Hyder: A Transactional Indexed Record Manager for Shared Flash Storage

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What is Hyder?

It's a research project.

- We have two implementations

A software stack for transactional record management

- Stores [key, value] pairs, which are accessed within transactions
- It's a standard interface that underlies all database systems

Functionality

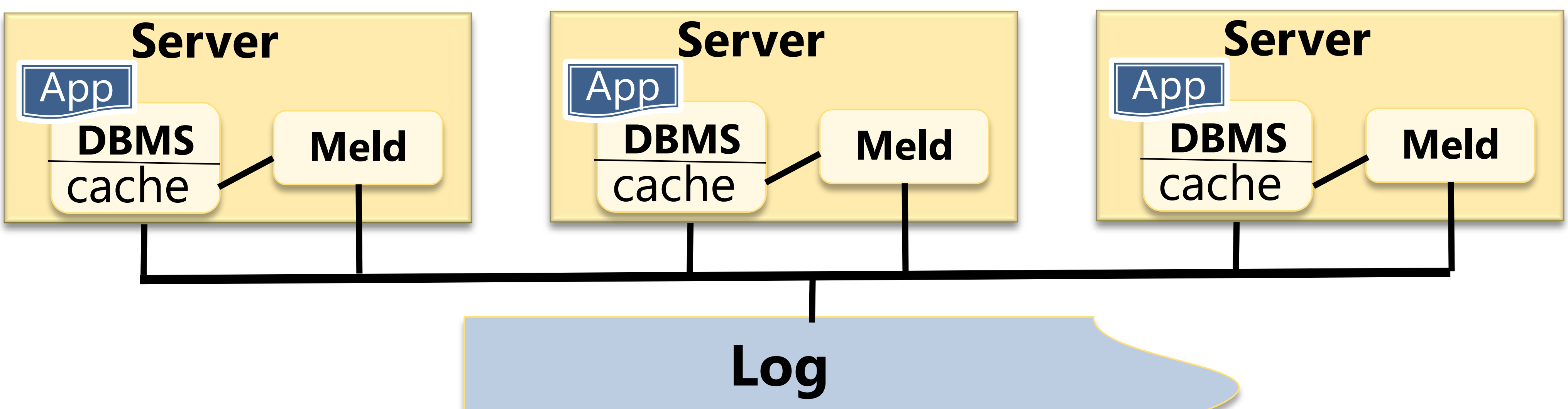
- Records: Stored [key, value] pairs
- Record operations: Insert, Delete, Update,
  Get record where field = X; Get next
- Transactions: Start, Commit, Abort

Why Build Another One?

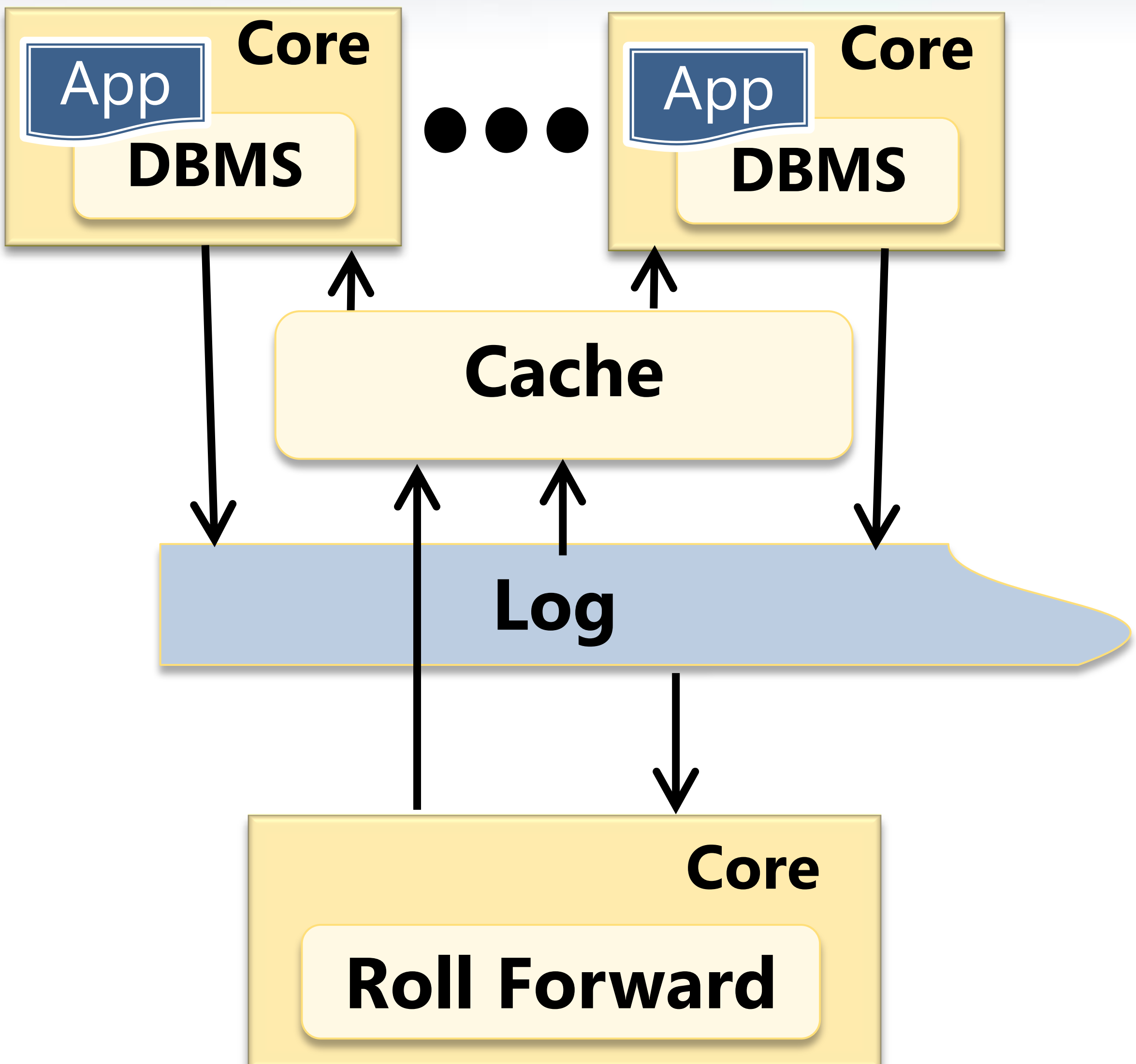
- Enables scaling-out large-scale web services without partitioning data or application
- Supports real-time data analytics
  - Uses multi-version data for high-speed transaction processing and queries on the same server
  - All isolation levels, including concurrency control over key-range operations.
- Exploits technology trends
  - flash memory, high-speed networks, multi-core

Scenario 1: A data-sharing System

- The log is the database. All servers can access it.
- Each transaction executes against its partial, cached, DB copy
- Then it appends its after-images to the log.
- Each server rolls forward the log on its partial, cached DB copy
- Roll forward (a.k.a. meld) does optimistic concurrency control
- N.B.: Log-append is the only server-to-server synchronization



Scenario 2

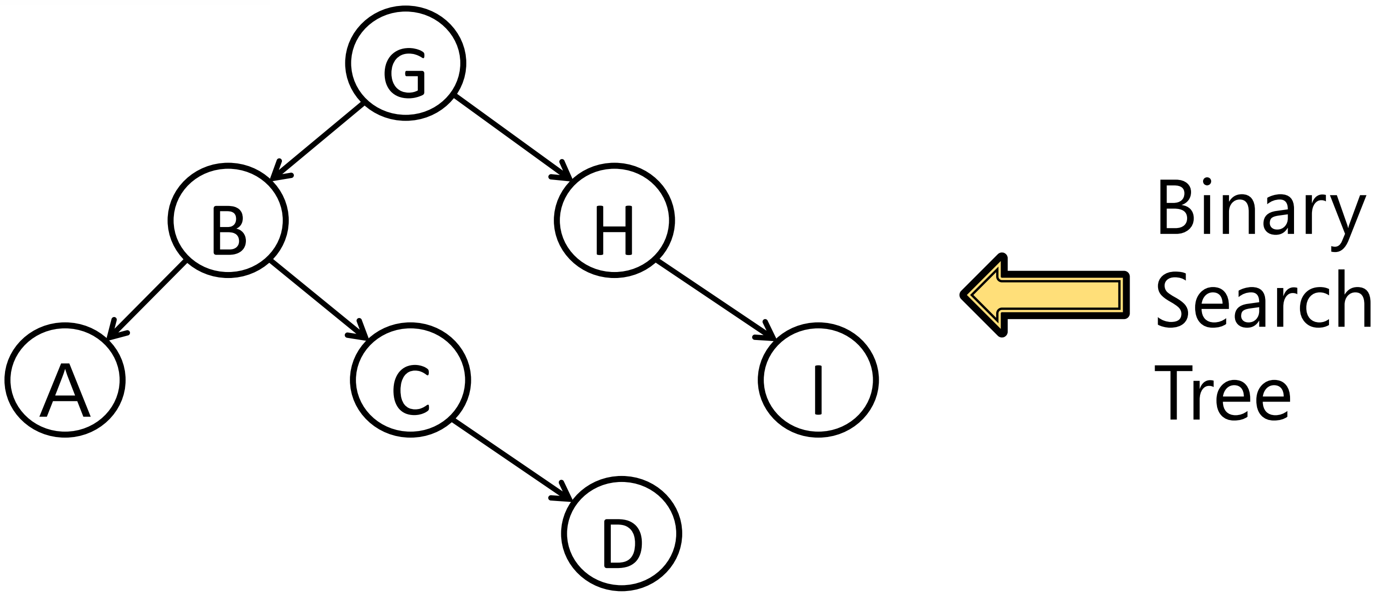


- The log is the database.
- All cores can access it.
- Each transaction appends its after-images to the log.
- One core runs meld to do OCC and roll forward the log

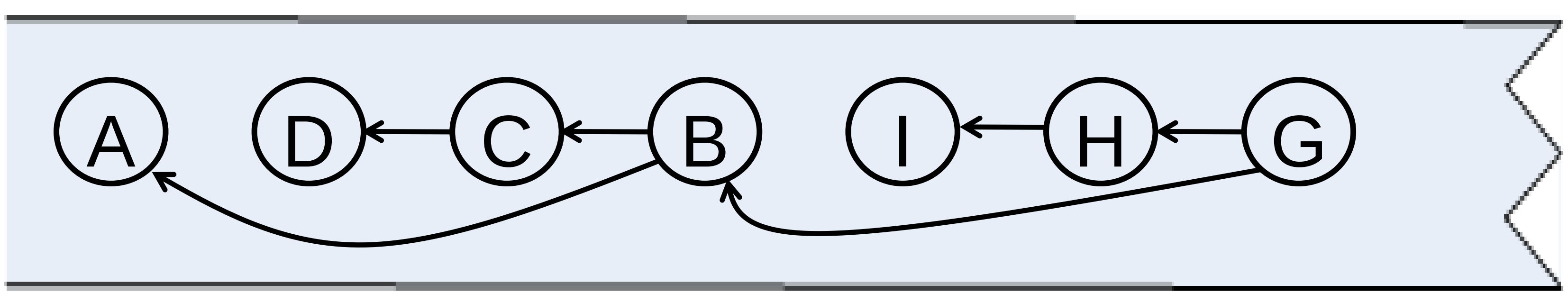
Outline

- ✓ Motivation
- System architecture
- Performance
- Related Work
- Conclusion

Database is a Binary Search Tree

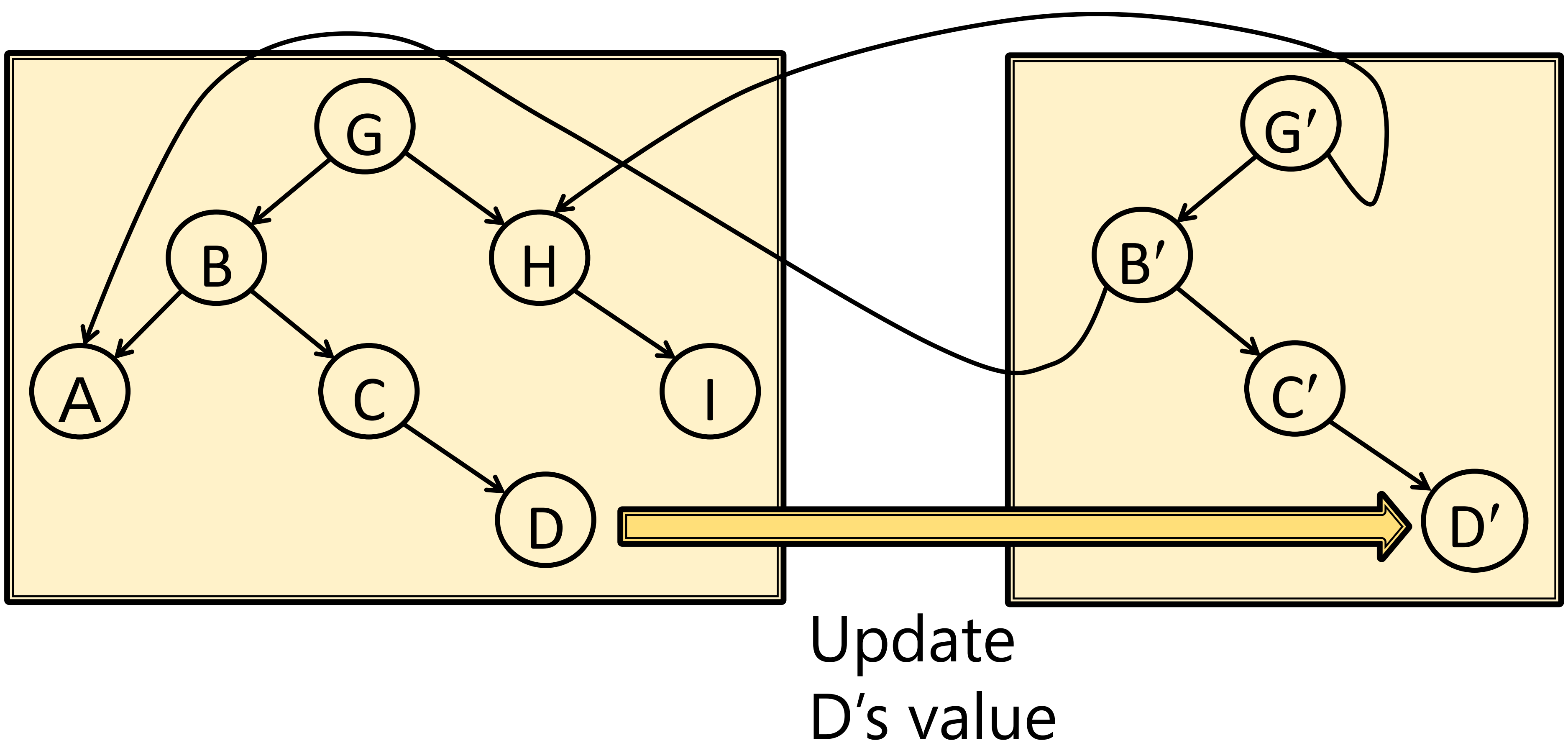


Tree is marshaled into the log



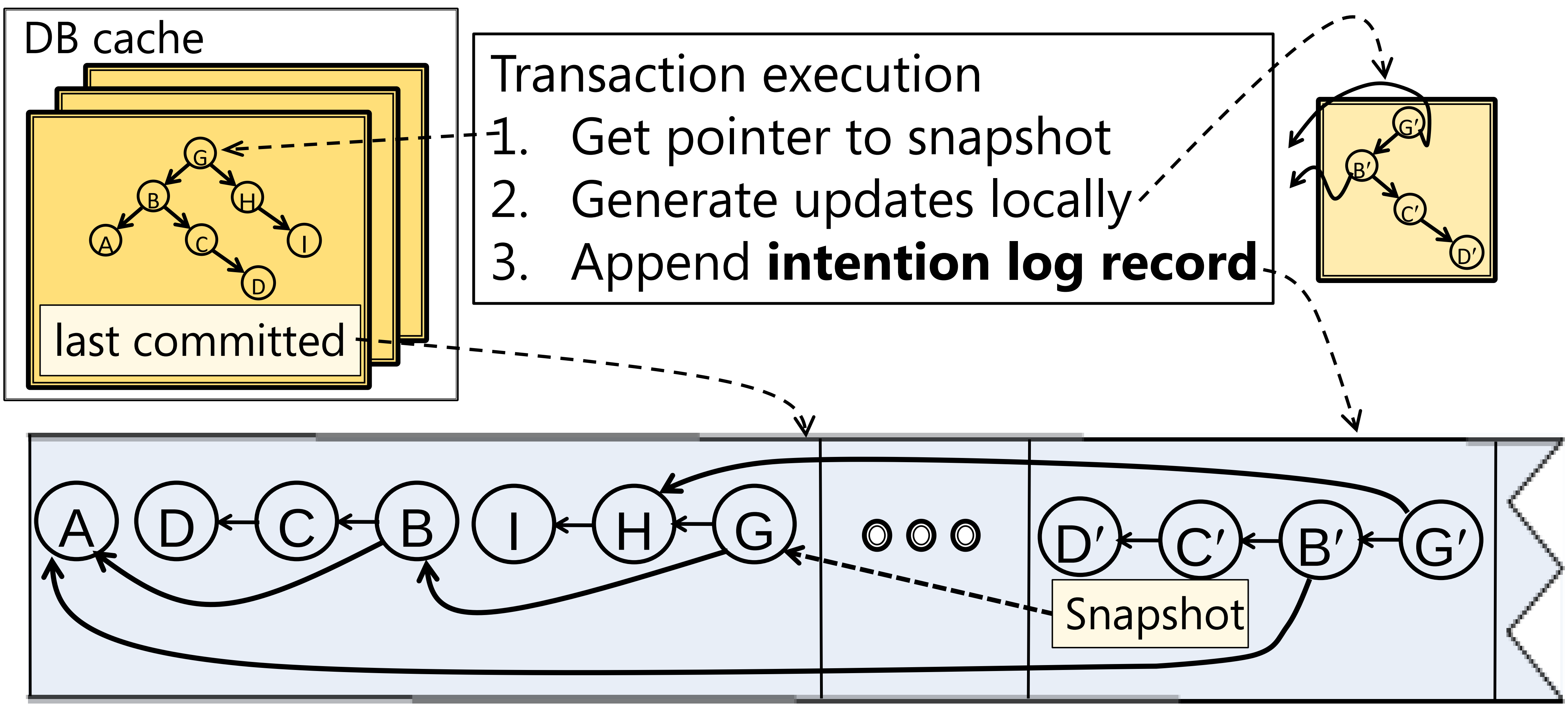
Binary Tree is Multi-versioned

- Copy on write
- To update a node, replace nodes up to the root



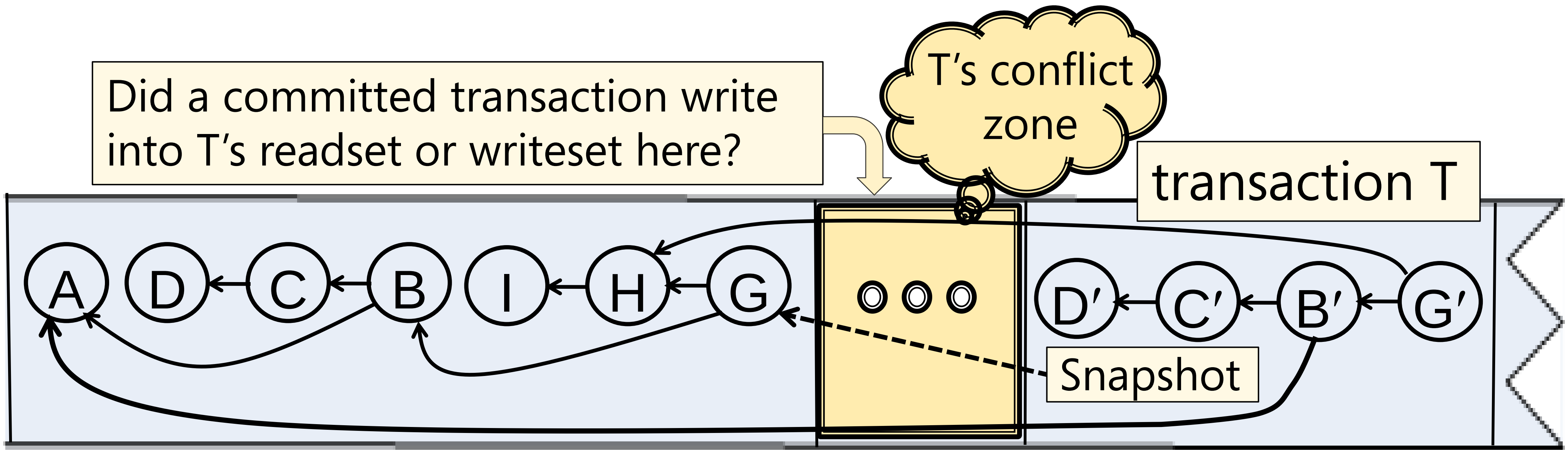
Transaction Execution

- Each server has a cache of the last committed DB state



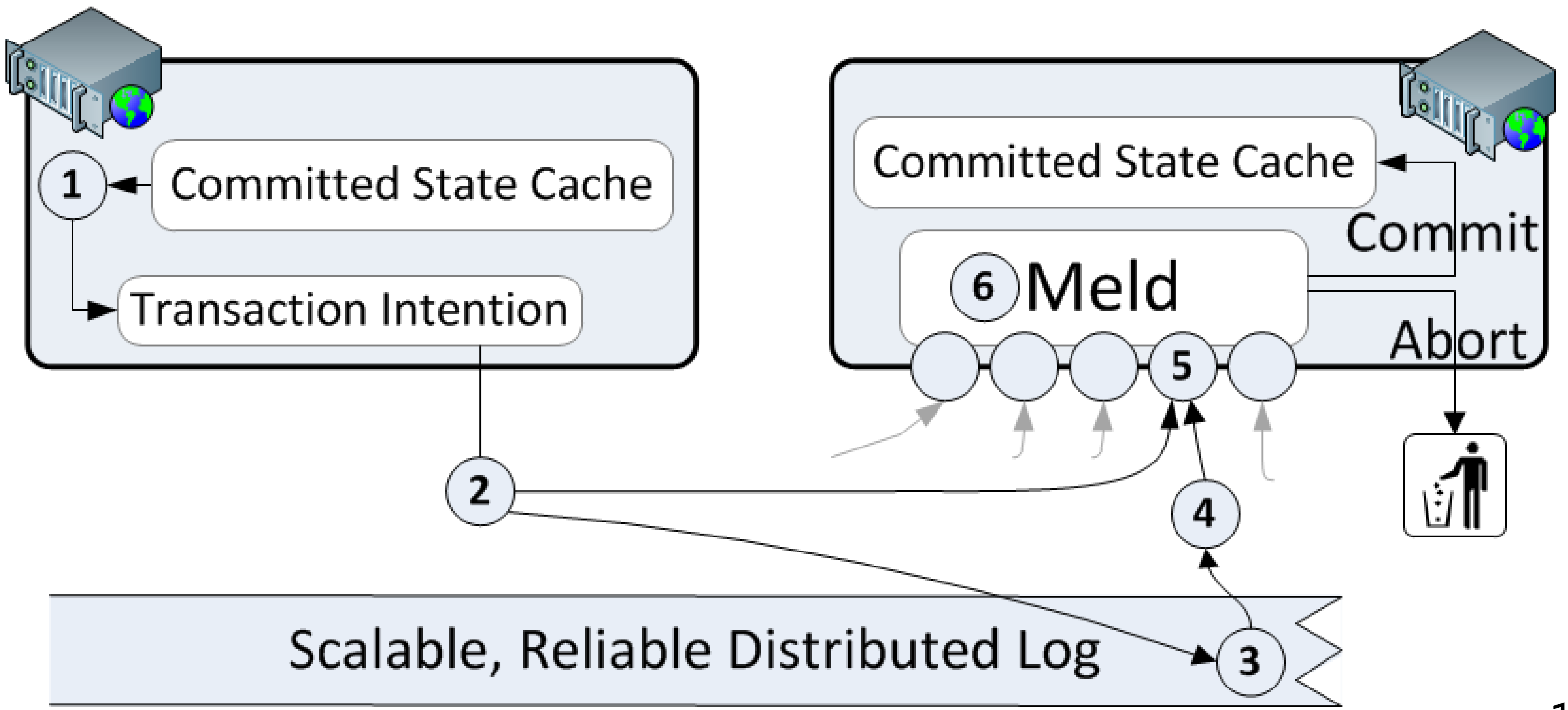
Meld: Log Roll-forward

- Each server processes intention records in sequence
- To process transaction T's intention record.
  - Check whether T experienced a conflict
  - If not, T committed, so the server merges the intention into its last committed state
- All servers make the same commit/abort decisions



Transaction Flow

1. Run transaction
2. Broadcast intention
3. Append intention to log
4. Send log location
5. De-serialize intention
6. Meld



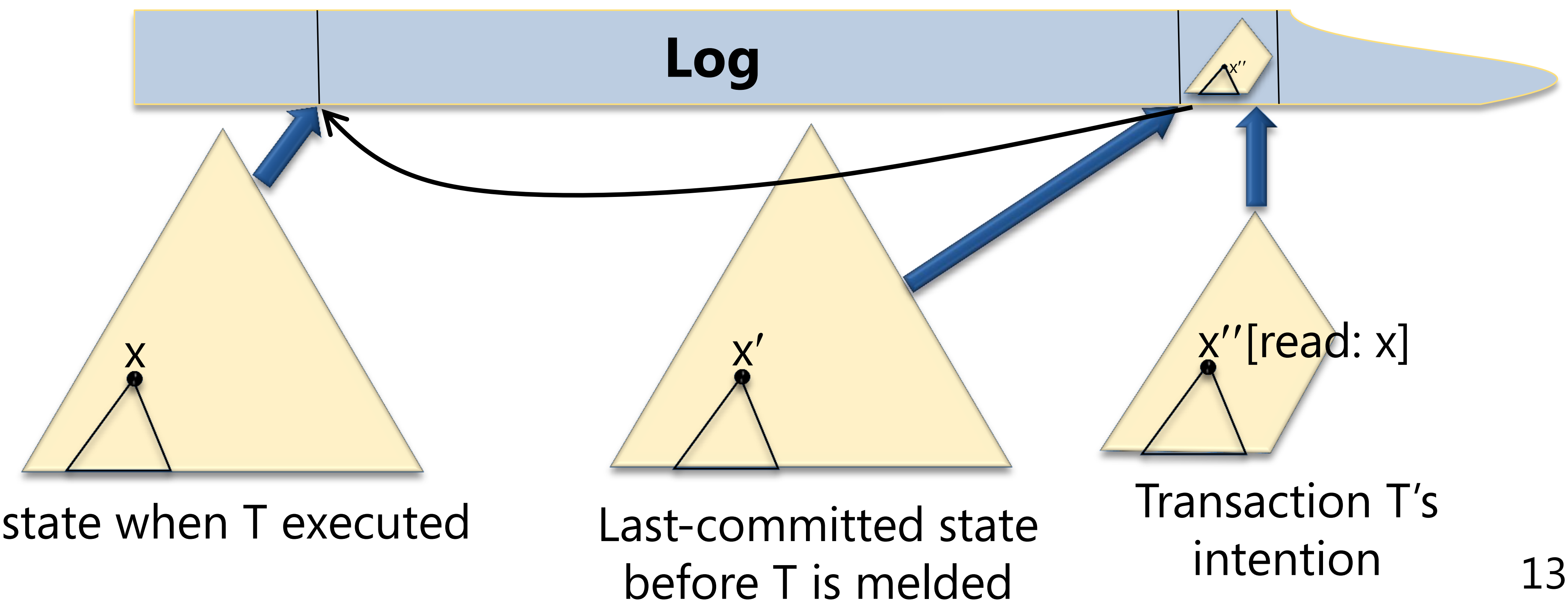
Bottlenecks

1. Broadcasting the intention
2. Appending intention to the log
3. Optimistic concurrency control (OCC)
4. Meld

- Technology will improve 1 & 2
- For 3, app behavior drives OCC performance
- But 4 depends on single-threaded processor performance, which isn't improving
- Hence, it's important to optimize Meld

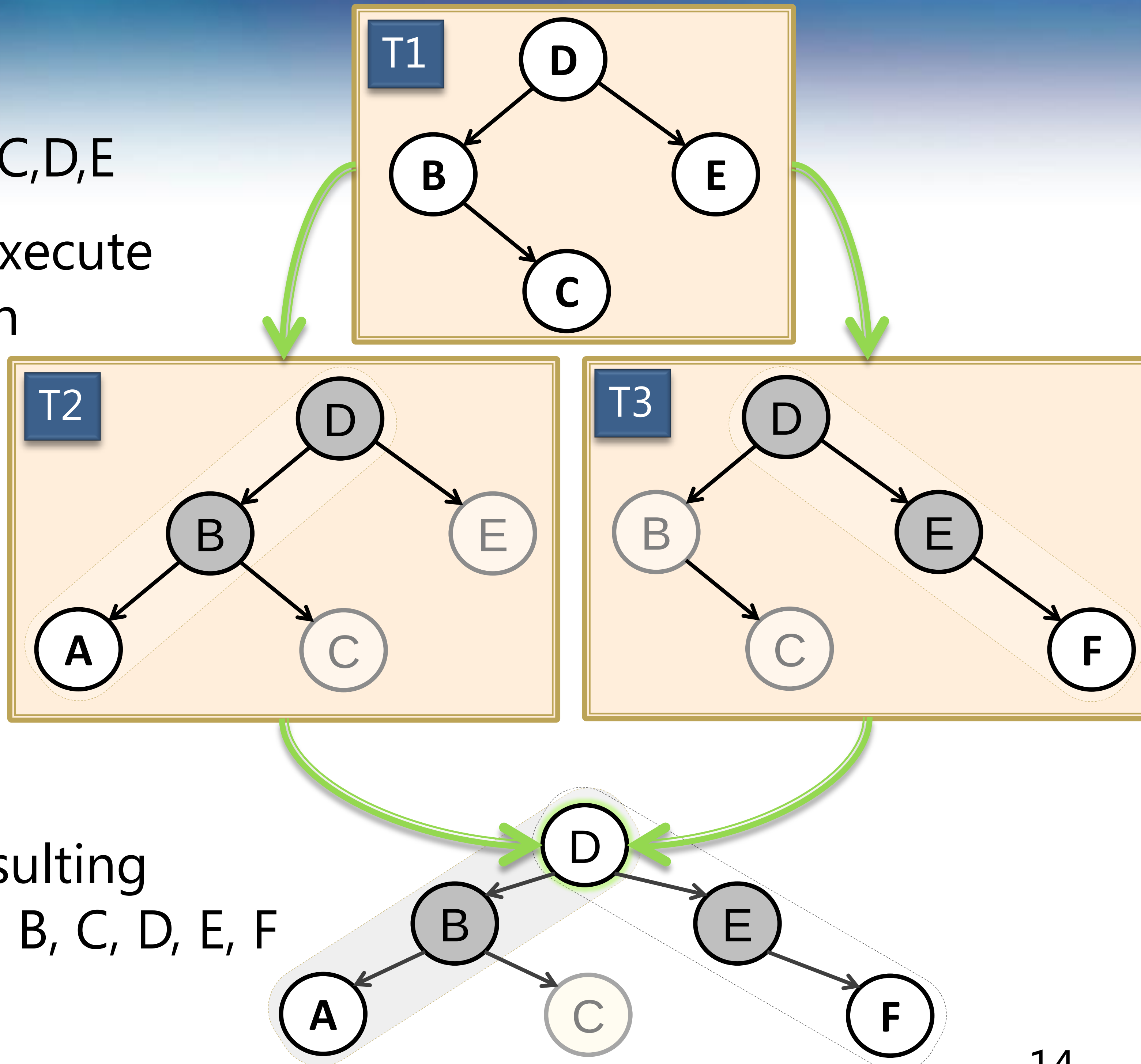
Main Idea: Fast Conflict Check

- Compare transaction T's after-image to the last committed state
  - which is annotated with version and dependency metadata
- Traverse T's intention, comparing versions to last-committed state
- Stop traversing when you reach an unchanged subtree
- If version(x)=version(x′) then simply replace x′ by x′′



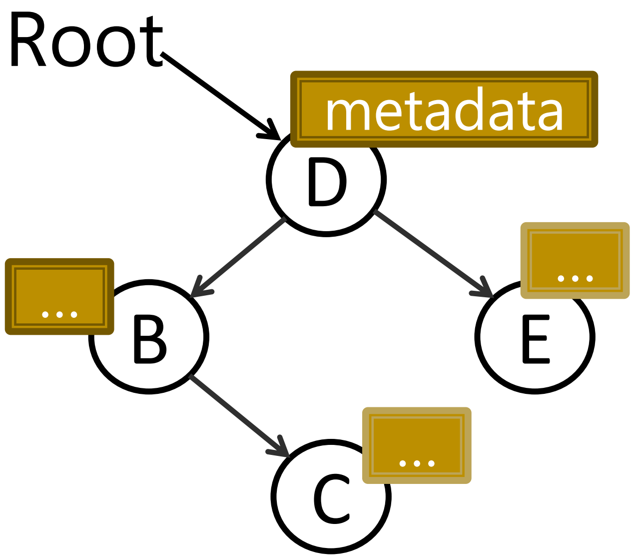
Running Example

- T1 creates keys B,C,D,E
- Then T2 and T3 execute concurrently, both based on the result of T1
- T2 inserts A
- T3 inserts F
- T2 and T3 do not conflict, so the resulting melded state is A, B, C, D, E, F



Intention Metadata

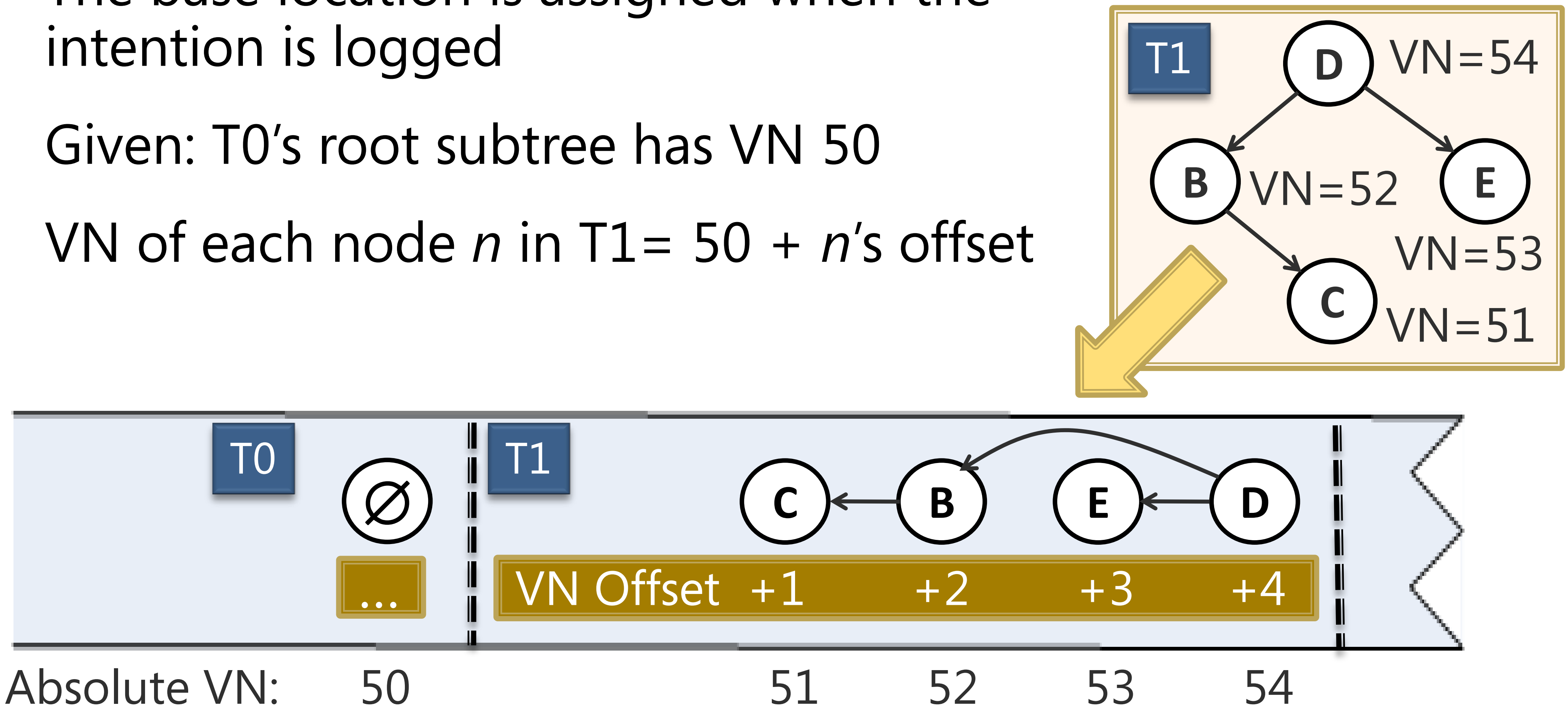
Node Metadata
- version of the subtree
- dependency info



- Every node *n* has a unique version number, VN(*n*), which identifies the exact content of *n*'s subtree
- Every node *n* in an intention T stores metadata about T's snapshot
  - Version of *n* in T's snapshot
  - Dependency information
  - metadata compresses to ~30 bytes

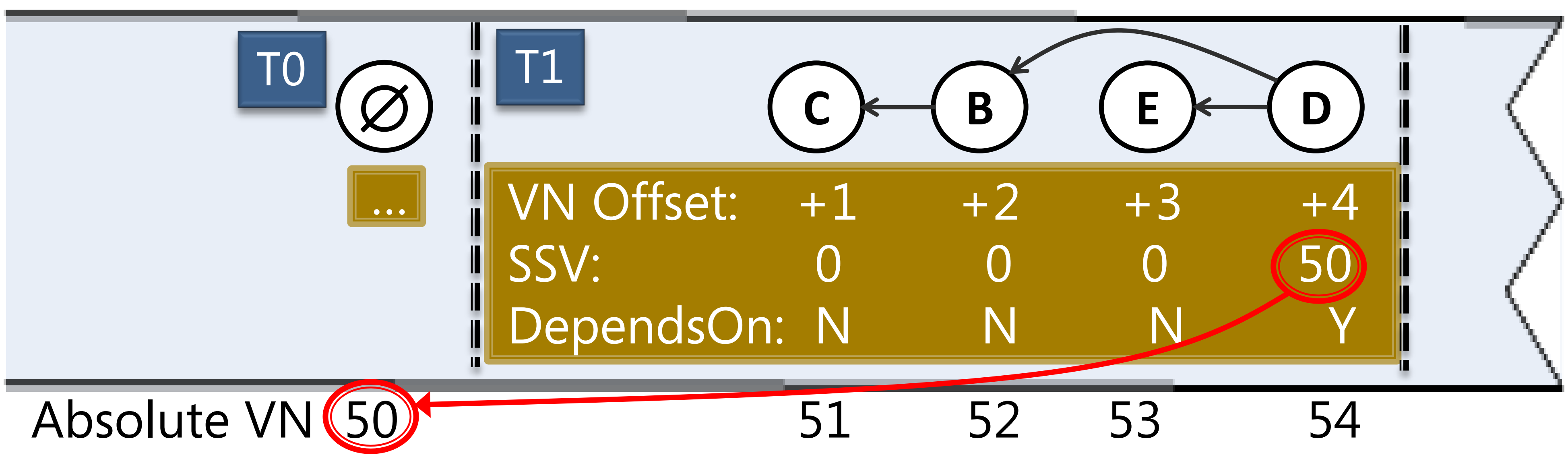
Lazy VN Assignment

- We need to avoid synchronization when assigning VNs
- VN(*n*) = intention base location + offset of *n* in its intention
- The base location is assigned when the intention is logged
- Given: T0's root subtree has VN 50
- VN of each node *n* in T1= 50 + *n*'s offset



Source Versions and Dependencies

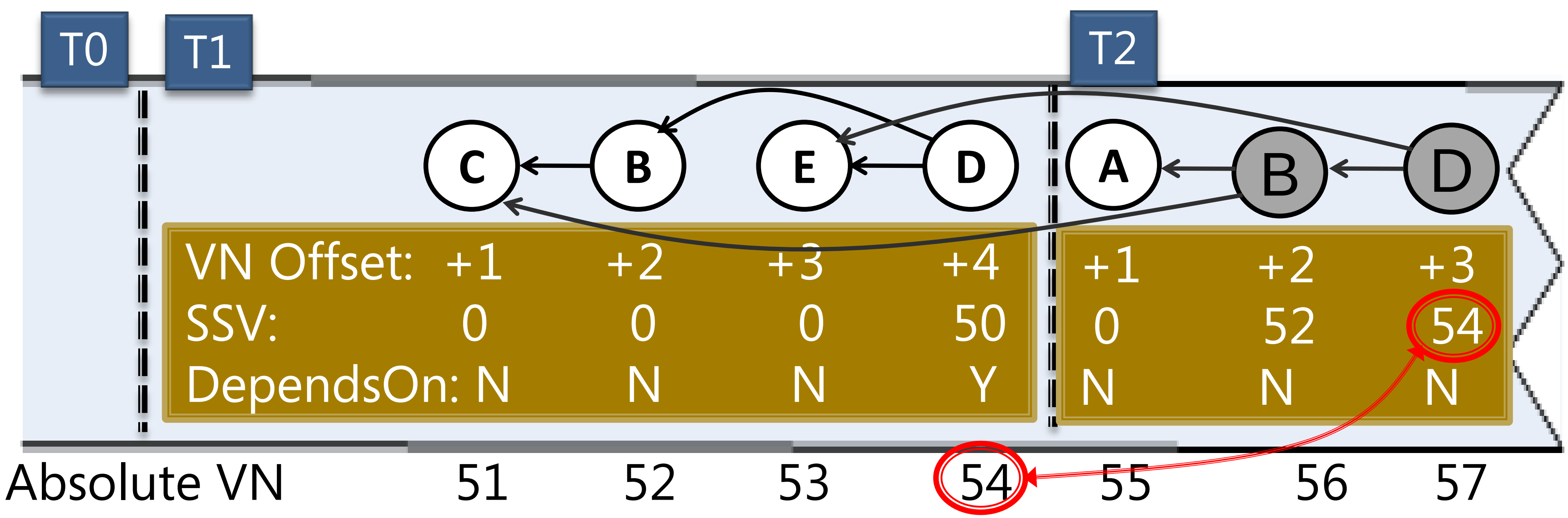
- Subtree metadata includes a **source structure version** (SSV).
- Intutively, SSV(*n*) = version of *n* in transaction T's snapshot
- DependsOn(*n*) = Yes if T depends on *n* not having changed while T executed



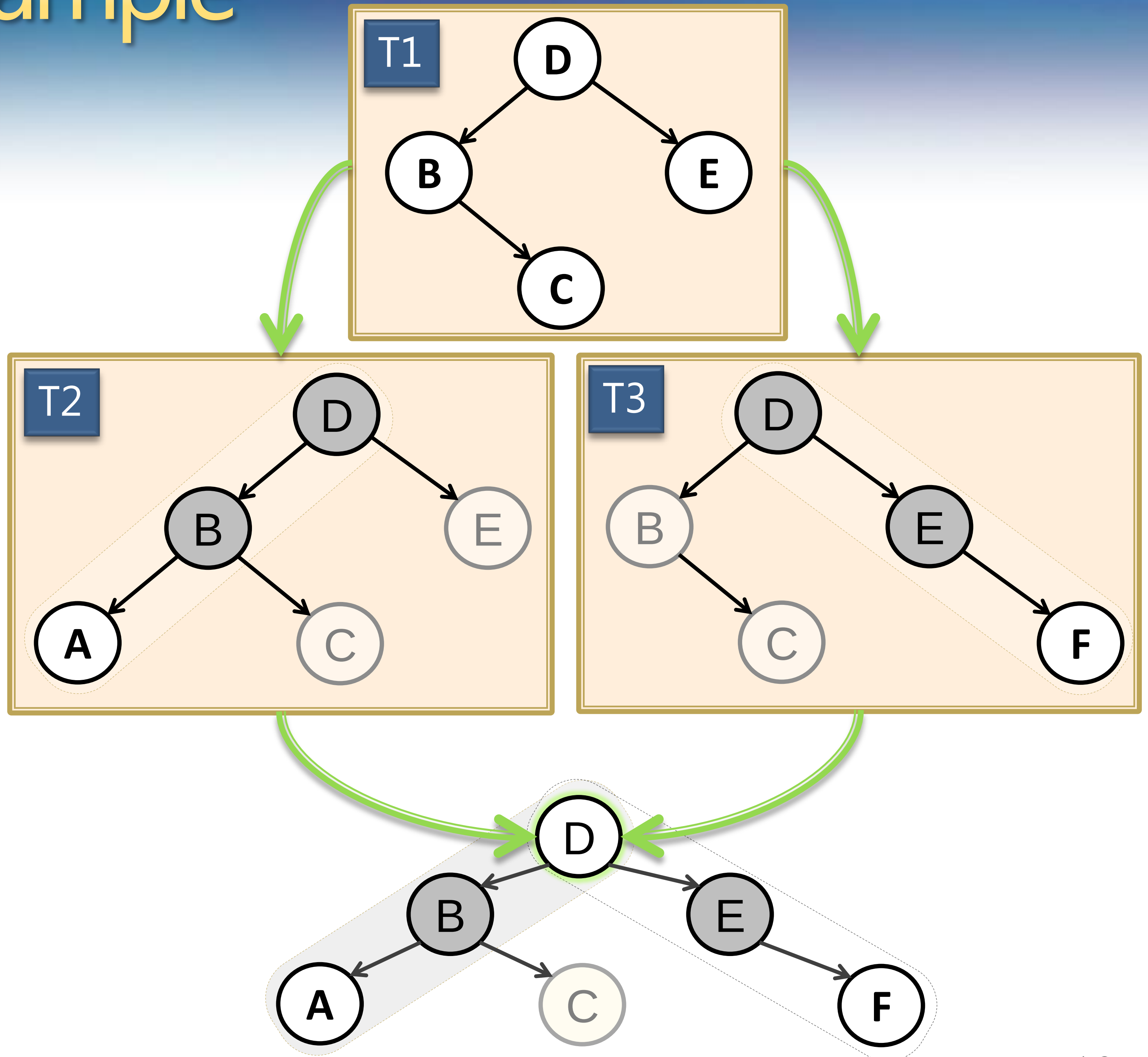
- T1's root subtree depends on the entire tree version 50.
- Since SSV(D) = VN(∅), T1 becomes the last-committed state.

Serial Intentions

- A **serial intention** is one whose source version is the last committed state.
- Meld is then trivial and needs to consider only the root node.
  - T1 was serial.
  - T2 is serial, so meld makes T2 the last committed state.
- Thus, a meld of a serial intention executes in constant time.

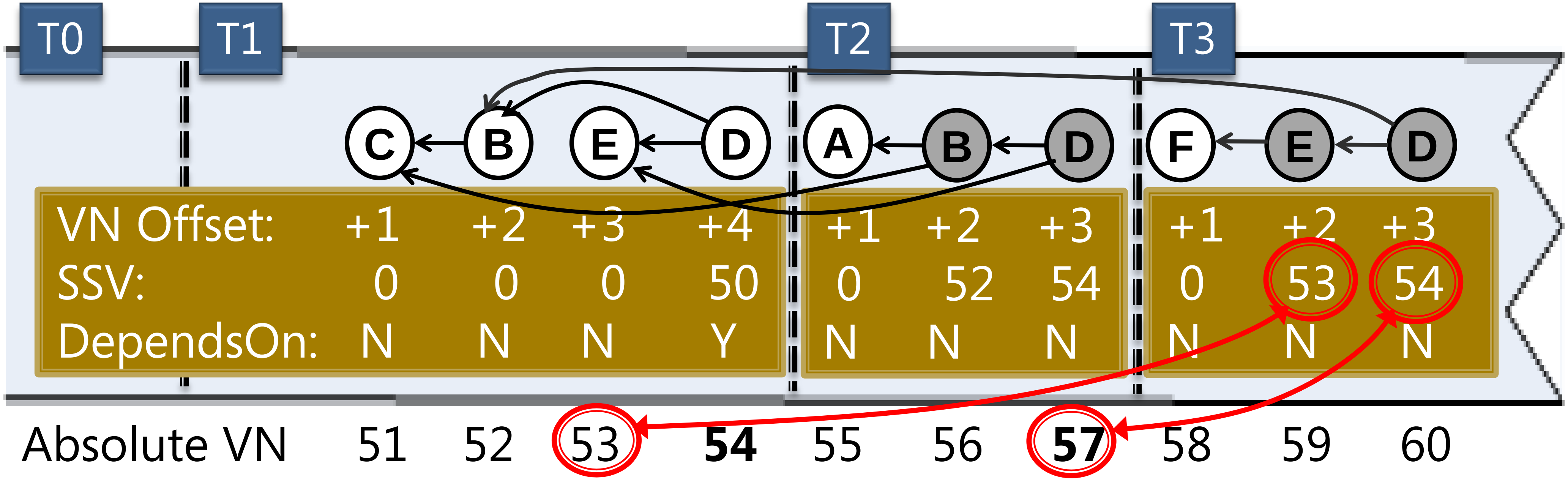


Running Example



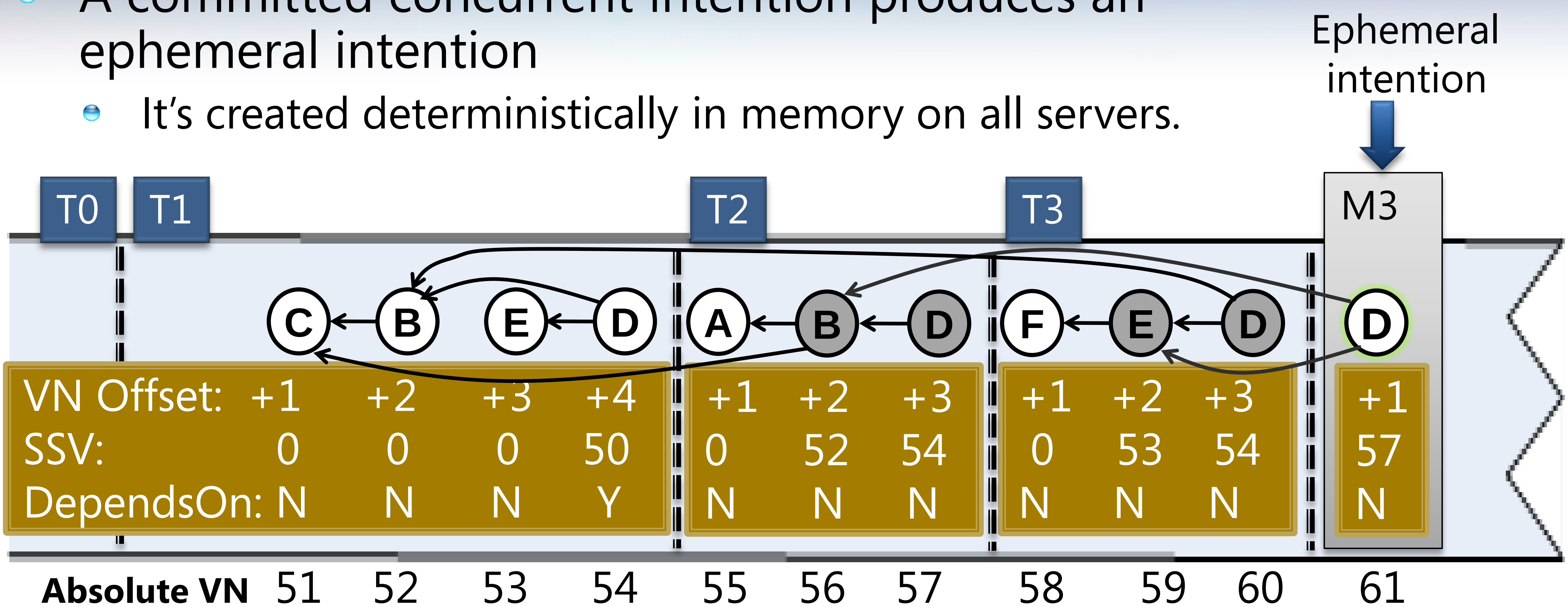
Concurrent (= non-serial) Intentions

- T3 is not serial because VN of D in T2 (= **57**) ≠ SSV(D) in T3 (= **54**).
- Meld checks if T3 conflicts with a transaction in its conflict zone
- Traverses T3, comparing T3's nodes to the last-committed state
- When a concurrent transaction (e.g. T3) experiences no conflicts, meld creates an **ephemeral intention** to merge its state



Ephemeral Intentions

- A committed concurrent intention produces an ephemeral intention
  - It's created deterministically in memory on all servers.



- It logically commits immediately after the intention it melds.

Other Important Details

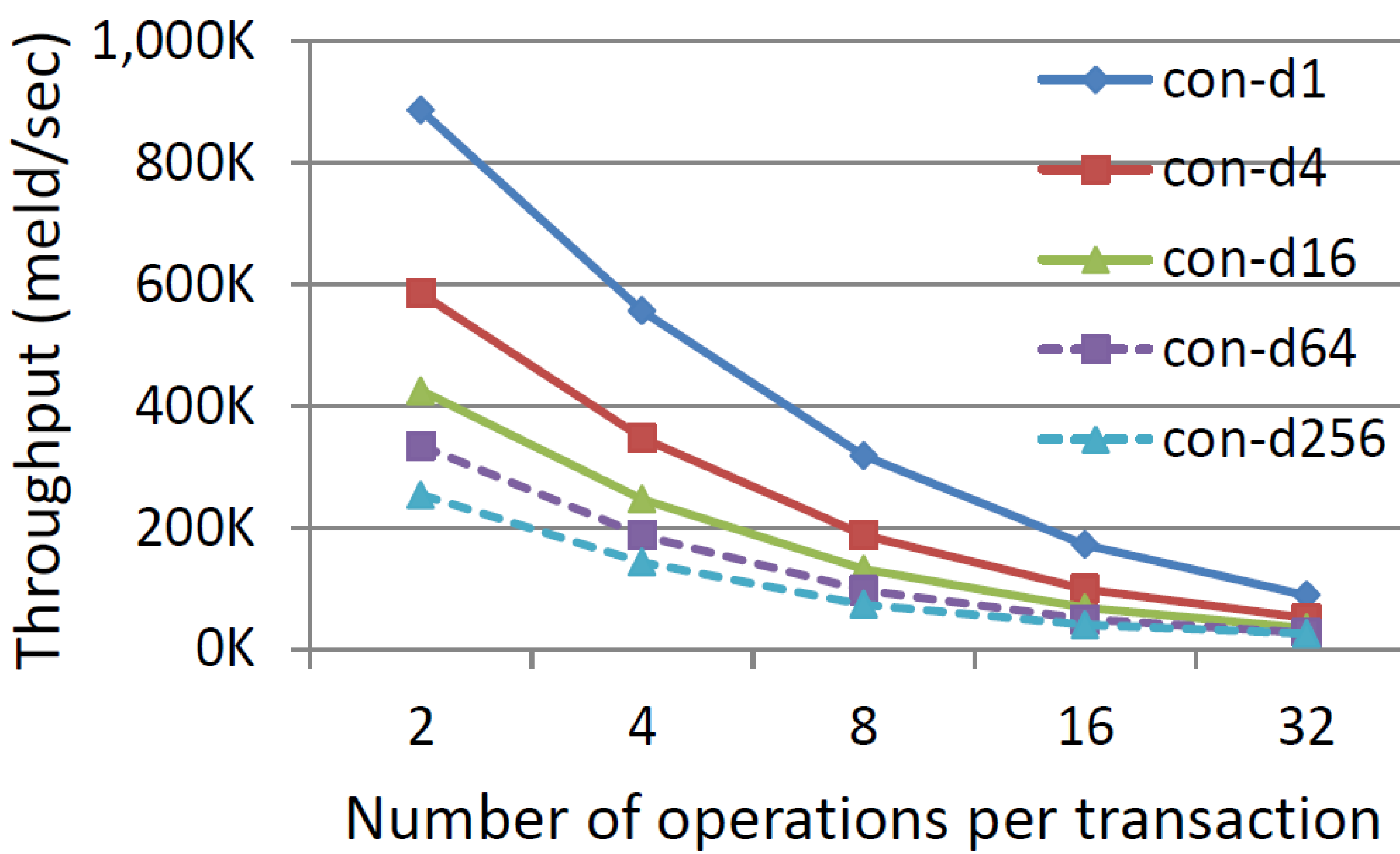
- Distinguishing payload updates from subtree updates
- Phantom detection
- Asymmetric meld operations
- Deletions, using tombstones in the intention header
- Garbage collection
- Checkpointing and recovery
- See [Bernstein et al., VLDB 2011]

Performance

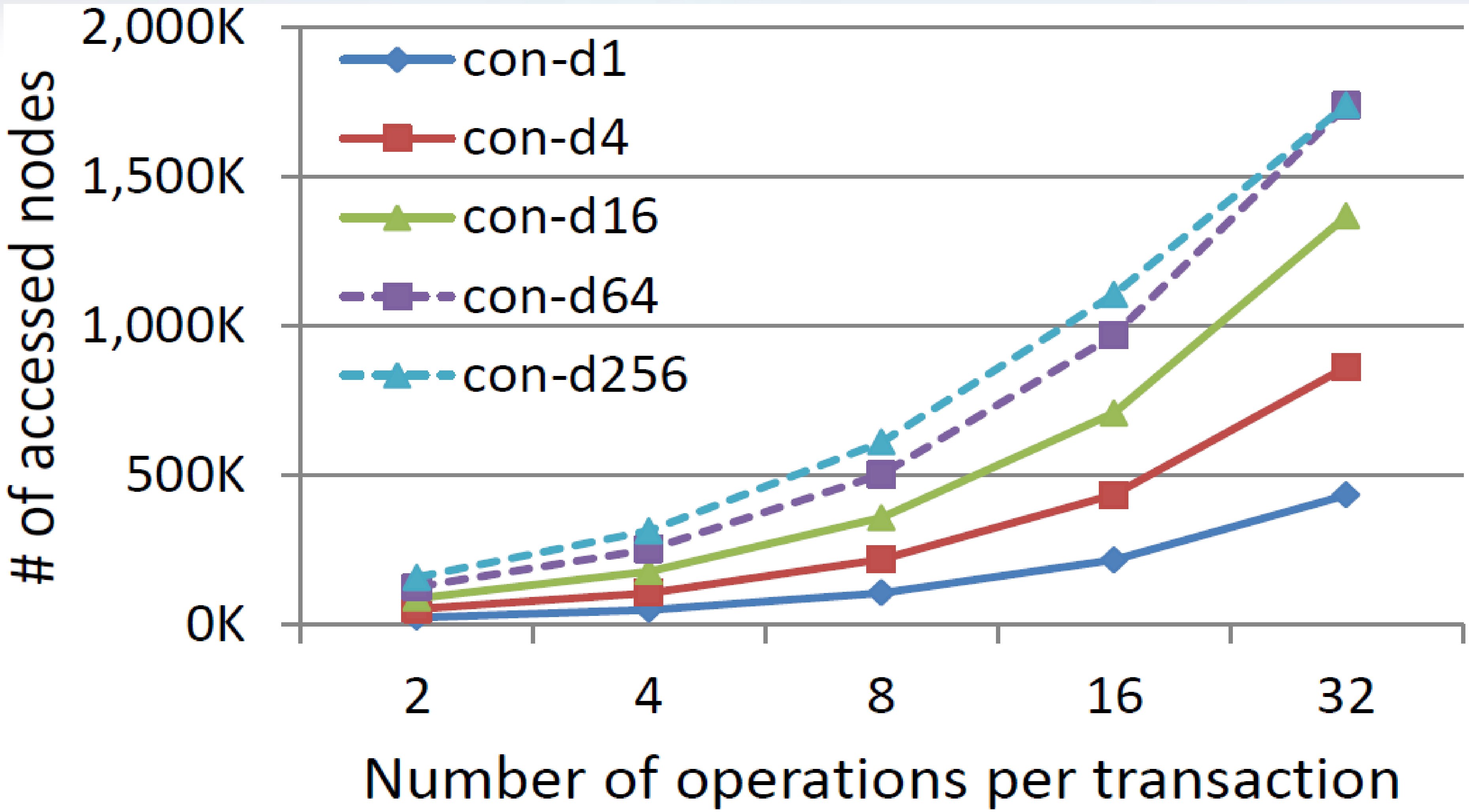
- Focus here is on meld throughput only
  - For latency, see our VLDB 2011 paper
  - We count committed and aborted transactions
- Experiment setup
  - 128K keys, all in main memory. Keys and payloads are 8 bytes.
  - Serializable isolation, so intentions contain readsets
  - De-serialize intentions on separate threads before meld
- Meld throughput depends on transaction size and conflict zone size (“concurrency degree”)
  - As transaction size or concurrency degree increase
    $\Rightarrow$ more concurrent transactions update keys with common ancestors
    $\Rightarrow$ meld has to traverse deeper in the tree

Throughput

- r:w ratio is 1:1
- con-d*i* = concurrency degree *i*

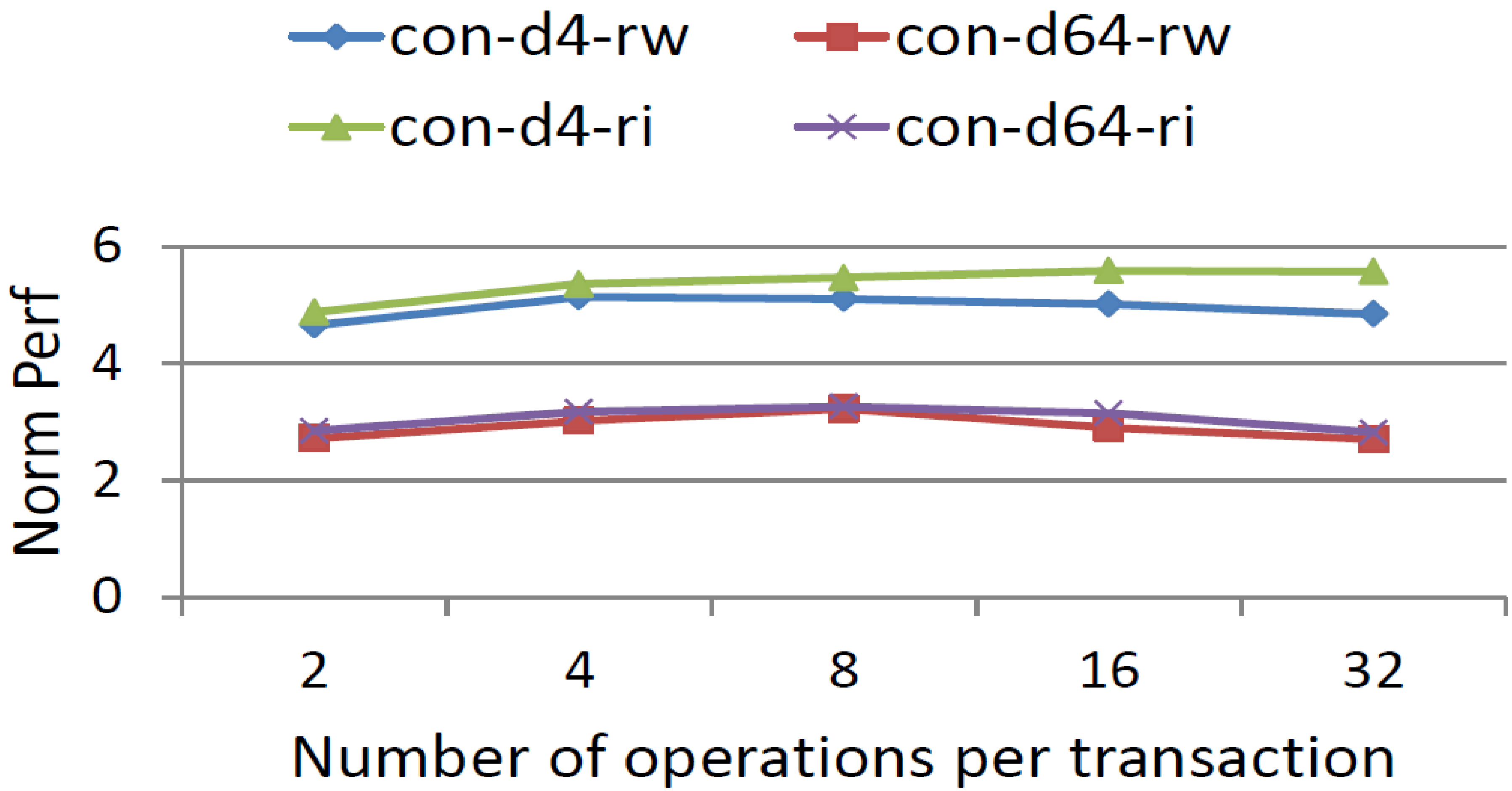


Number of Nodes Accessed



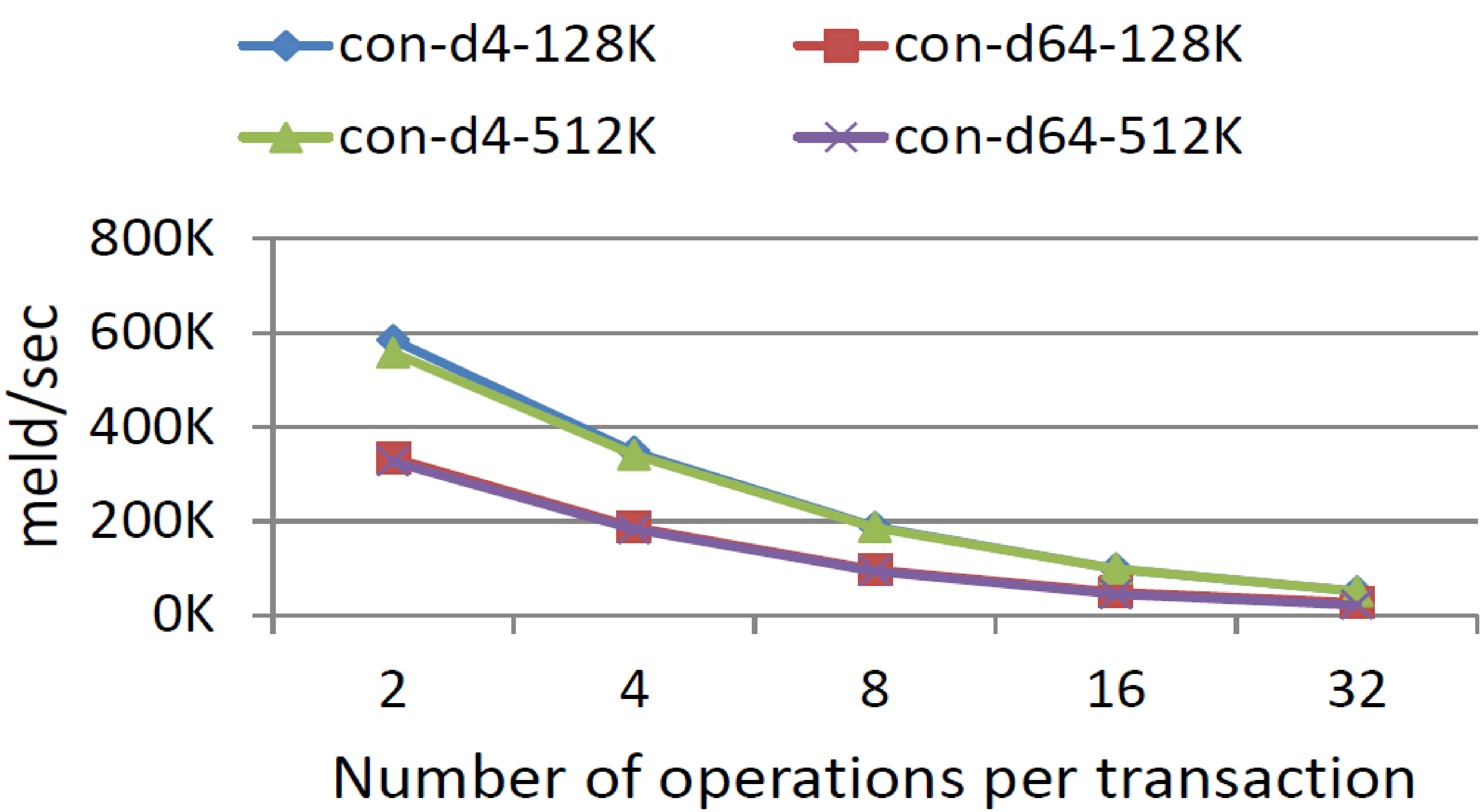
Meld Performance vs. Brute Force

- Brute force = traverse the whole tree



Effect of Tree Depth

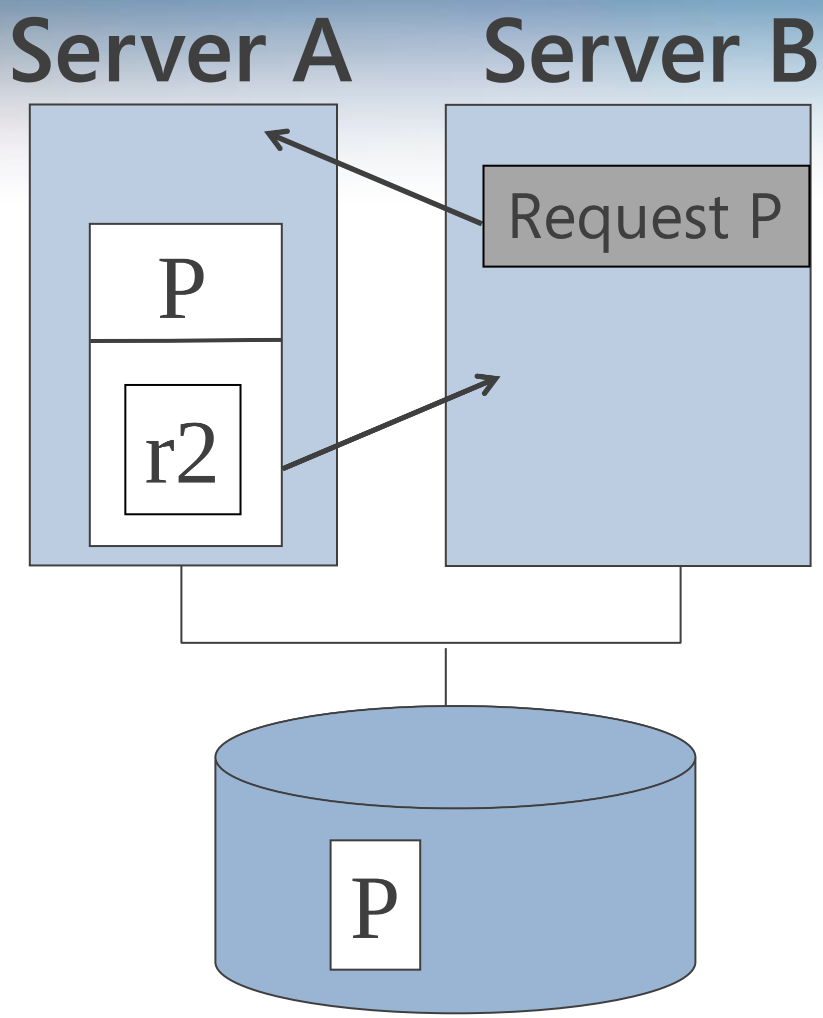
- Hardly any effect, indicating most traversals short-circuit high in the tree.



Related Work

- Hyder resembles a primary-copy replicated DB
  - Primary copy broadcasts only committed updates
  - Central transaction server is a bottleneck
  - In Hyder, only the log is centralized
- Hyder is a “data-sharing” DB system
  - Classical approach uses a distributed lock manager
  - Each server runs an ordinary single-server DBMS
  - But, before a server fetches a page, it locks the page

Data Sharing via Locking



- Server A gets a write-lock on page P and fetches P
- Server B requests a lock on P
- Lock manager forward request to A
- When A is able to unlock P, it releases the lock and sends P to B
- Need this synchronization even if B wants a different record than A

- Performance issues: remote lock requests; ping-pong pages
- Used in Oracle RAC & Exadata and IBM DB2 Data-Sharing
- Have not yet compared its performance to Hyder

Related Work on Meld

- Lots of OCC papers but none that give details of efficient conflict-testing
- By contrast, there's a huge literature on conflict-testing for locking
- Oxenstored [Gazagnairem & Hanquezis, ICFP 09]
  - Similar scenario: MV trees and OCC
  - However, very coarse-grain conflict-testing
  - Uses none of our optimizations

Summary

- New algorithm for OCC
- Developed many optimizations to truncate the conflict checking early in the tree traversal
- Implemented and measure it
- Future work:
  - Apply it to other tree structures
  - Measure it on various storage devices
  - Compare it with locking and other OCC methods on multiversion trees
  - Try to apply it to physiological logging

Publications

- C.W. Reid, P.A. Bernstein: Implementing an Append-Only Interface for Semiconductor Storage. IEEE Data Eng. Bull. 33(4): 14-20 (2010)
- P.A. Bernstein, C.W. Reid, S. Das: Hyder - A Transactional Record Manager for Shared Flash. CIDR 2011: 9-20
- P.A. Bernstein, C.W. Reid, M. Wu, X. Yuan: Optimistic Concurrency Control by Melding Trees. PVLDB 4(11): 944-955 (2011)

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