Concurrency Control

Ensuring Isolation

Concurrency control

Concurrency

To increase throughput and response time, a DBMS will execute multiple transactions at the same time.

Concurrency control ensures that transactions have the same effect as if they were executed in isolation

Concurrency control

Problem: WR conflict

T_1	T_2
`READ(A,s)`	
`s -= 100`	
`WRITE(A,s)`	
	`READ(A,t)`
	`t *= 1.06`
	`WRITE(A,t)`
	`READ(B,t)`
	`t *= 1.06`
	`WRITE(B,t)`
`READ(B,s)`	
`s += 100`	
`WRITE(B,s)`	

Concurrency control

Problem: WW conflict

T_1	T_2
`s = 100`	
`WRITE(A,s)`	
	`t = 200`
	`WRITE(A,t)`
	`t = 200`
	`WRITE(B,t)`
`s = 100`	
`WRITE(B,s)`	

Concurrency control

Definitions

- An action is an expression of the form $r(X)$ or $w(X)$
- A transaction is a sequence of actions.

  $r(A), r(B), w(A), w(B)$

  We abstract away from the actual values read or written.
- A schedule is a sequence of actions belonging to multiple transactions. Subscripts indicate to which transaction an action belongs.

  $r_1(A), w_1(A), r_2(A), w_2(A), r_1(B), w_1(B), r_2(B), w_2(B)$
- A serial schedule is a schedule in which transactions are not executed concurrently. In a serial schedule the actions hence occur grouped per transaction.

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

Concurrency control

Serializability

A schedule is called serializable if there exists an equivalent serial schedule.

Example

The following schedules are equivalent:

$$S_1 := r_1(A), w_1(A), r_2(A), w_2(A), r_1(B), w_1(B), r_2(B), w_2(B)$$
$$S_2 := r_1(A), w_1(A), r_1(B), w_1(B), r_2(A), w_2(A), r_2(B), w_2(B)$$

Hence S_1 is serializable.

Concurrency control

Conflict-serializability

- Two actions in a schedule are in conflict if:
  1. they belong to the same transaction; or
  2. act upon the same element, and one of them is a write.

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

- A schedule is conflict-serializable if we can obtain a serial schedule by (repeatedly) swapping non-conflicting actions.

Example

We can obtain S_2 by swapping only non-conflicting actions from S_1:

$$S_1 := r_1(A), w_1(A), r_2(A), w_2(A), r_1(B), w_1(B), r_2(B), w_2(B)$$
$$S_2 := r_1(A), w_1(A), r_1(B), w_1(B), r_2(A), w_2(A), r_2(B), w_2(B)$$

Consequently S_1 is conflict-serializable.

Concurrency control

Clearly, conflict-serializability implies serializability

The converse is not true

S_1 is equivalent to S_2, but S_2 cannot be obtained from S_1 by conflict-free swapping:

$$S_1 := w_1(Y), w_2(Y), w_2(X), w_1(X), w_3(X)$$
$$S_2 := w_1(Y); w_1(X); w_2(Y); w_2(X); w_3(X)$$

Hence S_1 is not conflict-serializable, but it is serializable.

In practice, a DBMS will only allow conflict-serializable schedules

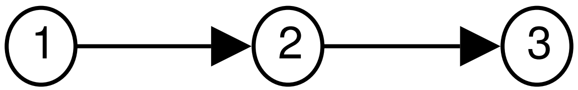
Concurrency control

A simple algorithm to check conflict-serializability

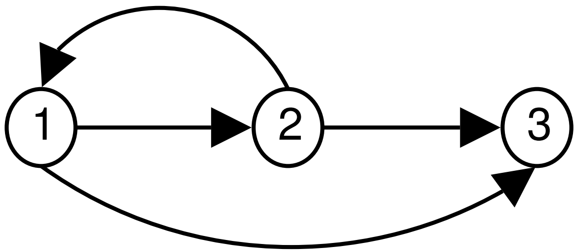
- Construct the precedence graph
- Check whether this graphs contains cycles. If so, output "no", otherwise output "yes"

Example

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



$$S_2 := w_1(Y), w_2(Y), w_2(X), w_1(X), w_3(X)$$



Concurrency control

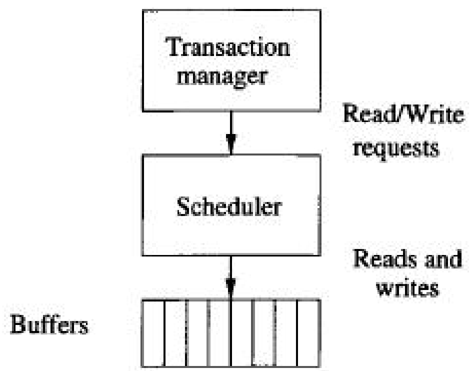
Why does this work?

- If there exists a cycle $T_1 \rightarrow T_2 \rightarrow \cdots \rightarrow T_n \rightarrow T_1$ in the dependency graph then we there are actions from T_1 that (1) follow actions from T_n and (2) cannot be moved before the start of T_n by means of conflict-free swapping. Conversely, there are also actions of T_n that follow actions of T_1 and that cannot be moved before T_{n-1} by means of conflict-free swapping. As a consequence, we can never obtain a serial schedule by means of conflict-free swapping (in a serial schedule all actions of T_1 must occur together).
- If there is no cycle in the dependency graph then we can obtain an equivalent serial schedule by topologically sorting the dependency graph. Illustration on the blackboard.
- See Section 18.2.3 in the book

Concurrency control

The scheduler in a DBMS

- It is the taks of the scheduler in a DBMS to create, given a number of transactions, a (conflict-)serializable schedule to be executed.
- New transactions arrive continuously, however, and the scheduler never fully knows the transactions (e.g., because the transactions are large and require a lot of time to run)
- The scheduler hence needs to construct its schedule dynamically, by allowing certain read and write requests; blocking others; and restarting transactions when necessary



Concurrency control

Multiple kinds of schedulers:

- Based on locking
- Based on timestamping
- Based on validation

Concurrency control

Lock-based schedulers

- Add actions of the form $l(X)$ and $u(X)$ to schedules.
- Before an item can be read or written, a transaction must have a lock.
- If transaction i requests a lock that is already taken by another transaction j, the scheduler will pause the execution of i until j releases the lock. It is in particular impossible for two transaction to possess a lock on the same item at the same time.

Concurrency control

Example:

T_1	T_2
$l_1(A), r_1(A)$	
$w_1(A), l_1(B)$	
$u_1(A)$	
	$l_2(A), r_2(A)$
	$w_2(A)$
	$l_2(B)$ denied
$r_1(B), w_1(B)$	
$u_1(B)$	
	$l_2(B), u_2(A)$
	$r_2(B), w_2(B)$
	$u_2(B)$

Concurrency control

Example:

$$l_1(A), r_1(A), w_1(A), u_1(A), l_2(A), r_2(A), w_2(A), u_2(A),$$
$$l_2(B), r_2(B), w_2(B), u_2(B), l_1(B), r_1(B), w_1(B), u_1(B)$$

Question: is this conflict-serializable?

Concurrency control

Two-phase locking

In order to always obtain a conflict-serializable schedule using locks, we require that in each transaction all lock requests precede all unlock requests.

Why is this sufficient to guarantee conflict-serializability?

Illustration on the blackboard. See Section 18.3.3 in book.

Concurrency control

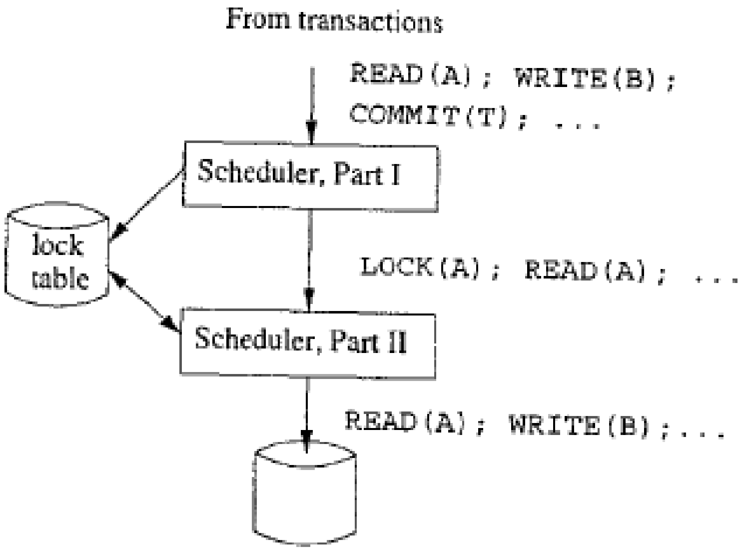
Observe:

- It is harmless for multiple transactions to read the same item at the same time.

  → shared and exclusive locks. See Section 18.4 in book.

- In practice transactions will only make read and write requests. They do not make lock and unlock requests. It is the task of the scheduler to add the latter to the schedule

  → see Section 18.5 in book



Concurrency control

Schedulers based on timestamping

- Are optimistic schedulers
- Assume that we execute transactions T_1, T_2, and T_3 where T_1 was started first, T_2 second, and T_3 third. A timestamping scheduler allows arbitrary reorderings of actions from these transactions, but checks at appropriate times if the reordering used are equivalent to the serial schedule T_1, T_2, T_3. If not, certain transactions are aborted and restarted.

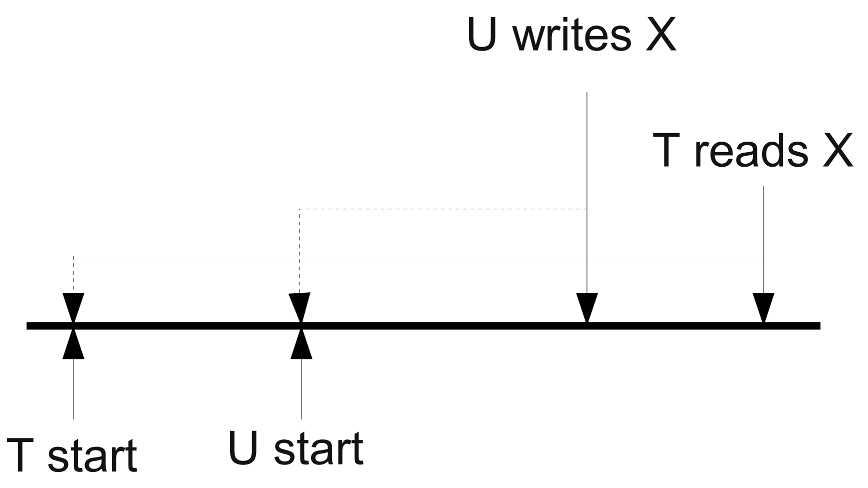
Concurrency control

How does it work?

- Every transaction T receives a timestamp $\mathrm{TS}(T)$ upon creation. This can just be a counter that is incremented for each new transaction.
- To each item X we associate two timestamps $\mathrm{RT}(X)$ and $\mathrm{WT}(X)$, and a boolean $\mathrm{C}(X)$.
  - $\mathrm{RT}(X)$ is the highest timestamp of a transaction that has read X
  - $\mathrm{WT}(X)$ is the highest timestamp of a transaction that has written X
  - $\mathrm{C}(X)$ is true if, and only if, the most recent transaction to write X has already committed.

Concurrency control

Unrealizable behavior that we want to avoid (1/4)

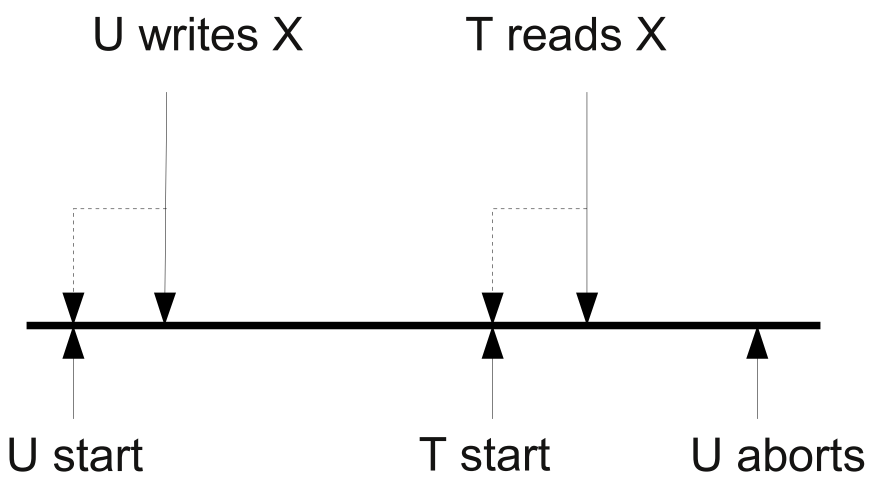


Hence

A read request $r_T(X)$ should only be granted if $\mathrm{TS}(T) \geq \mathrm{WT}(X)$.

Concurrency control

Unrealizable behavior that we want to avoid (2/4)



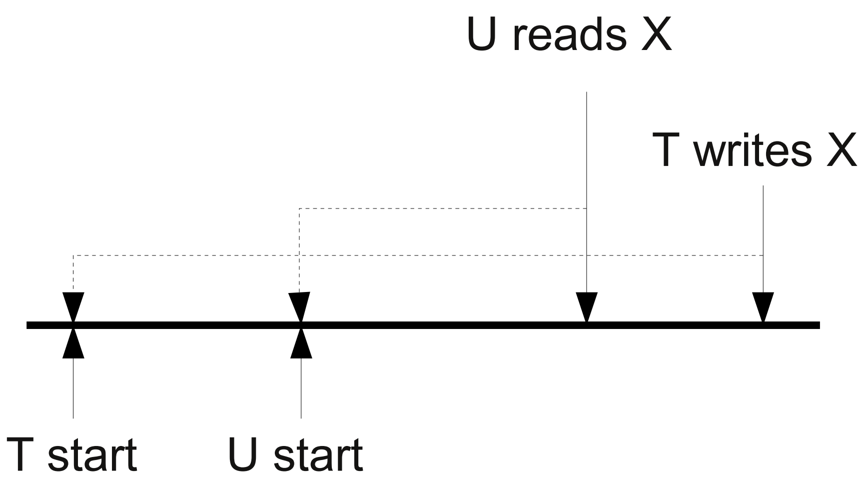
Hence

Read to X should be delayed until the transaction with timestamp $\mathrm{WT}(X)$ commits (i.e., $\mathrm{C}(X)$ becomes true).

Concurrency control

Unrealizable behavior that we want to avoid (3/4)

Suppose $\mathrm{TS}(U) \geq \mathrm{WT}(X)$ at the time when U requests $r_U(X)$.

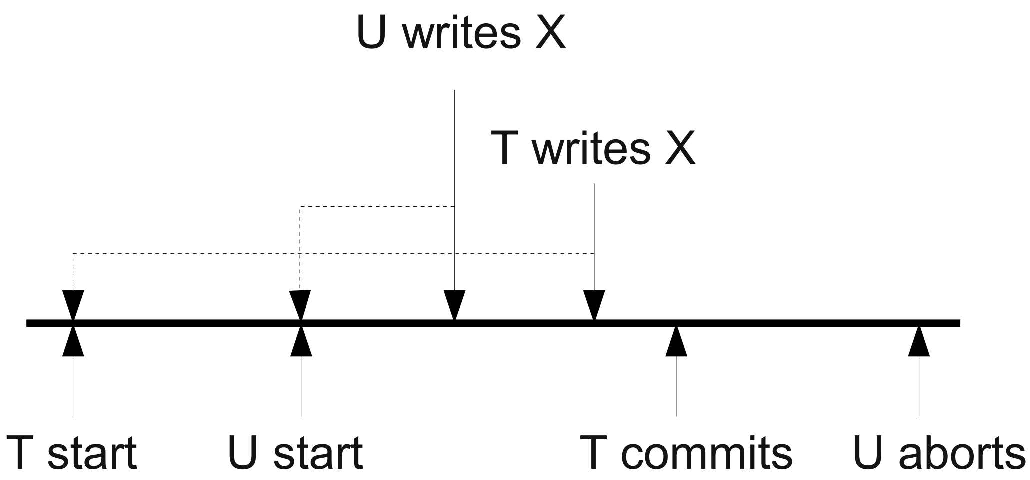


Hence

A write request $w_T(X)$ should only be granted if $\mathrm{TS}(T) \geq \mathrm{RT}(X)$

Concurrency control

Unrealizable behavior that we want to avoid (4/4)



Hence

Request $w_T(X)$ is realizable if $\mathrm{TS}(T) \geq \mathrm{RT}(X)$ and $\mathrm{TS}(T) < \mathrm{WT}(X)$ **BUT**:

- if $\mathrm{C}(X)$ is false then T must be delayed until the transaction with timestamp $\mathrm{WT}(X)$ commits (i.e. $\mathrm{C}(X)$ becomes true)
- if $\mathrm{C}(X)$ is true then the write can be ignored

Concurrency control

How does it work: conclusion

- Every transaction receives a timestamp upon creation. This can just be a counter that is incremented for each new transaction.
- To each item X we associate two timestamps $\mathrm{RT}(X)$ and $\mathrm{WT}(X)$, and a boolean $\mathrm{C}(X)$.
- A transaction with timestamp t is allowed to read item X if $t \geq \mathrm{WT}(X)$. If $\mathrm{C}(X)$ is false then the execution is paused until $\mathrm{C}(X)$ becomes true or the transaction that has last written X aborts. If $t < \mathrm{WT}(X)$ then the transaction is aborted and restarted with a larger timestamp.
- A transaction with timestamp t is allowed to write item X if $\mathrm{RT}(X) \leq t$ and $\mathrm{WT}(X) \leq t$. If $t < \mathrm{RT}(X)$ then the transaction is aborted and restarted with a larger timestamp. If $\mathrm{RT}(X) \leq t < \mathrm{WT}(X)$ and $\mathrm{C}(X)$ is true then we keep the current value of X. Otherwise the execution is paused until $\mathrm{C}(X)$ becomes true, or until the transaction that last wrote X aborts.

Concurrency control

Locking versus timestamping

- Locking is very efficient when we have many transactions that both read and write. In that case, timestamping will need to abort and restart many transactions.
- Timestamping is very efficient when we have many transactions that make only read requests. In that case, many transactions would have to wait for locks when using a lock-based scheduler, while they can immediately proceed with timestamping-based schedulers.

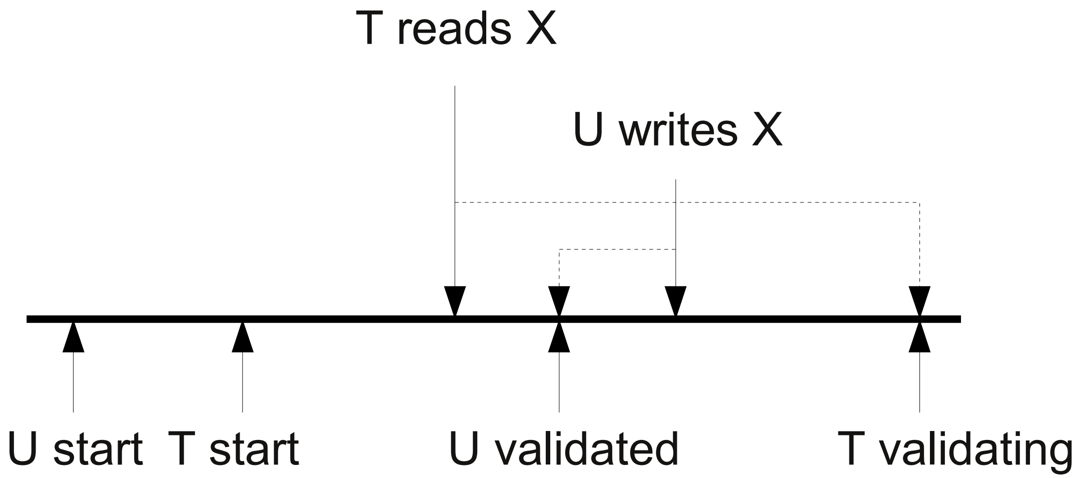
Concurrency control

Schedulers based on validation

- Are optimistic
- The scheduler records, for every transaction T, the set $\mathrm{RS}(T)$ of items read by T, and the set $\mathrm{WS}(T)$ of items written by T.
- Transactions are executed in three phases. In the first phase a transaction reads all items in $\mathrm{RS}(T)$. In the second phase, the scheduler validates the transaction based on $\mathrm{RS}(T)$ and $\mathrm{WS}(T)$. If validation fails, the transaction is aborted and restarted. In the third phase the transaction writes all items in $\mathrm{WS}(T)$.
- The goal is again to obtain a schedule that is equivalent with the serial transaction schedule that orders transactions by their starting time.

Concurrency control

Unrealizable behavior that we want to avoid (1/2)

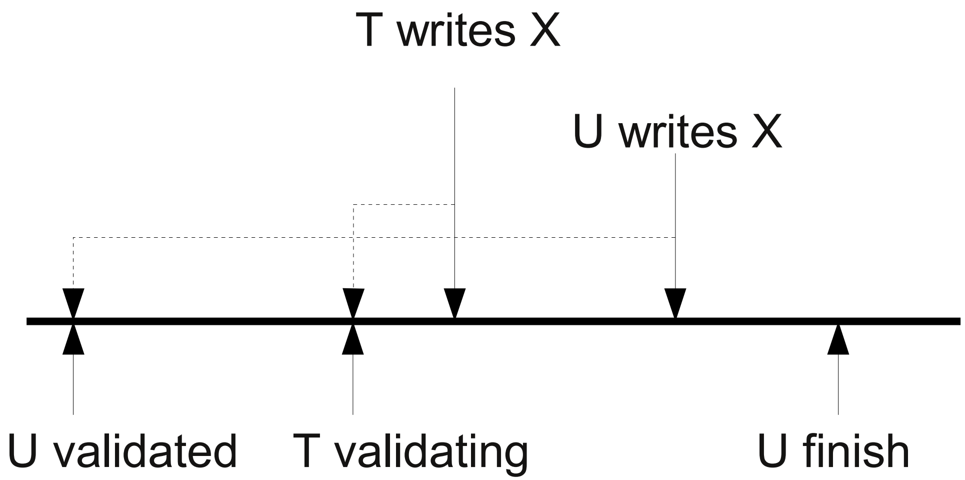


Hence

- Record, for every transaction V, the time $\mathrm{START}(V)$, $\mathrm{VAL}(V)$, and $\mathrm{FIN}(V)$ at which V starts, validates, and finishes, respectively.
- T can only successfully validate if $\mathrm{RS}(T) \cap \mathrm{WS}(U) = \emptyset$ for any previously validated transaction U that was not yet finished when T started, i.e., $\mathrm{FIN}(U) > \mathrm{START}(T)$.

Concurrency control

Unrealizable behavior that we want to avoid (2/2)



Hence

T can only successfully validate if $\mathrm{WS}(T) \cap \mathrm{WS}(U) = \emptyset$ for every previously validated U that did not finish before T validated, i.e., $\mathrm{FIN}(U) > \mathrm{VAL}(T)$.

Concurrency control

How does the scheduler validate?

A transaction T passes validation if:

1. $\mathrm{RS}(T) \cap \mathrm{WS}(U) = \emptyset$ for every transaction U that has already been validated, but was not finished when T started.
2. $\mathrm{WS}(T) \cap \mathrm{WS}(U) = \emptyset$ for every transaction U that has already been validated, but is currently not yet finished.

If T does not pass validation, it is aborted and restarted.