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Cloud Computing

Towards Elastic Transactional Cloud Storage with Range Query Support

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Outline

- Motivation
- Related work
- System architecture of ecStore
  - distributed storage layer (BATON)
  - replication layer (self-tuning range histogram)
  - transaction layer
- Performance study
- Conclusion

Motivation

- Cloud computing should be used as a utility

- Cloud storage has to be adjusted dynamically
- Minimal startup costs
- Pay-per-use model
- Elastically scale on-demand
  - Allow users scale up and down on the fly

- Can only be archived when storage nodes could be easily added into or removed from the system

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Related work

- Replication in distributed and peer-to-peer systems
  - Primary copy of data is responsible to handle both read and write request from clients
  - Only support operations on a single data items
  - Data resided on a storage node is replicated on the successor node
  - Pessimistic replication technique

Related work

- Distributed and parallel databases
  - B+-tree, optimistic scheme, two-phase commit protocol
  - Online load balancing in range-partitioned systems using data migration and self-tuning approach to re-organize the data in a shared-nothing system
  - Traditional parallel database technologies not fit 100% for scalable storage

Related work

- Cloud data and transaction service
  - Data management system on top of the Amazon S3 based on the client-server model
  - System with a not tightly coupled transactional component and a data component
  - Storage nodes are organized on a ring-based distributed hash table (DHT) and each data item is asynchronously replicated on the successor storage nodes

Weaknesses of cloud storage services

- Guarantees on consistency (data updates)
- No range query support
- Data migration to balance the storage load
- No support transactional semantics across multiple keys

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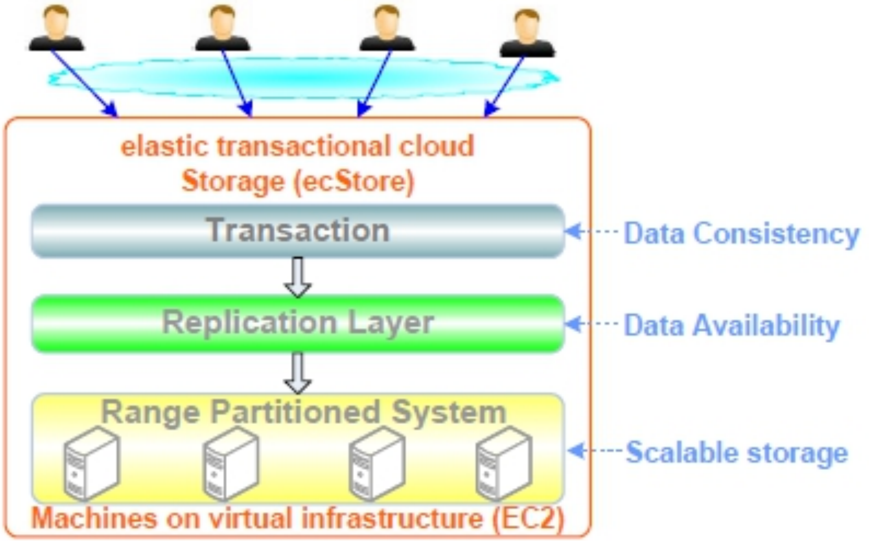
ecStore (elastic cloud storage system)

- Scalable storage system within the cloud cluster
- The architecture follows a stratum design
- Organizes storage nodes as a balanced tree structured overlay and assigns a data range for each storage node

- Data objects are distributed and replicated in a cluster of commodity computer nodes

Architecture of ecStore

- Automated data partitioning and replication
- Load balancing
- Efficient range query
- Transactional access



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Distributed storage layer

- Distributed data structure
  - Decluster data objects across storage nodes
  - Facilitates parallelism to improve performance
- DHT-based structure (distributed hash table)
  - BATON (BAlance Tree Overlay Network)

BATON

- Tree-based structure
  - To realize a scalable range-partitioned system
- Support efficient range query processing
- Automatically repartition and redistribute the data when storage nodes are added into or removed from the system

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Replication layer

- BATON does not provide replication and transaction support
- Extend BATON to efficiently support load-adaptive replication for large-scale data
  - Two-tier partial replication strategy
    - Data availability
    - Load balancing function
- Tuning the replication process based on data popularity in common
  - Self-tuning range histogram

Replication in BATON

- Usually BATON is range instead of hash based
- “Where to replicate a certain data object?”

- Approaches
  - Straightforward approach
  - Replication based on data range
  - Shift key value scheme (ecStore)

Replication in BATON

- Straightforward approach
  - Replicate data on the surrounding nodes
  - Replicas indentified by the location of primary copy
  - It is complicated to identify the surrounding links of a failure node

Replication in BATON

- Replication based on data range
  - If the key of a data item belongs to a certain range
    - Hash the range value
    - Use the output to determine the identity of the storage node where we can store the replica
  - Hashing breaks the order of replicated data

Replication in BATON

- Shift key value scheme (ecStore)
  - Different replicas will be stored in the same BATON structure of the primary copy but associated with their virtual keys
  - Well distributed across the storage nodes in the cluster
  - Shifting the initial key to multiple virtual keys
  - Preserves the order of replicated data

Two-tier partial replication

- “Which data should be replicated?”
- Approaches
  - Straightforward approach
  - Data migration
  - Two-tier replication mechanism (ecStore)

Two-tier partial replication

- Straightforward approach
  - Replicate all data objects with the same replication level K
  - If K is large, the system storage and the overhead to keep them consistent can be considerably high
- Data migration
  - Migrating hot data from one overloaded node to another node only shuffles the hotspot throughout the system

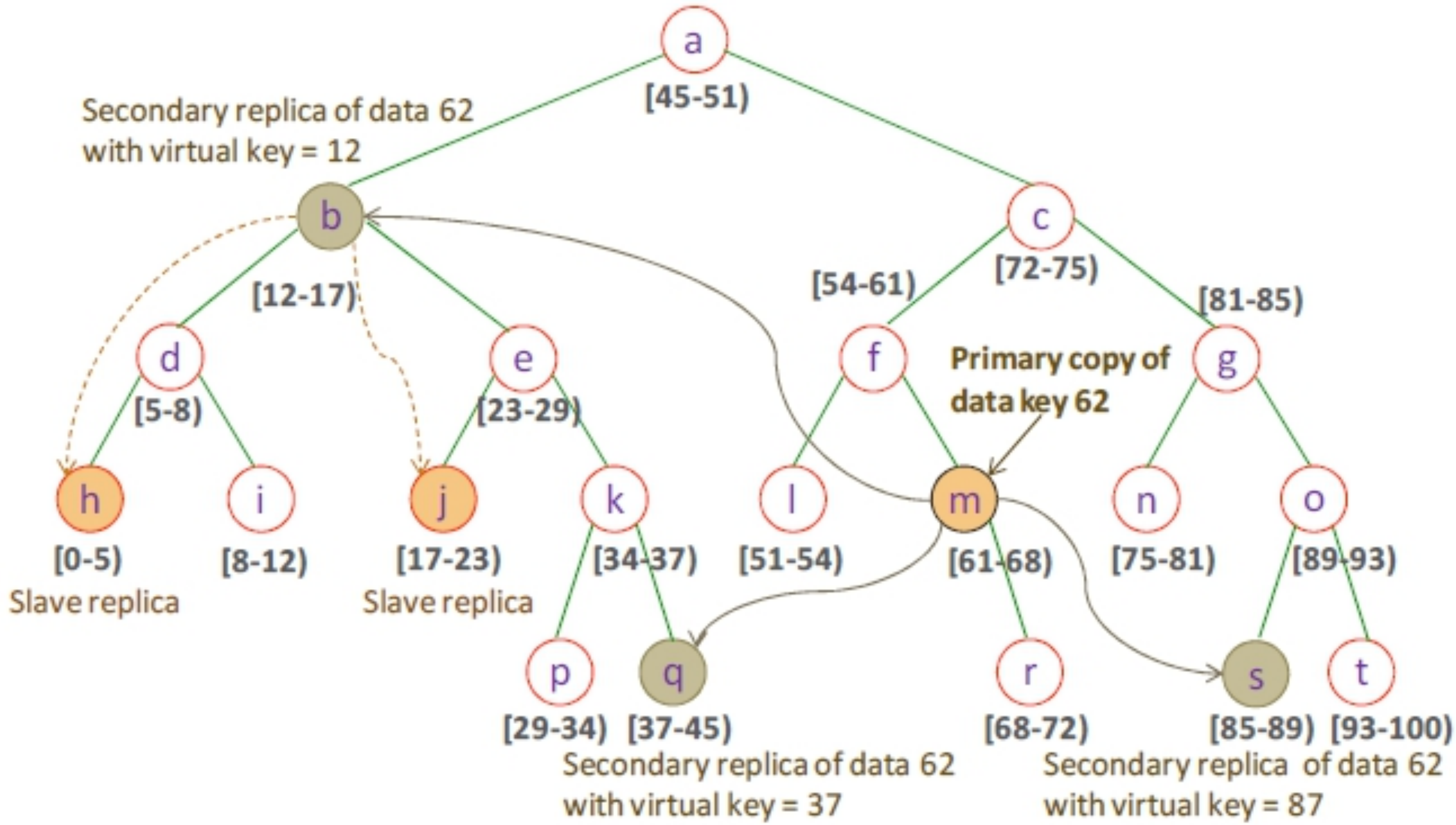
Two-tier partial replication

- Two-tier replication mechanism (ecStore)
  - Provide both data availability and load balancing
  - Each data object is associated with two kinds of replicas – secondary and slave replicas

Two-tier partial replication

- First tier
  - Small level K replication for all data objects
- Second tier
  - Popular data objects are associated with additional replicas – called slave replicas
  - Facilitate load balancing for frequently accessed objects

BATON-Two-tier partial replication



Self-tuning range histogram

- Only a small number of replicas
  - Histogram maintenance cost minimal

- Histogram to approximately estimate the access frequency of a data range
- When load balancing process is triggered, the storage node will replicate most popular data ranges to other lighter-loaded nodes
- Piggy-back the load information on the query

Self-tuning range histogram

- Dynamically restructuring the histogram
  - Splitting/merging the buckets
- Total number of buckets is kept constant
  - Merge consecutive buckets with similar frequency into a bucket with a larger data range
  - Split the bucket with high access frequency into buckets with smaller data range

- Only replicate the data ranges maintained by small buckets

Self-tuning range histogram

- Reduce the cost of maintaining unnecessary replicas
- No benefits for load balancing anymore
  - Discard slave replica of a data range

Replica consistency management

- cloud storage has provide 24x7 data availability
- Updating all copies synchronously is not suitable

- Pessimistic replication technique
  - Update needs to be reflected on all replicas before coming to effect
- Optimistic replication method (ecStore)
  - Primary copy is always updated immediately

Replica consistency management

- Write-ahead logging scheme
- Guarantees that updates to the primary copy are durable and eventually propagated to the secondary copies

- Adaptive read consistency by using the quorum model for read operations
- Write request will update primary copy first and asynchronously propagate it to the replicas

Replica consistency Management

- Adopts the notion of BASE (BAsically available, Soft state, Eventually consistency)
- Does not need to implement the two-phase commit protocol for refresh transaction

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Transaction management layer

- Multi-versioning
  - Enhances the performance of read-dominant apps
  - Can benefit the read-only transactions
- Optimistic concurrency control
  - Advantages of apps where users access mutually exclusive data
  - Protects system from locking overheads
- Commit protocol and Recovery control
  - Guarantees the data durability requirement
  - Atomicity and durability

Transaction management layer

- Data in the Cloud
  - Perform operations on recent snapshot of data
  - Independent between concurrent transactions
  - Hybrid scheme of multi-version and optimistic concurrency control
    - Isolation and consistency for large-scale databases

Transaction management layer

- Multi-version Optimistic Concurrency Scheme
  - Startup timestamp, commit timestamp
  - Read-only transactions runs against a consistent snapshot of the database
    - Can commit without the validation phase
  - Update transactions uses version number
    - To check for write-write/write-read conflicts
  - Update transaction can only commit if the version of the object is the same as in the read phase
  - Snapshot isolation property
    - Not serializable in all executions
      - Not checking read-before-write conflicts

Transaction management layer

- Commit protocol
  - Read-only transactions
    - Consistent snapshot of the database – no commit
  - Update transactions
    - The log and commit records are stored in a local dedicated disk and also replicated over the storage nodes in the system

Transaction management layer

- Recovery control
  - A storage node can safely leave the system
    - No recovery process is needed
  - Unsafe departure
    - Short-term failure (software bugs …)
      - Check its local log store
    - Long-term failure (hardware crashes …)
      - Another healthy node take care of the range index that previously is managed by the failure node
      - New responsible node will recover the data
      - New responsible node will check the transaction logs
        - Redo operations by forwarding the log records

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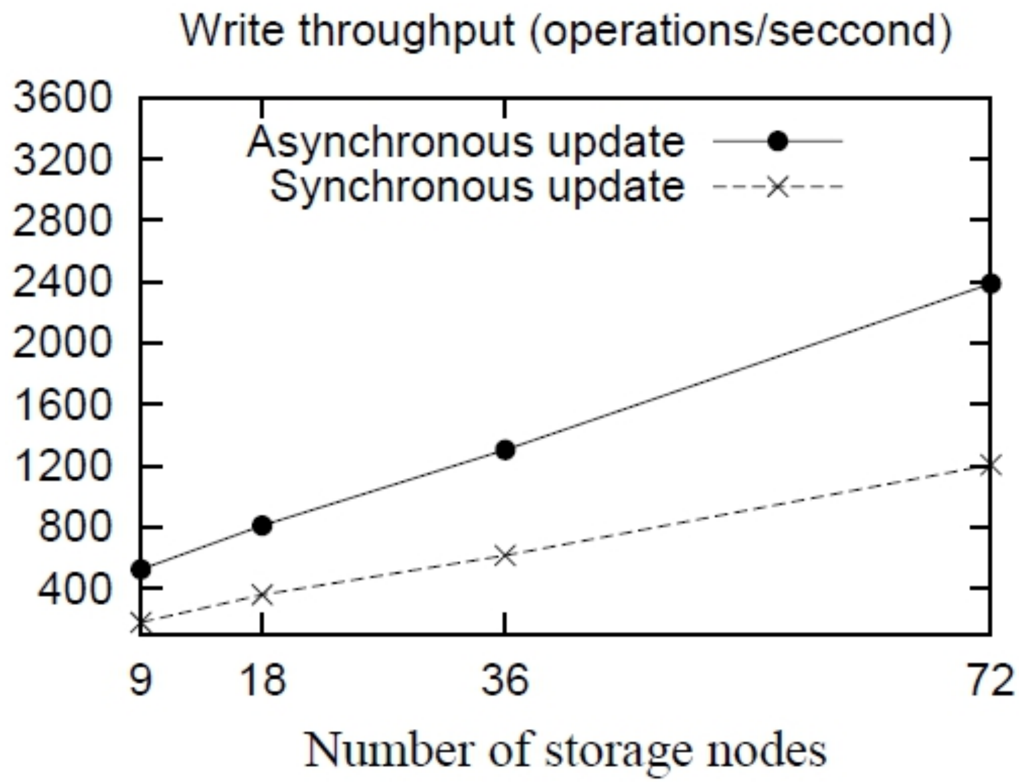
Performance study

- Pessimistic replication method is outperformed by the optimistic replication



Performance study

- Results show that the proposed load-adaptive replication method can effectively balance the system load distribution under skewed workloads

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Conclusion

- ecStore
  - Underlying BATON distributed index
    - Load-adaptive replication
    - Multi-version optimistic concurrency control

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Thanks for your attention!

Questions?