More on Locking

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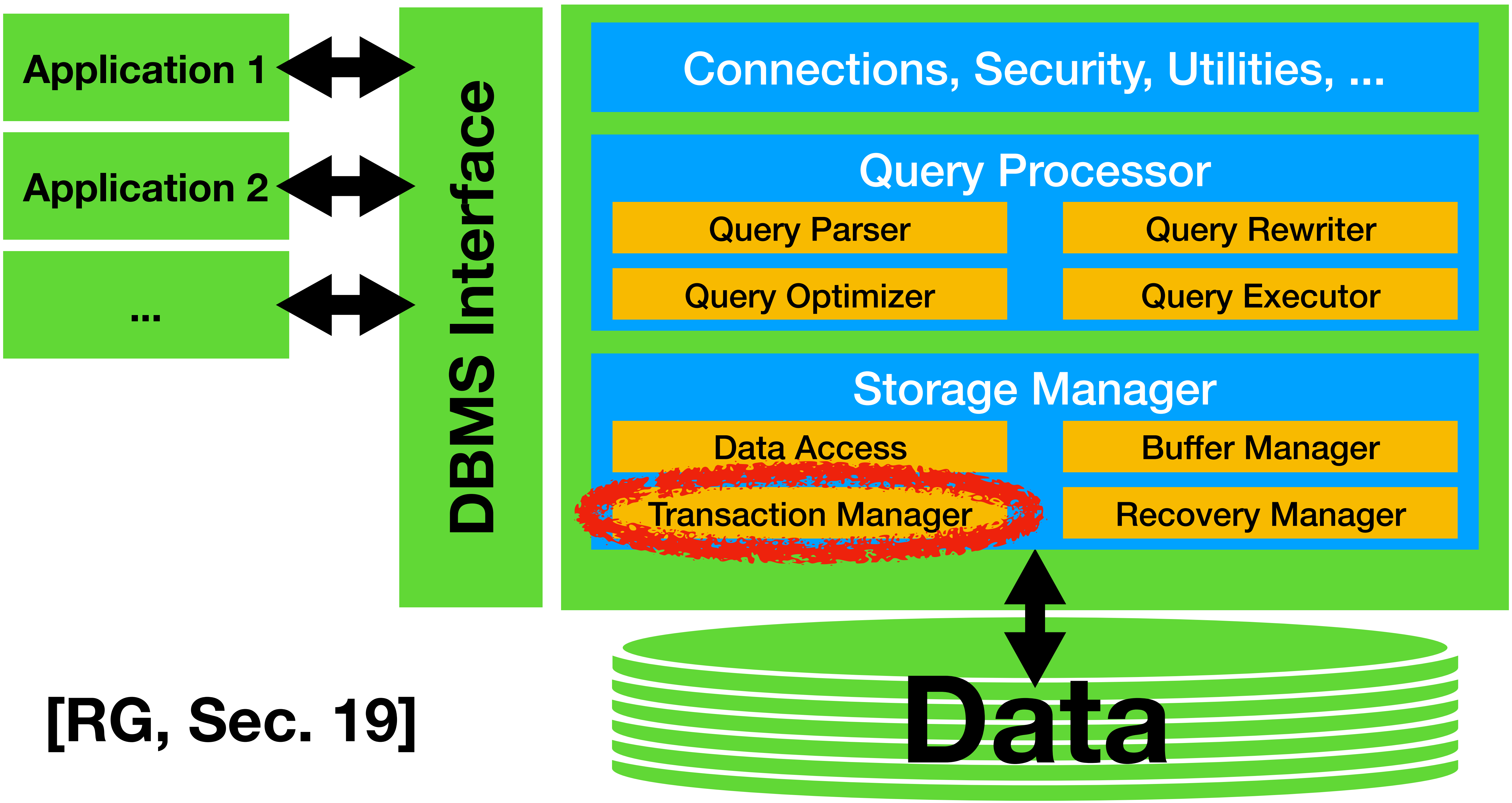
Database Management Systems (DBMS)



[RG, Sec. 19]

Outlook

- Handling **deadlocks**
- Handling **phantoms**
- Efficient **index** locking
- **Multi**-granularity locking

Deadlocks

Handling Deadlocks

- **Deadlocks** can arise when using non-conservative 2PL
  - Deadlock: **transactions waiting** in a "circle"
  - May be acceptable if deadlocks are **rare**
- Two ways for **handling deadlocks**
  - **Detect** and resolve deadlocks
  - **Prevent** deadlocks from happening

Task: Generate Deadlock in Postgres!

Deadlock Detection

- Simplest option: assume deadlock after **timeout**
- Maintain **waits-for graph** to detect deadlocks
  - One node for each **transaction**
  - Edge from T1 to T2 if T1 **waits for** lock held by T2
  - Edges are added as **lock requests** come in
  - **Cycle** in waits-for graph indicates a deadlock

Resolving Deadlocks

- Only possibility: **abort** one deadlocked transaction
- Aborted transaction is typically **restarted**
- Can try to **optimize** selection of aborted transaction
  - E.g., abort **youngest** transaction for least overhead

Avoiding Deadlocks

- **Proactively abort transactions** that may cause deadlocks
- Priority based **on timestamps** (older transaction - higher priority)
- Transaction T1 needs lock held by T2 - **Wound-wait protocol**:
    - T1 causes T2 abort if T1 has **higher** priority
    - T1 waits for lock from T2 if T1 has **lower** priority
- Transaction T1 needs lock held by T2 - **Wait-die protocol**:
    - T1 waits for lock from T2 if T1 has **higher** priority
    - T1 aborts itself if it has **lower** priority than T2

Wound Wait Deadlock Prevention Proof

- A deadlock means transactions **wait in a cycle**
- Only **lower priority transaction can wait** for higher priority
  - Due to definition of wound-wait protocol
- **Assume cycle** in waits-for graph, transaction T1 in cycle
  - T1 → T2: T1 must have **lower** priority than T2
  - T1 → T2 → T3: T1 must have **lower** priority than T3
  - T1 → ... → T1: T1 must have **lower** priority than T1
  - Leads to a **contradiction** so no cycle is possible!

Wait-Die Deadlock Prevention Proof

- A deadlock means transactions **wait in a cycle**
- Only **higher priority transaction can wait** for lower priority
  - Due to definition of wait-die protocol
- **Assume cycle** in waits-for graph, transaction T1 in cycle
  - T1 → T2: T1 must have **higher** priority than T2
  - T1 → T2 → T3: T1 must have **higher** priority than T3
  - T1 → ... → T1: T1 must have **higher** priority than T1
  - Leads to a **contradiction** so no cycle is possible!

Wound-Wait vs. Wait-Die

- **Advantage** of Wait-Die:
  - Transactions that acquired all locks won't abort
- **Disadvantage** of Wait-Die:
  - Young transaction may re-abort for same reason

Avoiding Starvation

- Higher priority transaction is **never restarted** for both
- When restarting transaction, assign **original timestamp**
- So transaction will be **eventually prioritized**
- Avoids **starvation** (i.e., no transaction never processed)

Phantoms

Phantom Example

- Transaction 1 selects students with name **starting with F**
- Transaction 2 inserts new student "**Frank**"
- Transaction 1 selects students **starting with F again**
  - Suddenly we see **a new student** in the query result
  - Similar to **unrepeatable read**, caused by insertions
- Problem: 2PL only locked students present **at first query**

Avoiding Phantoms

- **Predicate locking**: lock tuples satisfying certain predicate
  - E.g., predicate "**name starts with F**" in the example
  - Locks **current and future** entries equally
  - **Complex** to realize for arbitrary predicates
- **Can use index** when considering equality predicates
  - **Lock index page** that would change at insertion
  - **Cannot insert** as long as index page is locked

Efficient Index Locking

Tree Indexes: Why Not Use Generic 2PL?

Locking in Tree Indexes

- Observation: we traverse tree into **one direction** only
- **Locking one node** sufficient to block other transactions
    - I.e., keeping later transactions **out** of current sub-tree
- Locking for **index lookups** ("crabbing"):
    - Identify **next node** (child node or root at start)
    - Lock **next** (read lock), then **unlock** parent - repeat

Illustration of Crabbing

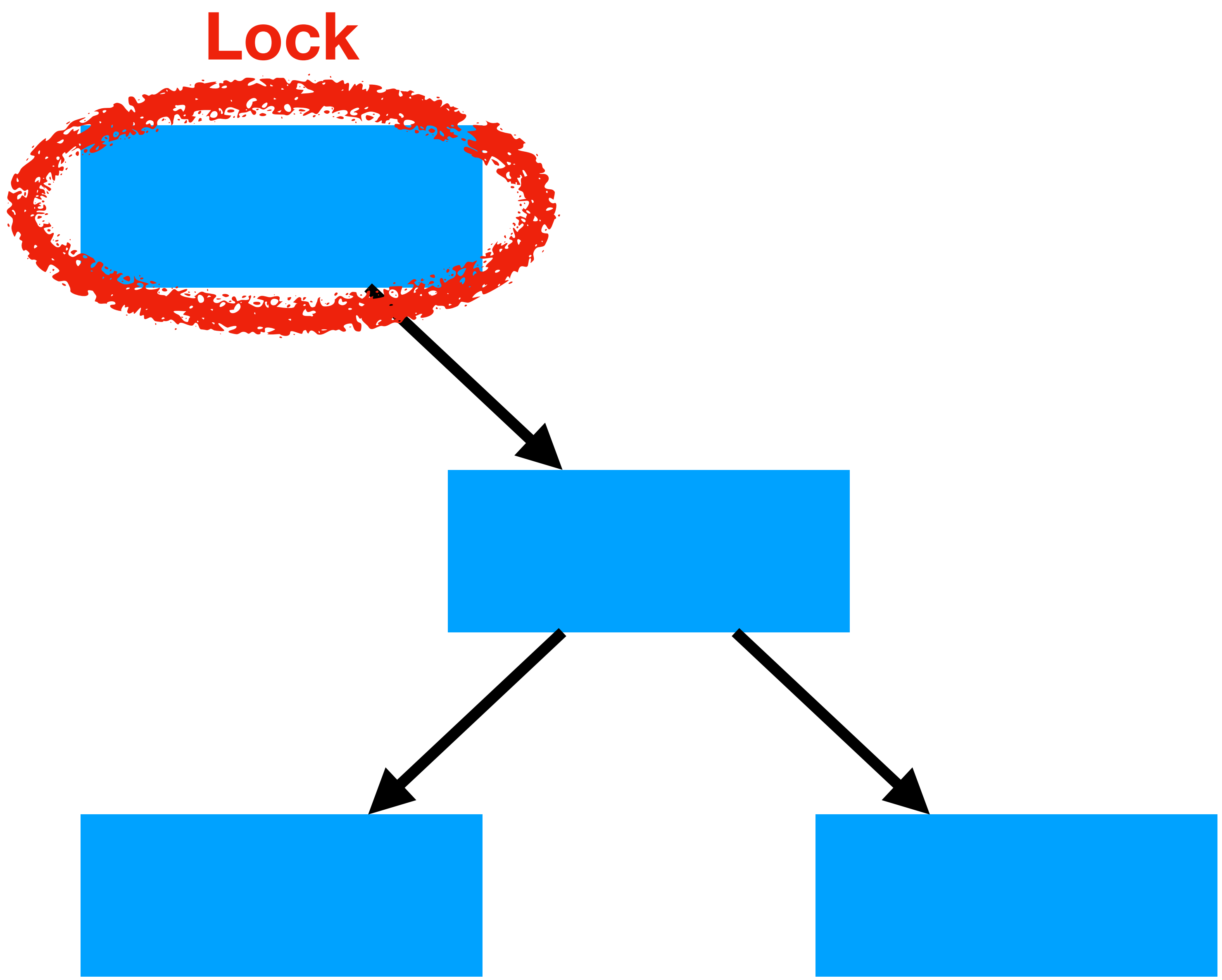
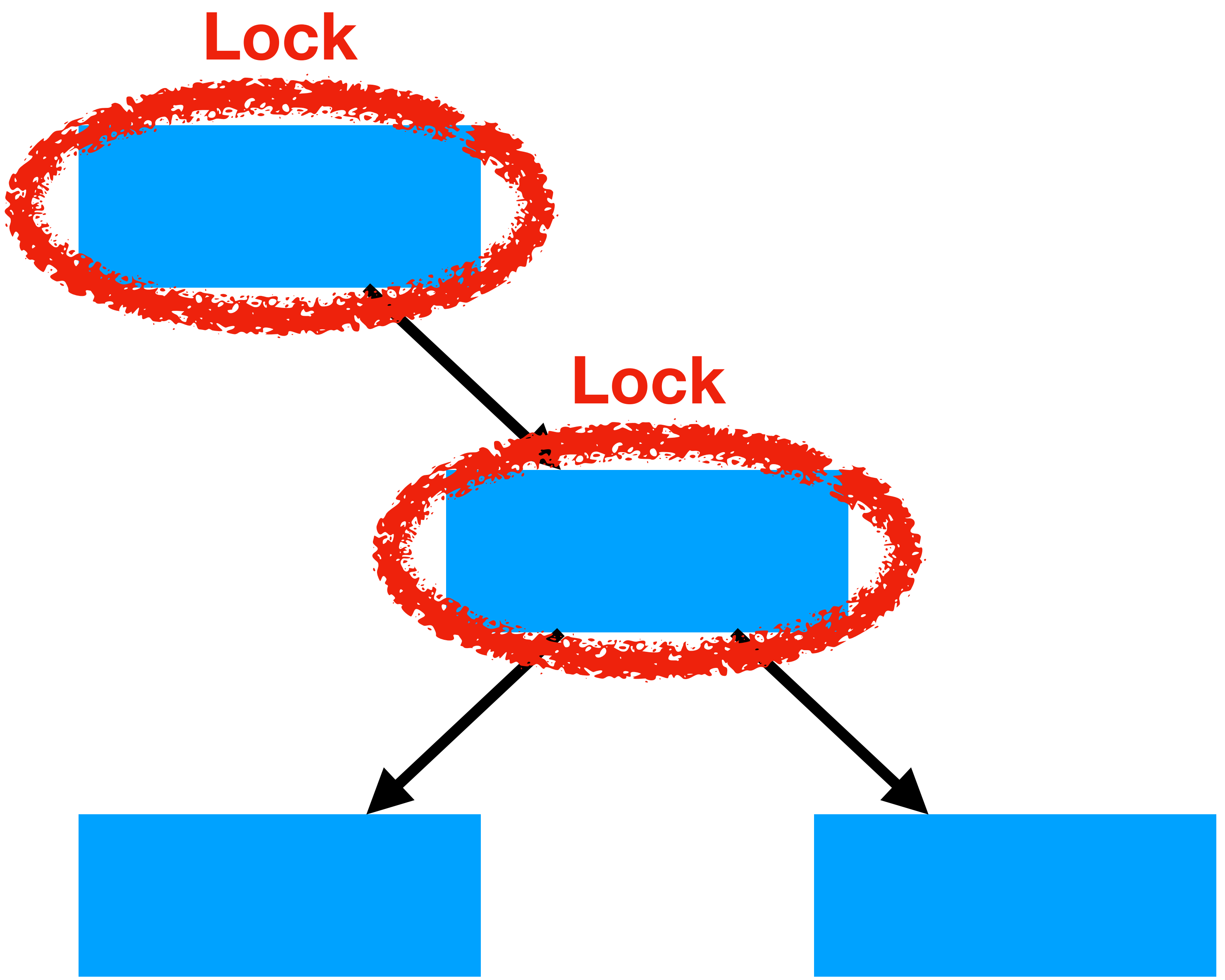


Illustration of Crabbing



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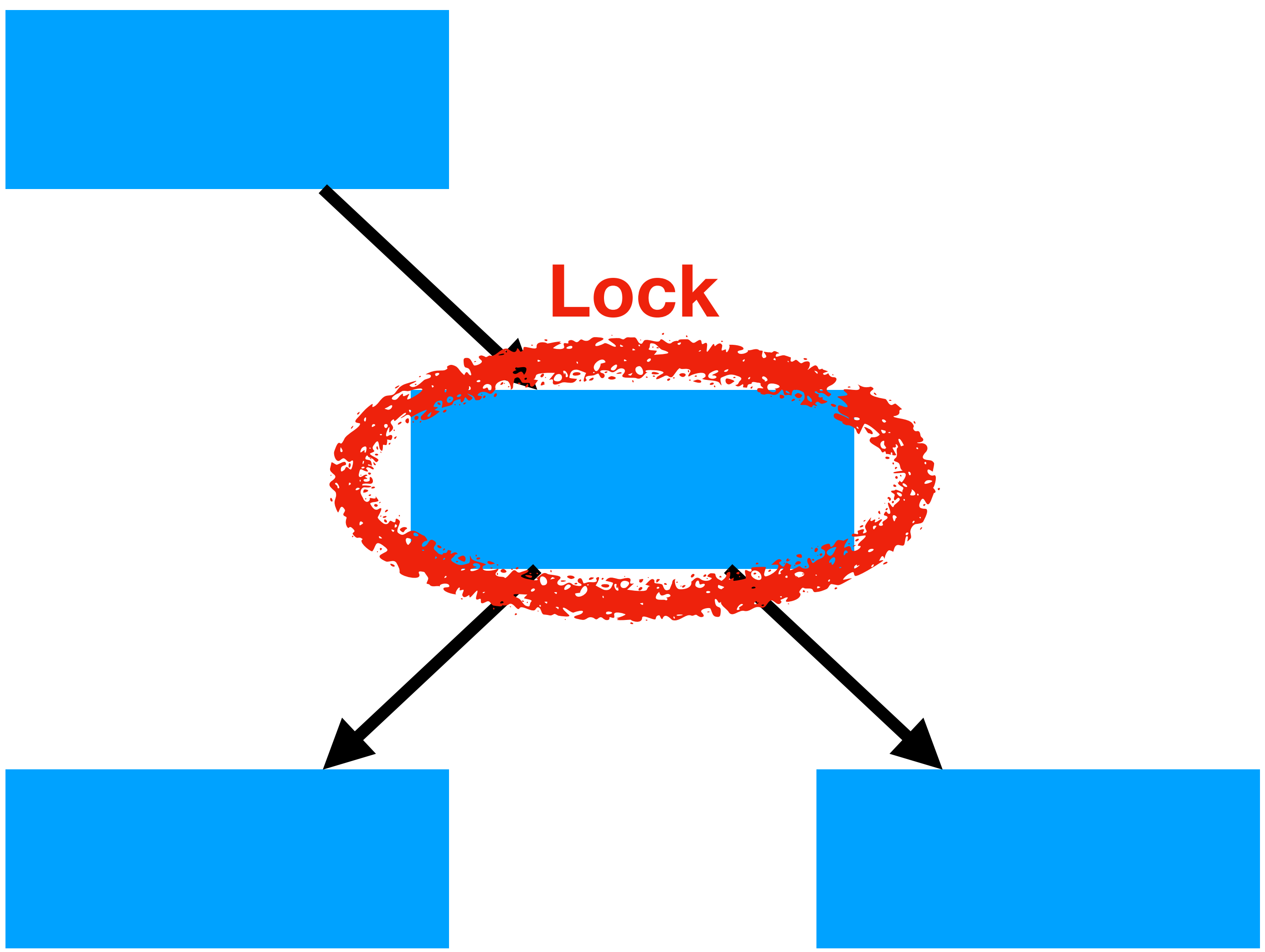

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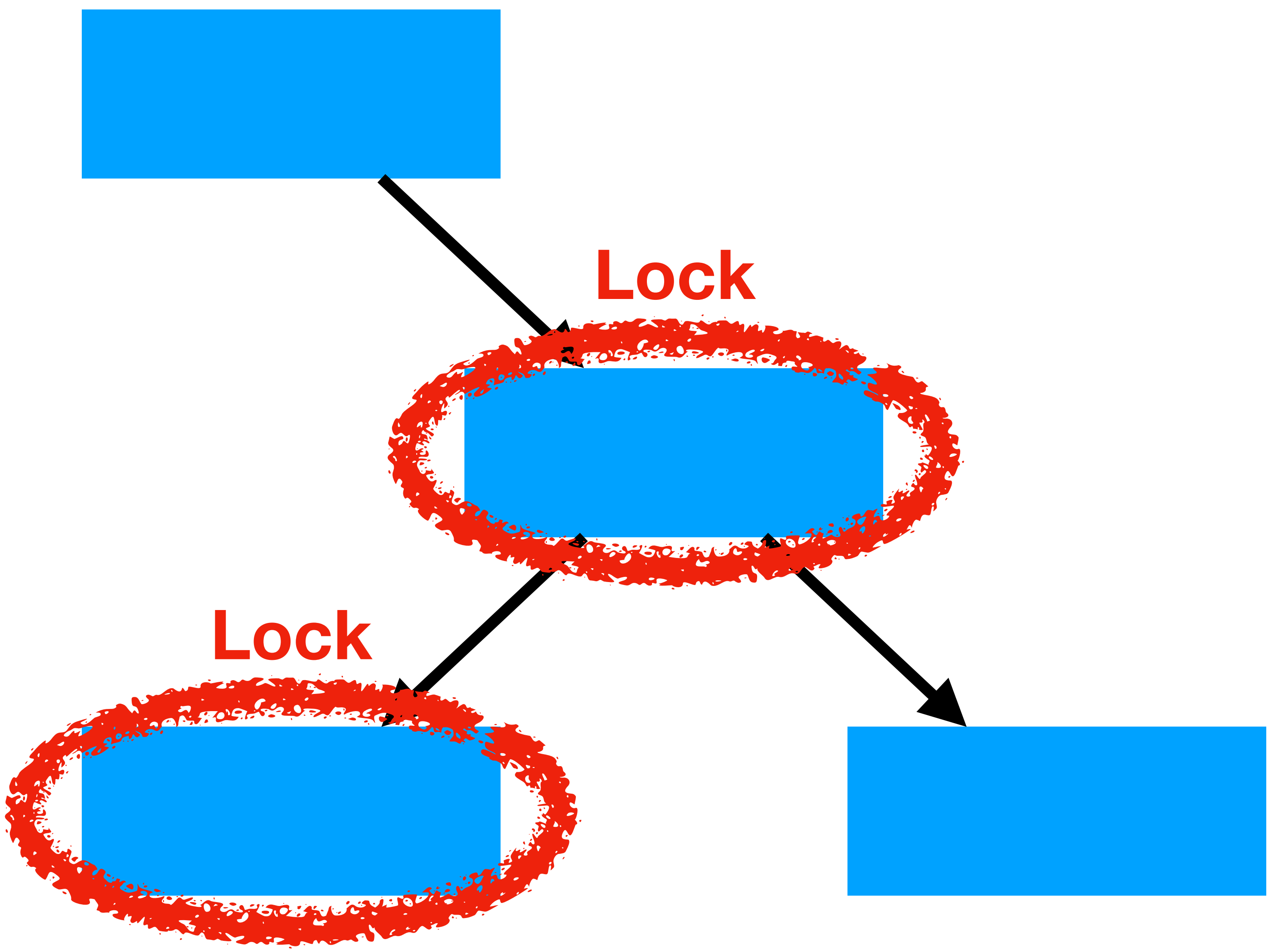

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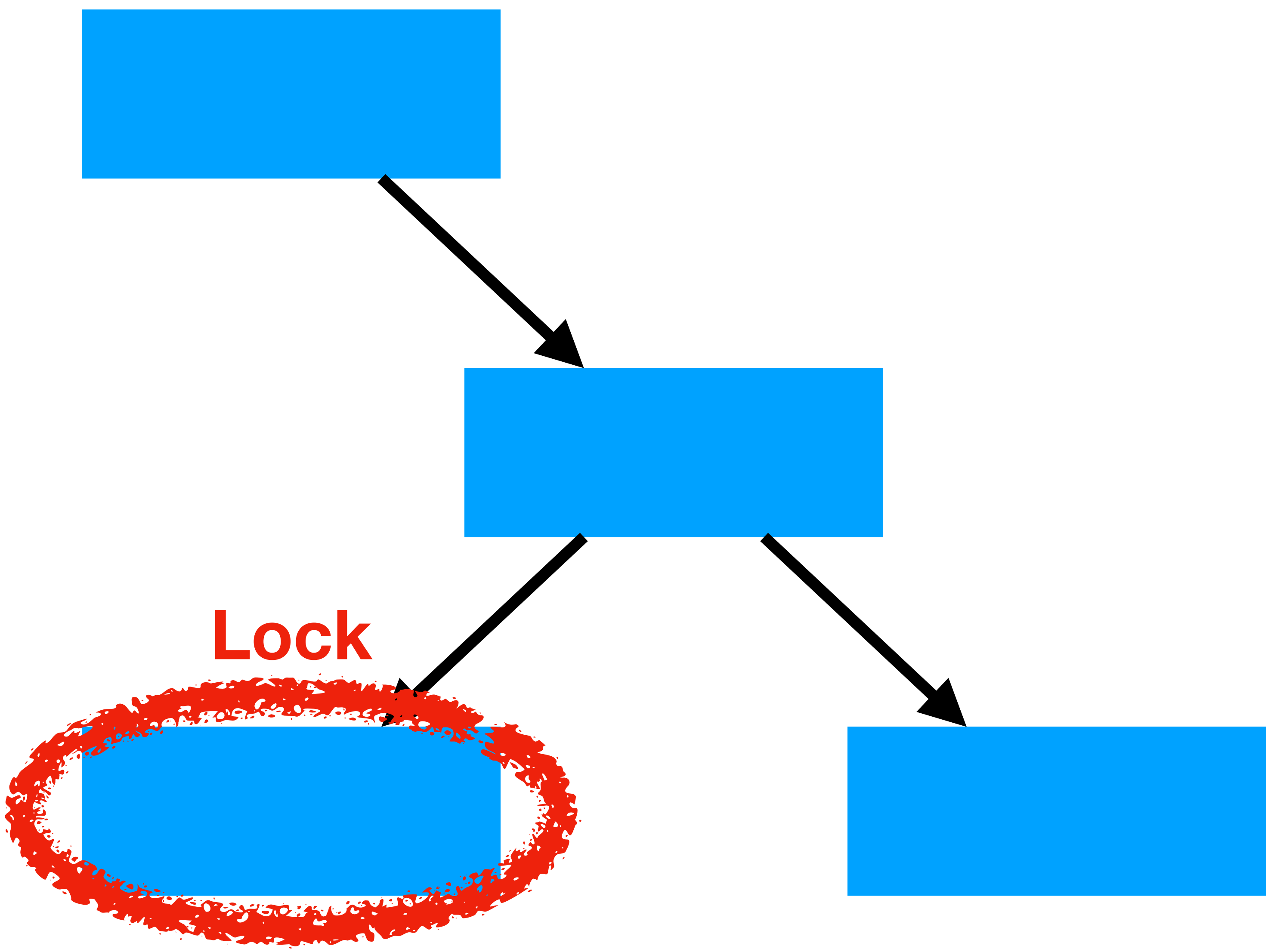


Locking for Index Updates

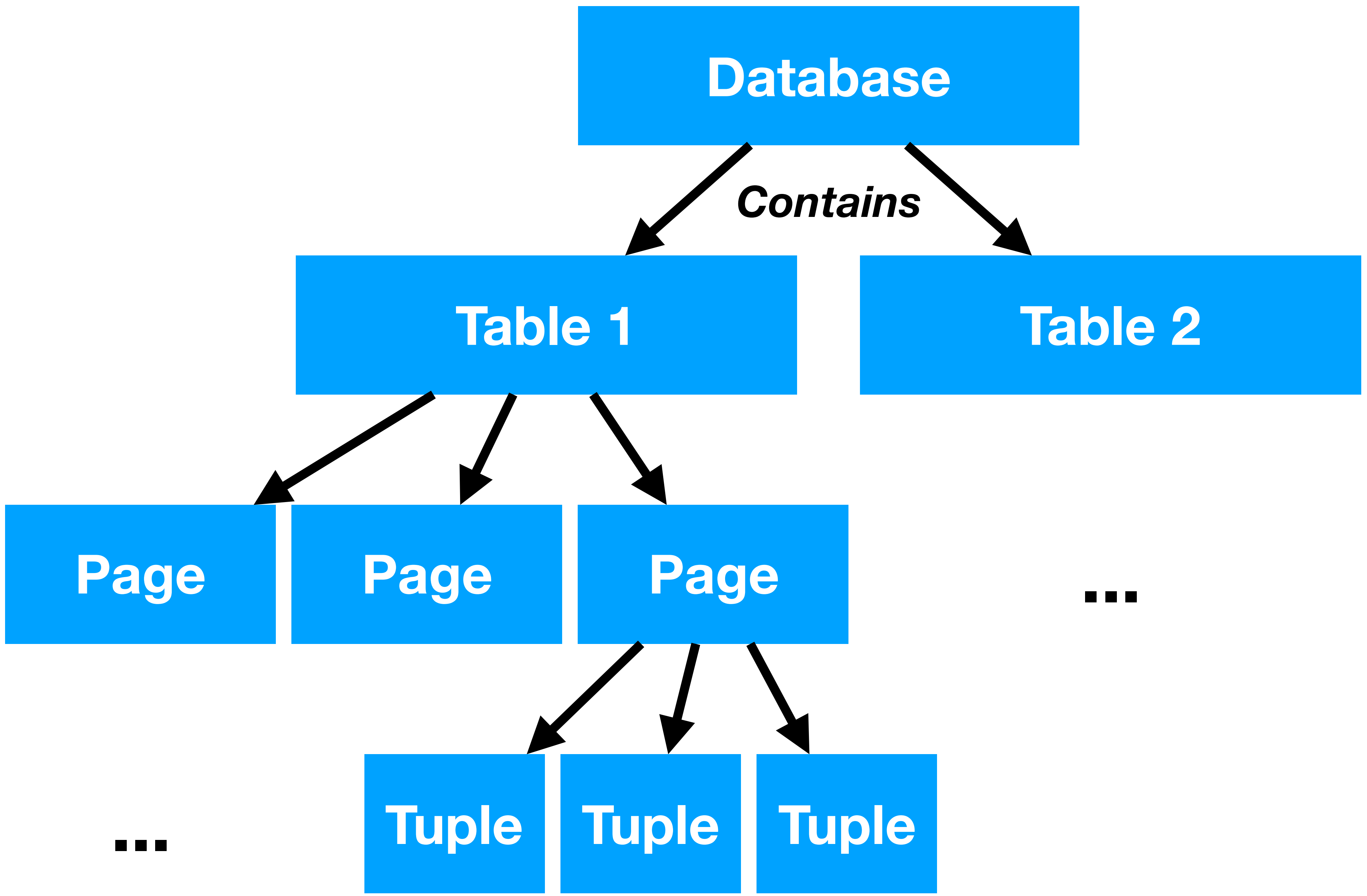
- So far: only considered index lookups; next: **updates**
- Index updates change index **leaf nodes,** may **propagate** up
- However, updates may not propagate upwards of "**safe**" nodes
  - Safe node is less than full (insertions)/more than half full (deletions)
- When traversing tree, **release prior locks** at each safe node
- May **pessimistically** request write locks but reduces performance
- Can **optimistically** request read locks for all nodes except leaf
  - Bets on **no propagation**, may have to restart if we lose

Multi-Granularity Locks

Multiple-Granularity Locks

- Fine-grained locking can **increase degree of parallelism**
- But fine-grained locking also **increases locking overheads**
- **Best granularity** may depend on query
  - E.g., whether we access **most** or **few** table rows
- Multiple-granularity locking **mixes lock granularities**
  - Have locks for entire table and locks for single rows
- Challenge: granting locks of diverse granularity **consistently**

Hierarchy of DB Objects



Multi-Granularity Locking

- **Cannot** treat locks at different granularities separately
  - May grant **conflicting** locks otherwise
- Need **locks on containing** objects before locking object
- Introduce new type of lock: **intention locks**
  - **IS (Intention Shared)**:
    want shared lock on contained object
  - **IX (Intention Exclusive)**:
    want exclusive lock on contained object

Lock Compatibility

	IS	IX	S	X
IS	✔	✔	✔	✘
IX	✔	✔	✘	✘
S	✔	✘	✔	✘
X	✘	✘	✘	✘

Lock Compatibility

	IS	IX	S	X
IS	✔	✔	✔	✘
IX	✔	✔	✘	✘
S	✔	✘	✔	✘
X	✘	✘	✘	✘

Lock Compatibility

Want shared lock on contained object

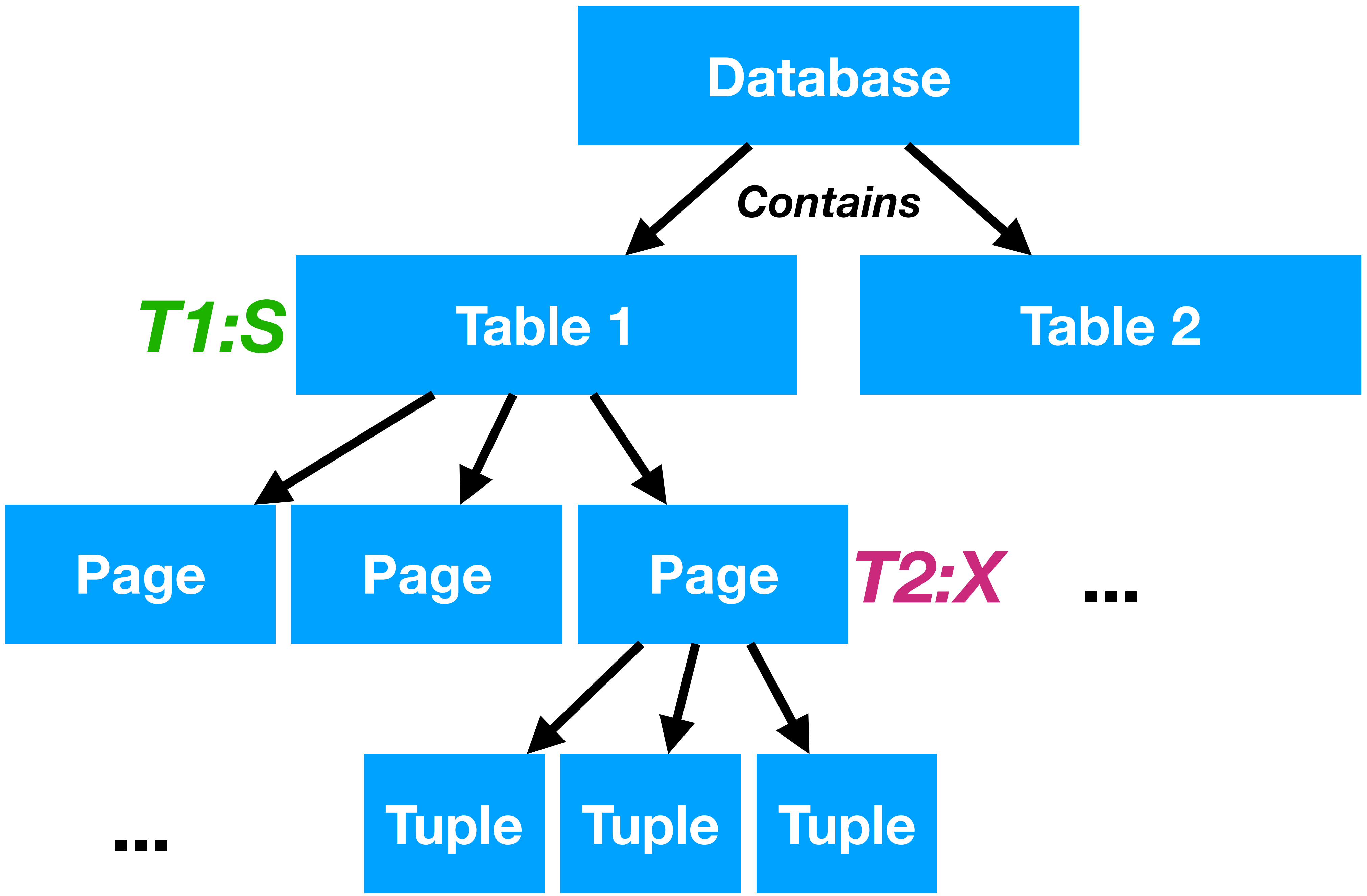
	IS	IX	S	X
IS	✔	✔	✔	✘
IX	✔	✔	✘	✘
[illegible]	✔	✘	✔	✘
X	✘	✘	✘	✘

Want exclusive lock on contained object

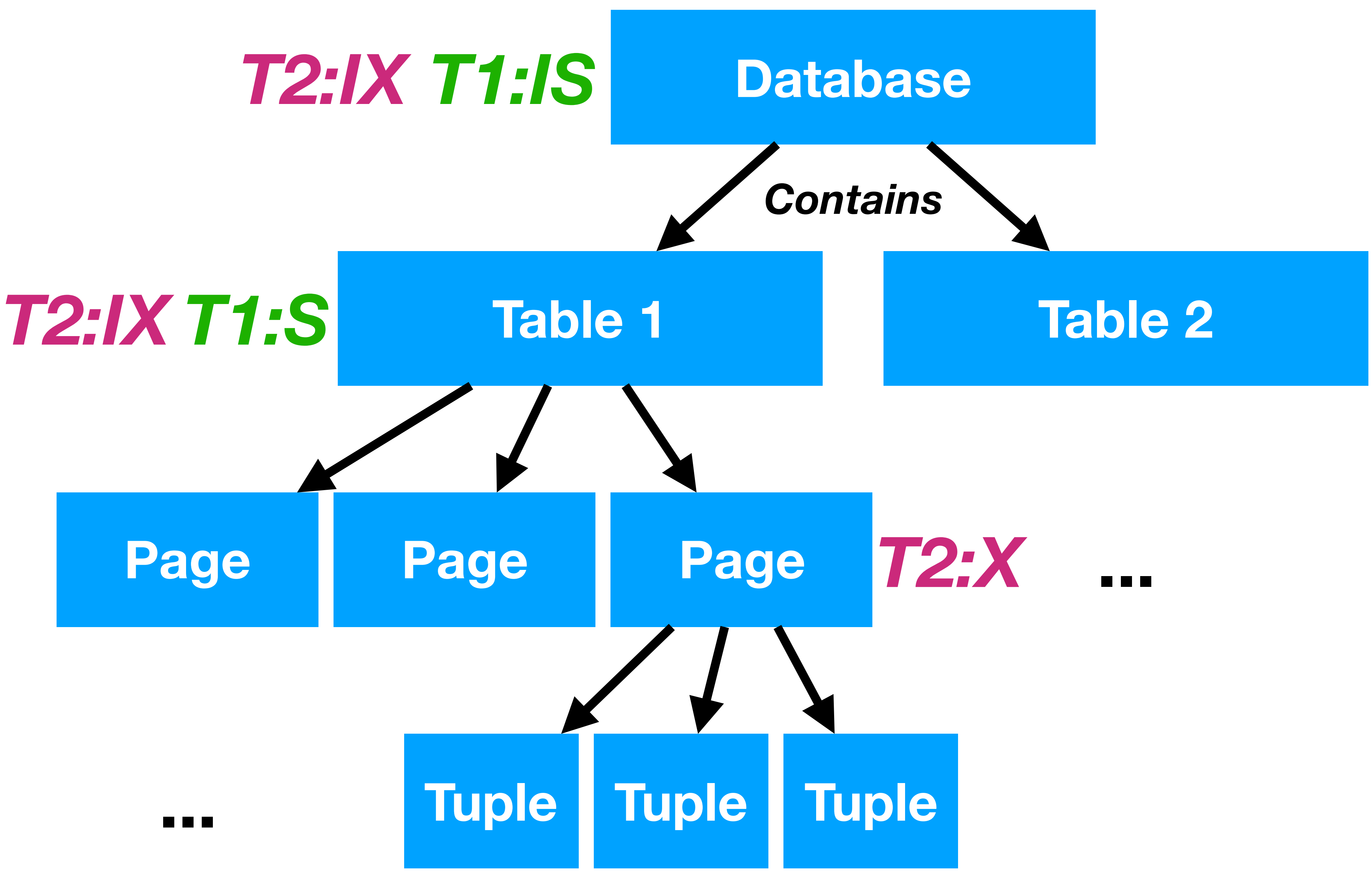
Using Intention Locks

- Need **IS** lock on **ancestors** before requesting Shared lock
- Need **IX** lock on **ancestors** before Exclusive lock
- Release intention locks from **leaf to root** node
  - Otherwise may have **inconsistent** locks

Inconsistent Locks



Intention Locks Help



Intention Locks Help