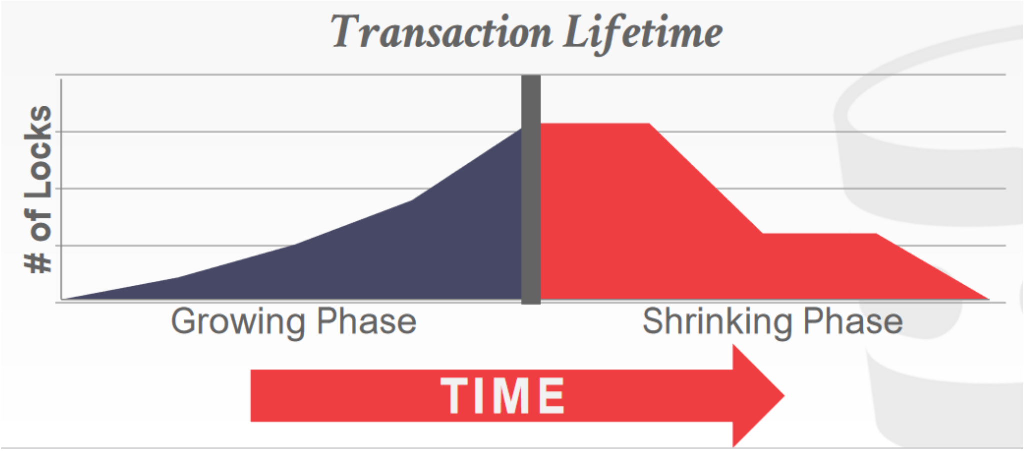


T_1 is expecting to read what it wrote but ends up reading what T_2 wrote.

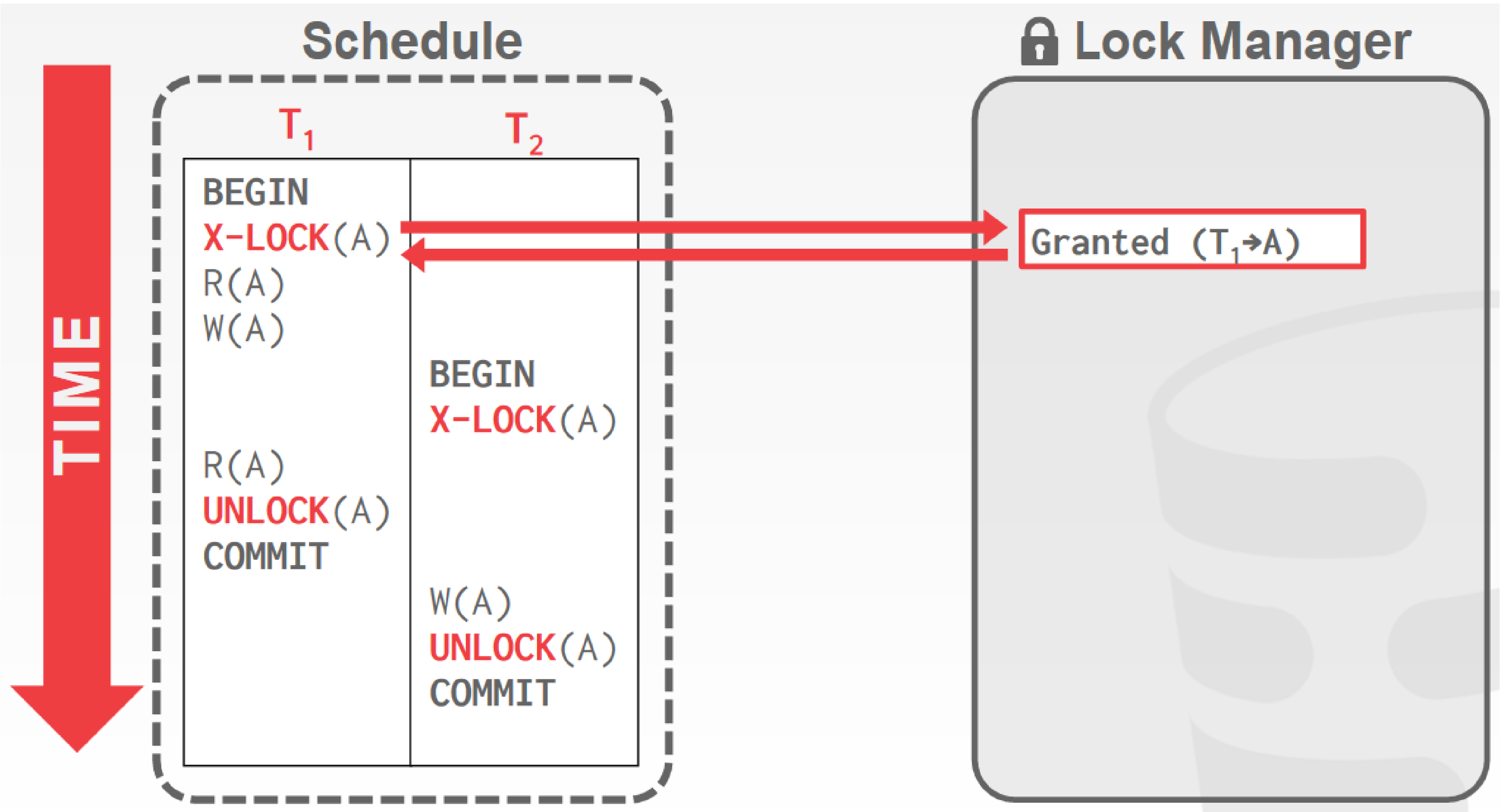
What if T_2 decides to abort later?

Two-Phase Locking

- **Two-phase locking (2PL)** is a commonly used concurrency control protocol.
  - Phase #1: **Growing**
    - Each transaction requests locks from DBMS lock manager.
    - Lock manager grants or denies lock requests.
  - Phase #2: **Shrinking**
    - The transaction is allowed to release previously acquired locks, but it is not allowed to acquire new locks.

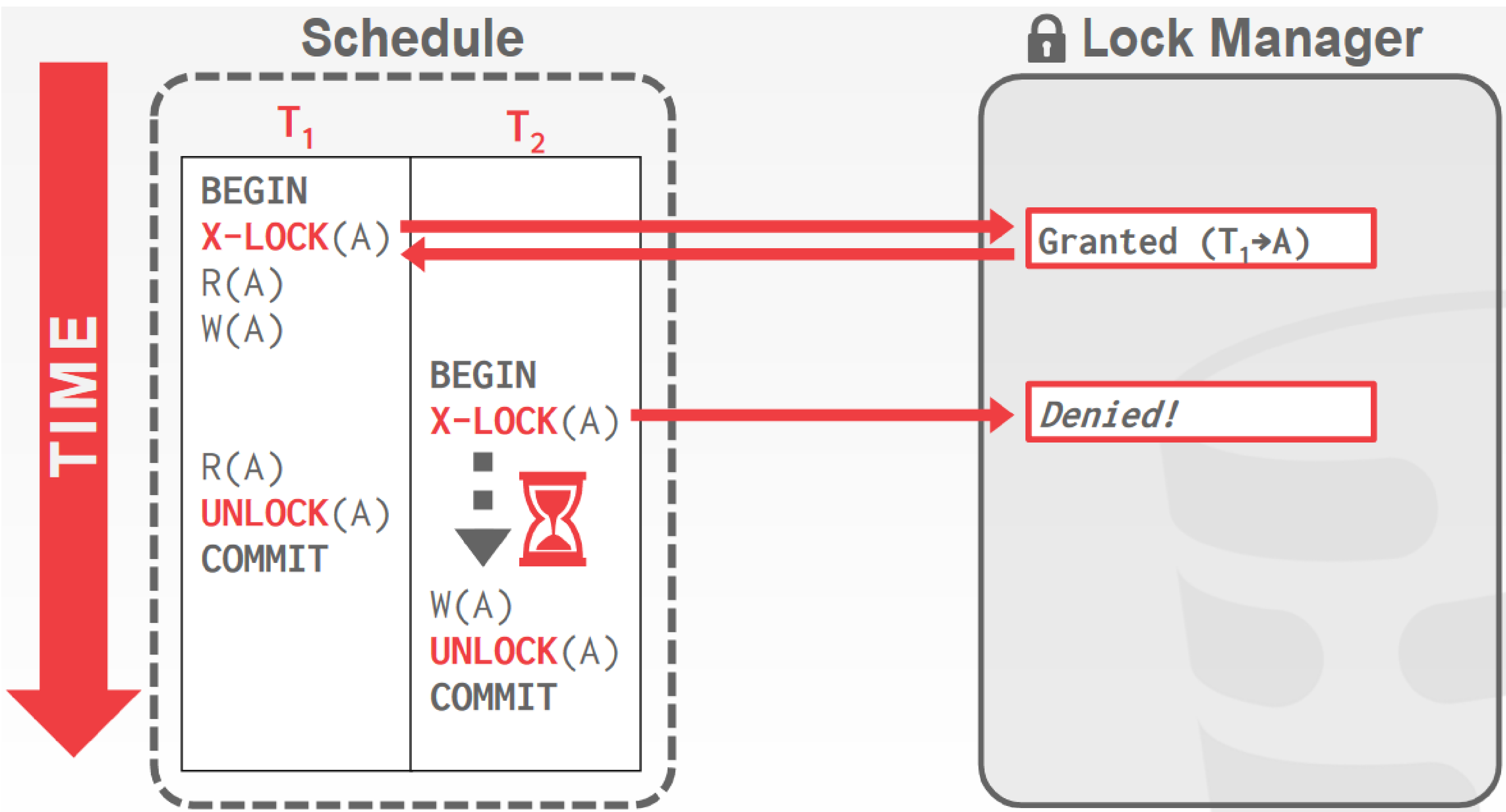


Executing with 2PL

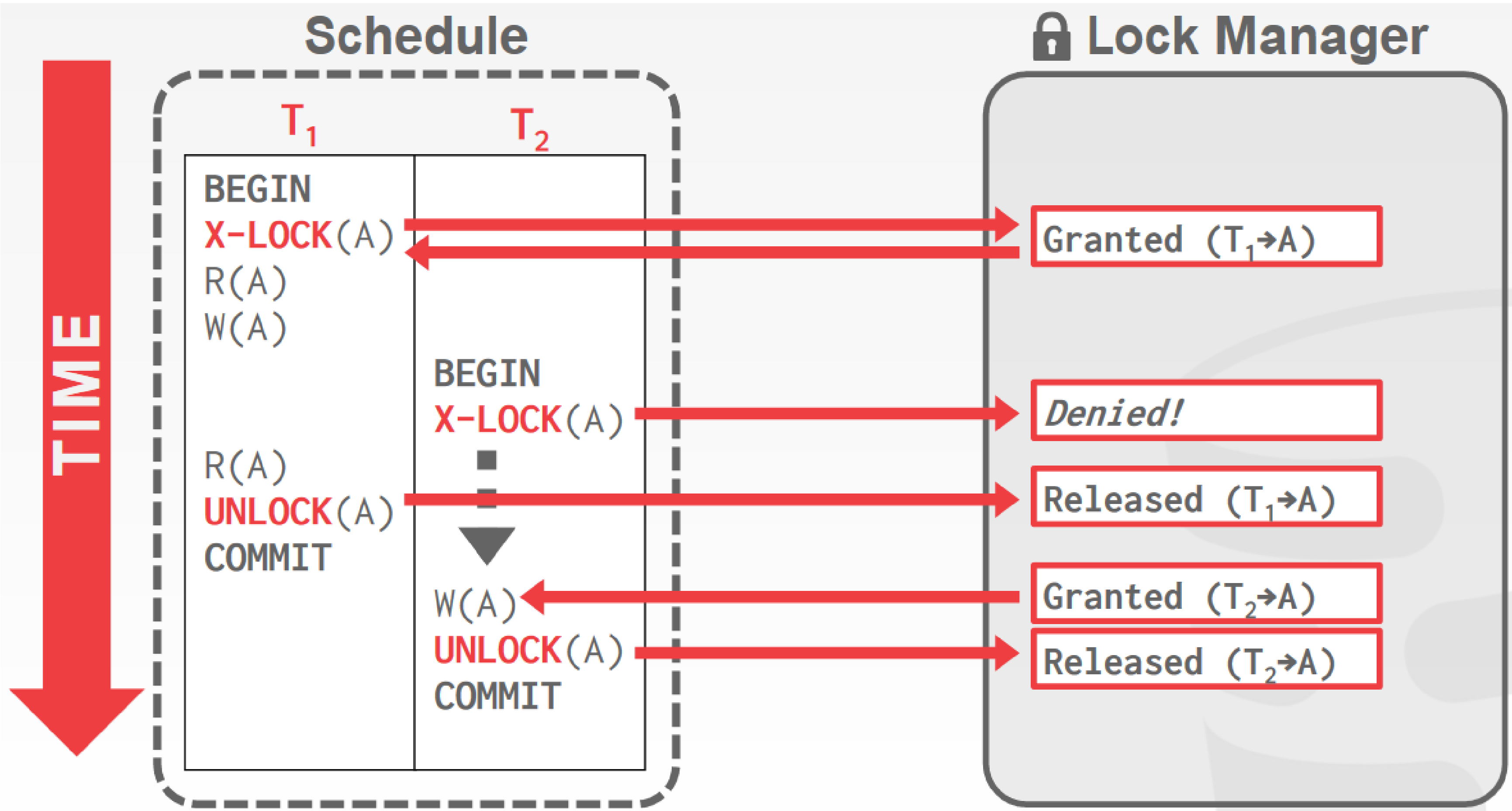


What is the main difference with the previous case?

Executing with 2PL

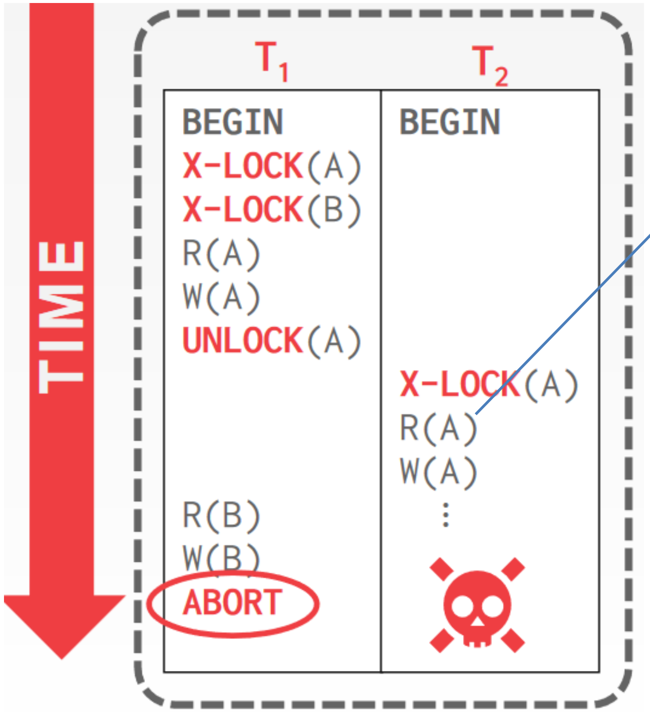


Executing with 2PL



Cascading Aborts

- 2PL is sufficient to guarantee conflict serializability.
- But 2PL is subject to the **cascading aborts** problem.
  - When a transaction aborts, it causes other transactions to also have to abort.

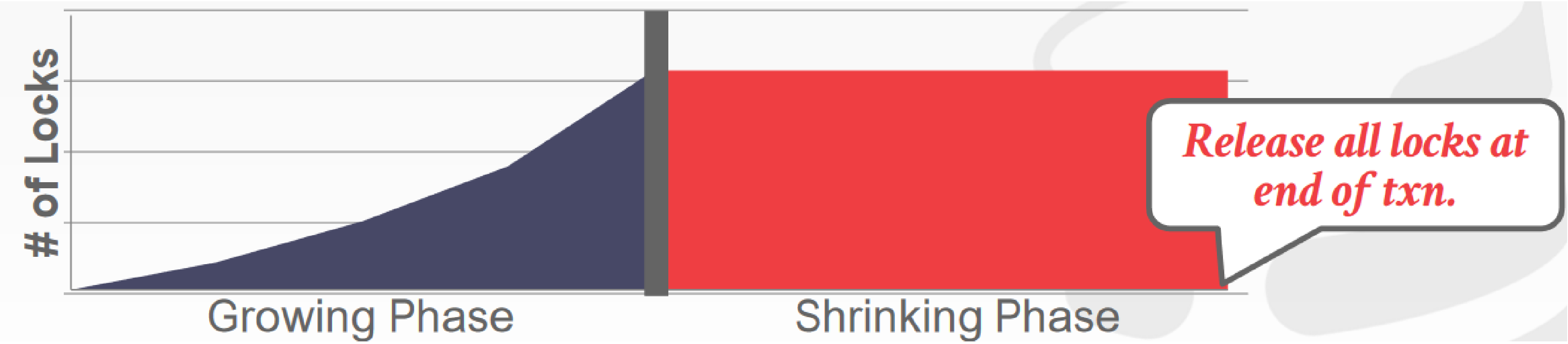


But T_2 had read what T_1 wrote and assumed that it was true!

So, when T_1 aborts we must also abort T_2.

Strict 2PL

- All locks held by a transaction are released when the transaction completes.
  - No unlocking in the middle of a transaction.
  - If I have an X-lock on A, noone else can get an S-lock or X-lock on A before I commit or abort.
  - Hence, noone can read/write on A before I am finished.
  - Hence, no cascading aborts.



Example (Non-2PL)

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	
	S-LOCK(A)
A=A-100	
W(A)	
UNLOCK(A)	
	R(A)
	UNLOCK(A)
	S-LOCK(B)
X-LOCK(B)	
	R(B)
	UNLOCK(B)
R(B)	ECHO A+B
B=B+100	COMMIT
W(B)	
UNLOCK(B)	
COMMIT	

Assume A=1000, B=1000 initially.

What are the two transactions intending to do?

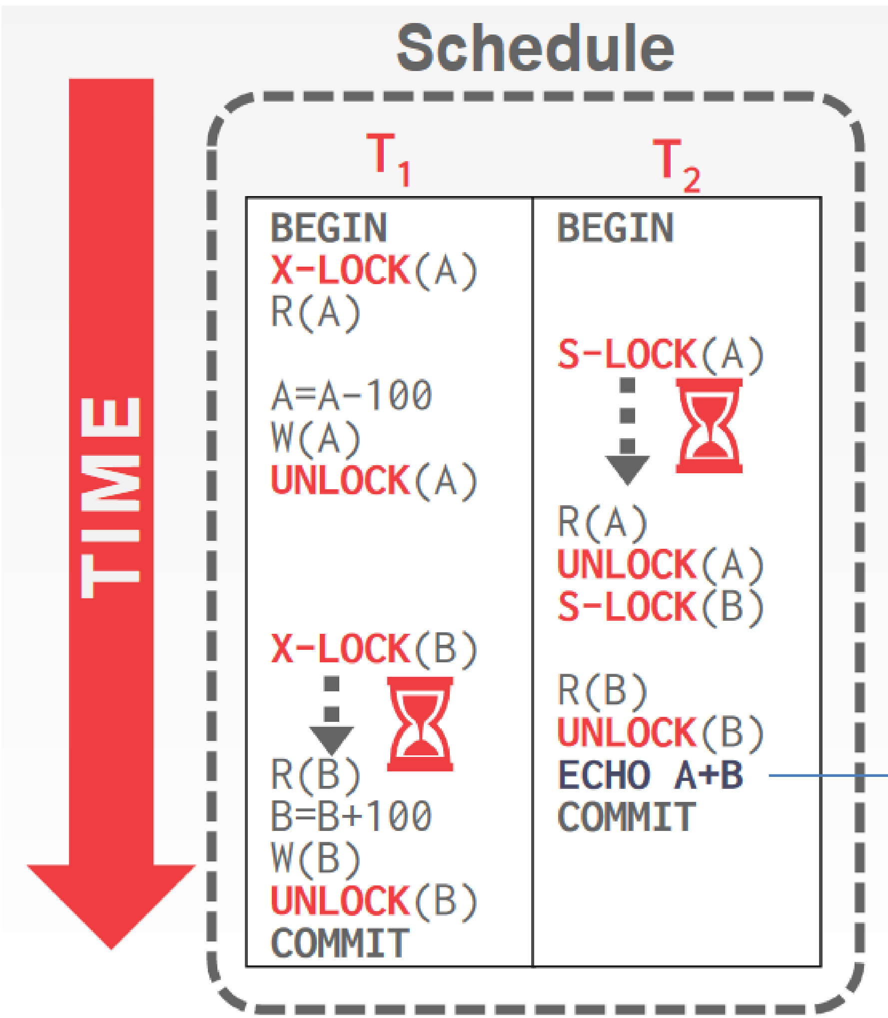
Example (Non-2PL)

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	
	S-LOCK(A)
A=A-100	
W(A)	
UNLOCK(A)	
	R(A)
	UNLOCK(A)
	S-LOCK(B)
X-LOCK(B)	
	R(B)
	UNLOCK(B)
R(B)	ECHO A+B
B=B+100	COMMIT
W(B)	
UNLOCK(B)	
COMMIT	

Example (Non-2PL)



Assume A=1000, B=1000 initially.

What gets printed out?

What are the final values of A and B?

Example (2PL)

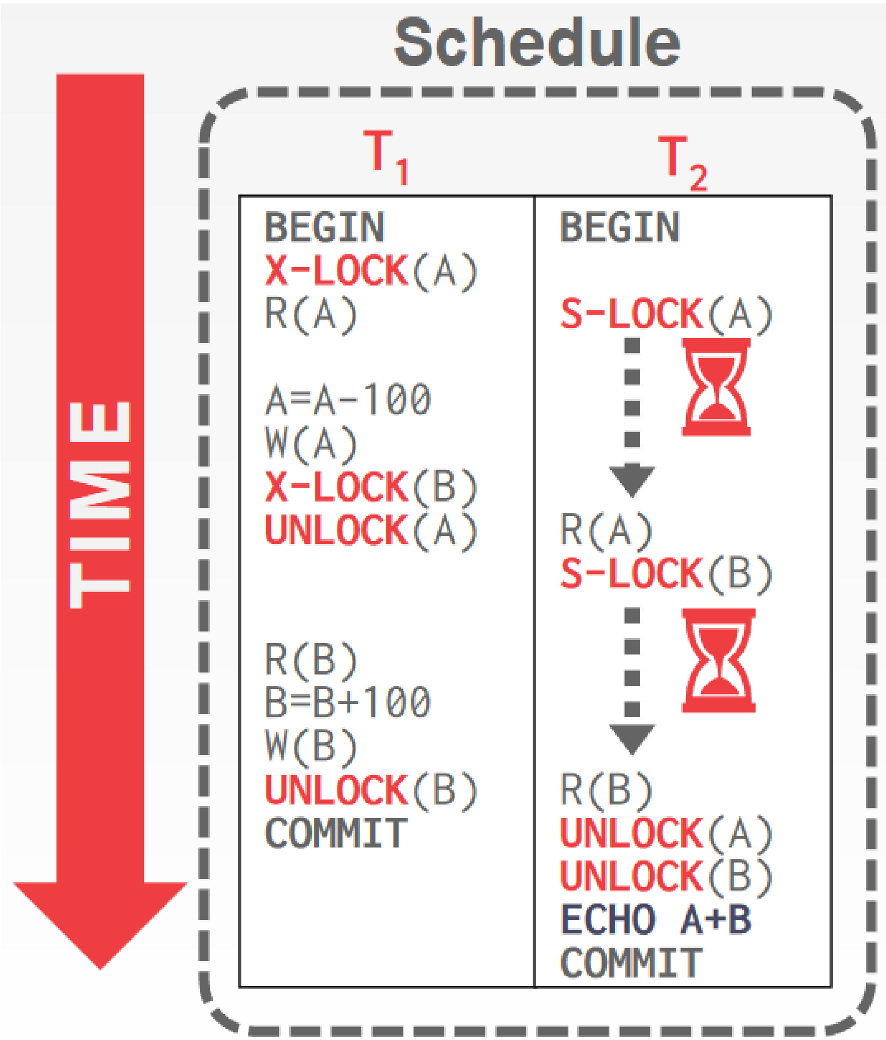
Schedule

TIME

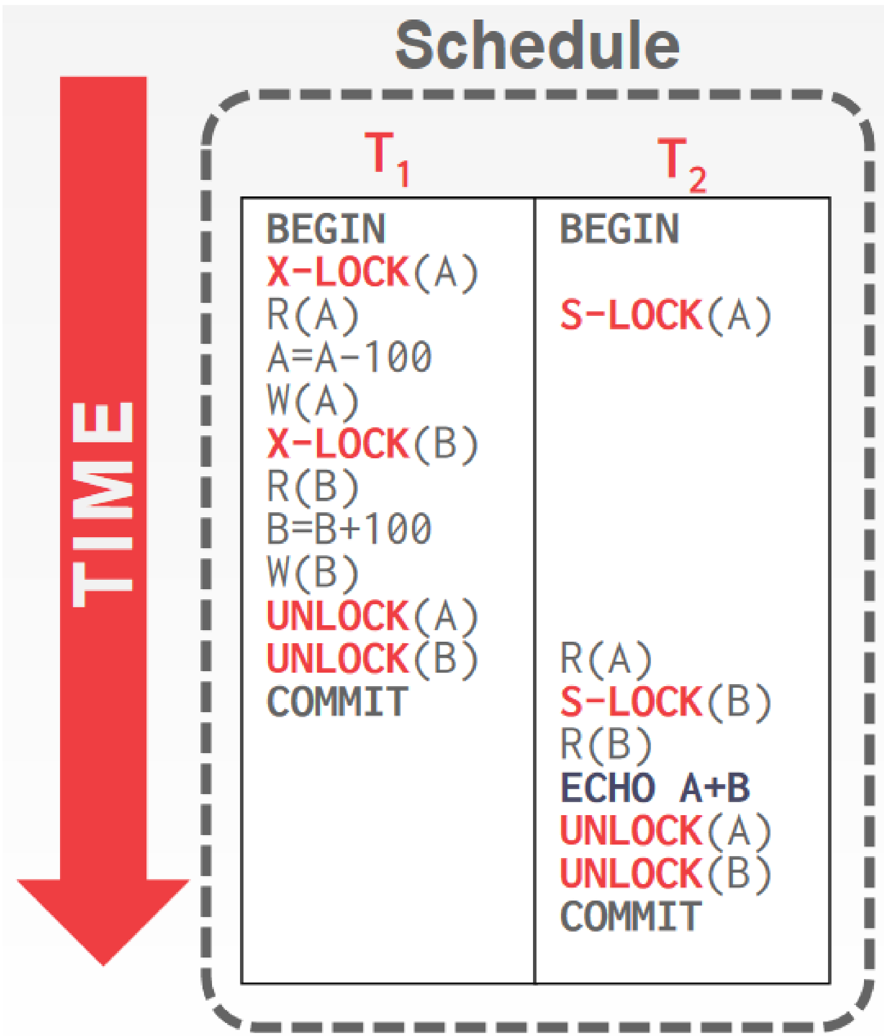
T_1	T_2
BEGIN	BEGIN
X-LOCK(A)	
R(A)	S-LOCK(A)
A=A-100	
W(A)	
X-LOCK(B)	
UNLOCK(A)	R(A)
	S-LOCK(B)
R(B)	
B=B+100	
W(B)	
UNLOCK(B)	R(B)
COMMIT	UNLOCK(A)
	UNLOCK(B)
	ECHO A+B
	COMMIT

Assume A=1000, B=1000 initially.

Example (2PL)


Schedule
TIME
T1
T2
BEGIN
X-LOCK(A)
R(A)
A=A-100
W(A)
X-LOCK(B)
UNLOCK(A)
R(B)
B=B+100
W(B)
UNLOCK(B)
COMMIT
BEGIN
S-LOCK(A)
R(A)
S-LOCK(B)
R(B)
UNLOCK(A)
UNLOCK(B)
ECHO A+B
COMMIT

Example (Strict 2PL)



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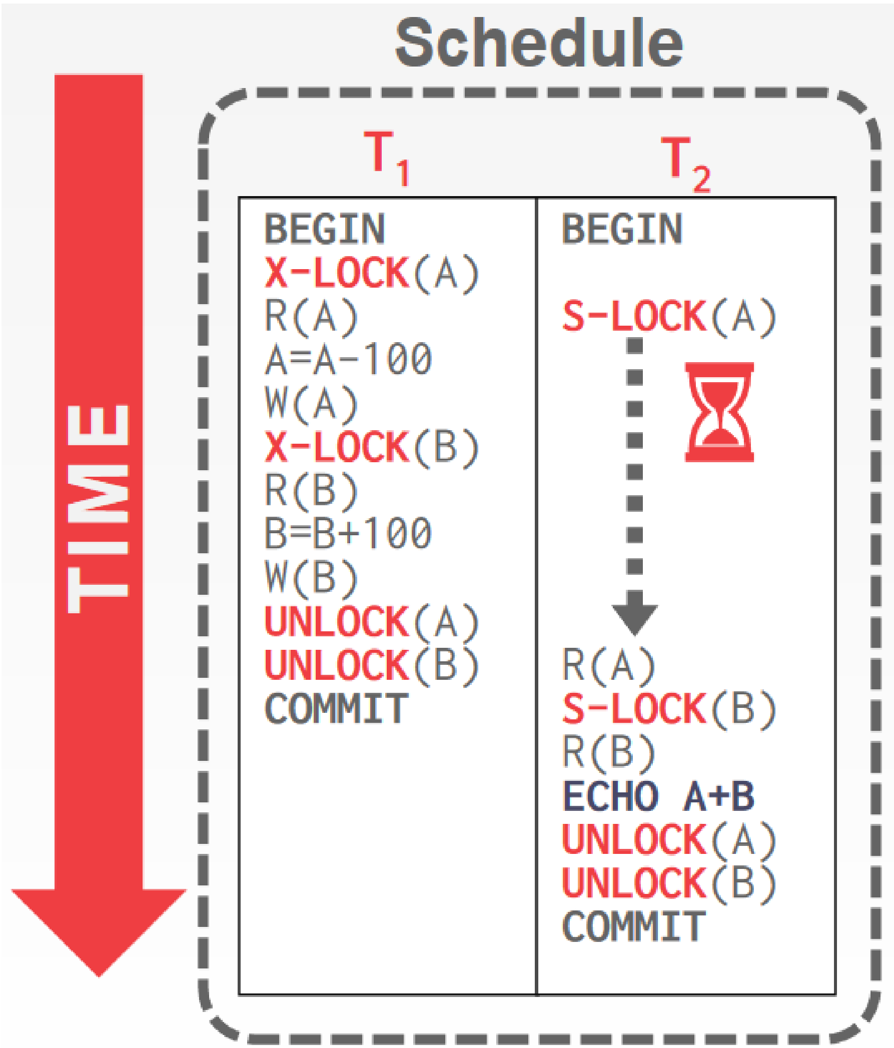
Example (Strict 2PL)



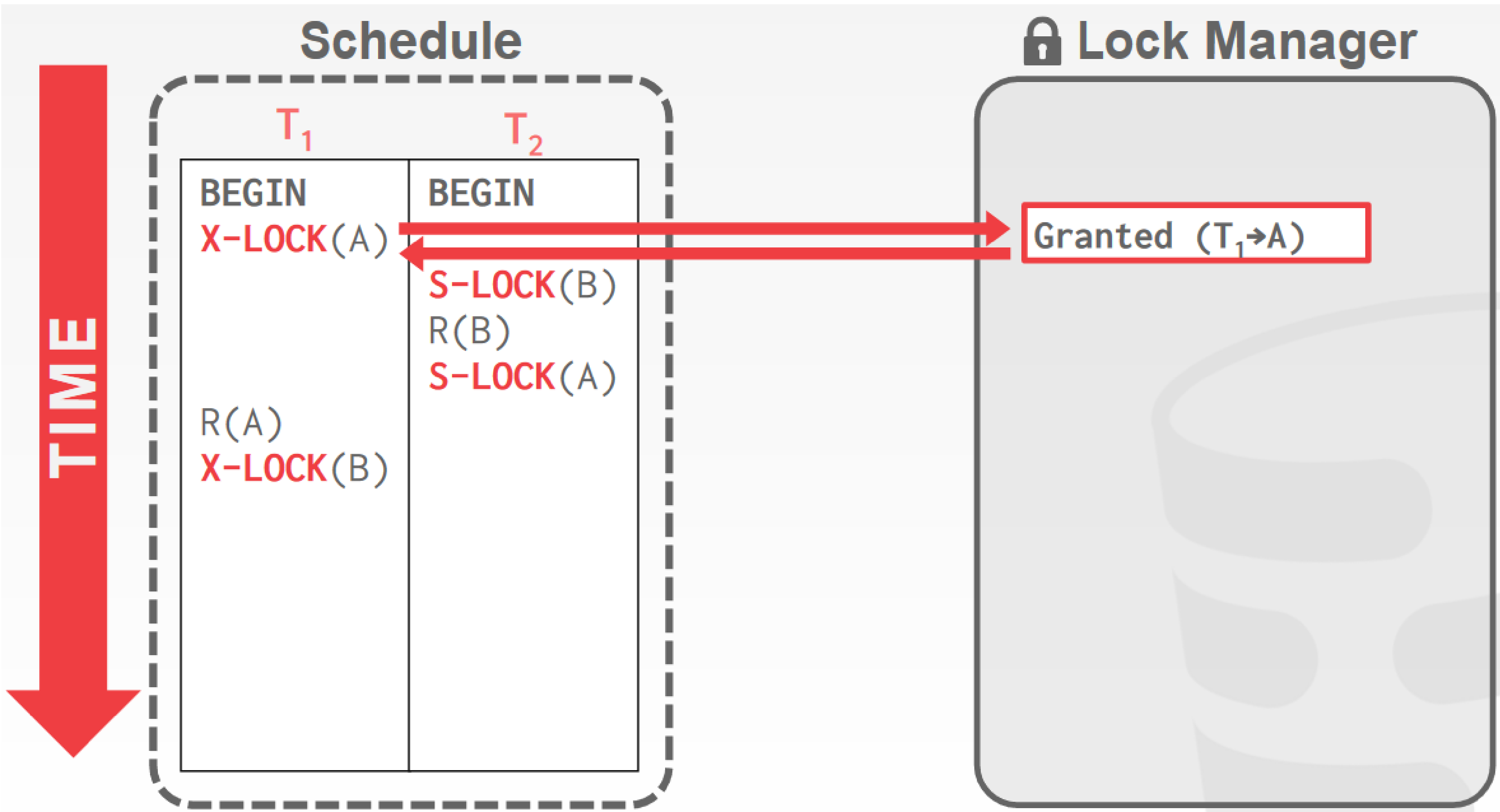
Deadlocks

- 2PL can lead to deadlocks.

- A <u>**deadlock**</u> is a cycle of transactions waiting for locks to be released by each other.
  - T_1 locks A, needs access to B in order to continue.
  - T_2 locks B, needs access to A in order to continue.

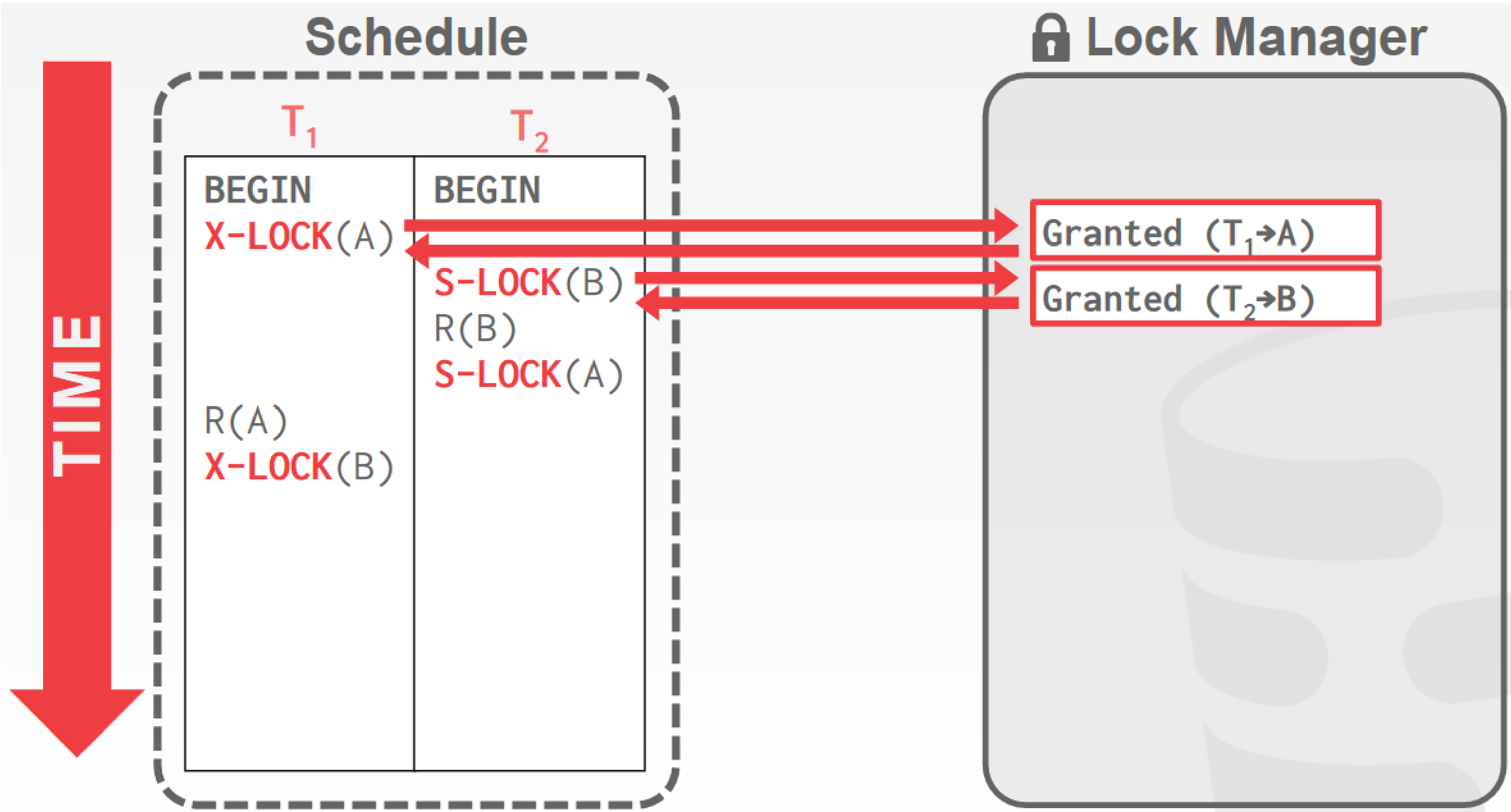
- Two issues related to deadlocks:
  - Deadlock detection
  - Deadlock prevention

Deadlocks



Schedule
Lock Manager
TIME
T1
T2
BEGIN
X-LOCK(A)
R(A)
X-LOCK(B)
BEGIN
S-LOCK(B)
R(B)
S-LOCK(A)
Granted (T1→A)

Deadlocks



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T_1
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BEGIN
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R(A)
X-LOCK(B)
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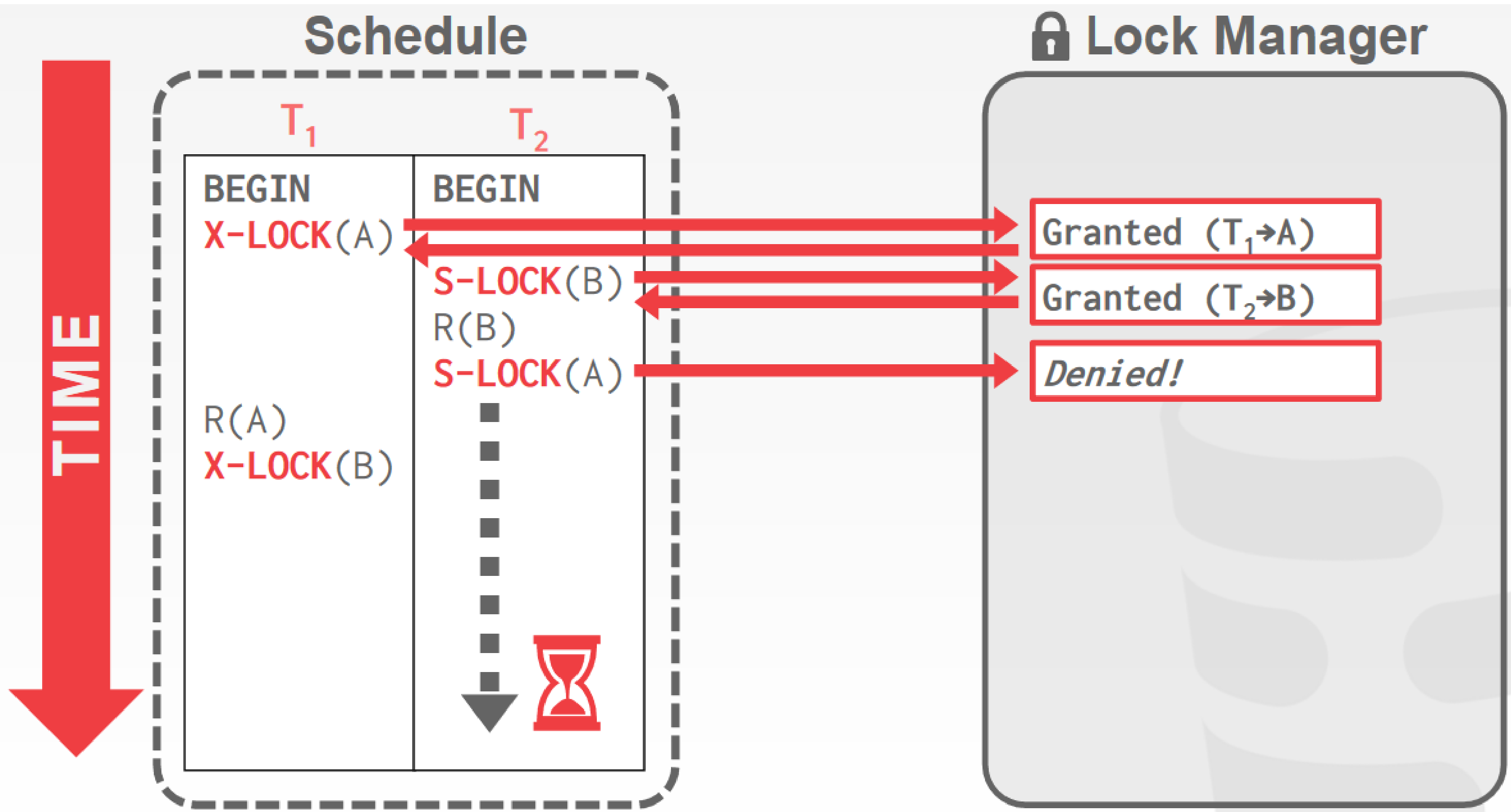
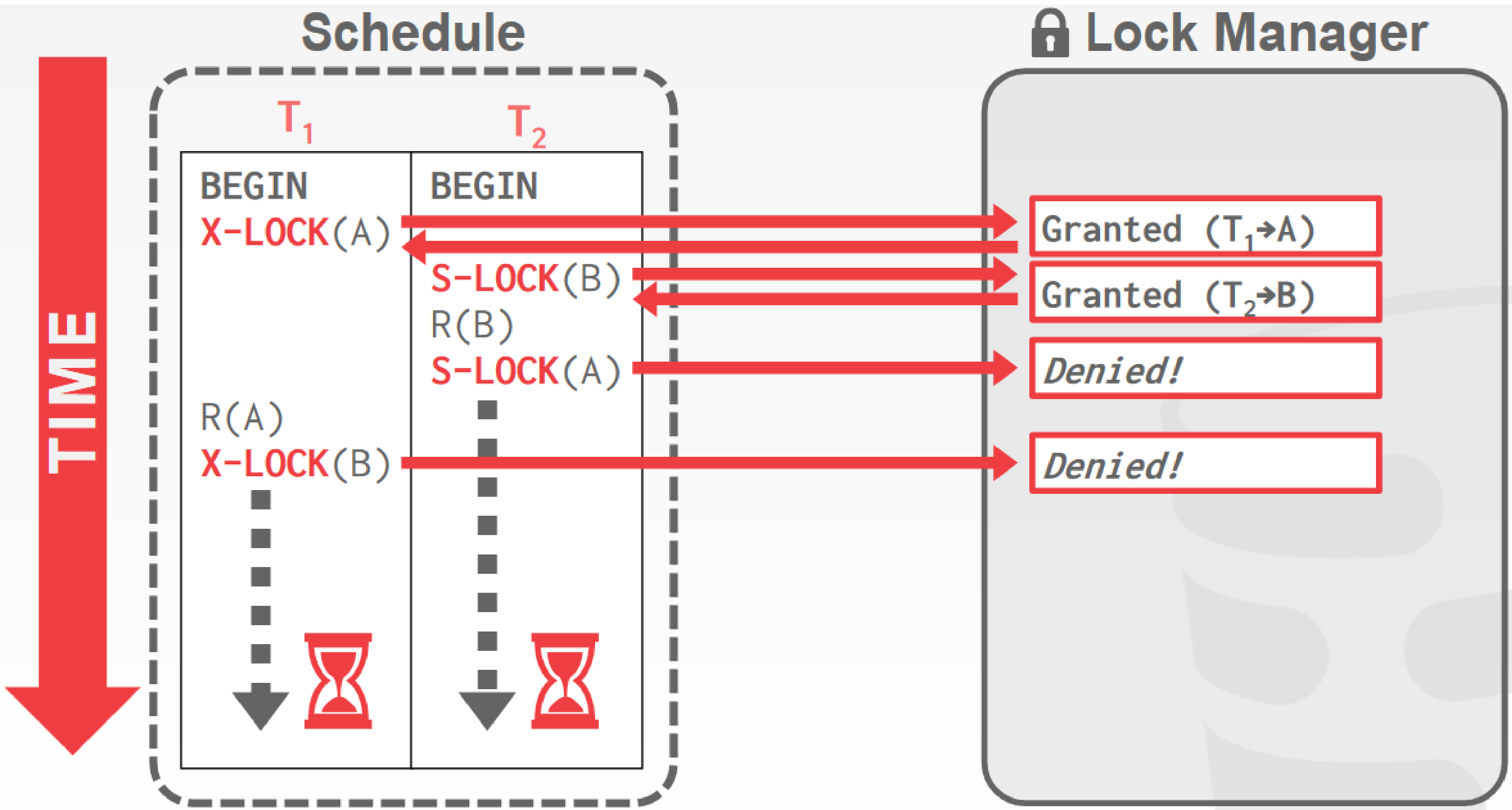
S-LOCK(B)
R(B)
S-LOCK(A)
Granted (T_1→A)
Granted (T_2→B)

Deadlocks



Schedule
Lock Manager
TIME
T_1
T_2
BEGIN
BEGIN
X-LOCK(A)
S-LOCK(B)
R(B)
S-LOCK(A)
R(A)
X-LOCK(B)
Granted (T_1→A)
Granted (T_2→B)
Denied!

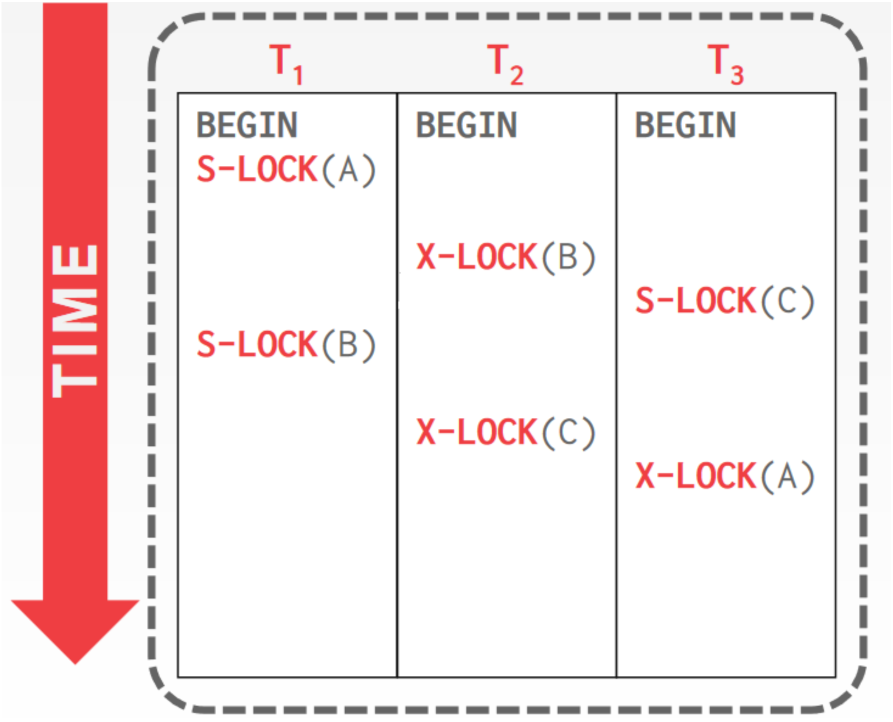
Deadlocks

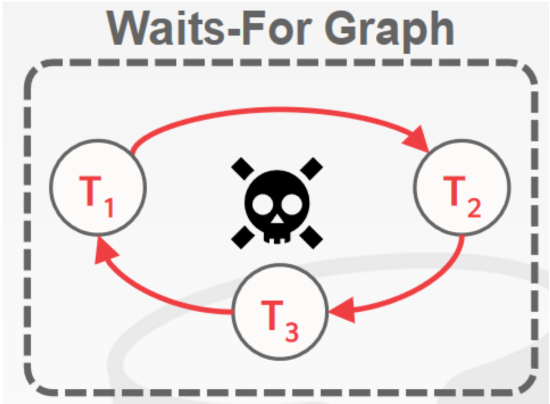


Schedule
Lock Manager
TIME
T_1
T_2
BEGIN
BEGIN
X-LOCK(A)
S-LOCK(B)
R(B)
S-LOCK(A)
R(A)
X-LOCK(B)
Granted (T_1→A)
Granted (T_2→B)
Denied!
Denied!

Deadlock Detection

- We create a **waits-for graph**:
  - Each node is a transaction
  - Edge from T_i to T_j if T_i is waiting for T_j to release a lock
- Cycle in the graph means there's a deadlock





Deadlock Detection

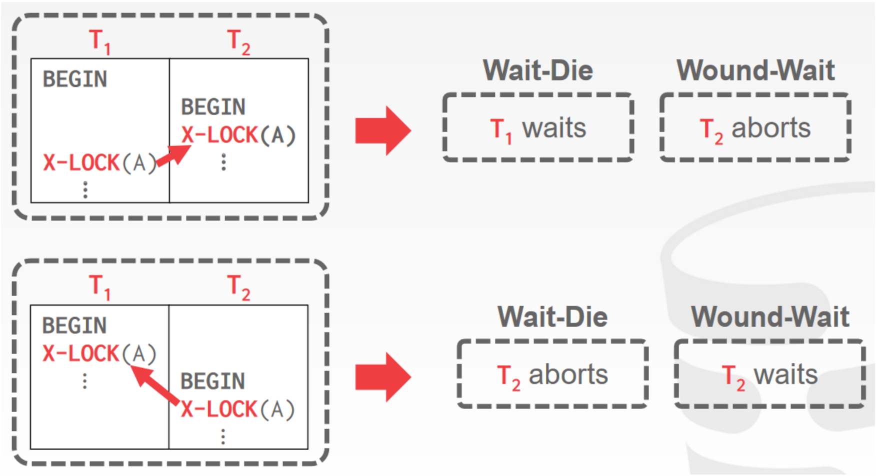
- When the DBMS detects a deadlock using the waits-for graph, it will select a victim transaction to break the cycle.
  - The victim is forced to restart or abort.

- How to select the proper victim? Possible heuristics:
  - By age (e.g., lowest timestamp)
  - By progress (e.g., fewest queries executed)
  - # of objects locked
  - ...

- We should keep in mind whether a transaction has been selected as a victim before, to avoid starvation.

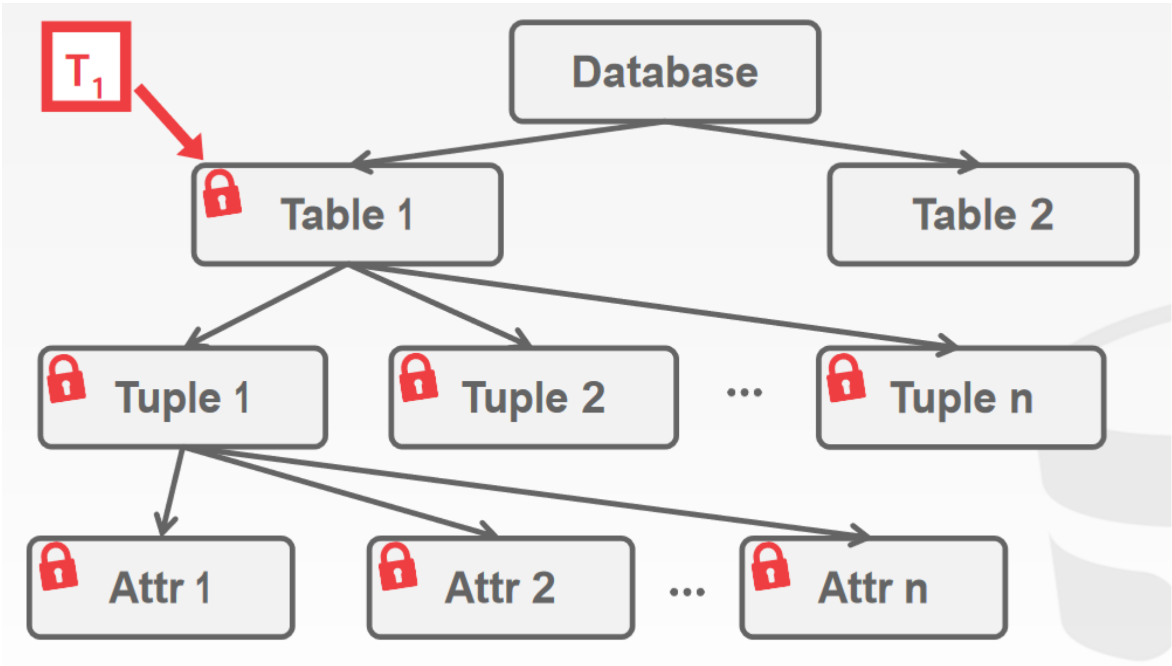
Deadlock Prevention

- When T_i tries to acquire a lock that is held by T_j, the DBMS "stops" one of them to prevent a deadlock.
  - Doesn't require a waits-for graph
- How to determine which transaction to stop?
  - **<u>Wait-Die:</u>** If T_i started earlier than T_j, then T_i waits for T_j. Otherwise T_i aborts.
  - **<u>Wound-Wait:</u>** If T_i started earlier than T_j, then T_j aborts and releases lock. Otherwise T_i waits.



Multi-Granularity Locking

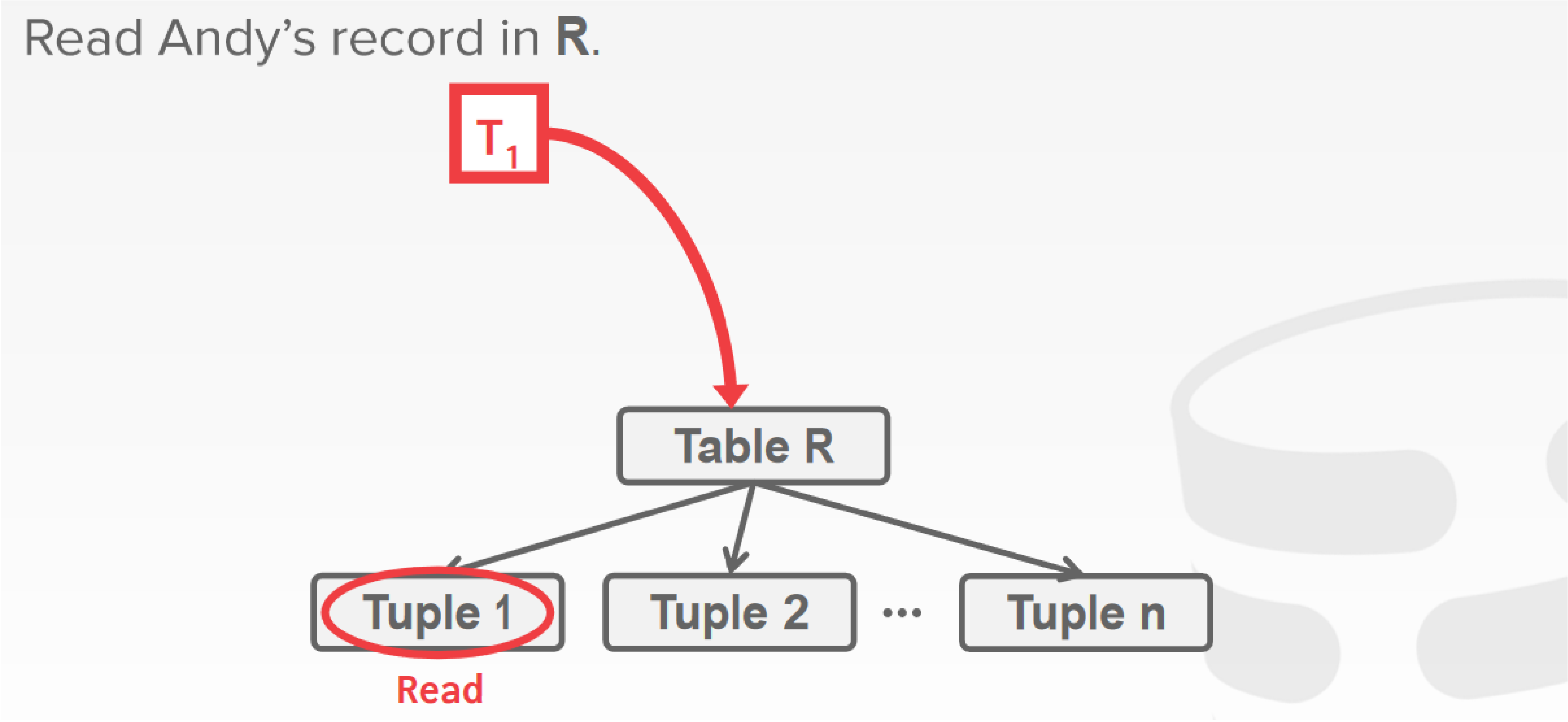
- What are these database objects we have been locking?
  - Tables? Tuples? Attributes?
  - Locking too coarse: many conflicts, deadlocks
  - Locking too granular: can be inefficient



Multi-Granularity Locking

- An **intention lock** allows a higher level node to be locked without having to check all descendant nodes.
  - If a node is intention locked, then explicit locking is being done at a lower level in the tree.
- Five types of locks:
  - S lock: shared lock (same as before)
  - X lock: exclusive lock (same as before)
  - IS lock: intention-shared lock
    - You get IS at the parent, then S at one or more descendants
  - IX lock: intention-exclusive lock
    - You get IX at the parent, then X or S at one or more descendants
  - SIX lock: S + IX together

Example



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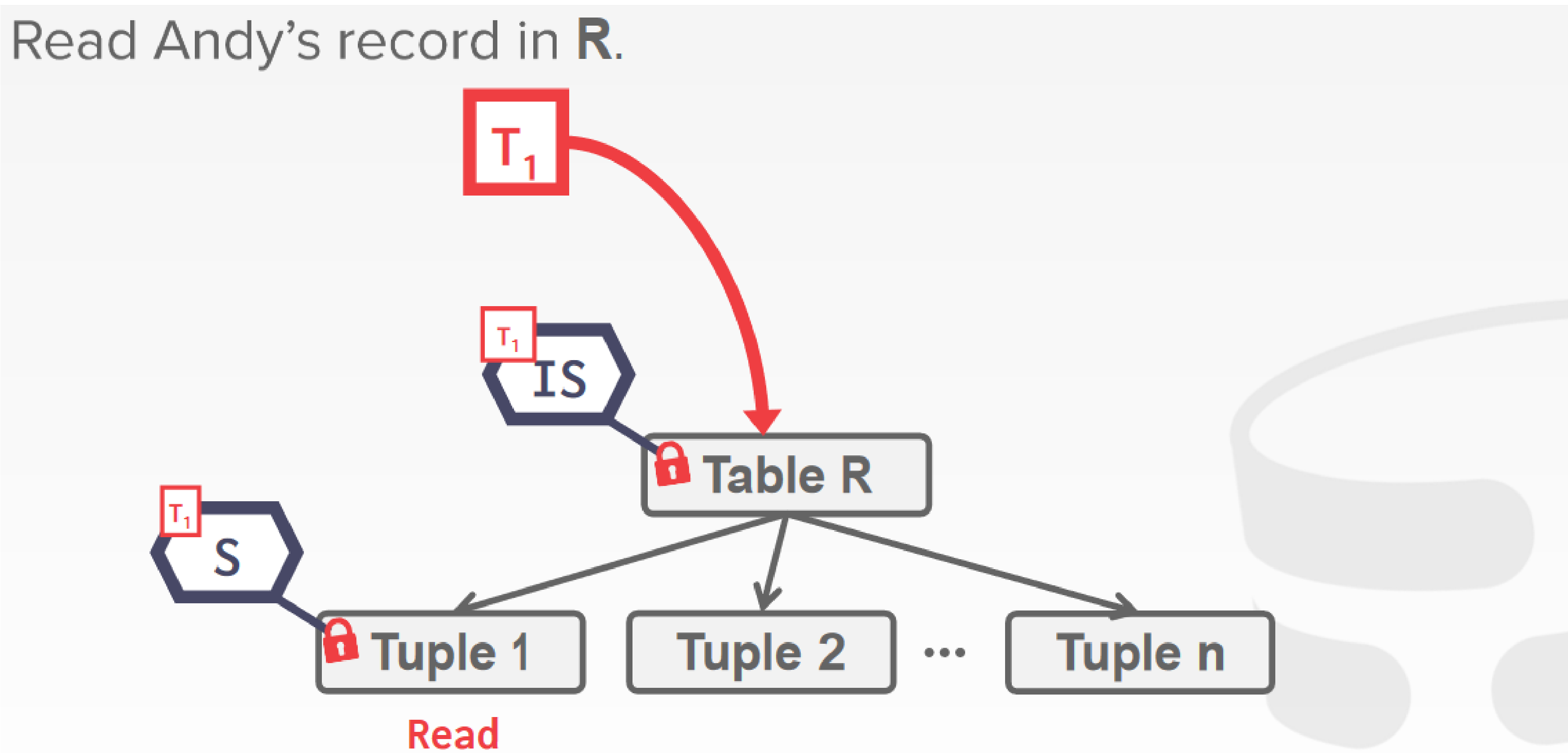
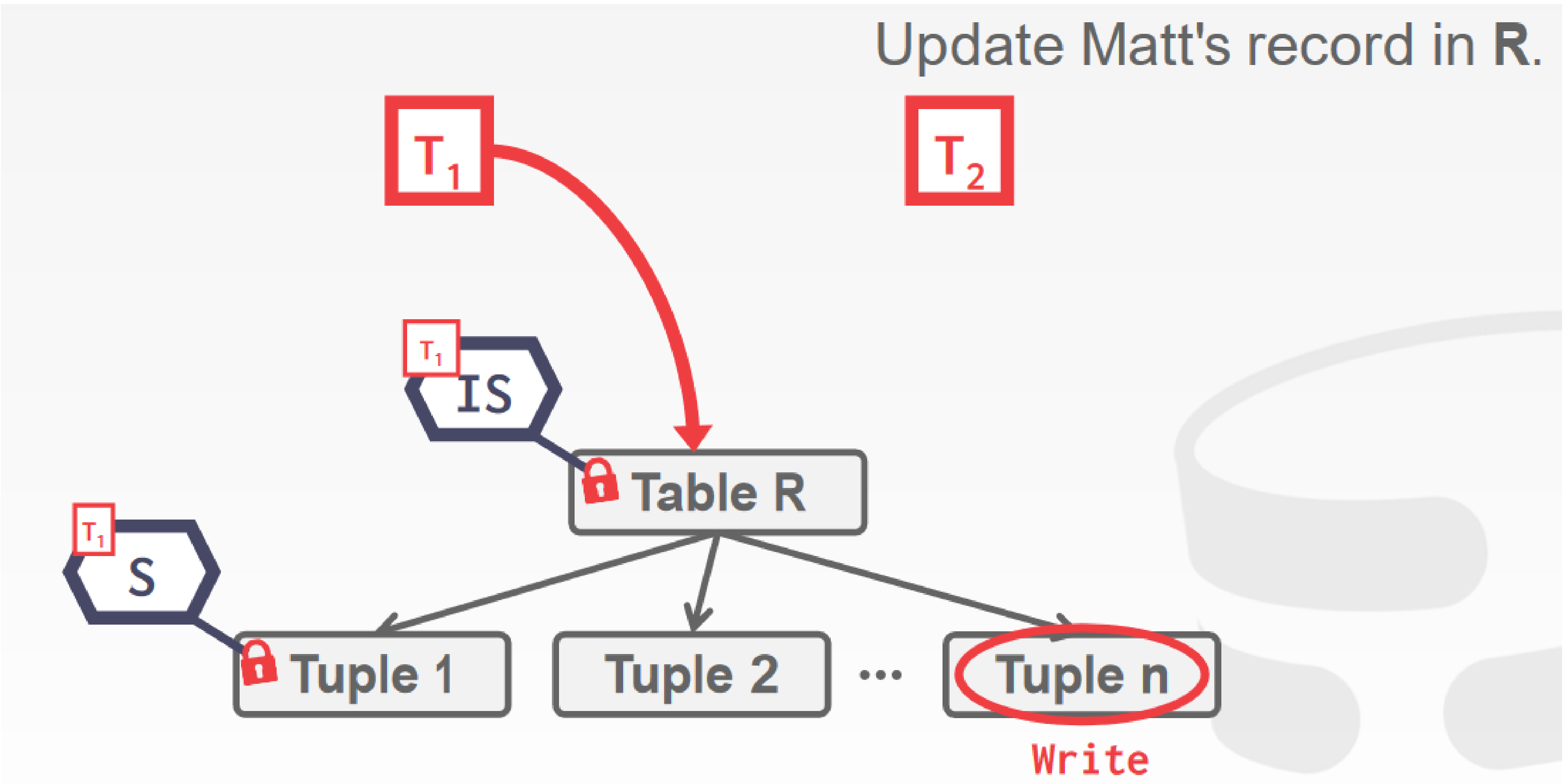


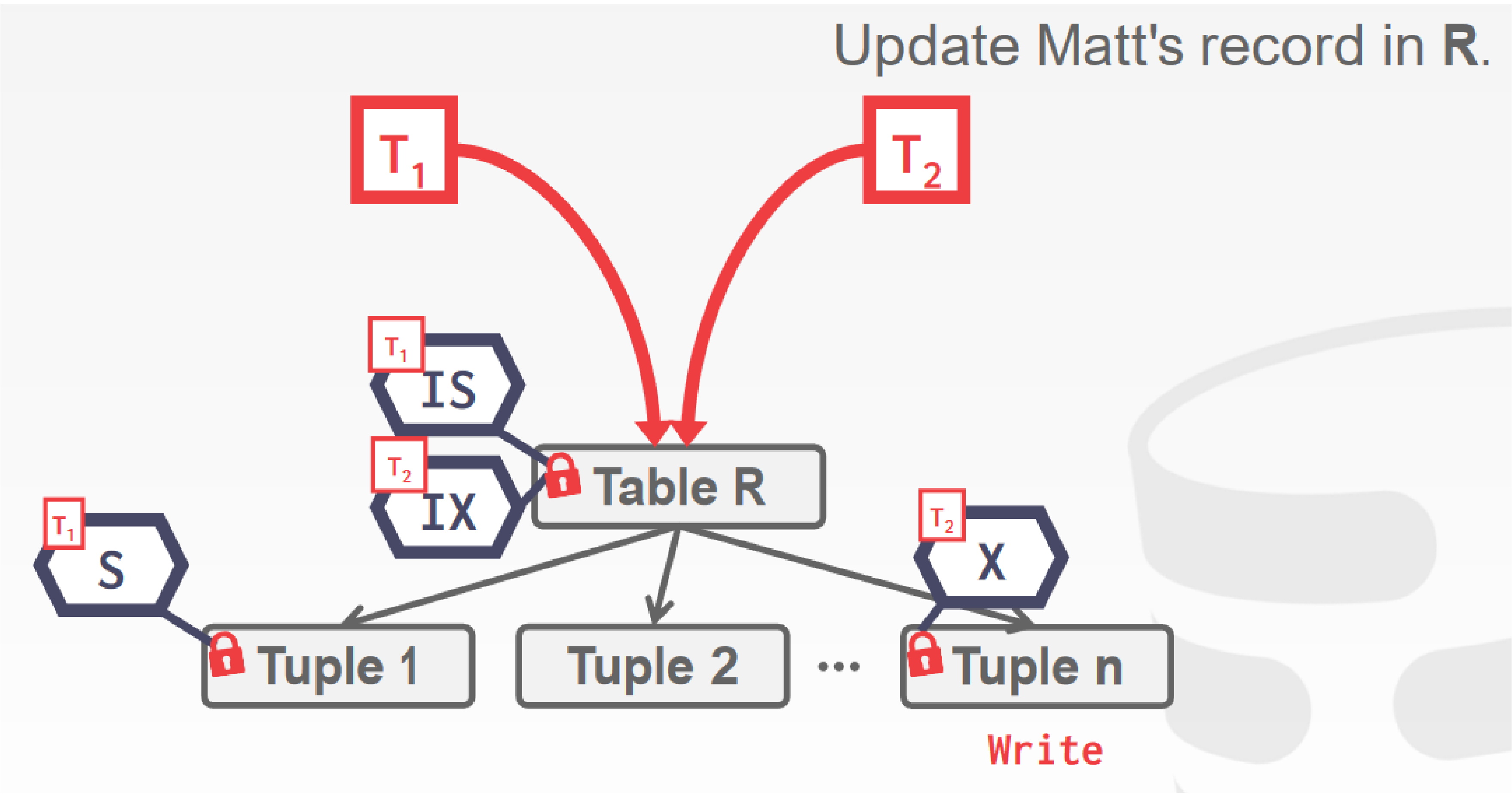
Read Andy's record in R.
T1
T1
IS
Table R
T1
S
Tuple 1
Tuple 2
···
Tuple n
Read

Example



Update Matt's record in R.
T1
T2
T1
IS
Table R
T1
S
Tuple 1
Tuple 2
...
Tuple n
Write

Example



Update Matt's record in R.
T1
T2
T1
IS
T2
IX
Table R
T1
S
T2
X
Tuple 1
Tuple 2
...
Tuple n
Write

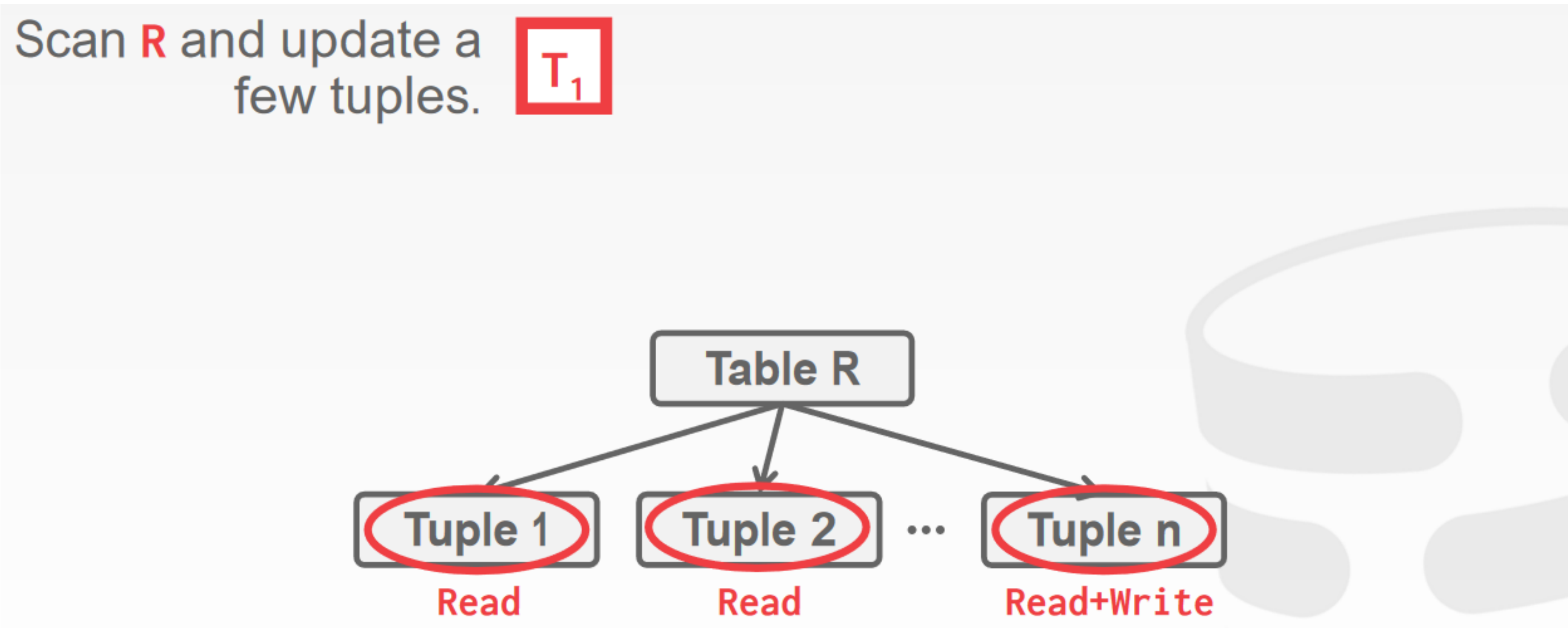
Compatibility

T_2 Wants

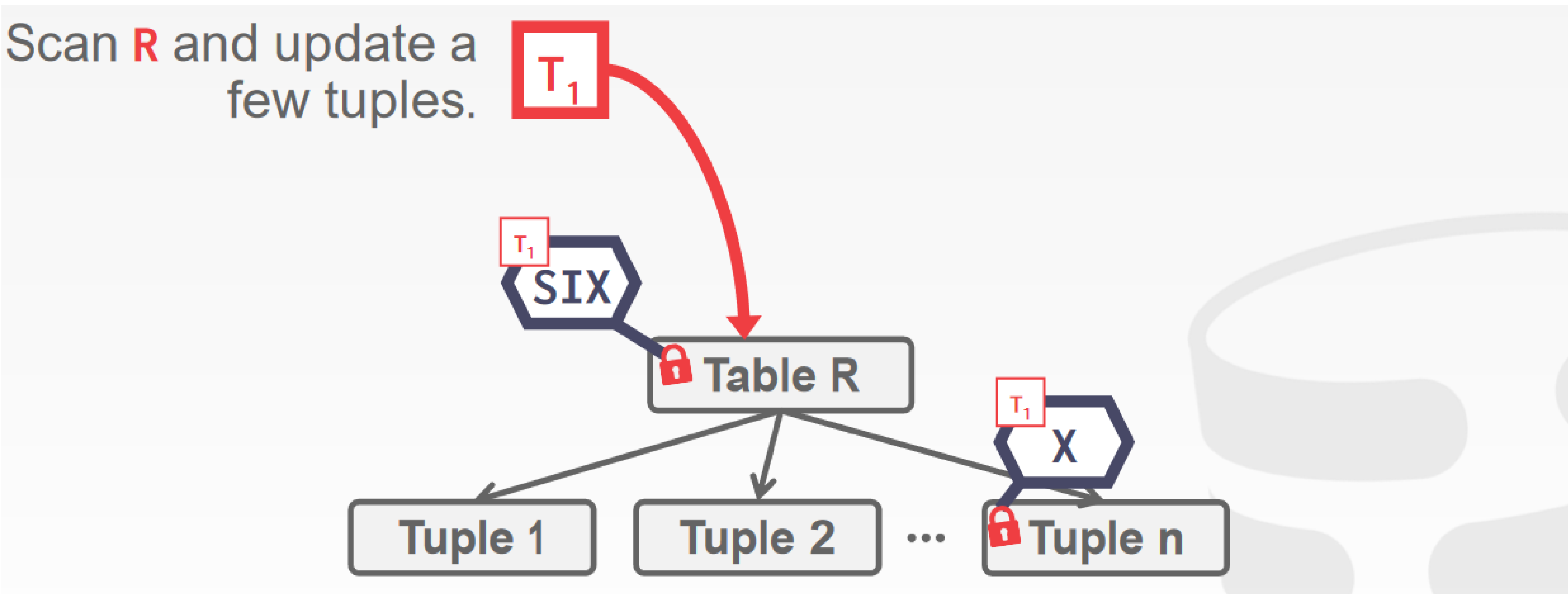
T_1 Holds	IS	IX	S	SIX	X
IS	✓	✓	✓	✓	×
IX	✓	✓	×	×	×
S	✓	×	✓	×	×
SIX	✓	×	×	×	×
X	×	×	×	×	×

- If transactions' locks are not compatible, they cannot execute concurrently!

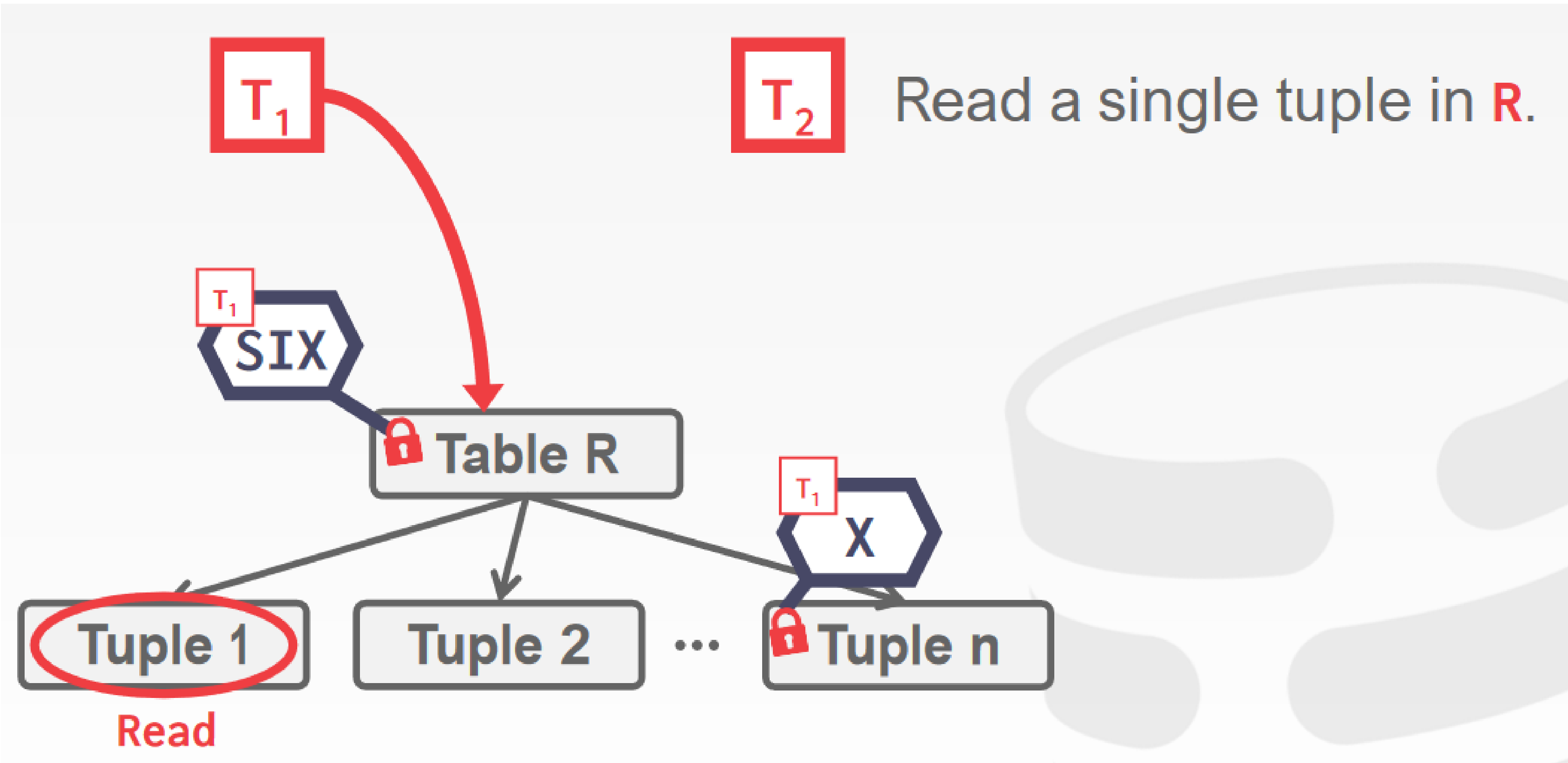
Example


Scan R and update a few tuples.
T1
Table R
Tuple 1
Tuple 2
...
Tuple n
Read
Read
Read+Write

Example

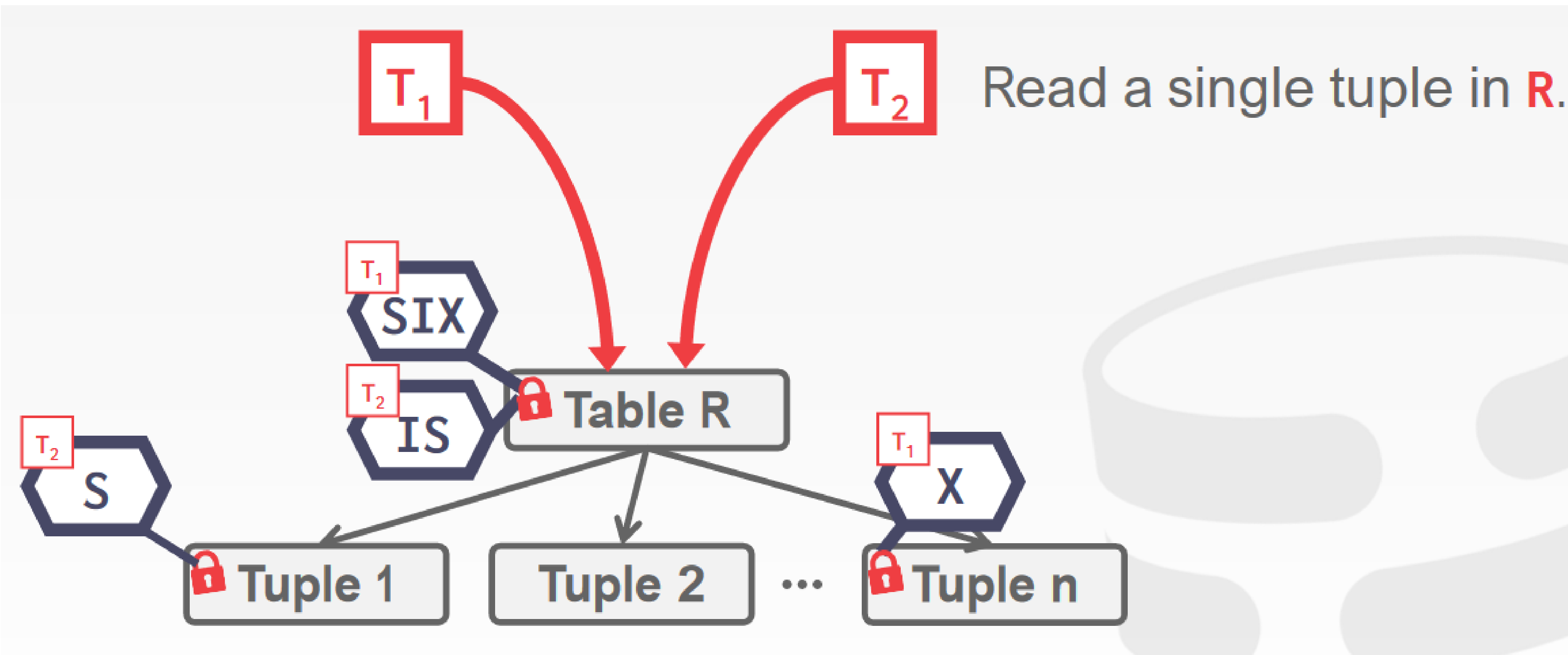

Scan R and update a few tuples.
T1
T1
SIX
Table R
T1
X
Tuple 1
Tuple 2
...
Tuple n

Example



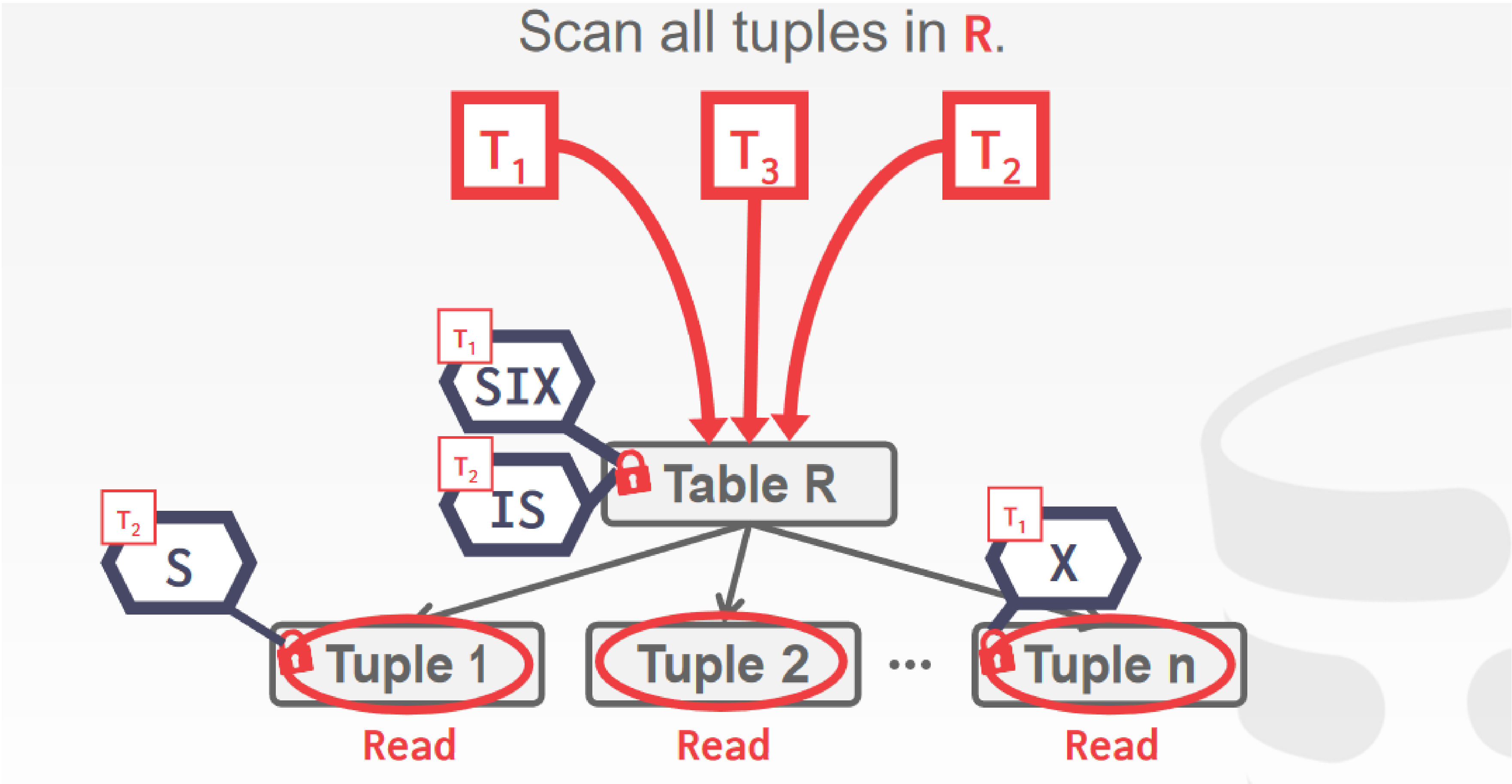
T_1
T_2
Read a single tuple in R.
T_1
SIX
Table R
T_1
X
Tuple 1
Tuple 2
...
Tuple n
Read

Example



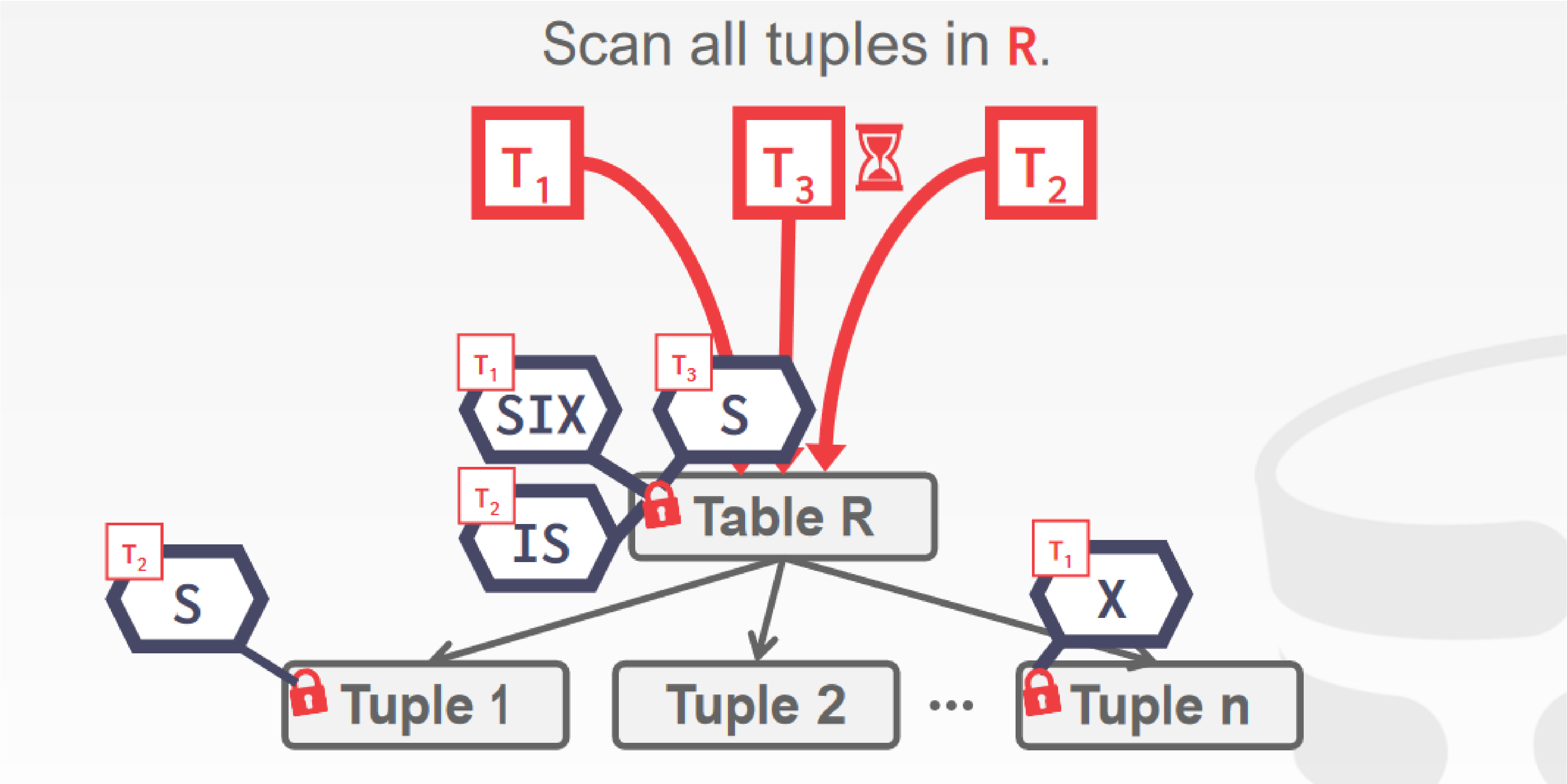
T_1
T_2
Read a single tuple in R.
T_1
SIX
T_2
IS
Table R
T_2
S
T_1
X
Tuple 1
Tuple 2
...
Tuple n

Example



Scan all tuples in R.
T1
T3
T2
T1
SIX
T2
IS
Table R
T2
S
T1
X
Tuple 1
Tuple 2
...
Tuple n
Read
Read
Read

Example



Are the locks of these transactions compatible?

Locking in Practice

- Different DBMSs use different locking methods
- The DBMS can automatically take care of locking, unlocking, etc.
- But there are methods for explicit, manual locking
  - Depends on which DBMS you are using
    - PostgreSQL: Locking in SHARE, EXCLUSIVE, and other modes
    - MySQL: Locking in READ,WRITE modes

```
LOCK TABLE <table> IN <mode> MODE;
```

```
SELECT 1 FROM <table> WITH (TABLOCK, <mode>);
```

```
LOCK TABLE <table> <mode>;
```