Example Algorithms: Precedence Graph, Waits for Graph and Timestamping

Topic 6, Lesson 7
ACID and the algorithms to support it

Deadlock

- 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).

Comparing the differences

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

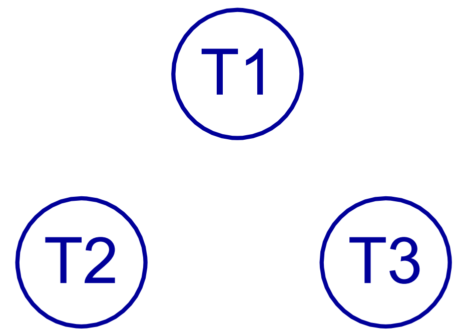
Wait-for Graph

- 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

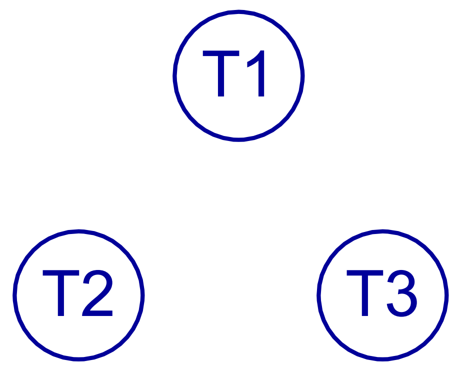
Example

- A node per transaction

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)



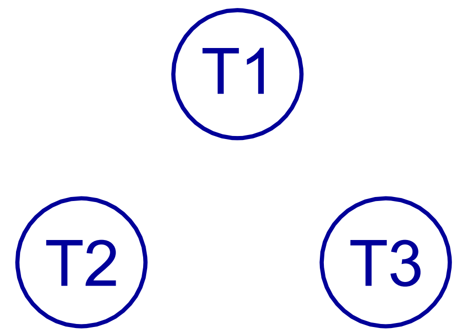
Wait-for graph



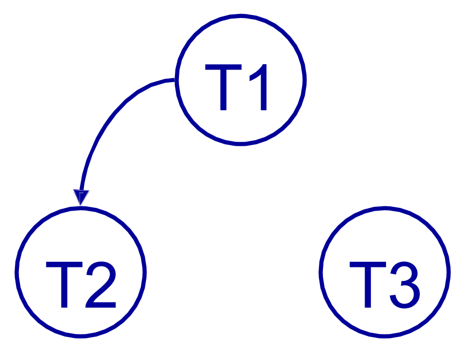
Precedence graph

Example – add an edge

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)



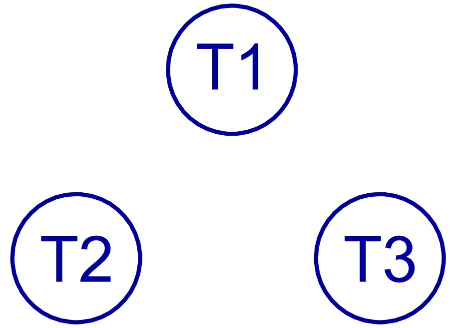
Wait-for graph



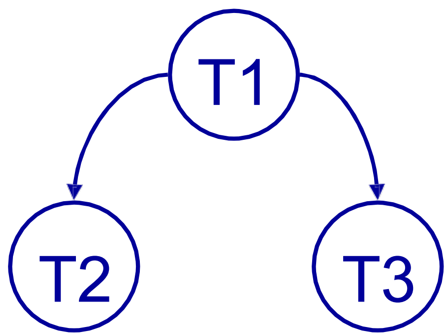
Precedence graph

Example – find another conflict

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)



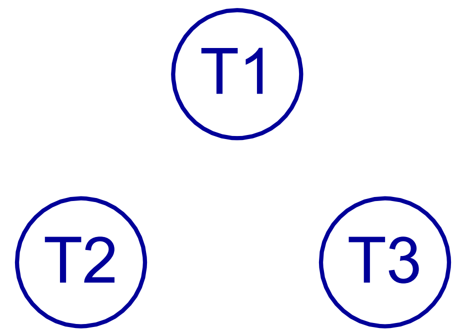
Wait-for graph



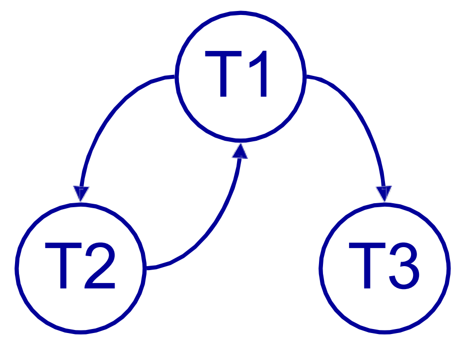
Precedence graph

Example – find another conflict

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)



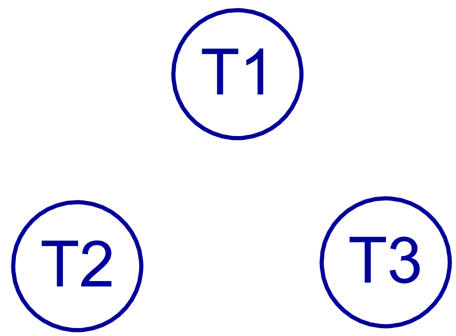
Wait-for graph



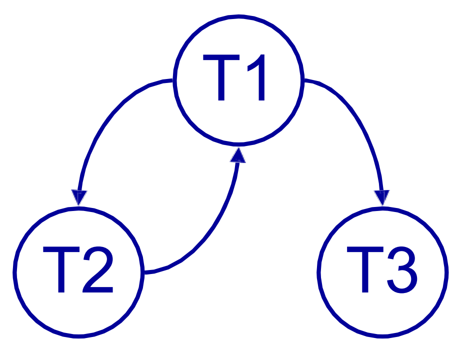
Precedence graph

Example – WFG

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 – WFG object already locked

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)**

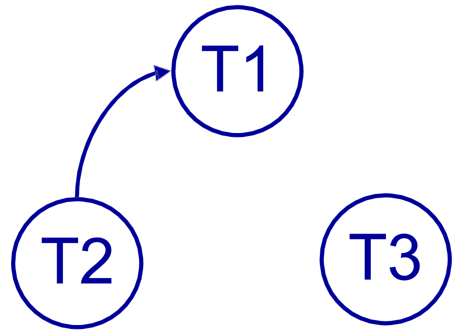
T3 Read(Z)

T3 Write(Z)

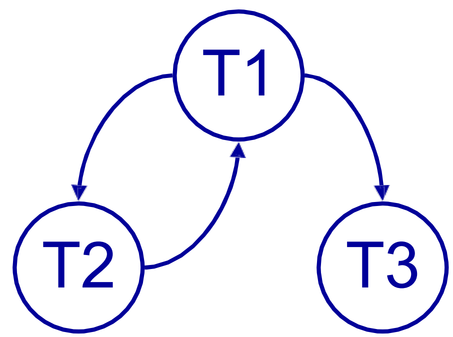
T1 Read(Y)

T3 Read(X)

T1 Write(Y)



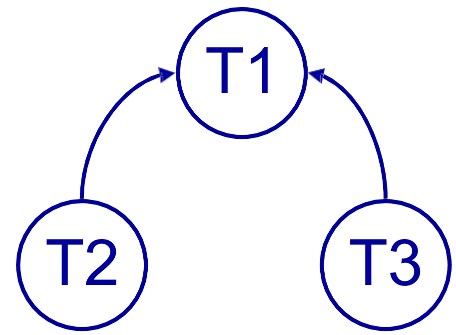
Wait-for graph



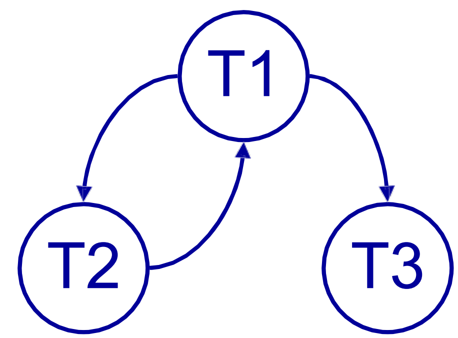
Precedence graph

Example – WFG object already locked

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)



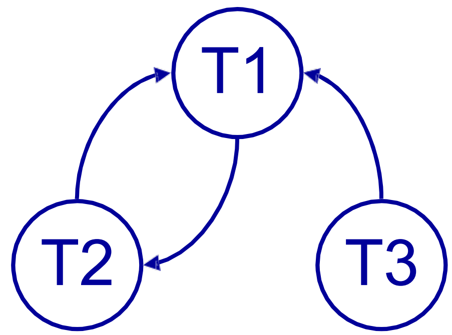
Wait-for graph



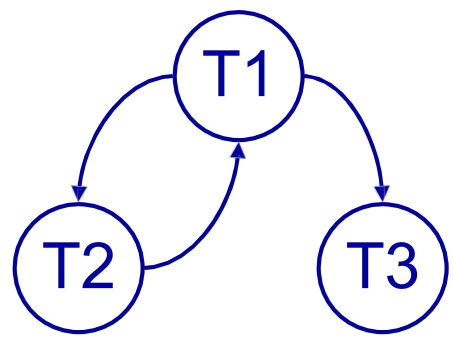
Precedence graph

Example – WFG object already locked

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)**



Wait-for graph



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 utilisation' - 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.

Timestamping

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

Timestamps needed

- 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

Timestamp 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)

Timestamping Example

- Given T1 and T2 we will assume
  - The transactions make alternate operations
  - Timestamps 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)

Timestamp 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		

Timestamp 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	

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp 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

Timestamp Issues

- 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