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
Concurrent 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:

```sql
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)
```
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
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

Transaction 1
- Lock("name")
  name="Bob"
- Release("name")
- Lock("age")
  age=72
- Release("age")

Transaction 2
- Lock("name")
  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!
This violates 2-phase locking

Cannot grab a lock if you already released any locks. Move this before release("name")

Transaction 1
- Lock("name")
  name="Bob"
- Release("name")
- Lock("age")
  age=72
- Release("age")

Transaction 2
- Lock("name")
  name="Linda"
- Release("name")
- Lock("age")
  age=25
- Release("age")

Transaction 3
- Lock("name", "age")
  name == "Linda"
  age == 72
- Release("name", "age")

Name & age are inconsistent!
With 2-phase locking

Transaction 1

- Lock("name")
  name="Bob"
- Lock("age")
- Release("name")
- age=72
- Release("age")

Transaction 2

- Lock("name")
  BLOCKED
- Lock("age")
  BLOCKED
- name="Linda"
- Release("name")
- age=25
- Release("age")

Transaction 3

- Lock("name", "age")
  BLOCKED
- Read name, age
  name == "Linda"
  age == "25"
- Release("name", "age")

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