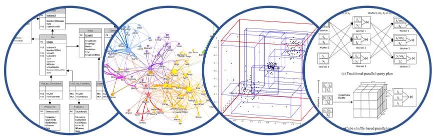

Database System Internals
Concurrency Control Intro

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Announcements

- Lab 2 due tonight
  - Before final submission, clone fresh repo on attu and run "ant test-report"
- Lab 1+2 quiz on Wednesday in-class
  - Closed book. Calculator allowed but you won't need one.
- 544M Paper 2 due next week

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About Lab 3

- In lab 3, we implement transactions
- Focus on concurrency control
  - Want to run many transactions at the same time
  - Transactions want to read and write same pages
  - Will use locks to ensure conflict serializable execution
  - Use strict 2PL
- Build your own lock manager
  - Understand how locking works in depth
  - Ensure transactions rather than threads hold locks
    - Many threads can execute different pieces of the same transaction
    - Need to detect deadlocks and resolve them by aborting a transaction
  - But use Java synchronization to protect your data structures

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Motivating Example

Client 1:
UPDATE Budget
SET money=money-100
WHERE pid = 1

UPDATE Budget
SET money=money+60
WHERE pid = 2

UPDATE Budget
SET money=money+40
WHERE pid = 3

Client 2:
SELECT sum(money)
FROM Budget

Would like to treat each group of instructions as a unit

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Transaction

Definition: a transaction is a sequence of updates to the database with the property that either all complete, or none completes (all-or-nothing).

START TRANSACTION

[SQL statements]

COMMIT or ROLLBACK (=ABORT)

May be omitted if autocommit is off: first SQL query starts txn

In ad-hoc SQL: each statement = one transaction
This is referred to as autocommit

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Motivating Example

START TRANSACTION
UPDATE Budget
SET money=money-100
WHERE pid = 1

UPDATE Budget
SET money=money+60
WHERE pid = 2

UPDATE Budget
SET money=money+40
WHERE pid = 3
COMMIT (or ROLLBACK)

SELECT sum(money)
FROM Budget

With autocommit and without **START TRANSACTION**, each SQL command is a transaction

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ROLLBACK

- If the app gets to a place where it can't complete the transaction successfully, it can execute **ROLLBACK**
- This causes the system to "abort" the transaction
  - Database returns to a state without any of the changes made by the transaction
- Several reasons: user, application, system

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Transactions

- Major component of database systems
- Critical for most applications; arguably more so than SQL
- Turing awards to database researchers:
  - Charles Bachman 1973
  - Edgar Codd 1981 for inventing relational dbs
  - **Jim Gray 1998 for inventing transactions**
  - Mike Stonebraker 2015 for INGRES and Postgres
    - And many other ideas after that

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ACID Properties

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ACID Properties

- **A**tomicity: Either all changes performed by transaction occur or none occurs
- **C**onsistency: A transaction as a whole does not violate integrity constraints
- **I**solation: Transactions appear to execute one after the other in sequence
- **D**urability: If a transaction commits, its changes will survive failures

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What Could Go Wrong?

Why is it hard to provide ACID properties?

- **Concurrent** operations
  - Isolation problems
  - We saw one example earlier
- **Failures** can occur at any time
  - Atomicity and durability problems
  - Later lectures
- Transaction may need to **abort**

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Terminology Needed For Lab 3

- **STEAL or NO-STEAL**
  - Can an update made by an uncommitted transaction overwrite the most recent committed value of a data item on disk?
- **FORCE or NO-FORCE**
  - Should all updates of a transaction be forced to disk before the transaction commits?
- Easiest for recovery: NO-STEAL/FORCE (lab 3)
- Highest performance: STEAL/NO-FORCE (lab 4)
- We will get back to this next week

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Concurrent Execution Problems

- Write-read conflict: dirty read, inconsistent read
  - A transaction reads a value written by another transaction that has not yet committed
- Read-write conflict: unrepeatable read
  - A transaction reads the value of the same object twice. Another transaction modifies that value in between the two reads
- Write-write conflict: lost update
  - Two transactions update the value of the same object. The second one to write the value overwrites the first change

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Schedules

A *schedule* is a sequence of interleaved actions from all transactions

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Example

A and B are elements in the database
t and s are variables in tx source code

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

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A Serial Schedule

T1	T2	
		A = 2 B = 2
READ(A, t)		
t := t+100		
WRITE(A, t)		
READ(B, t)		
t := t+100		
WRITE(B,t)		
		A = 102 B = 102
	READ(A,s)	
	s := s*2	
	WRITE(A,s)	
	READ(B,s)	
	s := s*2	
	WRITE(B,s)	
		A = 204 B = 204

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A Serial Schedule

T1	T2	
		A = 2 B = 2
	READ(A,s)	
	s := s*2	
	WRITE(A,s)	
	READ(B,s)	
	s := s*2	
	WRITE(B,s)	
		A = 4 B = 4
READ(A, t)		
t := t+100		
WRITE(A, t)		
READ(B, t)		
t := t+100		
WRITE(B,t)		
		A = 104 B = 104

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Serializable Schedule

A schedule is *serializable* if it is equivalent to a serial schedule

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A Serializable Schedule

T1	T2	
		A = 2, B = 2
READ(A, t) t := t+100 WRITE(A, t)		A = 102, B = 2
	READ(A,s) s := s*2 WRITE(A,s)	A = 204, B = 2
READ(B, t) t := t+100 WRITE(B,t)		A = 204, B = 102
	READ(B,s) s := s*2 WRITE(B,s)	A = 204, B = 204

This is a serializable schedule.
This is NOT a serial schedule

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A Non-Serializable Schedule

T1	T2	
		A = 2, B = 2
READ(A, t) t := t+100 WRITE(A, t)		A = 102, B = 2
	READ(A,s) s := s*2 WRITE(A,s)	A = 204, B = 2
	READ(B,s) s := s*2 WRITE(B,s)	A = 204, B = 4
READ(B, t) t := t+100 WRITE(B,t)		A = 204, B = 104

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Serializable Schedules

- The role of the scheduler is to ensure that the schedule is serializable

Q: Why not run only serial schedules ?
I.e. run one transaction after the other ?

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Serializable Schedules

- The role of the scheduler is to ensure that the schedule is serializable

Q: Why not run only serial schedules ?
I.e. run one transaction after the other ?

A: Because of very poor throughput due to disk latency.

Lesson: main memory databases *may* schedule TXNs serially

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Still Serializable, but…

T1	T2
READ(A, t) t := t+100 WRITE(A, t)	
	READ(A,s) s := s + 200 WRITE(A,s) READ(B,s) s := s + 200 WRITE(B,s)
READ(B, t) t := t+100 WRITE(B,t)	

Schedule is serializable because t=t+100 and s=s+200 commute

…we don't expect the scheduler to schedule this

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To Be Practical

- Assume worst case updates:
  - Assume cannot commute actions done by transactions
- Therefore, we only care about reads and writes
  - Transaction = sequence of R(A)'s and W(A)'s

T_1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$
T_2: $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_2(B)$

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Conflicts

- Write-Read – WR
- Read-Write – RW
- Write-Write – WW

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Conflict Serializability

Conflicts:

Two actions by same transaction T_i: $r_i(X); w_i(Y)$

Two writes by T_i, T_j to same element: $w_i(X); w_j(X)$

Read/write by T_i, T_j to same element: $w_i(X); r_j(X)$ / $r_i(X); w_j(X)$

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Conflict Serializability

Definition A schedule is *conflict serializable* if it can be transformed into a serial schedule by a series of swappings of adjacent non-conflicting actions

- Every conflict-serializable schedule is serializable
- The converse is not true in general

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Conflict Serializability

Example:

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

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Conflict Serializability

Example:

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

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

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Conflict Serializability

Example:

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

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

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Conflict Serializability

Example:

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

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

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

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Conflict Serializability

Example:

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

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

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

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Conflict Serializability

Example:

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

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

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

….

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

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Testing for Conflict-Serializability

Precedence graph:

- A node for each transaction T_i,
- An edge from T_i to T_j whenever an action in T_i conflicts with, and comes before an action in T_j
- No edge for actions in the same transaction

- **The schedule is serializable iff the precedence graph is acyclic**

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Testing for Conflict-Serializability

Important:

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

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Example 1

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

① ② ③

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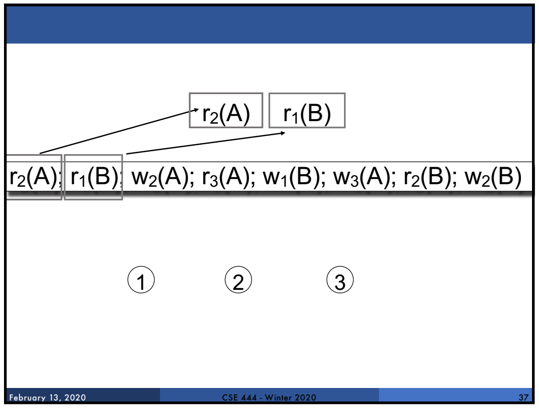

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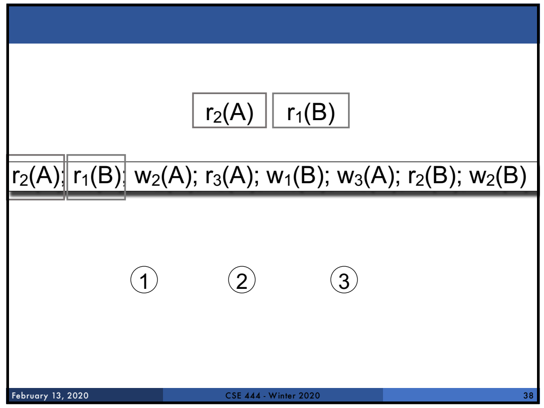

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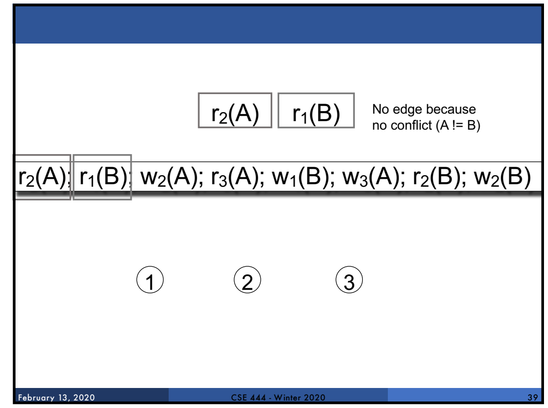

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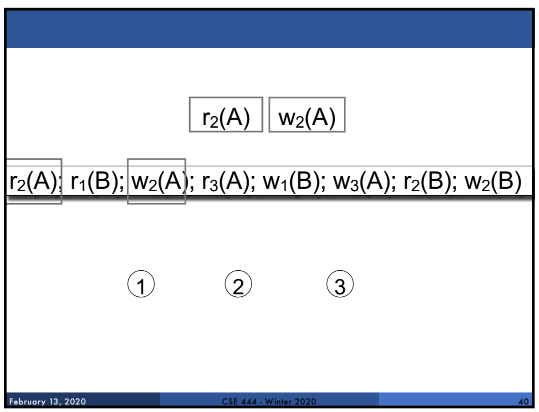

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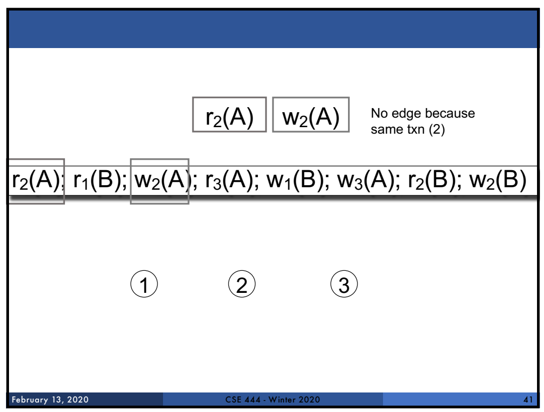

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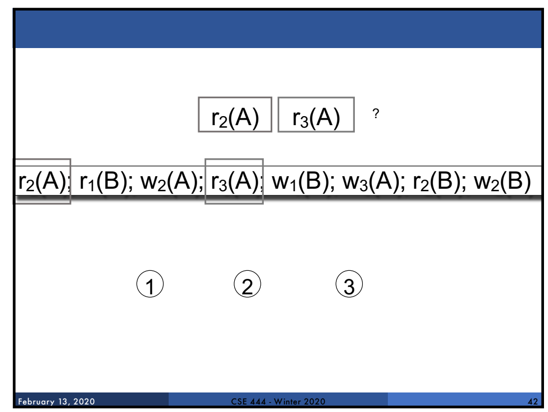

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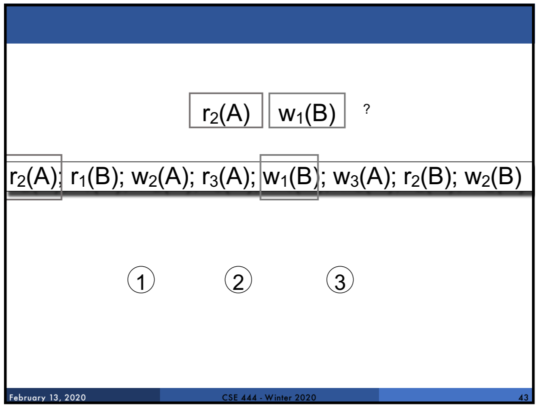

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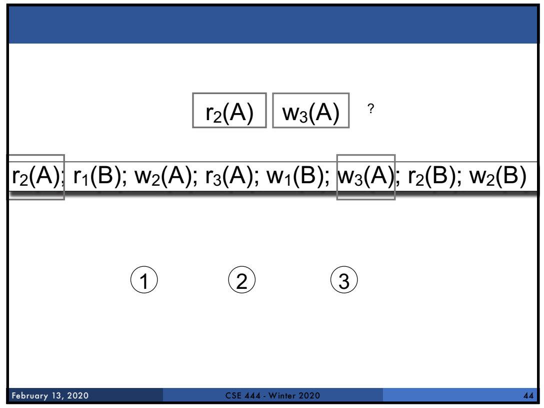

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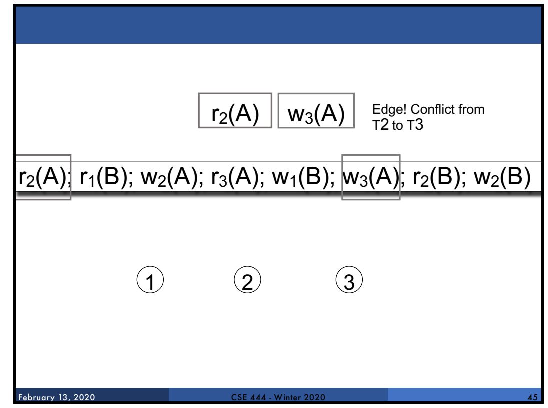

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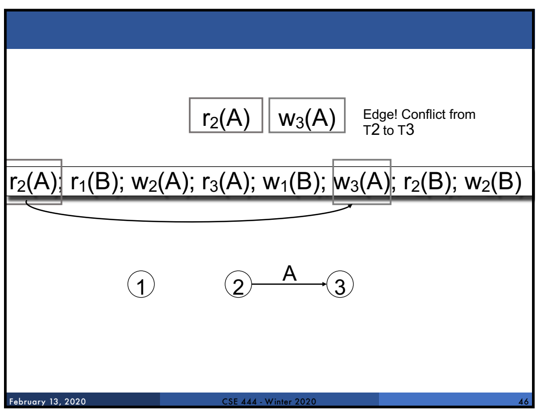

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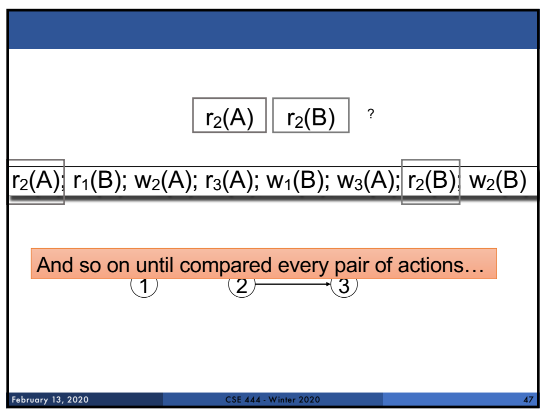

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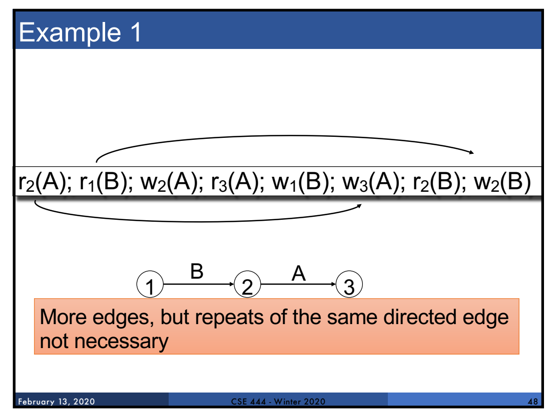

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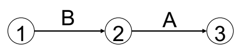
Example 1

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



This schedule is **conflict-serializable**

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Example 2

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

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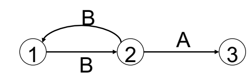
Example 2

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



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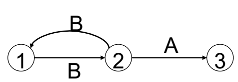
Example 2

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



This schedule **is NOT conflict-serializable**

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View Equivalence

- A serializable schedule need not be conflict serializable, even under the "worst case update" assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Is this schedule conflict-serializable ?

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View Equivalence

- A serializable schedule need not be conflict serializable, even under the "worst case update" assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Is this schedule conflict-serializable ?

No…

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View Equivalence

- A serializable schedule need not be conflict serializable, even under the "worst case update" assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Lost write

$w_1(X); w_1(Y); w_2(X); w_2(Y); w_3(Y);$

Equivalent, but not conflict-equivalent

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View Equivalence

T1	T2	T3
W1(X)		
	W2(X)	
	W2(Y)	
	CO2	
W1(Y)		
CO1		
		W3(Y)
		CO3

Lost

T1	T2	T3
W1(X)		
W1(Y)		
CO1		
	W2(X)	
	W2(Y)	
	CO2	
		W3(Y)
		CO3

Serializable, but not conflict serializable

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View Equivalence

Two schedules S, S' are *view equivalent* if:

- If T reads an initial value of A in S, then T reads the initial value of A in S'
- If T reads a value of A written by T' in S, then T reads a value of A written by T' in S'
- If T writes the final value of A in S, then T writes the final value of A in S'

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View-Serializability

A schedule is *view serializable* if it is view equivalent to a serial schedule

Remark:

- If a schedule is *conflict serializable*, then it is also *view serializable*
- But not vice versa

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Schedules with Aborted Transactions

- When a transaction aborts, the recovery manager undoes its updates
- But some of its updates may have affected other transactions !

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Schedules with Aborted Transactions

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

What's wrong?

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Schedules with Aborted Transactions

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

What's wrong?

Cannot abort T1 because cannot undo T2

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Recoverable Schedules

A schedule is *recoverable* if:

- It is conflict-serializable, and
- Whenever a transaction T commits, all transactions that have written elements read by T have already committed

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Recoverable Schedules

A schedule is *recoverable* if:

- It is conflict-serializable, and
- Whenever a transaction T commits, all transactions that have written elements read by T have already committed

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Recoverable Schedules

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

Nonrecoverable

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

Recoverable

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Recoverable Schedules

T1	T2	T3	T4
R(A)			
W(A)			
	R(A)		
	W(A)		
	R(B)		
	W(B)		
		R(B)	
		W(B)	
		R(C)	
		W(C)	
			R(C)
			W(C)
			R(D)
			W(D)
Abort			

How do we recover ?

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Cascading Aborts

- If a transaction T aborts, then we need to abort any other transaction T' that has read an element written by T
- A schedule *avoids cascading aborts* if whenever a transaction reads an element, the transaction that has last written it has already committed.

We base our locking scheme on this rule!

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Avoiding Cascading Aborts

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

With cascading aborts

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

Without cascading aborts

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Serializability

- Serial
- Serializable
- Conflict serializable
- View serializable

Recoverability

- Recoverable
- Avoids cascading deletes

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Scheduler

- The scheduler:
- Module that schedules the transaction's actions, ensuring serializability

- Two main approaches
  - Pessimistic: locks
  - Optimistic: timestamps, multi-version, validation

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