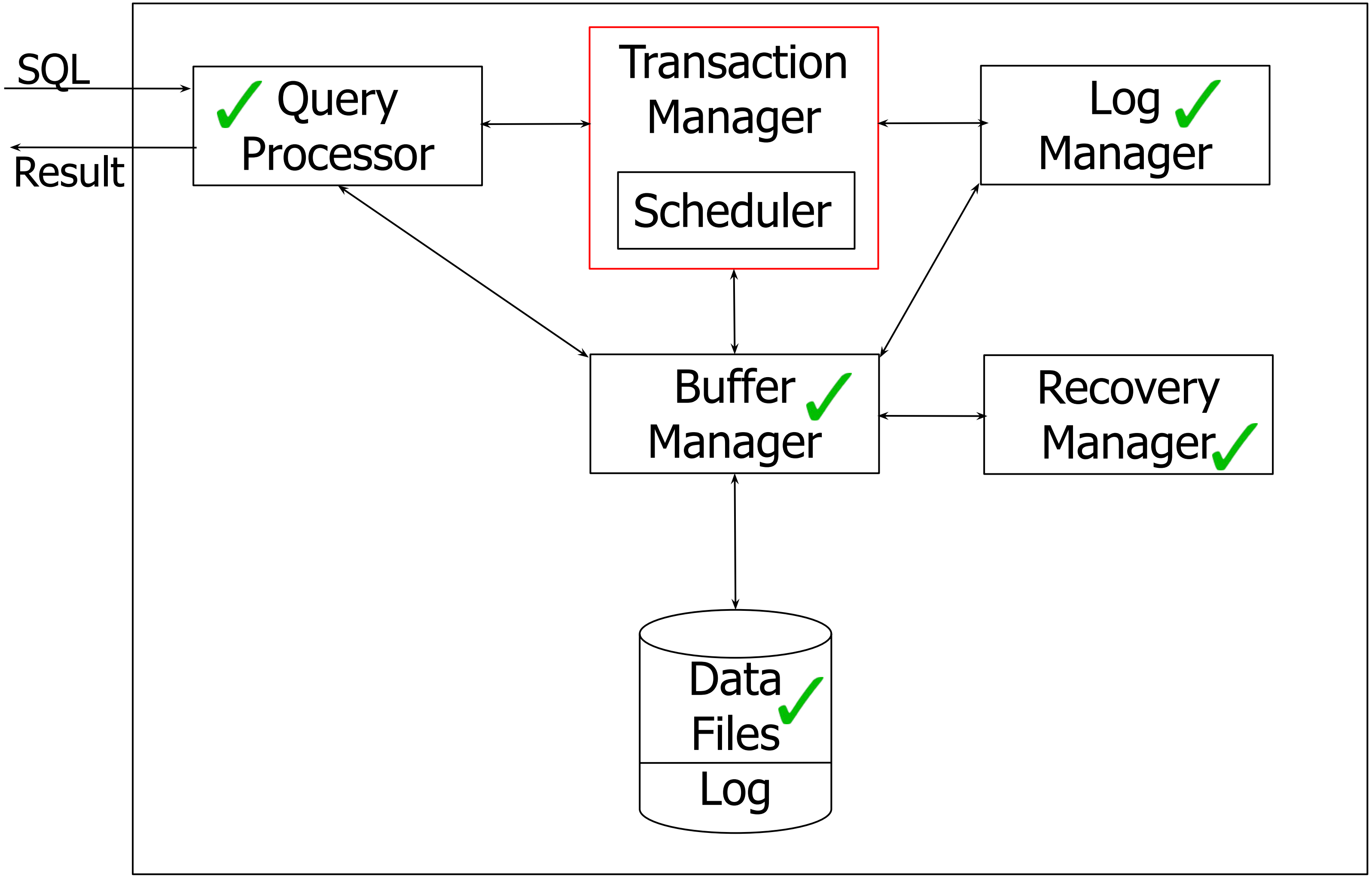
Lecture 9
Transactions

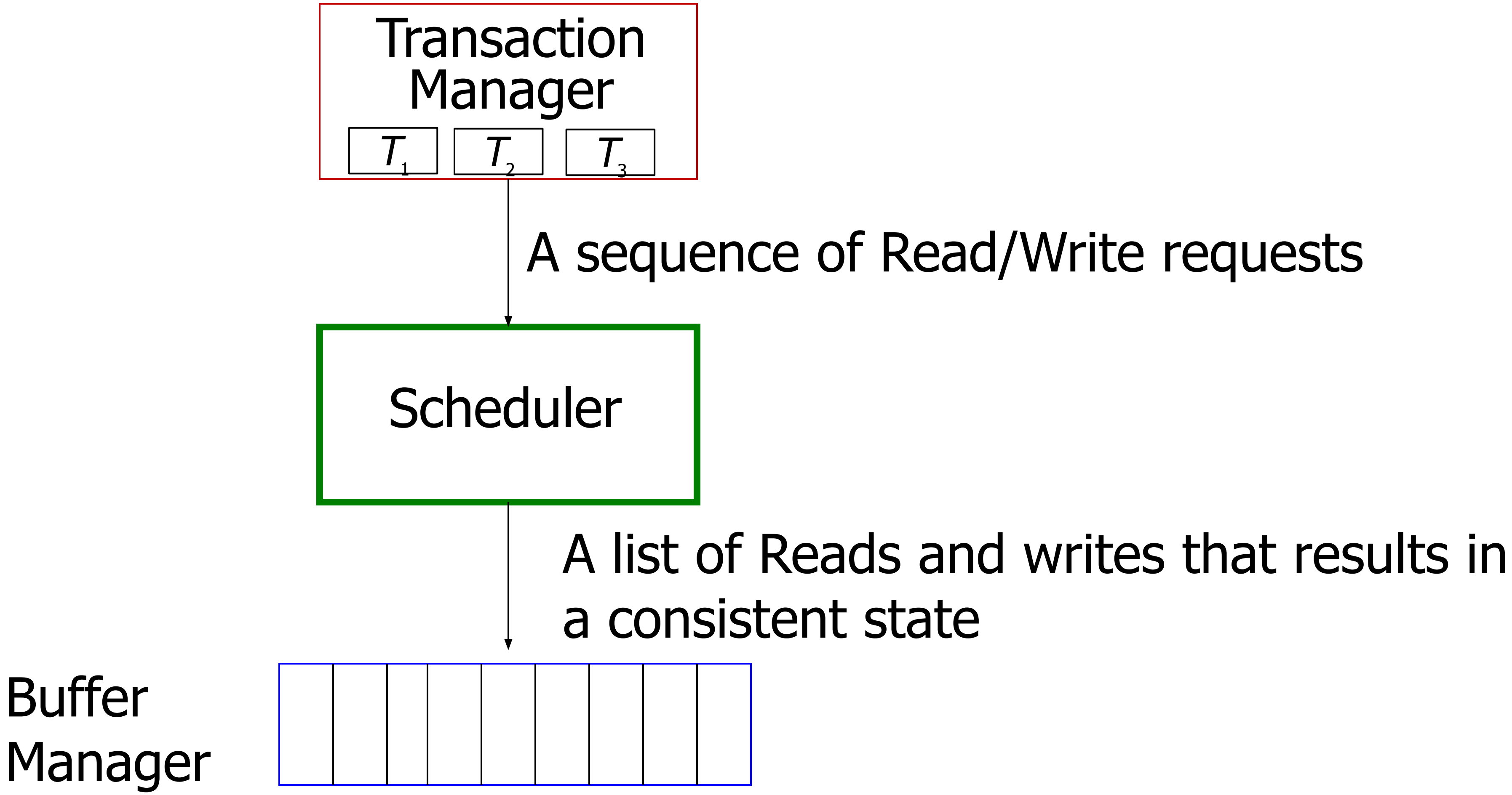
Dr. Caroline Sabty
caroline.sabty@giu-uni.de
Faculty of Informatics and Computer Science
German International University in Cairo

These slides are the slides of the course of CSEN 604 Data Bases II taught by Dr. Wael Abouelsaadat that are based on the book of Database Systems; the Complete Book

DBMS Architecture



Component for Concurrency Control



Transactions

- Historical note:
  - Turing Award for Transaction concept
  - Jim Gray (1998)

- Interesting reading (optional):

Transaction Concept: Virtues and Limitations by Jim Gray
http://www.hpl.hp.com/techreports/tandem/TR-81.3.pdf

Issues with Transactions: Example

Bank database: 3 Accounts

Account Balances

A = 500

B = 500

C = 500

Property: A + B + C = 1500

Money should not leave/enter

Issues with Transactions: Example

Transaction T1: Transfer 100 from A to B

A = 500, B = 500, C = 500 →

Read (A, t)

t = t - 100

Write (A, t)

Read (B, t)

t = t + 100

Write (B, t)

A = 400, B = 600, C = 500 →

Issues with Transactions: Example

Transaction T2: Transfer 100 from A to C

A = 500, B = 500, C = 500 →

Read (A, s)

s = s - 100

Write (A, s)

Read (C, s)

s = s + 100

Write (C, s)

A = 400, B = 500, C = 600 →

Transaction T1	Transaction T2	A	B	C
		500	500	500
Read (A, t)				
t = t - 100				
Write (A, t)		400	500	500
Read (B, t)				
t = t + 100				
Write (B, t)		400	600	500
	Read (A, s)			
	s = s - 100			
	Write (A, s)	300	600	500
	Read (C, s)			
	s = s + 100			
	Write (C, s)	300	600	600

300 + 600 + 600 = 1500

Transaction T1	Transaction T2	A	B	C
		500	500	500
Read (A, t)				
t = t - 100				
Write (A, t)		400	500	500
	Read (A, s)			
	s = s - 100			
	Write (A, s)	300	500	500
Read (B, t)				
t = t + 100				
Write (B, t)		300	600	500
	Read (C, s)			
	s = s + 100			
	Write (C, s)	300	600	600

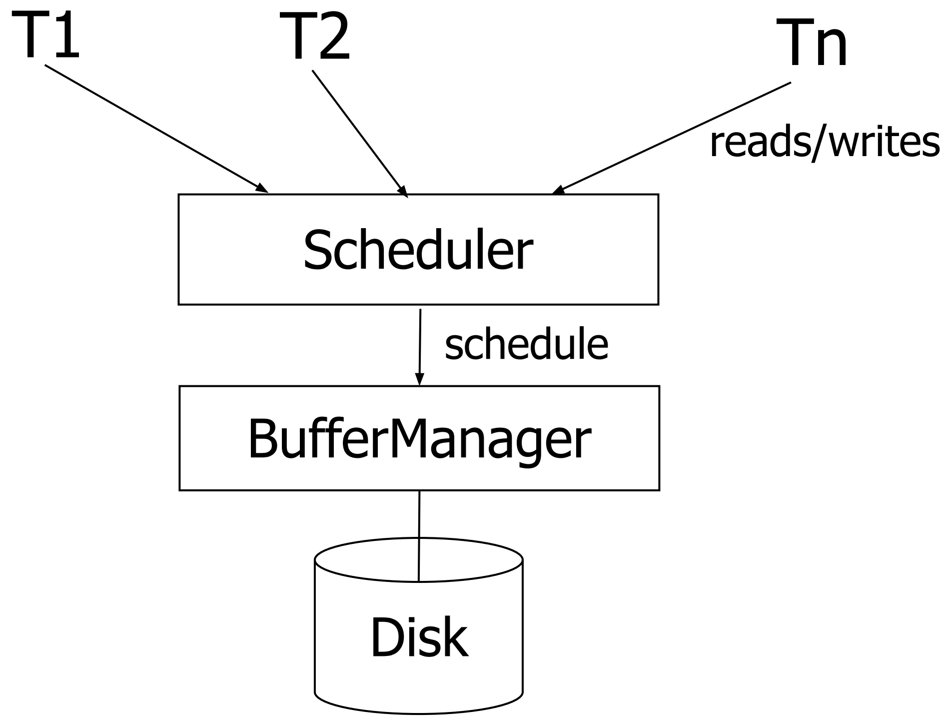
300 + 600 + 600 = 1500

Transaction T1	Transaction T2	A	B	C
		500	500	500
Read (A, t)				
t = t - 100				
	Read (A, s)			
	s = s - 100			
	Write (A, s)	400	500	500
Write (A, t)		400	500	500
Read (B, t)				
t = t + 100				
Write (B, t)		400	600	500
	Read (C, s)			
	s = s + 100			
	Write (C, s)	400	600	600

400 + 600 + 600 = 1600

Terminology

- Schedule:
  - The exact sequence of (relevant) actions of one or more transactions
  - The database engine scheduler task is to produce interleaving of transactions steps that result in a consistent database state



Problems

- Which schedules are “correct”?
  - Mathematical characterization
- How to build a system that allows only “correct” schedules?
  - Efficient procedure to enforce correctness

Serial Schedule

			A	B	C
	Read (A, t)		500	500	500
	t = t - 100				
T1	Write (A, t)				
	Read (B, t)				
	t = t + 100				
	Write (B, t)		400	600	500
		Read (A, s)			
		s = s - 100			
		Write (A, s)			
T2		Read (C, s)			
		s = s + 100			
		Write (C, s)	300	600	600

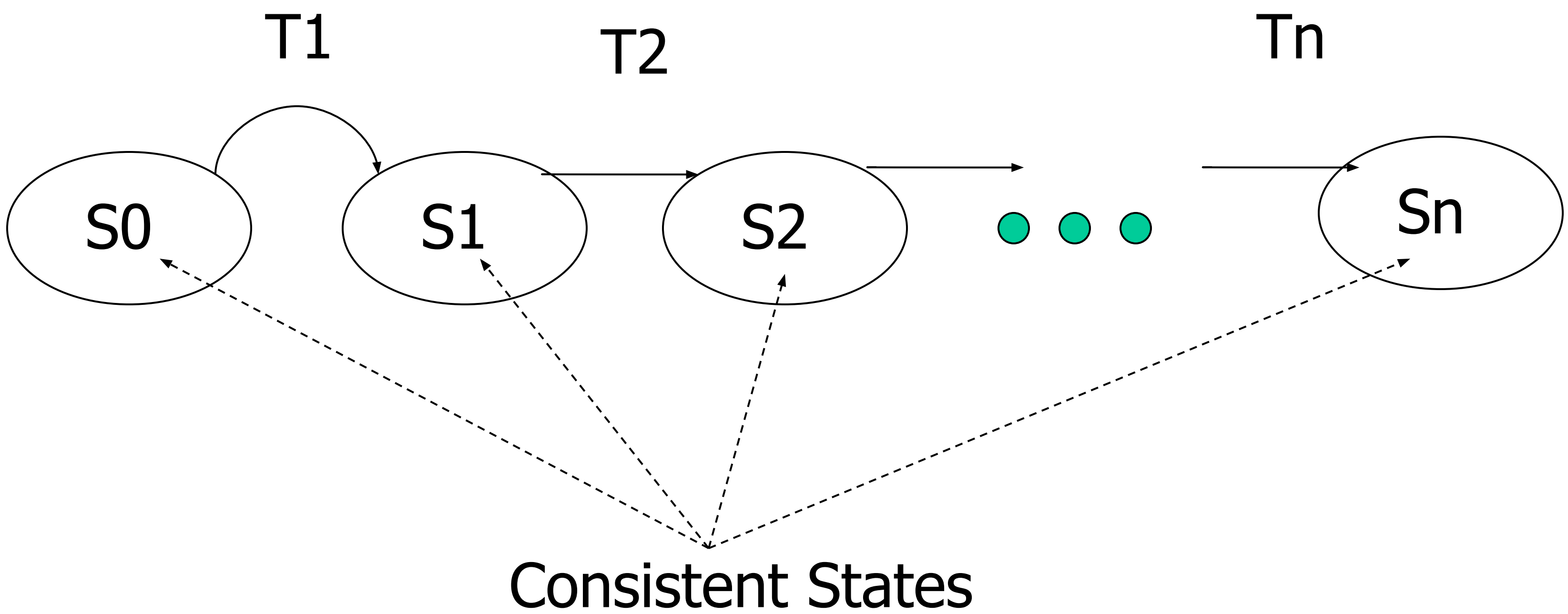
300 + 600 + 600 = 1500

Serial Schedule

			A	B	C
T2		Read (A, s)	500	500	500
		s = s - 100			
		Write (A, s)			
		Read (C, s)			
		s = s + 100			
		Write (C, s)	400	500	600
T1	Read (A, t)				
	t = t - 100				
	Write (A, t)				
	Read (B, t)				
	t = t + 100				
	Write (B, t)		300	600	600

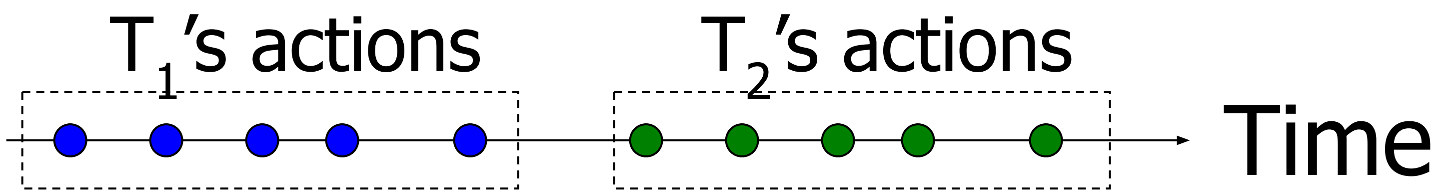
300 + 600 + 600 = 1500

Serial Schedule (Gold Standard)



Serial Schedule

- If any action of transaction T_1 precedes any action of T_2, then all action of T_1 precede all action of T_2
- The correctness principle tells us that every serial schedule will preserve consistency of the database state



- What's the problem with a Serial Schedule?

- A serial schedule is the gold standard as it guarantees that the database is in a consistent state. However, it is too slow to use since it means running one transaction at a time and thus no support for concurrency

Serializability

- A schedule is called *serializable* if its final effect is the same as that of a *serial schedule*

- Serializability: schedule is fine and does not result in inconsistent database
  - Since serial schedules are fine

- Non-serializable schedules are unlikely to result in consistent databases

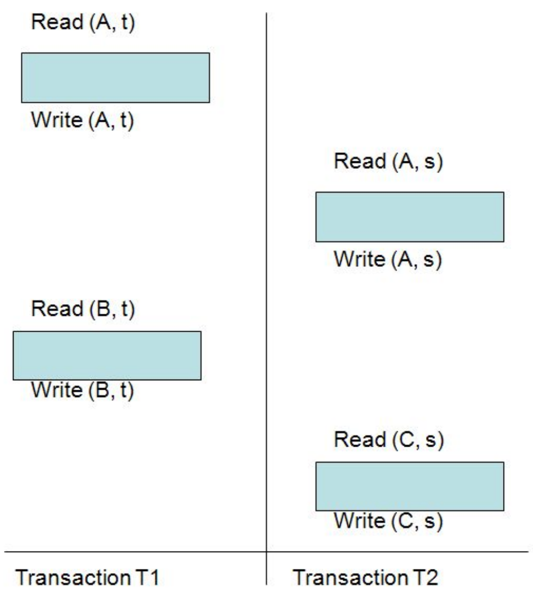
- Scheduler ensures serializability

Serializability

- Not possible to look at all *n!* serial schedules to check if the effect is the same
  - Instead we ensure serializability by allowing or not allowing certain schedules

Conflict Serializability

- Weaker notion of serializability
- Depends only on reads and writes
- Which steps can be interleaved and which cannot



Conflict Serializability

- Recall from OS course:
  - Multitasking
  - context switch

T1	T2
read(A)	
A = A -50	
write(A)	
read(B)	
B=B+50	
write(B)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
	read(B)
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
read(B)	
B=B+50	
write(B)	
	read(B)
	B = B+ tmp
	write(B)

T1	T2
read(A)	
A = A -50	
write(A)	
read(B)	
B=B+50	
write(B)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
	read(B)
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

==

Effect:	Before	After
A	100	45
B	50	105

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
read(B)	
B=B+50	
write(B)	
	read(B)
	B = B+ tmp
	write(B)

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
read(B)	
	write(A)
B=B+50	
write(B)	
	read(B)
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

==

Effect:	Before	After
A	100	45
B	50	105

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
read(B)	
B=B+50	
write(B)	
	read(B)
	B = B+ tmp
	write(B)

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
read(B)	
B=B+50	
	read(B)
write(B)	
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

! ==

Effect:	Before	After
A	100	45
B	50	55

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
	write(A)
read(B)	
B=B+50	
write(B)	
	read(B)
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

==

T1	T2
read(A)	
A = A -50	
write(A)	
	read(A)
	tmp = A*0.1
	A = A – tmp
read(B)	
B=B+50	
	write(A)
write(B)	
	read(B)
	B = B+ tmp
	write(B)

Effect:	Before	After
A	100	45
B	50	105

- A conflict serializable schedule produce the same result as one of the serial schedules. It is constructed by considering non-conflicting steps.

Simpler Notation

$r_T(X)$ Transaction T reads X

$w_T(X)$ Transaction T writes X

What is X in r (X)?

- X could be any component of a database:
  - Attribute of a tuple
  - Tuple
  - Block in which a tuple resides
  - A relation
  - …

Non-Conflicting Steps

- Two Reads

  - E.g., $r_i(X); r_i(Y)$

- Read and write of different database element

  - E.g., $r_i(X); w_j(Y)$

- Two writes of different database elements

  - E.g., $w_i(X); w_j(Y)$

Conflicting Steps

- Two actions of the same transaction

  - E.g., $r_i(X); w_i(Y)$

- Two writes of the same database element

  - E.g., $w_i(X); w_j(X)$

- A read and a write of the same database element

  - E.g., $r_i(X); w_j(X)$

Conflict Equivalent

- Conflict-equivalent schedules:
  - If S can be transformed into S’ through a series of swaps, S and S’ are called *conflict-equivalent*
  - *conflict-equivalent guarantees same final effect on the database*

- A schedule S is **conflict-serializable** if it is conflict-equivalent to a serial schedule

Conflict-Serializability

- Commercial systems generally support *conflict-serializability*
- Turn a given schedule to a serial one by make as many nonconflicting swaps as we wish

Testing for conflict-serializability

- Given a schedule, determine if it is conflict-serializable

- Construct a *precedence-graph* over the transactions
  - A directed edge from T1 and T2, if they have conflicting instructions, and T1's conflicting instruction comes first

- If there is a cycle in the graph → not conflict-serializable
  - Can be checked in at most *O(n+e)* time, where *n* is the number of vertices, and *e* is the number of edges

- If there is none → conflict-serializable

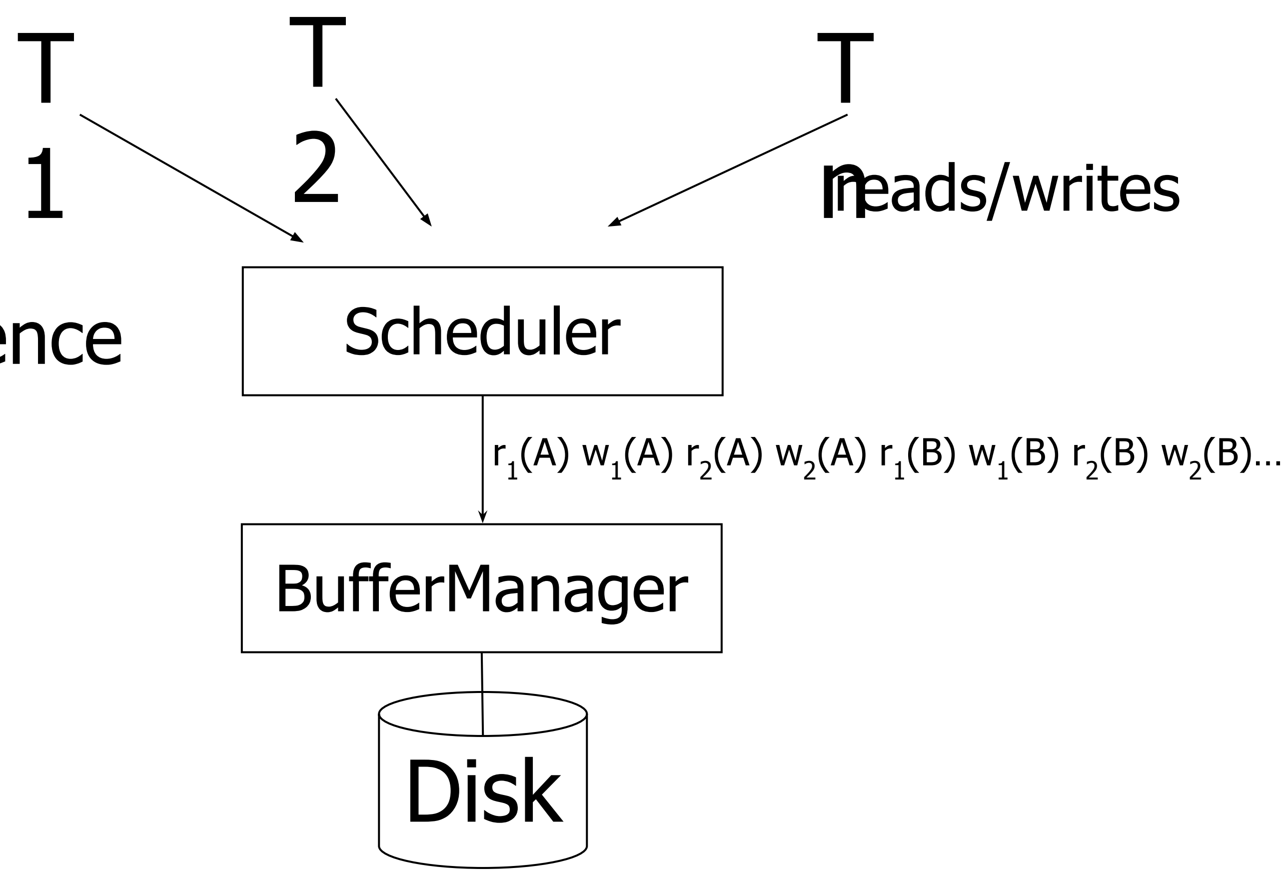
Precedence Graph

- Precedence graph for schedule S:
  - Nodes: Transactions in S
  - Edges: $T_i \rightarrow T_j$ whenever
    - S: … r_i (X) … w_j(X) …
    - S: … w_i (X) … w_j (X) …
    - S: … r_i(X) … w_j (X) …

Note: not necessarily consecutive

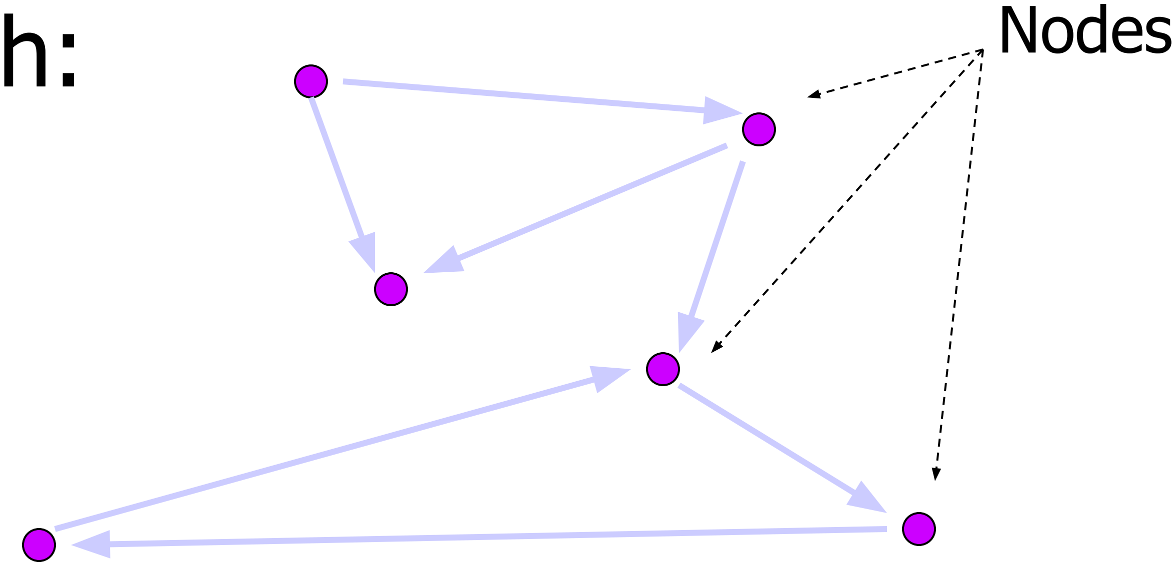
Enforcing Serializability

Strategy:
Prevent precedence graph cycles



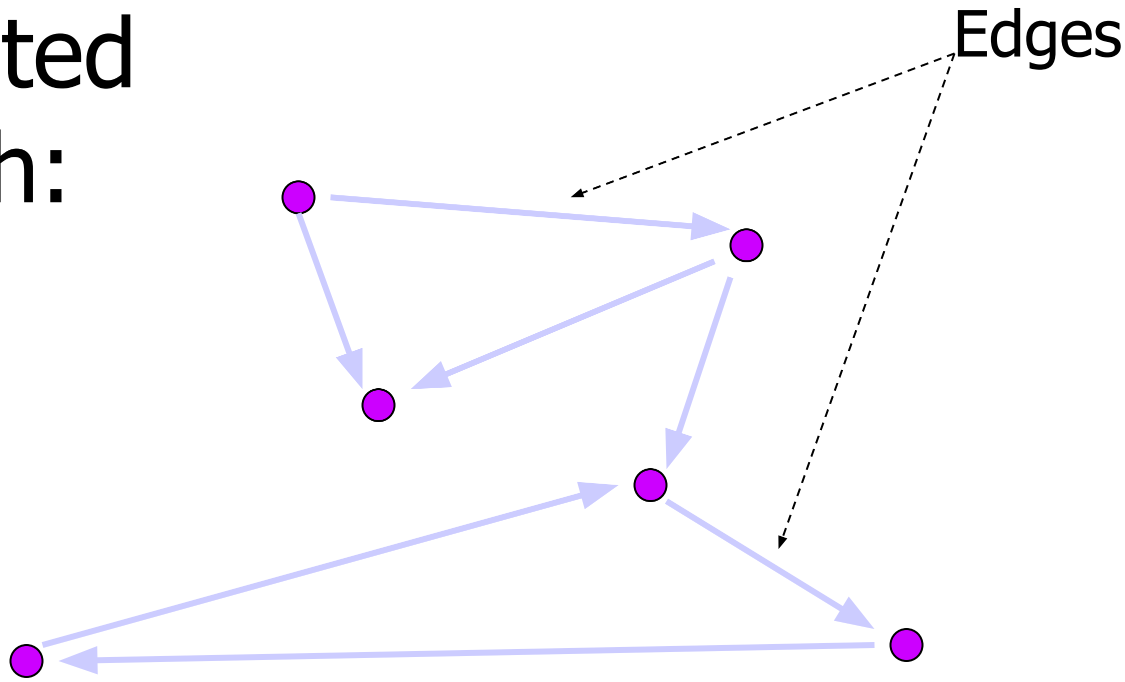
Graph Theory 101

Directed Graph:



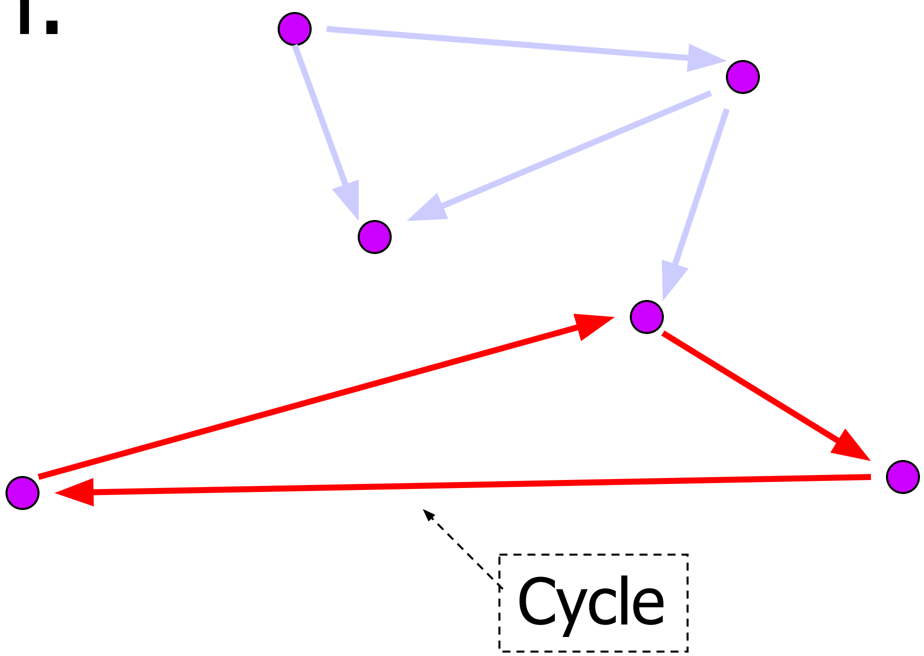
Graph Theory 101

Directed Graph:



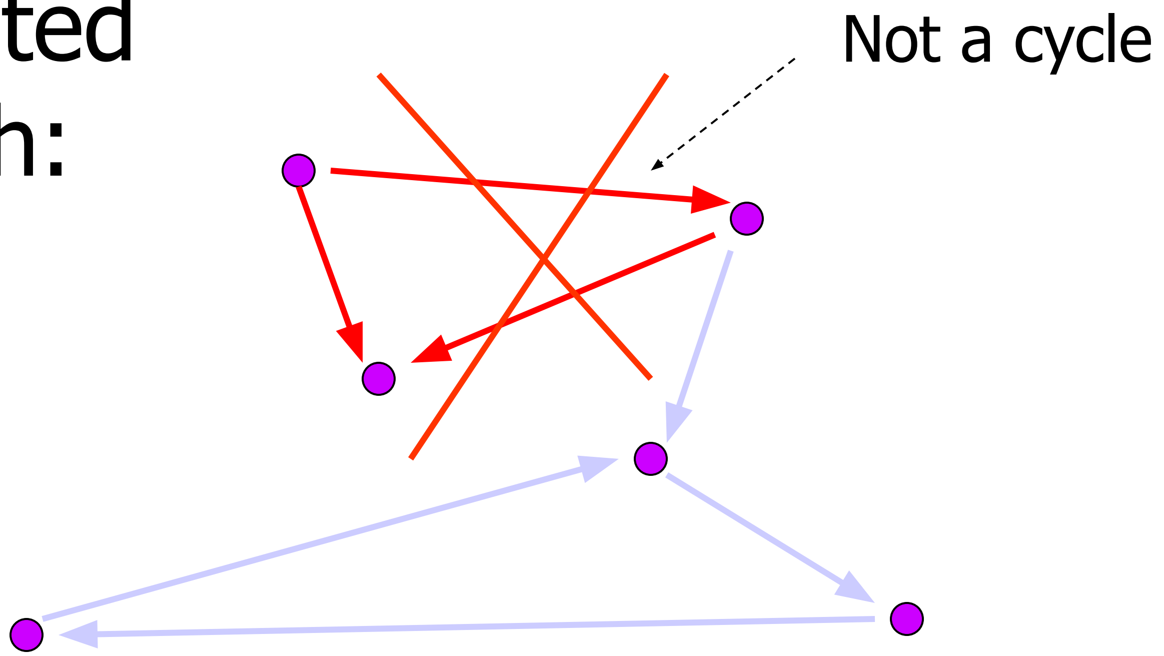
Graph Theory 101

Directed Graph:



Graph Theory 101

Directed Graph:

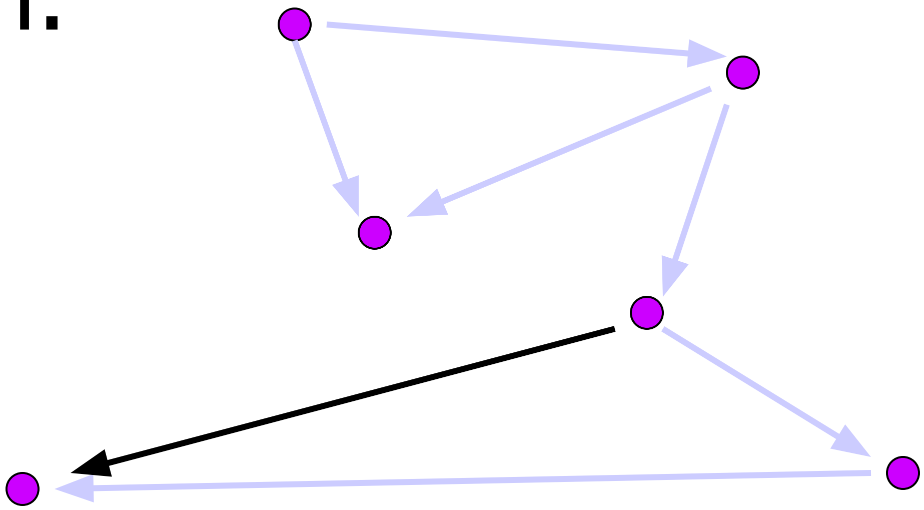


Graph Theory 101

Acyclic Graph: A graph with no cycles

Graph Theory 101

Acyclic Graph:



Precedence Graph - Example

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

Conflicting Steps

$r_i(X)$; $w_j(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph - Example

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_1: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;

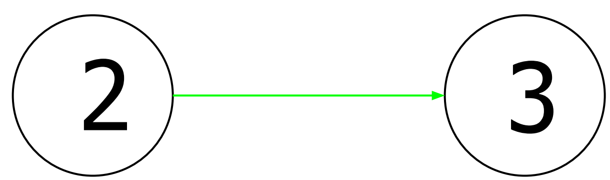
Conflicting Steps

$r_i(X)$; $w_i(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph - Example

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_1: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;



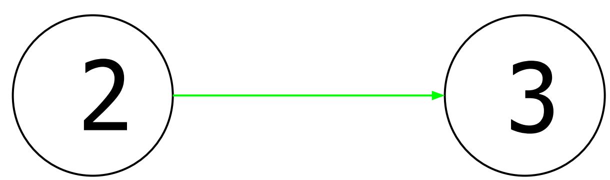
Conflicting Steps

$r_i(X)$; $w_i(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph - Example

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_1: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;



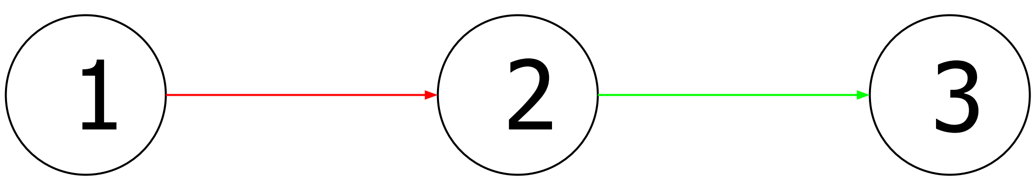
Conflicting Steps

$r_i(X)$; $w_i(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph - Example

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_1: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $r_2(B)$; $w_2(B)$;



Conflicting Steps

$r_i(X)$; $w_j(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph – Example 2

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_2: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_2(B)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $w_2(B)$;

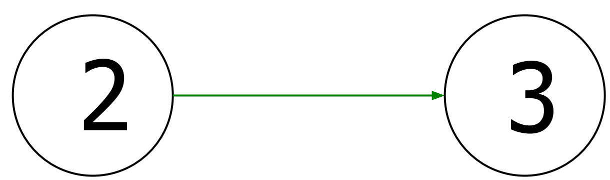
Conflicting Steps

$r_i(X)$; $w_j(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph – Example 2

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_2: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_2(B)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $w_2(B)$;



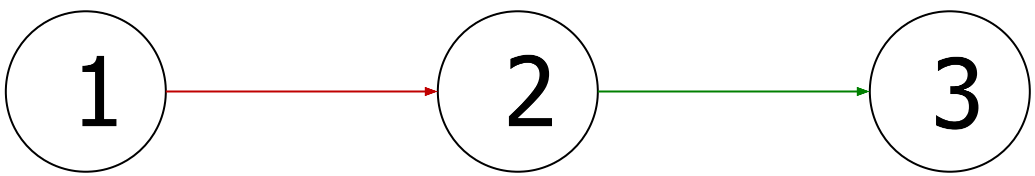
Conflicting Steps

$r_i(X)$; $w_i(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph – Example 2

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_2: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_2(B)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $w_2(B)$;



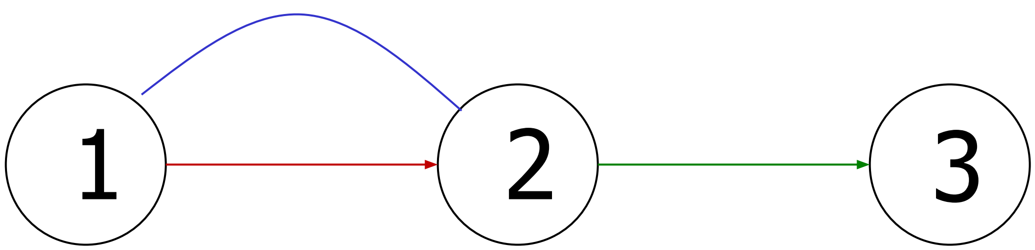
Conflicting Steps

$r_i(X)$; $w_j(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph – Example 2

- $T_i \rightarrow T_j$ whenever:
  - There is an action of T_i that occurs before a conflicting action of T_j.

S_2: $r_2(A)$; $r_1(B)$; $w_2(A)$; $r_2(B)$; $r_3(A)$; $w_1(B)$; $w_3(A)$; $w_2(B)$;

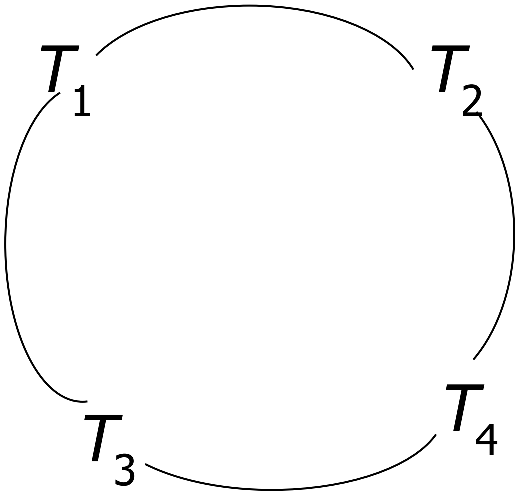


Conflicting Steps

$r_i(X)$; $w_j(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

Precedence Graph – Example 3

T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
			read(V)	
			read(W)	
			read(W)	
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
		read(Y)		
		write(Y)		
		read(Z)		
		write(Z)		
read(U)				
write(U)				



Conflicting Steps

$r_i(X)$; $w_i(Y)$
$w_i(X)$; $w_j(X)$
$r_i(X)$; $w_j(X)$

$r_2(X);r_1(Y);r_1(Z);r_5(V);r_5(W);r_5(W);r_2(Y);w_2(Y);w_3(Z);r_1(U);r_4(Y);w_4(Y);r_4(Z);w_4(Z);r_1(U);w_1(U)$

Conflict-Serializable

- Two schedules are *conflict-equivalent* if they can be turned one into the other by a sequence of nonconflicting swaps of adjacent actions

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

Thank you !