Transactional Information Systems:

Theory, Algorithms, and the Practice of Concurrency Control and Recovery

Gerhard Weikum and Gottfried Vossen

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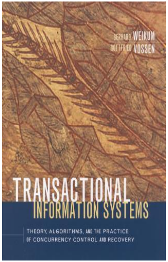

"Teamwork is essential. It allows you to blame someone else."(Anonymous)

Part II: Concurrency Control

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- 10.3 Multi-Granularity Locking and Lock Escalation
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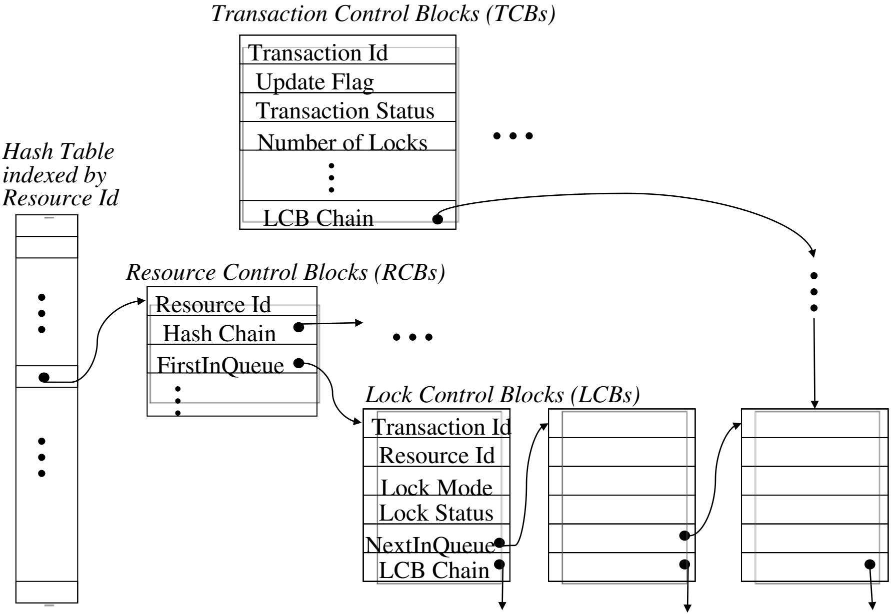
- 10.5 Nested Transactions for Intra-transaction parallelism
- 10.6 Tuning Options
- 10.7 Overload Control
- 10.8 Lessons Learned

"All theory, my friend, is grey;
but the precious tree of life."
(Johann Wolfgang von Goethe)

Organization of Lock Control Blocks



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Reconciling Coarse- and Fine-grained Locking

Problem: For reduced overhead, table scans should use coarse locks
Detect conflict of page lock with tablespace lock

Approach: Set "**intention locks**" on coarser granules

Multi-granularity locking protocol:

- A transaction can lock any granule in S or X mode.
- Before a granule p can be locked in S or X mode, the transaction needs to hold an IS or IX lock on all coarser granules that contain p.

	S	X	IS	IX	SIX
S	+	-	+	-	-
X	-	-	-	-	-
IS	+	-	+ +	+	
IX	-	-	+ +		-
SIX	-	-	+	-	-

Typical policy:

- use coarse locks for table scans
- use fine locks otherwise
- escalate dynamically to coarse locks when memory usage for LCBs becomes critical

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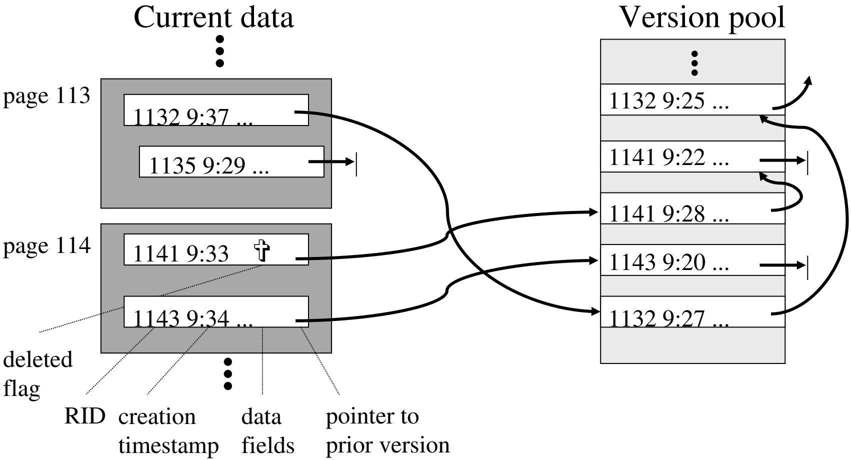
Storage Organization for Transient Versioning



- update on current data moves old version to version pool
- read-only transactions follow version chains
- old versions are kept sorted by their successor timestamps
  → garbage collection simply advances begin pointer

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Multi-threaded Transactions

Example:

t_1: t_{11} t_{12} t_{13} t_{14} with t_{12} and t_{13} as parallel threads

t_{11}: r(t) r(p) w(p) /* store new incoming e-mail */

t_{12}: t_{121} t_{122} t_{123} t_{124} with t_{122}, t_{123}, t_{124} as parallel threads

t_{121}: r(t) r(s) w(s) /* update folder by subject */

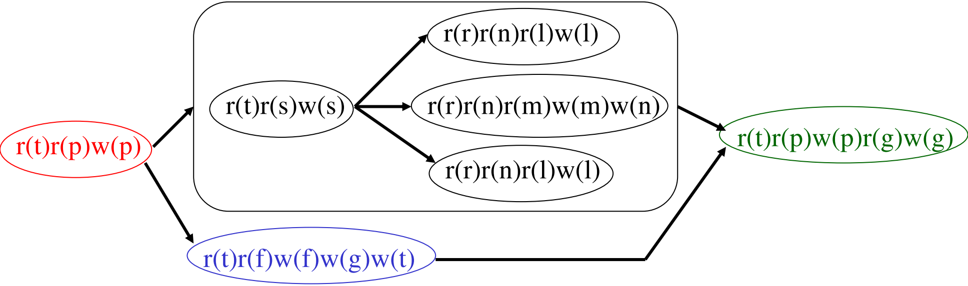
t_{122}: r(r) r(n) r(l) w(l) /* update text index for descriptor_1 */

t_{123}: r(r) r(n) r(m) w(m) w(n) /* update text index for descriptor_2 */

t_{124}: r(r) r(n) r(l) w(l) /* update text index for descriptor_3 */

t_{13}: r(t) r(f) w(f) w(g) w(t) /* update folder by sender */

t_{14}: r(t) r(p) w(p) r(g) w(g) /* assign priority */



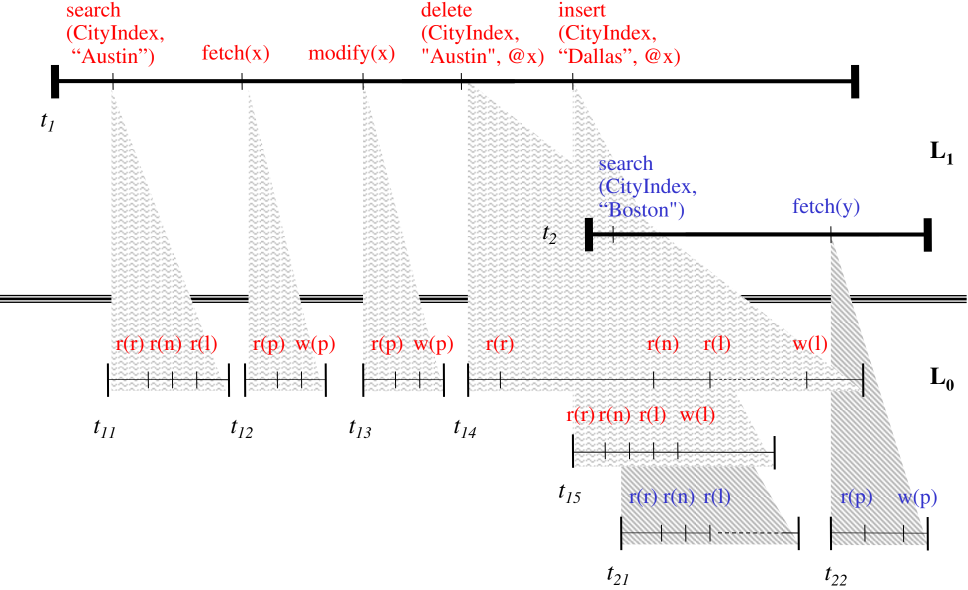
Locking for Nested Transactions

2PL protocol for nested transactions:

- Leaves of a transaction tree acquire locks as needed, based on 2PL for the duration of the transaction.
- Upon terminating a thread, all locks held by the thread are inherited by its parent.
- A lock request by a thread is granted if no conflicting lock on the same data item is currently held or the only conflicting locks are held by ancestors of the thread.

Theorem 10.1:
2PL for nested transactions generates only schedules that are equivalent to a serial execution of the transactions where each transaction executes all its sibling sets serially.

Layered Locking with Intra-transaction Parallelism



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Tuning Repertoire

- Manual locking (or manual preclaiming)
- Choice of SQL isolation level(s)
- Application structuring towards short transactions
- MPL control

SQL Isolation Levels

Definition 10.1 (Isolation Levels):

- A schedule s runs under isolation level **read uncommitted** (aka. dirty read or browse mode) if write locks are subject to S2PL.
- A schedule s runs under isolation **read committed** (aka. cursor stability) if write locks are subject to S2PL and read locks are held for the duration of an SQL operation.
- A schedule s runs under isolation level **serializability** if it can be generated by S2PL.
- A schedule s runs under isolation level **repeatable read** if all anomalies other than phantoms are prevented.

Remark: A scheduler can use different isolation levels for different transactions.

Observation: *read committed is susceptible to lost updates*

Example: $r_1(x)\ r_2(x)\ w_2(x)\ c_2\ w_1(x)\ c_1$

Multiversion Isolation Levels

Definition 10.2 (Multiversion Read Committed and Snapshot Isolation Levels):

- A transaction runs under isolation level **multiversion read committed** if it reads the most recent committed versions as of the transaction's begin and uses S2PL for writes.
- A transaction runs under **snapshot isolation** if it reads the most recent versions as of the transaction's begin and its write set is disjoint with the write sets of all concurrent transactions.

Observation: *snapshot isolation does not guarantee MVSR*

Example:

$r_1(x_0)\ r_1(y_0)\ r_2(x_0)\ r_2(y_0)\ w_1(x_1)\ c_1\ w_2(y_2)\ c_2$

Possible interpretation:

constraint $x + y \geq 0$, $x_0 = y_0 = 5$,

t_1 subtracts 10 from x, t_2 subtracts 10 from y

Application-level "Optimistic Locking"

Idea: strive for short transactions or short lock duration

Approach:

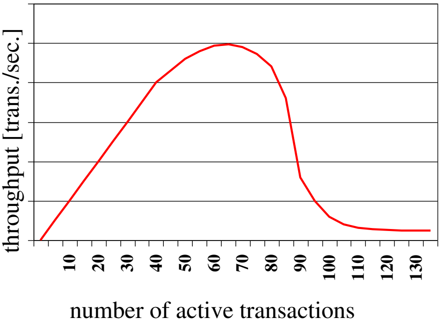
- aim at two-phase structure of transactions:
  read phase + short write phase
- run queries under relaxed isolation level (typically read committed)
- rewrite program to test for concurrent writes during write phase

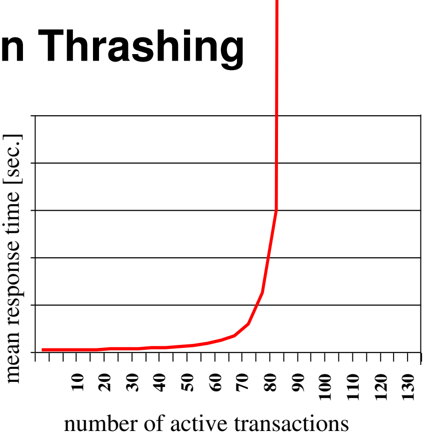
Example:

Select Balance, ***Counter*** *Into :b,* ***:c***
From Accounts Where AccountNo = :x
...
compute interests and fees, set b, ...
...
Update Accounts
Set Balance = :b, ***Counter = Counter + 1***
Where AccountNo =:x And ***Counter = :c***

avoids lost updates, but cannot guarantee consistency

Data-Contention Thrashing



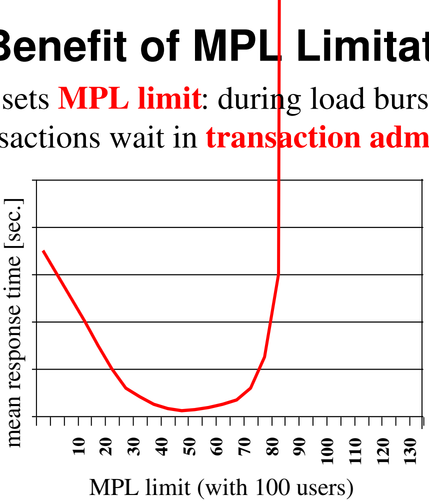


Unrestricted **multiprogramming level (MPL)** can lead to performance disaster known as **data-contention thrashing**:

- additional transactions cause superlinear increase of lock waits
- throughput drops sharply
- response time approaches infinity

Benefit of MPL Limitation

system admin sets **MPL limit**: during load bursts
excessive transactions wait in **transaction admission queue**



avoids thrashing, but poses a tricky tuning problem:

- overly low MPL limit causes long waits in admission queue
- overly high MPL limit opens up the danger of thrashing

problem is even more difficult for highly heterogeneous workloads

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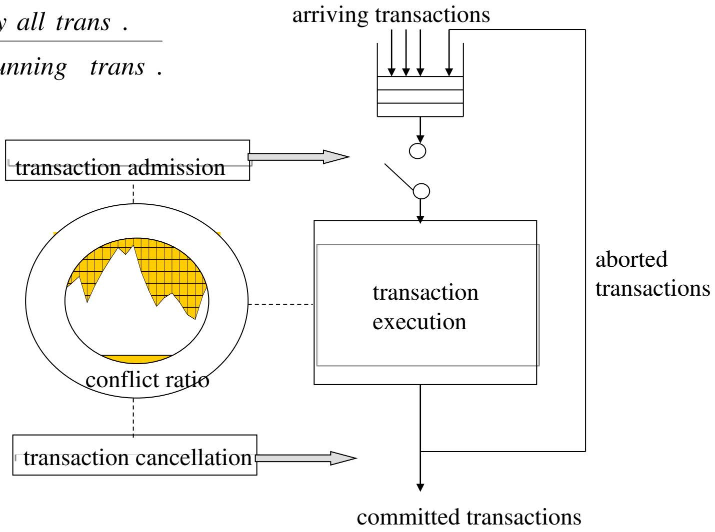
Conflict-ratio-driven Overload Control

$$conflict\ ratio = \frac{\#\,locks\ \ held\ \ by\ all\ trans.}{\#\,locks\ \ held\ \ by\ running\ \ trans.}$$

critical conflict ratio ≈ 1.3



Conflict-ratio-driven Overload Control Algorithm

```
upon begin request of transaction t:
        if conflict ratio < critical conflict ratio
        then admit t else put t in admission queue fi
upon lock wait of transaction t:
        update conflict ratio
        while not (conflict ratio < critical conflict ratio)
           among trans. that are blocked and block other trans.
              choose trans. v with smallest product
              #locks held * #previous restarts
           abort v and put v in admission queue od
upon termination of transaction t:
        if conflict ratio < critical conflict ratio then
           for each transaction q in admission queue do
                 if (q will be started the first time) or
                    (q has been a rollback/cancellation victim and
                     all trans. that q was waiting for are terminated)
                 then admit q fi od fi
```

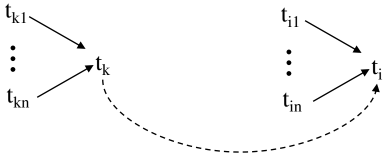
Wait-depth Limitation (WDL)

Wait depth of transaction t =

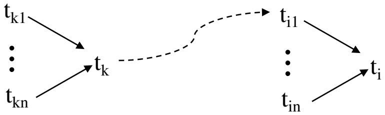
$$\left\{\begin{array}{ll} 0 & \textit{if}\ \ t\ \textit{is running} \\ i+1 & \textit{if}\ \ \max\{\textit{wait depth of transactions that block } t\} = i \end{array}\right\}$$

Policy: allow only wait depths ≤ 1

Case 1:



Case 2:



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Lessons Learned

- Locking can be efficiently implemented,
  with flexible handling of memory overhead
  by means of multi-granularity locks
- Tuning options include
  - choice of isolation levels
  - application-level tricks
  - MPL limitation
- Tuning requires extreme caution to guarantee correctness:
  if in doubt, don't do it!
- Concurrency control is susceptible to data-contention thrashing
  and needs overload control