Carnegie Mellon Univ.
Dept. of Computer Science
15-415/615 - DB Applications

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Lecture#22: Concurrency Control – Part 2

(R&G ch. 17)

Last Class

- A ***concurrency control*** scheme uses locks and aborts to ensure correctness.
- Conflict vs. View Serializability
- (Strict) 2PL is popular.
- We need to handle deadlocks in 2PL:
  - **Detection:** *Waits-for* graph
  - **Prevention:** Abort some txns, defensively

Last Class Assumption

- We assumed that the database was ***fixed*** collection of ***independent*** objects.
  - No objects are added or deleted.
  - No relationship between objects.
  - No indexes.

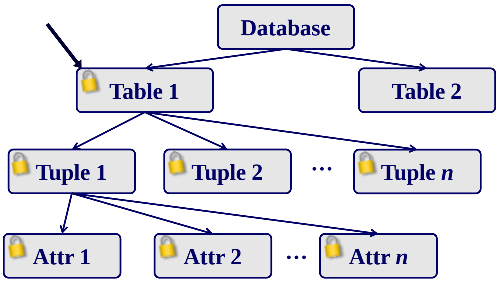
Today's Class

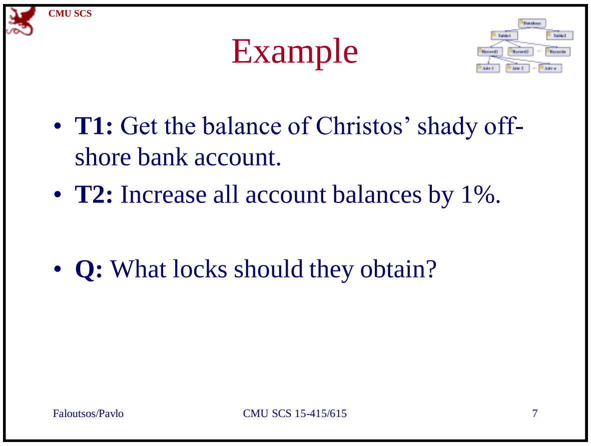
- Lock Granularities
- Locking in B+Trees
- The Phantom Problem
- Transaction Isolation Levels

Lock Granularities

- When we say that a txn acquires a "lock", what does that actually mean?
  - On a field? Record? Page? Table?
- Ideally, each txn should obtain fewest number of locks that is needed…

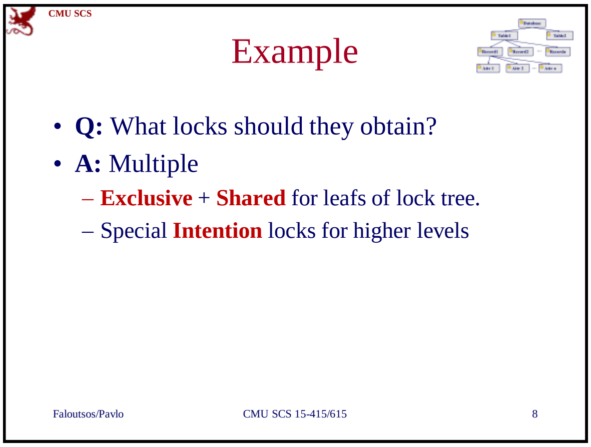
Database Lock Hierarchy





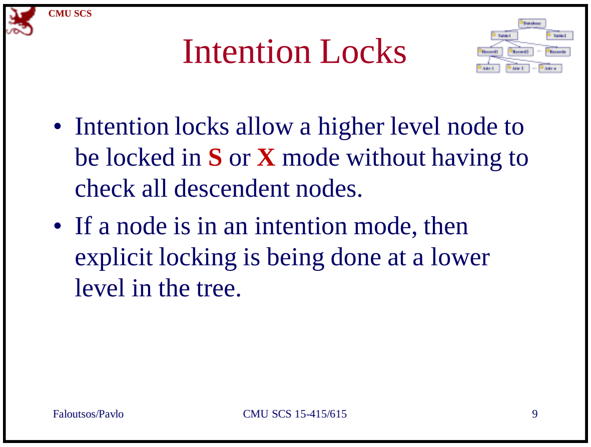
Example

- **T1:** Get the balance of Christos’ shady off-shore bank account.
- **T2:** Increase all account balances by 1%.
- **Q:** What locks should they obtain?



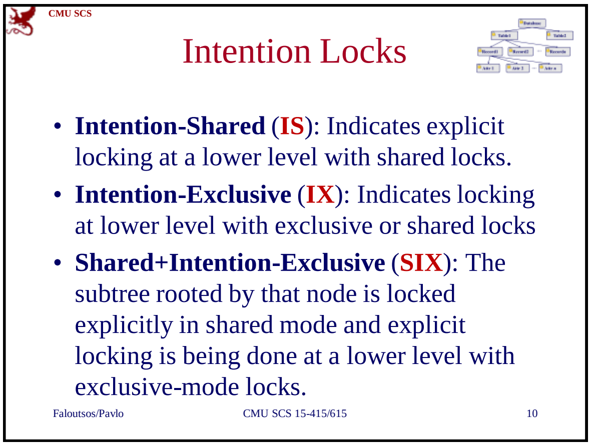
Example

- **Q:** What locks should they obtain?
- **A:** Multiple
  - **Exclusive** + **Shared** for leafs of lock tree.
  - Special **Intention** locks for higher levels



Intention Locks

- Intention locks allow a higher level node to be locked in **S** or **X** mode without having to check all descendent nodes.
- If a node is in an intention mode, then explicit locking is being done at a lower level in the tree.



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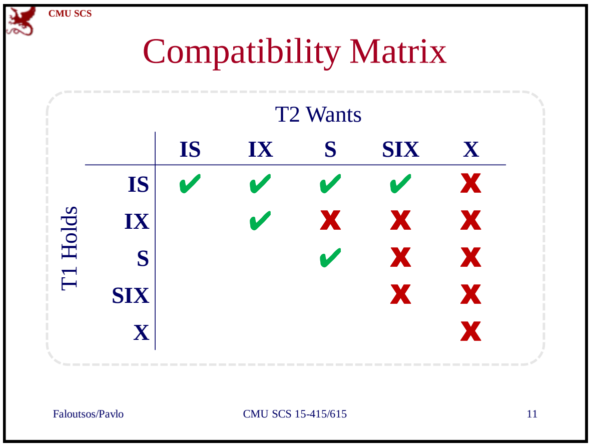
Intention Locks

- **Intention-Shared** (**IS**): Indicates explicit locking at a lower level with shared locks.
- **Intention-Exclusive** (**IX**): Indicates locking at lower level with exclusive or shared locks
- **Shared+Intention-Exclusive** (**SIX**): The subtree rooted by that node is locked explicitly in shared mode and explicit locking is being done at a lower level with exclusive-mode locks.



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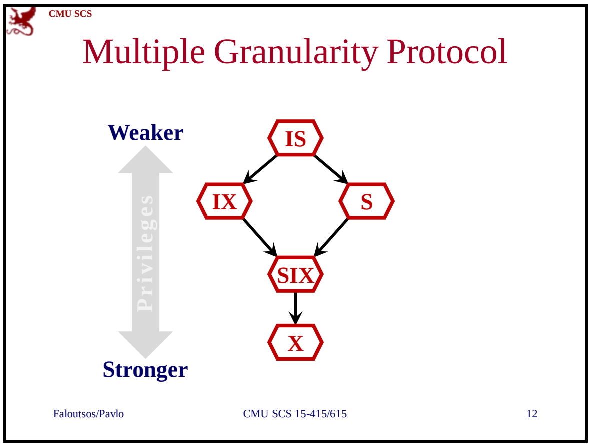
Compatibility Matrix

T2 Wants

T1 Holds

	IS	IX	S	SIX	X
IS	✓	✓	✓	✓	✗
IX		✓	✗	✗	✗
S			✓	✗	✗
SIX				✗	✗
X					✗



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Multiple Granularity Protocol

Weaker

Privileges

Stronger

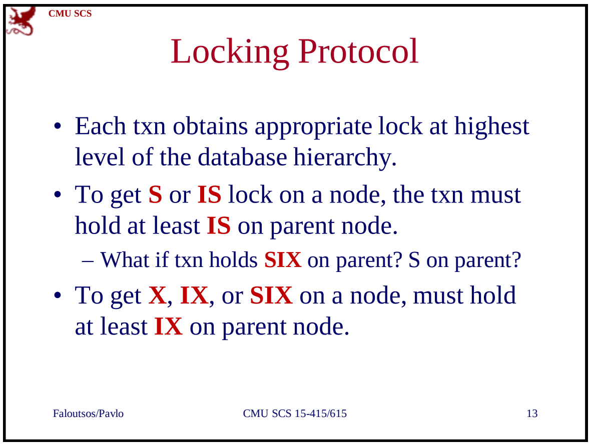
IS

IX

S

SIX

X



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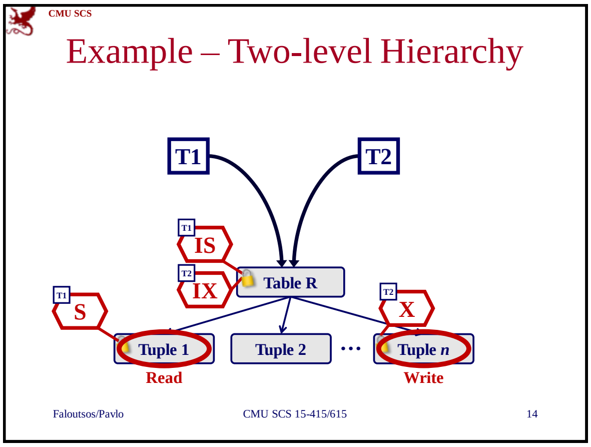
Locking Protocol

- Each txn obtains appropriate lock at highest level of the database hierarchy.
- To get **S** or **IS** lock on a node, the txn must hold at least **IS** on parent node.
  - What if txn holds **SIX** on parent? S on parent?
- To get **X**, **IX**, or **SIX** on a node, must hold at least **IX** on parent node.



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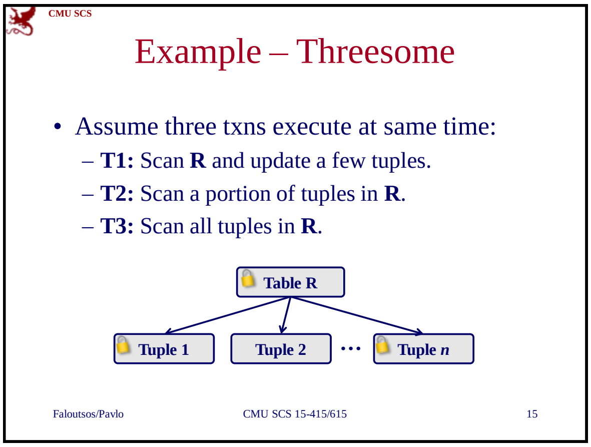
Example – Two-level Hierarchy



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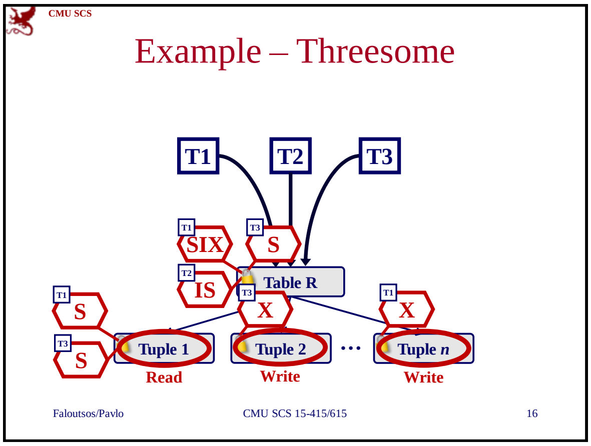
Example – Threesome

- Assume three txns execute at same time:
  - **T1:** Scan **R** and update a few tuples.
  - **T2:** Scan a portion of tuples in **R**.
  - **T3:** Scan all tuples in **R**.



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Example – Threesome

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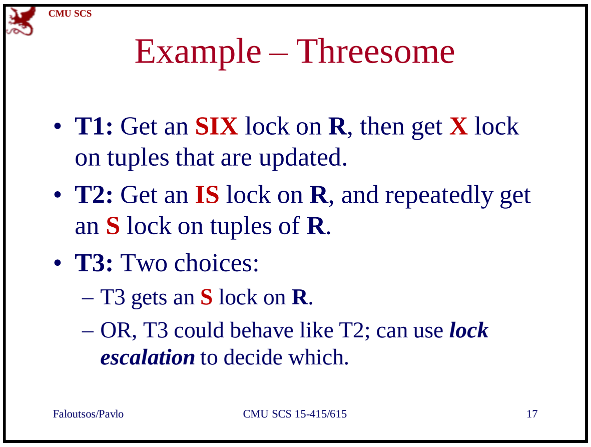

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Example – Threesome

- **T1:** Get an **SIX** lock on **R**, then get **X** lock on tuples that are updated.
- **T2:** Get an **IS** lock on **R**, and repeatedly get an **S** lock on tuples of **R**.
- **T3:** Two choices:
  - T3 gets an **S** lock on **R**.
  - OR, T3 could behave like T2; can use ***lock escalation*** to decide which.

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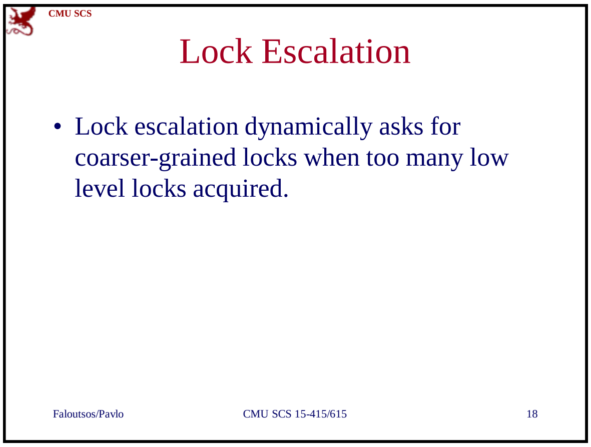

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Lock Escalation

- Lock escalation dynamically asks for coarser-grained locks when too many low level locks acquired.

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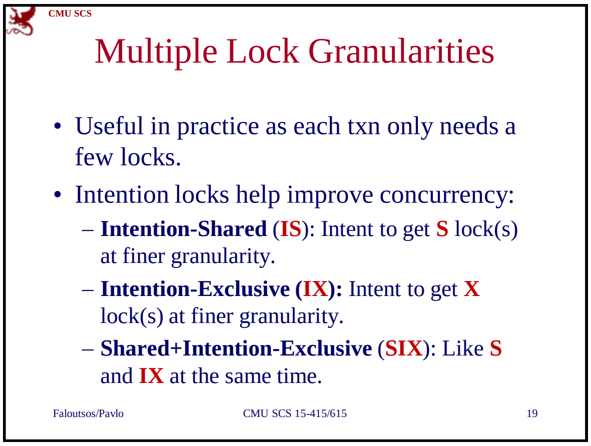

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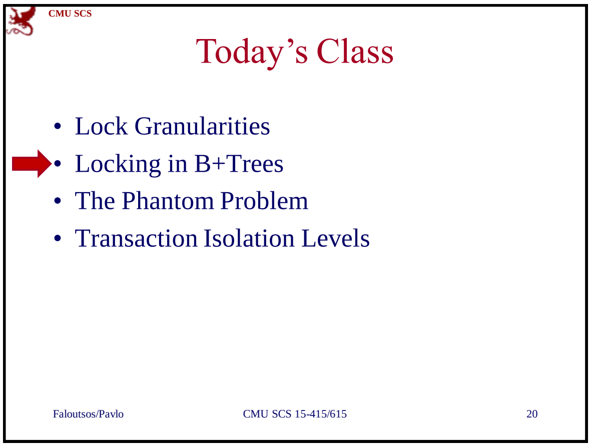
Multiple Lock Granularities

- Useful in practice as each txn only needs a few locks.
- Intention locks help improve concurrency:
  - **Intention-Shared** (**IS**): Intent to get **S** lock(s) at finer granularity.
  - **Intention-Exclusive** (**IX**)**:** Intent to get **X** lock(s) at finer granularity.
  - **Shared+Intention-Exclusive** (**SIX**): Like **S** and **IX** at the same time.



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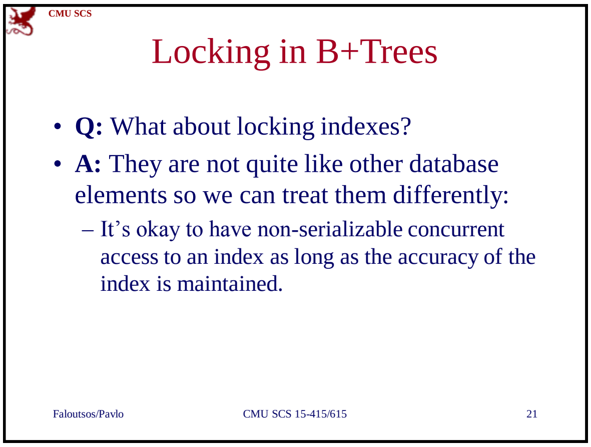
Today’s Class

- Lock Granularities
- ➡ Locking in B+Trees
- The Phantom Problem
- Transaction Isolation Levels



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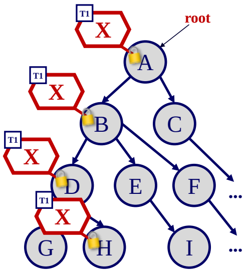
Locking in B+Trees

- **Q:** What about locking indexes?
- **A:** They are not quite like other database elements so we can treat them differently:
  - It’s okay to have non-serializable concurrent access to an index as long as the accuracy of the index is maintained.

Example

- T1 wants to insert in H
- T2 wants to insert in I
- **Q:** Why not plain 2PL?
- **A:** Because txns have to hold on to their locks for too long!



Lock Crabbing

- Improves concurrency for B+Trees.
- Get lock for parent; get lock for child; release lock for parent if "safe".
- **Safe Nodes:** Any node that won't split or merge when updated.
  - Not full (on insertion)
  - More than half-full (on deletion)

Lock Crabbing

- **Search:** Start at root and go down; repeatedly,
  - **S** lock child
  - then unlock parent
- **Insert/Delete:** Start at root and go down, obtaining **X** locks as needed. Once child is locked, check if it is safe:
  - If child is safe, release all locks on ancestors.

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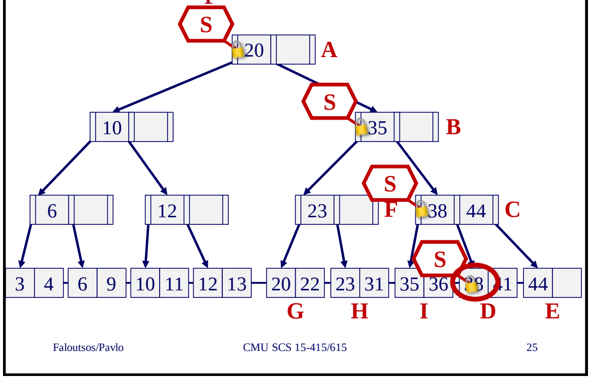
Example #1 – Search 38



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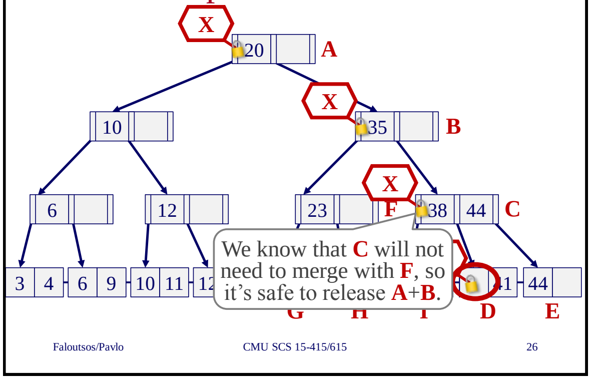
Example #2 – Delete 38



We know that **C** will not need to merge with **F**, so it's safe to release **A**+**B**.

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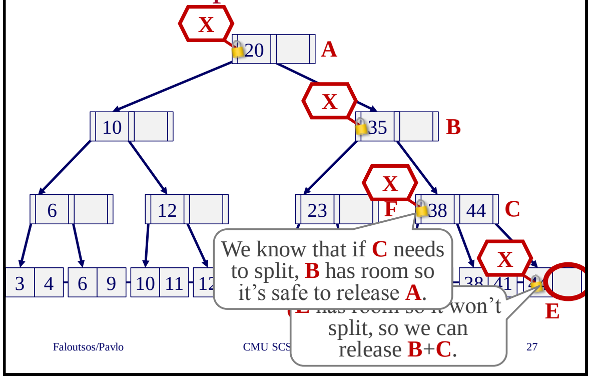
Example #3 – Insert 45



We know that if **C** needs to split, **B** has room so it's safe to release **A**.

E has room so it won't split, so we can release **B**+**C**.

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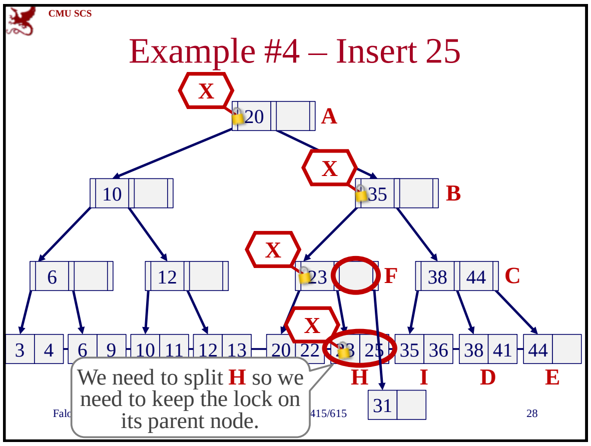

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Example #4 – Insert 25

We need to split **H** so we need to keep the lock on its parent node.

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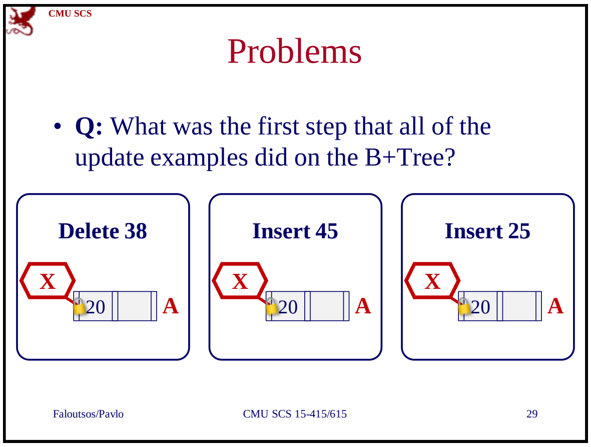

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Problems

- **Q:** What was the first step that all of the update examples did on the B+Tree?

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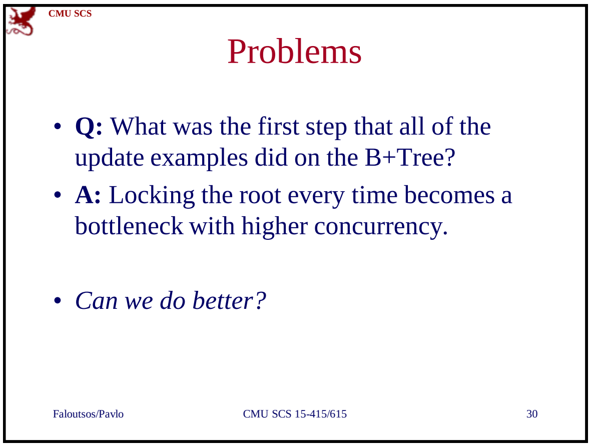

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Problems

- **Q:** What was the first step that all of the update examples did on the B+Tree?
- **A:** Locking the root every time becomes a bottleneck with higher concurrency.

- *Can we do better?*

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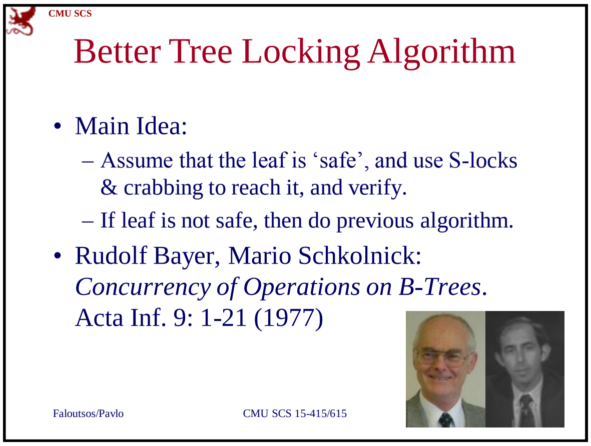

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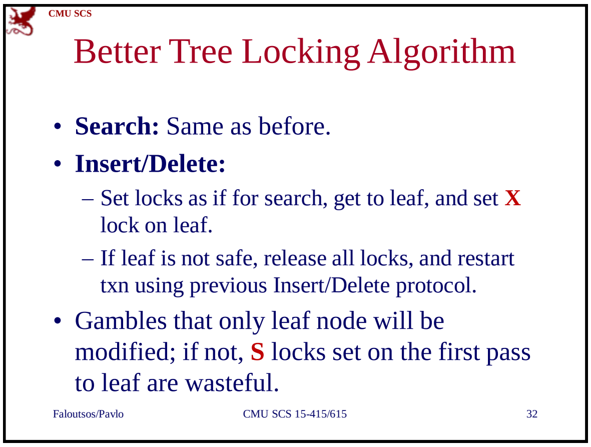
Better Tree Locking Algorithm

- Main Idea:
  - Assume that the leaf is ‘safe’, and use S-locks & crabbing to reach it, and verify.
  - If leaf is not safe, then do previous algorithm.
- Rudolf Bayer, Mario Schkolnick: *Concurrency of Operations on B-Trees*. Acta Inf. 9: 1-21 (1977)



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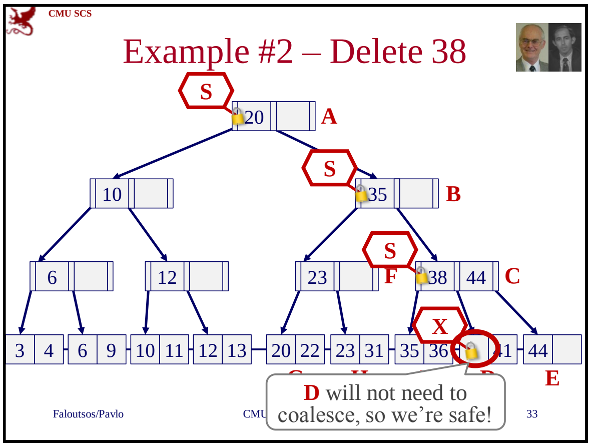
Better Tree Locking Algorithm

- **Search:** Same as before.
- **Insert/Delete:**
  - Set locks as if for search, get to leaf, and set **X** lock on leaf.
  - If leaf is not safe, release all locks, and restart txn using previous Insert/Delete protocol.
- Gambles that only leaf node will be modified; if not, **S** locks set on the first pass to leaf are wasteful.



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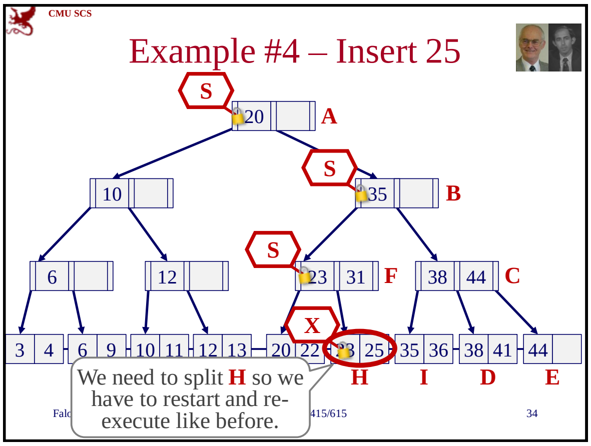
Example #2 – Delete 38

D will not need to coalesce, so we’re safe!



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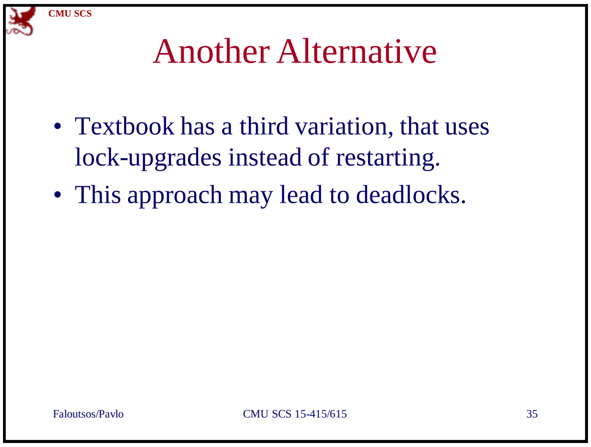
Example #4 – Insert 25

We need to split **H** so we have to restart and re-execute like before.



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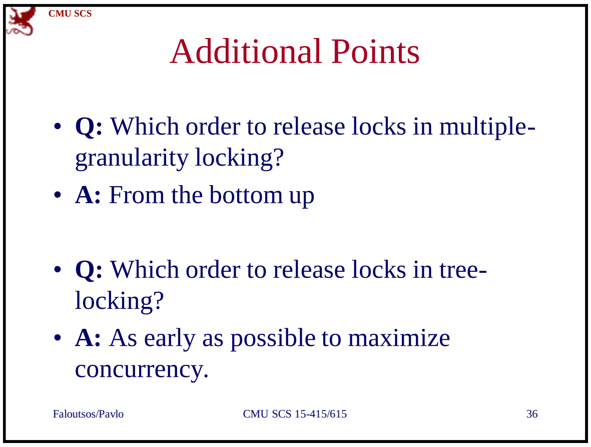
Another Alternative

- Textbook has a third variation, that uses lock-upgrades instead of restarting.
- This approach may lead to deadlocks.



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Additional Points

- **Q:** Which order to release locks in multiple-granularity locking?
- **A:** From the bottom up

- **Q:** Which order to release locks in tree-locking?
- **A:** As early as possible to maximize concurrency.

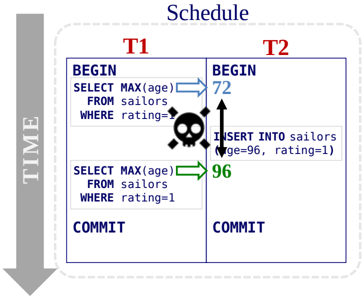
Today’s Class

- Lock Granularities
- Locking in B+Trees
- ➡ The Phantom Problem
- Transaction Isolation Levels

Dynamic Databases

- Recall that so far we have only dealing with transactions that read and update data.
- But now if we have insertions deletions, we have new problems…

The Phantom Problem



T1:

```
BEGIN
SELECT MAX(age)
  FROM sailors
 WHERE rating=1
SELECT MAX(age)
  FROM sailors
 WHERE rating=1
COMMIT
```

T2:

```
BEGIN
INSERT INTO sailors
(age=96, rating=1)
COMMIT
```

How did this happen?

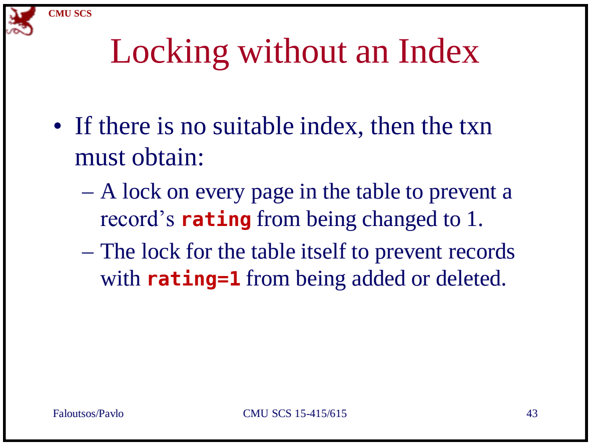
- Because T1 locked only existing records and not ones under way!
- Conflict serializability on reads and writes of individual items guarantees serializability only if the set of objects is fixed.
- Solution?

Predicate Locking

- Lock records that satisfy a logical predicate:
  - Example: **`rating=1`**.
- In general, predicate locking has a lot of locking overhead.
- **Index locking** is a special case of predicate locking that is potentially more efficient.

Index Locking

- If there is a dense index on the **`rating`** field then the txn can lock index page containing the data with **`rating=1`**.
- If there are no records with **`rating=1`**, the txn must lock the index page where such a data entry would be, if it existed.



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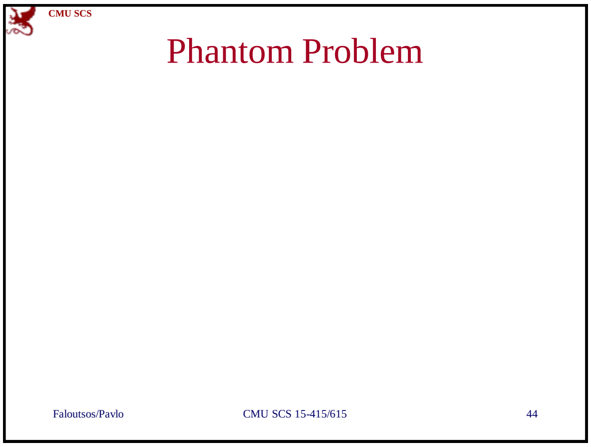
Locking without an Index

- If there is no suitable index, then the txn must obtain:
  - A lock on every page in the table to prevent a record’s **`rating`** from being changed to 1.
  - The lock for the table itself to prevent records with **`rating=1`** from being added or deleted.



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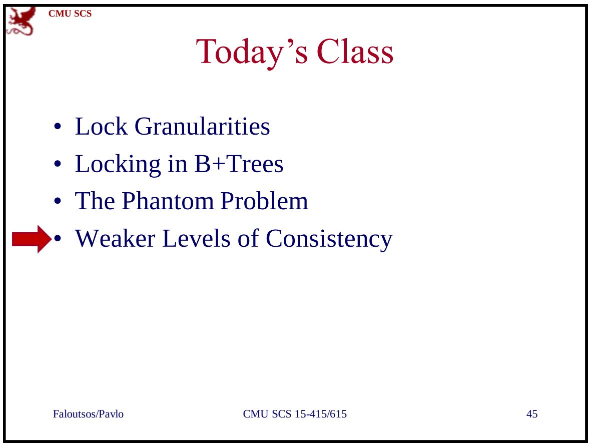
Phantom Problem



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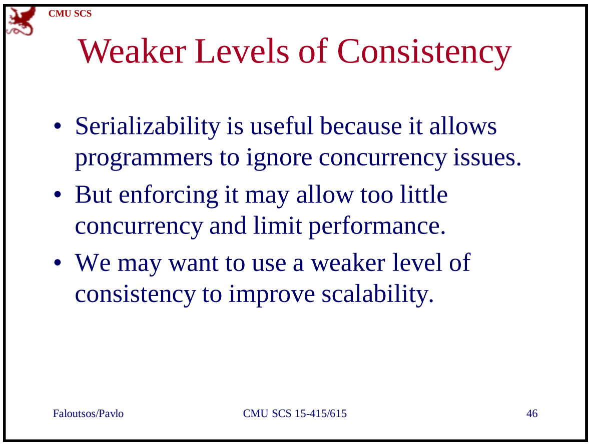
Today’s Class

- Lock Granularities
- Locking in B+Trees
- The Phantom Problem
- ➡ Weaker Levels of Consistency



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Weaker Levels of Consistency

- Serializability is useful because it allows programmers to ignore concurrency issues.
- But enforcing it may allow too little concurrency and limit performance.
- We may want to use a weaker level of consistency to improve scalability.

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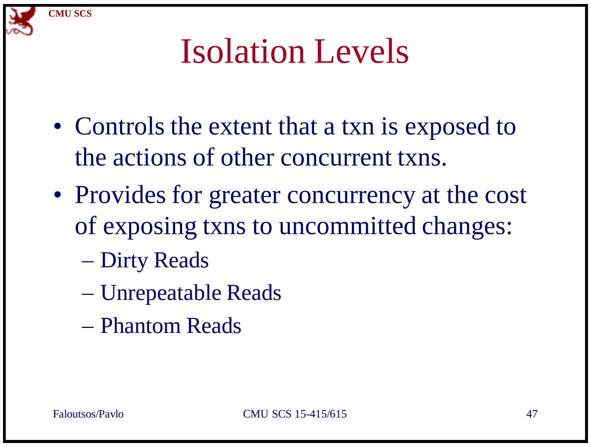

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Isolation Levels

- Controls the extent that a txn is exposed to the actions of other concurrent txns.
- Provides for greater concurrency at the cost of exposing txns to uncommitted changes:
  - Dirty Reads
  - Unrepeatable Reads
  - Phantom Reads

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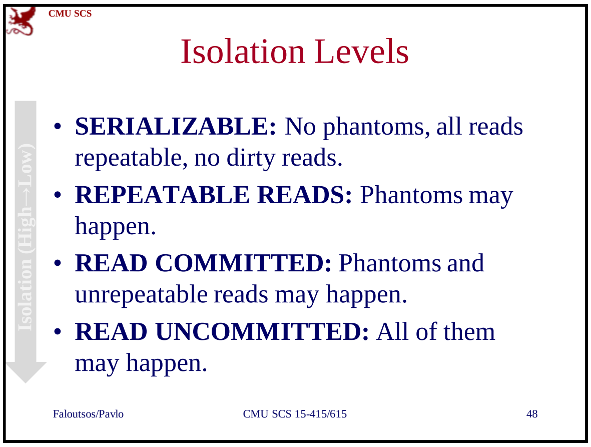

Isolation (High→Low)

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Isolation Levels

- **SERIALIZABLE:** No phantoms, all reads repeatable, no dirty reads.
- **REPEATABLE READS:** Phantoms may happen.
- **READ COMMITTED:** Phantoms and unrepeatable reads may happen.
- **READ UNCOMMITTED:** All of them may happen.

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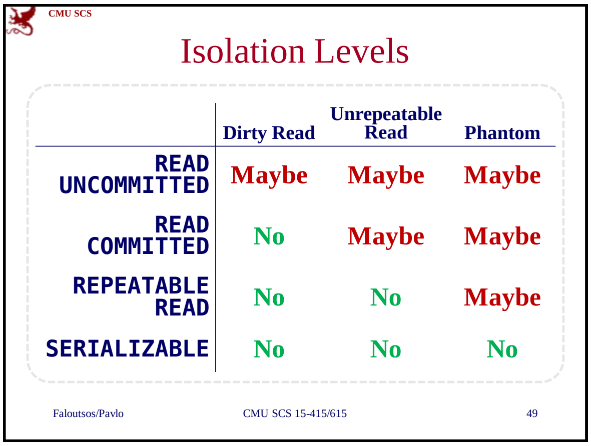

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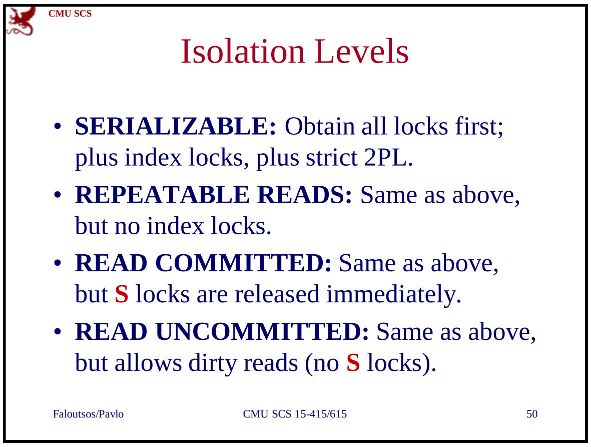
Isolation Levels

	Dirty Read	Unrepeatable Read	Phantom
READ UNCOMMITTED	Maybe	Maybe	Maybe
READ COMMITTED	No	Maybe	Maybe
REPEATABLE READ	No	No	Maybe
SERIALIZABLE	No	No	No



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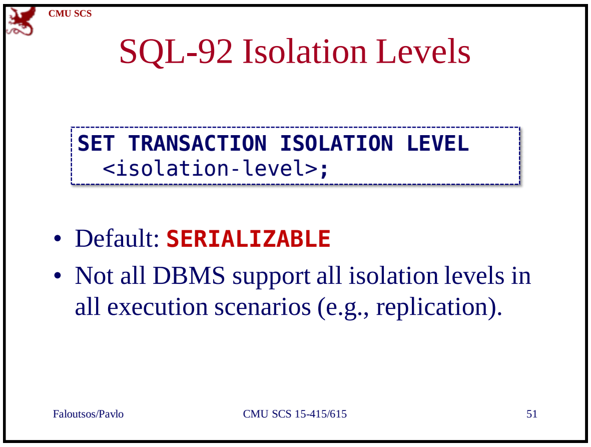
Isolation Levels

- **SERIALIZABLE:** Obtain all locks first; plus index locks, plus strict 2PL.
- **REPEATABLE READS:** Same as above, but no index locks.
- **READ COMMITTED:** Same as above, but **S** locks are released immediately.
- **READ UNCOMMITTED:** Same as above, but allows dirty reads (no **S** locks).



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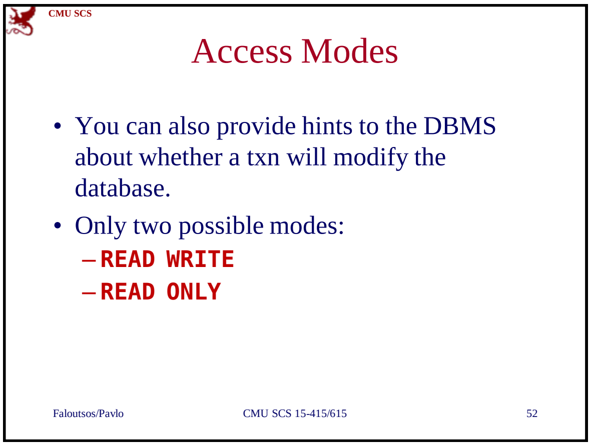
SQL-92 Isolation Levels

```
SET TRANSACTION ISOLATION LEVEL
  <isolation-level>;
```

- Default: **SERIALIZABLE**
- Not all DBMS support all isolation levels in all execution scenarios (e.g., replication).



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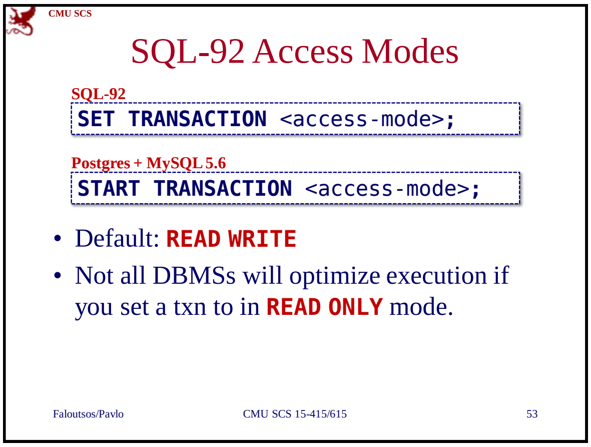
Access Modes

- You can also provide hints to the DBMS about whether a txn will modify the database.
- Only two possible modes:
  - `READ WRITE`
  - `READ ONLY`



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SQL-92 Access Modes

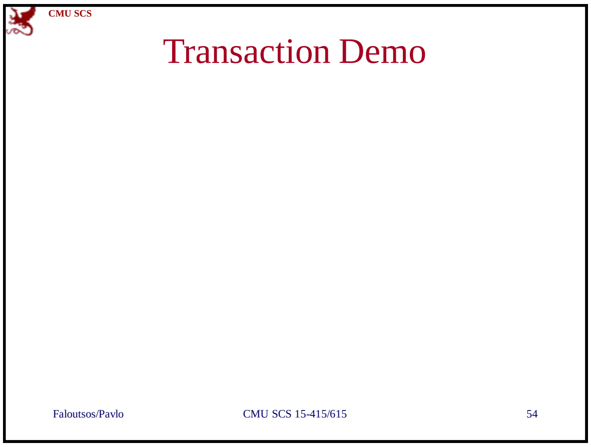
SQL-92

```
SET TRANSACTION <access-mode>;
```

Postgres + MySQL 5.6

```
START TRANSACTION <access-mode>;
```

- Default: `READ WRITE`
- Not all DBMSs will optimize execution if you set a txn to in `READ ONLY` mode.



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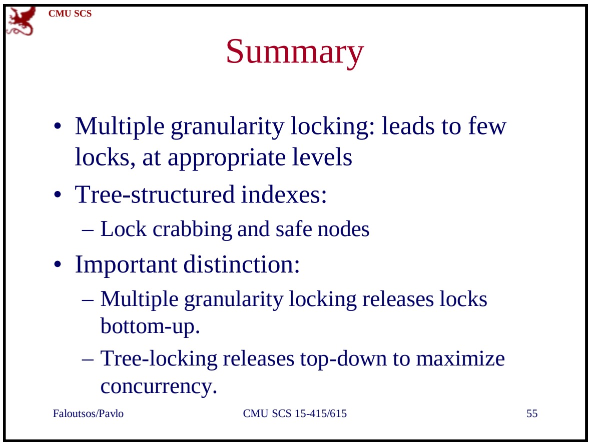
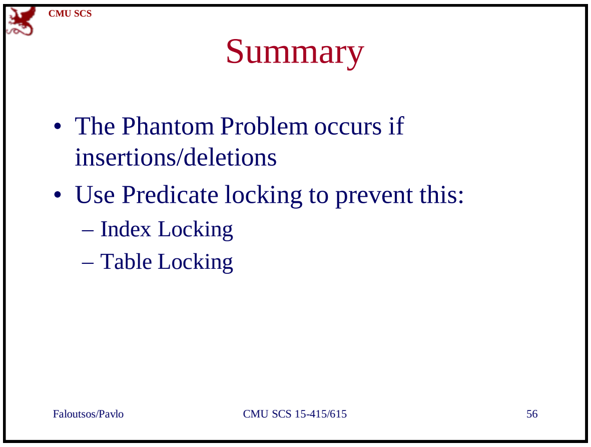
Transaction Demo



Summary

- Multiple granularity locking: leads to few locks, at appropriate levels
- Tree-structured indexes:
  - Lock crabbing and safe nodes
- Important distinction:
  - Multiple granularity locking releases locks bottom-up.
  - Tree-locking releases top-down to maximize concurrency.



Summary

- The Phantom Problem occurs if insertions/deletions
- Use Predicate locking to prevent this:
  - Index Locking
  - Table Locking