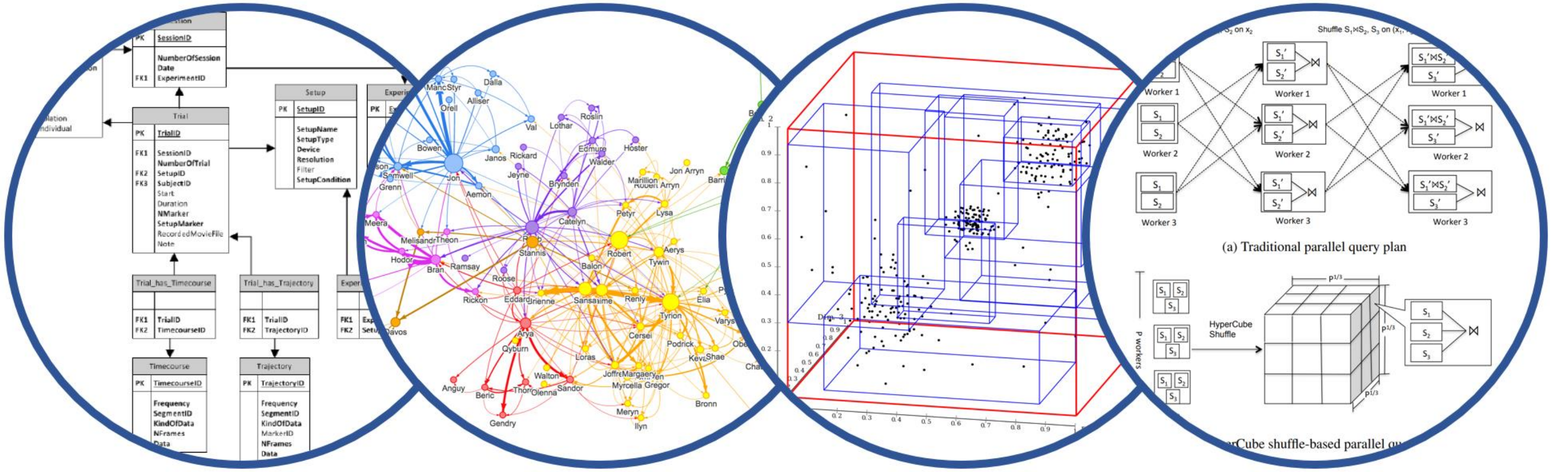

Introduction to Data Management

Transactions: Locks

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Announcements

- Quiz 2 available on Gradescope from Thursday Nov. 12th to Friday morning

- HW 5 we be released by Monday
  - Content is transactions and locking which we'll finish by Monday's lecture

- HW 3 grades are back now

Recap

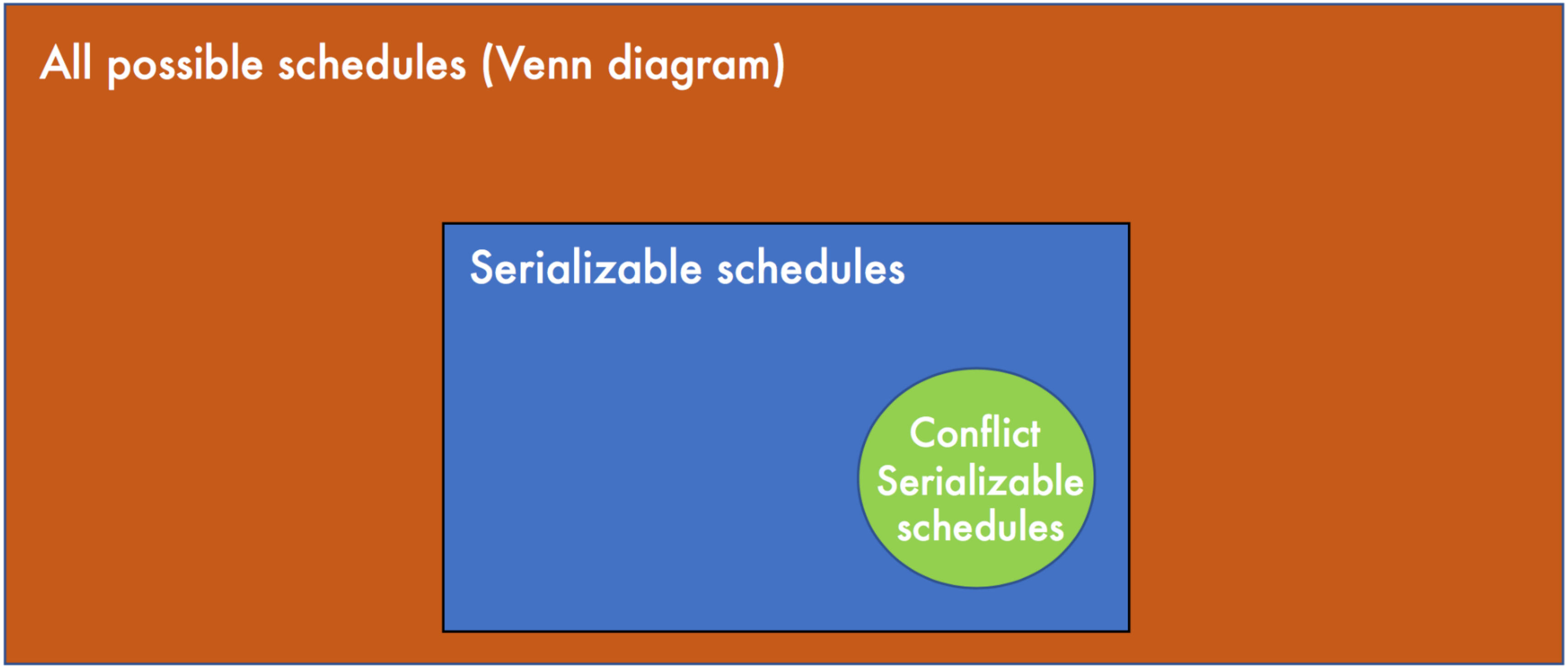
- Execute all parts of a transaction as a single action
- **Transactions are atomic**

```
BEGIN TRANSACTION
 [SQL Statements]
COMMIT -- finalizes execution
```

```
BEGIN TRANSACTION
 [SQL Statements]
ROLLBACK -- undo everything
```

Conflict Serializability

- Showing program serializability is hard
  - Needs lots of extra information besides R, W, I, D
- Observation: Enforce something something simpler but stronger than serializability



Conflict Order Rules

- Observation: Reordering operation of the same element around writes will cause different program behavior
- **Inter-transaction conflicts**
  - WW conflicts → $W_1(X)$, $W_2(X)$
    - Not always the same as $W_2(X)$, $W_1(X)$
  - WR conflicts → $W_1(X)$, $R_2(X)$
    - Not always the same as $R_2(X)$, $W_1(X)$
  - RW conflicts → $R_1(X)$, $W_2(X)$
    - Not always the same as $W_2(X)$, $R_1(X)$

  - RR is not a conflict!

Equivalent Behavior Schedules

- A reordered schedule of operations is **guaranteed to be equivalent** when WR, RW, and WW conflicts are preserved

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

→

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

Testing Conflict Serializability – Precendence Graph

Schedule is not conflict-serializable iff we find a **cycle** in the graph

$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B)$

1 2 3

Outline

- Testing for conflict serializability
- Locks
- 2PL and conflict serializability
- Deadlocks
- Strict 2PL and recoverability

Testing for Conflict-Serializability

Precedence graph core idea:

Compare each pair of operations to see if they **could be** reordered at some point

Each potential conflict enforces a temporal order among the transactions

Edge from earlier transaction to later one

Testing for Conflict-Serializability

Important:

Always draw the full graph, unless ONLY asked if (yes or no) the schedule is conflict serializable

Outline

- Testing for conflict serializability
- Locks
- 2PL and conflict serializability
- Deadlocks
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Scheduling

- **Scheduler** a.k.a. **concurrency control manager**
  - Impractical (slow and space inefficient) to issue R, W commands from a literal schedule
  - Use mechanisms like logs and locks to force ACID properties
- Why do we care? Application considerations!
  - **Pessimistic Concurrency Control** (this class) good for high-contention workloads
  - **Optimistic Concurrency Control** (CSE 444) good for low-contention workloads

Optimistic Scheduler

- Commonly interchangeable with **Multi Version Concurrency Control**
- “Optimistic” → Assumes transaction executions will not create conflicts
- Main Idea:
  - Execute first, check later
  - Cheap overhead cost but expensive aborting process
- (This is what happened in our movie reservation example)

Pessimistic Scheduler

- Commonly interchangeable with **Locking Scheduler**
- "Pessimistic" → Assumes transaction executions will conflict
- Main Idea:
  - Prevent executions that would create conflicts
  - Expensive overhead cost but cheap aborting process

Question for Today

What mechanisms do we use to make (conflict) serializable schedules?

Locks

- Pessimistic CC involves locks
- **Binary lock** mechanisms:
  - We have locks on objects that specify which transaction can do operations
  - A txn must **acquire** a lock before reading or writing
    - Notation: txn i acquires lock on element X → $\mathbf{L_i(X)}$
  - A txn must eventually **release** locks (unlock)
    - Notation: txn i releases lock on element X → $\mathbf{U_i(X)}$
  - If txn finds another txn holds a lock for the desired element, **wait for the unlock signal**
    - “blocking”

Element Granularity

- A DBMS (and sometimes user) may specify what **granularity of elements** are locked
  - Dramatically qualifies expected contention
- SQLite → Database locking only
- MySQL, SQL Server, Oracle, … → Row locking, table locking

A Non-Serializable Schedule

T1	T2
READ(A, t)	
t := t+100	
WRITE(A, t)	
	READ(A,s)
	s := s*2
	WRITE(A,s)
	READ(B,s)
	s := s*2
	WRITE(B,s)
READ(B, t)	
t := t+100	
WRITE(B,t)	

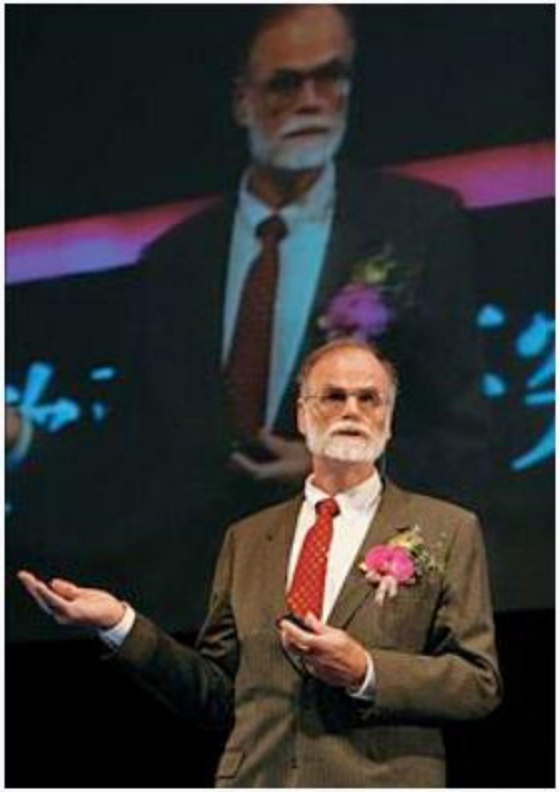
T1	T2
$L_1(A)$; READ(A, t)	
t := t+100	
WRITE(A, t); $U_1(A)$;	
	$L_2(A)$; READ(A,s)
	s := s*2
	WRITE(A,s); $U_2(A)$;
	$L_2(B)$; READ(B,s)
	s := s*2
	WRITE(B,s); $U_2(B)$;
$L_1(B)$; READ(B, t)	
t := t+100	
WRITE(B,t); $U_1(B)$;	

Locks did not enforce conflict-serializability !!! What's wrong ?

2-Phase Locking (2PL)

Protocol: In every transaction, all lock requests must precede all unlock requests

Jim Gray



2006

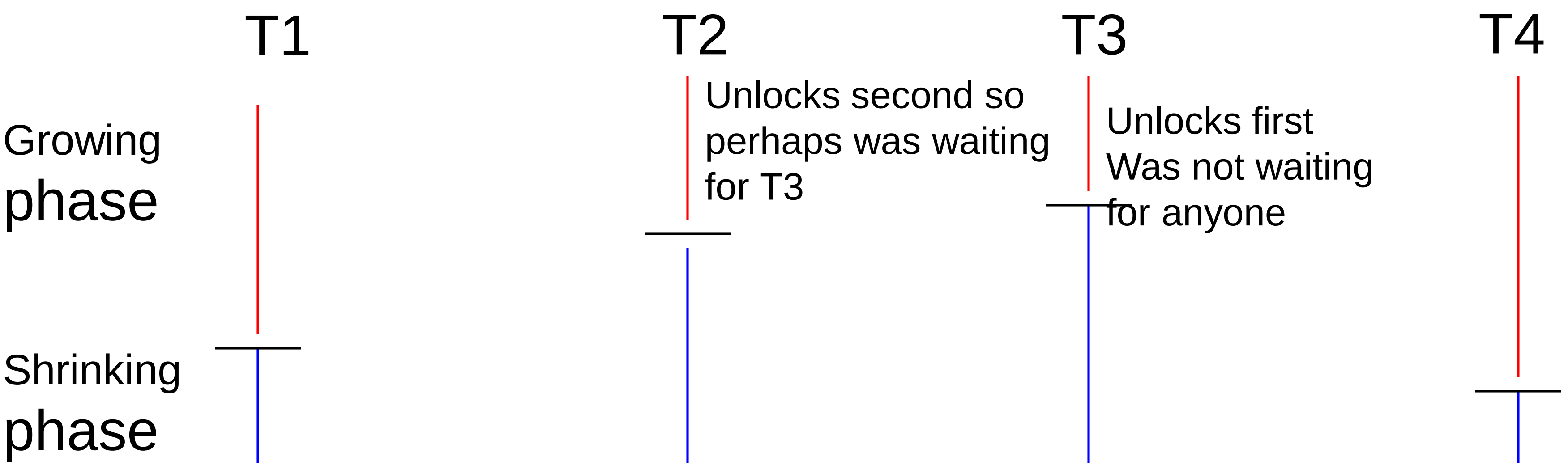
Born	James Nicholas Gray January 12, 1944[1] San Francisco, California[2]
Disappeared	January 28, 2007 (aged 63) Waters near San Francisco

Example: 2PL transactions

T1	T2
$L_1(A)$; $L_1(B)$; READ(A, t)	
t := t+100	
WRITE(A, t); $U_1(A)$	
	$L_2(A)$; READ(A,s)
	s := s*2
	WRITE(A,s);
	$L_2(B)$; DENIED…
READ(B, t)	
t := t+100	
WRITE(B,t); $U_1(B)$;	
	…GRANTED; READ(B,s)
	s := s*2
	WRITE(B,s); $U_2(A)$; $U_2(B)$;

Now it is conflict-serializable

Example with Multiple Transactions



Equivalent to each transaction executing entirely the moment it enters shrinking phase

Conflict Serializability through 2PL

Theorem: **2PL ensures conflict serializability**

(Not on exam)

Conflict Serializability through 2PL

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Proof by contradiction:

- Suppose a schedule was executed under 2PL that was not conflict serializable.

Conflict Serializability through 2PL

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- Suppose a schedule was executed under 2PL that was not conflict serializable.
- Then that schedule must have a **precedence graph** with a **cycle**.

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Theorem: **2PL ensures conflict serializability**

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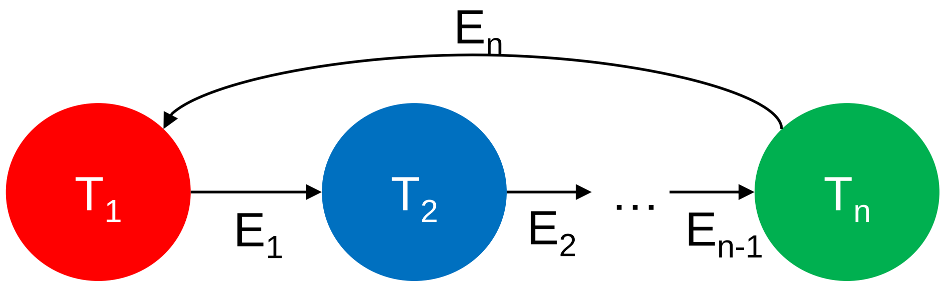
Proof by contradiction:

- Suppose a schedule was executed under 2PL that was not conflict serializable.
- Then that schedule must have a **precedence graph** with a **cycle**.
- Name the transactions in the cycle as $T_1, \ldots, T_n$ where:
  - An edge exists from T_i to T_{i+1} for $i < n$
  - An edge exists from T_n to T_1
- (An edge means there is a conflict on some element, call it E_i)



Conflict Serializability through 2PL

Theorem: **2PL ensures conflict serializability**

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- Suppose a schedule was executed under 2PL that was not conflict serializable.
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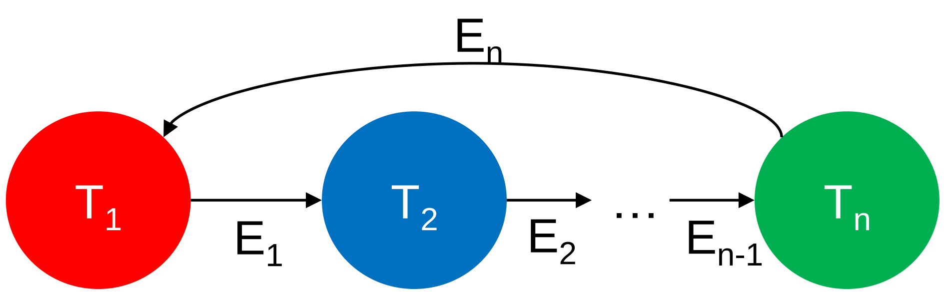
  - An edge exists from T_i to T_{i+1} for $i < n$
  - An edge exists from T_n to T_1
- (An edge means there is a conflict on some element, call it E_i)
- Under 2PL, we can guarantee the series of locks and unlocks in time:
  - $U_1(E_1)$ then $L_2(E_1)$
  - $L_2(E_1)$ then $U_2(E_2)$
  - $U_2(E_2)$ then $L_3(E_2)$
  - $L_3(E_2)$ then $U_3(E_3)$
  - …
  - $U_n(E_n)$ then $L_1(E_n)$
  - $L_1(E_n)$ then $U_1(E_1)$



- There is a **cycle in time** which is a contradiction

2PL Problems

- **Deadlocks!**
  - Byproduct of dealing with groups of locks

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)

2PL Deadlocks

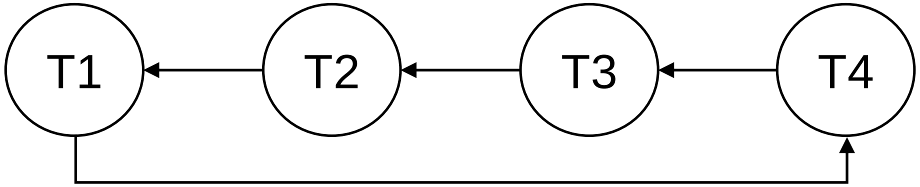
T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)

Can't make progress since locking phase is not complete for any txn!

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…

- Lock requests create a precedence/waits-for graph where deadlock → cycle (2PL is doing its job!).
- Cycle detection over a graph is somewhat expensive, so we check the graph only periodically



2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)

If the DBMS finds a cycle:

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)

If the DBMS finds a cycle:
- We rollback txns
- (Hopefully) make progress
- Eventually retry the rolledback txns

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)
		…granted L(D)	abort U(D)

If the DBMS finds a cycle:
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2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)
		…granted L(D)	abort U(D)
		R(D) W(D)	N/A

If the DBMS finds a cycle:
- We rollback txns
- (Hopefully) make progress
- Eventually retry the rolledback txns

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)
		…granted L(D)	abort U(D)
		R(D) W(D)	N/A
	…granted L(C)	U(D) U(C)	N/A

If the DBMS finds a cycle:
- We rollback txns
- (Hopefully) make progress
- Eventually retry the rolledback txns

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A) L(B) blocked…	L(B) L(C) blocked…	L(C) L(D) blocked…	L(D) L(A) blocked…
R(A) W(A)	R(B) W(B)	R(C) W(C)	R(D) W(D)
		…granted L(D)	abort U(D)
		R(D) W(D)	N/A
	…granted L(C)	U(D) U(C)	N/A
…	…	…	retry

If the DBMS finds a cycle:
- We rollback txns
- (Hopefully) make progress
- Eventually retry the rolledback txns

2PL Problems

- **Deadlocks!**
  - Byproduct of dealing with groups of locks
- **Recoverability**
  - Transactions might want an abort feature if not all consistency constraints are enforced by the DB
  - Can’t always abort txns under vanilla 2PL

Non-Recoverable Schedule

T1	T2
L(A) L(B)	L(A) blocked… L(B) blocked…
R(A) W(A)	
U(A)	…granted L(A)
R(B) W(B)	R(A) W(A)
U(B)	…granted L(B) U(A)
	R(B) W(B)
	U(B)
	COMMIT
ROLLBACK	

Non-Recoverable Schedule

T1	T2
L(A) L(B)	L(A) blocked… L(B) blocked…
R(A) W(A)	
U(A)	…granted L(A)
R(B) W(B)	R(A) W(A)
U(B)	…granted L(B) U(A)
	R(B) W(B)
	U(B)
	COMMIT
ROLLBACK	

ROLLBACK will try to signal the DBMS to revert to original values

Non-Recoverable Schedule

T1	T2
L(A) L(B)	L(A) blocked… L(B) blocked…
R(A) W(A)	
U(A)	…granted L(A)
R(B) W(B)	R(A) W(A)
U(B)	…granted L(B) U(A)
	R(B) W(B)
	U(B)
	COMMIT
ROLLBACK	

T2 already executed under modified A and B values (dirty read)

ROLLBACK will try to signal the DBMS to revert to original values

Non-Recoverable Schedule

T1	T2
L(A) L(B)	L(A) blocked… L(B) blocked…
R(A) W(A)	
U(A)	…granted L(A)
R(B) W(B)	R(A) W(A)
U(B)	…granted L(B) U(A)
	R(B) W(B)
	U(B)
	COMMIT
ROLLBACK	

T2 already executed under modified A and B values (dirty read)

ROLLBACK would break the COMMIT promise that T2's execution was valid

ROLLBACK will try to signal the DBMS to revert to original values

Strict 2PL

Protocol: 2PL + All unlocks are done together with the COMMIT or ROLLBACK

Strict 2PL guarantees schedule conflict serializability and recoverability

Recoverable Schedule

T1	T2
L(A) L(B)	L(A) blocked… L(B) blocked…
R(A) W(A)	
R(B) W(B)	
ROLLBACK U(A) U(B)	…granted L(A) …granted L(B)
	R(A) W(A)
	R(B) W(B)
	COMMIT U(A) U(B)

"Do I need to implement any of this?"

“Do I need to implement any of this?”

Short Answer: No

“Do I need to implement any of this?”

Long Answer:

These mechanisms are internal to the DBMS.

The DBMS manages locks with strict 2PL. The DBMS creates the precedence graph. The DBMS does the deadlock retry.

As an application programmer / database user you only need to (and should only need to) specify transactions and think about application-level consistency.