MORE CONCURRENCY

Introduction to Database Systems

Mahdi Akhi
Sharif University of Technology

IN THIS LECTURE

- Deadlock detection
- Deadlock prevention
- Time-stamping
- For more information
    - Connolly and Begg chapter 20

DEADLOCKS

- A deadlock is an impasse that may result when two or more transactions are waiting for locks to be released which are held by each other.
  - For example: T1 has a lock on X and is waiting for a lock on Y, and T2 has a lock on Y and is waiting for a lock on X.
- Given a schedule, we can detect deadlocks which will happen in this schedule using a **wait-for graph (WFG)**.

PRECEDENCE/WAIT-FOR GRAPHS

- **Precedence graph**
  - Each transaction is a vertex
  - Arcs from T1 to T2 if
    - T1 reads X before T2 writes X
    - T1 writes X before T2 reads X
    - T1 writes X before T2 writes X
- **Wait-for Graph**
  - Each transaction is a vertex
  - Arcs from T2 to T1 if
    - T1 read-locks X then T2 tries to write-lock it
    - T1 write-locks X then T2 tries to read-lock it
    - T1 write-locks X then T2 tries to write-lock it

EXAMPLE

T1 Read(X)

T2 Read(Y)

T1 Write(X)

T2 Read(X)

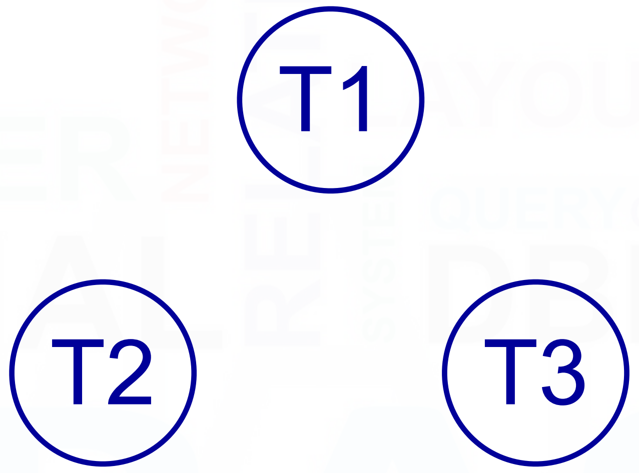
T3 Read(Z)

T3 Write(Z)

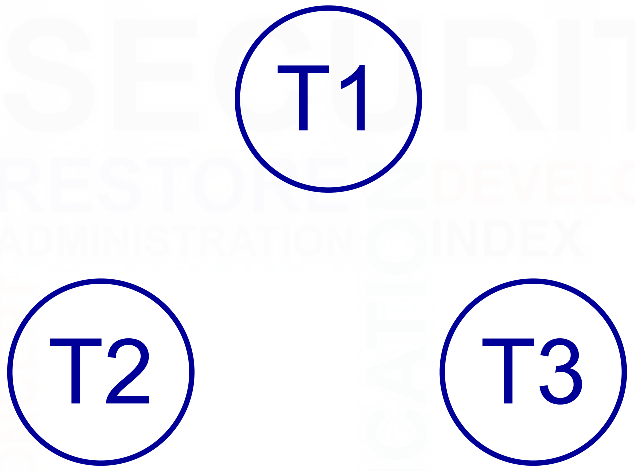
T1 Read(Y)

T3 Read(X)

T1 Write(Y)



Wait for graph



Precedence graph

EXAMPLE

T1 Read(X)

T2 Read(Y)

T1 Write(X)

T2 Read(X)

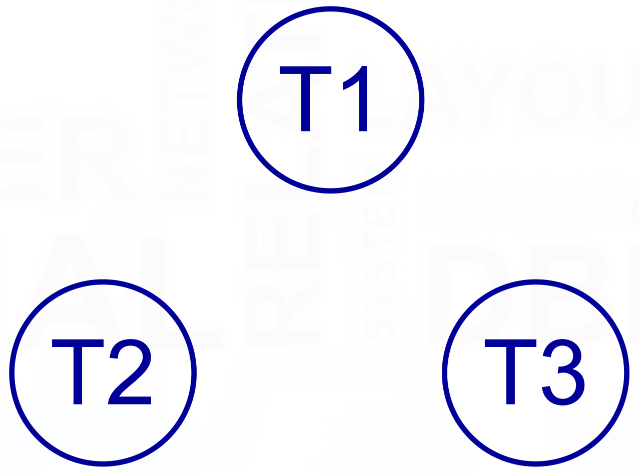
T3 Read(Z)

T3 Write(Z)

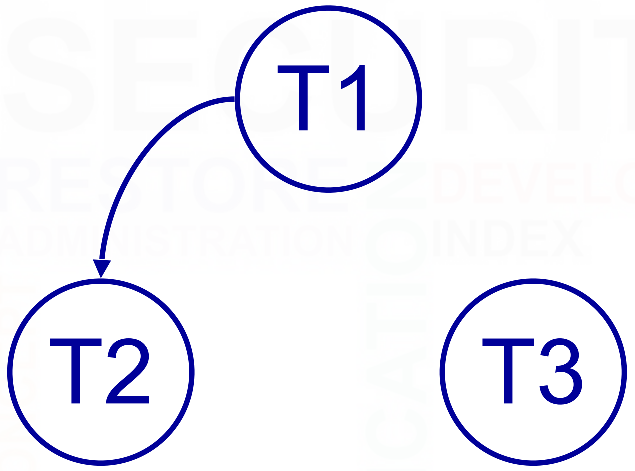
T1 Read(Y)

T3 Read(X)

T1 Write(Y)



Wait for graph



Precedence graph

EXAMPLE

T1 Read(X)

T2 Read(Y)

T1 Write(X)

T2 Read(X)

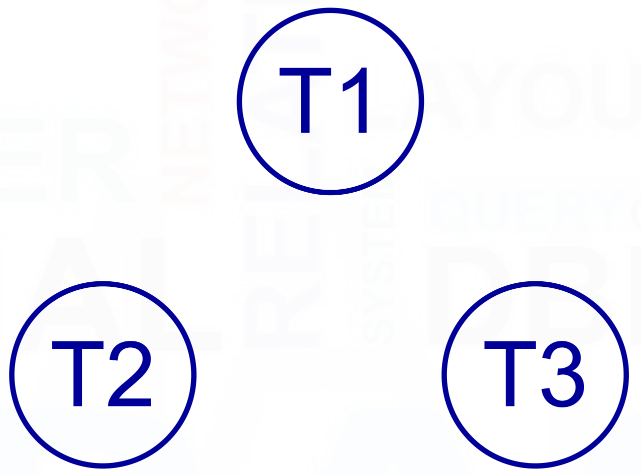
T3 Read(Z)

T3 Write(Z)

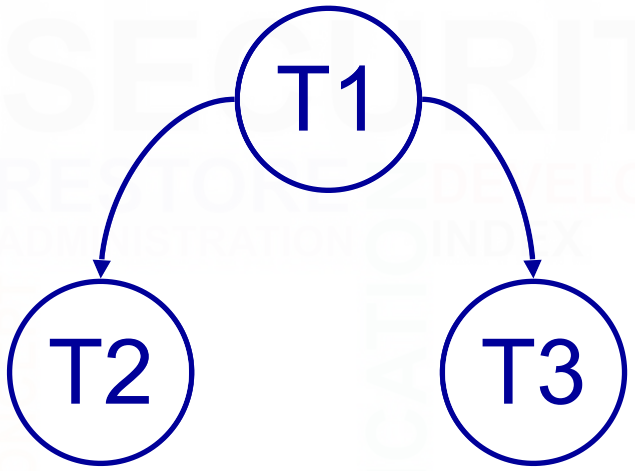
T1 Read(Y)

T3 Read(X)

T1 Write(Y)



Wait for graph



Precedence graph

EXAMPLE

T1 Read(X)

T2 Read(Y)

T1 Write(X)

T2 Read(X)

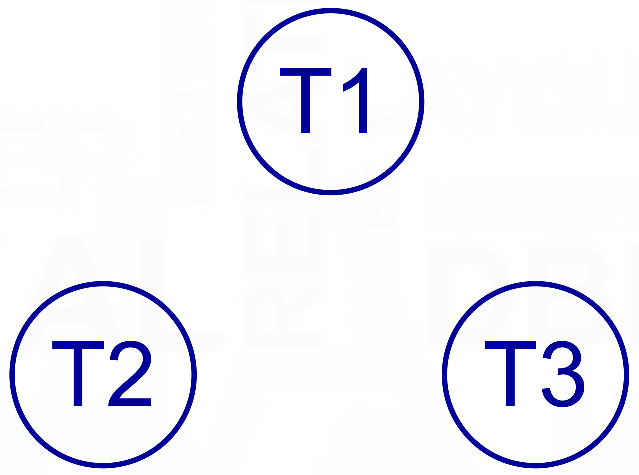
T3 Read(Z)

T3 Write(Z)

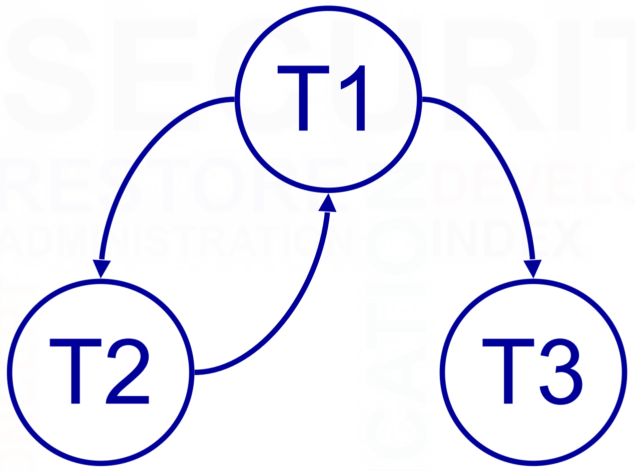
T1 Read(Y)

T3 Read(X)

T1 Write(Y)



Wait for graph



Precedence graph

EXAMPLE

T1 Read(X) read-locks(X)

T2 Read(Y) read-locks(Y)

T1 Write(X) **write-lock(X)**

T2 Read(X) **tries read-lock(X)**

T3 Read(Z)

T3 Write(Z)

T1 Read(Y)

T3 Read(X)

T1 Write(Y)

$$\begin{tikzcd}
 & T1 & \\
T2 \arrow[ur, bend left] & & T3
\end{tikzcd}$$

Wait for graph

$$\begin{tikzcd}
 & T1 \arrow[dl, bend right] \arrow[dr] & \\
T2 \arrow[ur, bend right] & & T3
\end{tikzcd}$$

Precedence graph

EXAMPLE

T1 Read(X) read-locks(X)

T2 Read(Y) read-locks(Y)

T1 Write(X) **write-lock(X)**

T2 Read(X) tries read-lock(X)

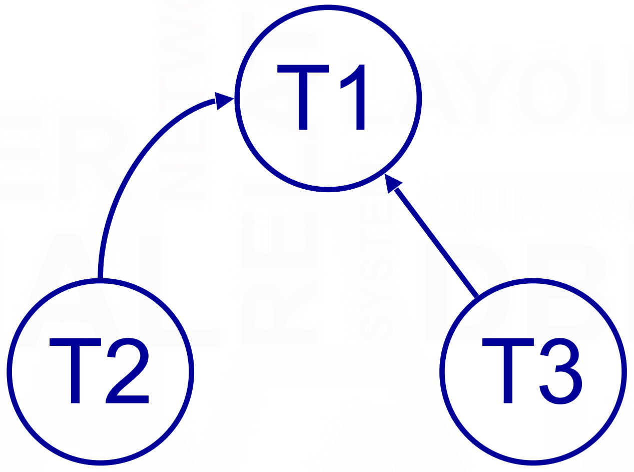
T3 Read(Z) read-lock(Z)

T3 Write(Z) write-lock(Z)

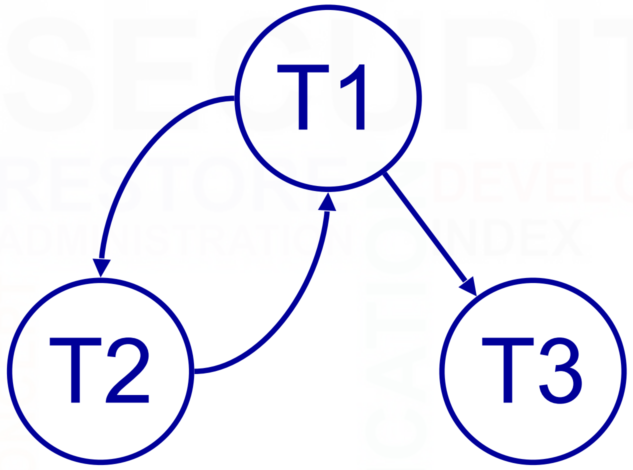
T1 Read(Y) read-lock(Y)

T3 Read(X) **tries read-lock(X)**

T1 Write(Y)



Wait for graph



Precedence graph

EXAMPLE

T1 Read(X) read-locks(X)

T2 Read(Y) **read-locks(Y)**

T1 Write(X) write-lock(X)

T2 Read(X) tries read-lock(X)

T3 Read(Z) read-lock(Z)

T3 Write(Z) write-lock(Z)

T1 Read(Y) read-lock(Y)

T3 Read(X) tries read-lock(X)

T1 Write(Y) **tries write-lock(Y)**

$$\begin{tikzcd}
 & T1 \arrow[dl, bend left] & \\
T2 \arrow[ur, bend left] & & T3 \arrow[ul]
\end{tikzcd}$$

Wait for graph

$$\begin{tikzcd}
 & T1 \arrow[dl, bend right] \arrow[dr] & \\
T2 \arrow[ur, bend right] & & T3
\end{tikzcd}$$

Precedence graph

DEADLOCK PREVENTION

- Deadlocks can arise with 2PL
  - Deadlock is less of a problem than an inconsistent DB
  - We can detect and recover from deadlock
  - It would be nice to avoid it altogether
- **Conservative 2PL**
  - All locks must be **acquired before** the transaction **starts**
  - Hard to predict what locks are needed
  - Low '**lock utilization**' - transactions can hold on to locks for a long time, but not use them much

DEADLOCK PREVENTION

- We impose an **ordering on the resources**
    - Transactions must acquire locks in this order
    - Transactions can be ordered on the last resource they locked
- This prevents deadlock
    - If T1 is waiting for a resource from T2 then that resource must come after all of T1's current locks
    - All the arcs in the wait-for graph point 'forwards' - no cycles

EXAMPLE OF RESOURCE ORDERING

- Suppose resource order is: **X < Y**
- This means, if you need locks on X and Y, you first acquire a lock on X and only after that a lock on Y
  - (even if you want to write to Y before doing anything to X)
- It is impossible to end up in a situation when T1 is waiting for a lock on X held by T2, and T2 is waiting for a lock on Y held by T1.

TIME-STAMPING

- Transactions can be run concurrently using a variety of techniques
- We looked at using locks to prevent interference
- An alternative is time-stamping
  - Requires less overhead in terms of tracking locks or detecting deadlock
  - Determines the order of transactions before they are executed

TIME-STAMPING

- Each transaction has a timestamp, TS, and if **T1** starts **before T2** then **TS(T1) < TS(T2)**
  - Can use the system clock or an incrementing counter to generate timestamps

- Each resource has two timestamps
  - **R(X)**, the **largest timestamp** of any transaction that has **read** X
  - **W(X)**, the **largest timestamp** of any transaction that has **written** X

TIME-STAMP PROTOCOL

- If T tries to **read X**
  - If **TS(T) < W(X)** T is **rolled-back** and restarted with a later timestamp
  - If **TS(T) ≥ W(X)** then the read succeeds and we set R(X) to be **max(R(X), TS(T))**

- T tries to **write X**
  - If **TS(T) < W(X)** or **TS(T) < R(X)** then T is **rolled-back** and restarted with a later timestamp
  - Otherwise the write succeeds and we set W(X) to TS(T)

TIME-STAMPING EXAMPLE

- Given T1 and T2 we will assume
  - The transactions make alternate operations
  - Time-stamps are allocated from a counter starting at 1
  - T1 goes first

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R			
W			

	T1	T2
TS		

TIME-STAMP EXAMPLE

T1	T2
→ Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	1		
W			

	T1	T2
TS	1	

TIME-STAMP EXAMPLE

T1	T2
→ Read(X)	→ Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	2		
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	→ Read(X)
→ Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	2	1	
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
→ Read(Y)	→ Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	2	2	
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

T1		T2
Read(X)		Read(X)
Read(Y)	→	Read(Y)
→ Y = Y + X		Z = Y - X
Write(Y)		Write(Z)

	X	Y	Z
R	2	2	
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
→ Y = Y + X	→ Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	2	2	
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	→ Z = Y - X
→ Write(Y)	Write(Z)

	X	Y	Z
R	2	2	
W			

	T1	T2
TS	1	2

TIME-STAMP EXAMPLE

→ T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	→ Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	2	2	
W			

	T1	T2
TS	3	2

TIME-STAMP EXAMPLE

→ T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	→ Write(Z)

	X	Y	Z
R	2	2	
W			2

	T1	T2
TS	3	2

TIME-STAMP EXAMPLE

T1	T2
→ Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	3	2	
W			2

	T1	T2
TS	3	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
→ Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	3	3	
W			2

	T1	T2
TS	3	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
→ Y = Y + X	Z = Y - X
Write(Y)	Write(Z)

	X	Y	Z
R	3	3	
W			2

	T1	T2
TS	3	2

TIME-STAMP EXAMPLE

T1	T2
Read(X)	Read(X)
Read(Y)	Read(Y)
Y = Y + X	Z = Y - X
→ Write(Y)	Write(Z)

	X	Y	Z
R	3	3	
W		3	2

	T1	T2
TS	3	2

TIME-STAMPING

- The protocol means that transactions with higher times take precedence
  - Equivalent to running transactions in order of their final time values
  - Transactions don’t wait - no deadlock
- Problems
  - Long transactions might keep getting restarted by new transactions = **starvation**
  - Rolls back old transactions, which may have done a lot of work

END

Happy Ending!