Implementing a key-value store

for fun (and profit?)

André Silva @ ShiftForward

19th January 2017

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What's a key-value store?

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- `put(key, value)`

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- `put(key, value)`
- `get(key) -> value`

What's a key-value store?

- `put(key, value)`
- `get(key) -> value`
- `delete(key)`

What's a key-value store?

```
Map[String, String]
```

What's a key-value store?

`Map[String, String]`

- In-memory
- No persistence
- Cannot be shared

Why are key-value stores useful?

- Simple
- Fast
- You can build upon them
  - SQL
  - Graphs

Why would I want to implement one?

Why would I want to implement one?

Why would I want to implement one?

⚠️ Please don't roll your own database! ⚠️

Let's do this!

Goals

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- Low latency

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- High throughput

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- Handle datasets larger than memory

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- Handle datasets larger than memory
- Crash friendly

Goals

- Low latency
- High throughput
- Handle datasets larger than memory
- Crash friendly
- Simple design

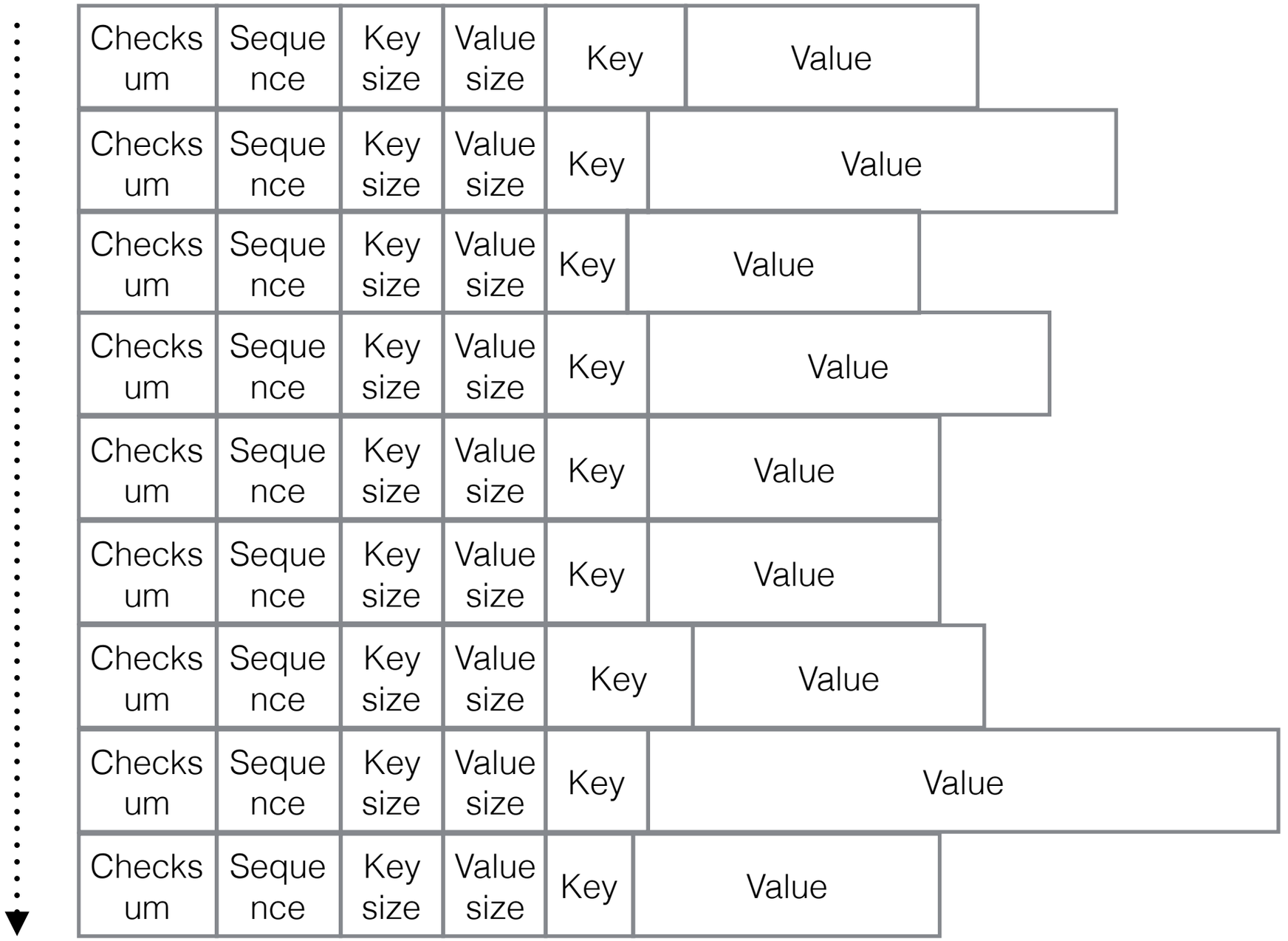
Basic design

- Log-structured hash table
- Two main components:
  - An in-memory **index** (`HashMap`)
  - A **log** file(s)

Log entry

Checksum	Sequence	Key size	Value size	Key	Value

Log



Database

- A directory with multiple files
- At any moment only one file is "active"
- When a size threshold is reached we create a new "active" file
- Append-only

Database

```
$ ls -1 test.db
0000000000.cask.data
0000000000.cask.hint
0000000001.cask.data
0000000001.cask.hint
0000000002.cask.data
0000000002.cask.hint
0000000003.cask.data
cask.lock
```

Database

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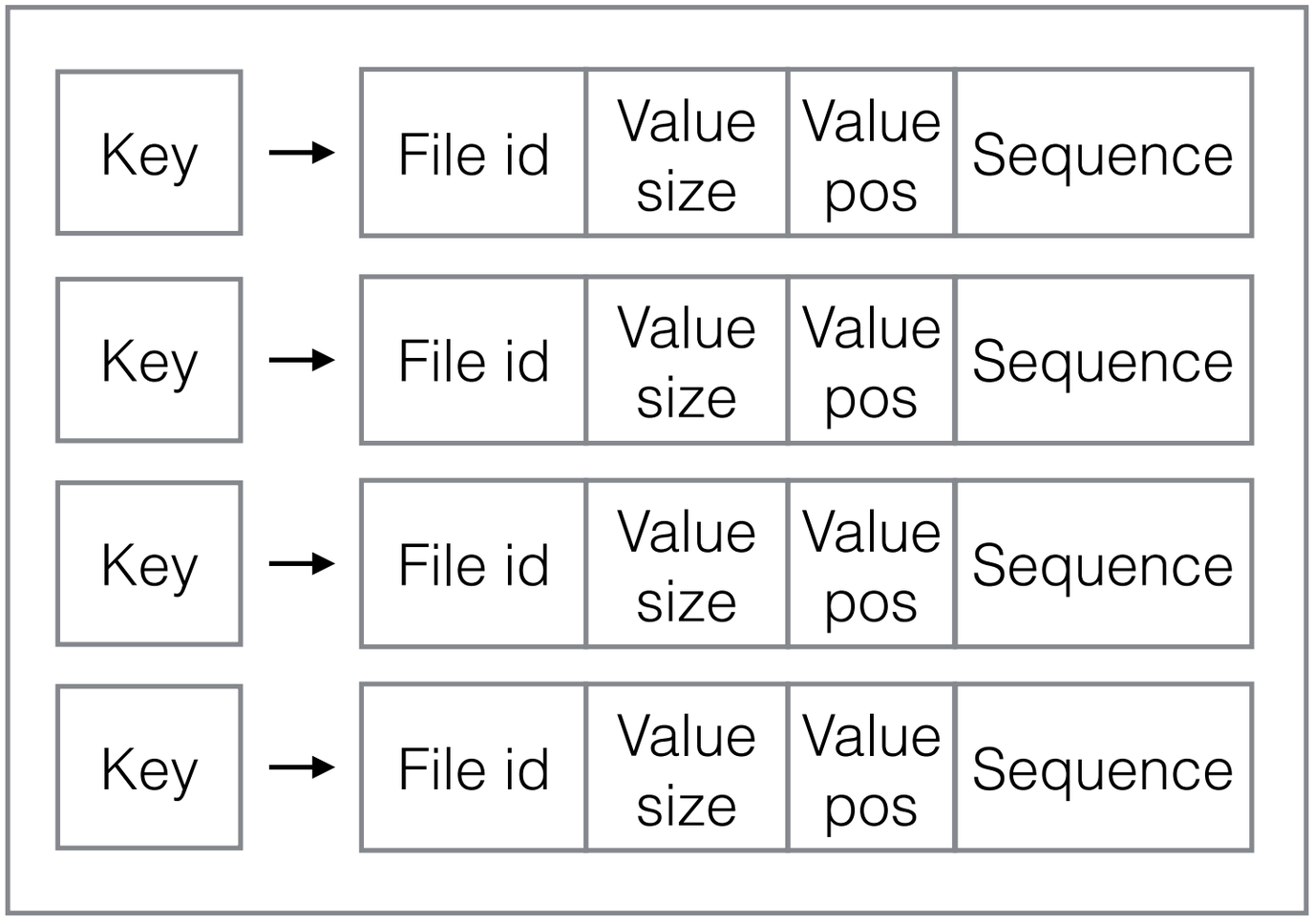
0000000003.cask.data
cask.lock
```

Active file

Index


Key
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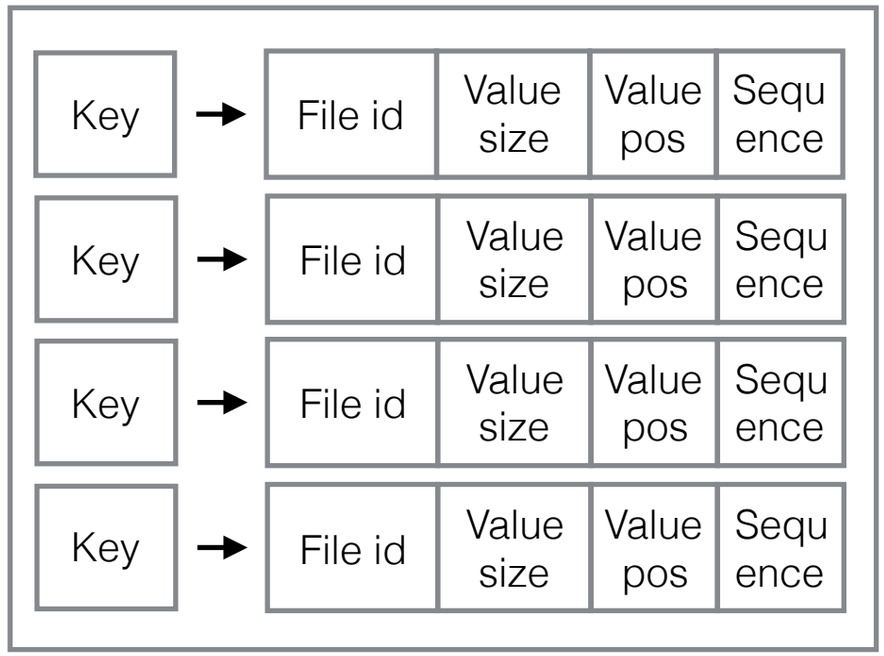
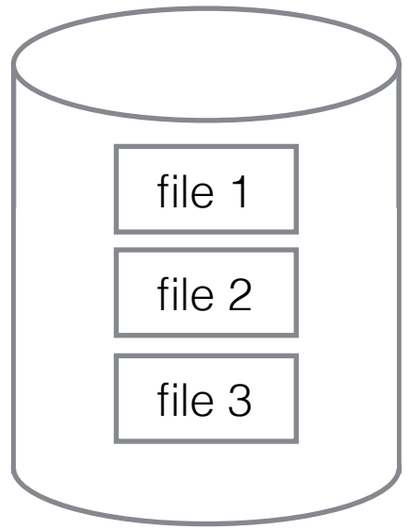
get(key)





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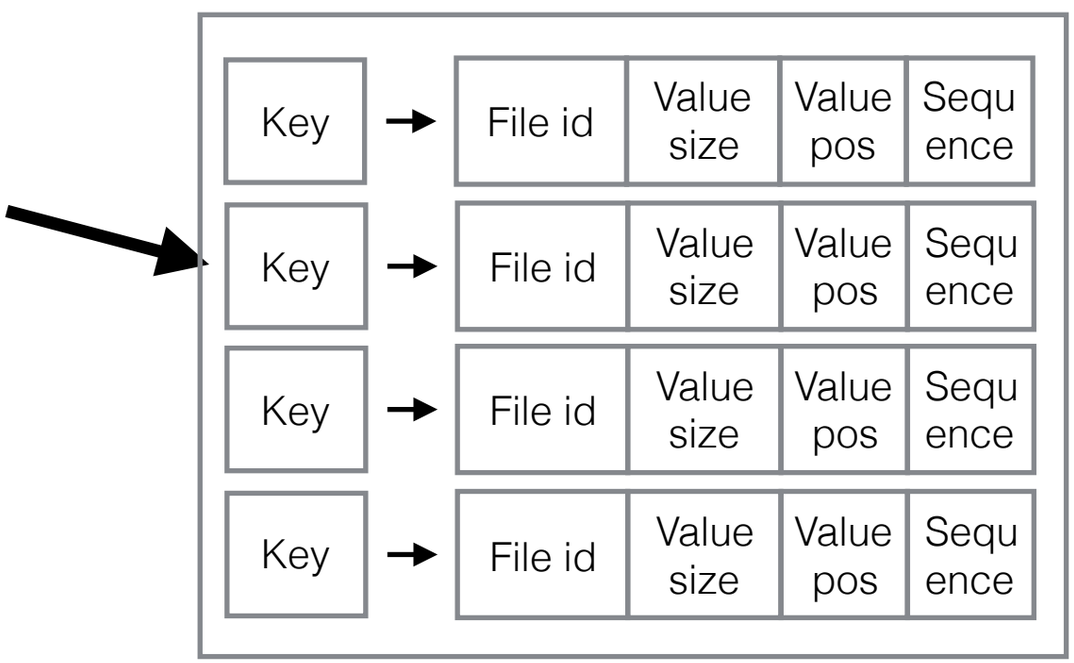

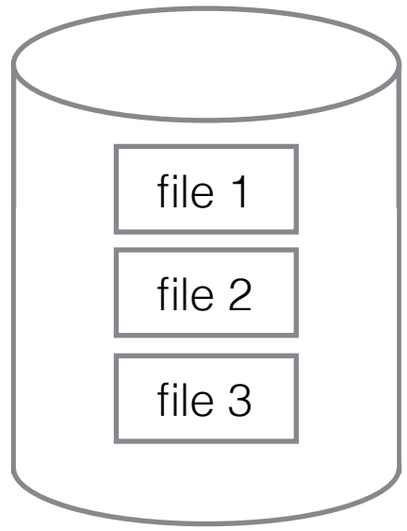

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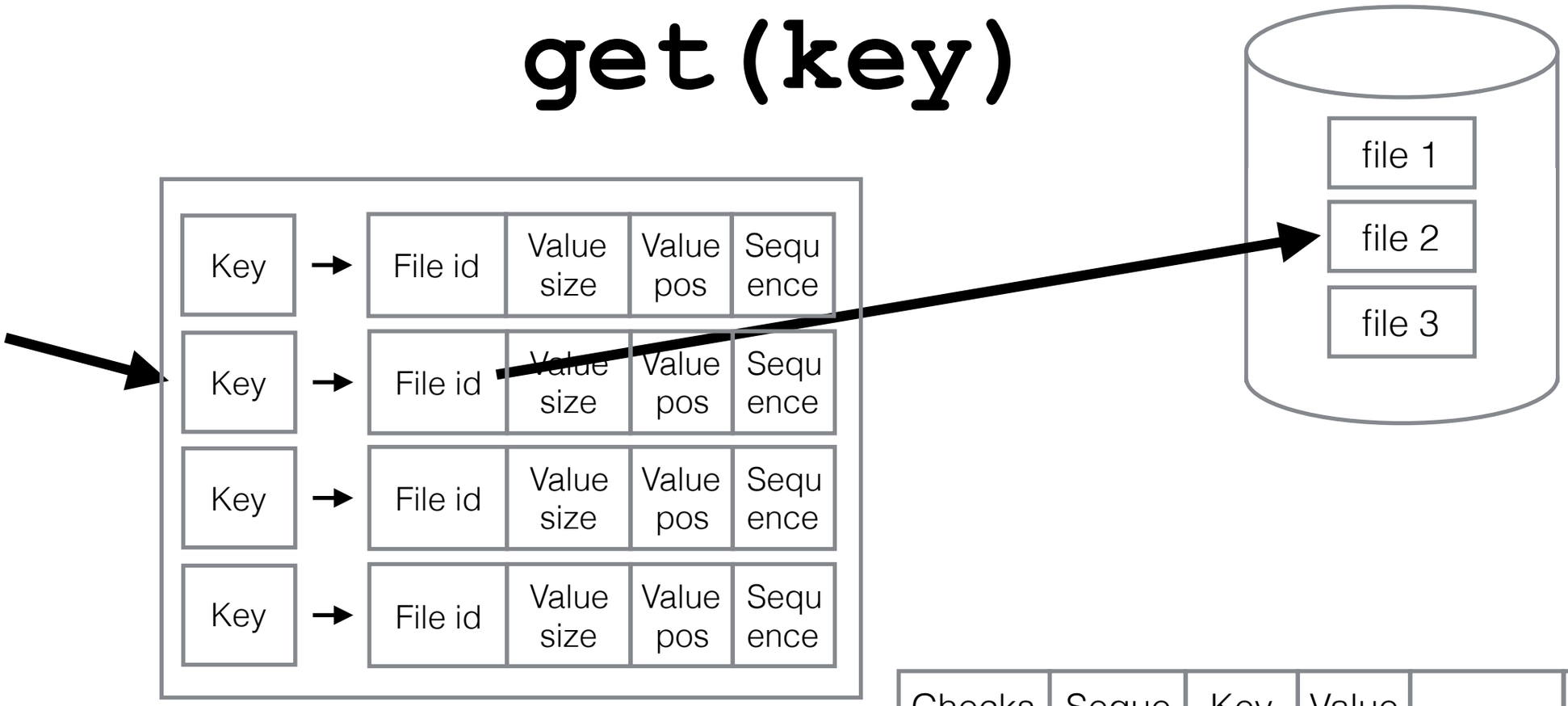
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Key
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file 1
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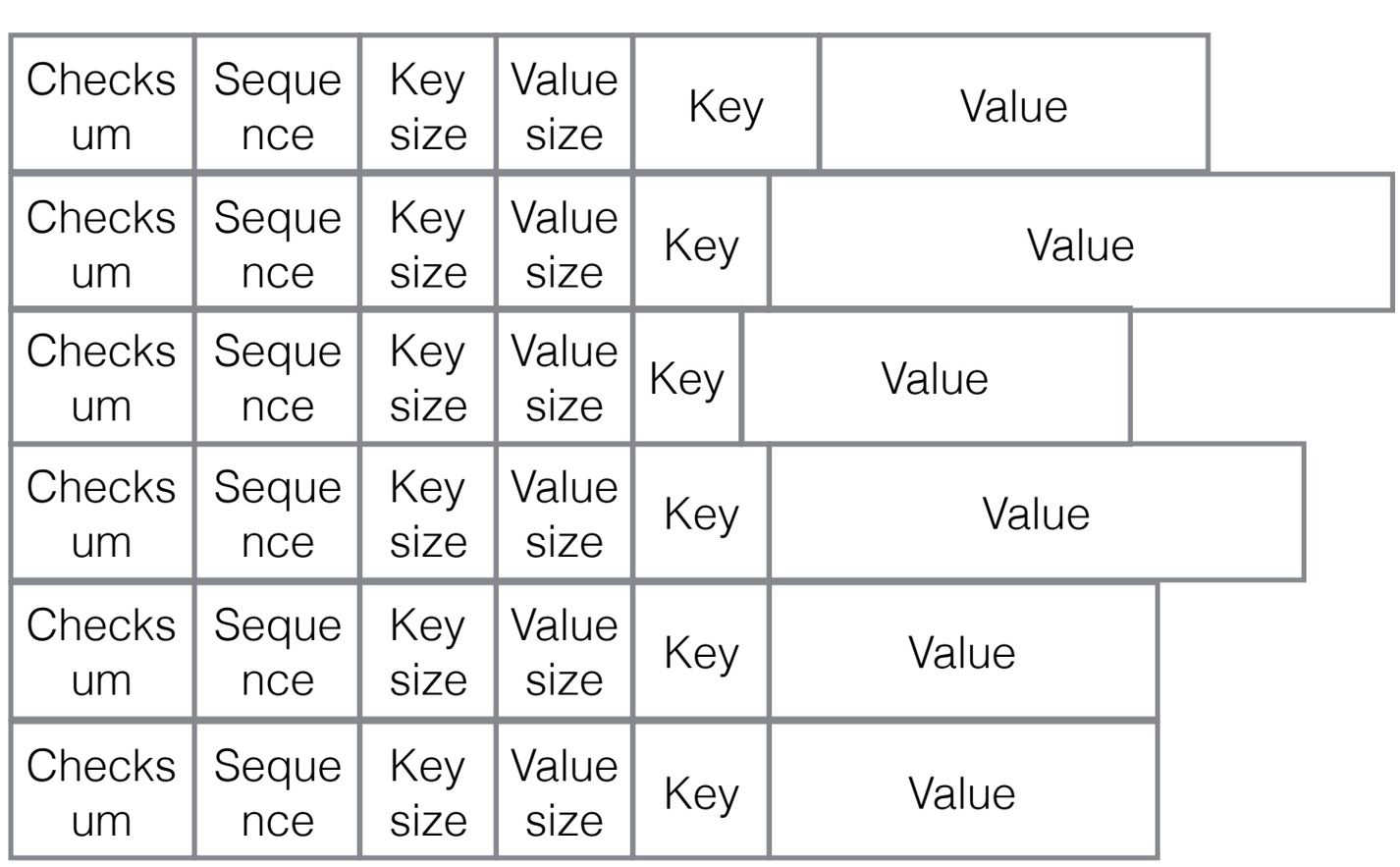
file 3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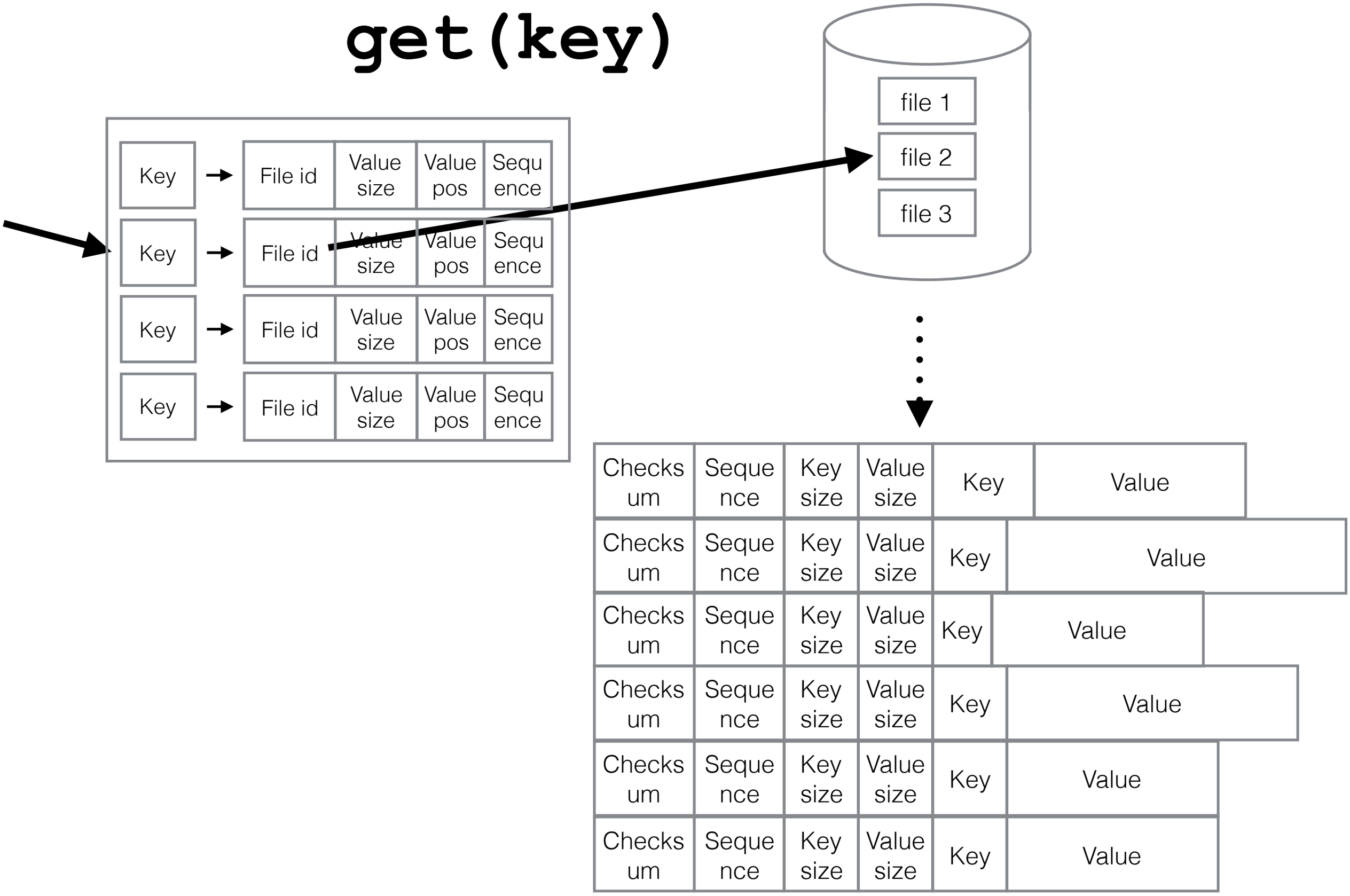
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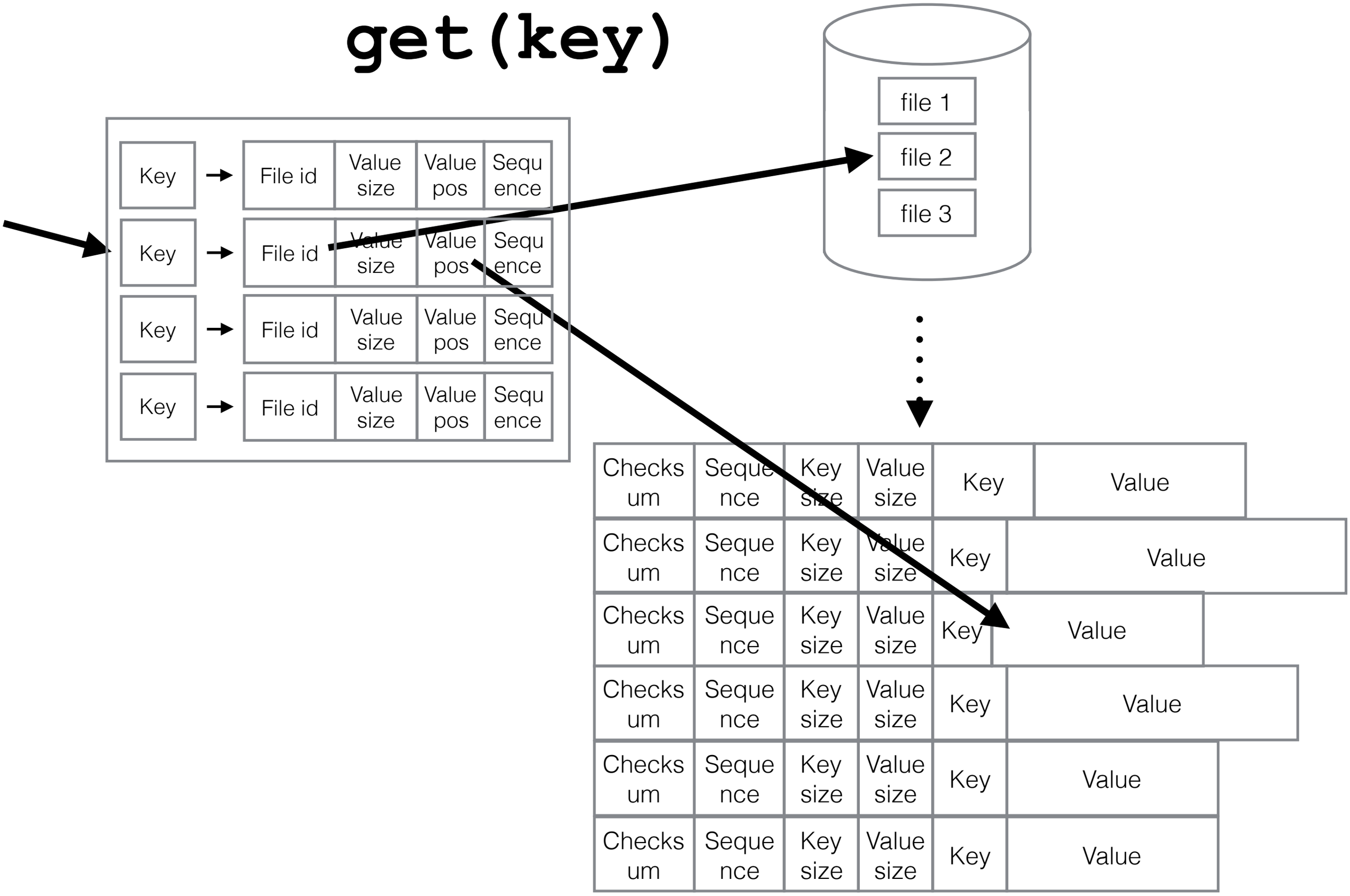
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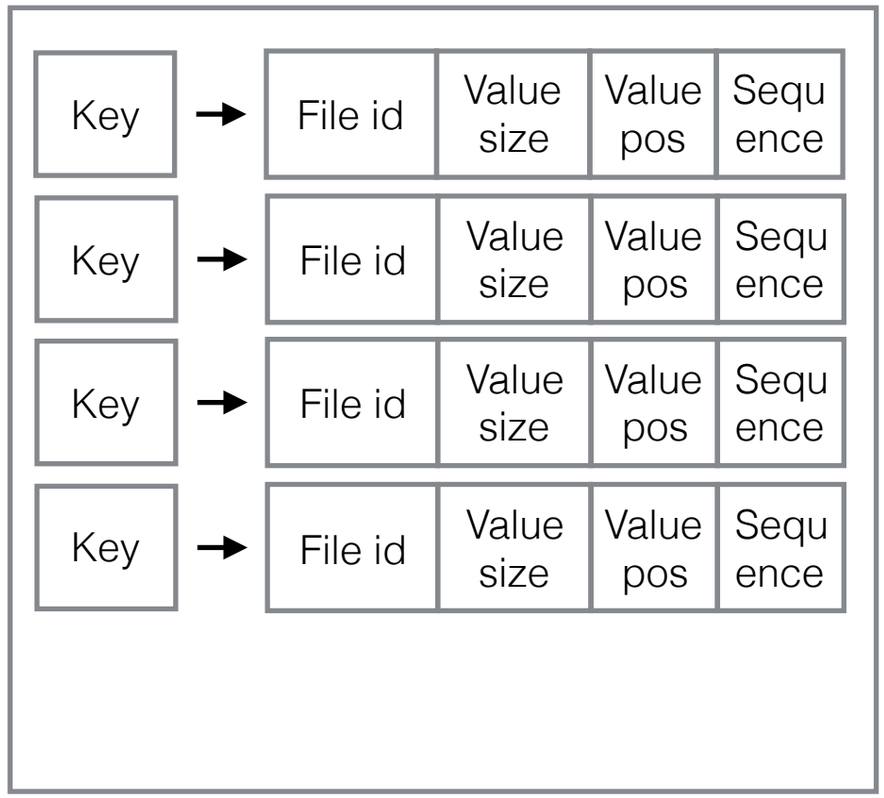
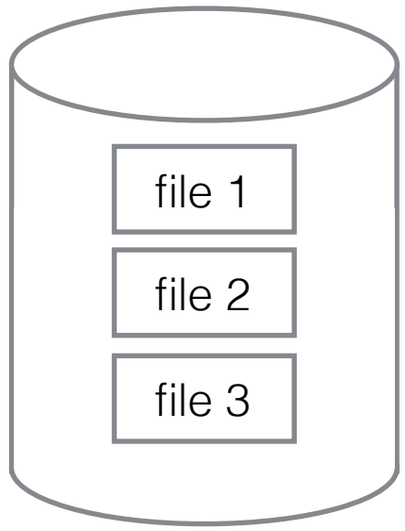
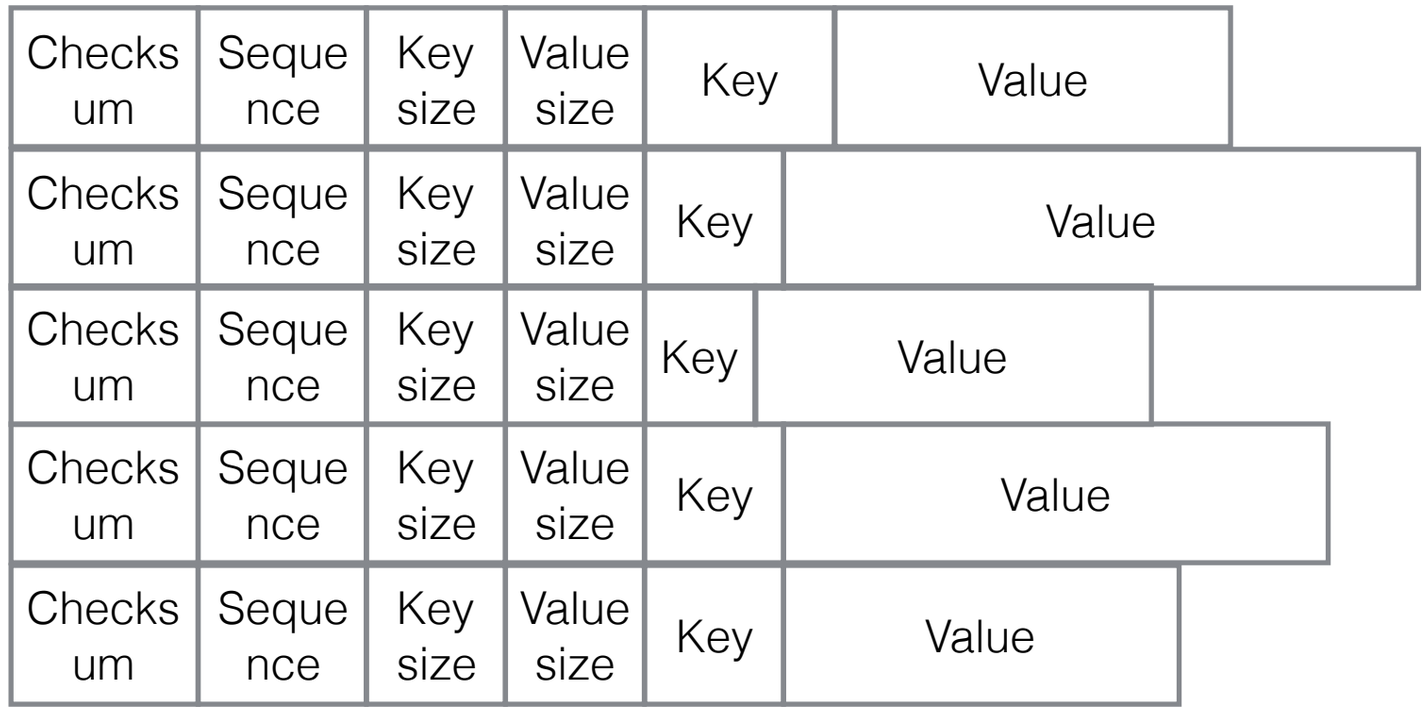
set(key, value)







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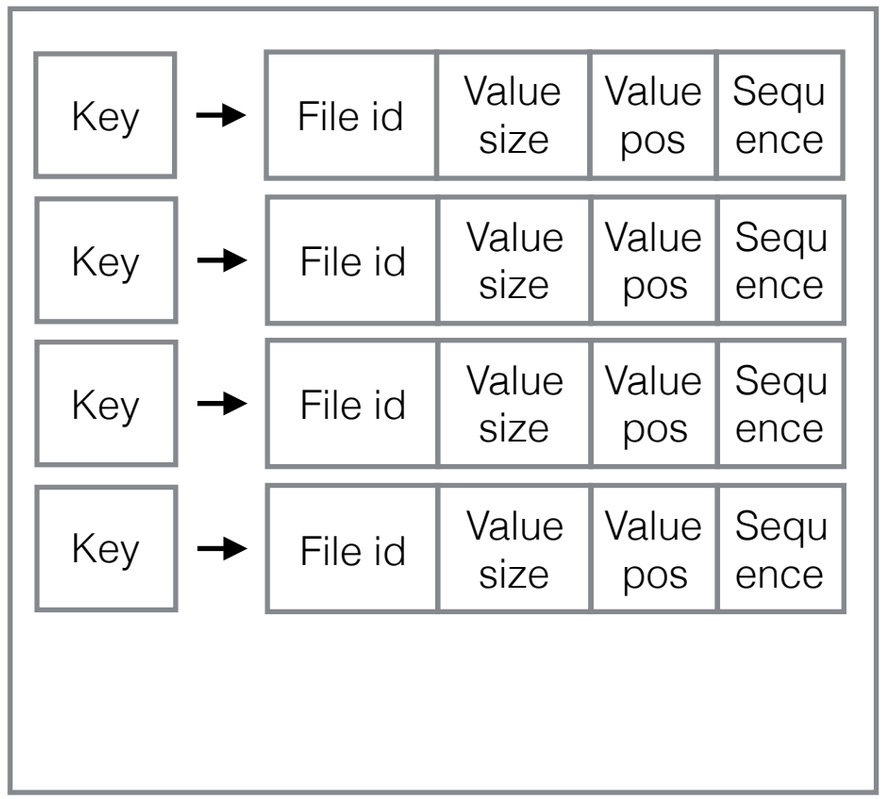

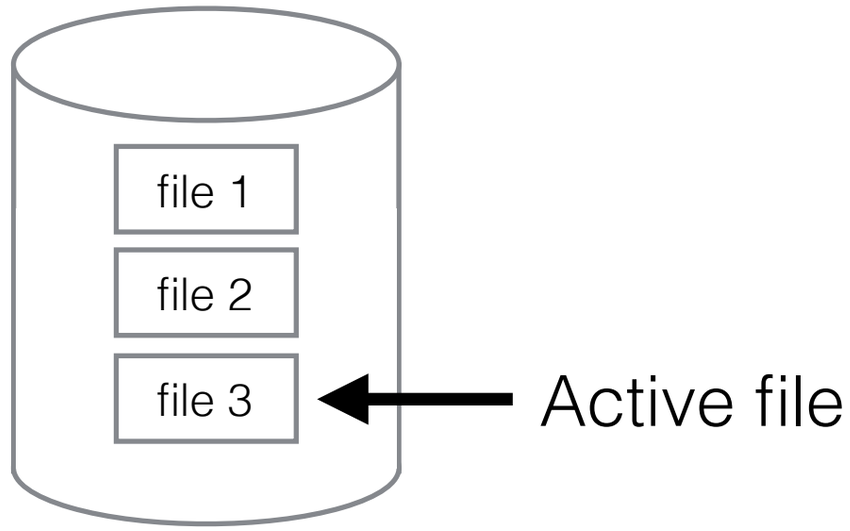

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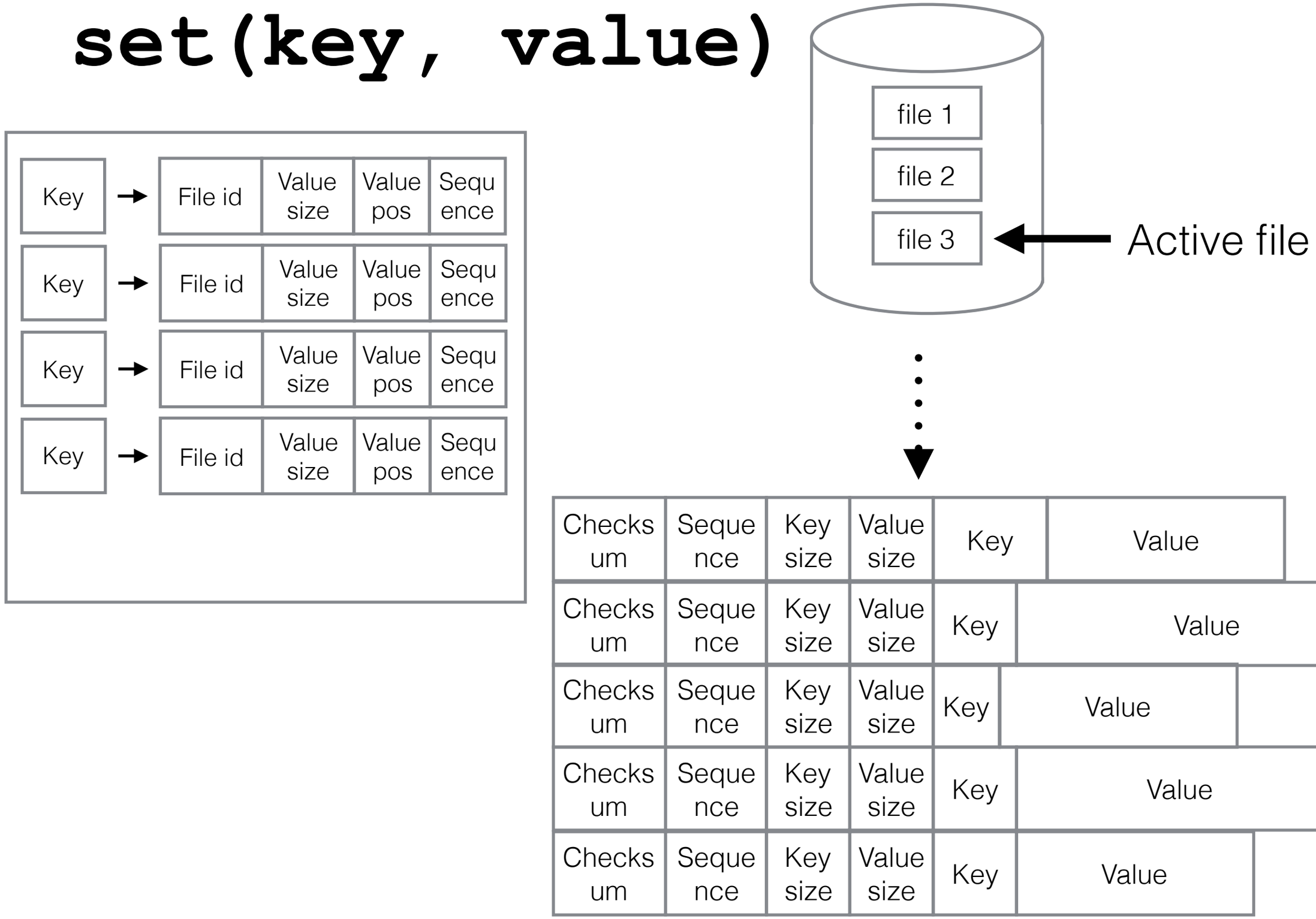

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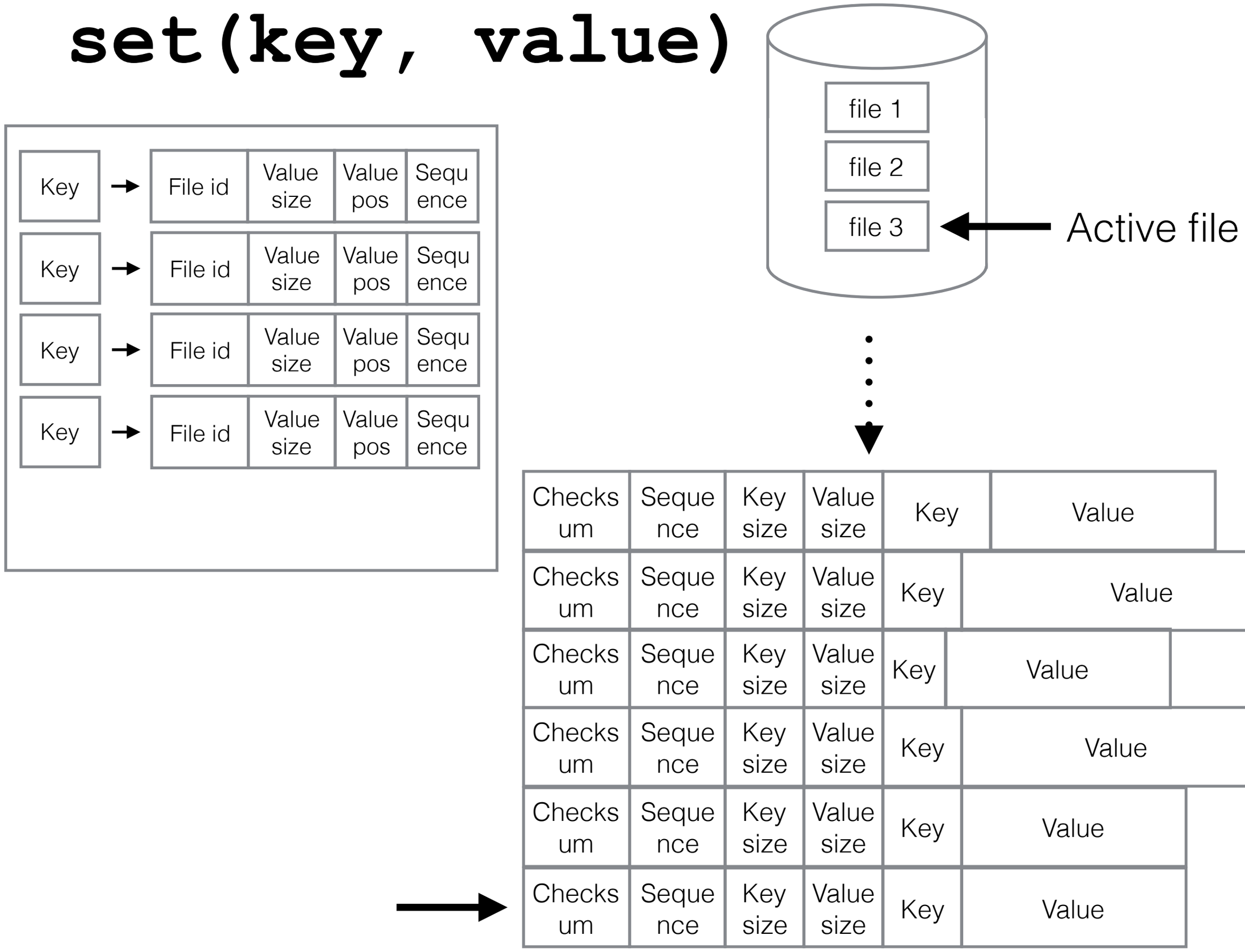

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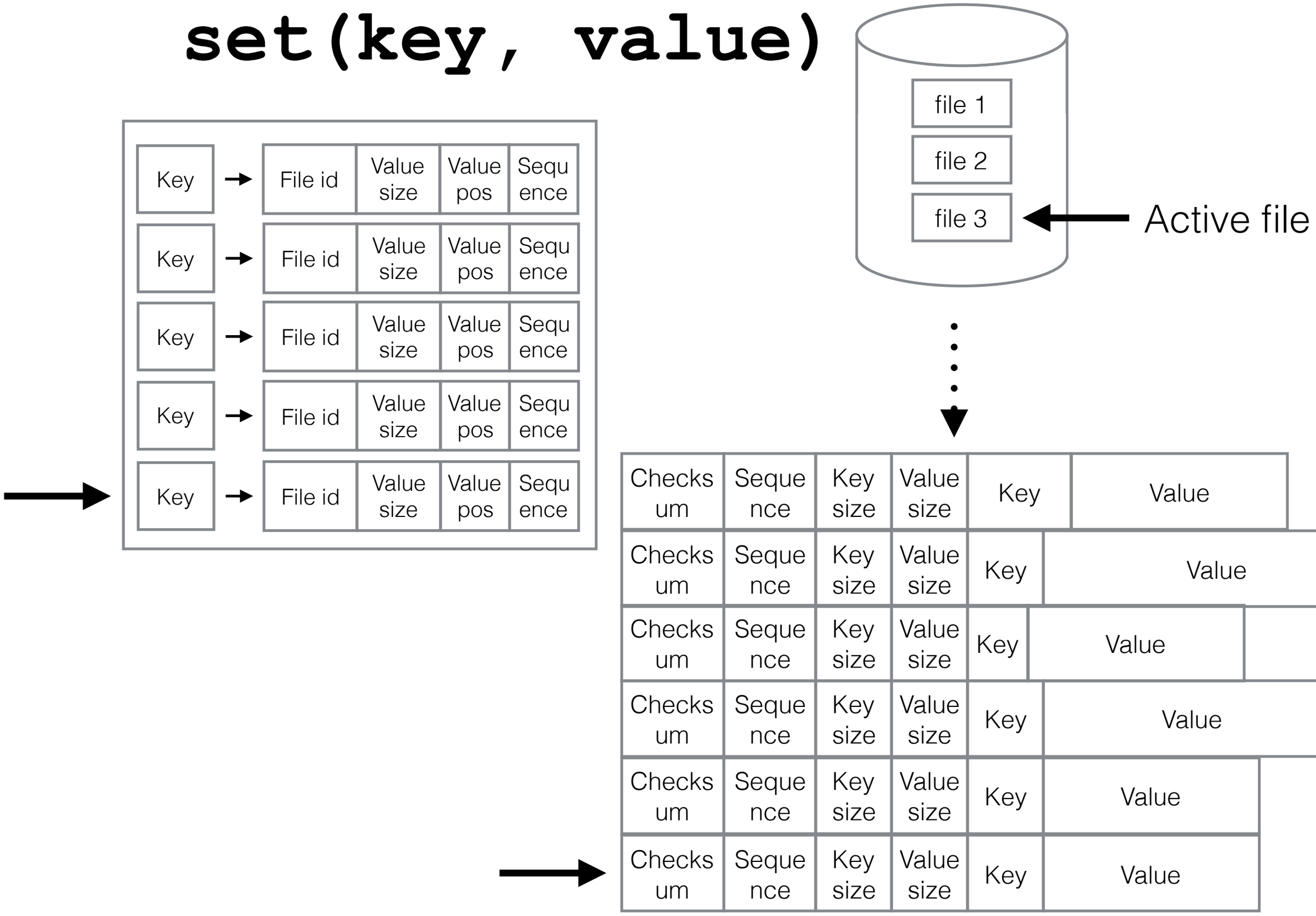
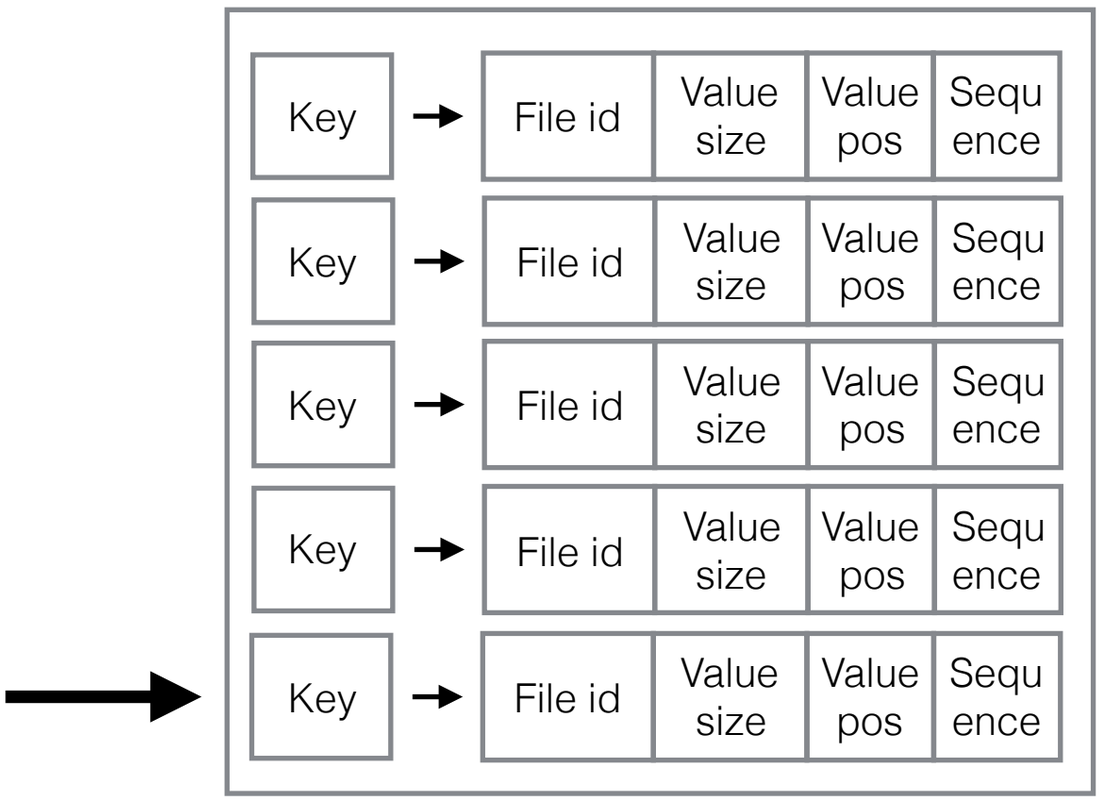
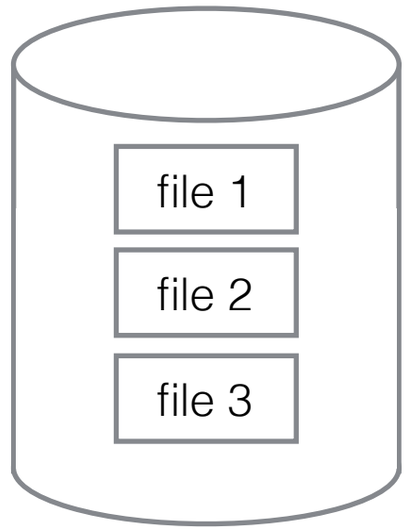


delete(key)





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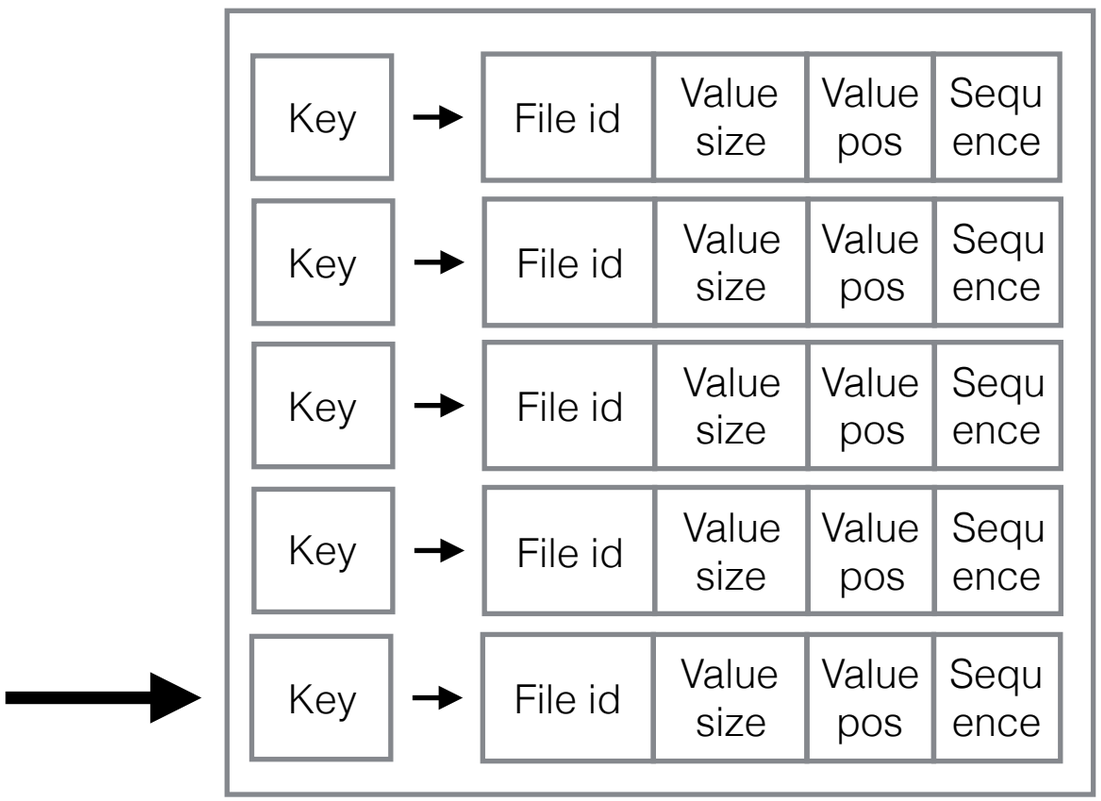

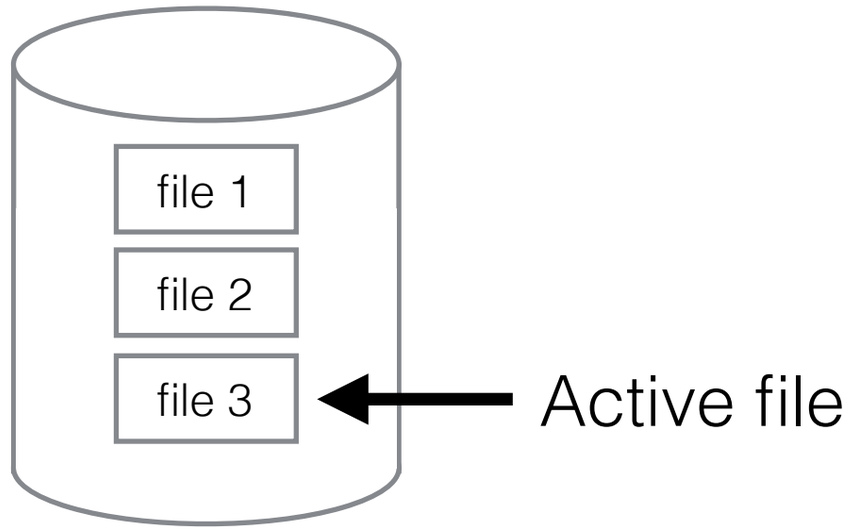

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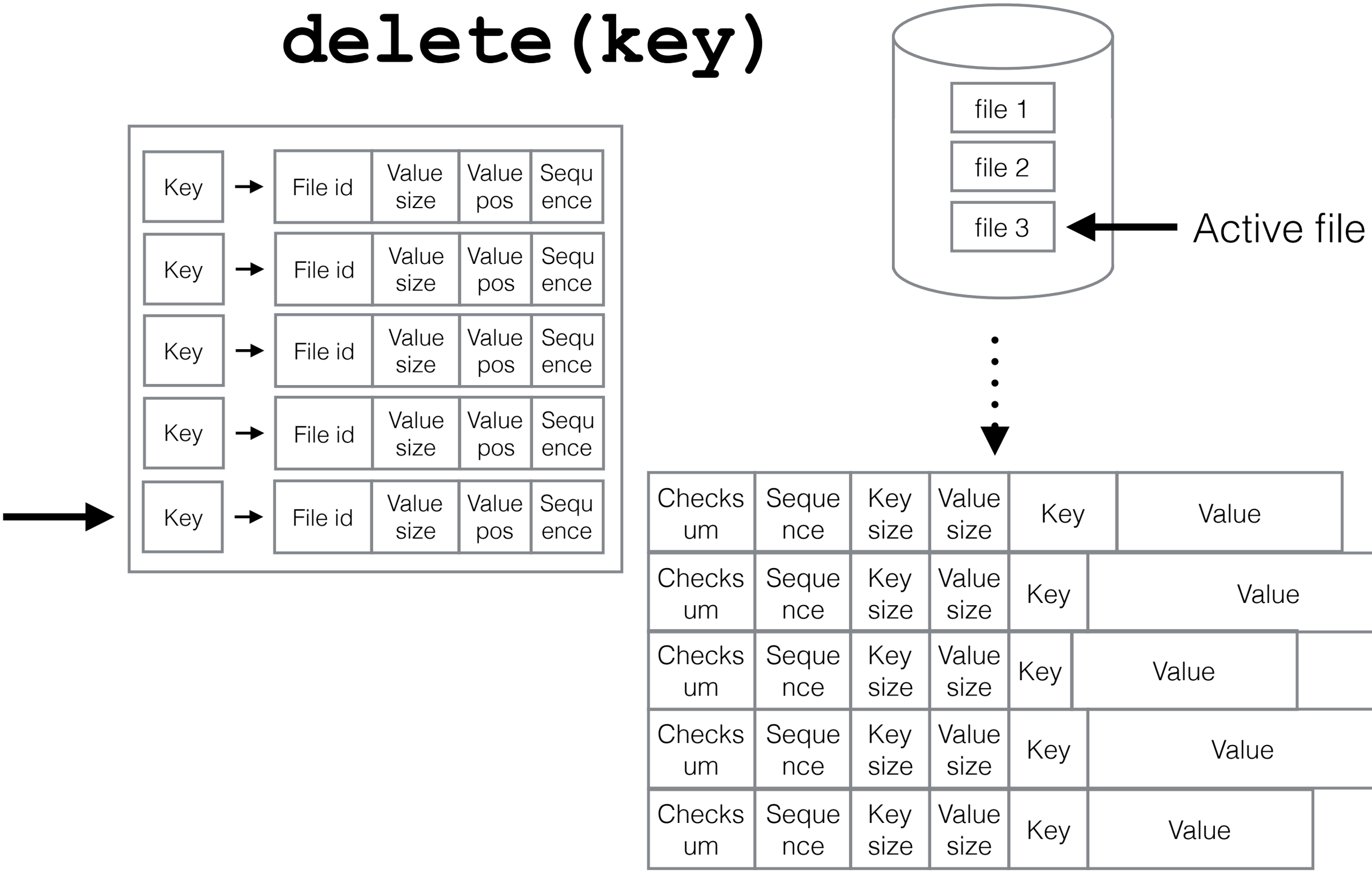
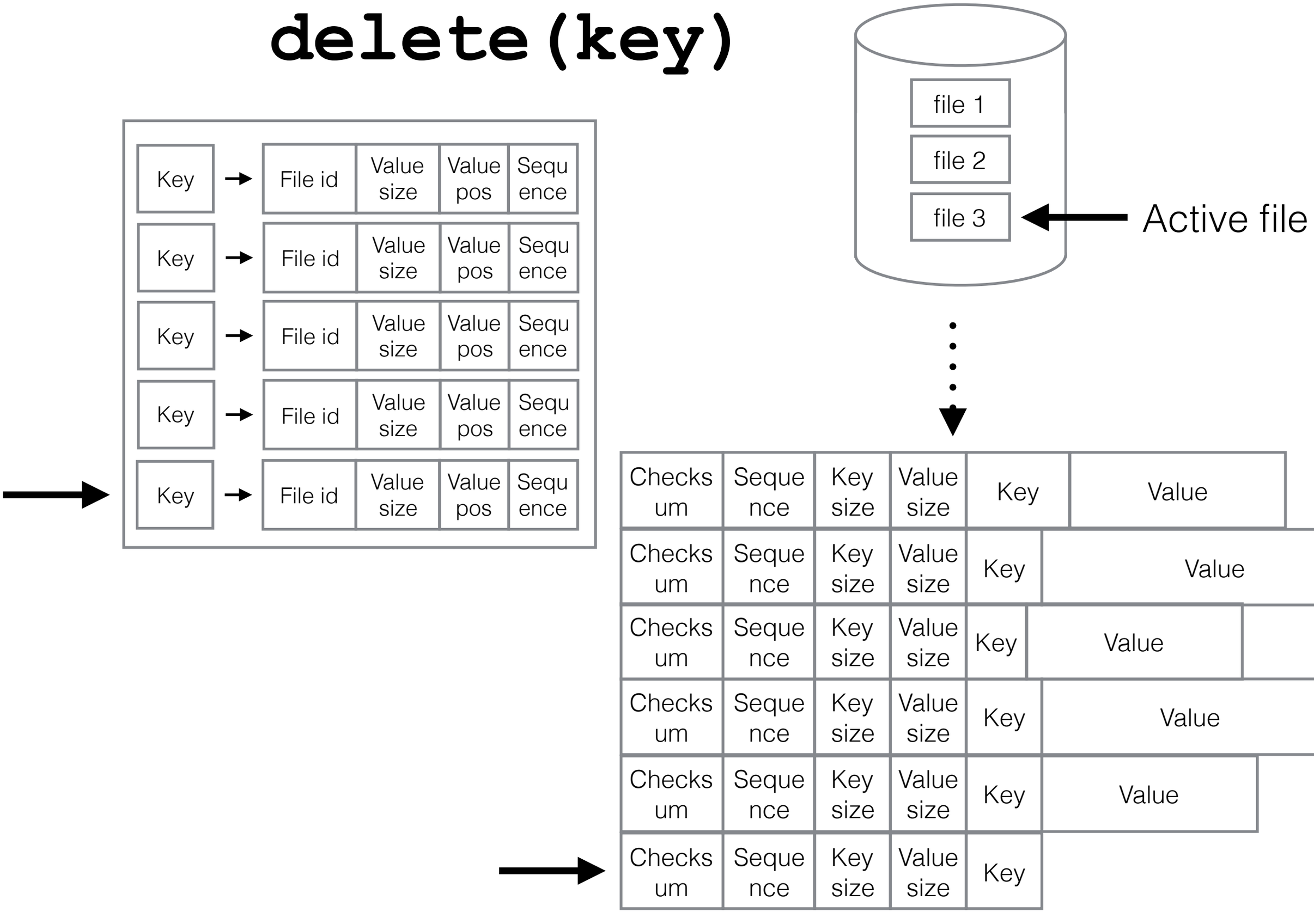

Key
File id
Value size
Value pos
Sequence
file 1
file 2
file 3
Active file
Checksum
Sequence
Key size
Value size
Key
Value

delete(key)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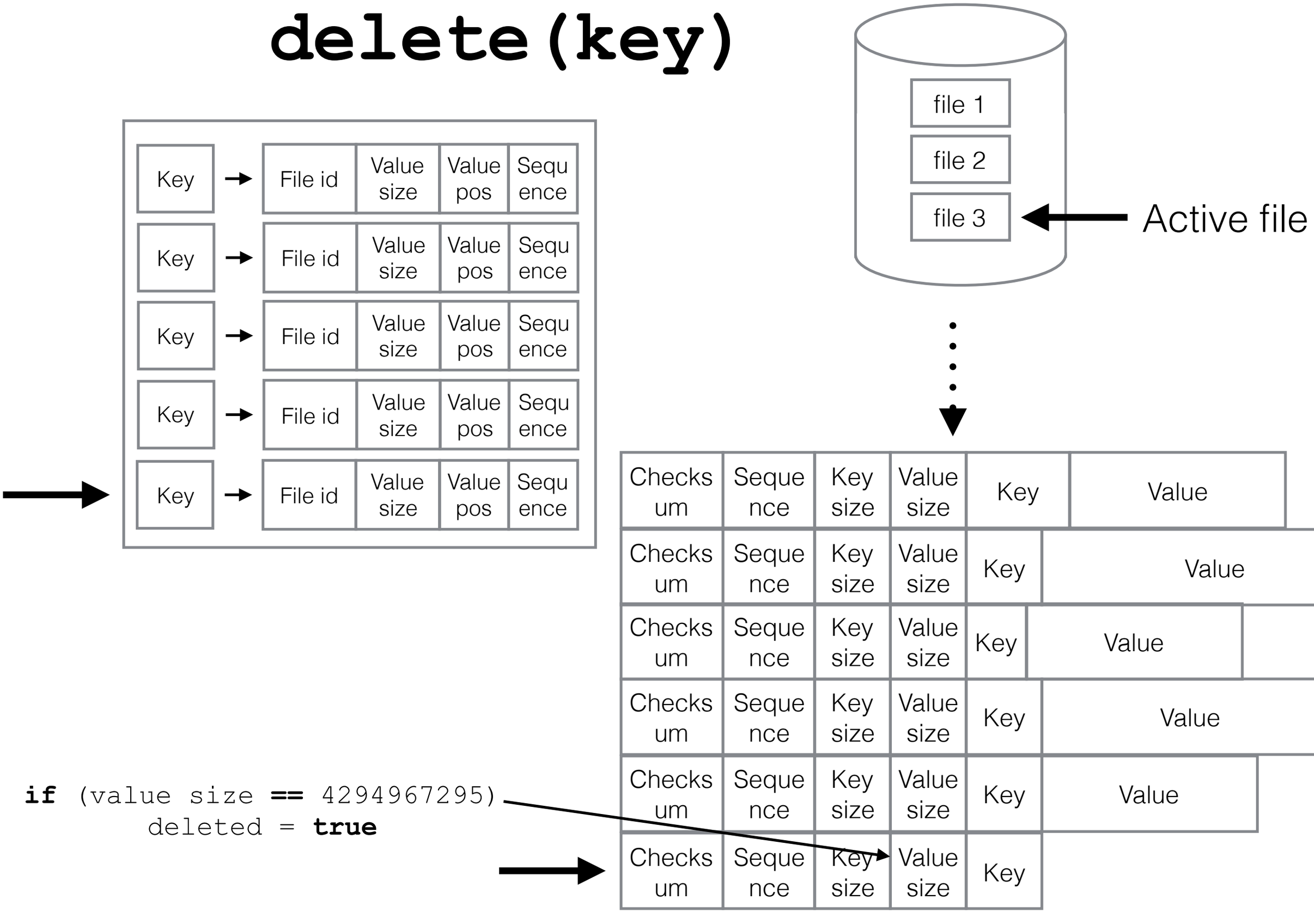
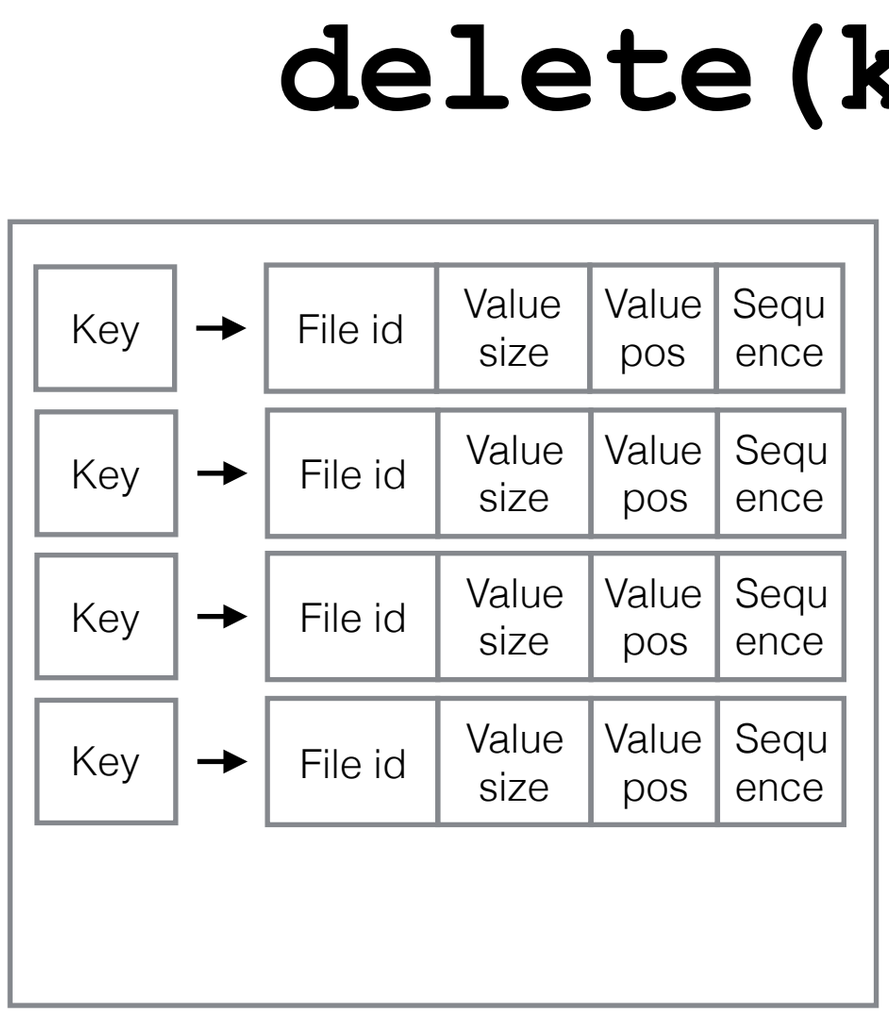
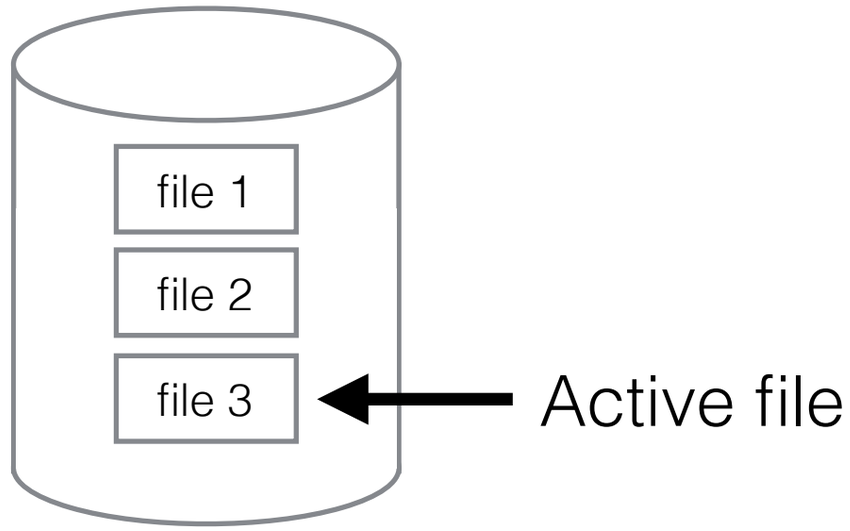
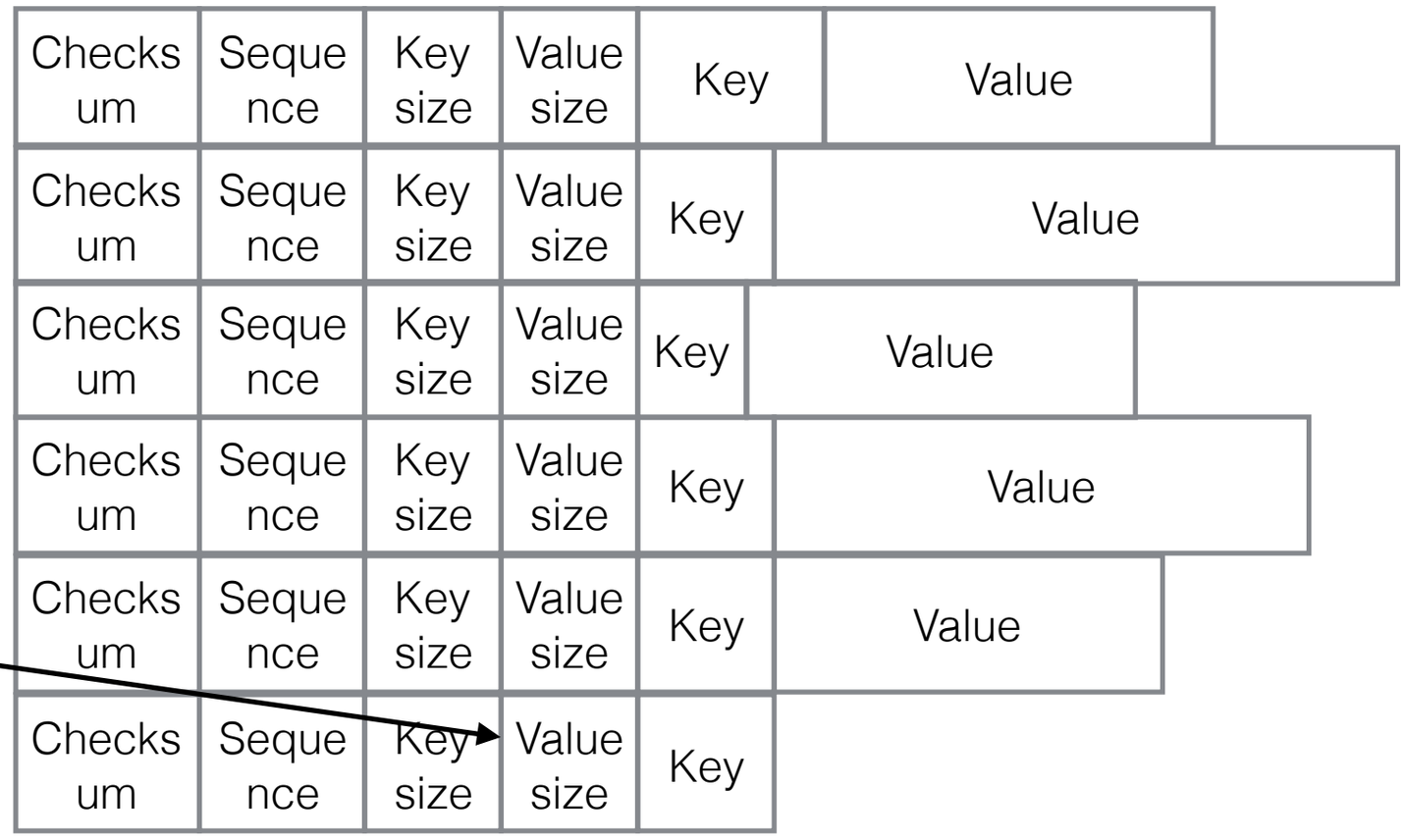

Key
File id
Value size
Value pos
Sequence
file 1
file 2
file 3
Active file
Checksum
Sequence
Key size
Value size
Key
Value
if (value size == 4294967295)
deleted = true

delete(key)








```
if (value size == 4294967295)
        deleted = true
```

Analysis

- Predictable
    - At most one disk seek for reads
    - No seeking for writes
- OS's filesystem read-ahead cache friendly
- Append-only is crash friendly

Startup

Startup

- What happens when we open the key-value store again?

Startup

- What happens when we open the key-value store again?
    - Must read the complete log to recreate index

Startup

```
for file in data_files {
  for entry in file {
    let index_entry = index.get(entry.key)
    if (!index_entry && !entry.deleted)
      index.insert(entry)
    else if (index_entry.sequence <= entry.sequence) {
      if (entry.deleted) index.delete(entry.key)
      else index.insert(entry)
    }
  }
}
```

Except it will fill all your disks

Garbage collection

- We need to **delete dead entries** from the log

Garbage collection

- We need to **delete dead entries** from the log

"hello"	"world"
"foo"	"bar"
"hello"	"baz"
"key"	"value"
delete	"key"

(simplified log)

Garbage collection

- We need to **delete dead entries** from the log

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← dead

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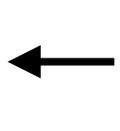
dead


dead

(simplified log)

Garbage collection

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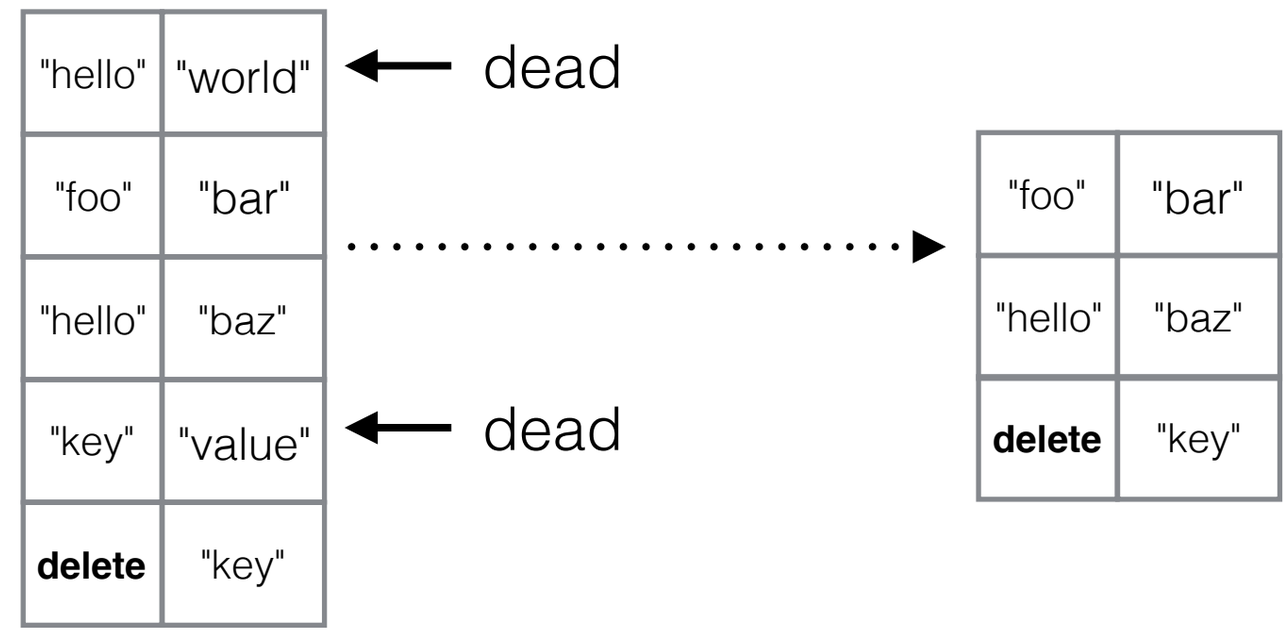

(simplified log)

Garbage collection

```
let deletes = HashMap::new()
for entry in file {
  let index_entry = index.get(entry.key)
  if (index_entry && index_entry.sequence == entry.sequence) {
    log.write(entry)
  }
  else if (!index_entry && entry.deleted) {
    let delete = deletes.get(entry.key)
    if (!delete || delete < entry.sequence)
      deletes.insert(entry.key, entry.sequence)
  }
}

for (key, sequence) in deletes {
  log.write(Entry::deleted(sequence, key))
}
```

Garbage collection

```
let deletes = HashMap::new()
for entry in file {
  let index_entry = index.get(entry.key)
  if (index_entry && index_entry.sequence == entry.sequence) {
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  else if (!index_entry && entry.deleted) {
    let delete = deletes.get(entry.key)
    if (!delete || delete < entry.sequence)
      deletes.insert(entry.key, entry.sequence)
  }
}

for (key, sequence) in deletes {
  log.write(Entry::deleted(sequence, key))
}
```

Garbage collection

- Background thread
- Creates a new file with only "live" entries
- Updates all the entries in the index to point to the new file
- Delete the old file

Where is the garbage?

- Keep statistics for the amount of "garbage" in each file
  - Dead entries
  - Dead bytes
  - Fragmentation
    - `dead_entries / total_entries`

All the keys must be in-memory

What's the index size?

- Overhead per key: ~ 40 bytes
- Lets assume keys are UUID strings: 32 bytes
- Given 4GB of memory we can store
  - ~ 55 million keys

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We can do better

- If keys are **"hierarchical"**
  - DNS names
  - IP addresses
- Use a **radix trie** for the **index**

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- If keys are **"hierarchical"**
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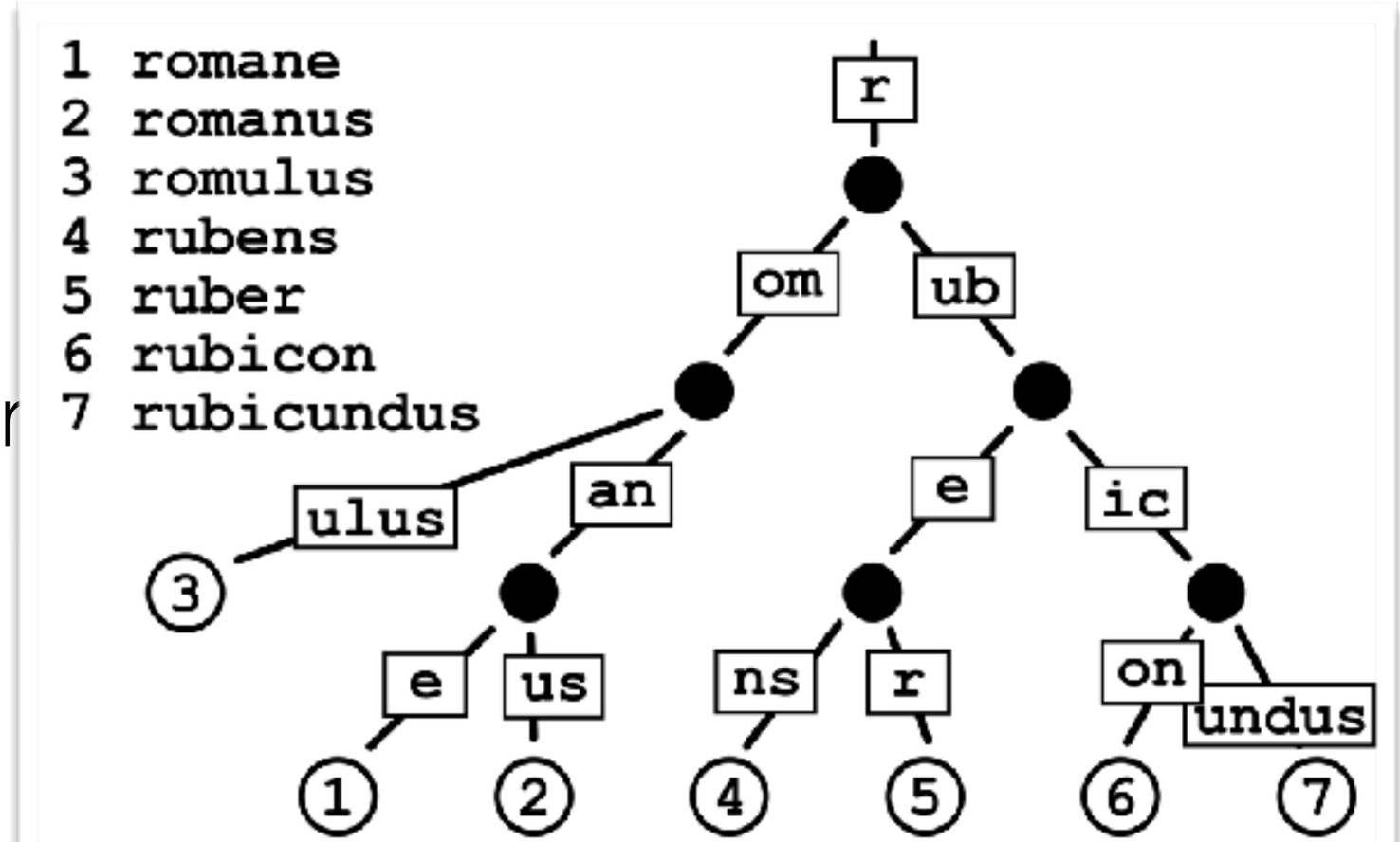
  - IP addresses
- Use a **radix trie** for



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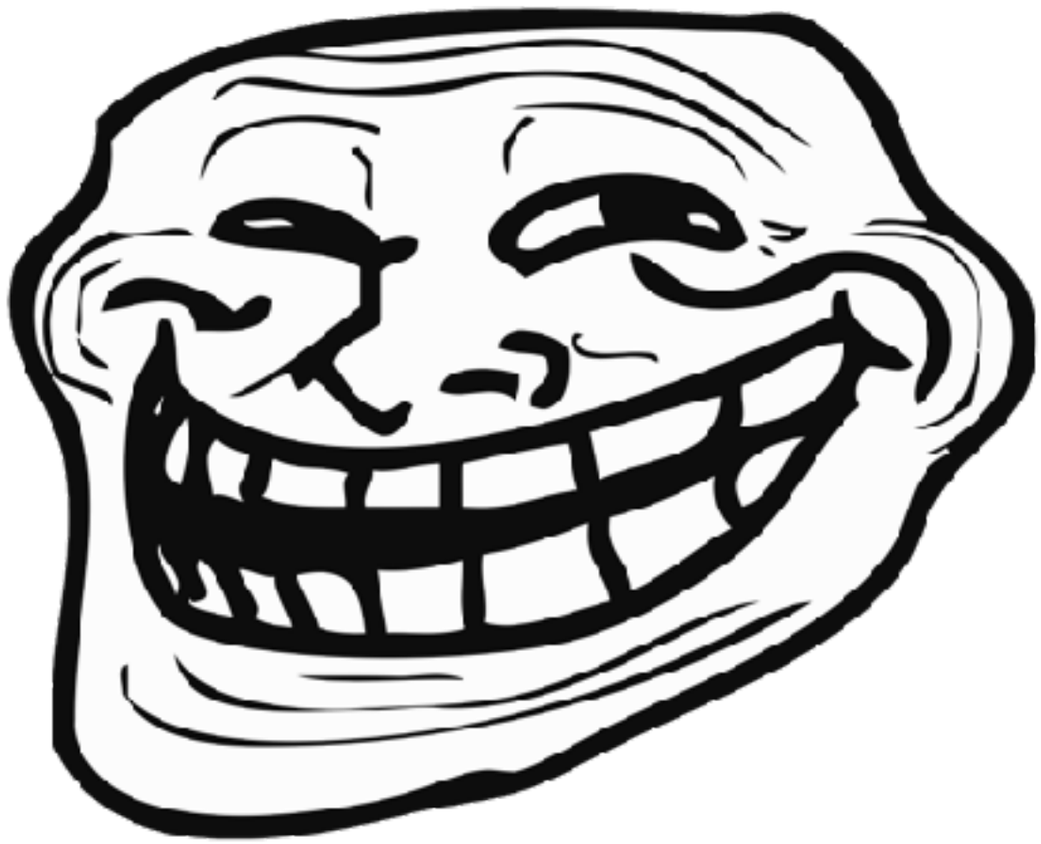

Just kidding

Demo time

Going further

- Multiple logs to increase write throughput
- Parallel garbage collection
- Ordering
  - Log-structured merge-tree (LevelDB)

References

- https://github.com/andrebeat/cask
  - **Rust** implementation
- https://github.com/basho/bitcask
  - Original implementation in **C** and **Erlang**
- http://basho.com/wp-content/uploads/2015/05/bitcask-intro.pdf

Questions?

Speedup startup