Distributed Systems

12. Concurrency Control

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Fall 2017

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

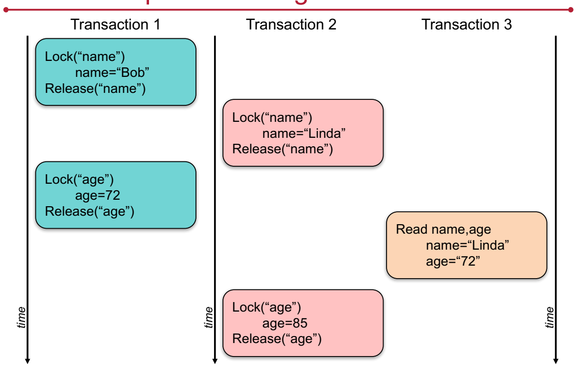
⇒ concurrency control

- *schedule*: valid order of interleaving

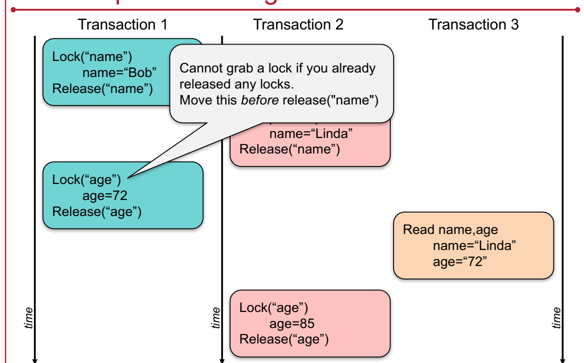
Two-phase locking

- Transactions run concurrently until they compete for the same resource
  - Only one will get to go … others 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 not allowed new locks after it has released a lock
  - This ensures serial ordering on resource access

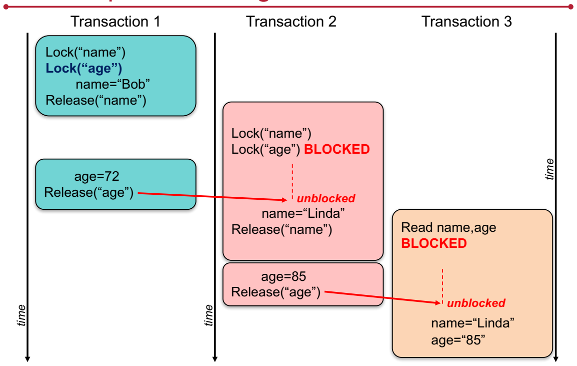
Without 2-phase locking



With 2-phase locking



With 2-phase locking



Strict 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**
- 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 → higher concurrency

Multiple readers/single writer

- Improve concurrency by supporting **multiple readers**
  - There is no problem with multiple transactions *reading* data from the same object
  - 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 writing
  - Set a *write lock* before doing a write on an object
    - A *write lock* prevents reading and writing
  - Block (wait) if transaction cannot get the lock

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

Increasing concurrency: two-version locking

- 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 by having transactions hold the locks until the transaction commits (strict two-phase locking)

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
- *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

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

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