RAMCloud: Low-latency DRAM-based storage

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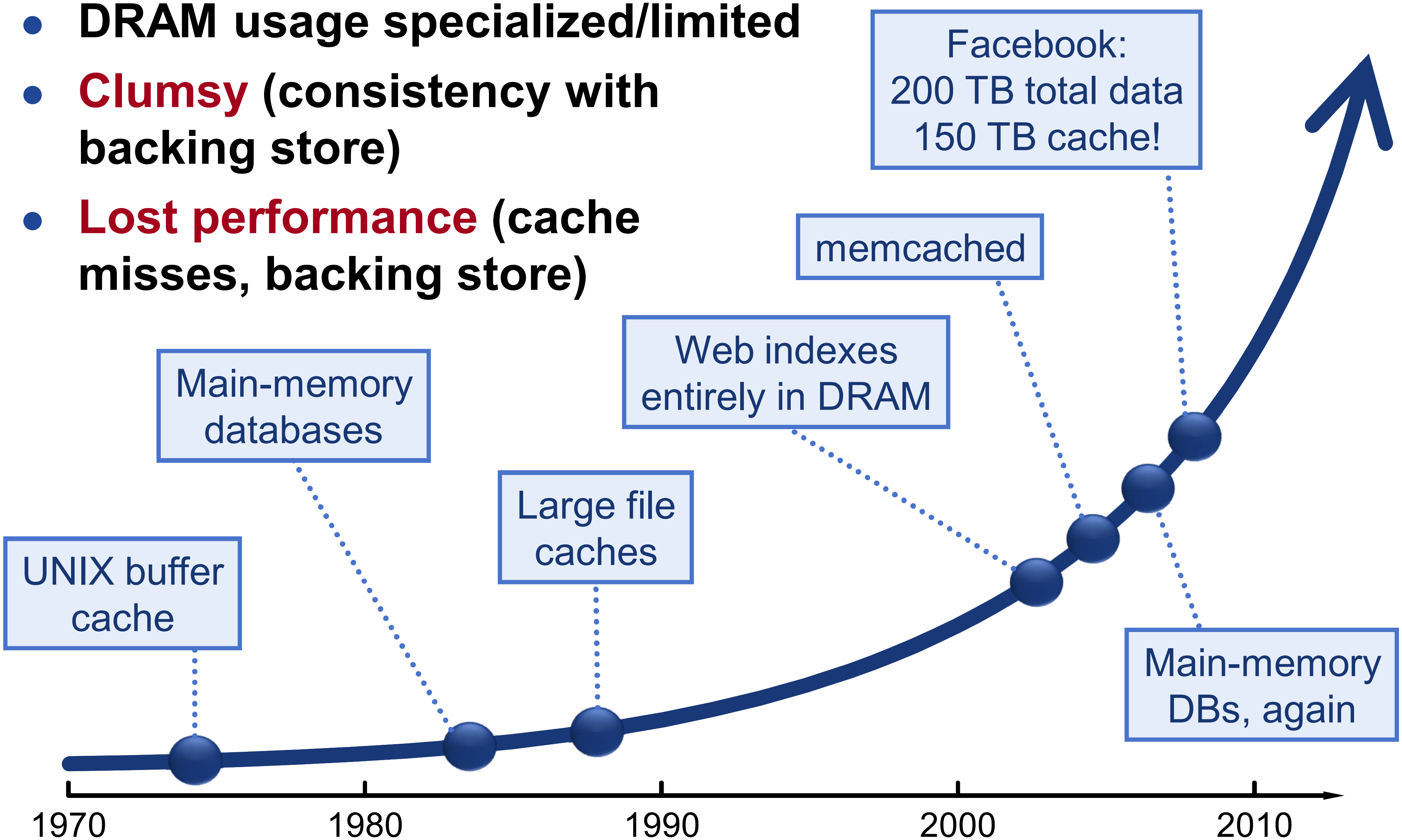
http://ramcloud.stanford.edu

DRAM in Storage Systems

- **DRAM usage specialized/limited**
- **Clumsy (consistency with backing store)**
- **Lost performance (cache misses, backing store)**



RAMCloud Overview

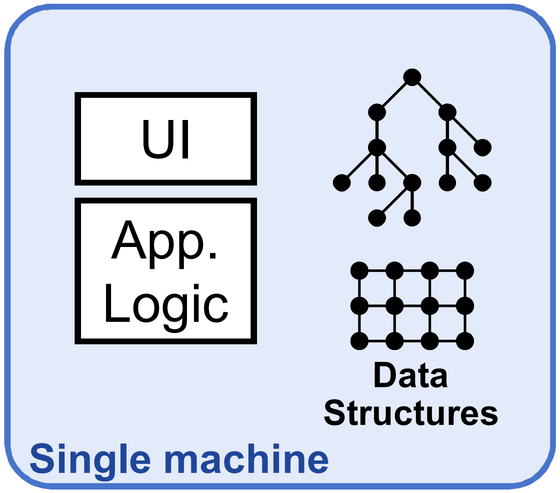
Harness full performance potential of large-scale DRAM storage:

- **General-purpose storage system**
- **All data always in DRAM (no cache misses)**
- **Durable and available**
- **Scale: 1000+ servers, 100+ TB**
- **Low latency: 5-10µs remote access**

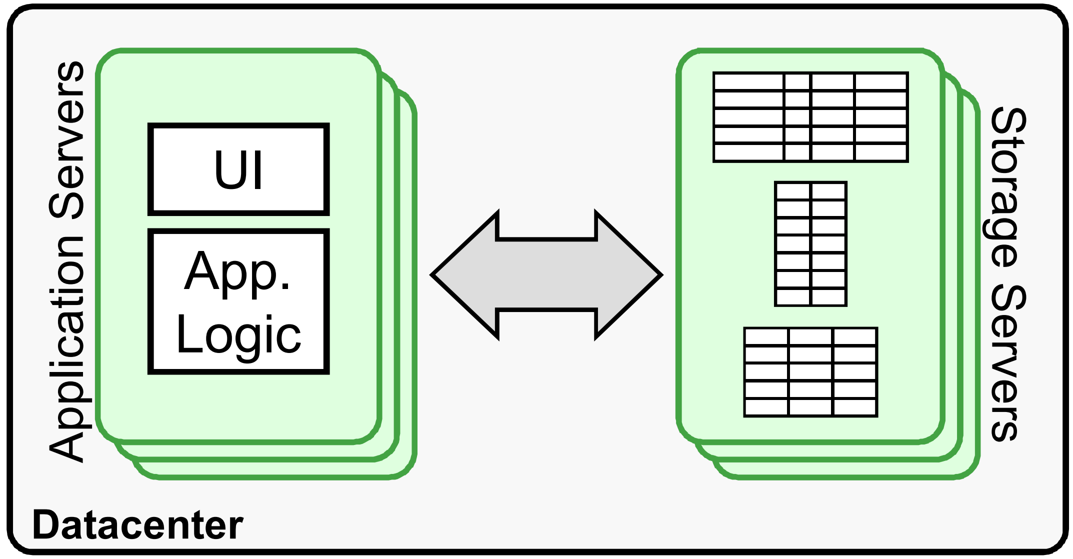
Potential impact: enable new class of applications

Why Does Latency Matter?

Traditional Application



Web Application



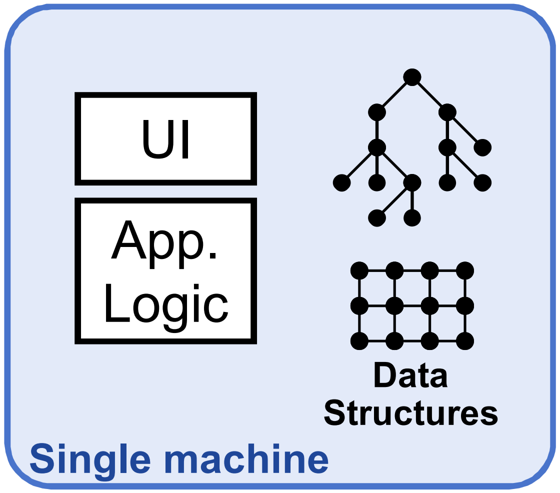
<< 1µs latency

0.5-10ms latency

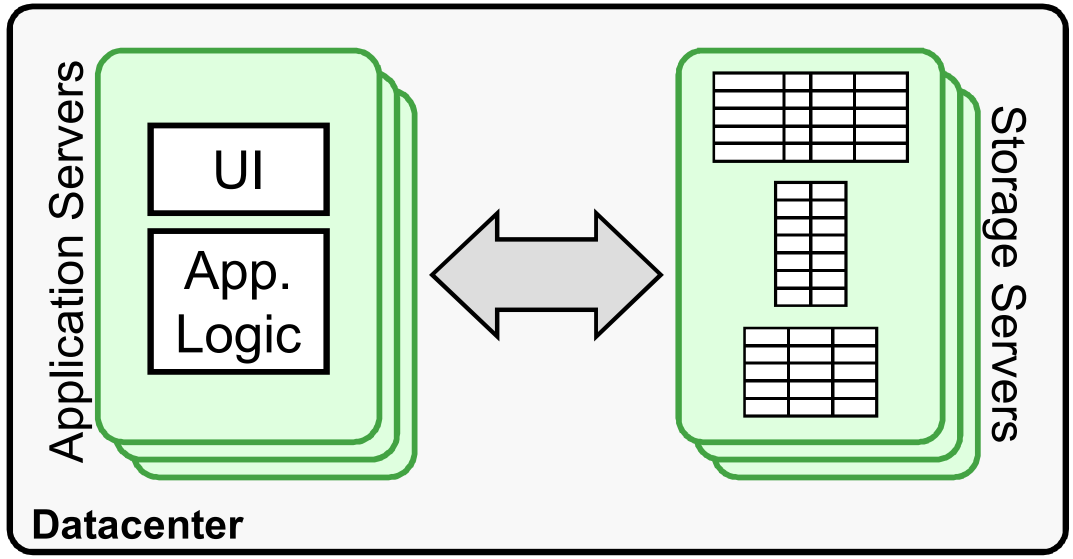
- **Large-scale apps struggle with high latency**
  - Random access data rate has not scaled!
  - Facebook: can only make 100-150 internal requests per page

Goal: Scale and Latency

Traditional Application



Web Application



<< 1µs latency

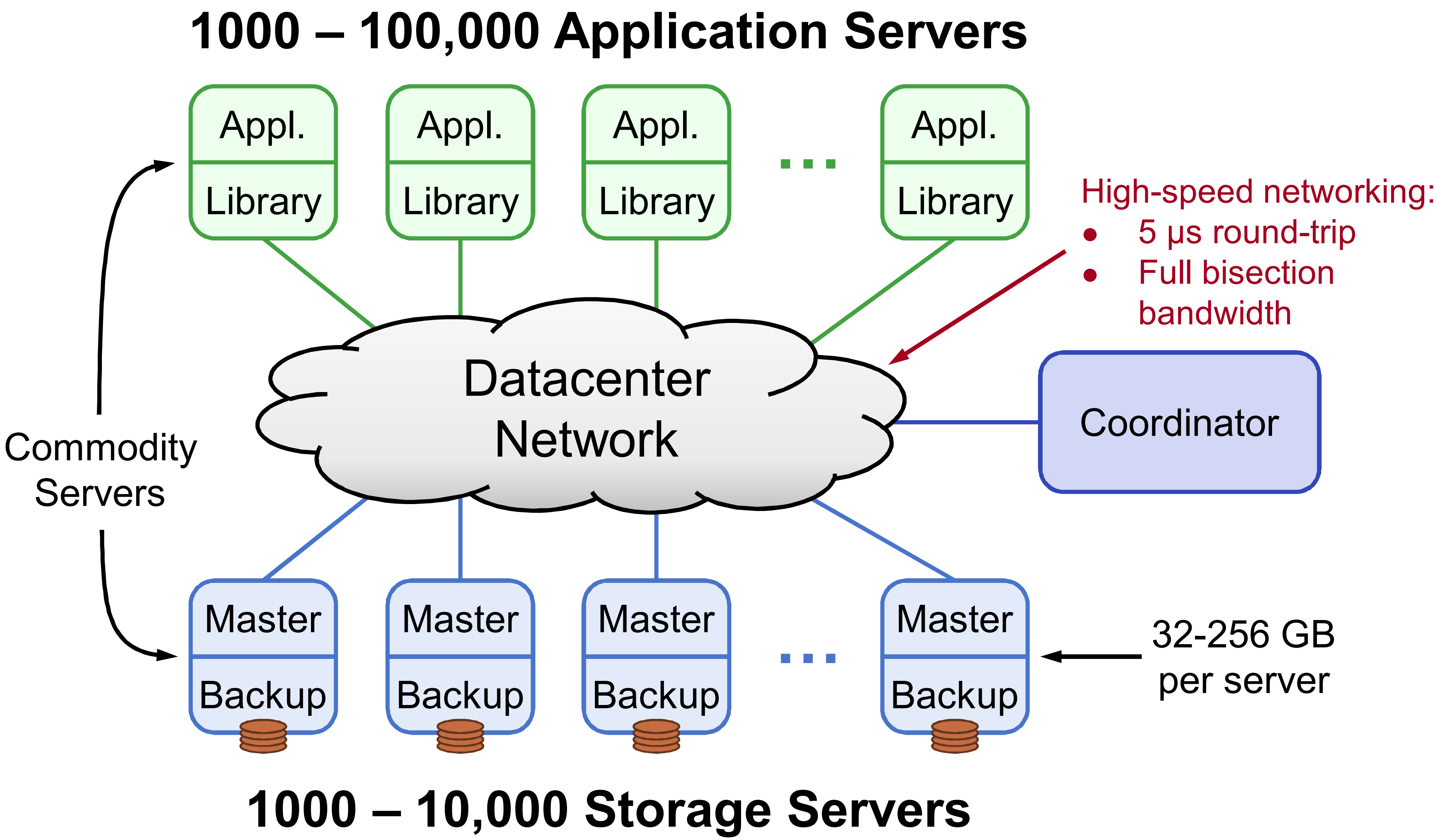
~~0.5-10ms~~ latency
5-10µs

- **Enable new class of applications:**
  - Crowd-level collaboration
  - Large-scale graph algorithms
  - Real-time information-intensive applications

Project Status

- **Started in 2009**
- **Building production-quality code**
  - About 125,000 lines of C++, permissive license
- **RAMCloud 1.0 released**
- **Looking for more users!**

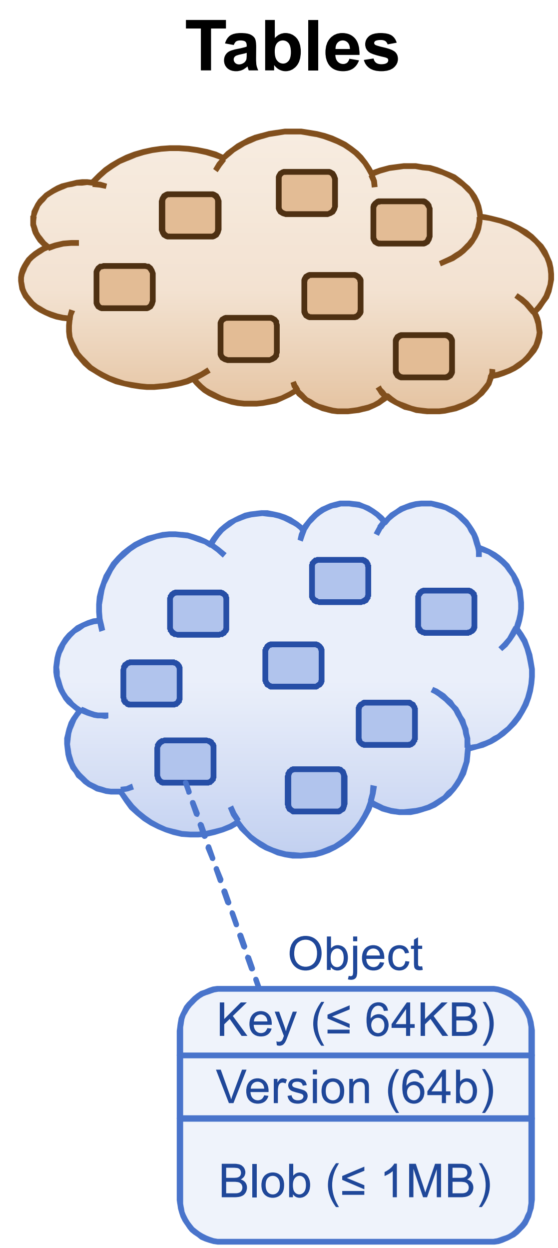
RAMCloud Architecture



Data Model: Key-Value Store

- **Basic operations:**
  - `read(tableId, key)`
    `=> blob, version`
  - `write(tableId, key, blob)`
    `=> version`
  - `delete(tableId, key)`
- **Other operations:**
  - `cwrite(tableId, key, blob, version)`
    `=> version`

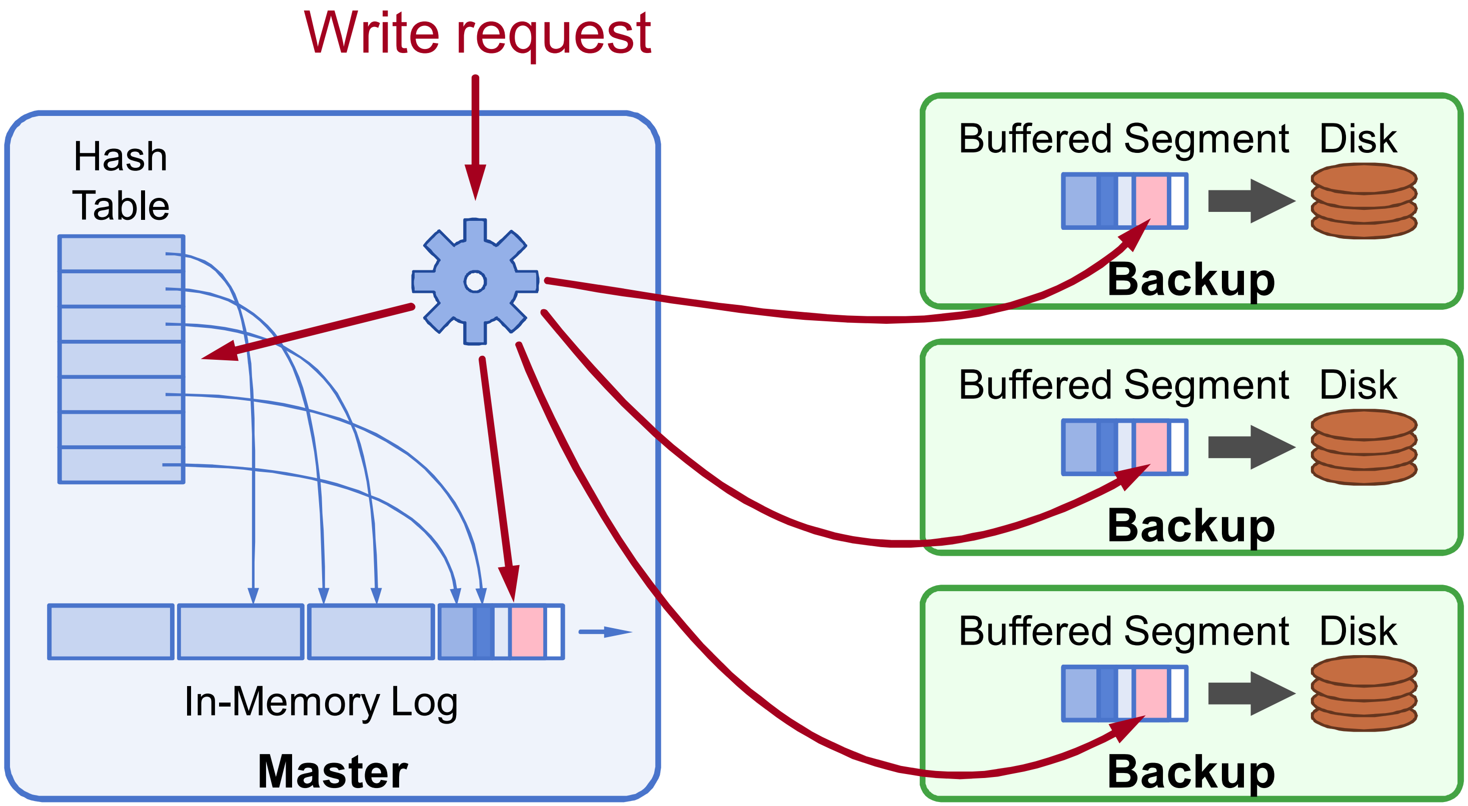
    (Only overwrite if version matches)
  - Enumerate objects in table
  - Efficient multi-read, multi-write
  - Atomic increment
- **Planned / in development:**
  - Atomic updates of multiple objects
  - Secondary indexes



Durability and Availability

- **Challenge: making volatile memory durable**
- **Keep replicas in DRAM of other servers?**
  - 3x system cost, energy
  - Still have to handle power failures
- **RAMCloud approach:**
  - 1 copy in DRAM
  - Backup copies on disk/flash: durability ~ free!

Buffered Logging



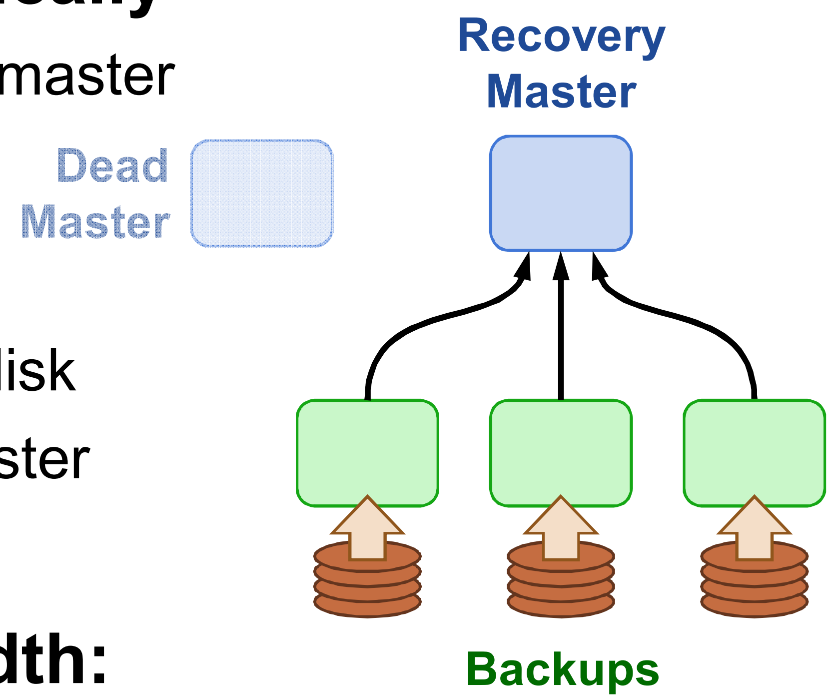
- **Log-structured: backup disk and master's memory**
- **Log cleaning ~ generational garbage collection**
- **No disk I/O during write requests**
  - Backups need ~64 MB NVRAM (or battery) for power failures

Crash Recovery

- **Applications depend on 5µs latency: must recover crashed servers quickly!**
- **Traditional approaches don't work**
  - Can't afford latency of paging in from disk
  - Replication in DRAM too expensive, doesn't solve power loss
- **Crash recovery:**
  - Need data loaded from backup disks back into DRAM
  - Must replay log to reconstruct hash table
  - Meanwhile, data is unavailable
  - Solution: fast crash recovery (1-2 seconds)
  - If fast enough, failures will not be noticed
- **Key to fast recovery: use system scale**

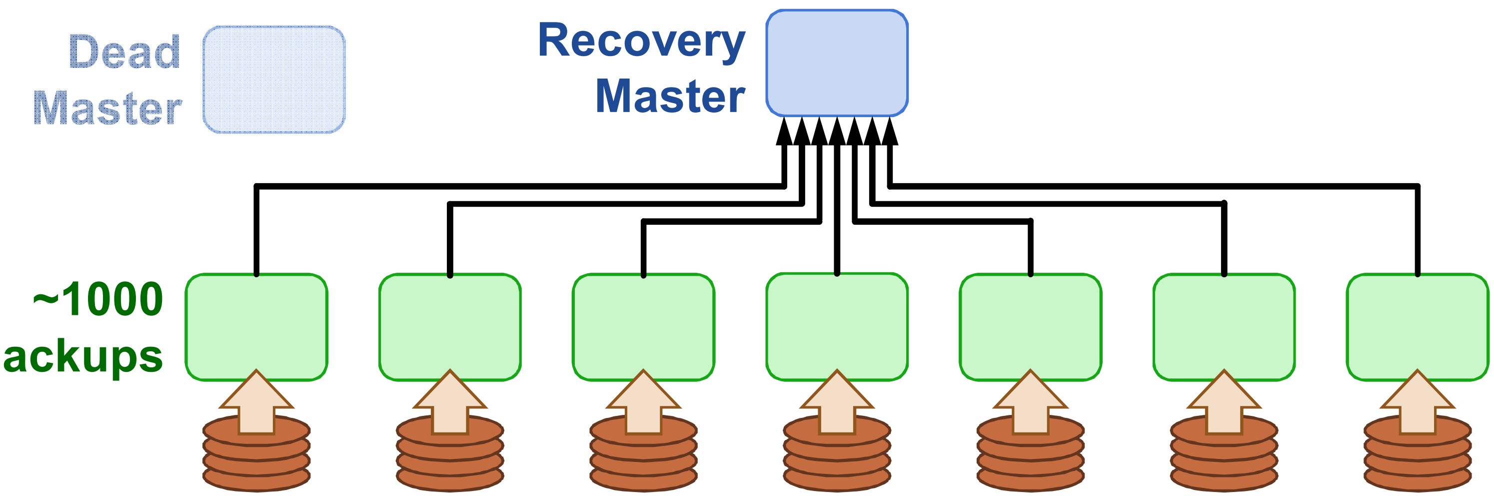
Recovery, First Try

- **Master chooses backups statically**
  - Each backup mirrors entire log for master
- **Crash recovery:**
  - Choose recovery master
  - Backups read log segments from disk
  - Transfer segments to recovery master
  - Recovery master replays log
- **First bottleneck: disk bandwidth:**
  - 64 GB / 3 backups / 100 MB/sec/disk
    ≈ 210 seconds
- **Solution: more disks (and backups)**

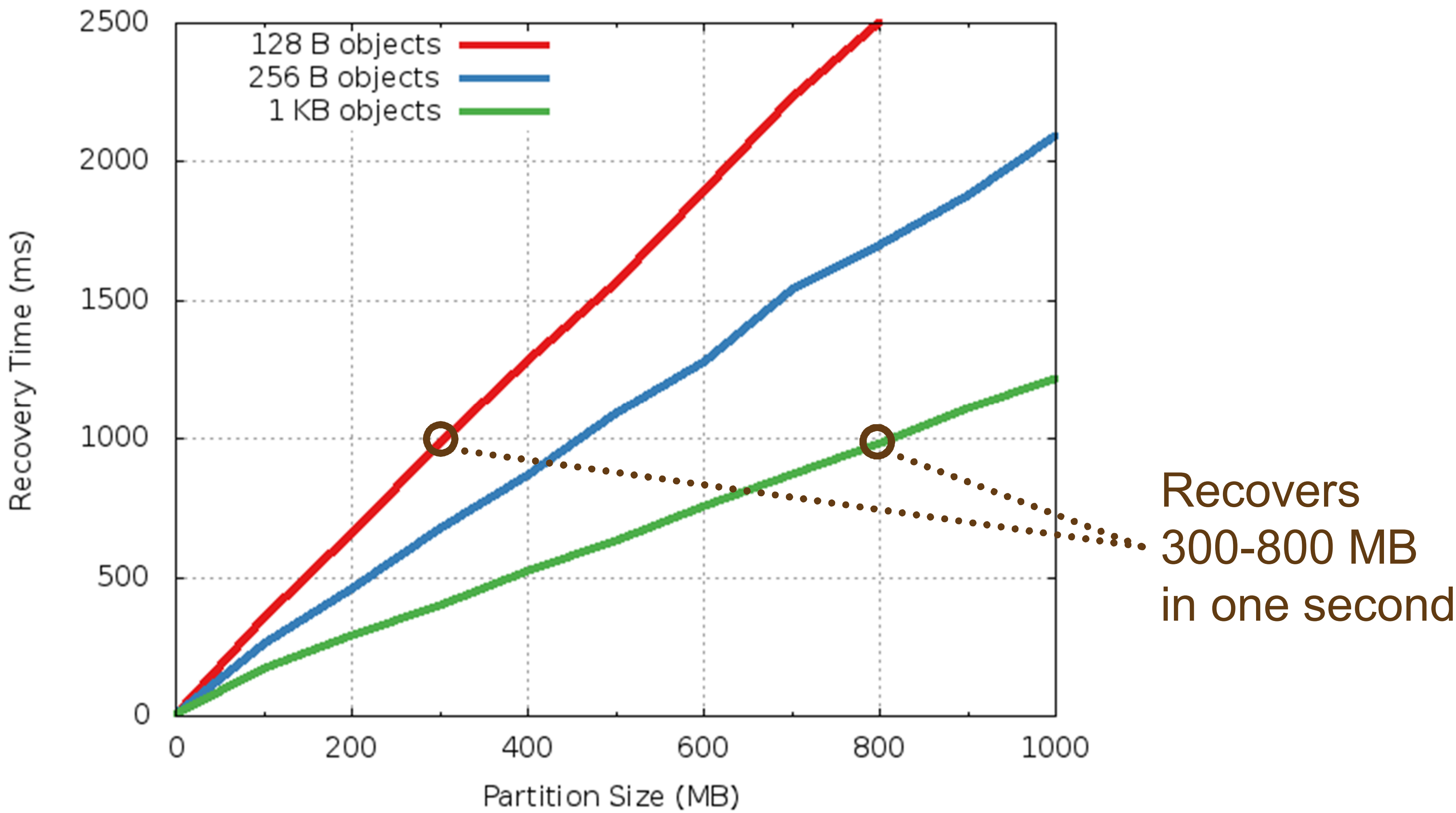


Recovery, Second Try

- **Scatter logs:**
  - Each log divided into 8MB segments
  - Master chooses different backups for each segment (randomly)
  - Segments scattered across all servers in the cluster
- **Crash recovery:**
  - All backups read from disk in parallel (100-500 MB each)
  - Transmit data over network to recovery master



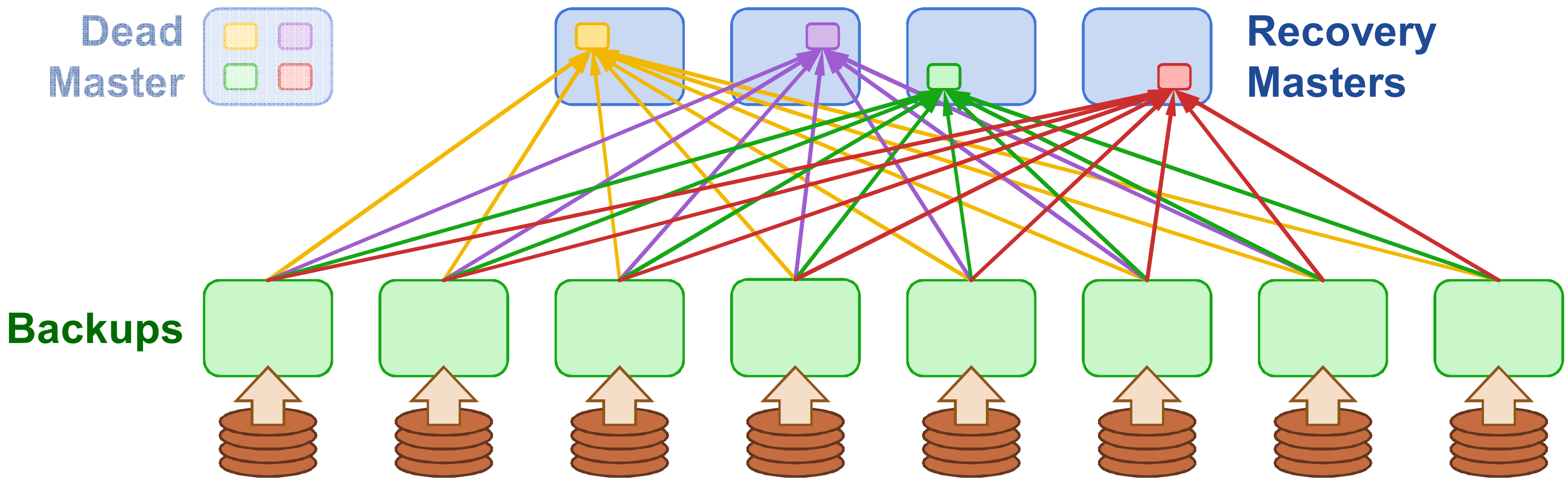
Single Recovery Master



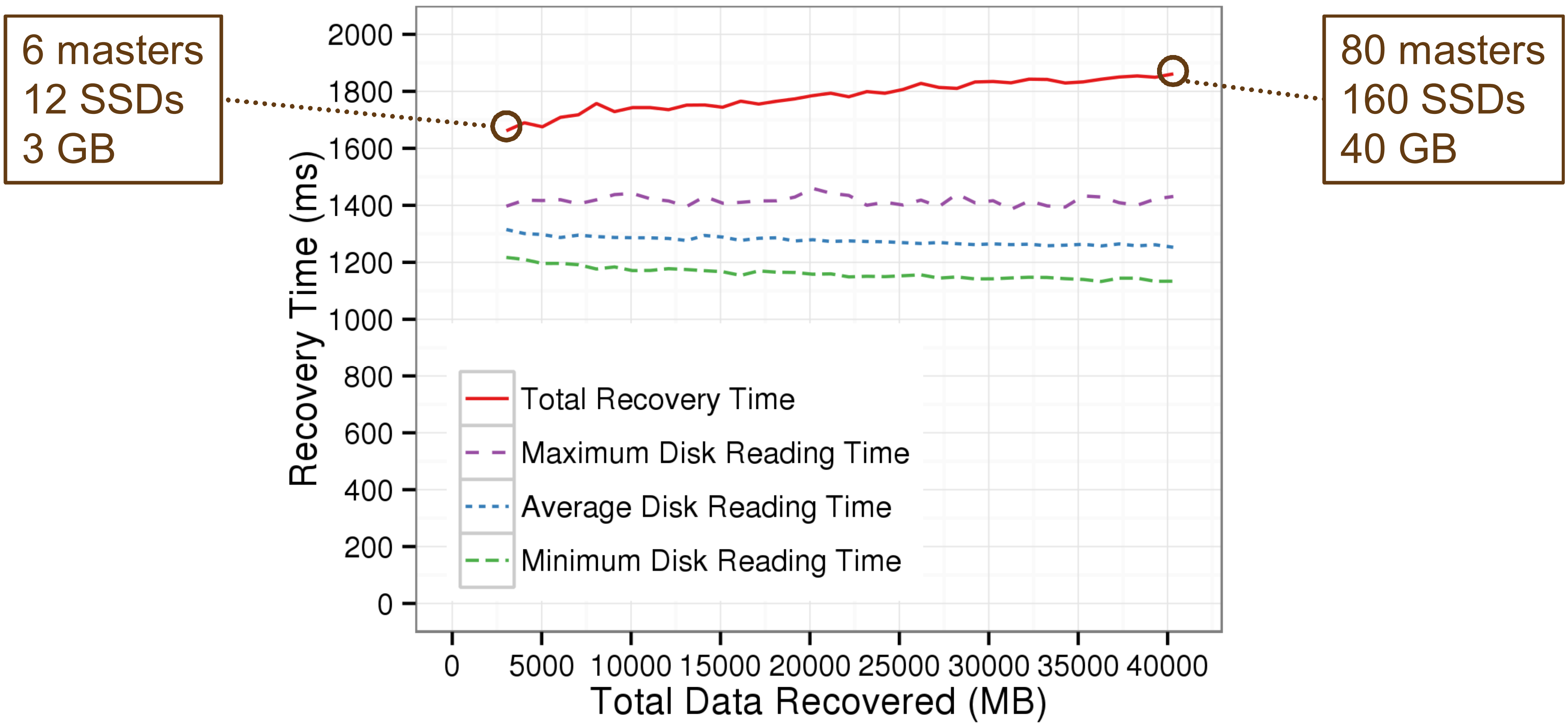
- **New bottlenecks: recovery master's NIC and CPU**

Recovery, Third Try

- Divide dead master's data into partitions
  - Recover each partition on a separate recovery master
  - Partitions based on key ranges, *not log segment*
  - Each backup divides its log data among recovery masters
  - Highly parallel and pipelined



Scalability



- **Nearly flat (needs to reach 120-200 masters)**
- **Expect faster: out of memory bandwidth (old servers)**

RAMCloud Summary

- **RAMCloud goals:**
  - Harness full performance potential of DRAM-based storage
  - Enable new applications: intensive manipulation of big data
- **Achieved low latency (at small scale)**
- **Not yet at large scale (but scalability encouraging)**
- **Fast crash recovery:**
  - Recovered 40GB in < 2 seconds; more with larger clusters
  - Durable + available DRAM storage for the cost of volatile cache
- **Looking for users!**
- **http://ramcloud.stanford.edu for code, papers**

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