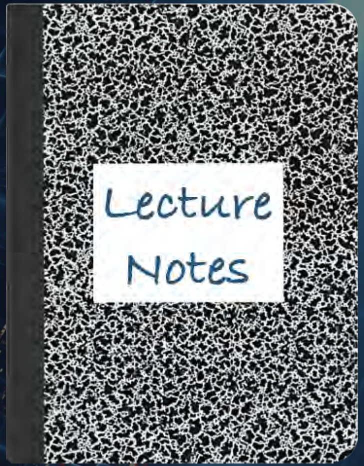
CS 417 – DISTRIBUTED SYSTEMS



Week 10: Distributed Transactions

Part 3: Concurrency Control

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Properties of transactions: ACID

- **Atomic** – transaction completes fully or is rolled back
- **Consistent** – transaction cannot leave data in an inconsistent state
- **Isolated (Serializable)** – transactions cannot interfere with each other
- **Durable** – results are made permanent when a transaction commits

How do we ensure one transaction does not interfere with another?

- Run one transaction at a time
- Use *locks* to give a transaction lock exclusive access to data – mutual exclusion

Concurrency control

- **Concurrency control** = managing how transactions can interact with objects without interfering with each other

- **Pessimistic concurrency control**
  - Transaction locks objects it needs so other transactions can't access them

- **Optimistic concurrency control**
  - Assume concurrent transactions will not access the same objects
  - Check later – at time of commit

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)
```

Serialized Execution: Schedules

Transactions must be scheduled so that results are equivalent to some serial order of execution

How do we achieve this?

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

or…

- Allow multiple transactions to execute concurrently
  - Lock the objects they access
  - Concurrency control must ensure serializability

schedule = valid order of interleaving transactions

Valid schedules

$T_0 \rightarrow T_1 \rightarrow T_2$

$T_0 \rightarrow T_2 \rightarrow T_1$

$T_1 \rightarrow T_2 \rightarrow T_0$

$T_1 \rightarrow T_0 \rightarrow T_2$

$T_2 \rightarrow T_0 \rightarrow T_1$

$T_2 \rightarrow T_1 \rightarrow T_0$

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 <u>not allowed</u> new locks after it has released a lock
  - This ensures *serial ordering* on resource access

Without 2-phase locking

Transaction 1

Lock(“name”)
    name=“Bob”

Release(“name”)

Lock(“age”)
    age=72
Release(“age”)

Transaction 2

Lock(“name”)
BLOCKED

    name=“Linda”
Release(“name”)

Lock(“age”)
    age=25
Release(“age”)

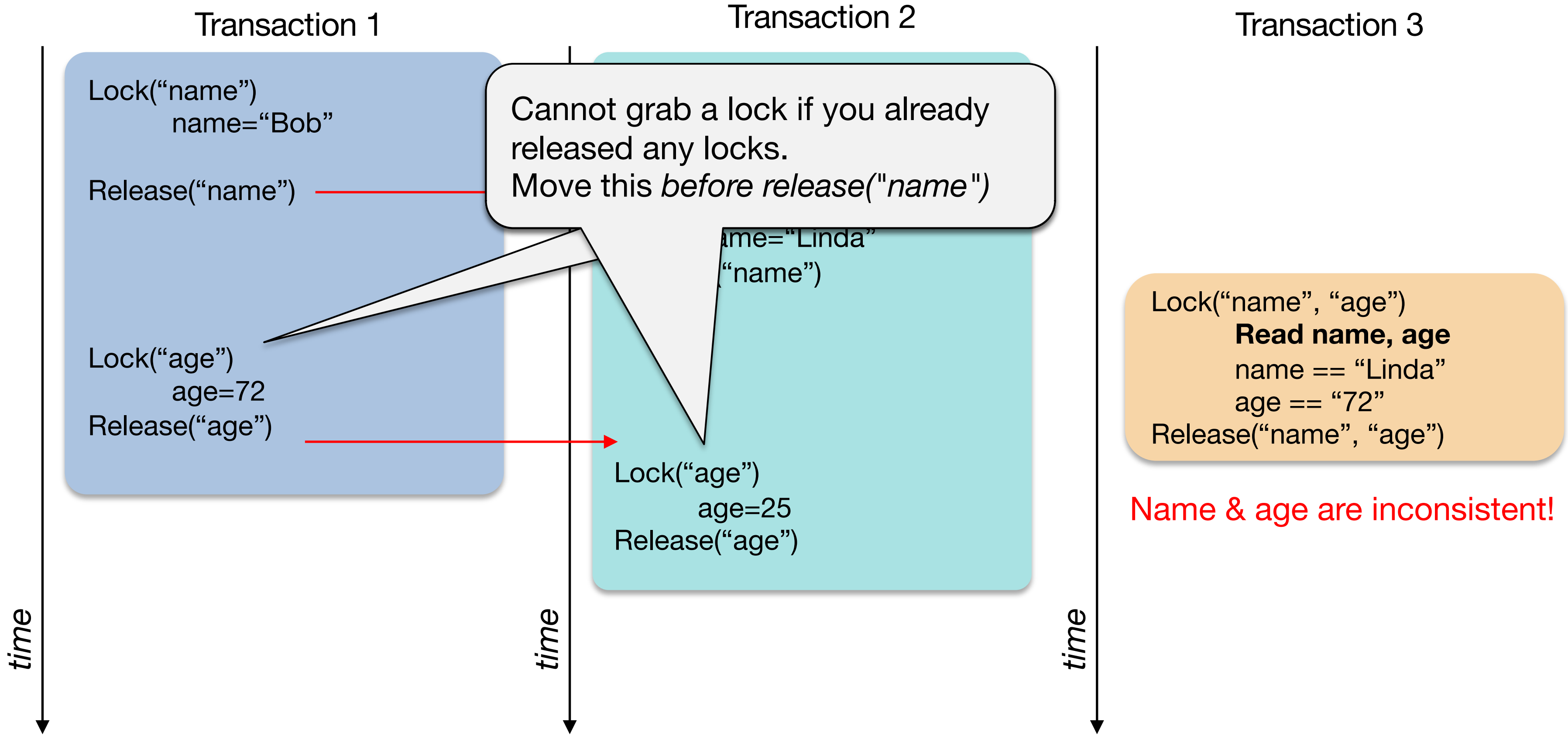
Transaction 3

Lock(“name”, “age”)
    Read name, age
    name == “Linda”
    age == “72”
Release(“name”, “age”)

Name & age are inconsistent!

time *time* *time*

This violates 2-phase locking



Name & age are inconsistent!

With 2-phase locking

Transaction 1

Lock(“name”)
name=“Bob”

Lock("age")
Release(“name”)

age=72
Release(“age”)

time

Transaction 2

Lock(“name”)
BLOCKED

name=“Linda”
Lock(“age”)
BLOCKED

Release(“name”)
age=25
Release(“age”)

time

Transaction 3

Note that **name=="Linda"** and **age==72** at this point … but nobody can see this state because T1 has a lock on age.

Lock(“name”, “age”)
BLOCKED

Read name, age
name == “Linda”
age == “25”
Release(“name”, “age”)

time

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) must be aborted
  - **Cascading aborts**
    - Otherwise, serial order is violated

- Avoid this situation:
  - Transaction **holds all locks** until it commits or aborts

⇒ **Strong strict two-phase locking**

Increasing concurrency: locking granularity

- There will often be many objects in a system
  - A typical transaction will access only a few of them
    (and may be unlikely to clash with other transactions for those objects)

- ***Granularity*** of locking affects concurrency
  - Smaller amount of data locked → higher concurrency

Example:

Lock an entire database vs. a table vs. a record in a table vs. a a field in a record

Exclusive & Shared Locks

- 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***

Exclusive & Shared Locks

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

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

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 Based Concurrency Control

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

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 combine *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:
    - A transaction has a *Transaction timestamp* = sequence # of transaction
    - Each instance of an object has associated timestamps:
      - *Read timestamp* = transaction timestamp that last read the object
      - *Write timestamp* = transaction timestamp that last modified the object
  - **Reads never block** but instead 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

The End