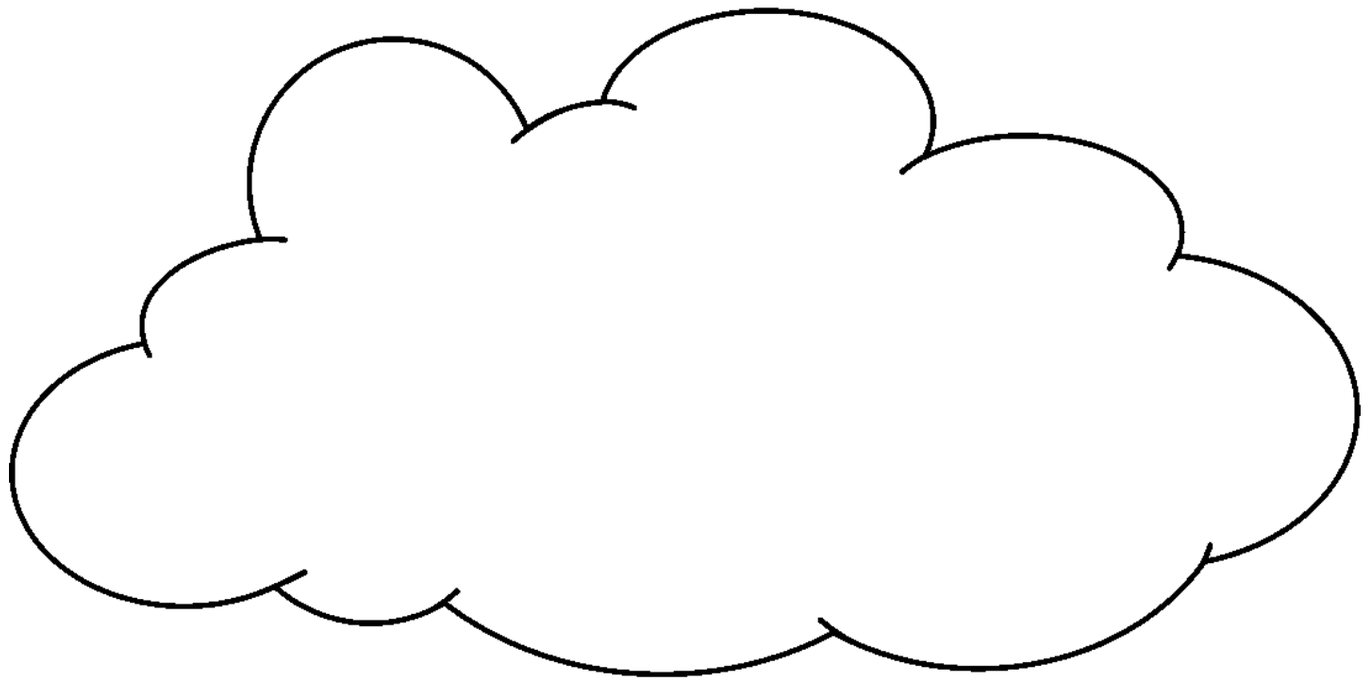
MiniCrypt: Reconciling Compression and Encryption in Big Data Stores

Wenting Zheng, Frank Li,
Raluca Ada Popa, Ion Stoica, Rachit Agarwal

A lot of sensitive data is collected

Sensitive data



client

cloud provider

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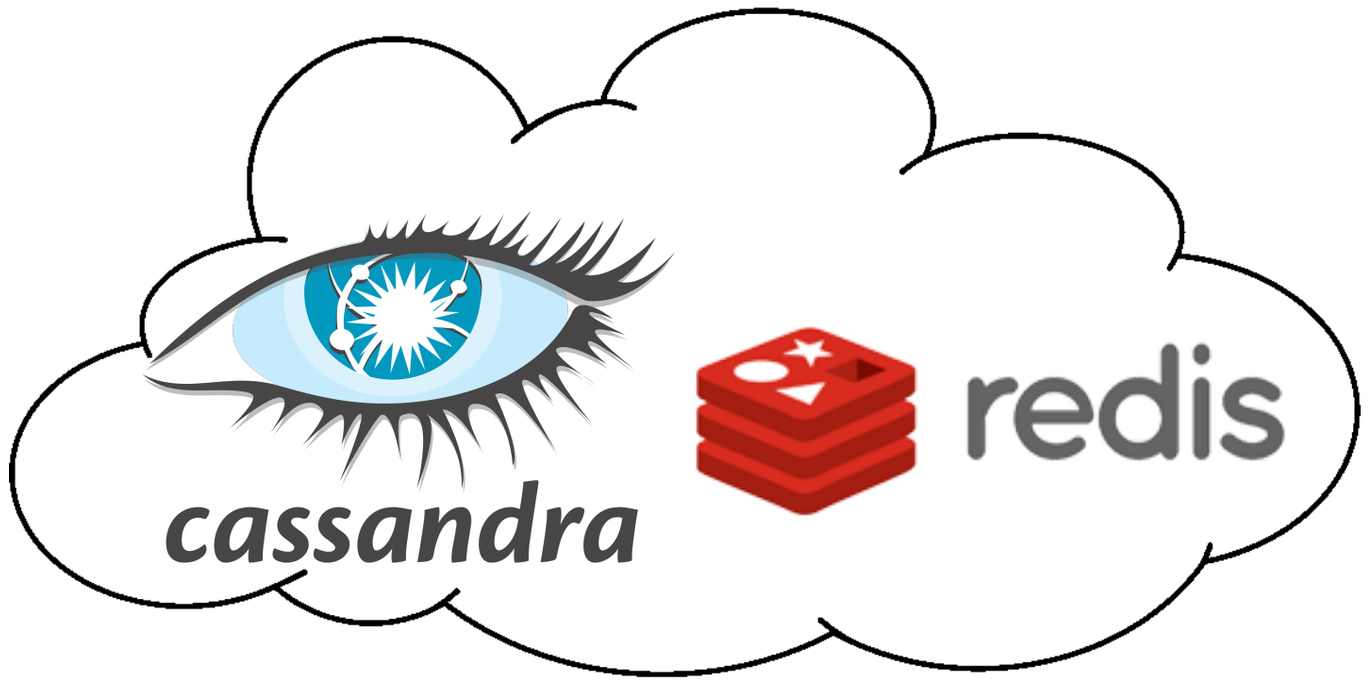

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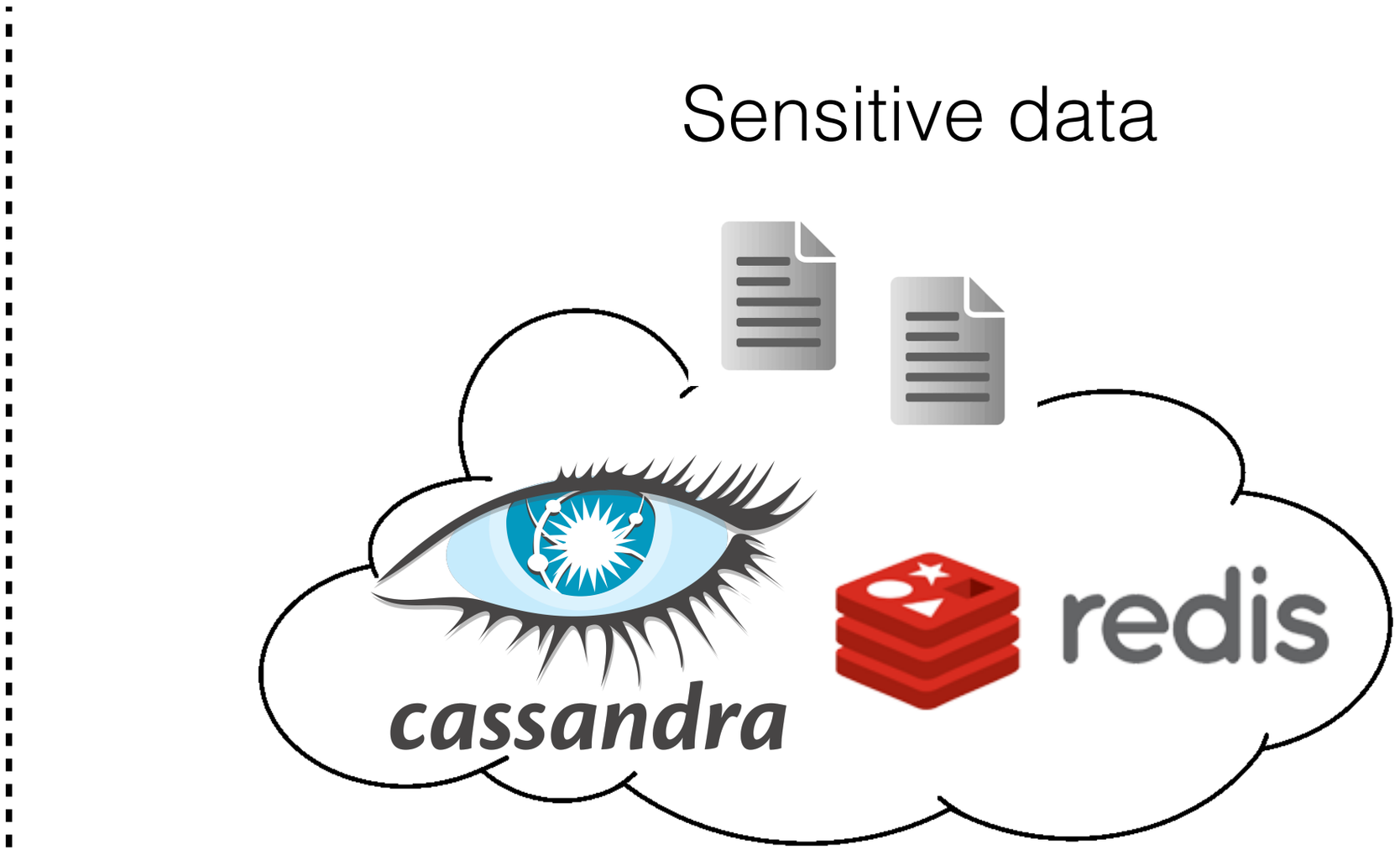

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Existing systems

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Systems	Compression	Encryption

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How to combine compression and encryption?

MiniCrypt

MiniCrypt

Provides *both compression and encryption* for key-value stores

MiniCrypt

Provides *both* *compression* *and* *encryption* for key-value stores

Works on top of *existing* key-value stores without modification

System setup

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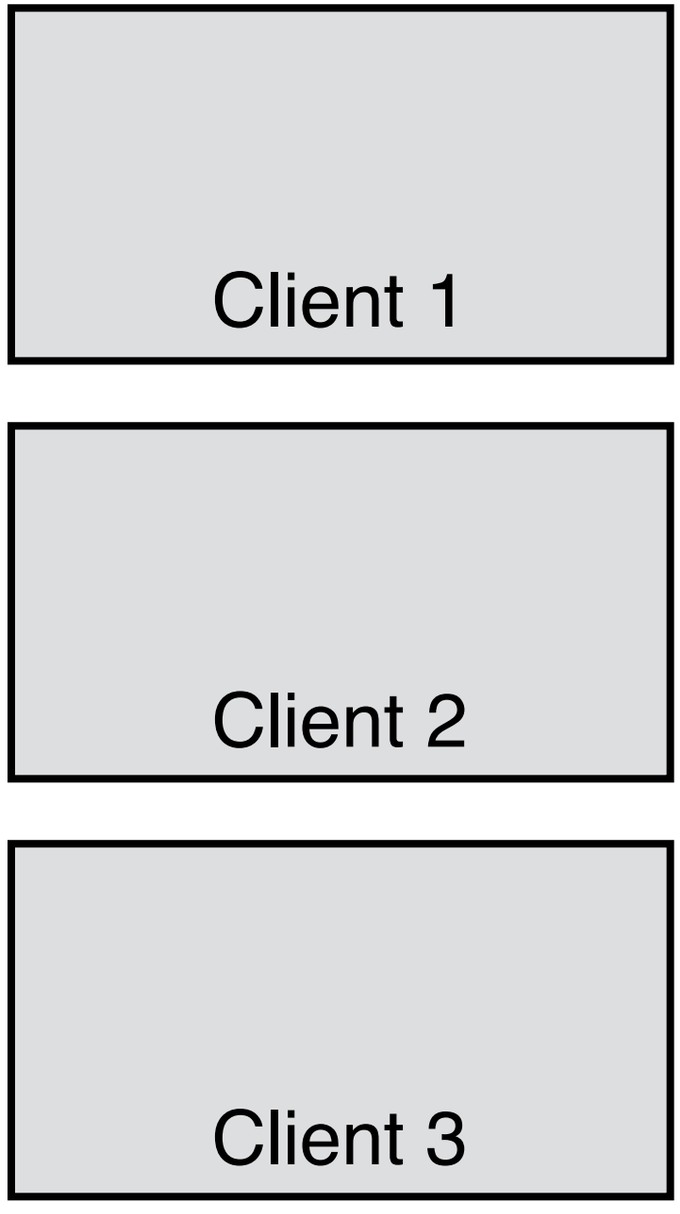

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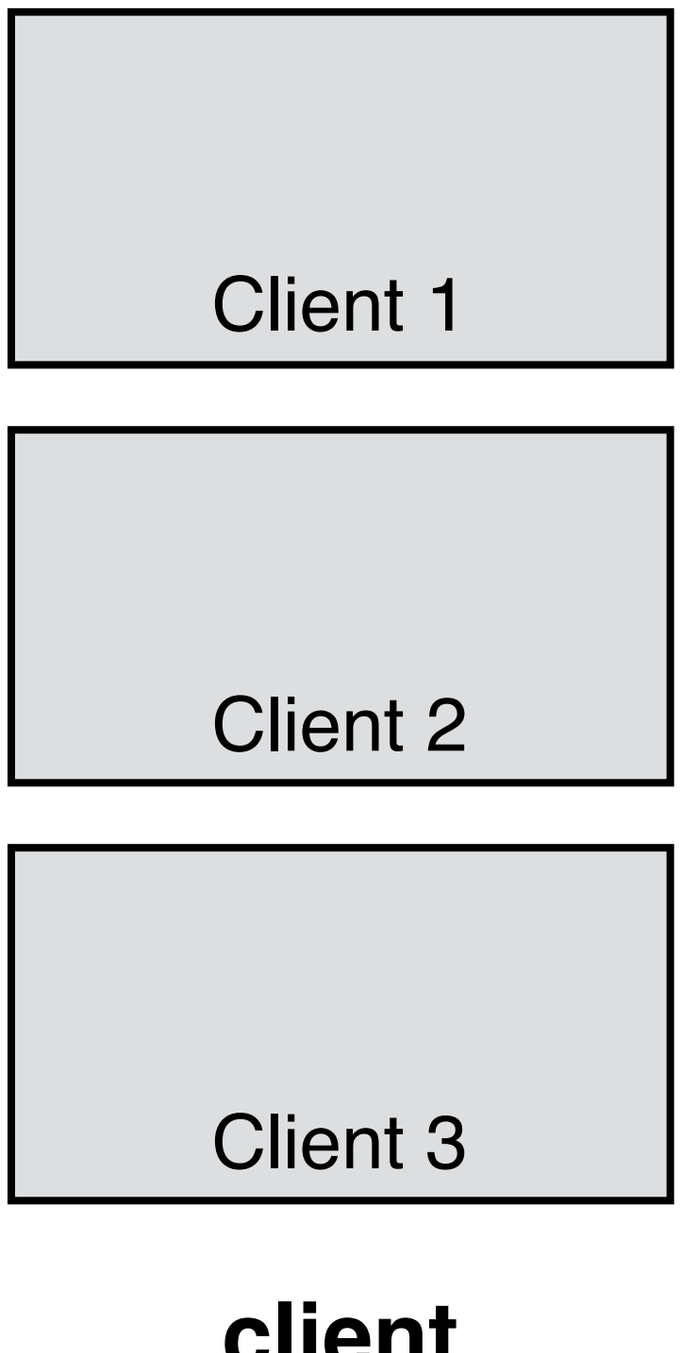

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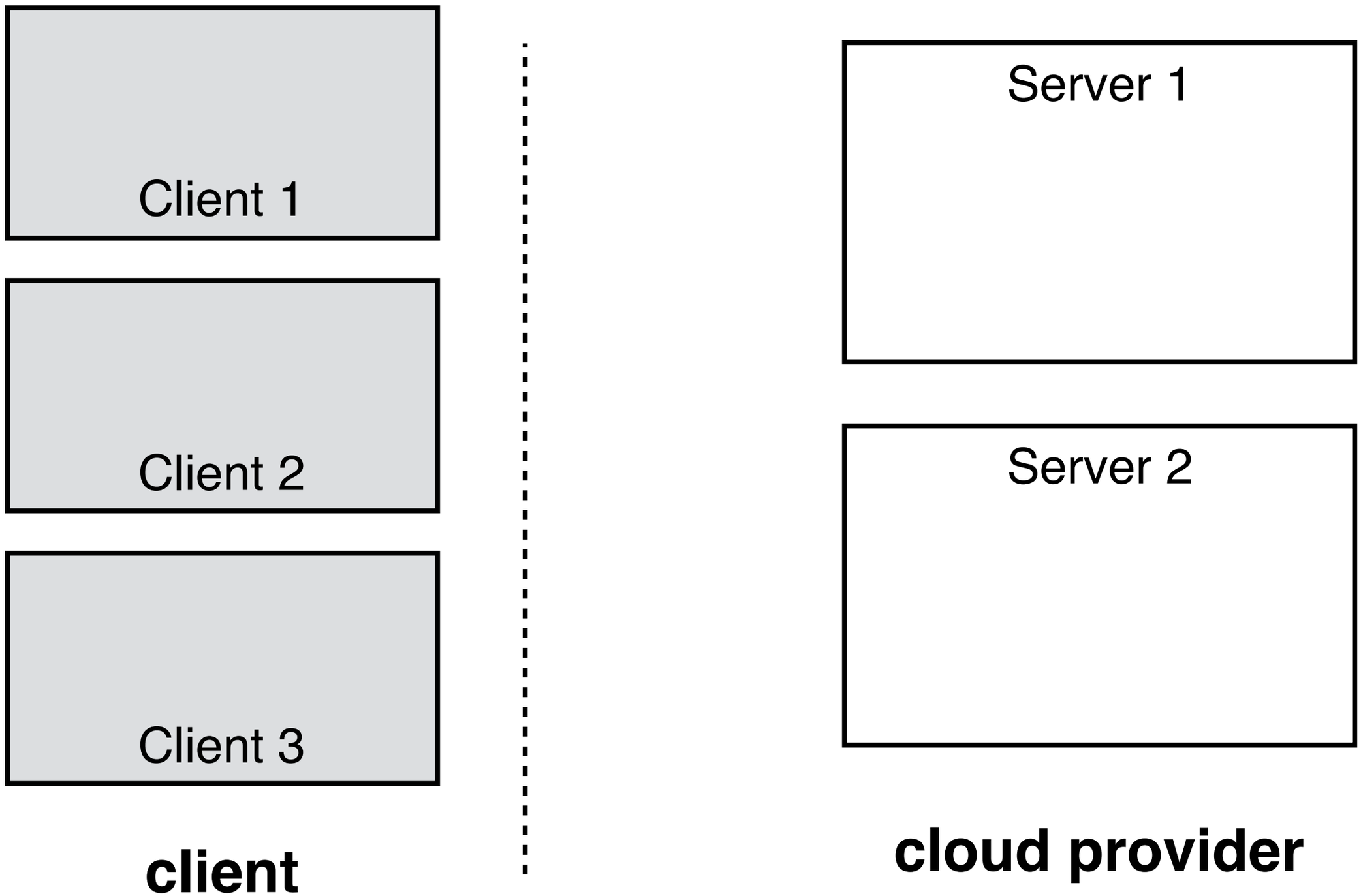

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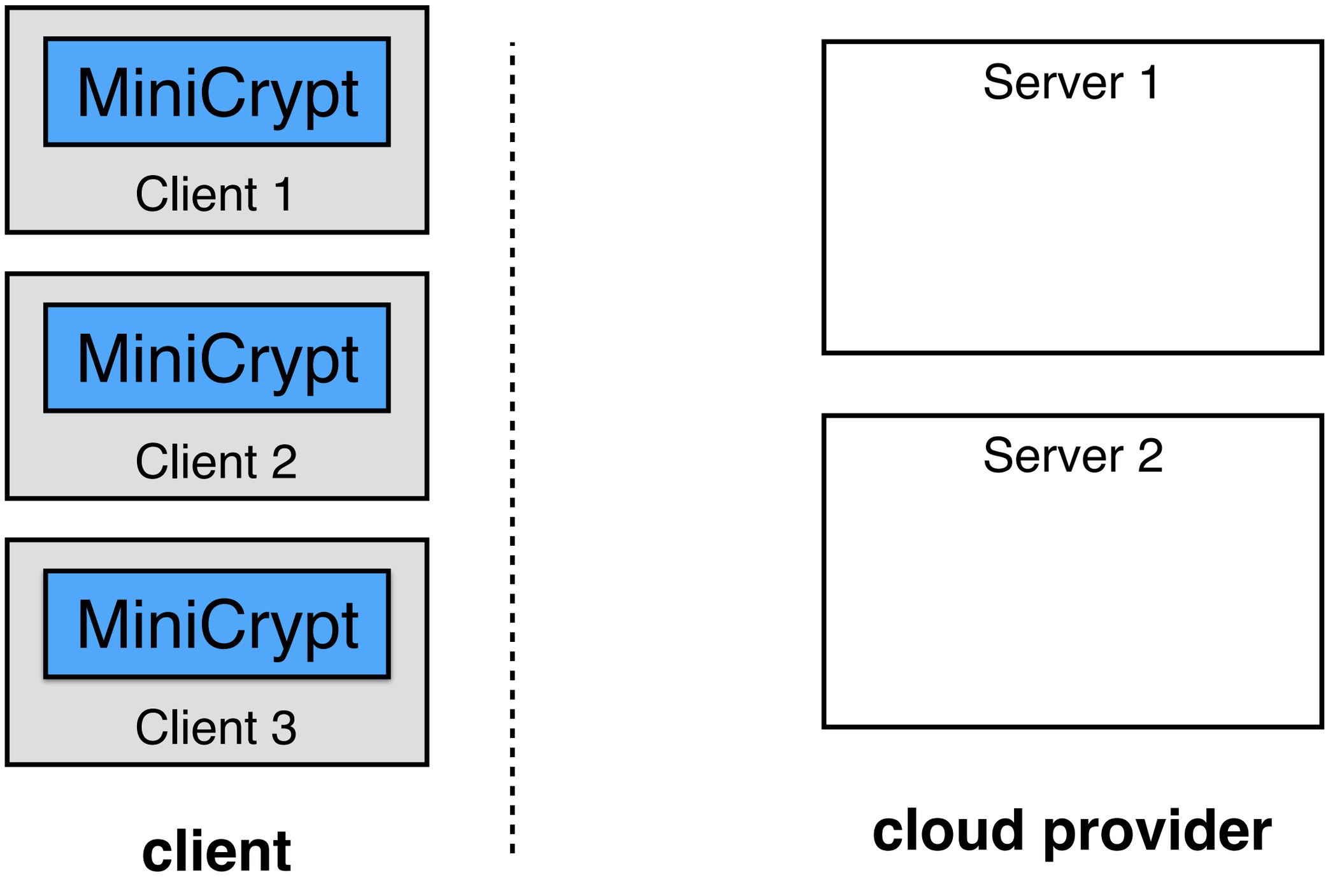

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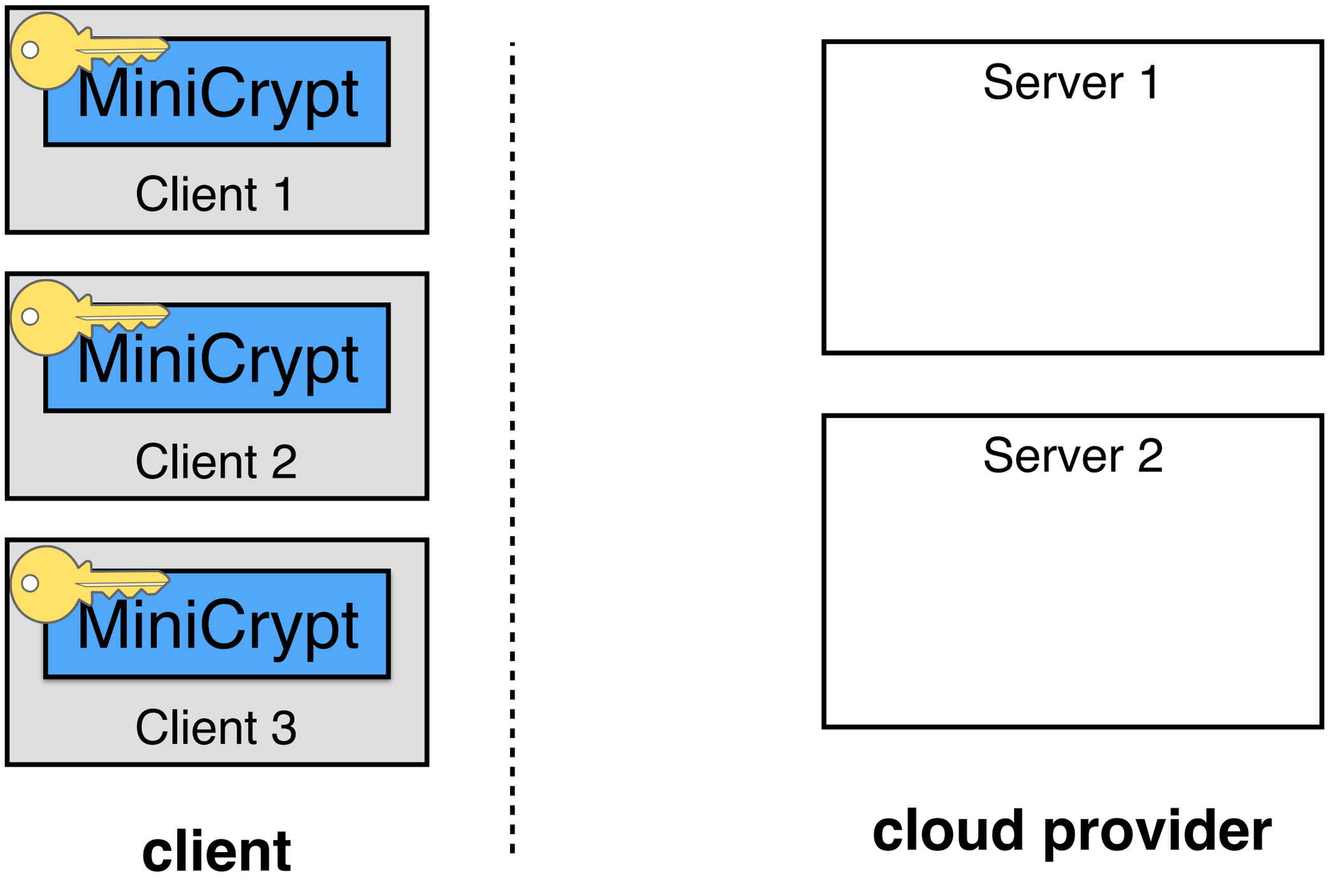

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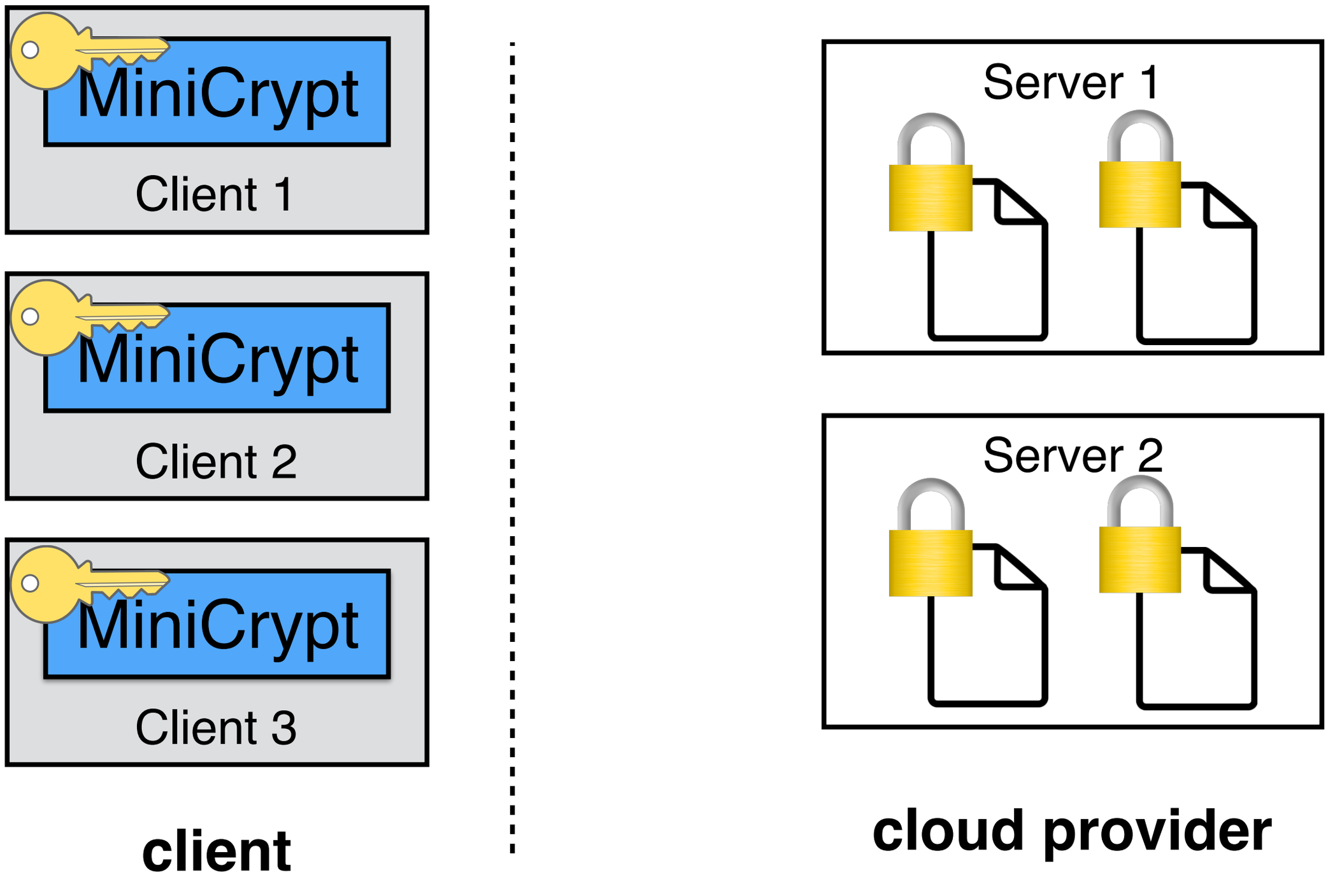
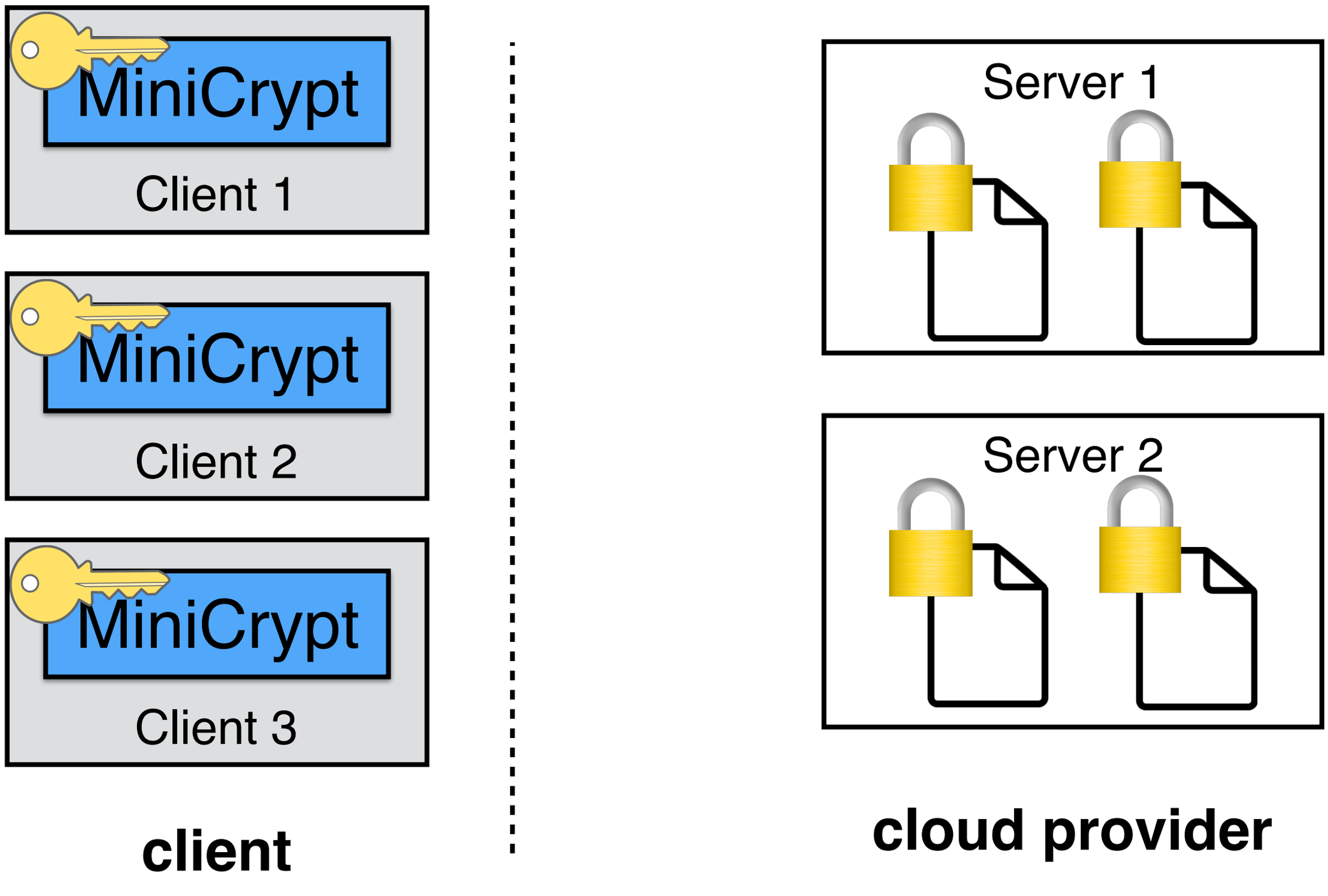


Threat model



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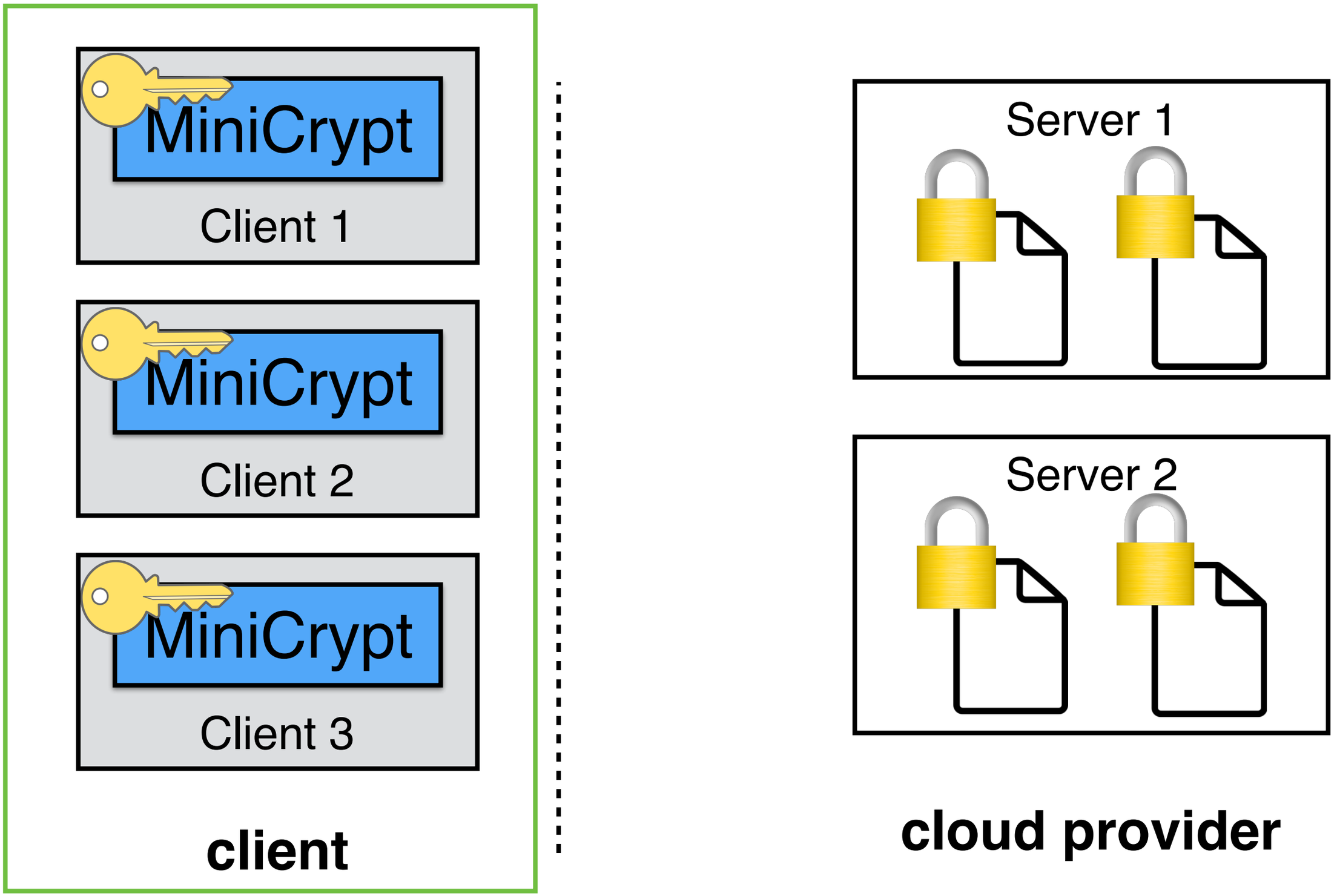

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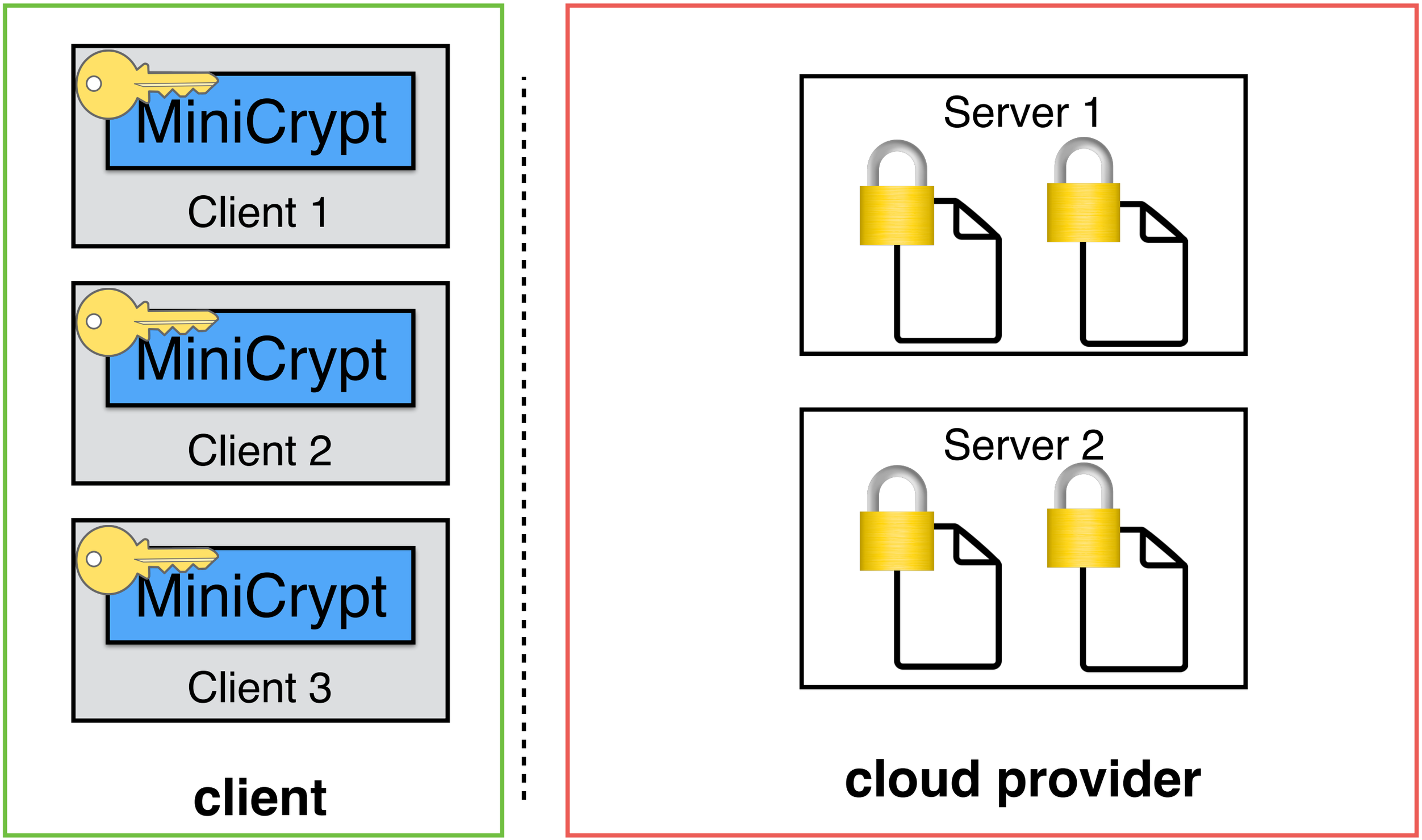

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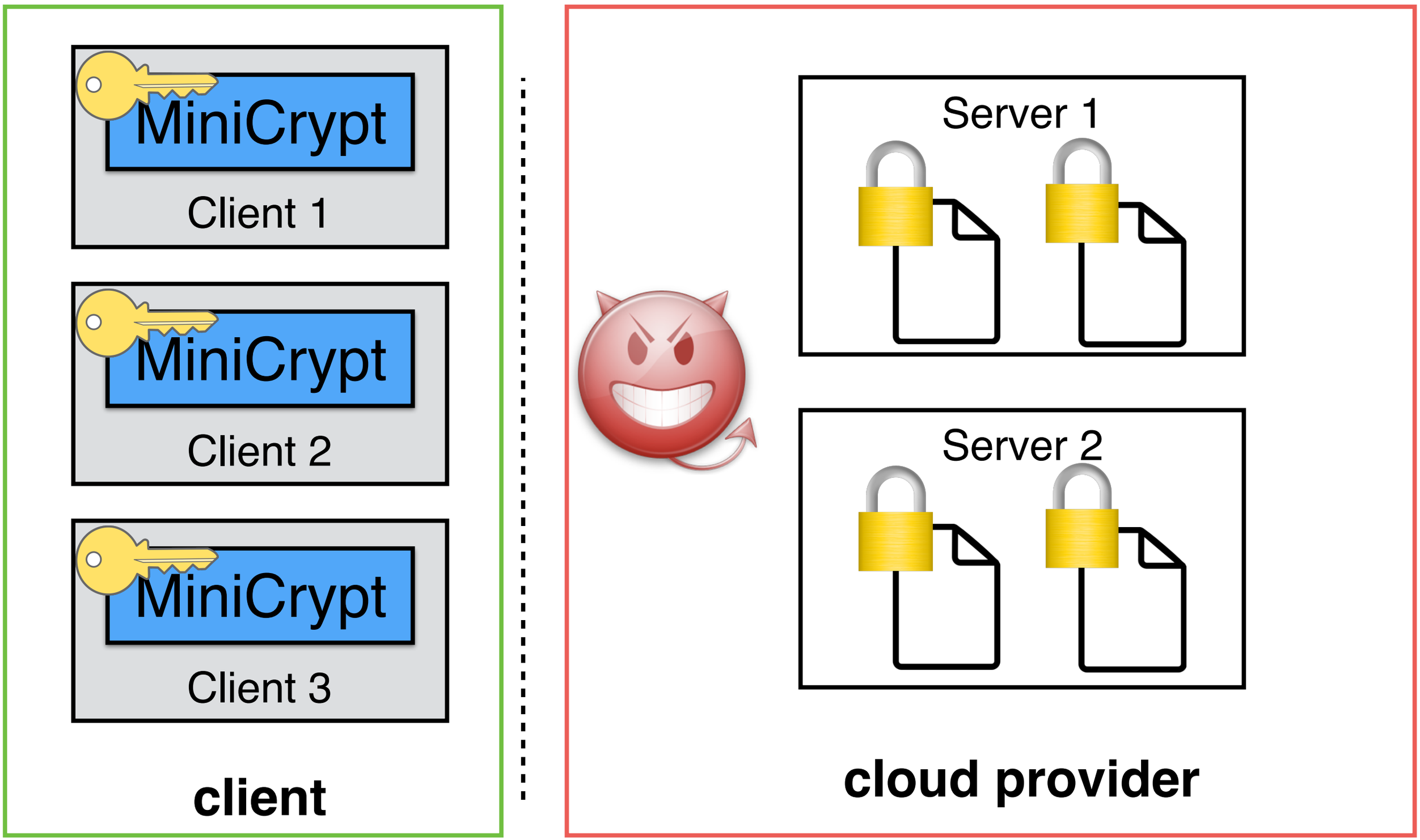

Encryption before compression?

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Ticking away the moments that make up a dull day
Fritter and waste the hours in an off-hand way
Kicking around on a piece of ground in your home town
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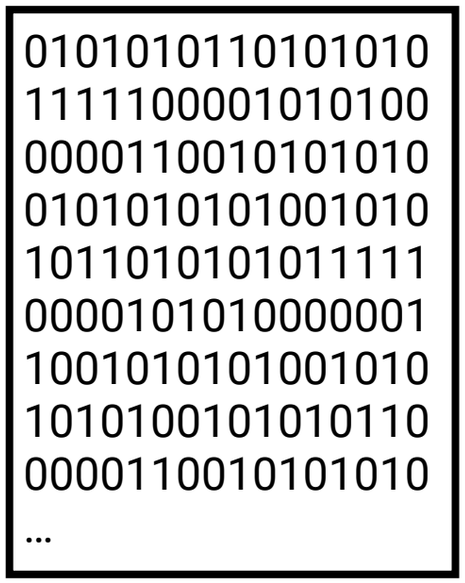

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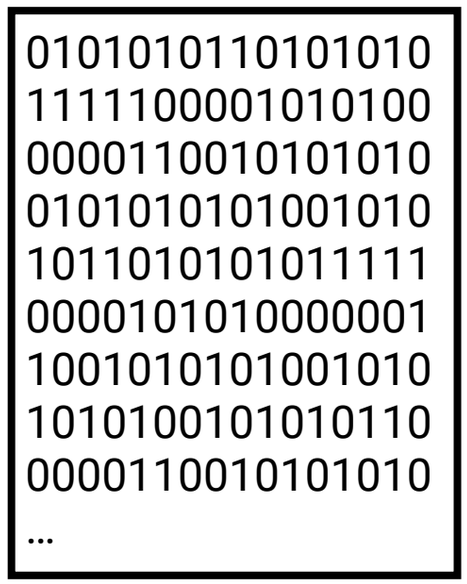

0101010110101010
1111100001010100
0000110010101010
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1011010101011111
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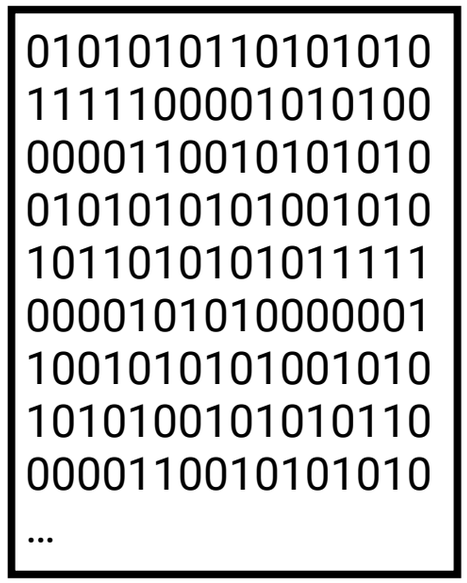

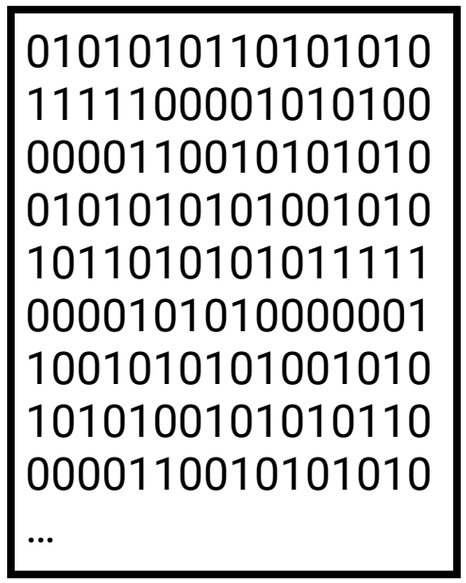

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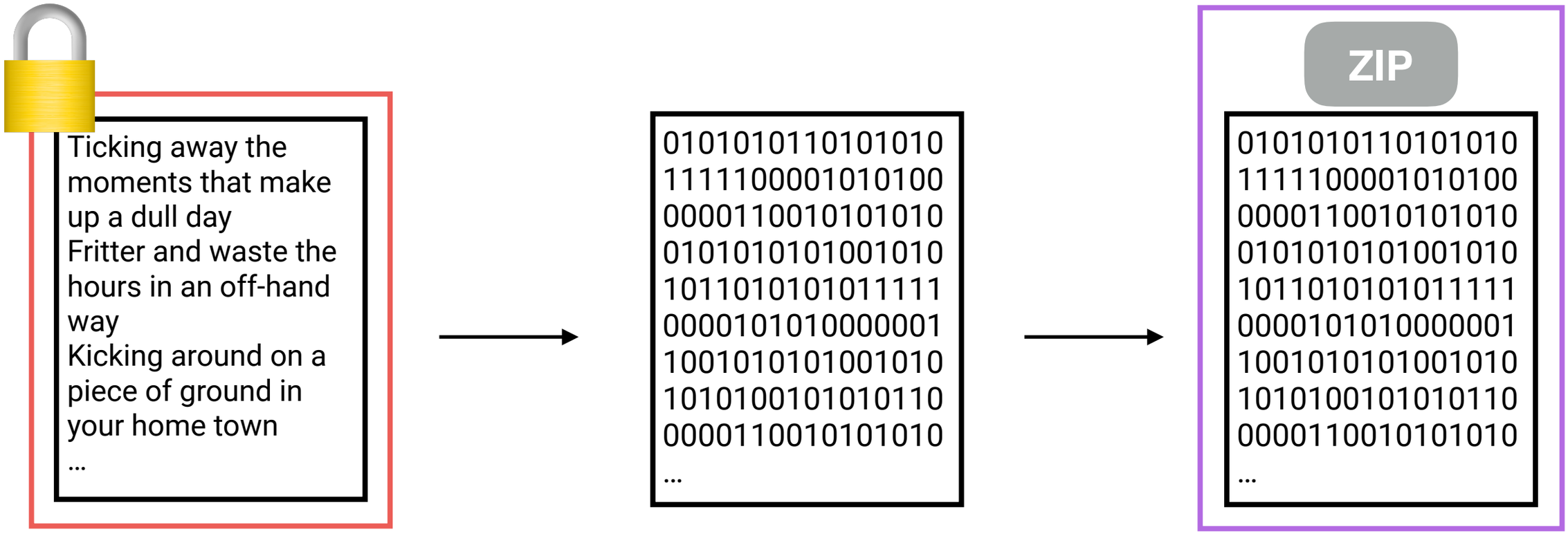

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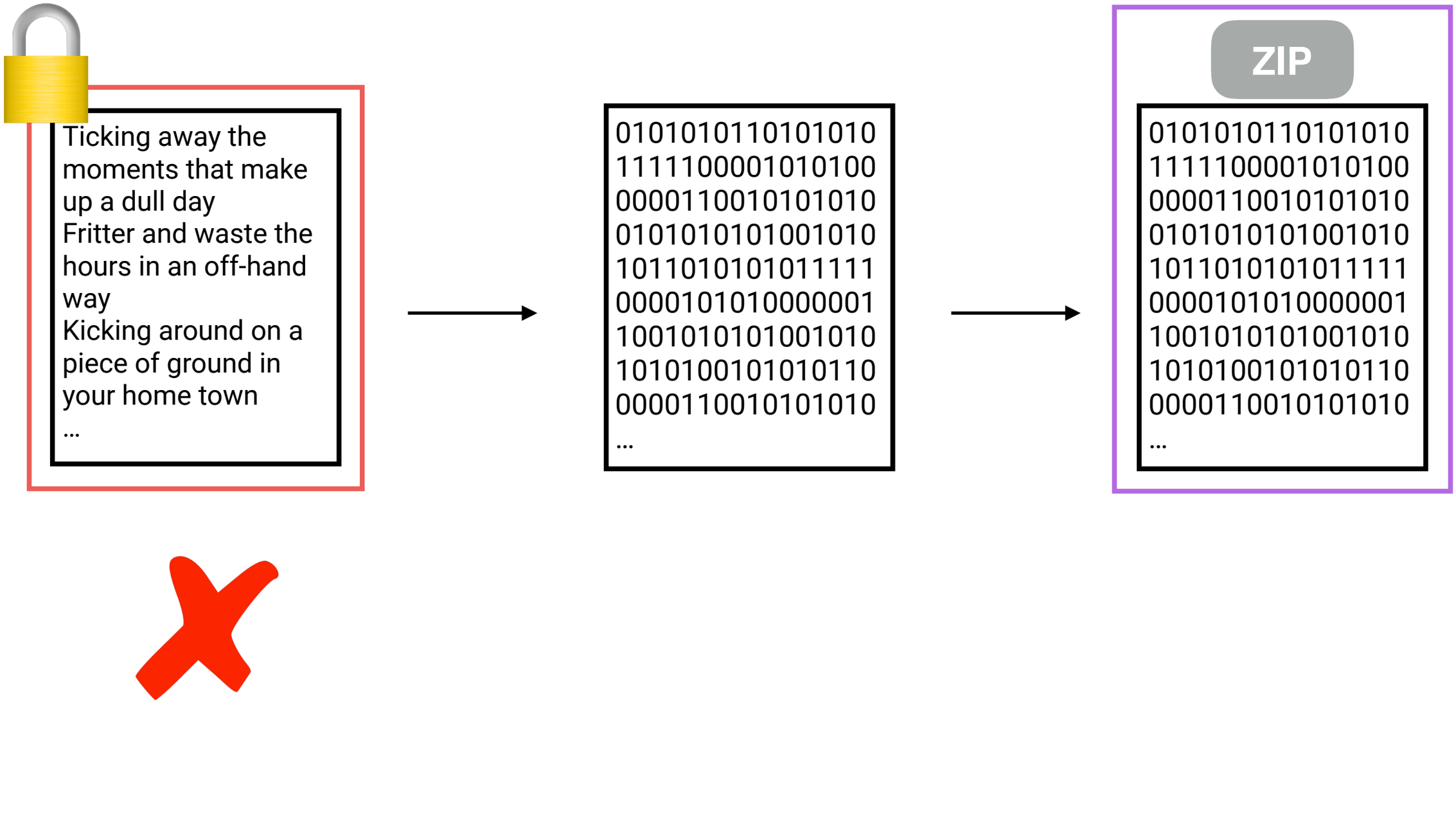

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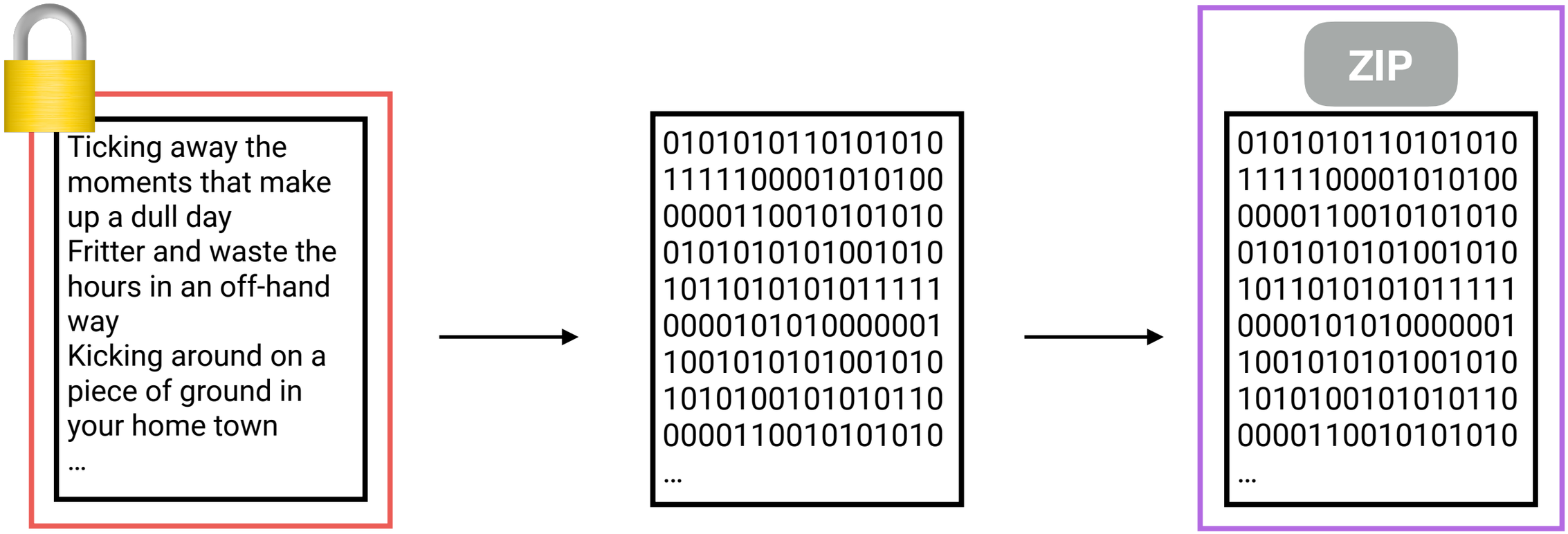

Pseudorandom data is not compressible

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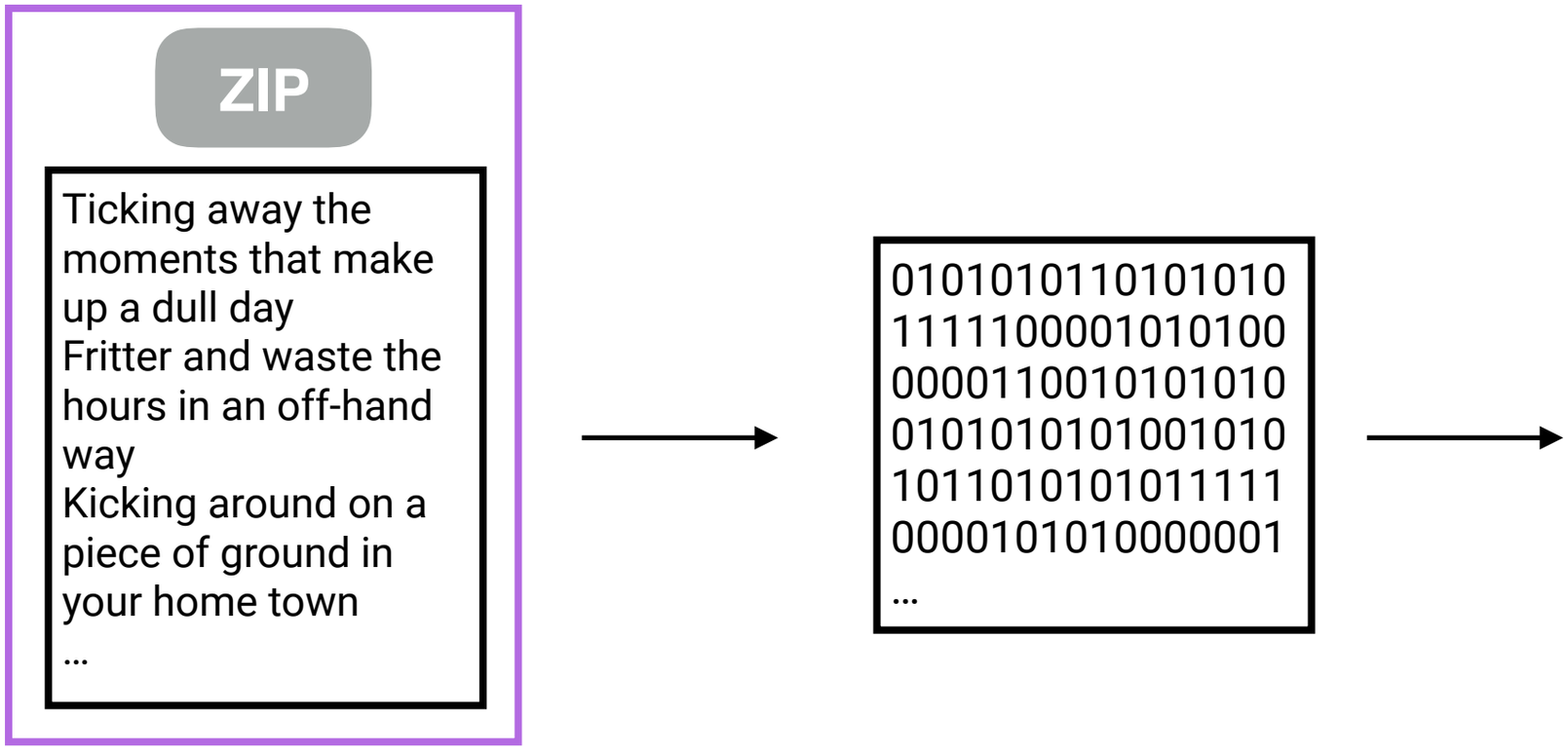

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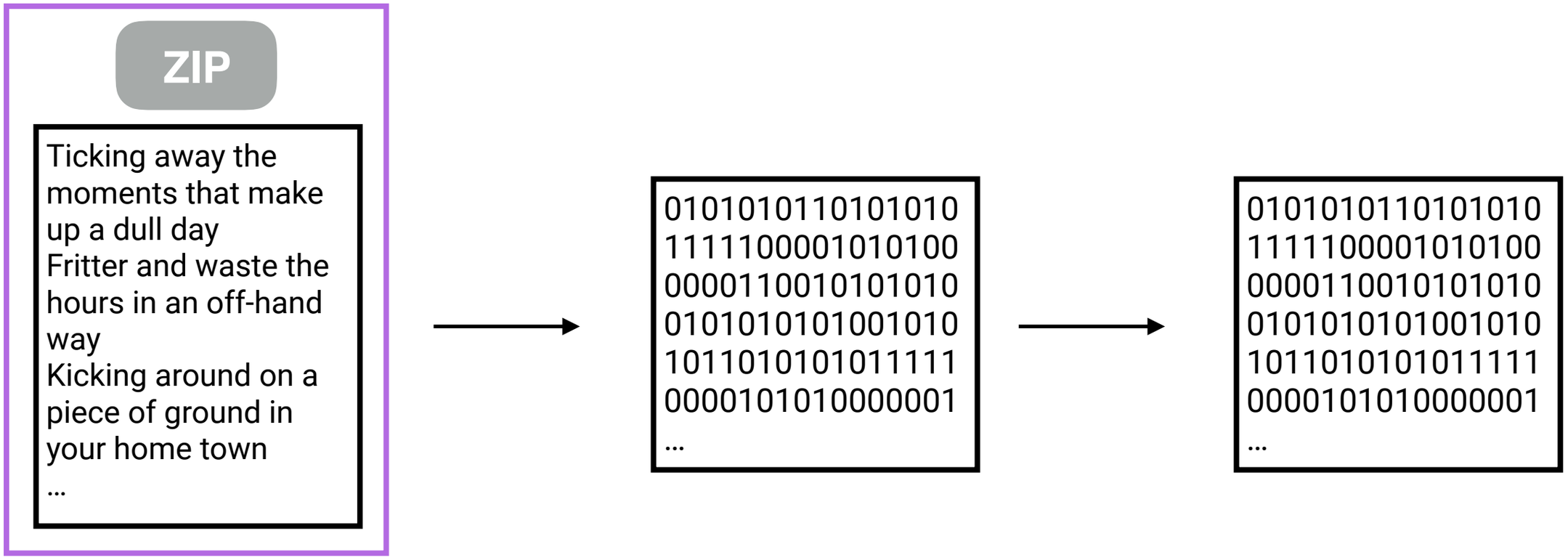

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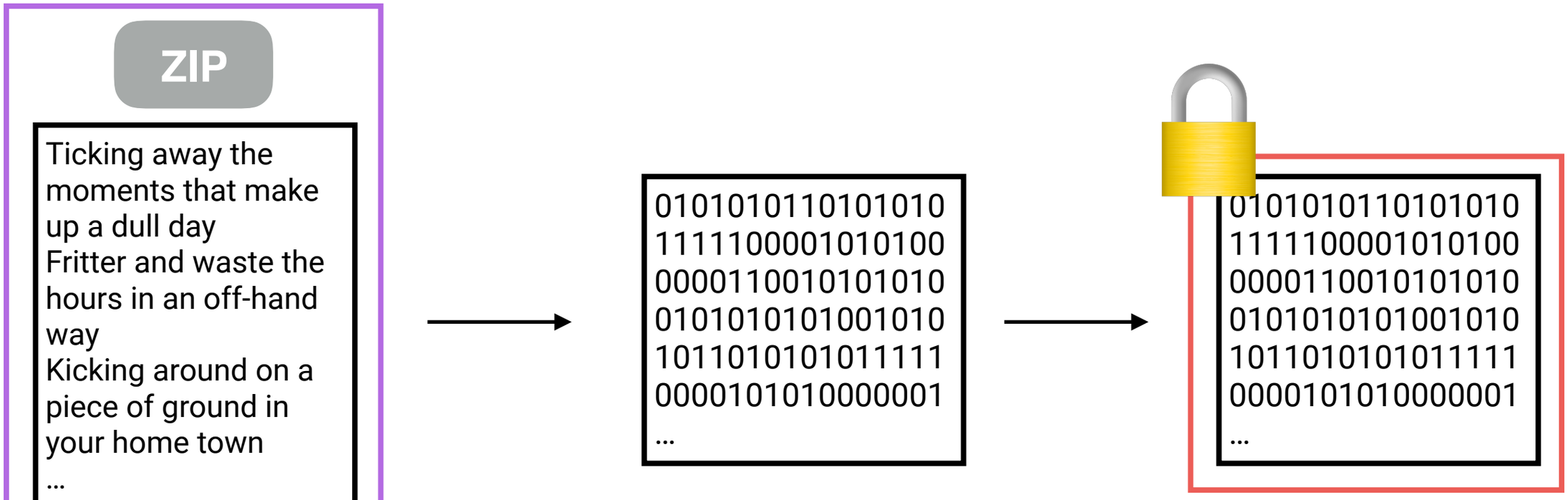

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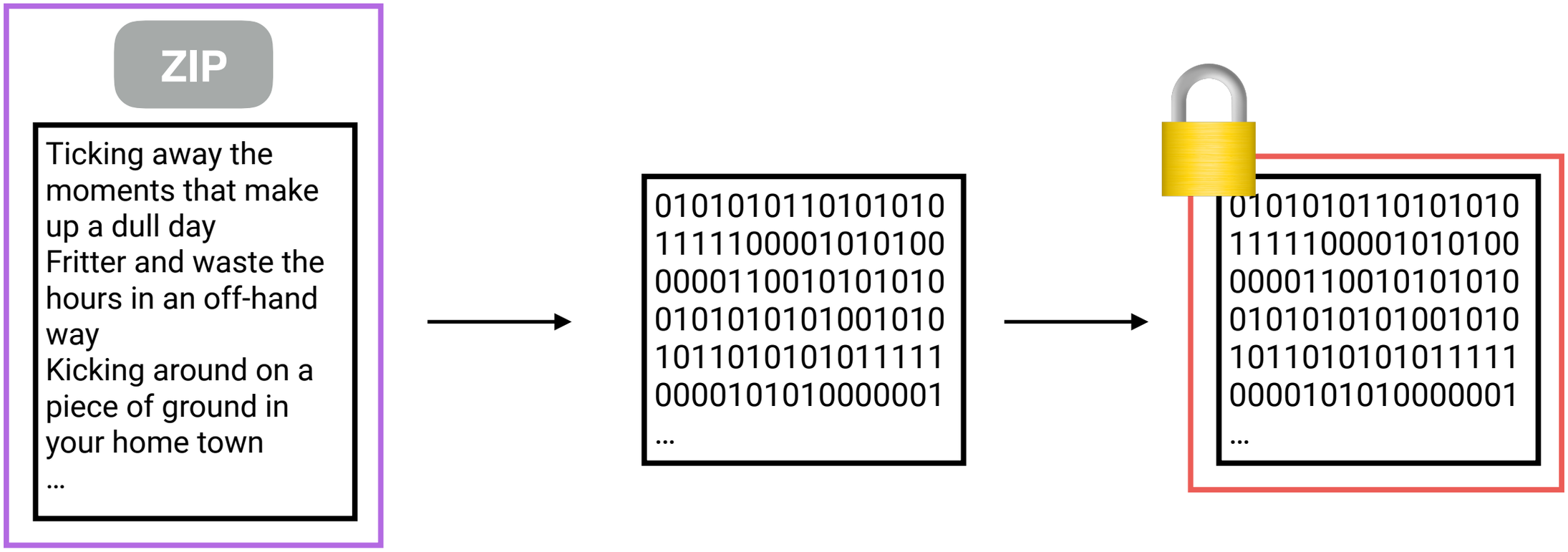

Compression and encryption

Strawman #1:
compress & encrypt entire database

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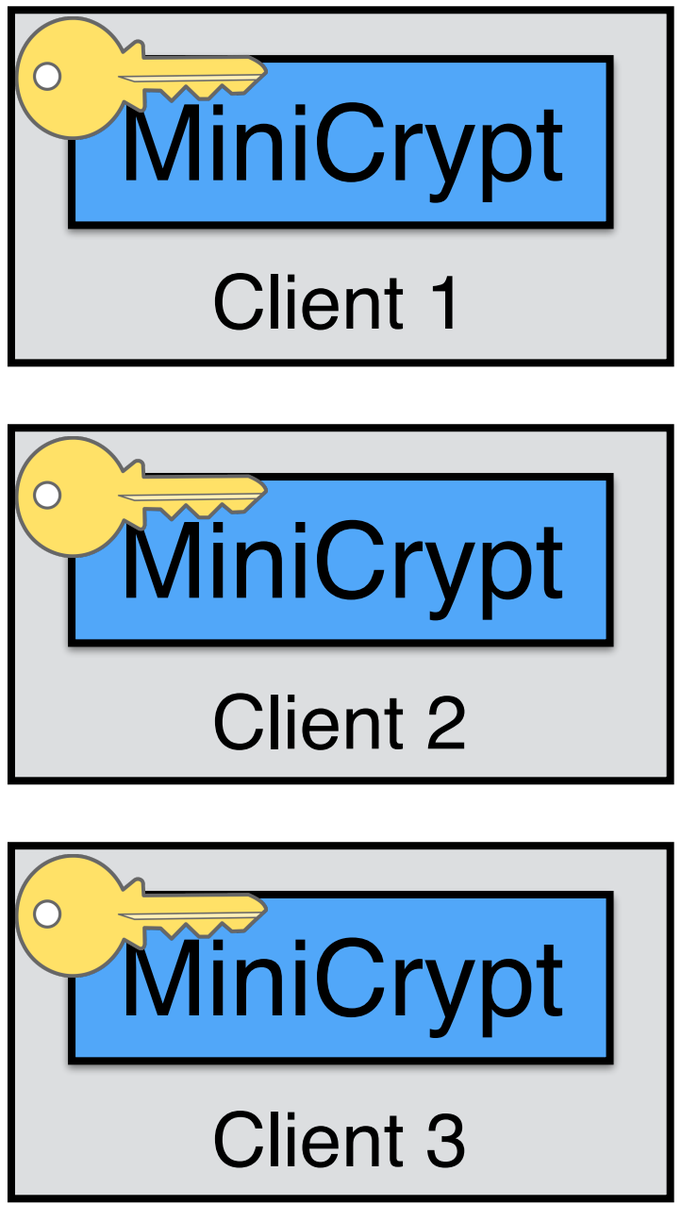

12809	Amanda D. Edwards	40	Diabetes
29489	Robert R. McGowan	56	Diabetes
13744	Kimberly R. Seay	51	Cancer
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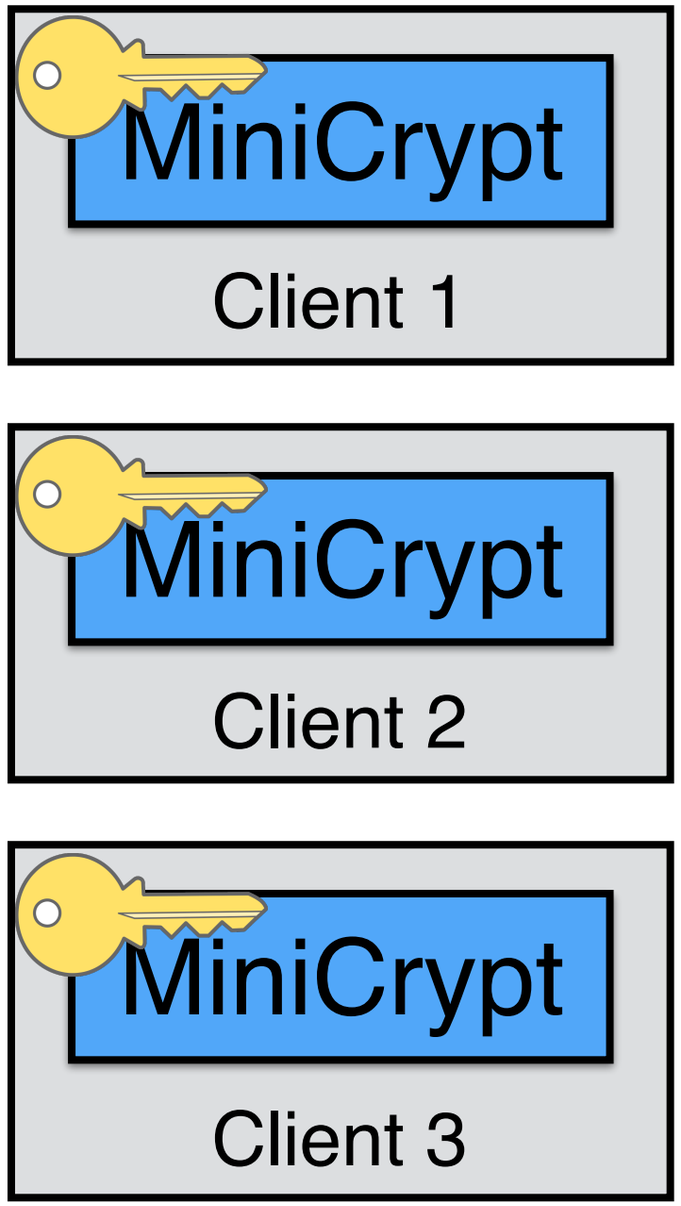

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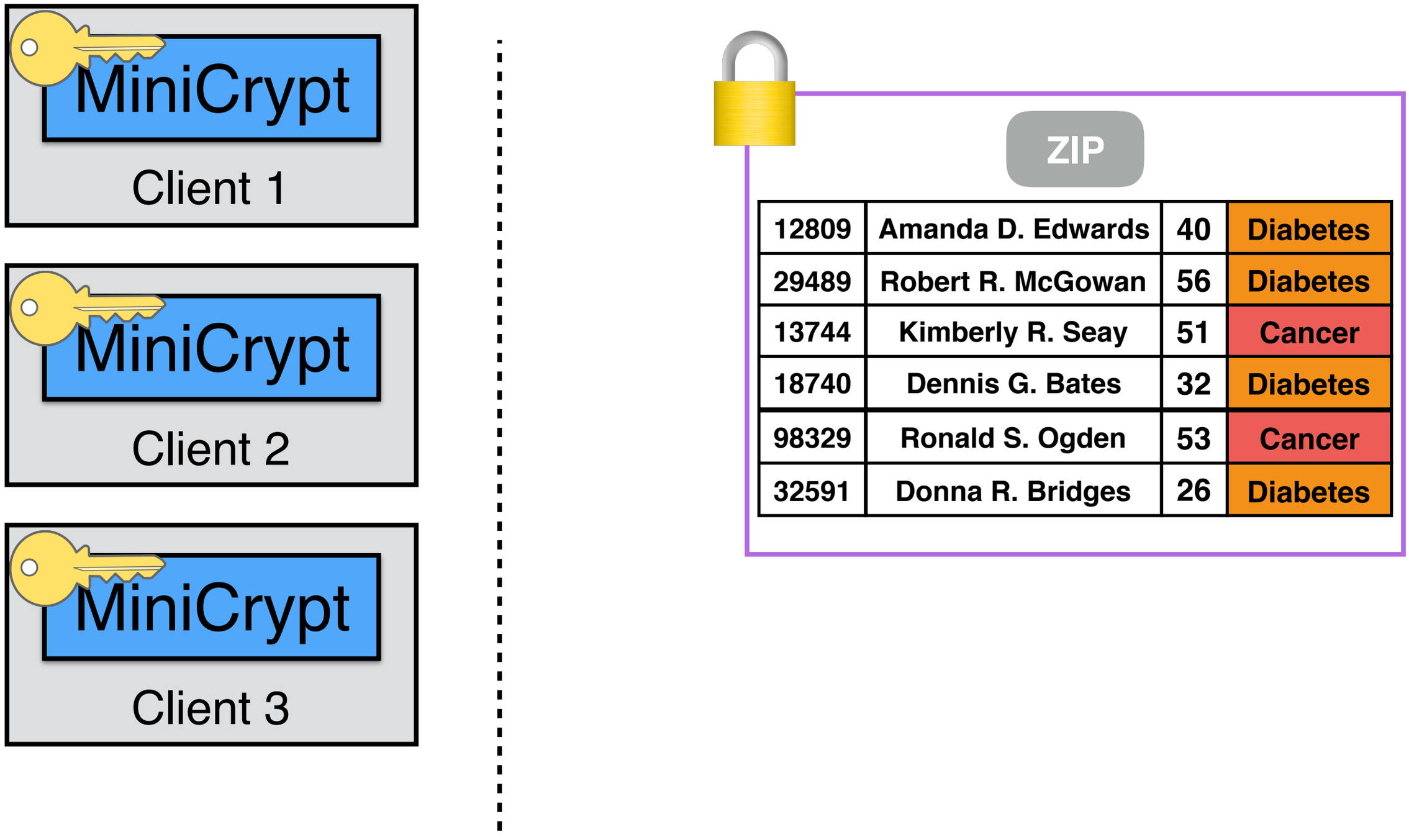

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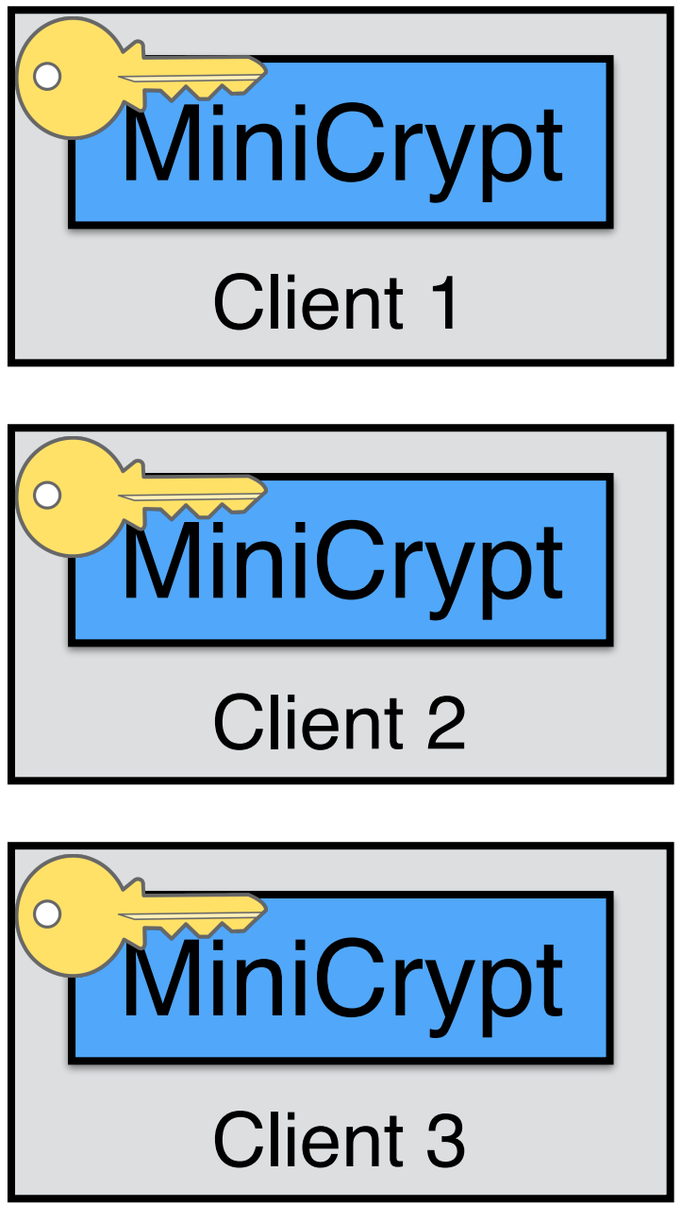

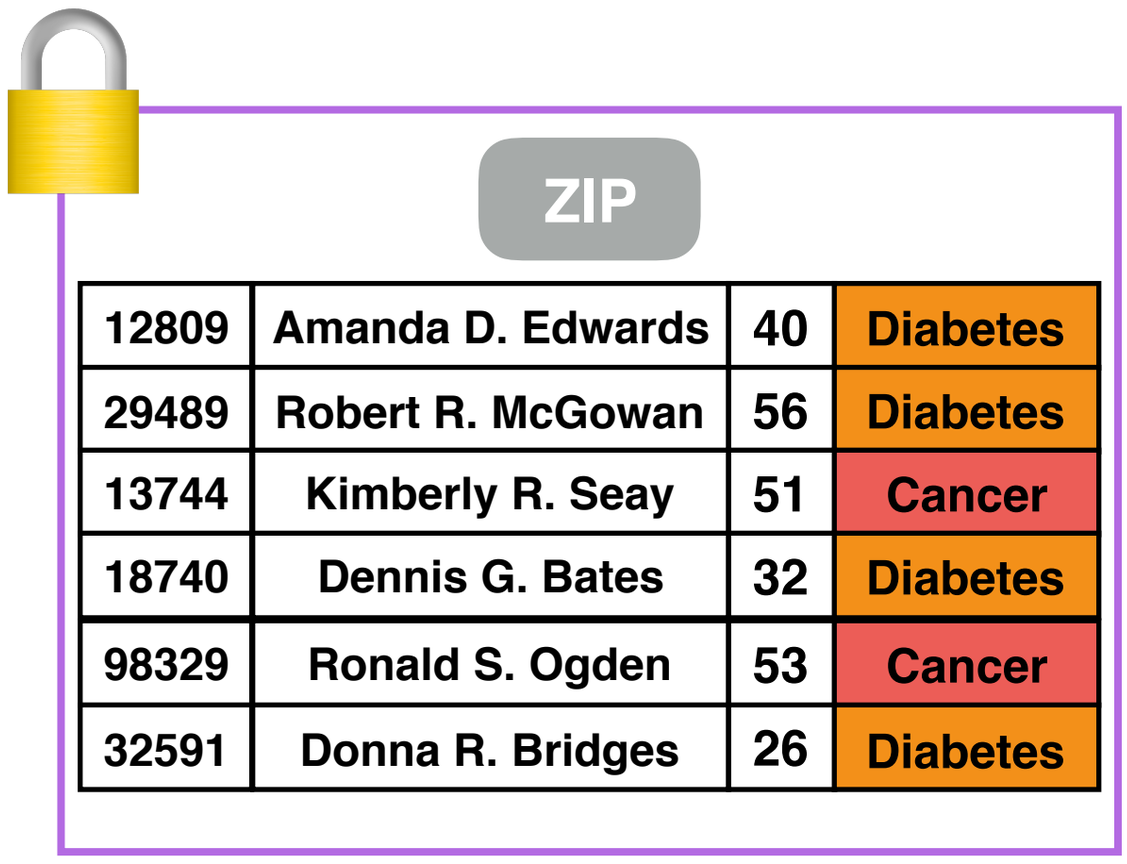

Problem: high network bandwidth

Strawman #2:
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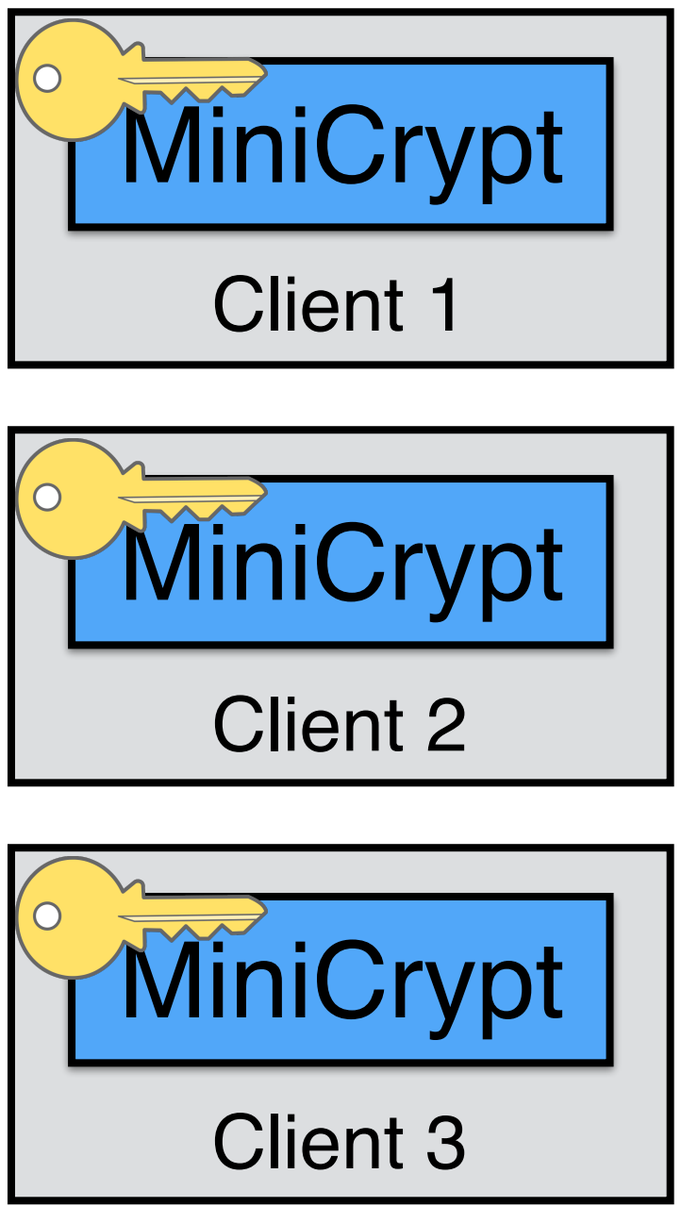

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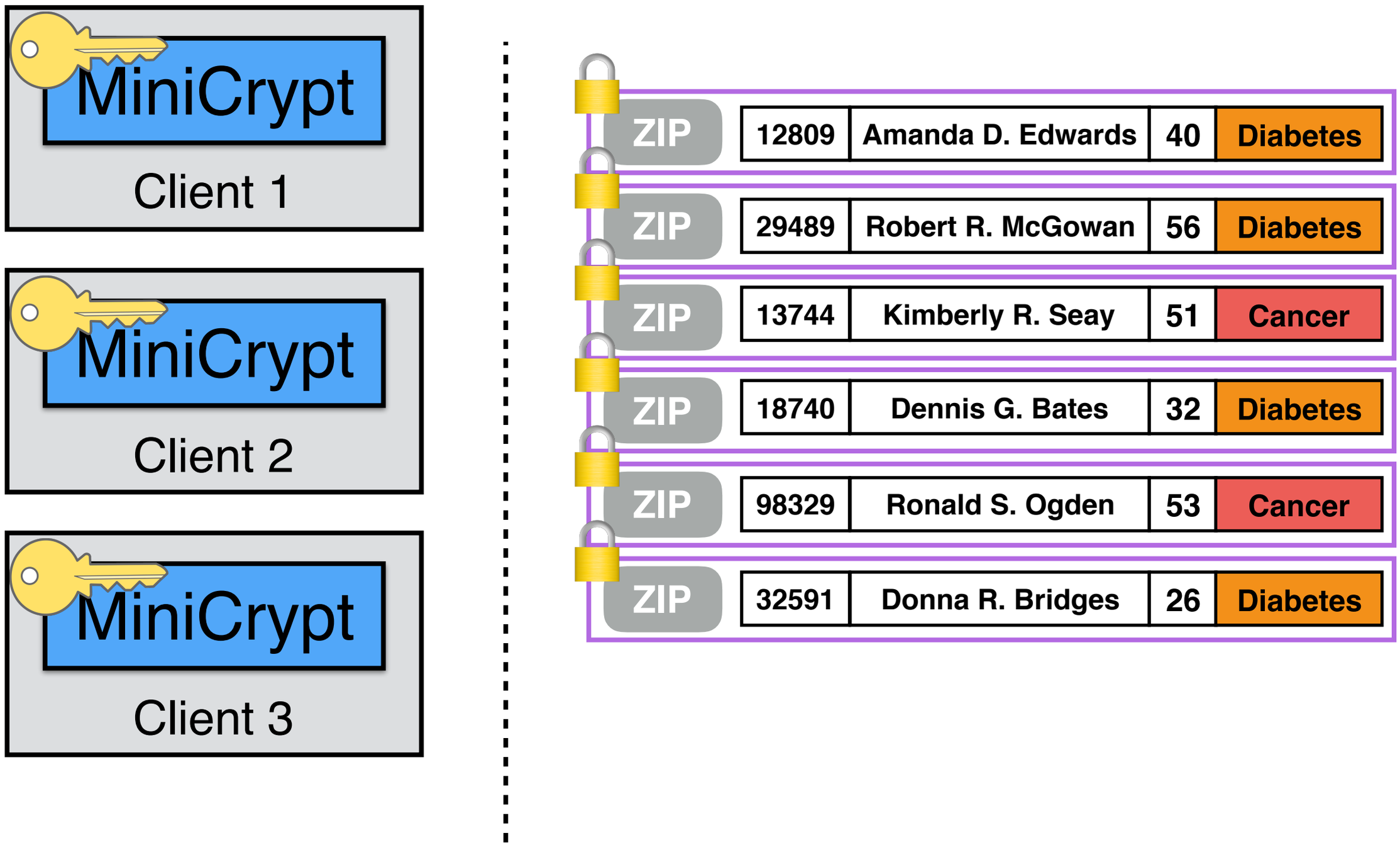

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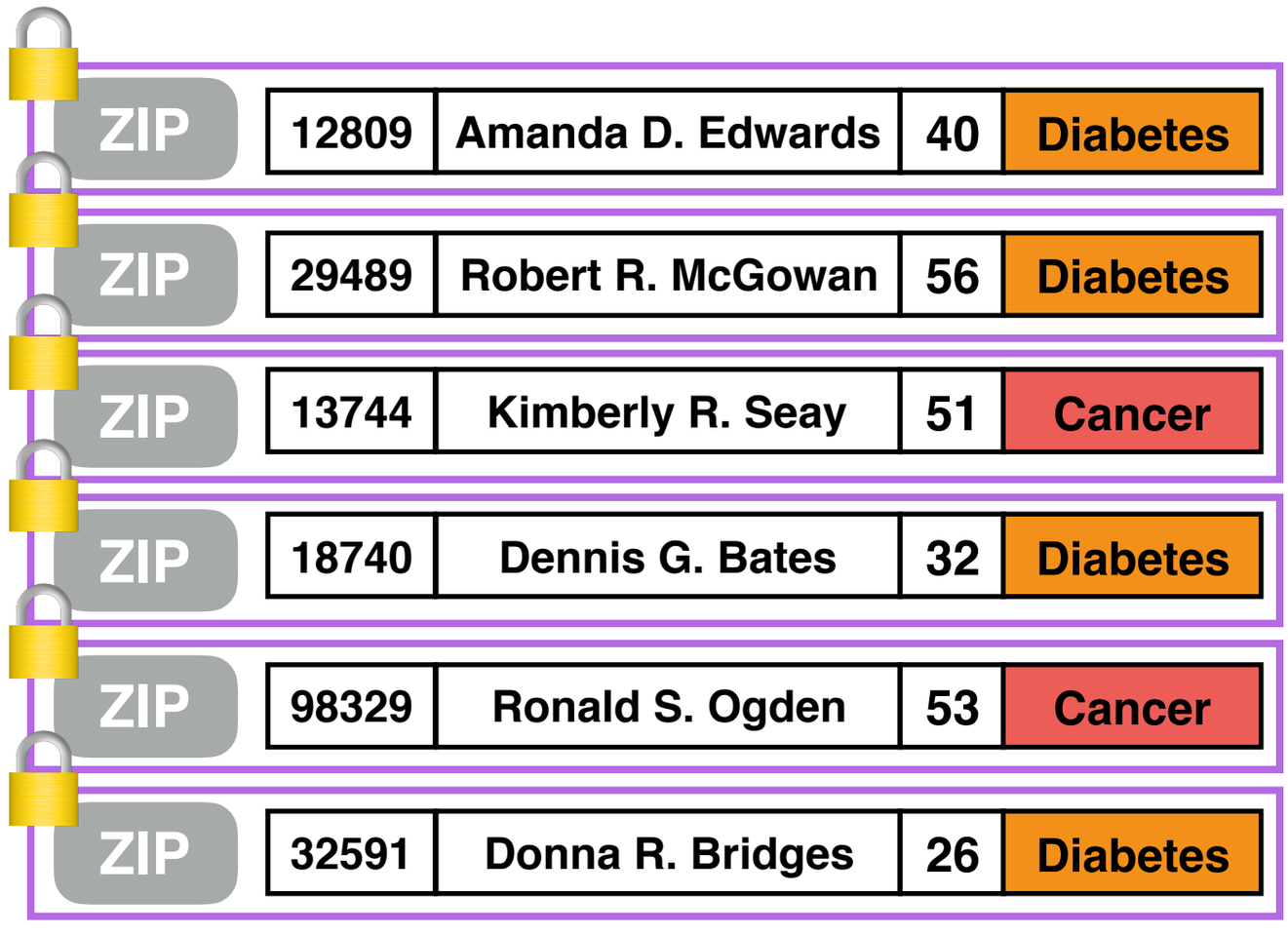

Problem: small compression ratio

Observation

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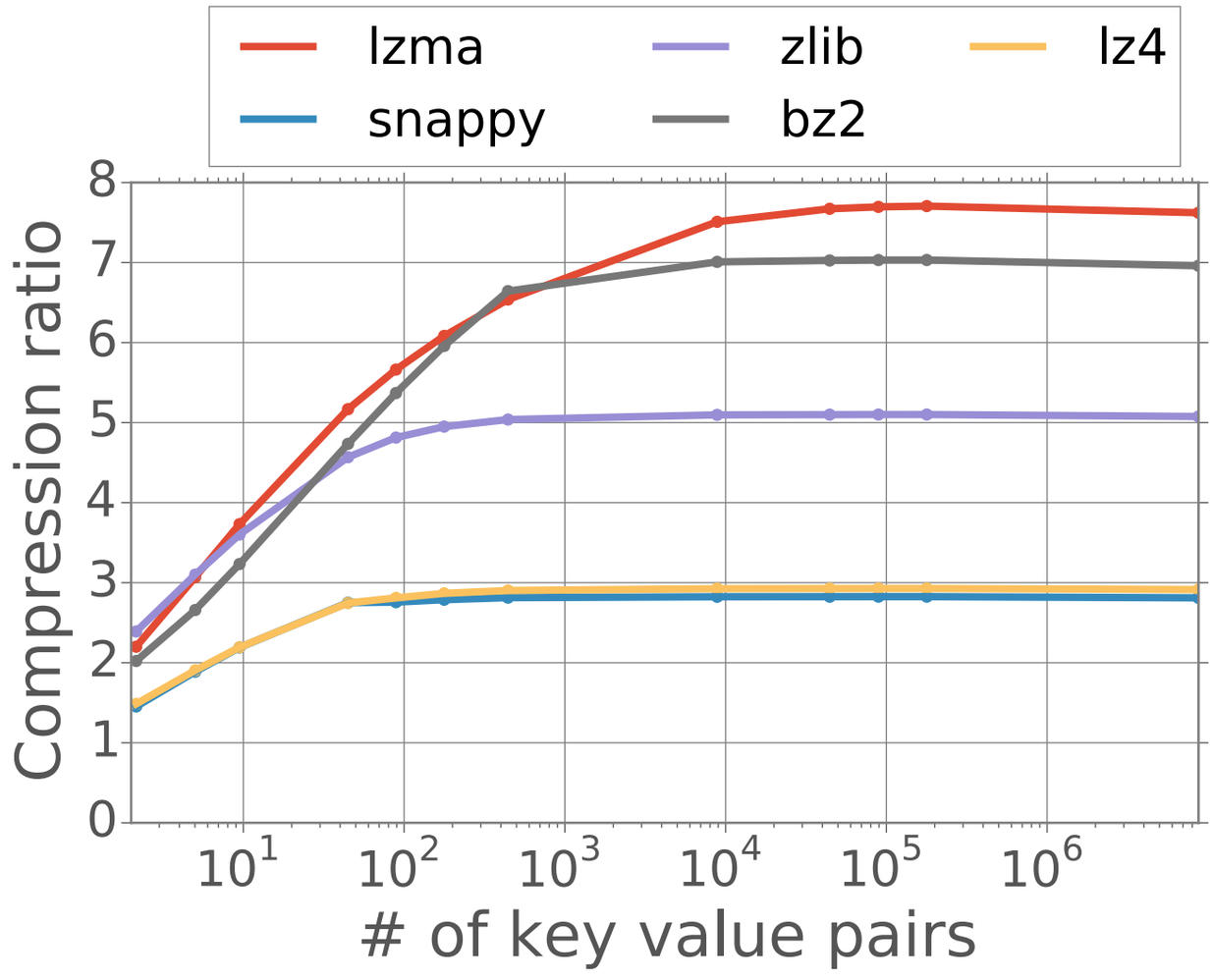

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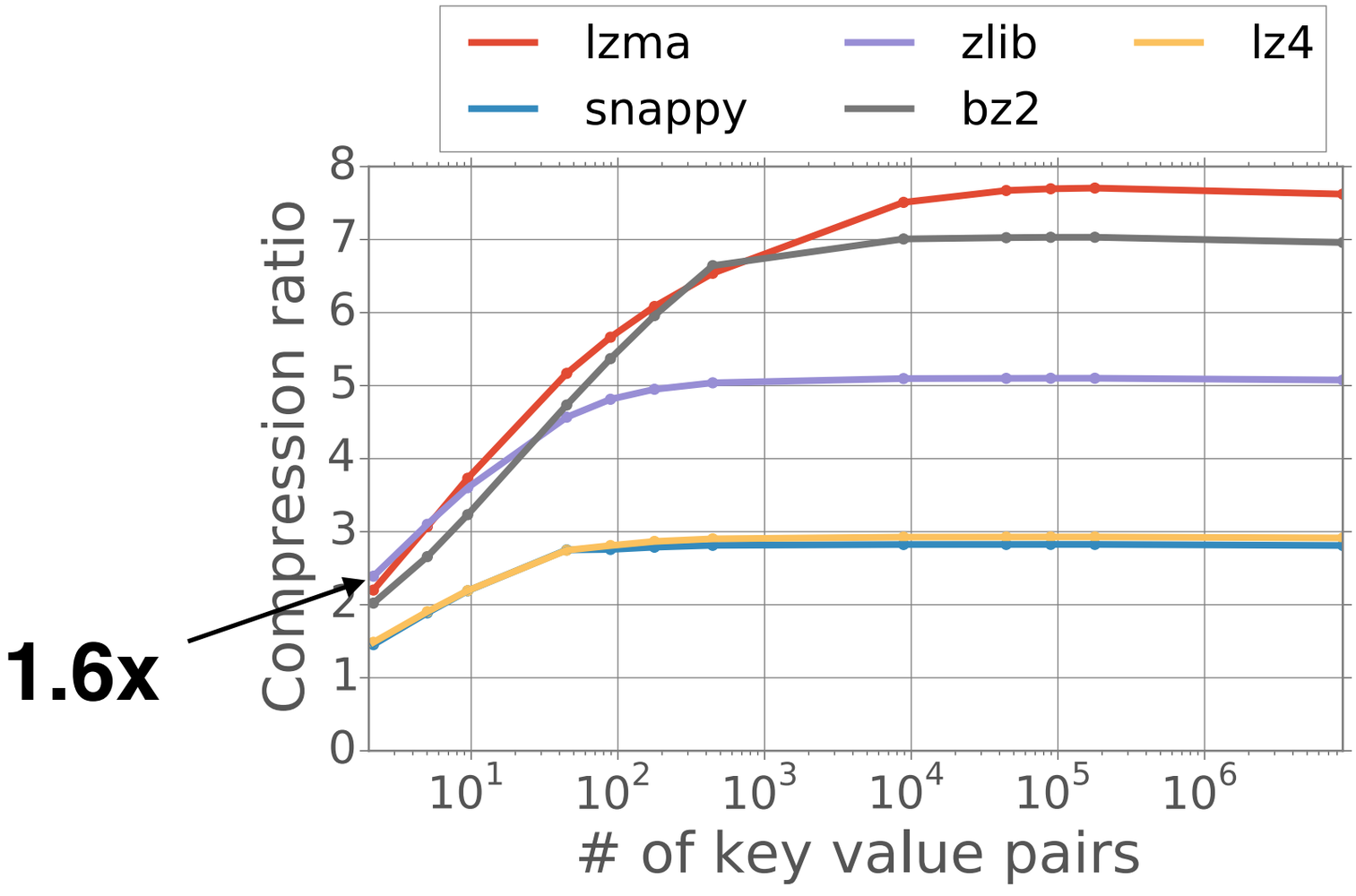

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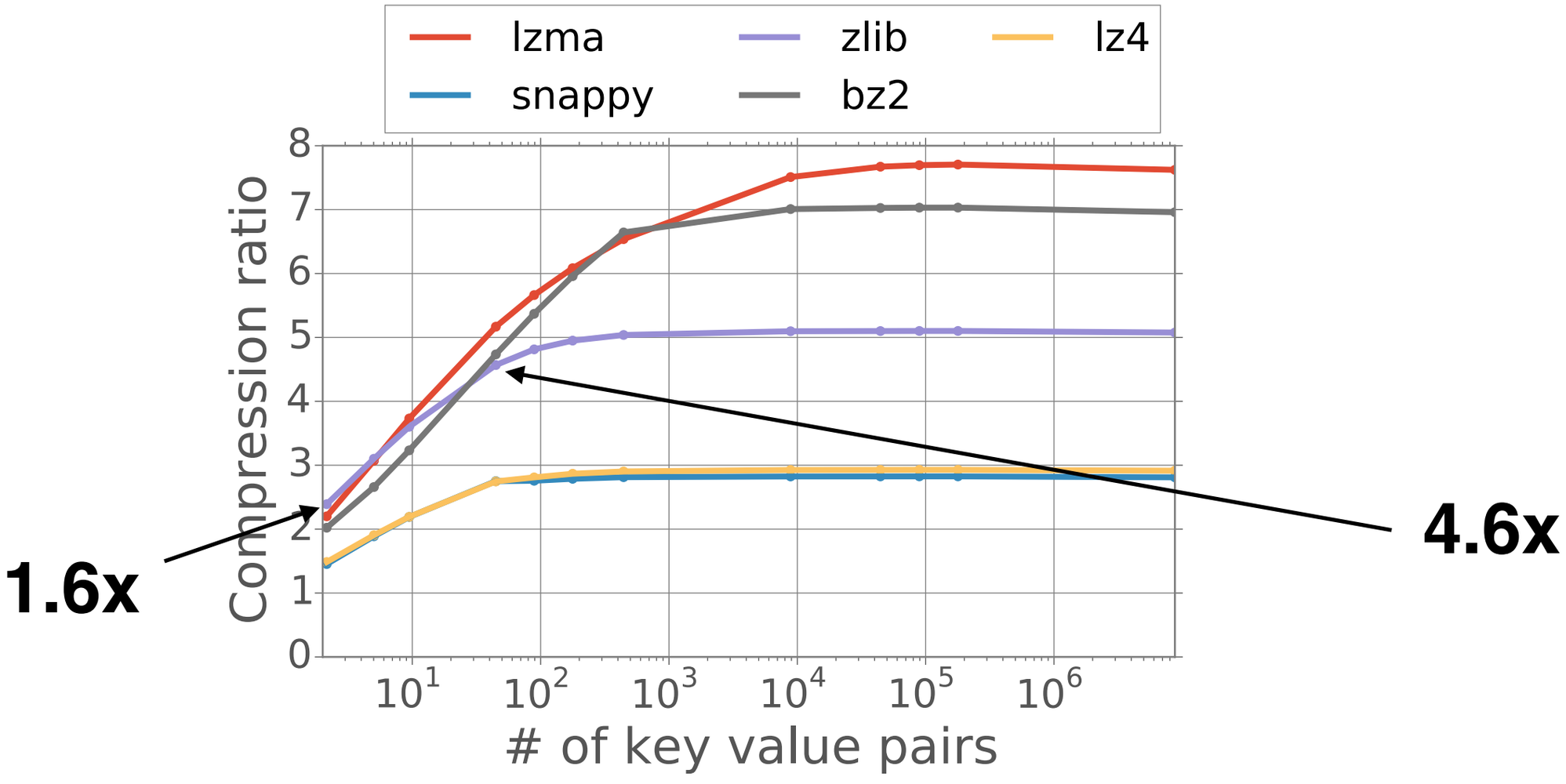

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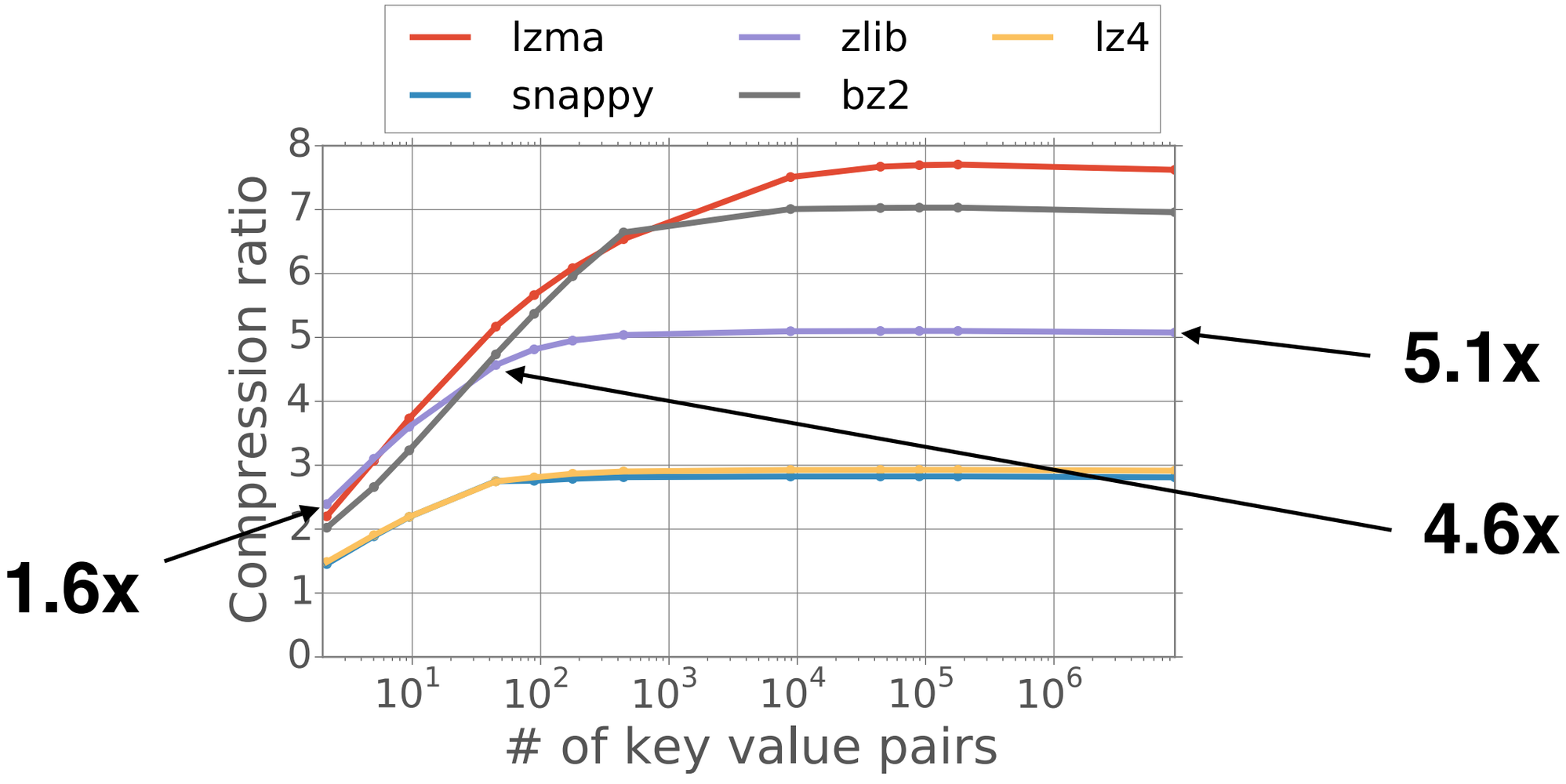

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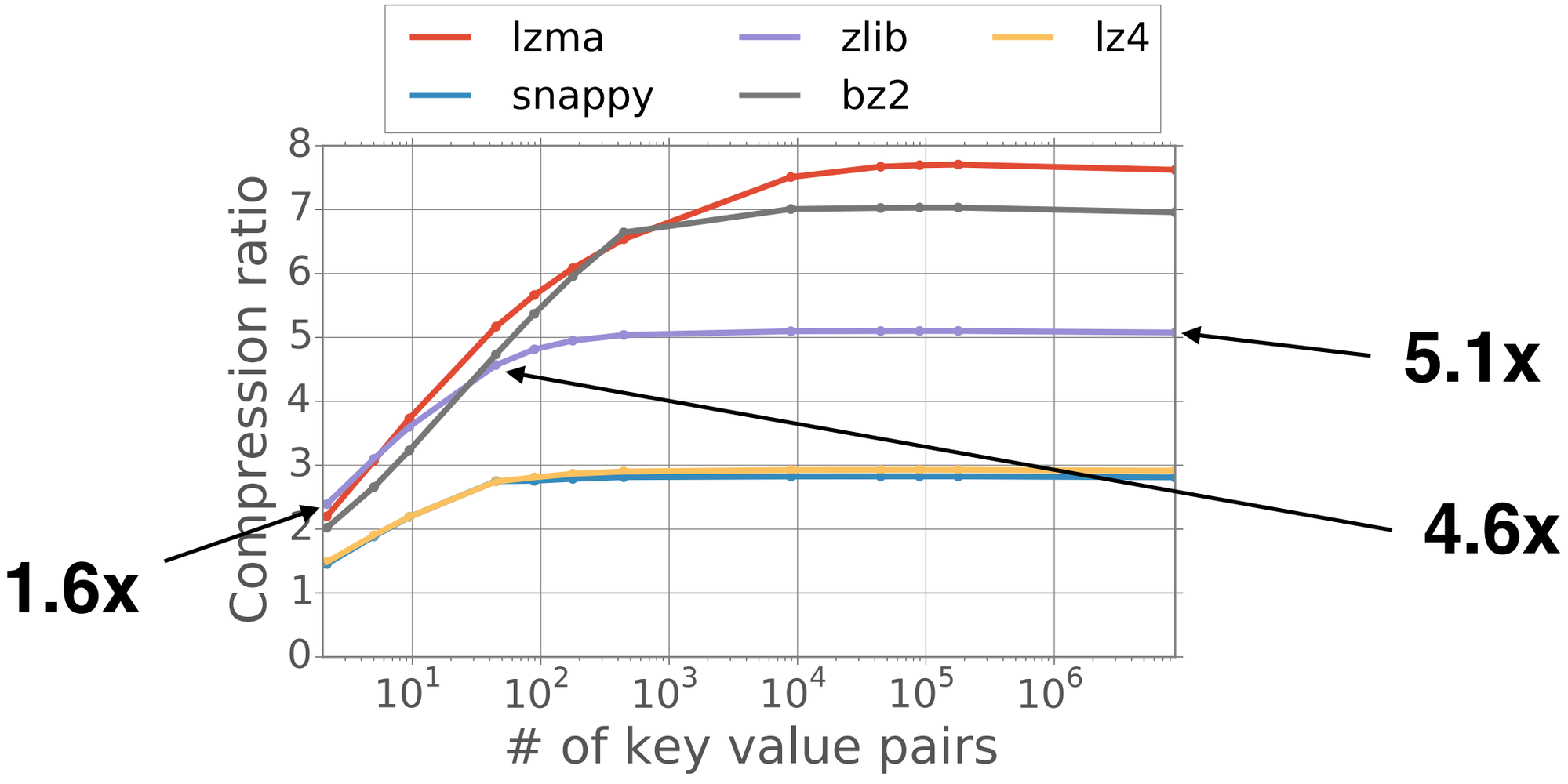

Small # of key-value pairs gives high compression

Approach

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1. Combine small number of key-value pairs into packs

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2. Compress and encrypt each pack

Challenges

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1. Server cannot decrypt packs

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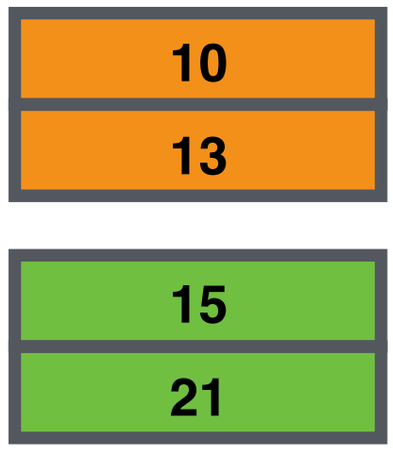
2. Multi-key transactions are expensive and not available for some key-value stores

Problem 1

Updates to different keys within a pack can overwrite each other



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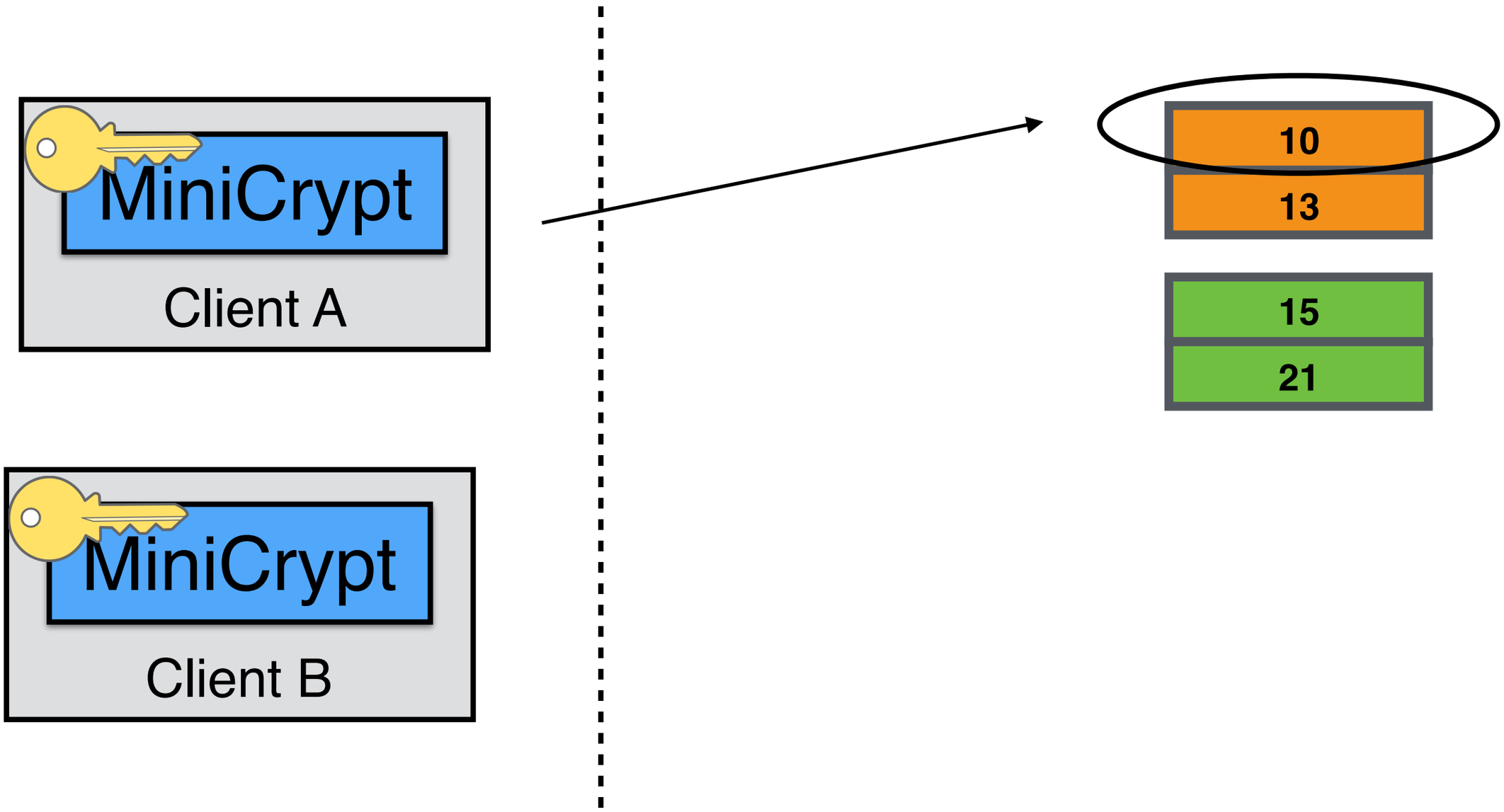

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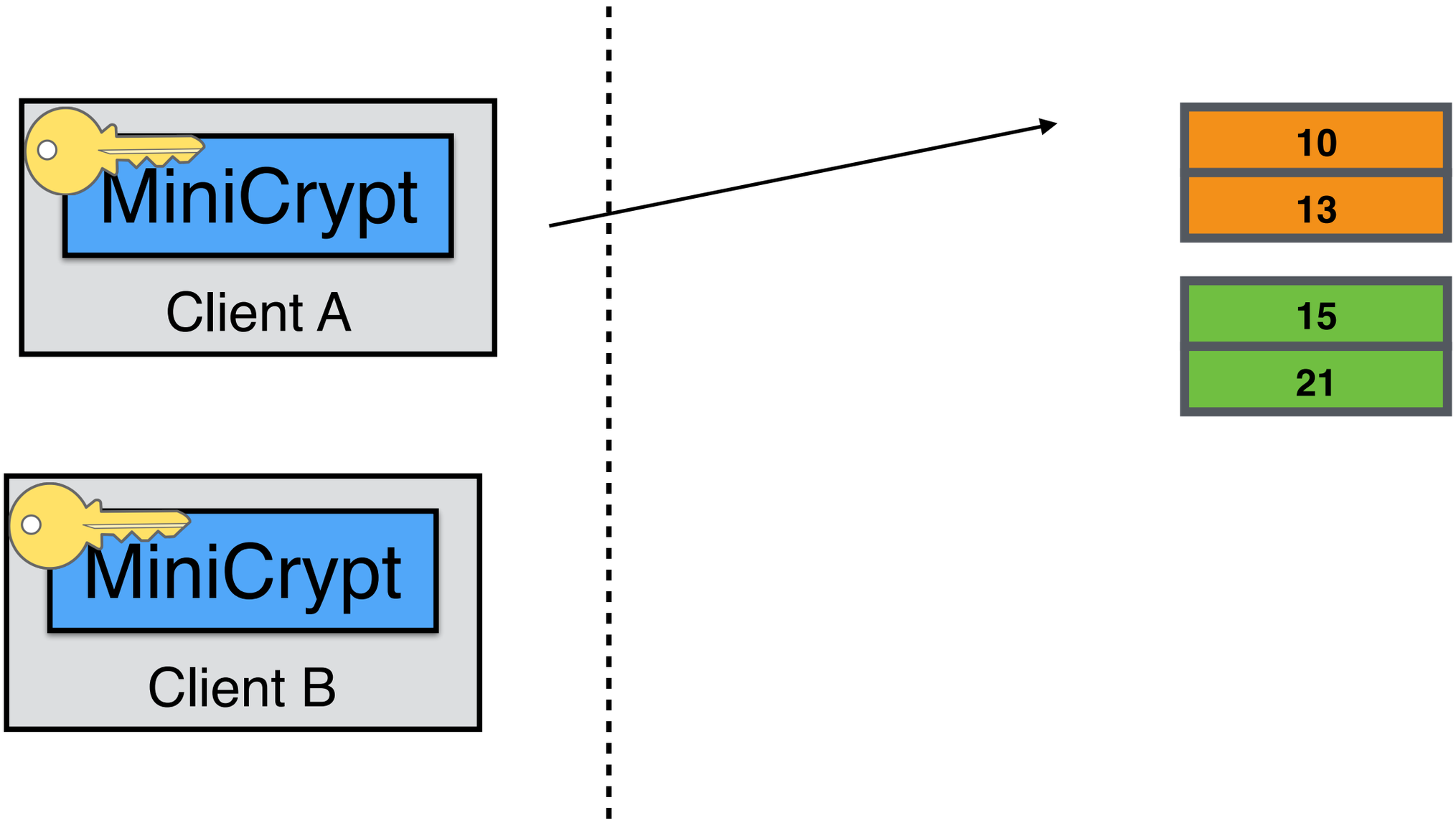

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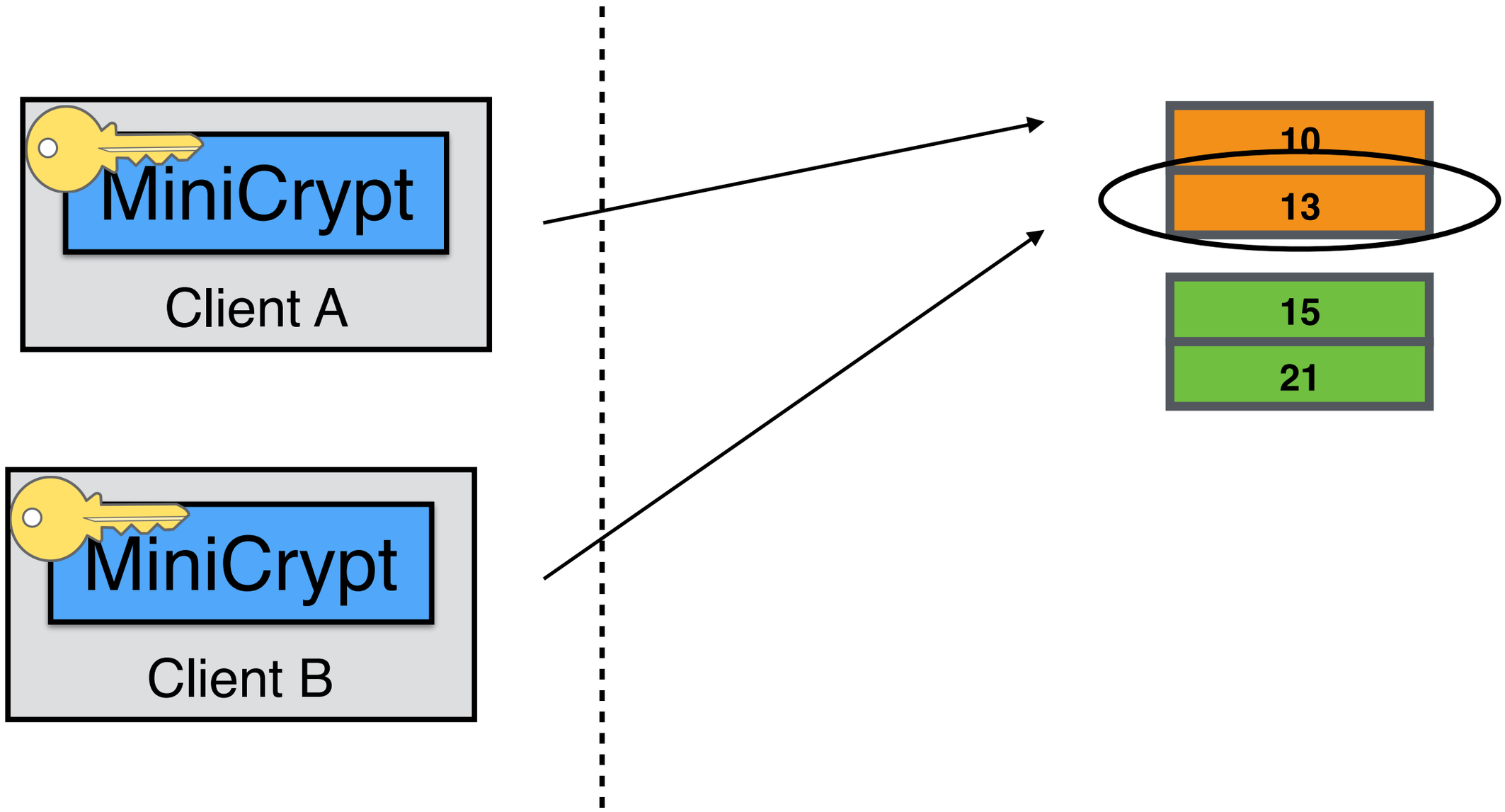

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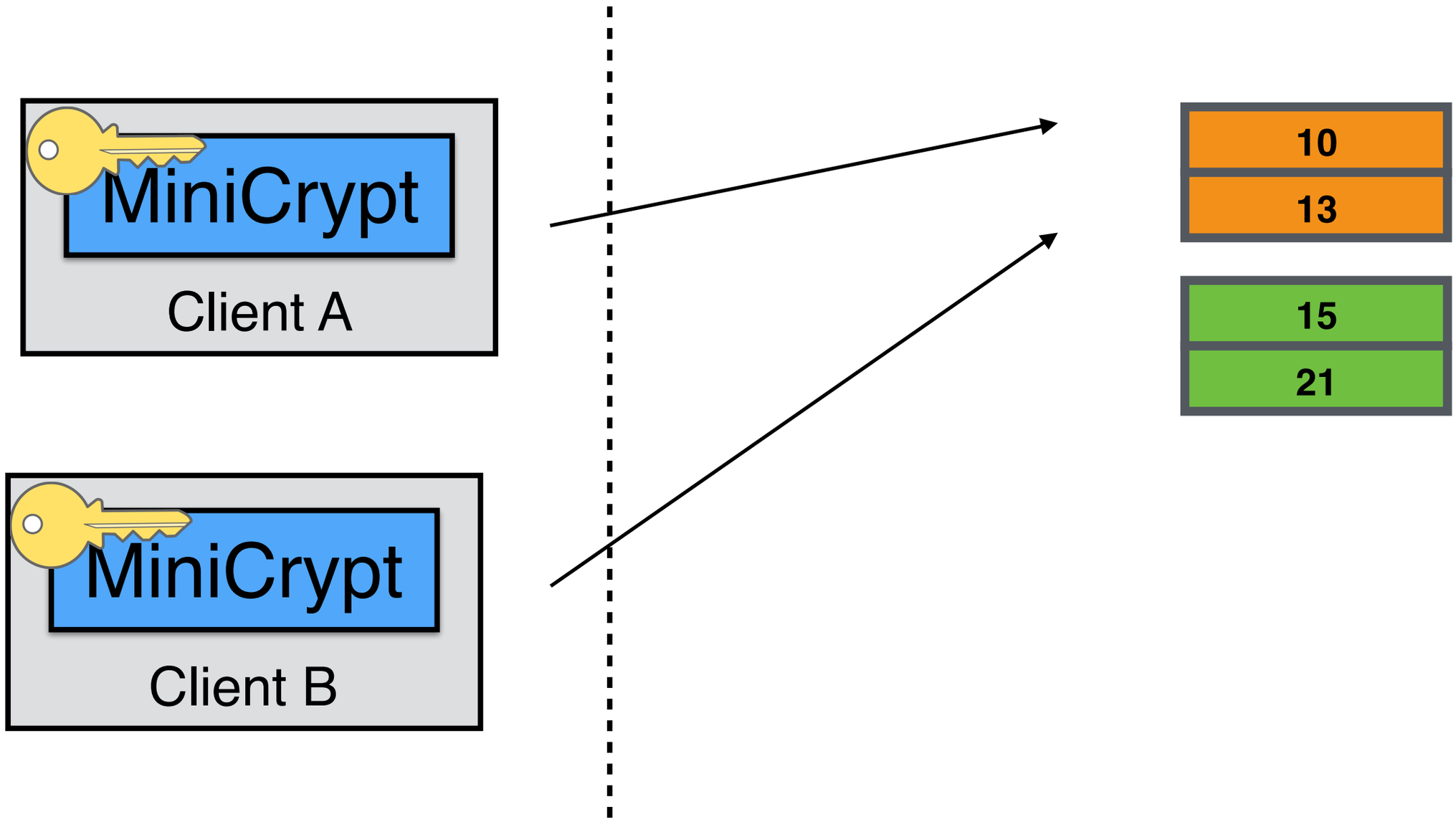
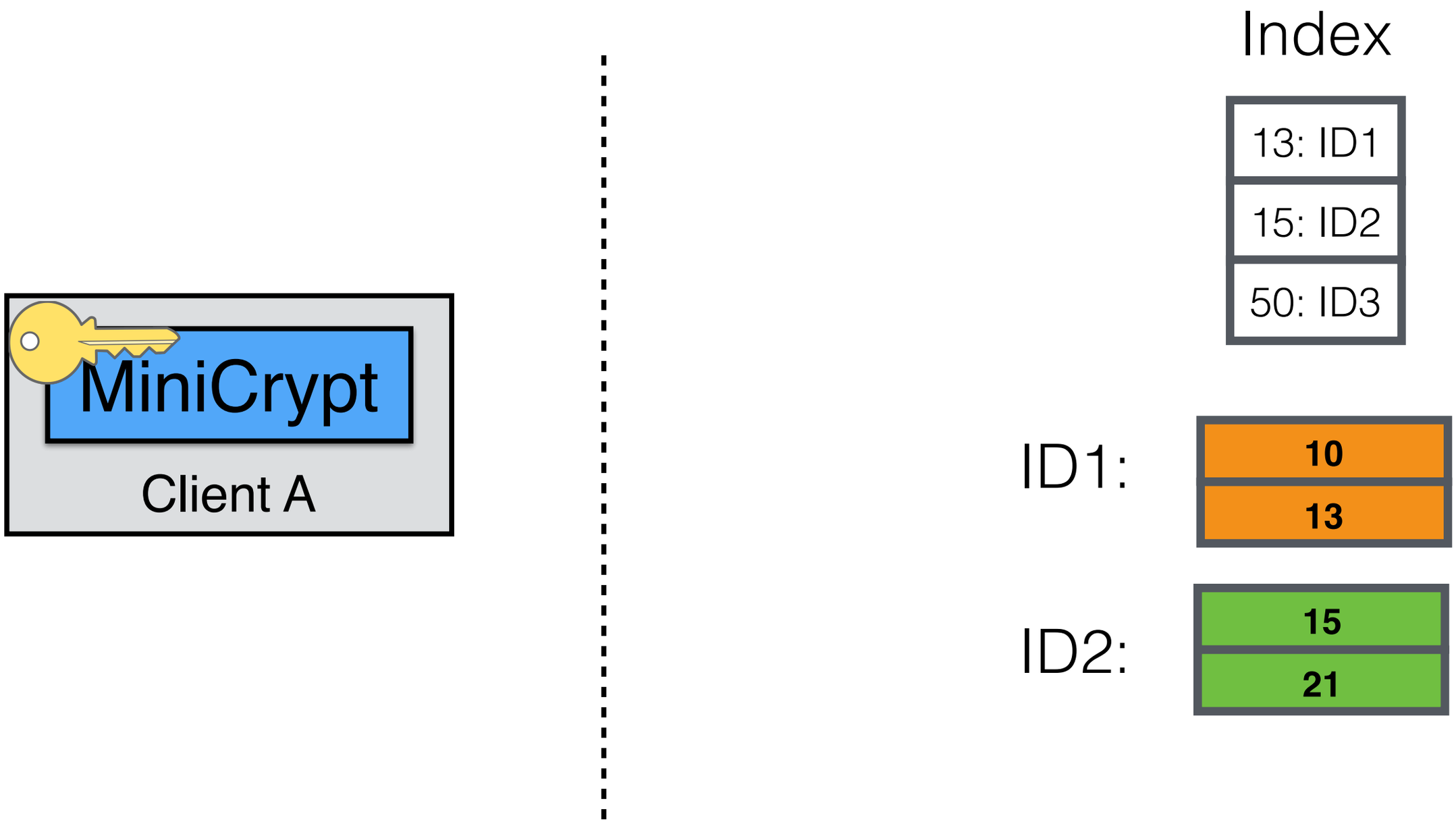


Problem 2

Additional index is difficult to keep consistent



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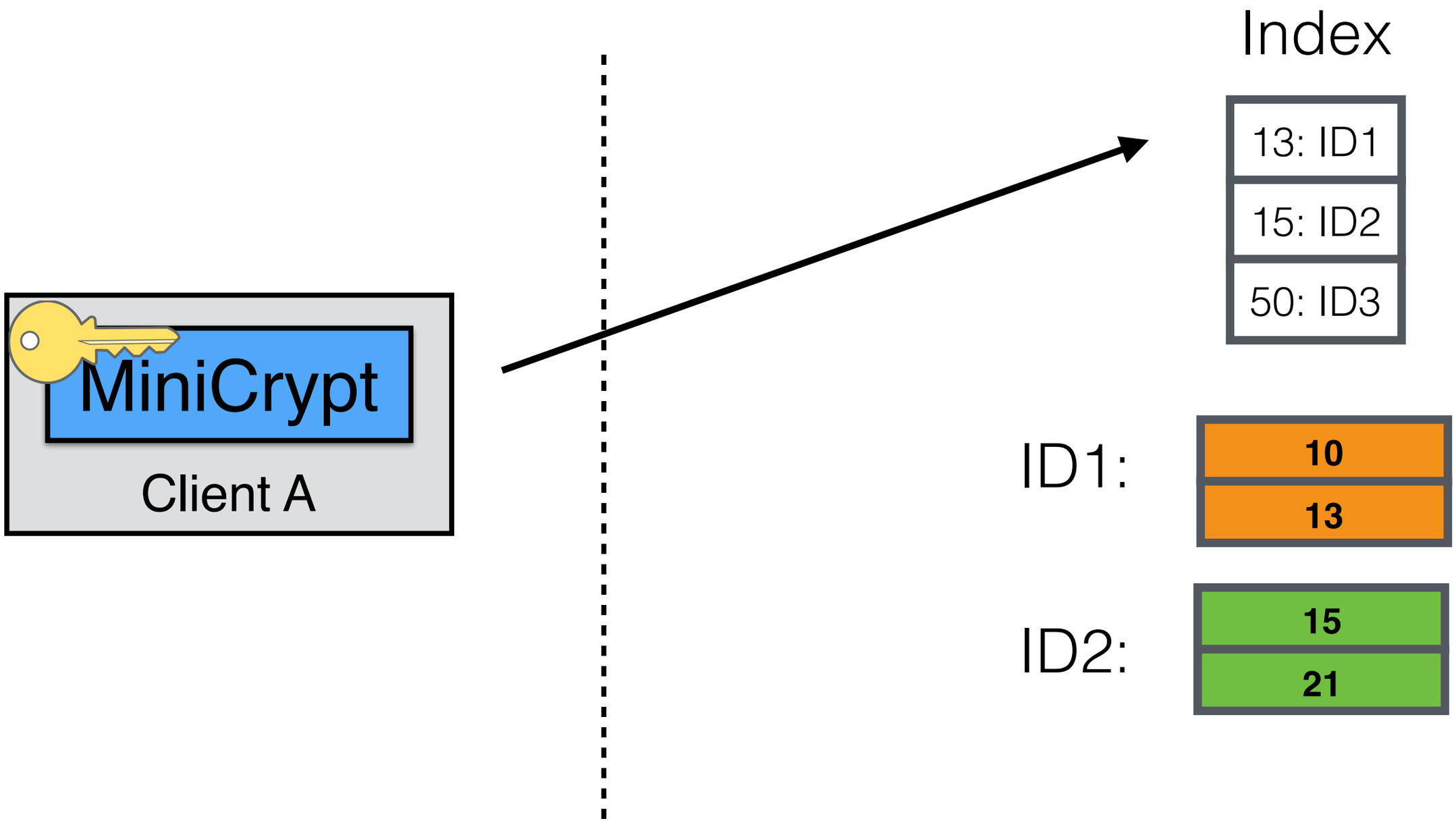

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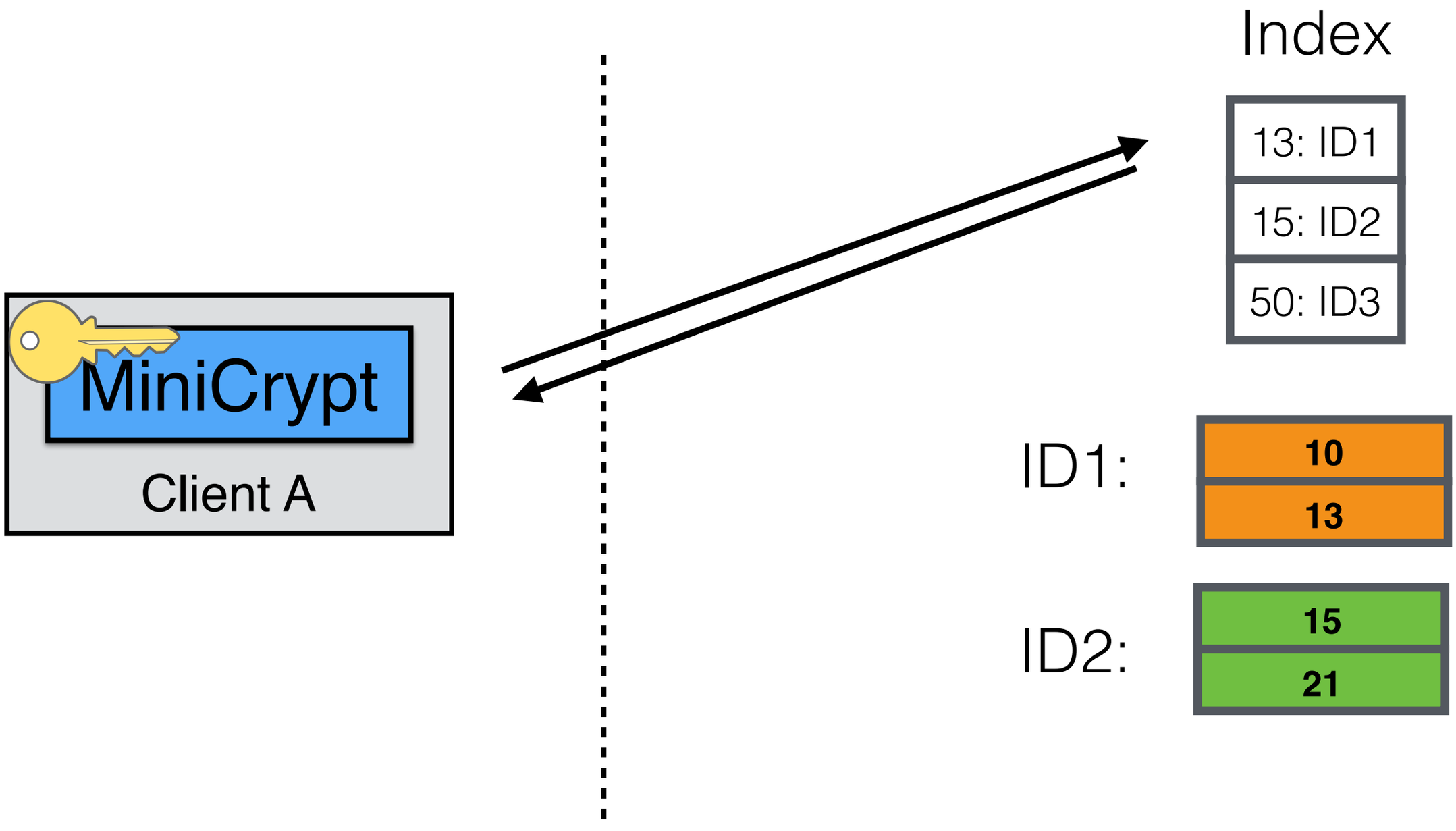

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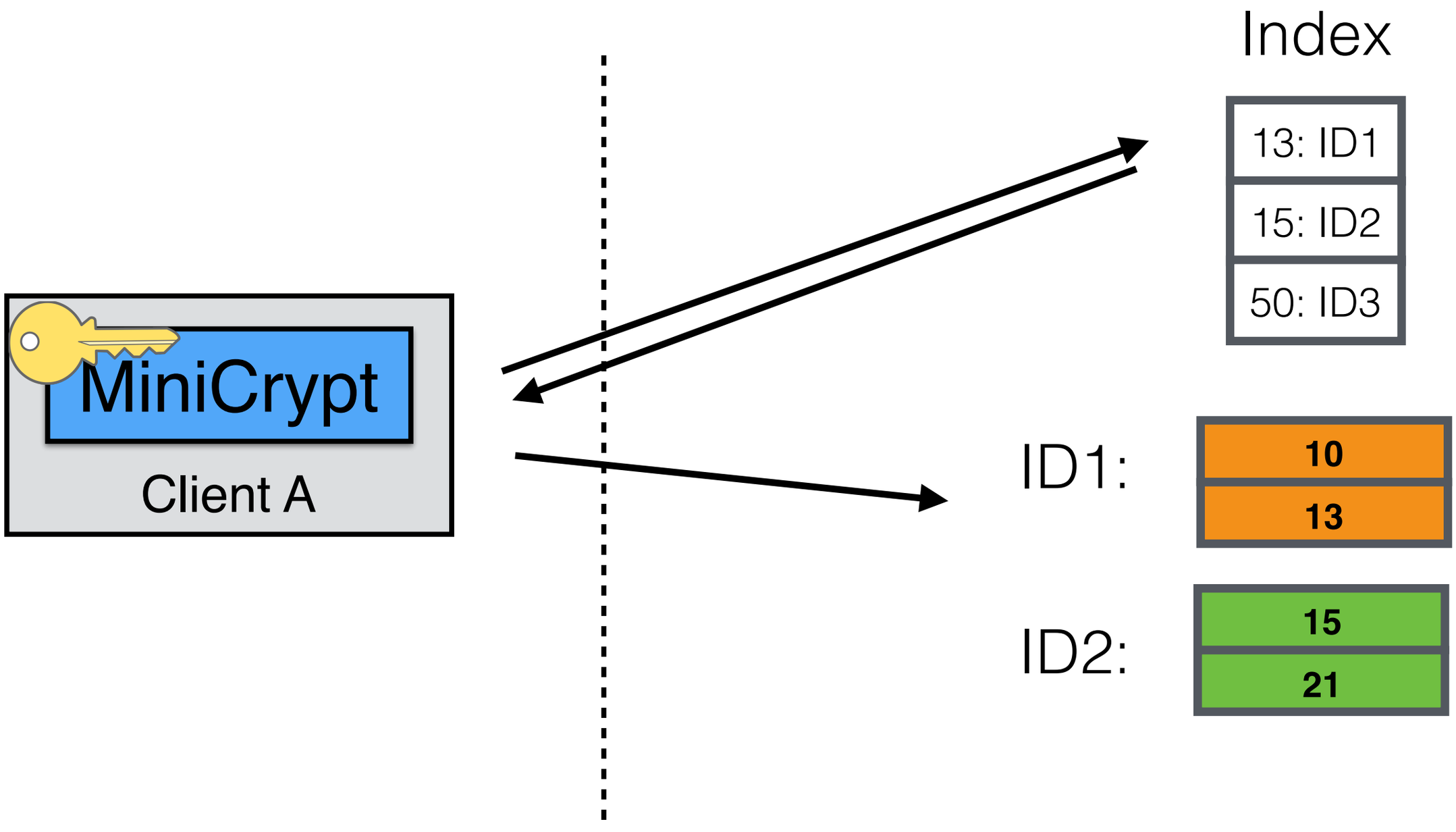

MiniCrypt's techniques

- lookup algorithm
- update algorithm
- splitting algorithm
- epoch-based appends
- merge algorithm

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using only

- single-key atomic compare-and-swap

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using only

- single-key atomic compare-and-swap
- sorted index on the primary key

API

- **get(key)**
- **put(key, value)**
- **delete(key)**
- **range(low_key, high_key)**

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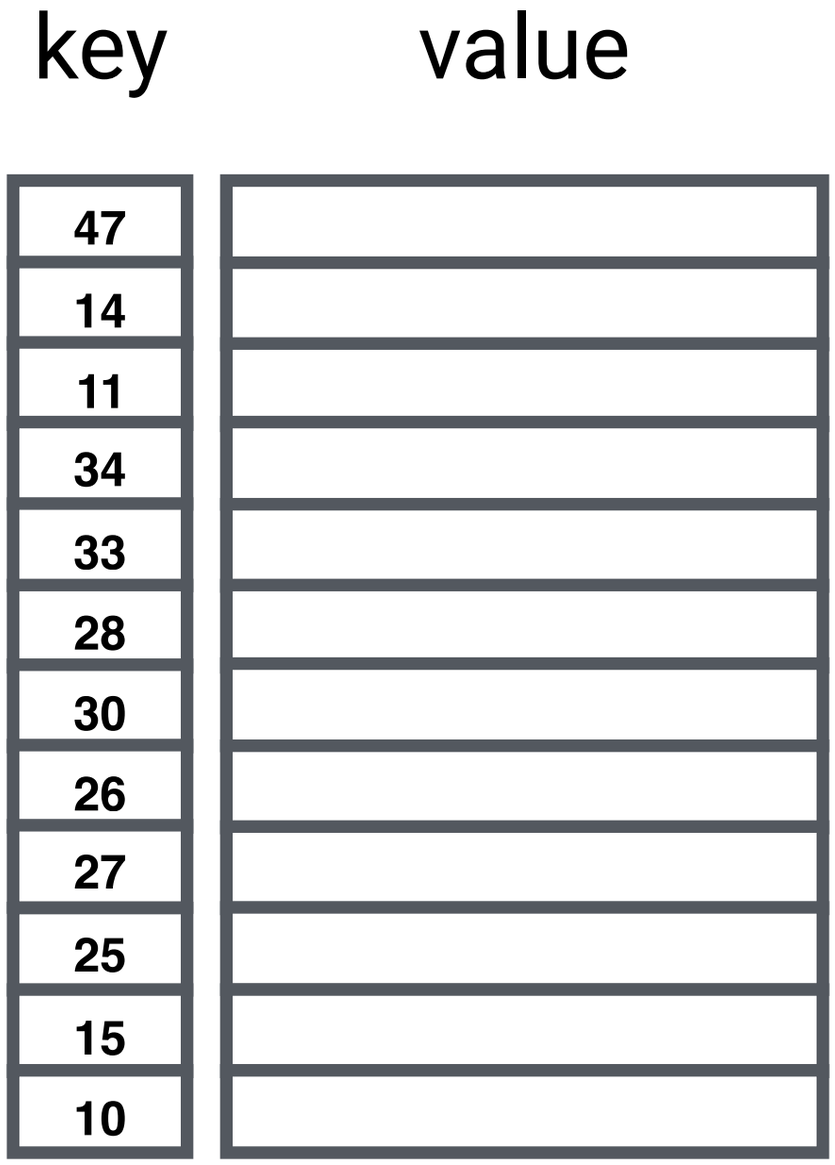
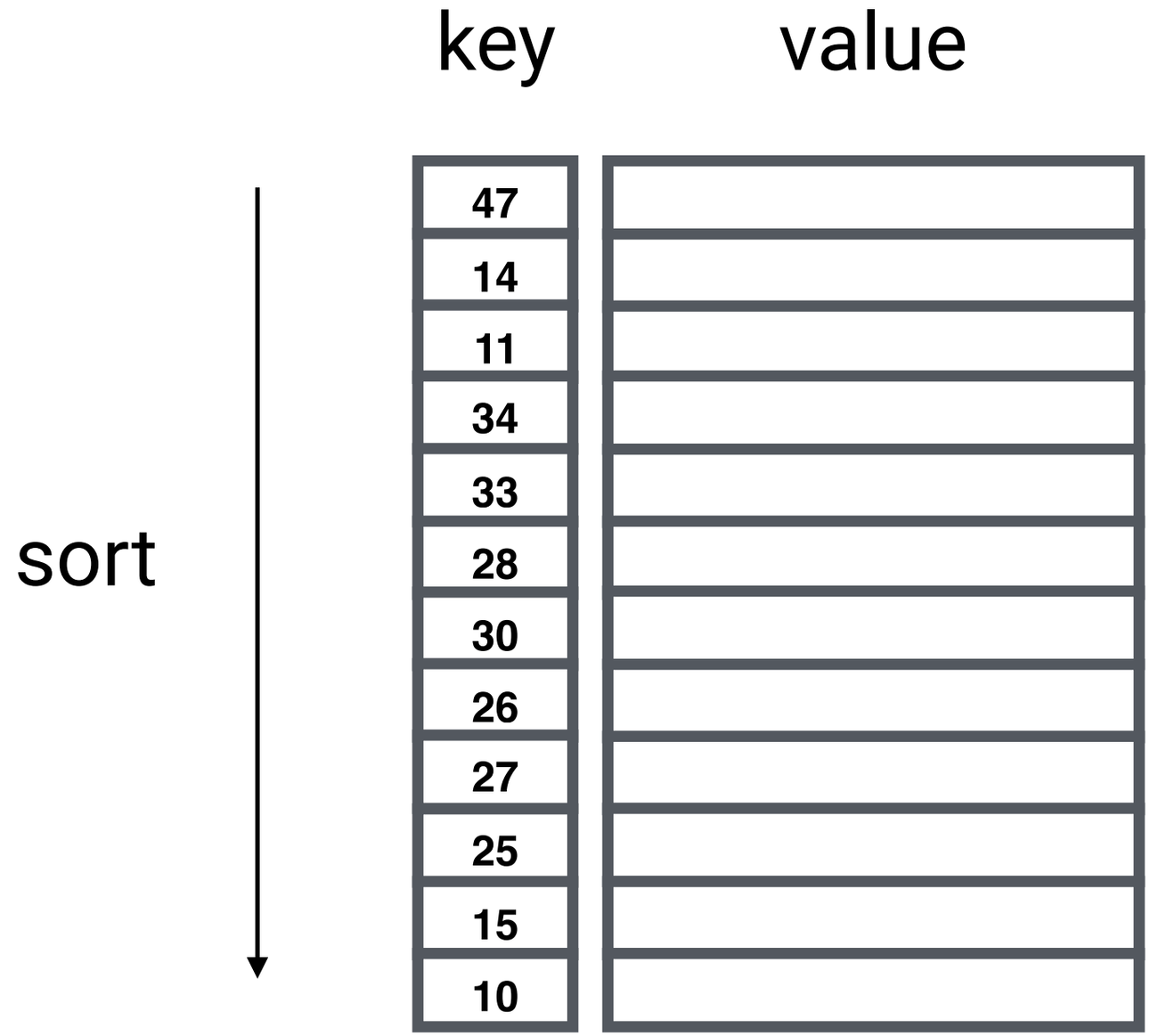
Packing



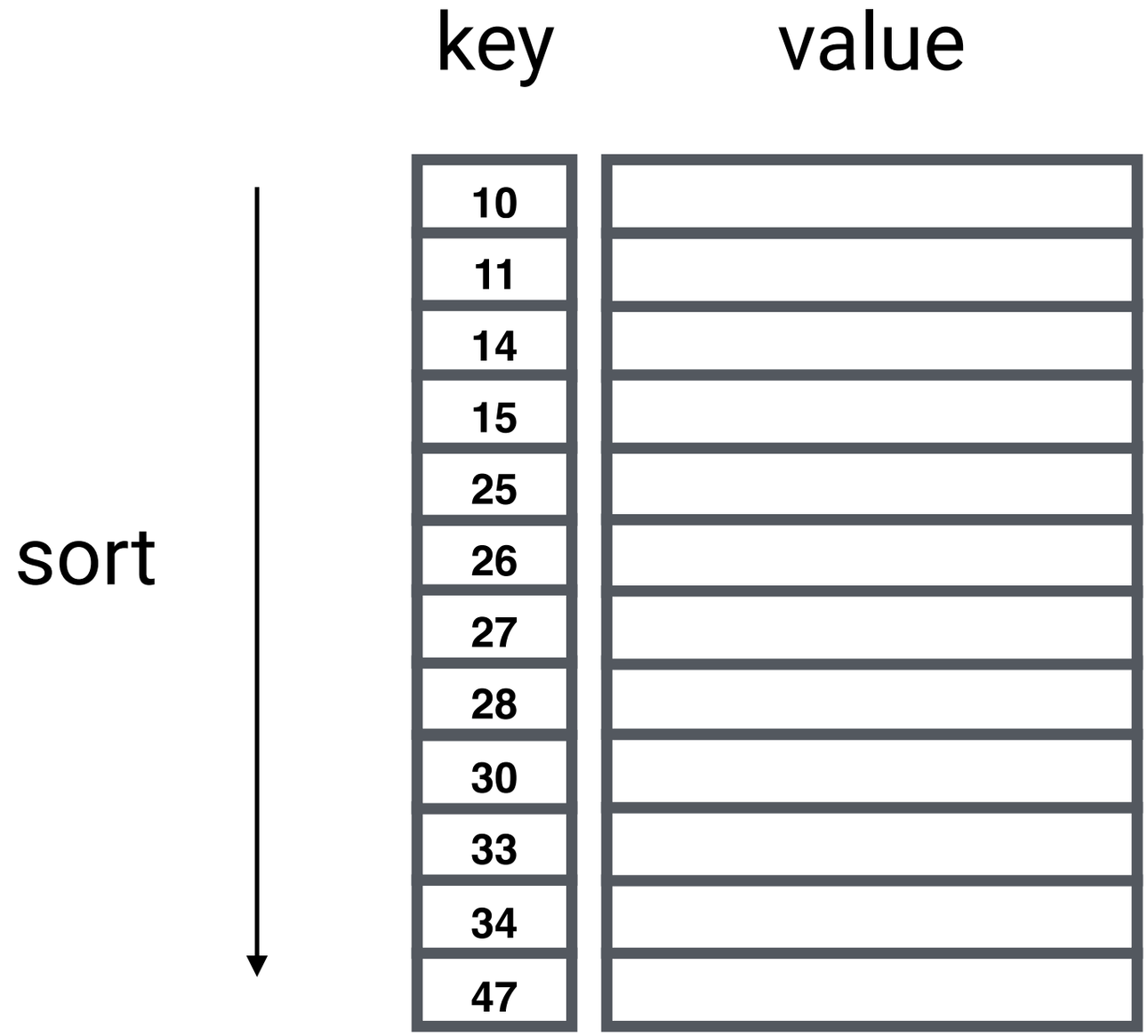
Sort by primary key

Packing



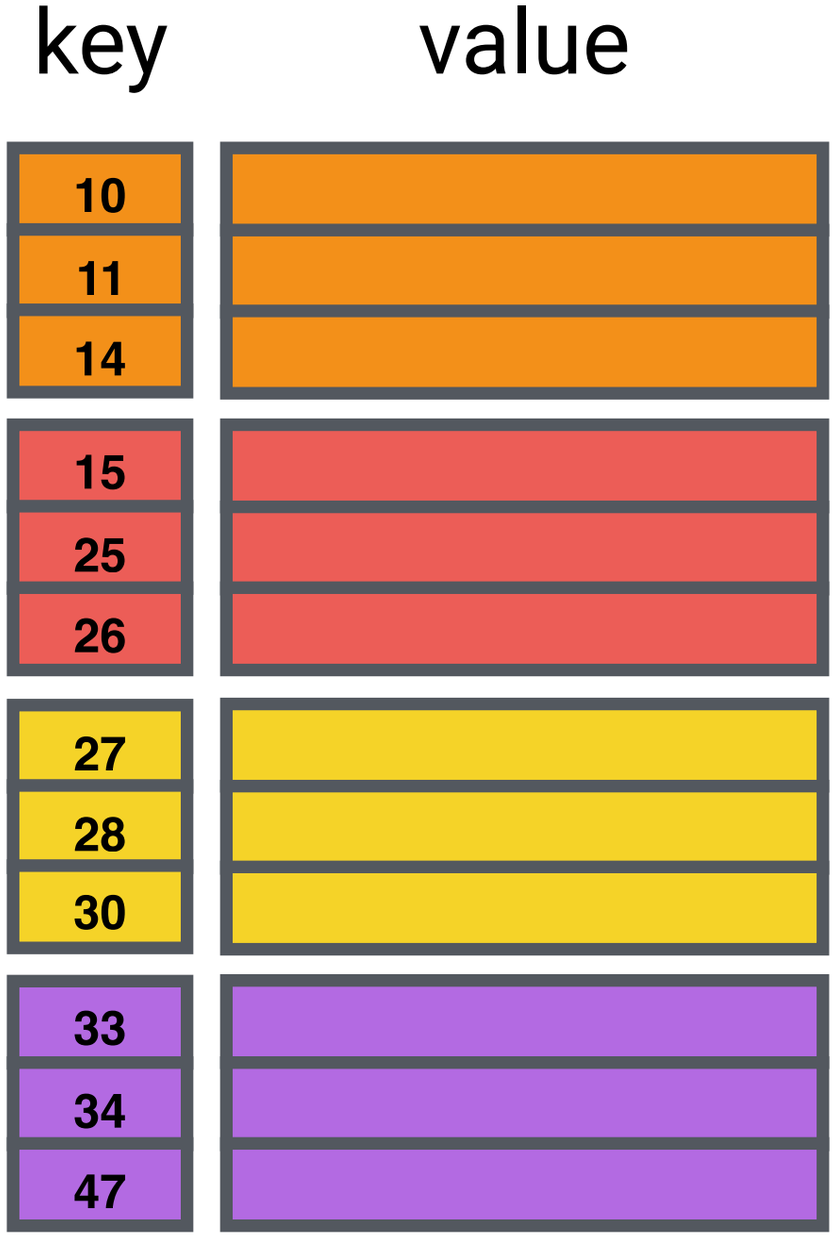
Sort by primary key

Packing



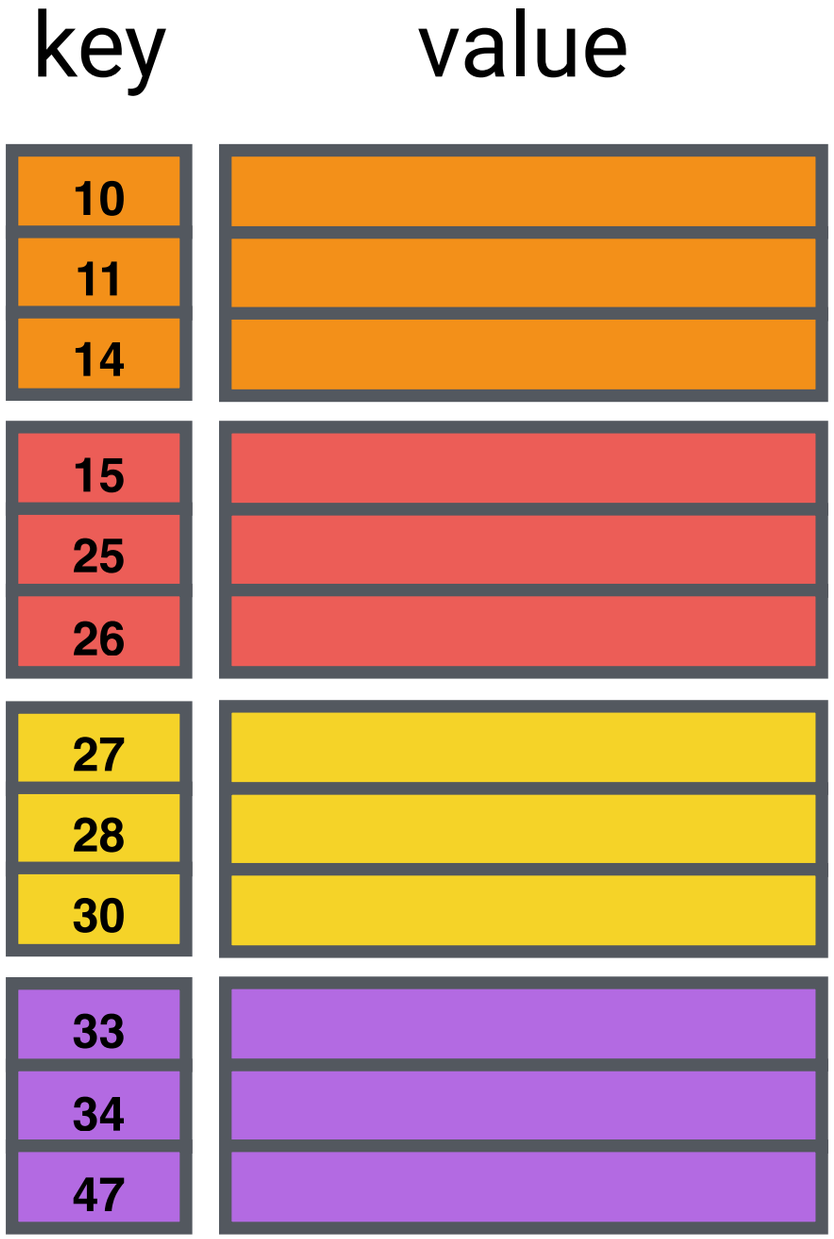
Sort by primary key

Packing

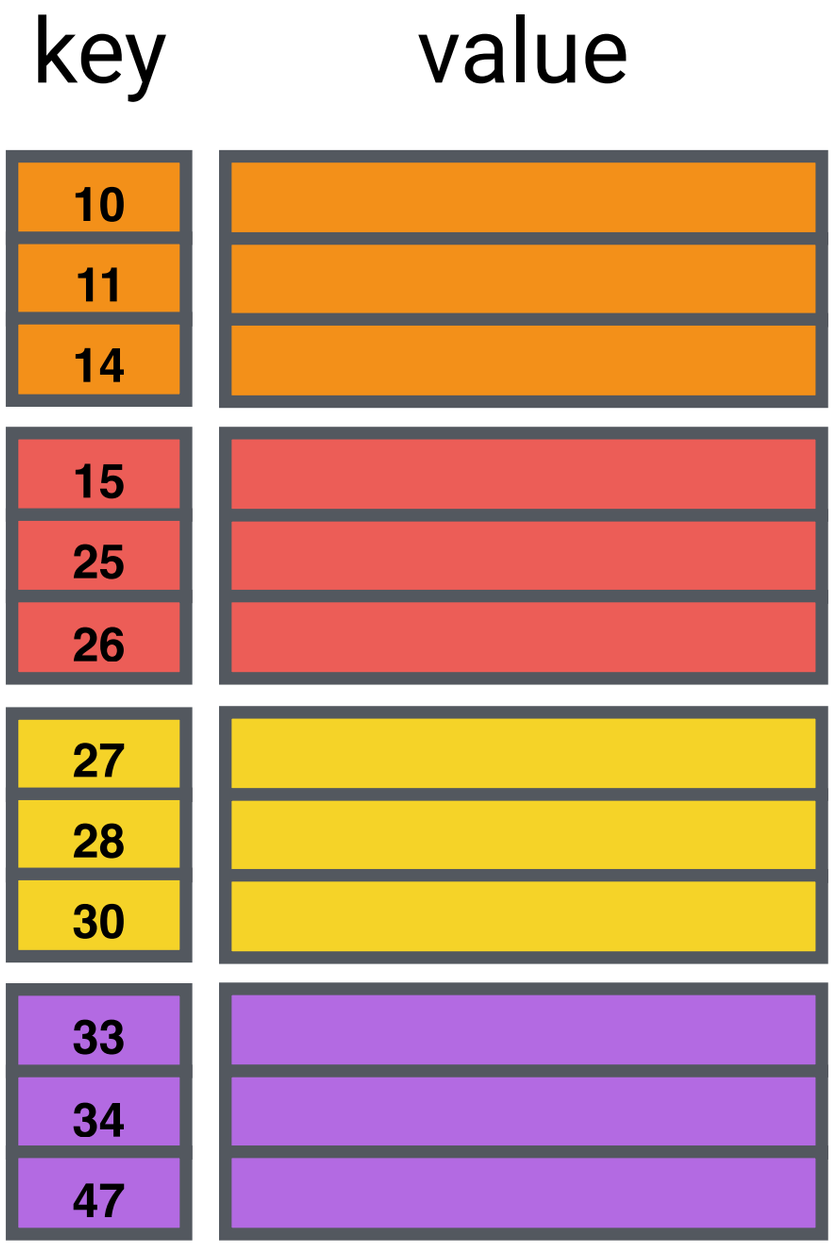


Partition into packs

Packing

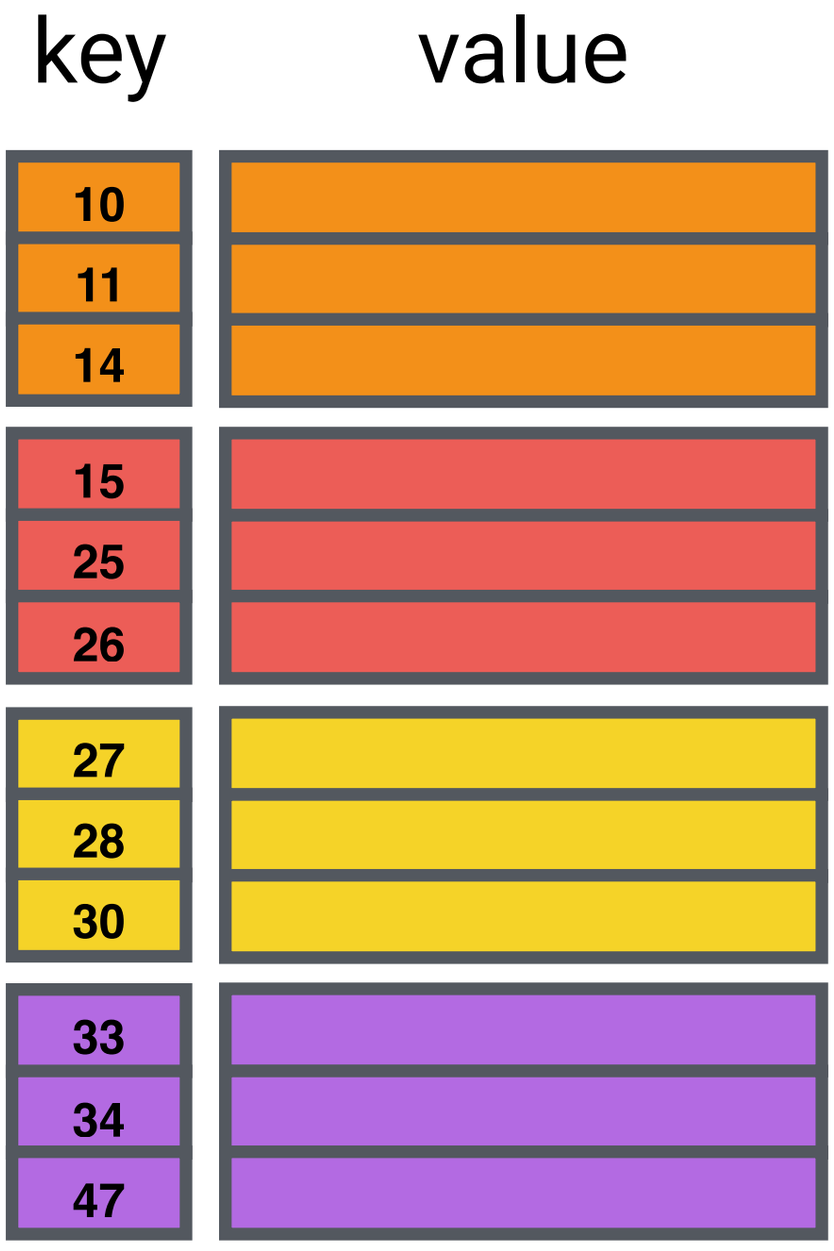


Packing



New key =
smallest key
in the pack

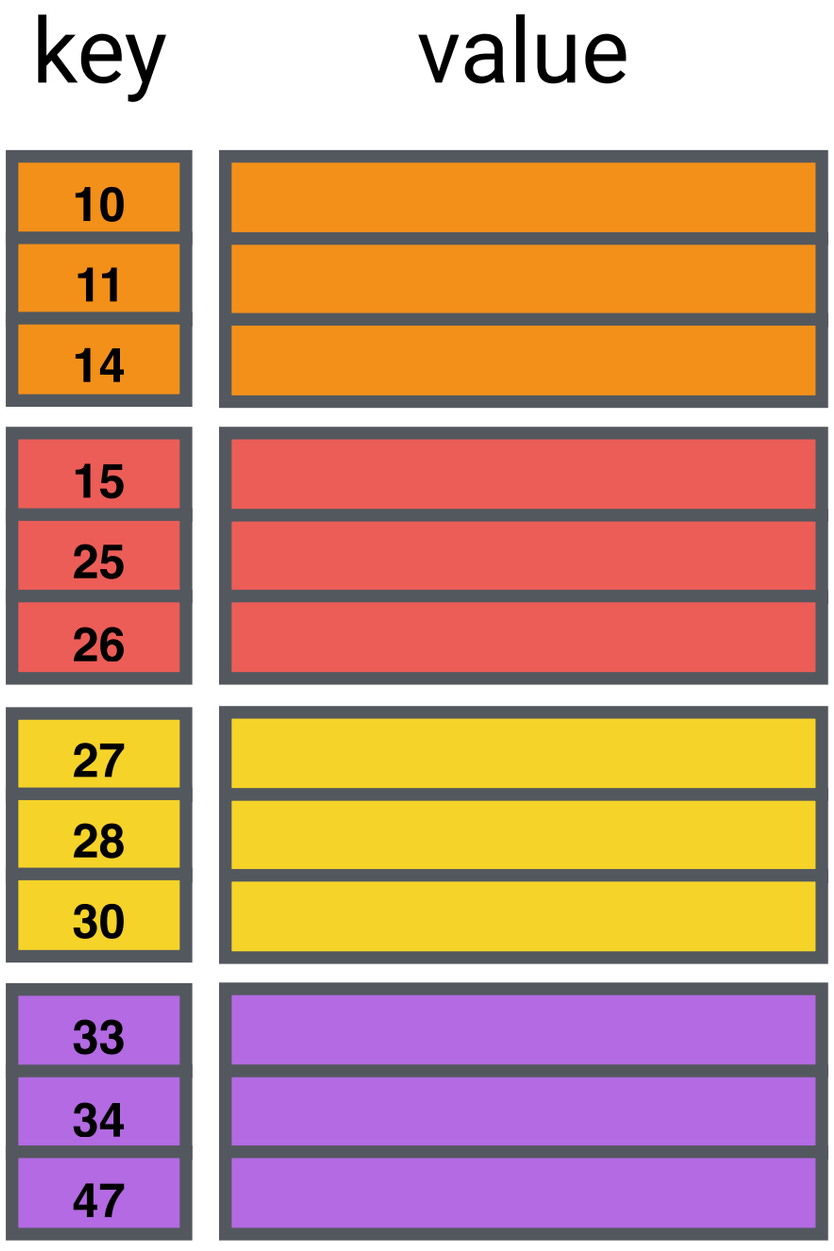
Packing



New key = smallest key in the pack

New value = a pack of key-value pairs

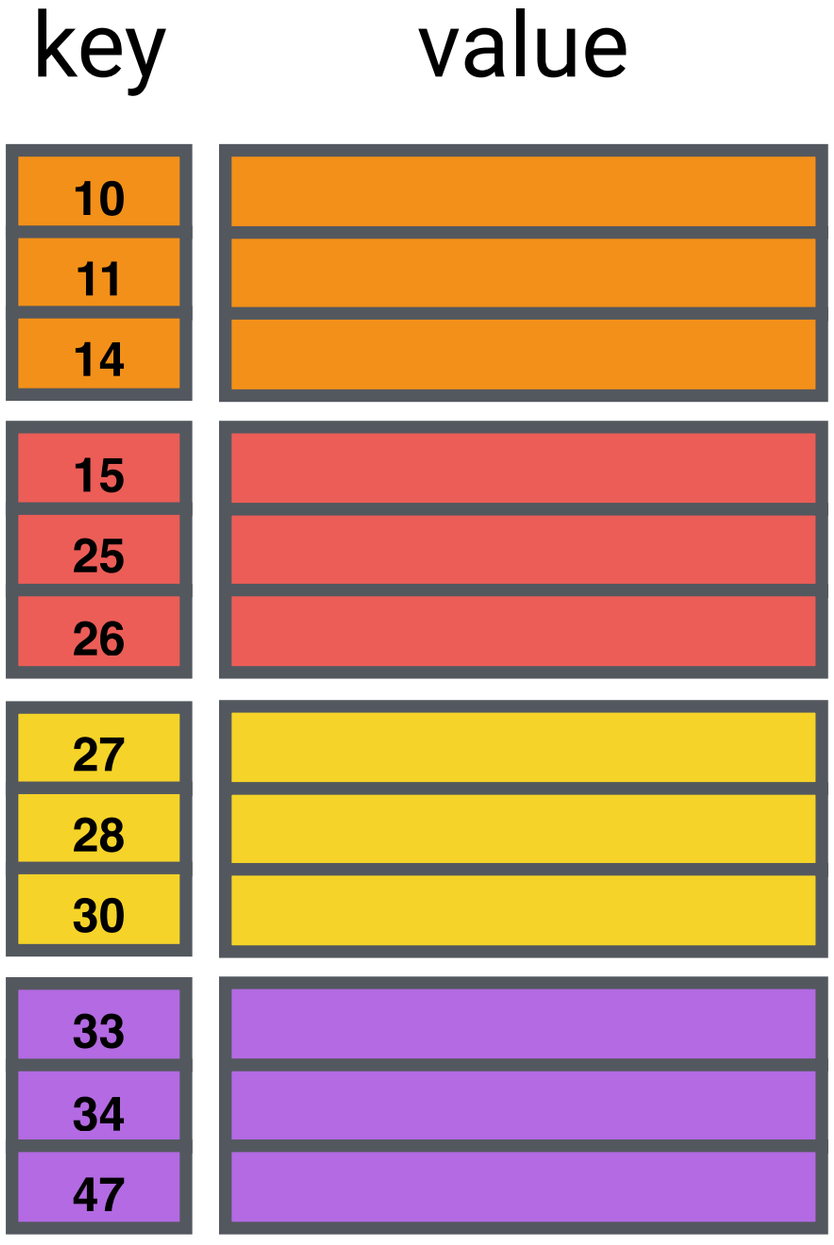
Packing



New key =
smallest key
in the pack

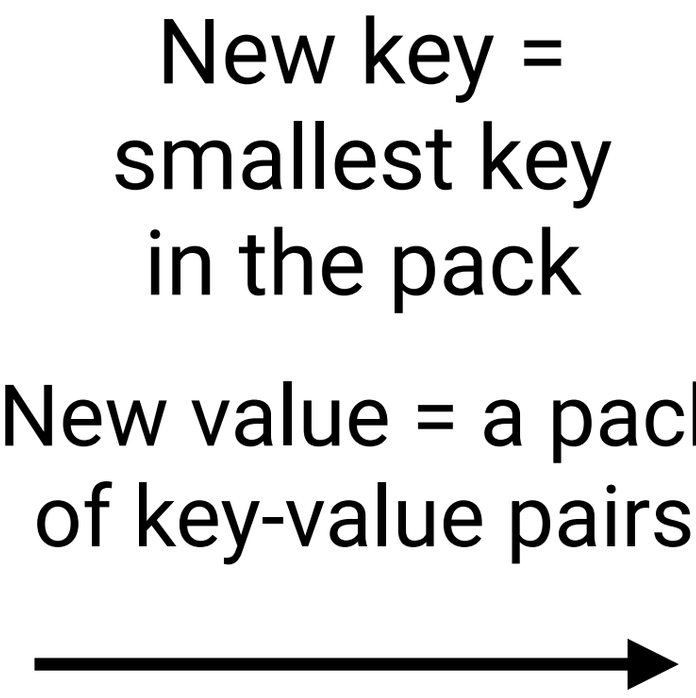
New value = a pack
of key-value pairs

Packing



New key = smallest key in the pack

New value = a pack of key-value pairs



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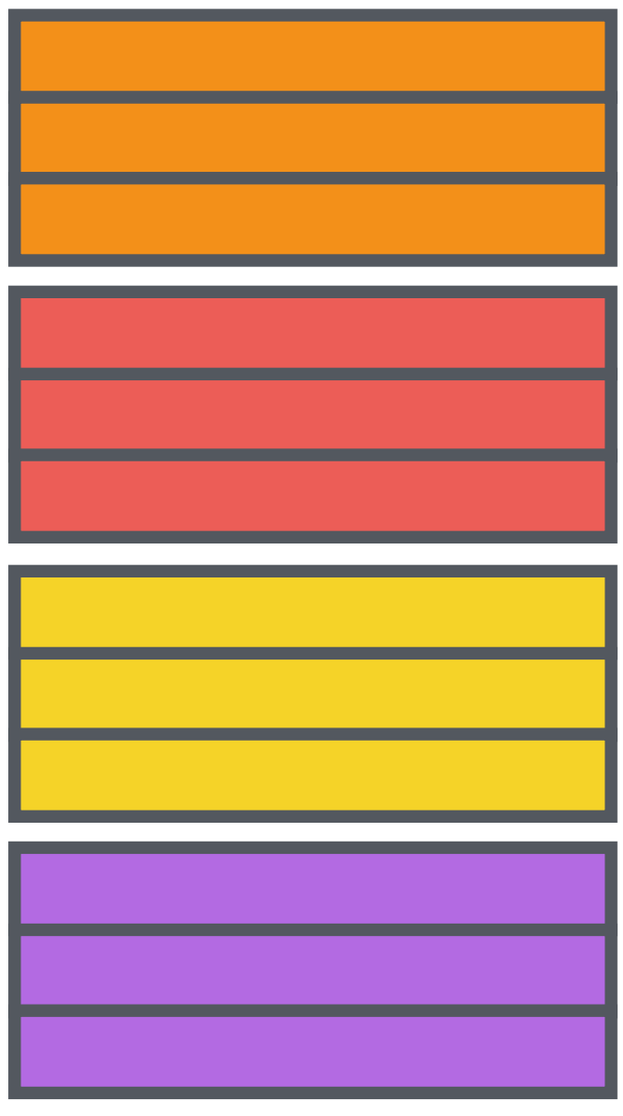
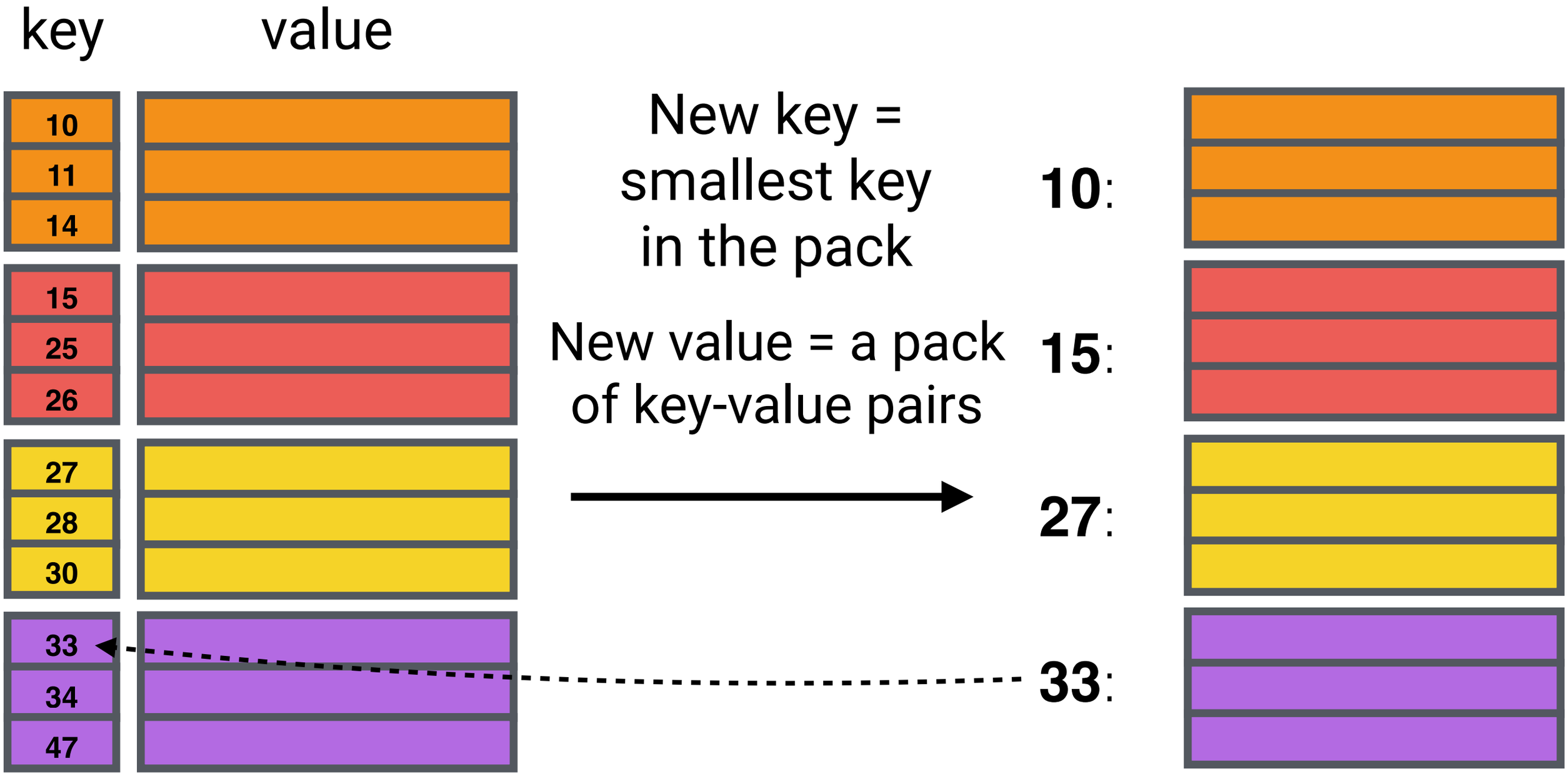


Packing


key
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New key = smallest key in the pack
New value = a pack of key-value pairs
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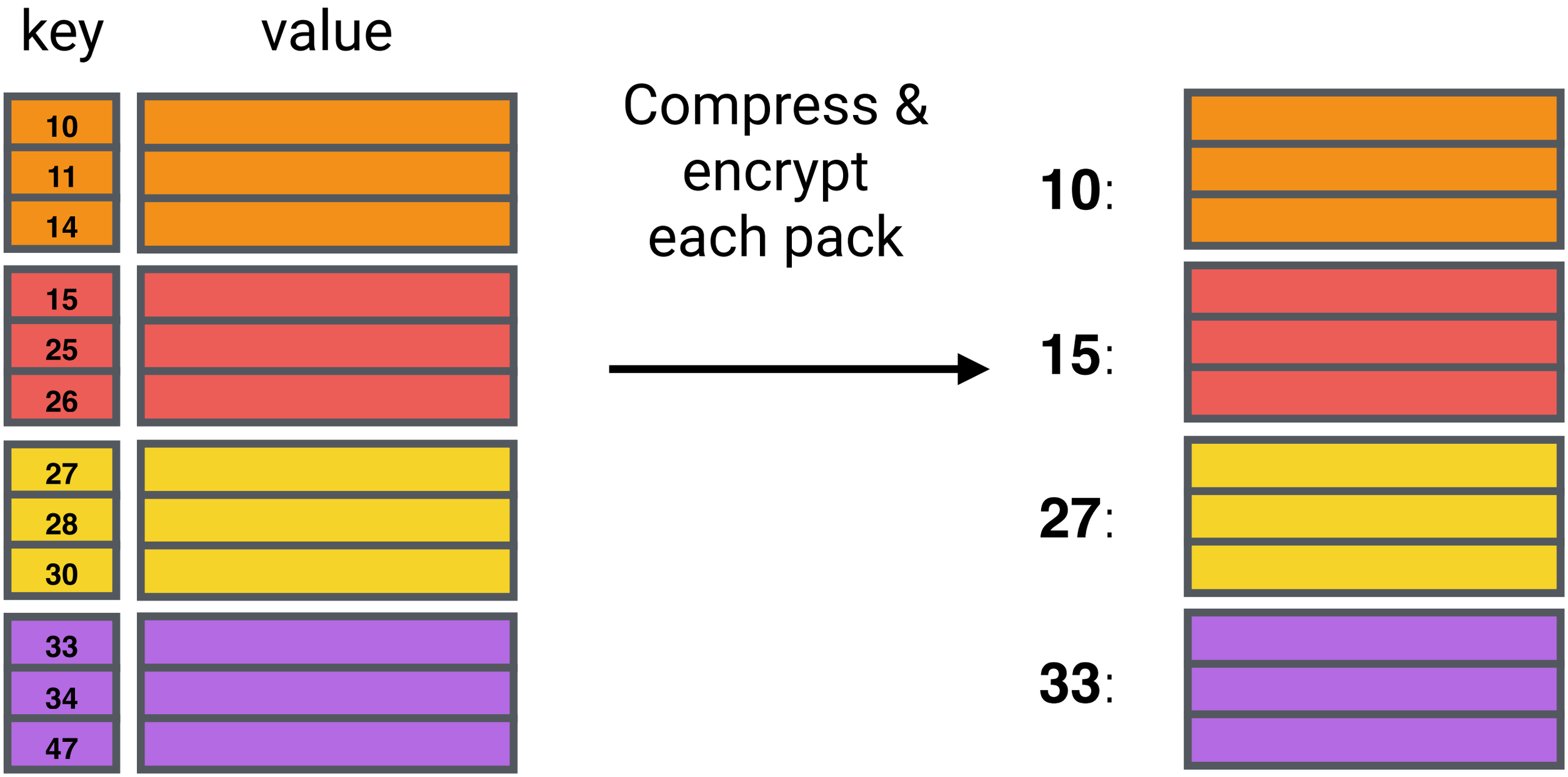
27:
33:

Packing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Compress &
encrypt
each pack
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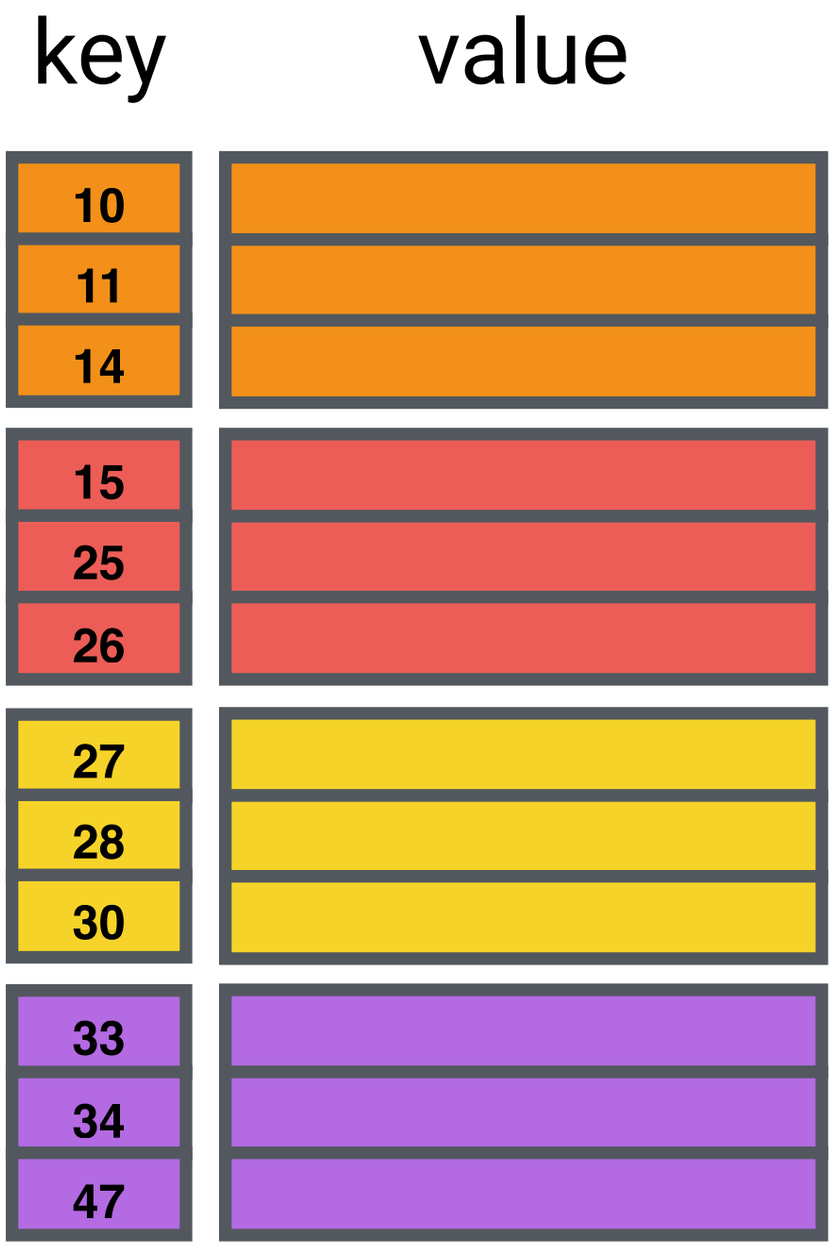
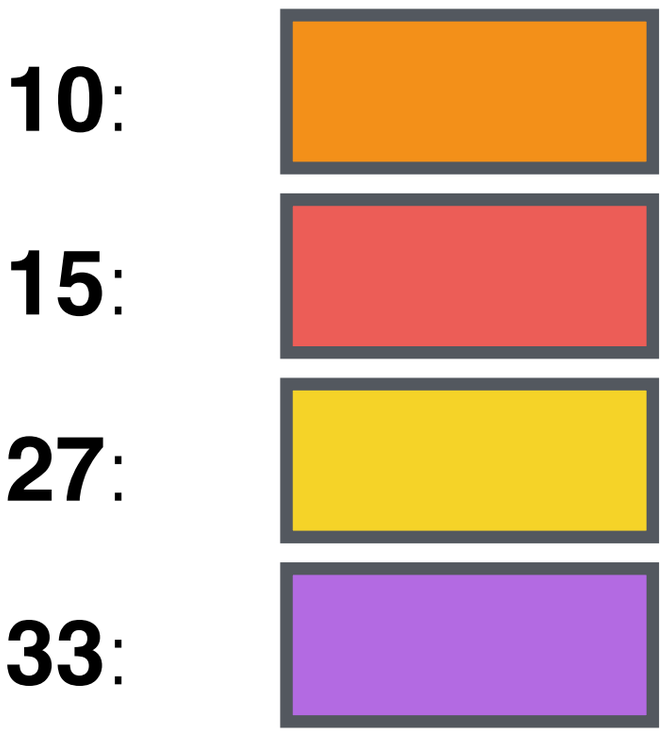
15:
27:
33:

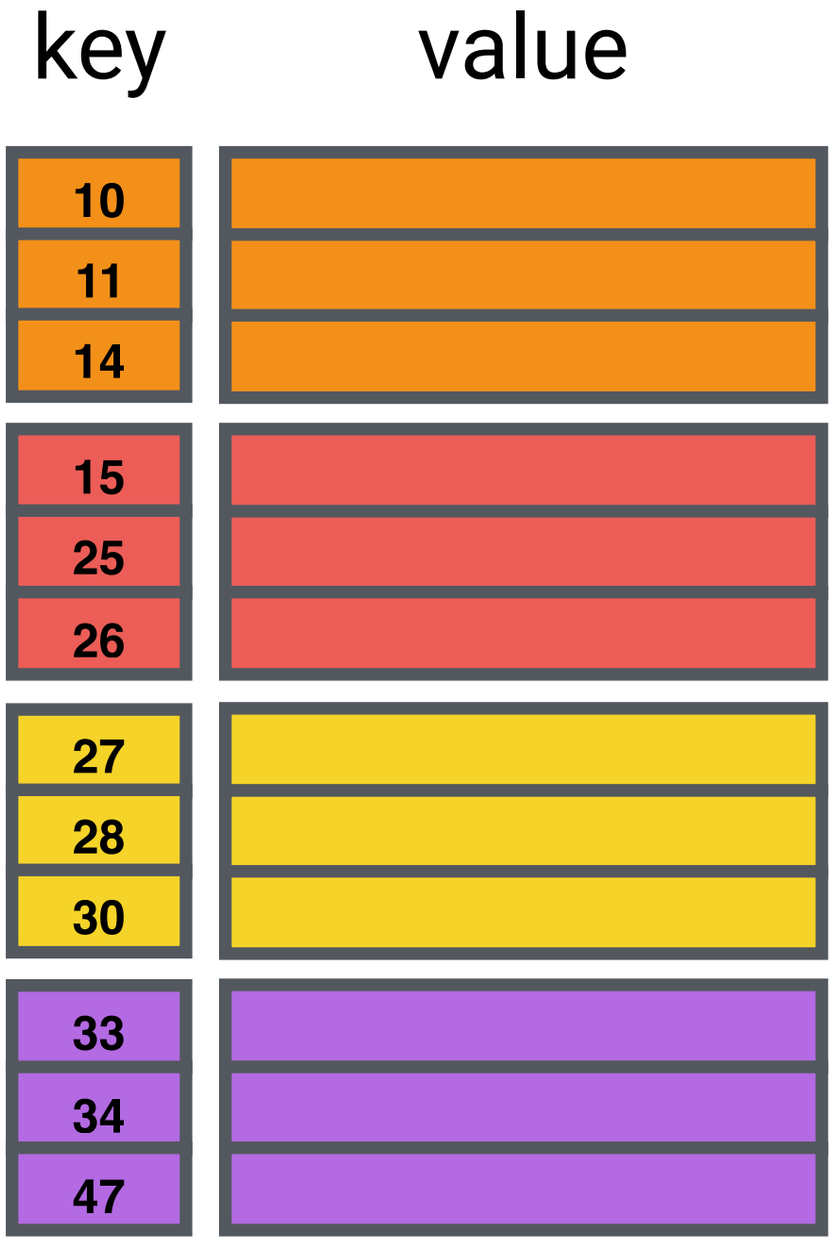
Packing



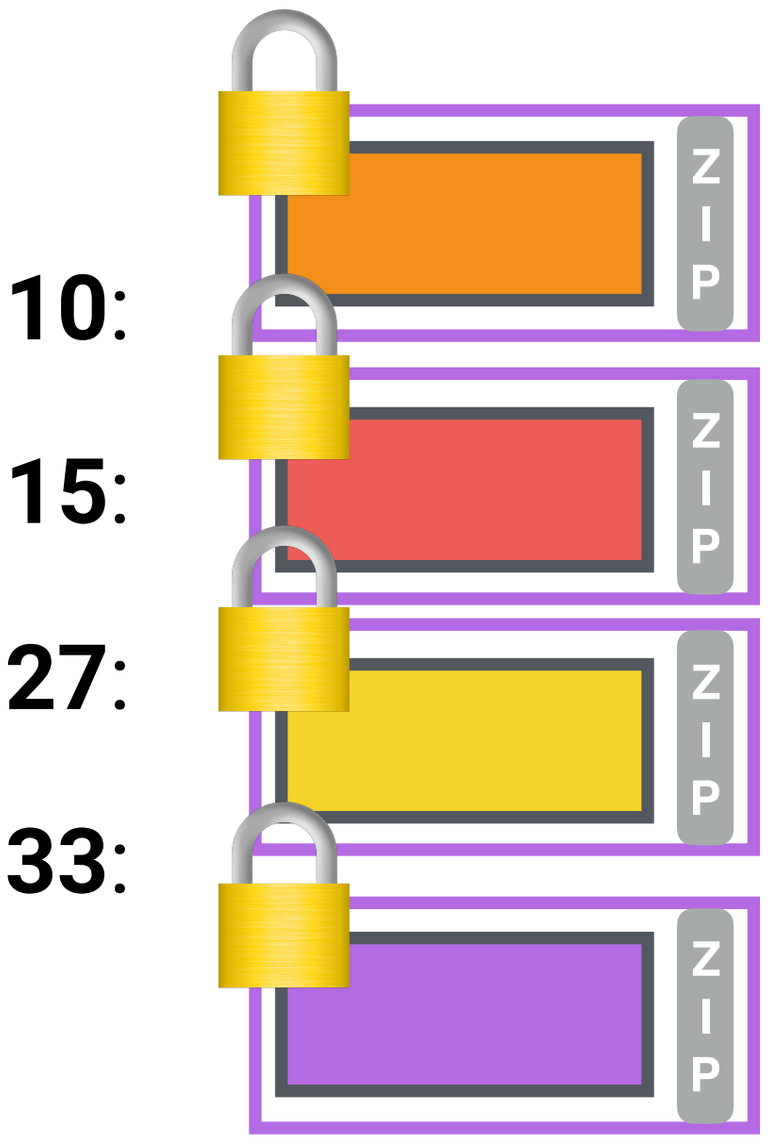
Compress & encrypt each pack



Packing



Compress & encrypt each pack



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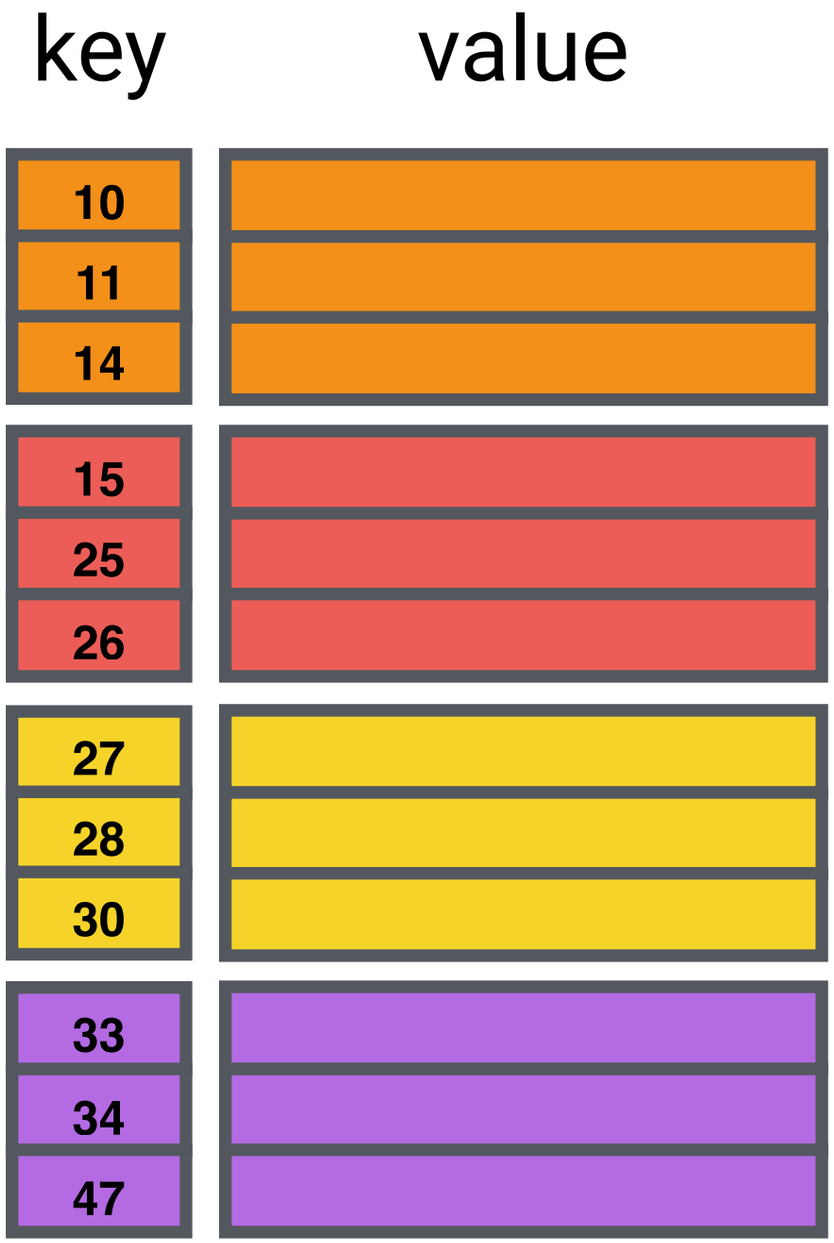
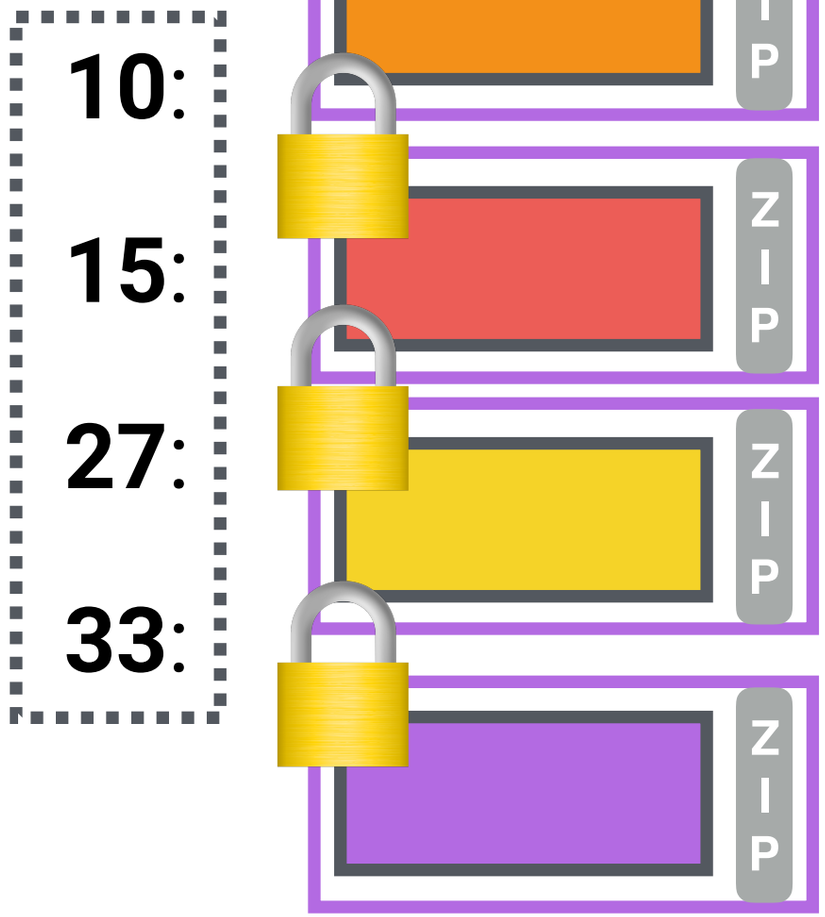
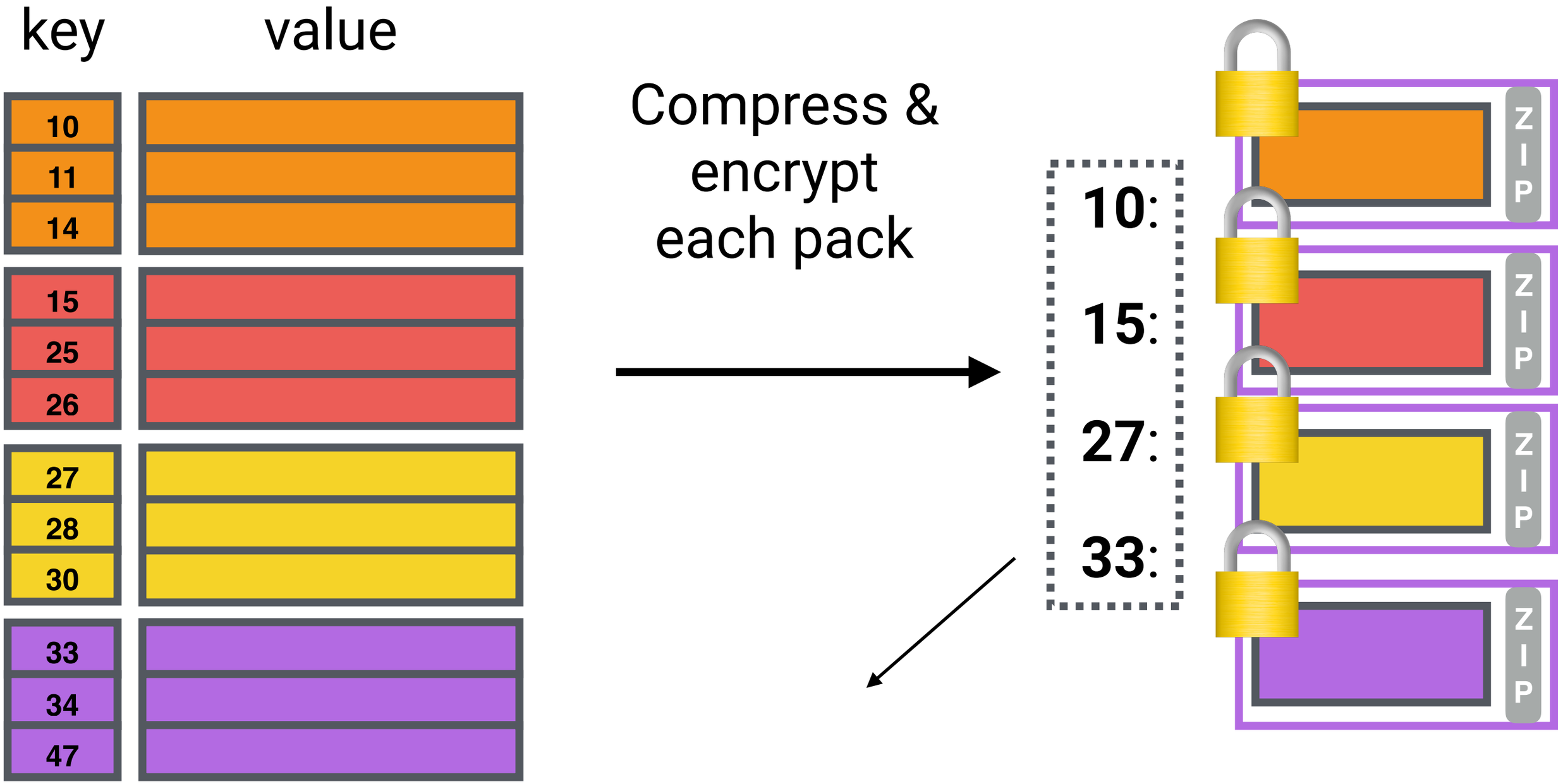


Compress & encrypt each pack



Packing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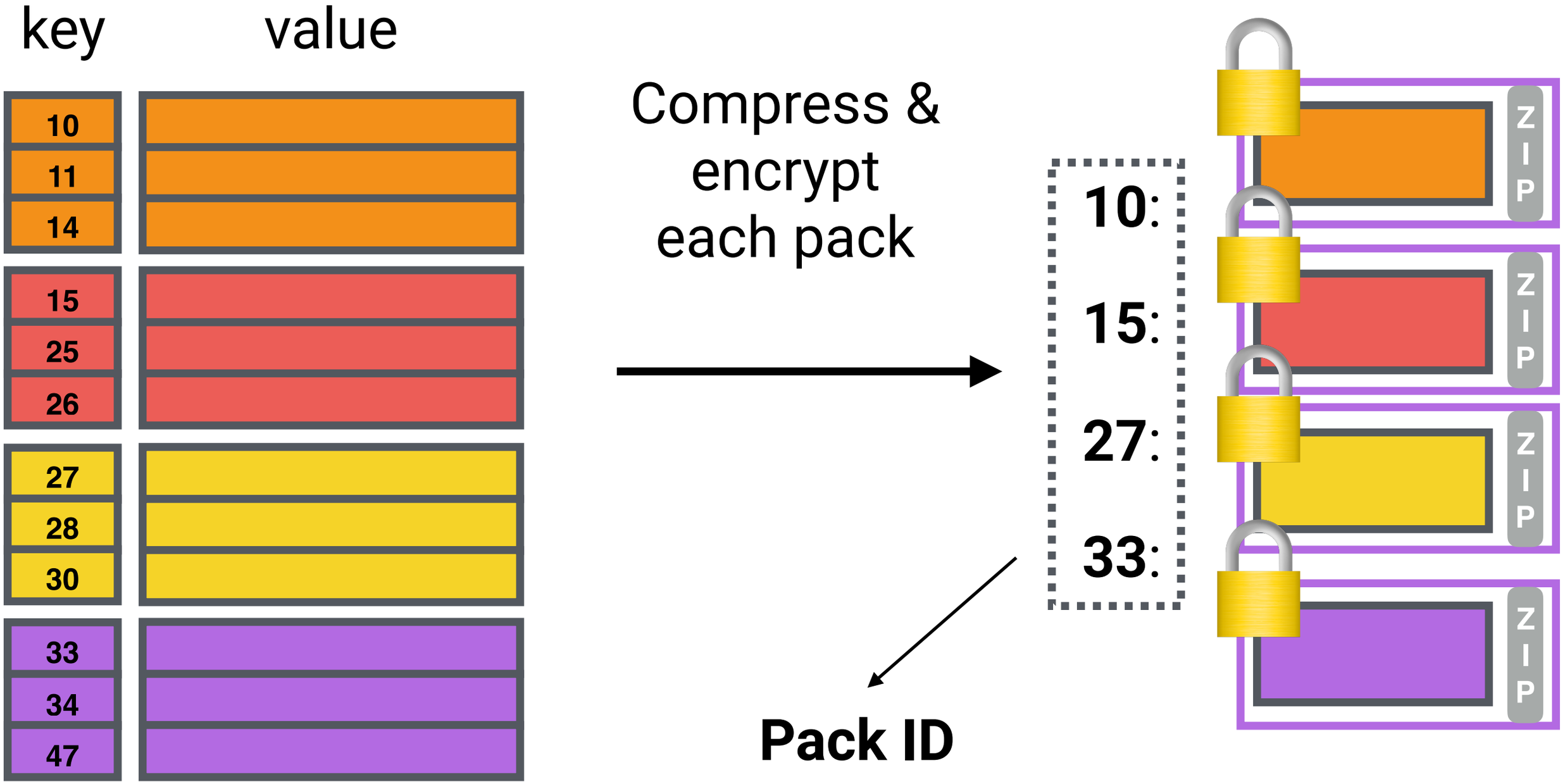
Packing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Compress &
encrypt
each pack
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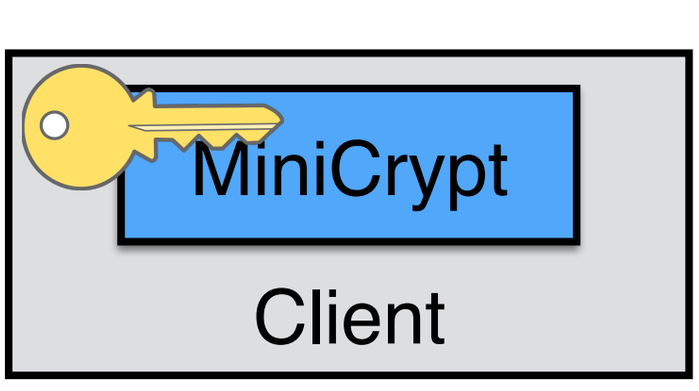
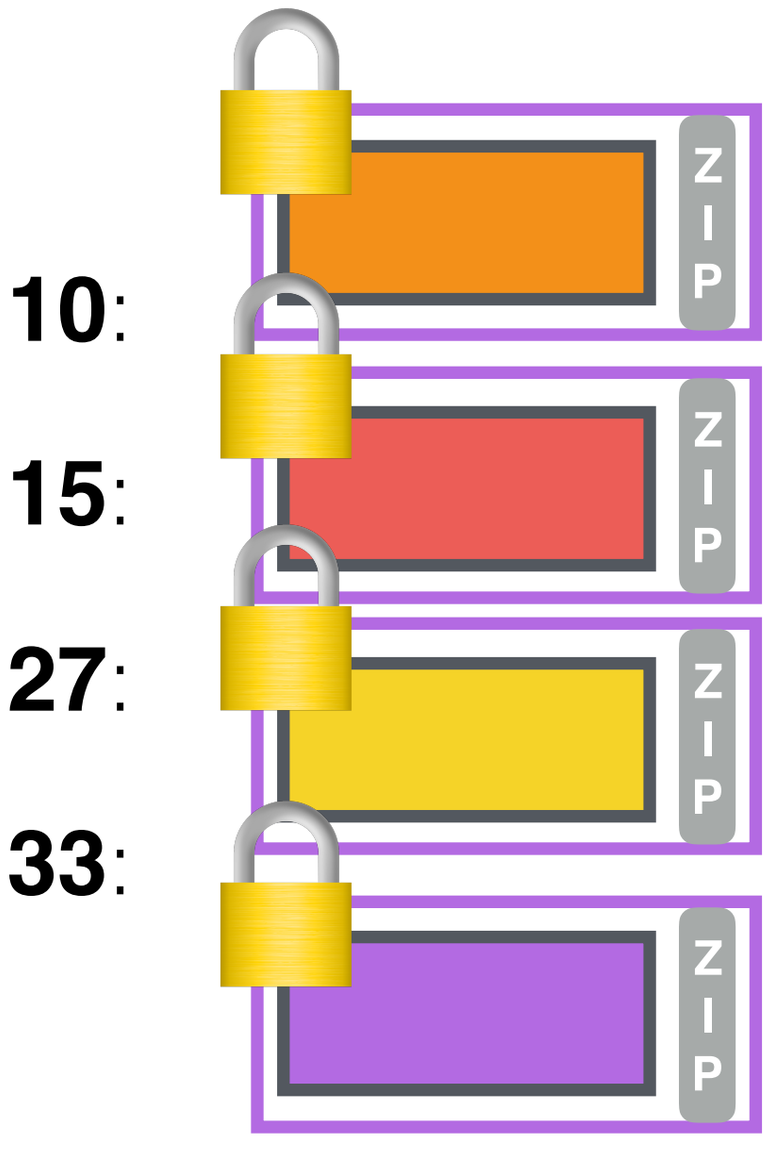
ZIP
Pack ID

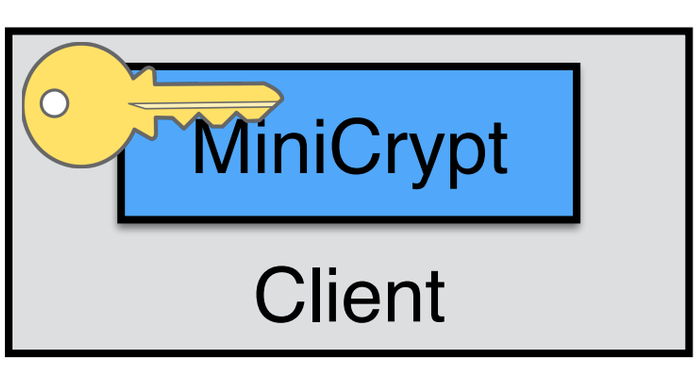
Single-key get



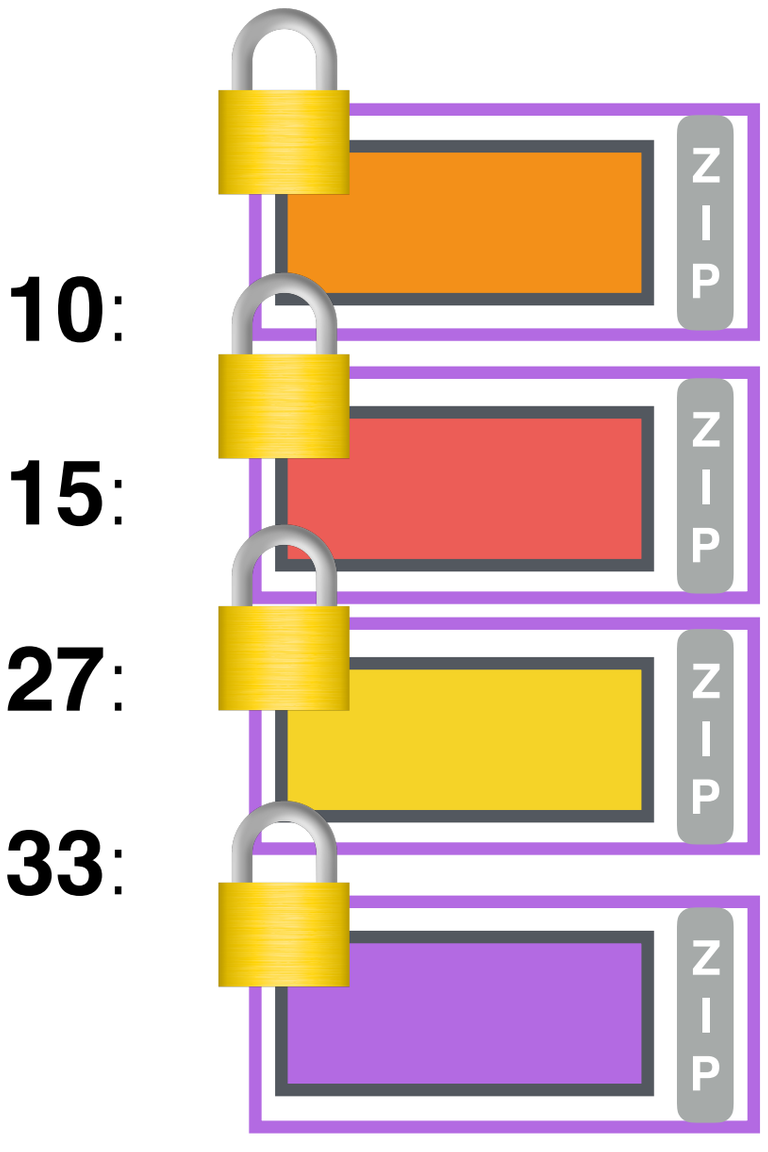


get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

Single-key get

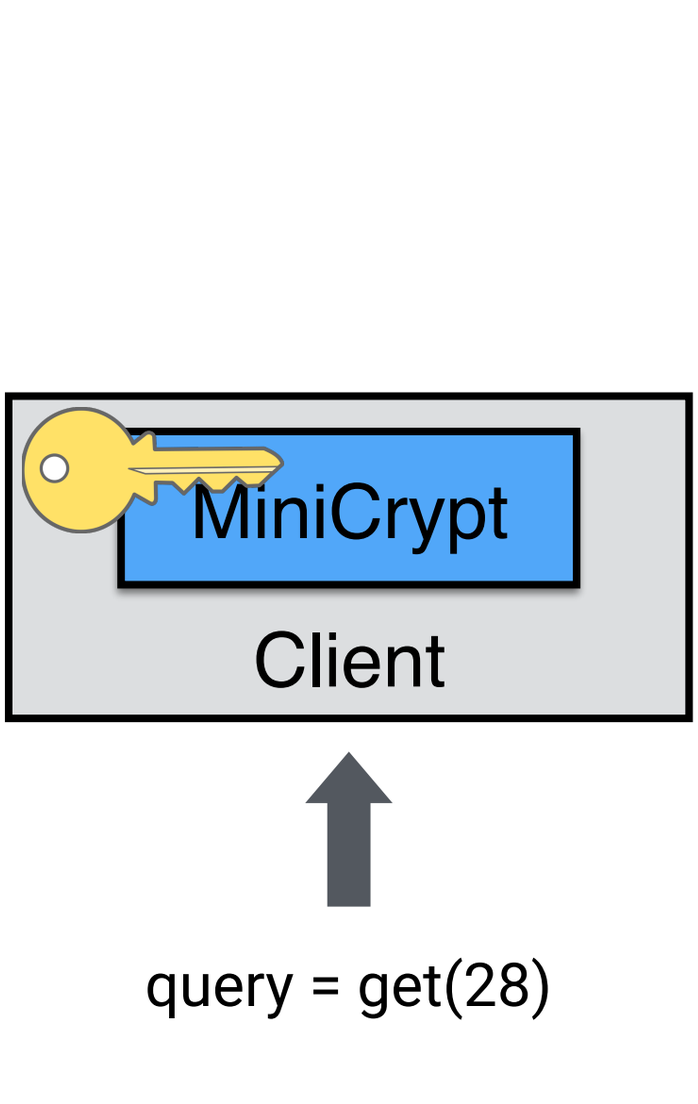


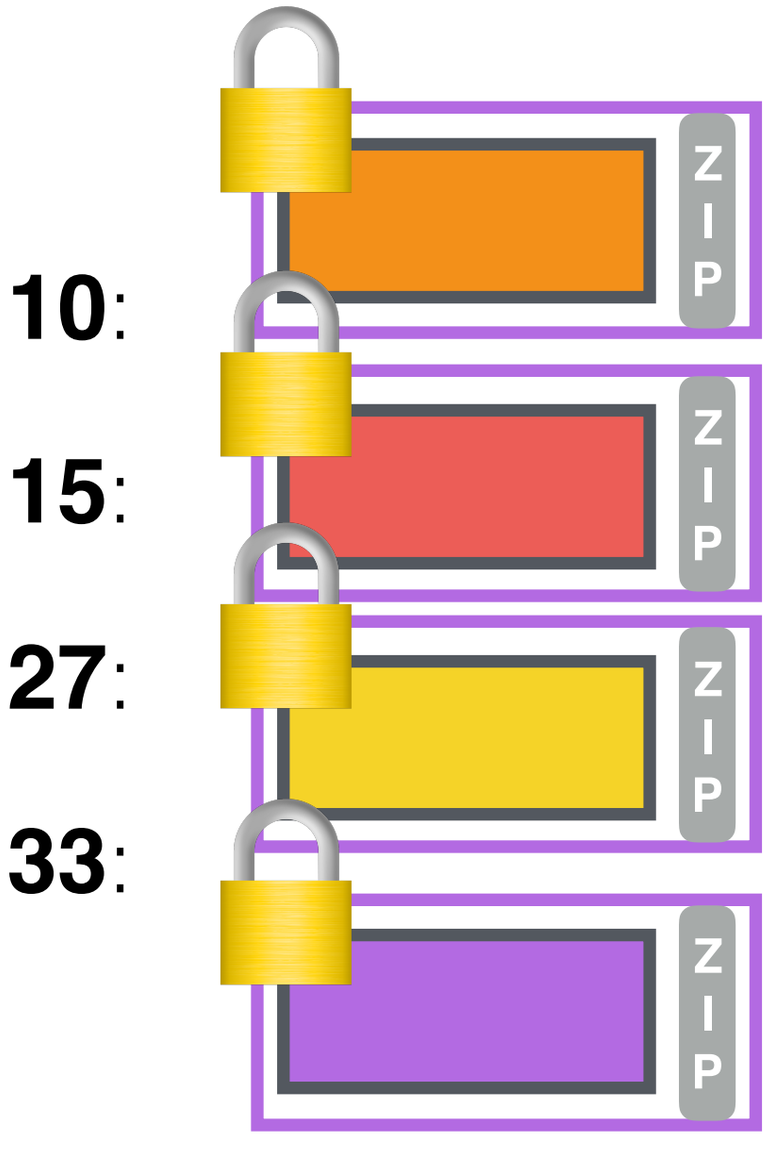
query = get(28)



get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

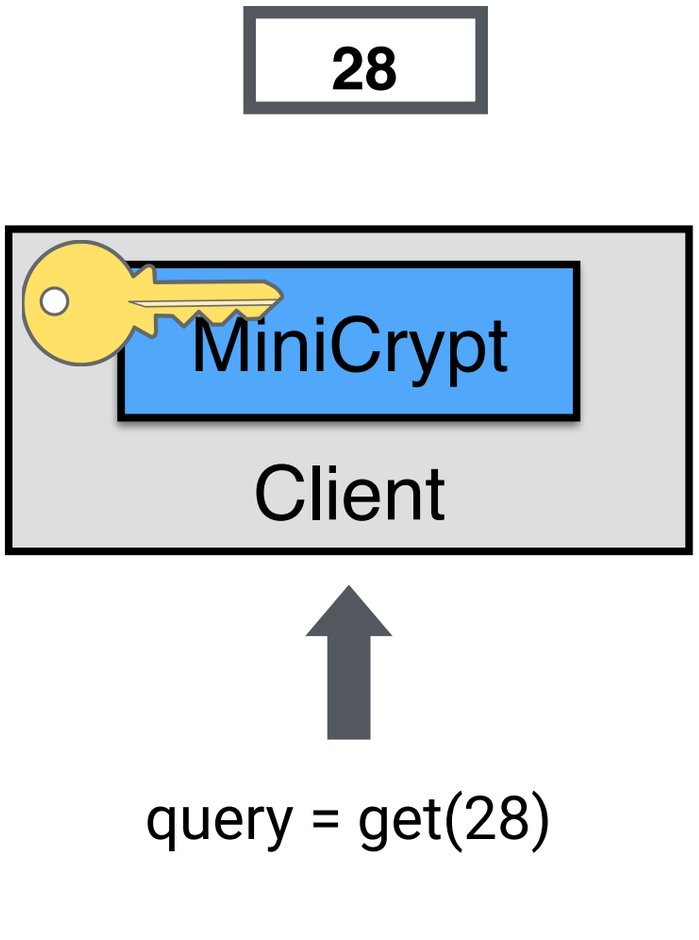
Single-key get

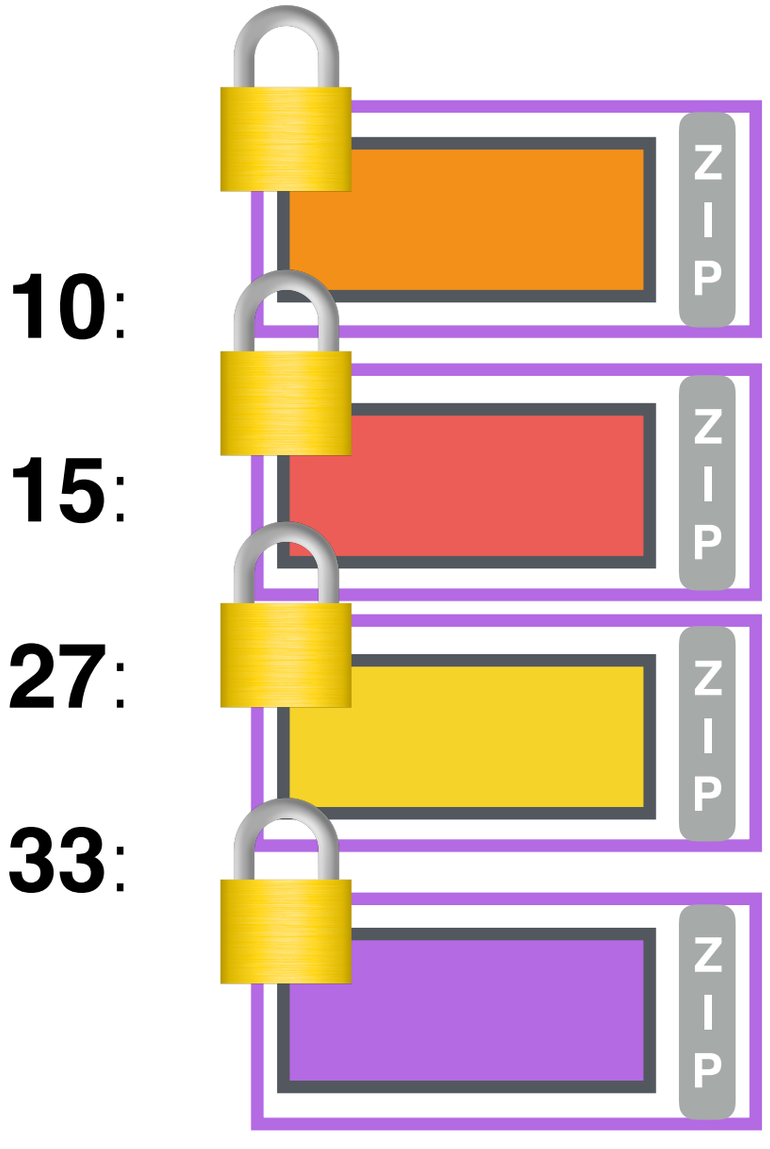




get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

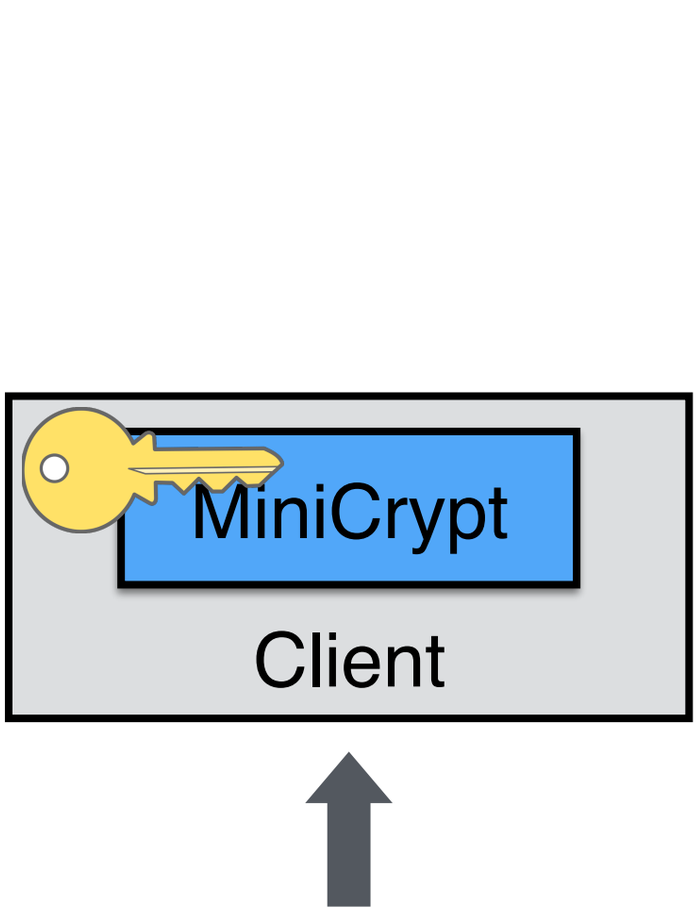
Single-key get

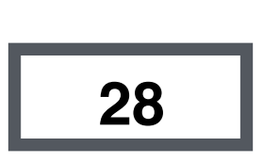


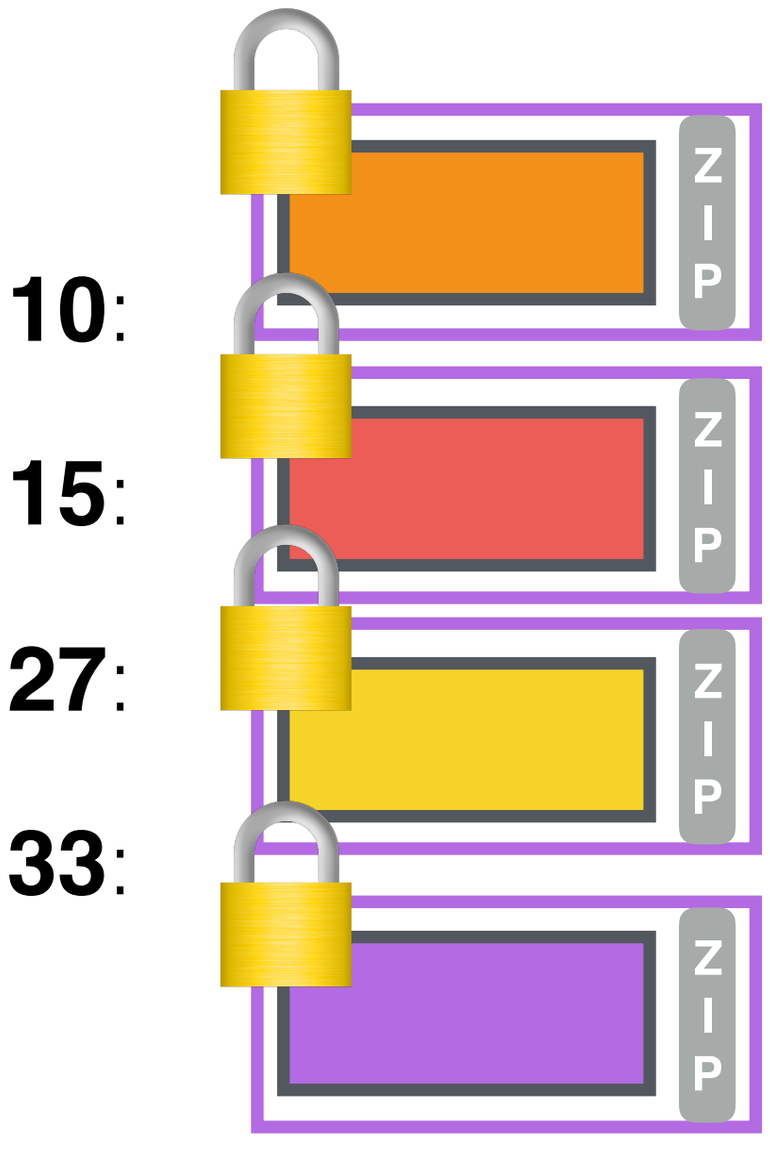


get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

Single-key get

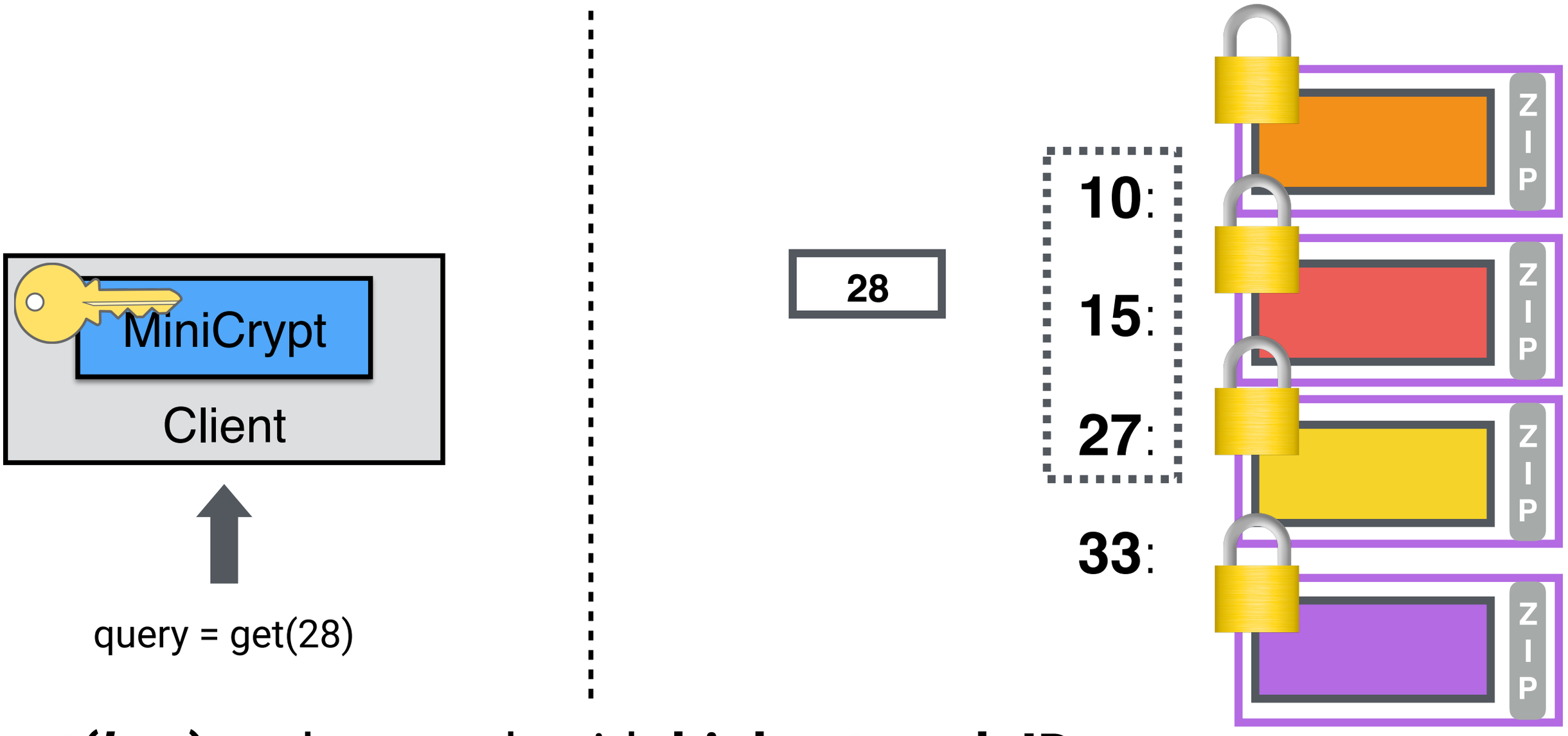






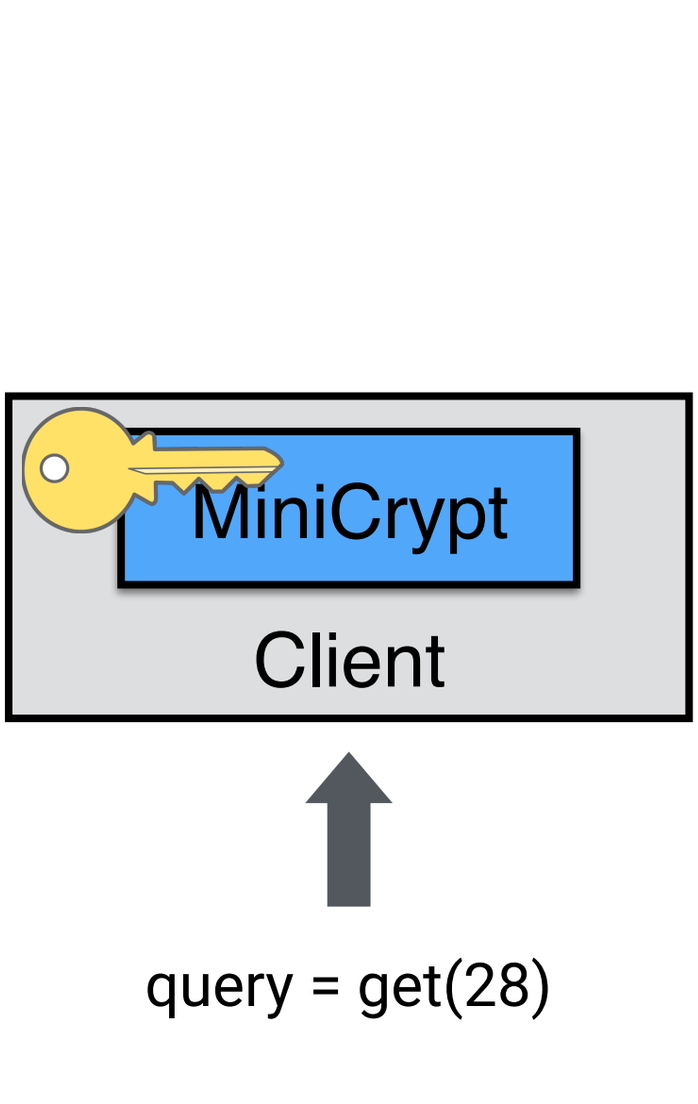
get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

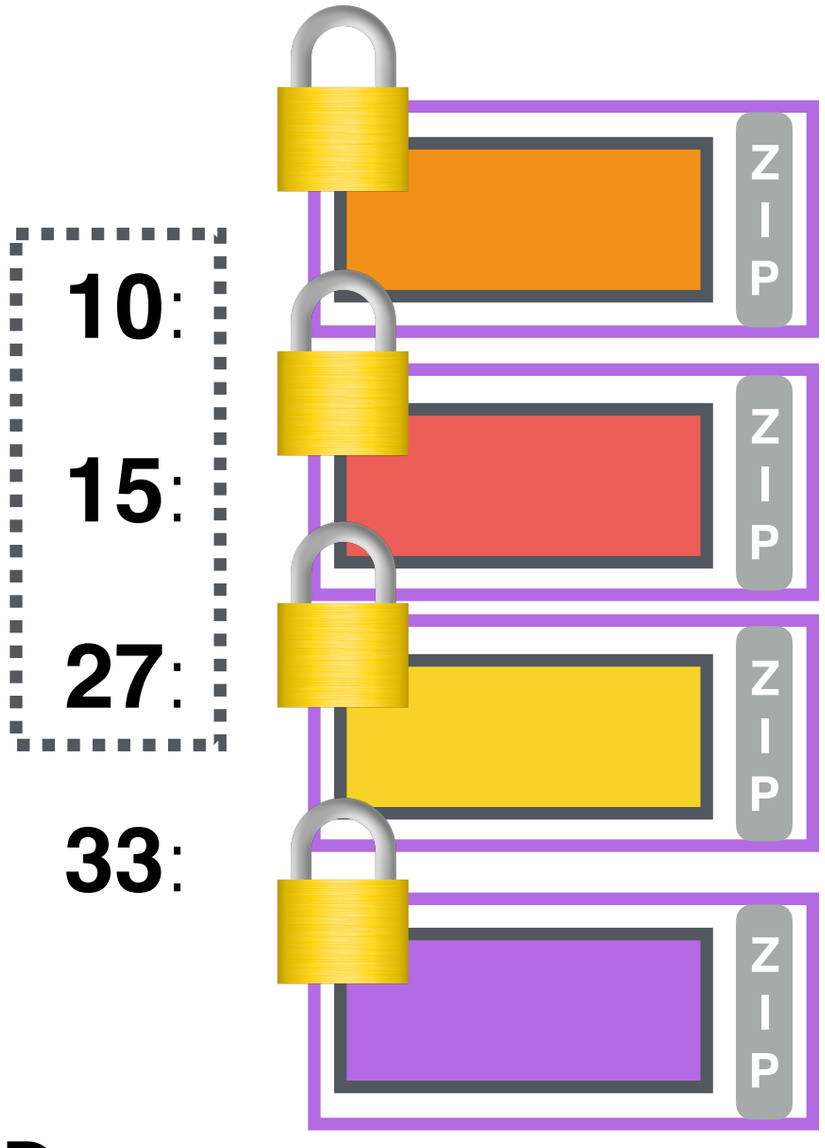
Single-key get



get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

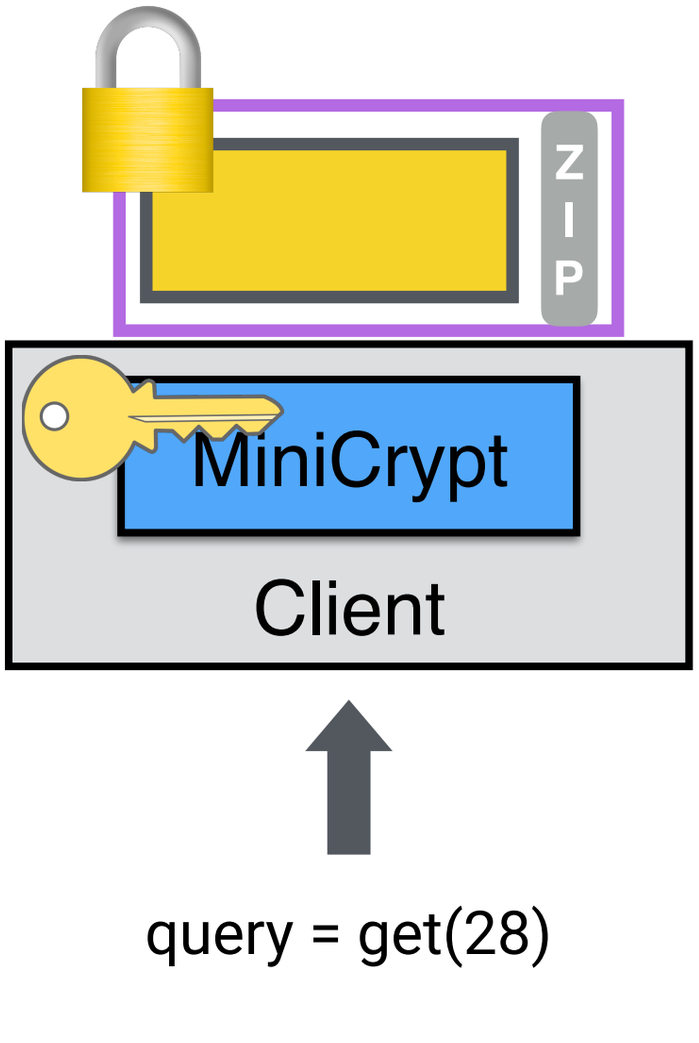
Single-key get

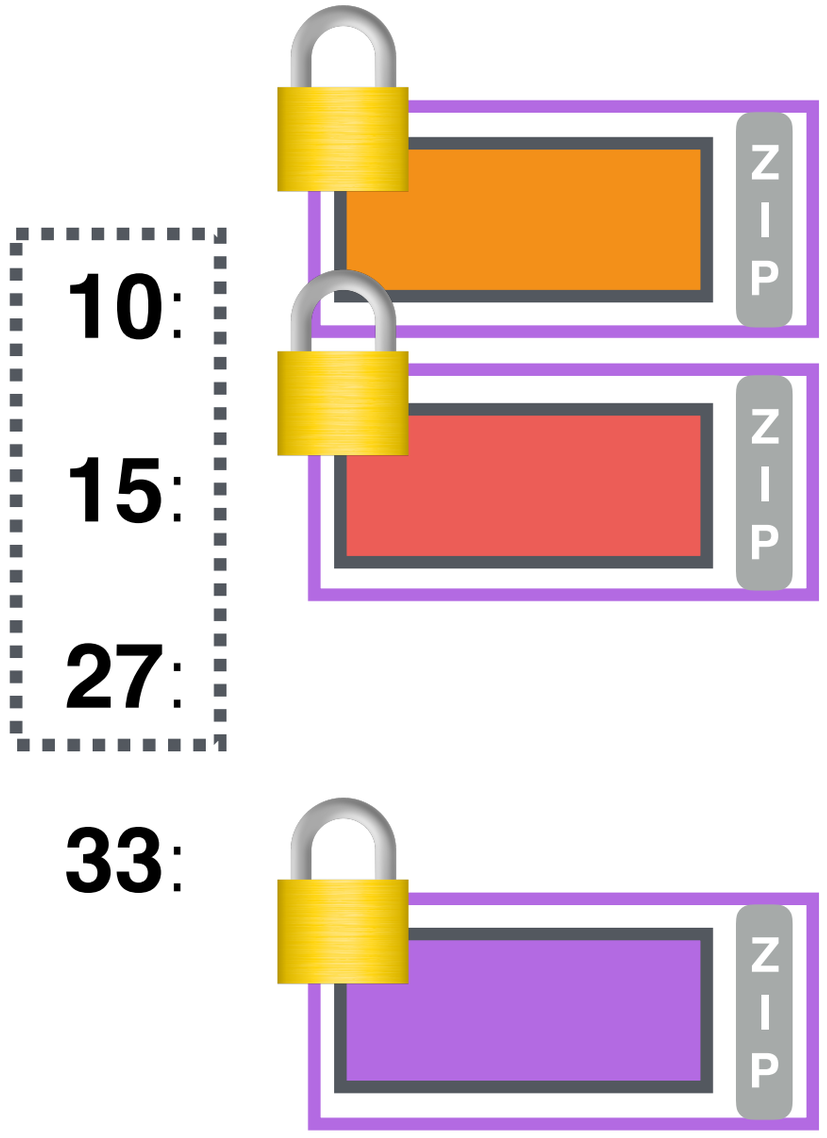




get(*key*): select pack with **highest pack ID** from all pack ID's that are at most *key*

Single-key get





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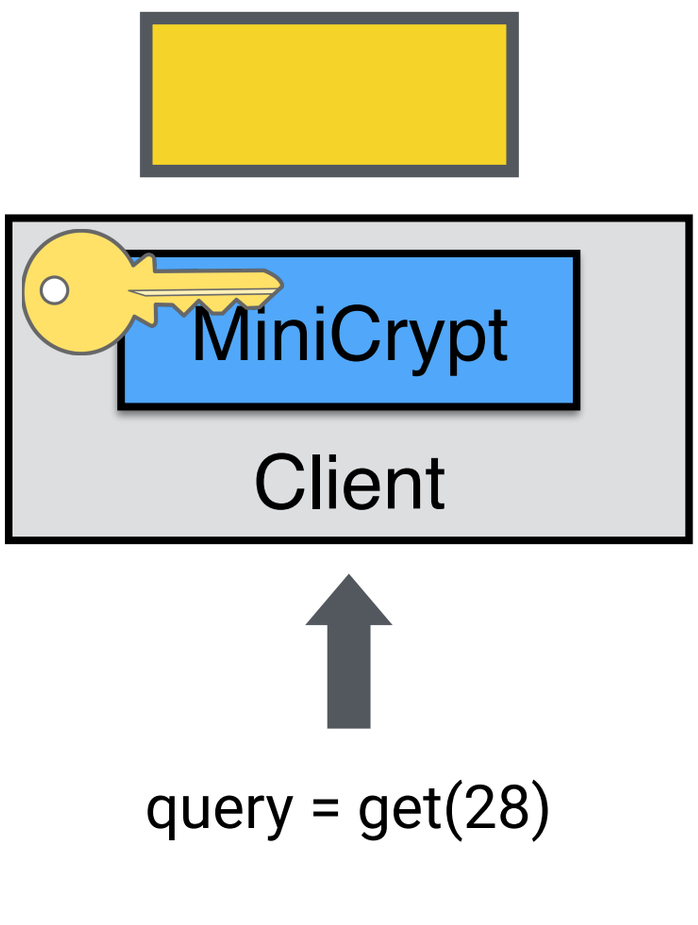
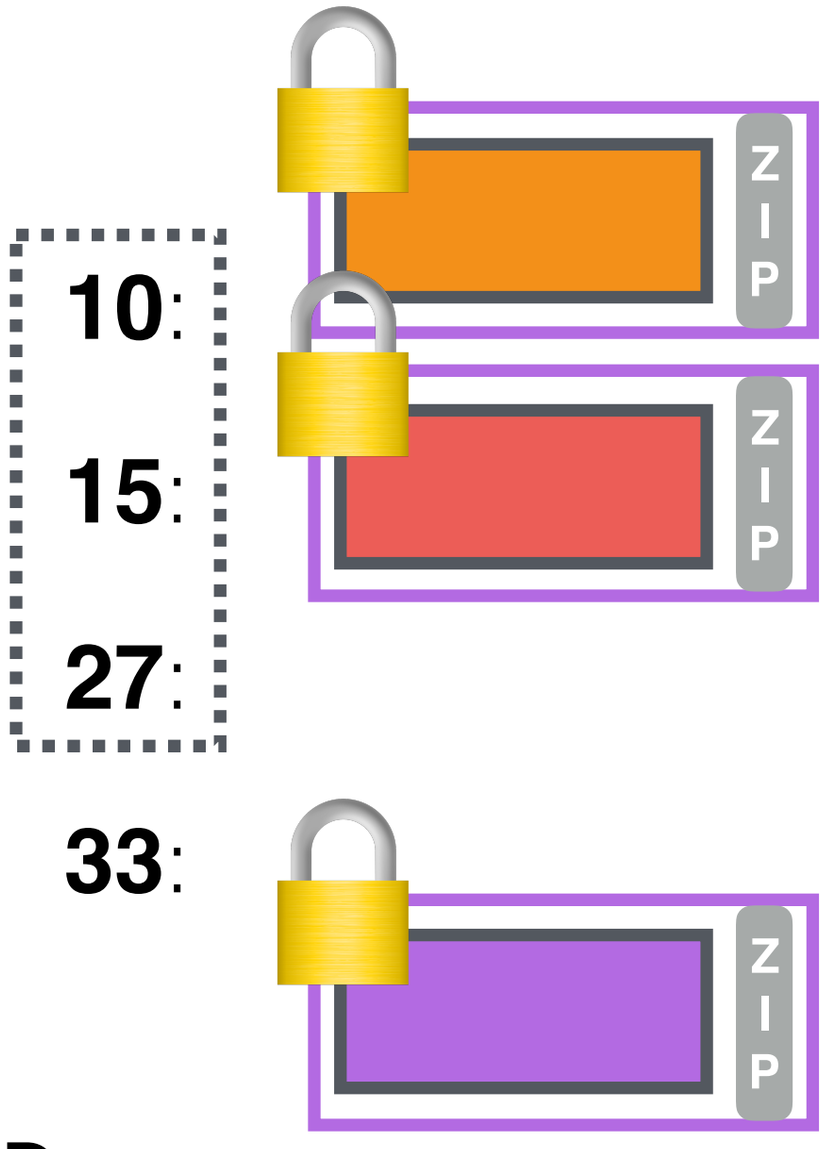
Single-key get





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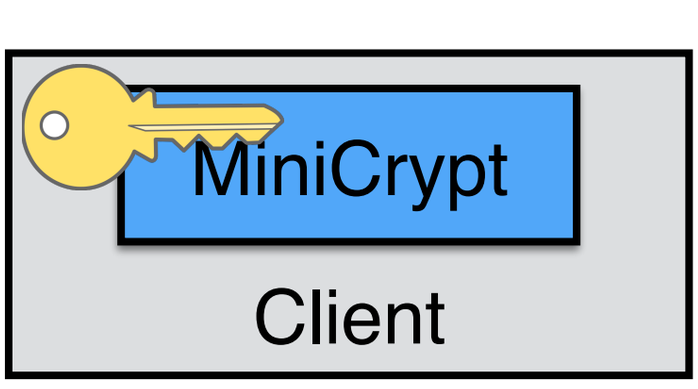
Single-key put



put(*key, value*):
find pack using get()

10:

15:

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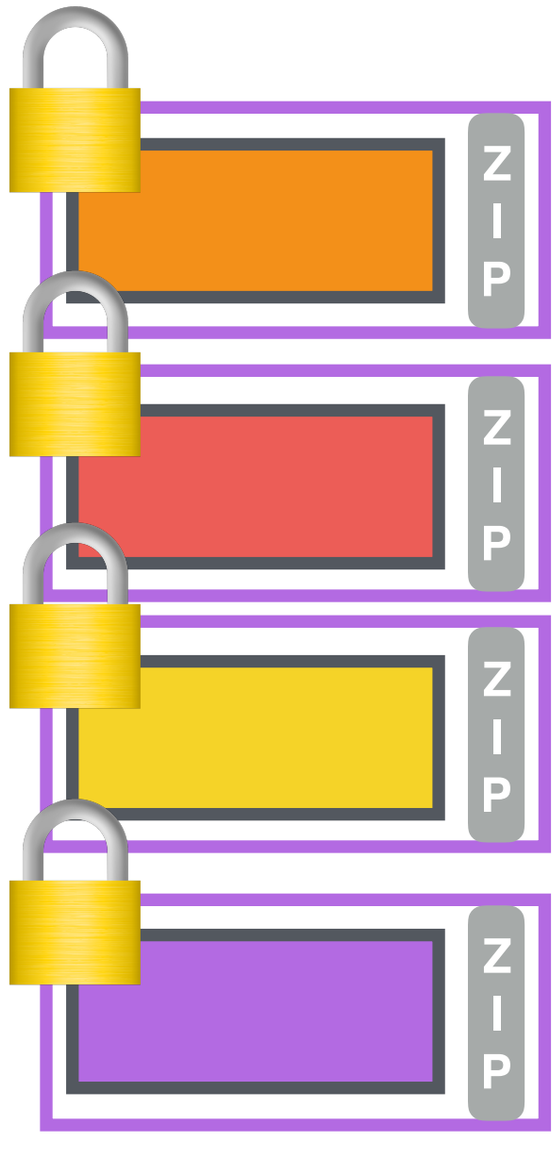
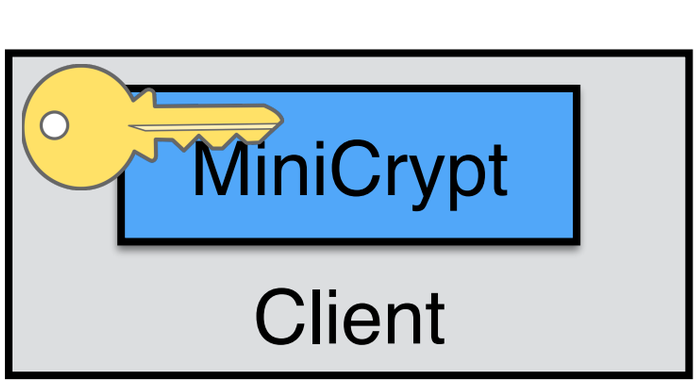
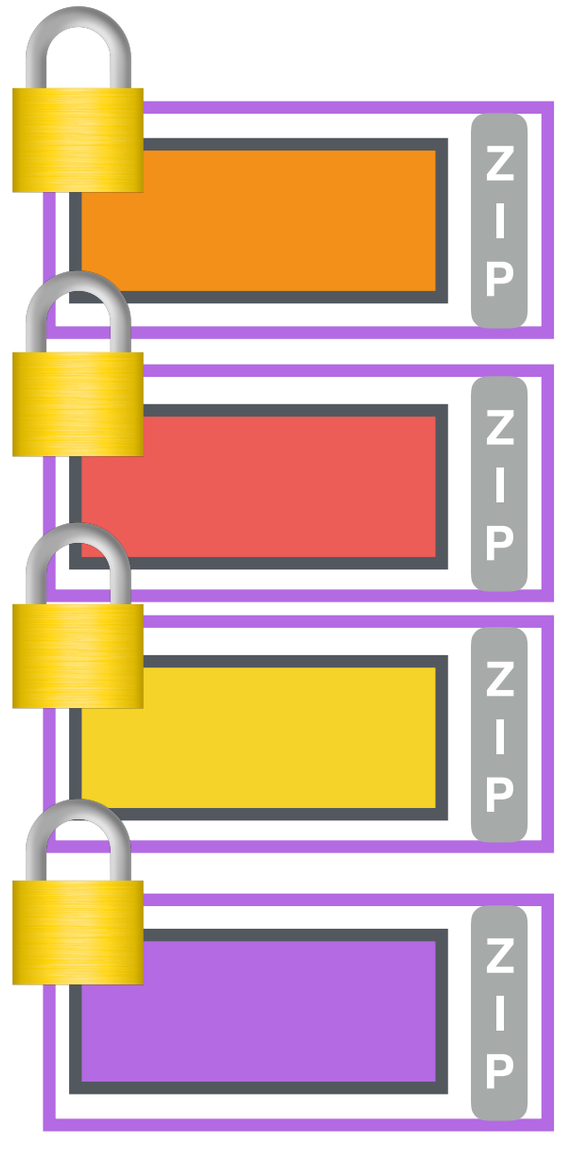


Single-key put

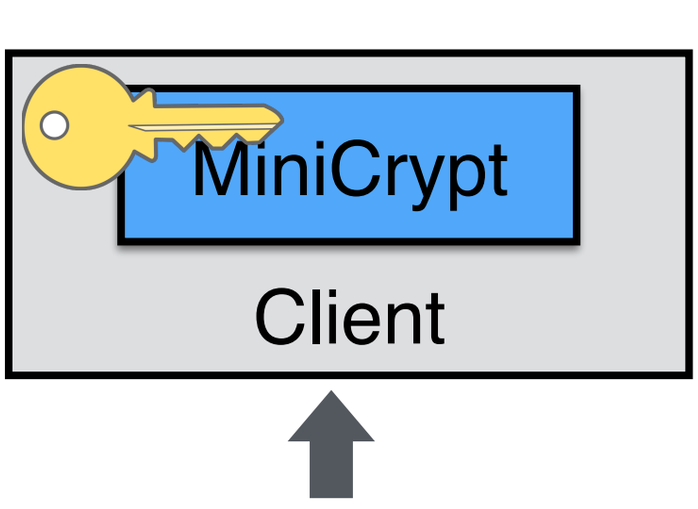


query = put(28, 5)

put(*key, value*):
find pack using get()



Single-key put



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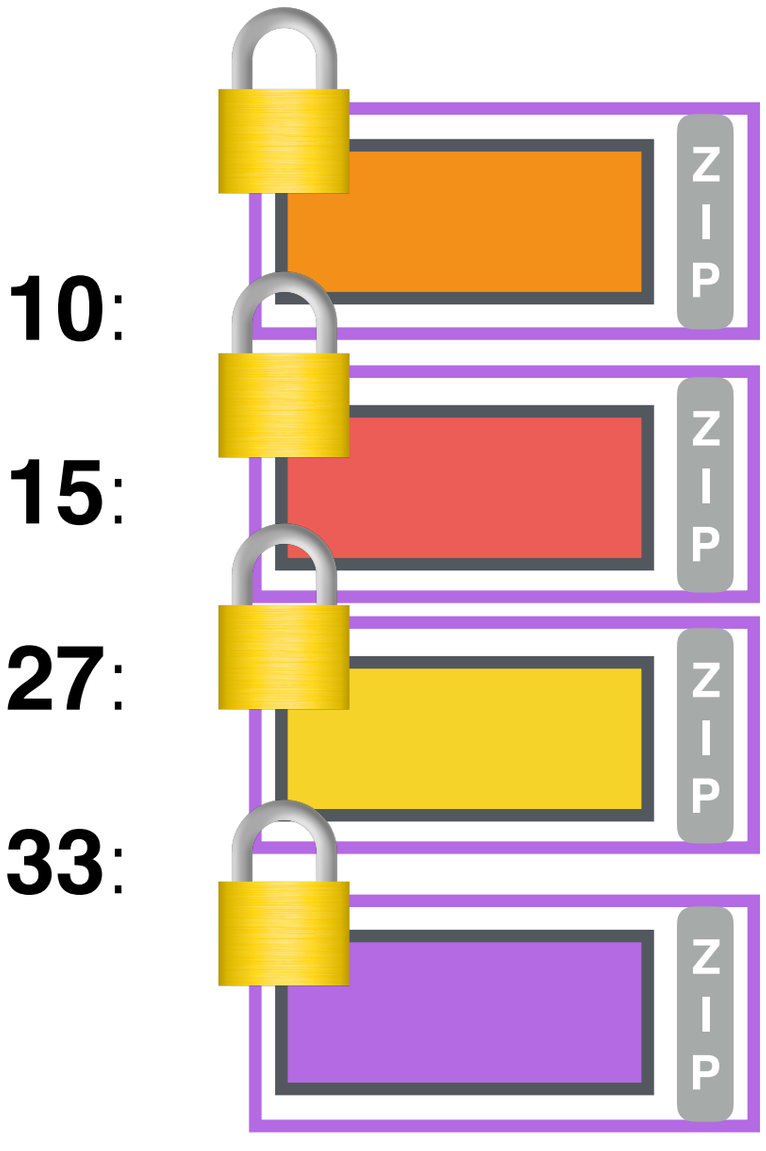
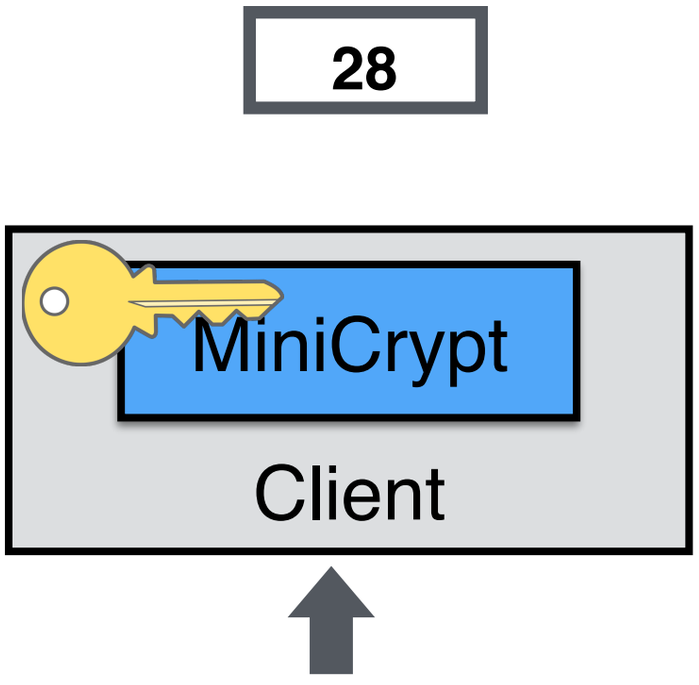


Single-key put



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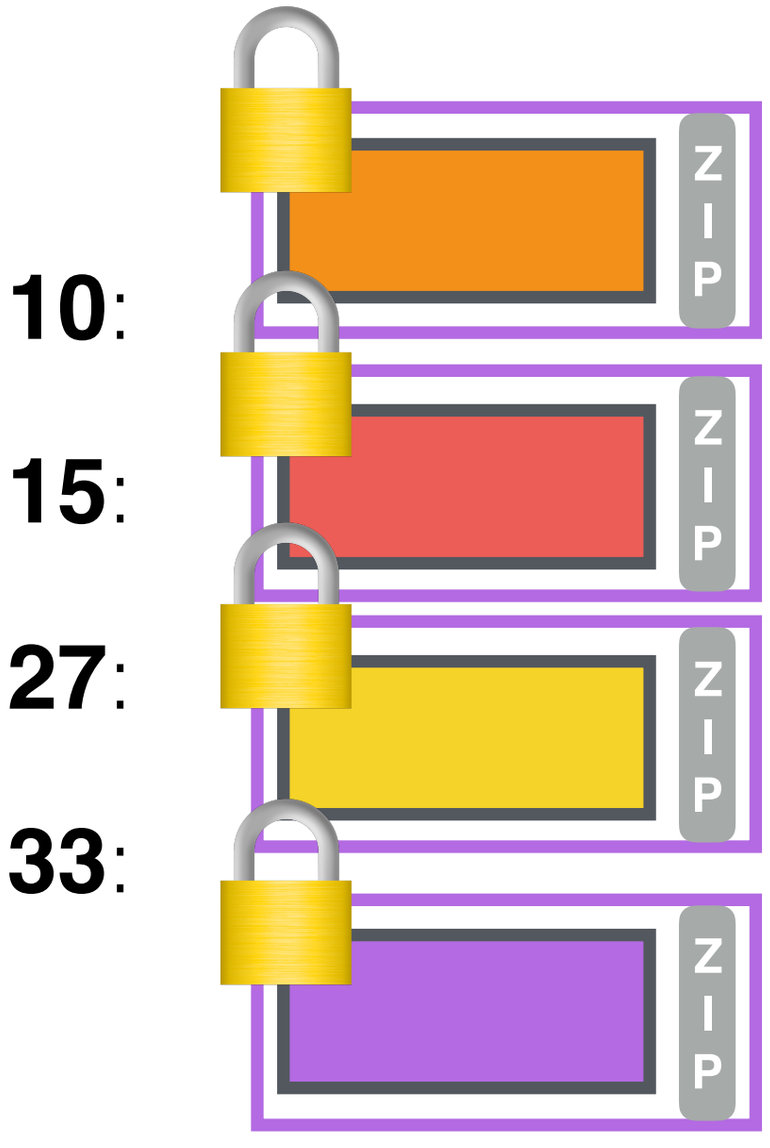
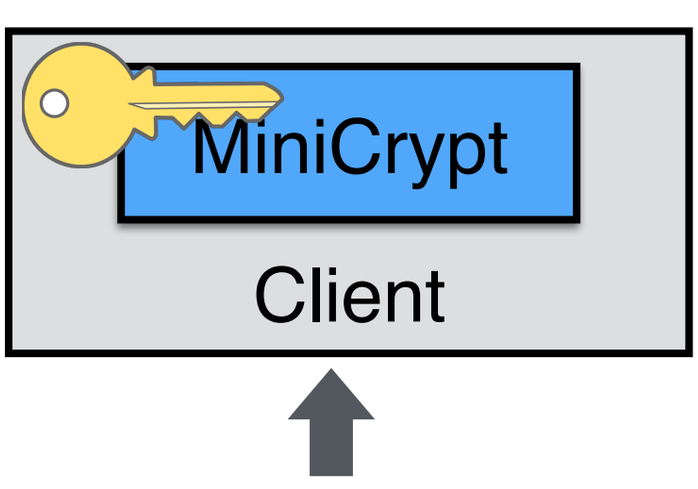


Single-key put



query = put(28, 5)

put(*key, value*):
find pack using get()

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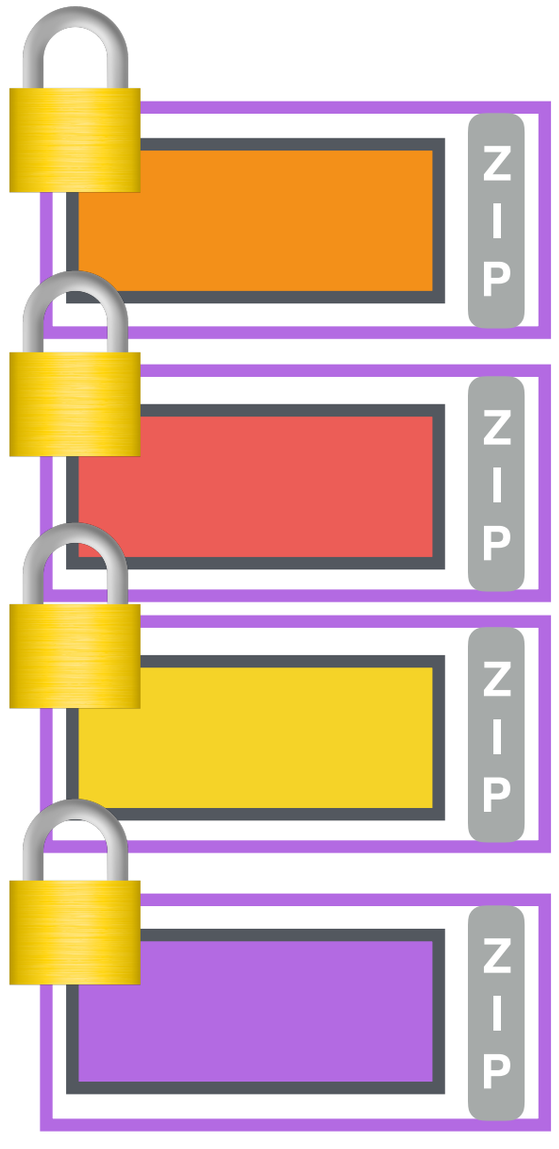
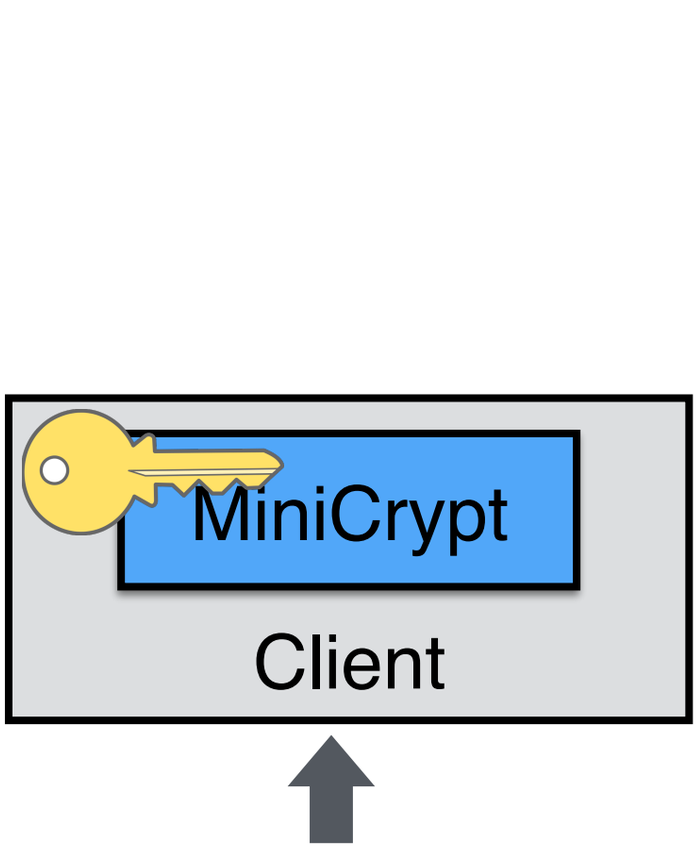
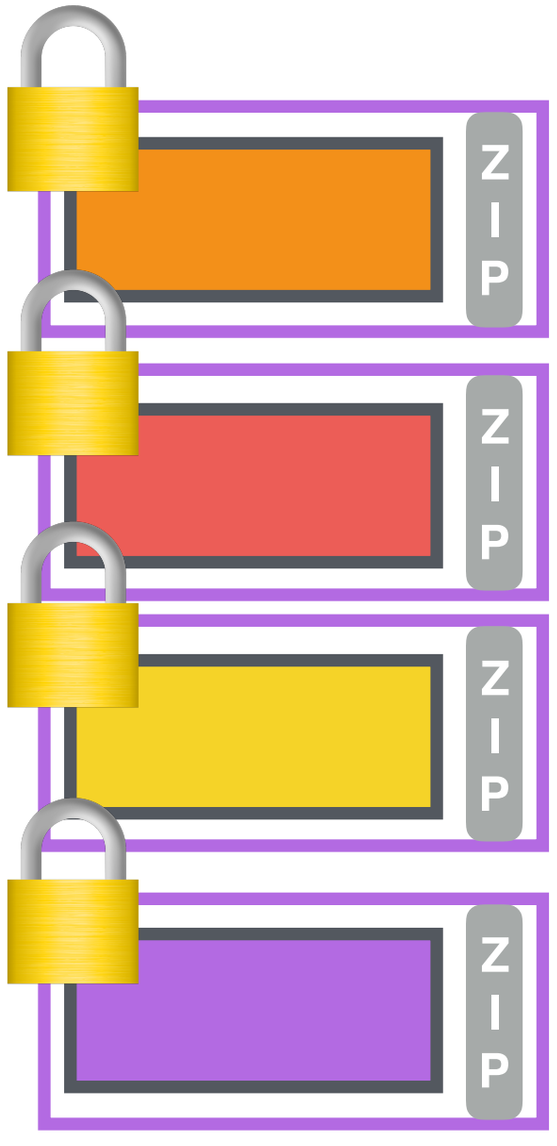


Single-key put

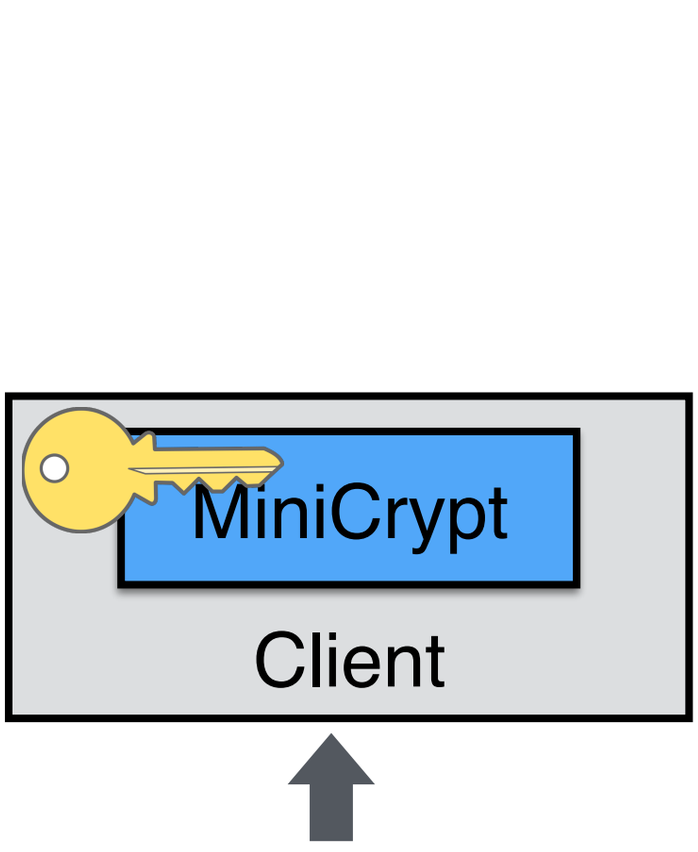


query = put(28, 5)

put(*key, value*):
find pack using get()

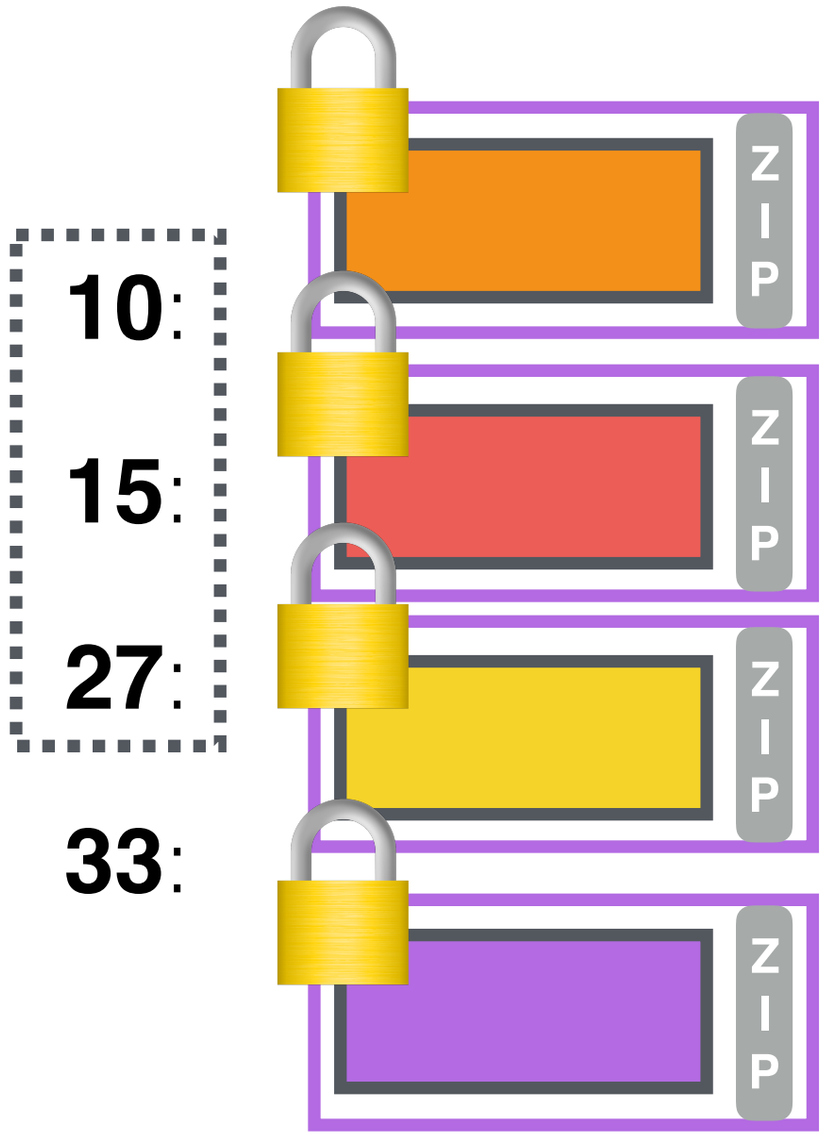


Single-key put

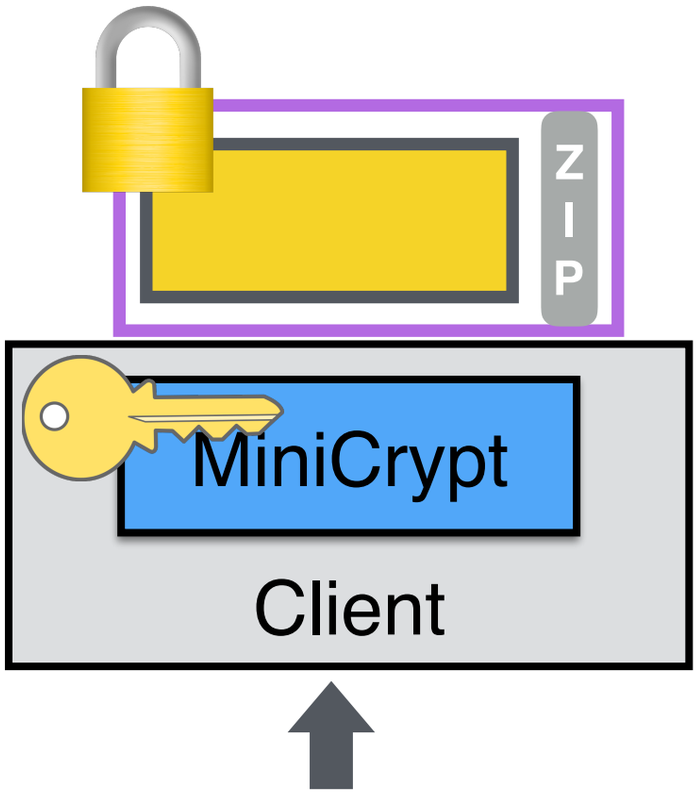


query = put(28, 5)

put(*key, value*):
find pack using get()

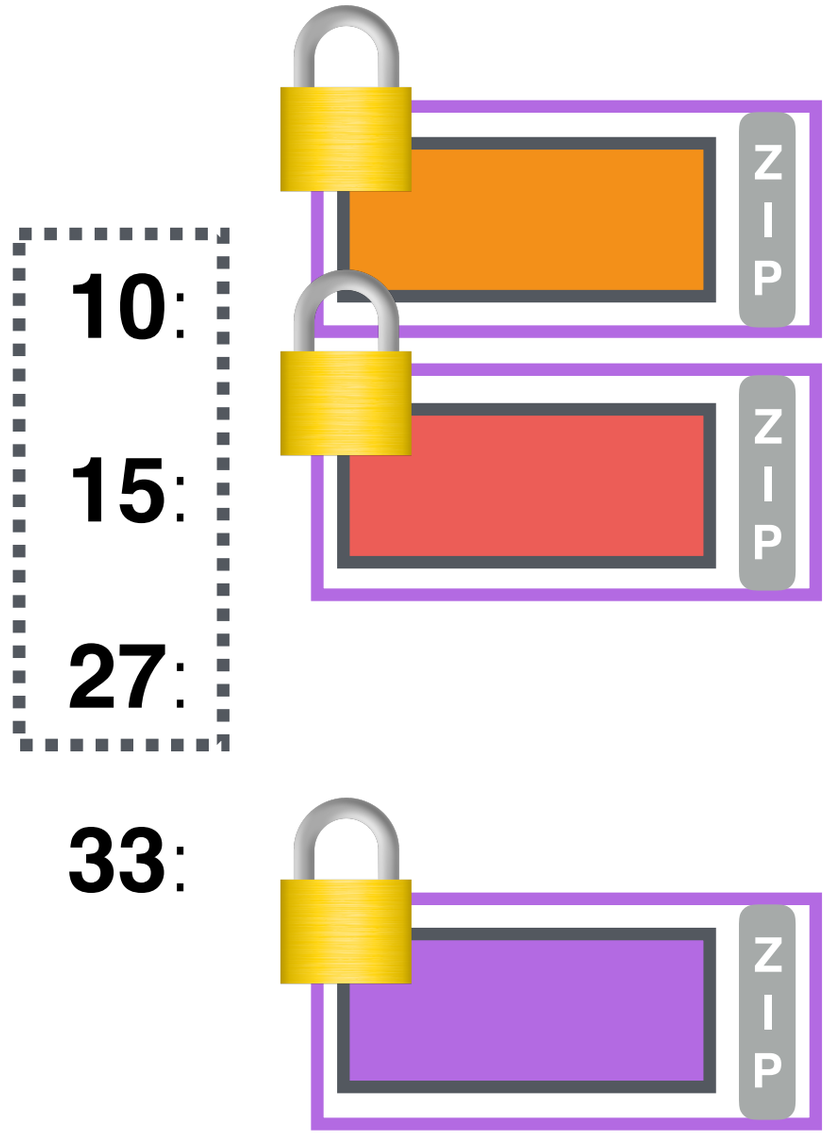


Single-key put

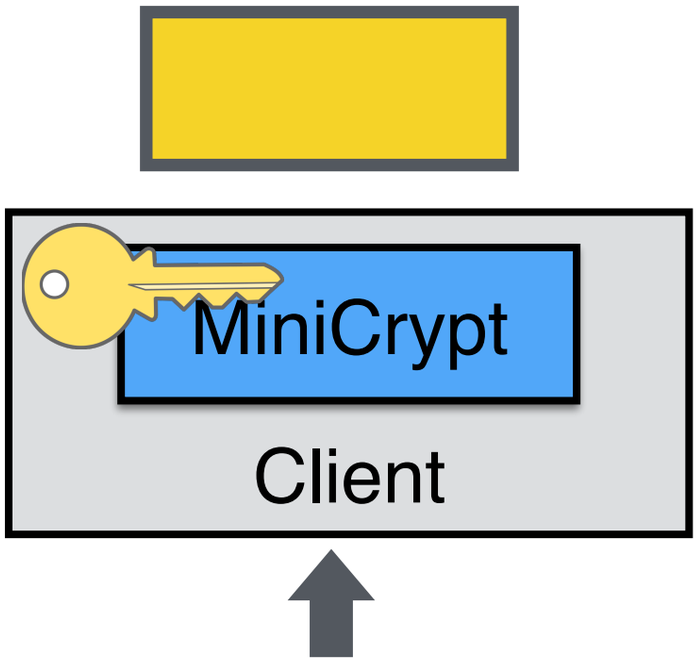


query = put(28, 5)

put(*key, value*):
find pack using get()

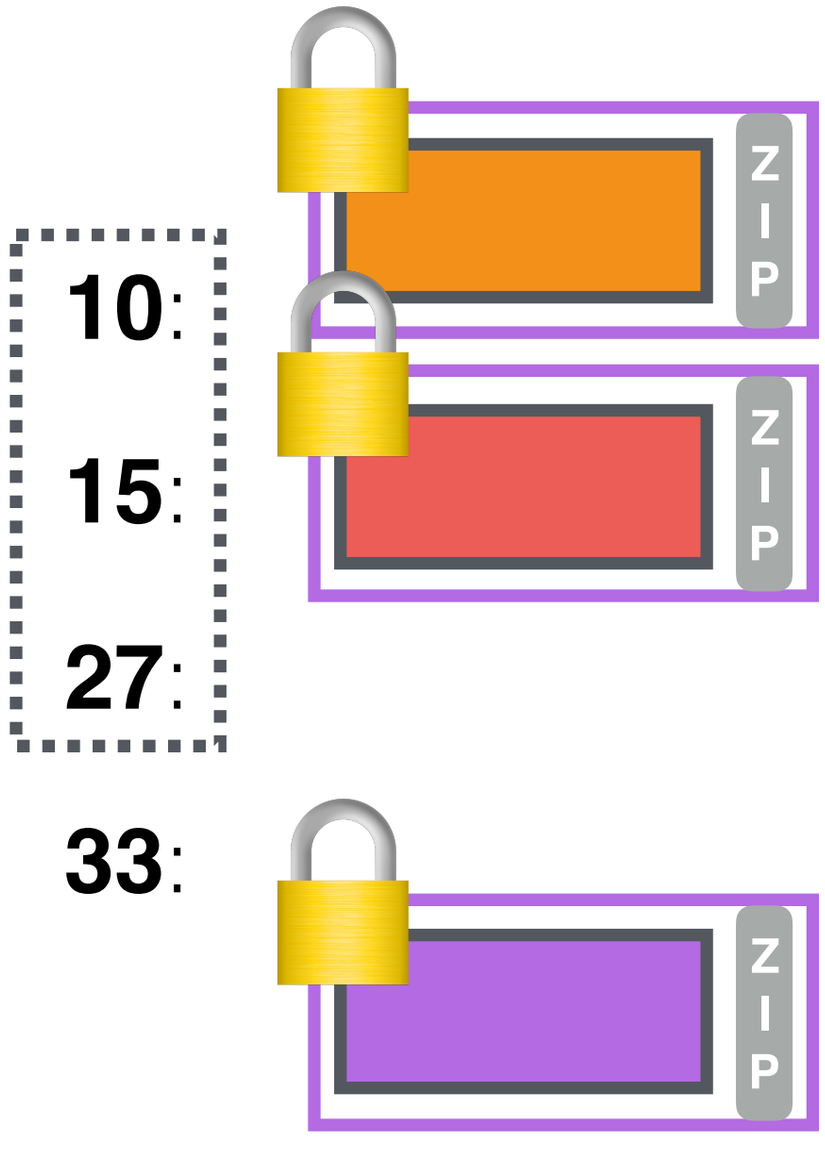


Single-key put

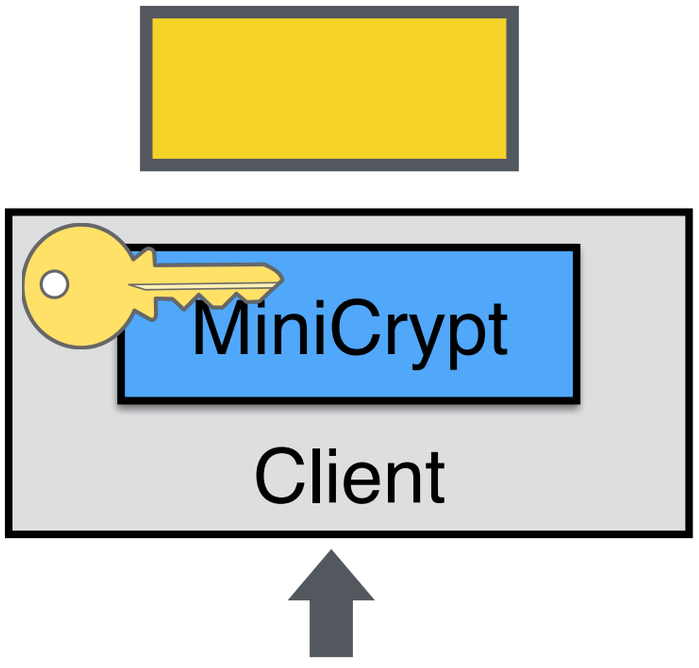


query = put(28, 5)

put(*key, value*):
find pack using get()

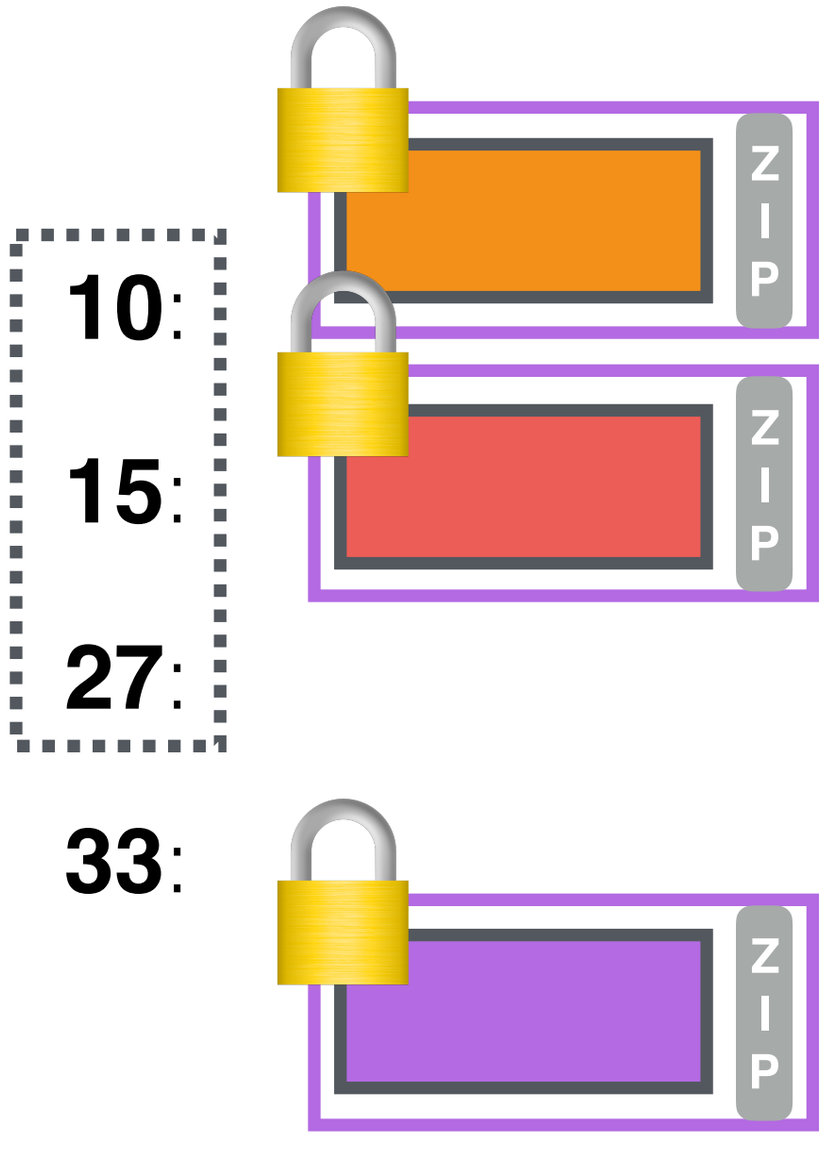


Single-key put

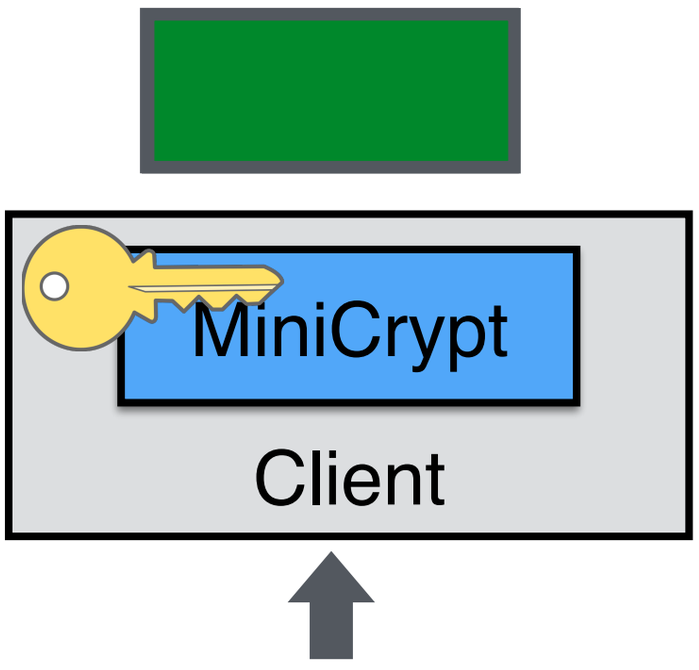


query = put(28, 5)

put(*key, value*):
find pack using get()
modify pack



Single-key put



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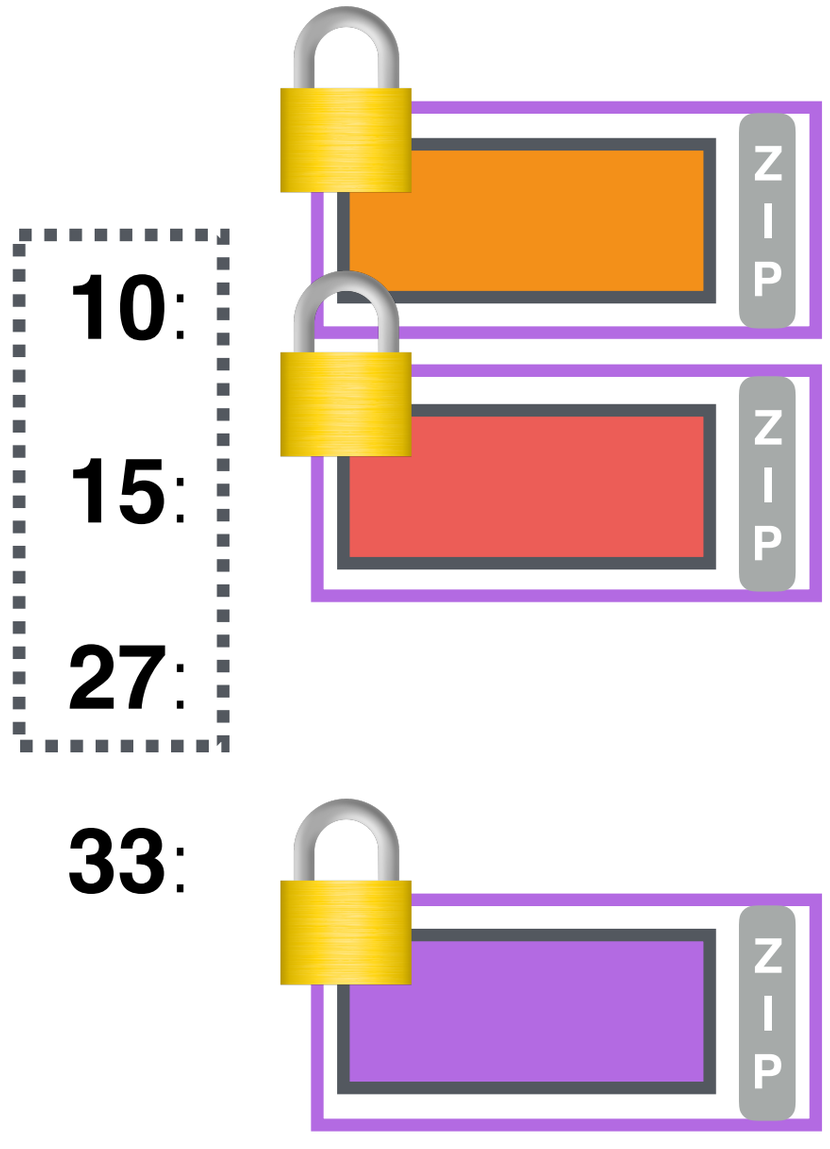
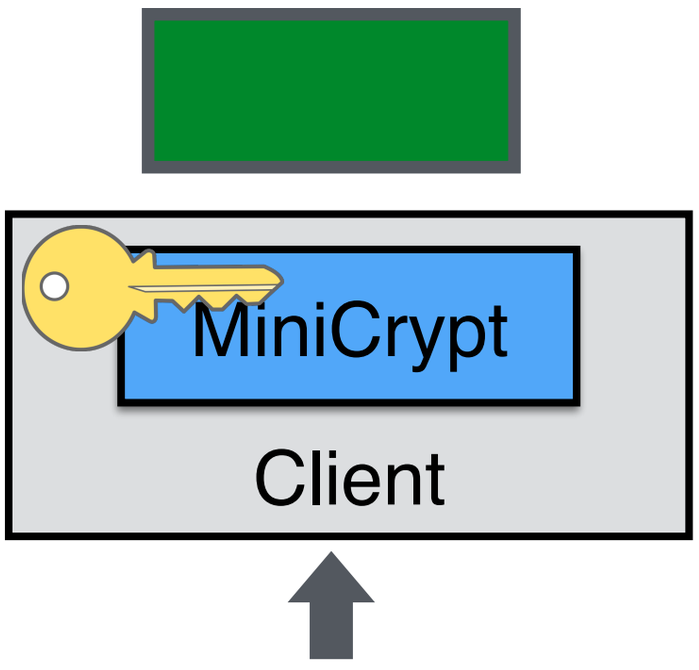


Single-key put



query = put(28, 5)

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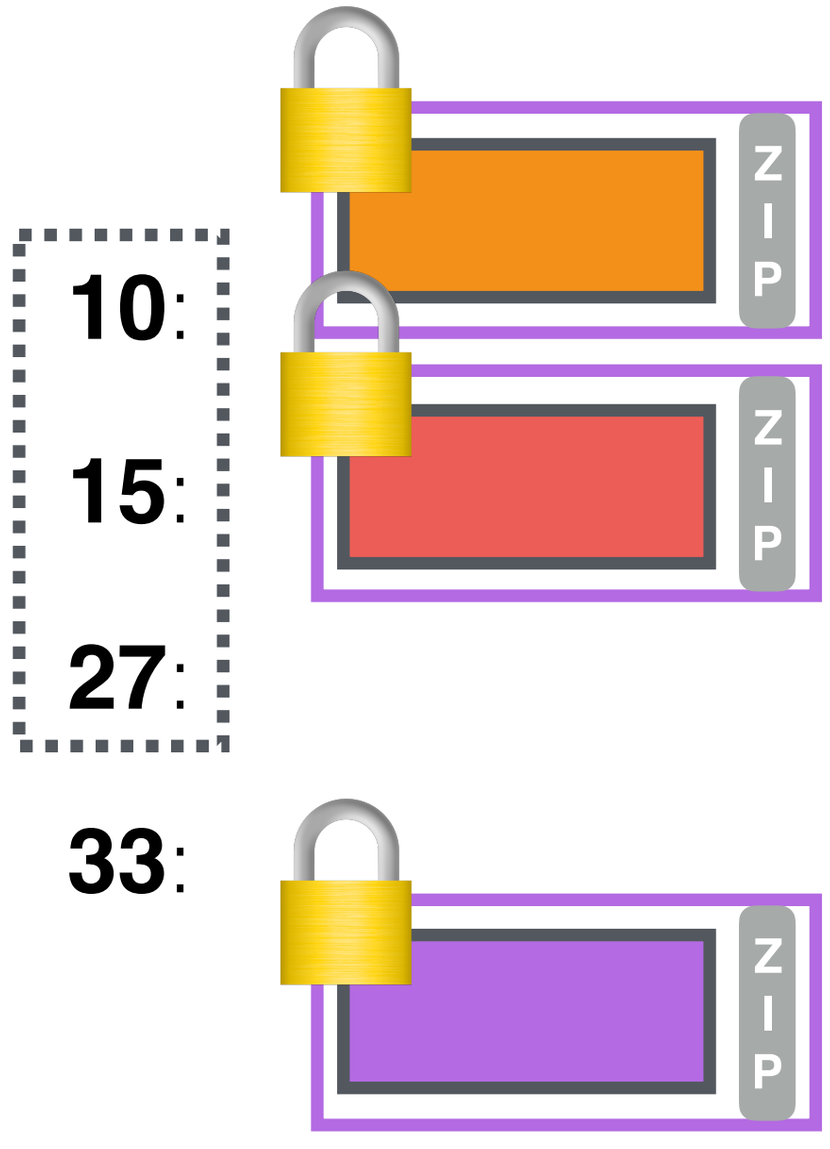
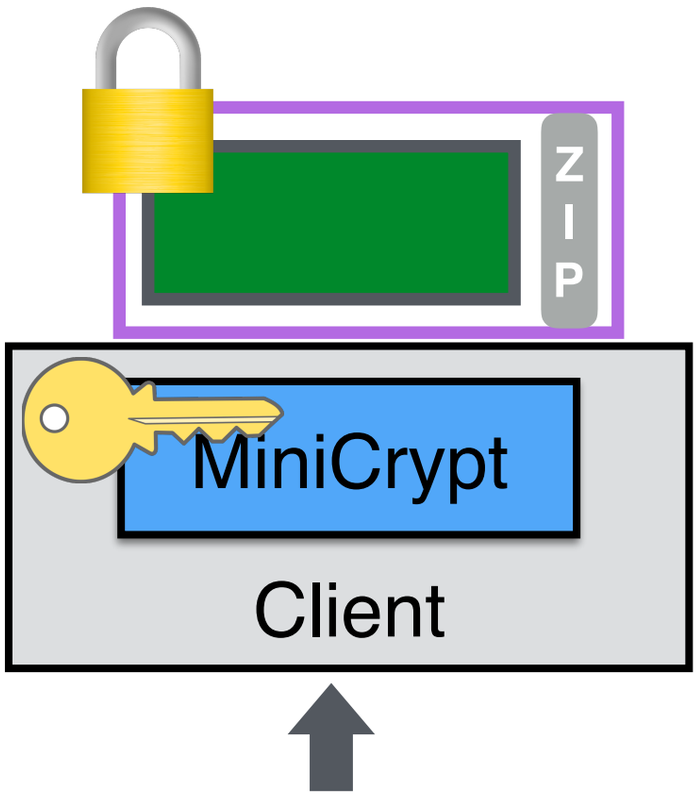


Single-key put



query = put(28, 5)

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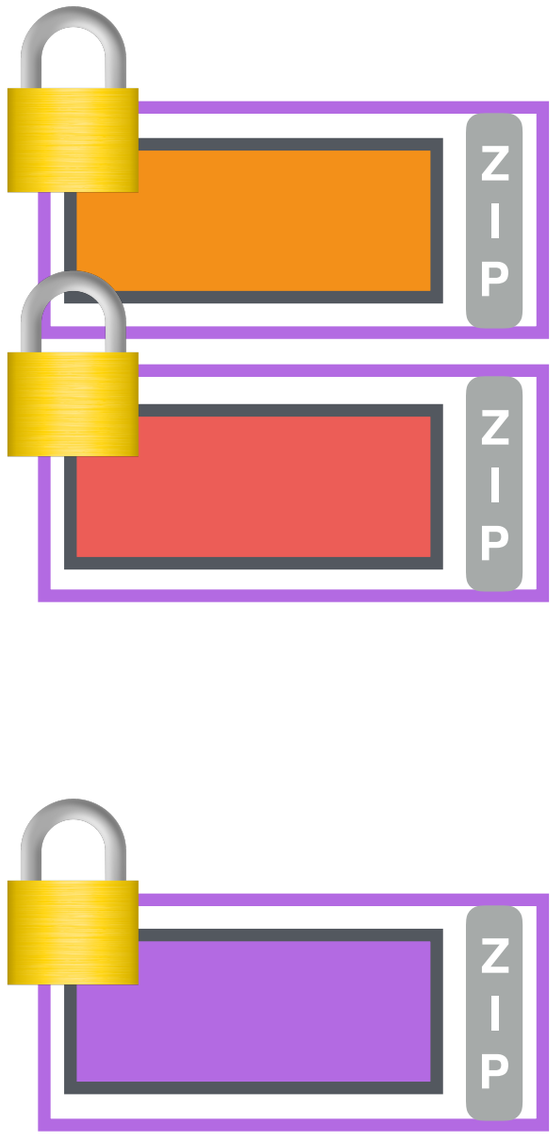
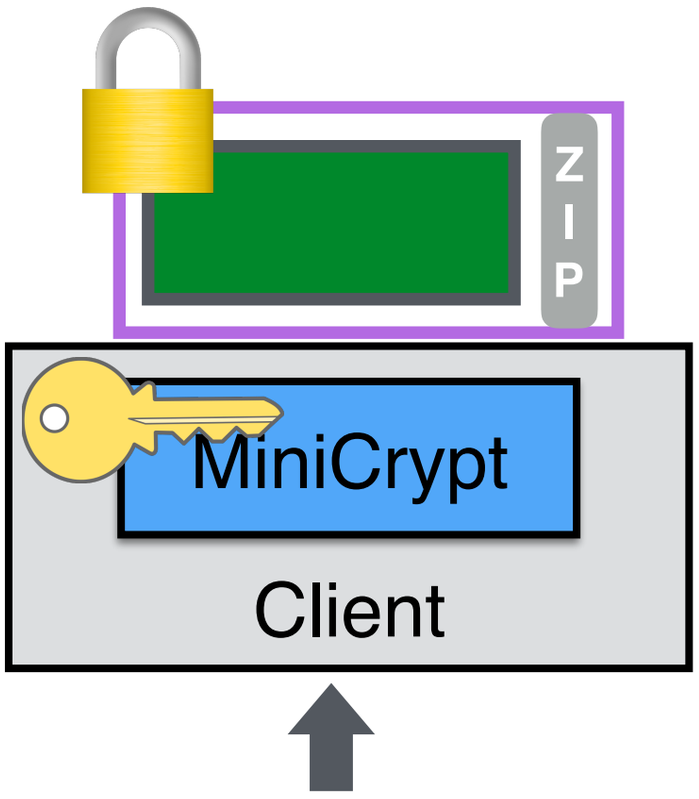
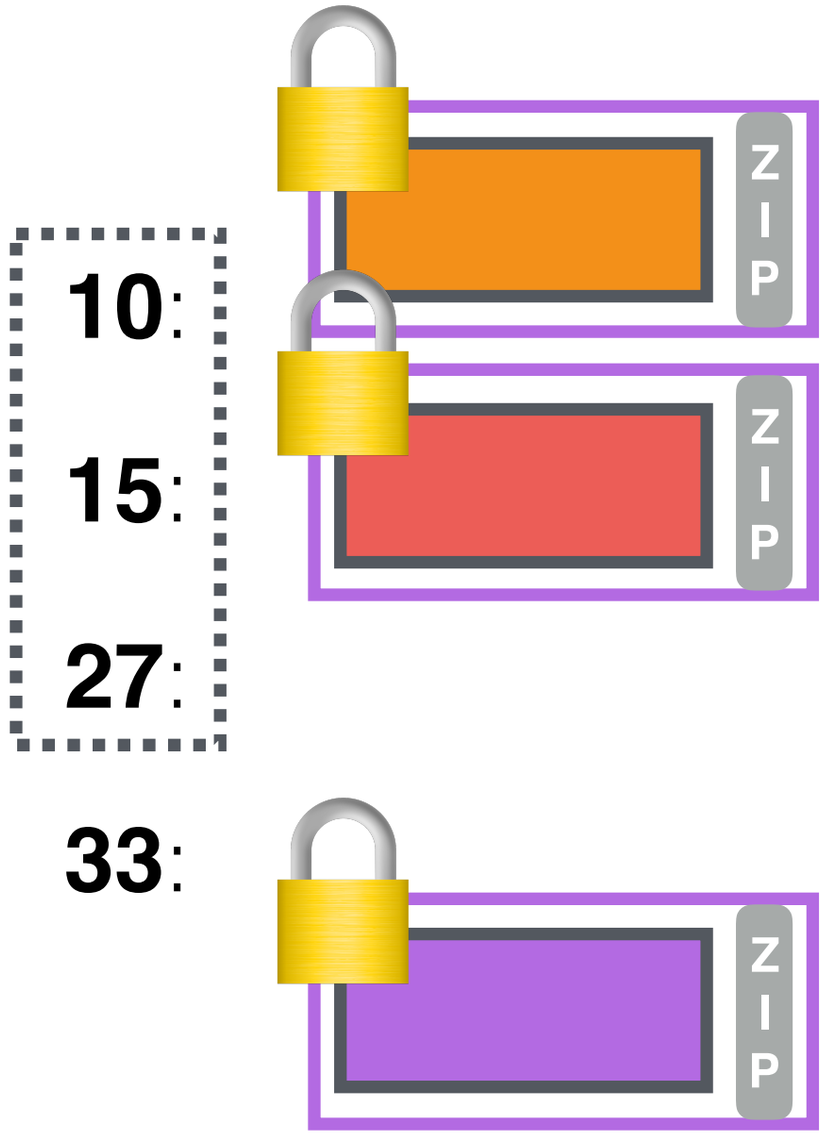


Single-key put

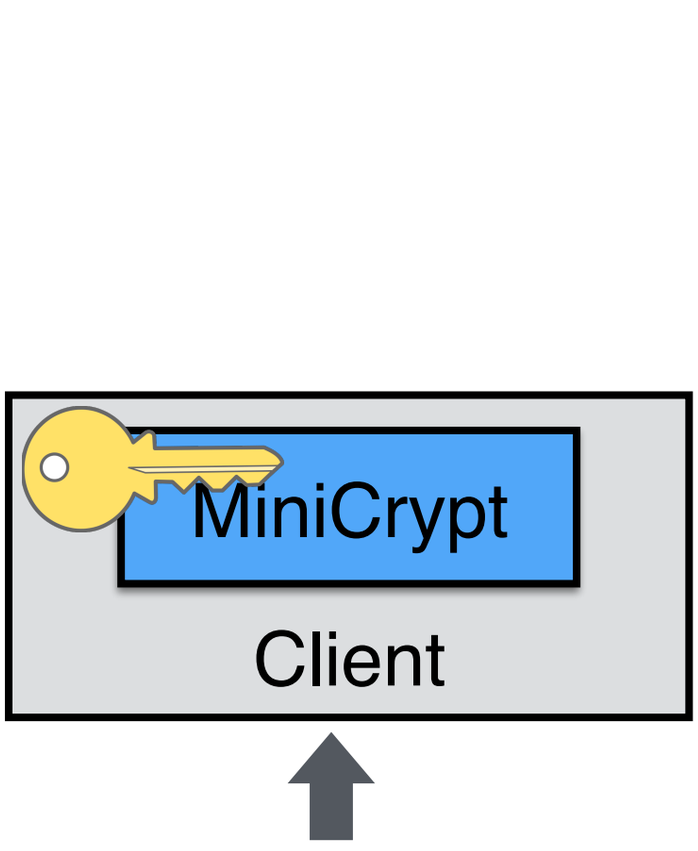


query = put(28, 5)

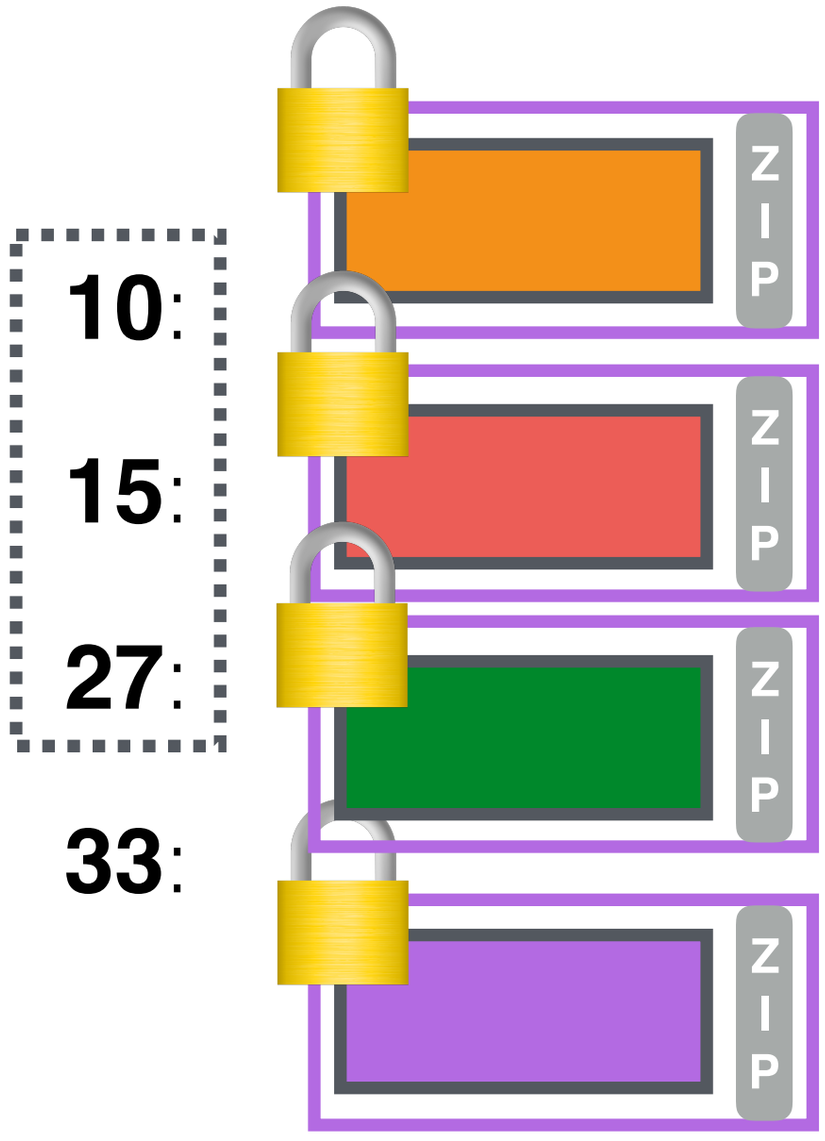


put(*key, value*):
find pack using get()
modify pack
write back using compare-and-swap

Single-key put



query = put(28, 5)



put(*key, value*):
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modify pack
write back using compare-and-swap

Problem: writes are expensive

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- Solution: append-only mode

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  - Inserted keys are roughly monotonically increasing
  - Key-value pairs can be modified within some bounded time
  - Applications: streaming data, time-series data

Approach

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- Server keeps track of *epoch*

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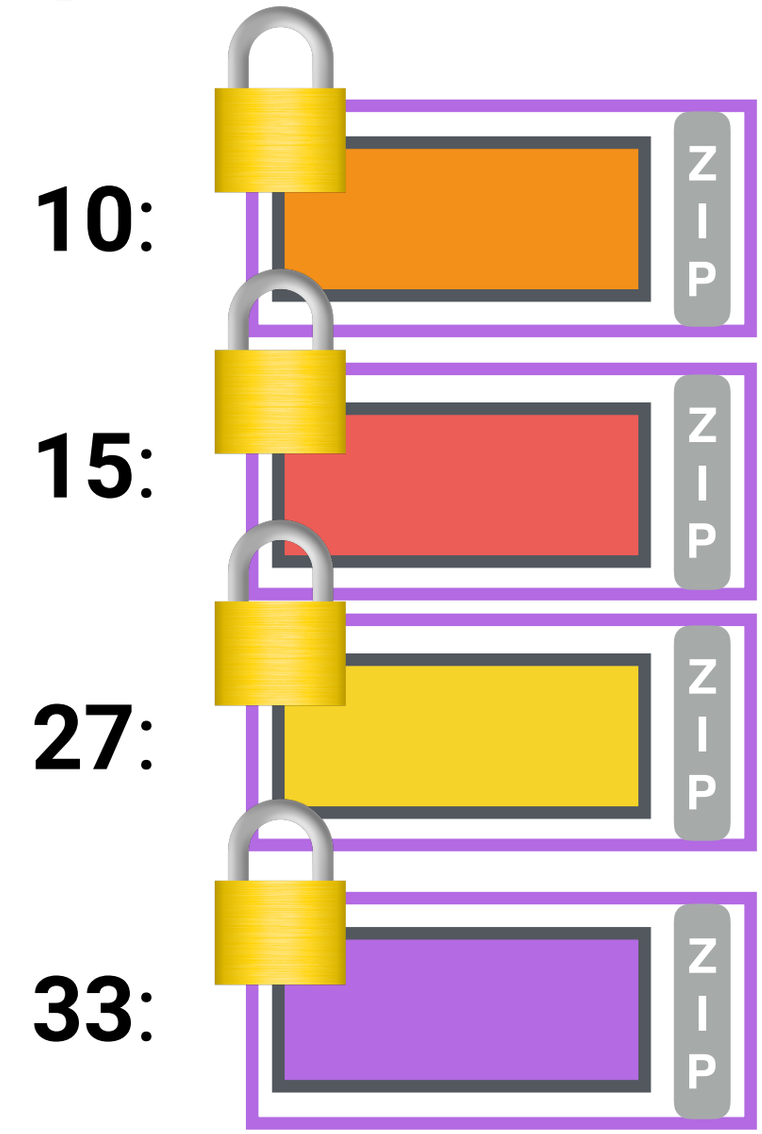
- Each insert assigned an epoch
  - Each new record inserted normally

Approach

- Server keeps track of *epoch*
- Each insert assigned an epoch
  - Each new record inserted normally
- Merge epochs into packs in the background
  - merge deterministically

Append mode



Append mode

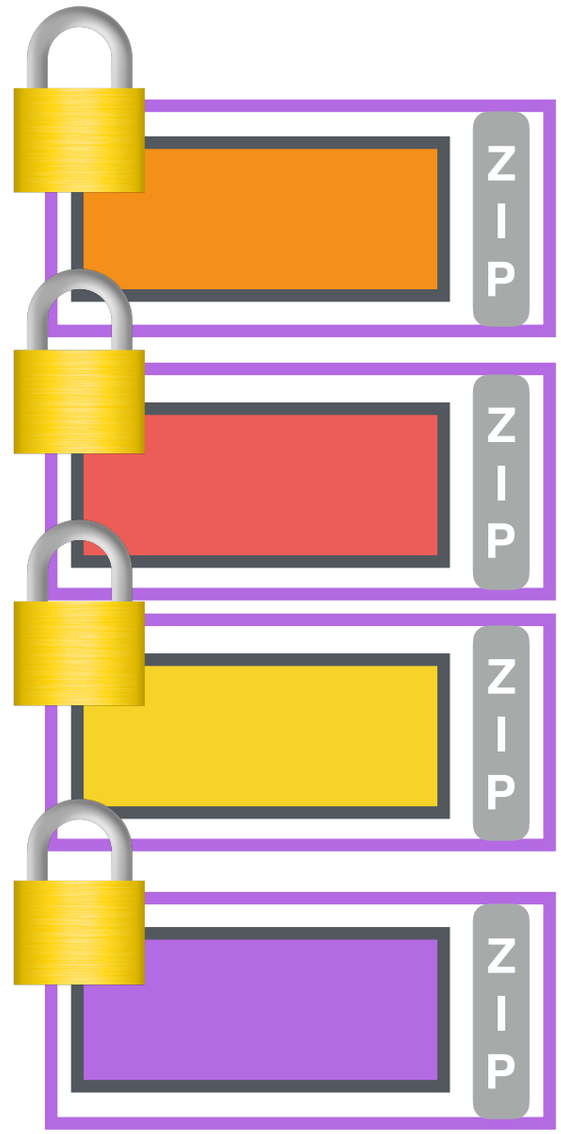
Current epoch: 4

10:

15:

27:

33:



Append mode

Current epoch: 4

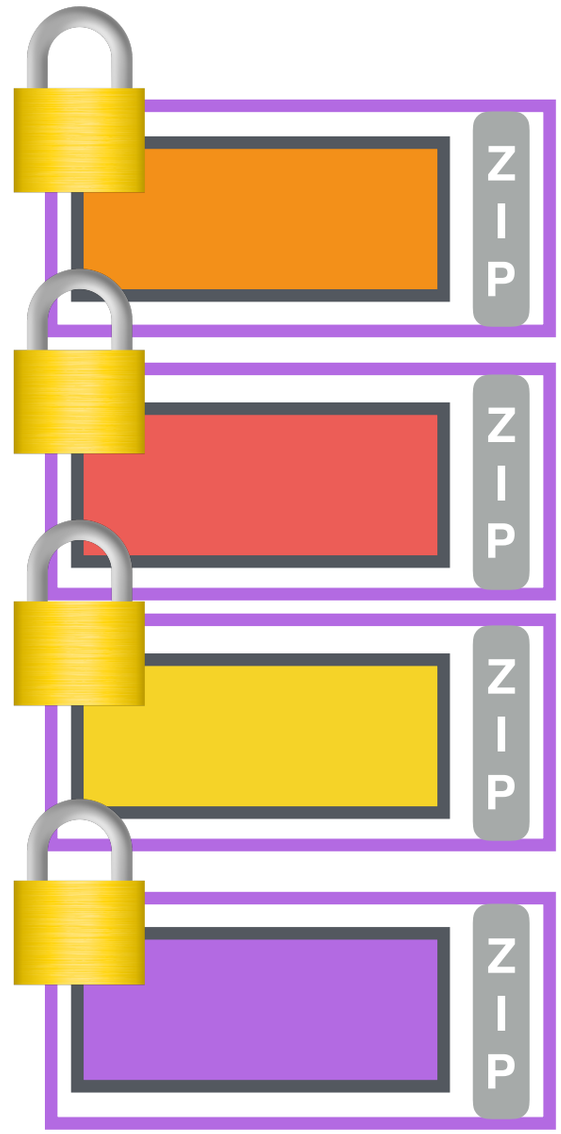
time

10:

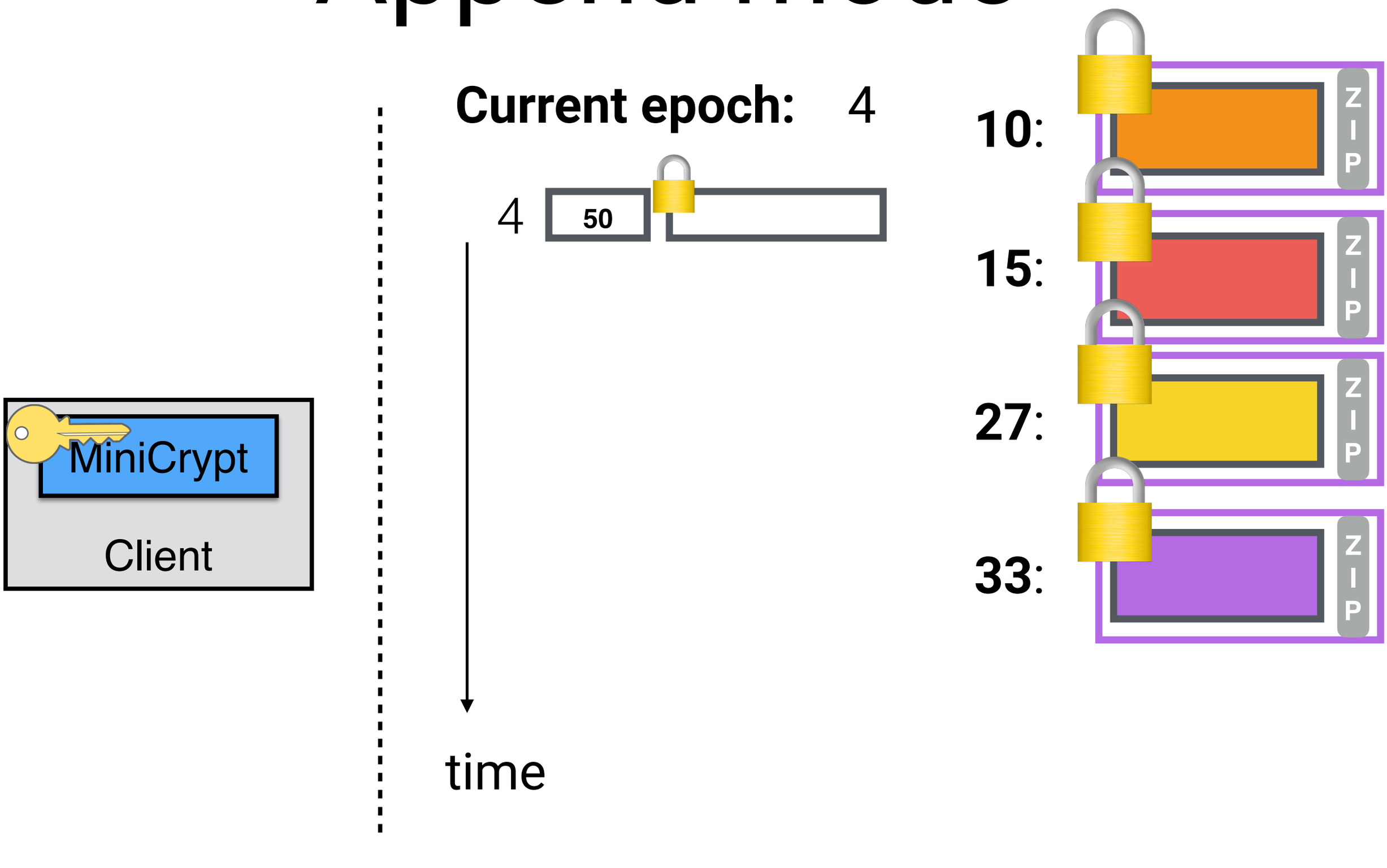
15:

27:

33:



Append mode


Current epoch: 4
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50
MiniCrypt
Client
time
10:
15:
27:
33:
ZIP
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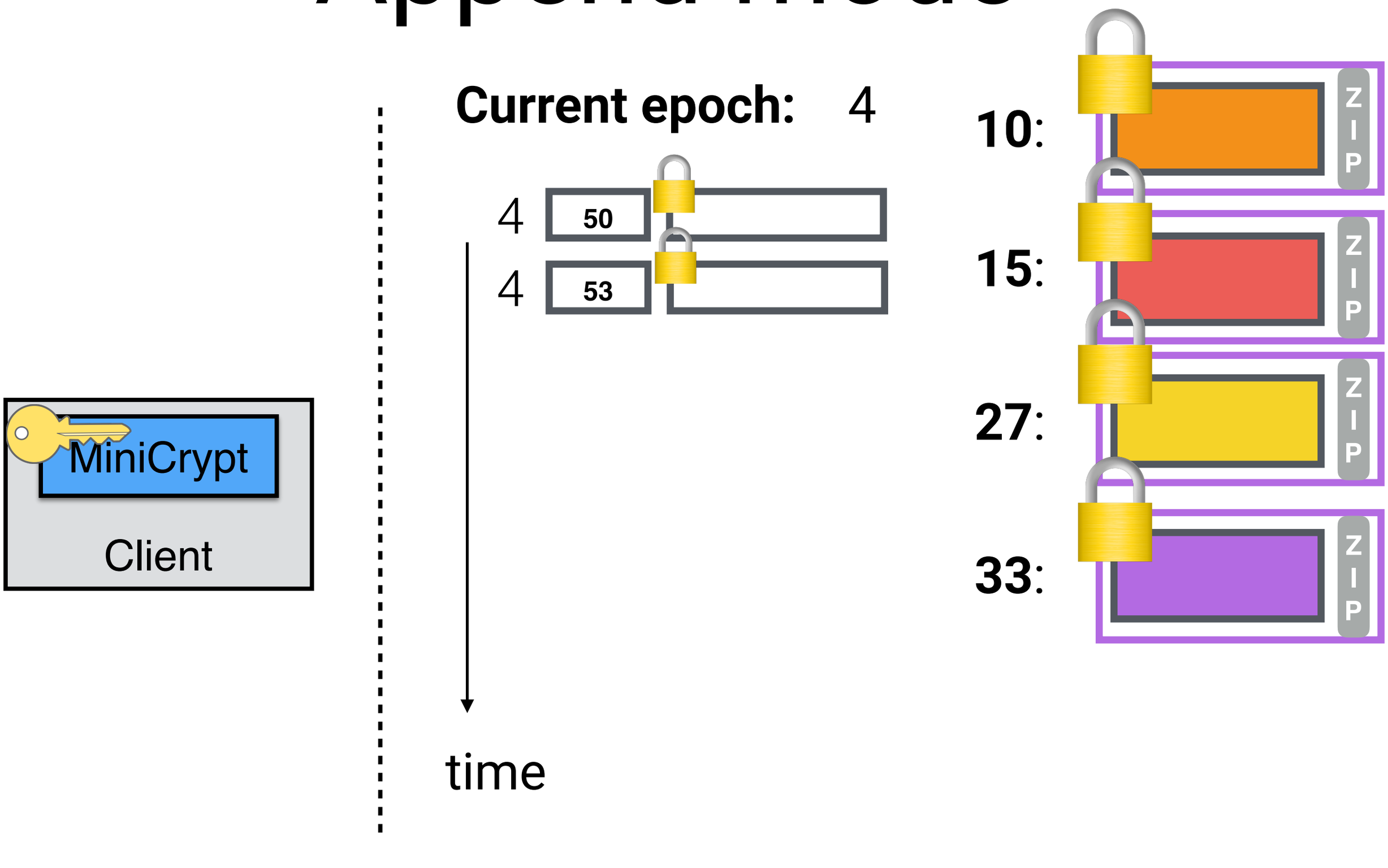
Append mode


Current epoch: 4
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ZIP
ZIP
ZIP
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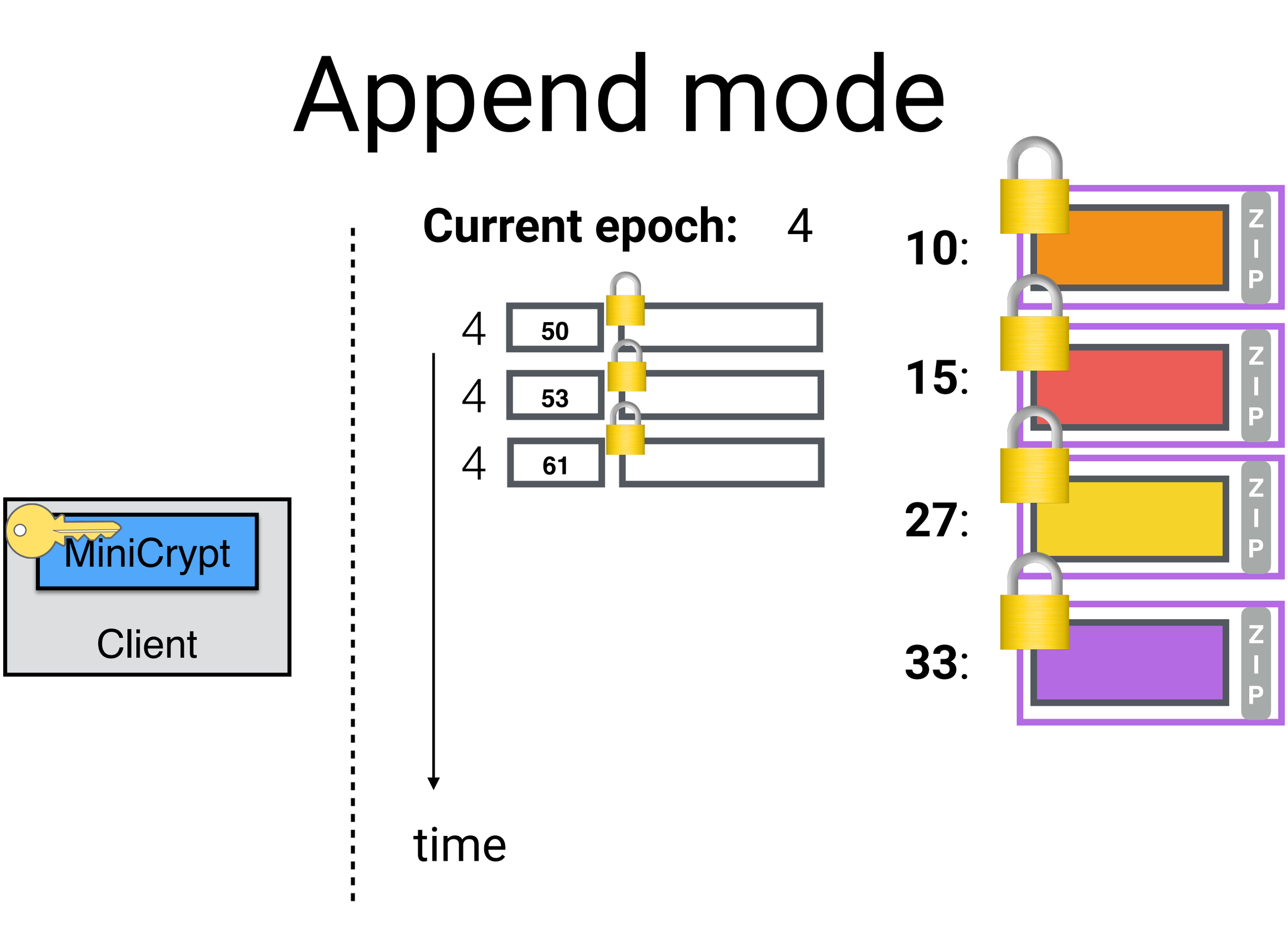
MiniCrypt
Client
time

Append mode


Current epoch: 4
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time
MiniCrypt
Client
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27:
33:
ZIP
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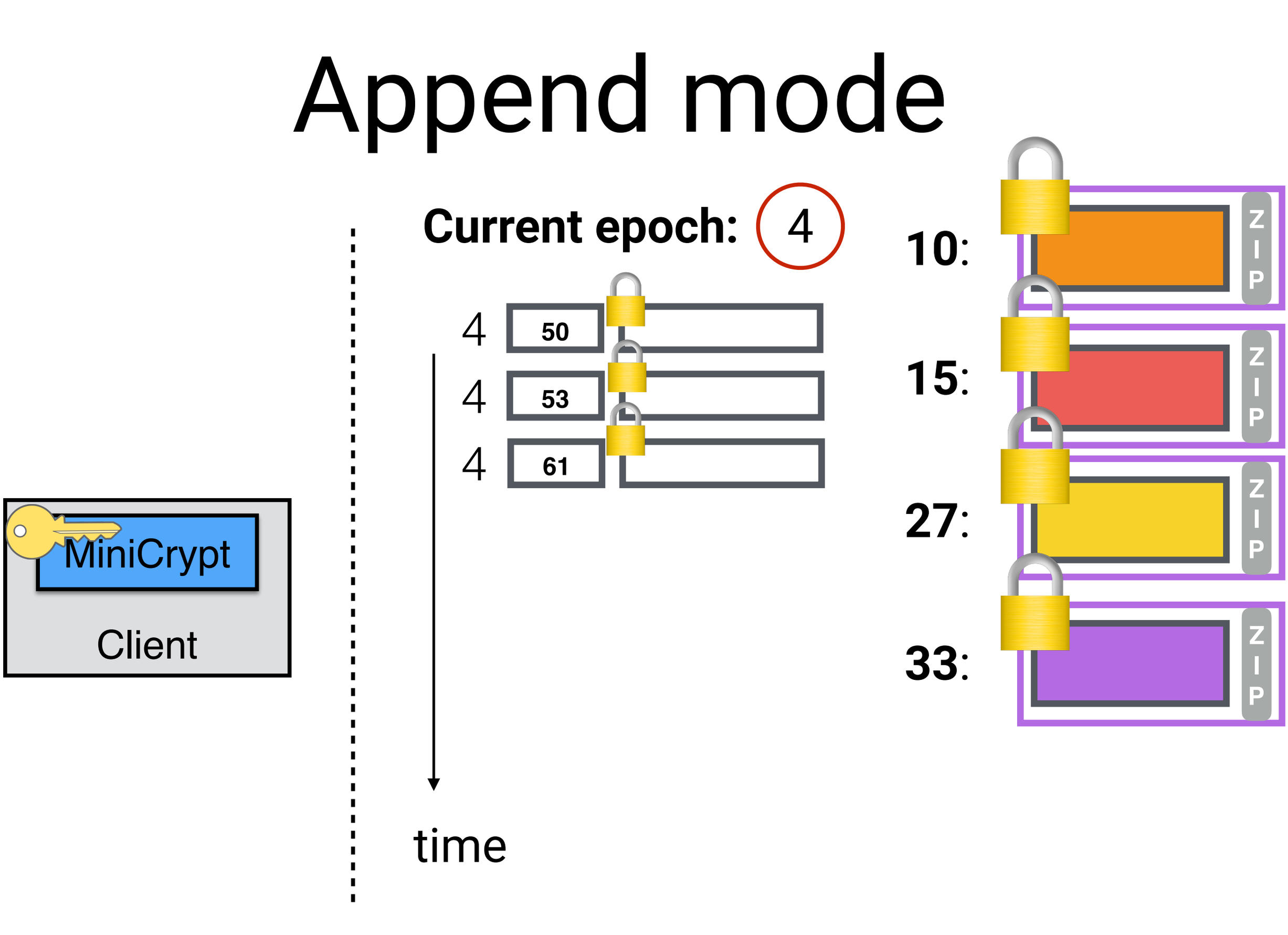
ZIP
ZIP

Append mode


Current epoch: 4
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time
MiniCrypt
Client
10:
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33:
ZIP
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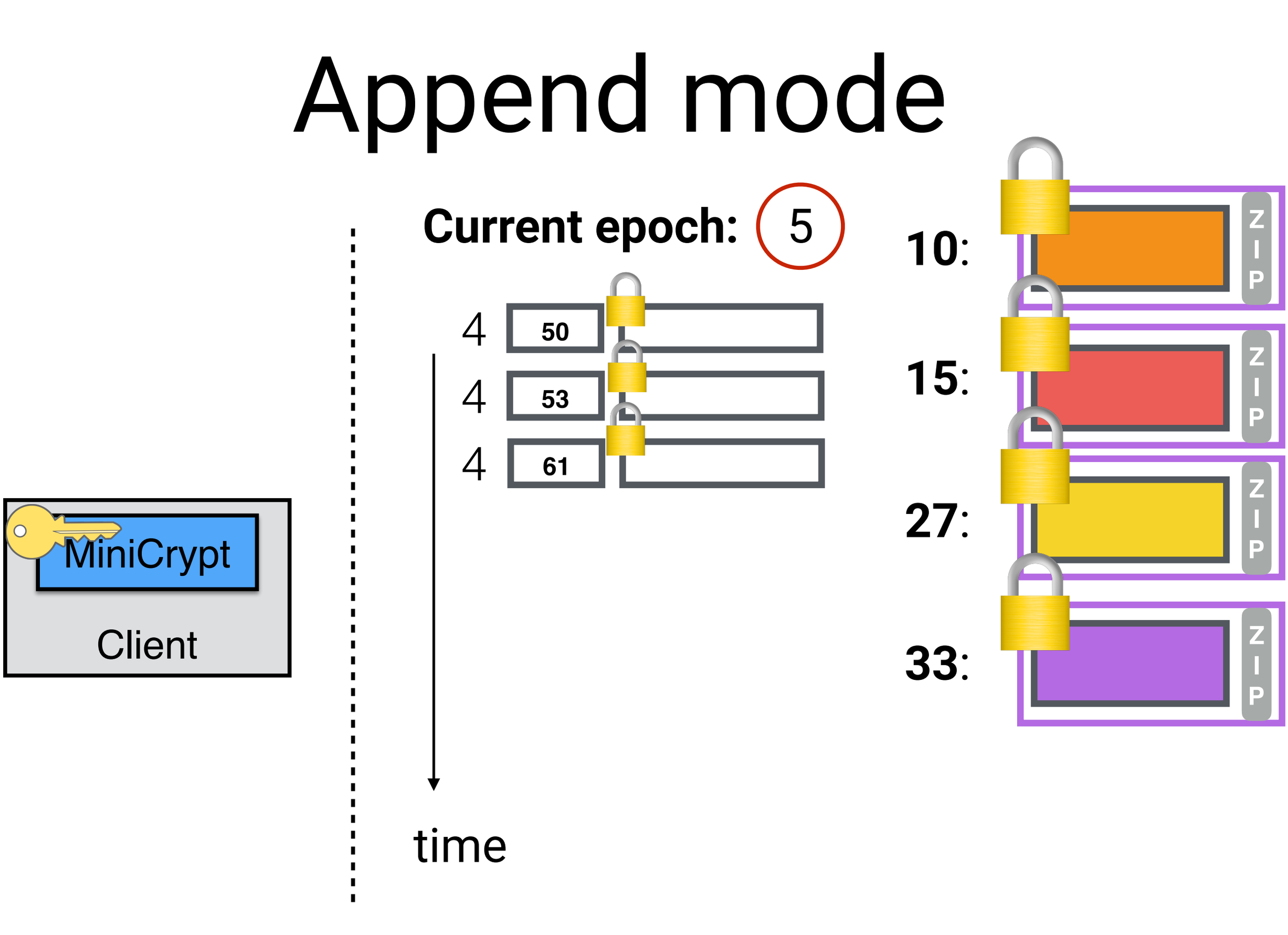
ZIP

Append mode


Current epoch: 5
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time
MiniCrypt
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ZIP
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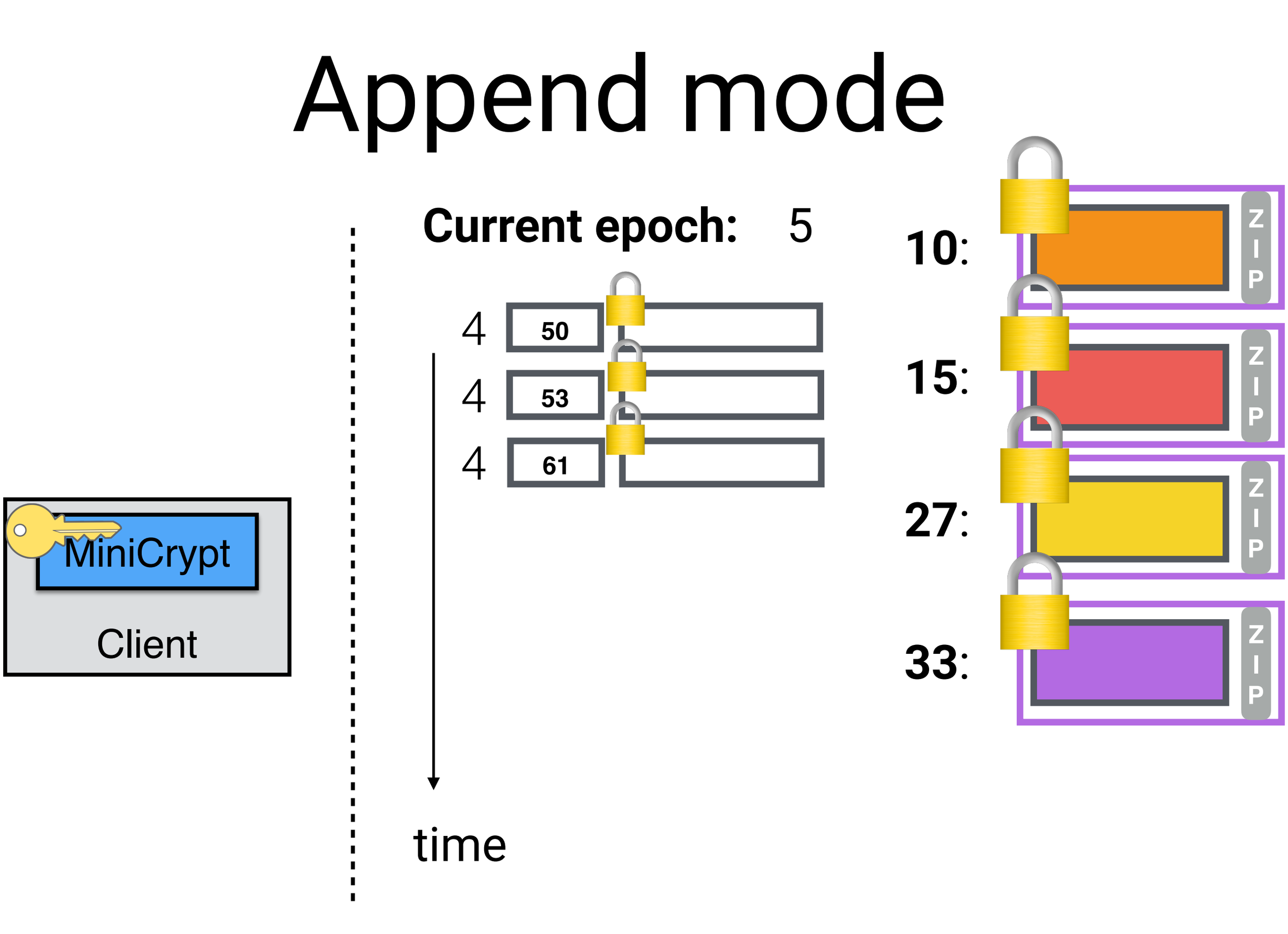
ZIP

Append mode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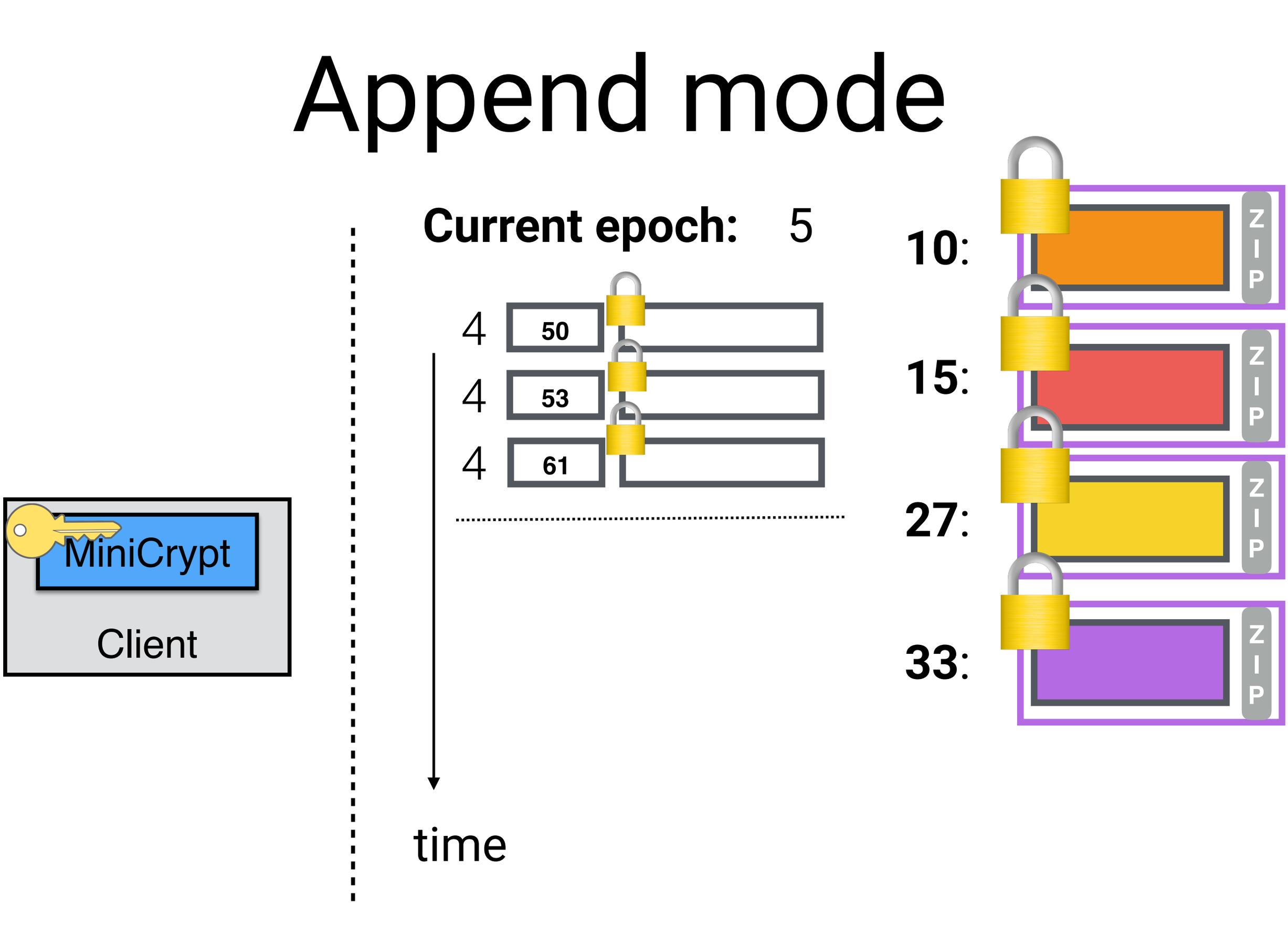
Current epoch: 5
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time
MiniCrypt
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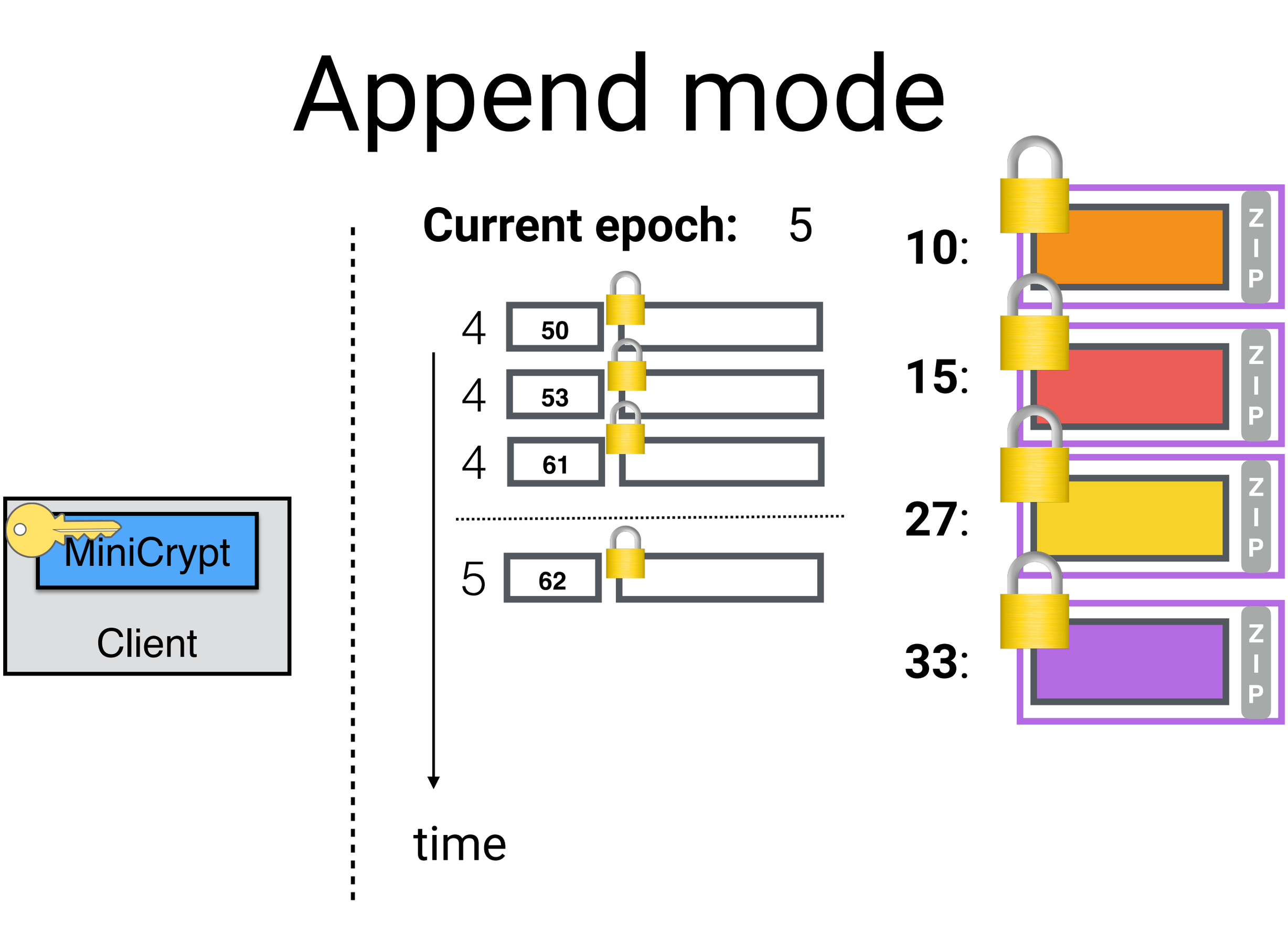
Current epoch: 5
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time
MiniCrypt
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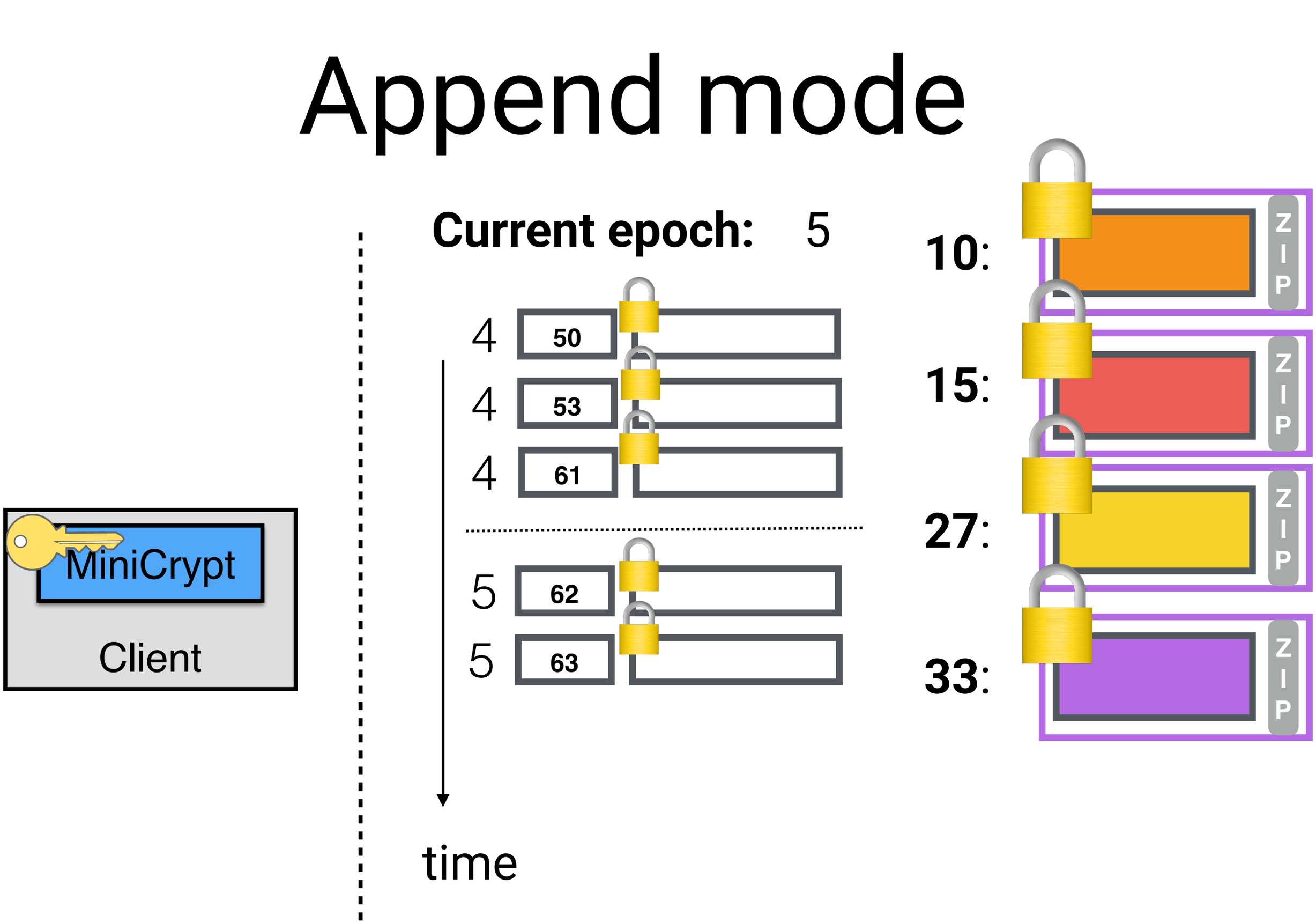
MiniCrypt
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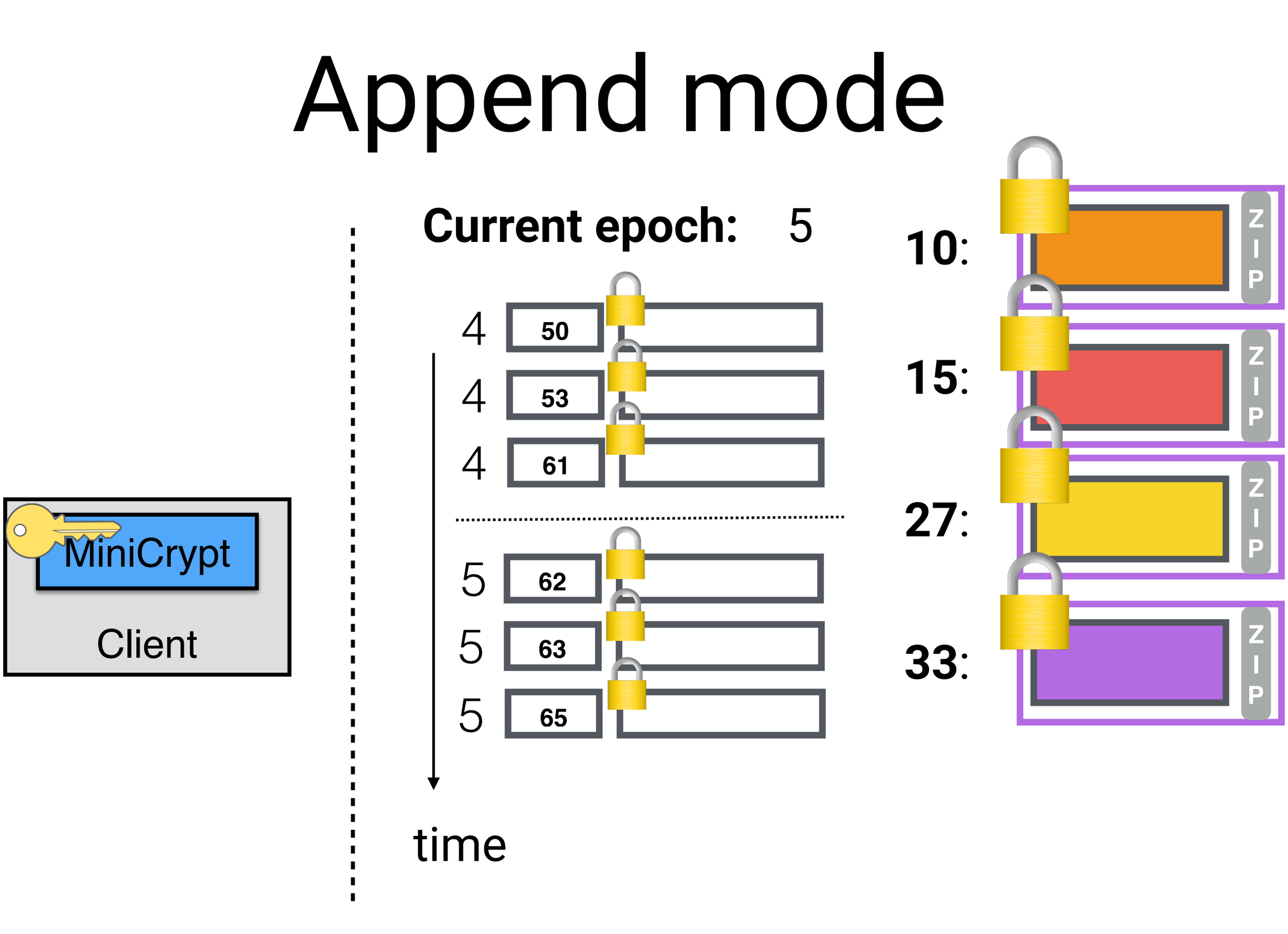
Current epoch: 5
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time
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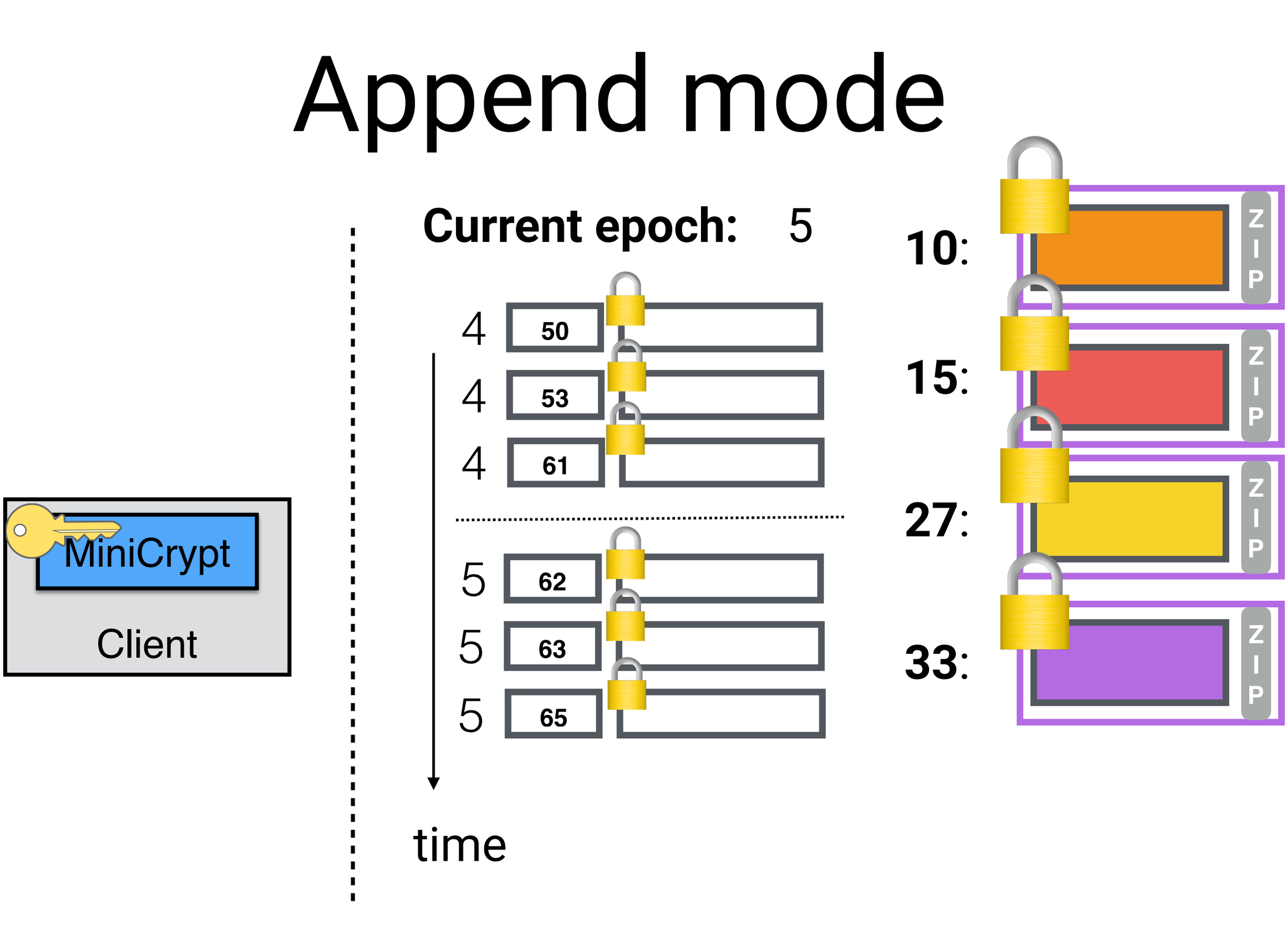
Current epoch: 5
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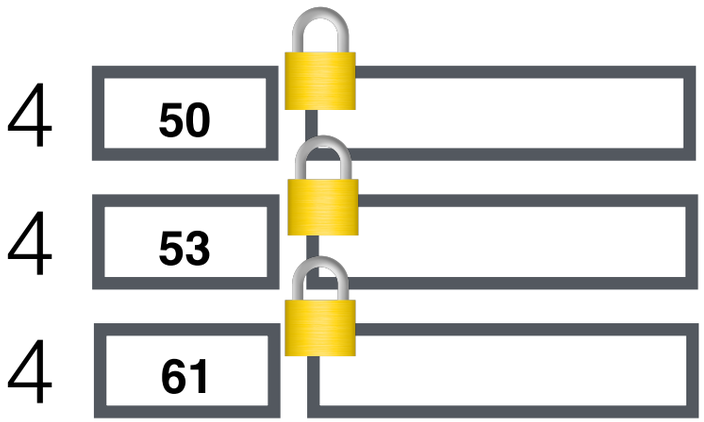

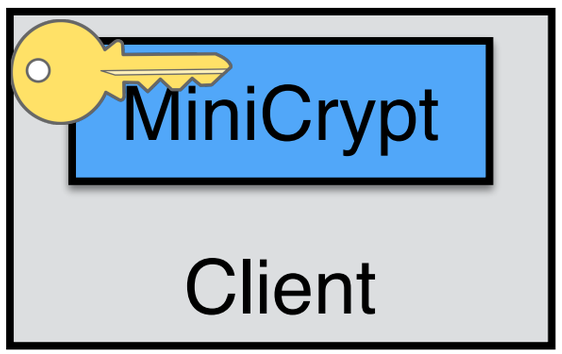

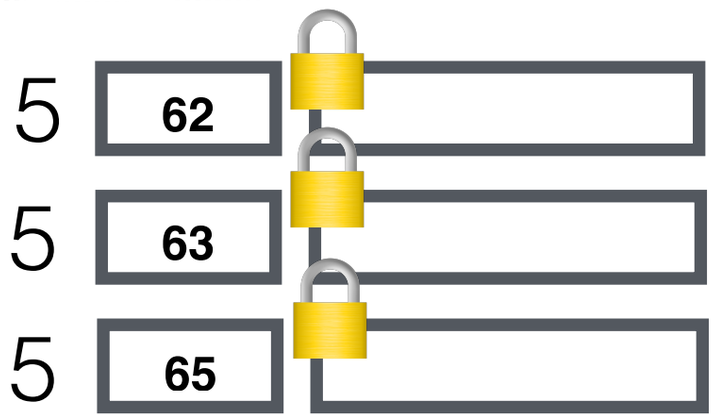

time

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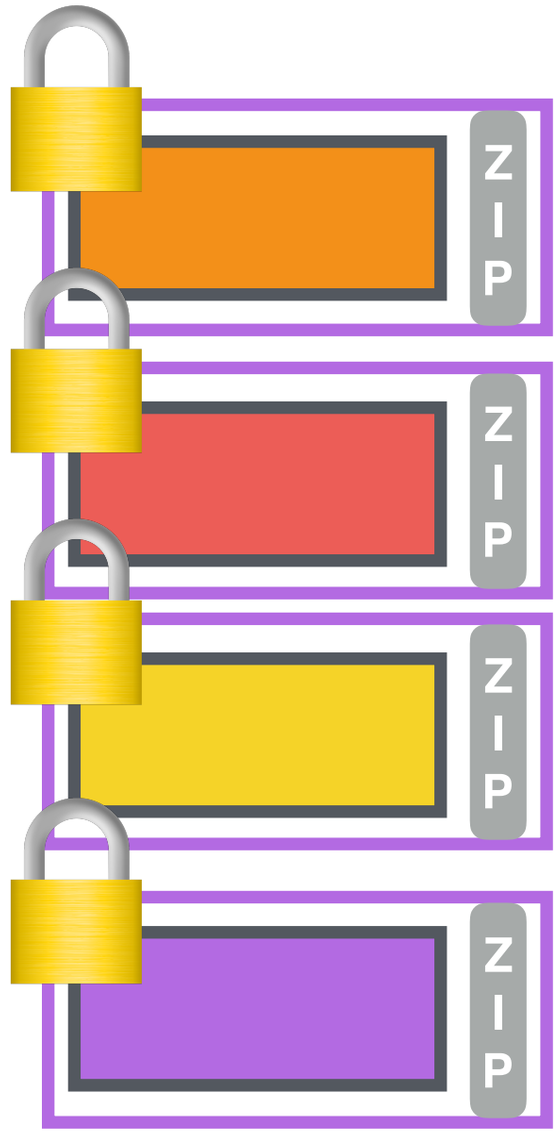
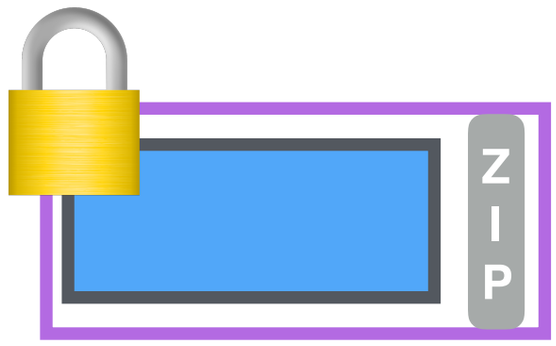
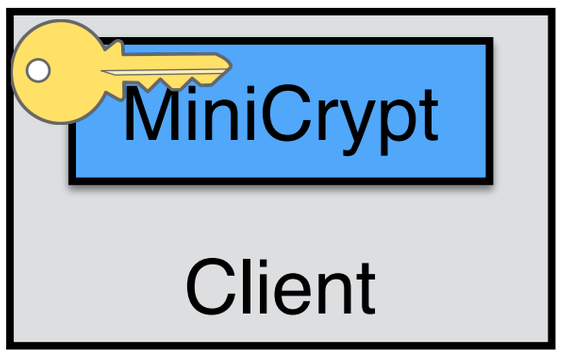
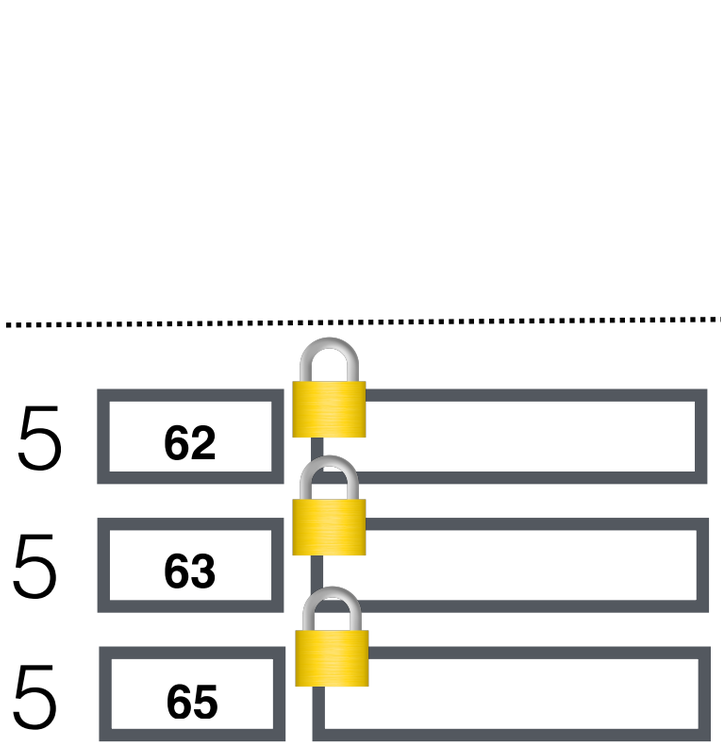


Append mode





Current epoch: 5



time

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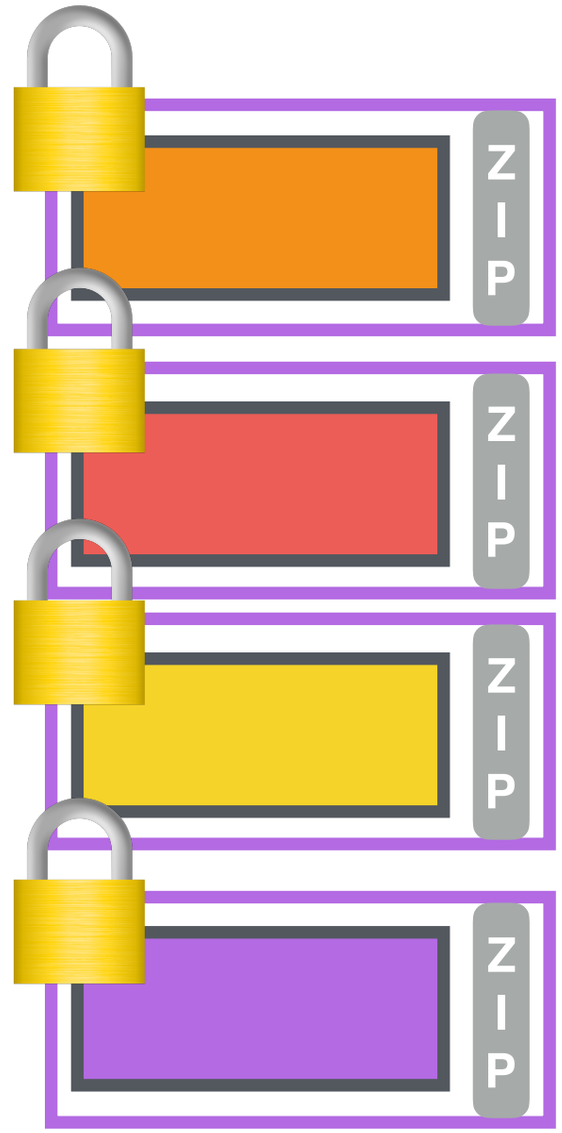
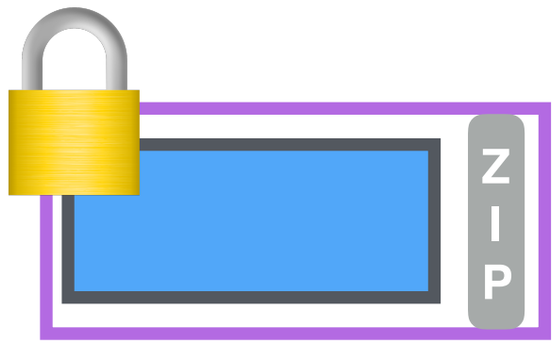
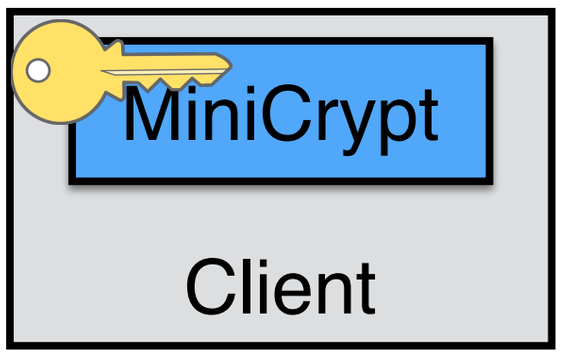
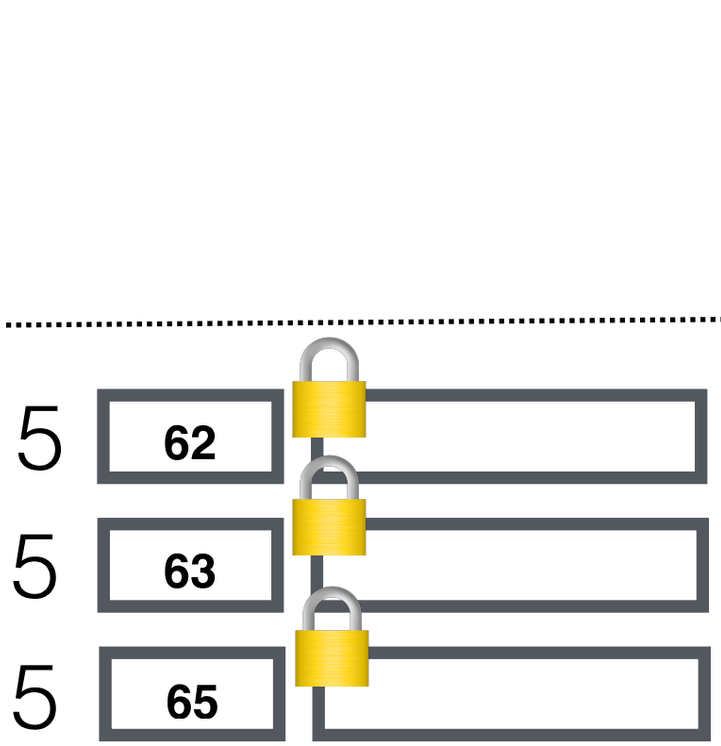


Append mode





Current epoch: 5



time

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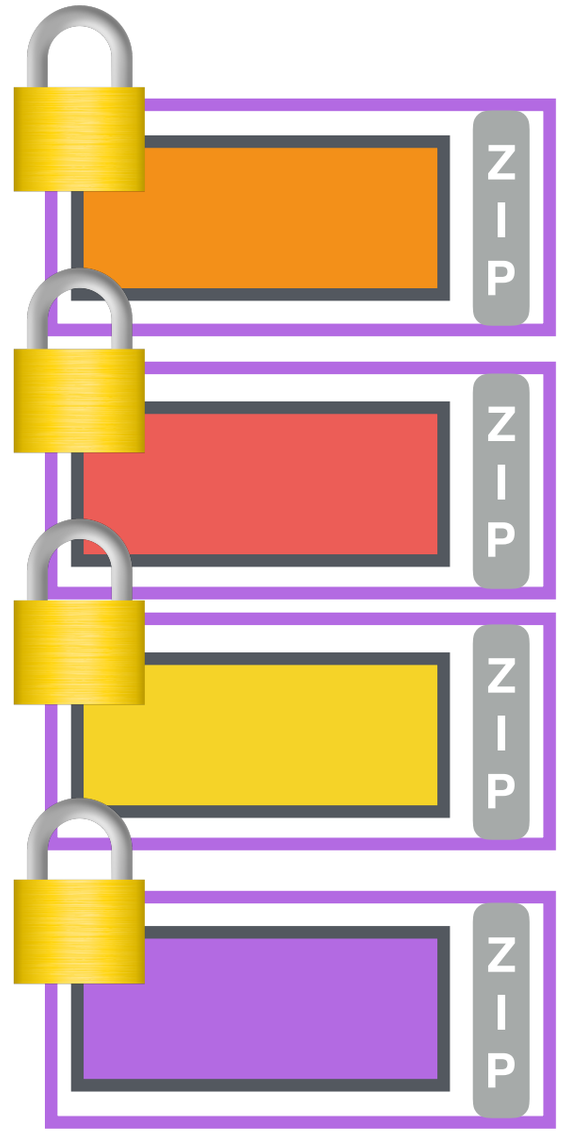
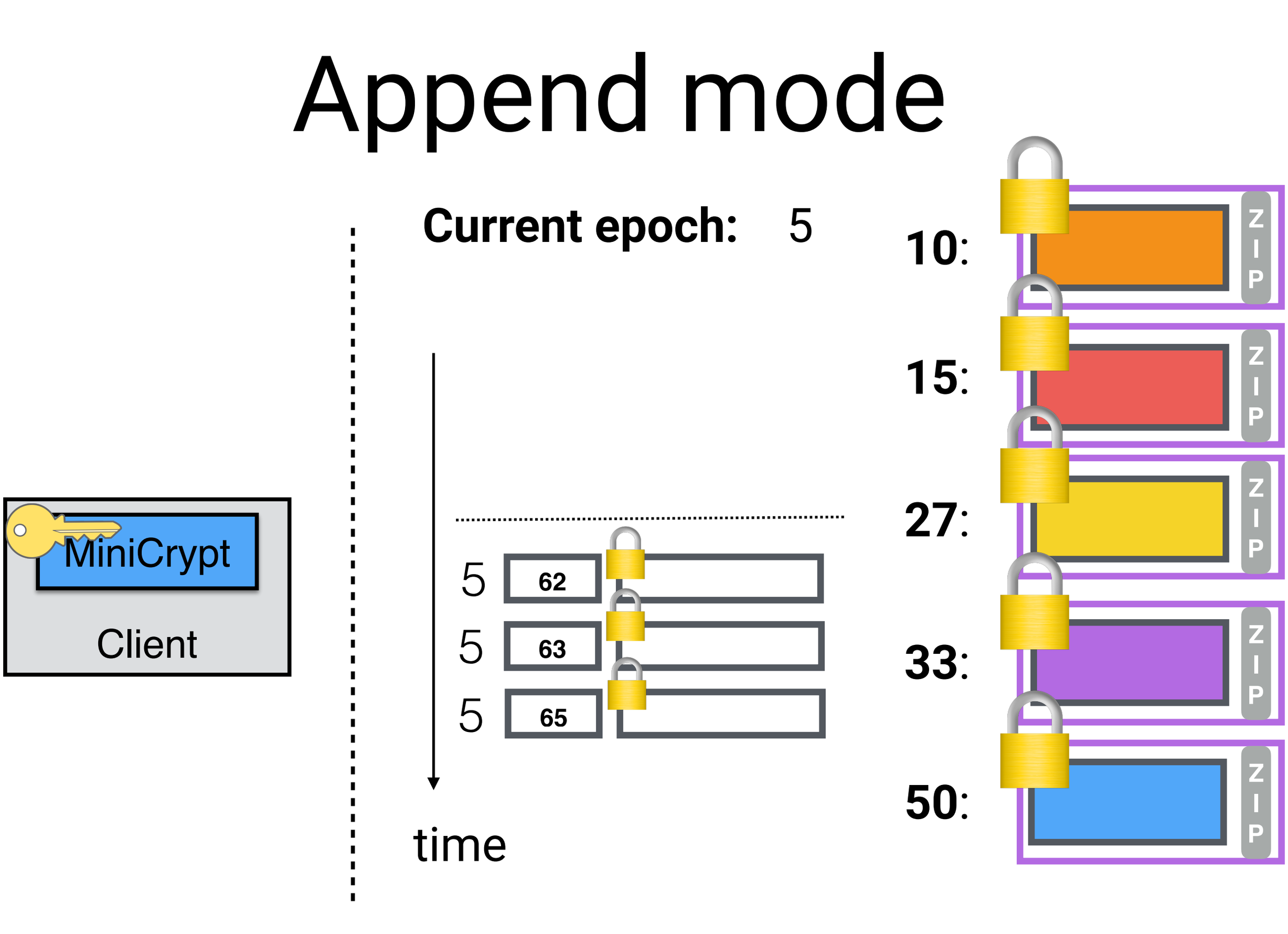


Append mode


Current epoch: 5
MiniCrypt
Client
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62
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time
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ZIP
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Evaluation

Evaluation

- MiniCrypt built on ***unmodified*** Cassandra

Evaluation

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- Comparison with

Evaluation

- MiniCrypt built on ***unmodified*** Cassandra
- Comparison with
  - Baseline: each row compressed and encrypted

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  - Vanilla: no encryption

Evaluation

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- Comparison with
  - Baseline: each row compressed and encrypted
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- YCSB benchmark

Evaluation

- MiniCrypt built on ***unmodified*** Cassandra
- Comparison with
  - Baseline: each row compressed and encrypted
  - Vanilla: no encryption
- YCSB benchmark
  - Anonymized Conviva data (video analytics)

Evaluation setup

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- Amazon EC2 cluster of 3 instances

Evaluation setup

- Amazon EC2 cluster of 3 instances
  - 15 GB of memory

Evaluation setup

- Amazon EC2 cluster of 3 instances
  - 15 GB of memory
  - 8 cores

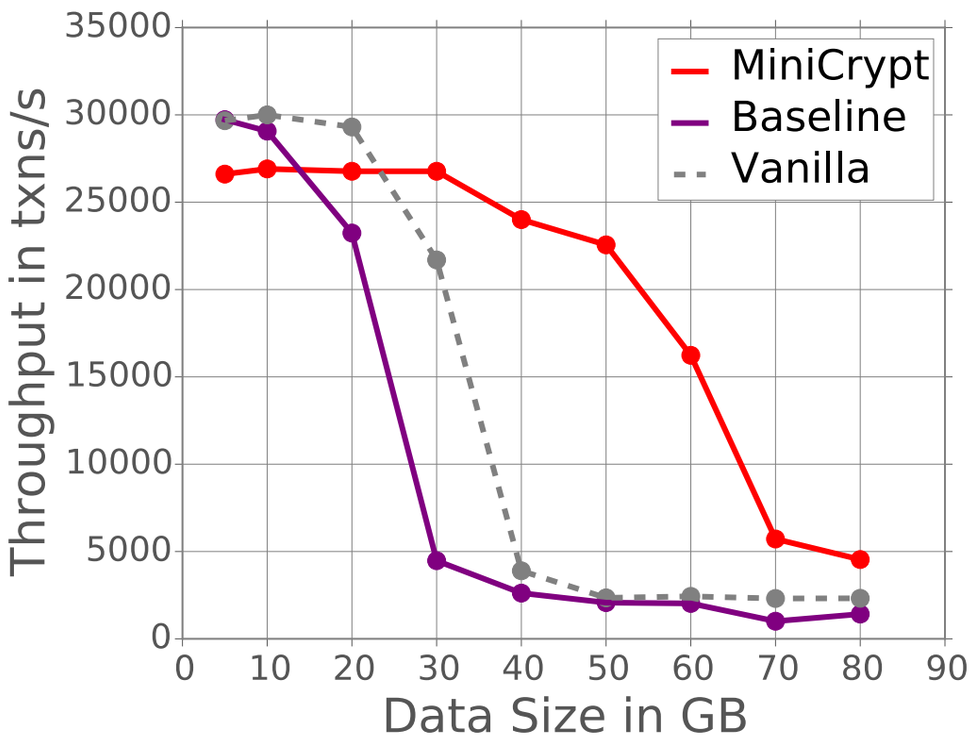
Evaluation setup

- Amazon EC2 cluster of 3 instances
  - 15 GB of memory
  - 8 cores
- Zlib compression

Evaluation setup

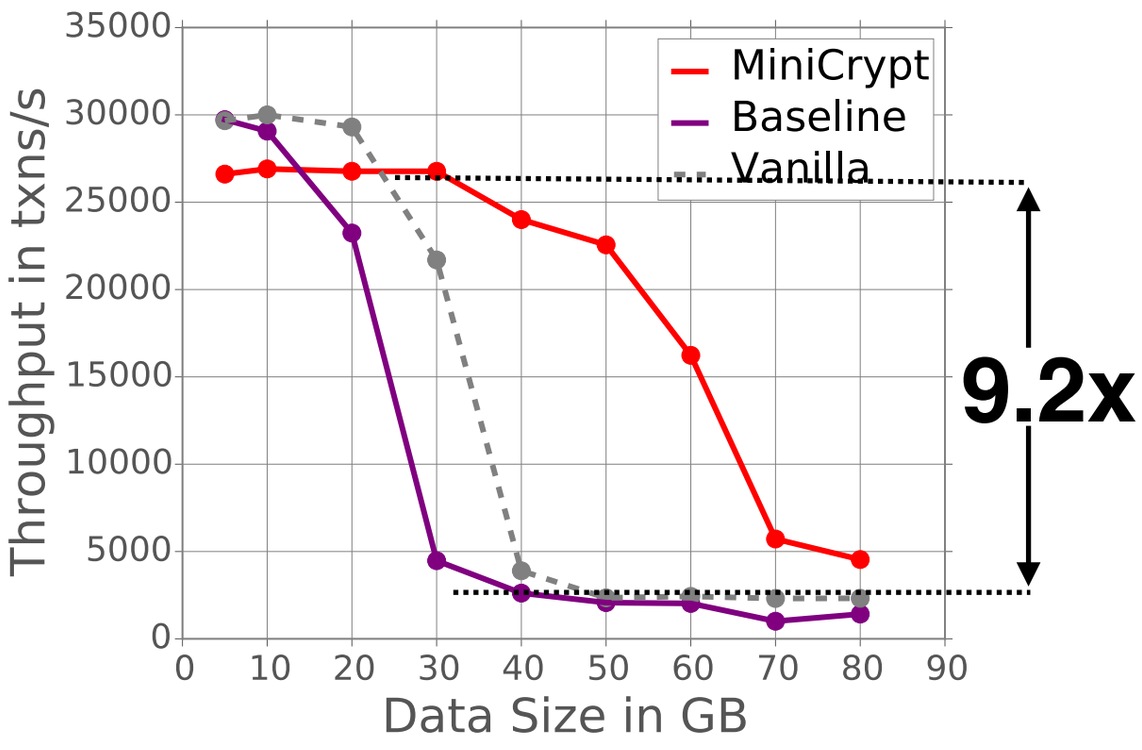
- Amazon EC2 cluster of 3 instances
  - 15 GB of memory
  - 8 cores
- Zlib compression
- AES-256 CBC for encryption

YCSB
100% single-record read



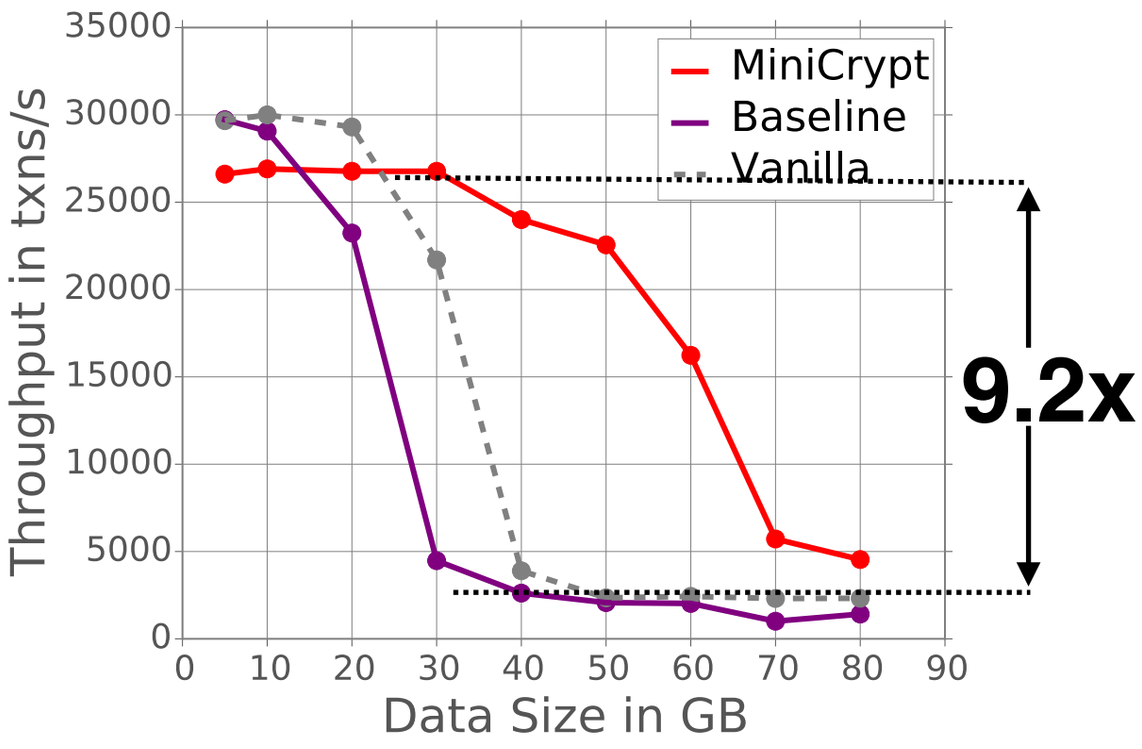
SSD

YCSB
100% single-record read

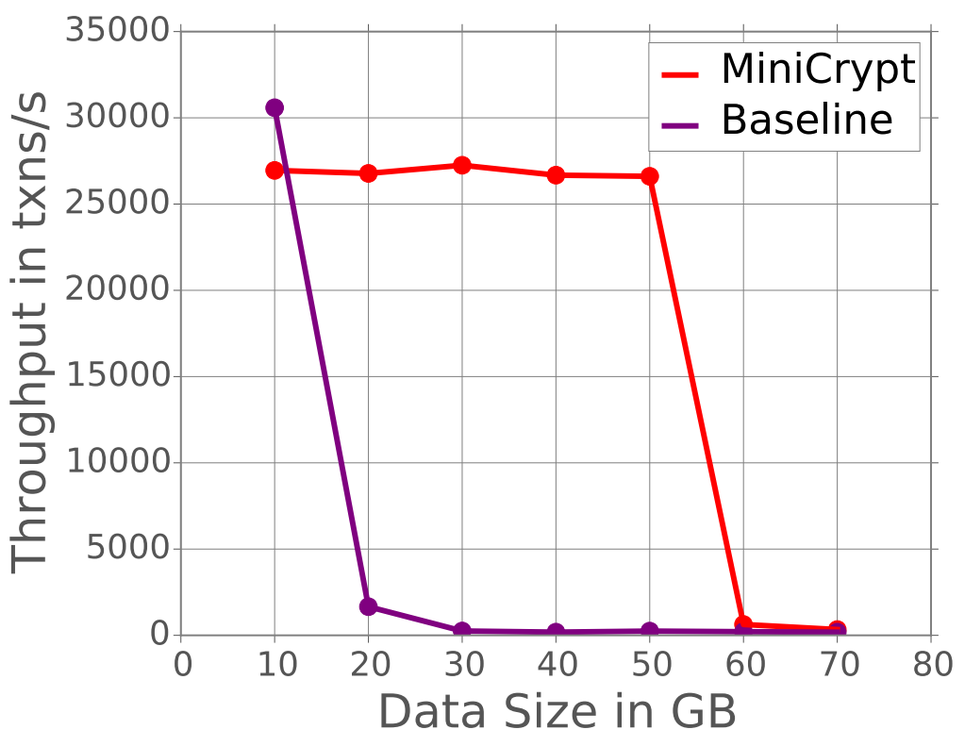


SSD

YCSB
100% single-record read

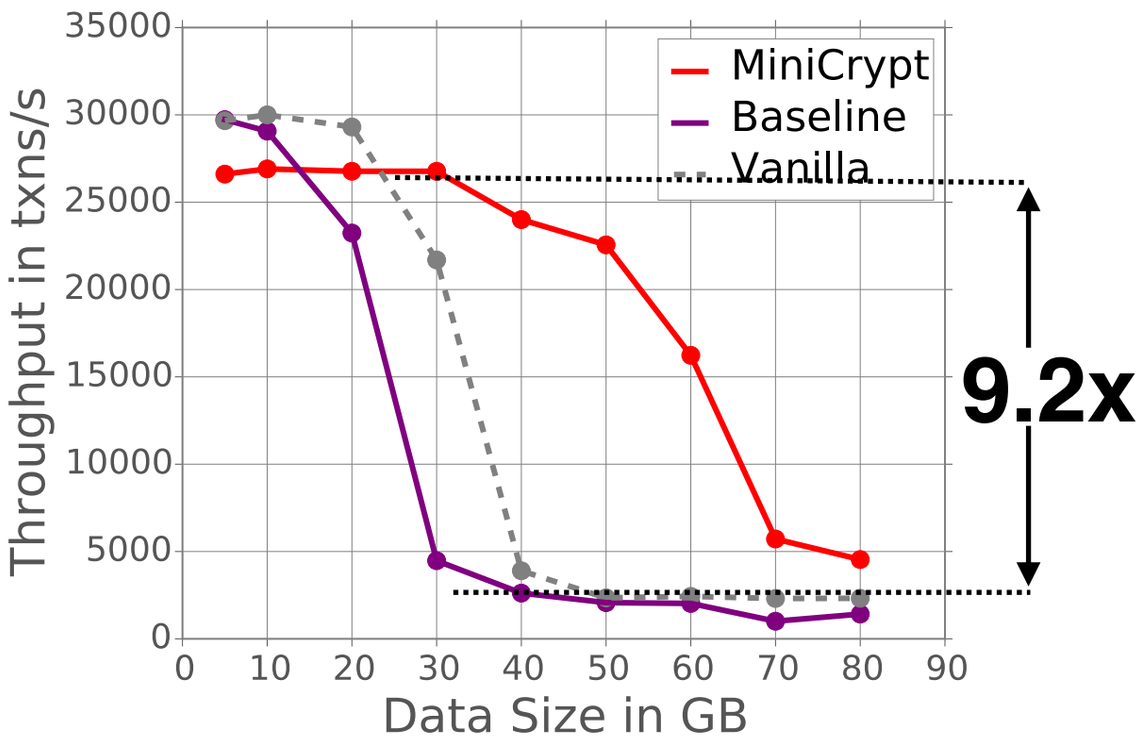


SSD

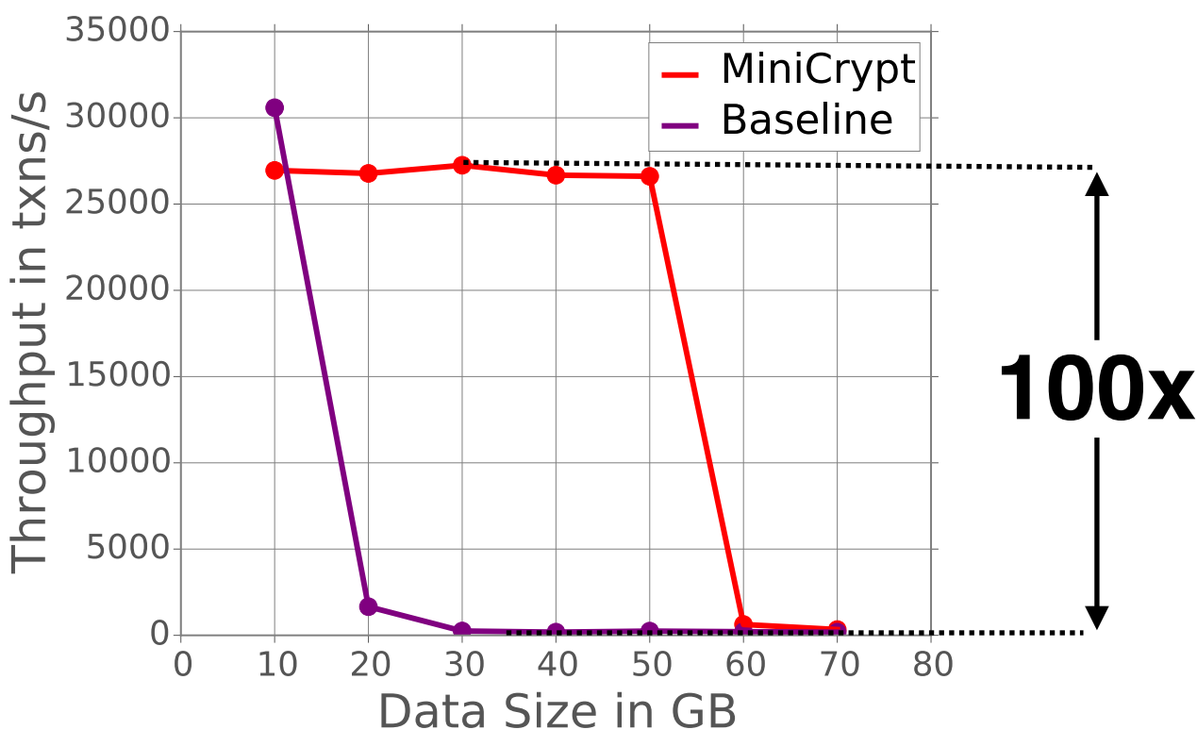


Disk

YCSB
100% single-record read

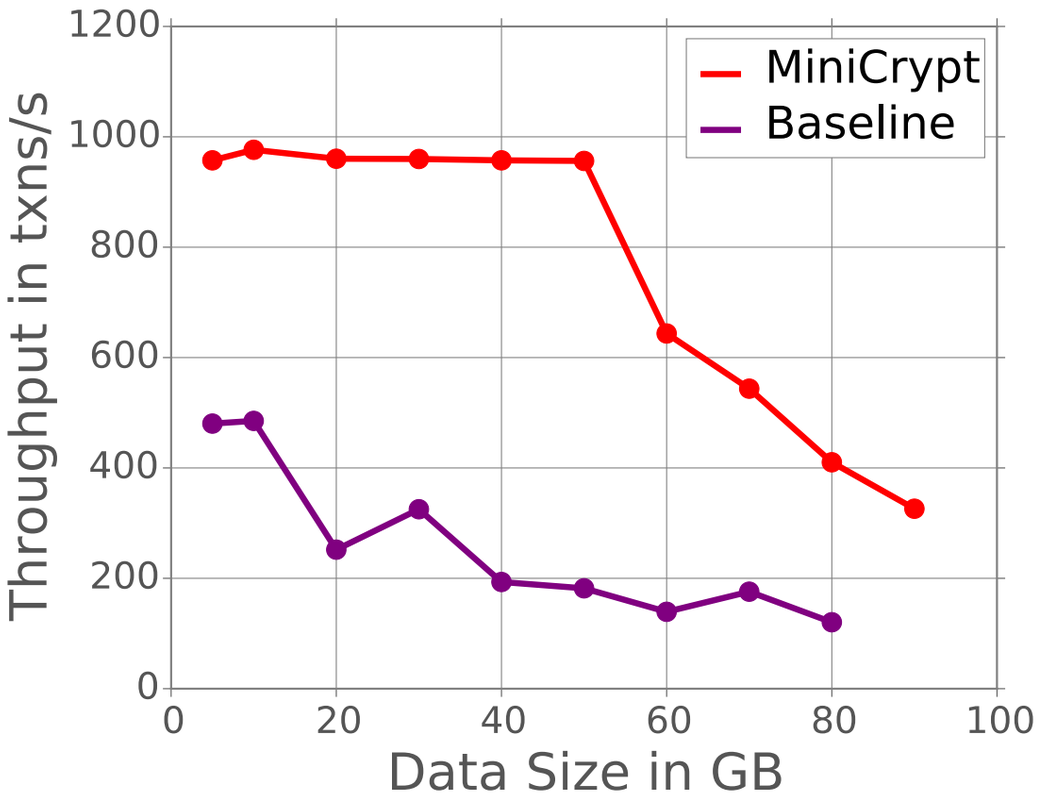


SSD



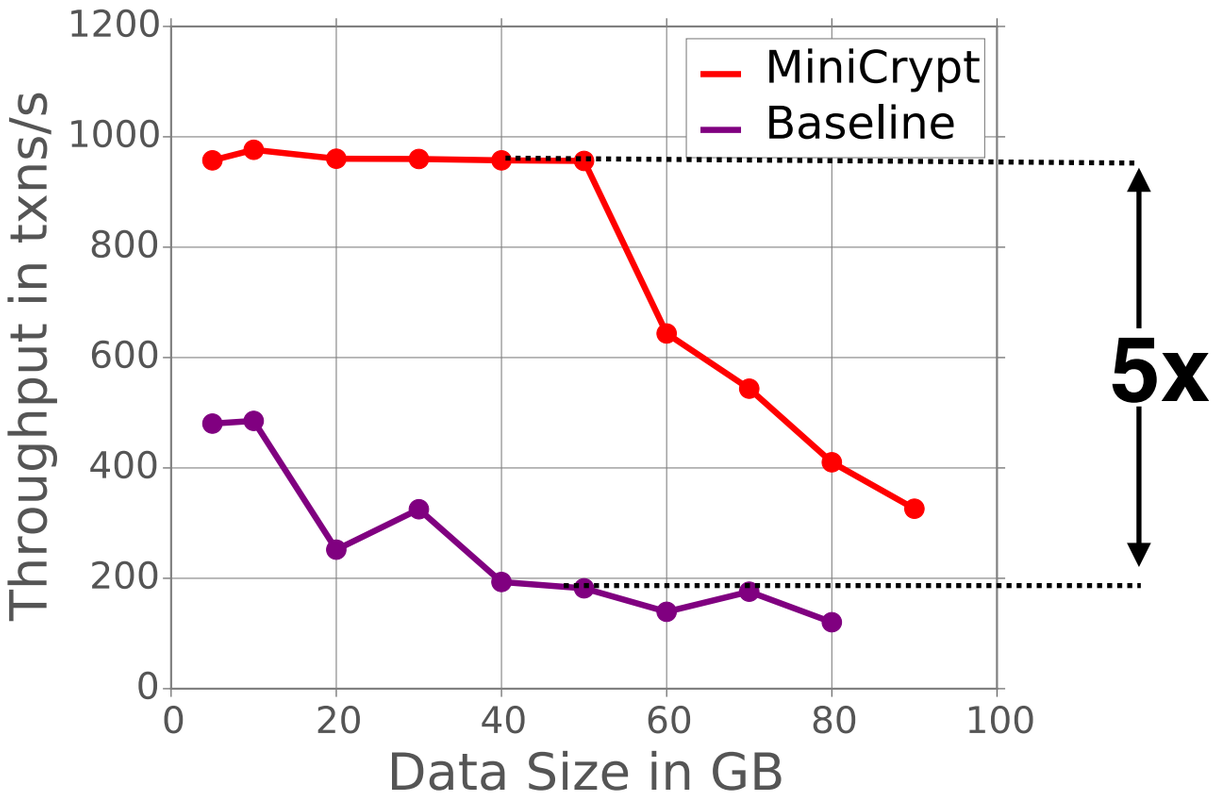
Disk

YCSB
100% range query



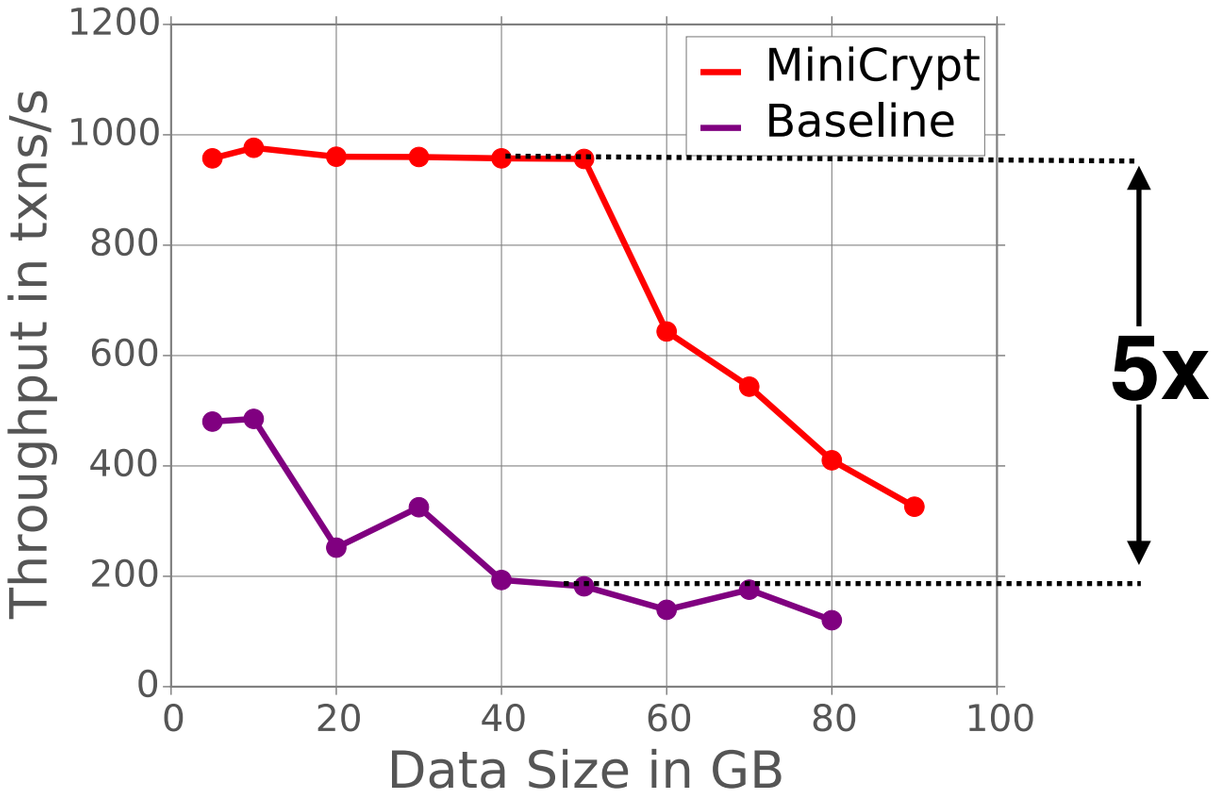
SSD

YCSB
100% range query



SSD

YCSB
100% range query



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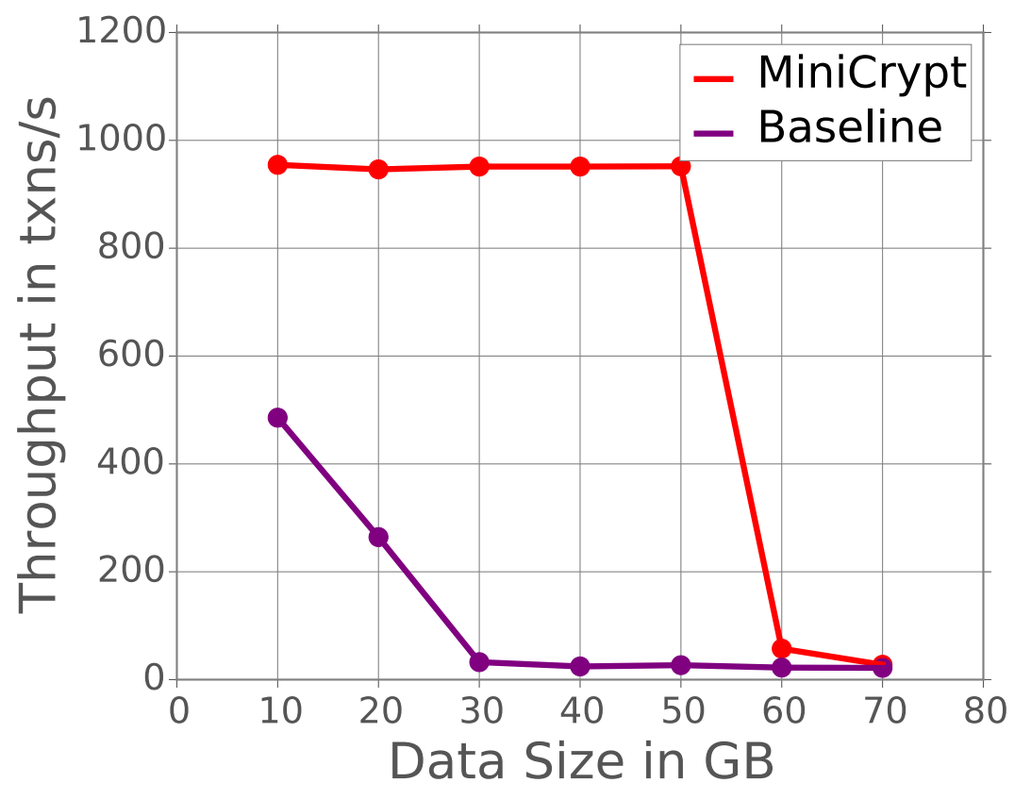
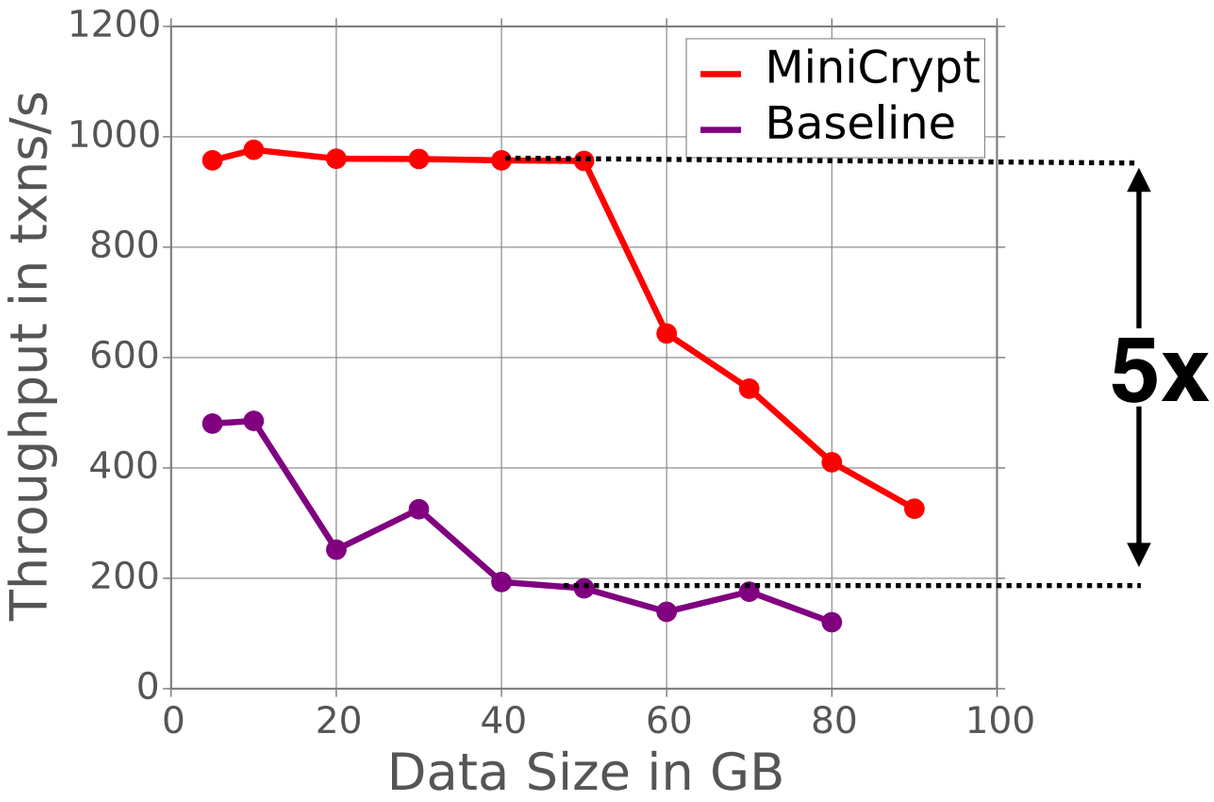
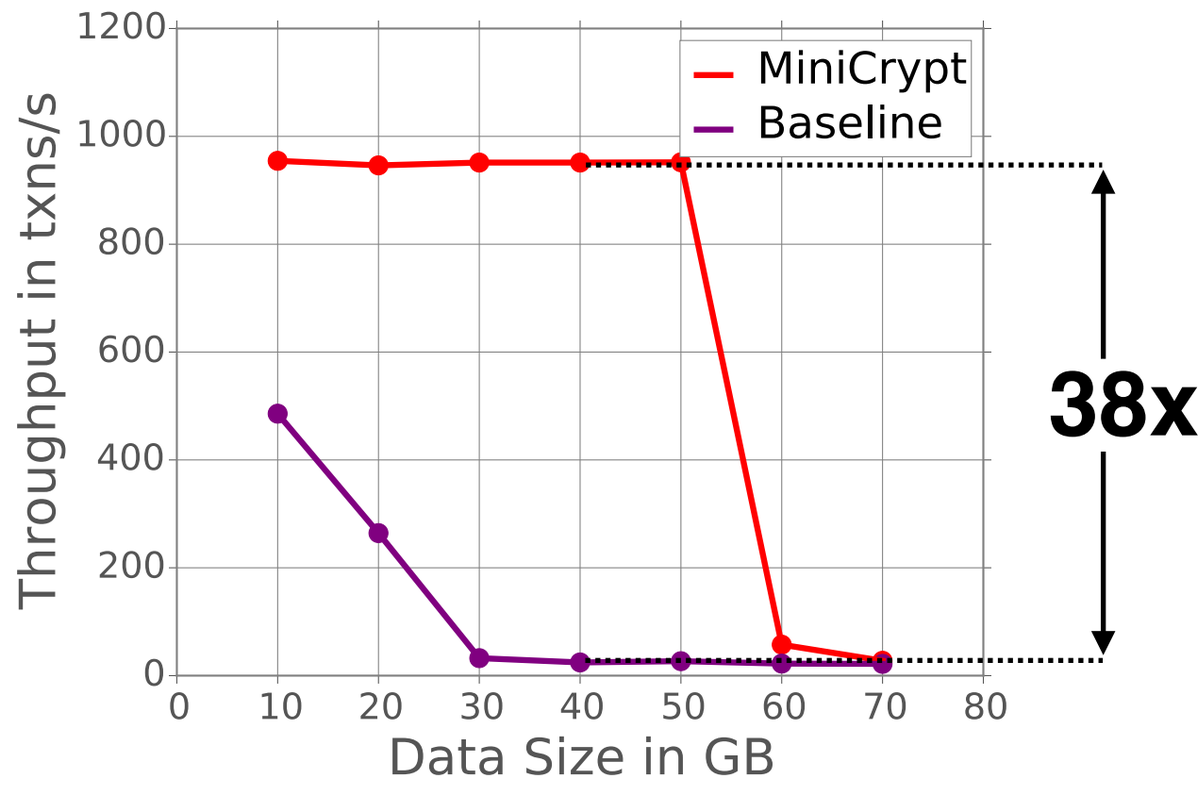


Disk

YCSB
100% range query



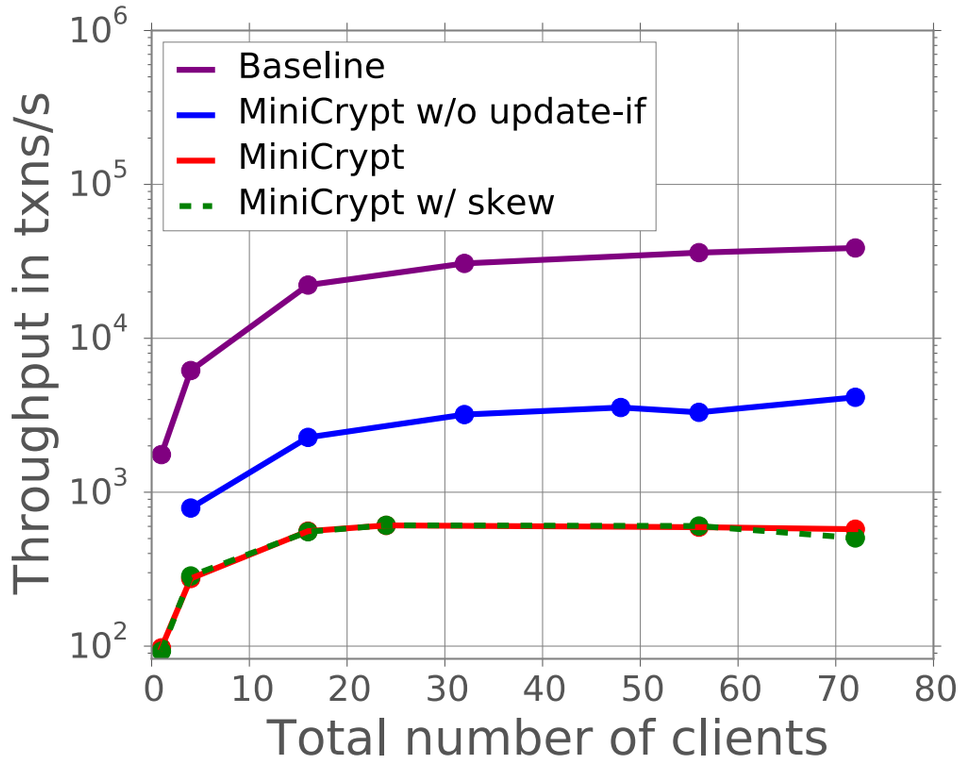
SSD



Disk

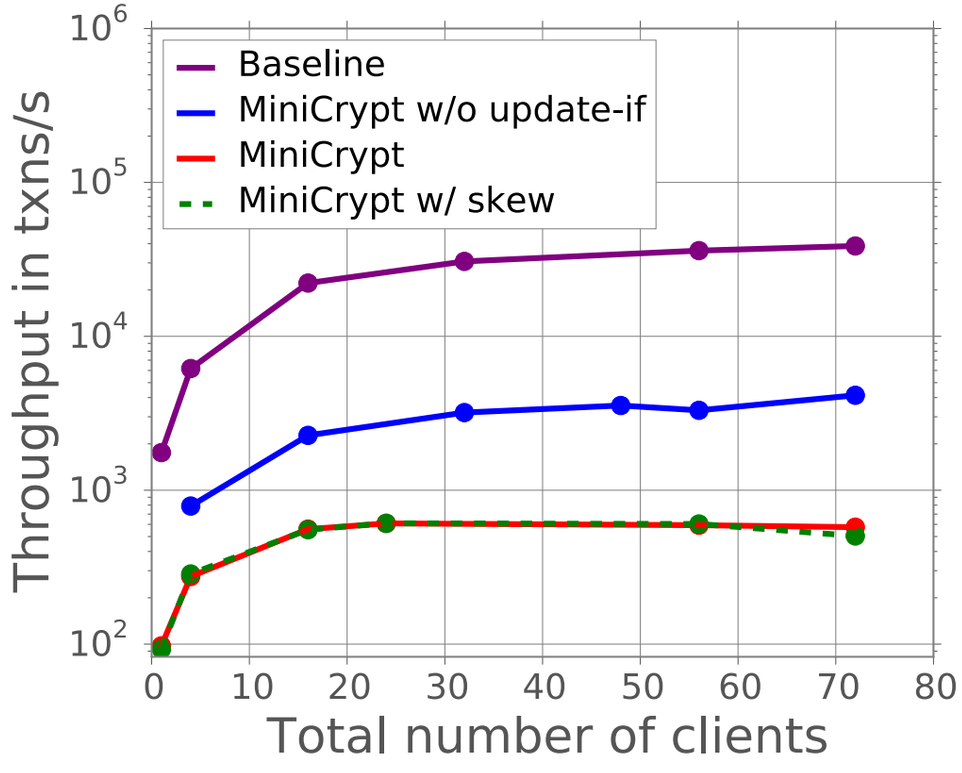
YCSB
100% single-record write

Default

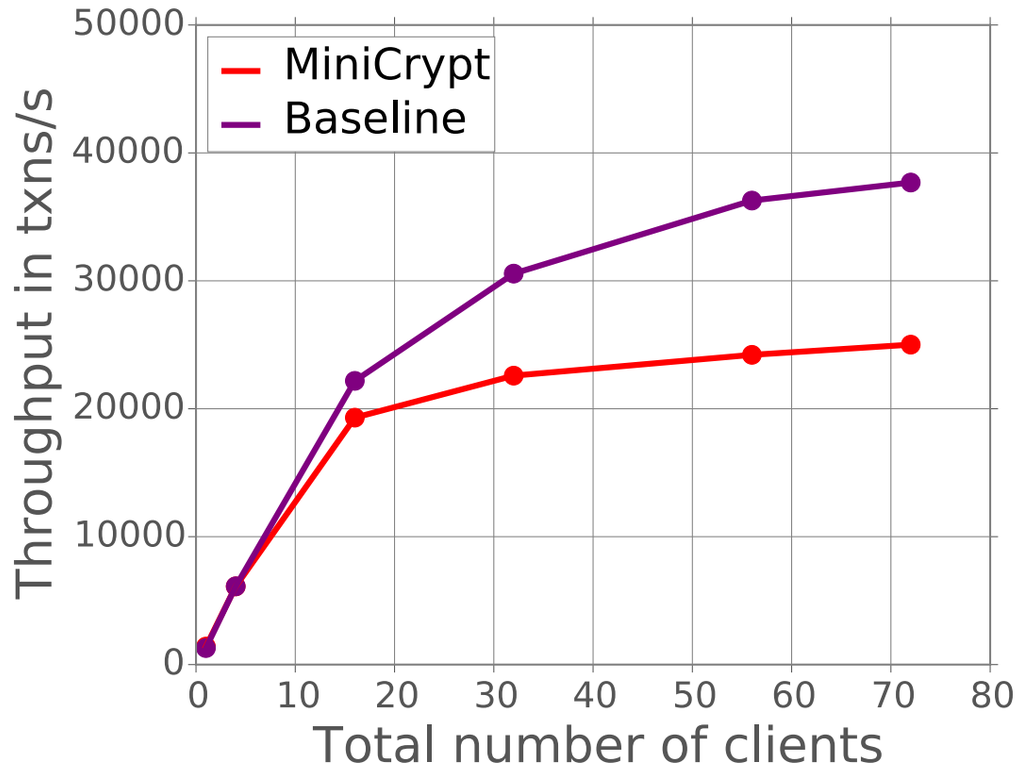


YCSB
100% single-record write

Default



Append-only



Conclusion

MiniCrypt shows that we can achieve compression and encryption using systems techniques

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Thank you!