Secondary Indexing in RAMCloud

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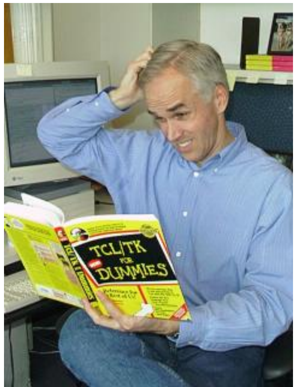
(Joint work with Arjun Gopalan, Ashish Gupta and John Ousterhout)



Introduction

- **RAMCloud 1.0**
- **Higher-level data models**
  - Without sacrificing latency and scalability
- **Secondary Indexes: lookups and range queries on attributes that are not the primary key**
- **Feedback welcome!**

Key Design Issues

- API and RAMCloud object format
- **Index placement / partitioning**
- Index memory allocation
- **Failure / Restoration**
- **Consistency**

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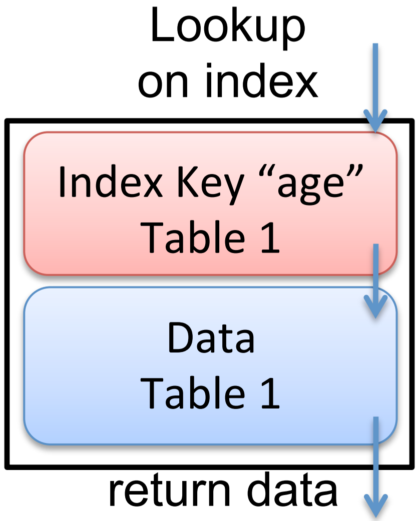
Index Placement



Lookup on index

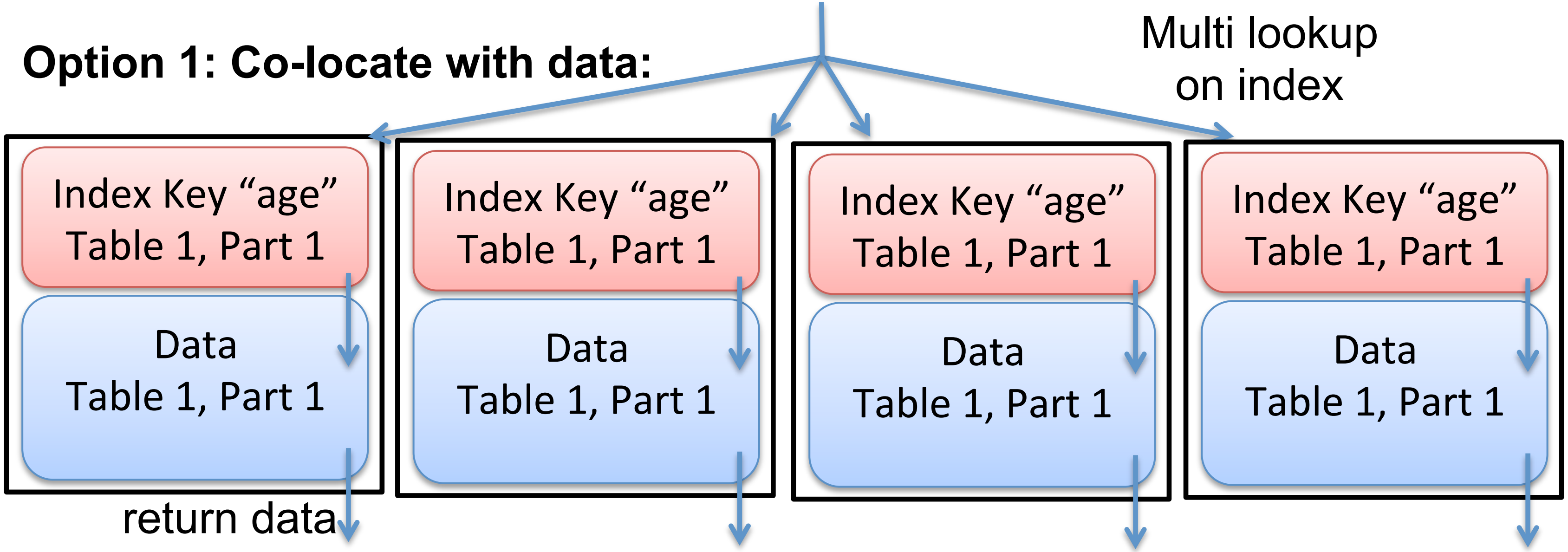
Index Key "age" Table 1

Data Table 1

return data

Index Partitioning

Option 1: Co-locate with data:



Multi lookup on index

Index Key "age"
Table 1, Part 1

Data
Table 1, Part 1

Index Key "age"
Table 1, Part 1

Data
Table 1, Part 1

Index Key "age"
Table 1, Part 1

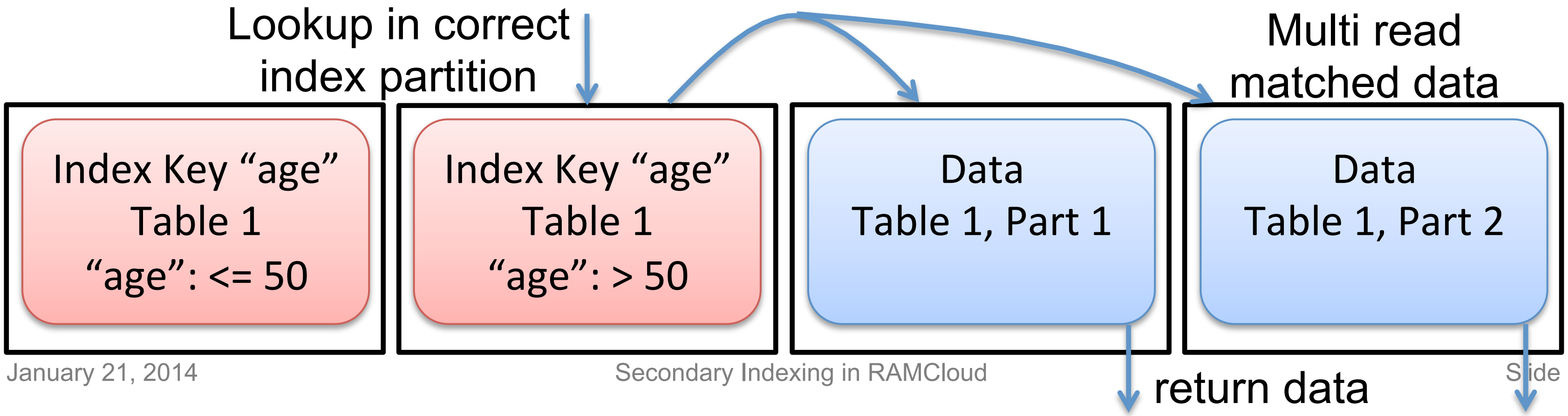
Data
Table 1, Part 1

Index Key "age"
Table 1, Part 1

Data
Table 1, Part 1

return data

Option 2: Partition based on index key:



Lookup in correct index partition

Multi read matched data

Index Key "age"
Table 1
"age": <= 50

Index Key "age"
Table 1
"age": > 50

Data
Table 1, Part 1

Data
Table 1, Part 2

return data

Index Partitioning

- **Index lookup:**
  - Assume data + index on n servers
  - Opt 1: multiLookup to n servers + local reads
  - Opt 2: lookup to index server + multiRead to x servers
    - $x \in [0, n-1]$
    - For small n: expect $x \approx n-1$
    - For large n: expect $x << n$
  - Option 2 more scalable
- **Index entry format:**
  - <index key, primary key hash>

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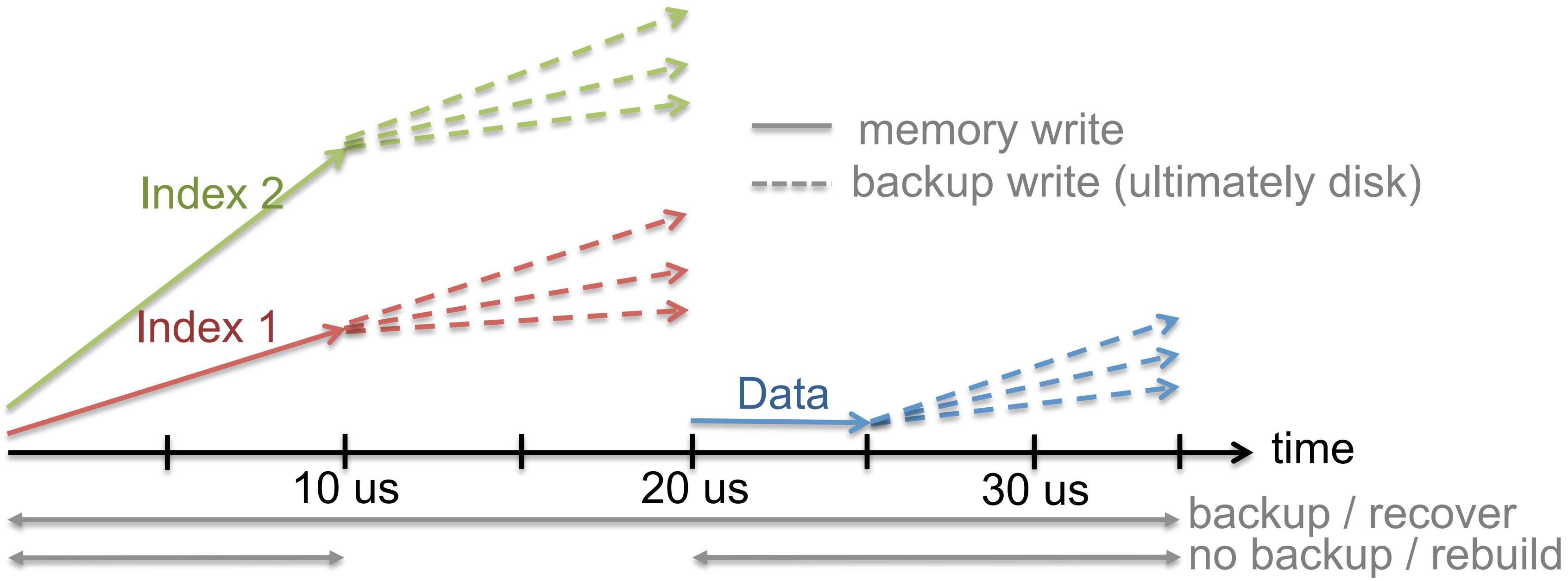
Failure / Restoration

- **Tablet Server**
  - Doesn’t affect indexes
  - “Normal” RAMCloud data recovery

- **Index server**
  - Backup / Recover
  - No backup / Rebuild

Failure/Restoration: Write Latency



	Latency	# Mem writes	# Backup writes	# Msgs from data to index servers	# Msgs to backups
No indexing	15 us	1	R	0	R
Indexing w/ backup/restore	35 us	m+1	R*(m+1)	m	R*(m+1)
Indexing w/ no-backup/rebuild	25 us	m+1	R	m	R

Failure/Restoration: Restoration Time

- **Recovery: Similar to RAMCloud data recovery: 1-2 s**
- **Rebuild: Cost analysis:**

Setting	Index partition to be recovered	1 GB
	Size of index entries	50 B (42 for key + 8 for keyhash)
	Num of index entries	2 * 10^7
Data master	Max memory bandwidth	35 GB/s
	Memory bw with overheads	20 GB/s
	Hash table size (10% of total mem)	25 GB (for 256 GB machine)
	Time to scan hash table	**1.25 s**
	Time to compare hash info from bucket	negligible
	Num objects to check if all match	2.5 * 10^9 (for 100B objects)
	Cache miss time	0.5 * 10^9 cache miss / s
	Total cache miss time	**5.12 s**
Network	Bandwidth	1 GB/s
	Time to transfer over network	**1 s**
Index Recovery Master	Time per object to insert	1.5 us
	Total time to insert	30 s
	Total time to insert with parallelization	**1 s**

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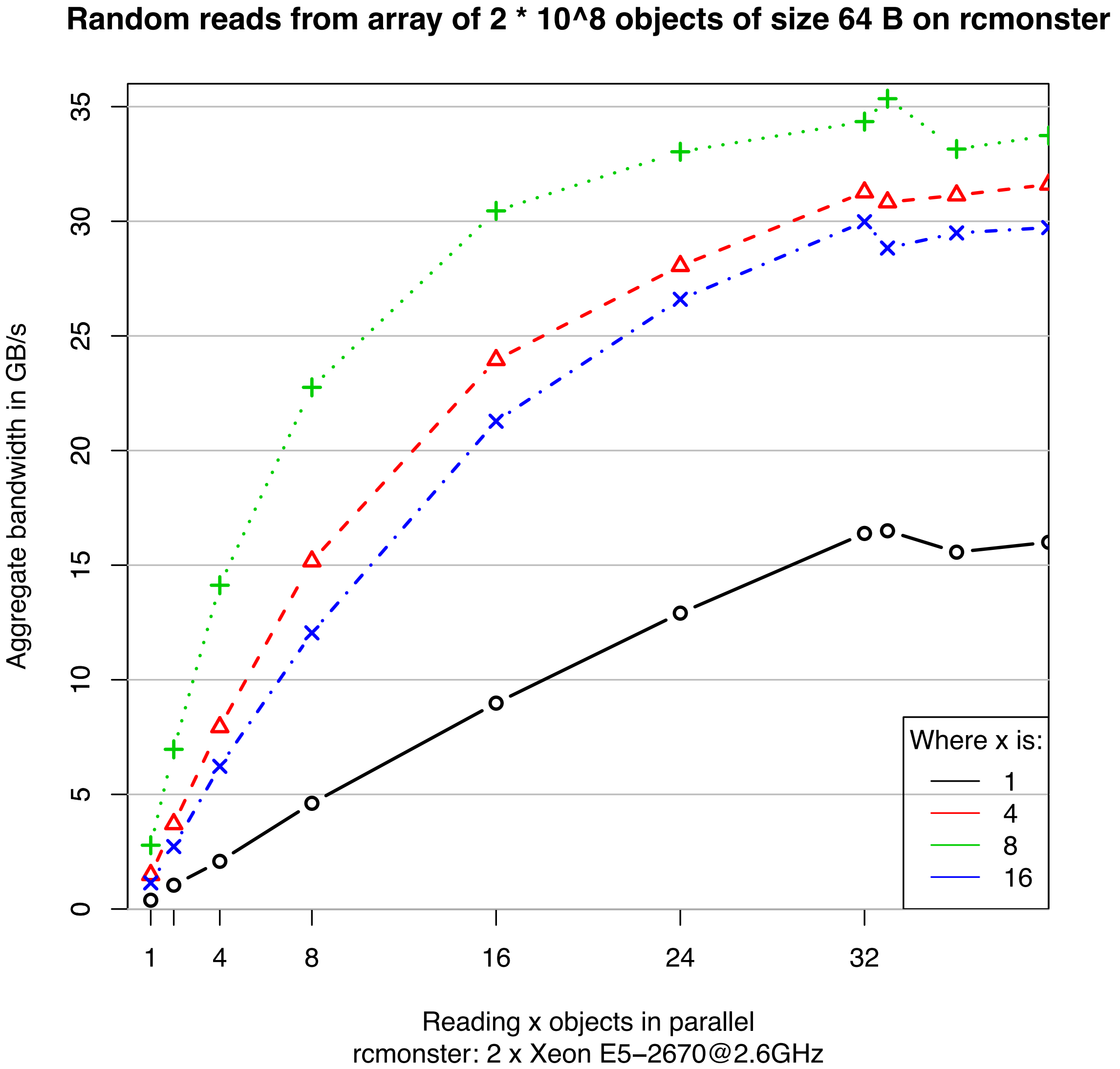
Memory Benchmark



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Consistency

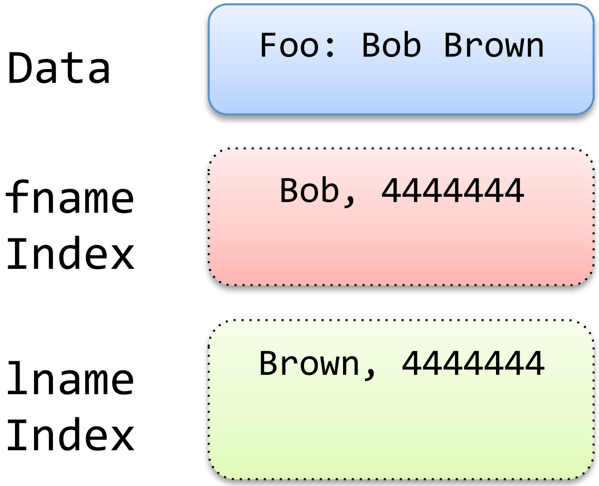
- **At any time, data is consistent with index entries corresponding to it, if:**
  - If data X exists, X is reachable from all key indexes.
  - Data returned to client is consistent with key used to look it up.
- **Provides linearizability**
  - Tradeoff with performance
- **Also desirable:**
  - Dangling pointers are not accumulating.
  - Memory footprint will not increase beyond what is necessary.

Consistency

- **Simple solution:**
  - Lock indexes and tablets for the entire duration of index update – affects scalability and performance
- **Our solution: Key Idea:**
  - Writing object is the commit point
- **Interesting situations:**
  - For multi-threaded write/read, non-locking, no failures
  - For multi-threaded write/write, non-locking, no failures
  - Failure of an Index Server
  - Failure of Master Server

Consistency

- Multi-threaded write/read, non-locking, no failures: Object Update
- There exists time x, s.t.: at time < x, client can lookup old data; at time >= x, it can lookup the new data.



Data

Foo: Bob Brown

fname Index

Bob, 4444444

lname Index

Brown, 4444444

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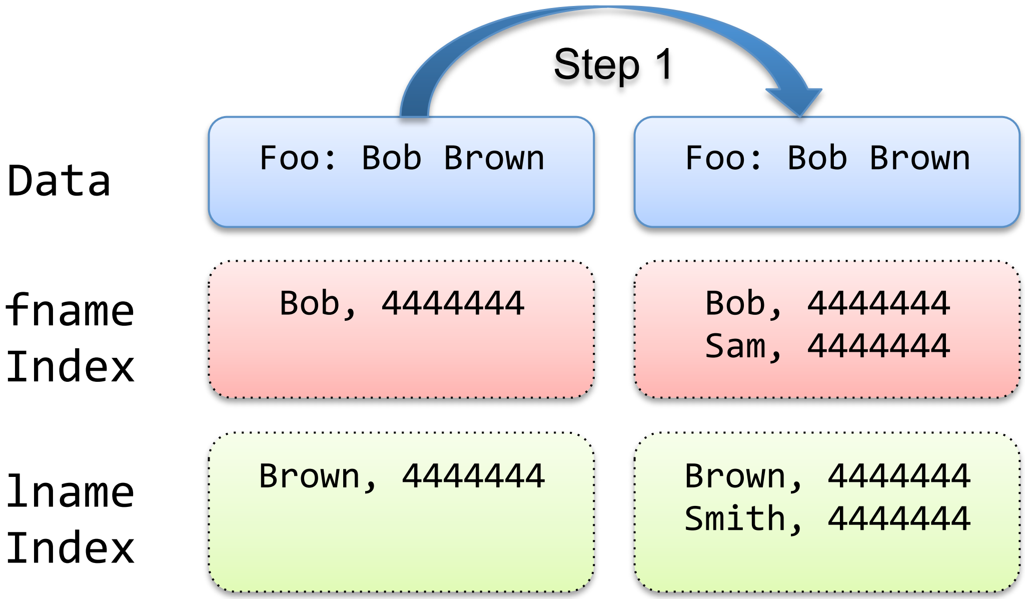

Step 1

Data	Foo: Bob Brown	Foo: Bob Brown
fname Index	Bob, 4444444	Bob, 4444444 Sam, 4444444
lname Index	Brown, 4444444	Brown, 4444444 Smith, 4444444

Consistency

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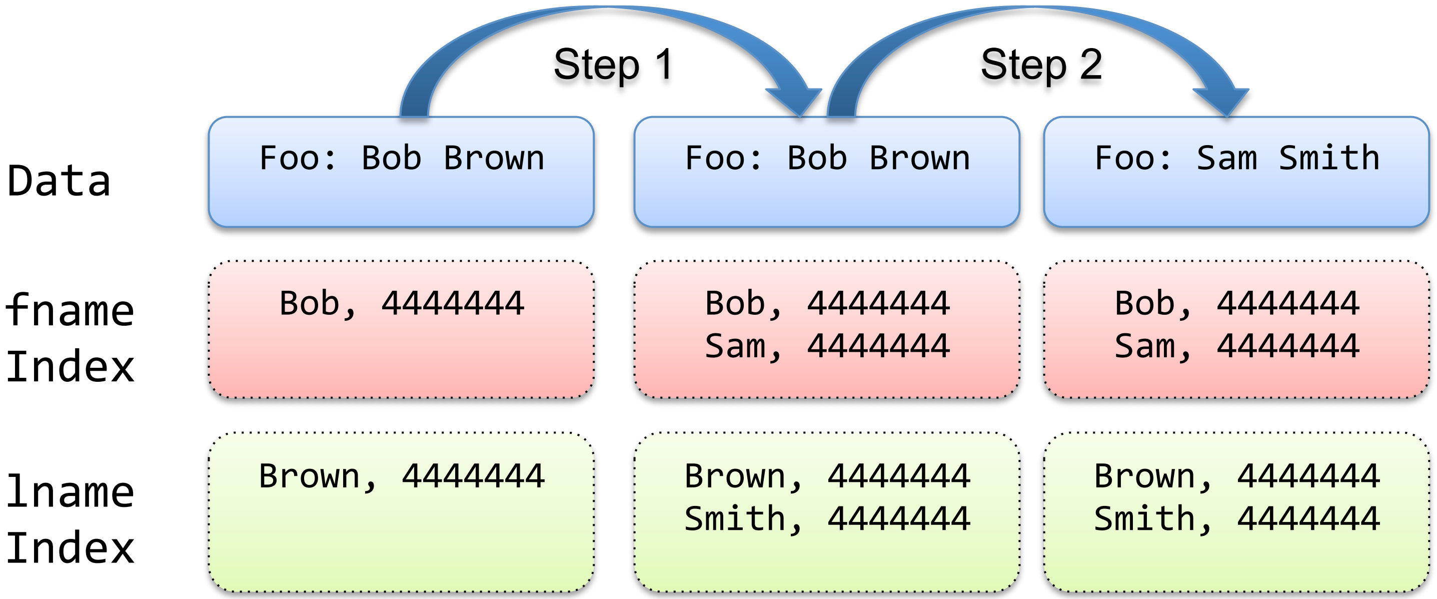

Step 1

Step 2

Data	Foo: Bob Brown	Foo: Bob Brown	Foo: Sam Smith
fname Index	Bob, 4444444	Bob, 4444444 Sam, 4444444	Bob, 4444444 Sam, 4444444
lname Index	Brown, 4444444	Brown, 4444444 Smith, 4444444	Brown, 4444444 Smith, 4444444

Consistency

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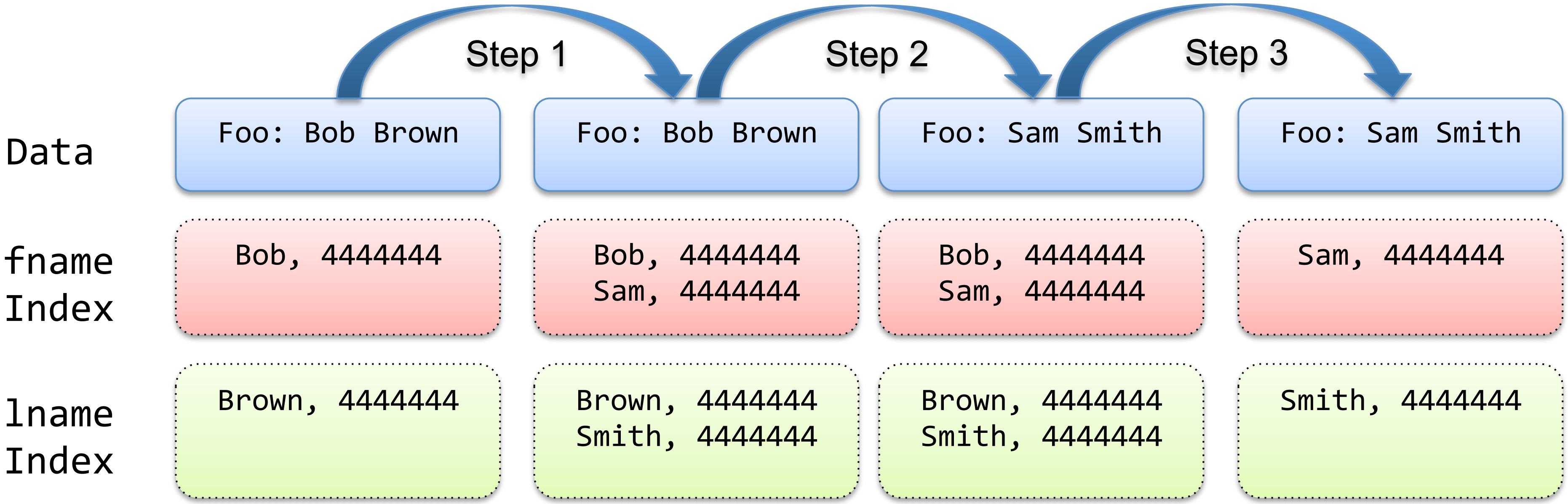

Data	Foo: Bob Brown	Foo: Bob Brown	Foo: Sam Smith	Foo: Sam Smith
fname Index	Bob, 4444444	Bob, 4444444 Sam, 4444444	Bob, 4444444 Sam, 4444444	Sam, 4444444
lname Index	Brown, 4444444	Brown, 4444444 Smith, 4444444	Brown, 4444444 Smith, 4444444	Smith, 4444444

Summary

- **Secondary Indexes: lookups & range queries on attributes that are not the primary key**
- **Key design issues:**
  - Index partitioning
    - Co-locate with data
    - Partition based on index key
  - Failure / Restoration
    - Backup / recover
    - No backup / rebuild
  - Consistency: Linearizability
    - Key idea: Writing object is the commit point
- **Feedback welcome!**

Thank you!