Concurrency Control

P.J. McBrien

Imperial College London

Transactions: ACID properties

ACID properties

database management systems (DBMS) implements indivisible tasks called **transactions**

Atomicity	all or nothing
Consistency	consistent before → consistent after
Isolation	independent of any other transaction
Durability	completed transaction are durable

```
BEGIN TRANSACTION
   UPDATE branch
   SET    cash=cash -10000.00
   WHERE  sortcode=56

   UPDATE branch
   SET    cash=cash +10000.00
   WHERE  sortcode=34
COMMIT TRANSACTION
```

Note that if total cash is £137,246.12 before the transaction, then it will be the same after the transaction.

Example Data

branch		
sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

movement			
mid	no	amount	tdate
1000	100	2300.00	5/1/1999
1001	101	4000.00	5/1/1999
1002	100	-223.45	8/1/1999
1004	107	-100.00	11/1/1999
1005	103	145.50	12/1/1999
1006	100	10.23	15/1/1999
1007	107	345.56	15/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

key branch(sortcode)
key branch(bname)
key movement(mid)
key account(no)

movement(no) $\stackrel{fk}{\Rightarrow}$ account(no)

account(sortcode) $\stackrel{fk}{\Rightarrow}$ branch(sortcode)

Transaction Properties: Atomicity

```
BEGIN TRANSACTION
  UPDATE branch
  SET    cash=cash - 10000.00
  WHERE  sortcode=56
```

CRASH

Suppose that the system crashes half way through processing a cash transfer, and the first part of the transfer has been written to disc

- The database on disc is left in an inconsistent state, with £10,000 'missing'
- A DBMS implementing **Atomicity** of transactions would on restart UNDO the change to branch 56

Transaction Properties: Consistency

```
BEGIN TRANSACTION
    DELETE FROM branch
    WHERE sortcode=56

    INSERT INTO account
    VALUES (100,'Smith, J','deposit',5.00,34)
END TRANSACTION
```

Suppose that a user deletes branch with sortcode 56, and inserts a deposit account number 100 for John Smith at branch sortcode 34

- The database is left in an inconsistent state for two reasons
  - it has three accounts recorded for a branch that appears not to exist, and
  - it has two records for account number 100, with different details for the account
- A DBMS implementing **Consistency** of transactions would forbid both of these changes to the database

Transaction Properties: Isolation

```
BEGIN TRANSACTION
    UPDATE branch
    SET    cash=cash -10000.00
    WHERE  sortcode=56
```

```
BEGIN TRANSACTION
    SELECT SUM(cash) AS net_cash
    FROM   branch
END TRANSACTION
```

```
    UPDATE branch
    SET    cash=cash+10000.00
    WHERE  sortcode=34
END TRANSACTION
```

Suppose that the system sums the cash in the bank in one transaction, half way through processing a cash transfer in another transaction

- The result of the summation of cash in the bank erroneously reports that £10,000 is missing
- A DBMS implementing **Isolation** of transactions ensures that transactions always report results based on the values of committed transactions

Transaction Properties: Durability

```
BEGIN TRANSACTION
   UPDATE branch
   SET    cash=cash −10000.00
   WHERE  sortcode=56

   UPDATE branch
   SET cash=cash+10000.00
   WHERE sortcode=34
END TRANSACTION
CRASH
```

Suppose that the system crashes after informing the user that it has committed the transfer of cash, but has not yet written to disc the update to branch 34

- The database on disc is left in an inconsistent state, with £10,000 'missing'
- A DBMS implementing **Durability** of transactions would on restart complete the change to branch 34 (or alternatively never inform a user of commitment with writing the results to disc).

SQL Conversion to Histories

branch		
sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

```
BEGIN TRANSACTION T1
      UPDATE branch
      SET cash=cash-10000.00
      WHERE sortcode=56

      UPDATE branch
      SET cash=cash+10000.00
      WHERE sortcode=34
COMMIT TRANSACTION T1
```

⇨

$H_1 = r_1[b_{56}]$, cash=94340.45,
$w_1[b_{56}]$, cash=84340.45,
$r_1[b_{34}]$, cash=8900.67,
$w_1[b_{34}]$, cash=18900.67, c_1

history of transaction T_n

1. Begin transaction b_n (only given if necessary for discussion)
2. Various read operations on objects $r_n[o_j]$ and write operations $w_n[o_j]$
3. Either c_n for the commitment of the transaction, or a_n for the abort of the transaction

SQL Conversion to Histories

branch		
sortcode	bname	cash
56	'Wimbledon'	84340.45
34	'Goodge St'	18900.67
67	'Strand'	34005.00

```
BEGIN TRANSACTION T2
    UPDATE branch
    SET cash=cash-2000.00
    WHERE sortcode=34

    UPDATE branch
    SET cash=cash+2000.00
    WHERE sortcode=67
COMMIT TRANSACTION T2
```

⇒

$H_2 = r_2[b_{34}]$, cash=18900.67,
$w_2[b_{34}]$, cash=16900.67,
$r_2[b_{67}]$, cash=34005.00,
$w_2[b_{67}]$, cash=36005.00, c_2

history of transaction T_n

1. Begin transaction b_n (only given if necessary for discussion)
2. Various read operations on objects $r_n[o_j]$ and write operations $w_n[o_j]$
3. Either c_n for the commitment of the transaction, or a_n for the abort of the transaction

Concurrent Execution

Concurrent Execution of Transactions

- Interleaving of several transaction histories
- Order of operations within each history preserved

$H_1 = r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1$

$H_2 = r_2[b_{34}], w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2$

Some possible concurrent executions are

$H_x = r_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2$

$H_y = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, c_1$

$H_z = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_2[b_{67}], w_2[b_{67}], c_2$

Which concurrent executions should be allowed?

Concurrency control $\rightarrow$ controlling interaction

serialisability

A concurrent execution of transactions should always has the same end result as some serial execution of those same transactions

recoverability

No transaction commits depending on data that has been produced by another transaction that has yet to commit

Quiz 1: Serialisability and Recoverability (1)

$H_x = \boxed{r_2[b_{34}]}, \boxed{r_1[b_{56}]}, \boxed{w_1[b_{56}]}, \boxed{r_1[b_{34}]}, \boxed{w_1[b_{34}]}, \boxed{c_1}, \boxed{w_2[b_{34}]}, \boxed{r_2[b_{67}]}, \boxed{w_2[b_{67}]}, \boxed{c_2}$

Is H_x

A

Not Serialisable, Not Recoverable

B

Not Serialisable, Recoverable

C

Serialisable, Not Recoverable

D

Serialisable, Recoverable

Quiz 2: Serialisability and Recoverability (2)

$H_y = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, c_1$

Is H_y

A

Not Serialisable, Not Recoverable

B

Not Serialisable, Recoverable

C

Serialisable, Not Recoverable

D

Serialisable, Recoverable

Quiz 3: Serialisability and Recoverability (3)

$H_z = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_2[b_{67}], w_2[b_{67}], c_2$

Is H_z

A

Not Serialisable, Not Recoverable

B

Not Serialisable, Recoverable

C

Serialisable, Not Recoverable

D

Serialisable, Recoverable

Anomaly 1: Lost update

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,2000.00)
COMMIT TRANSACTION T2

$r_1[b_{56}]$, $w_1[b_{56}]$, $r_1[b_{34}]$, $w_1[b_{34}]$, c_1

$r_2[b_{34}]$, $w_2[b_{34}]$, $r_2[b_{67}]$, $w_2[b_{67}]$, c_2

$r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_1[b_{34}]$, cash=8900.67,
$r_2[b_{34}]$, cash=8900.67, $w_1[b_{34}]$, cash=18900.67$lost update$, c_1, $w_2[b_{34}]$, cash=6900.42
$r_2[b_{67}]$, cash=34005.00, $w_2[b_{67}]$, cash=36005.25, c_2

− serialisable | + recoverable

Anomaly 2: Inconsistent analysis

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T4
SELECT SUM(cash) FROM branch
COMMIT TRANSACTION T4

$r_1[b_{56}]$, $w_1[b_{56}]$, $r_1[b_{34}]$, $w_1[b_{34}]$, c_1

$H_4 = r_4[b_{56}], r_4[b_{34}], r_4[b_{67}], c_4$

$r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_4[b_{56}]$, cash=84340.45, $r_4[b_{34}]$, cash=8900.67, $r_4[b_{67}]$, cash=34005.00, $r_1[b_{34}]$, cash=8900.67, $w_1[b_{34}]$, cash=18900.67, c_1, c_4

$-$ serialisable $+$ recoverable

Anomaly 3: Dirty Reads

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

$r_1[b_{56}]$, $w_1[b_{56}]$, $r_1[b_{34}]$, $w_1[b_{34}]$, c_1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,2000.00)
COMMIT TRANSACTION T2

$r_2[b_{34}]$, $w_2[b_{34}]$, $r_2[b_{67}]$, $w_2[b_{67}]$, c_2

$r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_2[b_{34}]$, cash=8900.67, $w_2[b_{34}]$, cash=6900.42, $r_1[b_{34}]$, cash=6900.67, $w_1[b_{34}]$, cash=16900.67, c_1, $r_2[b_{67}]$, cash=34005.00, $w_2[b_{67}]$, cash=36005.25, a_2

+ serialisable

− recoverable

Quiz 4: Anomalies (1)

$H_x = r_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2$

Which anomaly does H_x suffer?

A

None

B

Lost Update

C

Inconsistent Analysis

D

Dirty Read

Quiz 5: Anomalies (2)

$H_y = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, c_1$

Which anomaly does H_y suffer?

A
None

B
Lost Update

C
Inconsistent Analysis

D
Dirty Read

Quiz 6: Anomalies (3)

$H_z = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_2[b_{67}], w_2[b_{67}], c_2$

Which anomaly does H_z suffer?

A
None

B
Lost Update

C
Inconsistent Analysis

D
Dirty Read

Worksheet: Anomalies

`rental_charge`

$H_1 = r_1[d_{1000}], w_1[d_{1000}], r_1[d_{1001}], w_1[d_{1001}], r_1[d_{1002}], w_1[d_{1002}]$

`transfer_charge`

$H_2 = r_2[d_{1000}], w_2[d_{1000}], r_2[d_{1002}], w_2[d_{1002}]$

`total_charge`

$H_3 = r_3[d_{1000}], r_3[d_{1001}], r_3[d_{1002}]$

Account Table

account				
no	type	cname	rate?	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

Anomaly 4: Dirty Writes

BEGIN TRANSACTION T5
    UPDATE account
    SET rate=5.5
    WHERE type='deposit'
COMMIT TRANSACTION T5
	BEGIN TRANSACTION T6
	    UPDATE account
	    SET rate=6.0
	    WHERE type='deposit'
	COMMIT TRANSACTION T6

⇓ ⇓

$H_5 = w_5[a_{101}]$, rate=5.5, $w_5[a_{119}]$, rate=5.5, c_5

$H_6 = w_6[a_{101}]$, rate=6.0, $w_6[a_{119}]$, rate=6.0, c_6

⇓ ⇓

$w_6[a_{101}]$, rate=6.0, $w_5[a_{101}]$, rate=5.5, $w_5[a_{119}]$, rate=5.5, $w_6[a_{119}]$, rate=6.0, c_5, c_6

− serialisable

+ recoverable

Serialisable Transaction Execution

- Solve anomalies $\rightarrow H \equiv$ serial execution
- Only interested in the **committed projection**

$H_c =$
$r_1[b_{56}]$, $r_2[b_{34}]$, $w_2[b_{34}]$,
$r_3[m_{1000}]$, $r_3[m_{1001}]$, $r_3[m_{1002}]$,
$w_1[b_{56}]$, $r_4[b_{56}]$,
$r_3[m_{1003}]$, $r_3[m_{1004}]$, $r_3[m_{1005}]$,
$r_1[b_{34}]$, a_3, $w_1[b_{34}]$, c_1, $r_4[b_{34}]$,
$r_2[b_{67}]$, $w_2[b_{67}]$, c_2, $r_4[b_{67}]$, c_4

$\Rightarrow$

$C(H_c) =$
$r_1[b_{56}]$, $r_2[b_{34}]$, $w_2[b_{34}]$,
$w_1[b_{56}]$, $r_4[b_{56}]$,
$r_1[b_{34}]$, $w_1[b_{34}]$, c_1, $r_4[b_{34}]$,
$r_2[b_{67}]$, $w_2[b_{67}]$, c_2, $r_4[b_{67}]$, c_4

Possible Serial Equivalents

$H_{cp} = r_1[b_{56}], r_2[b_{34}], w_2[b_{34}], w_1[b_{56}], r_4[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_4[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, r_4[b_{67}], c_4$

$\Downarrow$ H_1, H_2, H_4

$\Downarrow$ H_1, H_4, H_2

$\Downarrow$ H_2, H_1, H_4

$\Downarrow$ H_2, H_4, H_1

$\Downarrow$ H_4, H_1, H_2

$\Downarrow$ H_4, H_2, H_1

- how to determine that histories are equivalent?
- how to check this during execution?

Conflicts: Potential For Problems

conflict

A **conflict** occurs when there is an interaction between two transactions

- $r_x[o]$ and $w_y[o]$ are in H where $x \neq y$
  or
- $w_x[o]$ and $w_y[o]$ are in H where $x \neq y$

conflicts

$H_x = r_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2$

$H_y = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, c_1$

$H_z = r_2[b_{34}], w_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_2[b_{67}], w_2[b_{67}], c_2$

Conflicts

- $w_2[b_{34}] \rightarrow r_1[b_{34}]$ T1 reads from T2 in H_y, H_z
- $w_1[b_{34}] \rightarrow w_2[b_{34}]$ T2 writes over T1 in H_x
- $r_2[b_{34}] \rightarrow w_1[b_{34}]$ T1 writes after T2 reads in H_x

Quiz 7: Conflicts

$H_w = r_2[a_{100}], w_2[a_{100}], r_2[a_{107}], r_1[a_{119}], w_1[a_{119}], r_1[a_{107}], w_1[a_{107}], c_1, w_2[a_{107}], c_2$

Which of the following is not a conflict in H_w?

A

$r_2[a_{107}] \rightarrow r_1[a_{107}]$

B

$r_2[a_{107}] \rightarrow w_1[a_{107}]$

C

$r_1[a_{107}] \rightarrow w_2[a_{107}]$

D

$w_1[a_{107}] \rightarrow w_2[a_{107}]$

Conflict Equivalence and Conflict Serialisable

Conflict Equivalence

Two histories H_i and H_j are **conflict equivalent** if:

1. Contain the same set of operations
2. Order conflicts (of non-aborted transactions) in the same way.

Conflict Serialisable

a history H is **conflict serialisable** (**CSR**) if $C(H) \equiv_{CE}$ a serial history

Failure to be conflict serialisable

$H_x = r_2[b_{34}], r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2$

Contains conflicts $r_2[b_{34}] \rightarrow w_1[b_{34}]$ and $w_1[b_{34}] \rightarrow w_2[b_{34}]$ and so is not conflict equivalence to H_1, H_2 nor H_2, H_1, and hence is not conflict serialisable.

Testing for Conflict Equivalence

$$H_{cp} = r_1[b_{56}], r_2[b_{34}], w_2[b_{34}], w_1[b_{56}], r_4[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_4[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, r_4[b_{67}], c_4$$

$$\equiv$$

$$H_2, H_1, H_4 = r_2[b_{34}], w_2[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, r_1[b_{56}], w_1[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_4[b_{56}], r_4[b_{34}], r_4[b_{67}], c_4$$

1. H_{cp} and H_2, H_1, H_4 contain the same set of operations
2. conflicting pairs are
   $w_2[b_{34}] \rightarrow r_1[b_{34}]$, $w_2[b_{67}] \rightarrow r_4[b_{67}]$,
   $w_1[b_{34}] \rightarrow r_4[b_{34}]$, $w_1[b_{56}] \rightarrow r_4[b_{56}]$
3. $H_2, H_1, H_4 \equiv_{CE} H_{cp} \quad \rightarrow \quad H_{cp} \in CSR$

Serialisation Graph

Serialisation Graph

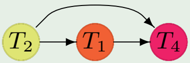
A **serialisation graph** $SG(H)$ contains a node for each transaction in H, and an edge $T_i \rightarrow T_j$ if there is some object o for which a conflict $rw_i[o] \rightarrow rw_j[o]$ exists in H. If $SG(H)$ is acyclic, then H is conflict serialisable.

Demonstrating that a History is CSR

Given H_{cp}= $r_1[b_{56}]$, $r_2[b_{34}]$, $w_2[b_{34}]$, $w_1[b_{56}]$, $r_4[b_{56}]$, $r_1[b_{34}]$, $w_1[b_{34}]$, c_1, $r_4[b_{34}]$, $r_2[b_{67}]$, $w_2[b_{67}]$, c_2, $r_4[b_{67}]$, c_4

Conflicts are $w_2[b_{34}] \rightarrow r_1[b_{34}]$, $w_2[b_{67}] \rightarrow r_4[b_{67}]$, $w_1[b_{34}] \rightarrow r_4[b_{34}]$, $w_1[b_{56}] \rightarrow r_4[b_{56}]$

Then serialisation graph is



$SG(H_{cp})$ is acyclic, therefore H_{cp} is CSR

Worksheet: Serialisability

$H_1 = r_1[o_1], w_1[o_1], w_1[o_2], w_1[o_3], c_1$

$H_2 = r_2[o_2], w_2[o_2], w_2[o_1], c_2$

$H_3 = r_3[o_1], w_3[o_1], w_3[o_2], c_3$

$H = r_1[o_1], w_1[o_1], r_2[o_2], w_2[o_2], w_2[o_1], c_2, w_1[o_2], r_3[o_1], w_3[o_1], w_3[o_2], c_3, w_1[o_3], c_1$

Recoverability

- Serialisability necessary for isolation and consistency of committed transactions
- Recoverability necessary for isolation and consistency when there are also aborted transactions

Recoverable execution

A **recoverable** (**RC**) history H has no transaction committing before another transaction from which it read

Execution avoiding cascading aborts

A history which **avoids cascading aborts** (**ACA**) does not read from a non-committed transaction

Strict execution

A **strict** (**ST**) history does not read from a non-committed transaction nor write over a non-committed transaction

$ST \subset ACA \subset RC$

Non-recoverable executions

```
BEGIN TRANSACTION T1
    UPDATE branch
    SET cash=cash-10000.00
    WHERE sortcode=56
    UPDATE branch
    SET cash=cash+10000.00
    WHERE sortcode=34
COMMIT TRANSACTION T1
```

```
BEGIN TRANSACTION T4
    SELECT SUM(cash) FROM branch
COMMIT TRANSACTION T4
```

$H_1 = r_1[b_{56}], w_1[b_{56}], a_1$

$H_4 = r_4[b_{56}], r_4[b_{34}], r_4[b_{67}], c_4$

$H_c = r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_4[b_{56}]$, cash=84340.45, $r_4[b_{34}]$, cash=8900.67, $r_4[b_{67}]$, cash=34005.00, c_4, a_1

$H_c \notin RC$

Cascading Aborts

```
BEGIN TRANSACTION T1
    UPDATE branch
    SET cash=cash-10000.00
    WHERE sortcode=56
    UPDATE branch
    SET cash=cash+10000.00
    WHERE sortcode=34
COMMIT TRANSACTION T1
```

```
BEGIN TRANSACTION T4
    SELECT SUM(cash) FROM branch
COMMIT TRANSACTION T4
```

$H_1 = r_1[b_{56}], w_1[b_{56}], a_1$

$H_4 = r_4[b_{56}], r_4[b_{34}], r_4[b_{67}], c_4$

$H_c = r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_4[b_{56}]$, cash=84340.45, $r_4[b_{34}]$, cash=8900.67, $r_4[b_{67}]$, cash=34005.00, a_1, a_4

$H_c \in RC$
$H_c \notin ACA$

Strict Execution

BEGIN TRANSACTION T5	BEGIN TRANSACTION T6
UPDATE account	UPDATE account
SET rate=5.5	SET rate=6.0
WHERE type='deposit'	WHERE type='deposit'
COMMIT TRANSACTION T5	COMMIT TRANSACTION T6

$H_5 = w_5[a_{101}]$, rate=5.5, $w_5[a_{119}]$, rate=5.5, a_5

$H_6 = w_6[a_{101}]$, rate=6.0, $w_6[a_{119}]$, rate=6.0, c_6

$H_c = w_6[a_{101}]$, rate=6.0, $w_5[a_{101}]$, rate=5.5, $w_5[a_{119}]$, rate=5.5, $w_6[a_{119}]$, rate=6.0, a_5, c_6

$H_c \in ACA$
$H_c \notin ST$

Quiz 8: Recoverability

$H_z = \boxed{r_2[b_{34}]}, \boxed{w_2[b_{34}]}, \boxed{r_1[b_{56}]}, \boxed{w_1[b_{56}]}, \boxed{r_1[b_{34}]}, \boxed{w_1[b_{34}]}, \boxed{c_1}, \boxed{r_2[b_{67}]}, \boxed{w_2[b_{67}]}, \boxed{c_2}$

Which describes the recoverability of H_z?

A
Non-recoverable

B
Recoverable

C
Avoids Cascading Aborts

D
Strict

Worksheet: Recoverability

$$H_w = r_2[o_1], r_2[o_2], w_2[o_2], r_1[o_2], w_2[o_1], r_2[o_3], c_2, c_1$$

$$H_x = r_2[o_1], r_2[o_2], w_2[o_1], w_2[o_2], w_1[o_1], w_1[o_2], c_1, r_2[o_3], c_2$$

$$H_y = r_2[o_1], r_2[o_2], w_2[o_2], r_1[o_2], w_2[o_1], c_1, r_2[o_3], c_2$$

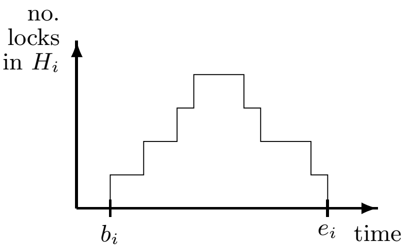
$$H_z = r_2[o_1], w_1[o_1], r_2[o_2], w_2[o_2], r_2[o_3], c_2, r_1[o_2], w_1[o_2], w_1[o_3], c_1$$

Maintaining Serialisability and Recoverability

- **two-phase locking (2PL)**
  - conflict based
  - uses **locks** to prevent problems
  - common technique
- **time-stamping**
  - add a timestamp to each object
  - write sets timestamp to that of transaction
  - may only read or write objects with earlier timestamp
  - abort when object has new timestamp
  - common technique
- **optimistic concurrency control**
  - do nothing until commit
  - at commit, inspect history for problems
  - good if few conflicts

The 2PL Protocol

1. read locks $rl[o], \ldots, r[o], \ldots, ru[o]$
2. write locks $wl[o], \ldots, w[o], \ldots, wu[o]$
3. Two phases
   i. **growing phase**
   ii. **shrinking phase**
4. refuse $rl_i[o]$ if $wl_j[o]$ already held
   refuse $wl_i[o]$ if $rl_j[o]$ or $wl_j[o]$ already held
5. $rl_i[o]$ or $wl_i[o]$ refused $\rightarrow$ delay T_i



Quiz 9: Two Phase Locking (2PL)

Which history is not valid in 2PL?

A

$rl_1[a_{107}]$, $r_1[a_{107}]$, $wl_1[a_{107}]$, $w_1[a_{107}]$, $wu_1[a_{107}]$, $ru_1[a_{107}]$

B

$wl_1[a_{107}]$, $wl_1[a_{100}]$, $r_1[a_{107}]$, $w_1[a_{107}]$, $r_1[a_{100}]$, $w_1[a_{100}]$, $wu_1[a_{100}]$, $wu_1[a_{107}]$

C

$wl_1[a_{107}]$, $r_1[a_{107}]$, $w_1[a_{107}]$, $wu_1[a_{107}]$, $wl_1[a_{100}]$, $r_1[a_{100}]$, $w_1[a_{100}]$, $wu_1[a_{100}]$

D

$wl_1[a_{107}]$, $r_1[a_{107}]$, $w_1[a_{107}]$, $wl_1[a_{100}]$, $r_1[a_{100}]$, $wu_1[a_{107}]$, $w_1[a_{100}]$, $wu_1[a_{100}]$

Anomaly 1: Lost update

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,2000.00)
COMMIT TRANSACTION T2

$r_1[b_{56}]$, $w_1[b_{56}]$, $r_1[b_{34}]$, $w_1[b_{34}]$, c_1

$r_2[b_{34}]$, $w_2[b_{34}]$, $r_2[b_{67}]$, $w_2[b_{67}]$, c_2

$r_1[b_{56}]$, cash=94340.45, $w_1[b_{56}]$, cash=84340.45, $r_1[b_{34}]$, cash=8900.67,
$r_2[b_{34}]$, cash=8900.67, $w_1[b_{34}]$, cash=18900.67$lost update$, c_1, $w_2[b_{34}]$, cash=6900.42
$r_2[b_{67}]$, cash=34005.00, $w_2[b_{67}]$, cash=36005.25, c_2

− serialisable + recoverable

Lost Update Anomaly with 2PL

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,2000.00)
COMMIT TRANSACTION T2

$b_1, wl_1[b_{56}], r_1[b_{56}], w_1[b_{56}], wl_1[b_{34}], r_1[b_{34}], w_1[b_{34}], c_1, wu_1[b_{56}], wu_1[b_{34}]$

$b_2, wl_2[b_{34}], r_2[b_{34}], w_2[b_{34}], wl_2[b_{67}], r_2[b_{67}], w_2[b_{67}], c_2, wu_2[b_{34}], wu_2[b_{67}]$

$b_1, wl_1[b_{56}], r_1[b_{56}], w_1[b_{56}], wl_1[b_{34}], r_1[b_{34}], b_2, wl_2[b_{34}], r_2[b_{34}], w_1[b_{34}], c_1, wu_1[b_{56}], wu_1[b_{34}], w_2[b_{34}], wl_2[b_{67}], r_2[b_{67}], w_2[b_{67}], c_2, wu_2[b_{34}], wu_2[b_{67}]$

Lost Update history not permitted by 2PL, since $wl_2[b_{34}]$ not granted

Lost Update Anomaly with 2PL

BEGIN TRANSACTION T1
EXEC move_cash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,2000.00)
COMMIT TRANSACTION T2

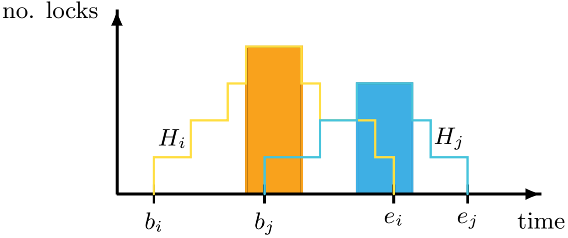
$b_1, wl_1[b_{56}], r_1[b_{56}], w_1[b_{56}], wl_1[b_{34}], r_1[b_{34}], w_1[b_{34}], c_1, wu_1[b_{56}], wu_1[b_{34}]$

$b_2, wl_2[b_{34}], r_2[b_{34}], w_2[b_{34}], wl_2[b_{67}], r_2[b_{67}], w_2[b_{67}], c_2, wu_2[b_{34}], wu_2[b_{67}]$

$b_1, wl_1[b_{56}], r_1[b_{56}], w_1[b_{56}], wl_1[b_{34}], r_1[b_{34}], b_2, w_1[b_{34}], c_1, wu_1[b_{56}], wu_1[b_{34}], wl_2[b_{34}], r_2[b_{34}], w_2[b_{34}], wl_2[b_{67}], r_2[b_{67}], w_2[b_{67}], c_2, wu_2[b_{34}], wu_2[b_{67}]$

2PL causes T2 to be delayed

Why does 2PL Work?



- two-phase rule → maximum lock period
- can re-time history so all operations take place during maximum lock period
- CSR since *all* conflicts prevented during maximum lock period

When to lock: Aggressive Scheduler

		$rl_1[b_{34}]$	$wl_1[b_{34}]$	$wl_1[b_{34}]$	
$rl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$\emptyset$
$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$

$b_1, \; r_1[b_{56}], \; w_1[b_{56}], \; r_1[b_{34}], \; w_1[b_{34}], \; c_1$

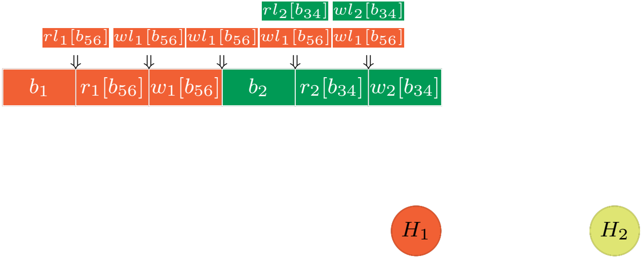
- delay taking locks as long as possible
- maximises concurrency
- might suffer delays later on

When to lock: Conservative Scheduler

$$
\begin{array}{cccccc}
 & wl_2[b_{34}] & wl_2[b_{34}] & & & \\
 & wl_2[b_{67}] & wl_2[b_{67}] & wl_2[b_{67}] & wl_2[b_{67}] & \emptyset \\
 & \Downarrow & \Downarrow & \Downarrow & \Downarrow & \Downarrow \\
b_2, & r_2[b_{34}], & w_2[b_{34}], & r_2[b_{67}], & w_2[b_{67}], & c_2
\end{array}
$$

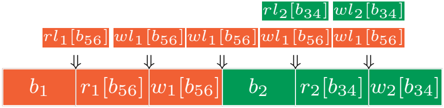
- take locks as soon as possible
- removes risks of delays later on
- might refuse to start

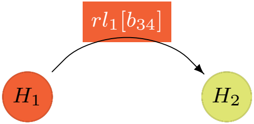
Deadlock Detection: WFG with No Cycle = No Deadlock



- **waits-for graph (WFG)**
- describes which transactions waits for others

Deadlock Detection: WFG with No Cycle = No Deadlock

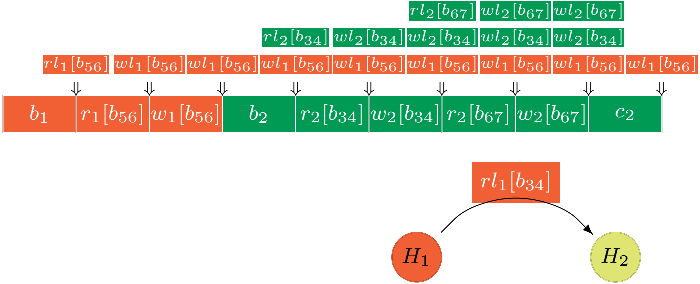




H_1 attempts $r_1[b_{34}]$, but is refused since H_2 has a write-lock, and so is put on WFG

- **waits-for graph** (**WFG**)
- describes which transactions waits for others

Deadlock Detection: WFG with No Cycle = No Deadlock



H_2 can proceed to complete its execution, after which it will have released all its locks

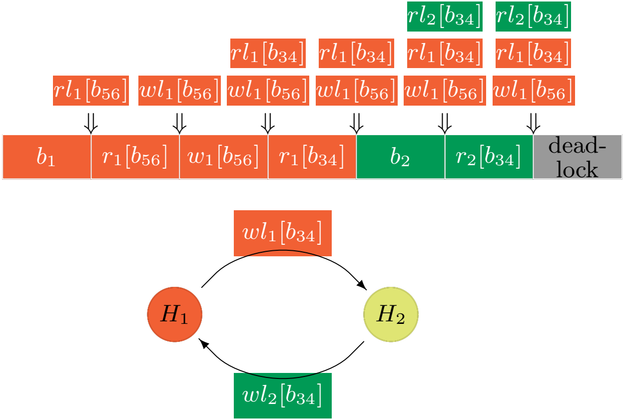
- **waits-for graph (WFG)**
- describes which transactions waits for others

Deadlock Detection: WFG with No Cycle = No Deadlock

					$rl_2[b_{67}]$	$wl_2[b_{67}]$	$wl_2[b_{67}]$				
			$rl_2[b_{34}]$	$wl_2[b_{34}]$	$wl_2[b_{34}]$	$wl_2[b_{34}]$	$wl_2[b_{34}]$	$rl_1[b_{34}]$	$wl_1[b_{34}]$	$wl_1[b_{34}]$	
$rl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	$wl_1[b_{56}]$	
$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	$\Downarrow$	
b_1	$r_1[b_{56}]$	$w_1[b_{56}]$	b_2	$r_2[b_{34}]$	$w_2[b_{34}]$	$r_2[b_{67}]$	$w_2[b_{67}]$	c_2	$r_1[b_{34}]$	$w_1[b_{34}]$	c_1

- **waits-for graph (WFG)**
- describes which transactions waits for others

Deadlock Detection: WFG with Cycle = Deadlock



Cycle in WFG means DB in a deadlock state, must abort either H_1 or H_2

Quiz 10: Resolving Deadlocks in 2PL

$H_1 = r_1[p_1], r_1[p_2], r_1[p_3], r_1[p_4], r_1[p_5], r_1[p_6]$

$H_2 = r_2[p_5], w_2[p_5], r_2[p_1], w_2[p_1]$

$H_3 = r_3[p_6], w_3[p_6], r_3[p_2], w_3[p_2]$

$H_4 = r_4[p_4], r_4[p_5], r_4[p_6]$

Suppose the transactions above have reached the following deadlock state

$H_d = r_1[p_1], r_1[p_2], r_1[p_3], r_1[p_4], r_2[p_5], w_2[p_5], r_2[p_1],$
$r_3[p_6], w_3[p_6], r_3[p_2], r_4[p_4]$

Which transaction should be aborted?

A	B	C	D
H_1	H_2	H_3	H_4

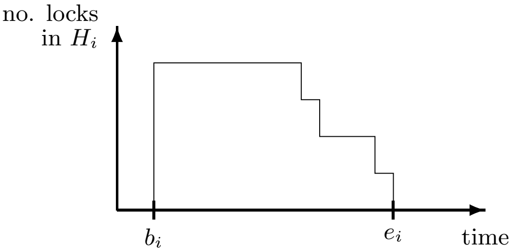
Worksheet: Deadlocks

$H_1 = \boxed{w_1[o_1]}, \boxed{r_1[o_2]}, \boxed{r_1[o_4]}$

$H_2 = \boxed{r_2[o_3]}, \boxed{r_2[o_2]}, \boxed{r_2[o_1]}$

$H_3 = \boxed{r_3[o_4]}, \boxed{w_3[o_4]}, \boxed{r_3[o_3]}, \boxed{w_3[o_3]}$

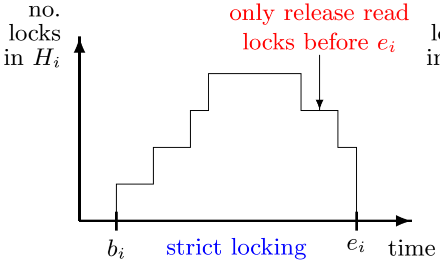
Conservative Locking

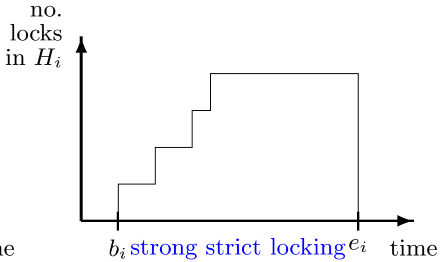


Conservative Locking

- prevents deadlock
- when to release locks problem
- not recoverable

Strict Locking





Strict Locking

- prevents write locks being released before transaction end
- allows deadlocks
- no dirty reads/writes → recoverable

Strong Strict Locking

In addition to strict locking properties

- prevents read locks being released before transaction end
- simple to implement
- suitable for distributed transactions (using atomic commit)

Transaction Isolation Levels

- Do we always need ACID properties?

```
BEGIN TRANSACTION T3
    SELECT DISTINCT no
    FROM movement
    WHERE amount>=1000.00
COMMIT TRANSACTION T3
```

- Some transactions only need 'approximate' results
  e.g. Management overview
  e.g. Estimates
- May execute these transactions at a 'lower' level of concurrency control
  SQL allows you to vary the level of concurrency control