Microsoft

FASTER

Efficient state management for the modern edge-cloud

github.com/microsoft/FASTER

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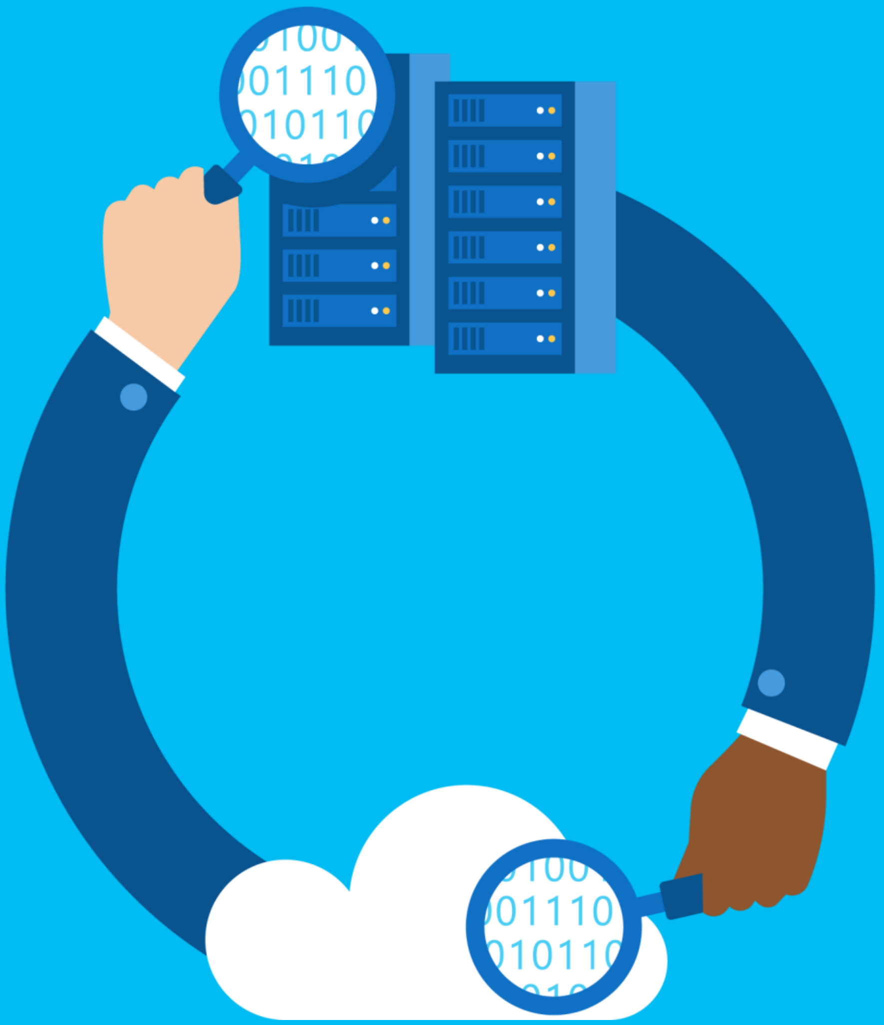

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Talk Outline

- SimpleStore - Research Project Summary
- FASTER & ecosystem
  - Architecture [SIGMOD 2018]
  - System features & use cases
  - A peek under the hood
    - Epoch protection
    - Async recoverability (CPR) [SIGMOD 2019]
  - Multi-node FASTER
    - Architecture [VLDB 2021]
    - Async recoverability [SIGMOD 2021]
- Summary

The SimpleStore Project

https://aka.ms/SimpleStore

Goal

Simplify app view of [storage + cache] at high perf
Create building block components

- Used by **user apps**, **cloud services, databases, functions**
- Used as **storage accelerator** or **point of truth**

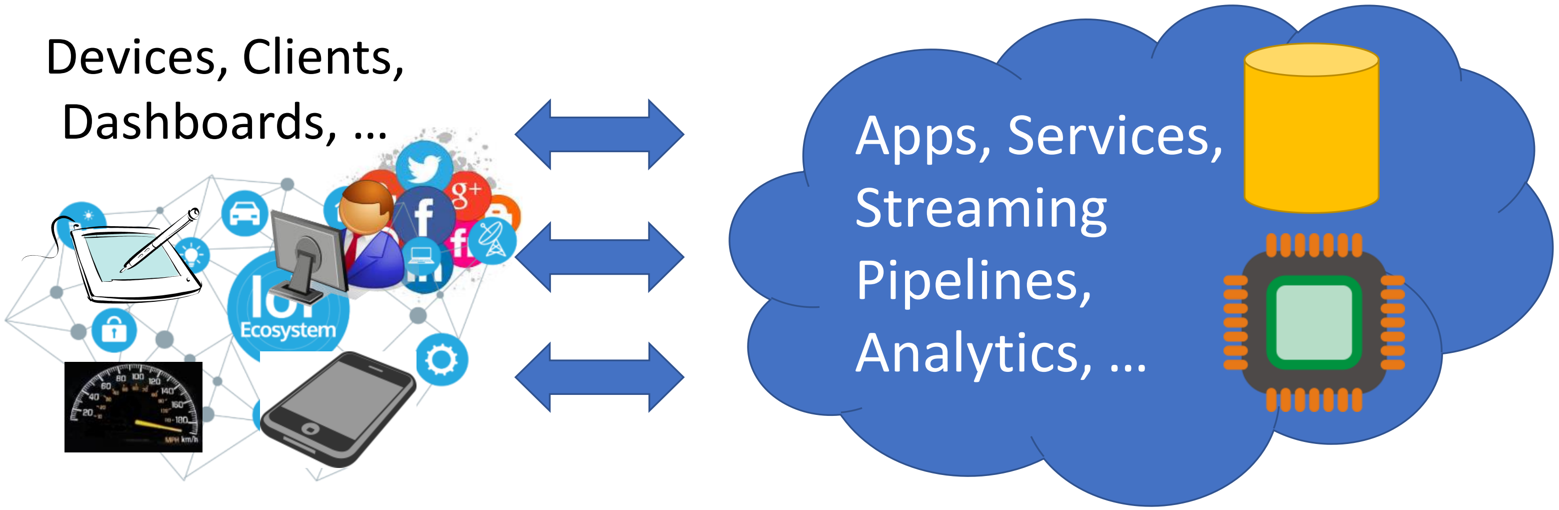
- Key Insights
  - Use concurrency & async recovery to create fast resilient components over tiered storage
  - Leverage predicates & temporal patterns at storage to optimize cache-store

- Compute Workloads
  - Cache-store & logging lib: FASTER KV & Log [SIGMOD 2018]
  - Recovery & Scale-out: CPR, DPR, Shadowfax [SIGMOD 2019, SIGMOD 2021, VLDB 2021]
  - Edge-cloud ecosystem: CRA, Surface Fleet, Ambrosia, Netherite [ICDE 2019, VLDB 2020]

- Analytics Workloads
  - Data layout for analytics: Qd-tree [SIGMOD 2020, SIGMOD 2021]
  - Caching for Analytics [work in progress]
  - Secondary Indexing: FishStore [SIGMOD 2019]

The Storage Problem

- Modern apps and services – common requirements
  - Apps access, update, cache huge volumes of state (or objects)
    - E.g., billions of per-device counters, per-ad statistics, sharded app state in actors & serverless
    - May not fit in memory, requires fast access and update, durability
  - Apps need fast reliable logging and messaging as key building blocks
  - Apps need to work in cloud, edge, serverless, multi-tenant environments



What is FASTER

An open-source library to accelerate object storage, indexing, logging

- High performance, concurrent, latch free, shared memory, in C# (also ported to C++)
- Two sub-components

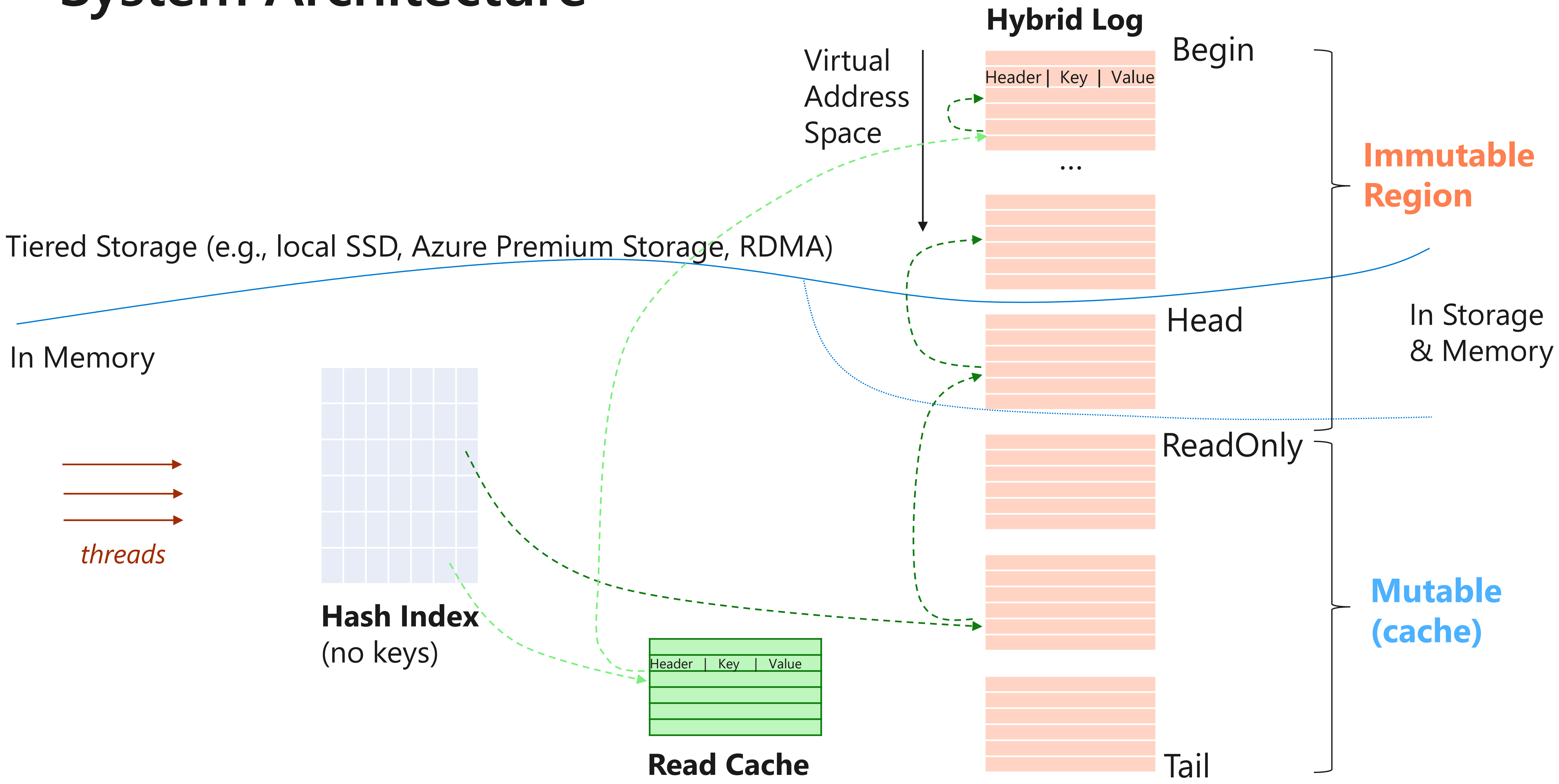
1) FasterLog

- Record log abstraction over tiered storage: enqueue, commit, scan, read, truncate
- In-memory part may be updated/accessed safely as a cache
- Can be used independently as a *persistent queue*

2) FasterKV

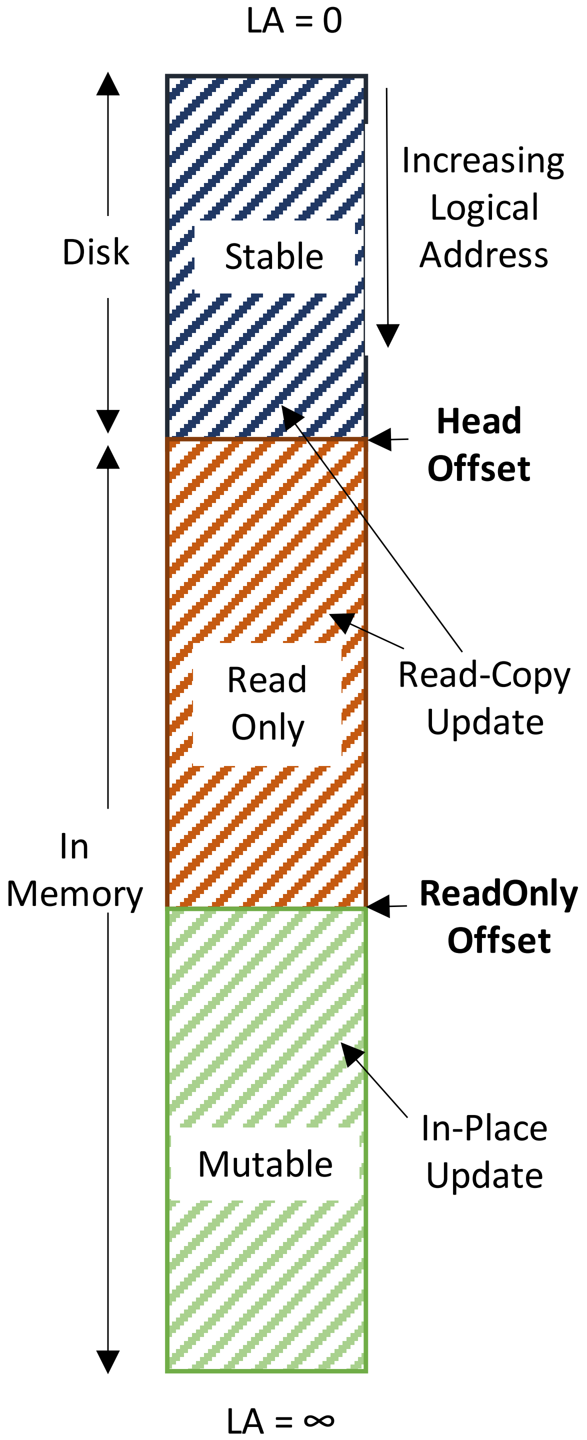
- Hash key-value store over the FASTER record log (*hybrid log*)
- Shapes the (changing) hot working set in memory → integrated cache
- Performance: >150 million ops/sec on one machine, for YCSB benchmark
  - Exceeds throughput of pure in-memory systems when working set fits in memory, linear scalability with #threads

System Architecture

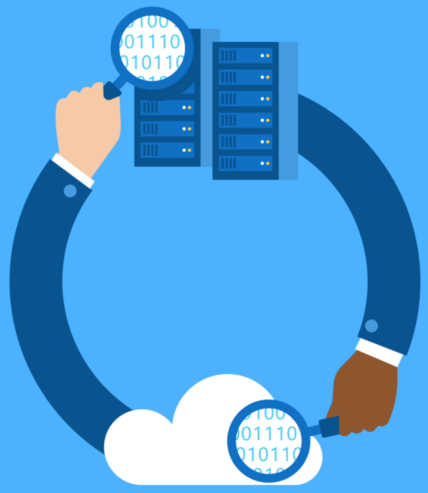


Hybrid Log in Detail

- Divide memory into three regions
  - Stable (on disk) → Read-Copy-Update (RCU)
  - Mutable (in memory) → In-Place Update (IPU)
  - Read-only (in memory) → Read-Copy-Update (RCU)
    - Memory: latch-free circular buffer with epoch protection for memory safety
- Hybrid concurrency model
  - Read-copy-update (RCU): compare-and-swap on index
  - In-place-update (IPU): user record-level concurrency
- Tail grows → offsets grow as well
  - New records allocated at tail
- New & updated records stay in mutable region for a while → captures temporal locality



Features, Use Cases, Performance



Basic FasterKV Features

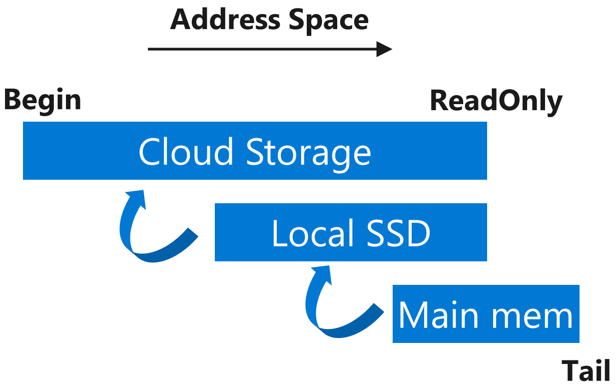
- Latch-free basic operations
  - Read, upsert, delete; *no transactions*
  - Atomic read-modify-write (RMW)
    - powerful primitive for aggregation
- Friendly session-based interface
  - Linearizable sequence of operations
  - Prefix recovery within session (later)
- Async ops within session
  - Works with C# task framework

```
await session.ReadAsync(key, input);
await session.RMWAsync(key, input);
```

- Dynamically grow index size

```
public static void Main()
{
  using var log = Devices.CreateLogDevice("hlog.log"); // backing storage device
  using var store = new FasterKV<long, long>(1L << 20, // hash table size (number of 64-byte buckets)
     new LogSettings { LogDevice = log } // log settings (devices, page size, memory size, etc.)
     );

  // Create a session per sequence of interactions with FASTER
  // We use default callback functions with a custom merger: RMW merges input by adding it to value
  using var s = store.NewSession(new SimpleFunctions<long, long>((a, b) => a + b));
  long key = 1, value = 1, input = 10, output = 0;

  // Upsert and Read
  s.Upsert(ref key, ref value);
  s.Read(ref key, ref output);
  Debug.Assert(output == value);

  // Read-Modify-Write (add input to value)
  s.RMW(ref key, ref input);
  s.RMW(ref key, ref input);
  s.Read(ref key, ref output);
  Debug.Assert(output == value + 20);

  Console.WriteLine("Success!");
}
```

Advanced Features



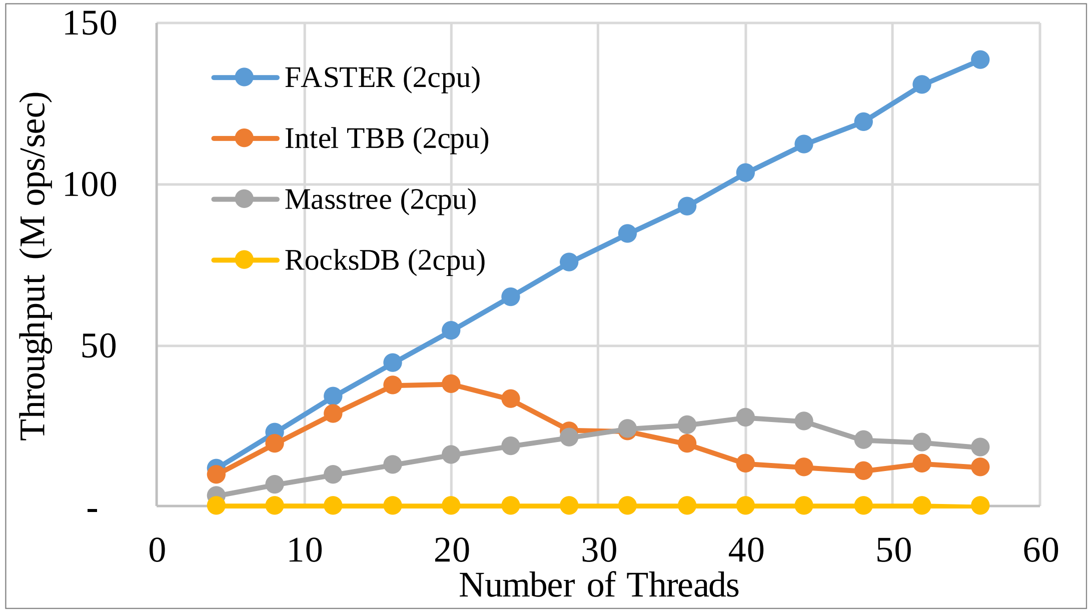
- Extensible `IDevice` storage interface
  - Local SSD, mounted drives, Azure page blobs, remote mem (RDMA)
  - Composable via Tiered & Sharded meta-device abstractions
- Non-blocking incremental checkpointing, recovery
- Log compaction
- Key iteration

```
long compactUntil = store.Log.BeginAddress + 0.2 * (store.Log.SafeReadOnlyAddress - store.Log.BeginAddress);
compactUntil = session.Compact(compactUntil, shiftBeginAddress: false);
await store.TakeHybridLogCheckpointAsync(CheckpointType.FoldOver);
store.Log.ShiftBeginAddress(compactUntil);
```

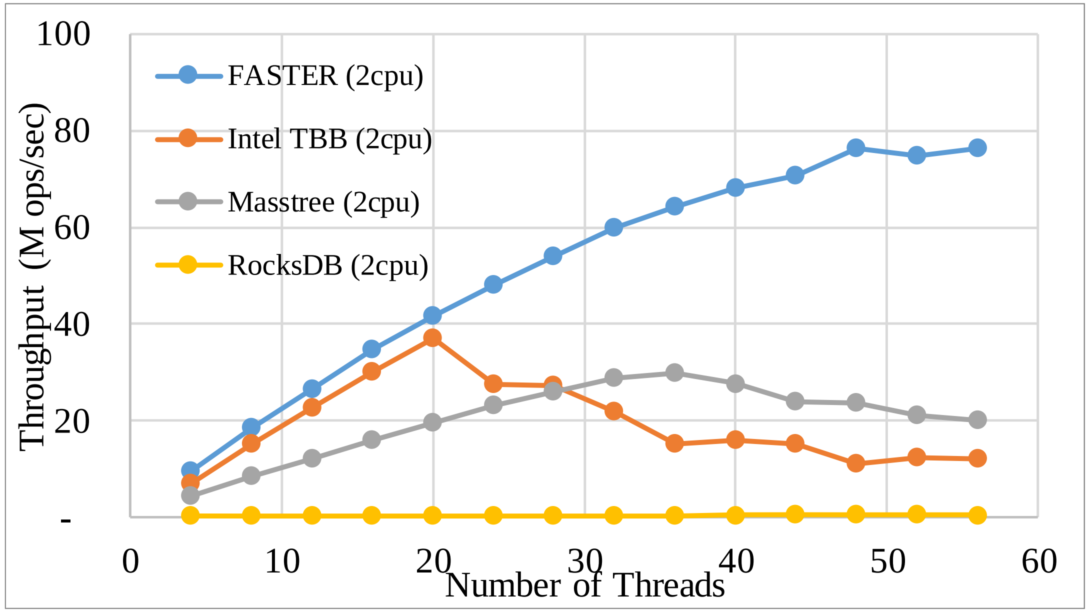
- FasterLog: Enqueue; Commit; Iterators
- Secondary indexing [coming soon]
  - Range index over keys or value fields
  - Hash index over value fields: e.g., register **`value.pet`**; query **`value.pet == "dog"`**
    - Based on "subset hash indexing" → see FishStore; SIGMOD 2019
    - First target customer: Azure Durable Functions/Netherite

Single-node scalability with # threads

- When current working set "happens to fit" in memory



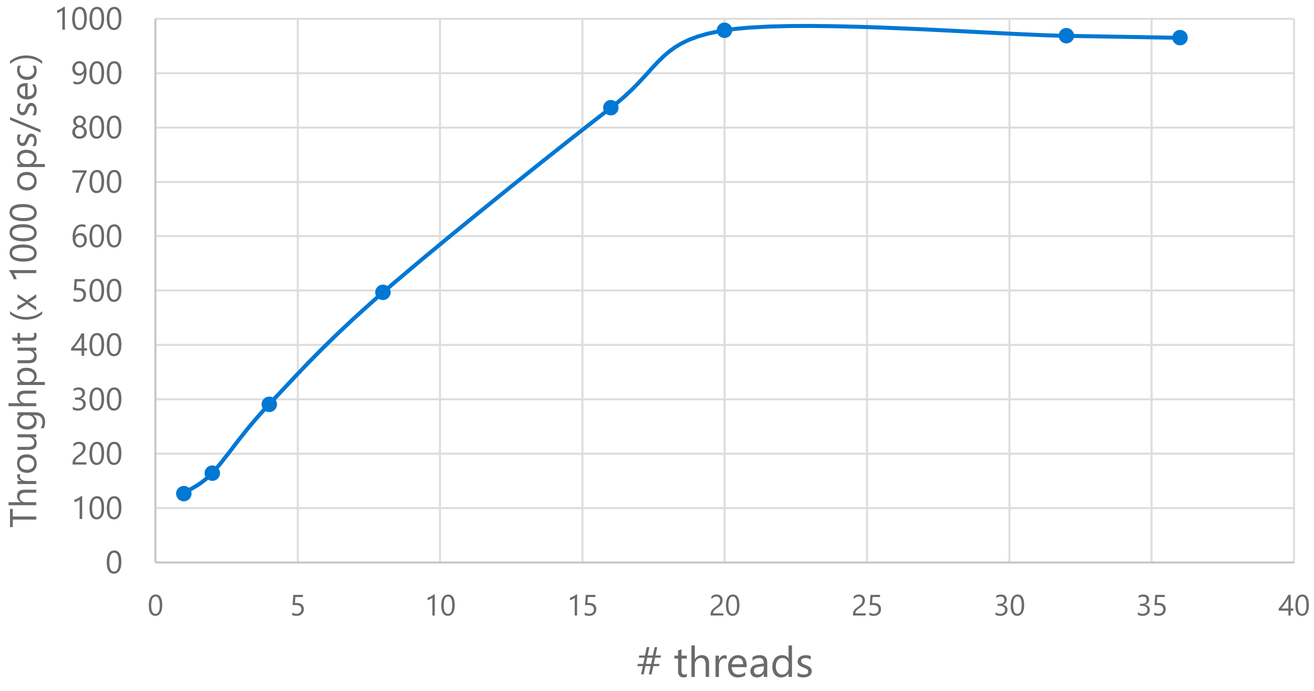
100% RMW; 8 byte payloads



100% blind updates; 100 byte payloads

Scalability with Disk-Resident Data

- YCSB, 100% read workload
- Hash table in memory, almost entire log on disk, no caching
- Local NVMe SSD capable of up to 1 million random IOPS.



Sample of Use Cases

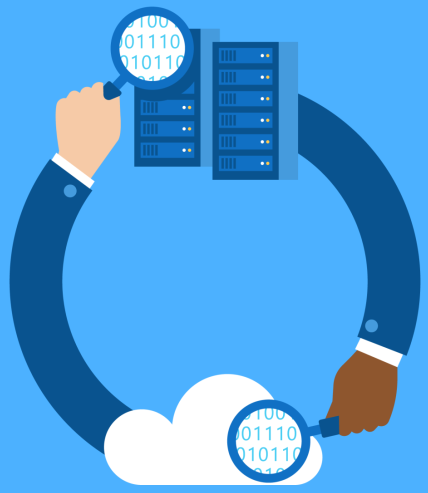
- Azure Stream Analytics
  - Uses FasterKV for externalizing reference data and records in large cloud streaming pipelines
- Azure Event Grid
  - Uses FasterLog for fast reliable routing and notification service on edge
- Azure Durable Functions
  - We built a new stateful serverless backend called Netherite
  - System uses FasterKV (for function state) and FasterLog (for fast replayable messaging)
  - See details in their paper: https://arxiv.org/abs/2103.00033
- Many GitHub use cases:

> Jan-2021:
> Using FasterKV.
> *I decided to run with Faster in our production system after your help and rewriting things a bit to suit our actual usecase. <snip> I think the speed is actually pretty good for 50k+ devices hitting our system in the short term and we can improve later.*

> Nov-2020:
> Using FasterLog
> On Azure D2as_v4 machines. *We have about 1000 stores but they are all really tiny (less than 1000 messages per store). The largest store is about 1mb and most of the stores are <100kb, for a total of some 200mb across 1k stores.*

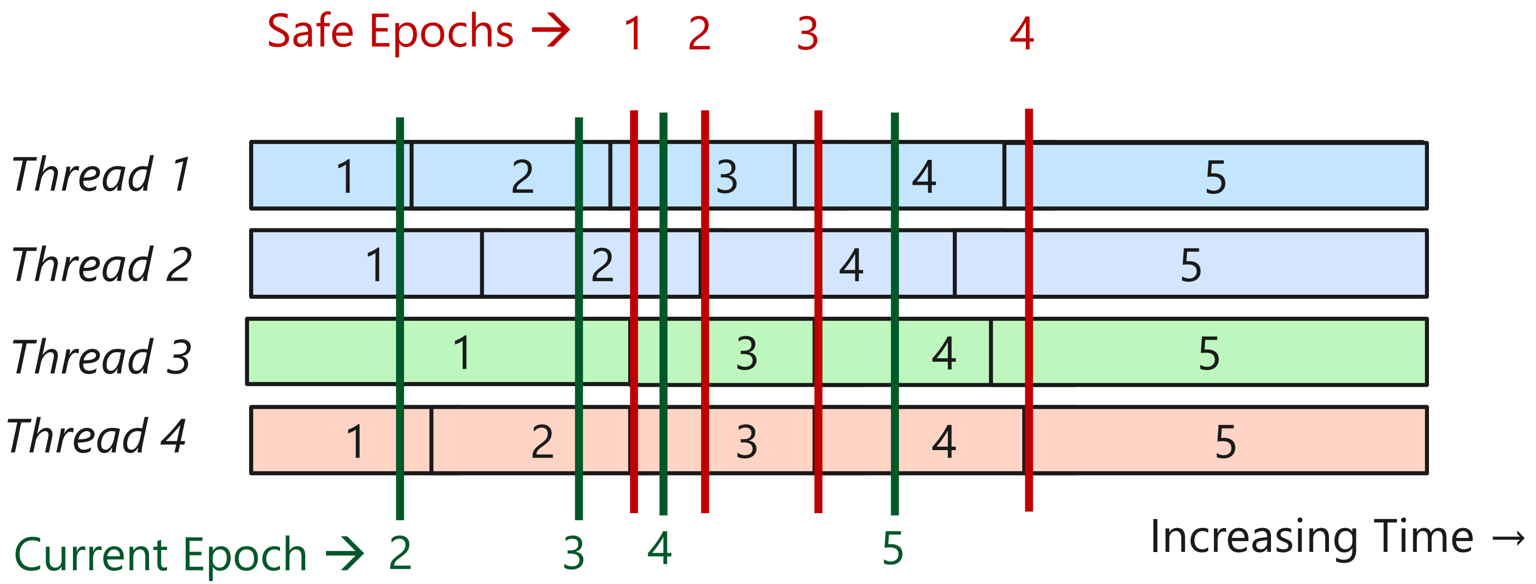
A Peek Under the Hood

the generalized epoch framework



Multi-Threading: Epoch Protection Basics

- System Requirement
  - avoid any coordination between threads in common case
  - agree on mechanism to synchronize on shared system state
- Solution: epoch protection
  - System maintains shared counter **E** (current epoch) - can be "bumped" by any thread
  - Each thread keeps a (stale) *local epoch* counter copied from **E**
  - An epoch *c* is "safe" if all thread-local epochs are greater than *c*

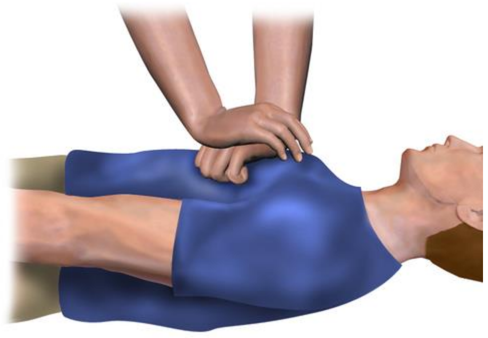


Extending Epochs: Trigger Actions & Marking

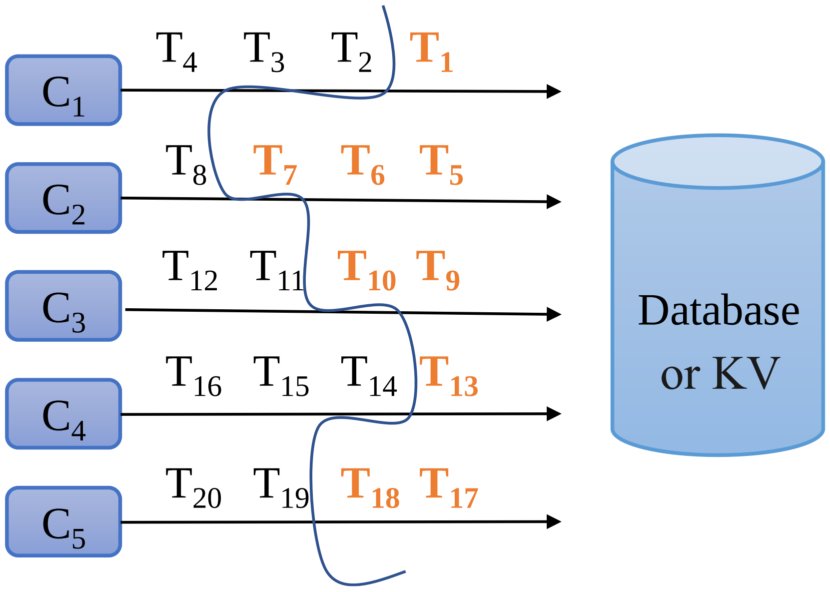
- Trigger Actions
  - Associate a trigger (function callback) with epoch bump from *c* to *c+1*
  - Trigger action will be executed later, when c becomes safe
  - Simplifies lazy synchronization in multi-threaded systems
  - Example: invoke function `F()` when (shared) status becomes “active”
    - Thread updates shared variable status = “active”, then bumps current epoch with trigger = “invoke function **`F()`**”

      ```
      BumpEpoch( () => F() );
      ```
    - Guaranteed that all threads have seen “active” status before **`F()`** is invoked
- Marking
  - Mark: thread “marks” an operation/phase as complete
  - CheckIfComplete: thread checks if everyone has completed phase; if yes: advance phase
- FASTER uses epochs, triggers, marking extensively
  - Threads agree to respect global system state at epoch refresh boundaries
  - Memory safety, index resizing, log buffer maintenance, checkpoint state machine

Recovery: Concurrent Prefix Recovery

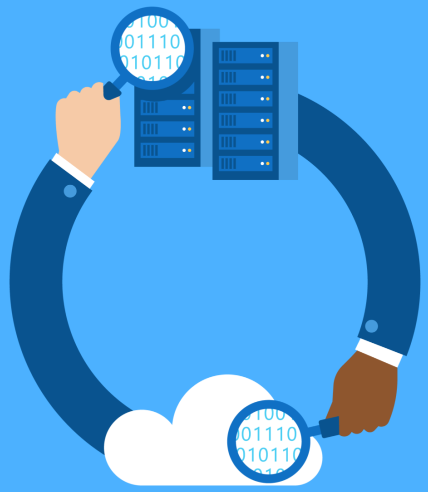


- In memory part of hybrid log is lost on update
- New recovery model for concurrent DB/KVS
  - Persist all ops until some point in input op sequence, per thread, none after
- Combines worlds of DB group commit and in-memory incr. checkpointing
- Admits scalable non-blocking implementation using epochs
- Fully implemented in FASTER
- See SIGMOD 2019 paper
  - https://aka.ms/FASTER



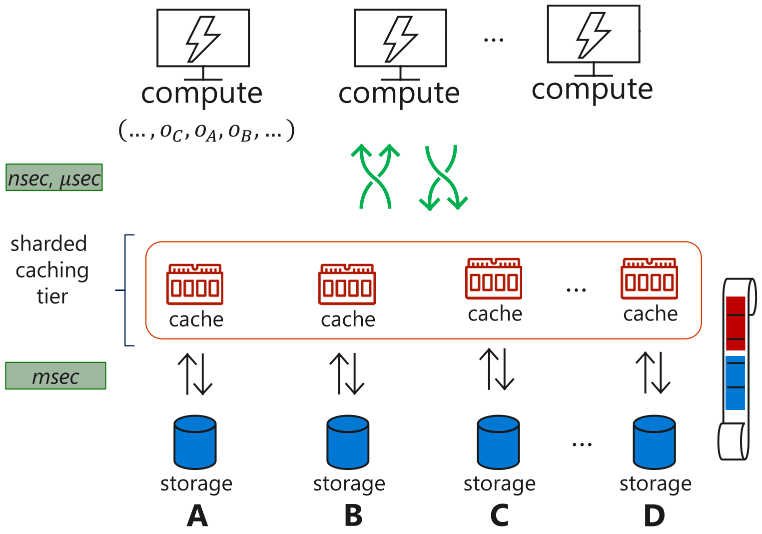
Remote FASTER

from embedded to clients → servers



Remote FASTER

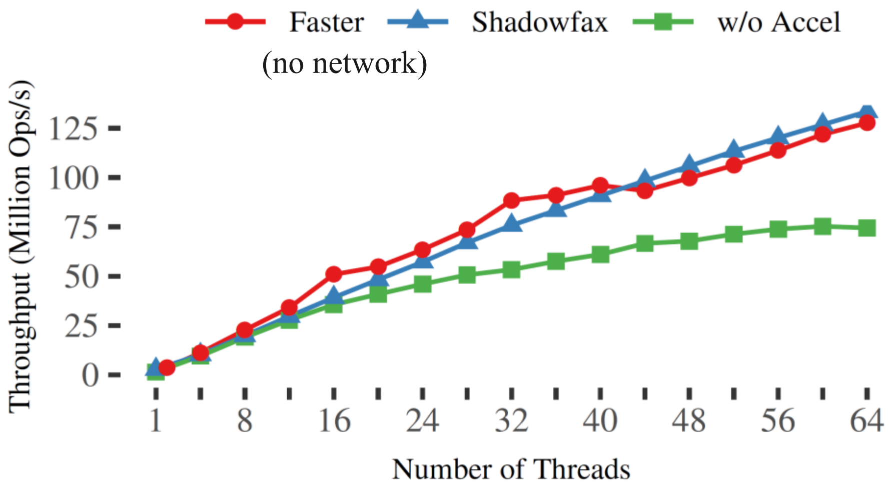
- Goal: access FASTER as mid-tier cache/store from remote clients



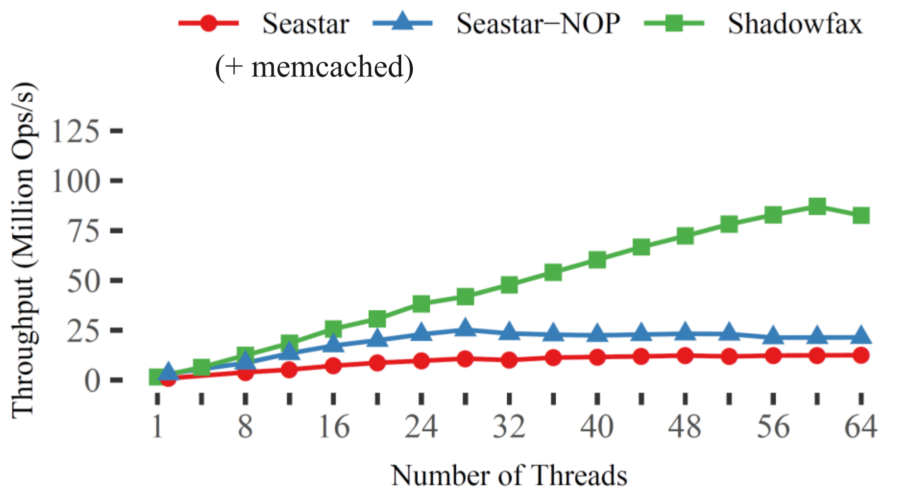
- Brief Summary
  - Get the same FASTER throughput scalable with #threads, from **remote client sessions**
  - Low round-trip latencies (<100microsec for one request in datacenter)
  - Uses standard TCP protocol; also supports RDMA
  - Server inherits rich FASTER features (tiered storage, checkpoints, RMW, …)

Shadowfax

- Elastic client-server prototype FASTER C++
- Uses standard TCP on cloud VMs
  - We get high performance (100+ Mops/sec per server)
  - Low latency <100 μsec round-trip in Azure data center
  - Also supports RDMA access
- Key ideas in Shadowfax
  - Eliminate "shuffle" at network layer
  - Use "asynchronous global cuts" across machines + epochs within machine for elastic state migration
- Details: paper at VLDB 2021
  - https://arxiv.org/abs/2006.03206



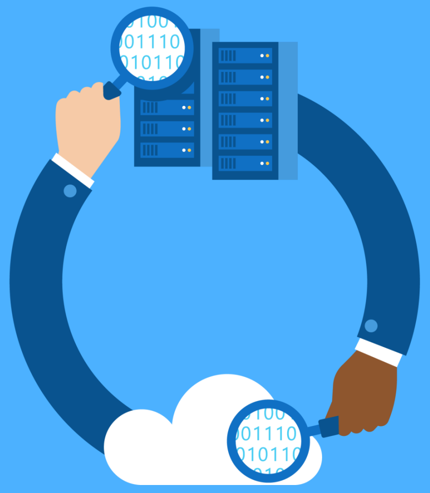
YCSB Zipf workload
8B key, 256B value



Uniform, with Accel
8B key, 256B value

Distributed Prefix Recoverability (DPR)

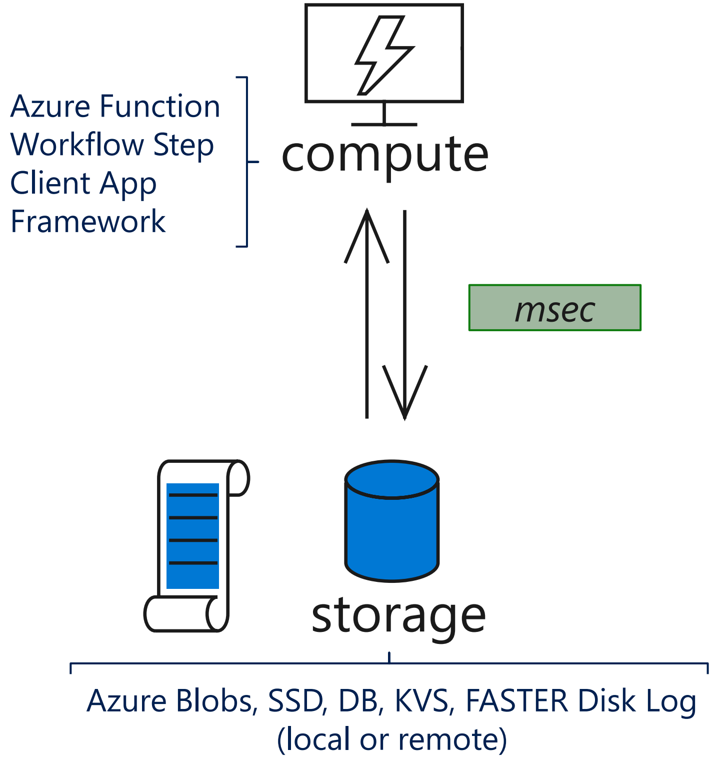
prefix recovery for client sessions
talking to multiple shards

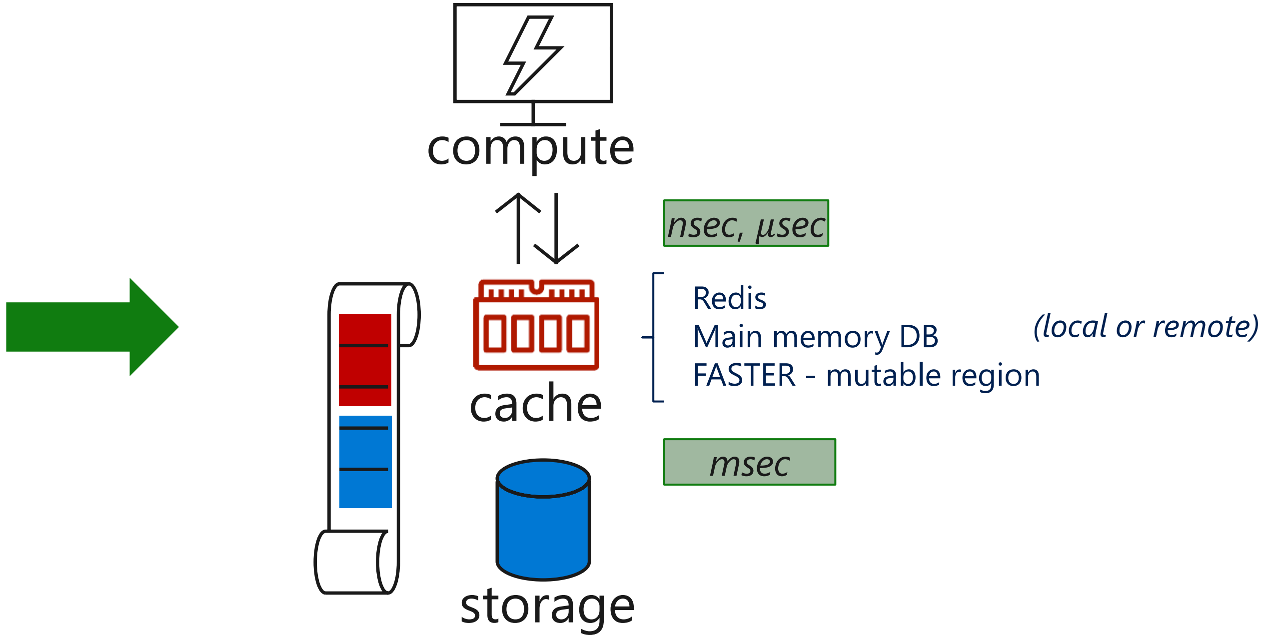


The Compute-Storage Pattern

- Read & write ops served from durable storage

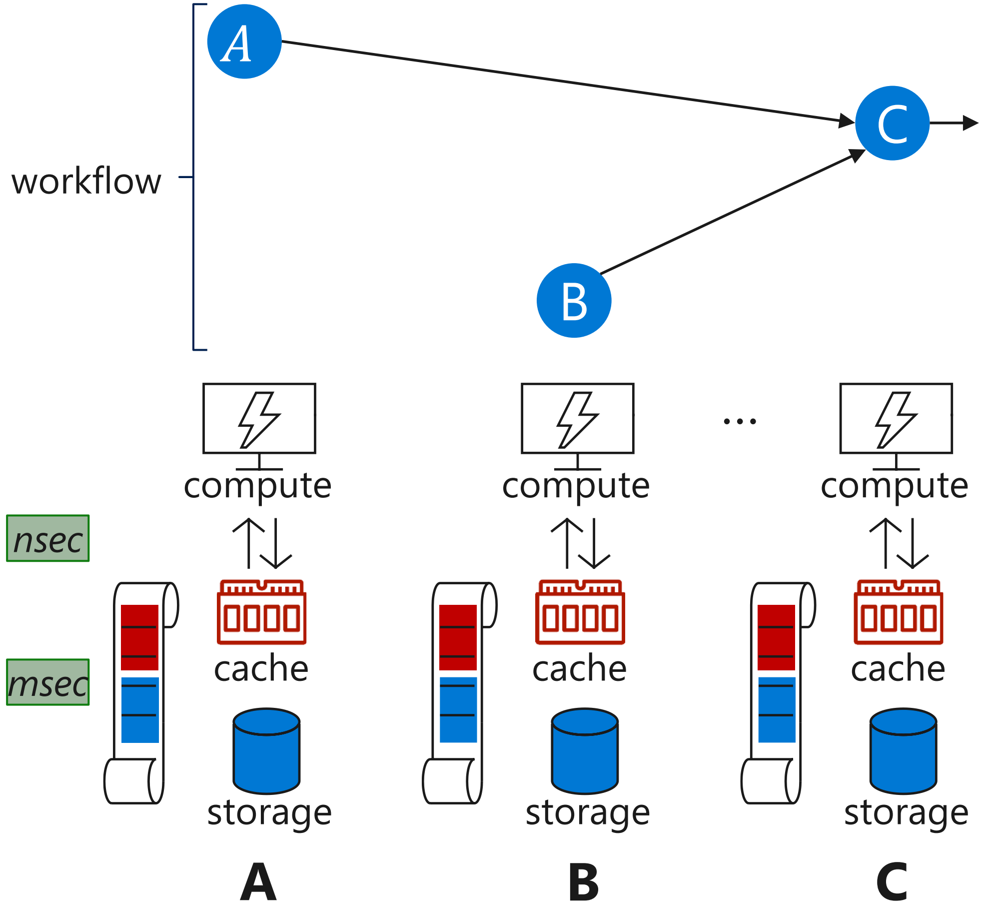
- Reads: served from cache
- Writes:
  - Go through to durable storage, or
  - In 1 failure domain: ops complete → commit



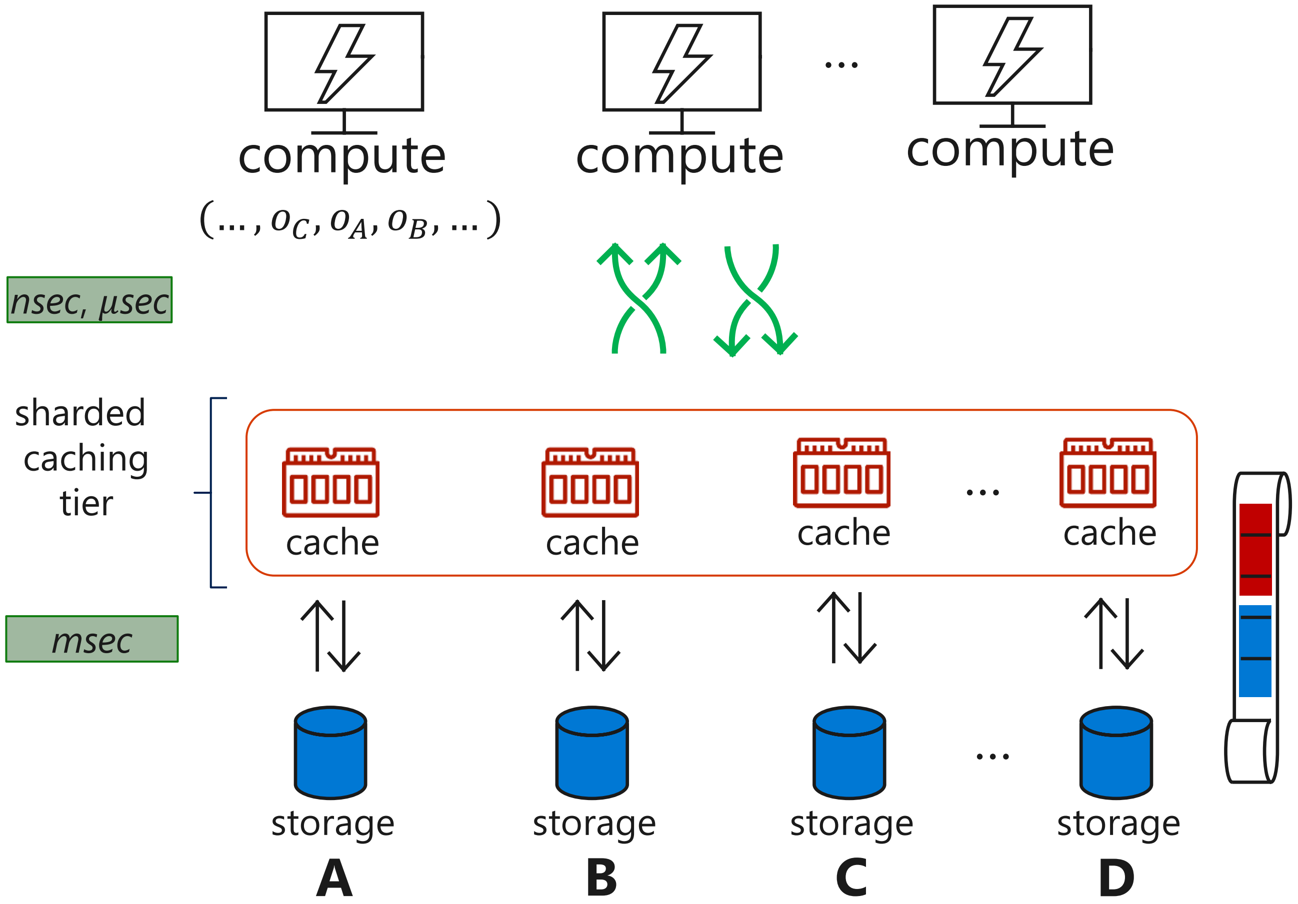


Let's Shard the Data

- Shared-nothing state

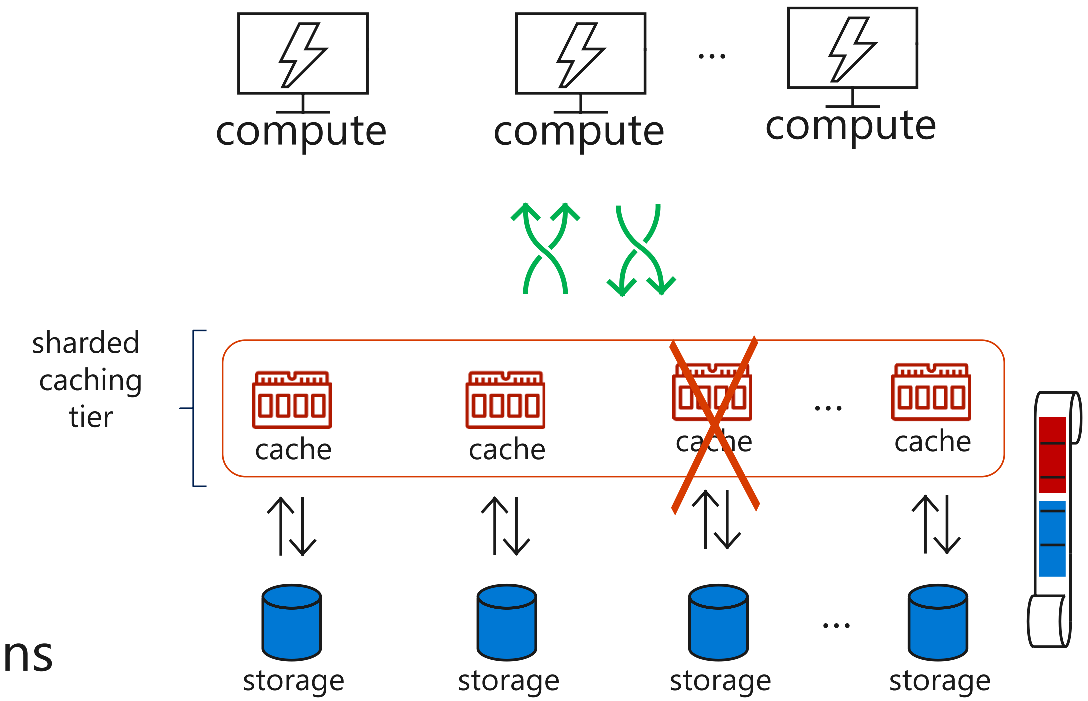


- Global shared state



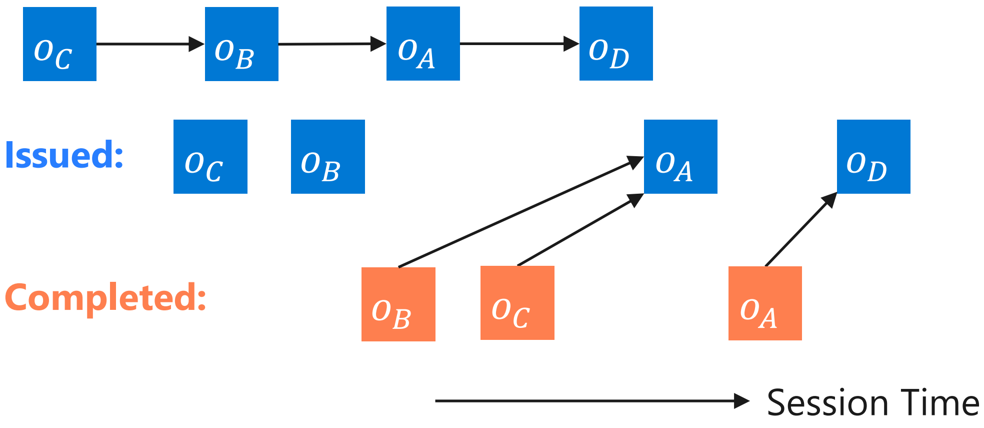
Goal: Distributed Compute on Sharded Cache-Stores

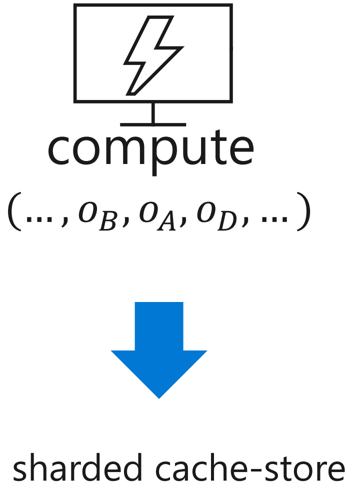
- Normal behavior
  - Return operations immediately; before commit
  - Including **writes, not just reads**
  - Preserve client's notion of operation dependencies via **lazy prefix commits**
  - At low cost with no cross-shard overheads
- Behavior on shard failure
  - Rollbacks will happen due to multiple failure domains (unlike CPR)
  - Limit effect of rollback to true dependencies
  - Make rollbacks non-blocking
  - Notify affected client sessions of rollback of uncommitted ops



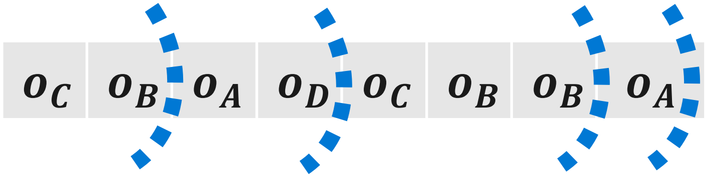
Basic Idea: Client Session to Capture Dependencies

- Clients issue ops to cache-store shards
  - Op status can be { issued, completed, committed }
- Client Session captures op dependencies
  - Issued op depends on all previous “completed” ops in session (transitive)
  - Issued==completed:
  - Issued != completed:





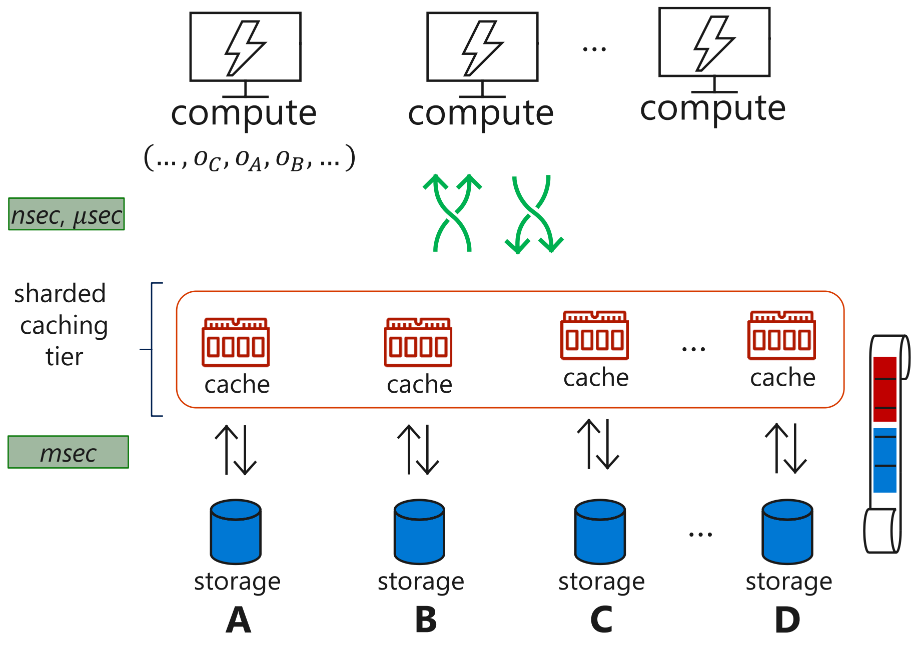
- Periodically commit prefixes of session order
  - An order of ops that respects partial order of op dependencies



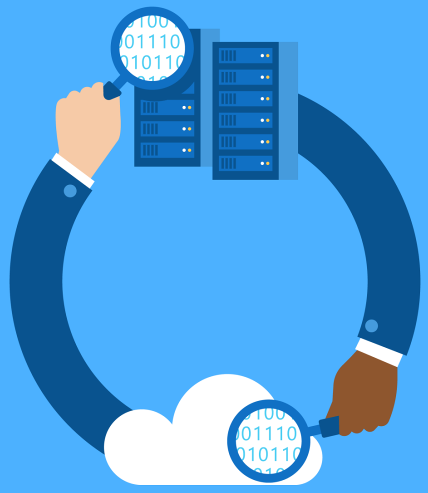
- Implemented DPR for FASTER & Redis
- Details: see SIGMOD 2021 (to appear)

Recoverability Summary

- Clients talk to sharded cache-stores via linear sessions
- Separate op completion from commit
- We provide a prefix recovery guarantee within each session
  - Requires dependency tracking mechanism
- Client rollback in case of failure
- Applicable to stores and workflows
- Details in paper at SIGMOD 2021



Talk Summary



Summary

- SimpleStore project aims to simplify the use of storage for apps, workflows, services, analytical databases, serverless
- The FASTER project offers
  - A concurrent latch-free embedded library for managing memory and tiered storage
  - Two concrete artifacts: FasterKV and FasterLog
  - Secondary indexing for log analytics & range queries
  - Remote access without performance loss
  - Novel recovery techniques for single- and multi-node DB
- DB techniques are generally applicable beyond artifacts
- More details at https://aka.ms/FASTER
  - Link to research papers: https://microsoft.github.io/FASTER/docs/td-research-papers/

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Thank you!

https://aka.ms/FASTER