DB Reading Group Fall 2015

slides by Dana Van Aken

Building Consistent Transactions with Inconsistent Replication

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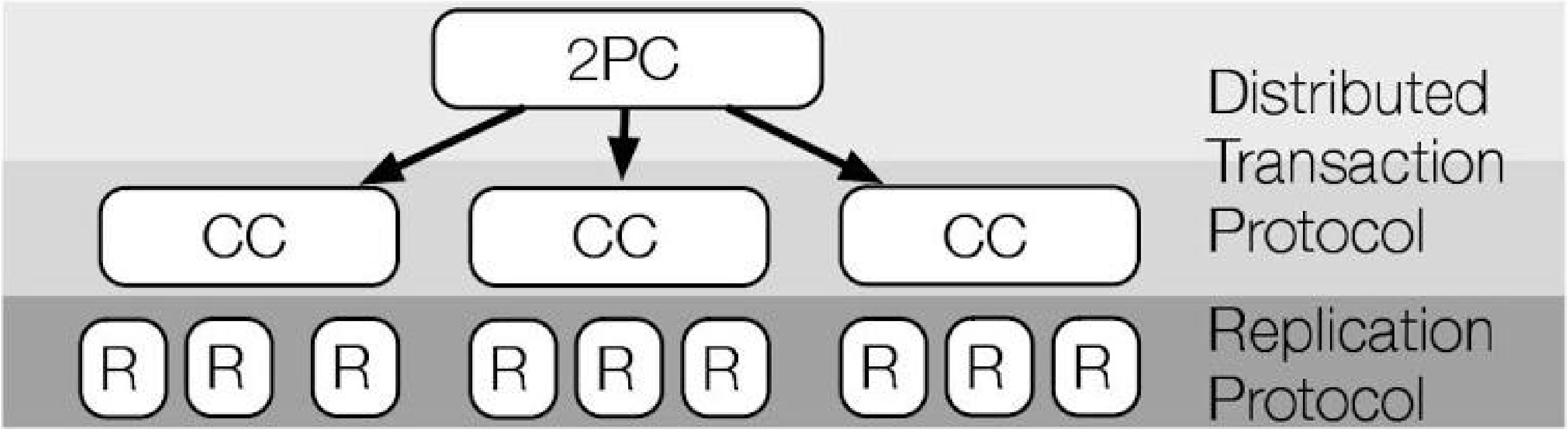
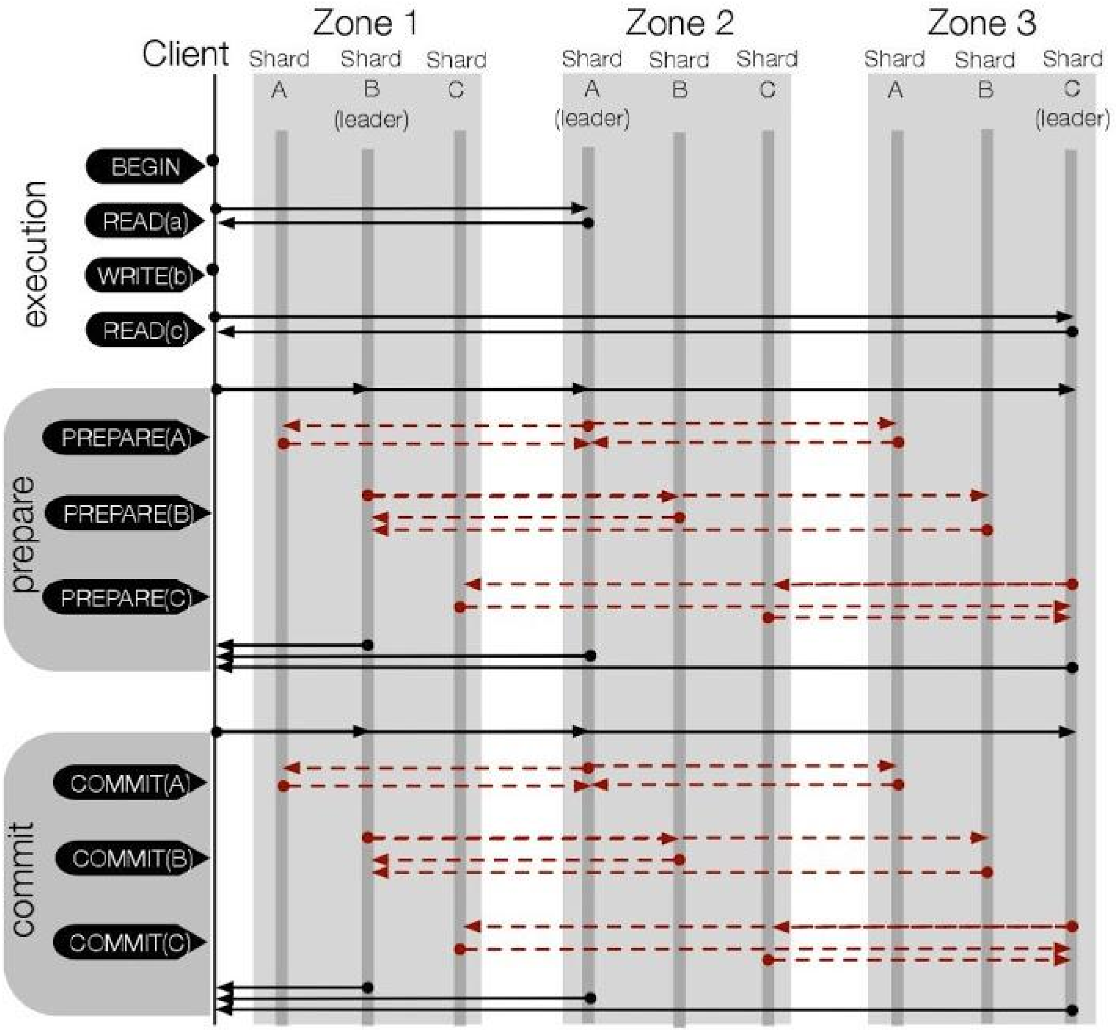
Motivation

- App programmers prefer distributed transactional storage with strong consistency
  - → ease of use, strong guarantees
- Tradeoffs
  - → fault tolerance: strongly consistent replication protocols are expensive (e.g. Paxos)
    - ➢ Megastore, Spanner
  - → weakly consistent protocols are less costly but provide fewer (if any) guarantees (e.g. eventual consistency)
    - ➢ Dynamo, Cassandra



Common architecture for distributed txn’l systems

- Distributed Transaction Protocol:
  - → atomic commitment protocol (2PC) + CC mechanism
  - → e.g. 2PC + (2PL | OCC | MVCC)
- Replication Protocol:
  - → e.g. Paxos, Viewstamped Replication



Spanner-like system

- writes buffered at client until commit
- read ops must go to shard leaders to ensure order across replicas (gets value & timestamp of any data read)
- Commit takes at least 2 round trips

Observation

- Existing distributed transaction storage systems that integrate both protocols waste work and performance due to this redundancy
- Is it possible to remove this redundancy and still provide *read-write* transactions with the same guarantees as Spanner? **YES.**
  → linearizable transaction ordering
  → globally consistent reads across database at a timestamp
- How? Replication with *no consistency*

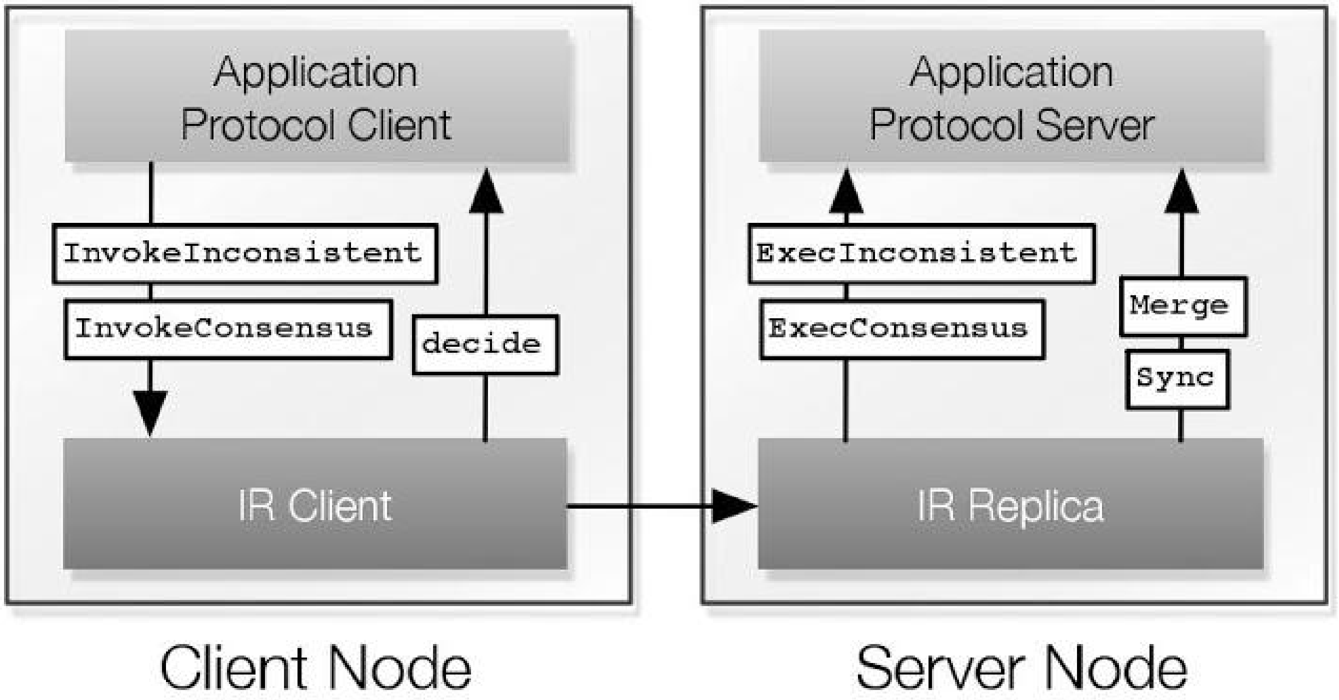
Key Contributions

- Define ***IR (inconsistent replication)***
  - → new replication protocol
  - → fault tolerance without consistency
- Design ***TAPIR (Transactional Application Protocol for IR)***
  - → new distributed transaction protocol
  - → linearizable transaction ordering using IR (Spanner)
- Build/evaluate ***TAPIR-KV***
  - → high-performance transactional storage (TAPIR + IR)

Inconsistent Replication

- Fault tolerance without consistency
  - → ordered op log replaced by an unordered op set
- Used with a higher-level protocol: *application protocol*
  - → to decide/recover the outcome of conflicting operations
- Can invoke ops in 2 modes: *inconsistent* and *consensus*
  - → Both: execute in any order
  - → Consensus only: returns a single consensus result
- Guarantees:
  - → fault tolerance: successful ops & consensus results are persistent
  - → visibility: for each pair of operations, at least one is visible to the other

IR Application Protocol Interface



IR Protocol: Operation Processing

- IR can complete **inconsistent operations** with a *single round-trip* to f+1 replicas and no coordination across replicas
- **consensus operations**
  - → fast path: if [3/2 f]+1 replicas return *matching* results
    - ➢ common case, single round-trip
  - → slow path: if otherwise
    - ➢ two round-trips to at least f+1 replicas

IR Protocol: Replica Recovery & Synchronization

- uses single protocol for recovering failed replicas & synchronizing replicas → **View change**
- Protocol is identical to Viewstamp Replication (Oki, Liskov) except that the leader must *merge* records from the latest view
  → leader relies on application protocol to determine consensus results
  → result of `merge` is the "master record", used to synchronize other replicas

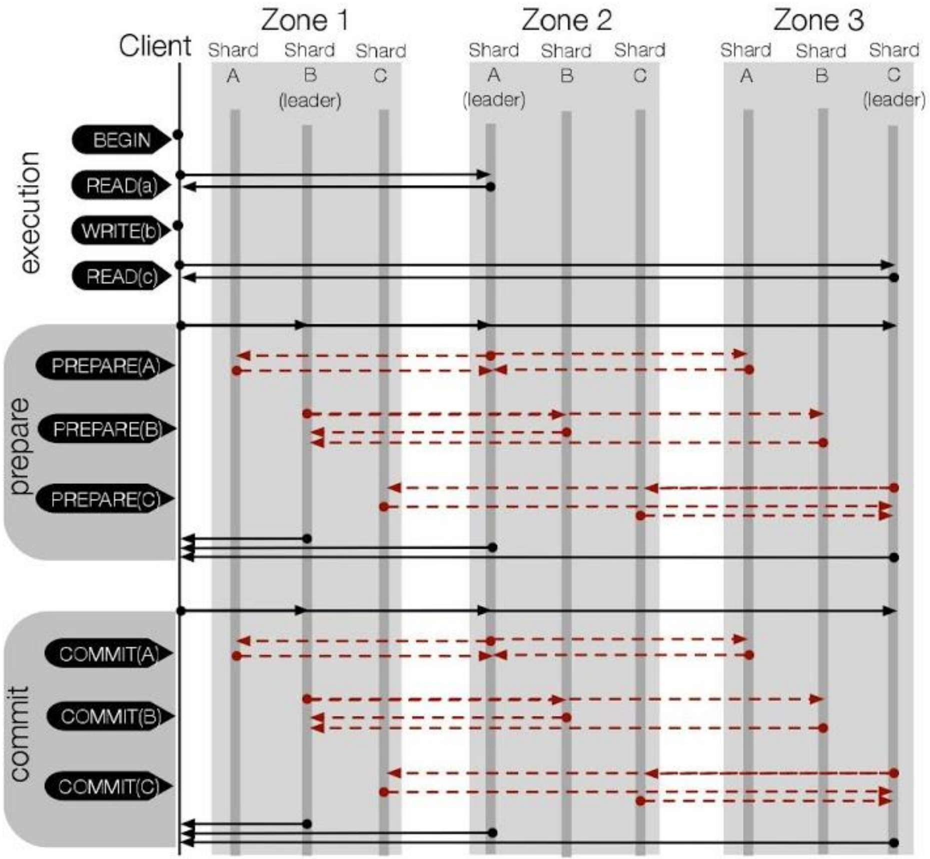
TAPIR

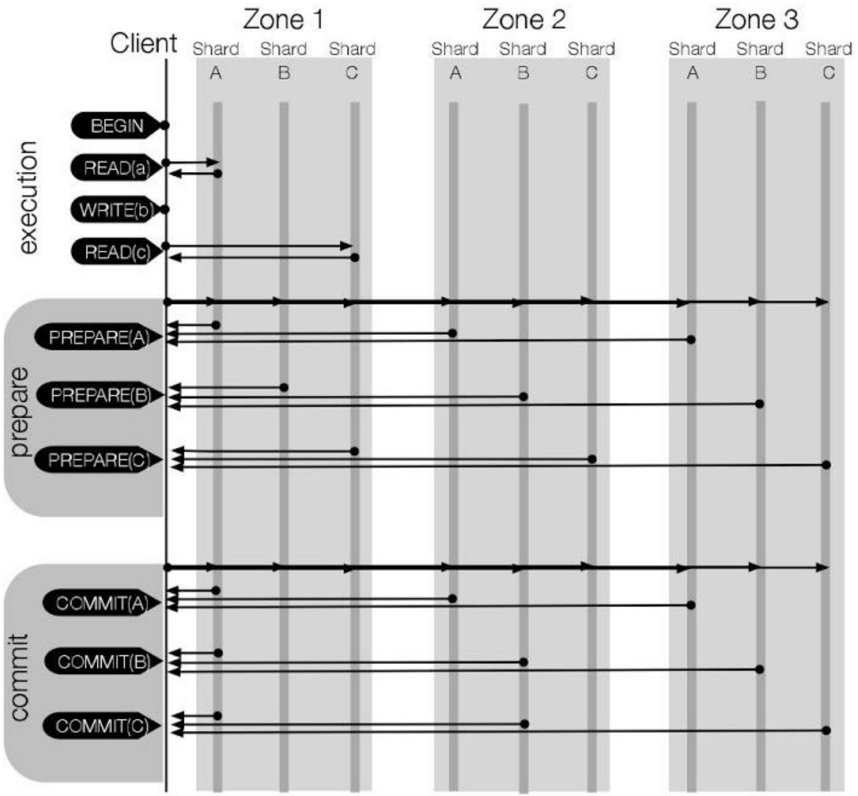
- Transactional Application Protocol for IR
  - → Efficiently leverages IR's weak guarantees to provide high-performance linearizable transactions (Spanner)
- Clients: front-end app servers (possibly at same datacenter)
- Applications interact with TAPIR (not IR)
  - → once an app calls "commit", it cannot abort
  - → this allows TAPIR to use clients as 2PC coordinators
- Replicas keep a log of committed/aborted txns in timestamp order
- Replicas also maintain a versioned data store

TAPIR: Transaction Processing

- Uses OCC
  - → concentrates all ordering decisions into a single set of validation checks
  - → only requires *one* consensus operation ("prepare")
    - ➢ *decide* function: commit if a majority of replicas replied "prepare-ok"

Spanner-like system vs TAPIR





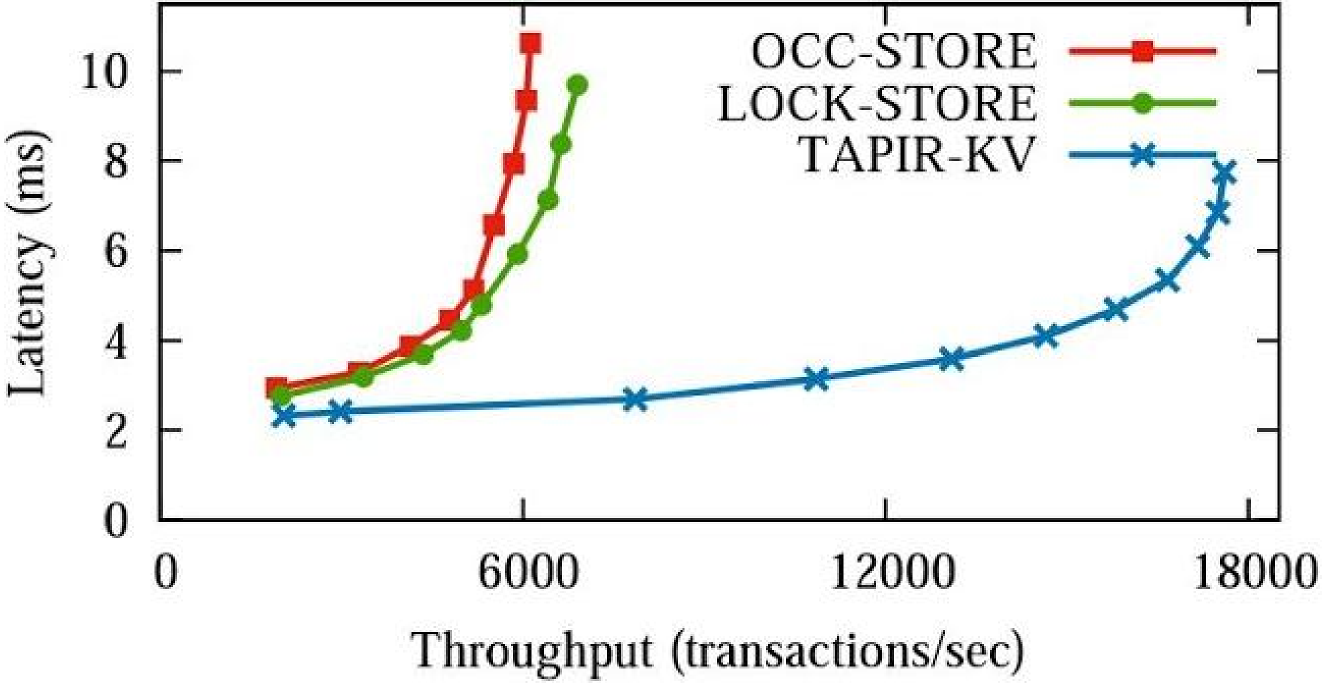
Experimental Setup

- built TAPIR-KV (transactional key-value store)
- Google Compute Engine (GCE), 3 geographical regions
  - → US, Europe, Asia
  - → VMs placed in different availability zones
- server specs:
  - → virt. single core 2.6 GHz Intel Xeon, 8 GB RAM, 1 Gb NIC
- comparison systems
  - → OCC-STORE (standard OCC + 2PC), LOCK-STORE (Spanner)
- workloads
  - → Retwis, YCSB+T

Results: RTT & clock synchronization

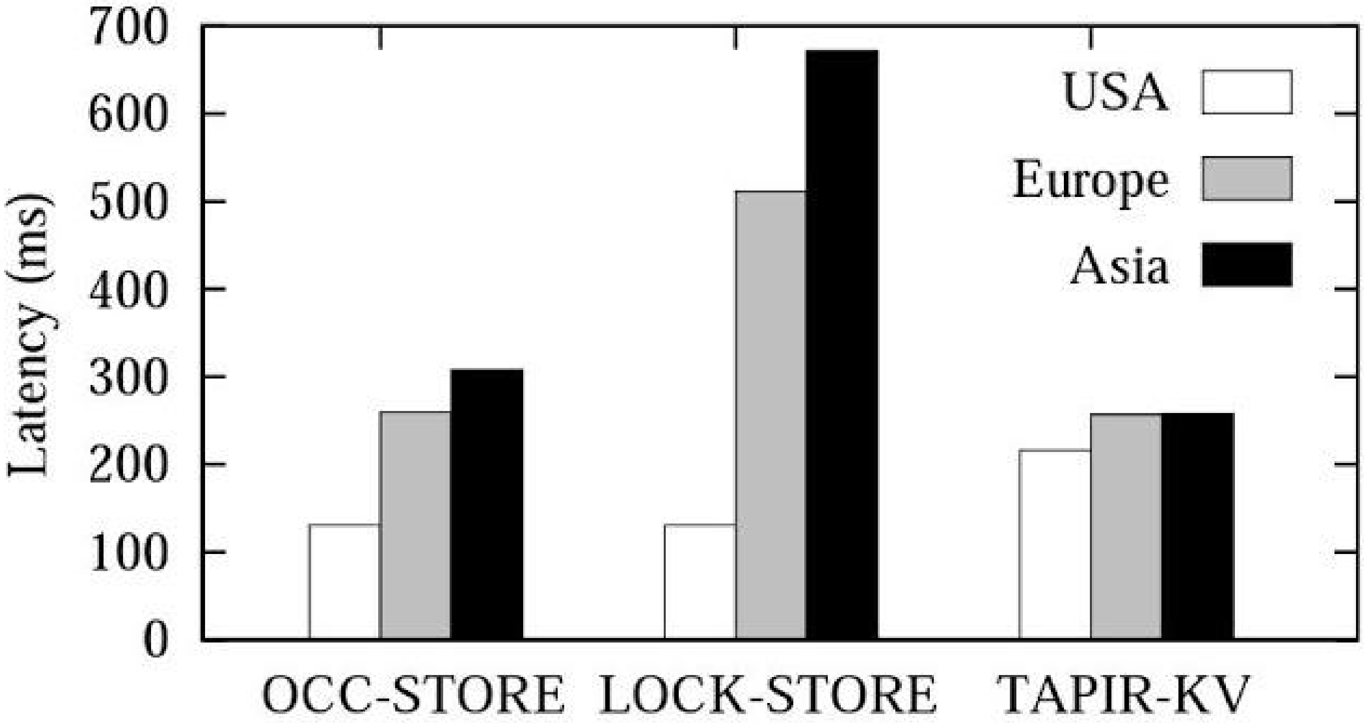
- RTTs:
  → US-Europe: 110 ms
  → US-Asia: 165 ms
  → Europe-Asia: 260 ms
- low clock skew (0.1 - 3.4 ms), BUT has a long tail
  → worst case ~27 ms
- unlike Spanner, TAPIR performance depends on ***actual*** clock skew, not a worst-case bound

Avg. Rewtis transactional latency vs. throughput



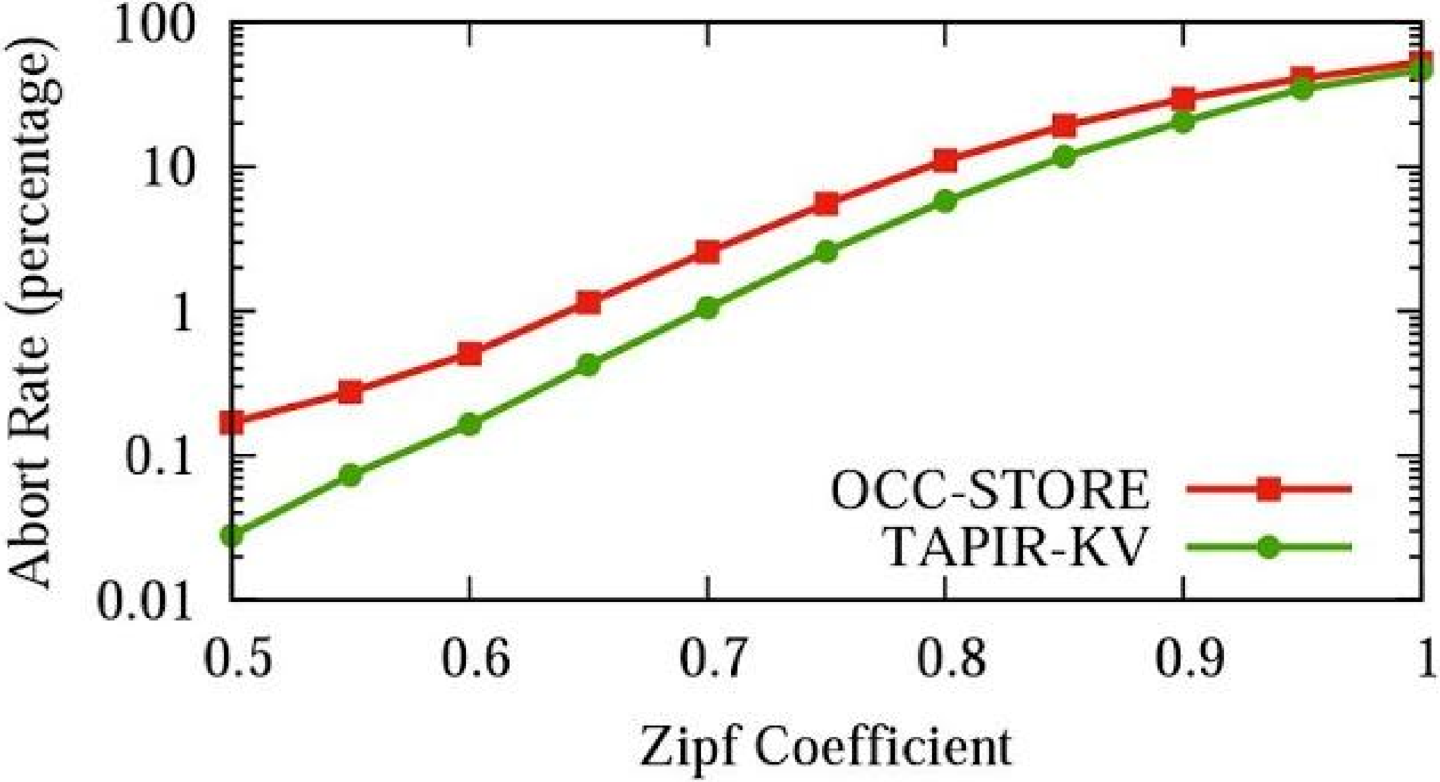
- Rewtis
- single data center
- US region only
- 10 shards
- 3 replicas/shard
- 10M keys
- zipf coef: 0.75

Avg. wide-area latency for Rewtis transactions



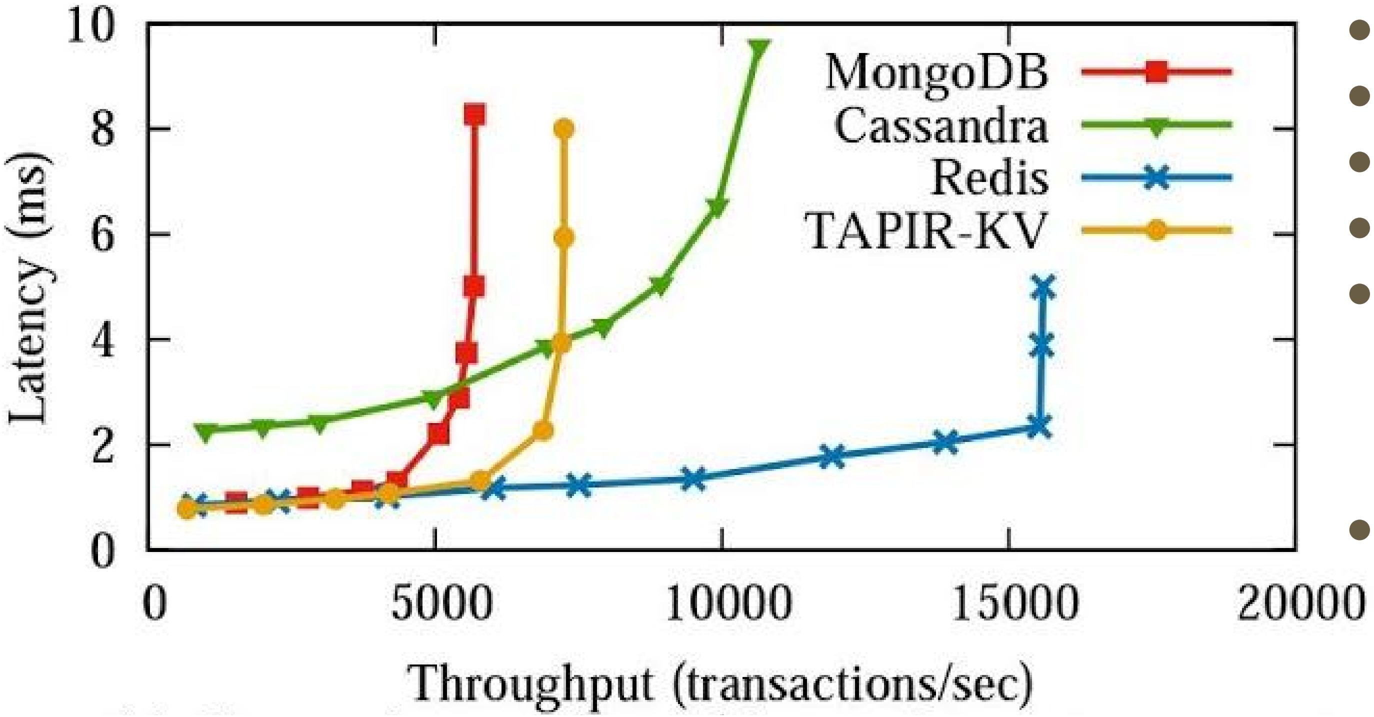
- 1 replica per shard in each geographical region
- leader in US (if any)
- client in US, Asia, or Europe

Abort rates at varying Zipf coefficients



- single region
- replicas in 3 availability zones
- constant load of 5000 txns/s

Comparison with weakly consistent storage systems



- YCSB+T
- single shard
- 3 replicas
- 1M keys
- MongoDB & Redis:
  - → master-slave
  - → set to use synch. replication
- Cassandra:
  - → set replication level to 2

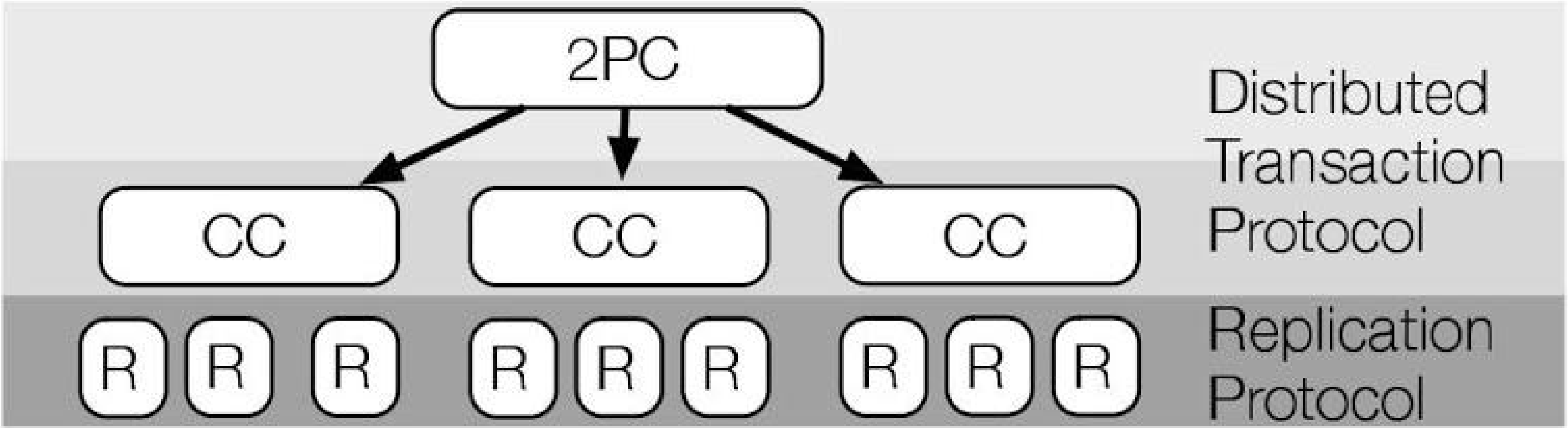
Conclusion

- possible build distributed transactions with better performance and strong consistency semantics on top of a replication protocol with *no* consistency
- relative to conventional transactional storage systems
  → lowers commit latency by 50%
  → increases throughput by 3x
- performance is competitive with weakly-consistent systems while offering much stronger guarantees

The end!

Techniques to improve performance

- optimize for read-only transactions
  → Megastore, Spanner
- use more restrictive transaction models
  → VoltDB
- provide weaker consistency guarantees
  → Dynamo, MongoDB



Observation

- Existing distributed transaction storage systems that integrate both protocols waste work and performance because both enforce strong consistency

IR Protocol

- Unique operation ID: IR client ID + op counter
- Replica maintain unordered records of executed ops and consensus results
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