Schedules: SERIAL and SERIALIZABLE
Definition of SCHEDULE

The sequence of the read/write operations of several transactions as they are executed in the Database
Serial Schedule

- Transactions execute fully.
- One at a time.
- No interleaving.
- Different orders of execution may produce different final values
Serializable Schedule

- Interleaved.
- Equivalent to SOME serial schedule.
- Equivalence does NOT mean "ending up with the same values as".
- Equivalence cannot depend on initial values of database items.
- Cannot depend on values written
  DB doesn’t know logic of transaction.
- Depends only on order of operations.
Conflicting Operations

• Used to define how schedules are equivalent
• 2 OPERATIONS CONFLICT if
  – belong to different transactions
  – access same data item
  – at least one is a write
• IMPORTANT: they do NOT have to ACTUALLY come into CONFLICT!
  – A better name would be ‘Potentially Conflicting Operations’
CONFLICT EQUIVALENCE

• 2 Schedules are Conflict Equivalent
• If the order of any 2 conflicting operations is the same in both schedules.
• SERIALIZABLE SCHEDULE is CONFLICT EQUIVALENT to some serial schedule
Example of Conflict Equivalence

- Transaction A and Transaction B each Read and Write X.
- Conflicting Operations:
  - Trans A Read X and Trans B Write X
  - Trans A Write X and Trans B Read X
  - Trans A Write X and Trans B Write X
- Trans A Read X and Trans B Read X do not conflict
Conflicting Operations

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Conflict Equivalence

Schedule 1

TRANS A
Read X
Read Z
Write Z
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Read Y
Write Y
Read X
Write X
## Conflict Equivalence

<table>
<thead>
<tr>
<th>Schedule 1</th>
<th>Schedule 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A</td>
<td>TRANS A</td>
</tr>
<tr>
<td>Read X</td>
<td>Read X</td>
</tr>
<tr>
<td>Read Z</td>
<td>Read Y</td>
</tr>
<tr>
<td>Write Z</td>
<td>Write Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
<tr>
<td>Read Y</td>
<td>Read X</td>
</tr>
<tr>
<td>Write Y</td>
<td>Read Z</td>
</tr>
<tr>
<td>Read X</td>
<td>Write Y</td>
</tr>
<tr>
<td>Write X</td>
<td>Write Z</td>
</tr>
<tr>
<td></td>
<td>Read X</td>
</tr>
<tr>
<td></td>
<td>Write X</td>
</tr>
</tbody>
</table>
Conflict Equivalence

Schedule 1

TRANS A
Read X
Read Y
Write X
Write Y

TRANS B
Read Y
Read Z
Write Z
Write X

Schedule 2

TRANS A
Read X
Read Y
Write Y
Write X

TRANS B
Read X
Read Z
Write Y
Write Z
Write X
Conflict Equivalence

Schedule 1

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Y
Write Z
Write X
Conflict Equivalence

Schedule 1

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Y
Write Z
Write X
Conflict Equivalence

Schedule 1
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Y
Write Z
Write X
Conflict Equivalence

Schedule 1
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Y
Write Z
Write X
Conflict Equivalence

Schedule 1
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2
TRANS A
Read Y
Write Z
Write X

TRANS B
Read X
Read Z
Write Y
Write Z

Read X
Write X
Conflict Equivalence

Schedule 1
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Schedule 2
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

For each pair of conflicting ops, order is the same.
Conflict Equivalence

They are conflict equivalent!

Schedule 1
- TRANS A
  - Read X
  - Read Z
  - Write Z
  - Write X

Schedule 2
- TRANS A
  - Read X
  - Read Z

For each pair of conflicting ops, order is the same.

Schedule 1
- TRANS B
  - Read Y
  - Write Y
  - Read X
  - Write X

Schedule 2
- TRANS B
  - Read Y
  - Write Y
  - Read X
  - Write X
Conflict Equivalence

They are conflict equivalent!

Serial Schedule 1

TRANS A
- Read Y
- Write Y
- Read X
- Write X

TRANS B
- Read X
- Read Z
- Write Z
- Write X

Schedule 2

TRANS A
- Read Y
- Read Z
- Write Z
- Write X

TRANS B
- Read X
- Read Z
- Write Y
- Write Z
- Read X
- Write X
Conflict Equivalence

They are conflict equivalent!

Schedule 1

Serial

TRANS A

Read Y
Write Y
Read X
Write X

TRANS B

Read X
Read Z
Write Z
Write X

Schedule 2

Serializable

TRANS A

Read Y
Write Y
Read X
Write X

TRANS B

Read X
Read Z
Write Z
Write X

For each pair of conflicting ops, order is the same.
Is Schedule 3 Serializable?

<table>
<thead>
<tr>
<th>Schedule 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A</td>
</tr>
<tr>
<td>Read Y</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Write Y</td>
</tr>
<tr>
<td>Read X</td>
</tr>
<tr>
<td>Write X</td>
</tr>
<tr>
<td>Schedule 3</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>TRANS A</td>
</tr>
<tr>
<td>Read Y</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Write Y</td>
</tr>
<tr>
<td>Read X</td>
</tr>
<tr>
<td>Write X</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
## Is Schedule 3 Serializable?

**Schedule 3**

<table>
<thead>
<tr>
<th>TRANS A</th>
<th>TRANS B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Y</td>
<td>Read X</td>
</tr>
<tr>
<td>Write Y</td>
<td>Read Z</td>
</tr>
<tr>
<td>Read X</td>
<td>Write Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
</tbody>
</table>

**Serial Sched 1**

<table>
<thead>
<tr>
<th>TRANS A</th>
<th>TRANS B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read X</td>
<td>Read Z</td>
</tr>
<tr>
<td>Write Z</td>
<td>Write X</td>
</tr>
<tr>
<td>Read Y</td>
<td>Write Y</td>
</tr>
<tr>
<td>Read X</td>
<td>Write X</td>
</tr>
</tbody>
</table>

The arrow indicates the order in which the transactions in Schedule 3 can be ordered to make it serializable.
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read X
Read Z
Write Z
Write X

TRANS B
Read Y
Write Y
Read X
Write X
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read X
Read Z
Write Z
Write X

TRANS B
Read Y
Write Y
Read X
Write X
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read X
Read Z
Write Z
Write X

TRANS B
Read Y
Write Y
Read X
Write X
Is Schedule 3 Serializable?

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 1

TRANS A
Read X
Write Y
Read X
Write X

TRANS B
Read Z
Write Z
Write X

Green & Blue in opposite orders. The two are not conflict equivalent.
We are not done!

• Schedule 3 is not equivalent to one serial schedule.
  Where Trans B precedes Trans A
• But it might be equivalent to another
  Where Trans A precedes Trans B
• To be serializable, it needs to be equivalent to only one serial schedule.
Is Schedule 3 Serializable? Again.

<table>
<thead>
<tr>
<th>Schedule 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A</td>
</tr>
<tr>
<td>Read Y</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Write Y</td>
</tr>
<tr>
<td>Read X</td>
</tr>
<tr>
<td>Write X</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Is Schedule 3 Serializable? Again.

<table>
<thead>
<tr>
<th>Schedule 3</th>
<th>Serial Sched 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A</td>
<td>TRANS B</td>
</tr>
<tr>
<td>Read Y</td>
<td>Read X</td>
</tr>
<tr>
<td>Read Z</td>
<td>Read Z</td>
</tr>
<tr>
<td>Write Y</td>
<td>Write X</td>
</tr>
<tr>
<td>Read X</td>
<td>Write Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
</tbody>
</table>
Is Schedule 3 Serializable? Again.

<table>
<thead>
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<th>Schedule 3</th>
<th>Serial Sched 2</th>
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<tbody>
<tr>
<td>TRANS A</td>
<td>TRANS A</td>
</tr>
<tr>
<td>Read Y</td>
<td>Read Y</td>
</tr>
<tr>
<td>Read X</td>
<td>Read X</td>
</tr>
<tr>
<td>Read Z</td>
<td>Write Y</td>
</tr>
<tr>
<td>Write Y</td>
<td>Read X</td>
</tr>
<tr>
<td>Read X</td>
<td>Write X</td>
</tr>
<tr>
<td>Write X</td>
<td>Write Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
</tbody>
</table>

TRANS A
Read Y
Write Y
Read X
Write X
Is Schedule 3 Serializable? Again.

<table>
<thead>
<tr>
<th>Schedule 3</th>
<th>Serial Sched 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A Read Y Write Y Read X Write X</td>
<td>TRANS A Read Y Write Y Read X Write X</td>
</tr>
<tr>
<td>TRANS B Read X Read Z Write Z Write X</td>
<td>TRANS B Read X Read Z Write Z Write X</td>
</tr>
</tbody>
</table>

Serial Schedule 2:
Is Schedule 3 Serializable? Again.

<table>
<thead>
<tr>
<th>Schedule 3</th>
<th>Serial Sched 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANS A</td>
<td>TRANS A</td>
</tr>
<tr>
<td>Read Y</td>
<td>Read X</td>
</tr>
<tr>
<td>Read Z</td>
<td>Write Y</td>
</tr>
<tr>
<td>Write Y</td>
<td>Read X</td>
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<td></td>
<td>Write X</td>
</tr>
<tr>
<td>Read X</td>
<td>Write Y</td>
</tr>
<tr>
<td>Write X</td>
<td>Read Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Again.
Is Schedule 3 Serializable? Again.

<table>
<thead>
<tr>
<th>Schedule 3</th>
<th>Serial Sched 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRANS A</strong></td>
<td><strong>TRANS A</strong></td>
</tr>
<tr>
<td>Read Y</td>
<td>Read Y</td>
</tr>
<tr>
<td>Read X</td>
<td>Write Y</td>
</tr>
<tr>
<td>Read Z</td>
<td>Write X</td>
</tr>
<tr>
<td>Write Y</td>
<td>Read X</td>
</tr>
<tr>
<td><strong>TRANS B</strong></td>
<td><strong>TRANS B</strong></td>
</tr>
<tr>
<td>Read X</td>
<td>Write Y</td>
</tr>
<tr>
<td>Read Z</td>
<td>Write X</td>
</tr>
<tr>
<td>Write X</td>
<td>Read X</td>
</tr>
<tr>
<td>Write Z</td>
<td>Read Z</td>
</tr>
<tr>
<td>Write X</td>
<td>Write X</td>
</tr>
</tbody>
</table>
Is Schedule 3 Serializable? Again.

Schedule 3
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 2
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Is Schedule 3 Serializable? Again.

Schedule 3
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 2
TRANS A
TRANS B
Read Y
Write Y
Read X
Write X

Write X
Read X
Read Z
Write Z
Write X
Is Schedule 3 Serializable? Again.

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 2

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Is Schedule 3 Serializable? Again.

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 2

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Write X
Write Z

Green in opposite orders. The two are not conflict equivalent.
Is Schedule 3 Serializable? Again.

Schedule 3
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Serial Sched 2
TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Write X
Write Z
Write X

Green in opposite orders. The two are not conflict equivalent.
Conclusion

• Schedule 3 is not equivalent to serial schedule Trans A; Trans B.
• Schedule 3 is not equivalent to serial schedule Trans B; Trans A.
• There are no other Trans A/Trans B serial schedules.
• Schedule 3 is not serializable.
A shorter way

Schedule 3

TRANS A
Read Y
Write Y
Read X
Read Z
Write X

TRANS B
Read X
Write Z
Write X
Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X
Write Z
Write X

Trans B Read X comes before Trans A Write X. If there is an equivalent serial schedule, it must be one where Trans B comes before Trans A.
A shorter way

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Trans B Read X comes before Trans A Write X. If there is an equivalent serial schedule, it must be one where Trans B comes before Trans A.
A shorter way

Schedule 3

TRANS A  TRANS B
Read Y
Read X
Read Z

Write Y
Read X
Write X
Write Z
Write X

Trans B Read X comes before Trans A Write X. If there is an equivalent serial schedule, it must be one where Trans B comes before Trans A.

Trans A Read X comes before Trans B Write X. If there is an equivalent serial schedule, it must be one where Trans A comes before Trans B.
A shorter way

Schedule 3

TRANS A  TRANS B
Read Y    Read X
Read X    Read Z
Write Y   Write Z
Read X    Write X
Write X

Trans B Read X comes before Trans A Write X. If there is an equivalent serial schedule, it must be one where Trans B comes before Trans A.

Trans A Read X comes before Trans B Write X. If there is an equivalent serial schedule, it must be one where Trans A comes before Trans B.

So there can be no equivalent serial schedule
A Graphical Representation

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X
Read Z
Write Z

TRANS B
Read Y
Read X
Write X

Precedence Graph
A Graphical Representation

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X
Read Z

TRANS B
Read X
Write Z
Write X

Precedence Graph
A Graphical Representation

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Precedence Graph
Schedule 3

TRANS A

Read Y
Write Y
Read X
Write X

TRANS B

Read X
Read Z

Trans B Read X -- Trans A Write X

Precedence Graph

A Graphical Representation
A Graphical Representation

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Trans B Read X -- Trans A Write X

Precedence Graph
A Graphical Representation

Schedule 3

TRANS A
Read Y
Write Y
Read X
Write X

TRANS B
Read X
Read Z
Write Z
Write X

Trans A Read X -- Trans B Write X
Trans B Read X -- Trans A Write X

Precedence Graph