Transaction state

- **Active**: a transaction is active while executing.
- **Partially committed**: after the final statement has executed
- **Failed**: after discovery that normal execution cannot proceed
- **Aborted**: transaction has been rolled-back and database restored to prior state.
- **Committed**: after successful completion.

Schedules involving abort

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
Abort	

This is an unrecoverable schedule

- Recoverable schedule: transactions commit only after all transactions whose changes they <u>read</u> commit.

Recoverable schedules

- We must also consider the impact of transaction failures on concurrently running transactions.
  - That is, schedules with ABORT
- **Recoverable schedule**: For any transactions Ti and Tj: if Tj reads data written by Ti, then *Ti commits before Tj commits*.

A Non-recoverable schedule.

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
Abort	

DBMS must ensure recoverable schedules.

Cascadeless schedules

- Even if schedule is recoverable, several transactions may need to be rolled back to recover correctly.
- **Cascading Rollback**: a single transaction failure

T1	T2	T3
R(A)		
R(B)		
W(A)		
	R(A)	
	W(A)	
		R(A)
Abort		

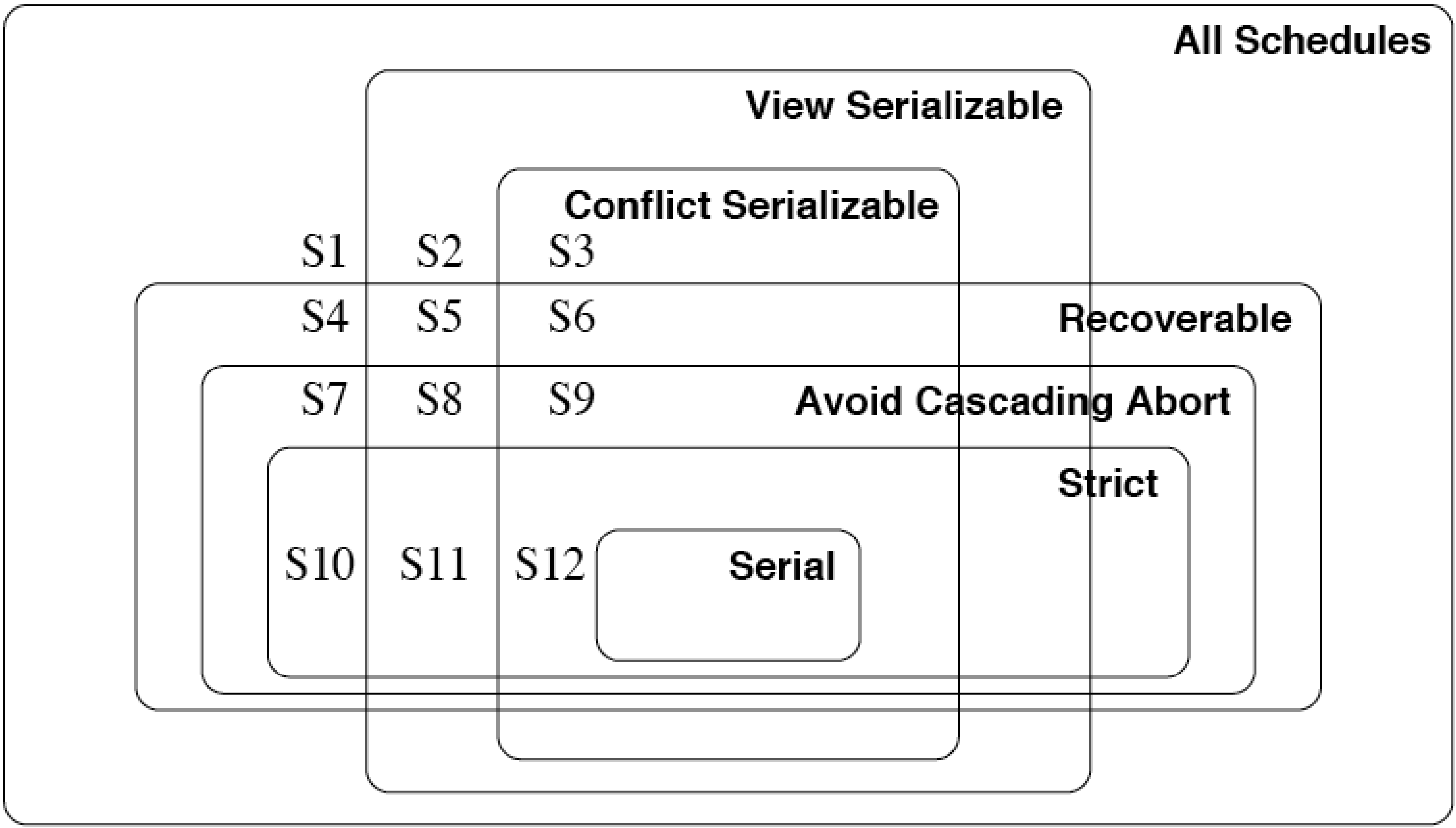
- **Cascadeless schedule**: For any transactions Ti and Tj: if Tj reads data written by Ti, then *Ti commits before read operation of Tj*.

Strict schedules

- A schedule is **strict** if:
  - A value written by a transaction T is not read or overwritten by other transactions until T either aborts or commits.

- Strict schedules are recoverable and cascadeless.

Properties of schedules



i-clicker

- Is this schedule conflict serializable?
  - A. Yes
  - B. No

T1	T2
R(A)	
	R(A)
	W(A)
	Commit
R(A)	
W(A)	
Commit	

i-clicker

- Is this schedule conflict serializable?
  - A. Yes
  - B. No

There is a cycle in the precedence graph

T1	T2
R(A)	
	R(A)
	W(A)
	Commit
R(A)	
W(A)	
Commit	

Anomalies with Interleaved Execution

- Not all interleavings of operations are okay.
- **Anomaly**: two consistency-preserving committed transactions that lead to an inconsistent state.
- Types of anomalies:
  - Reading Uncommitted Data (WR Conflicts) "dirty reads"
  - Unrepeatable Reads (RW Conflicts)
  - Overwriting Uncommitted Data (WW Conflicts)

Reading Uncommitted Data

"Dirty Read"

Inconsistent result of A is exposed to transaction T2

T1: Transfer	T2: Interest
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
R(B)	
W(B)	
Commit	

Unrepeatable Reads

T1 could see two values for A, although it has not changed A itself. (This could not happen in a serial execution.)

T1	T2
R(A)	
	R(A)
	W(A)
	Commit
R(A)	
W(A)	
Commit	

Overwriting Uncommitted Data

T1	T2
	W(A)
W(B)	
	W(B)
	Commit
W(A)	
Commit	

Here T2 overwrites value of B that has been modified by T1.

Example: Harry and Larry are 2 employees. Salaries must be kept equal.

T1: set salaries to 1000
T2 set salaries to 2000

Transaction support in SQL

- Transaction automatically started for SELECT, UPDATE, CREATE
- Transaction ends with COMMIT or ROLLBACK (abort)
- SQL 99 supports SAVEPOINTs which are simple nested transactions

Specify isolation level

- General rules of thumb w.r.t. isolation:
  - Fully serializable isolation is more expensive than "no isolation"
    - We can't do as many things concurrently (or we have to undo them frequently)
- For performance, we generally want to specify the most relaxed isolation level that's acceptable
  - Note that we're "slightly" violating a correctness constraint to get performance!

Specifying isolation level in SQL

SET TRANSACTION [READ WRITE | READ ONLY]
ISOLATION LEVEL [LEVEL];

LEVEL = SERIALIZABLE
REPEATABLE READ
READ COMMITTED
READ UNCOMMITED

↓ Less isolation

The default isolation level is SERIALIZABLE

REPEATABLE READ

- T reads only changes made by committed transactions
- No value read/written by T is changed by another transaction until T completes.

READ COMMITTED

- T reads only changes made by committed transactions
- No value ~~read~~/written by T is changed by another transaction until T completes.
- Value read by T may be modified while T in progress.

READ UNCOMMITTED

- Greatest exposure to other transactions
- Dirty reads possible
- Can’t make changes: must be READ ONLY
- Does not obtain shared locks before reading
  - Thus no locks ever requested.

Summary of Isolation Levels

Level	Dirty Read	Unrepeatable Read
READ UN-COMMITTED	Maybe	Maybe
READ COMMITTED	No	Maybe
REPEATABLE READ	No	No
SERIALIZABLE	No	No

Concurrency control schemes

- The DBMS must provide a mechanism that will ensure all possible schedules are:
  - serializable
  - recoverable, and preferably cascadeless
- Concurrency control protocols ensure these properties.

Lock-Based Concurrency Control

- Lock - associated with some object
  - shared or exclusive
- Locking protocol - set of rules to be followed by each transaction to ensure good properties.

Lock Compatibility Matrix

Locks on a data item are granted based on a lock compatibility matrix:

Request mode		Mode of Data Item		
		None	Shared	Exclusive
Request mode	Shared	Y	Y	N
	Exclusive	Y	N	N

When a transaction requests a lock, it must wait (block) until the lock is granted

Transaction performing locking

T1
lock-X(A) **R(A)** **W(A)** unlock(A) lock-S(B) **R(B)** unlock(B)

Two-Phase Locking (2PL)

- Two-Phase Locking Protocol
  - Each Xact must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - A transaction can not request additional locks once it releases any locks.
    - This implies two phases:
      - growing phase
      - shrinking phase

Strict Two-Phase Locking (Strict 2PL)

- Strict Two-phase Locking Protocol:
  - Each Xact must obtain a S (*shared*) lock on object before reading, and an X (*exclusive*) lock on object before writing.
  - A transaction can not request additional locks once it releases any locks.
  - All X (exclusive) locks acquired by a transaction must be held until completion (commit/abort).

Not admissible under 2PL

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
R(B)	
W(B)	
Commit	

Lock-based protocols

- 2PL ensures **conflict serializability**
  - Transactions can be ordered by their end of growing phase (called **lock point**)
  - A 2PL schedule is equivalent to the serial schedule where transactions ordered by lock point order.
- Strict 2PL ensures **conflict serializable** and **cascadeless** schedules
  - Writers hold an X lock until they commit.

Schedule following strict 2PL

T1	T2
S(A)	
R(A)	
	S(A)
	R(A)
	X(B)
	R(B)
	W(B)
	Commit
X(C)	
R(C)	
W(C)	
Commit	

Lock Management

- Lock and unlock requests are handled by the lock manager
- Lock table entry (for an object):
  - Number of transactions currently holding a lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests
- Locking and unlocking have to be atomic operations
- Lock upgrade: transaction that holds a shared lock can be upgraded to hold an exclusive lock

Deadlock

T1	T2	
X(A)		granted
	X(B)	granted
X(B)		queued
	X(A)	queued

- Deadlock: Cycle of transactions waiting for locks to be released by each other.

Deadlocks

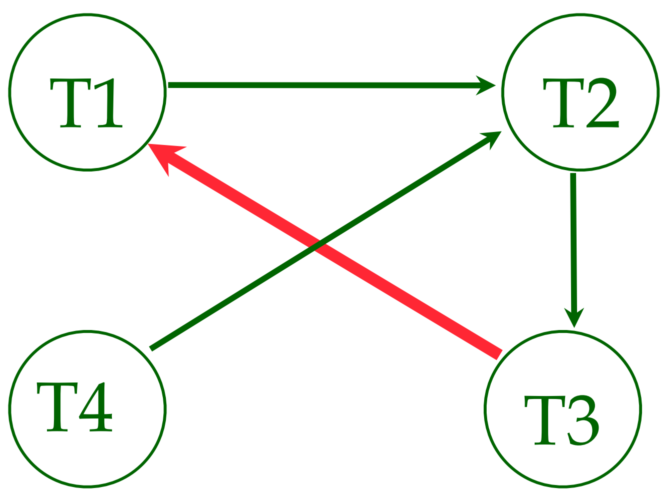
- Tend to be rare in practice.
- Two ways of dealing with deadlocks:
  - Deadlock <u>prevention</u>
  - Deadlock <u>detection</u>

Deadlock Detection

- Create a waits-for graph:
  - Nodes are transactions
  - There is an edge from Ti to Tj if Ti is waiting for Tj to release a lock
  - add edge when queueing a lock request,
  - remove edge when granting lock request.
- Periodically check for cycles in the waits-for graph
- Resolve by aborting a transaction on cycle, releasing its locks.

Deadlock Detection (Continued)

T1	T2	T3	T4
S(A)			
R(A)			
	X(B)		
	W(B)		
S(B)			
		S(C)	
		R(C)	
	X(C)		
			X(B)
		X(A)	



Deadlock Prevention

- Assign priorities based on timestamps. Assume Ti wants a lock that Tj holds. Two policies are possible:
  - **Wait-Die**: If Ti has higher priority, Ti waits for Tj; otherwise Ti aborts
  - **Wound-wait**: If Ti has higher priority, Tj aborts; otherwise Ti waits
- If a transaction re-starts, make sure it has its original timestamp (to avoid **starvation** of a transaction).

Performance of Locking

- Lock-based schemes resolve conflicting schedules by **blocking** and **aborting**
  - in practice few deadlocks and relatively few aborts
  - most of penalty from blocking
- To increase throughput
  - lock smallest objects possible
  - reduce time locks are held
  - reduce hotspots

Summary

- Concurrency control and recovery are among the most important functions provided by a DBMS.
- Users need not worry about concurrency.
  - System guarantees nice properties: ACID
  - This is implemented using a locking protocol
- Users can trade isolation for performance using SQL commands