Managing Compliance Data: Addressing the Insider Threat Exemplified by Enron

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When something really bad happens, the government likes to quickly take action to reassure people that it will never happen again

- FDIC
- Sarbanes-Oxley Act
- $700B bailout

SOX had major repercussions for corporate IT

- Most people at the top got away with millions and many did no jail time ➔ top execs have to sign off on financial reports
- No paper trail available for prosecution ➔ retain routine business documents for (typically) 7 years, tamper-proof (*term-immutable*)

Compliance regulations have teeth: periodic audits, fines, jail terms

SEC: $1.65M each

- Deutsche Bank
- Goldman Sachs
- Morgan Stanley
- Solomon Smith Barney
- U.S. Bancorp

SOX:

- Rica Foods CEO $25K
- Deloitte $1M poor audit

The government likes to step in for non-corporate scandals as well.

- Video Privacy Protection Act of 1988
- Gramm-Leach-Bliley Act’s Financial Privacy Rule
- Health Insurance Portability and Accountability Act (HIPAA)

E-government records are also at risk for falsification.

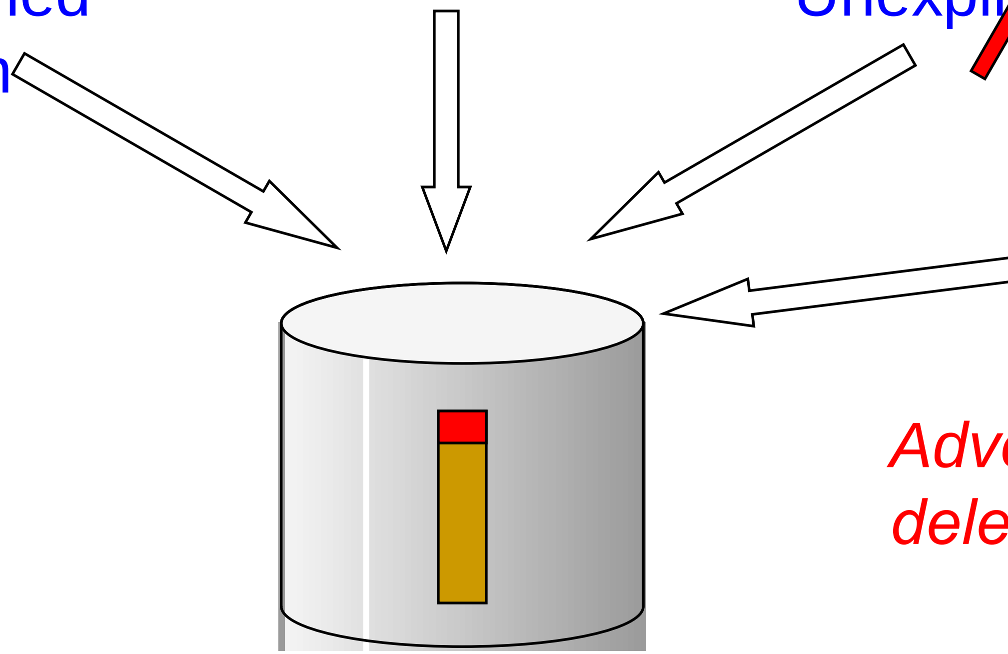
WORM storage helps secure documents against insider tampering

Commit File for Prespecified Retention Period

Append to File
on certain volumes

~~Overwrite/Delete Unexpired File~~

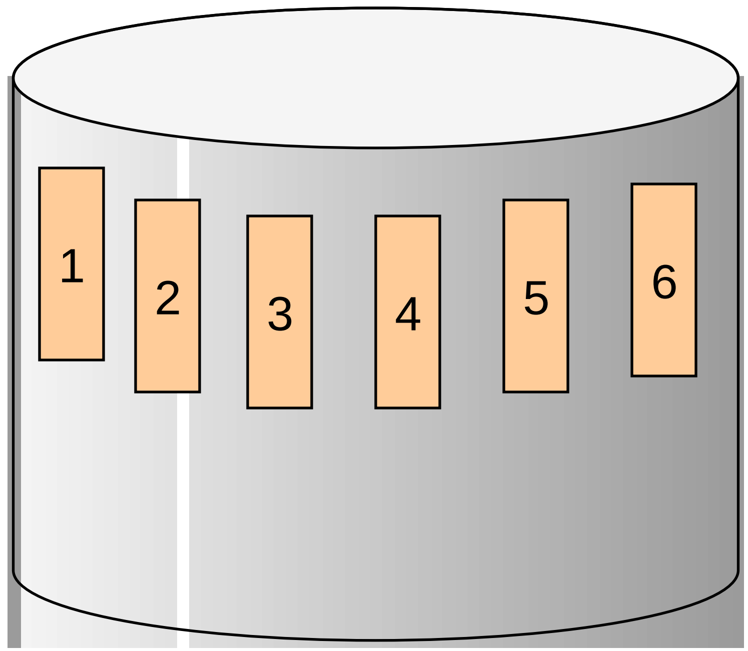
Delete Expired File



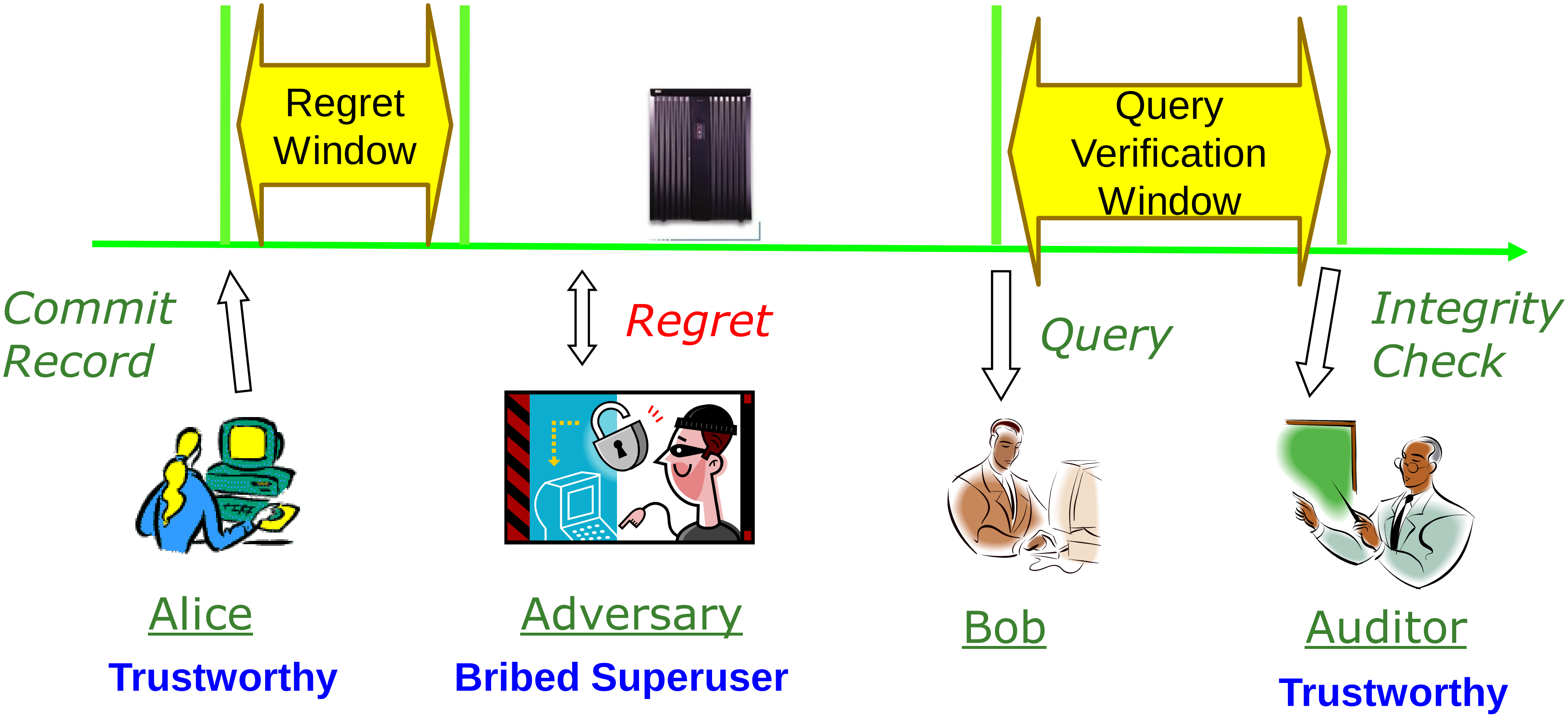
Adversary cannot delete Alice's file

Write Once, Read Many

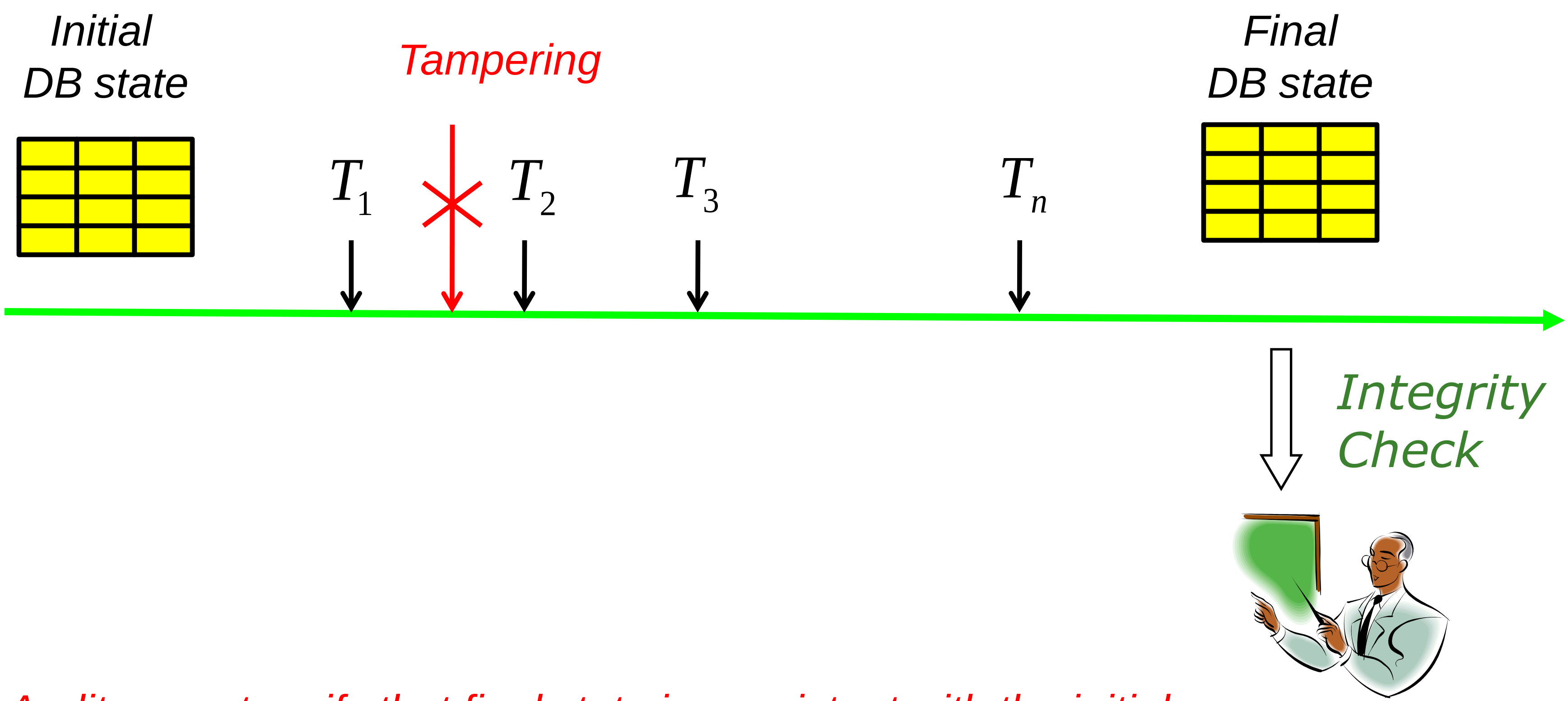
WORM can be used for IM, email, spreadsheets, reports, and even indexes over them. But what about ***structured*** data?



The main "new" threat to tuples is undetected tampering with history.



The goal: a high-performance tamper-evident database that supports term-immutability.

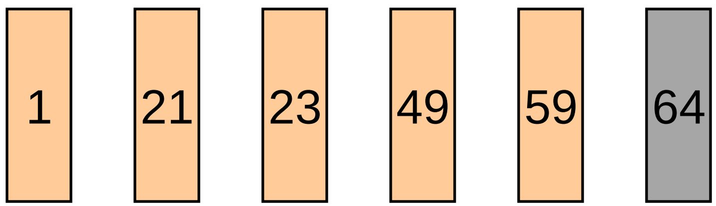


Auditor must verify that final state is consistent with the initial state and sequence of transactions, even with crashes

Auditor

To support term-immutability, we'll use a "transaction-time" database.

When tuple t is updated/deleted,
create a timestamped new copy of it



After 7 years:
Shred!

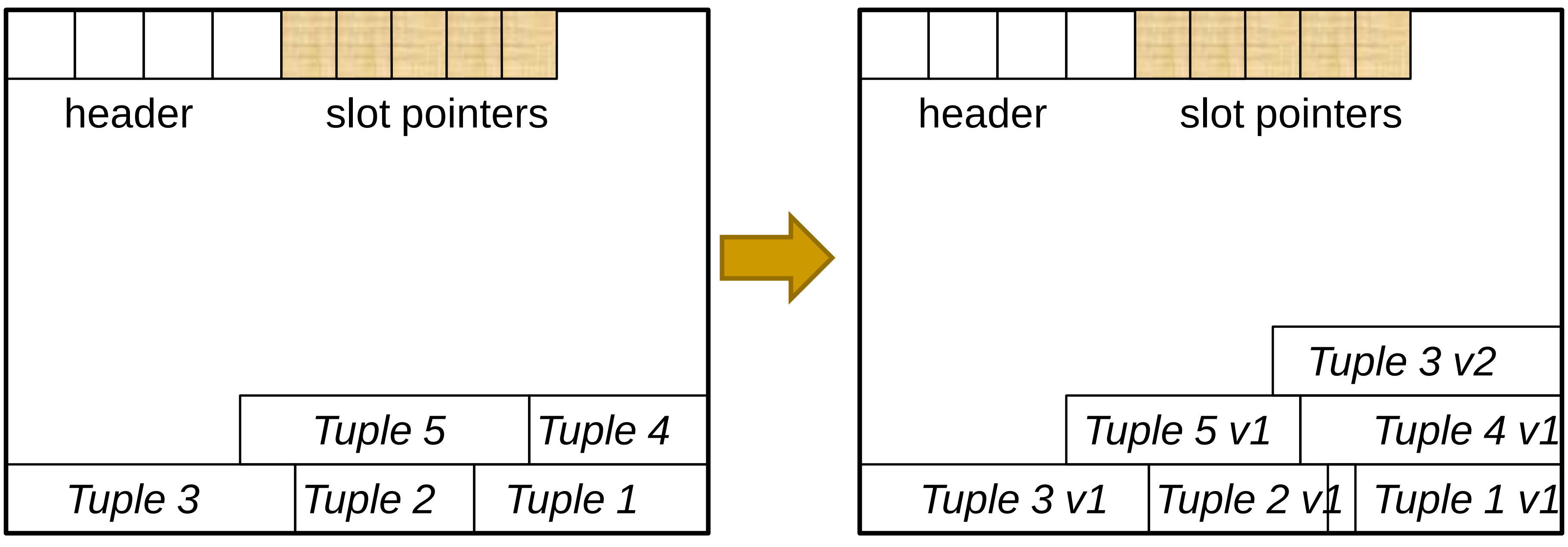
Legitimate update: modifies/deletes the latest version

Tampering: modifies an old version, shreds unexpired tuple

Shredding: after expiration

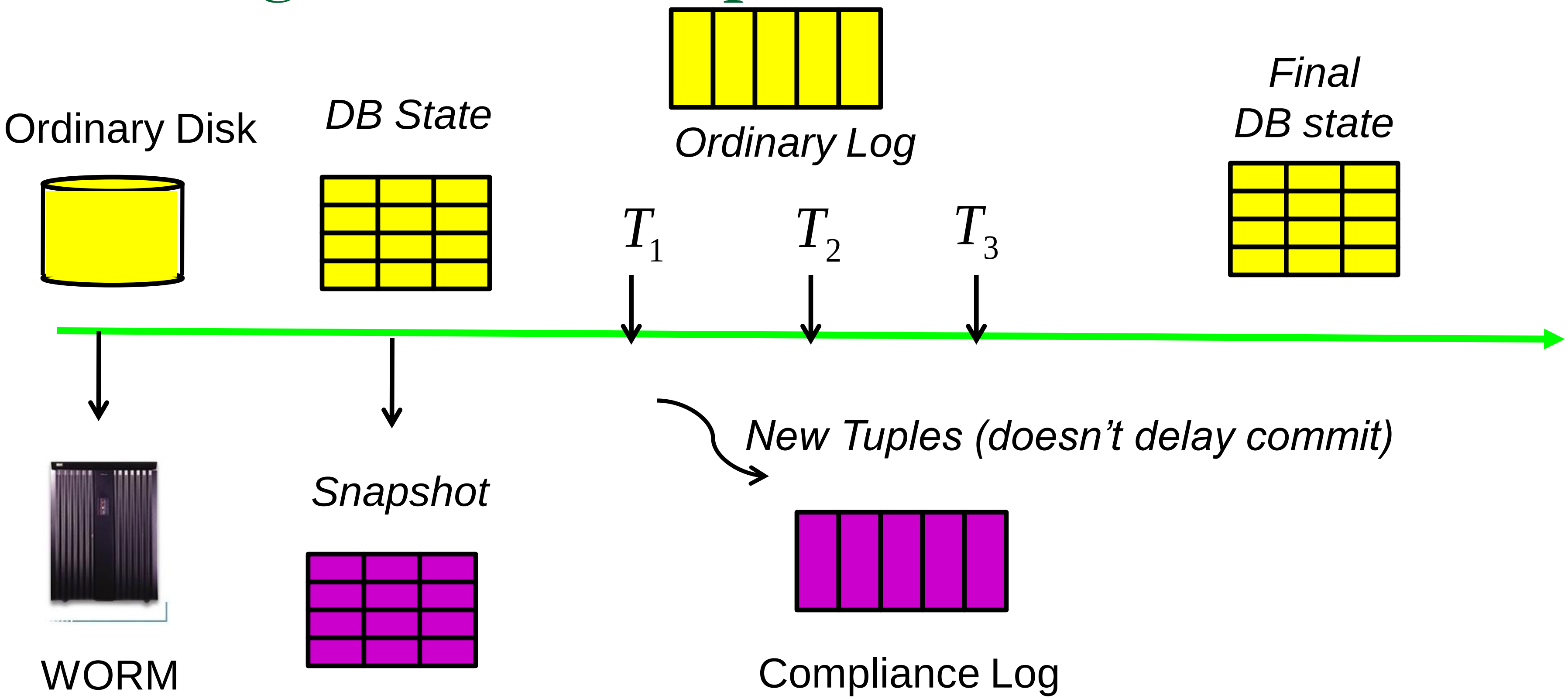
No changes to existing DB applications

The database is *logically* append-only. Pages are modified *in place*.



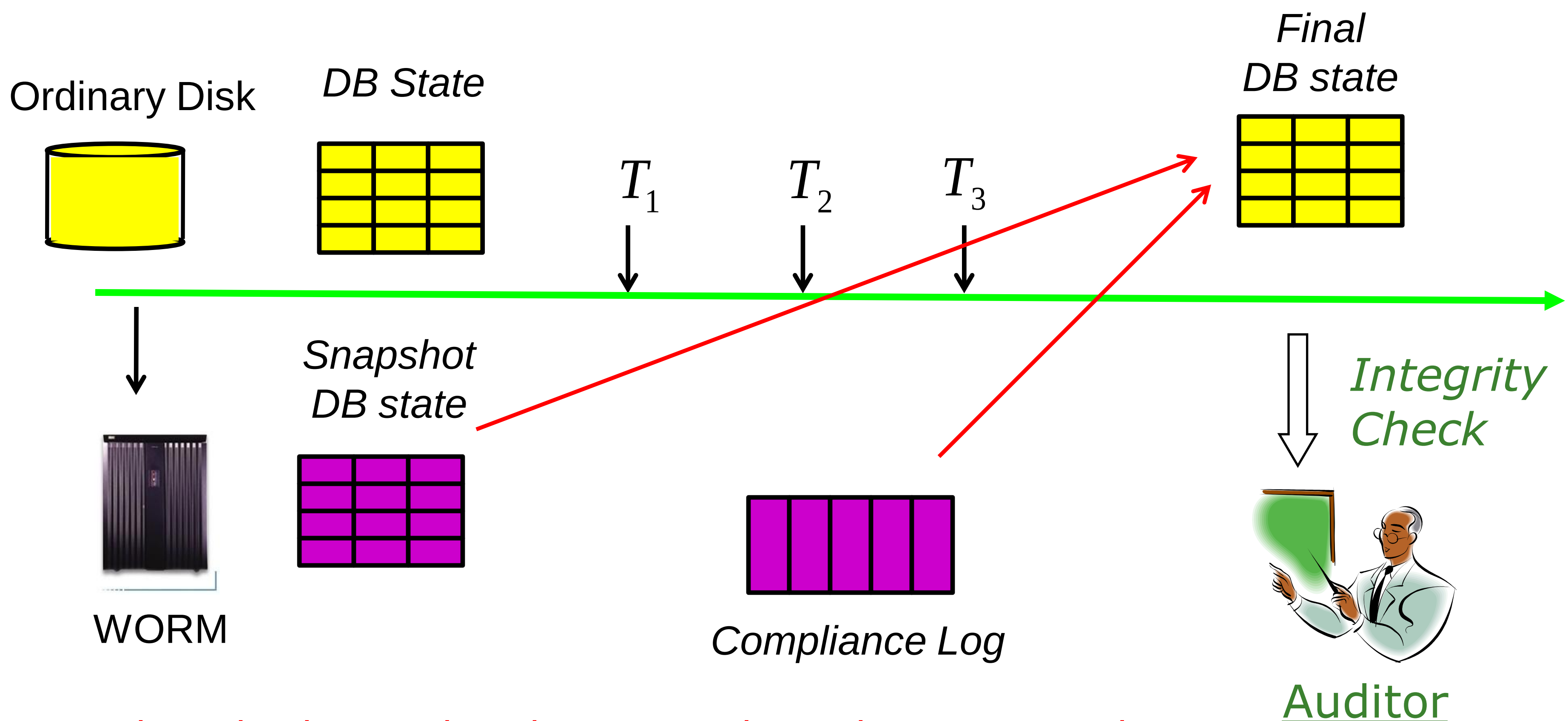
Can be implemented atop an ordinary DBMS on ordinary disk.

Log-consistent DBMS: keep snapshot of DB and log of all new tuples on WORM.



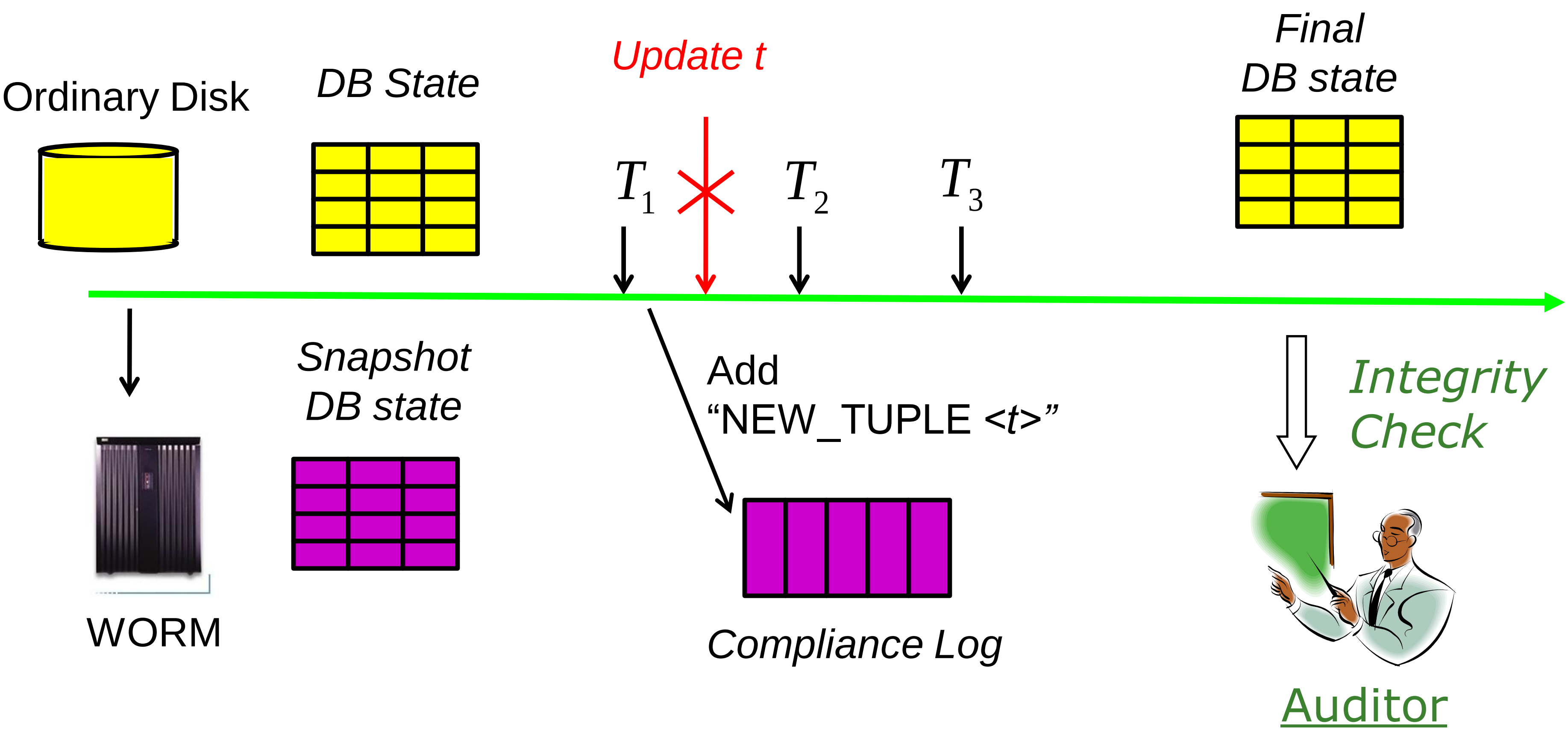
(Trusted) auditor takes signed snapshot.
Space-efficient: delete after audit.

Auditor checks if every record in initial state and in the log is in the final state.



Then check snapshot signature, write & sign new snapshot.
(Also validate integrity of pages, indexes, metadata.)

Tampering will make the compliance log and DB inconsistent.

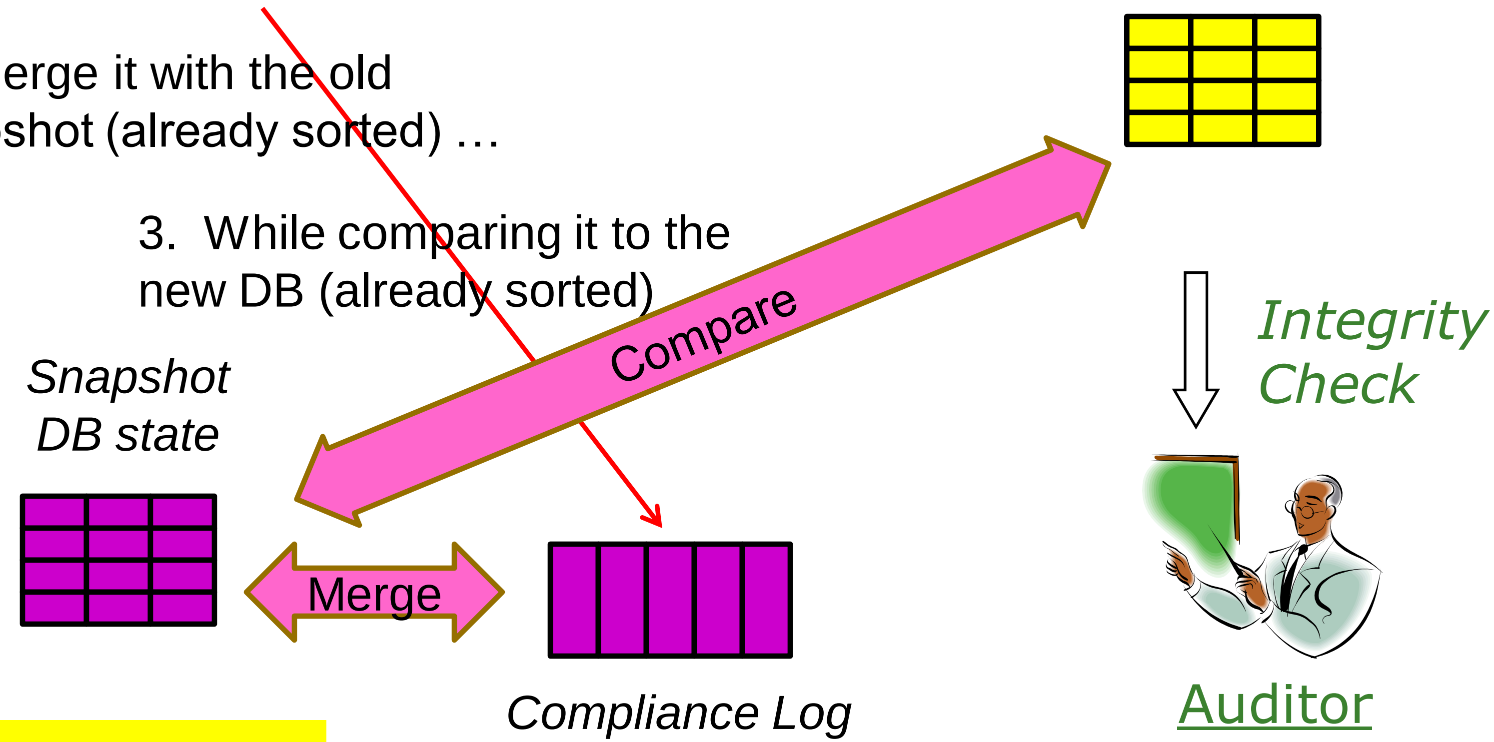


We can speed up audits by using existing B-trees during comparison.

1. Sort the compliance log on <relation name, primary key, timestamp>

2. Merge it with the old snapshot (already sorted) …

3. While comparing it to the new DB (already sorted)



Cost: $O(L \log L + D_s + D_f)$

We can make audits even faster with a commutative incremental cryptographic hash function

1. Compute h(t), for all t
2. Add the h(t) (mod large number)
3. Compare old and new sums
4. Store the new sum (and possibly the new (unsorted) snapshot)

Final DB state

Compare the two sums

Integrity Check

Snapshot DB state

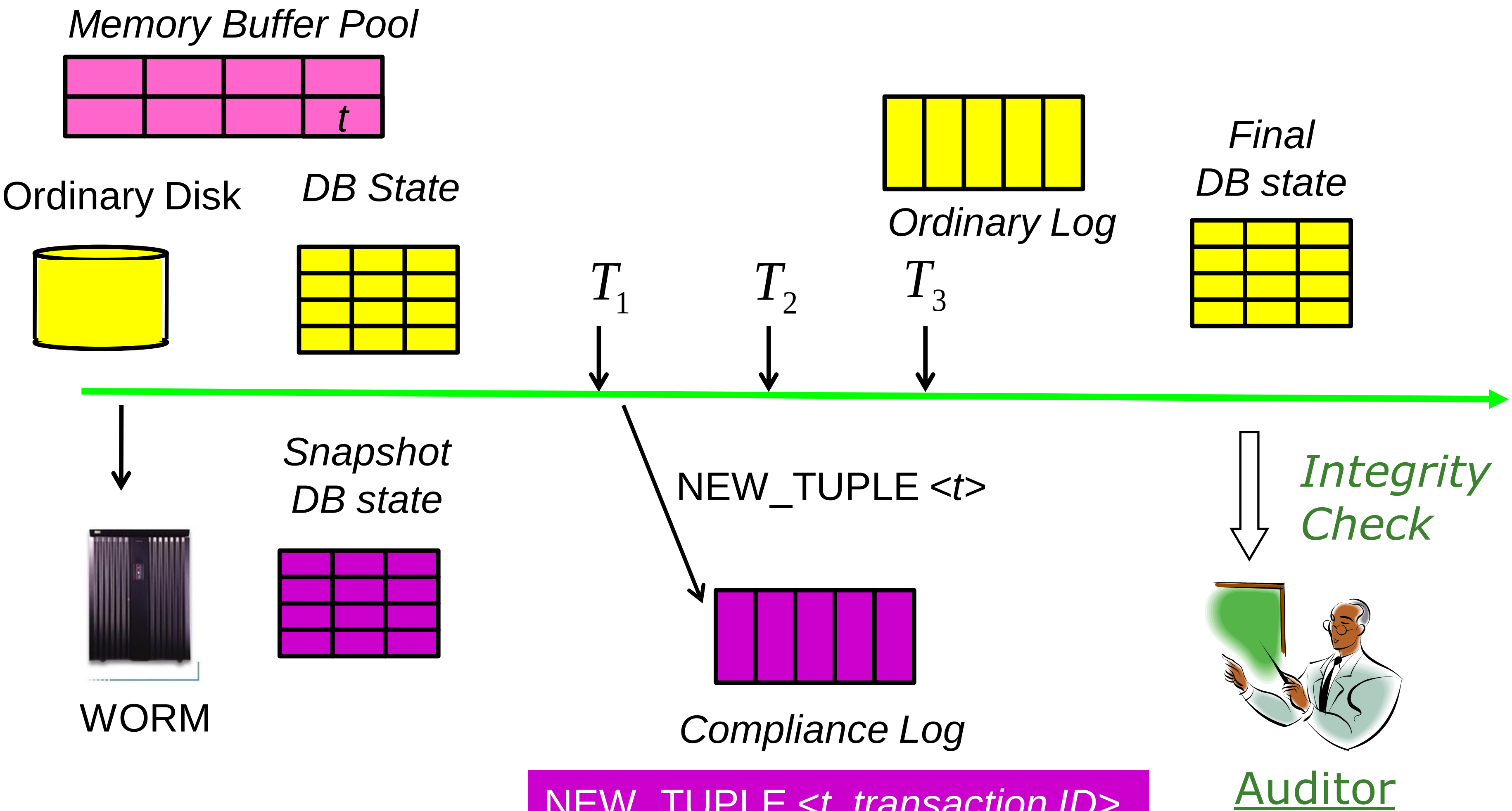
Add h(t)

Compliance Log

Auditor

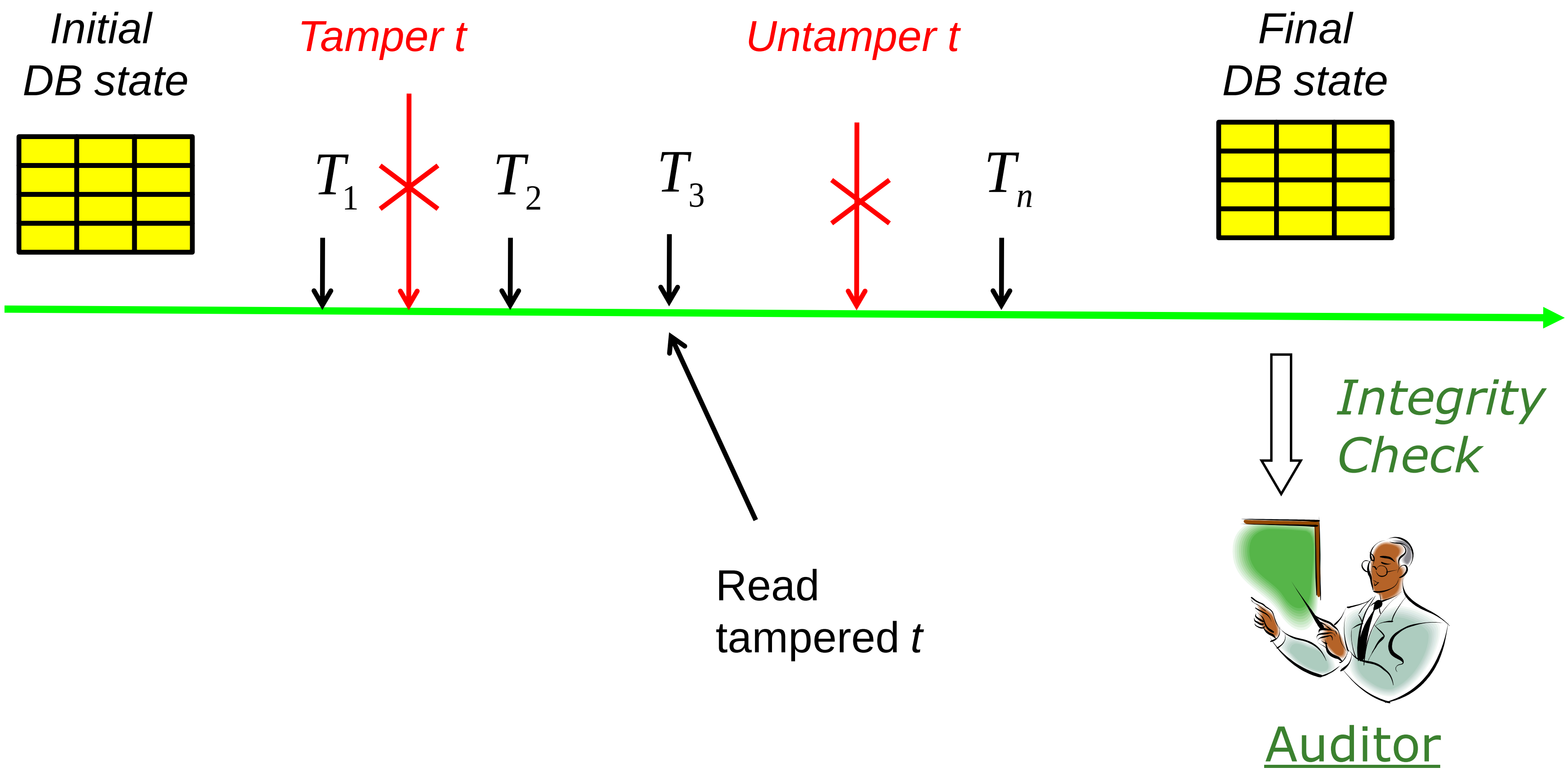
Cost: O(L + D_f)

Compliance log records from aborted transactions will make the audit fail

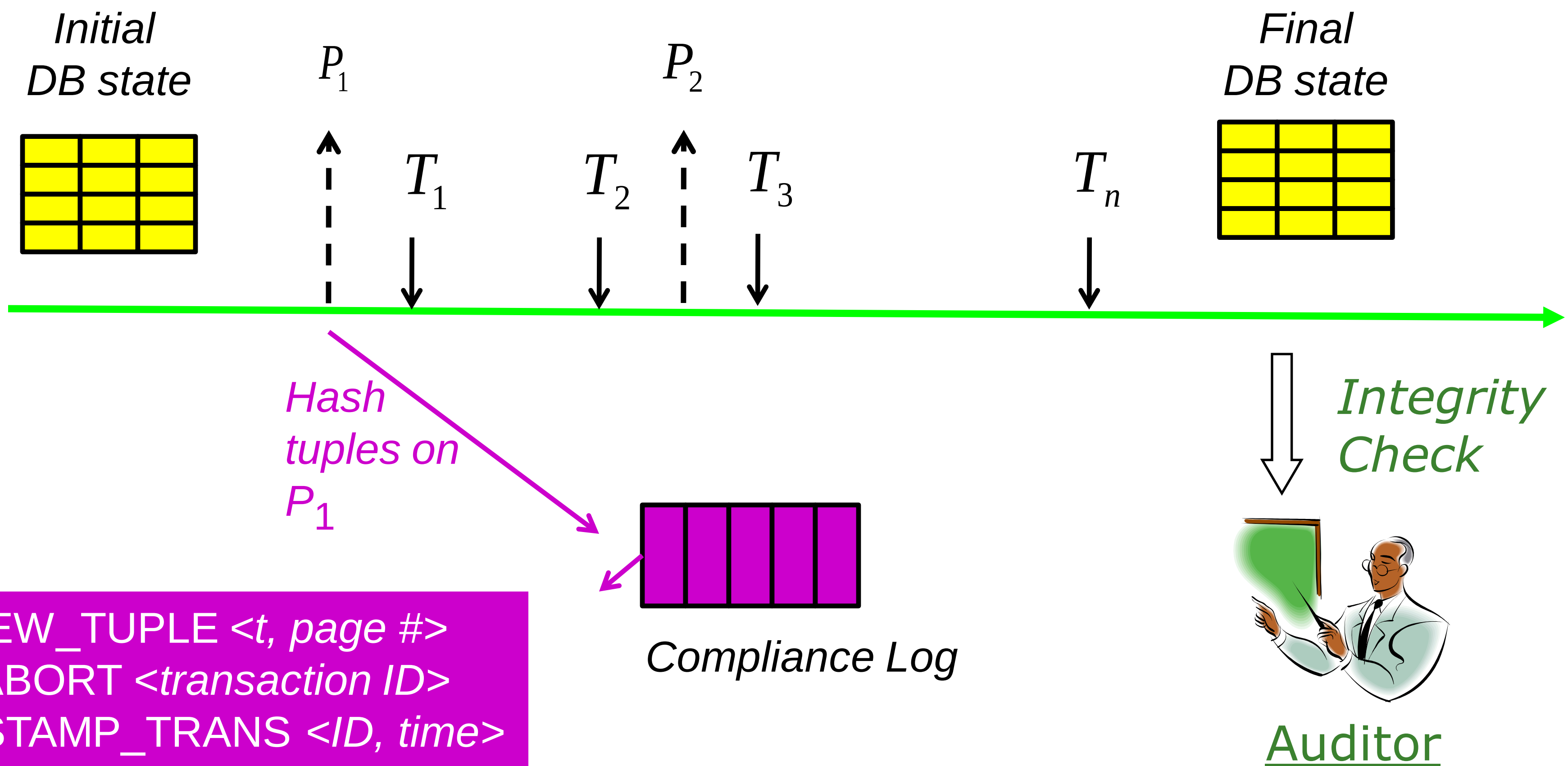


NEW_TUPLE <*t, transaction ID*>
ABORT <*transaction ID*>
STAMP_TRANS <*ID, time*>

But queries between audits may read tampered values.

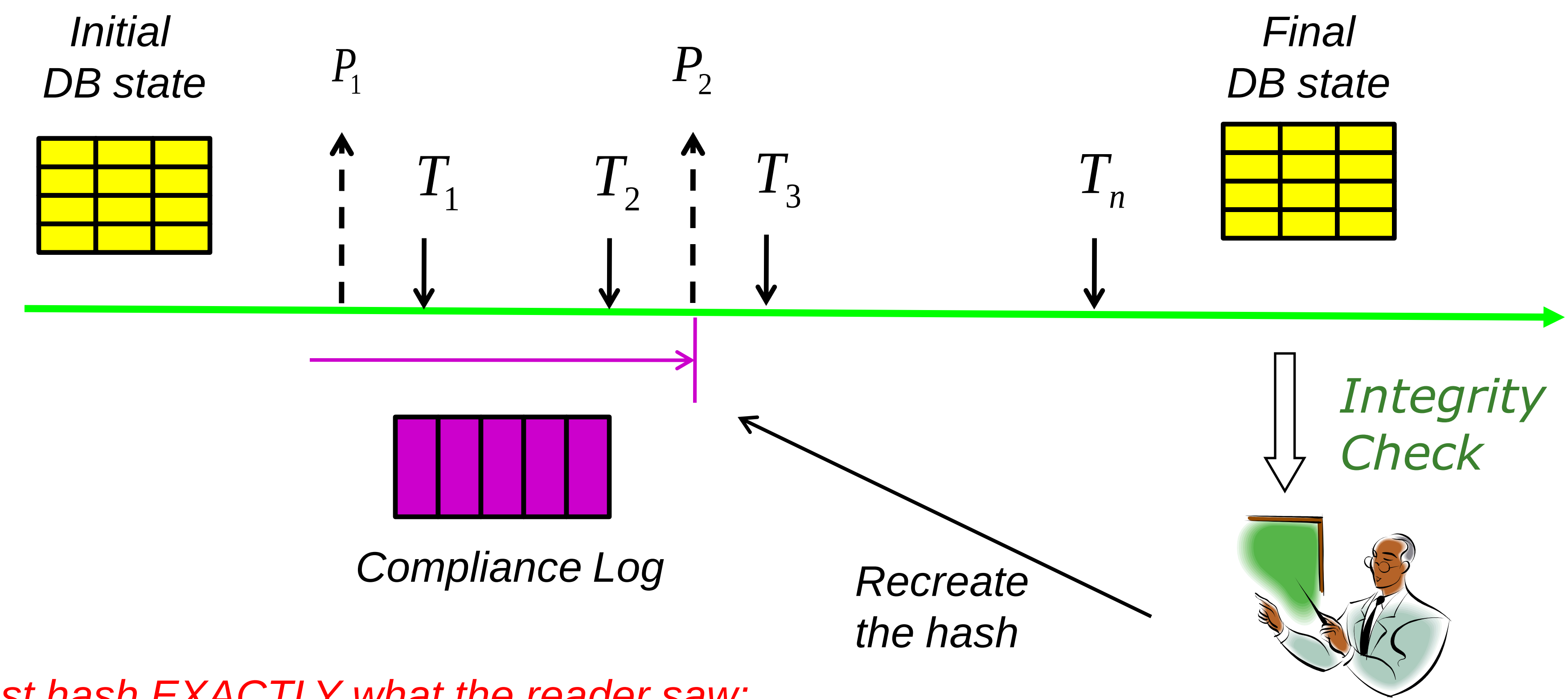


Record page hashes in the compliance log.



NEW_TUPLE <*t, page #*>
ABORT <*transaction ID*>
STAMP_TRANS <*ID, time*>
READ <*page #, hash*>
SPLIT_PAGE <#, #, #,
new contents>

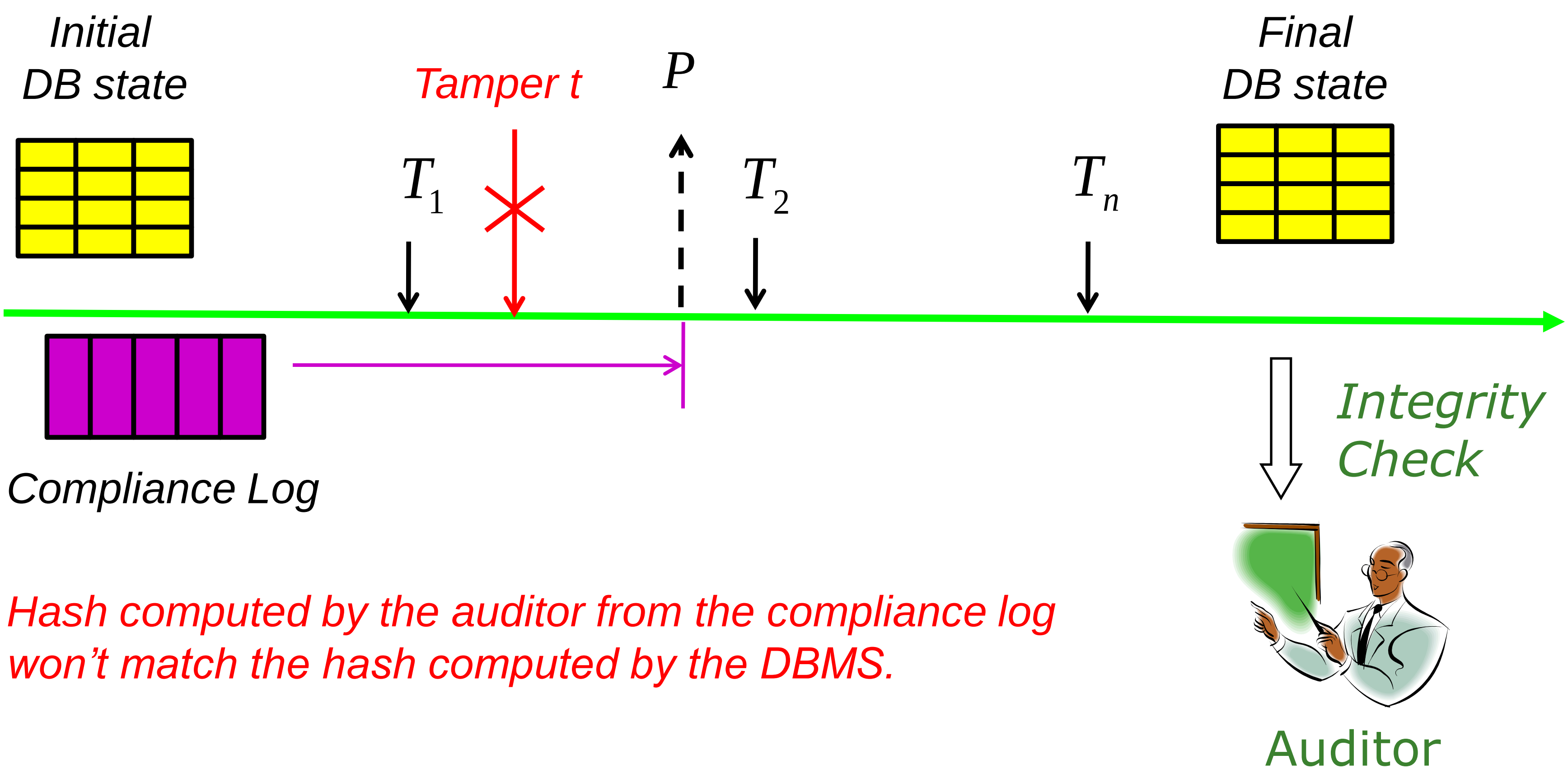
The auditor can replay the log to compute the page hash.



Must hash EXACTLY what the reader saw:
Uncommitted tuples, missing timestamps, no already-aborted tuples.

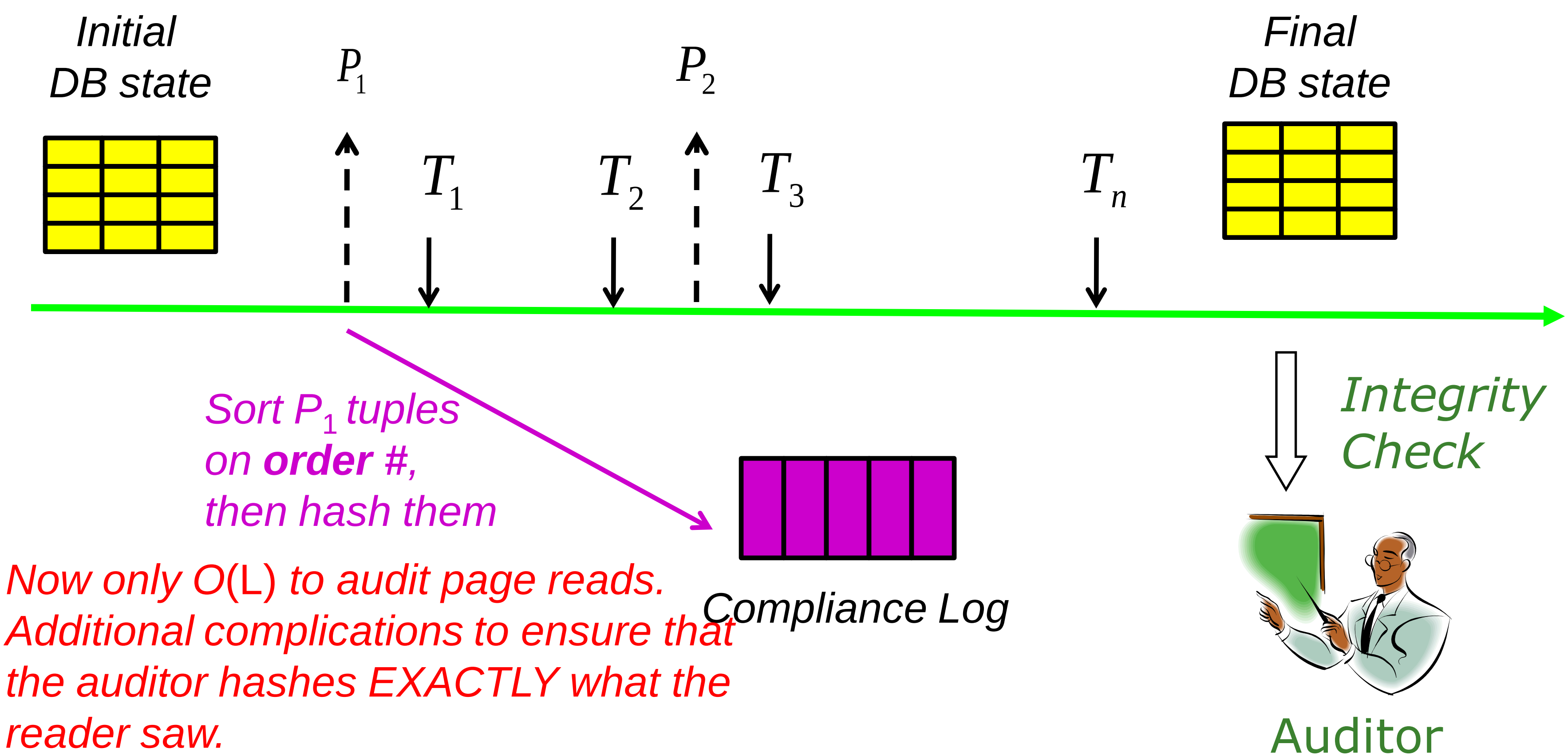
Auditor

Tampering will cause the page hash to change.



Hash computed by the auditor from the compliance log won't match the hash computed by the DBMS.

Replaying the log can be slow. Instead, use an incremental sequential hash function, assign each tuple an order # on its page.



Now only O(L) to audit page reads. Additional complications to ensure that the auditor hashes EXACTLY what the reader saw.

Over time, the DB can get very big, making page integrity checks costly.

- Use time-split B-trees (Lomet & Salzberg) to separate out historical versions of tuples & their index entries
- Put historical tuples/index entries on WORM
- Only audit them one time on WORM
- Log changes to index pages as for data pages

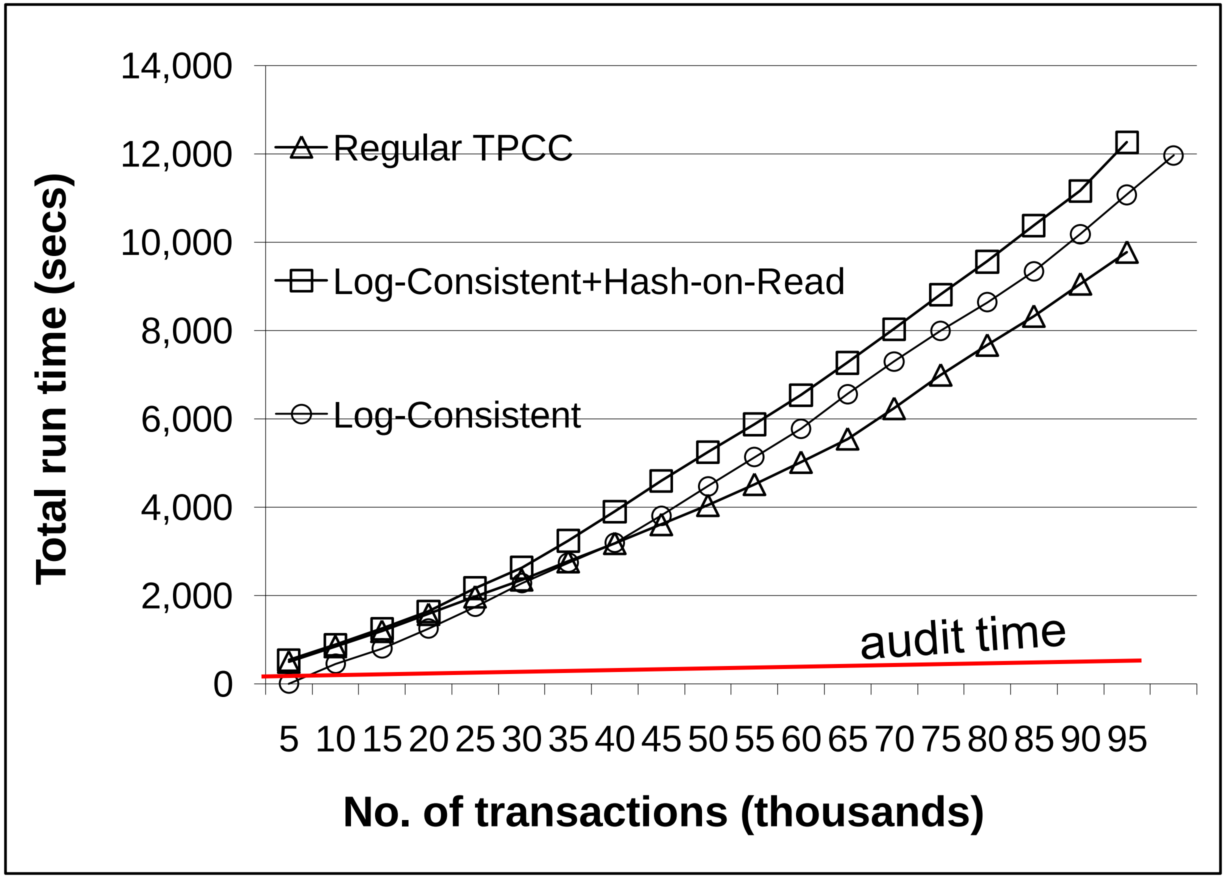
The hard part: log-consistent DBs must handle crashes correctly

- Transaction committed but its entries are not in the compliance log
  - Flush the entries every *regret interval*
- Uncommitted transaction's entries reach the compliance log
  - Entries must be *logically* removed from the log
  - The adversary should not be able to exploit this to delete records of committed transactions
- Recovery: put all new ABORT/STAMP_TRANS records on WORM before traditional recovery

Our implementation used Berkeley DB + transaction time layer + compliance plugin + time-split B-trees

- Not-quite-met goal: *don't change BDB*
  - Log which transactions commit, abort
  - Clean up compliance log at beginning of recovery
  - Could implement these outside of kernel in future
- Logger taps into pread/pwrite
  - Compare new, old versions of page; differences go in compliance log
  - Hash page on pread → trust the buffer cache
- TPC-C + tuple order #s, over NFS

Compliance logging and hash-on-read have very reasonable overhead.



Details, details, details in ICDE 2009 paper

- How to shred tuples (complicated but no fancy crypto)
- Non-quiescent audits
- Lazy/eager metadata changes
- Crash before committed transaction's NEW_TUPLEs reach WORM
- Preventing attacks that exploit "quiet" DB times
- Duplicate NEW_TUPLE , UNDO entries due to crash recovery
- How to decide when to time split
- More experiments

…

In conclusion: we can provide term-immutability for RDBs at modest cost

- Keep signed DB snapshot, log of updates on WORM
  - TPC-C ~10% slower
  - 5-6.5 minute audit for 100K transactions
- Modest changes to DBMS kernel