Distributed Systems

12. Concurrency Control

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Why do we lock access to data?

- Locking (leasing) provides mutual exclusion
  - Only one process at a time can access the data (or service)
- Allows us to achieve *isolation*
  - Other processes will not see or be able to access intermediate results
  - Important for consistency

Example:

```
Lock(table=checking_account, row=512348)
Lock(table=savings_account, row=512348)
checking_account.total = checking_account.total - 5000
savings_account.total = savings_account.total + 5000
Release(table=savings_account, row=512348)
Release(table=checking_account, row=512348)
```

Schedules

Transactions must be scheduled so that data is serially equivalent

How?

- Use mutual exclusion to ensure that only one transaction executes at a time

  or…

- Allow multiple transactions to execute concurrently
  - but ensure serializability

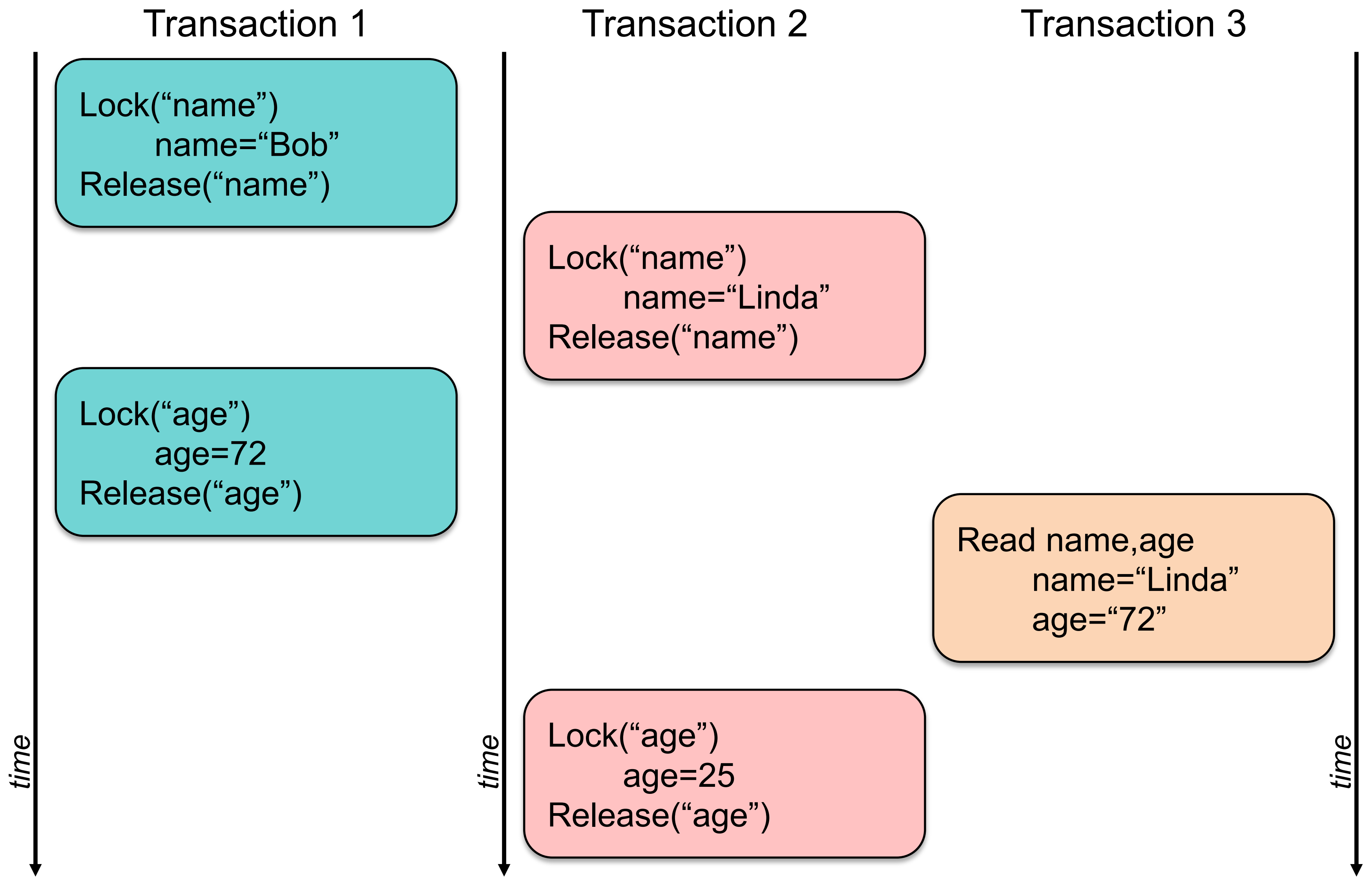
⇒ concurrency control

schedule: valid order of interleaving

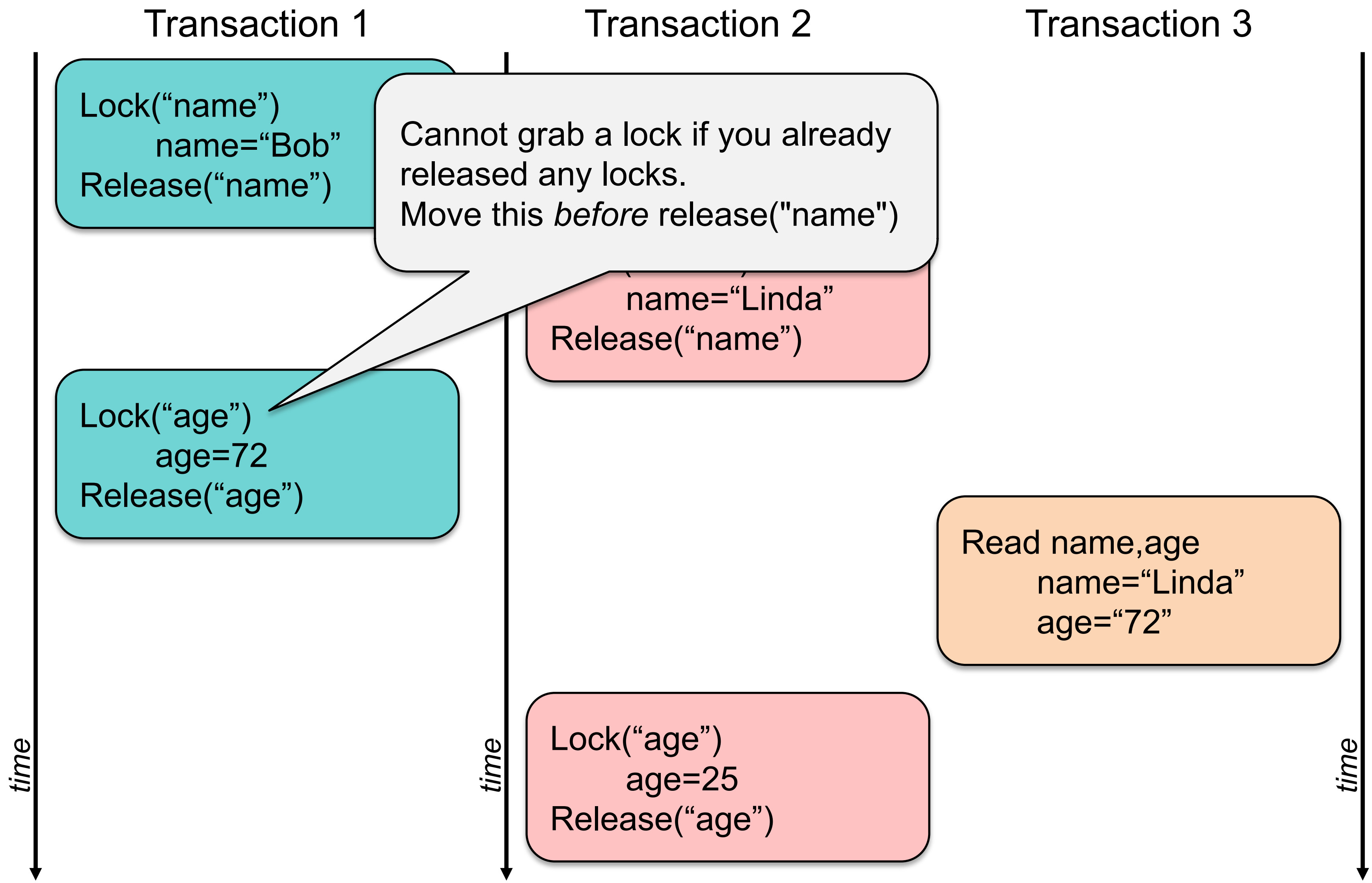
Two-Phase Locking (2PL)

- Transactions run concurrently until they compete for the same resource
  - Only one will get to go … others must wait
- Grab exclusive locks on a resource
  - Lock data that is used by the transaction (e.g., fields in a DB, parts of a file)
  - Lock manager = mutual exclusion service
- **Two-phase locking**
  - phase 1: growing phase: acquire locks
  - phase 2: shrinking phase: release locks
- Transaction is not allowed new locks after it has released a lock
  - This ensures *serial ordering* on resource access

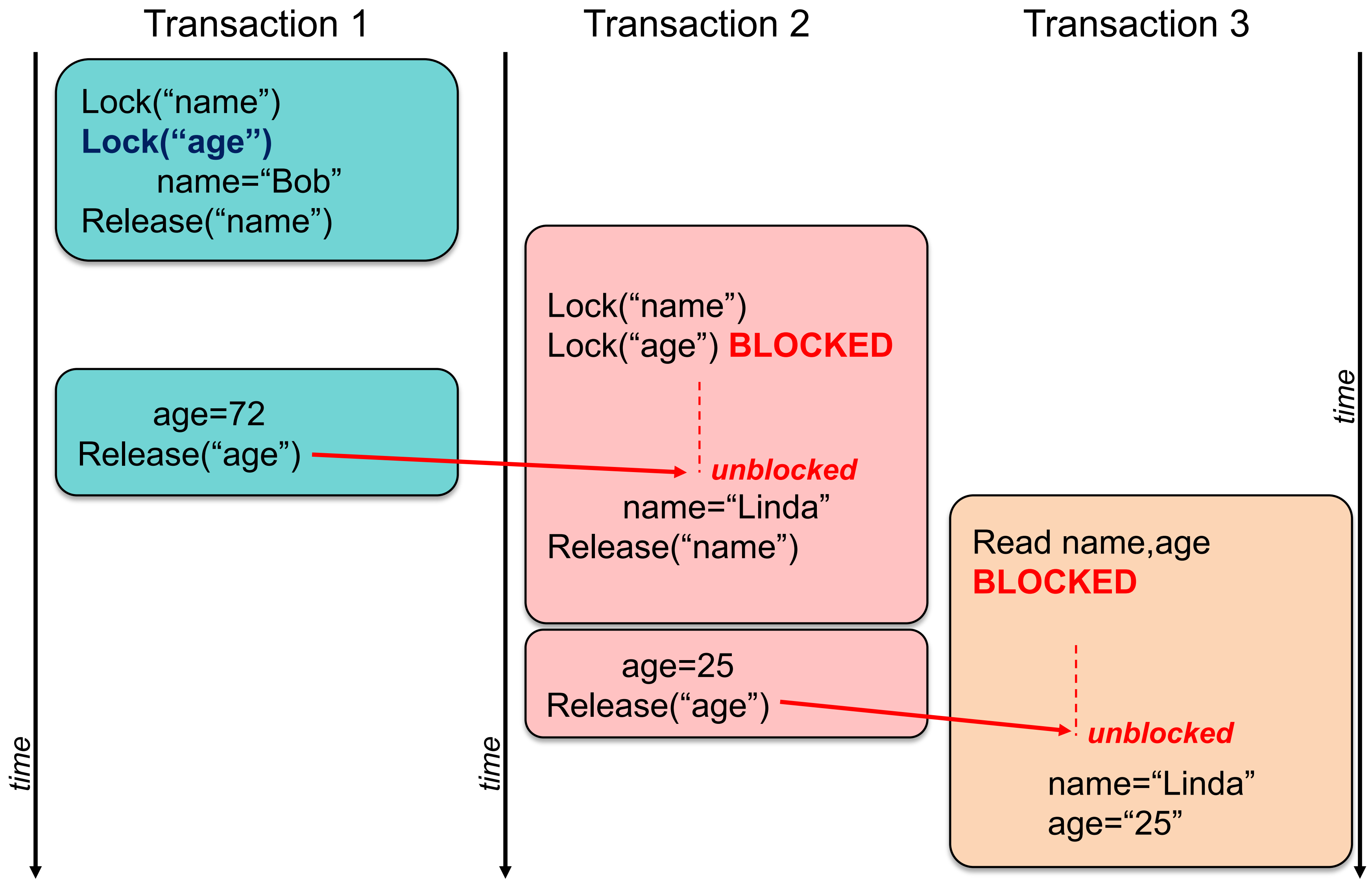
Without 2-phase locking



With 2-phase locking



With 2-phase locking



Strong Strict Two-Phase Locking (SS2PL)

- Problem with two-phase locking
  - If a transaction aborts
    - Any other transactions that have accessed data from released locks (uncommitted data) have to be aborted
    - **Cascading aborts**
      - Otherwise, serial order is violated
- Avoid this situation:
  - Transaction **holds all locks** until it commits or aborts
- **Strict two-phase locking**

Increasing concurrency: locking granularity

- Typically there will be many objects in a system
  - A typical transaction will access only a few of them (and is unlikely to clash with other transactions)
- ***Granularity*** of locking affects concurrency
  - Smaller amount locked $\rightarrow$ higher concurrency
- Example:
  - Lock an entire database vs. a table vs. a record in a table vs. a a field in a record

Multiple readers/single writer

- Improve concurrency by supporting **multiple readers**
  - There is no problem with multiple transactions *reading* data from the same object
  - But only one transaction should be able to write to an object
    - and no other transactions should read that data
- Two types of locks: ***read locks*** and ***write locks***
  - Set a *read lock* before doing a read on an object
    - A *read lock* prevents others from writing
  - Set a *write lock* before doing a write on an object
    - A *write lock* prevents others from reading or writing
  - Block (wait) if transaction cannot get the lock

Read locks are often called ***shared locks***

Write locks are often called ***exclusive locks***

Multiple readers/single writer

If a transaction has

- No locks for an object:
  - Other transactions may obtain a *read* or *write* lock

- A *read* lock for an object:
  - Other transactions may obtain a *read lock* but must wait for a *write* lock

- A *write* lock for an object:
  - Other transactions will have to wait for a *read* or a *write* lock

Two-Version Based Concurrency Control

- A transaction can write *tentative versions* of objects
  - Others read from the original (previously-committed) version
- *Read* operations wait only when another transaction is committing the same object
- Allows for more concurrency than read-write locks
  - Transactions with writes risk waiting or rejection at commit
  - Transactions cannot commit if other uncompleted transactions have read the objects and committed

Two-version locking

- Three types of locks:
  1. ***read*** *lock*
  2. ***write*** *lock*
  3. ***commit*** *lock*
  – Transaction cannot get a *read* or *write* lock if there is a commit lock

- When the transaction coordinator receives a request to commit
  – Write locks: convert to *commit locks*
  – Read locks: wait until the transactions that set these locks have completed and locks are released

- Compare with read/write locks:
  – *read* operations are delayed only while transactions are being committed
  – BUT *read* operations of one transaction can cause a delay in the committing of other transactions

Problems with locking

- Locks have an overhead: maintenance, checking
- Locks can result in deadlock
- Locks may reduce concurrency
  - Transactions hold the locks until the transaction commits (strong strict two-phase locking)
- But … If data is not locked
  - A transaction may see inconsistent results
  - Locking solves this problem … but incurs delays

Optimistic concurrency control

- In many applications the chance of two transactions accessing the same object is low
- Allow transactions to proceed without obtaining locks
- Check for conflicts at commit time
  - Check versions of objects against versions read at start
  - If there is a conflict then *abort* and restart some transaction
- Phases:
  - Working phase: write results to a private workspace
  - Validation phase: check if there's a conflict with other transactions
  - Update phase: make tentative changes permanent

Timestamp ordering

- Assign unique timestamp to a transaction when it begins
- Each object two timestamps associated with it:
  - *Read timestamp:* updated when the object is read
  - *Write timestamp:* updated when the object is written
- Each transaction has a timestamp = start of transaction
- *Good ordering*:
  - Object's *read* and *write* timestamps will be older than the current transaction if it wants to write an object
  - Object's *write* timestamps will be older than the current transaction if it wants to read an object
- Abort and restart transaction for improper ordering

Multiversion Concurrency Control (MVCC)

We can use timestamp ordering AND multiple versions of an object to achieve even greater concurrency

- When a transaction wants to modify data, it creates a new version
- Store multiple versions of each object

Multiversion Concurrency Control (MVCC)

- **Snapshot isolation**
  - Each transaction sees the versions of data in the state when the transaction started
  - Data is consistent for that point in time
- **Timestamps**
  - Similar to timestamp ordering:
    - Each instance of an object has associated timestamps
      - *Read* timestamp = when the object was last read
      - *Write* timestamp = when the object was last modified
    - *Transaction* timestamp = start of transaction
  - **Reads never block** but read a **version < timestamp(transaction)**
  - Writes cannot complete if there are active transactions with earlier read timestamps for the object
    - This means a later transaction is dependent on an earlier value of the object
    - The transaction will be aborted and restarted
- Old versions of objects will have to be cleaned up periodically

Leasing versus Locking

- Common approach:
  - Get a lock for exclusive access to a resource
- But locks are not fault-tolerant
  - What if the process that has the lock dies?
  - It's safer to use a lock that expires instead
  - Lease = lock with a time limit
- Lease time: trade-offs
  - Long leases with possibility of long wait after failure
  - Or short leases that need to be renewed frequently
- Danger of leases
  - Possible loss of transactional integrity

Hierarchical Leases

- For fault tolerance, leases should be granted by consensus
- But consensus protocols aren't super-efficient
- Compromise: use a hierarchy
  - Use consensus as an election algorithm to elect a coordinator
  - Coordinator is granted a lease on a large set of resources
    - **Coarse-grained locking**: large regions; long time periods
  - Coordinator hands out sub-leases on those resources
    - **Fine-grained locking**: small regions (objects); short time periods
- When the coordinator's lease expires
  - Consensus algorithm is run again

The end