Atlas: Baidu's Key-value Storage System for Cloud Data

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Cloud Storage Service

- Cloud storage services become increasingly popular.
  - Baidu Cloud has over 200 million users and 200PB user data.
- To be attractive and competitive, they often offer large free space and price the service modestly.
  - Baidu offers 2TB free space for each user.
- The challenge is how to economically provision resources and also achieve service quality.
  - A large number of servers, each with local large storage space.
  - The data must be reliably stored with a high availability.
  - Requests for any data in the system should be served reasonably fast.

Challenges on Baidu's System

- The workload
  - Request size is capped at 256KB for system efficiency.
  - Majority of the requests are for data between 128KB and 256KB.

Distribution of requests on a typical day in 2014.

Request Size (Bytes)	Read (%)	Write (%)	#Read / #Write
[0, 4K]	0.6%	1.2%	1.45
(4K, 16K]	0.5%	1.0%	1.41
(16K, 32K]	0.5%	0.8%	1.67
(32K, 64K]	0.8%	1.2%	1.94
(64K, 128K]	1.3%	1.7%	2.08
(128K, 256K]	96.3%	94.1%	2.84
Sum	100.0%	100.0%	2.78

- The Challenges
  - Can the X86 processors be efficiently used?
  - Can we use a file system to store data at each server?
  - Can we use an LSM-tree-based key-value store to store the data?

Challenge on Processor Efficiency

- The X86 processors (two 4-core 2.4GHz E5620) were consistently under-utilized
  - Less than 20% utilization rate with nine hard disks installed on a server.
  - Adding more disks is not an ultimate solution.

- The ARM processor (one 4-core 1.6GHz Cortex A9) can provide similar I/O performance.
  - The ARM processor is more than 10X cheaper and more energy-efficient.

- Baidu's customized ARM-based server.
  - Each 2U chassis has six 4-core Cortex A9 processors.
  - Each processor comes with four 3TB SATA disks.
- However, each processor can support only 4GB memory.
  - On each chassis only 24GB memory available for accessing data as large as 72TB data.

Challenge on Using a File System

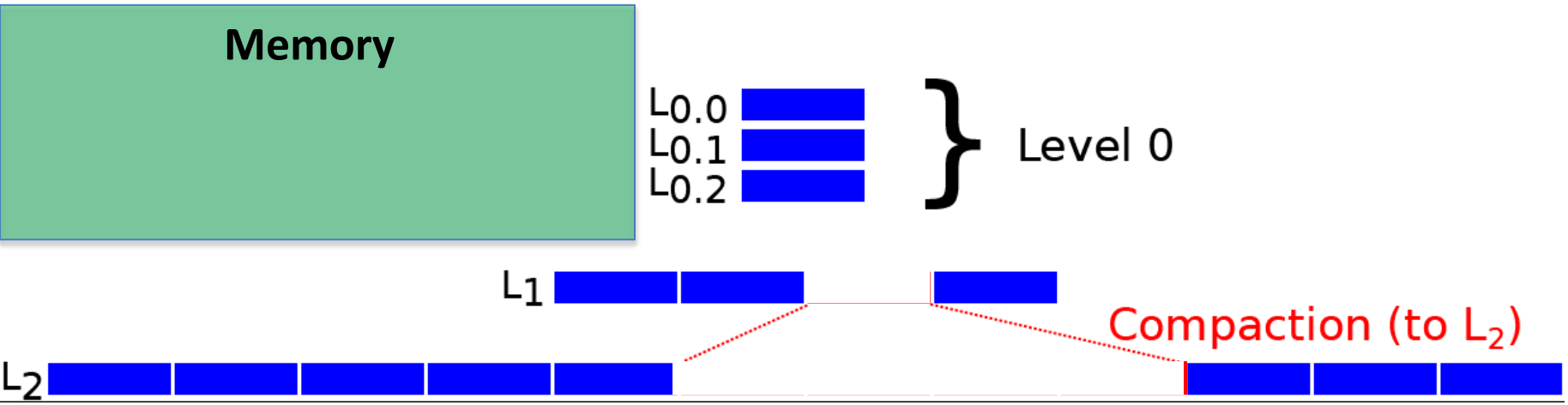
- Memory cannot hold all metadata.
  - Most files would be of 128-256KB.
  - Access on the storage has little locality.
  - More than one disk accesses are often required to access a file.
- The approach used in Facebook's Haystack is not sufficient.
  - There are 3.3GB metadata for 16TB 128KB-data.
  - System software and buffer cache also compete for 4GB memory.

Challenge on Using LSM-tree Based Key-value Store

- LSM-tree-based KV store is designed for storing many small key-value items, represented by Google's LevelDB.

- The store is memory efficient.
  - The metadata is only about 320MB for 16TB 128KB-data.

- However, the store needs constant compaction operations to sort its data distributed across levels of the store.
  - For a store of 7 levels, the write amplification can be over 70.
  - Very limited I/O bandwidth is left for servicing frond-end user requests.



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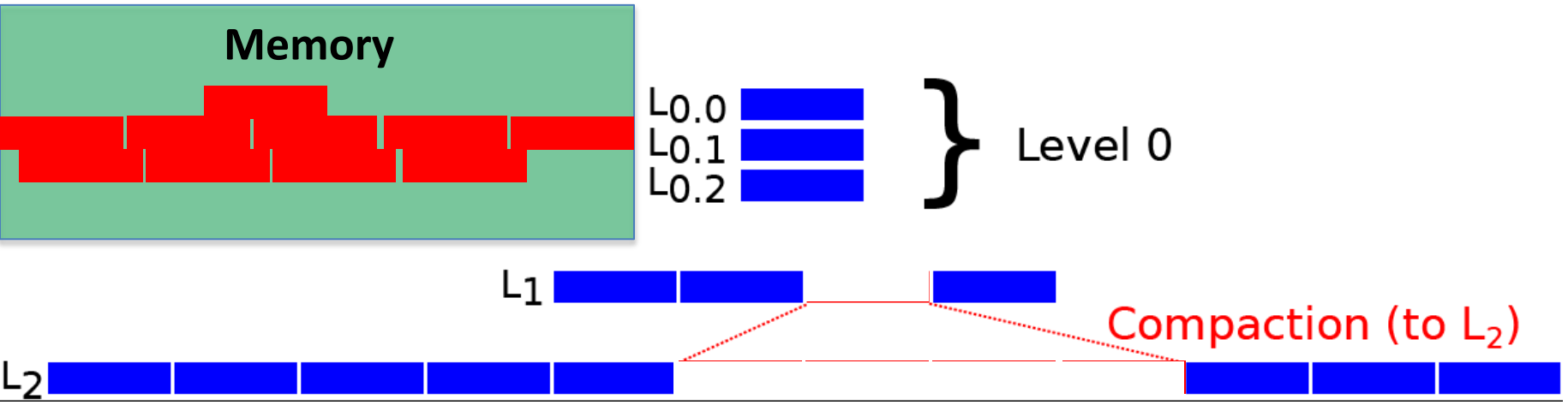

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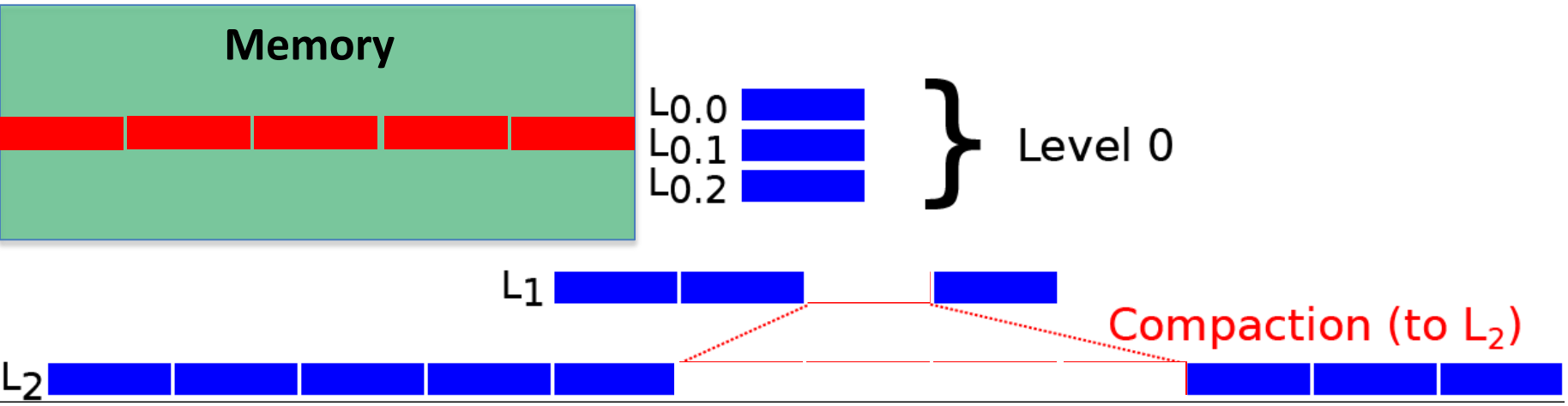
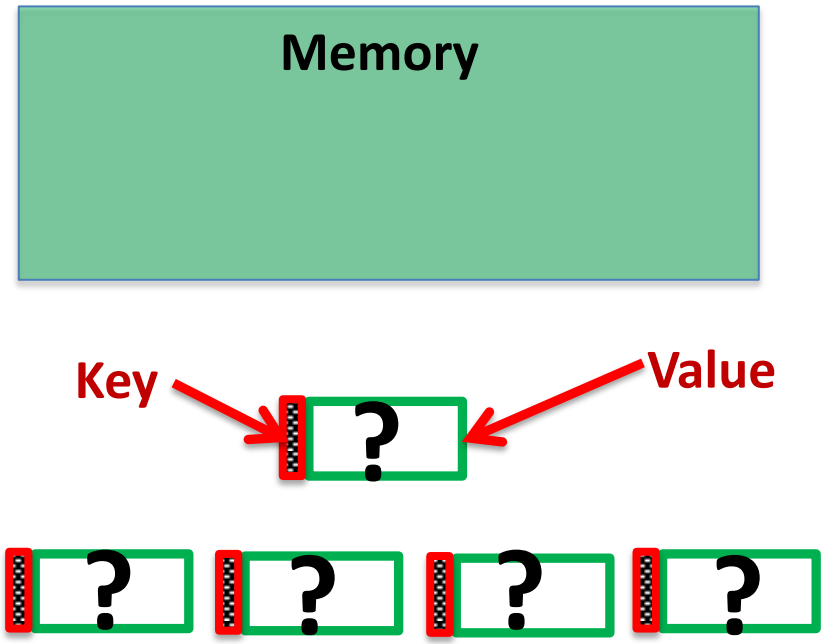


Reducing Compaction Cost

- In a KV item, value is usually much larger than the key.
- Values are not necessary to be involved in compactions.
- Move and place the values in a fixed-size container (block), and replace the values with pointers in KV items.



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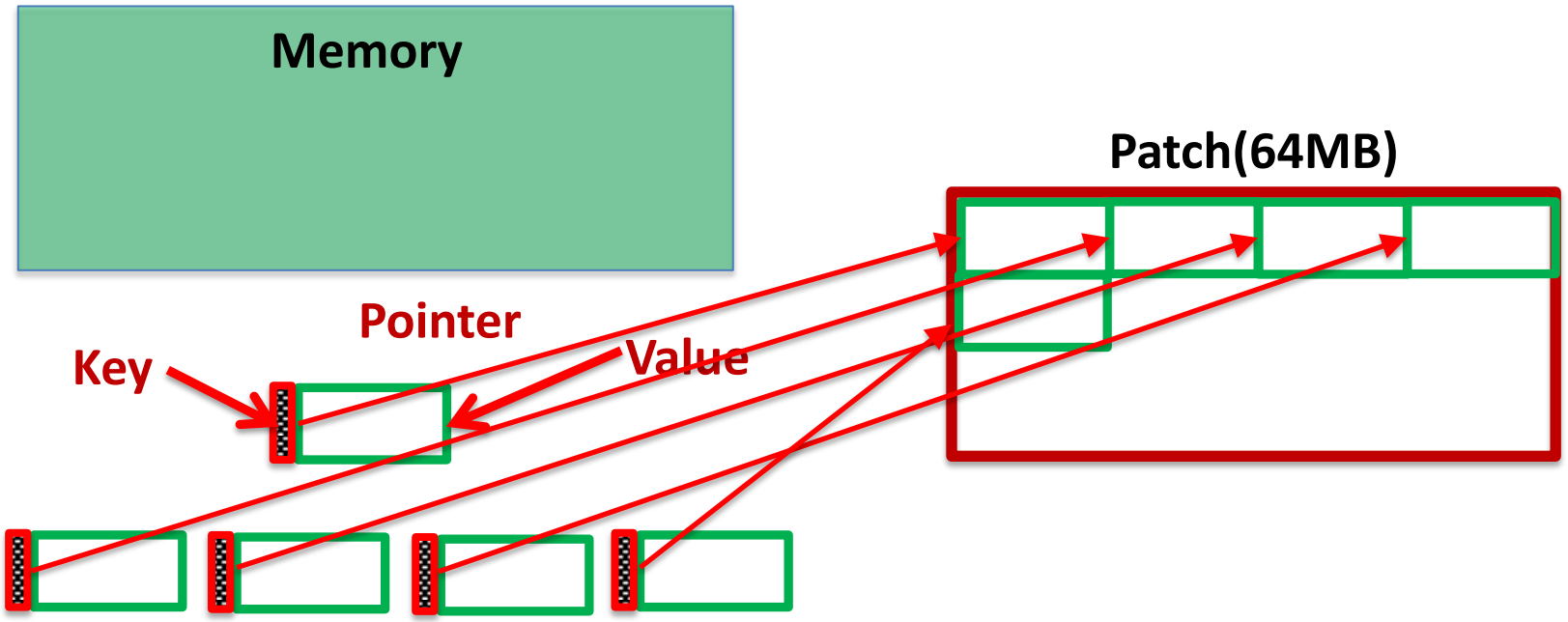

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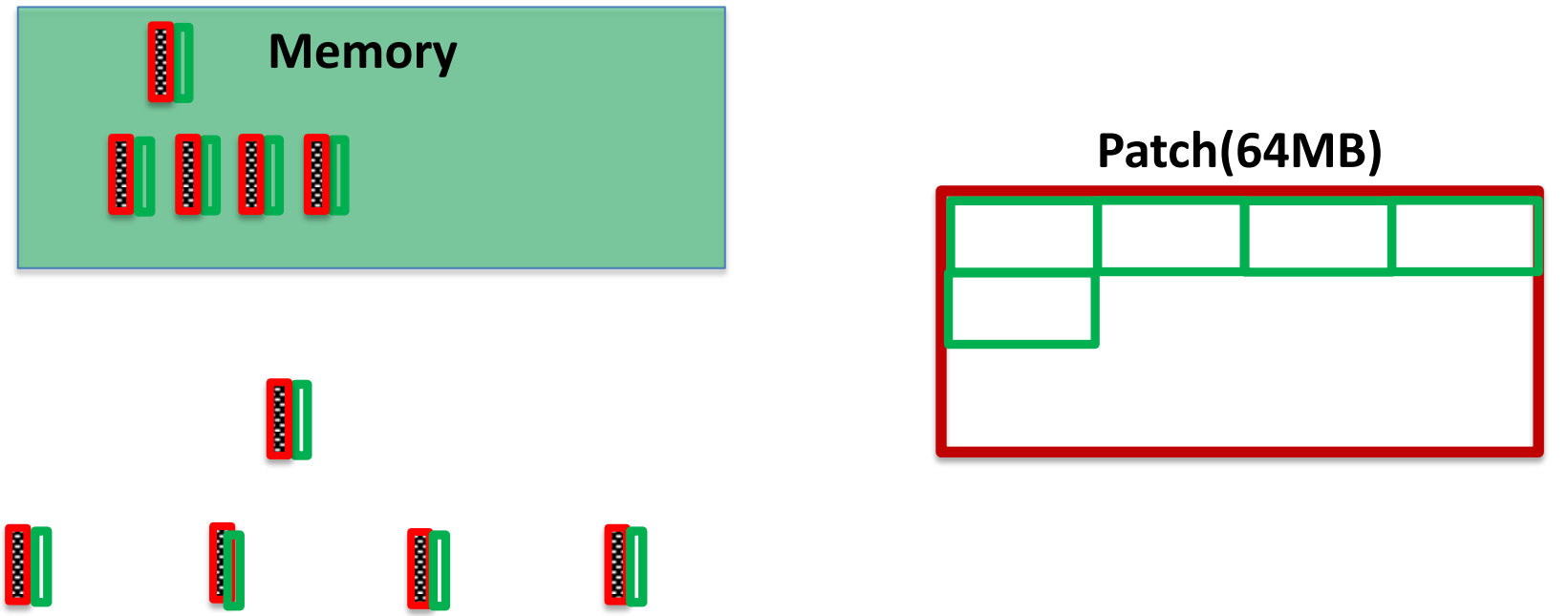

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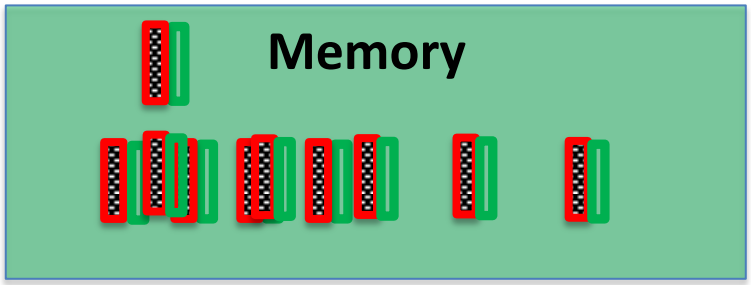

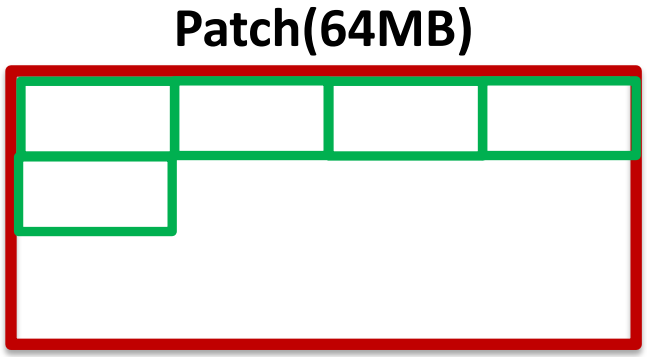

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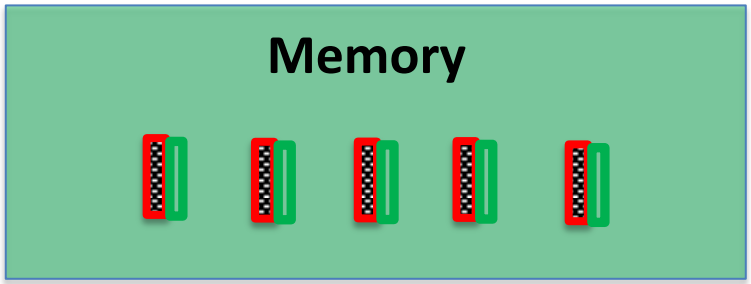
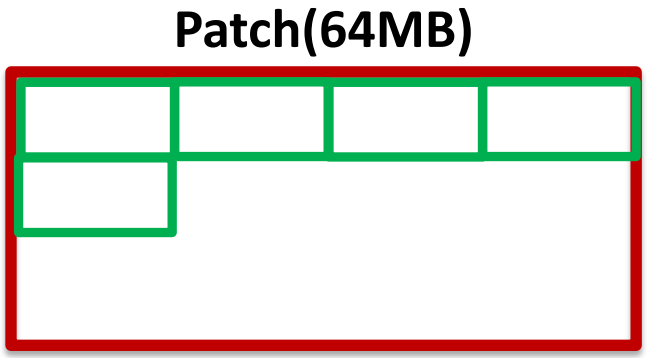
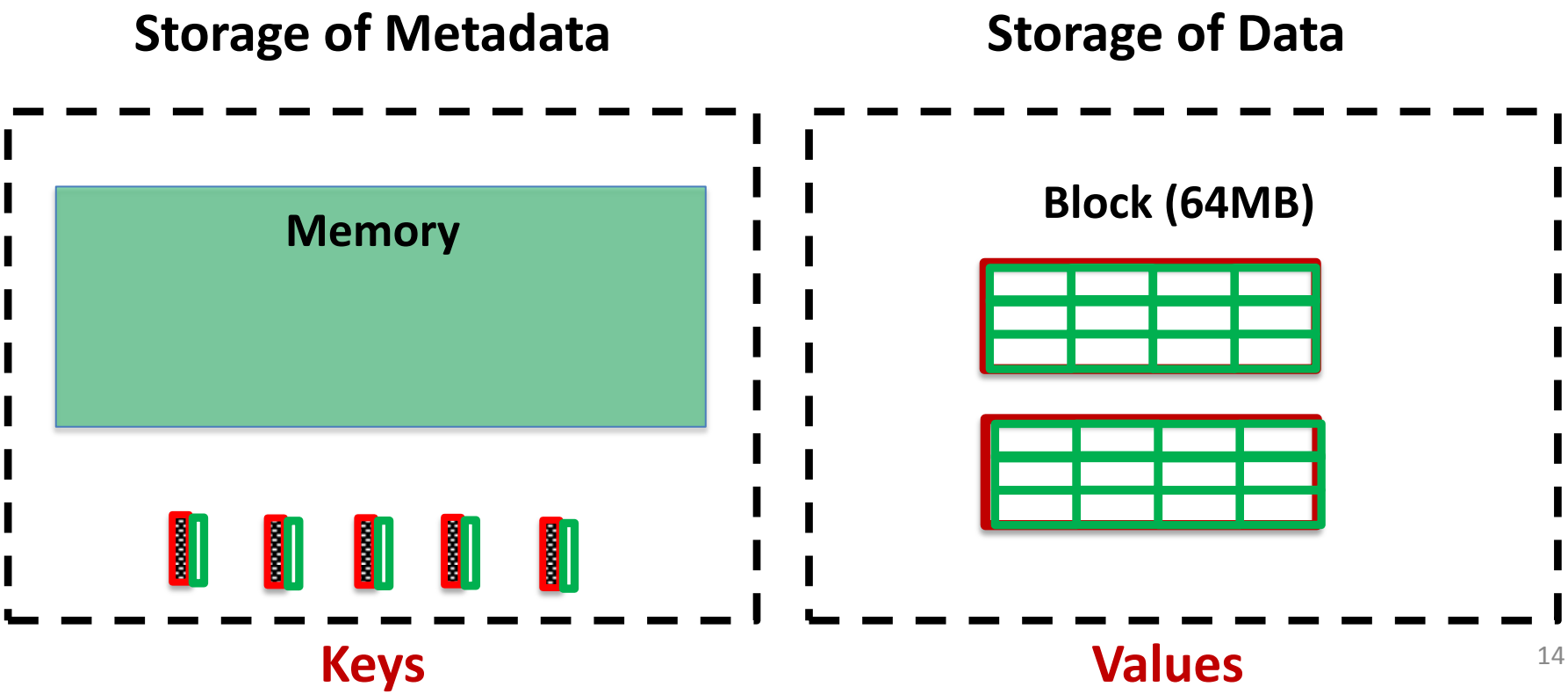


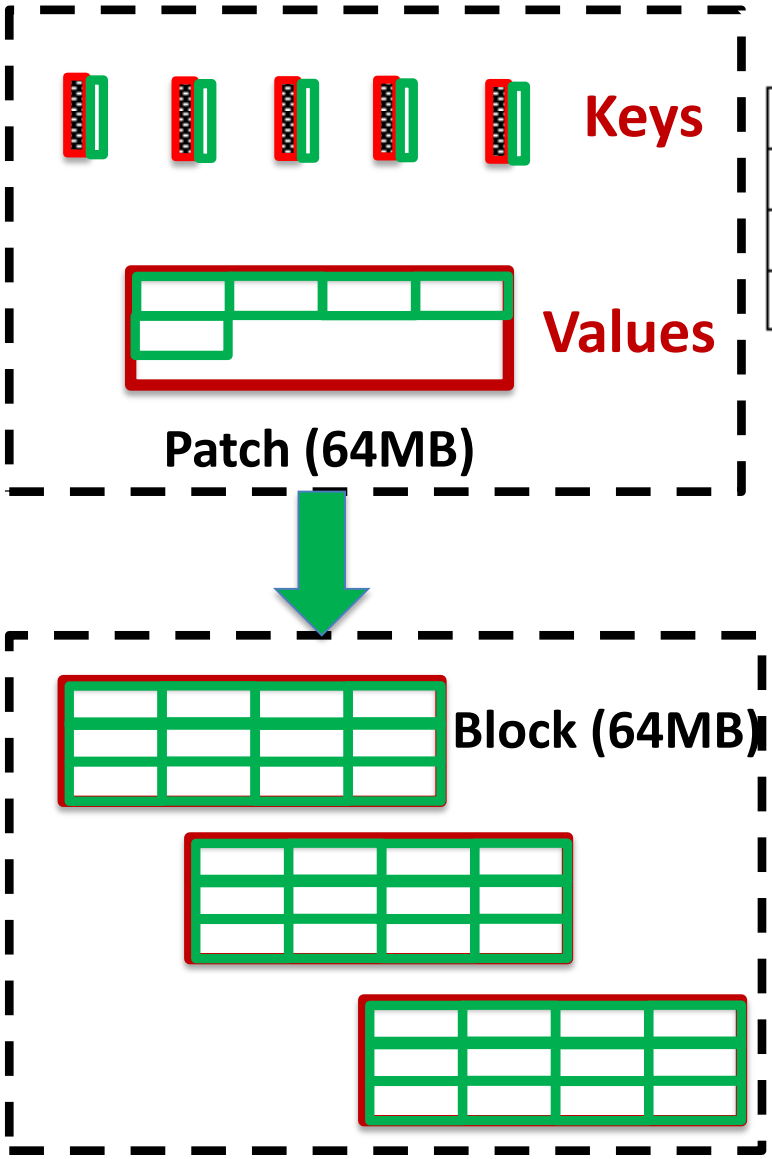


Features of Baidu's Cloud Storage System (Atlas)

- A hardware and software co-design with customized low-power servers for high resource utilization
- Separate metadata (keys and offsets) and data (value blocks) management systems.
- Data are efficiently protected by erasure coding.



Big Picture of the Atlas System



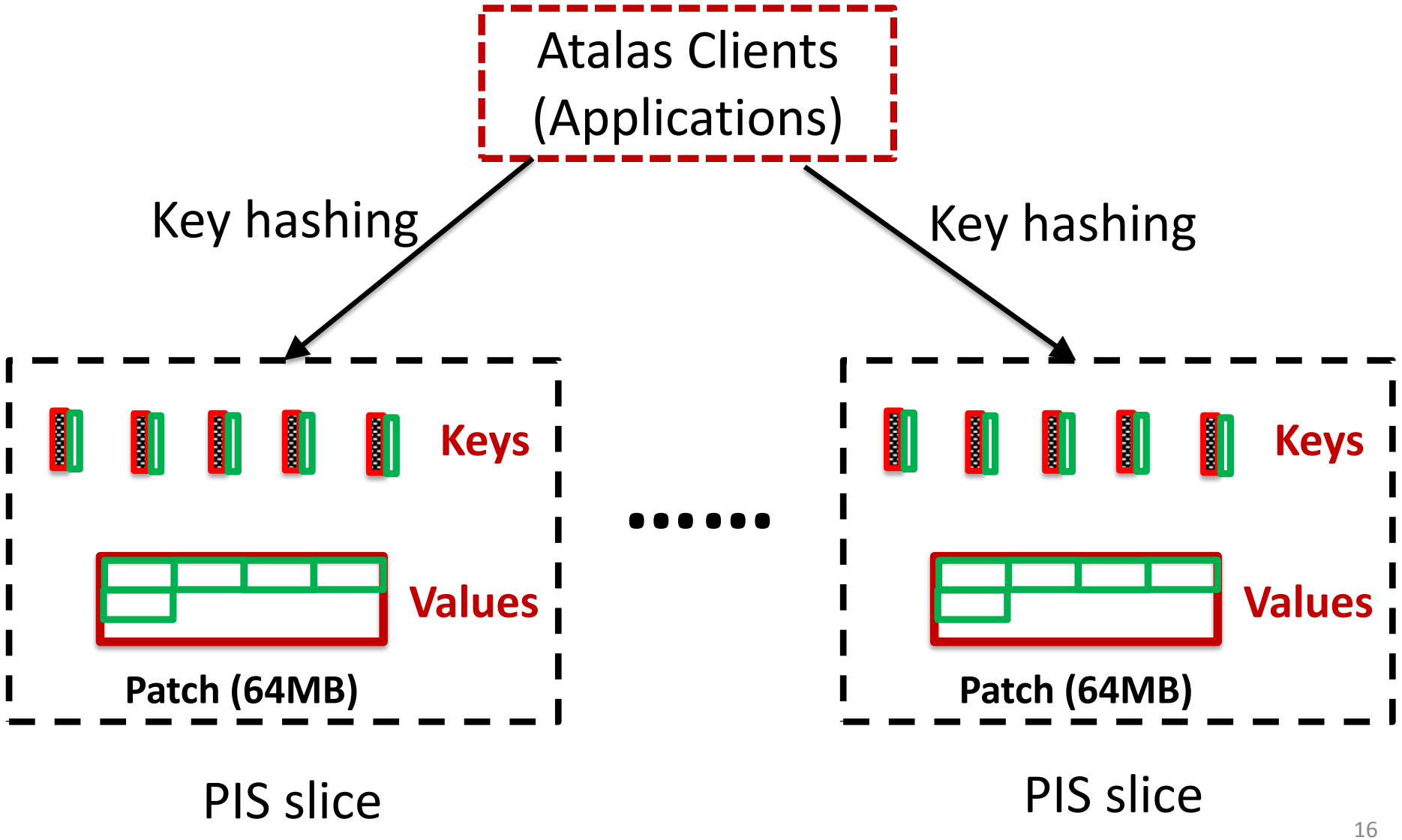
PIS (Patch and Index System)

Command	Format
Read	Get (UINT128 key, BYTE* value)
Write	Put (UINT128 key, BYTE *value)
Delete	Del (UINT128 key)

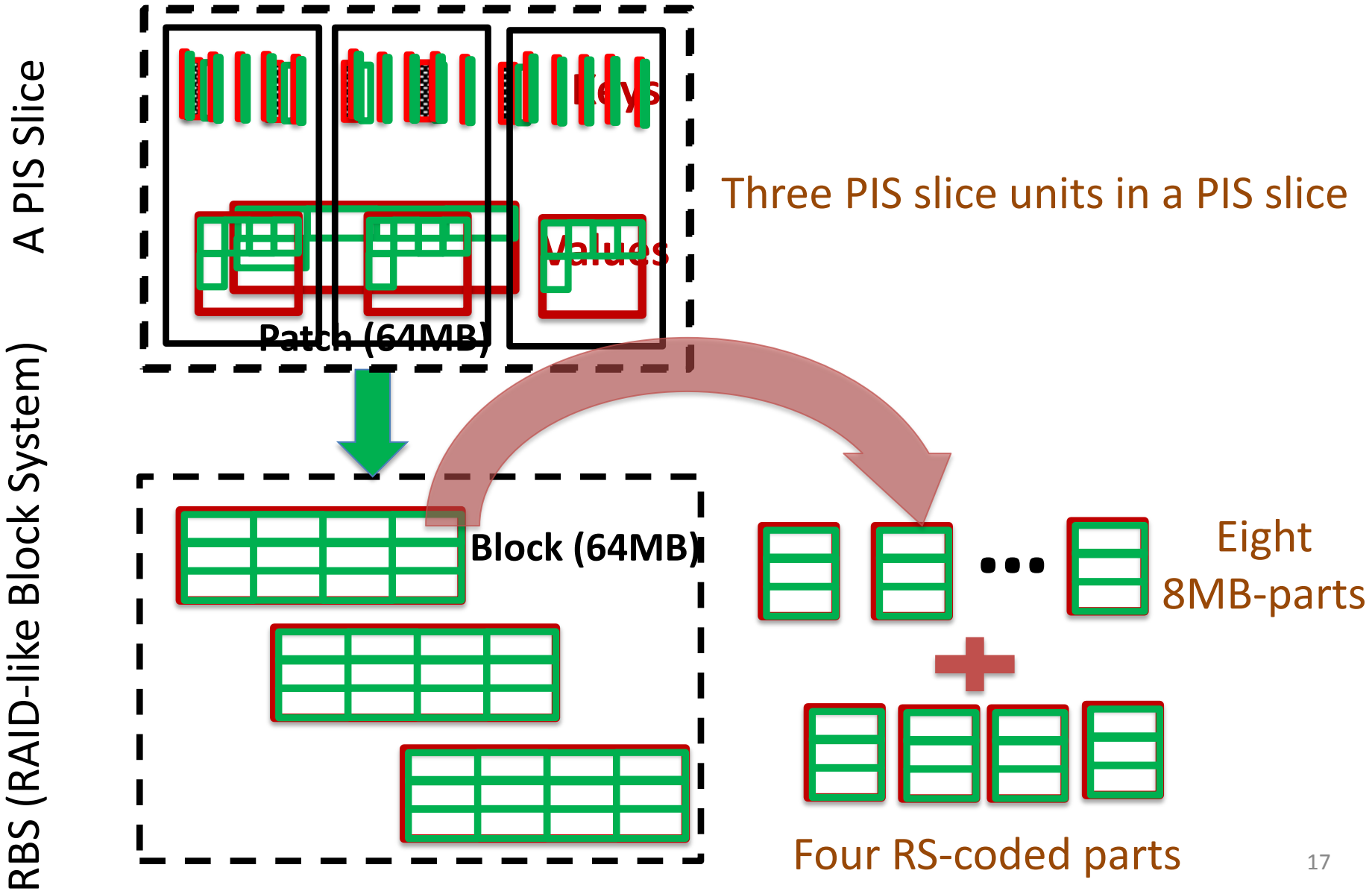
RBS (RAID-like Block System)

Command	Format
Write	Write (UINT64* block_id, BYTE *data)
Read	Read (UINT64 block_id, UINT32 offset, UINT32 length, BYTE* data)
Deletion	Delete (UINT64 block_id)

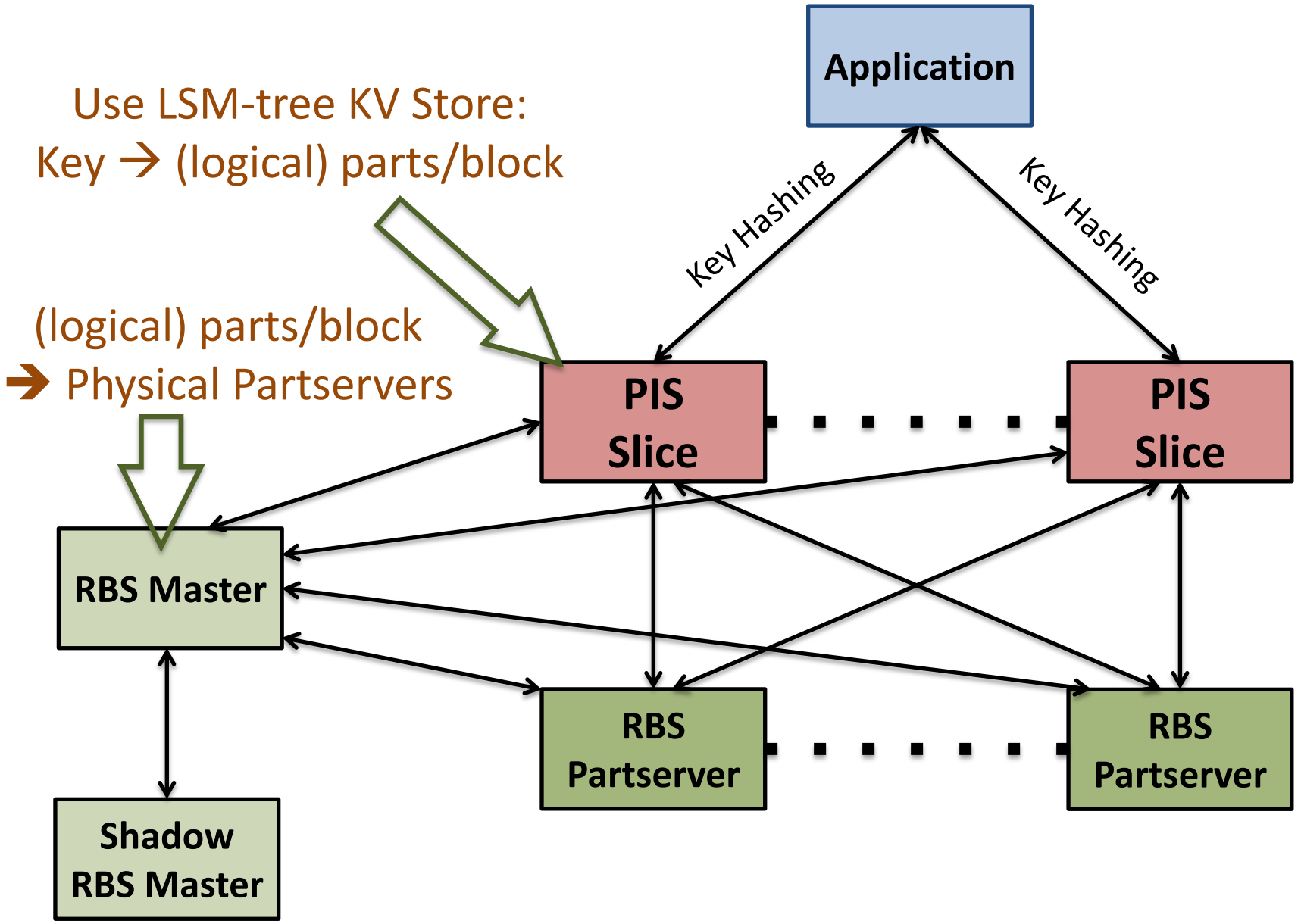
Distribution of User Requests



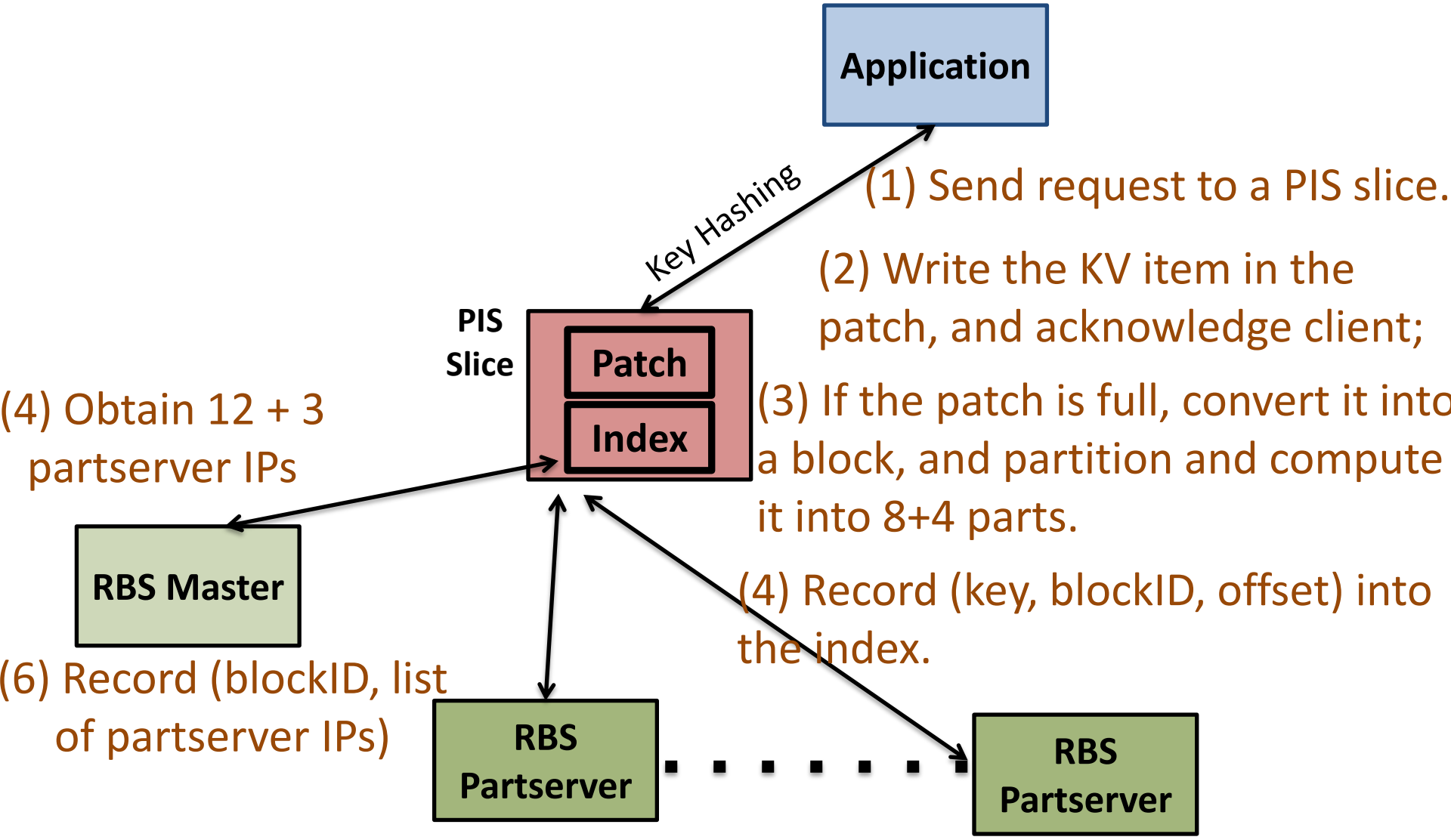
Redundancy for Protecting KV items



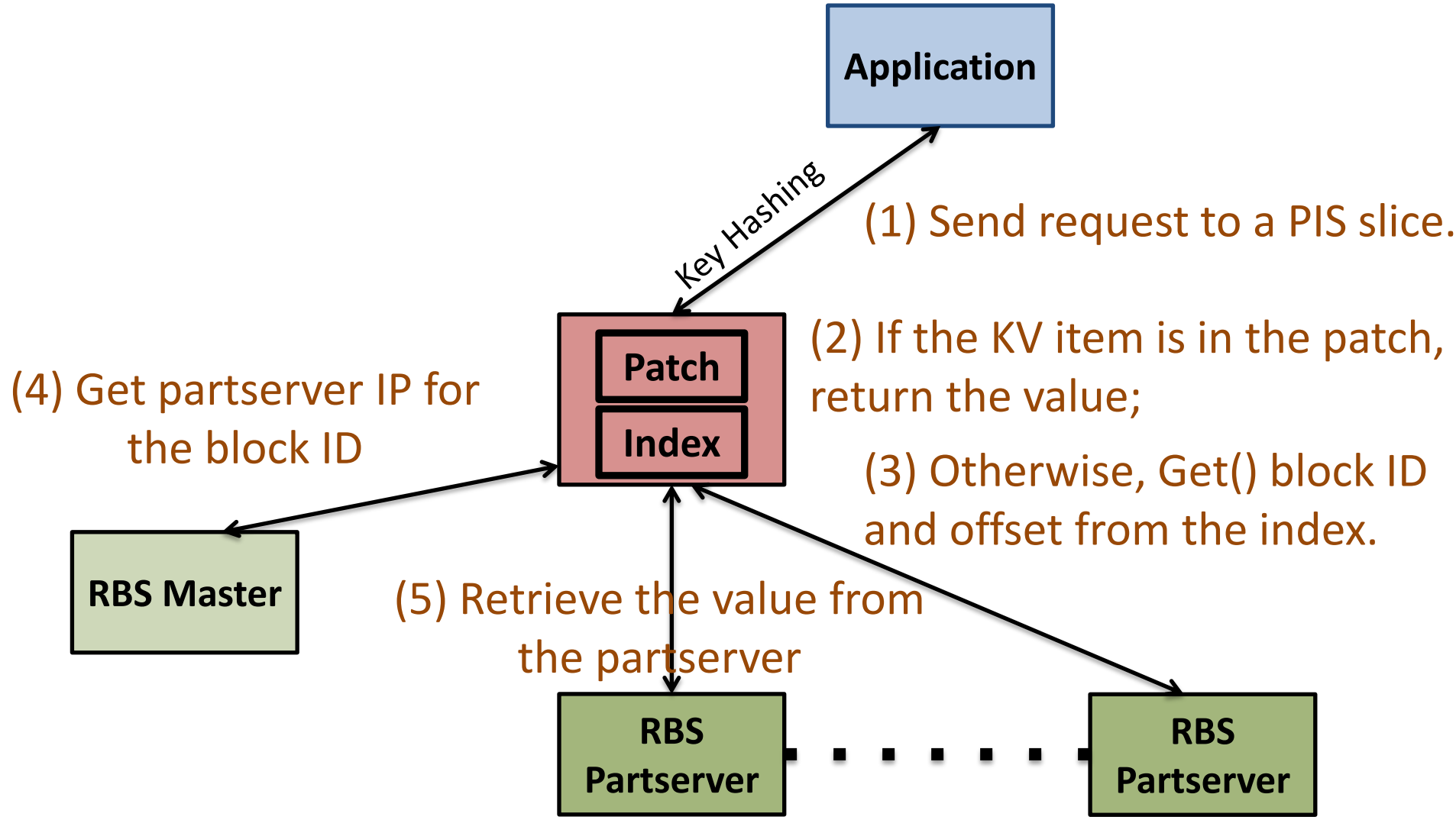
The Architecture of Atlas



Serving a Write Request



Serving a Read Request



Serving Delete/Overwrite Requests

- KV pairs stored in Atlas are immutable.
- Blocks in Atlas are also immutable.
- A new KV item is written into the system to service a delete/overwritten request.
- Space occupied by obsolete items are reclaimed in a garbage collection (GC) process.
- Periodically two questions are asked about a block in the RBS subsystem, and positive answers to both lead to a GC.

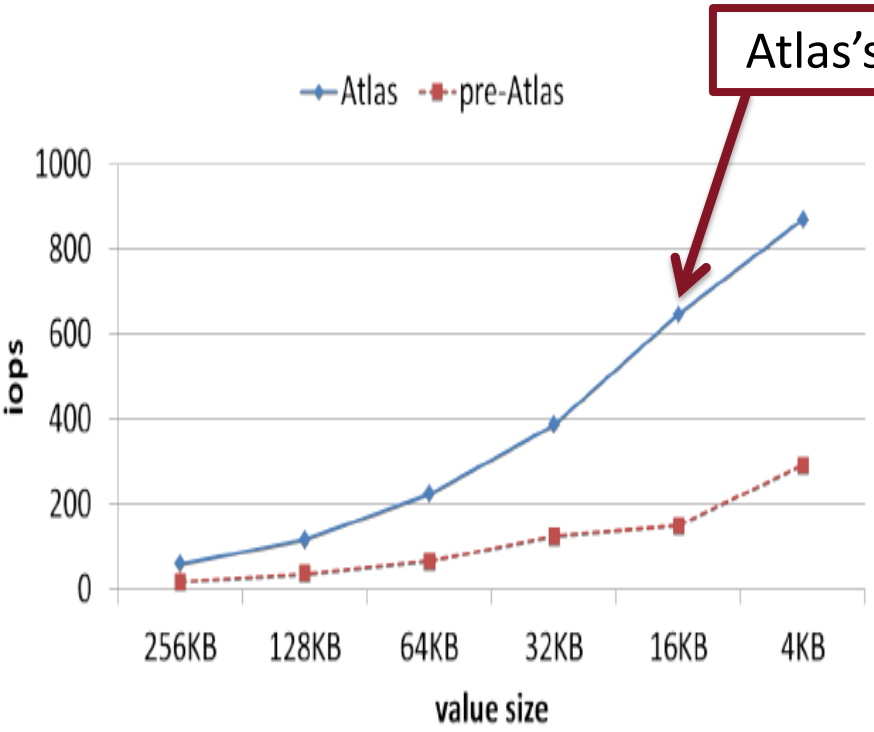
1) Is the block created earlier than a threshold (such as one week ago)?
2) Is the ratio of valid data in the block smaller than a threshold (such as 80%)?

Atlas's Advantages on Hardware Cost and Power

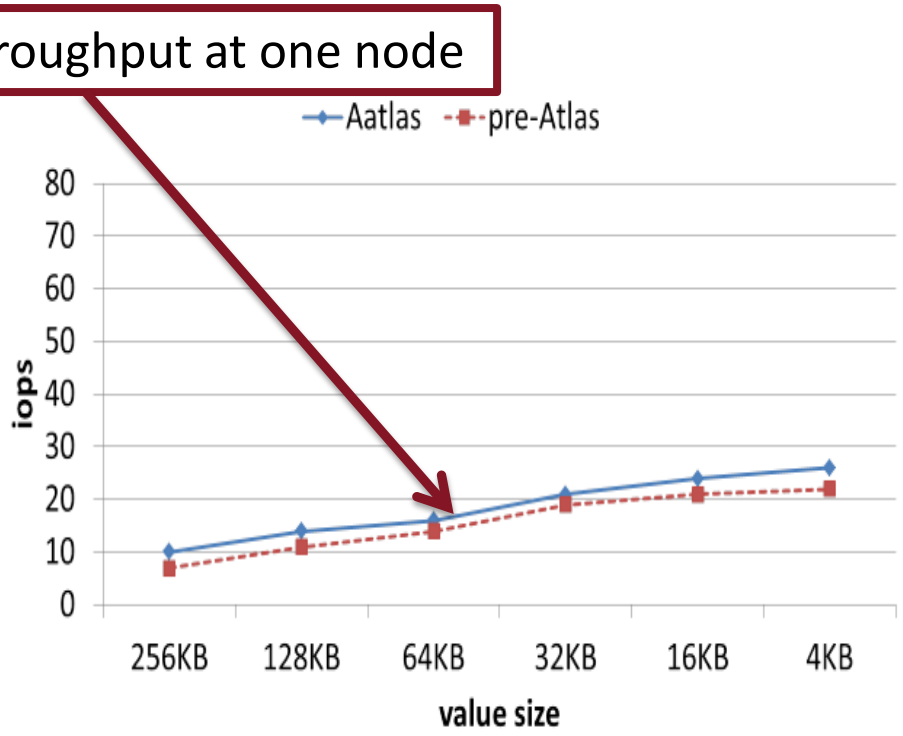
- Atlas saves about 70% of hardware cost per GB storage
  - Using ARM servers to replace x86 servers
  - Using erasure coding to replace 3-copy replication.
- Power consumption is reduced by about 53% per GB storage.
  - The ARM processors are more power efficient.
  - The ARM server racks are more space efficient, reducing energy cost for power supply and thermal dissipation.

Comparison with the Prior System

- Reference system (pre-Atlas)
  - Similar PIS subsystem.
  - All data are managed solely by the LSM-tree-based KV store.
- Run on a 12-server X86 cluster.



All writes

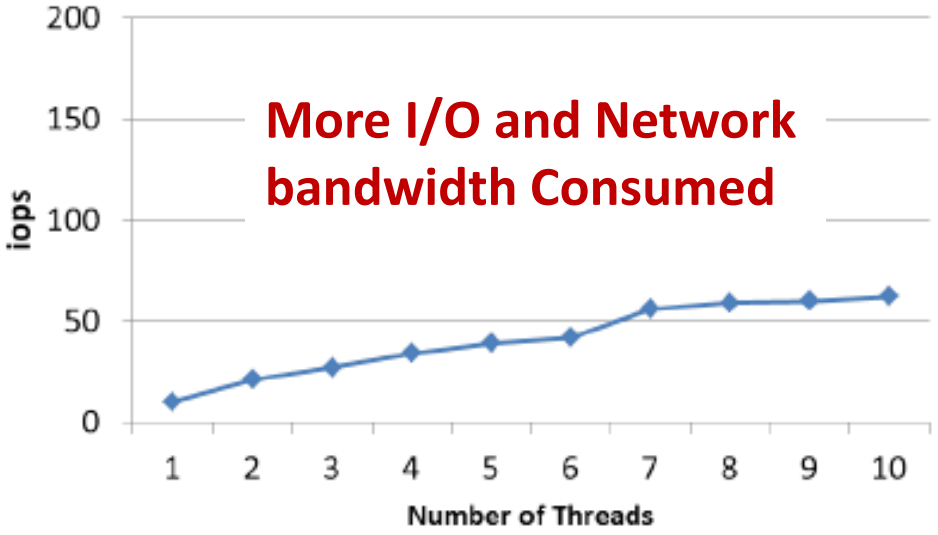


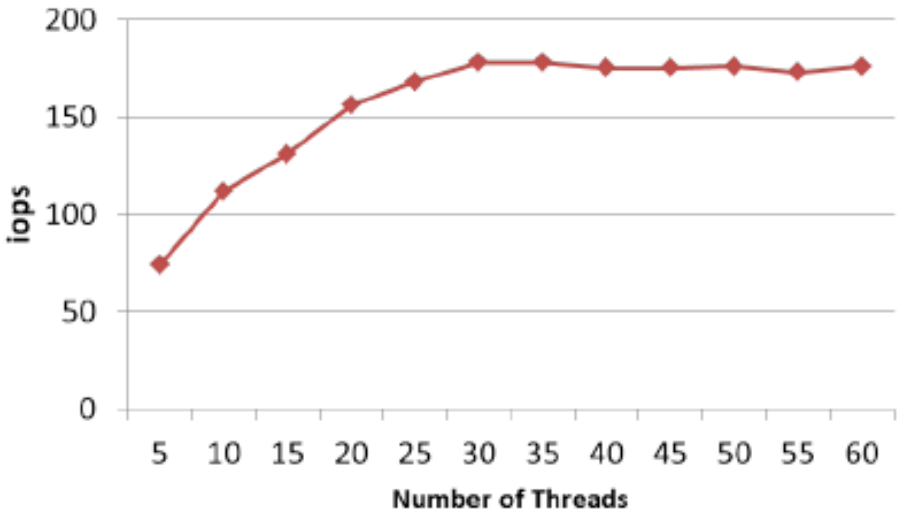
Read : Write = 3:1

Atlas on a Customized ARM cluster

- A cluster of 12 ARM servers.
- Each hosts multiple PIS slices and RBS partservers.
- Each server has a 4-core Marvell processor, 4GB memory, four 3TB disks.
- 1Gbps full-duplex Ethernet adapter.
- Request size is 256KB.

Throughput at One Node with Diff. Request Types





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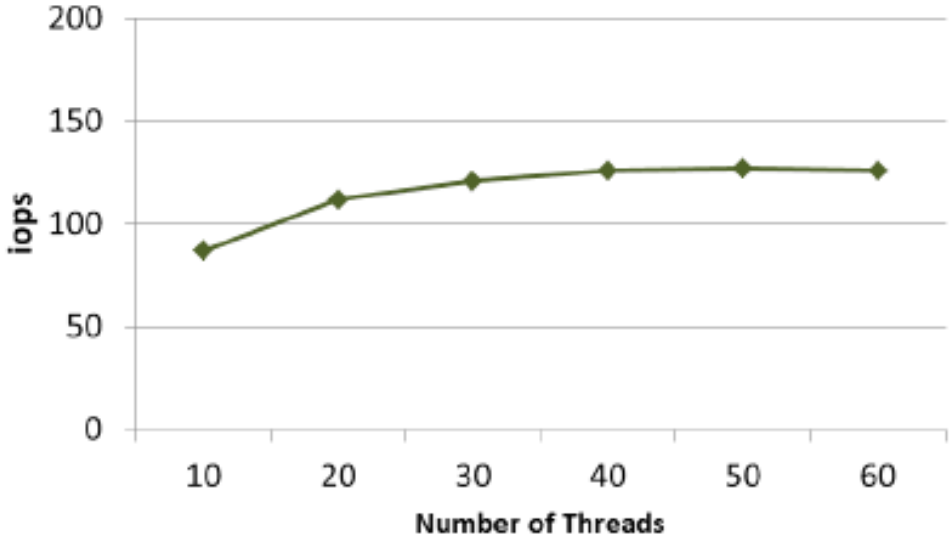
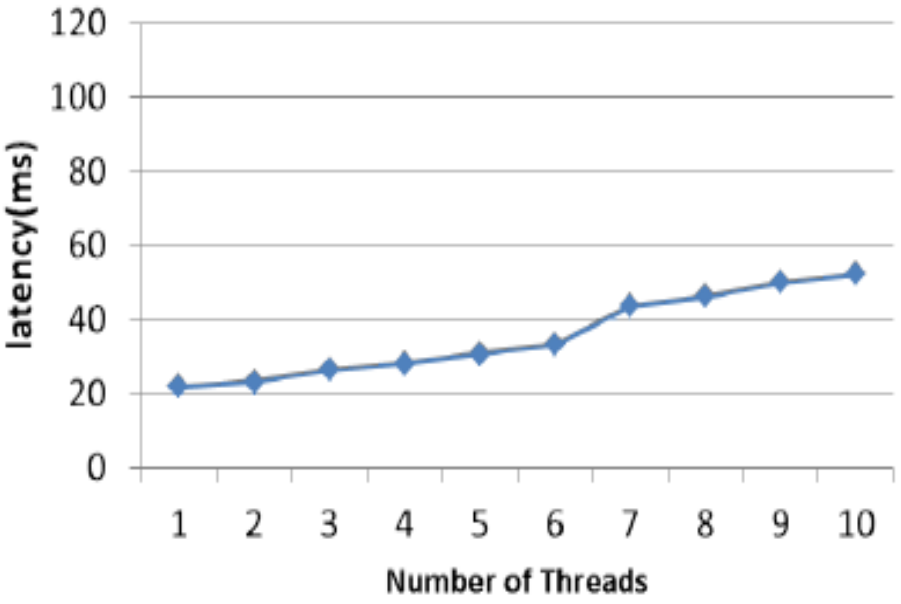
All Reads



Read : Write = 3:1

Latencies with Diff. Request Types



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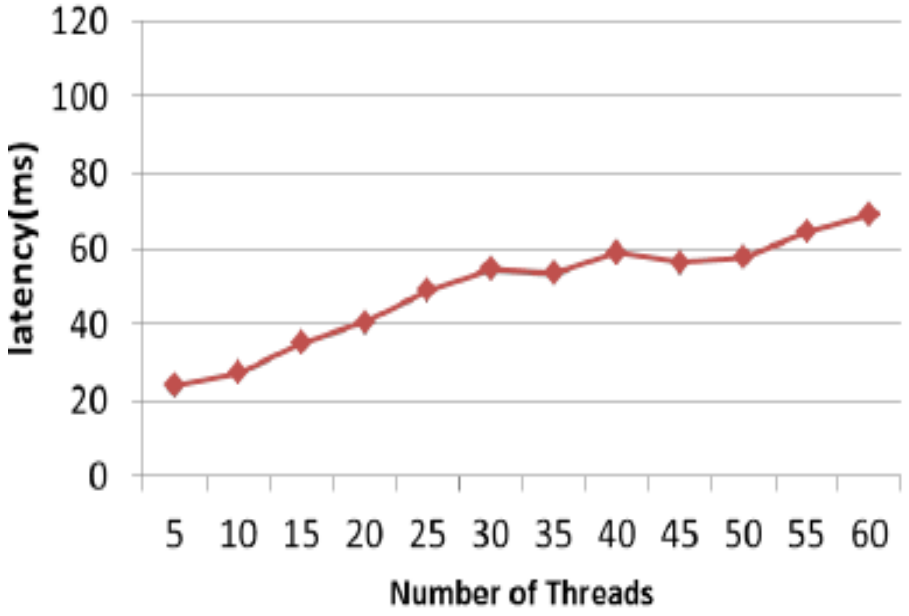
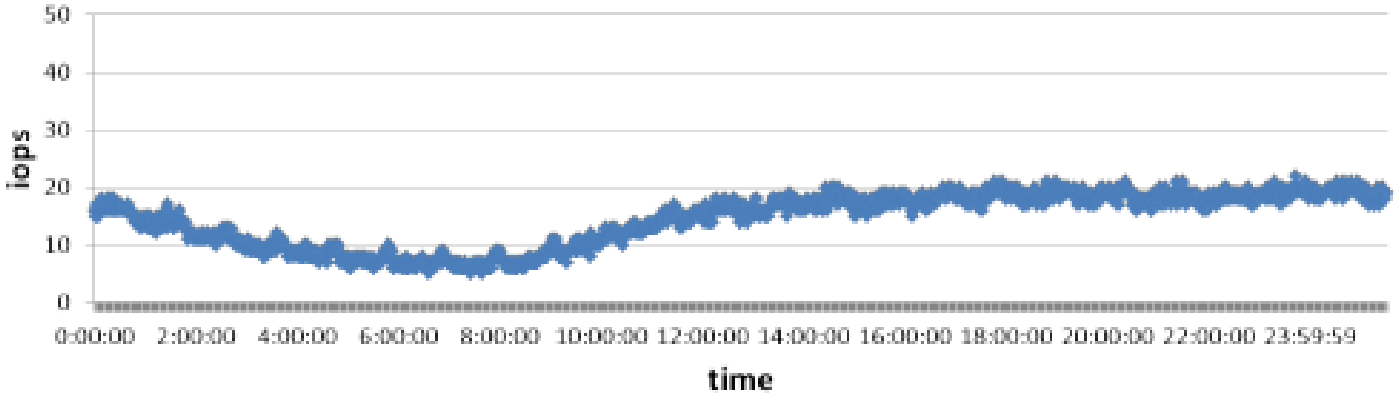
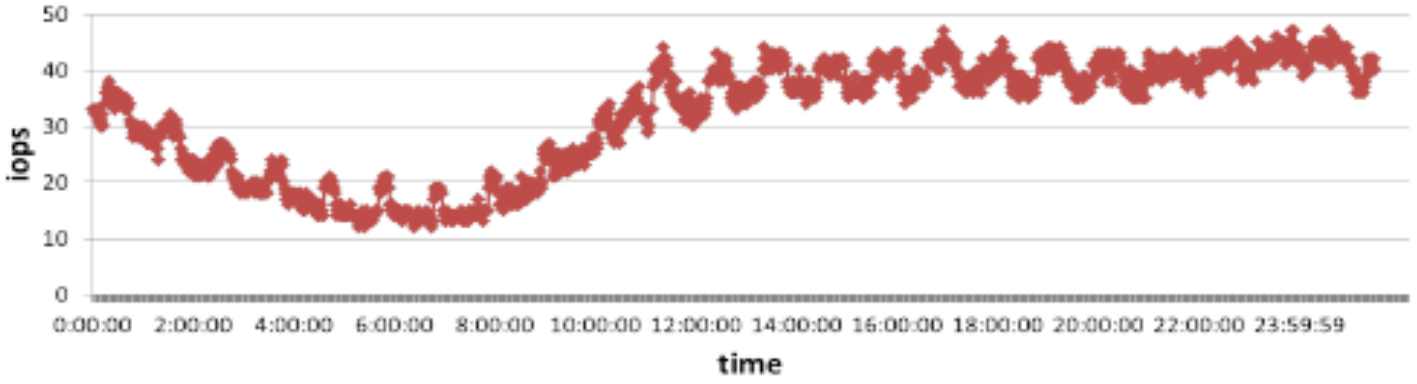


All Reads

Throughput at one Node of a Production System

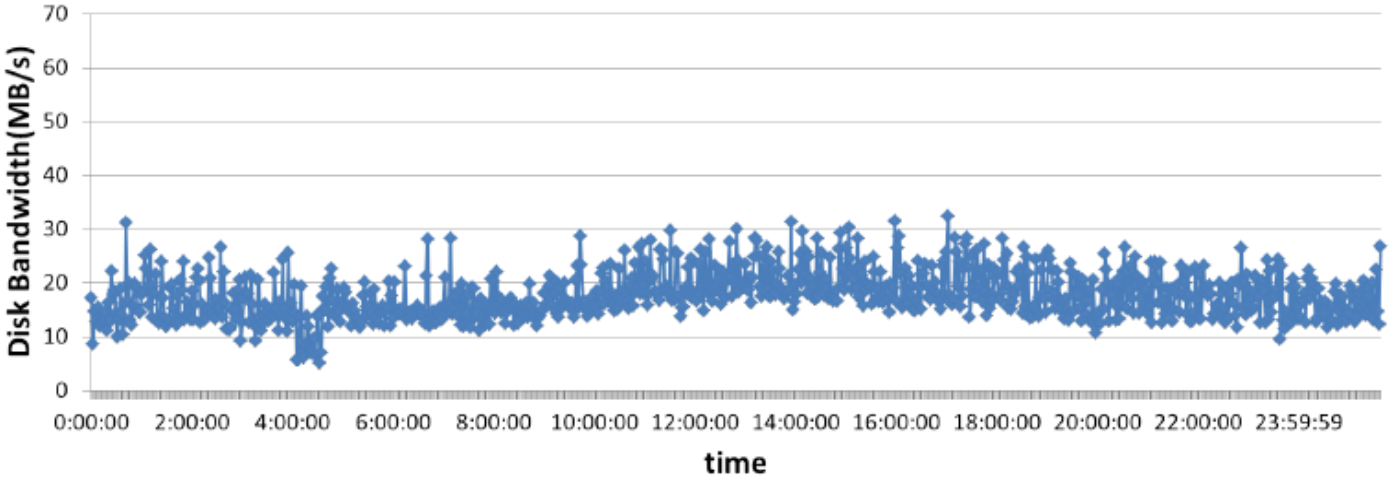


write



Reads

Disk Bandwidth at one Node of a Production System



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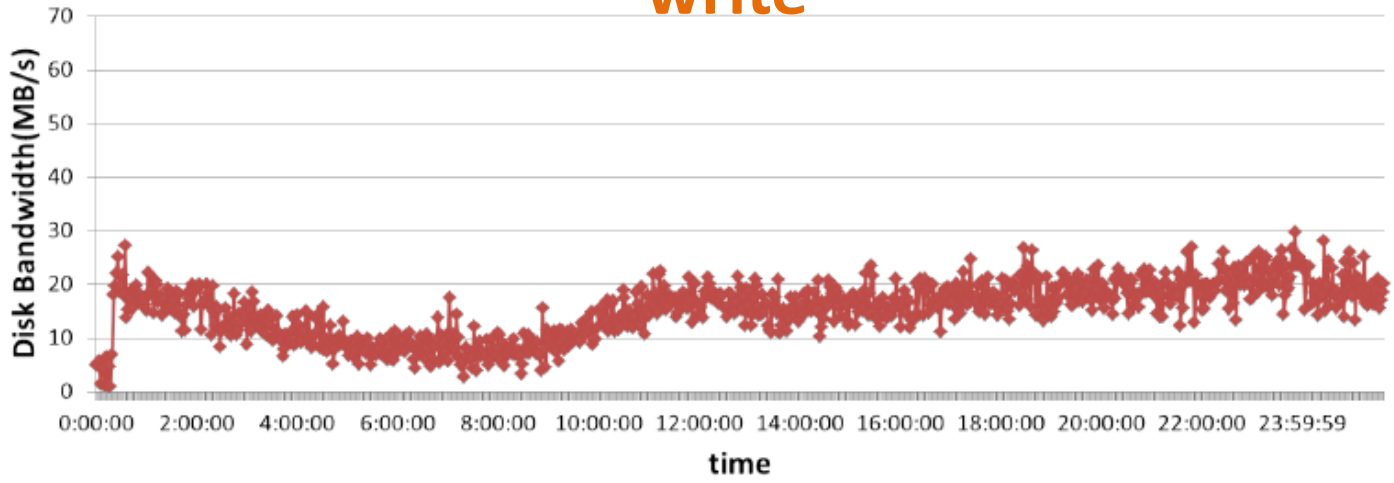

Reads

Summary

- Atlas is an object store using a two-tier design separating the managements of keys and values.
- Atlas uses a hardware-software co-design for high cost-effectiveness and energy efficiency.
- Atlas adopts the erasure coding technique for space-efficient data protection.