4. Transaction management

12 Architecture of the Transaction Management
4. Transaction management

12 Architecture of the Transaction Management

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4. Transaction management

12 Architecture of the Transaction Management

13 Locking Methods

14 Non-locking Methods
4. Transaction management

12 Architecture of the Transaction Management

13 Locking Methods

14 Non-locking Methods

15 Multiversion concurrency control
4. Transaction management

12. Architecture of the Transaction Management

13. Locking Methods

14. Non-locking Methods

15. Multiversion concurrency control

16. Transactions in SQL
Schedulers

- Schedulers
- T1, T2, ..., Tn (consisting of Dr, Dw, Dc, Da)
- Transaction Manager (TM)
- Scheduler (SC)
- Correct schedules (consisting of r, w, c, a)
- Storage Manager (SM)
- Recovery Manager (RM)
- Buffer Manager (BM)
- DB
Transaction Operations

- **Transaction brackets**
  - **BOT** *(Begin of Transaction)*
  - **EOT** *(End of Transaction)*

- **Steps:**
  - *r* *(read)*,
  - *w* *(write)*,
  - *a* *(abort)*, and
  - *c* *(commit)*.

\[
t = \{r|w\}^*(a|c)
\]
States of a transaction

- **initial**
- **running**
- **delayed**
- **aborted**
- **stopped**
- **committed**

**Transitions:**
- **BOT**
- **retry**
- **reject**
- **delay**
- **execute**
- **restart**
- **EOT**
- **stop**
Treatment of a step

- **Execute** transaction $\rightarrow$ state *running*
- **Delay** transaction $\rightarrow$ state *delayed*
- **Reject** transaction $\rightarrow$ state *aborted*
Aggressive Schedulers

- A scheduler is **aggressive**, if it allows conflicts and later attempts to identify and resolve conflicts
- Maximizes parallelism of transactions
- Risk: Transactions are reset at the end of an execution
- Also known as **optimistic** methods
Conservative Schedulers

- A scheduler is **conservative**, if it avoids conflicts and in return accepts possible delays of transactions.
- Allows only low parallelism of transactions.
- Minimizes the effort of resetting aborted transactions.
- In extreme cases, no parallelism of transactions takes place. This means that all transactions except for one will be delayed.
- Also known as **pessimistic** methods.
Lock Models

- Write and read locks in the following notation:
  - $rl(x)$: read lock on object $x$
  - $wl(x)$: write lock on object $x$

- Unlock $ru(x)$ and $wu(x)$, often summarized as unlock $u(x)$
Locking rules

- Write access $w(x)$ only possible after setting write lock $wl(x)$
- Read access $r(x)$ only valid after $rl(x)$ or $wl(x)$
- Lock only objects that have not yet been locked by another transaction
- After $rl(x)$ only $wl(x)$ valid, no lock on $x$ after that; locks of the same kind are used only once
- After $u(x)$ by $t_i$, $t_i$ may not perform another $rl(x)$ or $wl(x)$
- Before a `commit`, all locks must be removed
Deadlocks

Alternatives:
- Identify and remove deadlocks
- Avoid deadlocks in the first place
Identification and Removal

- **Waiting Graph**

```
6 --> 5 --> 4
  |     |
  v     v
1 --> 2 --> 3
```

- **Solving by aborting a transaction**, Criteria:
  - Number of resolved loops,
  - Length of a transaction,
  - Effort of resetting a transaction,
  - Importance of a transaction, ...
Livellok Problem

1. $T_1$ locks $A$
2. $T_2$ attempts to lock $A$, but has to wait
3. $T_3$ attempts to lock $A$, but has to wait as well
4. $T_1$ unlocks $A$
5. $T_3$ gets a time slice before $T_2$ locks $A$
6. $T_2$ still attempts to lock $A$, but has to wait
7. $T_4$ attempts to lock $A$, afterwards but has to wait as well
8. $T_3$ unlocks $A$
9. $T_4$ gets the next time slice before $T_2$ ...
## Locking Protocols: Necessity

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$wl(x)$</td>
<td>$wl(x)$</td>
</tr>
<tr>
<td></td>
<td>$w(x)$</td>
<td>$w(x)$</td>
</tr>
<tr>
<td></td>
<td>$u(x)$</td>
<td>$u(x)$</td>
</tr>
<tr>
<td></td>
<td>$wl(y)$</td>
<td>$wl(y)$</td>
</tr>
<tr>
<td></td>
<td>$w(y)$</td>
<td>$w(y)$</td>
</tr>
<tr>
<td></td>
<td>$u(y)$</td>
<td>$u(y)$</td>
</tr>
</tbody>
</table>
Two-phase Locking Protocol

2PL guarantees conflict serializability!
Conflict caused by non-compliance with 2PL

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u(x)$</td>
<td>$wl(x)$</td>
</tr>
<tr>
<td>$wl(y)$</td>
<td>$wl(y)$</td>
</tr>
<tr>
<td>:</td>
<td>$u(x)$</td>
</tr>
<tr>
<td></td>
<td>$u(y)$</td>
</tr>
</tbody>
</table>
Strict Two-phase Locking Protocol

Avoids cascading aborts!
Conservative 2PL Protocol

Avoids deadlocks!
Lock Granularity

- Granularity hierarchies in databases
- Hierarchical locks
- Tree protocols for tree indexes
Granularity Hierarchies in RDBS

Granularity hierarchy

Logical
- Database
  - Relation
  - Tuple
  - Attribute

Physical
- Database
  - File
  - Cluster
  - Page
Hierarchical Locks

- Locks are passed from top-to-bottom (in direction to the leaves)
- Locks must not be overwritten from the top (coming from the root)
- Additionally: *Intentional locks* warn of locks further down in the hierarchy
  - irl (*Intentional read lock*)
  - iwl (*Intentional write lock*)
Compatibility Matrix

For elementary locks:

<table>
<thead>
<tr>
<th></th>
<th>$rl_i(x)$</th>
<th>$wl_i(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$rl_j(x)$</td>
<td>✓</td>
<td>—</td>
</tr>
<tr>
<td>$wl_j(x)$</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
## Compatibility Matrix

For hierarchical locks:

<table>
<thead>
<tr>
<th></th>
<th>$rl_i(x)$</th>
<th>$wl_i(x)$</th>
<th>$irl_i(x)$</th>
<th>$iwl_i(x)$</th>
<th>$riwl_i(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$rl_j(x)$</td>
<td>√</td>
<td>—</td>
<td>√</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$wl_j(x)$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$irl_j(x)$</td>
<td>√</td>
<td>—</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>$iwl_j(x)$</td>
<td>—</td>
<td>—</td>
<td>√</td>
<td>√</td>
<td>—</td>
</tr>
<tr>
<td>$riwl_j(x)$</td>
<td>—</td>
<td>—</td>
<td>√</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Process of Hierarchical Locking

1. Locks are placed on a path from the root towards the target
2. Data object which should be worked on is locked: Write or read lock (Compatibility matrix has to be observed!)
3. All other vertices on the path receive intentional locks
4. Locks can be intensified, which means that $rl$ can become $wl$, $irl$ can become $rl$ and $irl$ can become $iwl$
5. Unlocking happens the other way around
Hierarchical Locks: Example I

- **T₁**
  - OrderDB
    - irl(explicit)
  - Product
    - rl(explicit)
  - NY Espresso, ..., Arabica
    - rl(implicit)
  - Price, ..., MinQuantity
    - rl(implicit)

- **Database**
  - (OrderDB)

- **Relation**
  - (Product)

- **Tuple**
  - (NY Espresso)
  - Price, MinQuantity

- **Relation**
  - (Order)

- **Tuple**
  - (Arabica Blue)

- **T₂**
  - OrderDB
    - irl(explicit)
  - Product
    - iwl(explicit)
 Hierarchical Locks: Example II

\( T_1 \)
- OrderDB
  - irl(explicit)
- Product
  - irl(explicit)
- NY Espresso
  - irl(explicit)
- Price
  - rl(explicit)

\( T_2 \)
- OrderDB
  - iwl(explicit)
- Product
  - iwl(explicit)
- Espresso
  - iwl(explicit)
- MinQuantity
  - wl(explicit)
Hierarchical Locks: riwl

T₁
OrderDB riwl(explicit)
Product riwl(explicit)
NY Espresso, ..., Arabica rl(implicit)
NY Espresso wl(explicit)

Database (OrderDB)
Relation (Product)
Tuple (NY Espresso)

T₂
OrderDB irl(explicit)
Product irl(explicit)
Arabica Blue rl(implicit)

Relation (Order)
Tuple (Arabica Blue)
Lock Escalation

- Choice of lock granularity
- When executing transactions: many fine-grained locks
  Overhead by the lock manager

**Lock Escalation**

- Dynamic union of many fine-grained locks to one (or a few) coarse-grained locks
- Typically: When the number of locks exceed a threshold
Locks in Index Structures

**Tree Protocol**

1. Unlocked object $o$ can only be locked by $T$ if its direct predecessor has already been locked by $T$
2. This rule does not apply to the first lock of a transaction
3. Locks can be unlocked at any time
4. No object within the same transaction $T$ can be locked more than once
Tree Protocol: Example

lock A; lock B; unlock A; lock D
## Sequence within the Tree Protocol

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>lock $A$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lock $B$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lock $D$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>unlock $B$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lock $C$</td>
<td>lock $B$</td>
<td></td>
</tr>
<tr>
<td>unlock $D$</td>
<td></td>
<td>lock $E$</td>
</tr>
<tr>
<td>unlock $A$</td>
<td></td>
<td>lock $F$</td>
</tr>
<tr>
<td>unlock $C$</td>
<td></td>
<td>lock $G$</td>
</tr>
<tr>
<td>lock $E$</td>
<td></td>
<td>unlock $E$</td>
</tr>
<tr>
<td>unlock $B$</td>
<td></td>
<td>unlock $F$</td>
</tr>
<tr>
<td>unlock $E$</td>
<td></td>
<td>unlock $G$</td>
</tr>
</tbody>
</table>
Properties of Tree Protocols

Tree protocol does not force 2PL!

If all transactions fulfill the tree protocol, each correct schedule is serializable.
Latches

- Lightweight (few CPU instructions) objects for short term locks
  - Transport of a record from the buffer to the storage system
  - When inserted into table: Latch for corresponding index block
- Unlike locks, only for in-memory objects
Non-locking Methods

- **Timestamp-based approaches** force a correct order of steps, by marking the transactions appropriately.

- **Serializability testers** manage a conflict graph and therefore verify the conflict serializability directly.

- **Certifiers** execute the complete transaction and later check if the conditions of serializability were fulfilled.
Timestamps

- Timestamps are unique and are allocated consecutively
- For every data object $x$ two values are managed:
  - $\text{max-r-scheduled}[x]$:
    Variable that contains the timestamp of the last read operation on $x$
  - $\text{max-w-scheduled}[x]$:
    Variable that contains the timestamp of the last write operation on $x$
Timestamp-ordering rule

An operation $p_i[x]$ is executed before $q_k[x]$ if and only if $ts(T_i) < ts(T_k)$ applies.

- $p$ and $q$: incompatible operations of transactions $T_i$ or respectively $T_k$ ($i \neq k$) on object $x$
- $ts(T_i)$ and $ts(T_k)$ are timestamps of transaction $T_i$ or respectively $T_k$
- Formally:

  If $p_i(x)$ and $q_j(x)$ are in conflict, the following applies:

  $p_i(x)$ is executed before $q_j(x) \iff ts(T_i) < ts(T_j)$.
Basic timestamp-ordering-algorithm

\[
\text{if } p_i[x] \text{ is fulfilled then}
\]
\[
\text{if } p_i[x] \text{ is } r_i[x] \text{ then}
\]
\[
\text{if } ts(T_i) < \text{max-w-scheduled}[x] \text{ then}
\]
\[
\text{reject operation};
\]
\[
\text{else}
\]
\[
\text{max-r-scheduled}[x] := \\
\text{max}(\text{max-r-scheduled}[x], ts(T_i));
\]
\[
\text{execute operation;}
\]
\[
\text{else} /\star p_i[x] \text{ ist } w_i[x] \star/
\]
\[
\text{if } ts(T_i) < \text{max-w-scheduled}[x] \text{ or}
\]
\[
ts(T_i) < \text{max-r-scheduled}[x] \text{ then}
\]
\[
\text{reject operation;}
\]
\[
\text{else}
\]
\[
\text{max-w-scheduled}[x] := ts(T_i);
\]
\[
\text{execute operation;}
\]
Advantages and disadvantages of the TO-method

- Disadvantages: Problems with varying run-time of transactions
  - Transactions that take a long time, process their last steps some time after the timestamp has been created
  - These steps are very likely to "be too late"

- Advantage: Easy to realize in distributed systems
## Timestamp method: Schedule

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ts</td>
<td>200</td>
<td>150</td>
<td>175</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>mrs</td>
<td>mws</td>
<td>mrs</td>
<td>mws</td>
</tr>
<tr>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>150</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>150</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

- Read B
- Read A
- Read C
- Write B
- Write A
- Write C
- Abort
Optimized timestamp-ordering method

- Optimized BTO-rule:
  - If the comparison of a write transaction with the \texttt{max-w-scheduled} stamp fails, the write is ignored, unless a conflict with the \texttt{max-r-scheduled} stamp occurs
  - The prior value of \texttt{max-w-scheduled} is assumed and the transaction runs on

\textit{“Optimization for blind writes”}
Optimized timestamp-ordering method: Schedule

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>$A$</th>
<th>$C$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>mrs</td>
<td>mws</td>
</tr>
<tr>
<td>$t_s = 200$</td>
<td>$t_s = 150$</td>
<td>$t_s = 175$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>write $A$</td>
<td>read $A$</td>
<td></td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>read $C$</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>write $A$ &amp; $\sqrt{\downarrow}$</td>
<td>150 &amp; 200</td>
<td>175</td>
</tr>
</tbody>
</table>

Thomas Leich, Gunter Saake
Transaction Management
Last updated: 23.11.2018 4–40
## Livelocks and timestamp-ordering method

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T'_1$</th>
<th>$T'_2$</th>
<th>$A$</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ts = 100$</td>
<td>$ts = 110$</td>
<td>$ts = 120$</td>
<td>$ts = 130$</td>
<td>mrs mws</td>
<td>mrs mws</td>
</tr>
<tr>
<td>write $B$</td>
<td>write $A$</td>
<td></td>
<td></td>
<td>0 0</td>
<td>0 100</td>
</tr>
<tr>
<td>read $A$</td>
<td></td>
<td></td>
<td></td>
<td>0 110</td>
<td>0 100</td>
</tr>
<tr>
<td></td>
<td>write $B$</td>
<td></td>
<td></td>
<td>0 110</td>
<td>0 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>write $A$</td>
<td></td>
<td>0 110</td>
<td>0 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>read $A$</td>
<td>0 130</td>
<td>0 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 130</td>
<td>0 120</td>
</tr>
</tbody>
</table>
Serializability testers I

Problem: Clean up the conflict graph

\[ r_0(x) w_1(x) w_1(y_1)c_1 \ldots w_n(x) w_n(y_n)c_n w_0(z) \]

Diagram:

- \( t_0 \) to \( t_1 \) to \( t_2 \) to \( \ldots \) to \( t_n \)
Serializability testers II

Problem: Clean up the conflict graph

Solution: Only completed transactions without incoming edges may be removed
Serializability testers III

Advantage: Accepts full classes of CSR-schedules

Disadvantage: Graph exhibits quadratic growth as the number of transactions increases
Optimistic approaches: Phases

1. **Execution phase** *(execute)*: Transaction is executed (all read and write operations); write operations however written to a local copy of the data object within the buffer.

2. **Validation phase** *(validate)*
   Any transaction that wants to perform a commit is checked for correctness with regard to conflict serializability.

3. **Persistency phase** *(persist)*:
   If no conflicts have occurred, all manipulated database objects are copied back into the persistent database.

---

*Step 2 and 3 often performed together*

*valpersist*: Joint atomic execution of validate and persist.
Validation criterion

- **Transaction counter** $TC$

- $\forall T_i, T_j : n(T_i) < n(T_j)$ with
  
  $n(T_i) =$ Value of $TC$ after validation of $T_i$:

  1. $T_i$ finishes its `valpersist`-phase, before $T_j$ starts.
  2. $x \in ws(T_i) \cap rs(T_j) \Rightarrow T_i$ finishes its `valpersist`-phase, before $T_j$ reads $x$.
  3. $x \in rs(T_i) \cap ws(T_j) \Rightarrow T_i$ reads $x$ before $T_j$ begins its `valpersist`-phase

- $ws(T_i) : write-set$ of $T_i$ (all DB-objects written by $T_i$)

- $rs(T_i) : read-set$ of $T_i$ (read DB-objects)
Optimistic scheduler I

T₁ | execute | validate | persist |
T₂ | execute | validate | persist |
T₃ | execute | validate | persist |

backward oriented validation

T₁ | execute | validate | persist |
T₂ | execute |
T₃ | execute |

forward oriented validation
Optimistic scheduler II

- **Backward oriented validation:**
  - Test $rs(T_i)$ against $ws(T_j)$ for already completed $T_j$
  - Excluded are $T_j$, that have already performed a **commit** before the begin of $T_i$
  - In case of conflict: Reset $T_i$
  - Example: Test $rs(T_1)$ against $ws(T_2)$ and $ws(T_3)$

- **Forward oriented validation:**
  - Test $ws(T_i)$ against $rs(T_j)$ for transactions $T_j$, that are active (in execution phase)
  - In case of conflict: Reset $T_j$
  - Example: $ws(T_1)$ against $rs(T_2)$ and $rs(T_3)$
Multiversion concurrency control (MVCC)

- Realization in Oracle, InterBase, PostgreSQL, ... 
- Given schedule $s$:

$$s = r_1(x)w_1(x)r_2(x)w_2(y)r_1(y)w_1(z)c_1c_2$$

- $s \notin CSR$
- Tolerable if $r_1(y)$ is able to read prior version of $y$ so that $r_1(y)$ is consistent to $r_1(x)$
- Then: $s$ equivalent to $s' = t_1t_2$
**MVCC: Principle**

- Each write operation $w$ creates a new version of the current data object.
- Read operations can choose a version.
- Versions are transparent for applications.
- **Advantages:**
  - Decoupling of read operation and write operation $\leadsto$ Read transaction has the same view on the database as at BOT.
  - No synchronization of read transactions as well as against read transactions necessary $\leadsto$ Reduction of conflict probability.
  - Synchronization of manipulating operations by other approaches (locking, timestamps).
### MVCC: Example

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w(x_0 \rightarrow x_1)$</td>
<td>$w(y_0 \rightarrow y_1)$</td>
<td>$r(y_0)$</td>
</tr>
<tr>
<td>$\text{commit}$</td>
<td></td>
<td>$w(x_1 \rightarrow x_2)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\text{commit}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$r(x_0)$</td>
</tr>
</tbody>
</table>
Task: Determination of versions that are to be read

- Global transaction counter $TNC$ (transaction number count)
- Commit timestamp $cts$ for manipulating transactions and $BOT$ timestamps $bts$ for read transactions
- Write timestamp $wts(x)$ for object $x$
MVCC: Version Management II

Commit of an update transaction $T_U$:
- Current $TNC$-value as a commit timestamp $cts$ as well as incrementation of $TNC$
- Modified Object: Write timestamp $wts(x) = cts(T_U)$

Read Transaction $T_R$:
- Current $TNC$-value as $BOT$-timestamp: $bts(T_R) = TNC$
- Has access to most recent version of $x$ with:

\[ wts(x) < bts(T_R) \]

i.e, Read from $x_i$ with

\[ i = \max\{j \mid wts((x_j) < bts(T_R))\} \]
MVCC: Version Management: III

- Task: Release of no longer required versions (*garbage collection*)
  - **BOT** timestamp of oldest read transaction: \( bts_{\text{min}} \)
  - Version \( x_i \) of object \( x \) may be deleted if more recent version \( x_j \) exists, so that the following requirement holds:
    \[
    wts(x_i) < wts(x_j) < bts_{\text{min}}
    \]
- Implementation as a ring buffer
Transactions in SQL-DBS

Weakening of ACID in SQL-92: Isolation levels

```sql
set transaction
    [ { read only | read write }, ]
[ isolation level
    { read uncommitted | read committed | repeatable read | serializable }, ]
[ diagnostics size ...]
```

Standard setting:

```sql
set transaction read write,
    isolation level serializable
```
Isolation levels I

- **read uncommitted**
  - Weakest level: Access to uncommitted data, only for read only transactions
  - Statistical and similar transactions (rough overview, no correct values)
  - No locks → can be executed efficiently, no other transactions are impaired

- **read committed**
  - Reading of committed data only, but *non-repeatable read* possible

- **repeatable read**
  - No *non-repeatable read*, but phantom problem may occur

- **serializable**
  - Guaranteed serializability
## Isolation levels II

<table>
<thead>
<tr>
<th>Isolation level</th>
<th>Dirty Read</th>
<th>Nonrepeatable Read</th>
<th>Phantom Read</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Uncommitted</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Read Committed</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Repeatable Read</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Serializable</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>
Isolation levels: *read committed*

<table>
<thead>
<tr>
<th></th>
<th>( T_1 )</th>
<th>( T_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><code>set transaction isolation level read committed</code></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><code>select LastName from CUSTOMER where CNr = 4711</code> → <em>Jagellowsk</em></td>
<td><code>update CUSTOMER set LastName = 'Heuer'</code></td>
</tr>
<tr>
<td>3</td>
<td><code>select LastName from CUSTOMER where CNr = 4711</code> → <em>Jagellowsk</em></td>
<td><code>set LastName = 'Heuer'</code></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td><code>commit</code></td>
</tr>
<tr>
<td>5</td>
<td><code>select LastName from CUSTOMER where CNr=4711</code> → <em>Heuer</em></td>
<td></td>
</tr>
</tbody>
</table>
## Isolation levels: read committed

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
</table>
| 1 | *set transaction*  
    *isolation level*  
    *read committed*     |                                                                      |
| 2 | *select* LastName *from* CUSTOMER *where* CNr = 4711                  | *update* CUSTOMER  
    *set* LastName = ‘Heuer’  
    *where* CNr = 4711       |
| 3 | *update* CUSTOMER  
    *set* LastName = ‘Saake’  
    *where* CNr = 4711       |                                                                      |
|   | ←→ *blocked*                                                         |                                                                      |
| 4 | *commit*                                                            |                                                                      |
| 5 | *commit*                                                            |                                                                      |
Isolation levels: **Serializable**

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>set transaction isolation level serializable</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>select</strong> LastName <strong>from</strong> CUSTOMER <strong>where</strong> CNr = 4711</td>
<td><strong>update</strong> CUSTOMER</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>set</strong> LastName = 'Heuer'</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>where</strong> CNr = 4711</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td><strong>commit</strong></td>
</tr>
<tr>
<td>5</td>
<td><strong>update</strong> CUSTOMER</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>set</strong> LastName = 'Saake'</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>where</strong> CNr = 4711</td>
<td></td>
</tr>
<tr>
<td></td>
<td>→ error</td>
<td></td>
</tr>
</tbody>
</table>
Oracle

- Support of isolation level *Read Committed* and *Serializable*
- Moreover: *Read-Only*-mode (not a component of SQL-92)

```sql
set transaction isolation level read committed;
set transaction isolation level serializable;
set transaction isolation level read only;
```
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- Isolation levels for a set of transactions

```sql
alter session
  set isolation_level isolation level;
```

- Explicit commands to put locks

```sql
lock table Table in row share mode;
lock table Table in share mode;
lock table Table in row exclusive mode;
lock table Table in share row exclusive mode;
lock table Table in exclusive mode;
```