# Concurrency Control



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# 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.

# 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



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

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

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

# Which concurrent executions should be allowed?



Concurrency control → 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)

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



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)

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



In $H_z$:

A

Not Serialisable, Not Recoverable



B

Not Serialisable, Recoverable



C

Serialisable, Not Recoverable

D

Serialisable, Recoverable

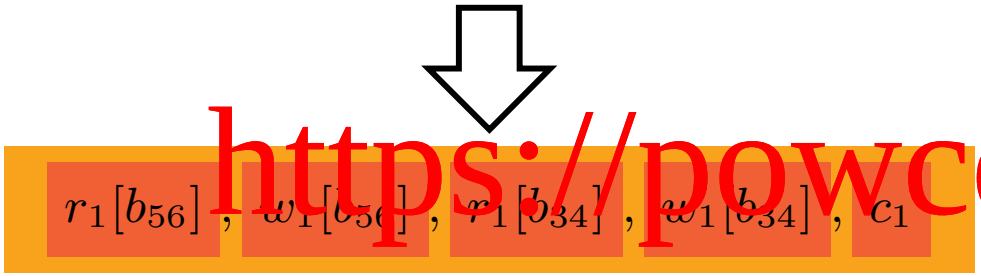
# Anomaly 1: Lost update

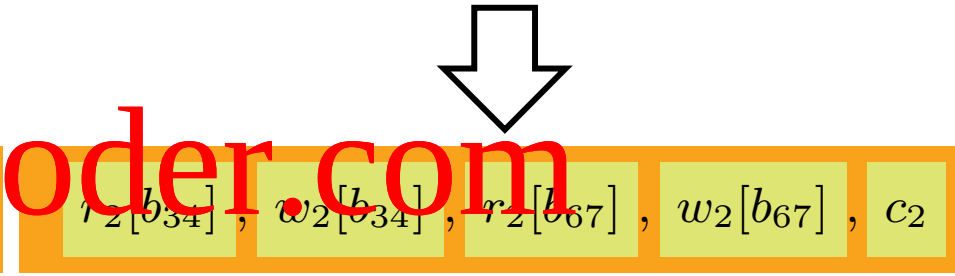


BEGIN TRANSACTION T1
EXEC moveCash(56,34,10000.00)
COMMIT TRANSACTION T1

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








$r_1[b_{56}]$, 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 *lostupdate*, $c_1$, $w_2[b_{34}]$, 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 moveCash(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 moveCash(56,34,10000.00)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC moveCash(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, $r_2[b_{34}]$, 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)



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

Which anomaly does $H_x$ suffer?



A
None

B
Lost Update

C
Inconsistent Analysis

D
Dirty Read

# Quiz 5: Anomalies (2)



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

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`

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

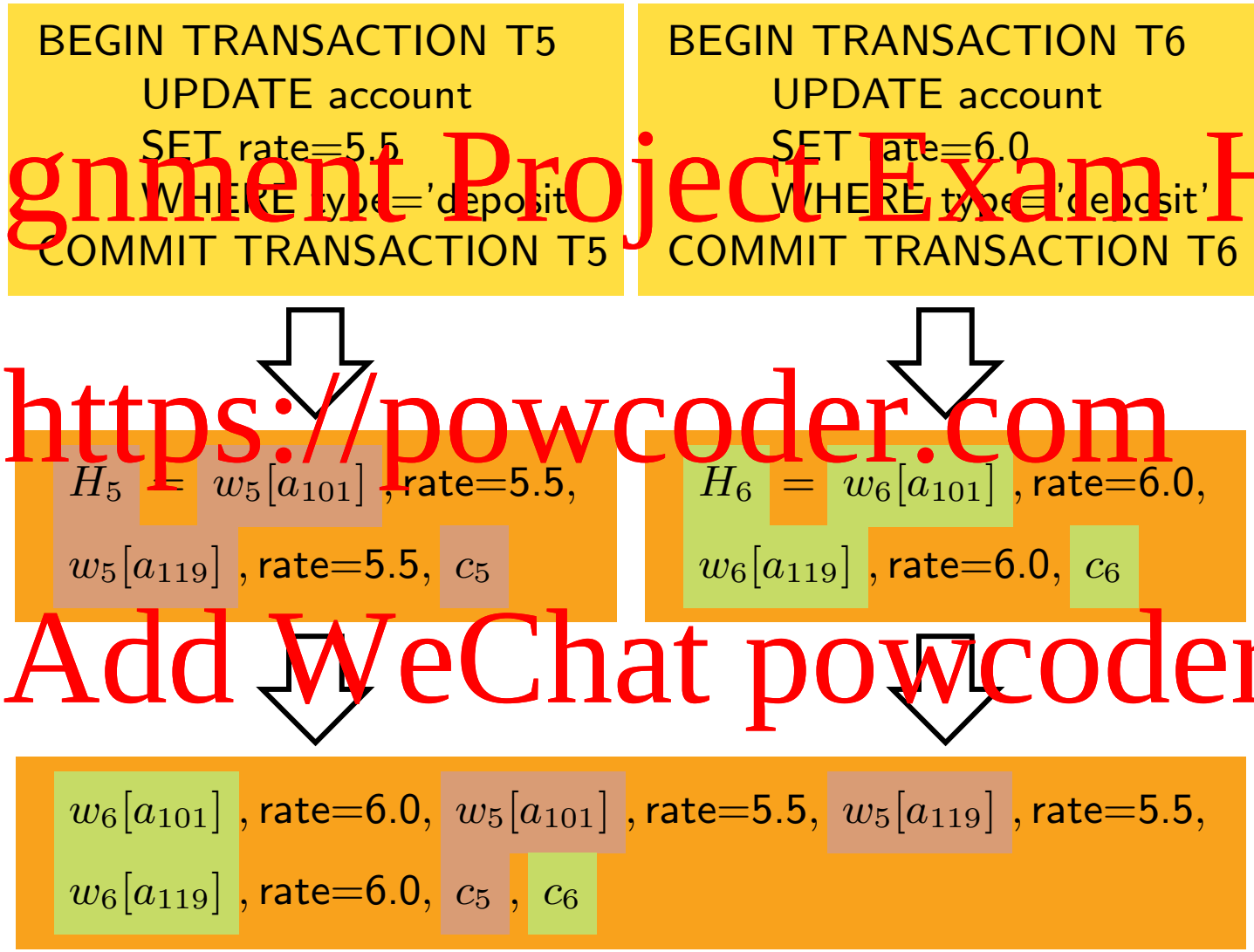
# Account Table



| 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






− serialisable  + recoverable

# Serialisable Transaction Execution

- Solve anomalies $\rightarrow H_c$ = serial execution
- Only interested in the **committed projection**



$H_c =$

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

$C(H_c) =$

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

# Possible Serial Equivalents



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



$H_1, H_2, H_4$ | $H_1, H_4, H_2$ | $H_2, H_1, H_4$ | $H_2, H_4, H_1$ | $H_4, H_1, H_2$ | $H_4, H_2, H_1$



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

# Conflicts: Potential For Problems

## conflict

A **conflict** occurs when there is a 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



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

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

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



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 6: Conflicts



$H_w =$

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

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 $H$ and $H_i$ 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 a History is CSR

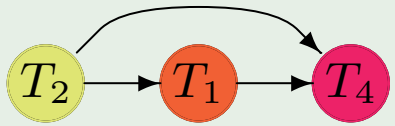


Given $H_{cp} = r_1[b_{56}], r_2[b_{34}], w_2[b_{34}], w_1[b_{56}], r_4[b_{56}], r_1[b_{34}], w_1[b_{34}], c_1, r_4[b_{34}], r_2[b_{67}], w_2[b_{67}], c_2, r_4[b_{67}], c_4$

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
```



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

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

$H_c =$ $r_1[b_{56}]$, 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
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, $a_5$

$H_6 = w_6[a_{101}]$, 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 7: Recoverability



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

Which 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

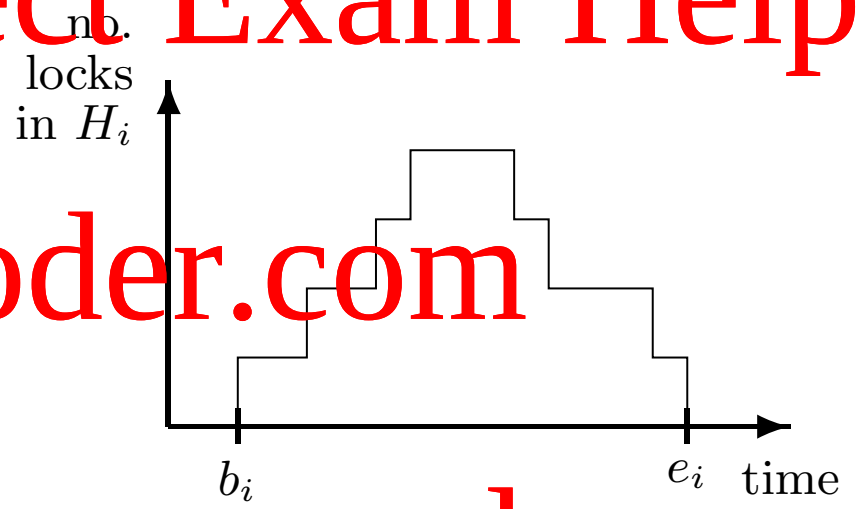


- **two-phase locking (2PL)**
  - conflict based
  - uses **locks** to prevent problems
  - common technique
- **time-stamping**
  - add a timestamp to each object
  - write sets timestamp to that of transaction
  - may only read or write objects with earlier timestamp
  - abort when object has new timestamp
  - 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 8: 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

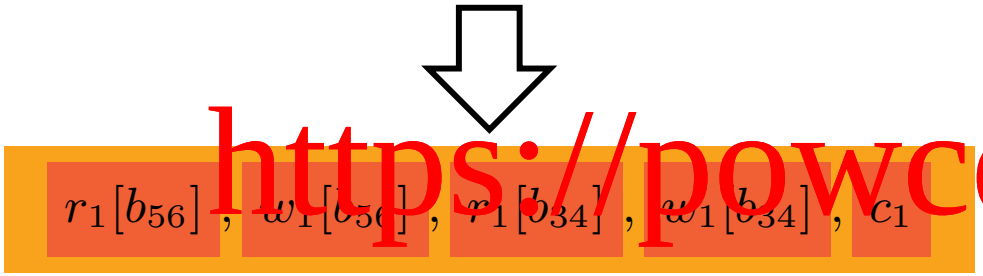
$wl_1[a_{107}]$, $r_1[a_{107}]$, $w_1[a_{107}]$, $wl_1[a_{100}]$, $r_1[a_{100}]$, $wu_1[a_{107}]$, $w_1[a_{100}]$, $wu_1[a_{100}]$

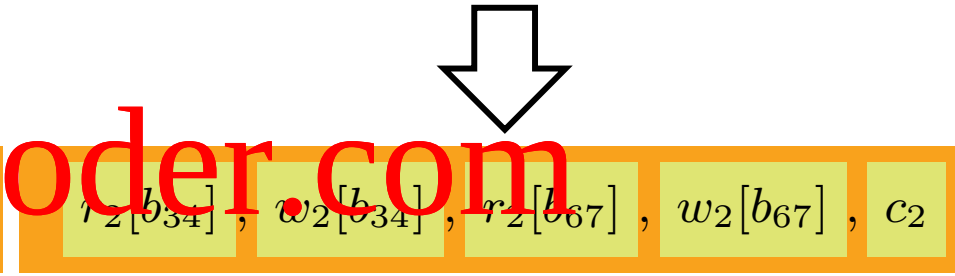
# Anomaly 1: Lost update

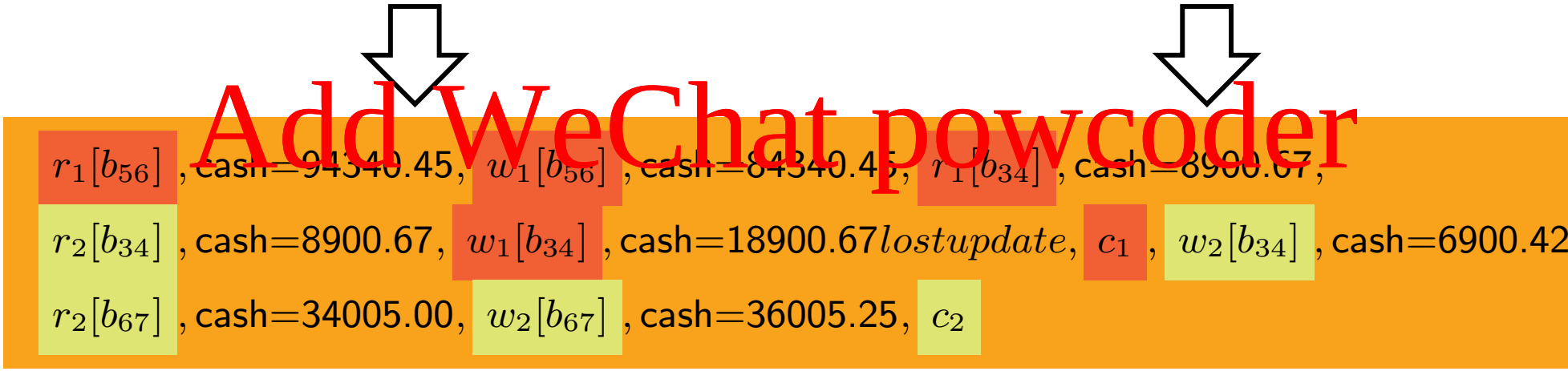


BEGIN TRANSACTION T1
EXEC moveCash(56,34,10000.00)
COMMIT TRANSACTION T1

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




− serialisable  + recoverable

# Lost Update Anomoly with 2PL



BEGIN TRANSACTION T1
EXEC move_cash(56,34,100000)
COMMIT TRANSACTION T1

BEGIN TRANSACTION T2
EXEC move_cash(34,67,200000)
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 Anomoly with 2PL



BEGIN TRANSACTION T1
EXEC move_cash(56,34,1000.00)
COMMIT TRANSACTION T1

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



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

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

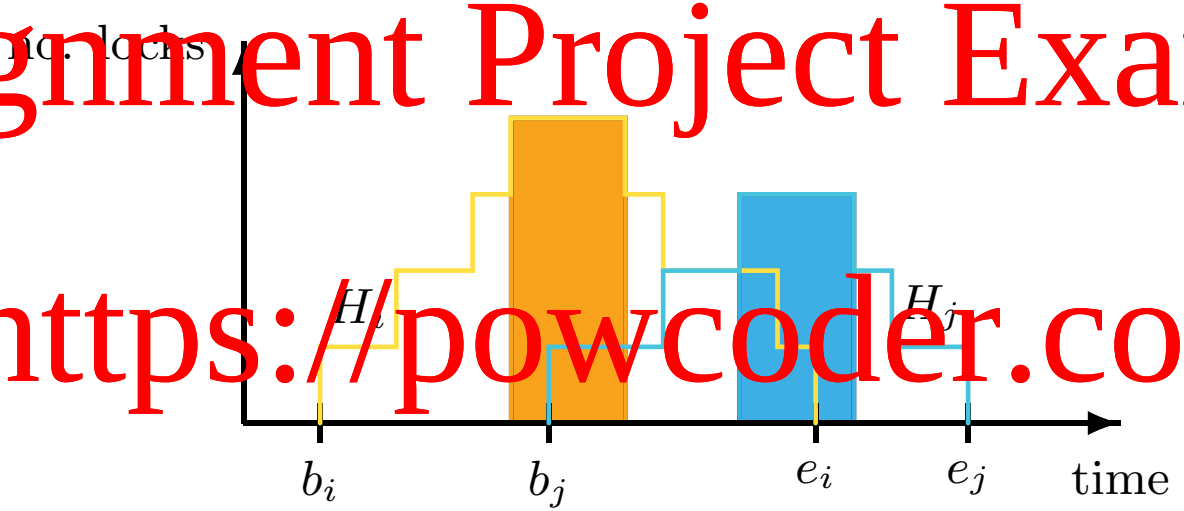


$b_1$ , $wl_1[b_{56}]$ , $r_1[b_{56}]$ , $w_1[b_{56}]$ , $wl_1[b_{34}]$ , $r_1[b_{34}]$ , $b_2$ , $w_1[b_{34}]$ , $c_1$ , $wu_1[b_{56}]$ , $wu_1[b_{34}]$ ,
$wl_2[b_{34}]$ , $r_2[b_{34}]$ , $w_2[b_{34}]$ , $wl_2[b_{67}]$ , $r_2[b_{67}]$ , $w_2[b_{67}]$ , $c_2$ , $wu_2[b_{34}]$ , $wu_2[b_{67}]$

2PL causes T2 to be delayed

# Why does 2PL Work?





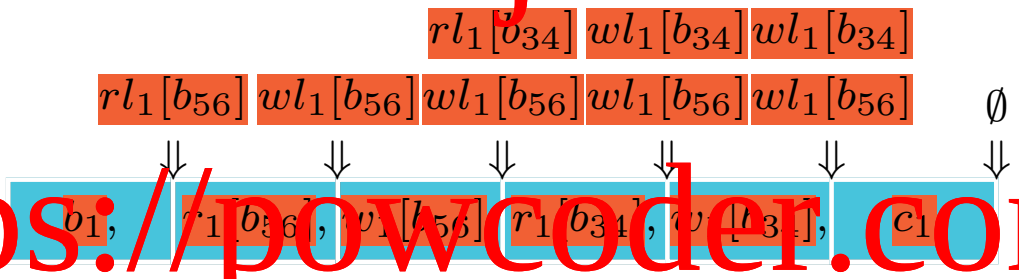





- two-phase rule — maximum lock period
- can re-time history so all operations take place during maximum lock period
- CSR since *all* conflicts prevented during maximum lock period

# When to lock: Aggressive Scheduler

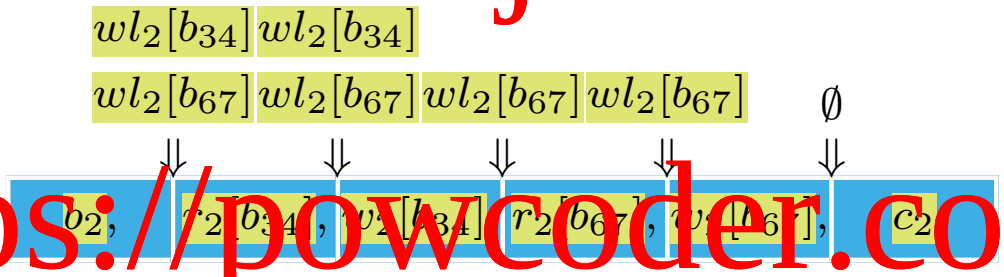





- delay taking locks as long as possible
- maximises concurrency
- might suffer delays later on

# When to lock: Conservative Scheduler

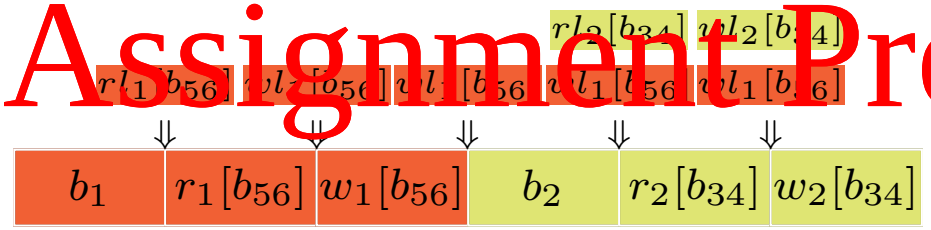





- take locks as soon as possible
- removes risks of delays later on
- might refuse to start

# Deadlock Detection: WFG with No Cycle = No Deadlock







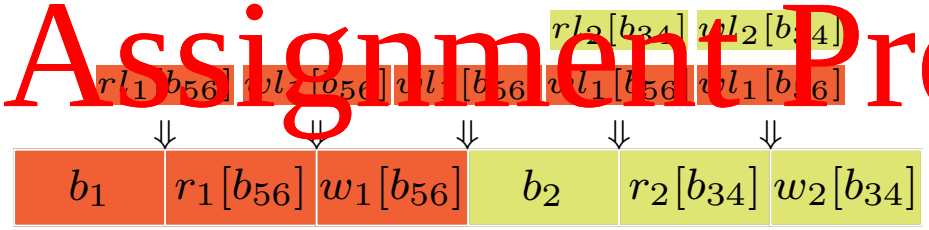




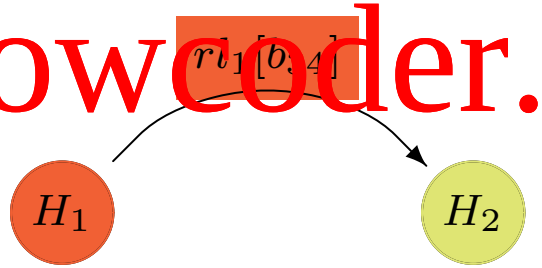
- **waits-for graph** (**WFG**)
- describes which transactions waits for others

# Deadlock Detection: WFG with No Cycle = No Deadlock







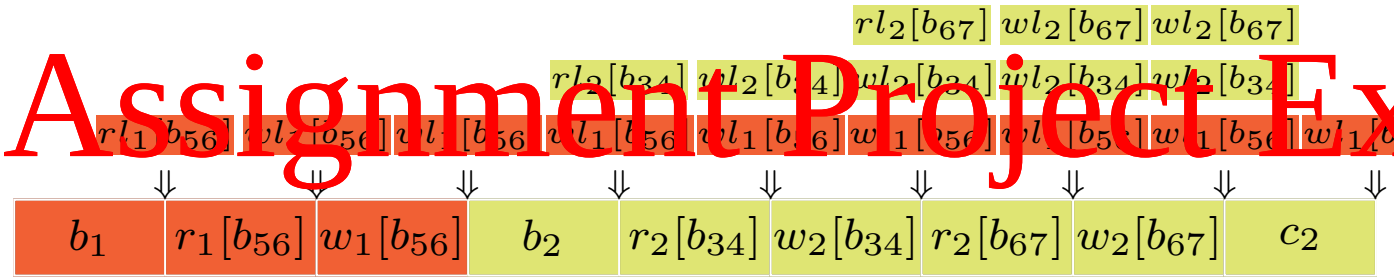



$H_1$ attempts $r_1[b_{34}]$, but is refused since $H_2$ has a write-lock, and so is put on WFG

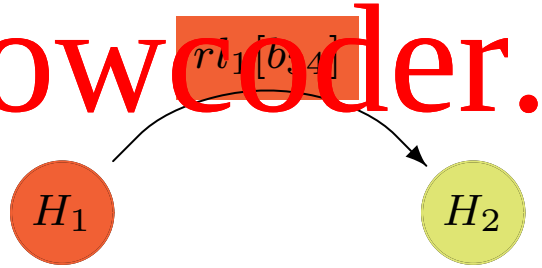
- **waits-for graph** (**WFG**)
- describes which transactions waits for others

# Deadlock Detection: WFG with No Cycle = No Deadlock







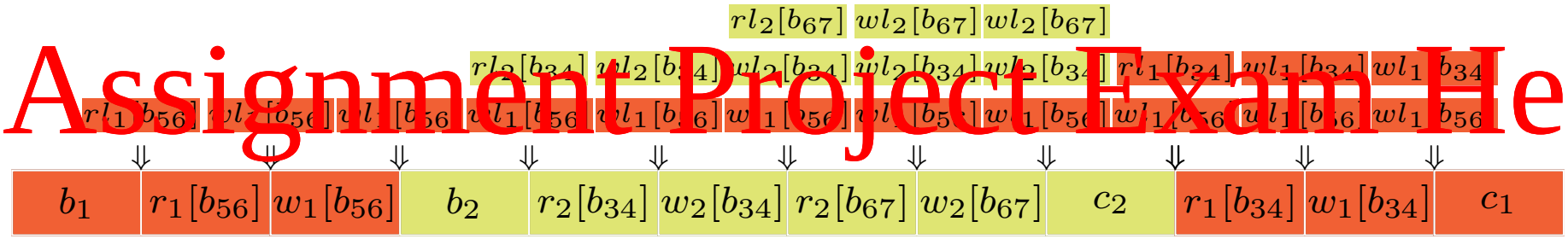



$H_2$ can proceed to complete its execution, after which it will have released all its locks

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

# Deadlock Detection: WFG with No Cycle = No Deadlock







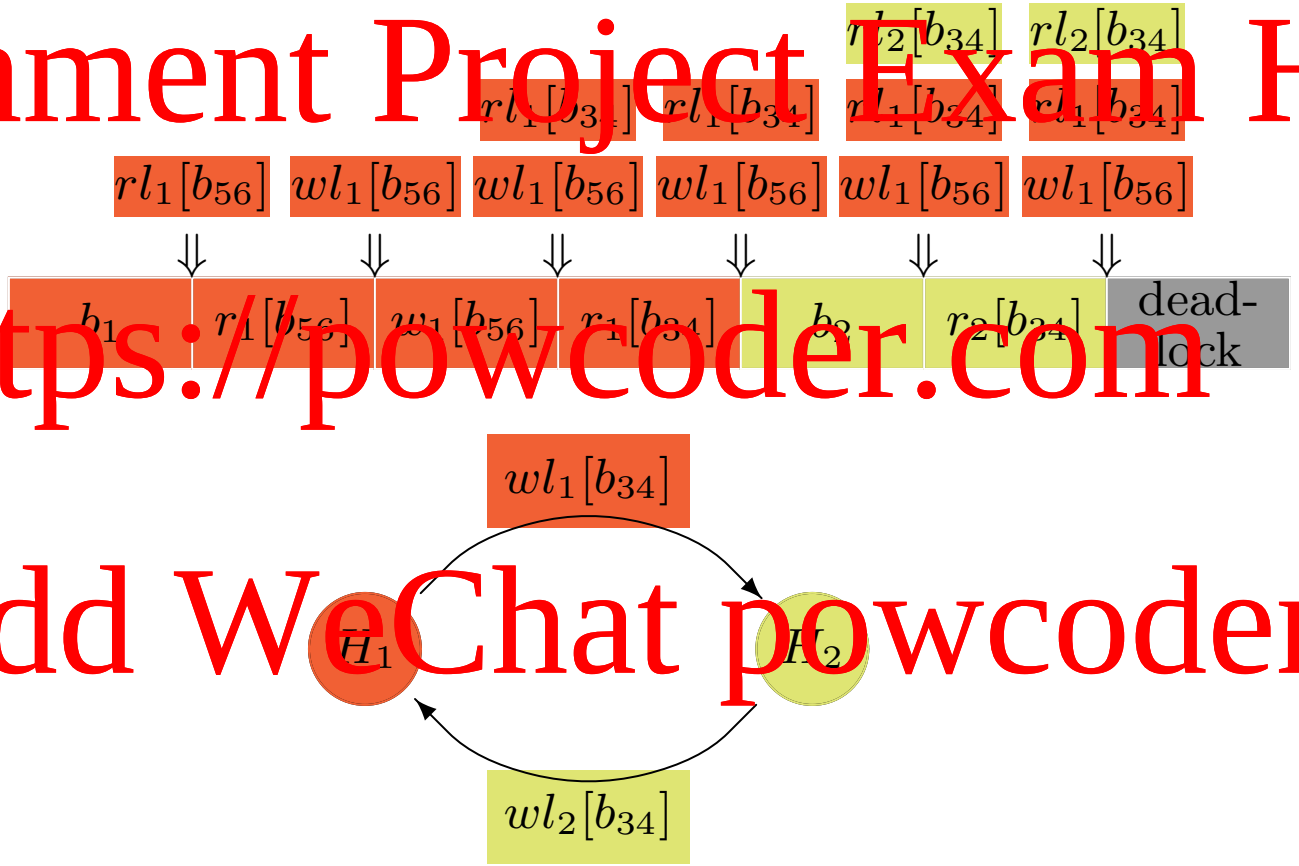

$H_1$



- **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 9: 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



$H_1 = w_1[o_1], r_1[o_2], r_1[o_4]$

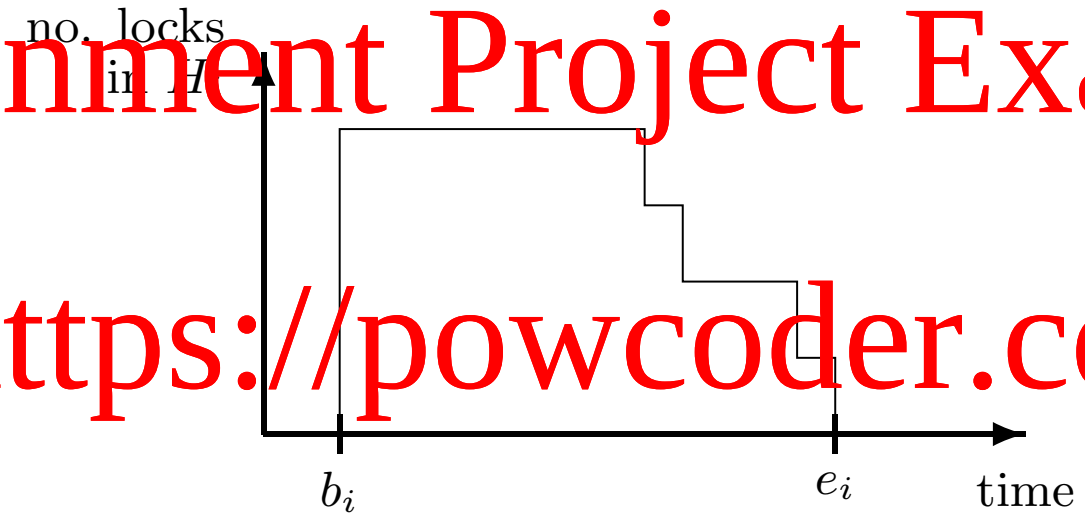


$H_2 = r_2[o_3], r_2[o_2], r_2[o_1]$

$H_3 = r_3[o_4], w_3[o_4], r_3[o_3], w_3[o_3]$

# Conservative Locking



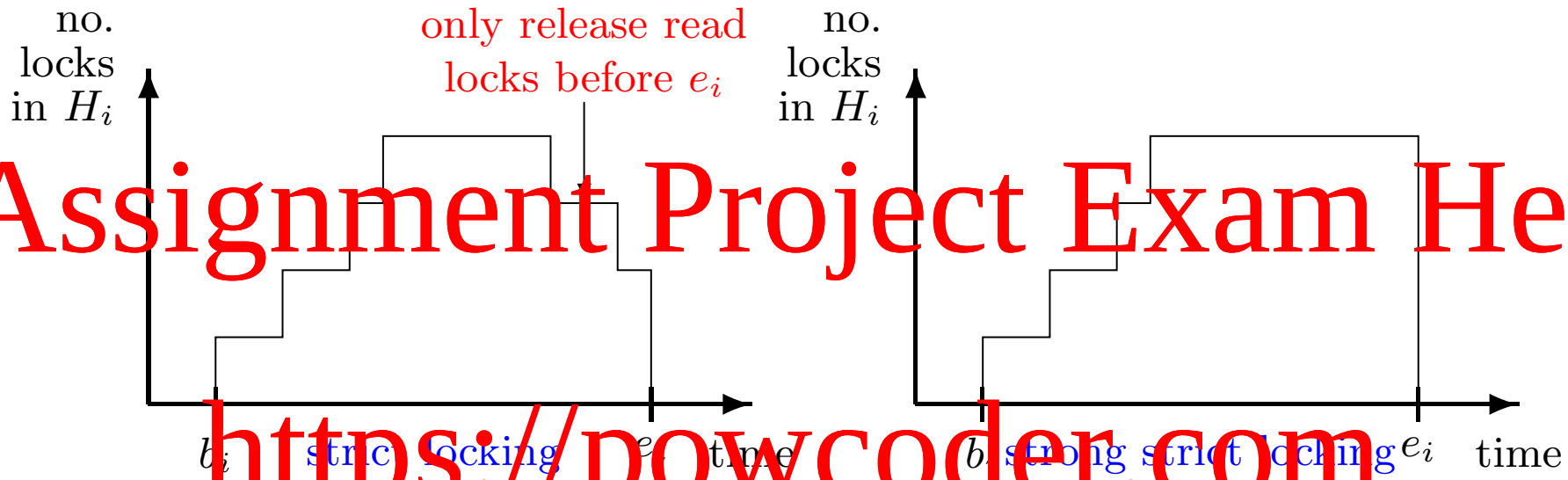





## Conservative Locking

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

# Strict Locking






## Strict Locking

- prevents write locks being released before transaction end
- recoverable (with cascading aborts) but allows deadlocks

## Strong Strict Locking

- no locks released before end → recoverable
- allows deadlocks
- no problem determining when to release locks
- 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>=100000
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*