# Transactional Information Systems:

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

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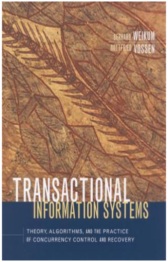


*"Teamwork is essential. It allows you to blame someone else."(Anonymous)*

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- 15.3 Intra-transaction Savepoints
- 15.4 Exploiting Parallelism During Restart
- 15.5 Main-Memory Data Servers
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*"Success is a lousy teacher." (Bill Gates)*

# 2-Level Logging for Index Operations

log entries for $insert_{ij}$ (k, @x)
on B-tree path along pages r, n, l, with split of l into l and m:

- $write_{ij1}(l)$
- $write_{ij2}(m)$
- $write_{ij3}(n)$
- $insert^{-1}_{ij}(k, @x)$

→ writes the original contents of l
twice on the log (undo/redo info for l and m)

# Logical Logging for Redo of Index Splits

log only $L_1$ operation for transaction redo (to save log space) and rely on careful flush ordering for subtransaction atomicity

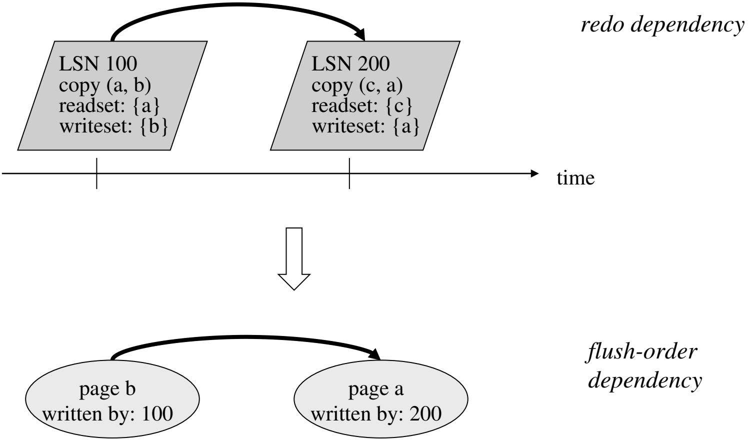
possible cases after a crash (because of arbitrary page flushing):

1) l, m, and n are in old state (none were flushed)
2) l is new, m and n are old
3) m is new, l and n are old
4) n is new, l and m are old
5) l and m are new, n is old
6) l and n are new, m is old
7) m and n are new, l is old
8) l, m, and n are in new state (all were flushed)

must avoid cases 2 and 6 (all other cases are recoverable) by enforcing flush order $m \prec l \prec n$

in addition, posting (n) could be detached from half-split (l and m) by link technique, so that $m \prec l$ is sufficient

# The Need for Redo and Flush-Order Dependencies




Problem: *if a were flushed before b and the system crashed in between, the copy operation with LSN 100 could not be redone*

# Redo and Flush-Order Dependencies

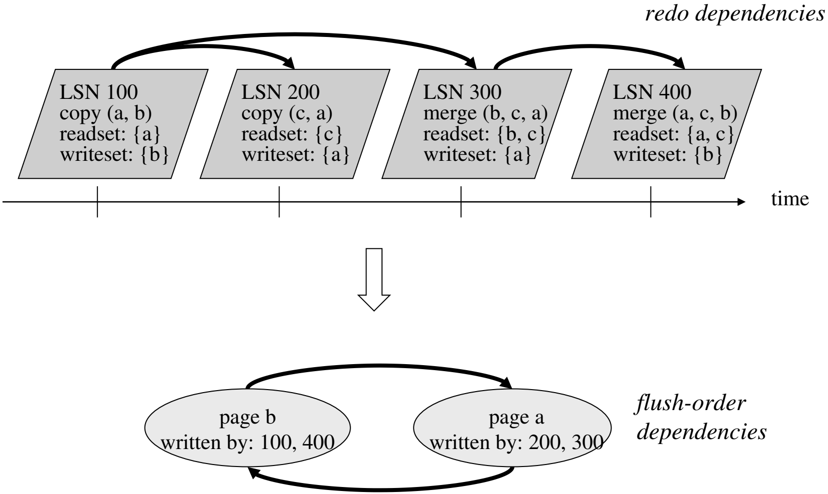
**Opportunity:** operations on large objects (BLOBs, stored procedure execution state) can achieve significant savings on log space by logical logging

**Difficulty:** redo of partially surviving multi-page operations

**Definition:**
There is a **redo dependency** from logged operation f(...) to logged operation g(...) if
- f precedes g on the log and
- there exists page x such that $x \in$ readset(f) and $x \in$ writeset(g)

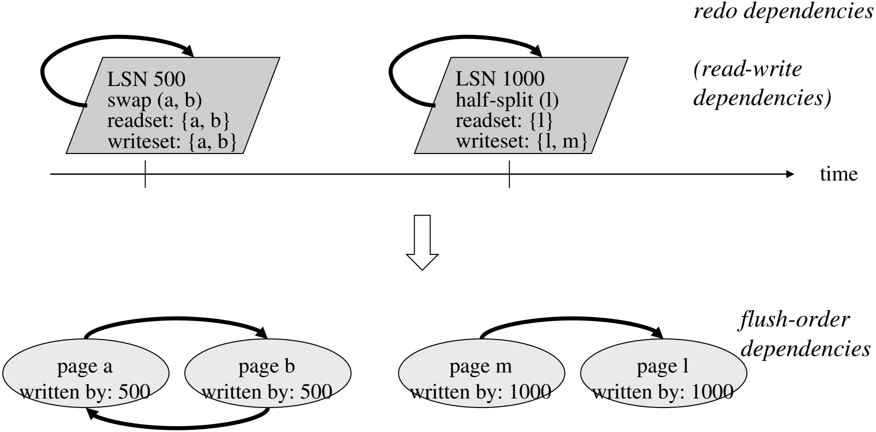
**Definition:**
There is a **flush order dependency** from page y to page z (i.e., page y must be flushed before page z) if
there are logged operations f and g with
- $y \in$ writeset(f) and $z \in$ writeset(g)
- and a redo dependency from f to g.

# Cyclic Flush-Order Dependencies




Need to flush all pages on the cycle atomically
or force physical, full-write, log entries (i.e., after-images) atomically

# Intra-Operation Flush-Order Dependencies



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# The Case for Partial Rollbacks

Additional calls during normal operation
(for partial rollbacks to resolve deadlocks or
application-defined intra-transaction consistency points):

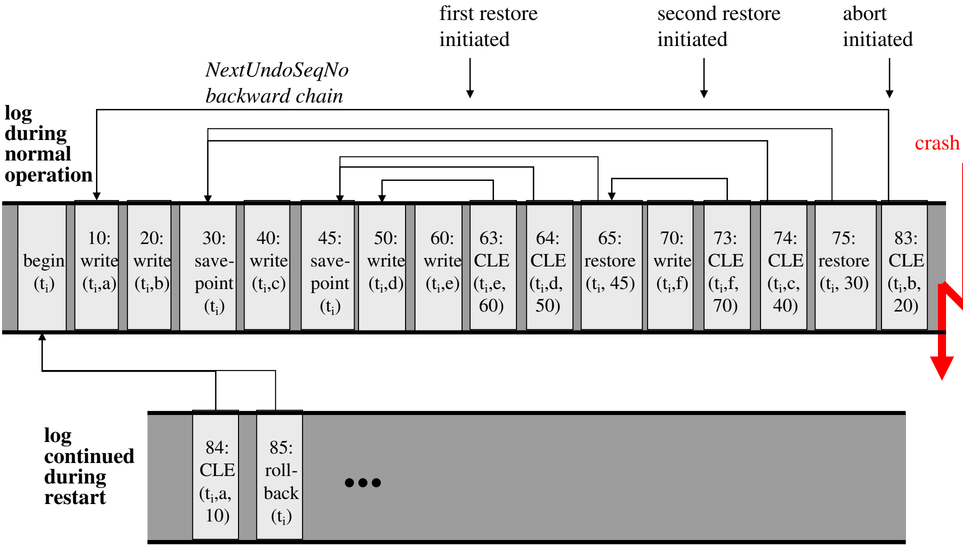
- *save (trans)* $\uparrow s$
- *restore (trans, s)*

Approach:
savepoints are recorded on the log, and restore creates CLEs

Problem with nested rollbacks:
$l_1(x)\ w_1(x)\ l_1(y)\ w_1(y)\ w_1^{-1}(y)\ u_1(y)\ l_2(y)\ w_2(y)\ c_2\ l_1(y)\ (w_1^{-1}(y)^{-1}\ w^{-1}(y)\ w^{-1}(x)$
→ not prefix reducible

Problem eliminated with NextUndoSeqNo backward chaining:
$l_1(x)\ w_1(x)\ l_1(y)\ w_1(y)\ w_1^{-1}(y)\ u_1(y)\ l_2(y)\ w_2(y)\ c_2\ w^{-1}(x)$
→ prefix reducible

# NextUndoSeqNo Backward Chain for Nested Rollbacks



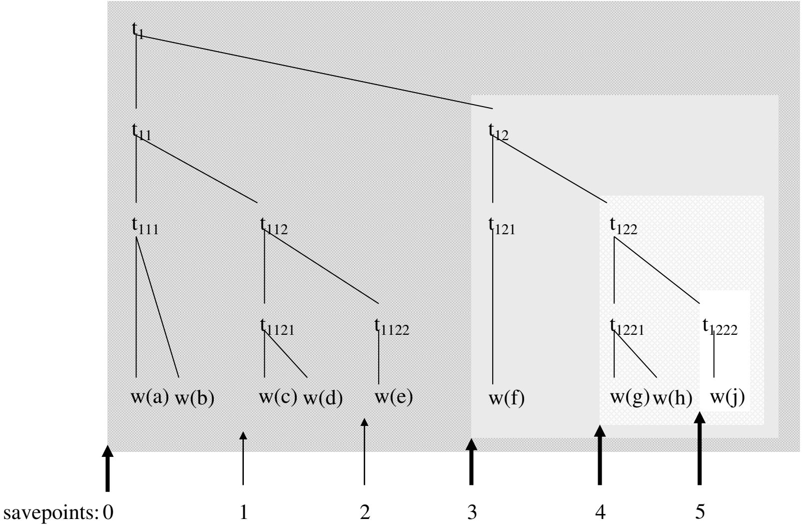
# Savepoint Algorithm

```
savepoint (transid):
        newlogentry.LogSeqNo := new sequence number;
        newlogentry.ActionType := savepoint;
        newlogentry.PreviousSeqNo :=
             ActiveTrans[transid].LastSeqNo;
        newlogentry.NextUndoSeqNo :=
             ActiveTrans[transid].LastSeqNo;
        ActiveTrans[transid].LastSeqNo := newlogentry.LogSeqNo;
        LogBuffer += newlogentry;
```

# Restore Algorithm

```
restore (transid, s):
   logentry := ActiveTrans[transid].LastSeqNo;
   while logentry is not equal to s do
      if logentry.ActionType = write or full-write then
        newlogentry.LogSeqNo := new sequence number;
        newlogentry.ActionType := compensation;
        newlogentry.PreviousSeqNo:=ActiveTrans[transid].LastSeqNo;
        newlogentry.RedoInfo :=
               inverse action of the action in logentry;
        newlogentry.NextUndoSeqNo := logentry.PreviousSeqNo;
        ActiveTrans[transid].LastSeqNo := newlogentry.LogSeqNo;
        LogBuffer += newlogentry;
        write (logentry.PageNo) according to logentry.UndoInfo;
        logentry := logentry.PreviousSeqNo;
      end /*if*/;
      if logentry.ActionType = restore then
        logentry := logentry.NextUndoSeqNo;
      end /*if*/
   end /*while*/
   newlogentry.LogSeqNo := new sequence number;
   newlogentry.ActionType := restore;
   newlogentry.TransId := transid;
   newlogentry.PreviousSeqNo := ActiveTrans[transid].LastSeqNo;
   newlogentry.NextUndoSeqNo := s.NextUndoSeqNo;
   LogBuffer += newlogentry;
```

# Savepoints in Nested Transactions




*beginnings of active subtransactions are feasible savepoints*

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# Exploiting Parallelism During Restart

- Parallelize redo by spawning multiple threads for different page subsets (driven by DirtyPages list), assuming physical or physiological log entries
- Parallelize log scans by partitioning the stable log across multiple disks based on hash values of page numbers
- Parallelize undo by spawning multiple threads for different loser transactions

Incremental restart with
early admission of new transactions right after redo

- by re-acquiring locks of loser transactions (or coarser locks) during redo of history, or
- right after log analysis by allowing access, already during redo, to all non-dirty pages p with p.PageSeqNo < OldestUndoLSN (p)

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# Considerations for Main-Memory Data Servers

Main-memory databases are particularly attractive for telecom or financial apps with < 50 GB of data, fairly uniform workload of short transactions, and very stringent response time requirements

Specific opportunities:

- crash recovery amounts to reloading the database
  $\rightarrow$ physical (after-image) logging attractive
- eager page flushing in the background
  amounts to “fuzzy checkpoint”
- in-memory versioning (with no-steal caching)
  can eliminate writing undo information to stable log
- log buffer forcing can be avoided by “safe RAM”
- incremental, page-wise, redo (and undo) on demand
  may deviate from chronological order

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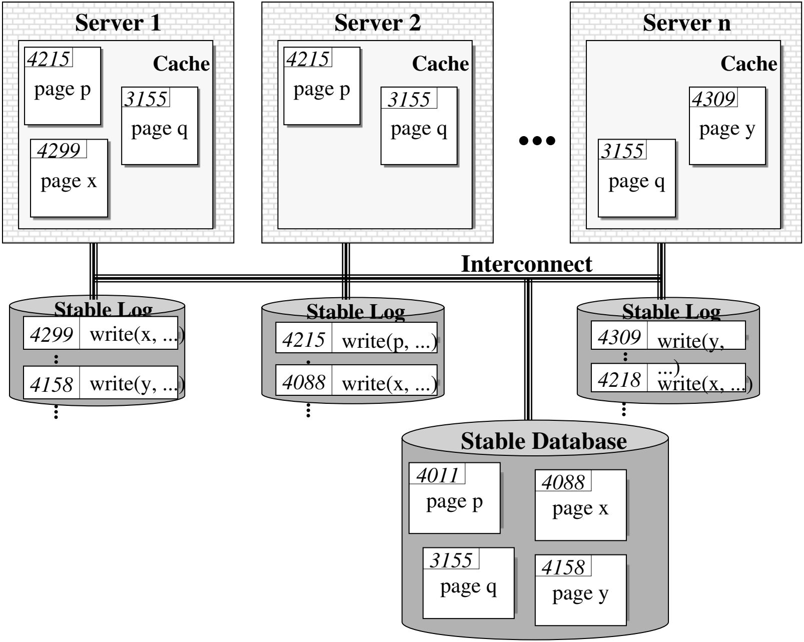
# Architecture of Data-Sharing Clusters

**Data-sharing cluster:**
multiple computers (as data servers) with local memory
and shared disks via high-speed interconnect
for load sharing, failure isolation, and very high availability

**During normal operation:**
- transactions initiated and executed locally
- pages transferred to local caches on demand (data shipping)
- coherency control eliminates stale page copies:
    - multiple caches can hold up-to-date copies read-only
    - upon update in one cache, all other caches drop their copies
    - can be combined with page-model or object-model CC
- logging to global log on shared disk or
  partitioned log with static assignment of server responsibilities or
  private logs for each server for perfect scalability

**Upon failure of a single server:**
failover to surviving servers

# Illustration of Data-Sharing Cluster



# Recovery with "Private" Logs

needs page-wise globally monotonic sequence numbers,
e.g., upon update to page p (without any extra messages):
p.PageSeqNo := max{p.PageSeqNo, largest local seq no} + 1

surviving server performs crash recovery on behalf of the failed one,

- with analyis pass on private log of failed seerver to identify losers,
- scanning and "merging" all private logs for redo,
  possibly with DirtyPages info from the failed server,
  (merging can be avoided by flushing before
  each page transfer across servers),
- scanning private log of failed server for undo

recovery from failure of entire cluster needs
analysis passes, merged redo passes, and undo passes
over all private logs

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# Lessons Learned

- The redo-history algorithms from Chapter 13 and 14 can be extended in a fairly localized and incremental manner.
- Practically important extensions are:
  - logical log entries for multi-page operations
  - as an additional option
  - intra-transaction savepoints and partial rollbacks
  - parallelized and incremental restart for higher availability
  - special architectures like
    - main-memory data servers
    - for sub-second responsiveness and
    - data-sharing clusters
    - for very high availability