Chapter 4: Transactions
4.0 Basics

- A database is a set of objects.

  logical units: *relation*, *tuple*,

  physical units: *block*, *page*.
- A transaction is a process having access to a database.
- Transaction T may read and write a database object: a sequence of read- and write-operations.
  - RA: the current value of A in the database is copied into the local address space of the respective transaction.
  - WA: the value of A in the local address space is copied in the database and becomes the new current value of A.
- read and write are atomic operations.

Schedule

- Let $\mathcal{T} = \{T_1, \ldots, T_n\}$ a set of transactions.
- The sequence of read- and write-operations of a transaction $T_i \in \mathcal{T}$ is called its *history* h_i.
- An execution of the transactions in $\mathcal{T}$ is called a *schedule* S of $\mathcal{T}$.
- A schedule is a sequence of read- and write-operations of the transactions in $\mathcal{T}$.
- The relative order of the operations in a transaction T mentioned in S is consistent with the history h of T.
- A *serial* schedule of $\mathcal{T}$ is a concatenation of the histories of the transactions in $\mathcal{T}$.

Example

- $\mathcal{T} = \{T_1, T_2, T_3\}$, where $T_1 = R_1A\ W_1A\ R_1B\ W_1B$, $T_2 = R_2A\ W_2A\ R_2B\ W_2B$ and $T_3 = R_3A\ W_3B$.
- There exist six serial schedules of $\mathcal{T}$, e.g. $S_1 = h_1 h_2 h_3$, $S_2 = h_2 h_3 h_1$.
- The following are not serial:

$$S_3 = R_1A\ W_1A\ R_3A\ R_1B\ W_1B\ R_2A\ W_2A\ W_3B\ R_2B\ W_2B,$$
$$S_4 = R_3A\ R_1A\ W_1A\ R_1B\ W_1B\ R_2A\ W_2A\ R_2B\ W_2B\ W_3B.$$

augmented schedule

- T_0 is a transaction with a write for each database object and no read. T_0 will create the initial state of the database.
- T_∞ has a read for each object and no writes. It will read the final state of the database. T_∞ reads the final state of the database.
- S a schedule to $\mathcal{T}$. $\widehat{S} = T_0\ S\ T_\infty$ is the augmented schedule.

4.1 Concurrency Control

Problem

T_1 adds 100 to A; T_2 subtracts 50 from A.

S_1	S_2	S_3	S_4	S_5	S_6
$A = 80$	$A = 80$	$A = 80$	$A = 80$	$A = 80$	$A = 80$
R_1A	R_1A	R_1A	R_2A	R_2A	R_2A
W_1A	R_2A	R_2A	W_2A	R_1A	R_1A
R_2A	W_1A	W_2A	R_1A	W_2A	W_1A
W_2A	W_2A	W_1A	W_1A	W_1A	W_2A
$A = 130$	$A = 30$	$A = 180$	$A = 130$	$A = 180$	$A = 30$

Which of the six schedules can be considered correct?

4.1.1 Serializability

Definition

A schedule is called *serializable*, if there exists an equivalent schedule with the same transactions.

Definition

Schedule S and S' over the same set of transactions are *equivalent*, if for any initial state of the database and any possible semantics of the transactions the following holds.

- The transactions read in S und S' the same values.
- S und S' produce the same final state of the database.

Example

- $T_1 = R_1A\ W_1A\ R_1B\ W_1B, \quad T_2 = R_2A\ W_2A\ R_2B\ W_2B.$
- $$S_1 = R_1A\ W_1A\ R_2A\ W_2A\ R_2B\ W_2B\ R_1B\ W_1B$$
  $$S_2 = R_1A\ W_1A\ R_2A\ W_2A\ R_1B\ W_1B\ R_2B\ W_2B$$

What's about semantics?

	schedule $T_1 T_2$		schedule $T_2 T_1$
R_1A	A_0	R_2A	A_0
W_1A	$f_{T_1,A}(A_0)$	W_2A	$f_{T_2,A}(A_0)$
R_1B	B_0	R_2B	B_0
W_1B	$f_{T_1,B}(A_0, B_0)$	W_2B	$f_{T_2,B}(A_0, B_0)$
R_2A	$f_{T_1,A}(A_0)$	R_1A	$f_{T_2,A}(A_0)$
W_2A	$f_{T_2,A}(f_{T_1,A}(A_0))$	W_1A	$f_{T_1,A}(f_{T_2,A}(A_0))$
R_2B	$f_{T_1,B}(A_0, B_0)$	R_1B	$f_{T_2,B}(A_0, B_0)$
W_2B	$f_{T_2,B}(f_{T_1,A}(A_0), f_{T_1,B}(A_0, B_0))$	W_1B	$f_{T_1,B}(f_{T_2,A}(A_0), f_{T_2,B}(A_0, B_0))$

dependency graph

A *dependency graph* of schedule S is a directed graph $AG(S) = (V, E)$, V the set of operations in S $\widehat{S}$ and E a set of edges $(i \neq j)$:

- $\widehat{S} = \ldots R_i B \ldots W_i A \ldots \;\Rightarrow\; R_i B \rightarrow W_i A \in E$,
- $\widehat{S} = \ldots W_i A \ldots R_j A \ldots \;\Rightarrow\; W_i A \rightarrow R_j A \in E$, if between $W_i A$ and $R_j A$ in $\widehat{S}$ there are no other writes to A.

Theorem

Schedules S and S' over the same transactions are equivalent, if $AG(S) = AG(S')$.

Conflict Graph

Conflict Graph of S is a directed graph $KG(S) = (V, E)$, where V set of transactions in $\widehat{S}$ and E the set of edges $(i \neq j)$:

- $\widehat{S} = \ldots W_iA \ldots R_jA \ldots \;\Rightarrow\; T_i \rightarrow T_j \in E$, if between W_iA and R_jA in $\widehat{S}$ no other writes to A. *(WR-conflict)*
- $\widehat{S} = \ldots W_iA \ldots W_jA \ldots \;\Rightarrow\; T_i \rightarrow T_j \in E$, if between W_iA and W_jA in $\widehat{S}$ no other writes to A. *(WW-conflict)*
- $\widehat{S} = \ldots R_iA \ldots W_jA \ldots \;\Rightarrow\; T_i \rightarrow T_j \in E$, if between R_iA and W_jA in $\widehat{S}$ no other writes to A. *(RW-conflict)*

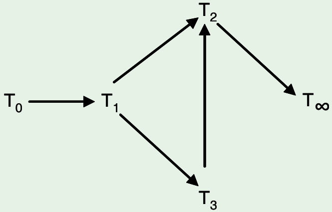
Theorem and definition

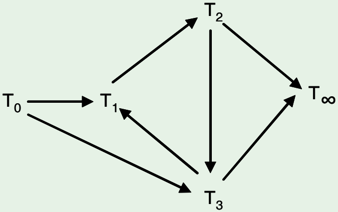
- Schedule S is serializable, if $KG(S)$ has no cycle.
- Schedule S is called *conflict-serializable*, if $KG(S)$ has no cycle.

Example

Schedule S_1: $R_1A\ W_1A\ R_3A\ R_1B\ W_1B\ R_2A\ W_2A\ W_3B\ R_2B\ W_2B$

Schedule S_2: $R_3A\ R_1A\ W_1A\ R_1B\ W_1B\ R_2A\ W_2A\ R_2B\ W_2B\ W_3B$





4.1.2 Locking

- Before reading and writing a lock has to be obtained.
- (*Lock*):
  - *Read-lock* $L^R A$
  - *Read- and Write-lock* LA
- (*Unlock*): UA, bzw. $U^R A$.
- *Locktable*
- *Compatibilitymatrix*:

lock hold to A:

lock acquired A:

	$L^R A$	LA
$L^R A$	J	N
LA	N	N

- *Livelock* and *Deadlock*.

Livelocks and Deadlocks

- avoid Livelocks: *first-come-first-served*-strategy
- avoid Deadlocks:
  - When being started, each transaction acquires for all locks in one atomic operation.
  - A linear order is defined on all objects; locks are acquired consistently to this order.
- *Wait-for-graph*: There is an edge $T_i \longrightarrow T_j$, if T_i acquires a lock, which T_j obtains and the acquired and the obtained locks are not compatible.

  There is a deadlock, iff there is a cycle in the wait-for-graph.

How to break a deadlock?

2-Phasen Sperren 2PL

After the first unlock, it is not allowed to lock again.

Lock- and unlock-operations of a 2PL transaction *RA WA RB WB RC WC*

$$LA\ RA\ WA\ LB\ RB\ WB\ LC\ RC\ WC\ UA\ UB\ UC,$$
$$LA\ RA\ WA\ LB\ LC\ UA\ RB\ WB\ UB\ RC\ WC\ UC,$$
$$LA\ LB\ LC\ RA\ WA\ UA\ RB\ WB\ UB\ RC\ WC\ UC,$$
$$LA\ LB\ LC\ RA\ WA\ RB\ WB\ RC\ WC\ UA\ UB\ UC.$$

2PL is called *strict*, if all unlock are postponed to the end of a transaction.

Satz

2Pl guarantees serializability.

Proof!

Power and optimality of 2PL

- 2PL is optimal in the sense, that for any non-2PL transaction T there exists a transaction T', such that there exists a not serializable schedule to $\{T, T'\}$.
- There exist serializable schedules, which cannot occur under 2PL.

4.1.3 Methods without locks

- A concurrency control can be formalized as a mapping Φ, which transforms an acquired sequence of operations S_I (input-schedule) into a serializable sequence of operations S_O(output-schedule) which then is being executed.
- $\Phi(S_I) = S_O$, where S_I is a prefix of a schedule and S_O a schedule.

Consider Φ_{2PL}. $T_1 = L_1A\ R_1A\ L_1B\ U_1A\ W_1B\ U_1B$, $T_2 = L_2A\ R_2A\ W_2A\ U_2A$, and $T_3 = L_3^RC\ R_3C\ U_3^RC$.

acquired sequence	locktable	executed sequence
L_1A	L_1A	
$L_1A\ R_1A$	L_1A	R_1A
$L_1A\ R_1A\ L_2A$	L_1A	R_1A
$L_1A\ R_1A\ L_2A\ L_3^RC$	L_1A, L_3^RC	R_1A
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C$	L_1A, L_3^RC	$R_1A\ R_3C$
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C\ L_1B$	L_1A, L_3^RC, L_1B	$R_1A\ R_3C$
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C\ L_1B\ U_1A$	L_3^RC, L_1B	$R_1A\ R_3C$
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C\ L_1B\ U_1A\ R_2A$	L_3^RC, L_1B, L_2A	$R_1A\ R_3C\ R_2A$
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C\ L_1B\ U_1A\ R_2A\ W_2A$	L_3^RC, L_1B, L_2A	$R_1A\ R_3C\ R_2A\ W_2A$
$L_1A\ R_1A\ L_2A\ L_3^RC\ R_3C\ L_1B\ U_1A\ R_2A\ W_2A\ U_2A$	L_3^RC, L_1B	$R_1A\ R_3C\ R_2A\ W_2A$
...	...	...

Conflict-graph analysis Φ_{KG}

Let S be the current sequence of operations being executed and let op be the next operation being acquired for execution of a transaction T.

If $KG(S\ op)$ acyclic, then execute op. Otherwise cancel T and all transactions depending on T and delete all their operations from S.

Timestamps Φ_{ZM}

Each transaction T is assigned an unique timestamp $Z(T)$ at its start.

Let S be the current sequence of operations being executed and let *op* be the next operation being acquired for execution of a transaction T.

If for all transactionen T', which have already executed an operation which is in conflict with *op* there hods $Z(T') \leq Z(T)$, then execute *op*. Otherwise cancel T and all transactions depending on T and delete all their operations from S.

Example

$S_I = R_1A\ R_2A\ W_2A\ R_3B\ W_3B\ W_1B.$
$T_1 = R_1A\ W_1B,\ T_2 = R_2A\ W_2A,\ T_3 = R_3B\ W_3B.$

S_I	S_O
Φ_{KG}	
Φ_{ZM}	
Φ_{2PL}	

4.1.4 Phantoms

implicit assumption

The set of objects does not change.

If not guaranteed: *Phantoms*.

Schedule with phantom

Consider T_1 with history $R_1 A_1 \; \ldots R_1 A_k \; R_1 B$.

Consider transaction T_2 with history $R_2 C \; W_2 A_{k+1} \; W_2 B$.

All A_i fulfill a predicate p. Assume, T_1 wants to read all objects which fulfill p.

$$R_2 C \; R_1 A_1 \; \ldots R_1 A_k \; W_2 A_{k+1} \; R_2 B \; W_2 B \; R_1 B$$

This schedule formally is equivalent to $T_2 \; T_1$; however, this is a wrong conclusion.

Solution to phantoms

- Enlarge granularity of objects.
- Consider read of the form $R_1\{A \mid p(A)\}$.
- Index-locking