10.3: Homogeneous Concurrency Control

Serializability by distributed 2-Phase Locking (2PL)

A transactions entry into the unlock-phase has to be synchronized among all sites the transaction is being executed.

Primary Site 2PL:

- One site is selected at which lock maintenance is performed exclusively.
- This site thus has global knowledge and enforcing the 2PL rule for global and local transactions is possible.
- The lock manager simply has to refuse any further locking of a subtransaction T_{ij} whenever a subtransaction T_{ik} has started unlocking already.
- Much communication is resulting which may create a bottleneck at the primary site.

Example

P $S_1 :$ L_1A R_1A W_1A U_1A R_2A W_2A

↑ ↕ L_2A

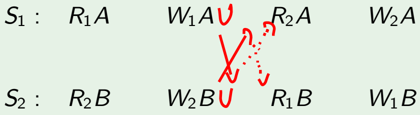
$S_2 :$ L_2B R_2B W_2B U_2B R_1B W_1B

L_1B

Distributed 2PL:

- When a server wants to start unlocking data items on behalf of a transaction, it communicates with all other servers regarding the lock point of the other respective subtransaction.
- The server has to receive a *locking completed*-message from each of these servers.
- This implies extra communication between servers.

Example



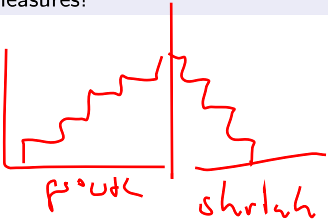
$S_1: \quad R_1A \quad W_1A$ U $\quad R_2A \quad W_2A$

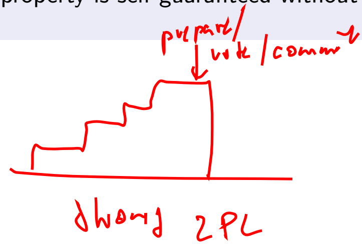
$S_2: \quad R_2B \quad W_2B$ U $\quad R_1B \quad W_1B$

Distributed Strong 2PL:

- Every subtransaction of a global transaction and every local transaction holds locks until commit.
- Then by the 2-phase-commit protocol the 2PL-rule is enforced as a side-effect.

Applying strong 2PL the global 2PL-property is self-guaranteed without any explicit measures!





Locking protocols are prone to deadlocks!

Global deadlock

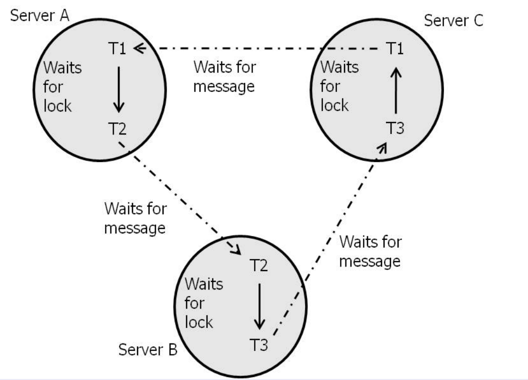
Wait graph

$T_1 \rightarrow T_2$

waits on

cycle $\Leftrightarrow$ deadlock

→ abort → restart



Global deadlock detection is difficult. Detection strategies:

- *Centralized detection*: Each site maintains its local wait-for graph. One distinguished site is selected to which all local wait-for graphs are send periodically. The selected site computes the union of all local wait-for graphs and checks for deadlocks.
- *Time-out based detection*: Whenever during a wait a *time-out* occurs, the respective transaction decides for a deadlock and aborts itself.
- *Edge chasing*: Whenever a transaction T waits for a transaction T', it sends its identification to T'. Whenever a transaction T' receives such a message, it sends the identification of such T to all transctions it is waiting for. If a transaction recieves its own identification, it decides for a deadlock and it aborts itself.
- *Path pushing:*

  (i) Each server that has a waits-for path from transaction t_i to transaction t_j such that T_i has an incoming waits-for-message edge and T_j has an outgoing waits-for-message edge sends that path to the server along the outgoing edge.

  (ii) Upon receiving a path the server concatenats this with the local paths that already exist, and forwards the result along its outgoing edges again. If there exists a cycle among k servers, at least one of them will detect the cycle in at most k rounds.

which TA to choose

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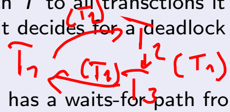

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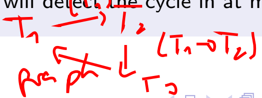

pass cycle fragment

Broader view of wait graph

Serializabilty by assigning timestamps to transactions

- Global and local transactions are timestamped; all subtransactions of a transaction obtain the same timestamp.
- Timestamps must be system-wide unique and based on synchronized clocks.
- To be system-wide unique, timestamps are values of local clocks concatenated with the site ID.

Time Stamp Protocol TS

- To each transaction T it is assigned a unique timestamp $Z(T)$ when it is started.
- A transaction T must not write an object which has been read by any T' where $Z(T') > Z(T)$.
- A transaction T must not write an object which has been written by any T' where $Z(T') > Z(T)$.
- A transaction T must not read an object which has been written by any T' where $Z(T') > Z(T)$.

serial order via start TS

The TS-protocol guarantees serializability of schedules.

Let S be a global schedule of a set of transactions $\mathcal{T} = \{T_1, \ldots, T_n\}$, which all apply TS.

Assume, S is not serializable, i.e. the conflict graph $G(S)$ is cyclic, where w.l.o.g. $T_1 \rightarrow T_2 \rightarrow \cdots \rightarrow T_k \rightarrow T_1$.

- Each edge $T \rightarrow T'$ implies T and T' have conflicting actions, where the action of T preceds the one of T'.
- Because of TS we know $Z(T) < Z(T')$. This implies the following:

$$Z(T_1) < Z(T_2) < \ldots < Z(T_n) < Z(T_1),$$

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Dealing with global timestamp ordering

- Global time with total ordering impossible in distributed systems: message delays, clock drift, ...
- Remember Lamport happened-before relationship (Chapter 4)
  - Local ordering on same node: $e \Rightarrow e'$ if e precedes e' on the same node
  - Message transfers: $e \Rightarrow e'$ if e is the send event and e' the receive event of the same message
  - Transitivity: $e \Rightarrow e'$ if $\exists e''$ so that $e \Rightarrow e'' \wedge e'' \Rightarrow e'$
- Lamport clocks:
  - Each site keeps a counter (acting as clock)
  - Each local step increases the clock
  - When sending a message, attach the local timestamp
  - When receiving a message, take the maximum of local time and received time and add 1

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Using Lamport clocks with TS

- Express logical time as (c, i): c is clock/counter, i transaction number ~ host number
- (c, i) represents time after an operations
- Use remote read/write operations to "piggyback" time: Increase time before/after transmission

How/why does work?

- Operations require a happened-before relationship with transactions
- Lamport clocks (with i as tie breaker) make sure that two operations do not get the same timestamp'

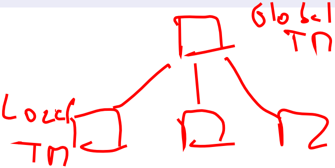
Lock-based vs timestamp-based approaches

- Both approaches guarantee serializability
- Lock-based approaches bear the cost of locks and risk deadlocks
- Timestamp-based approaches are deadlock-free, but face the risk of restarts
- All the approaches seen so far are pessimistic: check if an operations is possible, then execute it
- Extensions are possible in many ways:
  - Multi-version protocols: writes create new versions, operations pick up more recent versions if allowed
  - Optimistic protocols: Perform all operations, check at end of transaction if conflicts had occurred

10.4: Heterogeneous Concurrency Control

Local and global transaction managers

- Each server runs its own *local* transaction manager which guarantees local serializability, i.e. the serializable execution of its local transactions and subtransactions.
- To guarantee global serializability a *global* transaction manager controls the execution of the global transactions. This could either be based on ordering the commit of the transaction, or by introducing artificial data objects called *tickets* which have to be accessed by the subtransactions.



Global serializability through local guarantees: rigorous local schedules

Rigorous schedules (→ locally)

A local schedule $S = (OP_S, <_S)$ of a set of complete transactions is *rigorous* if for all involved transactions (local and subtransactions) T_i, T_j there holds:

> Let $p_j \in OP_j$, $q_i \in OP_i$, $i \neq j$ such that $(p_j, q_i) \in \mathit{conf}(S)$. Then either $a_j <_S q_i$ or $c_j <_S q_i$. strict 2PL

Commit-deferred transaction (→ global)

A global transaction T is *commit-deferred* if its commit action is sent by the global transaction manager to the local sites of T only *after* the local executions of all subtransactions of T at that sites have been acknowledged.

Commit-deferment is achieved as a side-effect of the 2-phase-commit protocol.

Examples

Consider two servers where $D_1 = \{A, B\}$ and $D_2 = \{C, D\}$. We have the following transactions:

$$\begin{array}{llcll} \text{global}: & T_1 = WA\ WD & \quad & \text{local}: & T_3 = RA\ RB \\ & T_2 = WC\ WB & & & T_4 = RC\ RD \end{array}$$

We have the following local schedules:

$$\begin{array}{llllllll} S_1: & W_1A & \boxed{c_1} & R_3A & R_3B & c_3 & W_2B & \boxed{c_2} \\ S_2: & W_2C & \boxed{c_2} & R_4C & R_4D & c_4 & W_1D & \boxed{c_1} \end{array}$$

Even though the local schedules are serializable, the two global transactions are not executed in a serializable manner. The local schedules are rigorous, however not commit-deferred.

Lemma

A schedule is serializable, whenever it is rigorous.

Sketch of proof: Assume the contrary. Then there exists a history which has a cyclic conflict graph, though rigorousness holds. As a commit is the final action of a transaction, rigorousness makes such a cycle impossible.

Theorem

Let S be a global history for local histories $S_1, \dots, S_n$. If S_i rigorous, $1 \leq i \leq n$ and all global transactions are commit-deferred, then S is globally serializable.

Sketch of proof: Assume the contrary. Then there exists a history which has a cyclic conflict graph, though rigorousness and commit-deferment hold. As rigorousness guarantees local serializability, such a cycle must involve at least two sites. As a commit is the final action of a transaction, commit-deferment makes such a cycle impossible.

Because of the 2-phase-commit protocol, under rigorousness global serializability practically comes for free!

Global serializability through explicit measures: tickets

(no rigorousness
or
commit deferment)

Ticket-based concurrency control

- Each server guarantees serializable local schedules in a way unknown for the global transactions.
- Each server maintains a special counter as database object, which is called *ticket*. Each subtransaction of a global transaction being executed at that server increments (reads and writes) the ticket (*take-a-ticket*-Operation). Doing so we introduce explicit conflicts between global transactions running at the same server.
- The global transaction manager guarantees that the order in which the tickets are accessed by the subtransactions will imply a linear order on the global transactions.

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Applying ticketing by examples

By I_j we denote the ticket at server j.

- Let $T_1 = R_1A\ R_1D$ and $T_2 = R_2B\ R_2C$ be global transactions and let $T_3 = R_3A\ R_3B\ W_3A\ W_3B$ and $T_4 = R_4D\ W_4D\ R_4C\ W_4C$ be local transactions.

  $S_1:\quad \boxed{R_1(I_1)\ W_1(I_1)}\ R_1A\ R_3A\ R_3B\ W_3A\ W_3B\ \boxed{R_2(I_1)\ W_2(I_1)}\ R_2B$

  $S_2:\quad R_4D\ W_4D\ \boxed{R_1(I_2)\ W_1(I_2)}\ R_1D\ \boxed{R_2(I_2)\ W_2(I_2)}\ R_2C\ R_4C\ W_4C$

  $T_1 \to T_2$ (ticket)

  $T_1 \to T_3 \to T_2$

  $T_2 \to T_4 \to T_1$

  $T_1 \to T_2$ (ticket)

  Not serializable - could be detected at server 2.

- Let $T_1 = R_1A\ W_1B$ and $T_2 = R_2B\ W_2A$ be global transactions.

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  $S_2:\quad R_2(I_2)\ W_2(I_2)\ R_2B\ R_1(I_2)\ W_1(I_2)\ W_1B$

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  B $S_2:\quad \boxed{R_2(I_2)\ W_2(I_2)}\ R_2B\ \boxed{R_1(I_2)\ W_1(I_2)}\ W_1B$

  $T: T_1 \to T_2\ /\ T_1 \to T_2$
  $T: T_2 \to T_1\ /\ T_2 \to T_1$

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