Two-Phase Locking

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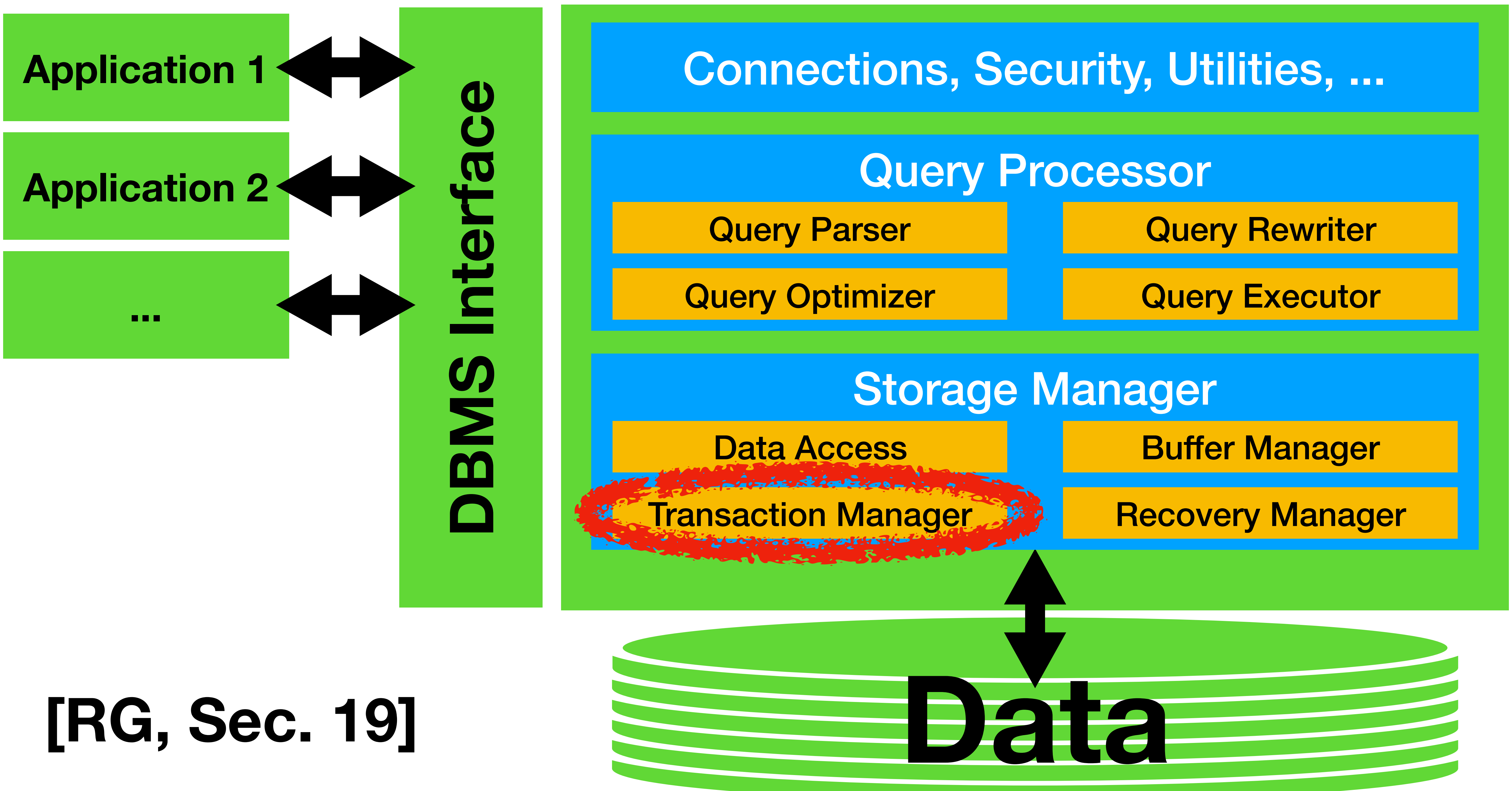
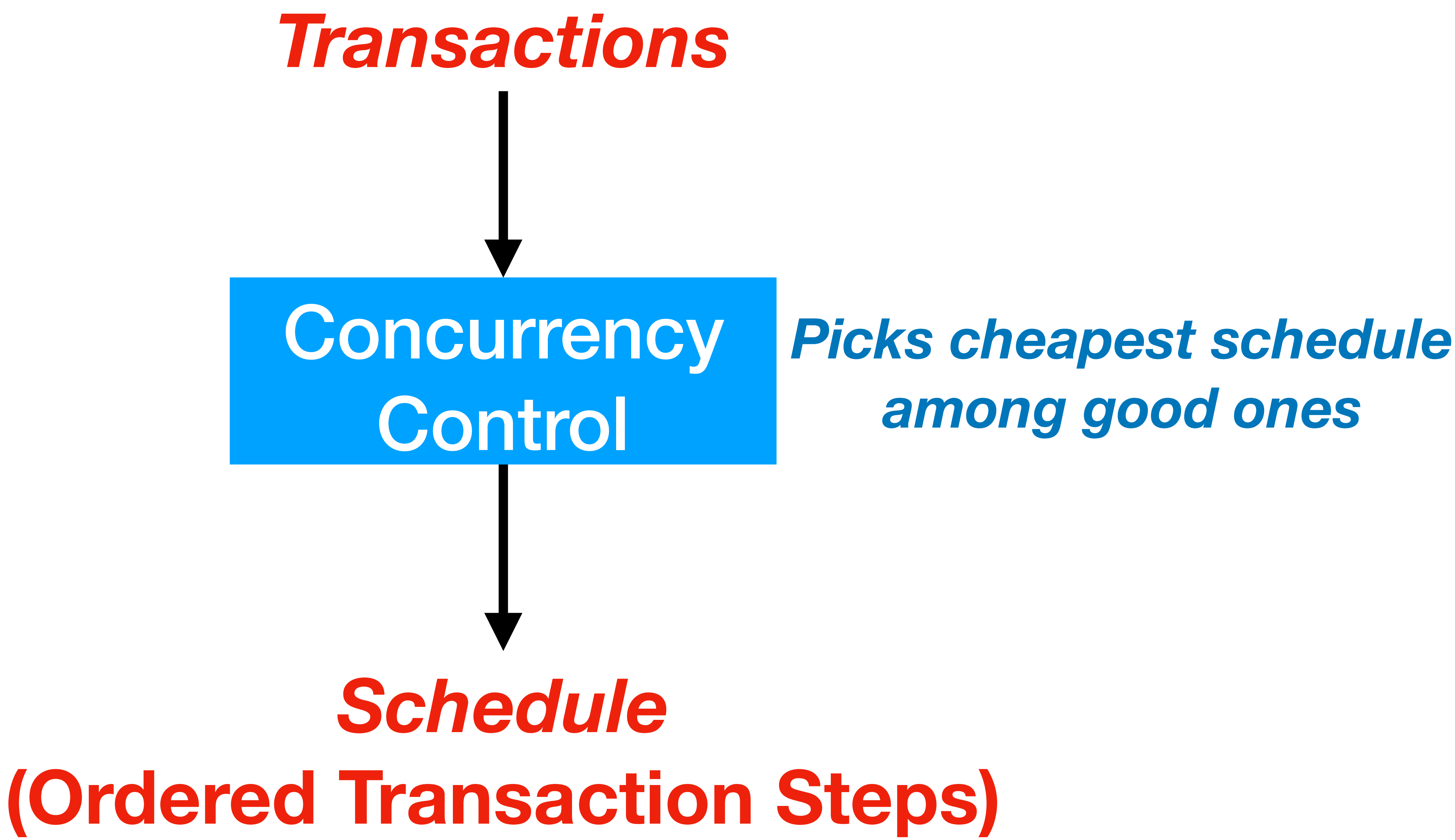
Database Management Systems (DBMS)



[RG, Sec. 19]

Concurrency Control



Concurrency Control Protocols

- Have seen **desirable properties** of schedules
    - **Conflict serializability**: efficient and quite permissive
    - Want **recoverable** schedules, possibly ACA or strict
- Now discuss **protocols** to enforce such schedules
    - Allowing more schedules: **more optimization** possible
    - Ok with less schedules if mechanism **more efficient**

Lock-Based CC

- **Lock**: permission to operate on specific objects
  - Transactions need lock **to work** on object
  - Transactions obtain locks via a **lock request**
  - May have to **wait** until desired lock is granted
- **Lock manager** component grants locks
  - **Keeps track** of which transaction holds which locks

Simple Locking Strategy

- Use **one lock** for the entire database
- Transactions requests lock at **transactions start**
- Transaction gives back lock at **transaction end**
- **Only one** transaction can hold at the same time

How Does This Perform?

Refining Lock Granularity

- Transactions can work on **different objects** in parallel
- Enable by locking **specific DB objects** (instead of DB)
- Locking **protocol** summary:
  - Transaction requests locks on all its objects **at start**
  - **Waits** until all locks have been granted
  - Transaction executes and releases locks **at end**

Introducing Lock Types

- All conflicts involve some **write operation**
- Multiple transactions can **read objects** without conflicts
- Idea: distinguish between **read and write locks**
  - **Read (aka shared) locks** allow only read access
  - **Write (aka exclusive)** locks allow read+write access
- Transactions specifically request either **read or write** lock
- Lock manager may grant **multiple read locks** on same object

Release Locks Early

- So far: transactions request locks at **start**, release at **end**
- **Releasing locks earlier** may increase parallelism
  - Release lock **after last operation** on associated object
- But doing so may lead to **cascading aborts**, e.g.:
  - W1(A) **[Lock on A from 1 → 2]** R2(A) A1

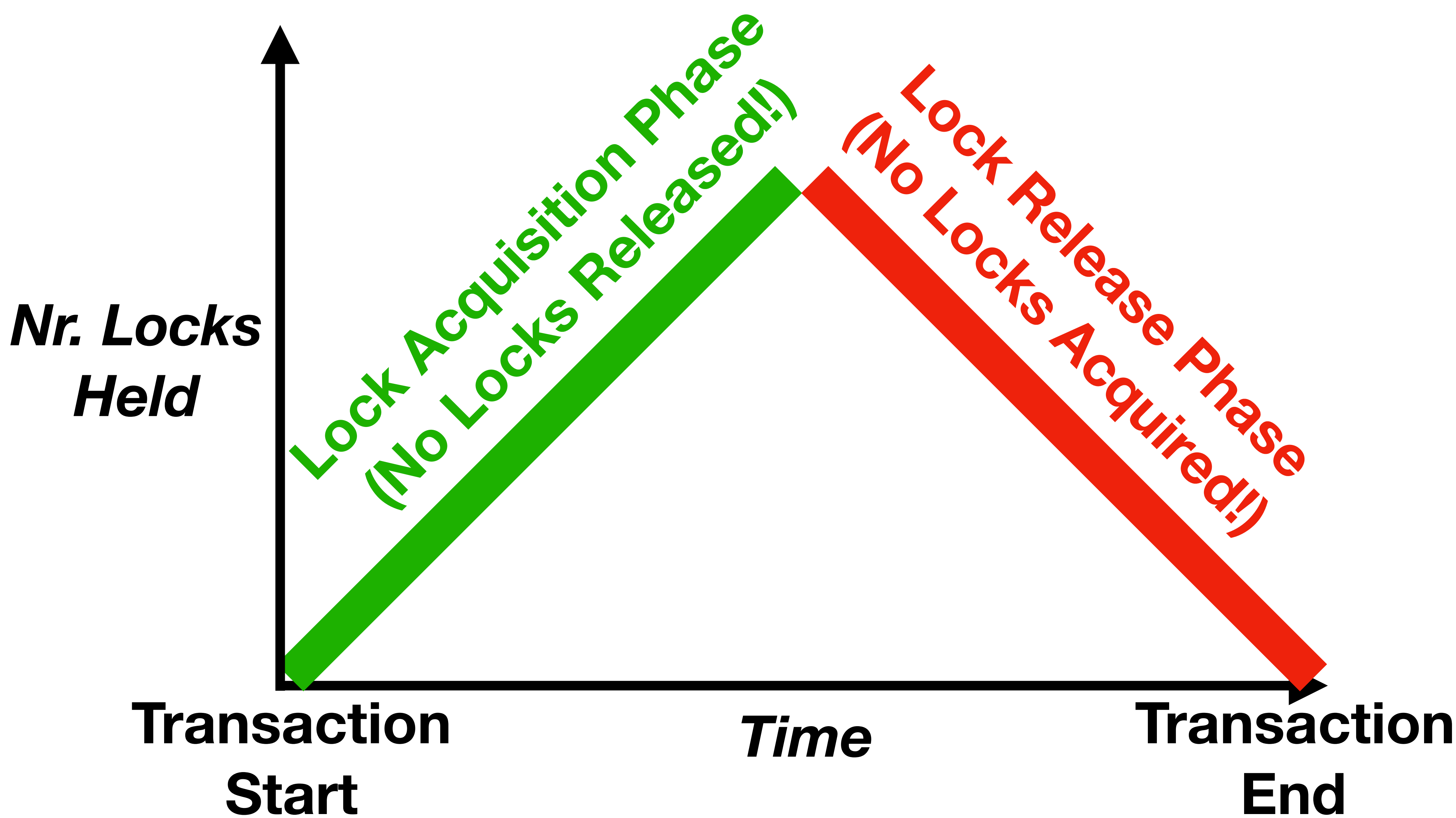
Acquire Locks Late

- Acquire locks **directly before** read or write operation
  - (So far: acquired all locks at transaction start)
- May improve performance by **increasing parallelism**
- May however lead to **deadlocks**:
  - Transaction 1 acquires **lock on A**, now **waiting for B**
  - Transaction 2 acquires **lock on B**, now **waiting for A**
  - Transaction are both waiting for each other, **no progress**

Two-Phase Locking

- **Combines all** of the aforementioned optimizations
  - **Fine-grained locks** on single objects
  - Distinguishes different **lock types**
  - Locks may be **acquired late** (depends on 2PL variant)
  - Locks may be **released early** (depends on 2PL variant)
  - But **restrictions** on when locks are acquired/released

The Two Phases of 2PL



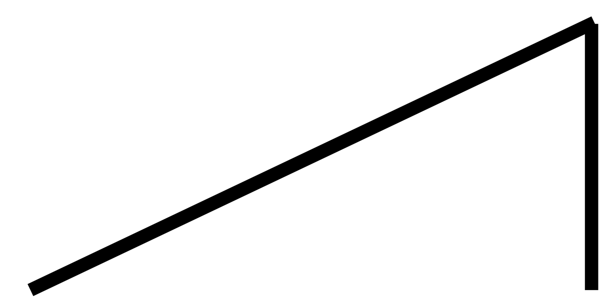
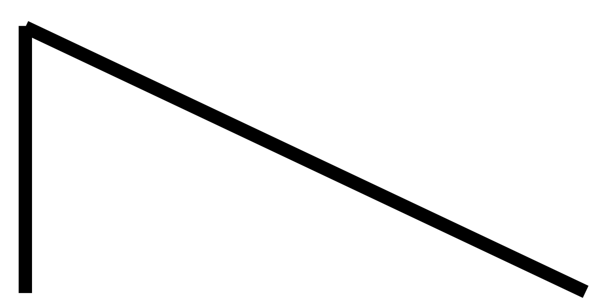
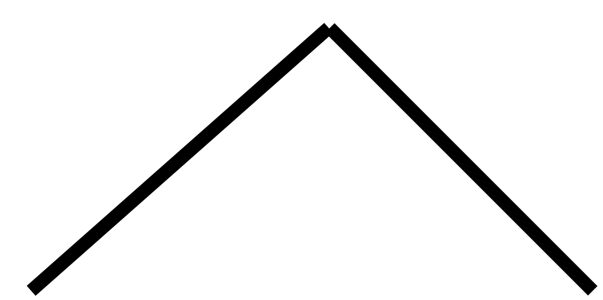
Two Phases Summary

- Each transaction has **two separate phases** with 2PL
- First phase: transaction may **acquire** locks but no release
- Second phase: transaction may only **release** locks
- Will see later that this restriction is necessary!
    - Guarantees **conflict-serializable** schedules

Two Phase Locking Variants

- **Conservative 2PL:** acquire all locks at transaction start
- **Strict 2PL:** release all locks at transaction end
- Can also **combine** the two (conservative strict 2PL)
- **Plain 2PL** makes no restrictions on locking periods

Illustration of 2PL Variants

	Conservative	Non-Conservative
Strict		
Non-Strict		

Pros and Const of Variants

- Being non-conservative or non-strict is **more permissive**
  - Allows more transactions to proceed **in parallel**
- **Conservative** 2PL prevents deadlocks
- **Strict** 2PL prevents cascading aborts
- Optimal variant **depends on workload**
  - E.g., how likely are deadlocks and cascading aborts?

Analyzing 2PL Schedules

- Agreed on aiming for **conflict-serializable** schedules
- Will prove that 2PL **generates** such schedules

Proof Overview

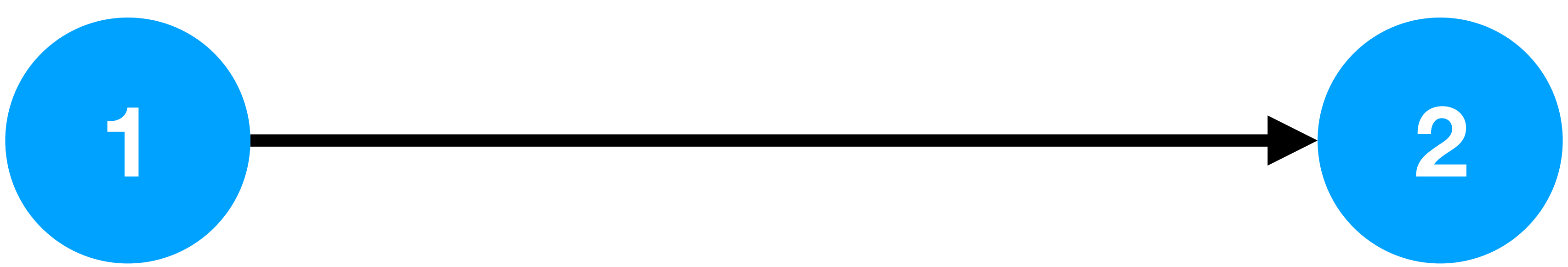
- Assume schedule was generated **using 2PL**
- Now imagine **conflict graph** of schedule
- Schedule is conflict serializable if it is **acyclic**
- Will show: assuming **cycle leads to contradiction**
  - Based on **lemma** introduced next

Release First Lemma

- Lemma: if conflict graph has **path from transaction T1 to transaction T2** then T1 **releases** some lock before T2 **acquires** some lock

- Will prove that **via induction**
  - **Induction start**: holds for paths of length 1
  - **Induction step**: from paths of length I to i+1

Induction Start



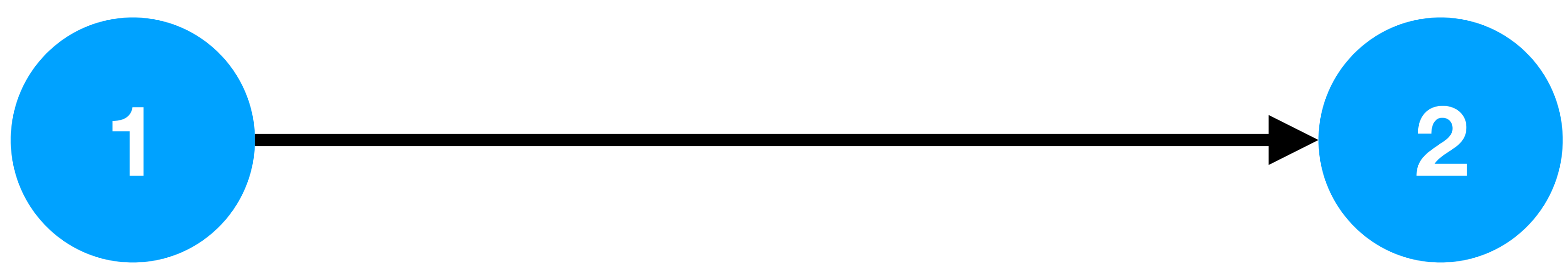
(Two transactions with conflict)

Induction Start

Possibility 1: R1(A) → W2(A)

Possibility 2: W1(A) → R2(A)

Possibility 3: W1(A) → W2(A)



(Two transactions with conflict)

Induction Start

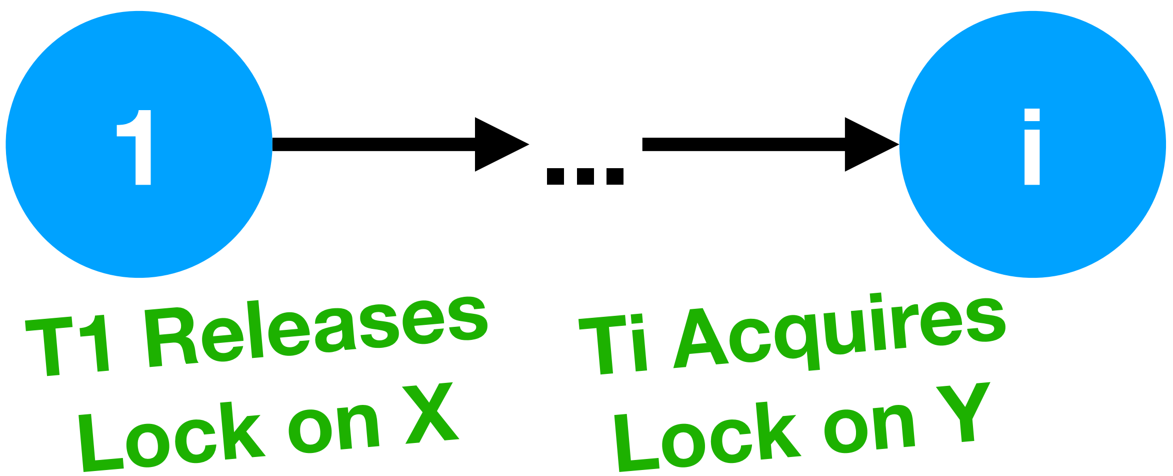
Possibility 1: R1(A) → W2(A)
T1 Releases Lock on A
T2 Acquires Lock on A

Possibility 2: W1(A) → R2(A)
T1 Releases Lock on A
T2 Acquires Lock on A

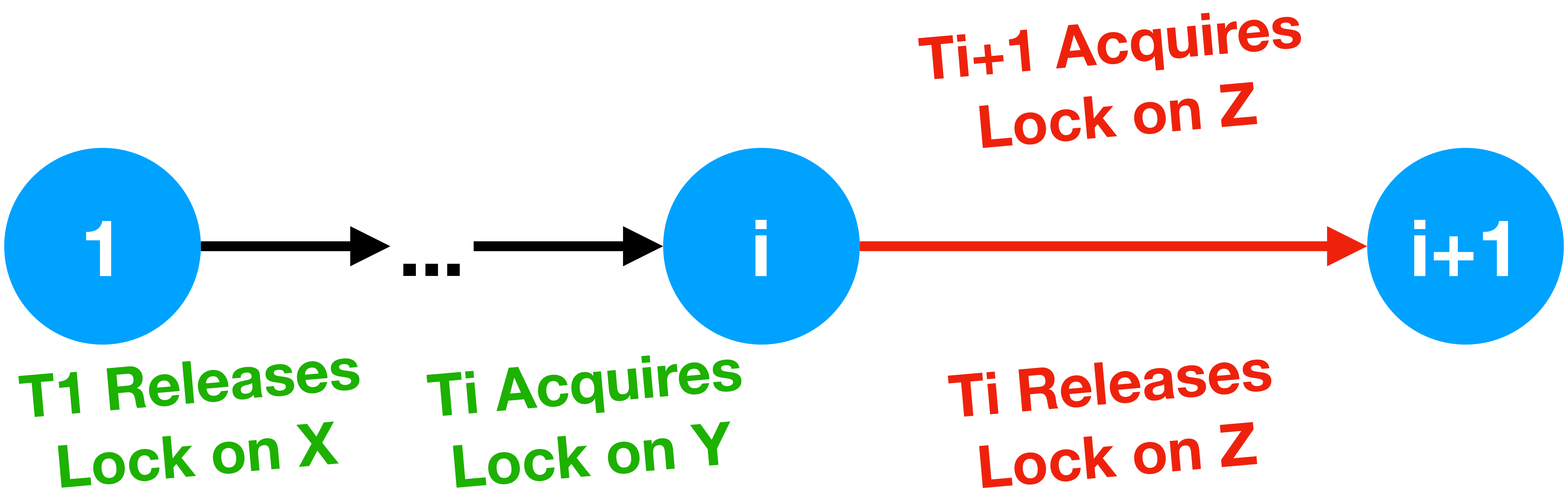
Possibility 3: W1(A) → W2(A)
T1 Releases Lock on A
T2 Acquires Lock on A

(Two transactions with conflict)

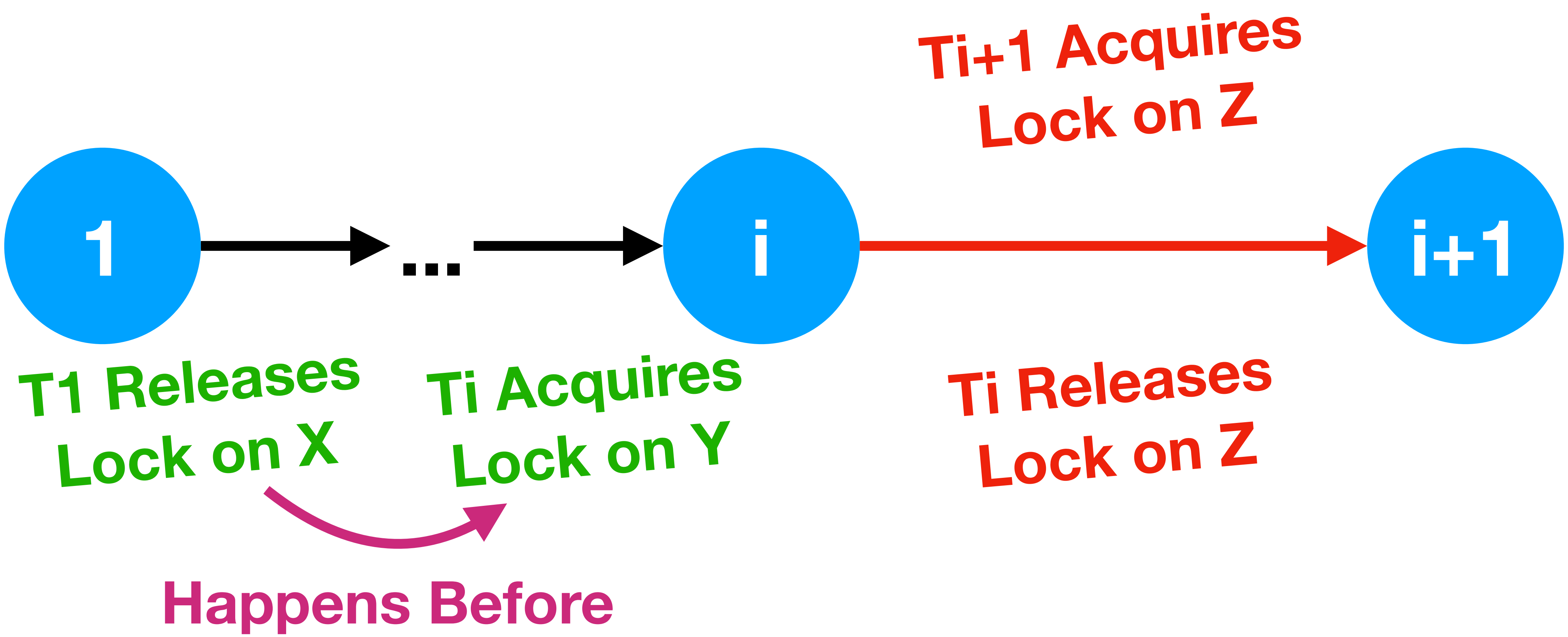
Induction Step



Induction Step

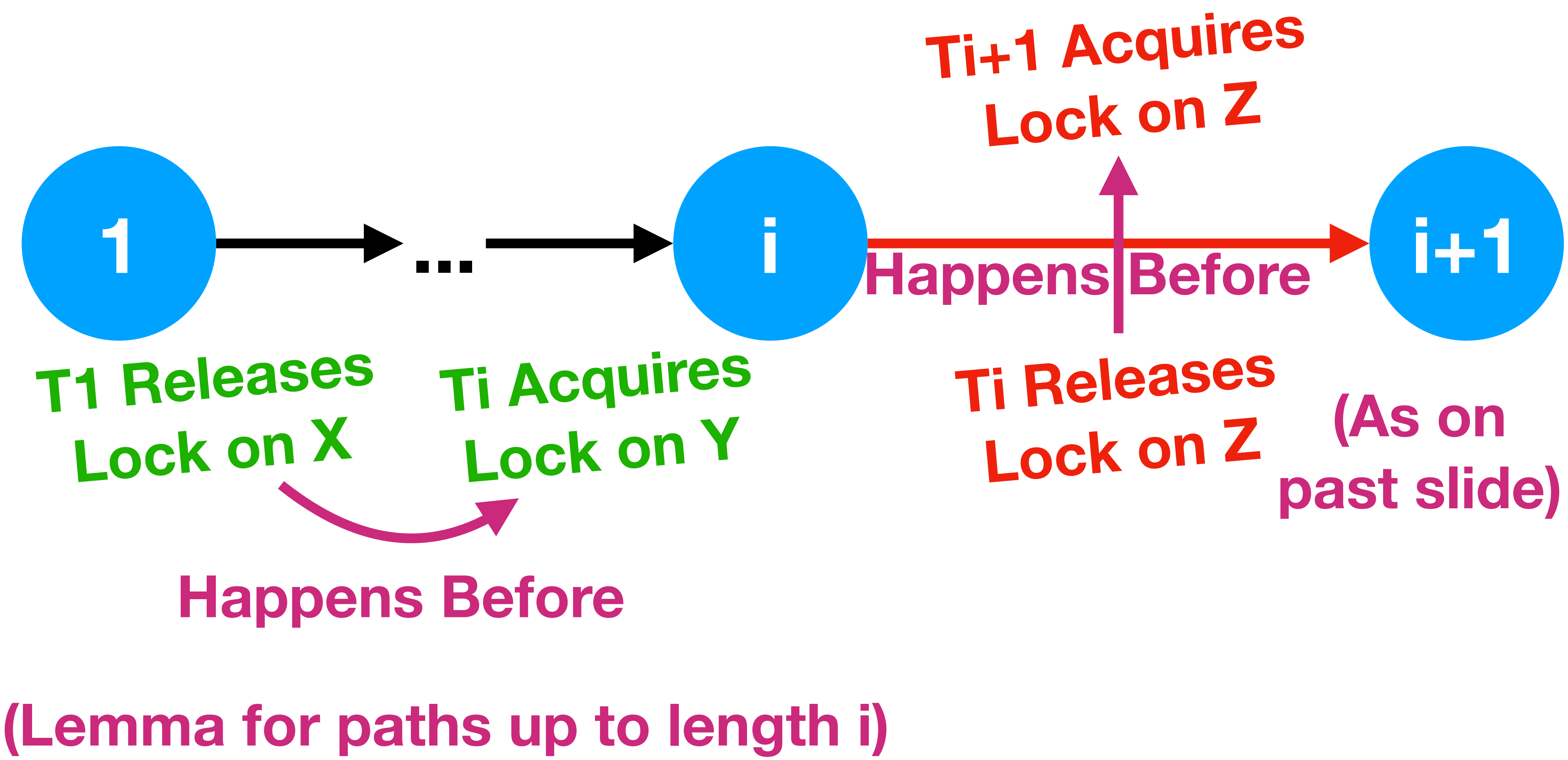


Induction Step

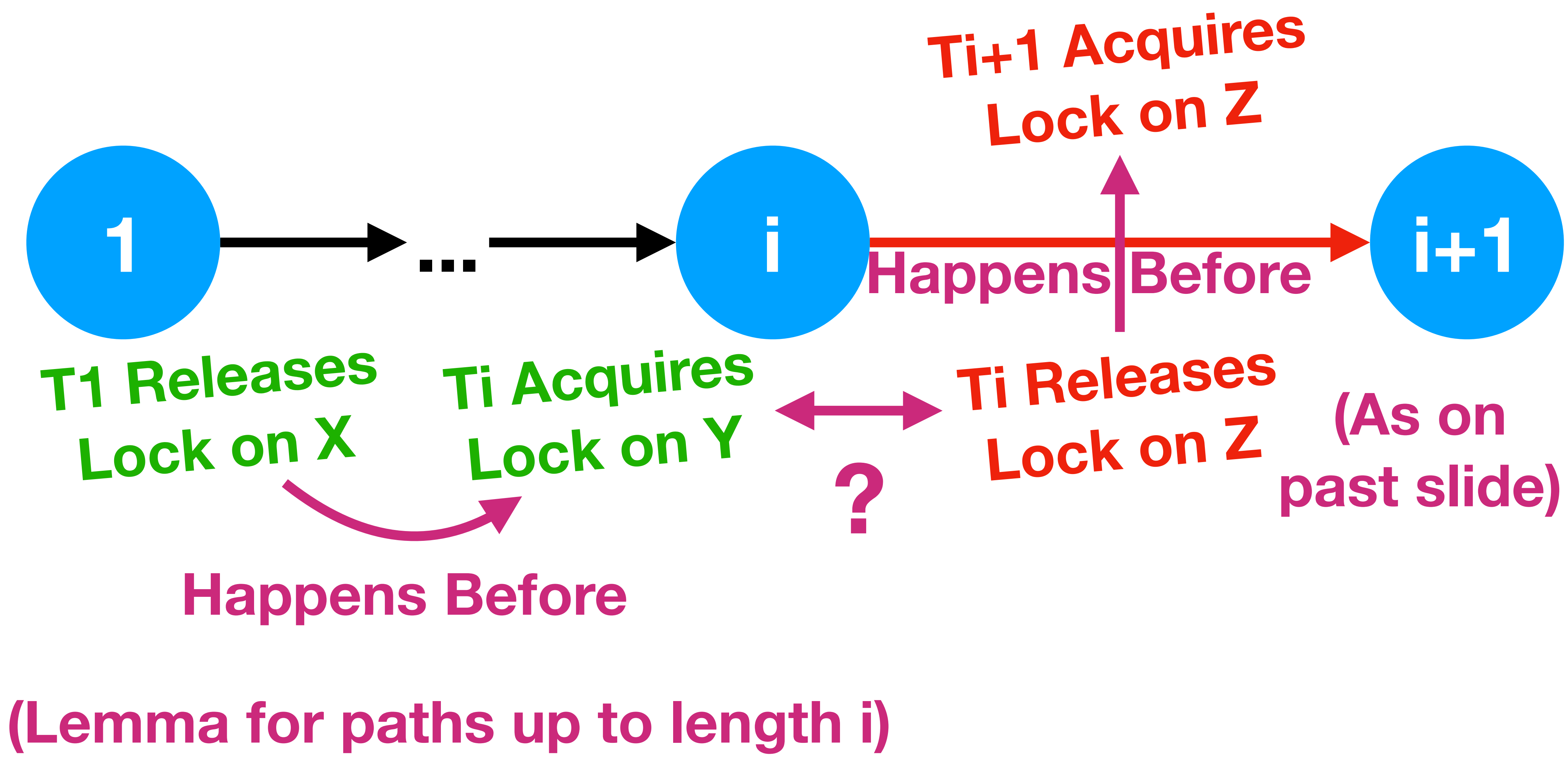


(Lemma for paths up to length i)

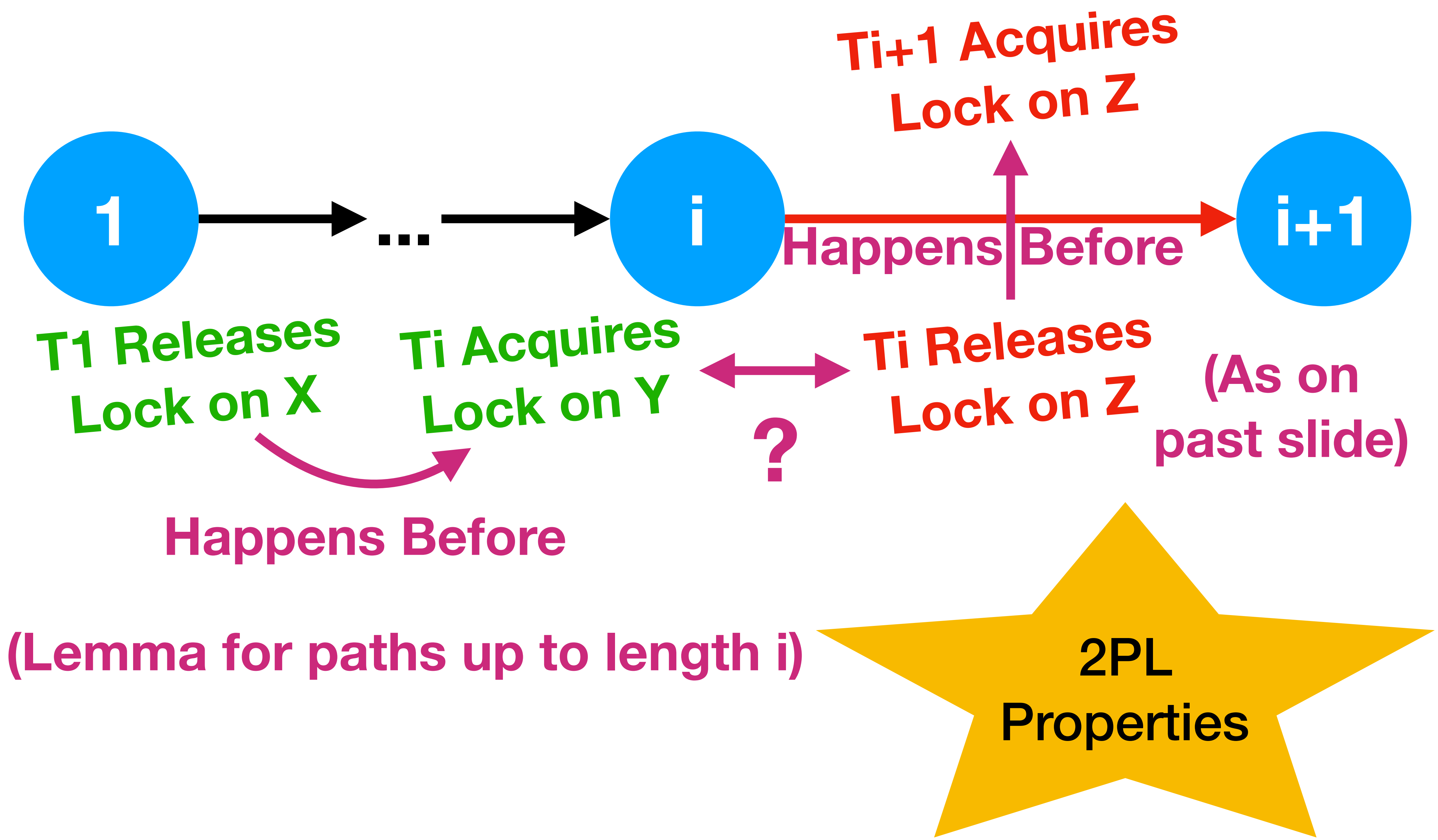
Induction Step



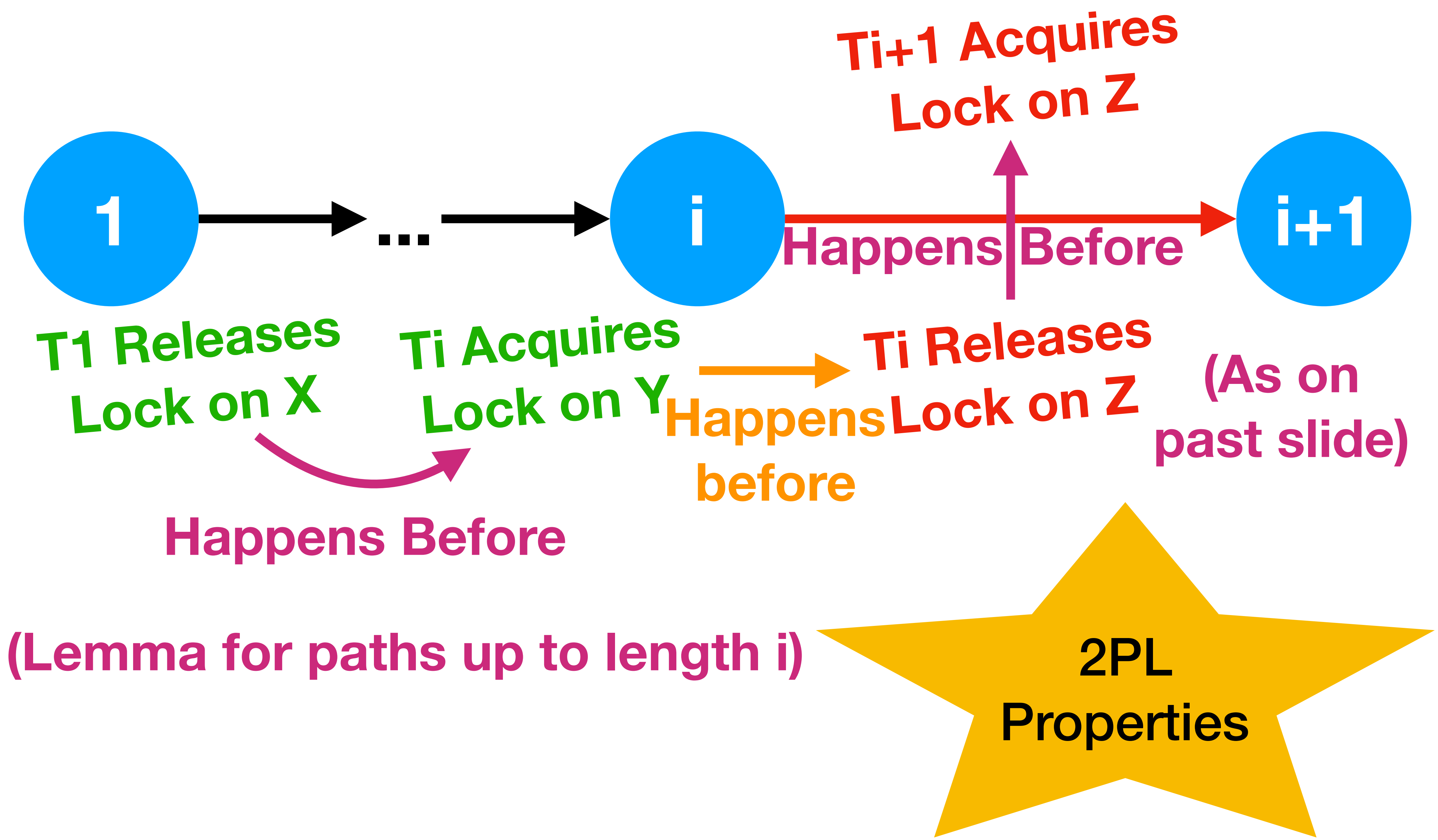
Induction Step



Induction Step



Induction Step



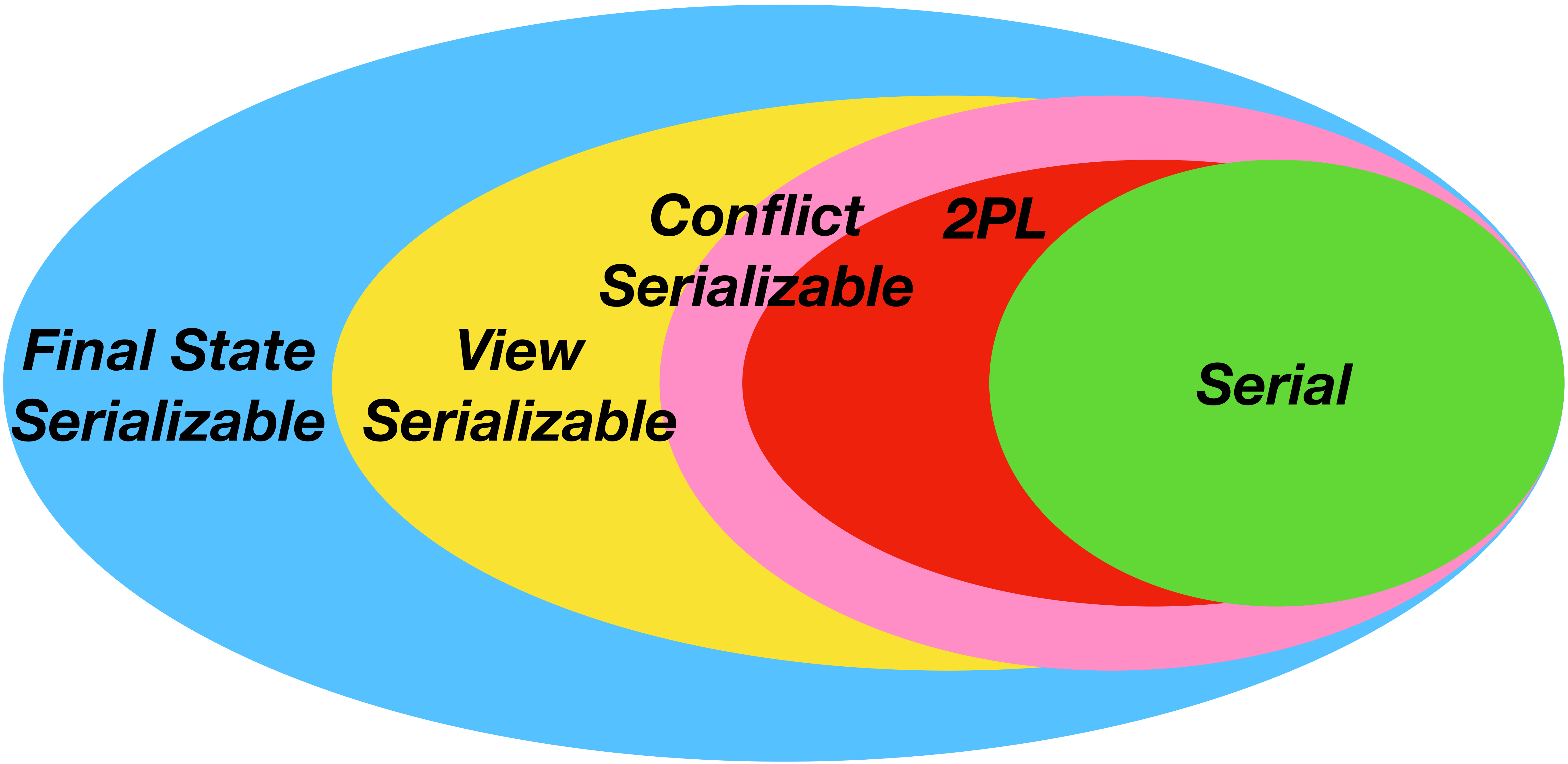
Wrapping Up Proof

- **Lemma**: path from T1 to T2 - T1 releases lock before T2 acquires lock
- **Cycle** means T1 releases lock before T1 acquires lock
- 2PL **does not acquire lock** after releasing them!
- Hence, we **cannot have a cycle** in conflict graph
- Hence, 2PL produces **conflict serializable** schedules

2PL vs. Conflict Serializable

- 2PL **only** produces conflict serializable schedules
- But can 2PL produce **all** conflict serializable schedules?
- The answer is "No" as **demonstrated** below:
    - **W1(A) R2(A) C2 R3(B) C3 W1(B) C1**
    - Conflict graph has three nodes, two edges → **no cycle**
    - ***Could this have been produced by 2PL?***

Classes of Schedules



All Schedules