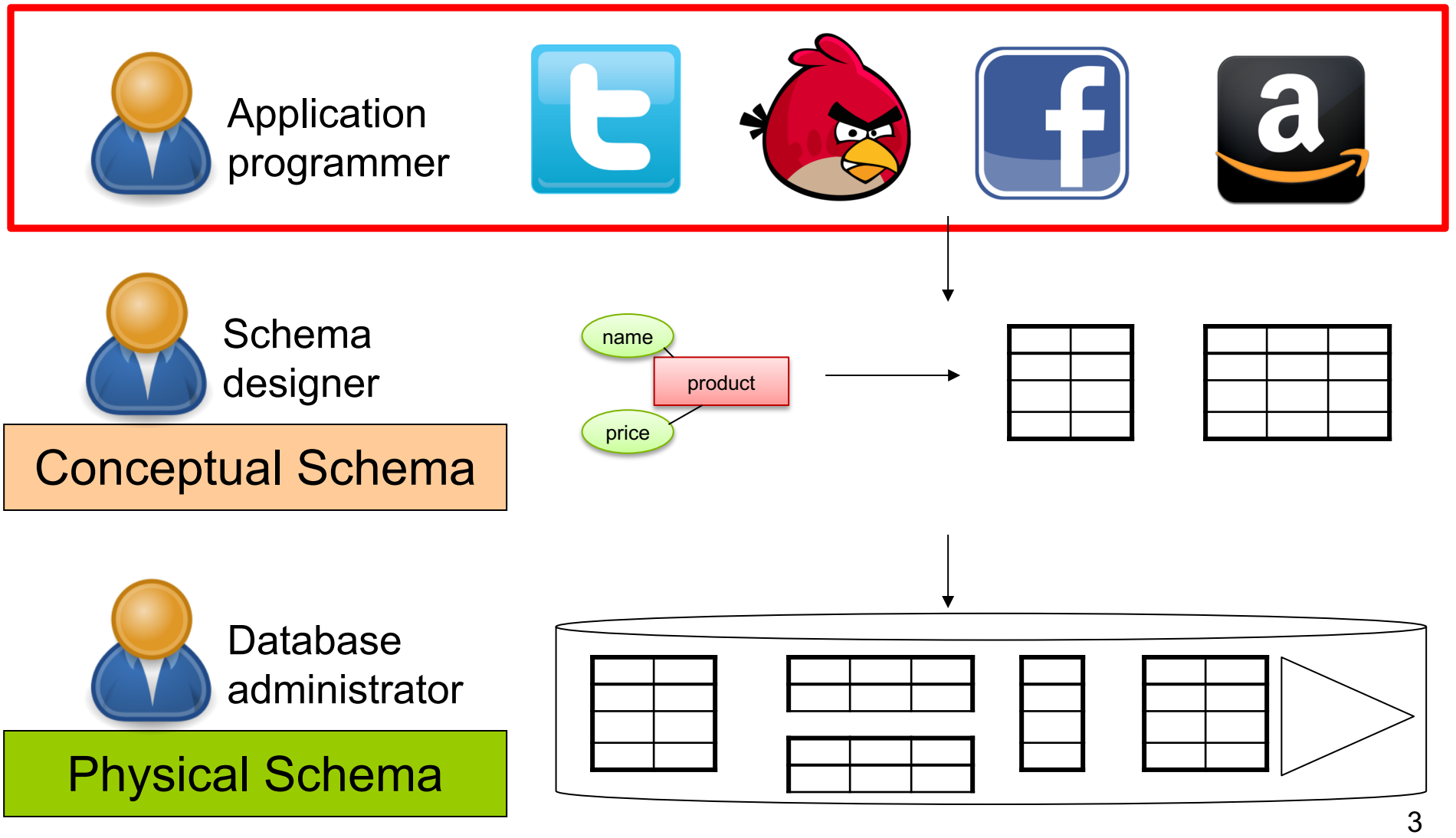
Introduction to Database Systems
CSE 414

Lecture 25: Introduction to Transactions

Class Overview

- Unit 1: Intro
- Unit 2: Relational Data Models and Query Languages
- Unit 3: Non-relational data
- Unit 4: RDMBS internals and query optimization
- Unit 5: Parallel query processing
- Unit 6: DBMS usability, conceptual design
- Unit 7: Transactions
  - Locking and schedules
  - Writing DB applications
- Unit 8: Advanced topics

Data Management Pipeline



Transactions

- We use database transactions everyday
  - Bank $$$ transfers
  - Online shopping
  - Signing up for classes

- For this class, a transaction is a series of DB queries
  - Read / Write / Update / Delete / Insert
  - Unit of work issued by a user that is independent from others

TRANSACTION
Do one specific thing for one specific user

What's the big deal?

Challenges

- Want to execute many apps concurrently
  - All these apps read and write data to the same DB
- Simple solution: only serve one app at a time
  - What's the problem?
- Want: multiple operations to be executed *atomically* over the same DBMS

bundled all into a single operation

What can go wrong?

- Manager: balance budgets among projects
  - Remove $10k from project A
  - Add $7k to project B
  - Add $3k to project C

- CEO: check company's total balance
  - `SELECT SUM(money) FROM budget;`

If you call this during the middle of the operations above, you will get a result inconsistent with reality

- This is called a dirty / inconsistent read aka a WRITE-READ conflict

Read in between write statements

What can go wrong?

- App 1:
```
SELECT inventory FROM products WHERE pid = 1
```

- App 2:
```
UPDATE products SET inventory = 0 WHERE pid = 1
```

- App 1:
```
SELECT inventory * price FROM products
WHERE pid = 1
```

- This is known as an unrepeatable read
  aka READ-WRITE conflict

write in between two read statements;

no communication between APP 1 and APP2 so APP 1 does not know the data has been changed!

What can go wrong?

Account 1 = $100
Account 2 = $100
Total = $200

- App 1:
  - Set Account 1 = $200
  - Set Account 2 = $0
- App 2:
  - Set Account 2 = $200
  - Set Account 1 = $0
- At the end:
  - Total = $200

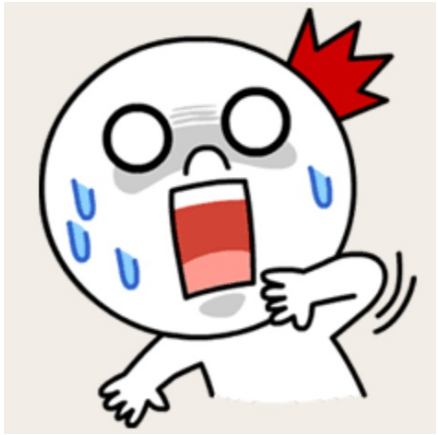
- App 1: Set Account 1 = $200
- App 2: Set Account 2 = $200
- App 1: Set Account 2 = $0
- App 2: Set Account 1 = $0
- At the end:
  - Total = $0

This is called the lost update aka WRITE-WRITE conflict

overwriting fields due to writes in unexpected order

What can go wrong?

- Buying tickets to the next Bieber concert:
  - Fill up form with your mailing address
  - Put in debit card number
  - Click submit
  - Screen shows money deducted from your account
  - [Your browser crashes]



Lesson:

Changes to the database should be ALL or NOTHING

ALL of the operations should happen all at once or none of them should happen

Transactions

- Collection of statements that are executed atomically (logically speaking)

```
BEGIN TRANSACTION
  [SQL statements]
COMMIT     or
ROLLBACK (=ABORT)
```

finished transaction

transaction failed for some reason

same command
dont use both

```
[single SQL statement]
```

Wrap a series of operations that need to occur together

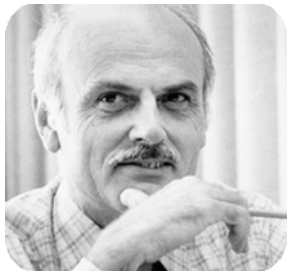
NO partial execution. either run all sql commands or none

If BEGIN... missing, then TXN consists of a single instruction

Transactions Demo

Turing Awards in Data Management

Charles Bachman, 1973
IDS and CODASYL



Ted Codd, 1981
Relational model

Jim Gray, 1998
Transaction processing

Michael Stonebraker, 2014
INGRES and Postgres

Know your ~~chemistry~~ transactions: ACID

- Atomic ALL OR NOTHING
  - State shows either all the effects of txn, or none of them
- Consistent If there was any kind of error, rollback all the work we did
  - Txn moves from a DBMS state where integrity holds, to another where integrity holds keys, referential constraints, etc
    - remember integrity constraints?
- Isolated
  - Effect of txns is the same as txns running one after another (i.e., looks like batch mode)
- Durable
  - Once a txn has committed, its effects remain in the database

Atomic

i.e. use transactions

- **Definition**: A transaction is ATOMIC if all its updates must happen or not at all.
- **Example**: move $100 from A to B
  - `UPDATE accounts SET bal = bal – 100 WHERE acct = A;`
  - `UPDATE accounts SET bal = bal + 100 WHERE acct = B;`

  - `BEGIN TRANSACTION;`
    `UPDATE accounts SET bal = bal – 100 WHERE acct = A;`
    `UPDATE accounts SET bal = bal + 100 WHERE acct = B;`
    `COMMIT;`

Isolated

- **Definition** An execution ensures that txns are isolated, if the effect of each txn is as if it were the only txn running on the system.

Consistent

- Recall: integrity constraints govern how values in tables are related to each other
  - Can be enforced by the DBMS, or ensured by the app
- How consistency is achieved by the app:
  - App programmer ensures that txns only takes a consistent DB state to another consistent state
  - DB makes sure that txns are executed atomically
- Can defer checking the validity of constraints until the end of a transaction

Durable

- A transaction is durable if its effects continue to exist after the transaction and even after the program has terminated

- How?
  - By writing to disk!
  - More in CSE 444

Rollback transactions

- If the app gets to a state where it cannot complete the transaction successfully, execute ROLLBACK
- The DB returns to the state prior to the transaction
- What are examples of such program states?

ACID

- Atomic
- Consistent
- Isolated
- Durable

- Enjoy this in HW8!

- Again: by default each statement is its own txn
  - Unless auto-commit is off then each statement starts a new txn

Transaction Schedules

Schedules

A schedule is a sequence of interleaved actions from all transactions

Serial Schedule

- A *serial schedule* is one in which transactions are executed one after the other, in some sequential order

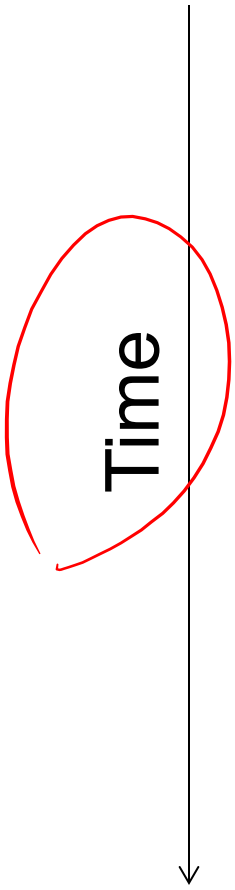
- **Fact:** nothing can go wrong if the system executes transactions serially
  - (up to what we have learned so far)
  - But DBMS don't do that because we want better overall system performance

Example

A and B are elements in the database
t and s are variables in txn 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)

Example of a (Serial) Schedule



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

Another Serial Schedule

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

Time

Review: Serializable Schedule

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

A Serializable Schedule

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

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

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)	

How do We Know if a Schedule is Serializable?

Notation:

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

Key Idea: Focus on *conflicting* operations

Conflicts

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

Conflict Serializability

Conflicts: (i.e., swapping will change program behavior)

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 $w_i(X); r_j(X)$

$r_i(X); w_j(X)$

Conflict Serializability

- 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 (why?)

Conflict Serializability

Example:

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

Conflict Serializability

Example:

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

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

Conflict Serializability

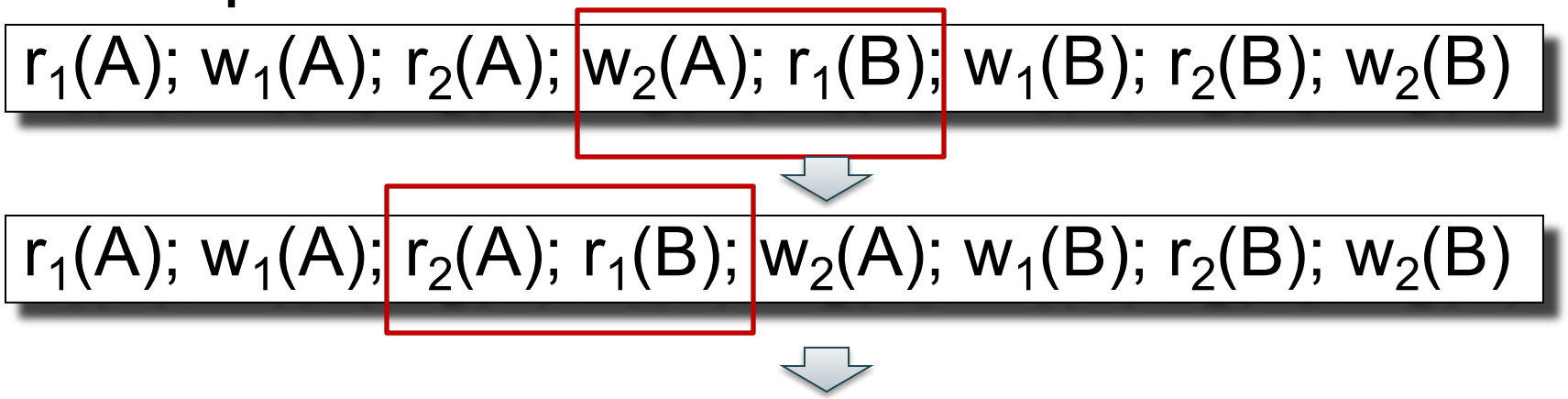
Example:

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

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

Conflict Serializability

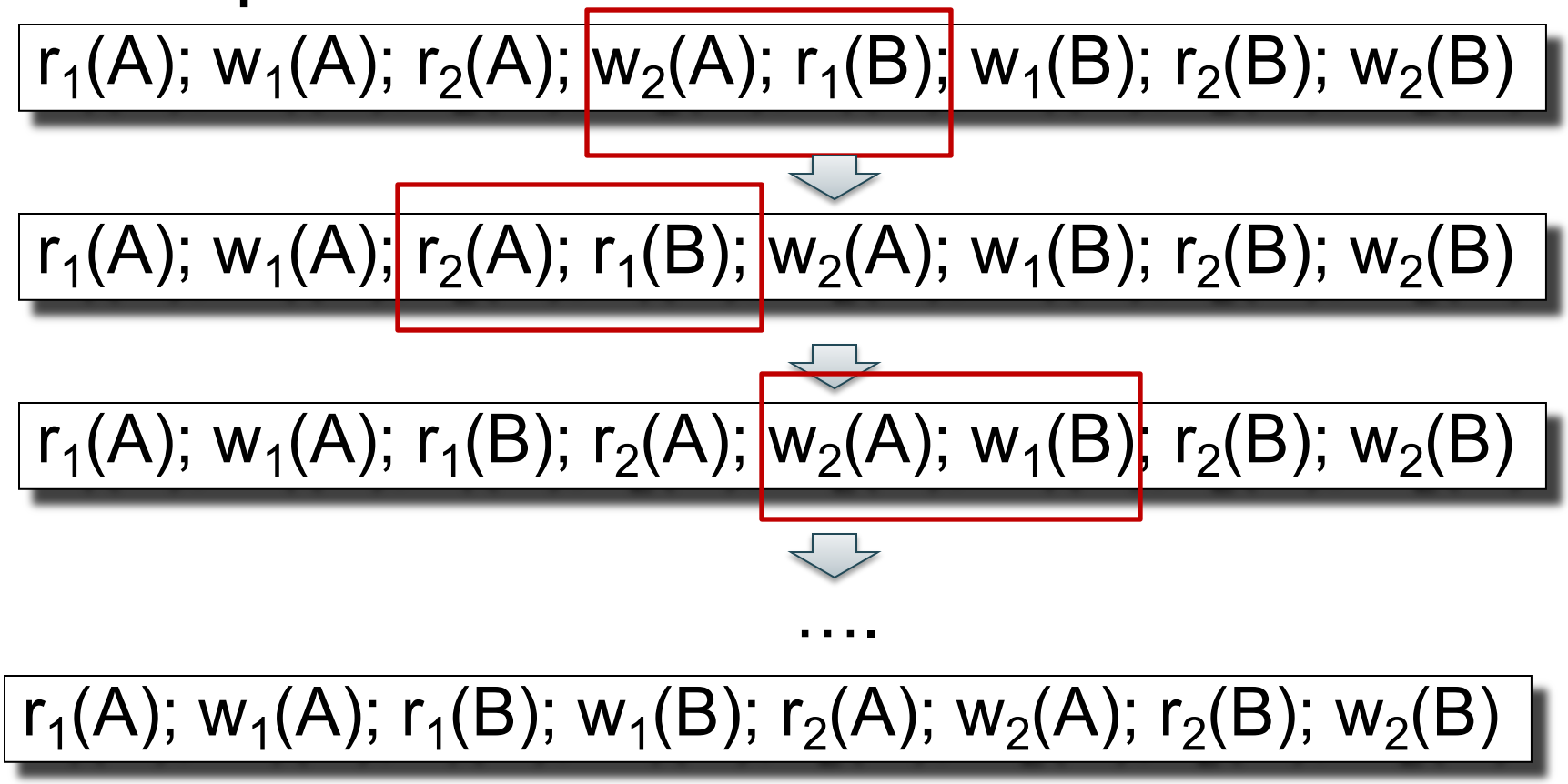
Example:



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

Conflict Serializability

Example:



Testing for Conflict-Serializability

Precedence graph:

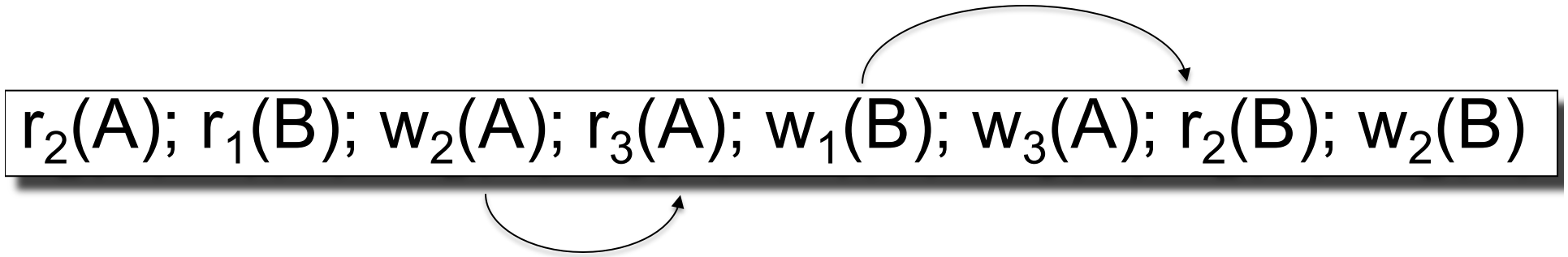
- A node for each transaction T_i,
- An edge from T_i to T_j whenever an action in T_i conflicts with, and comes before an action in T_j

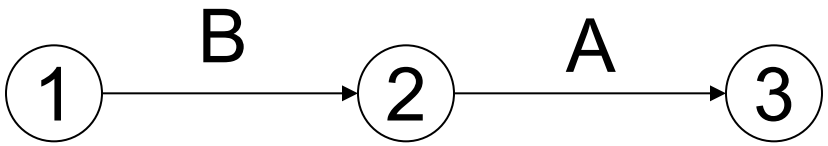
- The schedule is conflict-serializable iff the precedence graph is acyclic

Example 1

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

Example 1



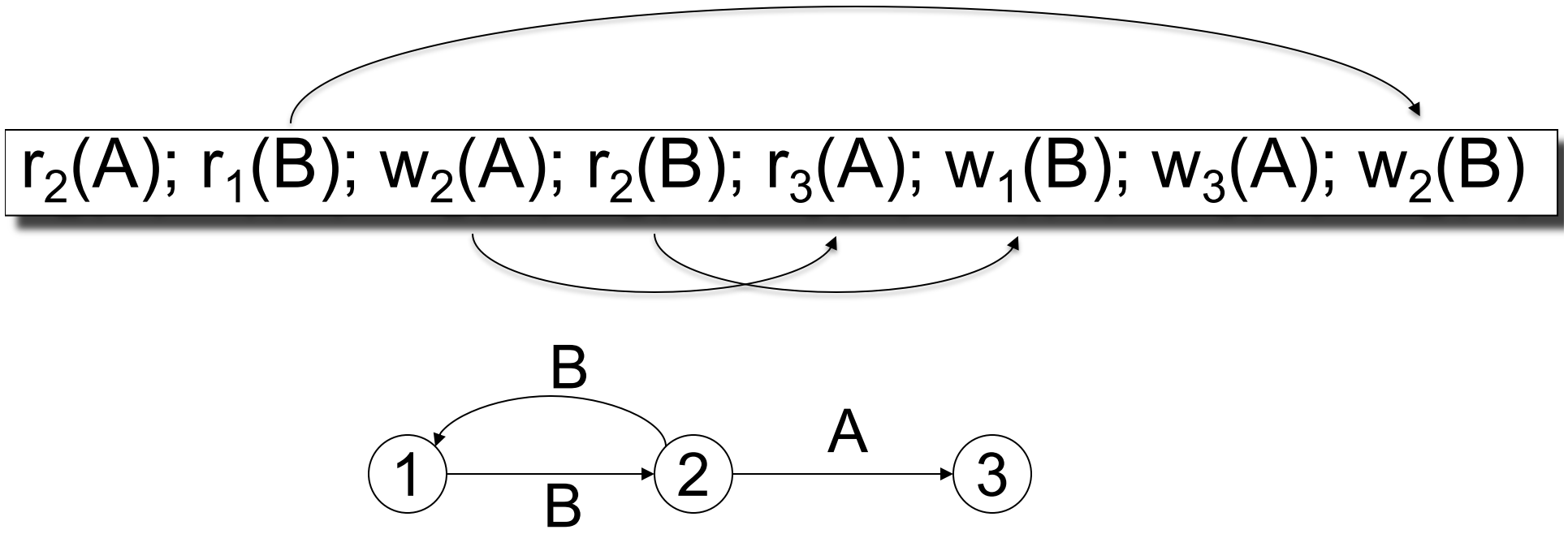


This schedule is conflict-serializable

Example 2

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

Example 2



This schedule is NOT conflict-serializable