Rethinking Storage

for the cloud, edge, serverless, and big data era

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Introduction

- The **cloud** has matured as the platform for compute and data processing
- The **edge** is becoming important as a source, destination, and conduit for cloud computation
- There is increased focus on simplicity, ease of adoption and deployment, and auto-scaling with **serverless** abstractions
- We are ingesting, storing, processing rich **big data** with dynamic schema, such as JSON
The Compute – Storage Gap

- Storage (be it main memory, local disk, or cloud storage) is not keeping up with advances in compute simplification

- Today’s state of the practice
  - Use auto-scaling compute (Lambda, Functions) or Kubernetes
  - Keep everything in memory: use input replay or tolerate data loss
  - Or, use remote elastic SQL/storage services (Aurora, Socrates, BigTable, ...) on every invocation/event
  - Throw in a cache as an afterthought – always Redis
The Landscape Today

- A kitchen sink of storage services and design patterns for stateful apps over modern compute substrates
- Poor memory & storage utilization, latency (last mile is longest)
- Unclear recovery & consistency guarantees in distributed deployments with caches
- An inability to ingest, store, process modern & rich evolving datasets quickly (e.g., the Twitter firehose)
- Too much user effort: choosing indices, storage formats, and data layouts, ...
Case Study: Trill for Bing Ads

- Trill is a high speed in-mem columnar streaming analytics library
- Now OSS; used across Microsoft: Azure, Bing, Office, Windows, ...
  - Library model of Trill was a huge success
  - Used with a variety of distributed fabrics (Orleans, Scope/Cosmos, Kubernetes, ...)
- Bing Ads uses Trill in scaled-out Scope compute infra
- Temporal Locality of State
  - Search engine maintains per-user stats over last week
  - Billions of users “alive” at given instant
  - But, only millions actively surfing
  - Everything stored in main memory
  - Storage is the main reason to scale out

Apps, Services, Streaming Pipelines, Analytics, ...
The SimpleStore Research Agenda

Simplify app view of [storage + cache]; high performance
Build single-node embedded storage artifacts
  • Use by end-user apps or cloud services
  • Use as storage accelerator or point of truth

• Compute Workloads
  • Unified log/storage abstraction across memory, local, cloud storage (FASTER Log)
  • Embedded KV store + cache (FASTER KV)
  • Scalable consistency & recovery models for such workloads (CPR)
  • Resilient stateful actors (CRA / Ambrosia)
  • In progress: auto-scaling and zero-config library for serverless storage

• Big Data Analytics Workloads
  • Embedded library for ingesting, storing, querying flexible-schema data (FishStore)
  • Fast partial parsing techniques for flexible schema data (Mison)
  • In progress: ML-driven automatic data layout and indexing of high-dimensional data
Talk Outline

- Introduction & Motivation
- SimpleStore for Compute Workloads
  - FASTER Log
  - FASTER KV + cache
  - Concurrent Prefix Recovery
  - Library for Serverless
- SimpleStore for Big Data Analytics
  - FishStore for flexible schema data
  - Learned data layouts for storage & caching
- Conclusions
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Compute over Fine-Grained Objects

- Many apps operate over billions of fine-grained objects
  - IoT device tracking, data center monitoring, streaming, online services, ...

- State consists of independent objects – *devices, users, ads*
  - Overall state doesn’t fit in memory
  - Point ops with lots of updates
    - e.g., *update per-device average CPU reading*
  - Atomic read-modify-write (RMW)
  - State exhibits temporal locality
  - State needs to be recoverable

- Problem across edge, cloud, multi-tenant, and serverless applications
What is FASTER

- An open-source library for accelerating object storage
  - High performance, concurrent, latch free, shared memory
  - Two sub-components

1) FASTER Log
   - Record log abstraction over tiered storage: enqueue, commit, scan, read, truncate
   - “Hybrid” support: tail may optionally be modified in-memory safely, as mutable region
   - Can be used independently as a persistent queue

2) FASTER KV
   - Hash key-value store over the record log
   - Shapes the (changing) hot working set in memory → integrated cache
   - Performance: up to 200 million ops/sec for YCSB variants
     - One Intel Xeon machine, two sockets, 72 threads
     - Exceeds throughput of pure in-memory systems when working set fits in memory
Architecture & Components

- Technical Innovations
  - **Indexing**: Concurrent Hash Index
  - **Record Storage**: “Hybrid Log” Record Allocator
  - **Threading**: Epoch Protection Framework with Trigger Actions
Hybrid Log in Brief

- Divide memory into three regions
  - Stable (on disk) → Read-Copy-Update (RCU)
  - Mutable (in memory) → In-Place Update (IPU) - **optional**
  - Read-only (in memory) → Read-Copy-Update (RCU)

- Hybrid concurrency model
  - RCU: compare-and-swap on index
  - 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

- Supports tiering, e.g., [memory, SSD, cloud storage]
Scalability of FASTER KV with # Threads

- When current working set “happens to fit” in hybrid log memory

100% RMW; 8 byte payloads

100% blind updates; 100 byte payloads
What About Durability?

- Write Ahead Log? Every change is recorded in WAL
- Stresses write bandwidth; log is a scalability bottleneck; fine-grained commit acks

FASTER + WAL:
>150M ops/sec → ~15M ops/sec

Custom in-mem txn database + WAL: bottleneck at ~20M single-key txns per sec
Towards Our Approach: Prefix Recovery

- Adopt the semantics of **group commit**
- **Prefix Recovery (PR)** based commit
  - Commit = \{ all ops issued up to time t \}
  - Clients can prune in-flight op log until t, expose commit

- Compatible with reliable messaging systems (e.g., Kafka)

- Today’s PR approaches are not scalable
  - Using WAL: \{ fuzzy chkpt + WAL \}
  - Atomic commit log of ops → scalability bottleneck
  - Quiesce the database → not desirable
Concurrent Prefix Recovery (CPR)

- System notifies each thread $S_i$ of a commit point $t_i$ in its local operation timeline
  - Eliminates system-wide single time point $t$
- All ops before $t_i$ are committed, and none after, $\forall i$
- Same consistency as PR, but allows scalable multi-threaded implementation
- System, not user, chooses exact CPR point per thread $\rightarrow$ key to non-blocking
Using CPR to Build Systems

- CPR makes it possible to implement scalable group commit
- But, non-trivial to design systems that achieve this scalability!
- We used CPR to add durability to
  - Simple concurrent shared-memory transactional database
  - FASTER KV
- Non-trivial details; based on epochs + state machine; see paper
- CPR model is interesting for distributed/serverless storage as well
In-mem DB Prototype + CPR

- Compared CPR against:
  - WAL
  - CALC (point-in-time checkpoints using atomic commit log of ops)

- Summary: CPR scales linearly with #threads
  - See paper for details
FASTER + CPR: End-to-End Experiment

- Vary client op buffer size; issue commit when buffer 80% full
- Use 36 client threads, YCSB 50:50 workload
- Figure shows a *commit latency vs. throughput tradeoff*
Current Status of FASTER

• Open sourced at https://github.com/microsoft/FASTER

  ![microsoft / FASTER](image)

  ![Watch](180) ![Unstar](3.7k) ![Fork](262)

• Research papers: SIGMOD 2018, VLDB 2018 demo, SIGMOD 2019

• Summary of Use Cases
  • State store for streaming pipelines
  • Edge cache in front of point-of-truth database backends
  • Scalable persistent queue abstraction for edge-cloud (FasterLog)
  • Integrated into Timely Dataflow (with Rust wrapper over FASTER C++)
  • Presented and evaluated recently as alternative to RocksDB (Flink Forward 2019)
Future: Storage for Serverless/Actor Apps

- CPR → Distributed CPR
- Leverage cloud services

- Decentralized Storage Library
Stateful Actor Frameworks

- Actor-oriented systems (Orleans, Ray, Durable Functions, Ambrosia) are helping simplify stateful applications
- Expose abstraction of [resilient compute + local memory]
  - Use DB ideas of checkpoint/replay or active-active for state recovery
- Reusable storage artifacts help build such systems, make it easier to manage app state
- Users still need storage + cache libraries
  - Applications do not always live within the confines of specific framework
  - Elasticity is easier, quicker, more reliable, manageable with stateless fabrics
  - Applications have diverse remote storage needs (e.g., store truth in CosmosDB, access larger-than-memory shards on compute node, map-reduce)
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Simplifying Analytics: FishStore

- Stands for Faster Ingestion with Subset Hashing
- Storage library for dynamic flexible-schema data, e.g., JSON, CSV
  - Based on registration of dynamic predicates/query templates over data
  - Query-driven dynamic schema inference
  - Rockset talk provided great motivational use cases
- Two bottlenecks: indexing & parsing
  - Extended FASTER to index “interesting subsets” of data in chains
  - Generic parser interface to parse only “interesting” fields → we use Mison & simdjson
- Ingests at 10GB/sec, saturates 2GB/sec SSD with < 8 cores
  - Details: SIGMOD 2019 paper, VLDB 2019 demo
  - Open source at https://github.com/microsoft/FishStore
FishStore Architecture

- Ingest + index: fast path
- Dynamically reg/dereg templates
- Query on registered templates
Future: Automatic Data Layout, Caching, Indexing

- Ultimate Goal
  - Ingest high-dim flexible schema data, impose access workload (queries) on library
  - Storage auto-optimizes layout/access methods over time

- First attempt: workload-driven data layout for OLAP
  - Leverage reinforcement learning

- Initial results are surprising
  - Data layouts are an order-of-magnitude better than traditional layouts
  - Produces data blocks: form basis for caching at storage clients
  - Supports advanced layouts where tuples may be in multiple blocks
Thank You

Find our open-source work at https://github.com/badrishc

Pubs at https://badrish.net/

Interested in working on SimpleStore? Contact me for internships @MSR.
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