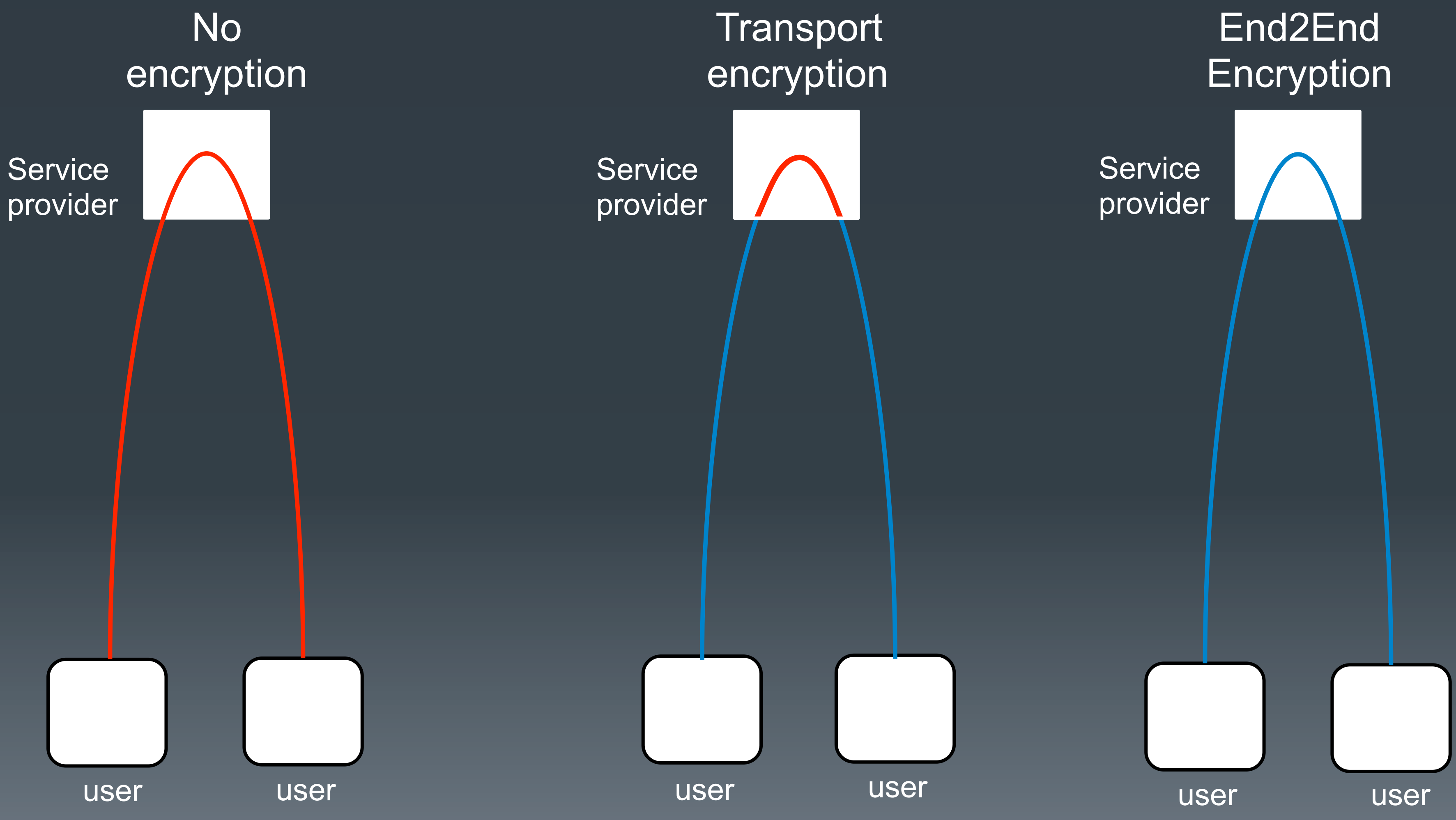
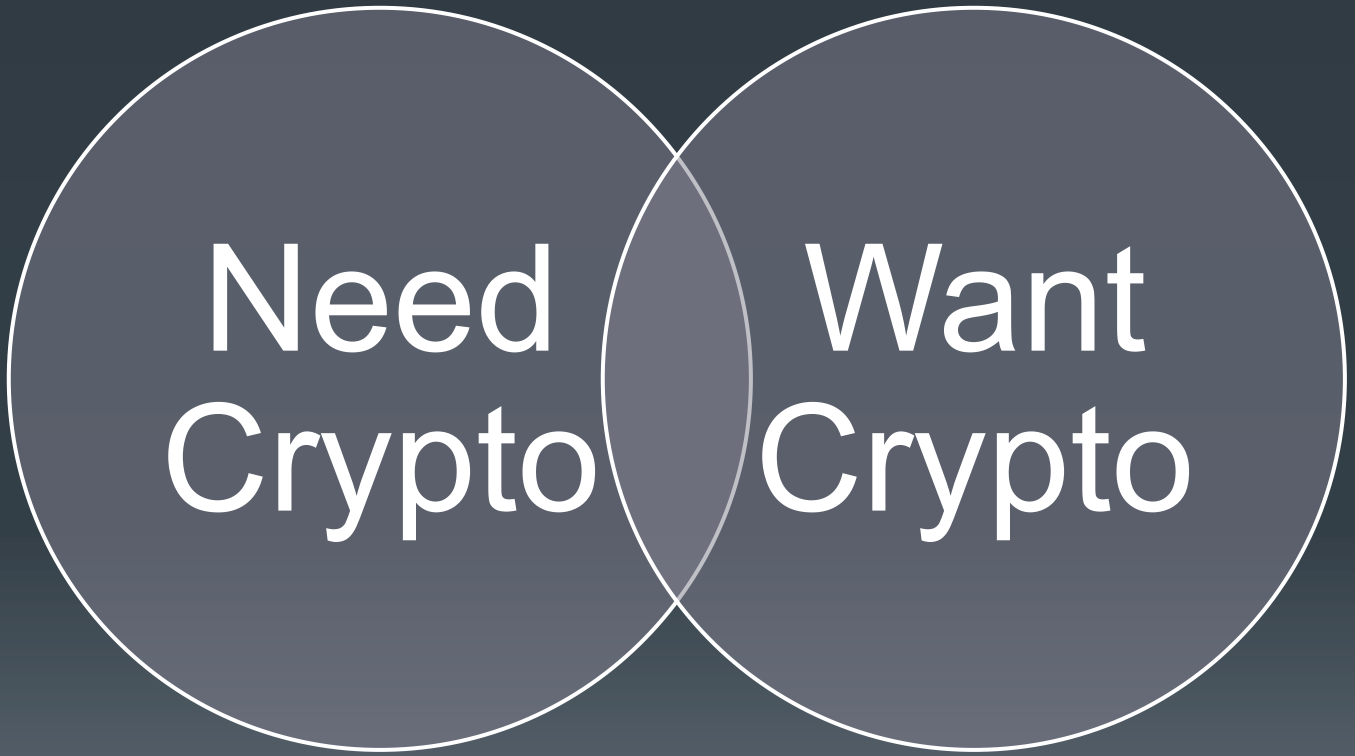
Making Searchable Encryption Scale to the Cloud

Ian Miers and Payman Mohassel

End to end Encryption



E2E Encrypted Messaging



E2E Encrypted Messaging

Ban Crypto

Need Crypto

Want Crypto

Deploying E2E encrypted messaging

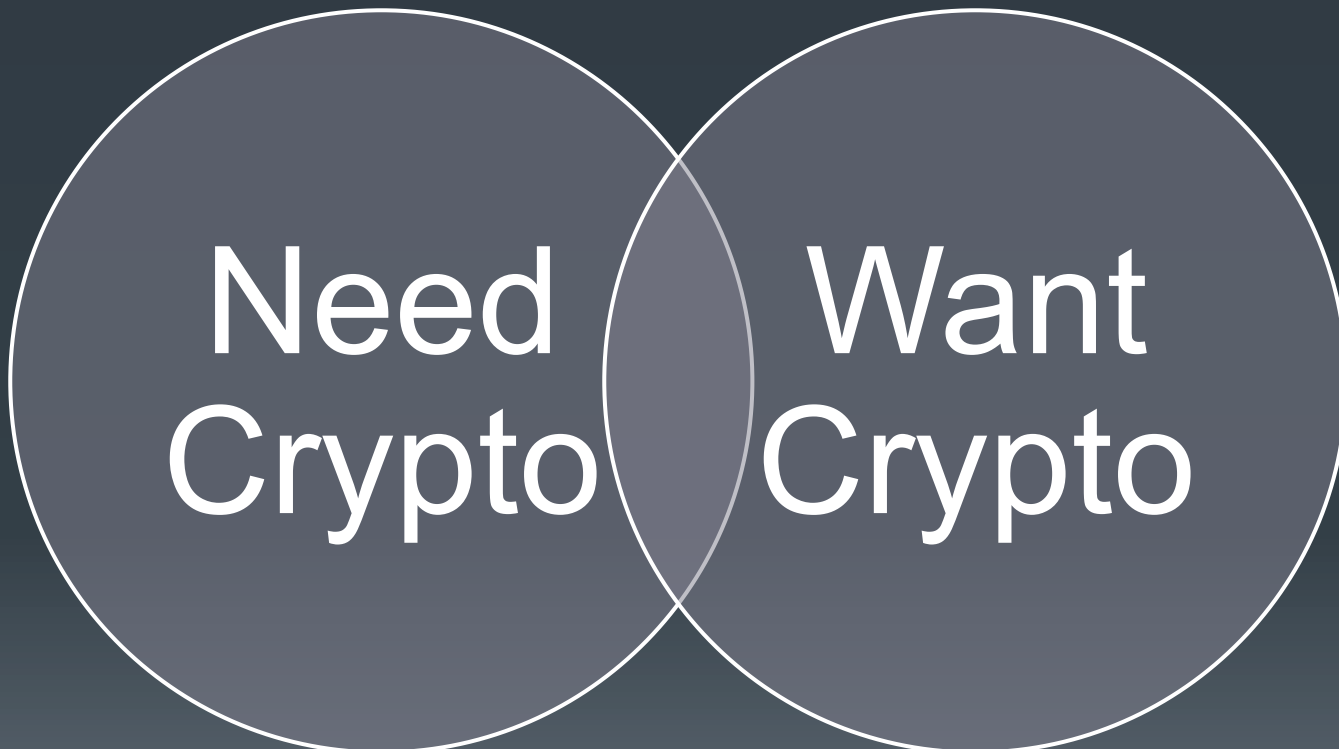
- WhatsApp
  - No feature loss
  - Many users probably don't know they are using it
- iMessage
  - Same features as SMS
- WebRTC video chat

Search

- For some communication mechanisms, people expect search
- Email is the canonical example, but not the only one.
  - Slack
  - Any “email replacement “

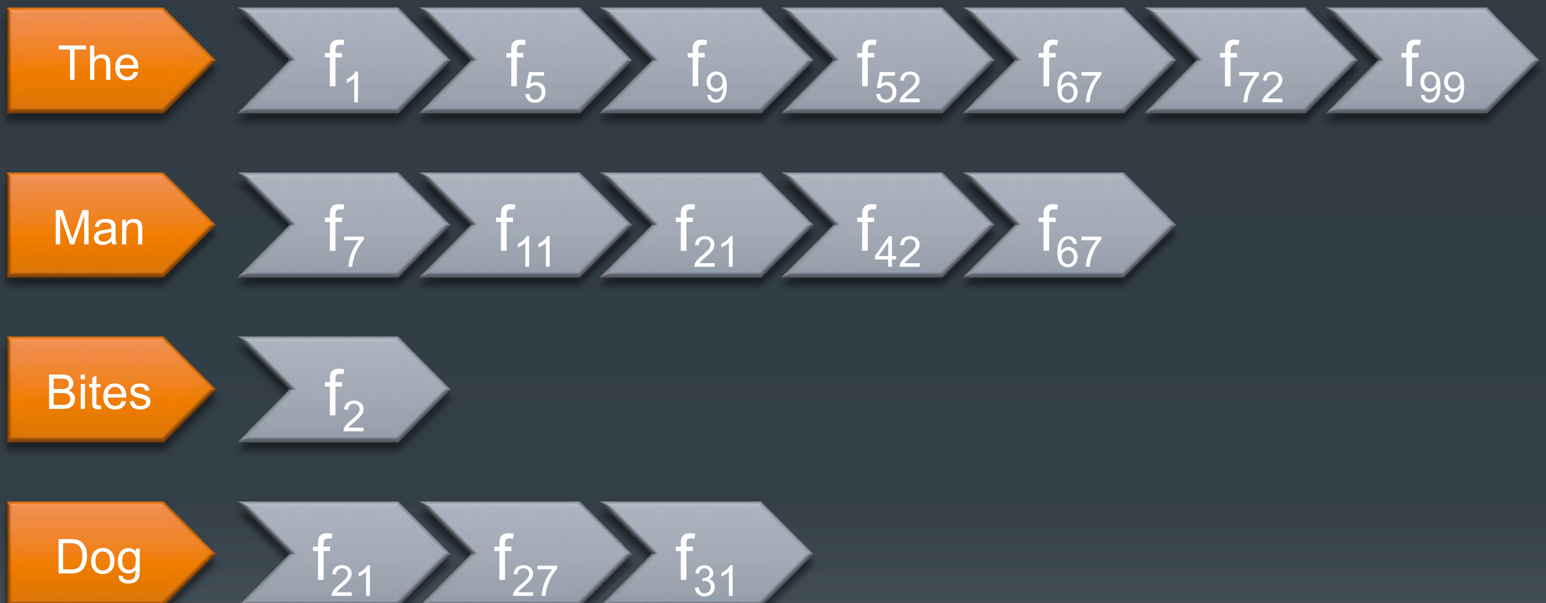
“I’m not particularly thrilled with building an apartment building which has the biggest bars on every window” – Jeff Bonforte (Yahoo VP mail and messagin)

E2E Encrypted Messaging



Searchable Encryption

An index for search



Index on client, store on server

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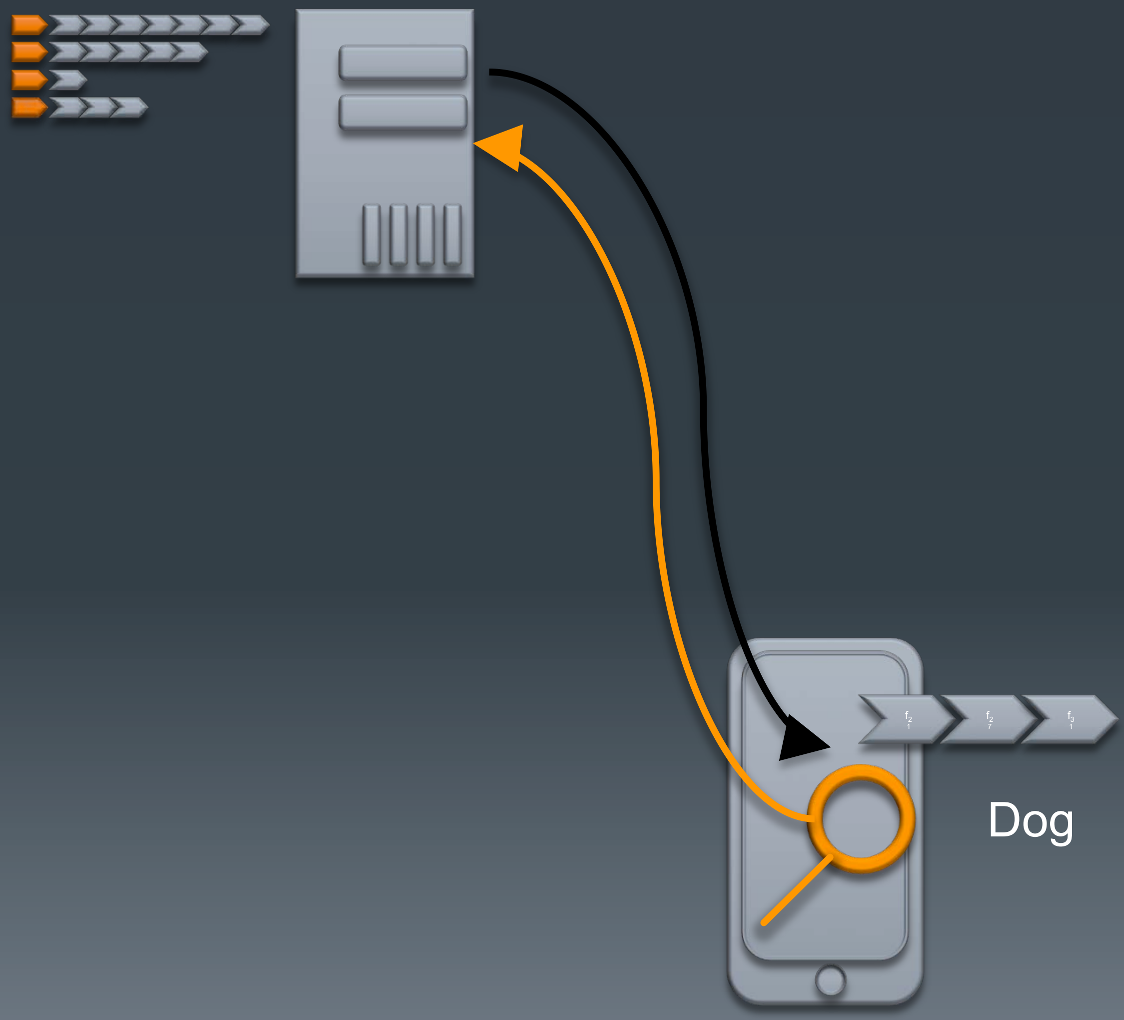

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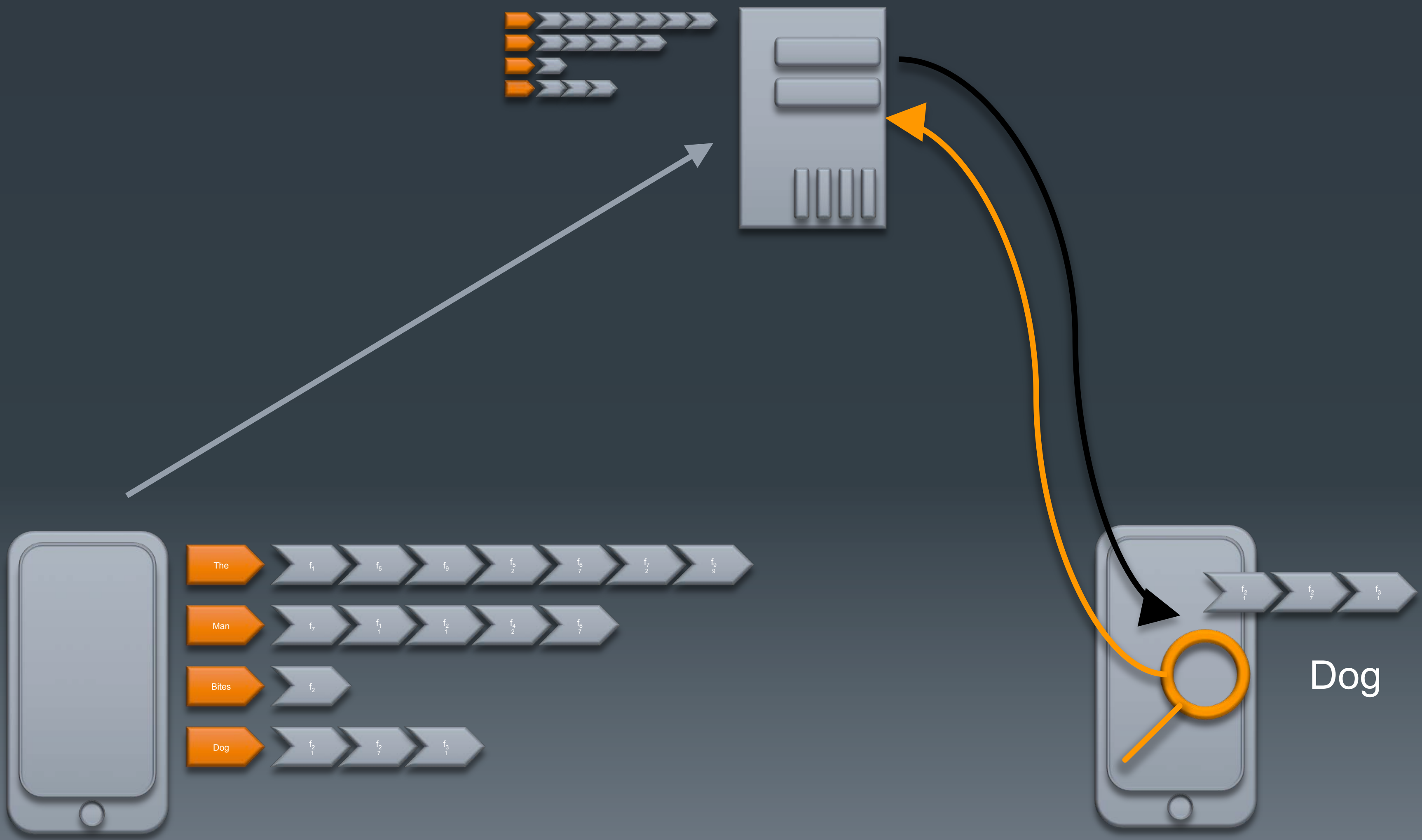
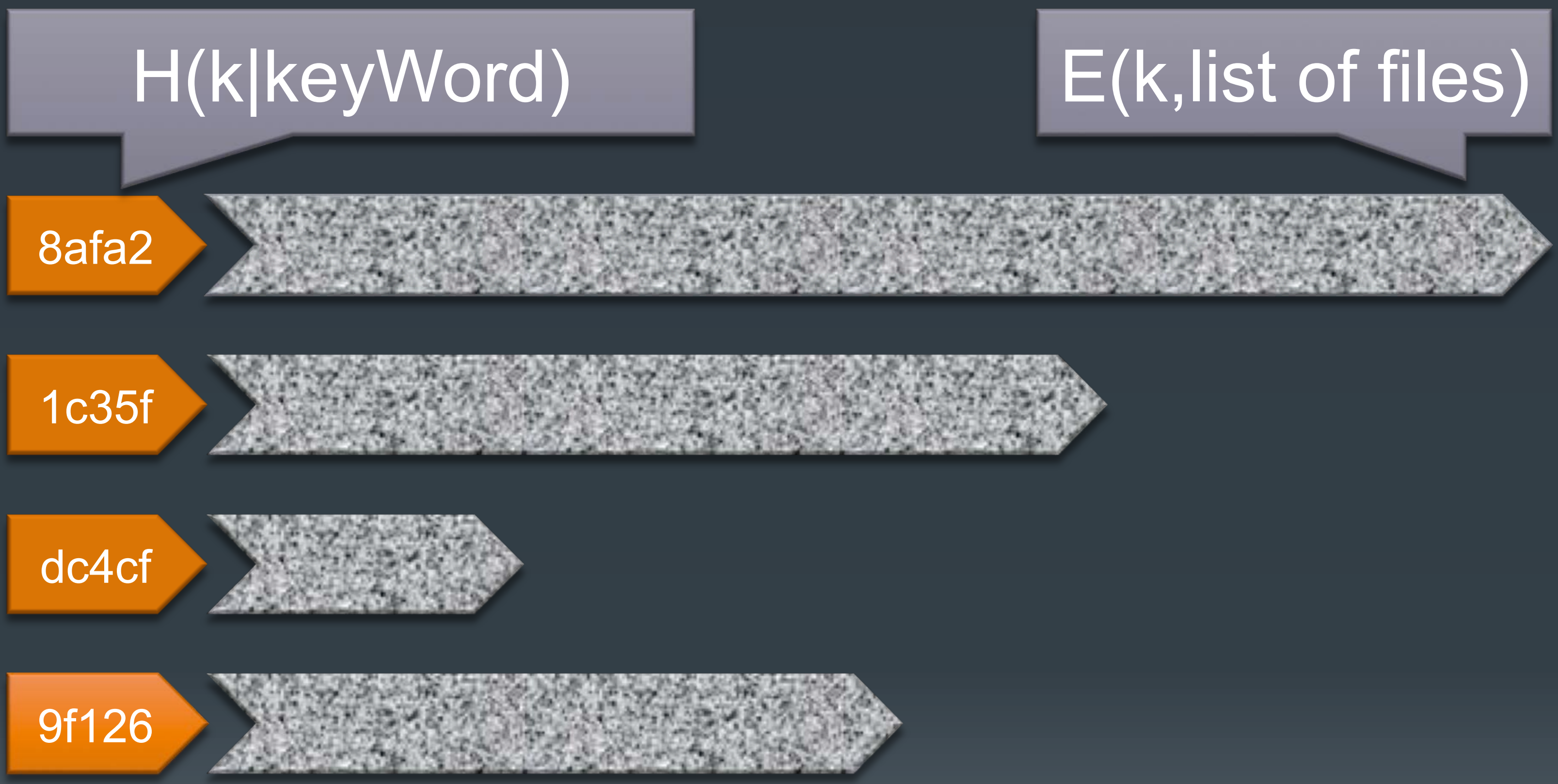


An index for search

A Naïvely Encrypted Index



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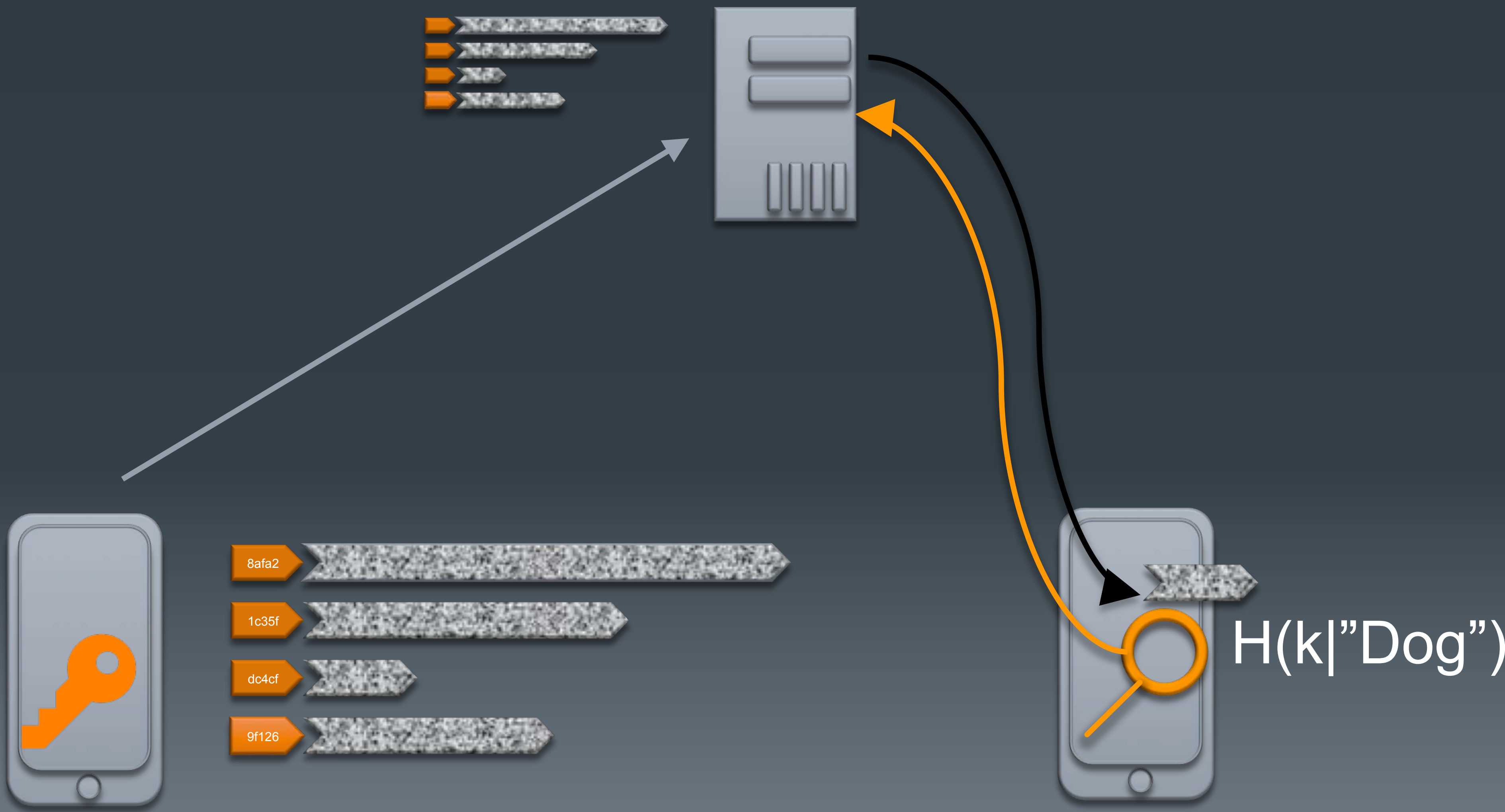


A Naïvely Encrypted Index

H(k|keyWord)

E(k,list of files)

8afa2

1c35f

dc4cf

9f126

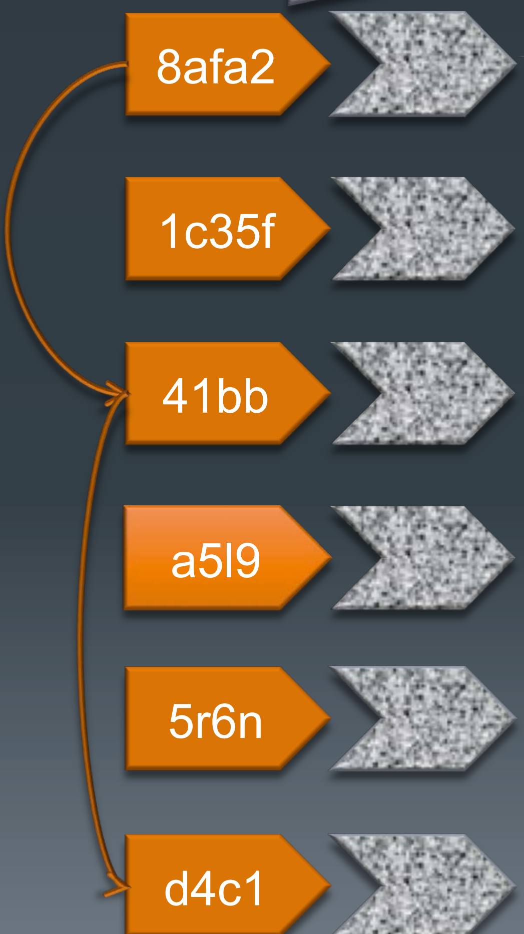
Leaks term frequency

- 8afa2 is the most frequent keyword
- "The" is the most frequent English word
- ……

An Inefficient Encrypted index

$H(k|keyWord|KeyWord\_ctr)$

$E(k, f_i)$



- For a given keyword, each file containing it is stored in a separate random location
- This hides keyword frequency in a space efficient way
- Very inefficient to search:
  - Requires one random read per result
  - Results in a ~25-50x increase in I/O usage
  - Yahoo! Mail search is already IO bound !!!
  - Not viable for a server supporting multiple users who are not paying for it

Search at Cloud Scale

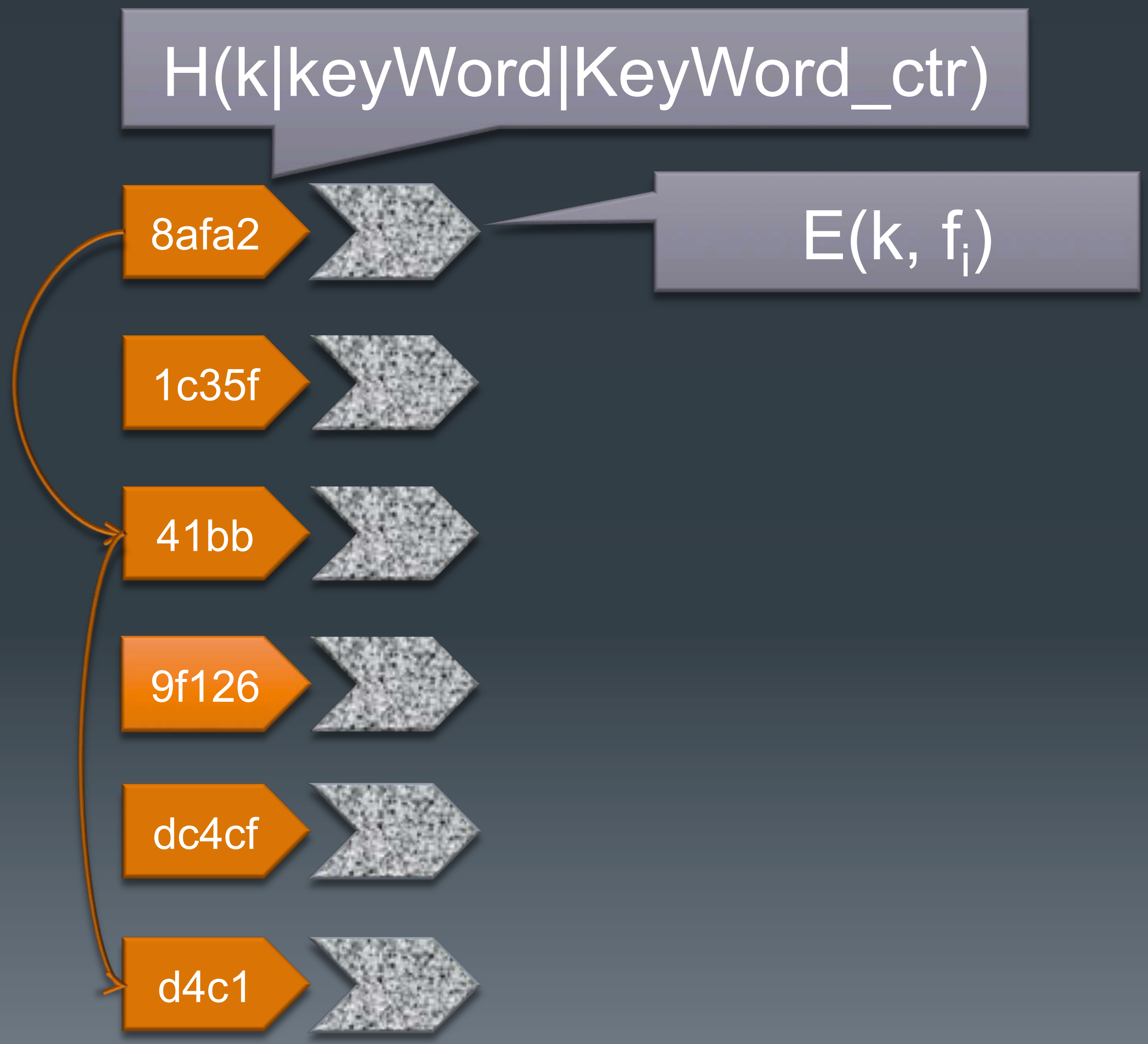
- Many small indexes
  - < 1GB each
  - > 1 Billion accounts
- Cannot store in memory
- Must use disk storage
- IO Bound
- Fragmented index causes massive increase in iO for search
- A search for one keyword returning N documents takes N times as many reads.

Good news

- Email search queries are fairly simple
  - Typically single keyword
  - Conjunctive search nice, but not necessary
- Most searches are on meta data
- Searches on mail content are rare
  - ~250 searches a second *across all users*
  - ~300 million monthly active users

- But we must solve the IO issue.

An Inefficient Encrypted index



IO Efficient search for static indexes

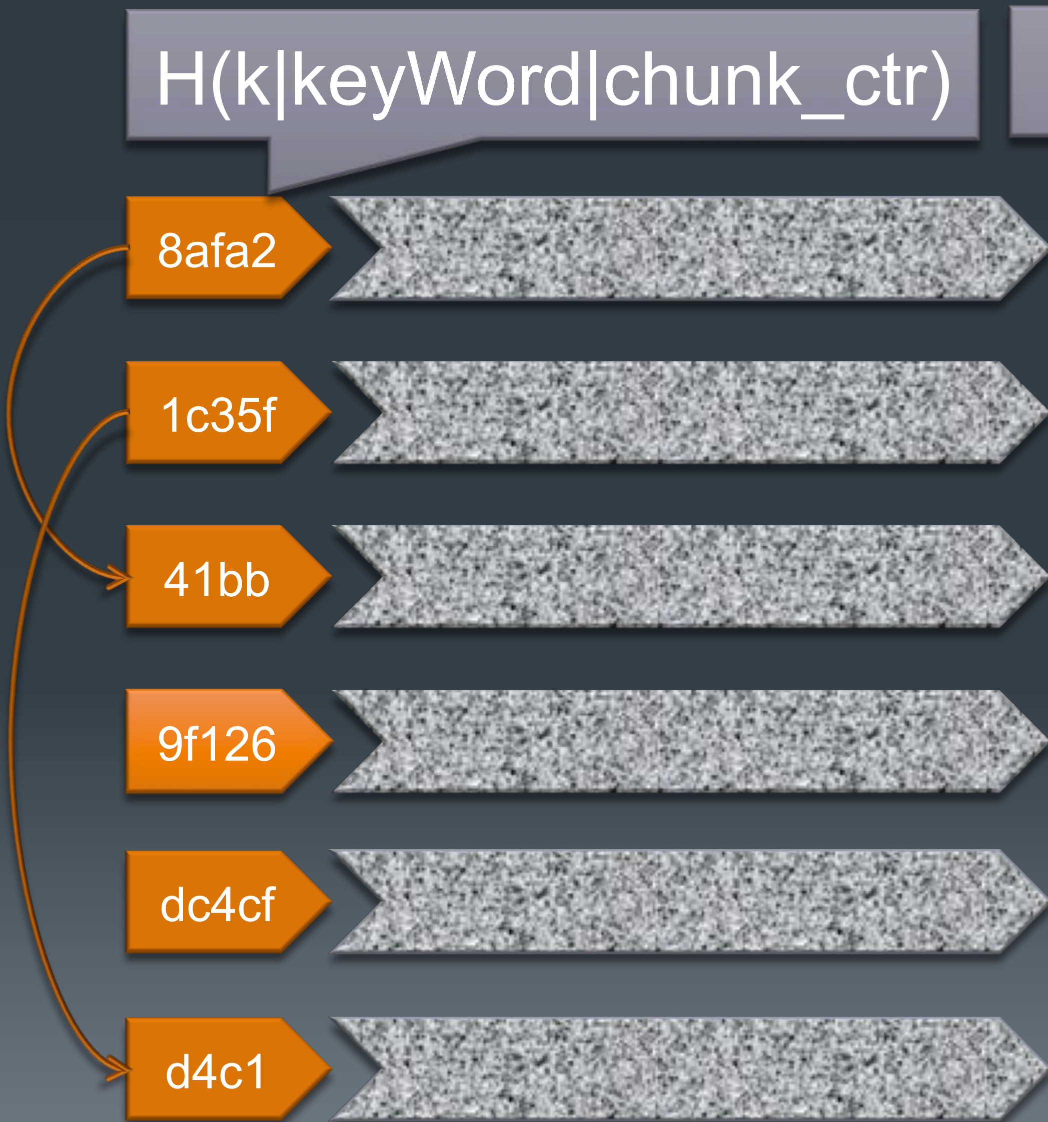
Chunked Encrypted Index

H(k|keyWord|chunk_ctr)

E(k, chunk of files)

- Assume we have all documents initially
- We break up the list into chunks
- Way more efficient to search
- Can scale to terabytes
- Cash et al (Crypto '13, NDSS '14)

Problem: updates



E(k, chunk of files)

- :“lost **DOG**”
- Dog is “9f126”
- Need to add to “Dog” entry.
- But … that leaks what we updated

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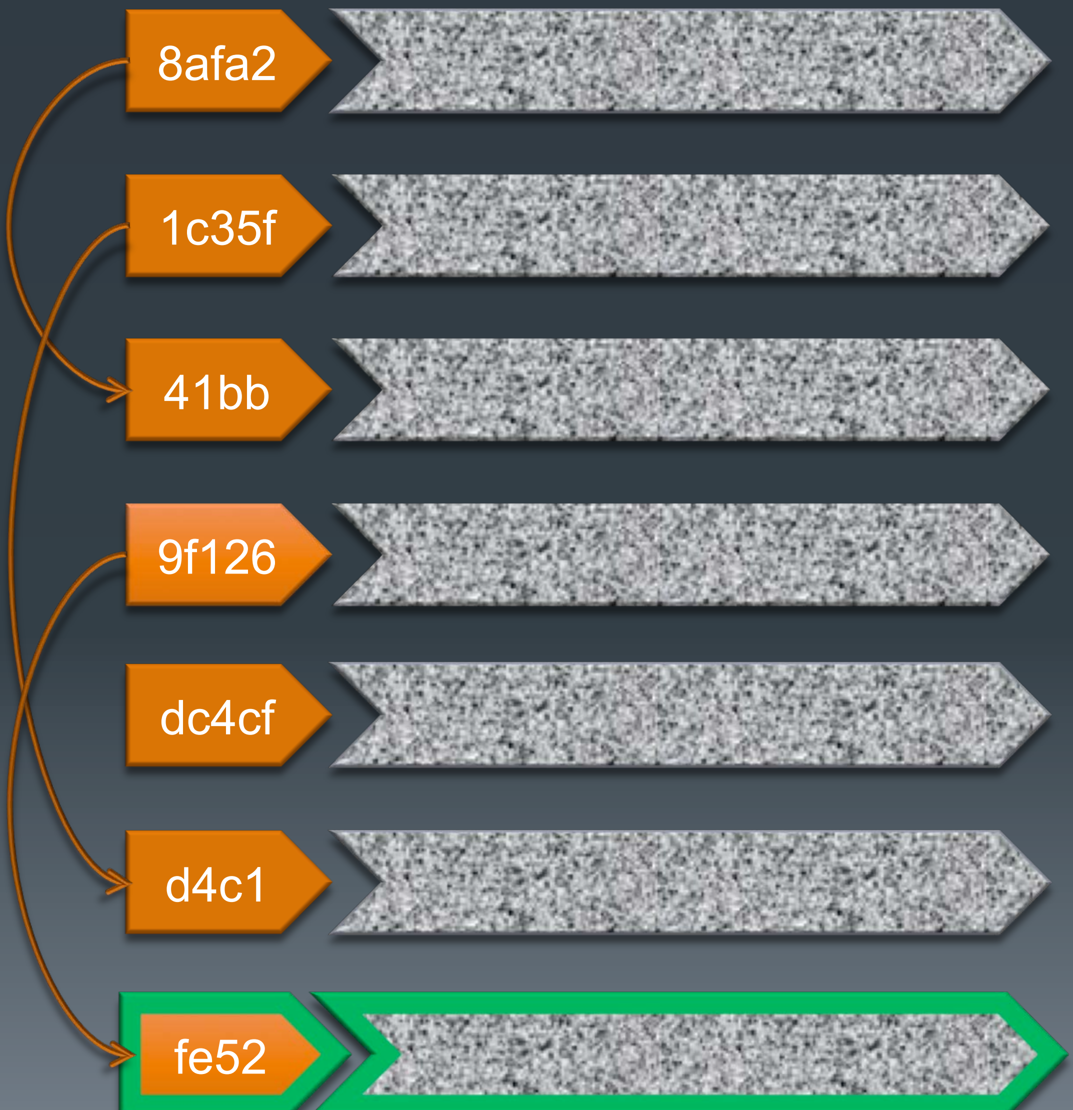

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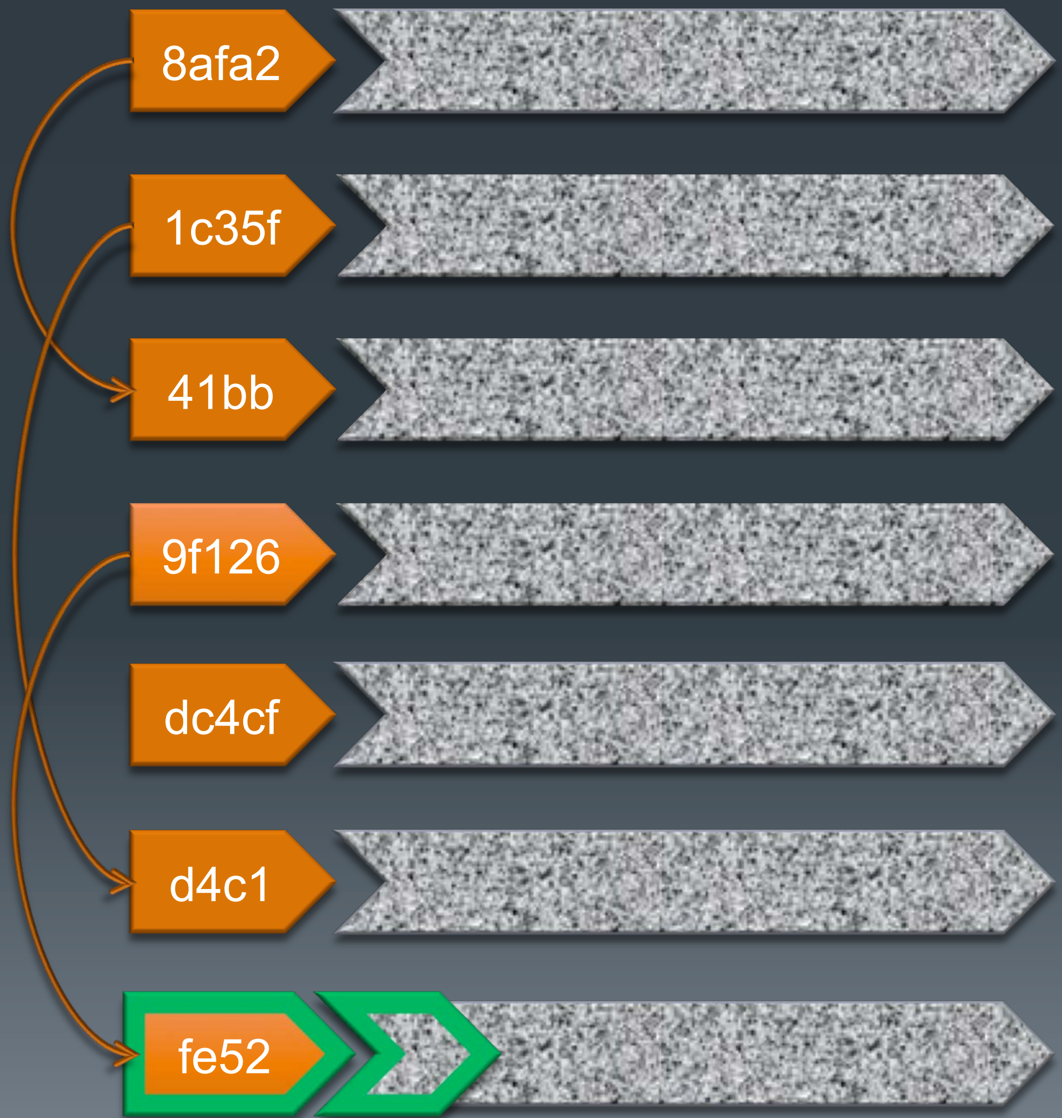
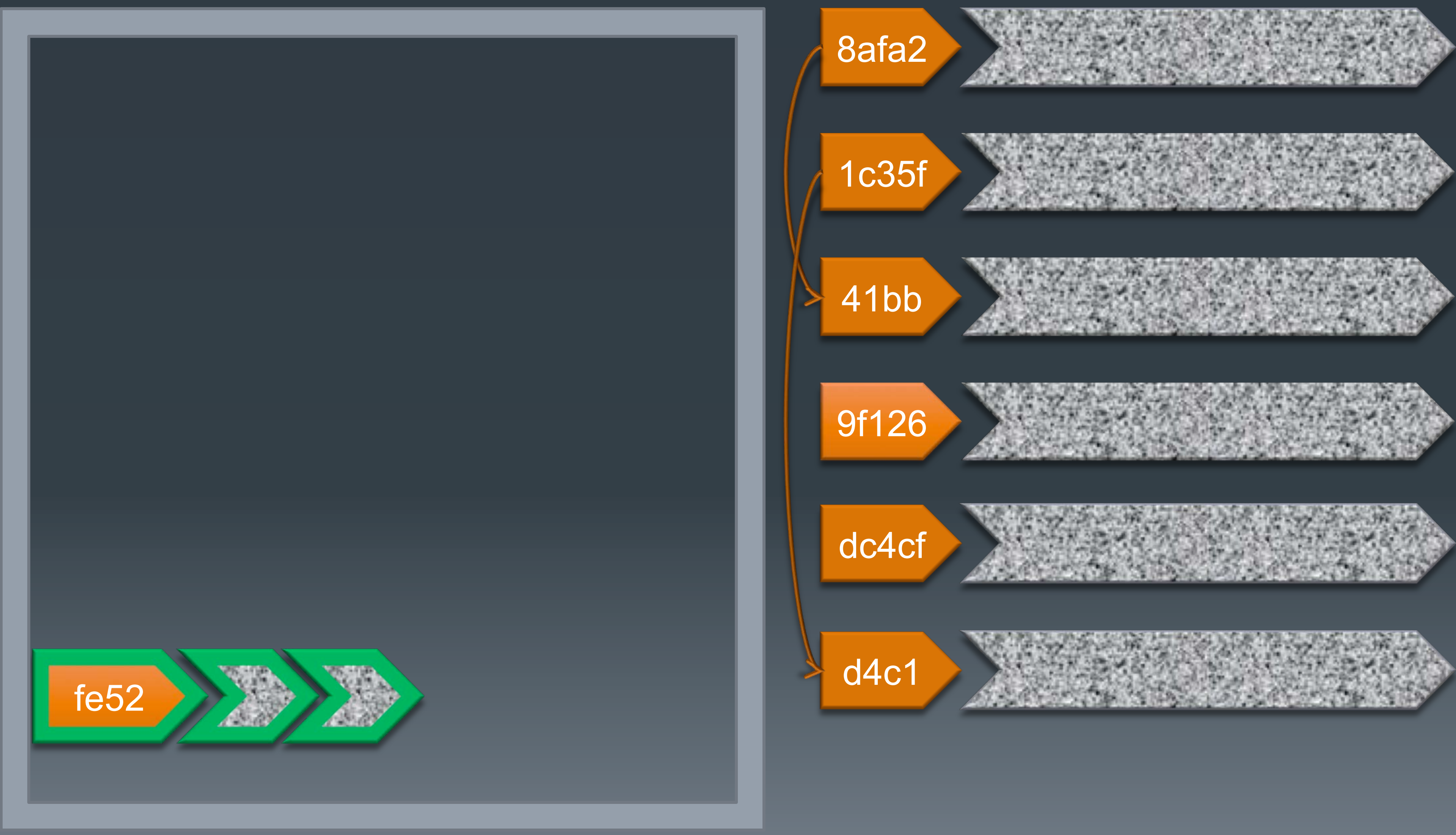


IO-DSSE: Scaling Dynamic Searchable Encryption to Millions of Indexes By Improving Locality

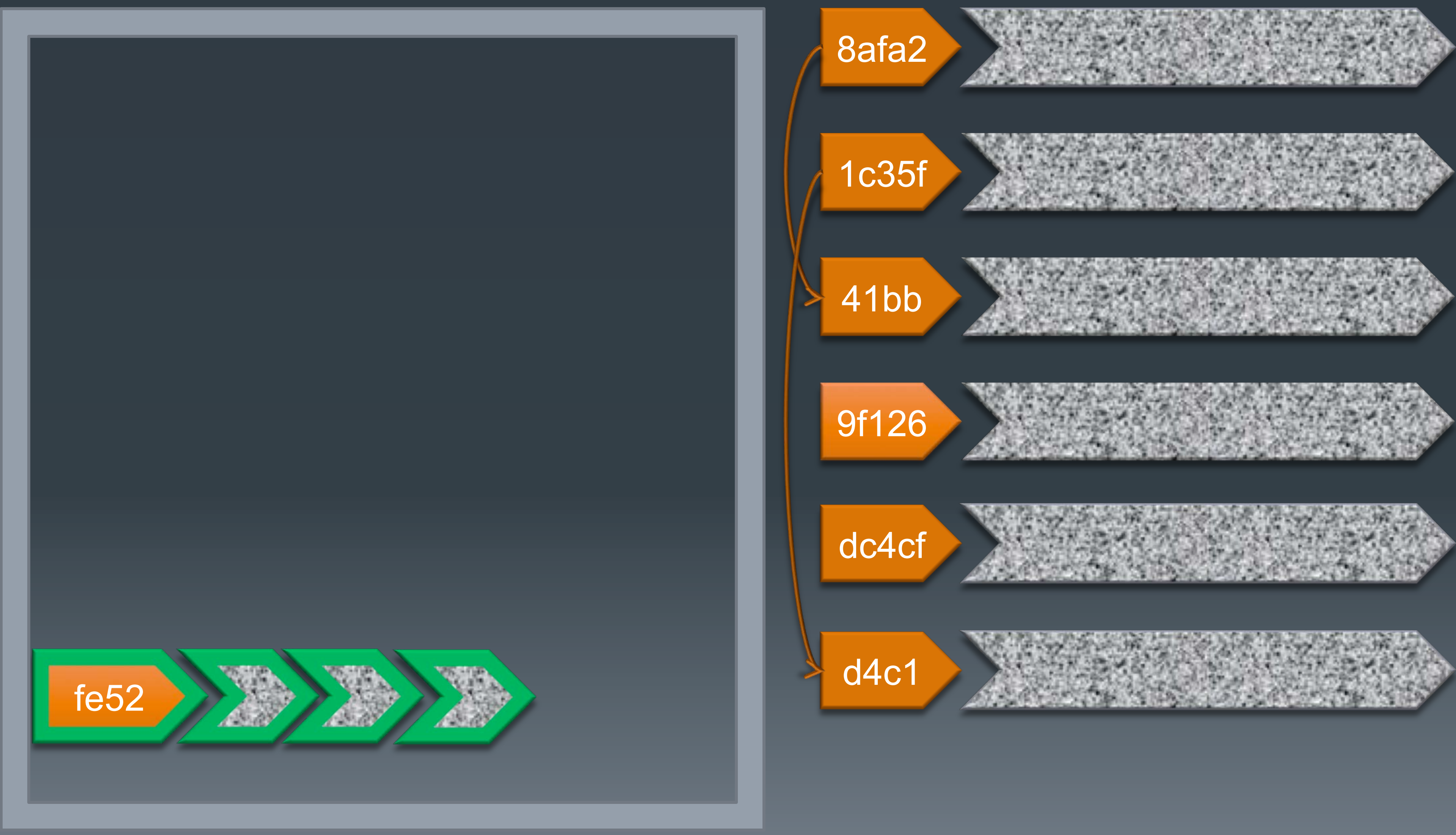
Obliviously Updateable Index

Standard search index

Obliviously Updateable Index



Obliviously Updateable Index



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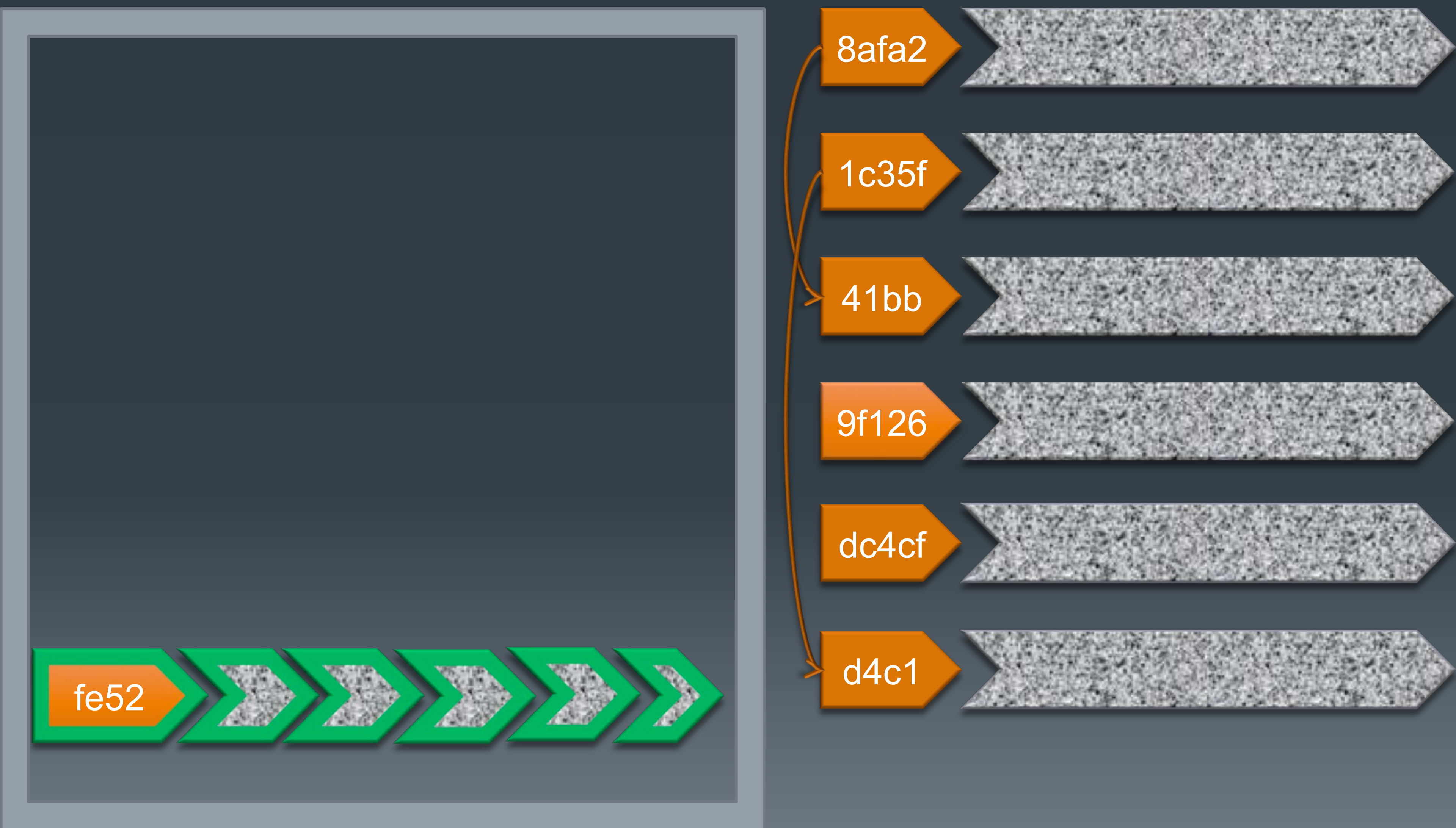

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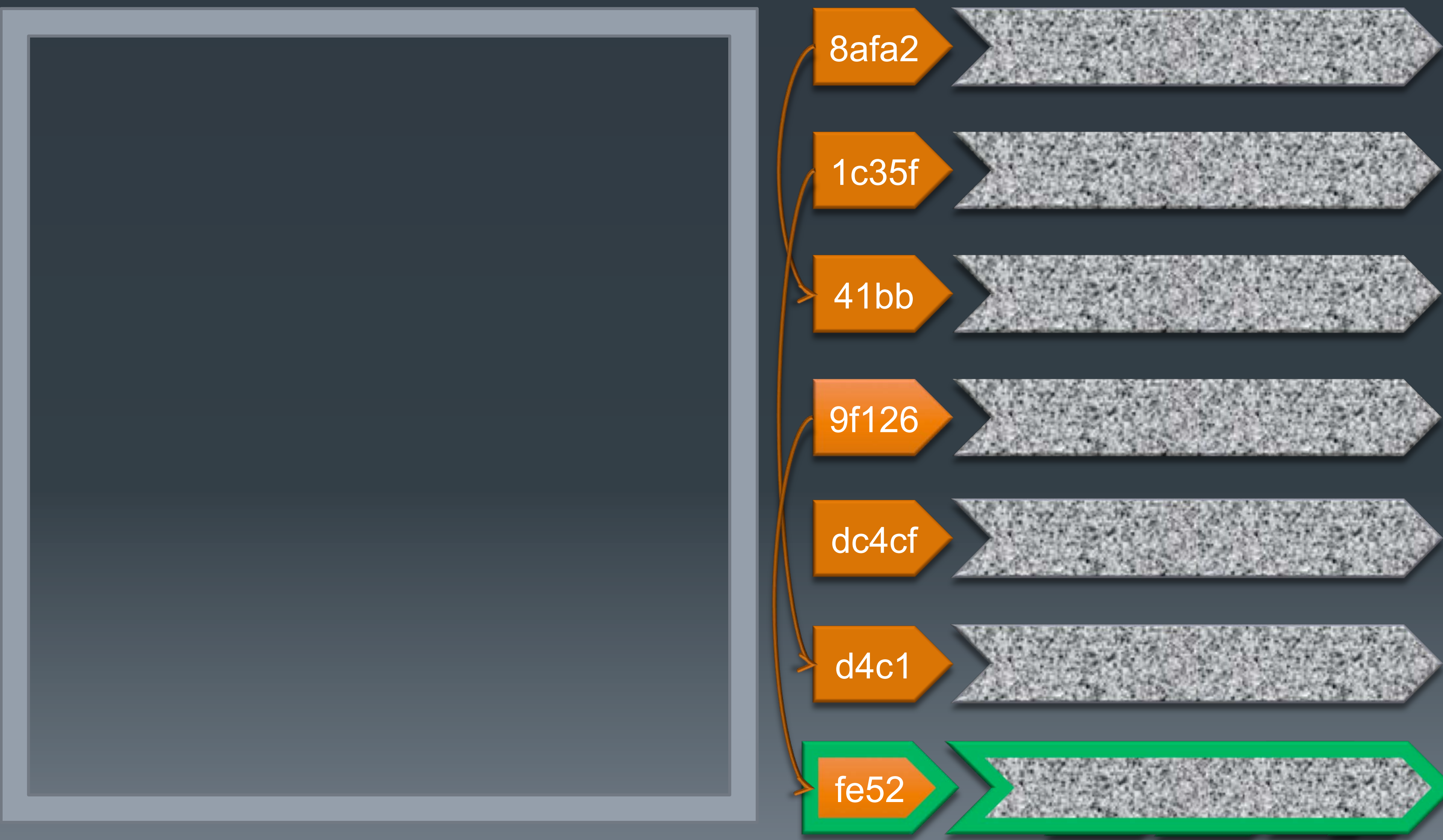
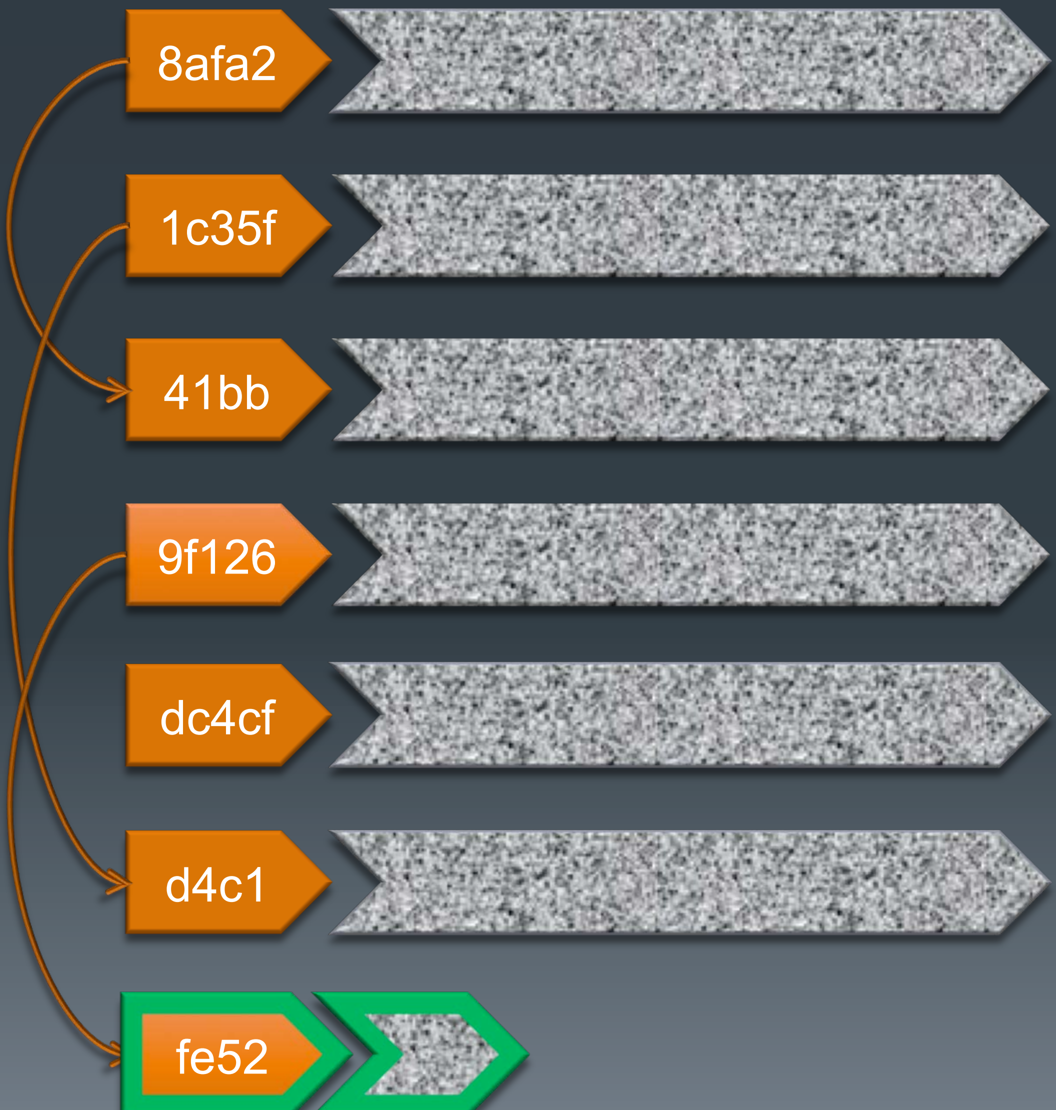


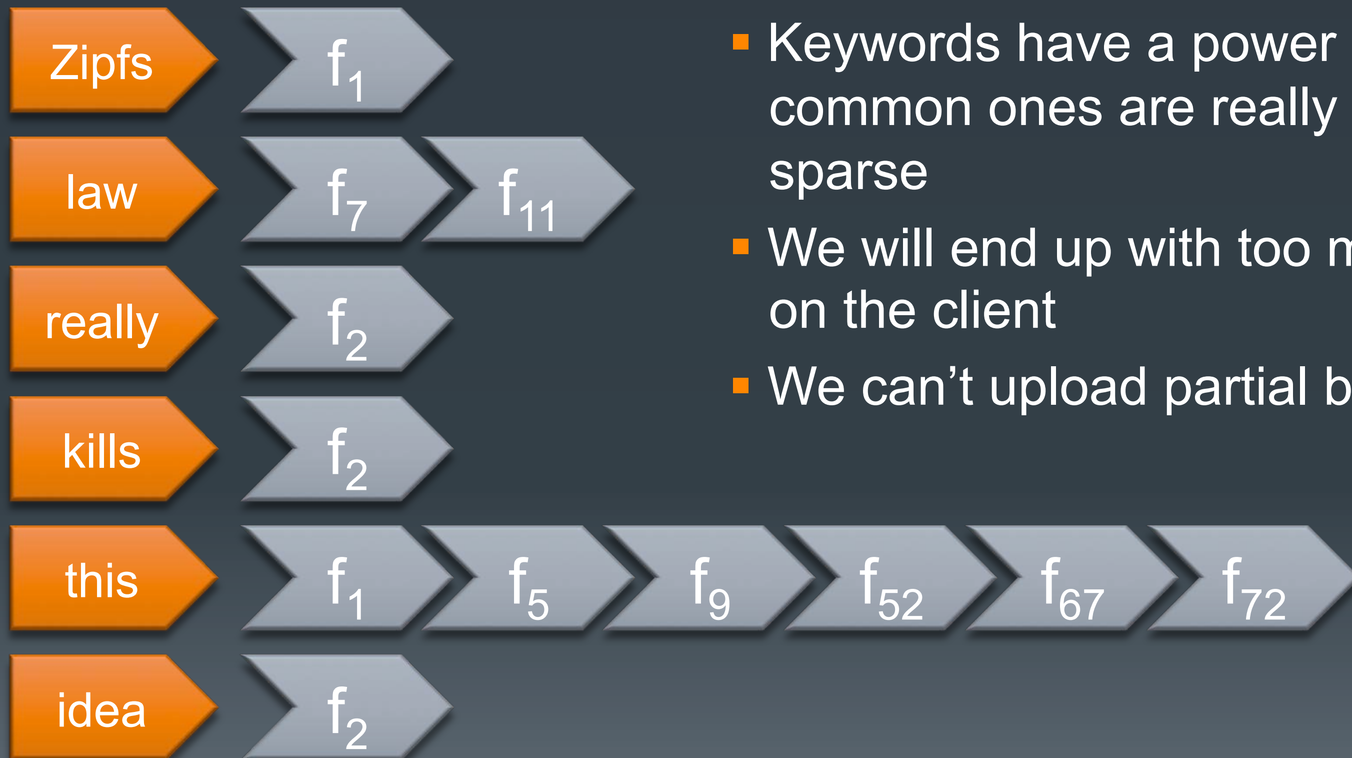
Obliviously Updateable Index

?

Chunked Encrypted Index

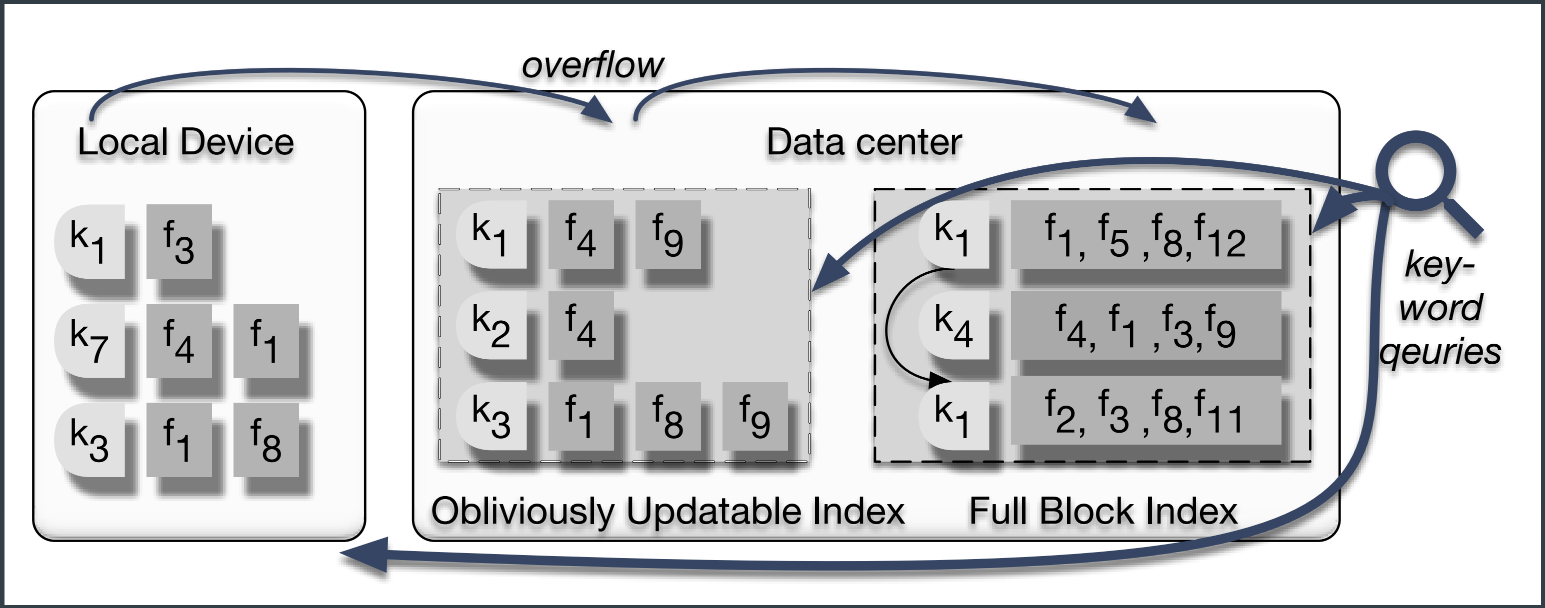


Buffer locally, put full chunks on server



- Keywords have a power law distribution: common ones are really frequent, others are sparse
- We will end up with too many partial buckets on the client
- We can’t upload partial buckets

We need an obliviously updatable index



Oblivious RAM

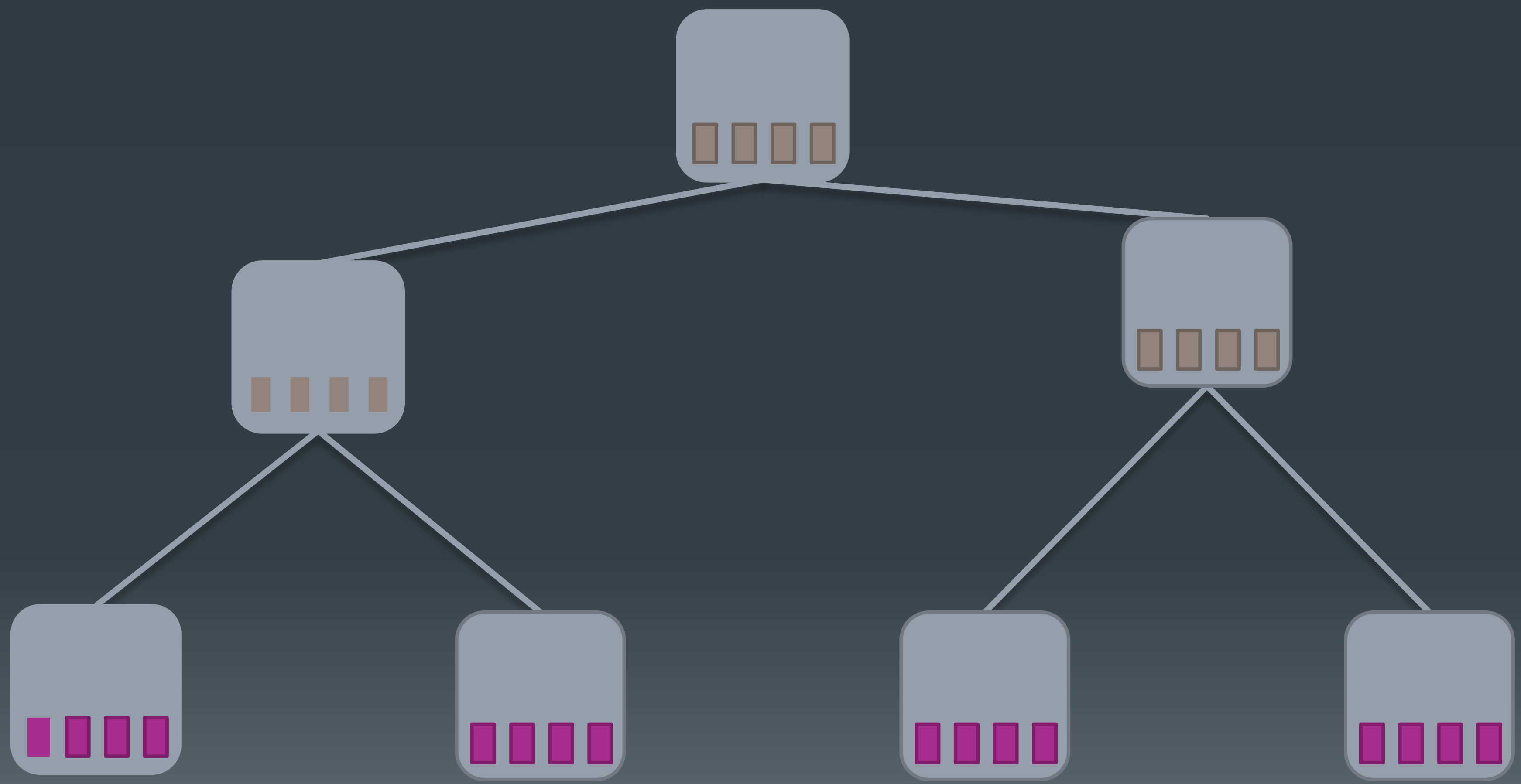
- ORAM hides locations of access to memory (both reads and writes)
- How to build ORAM
  1. Encrypt memory
  2. "Shuffle" memory locations on reads or writes to hide locations
- In Path ORAM, shuffling has logarithmic overhead.

OUI from Path ORAM RAM

1. Read(for search)
2. Shuffle
3. Read (for search)
4. Shuffle

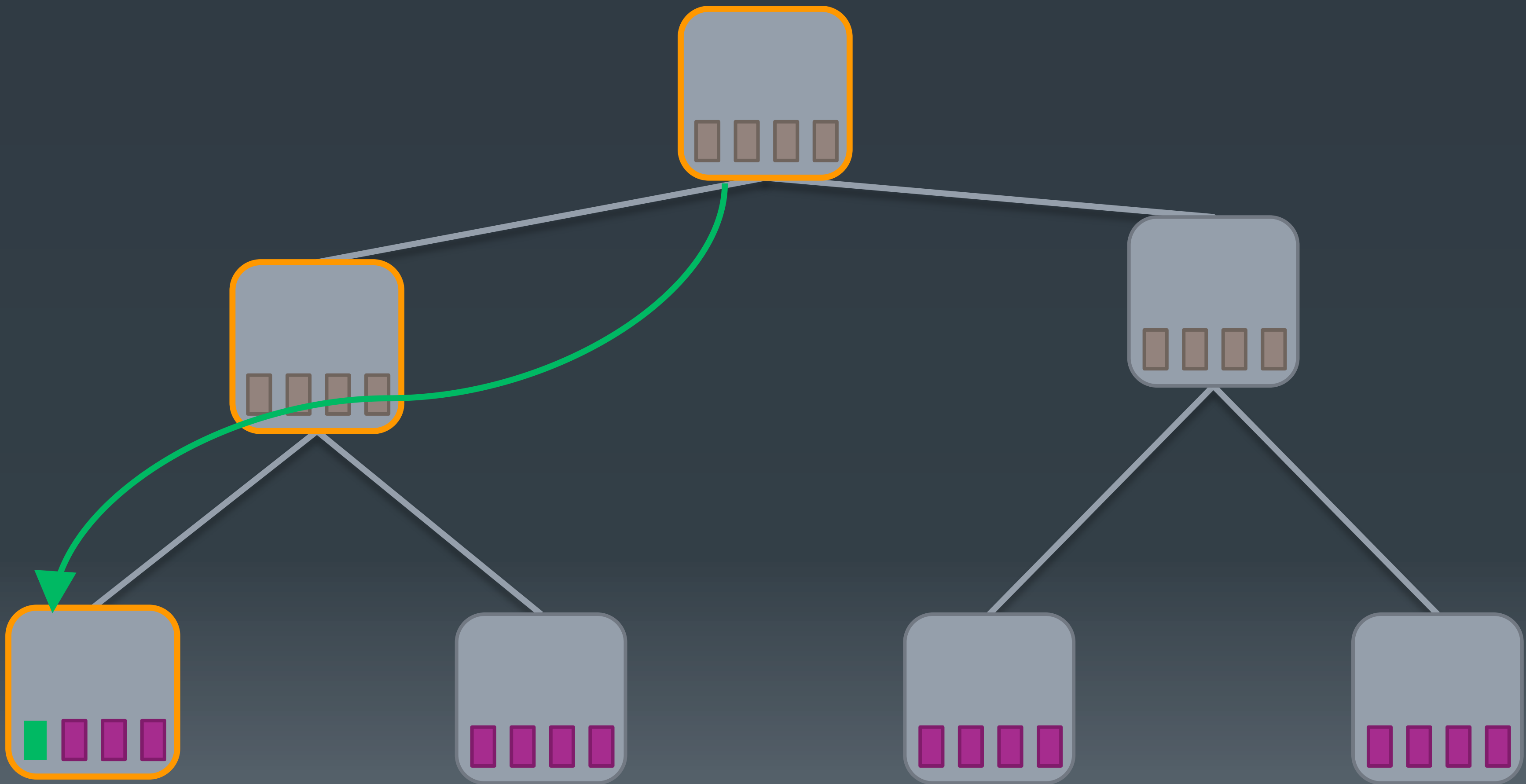
5. Read/write for update
6. Shuffle

Path ORAM



Client side stash

Path ORAM



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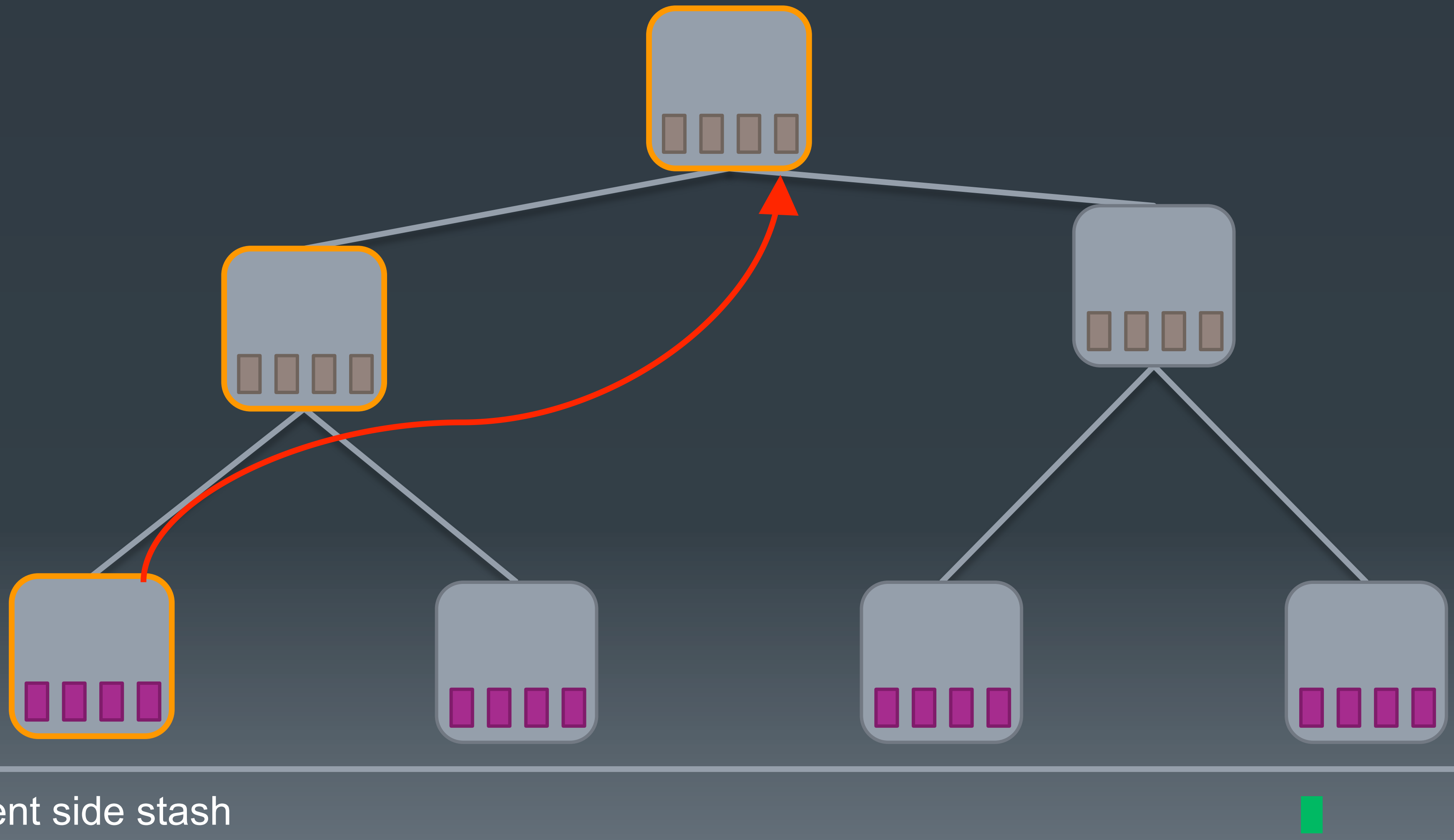

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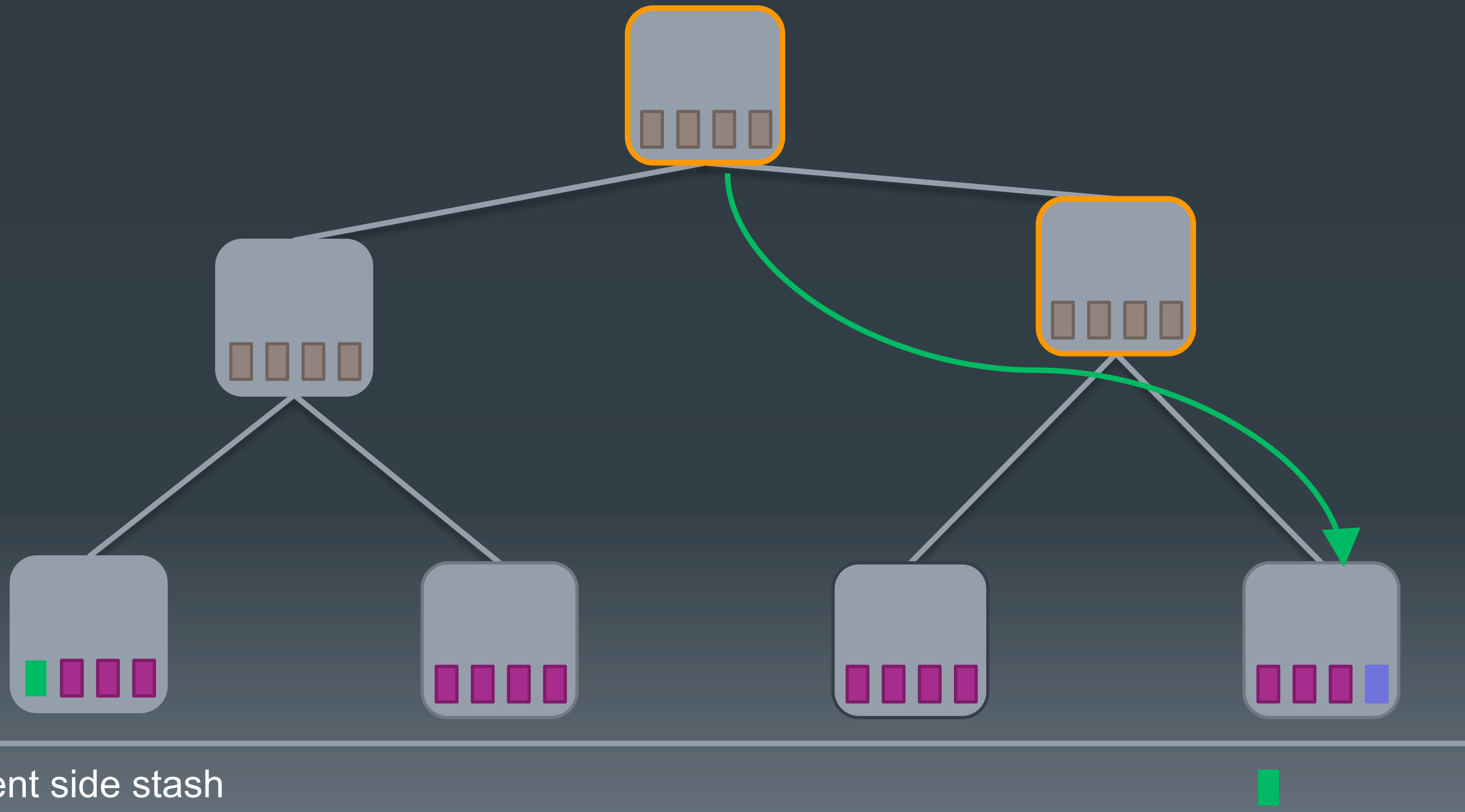

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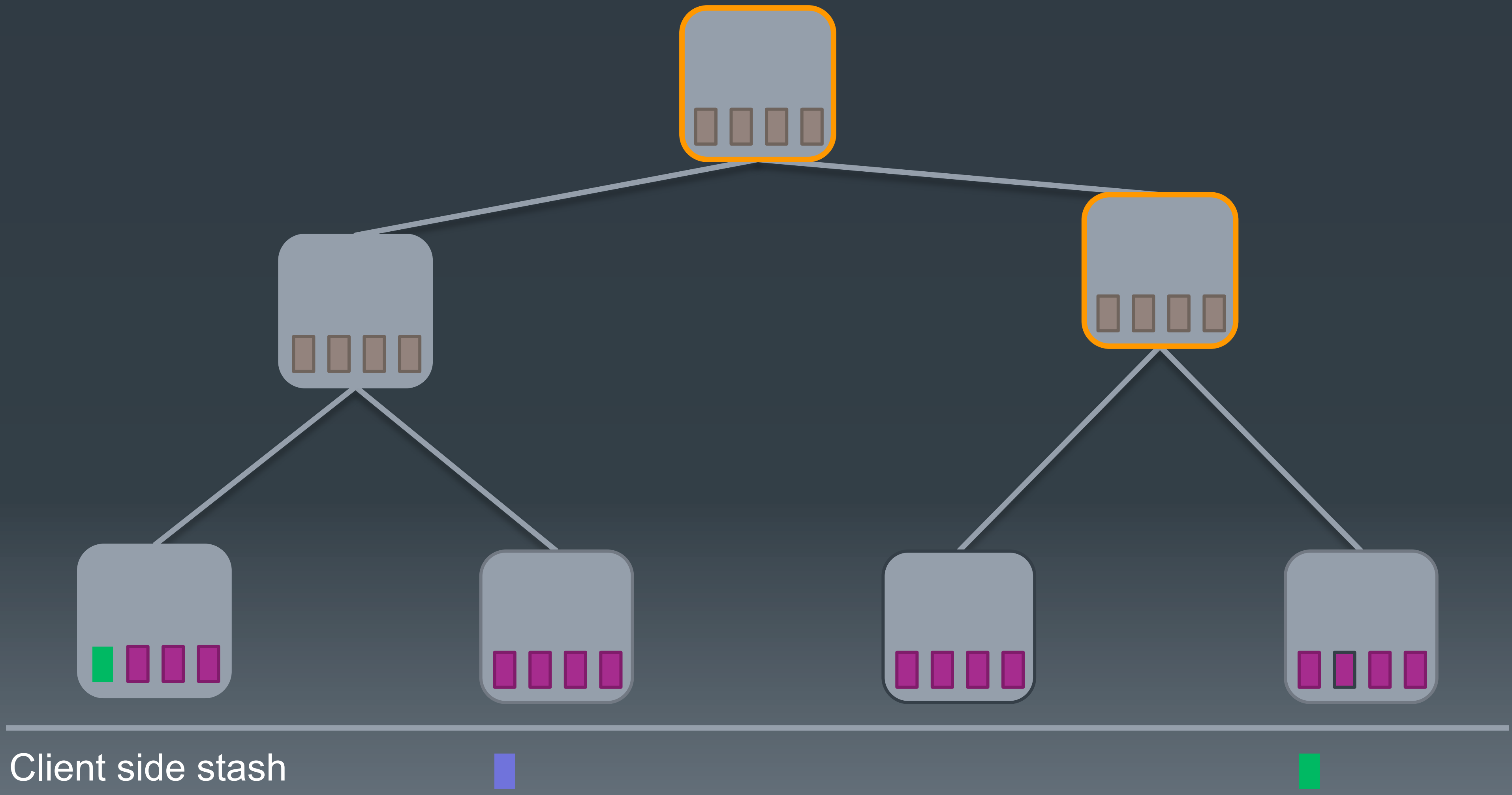

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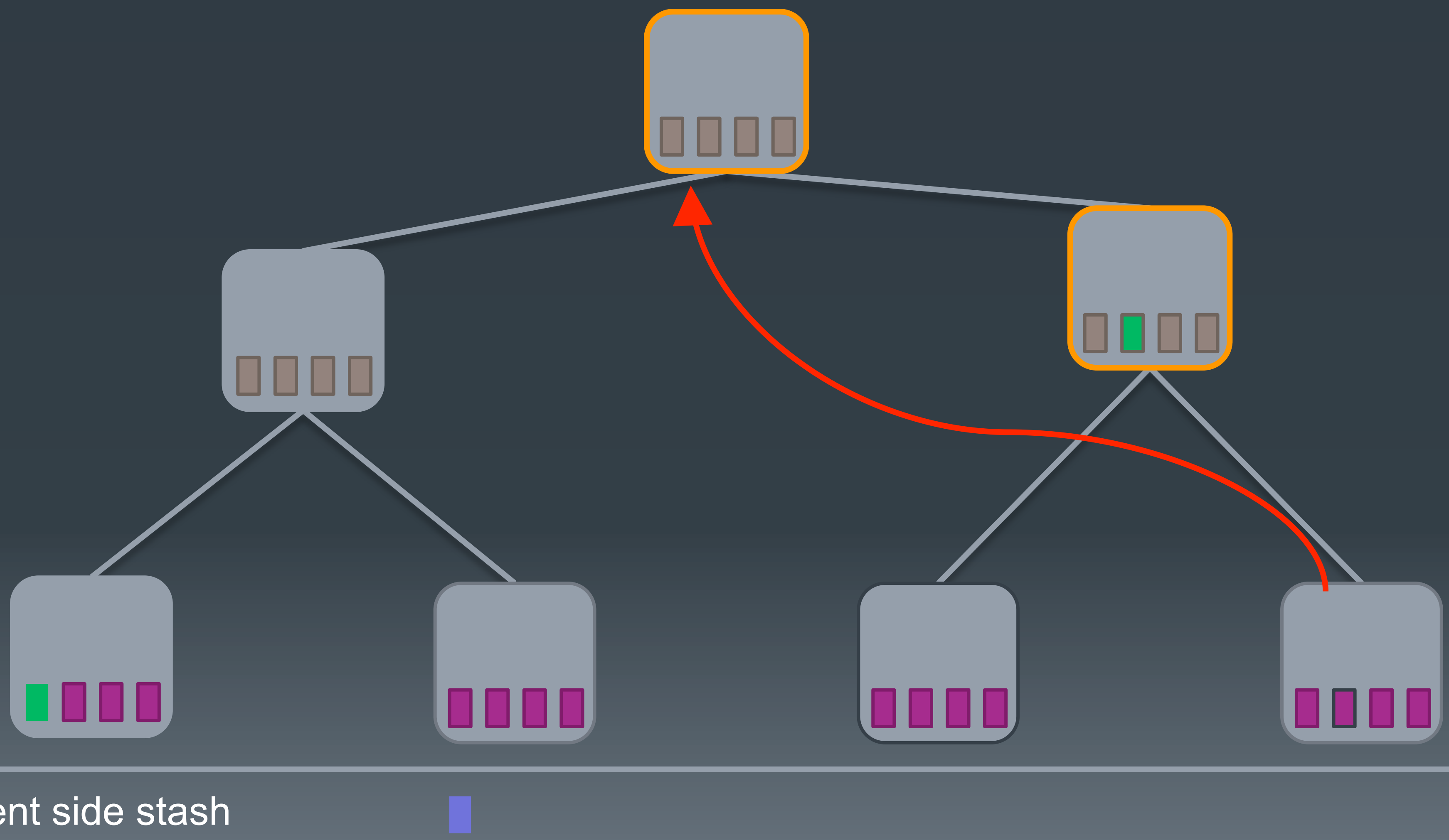

Client side stash

From ORAM to an OUI

- ORAM allows you to write to a location in memory without revealing the location
- Can add to a partial chunk without revealing we did so.
- Bandwidth costs get worse was ORAM gets larger
  - Requires you to read and write Log(N)*B bytes for a read of B bytes from an ORAM of size N
  - For 16GB of ORAM, server needs 32.06 GB of space and reading 4KB takes 350KB read + 350KB write.
- Storing full index in ORAM requires too much bandwidth

From ORAM to an OUI

- ORAM hides both reads and writes
- Search explicitly leaks repeated reads
  - Same files are returned each time.
  - Same search token/hash used.
  - No need to hide reads using ORAM
- Updates may happen in batches

OUI from Oblivious RAM

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2. Shuffle
3. Read (for search)
4. Shuffle

5. Read/write for update
6. Shuffle

Partial ORAM?

1. Read(for search)

2. Read (for search)

3. Read/write for update
4. Shuffle

OUI

1. Read(for search)
2. ~~Shuffle~~
3. Read (for search)
4. ~~Shuffle~~
5. Read/write for update
6. Shuffle

OUI

1. Read(for search)
2. Read (for search)
3. Shuffle + Shuffle
4. Read/write for update
5. Shuffle

OUI

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OUI

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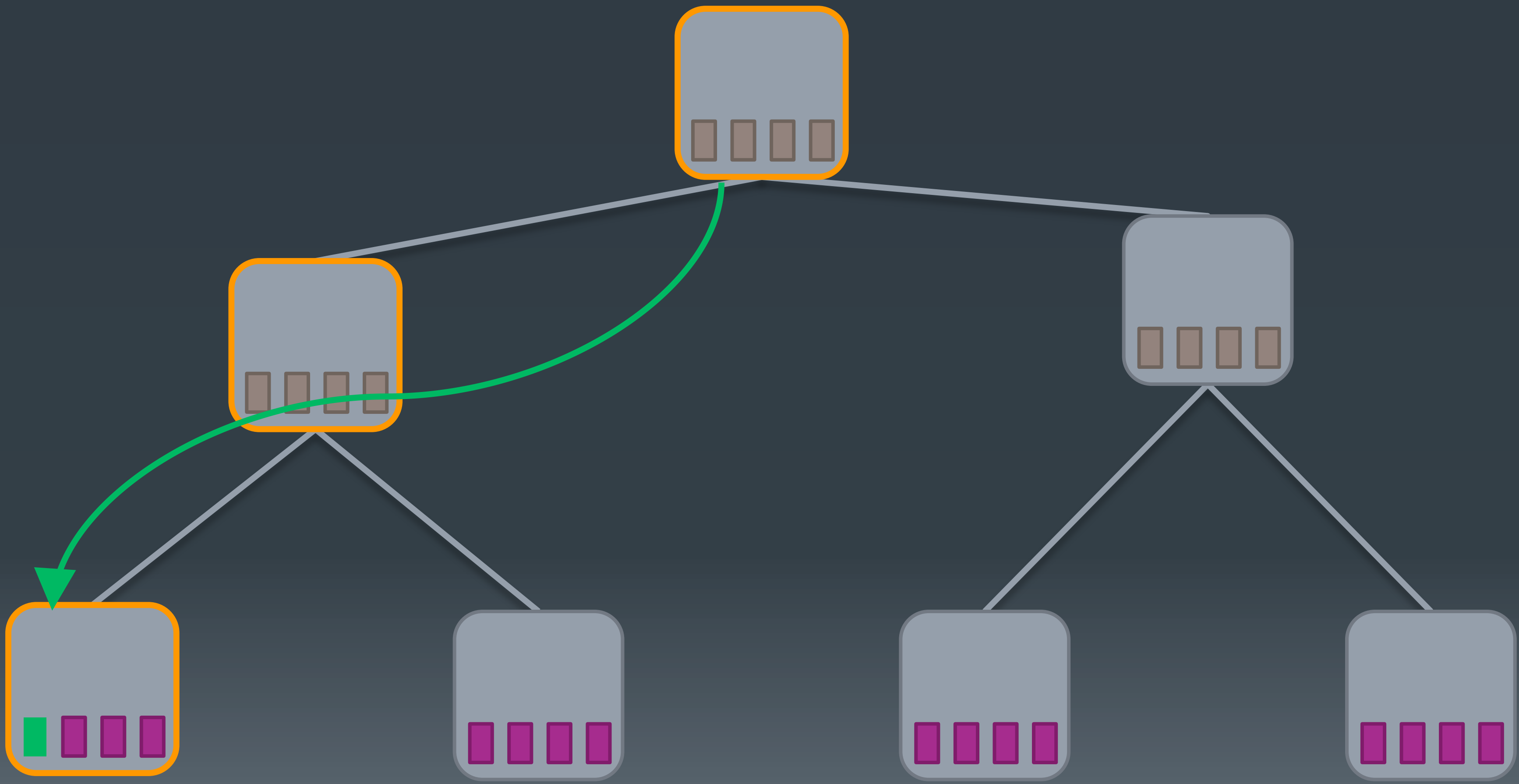
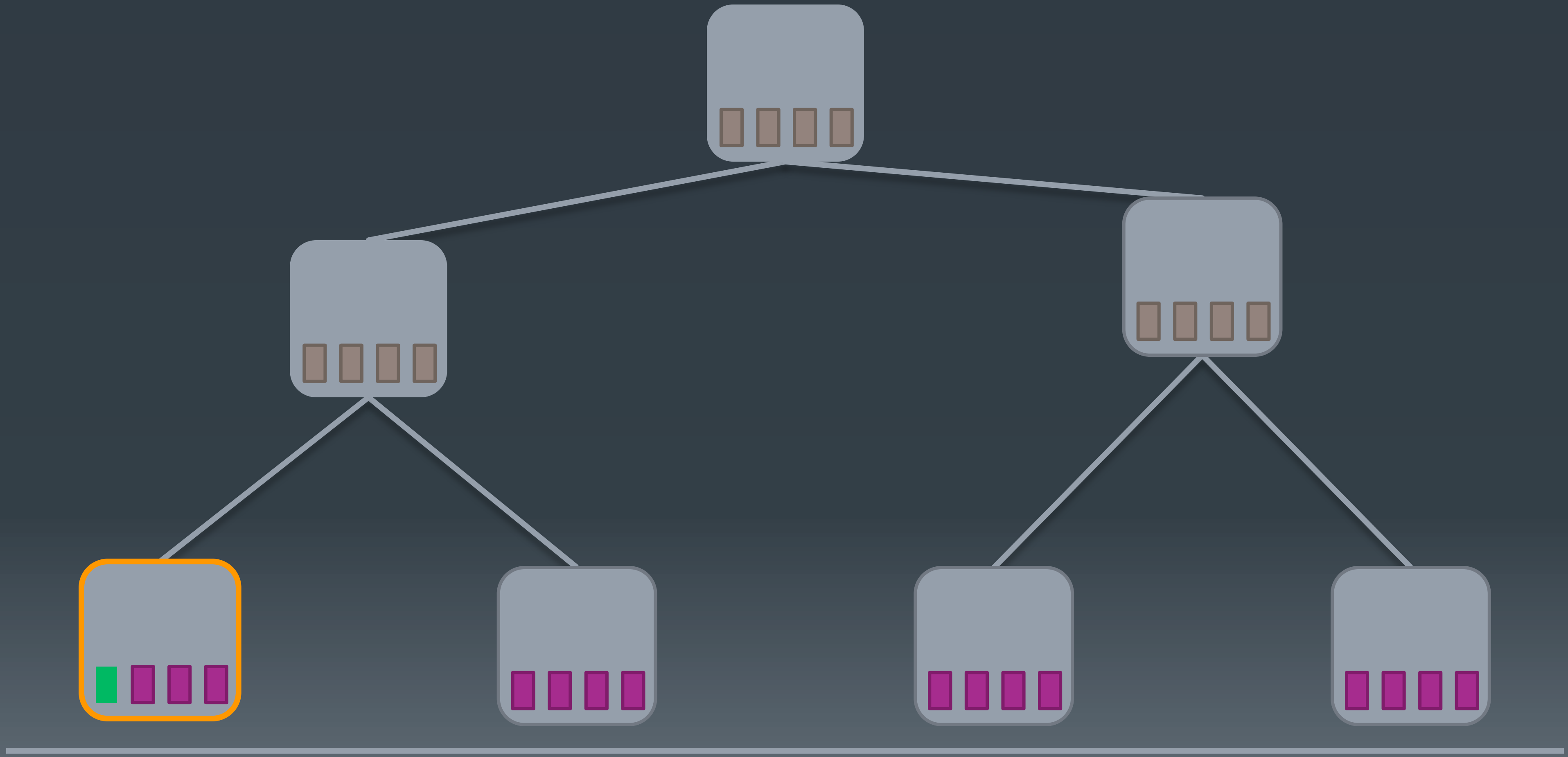
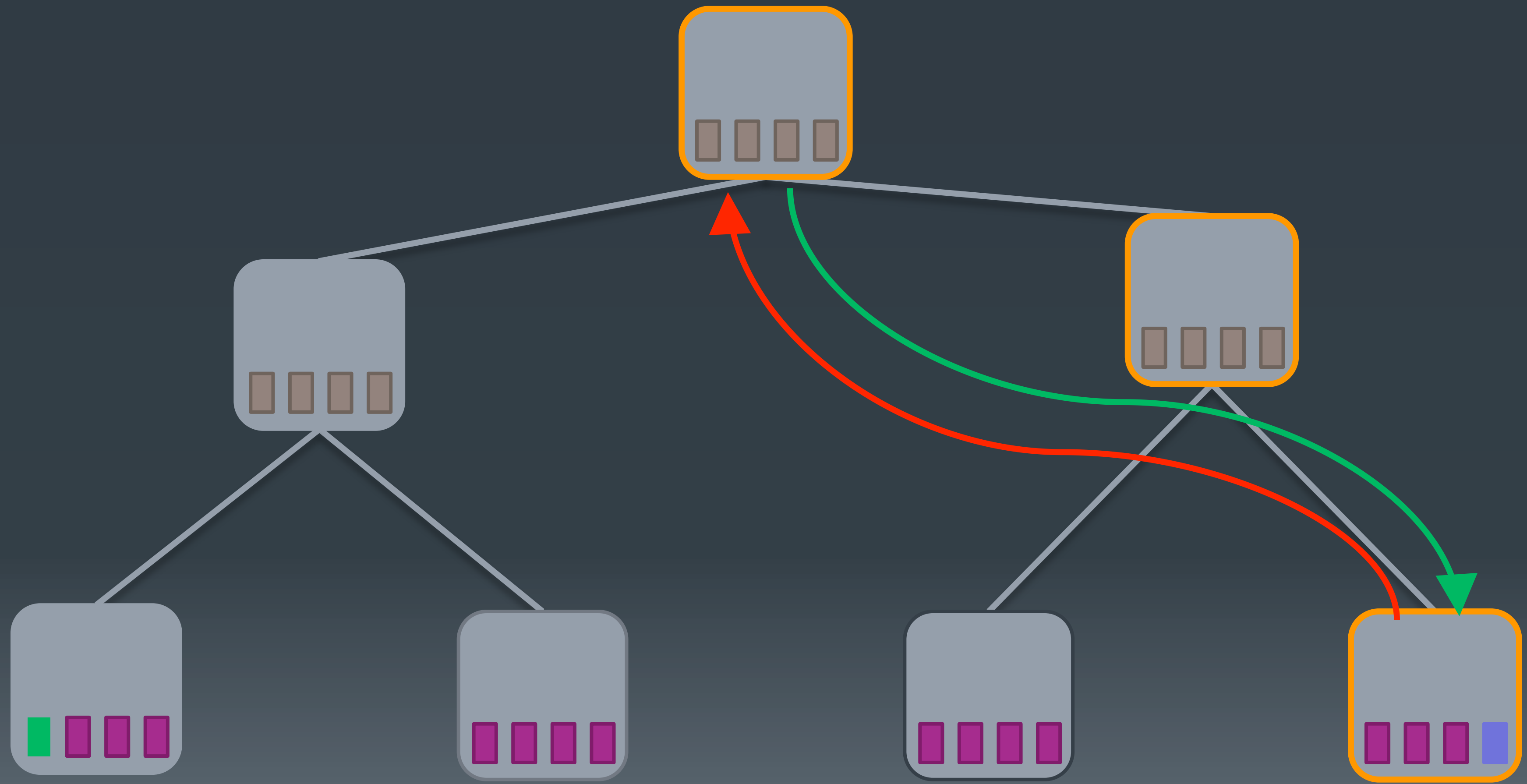
Reads



Why not just read directly?



Leaks updates



OUI from ORAM

- Searching triggers a read and write of Log(n)*B data
- To avoid Log(N)*B read +write for each search
  - Just read address for chunk for given keyword
  - Defer read and write until later (i.e. when the phone is plugged in and on Wi-Fi)
  - Search is constant bandwidth and has nice locality
- All updates <u>must</u> happen after deferred IO is done
- We get some savings from batching the IO together
- Multiple searches on the same keyword are free

OUI from ORAM

- Read directly from tree for search BUT
- Must complete full path read and write prior to any updates
- Call these “deferred” reads

Batched reads and writes

- Deferred (full reads) reads and updates are not random events
- They will happen in groups either
  - When an email comes in we get many updates
  - We might update the non local index only once a day (if system is not multi client)
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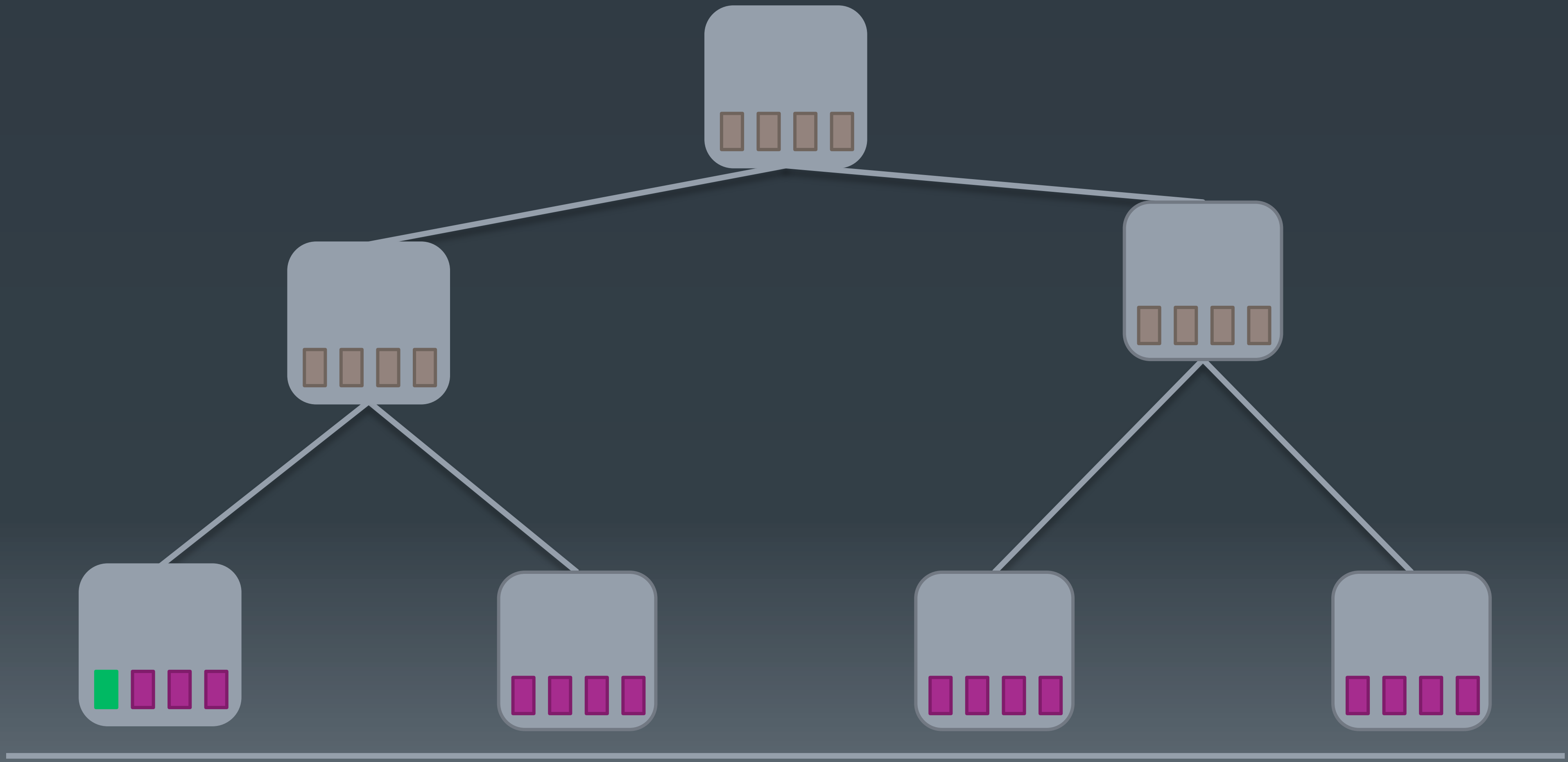
Deferred Reads



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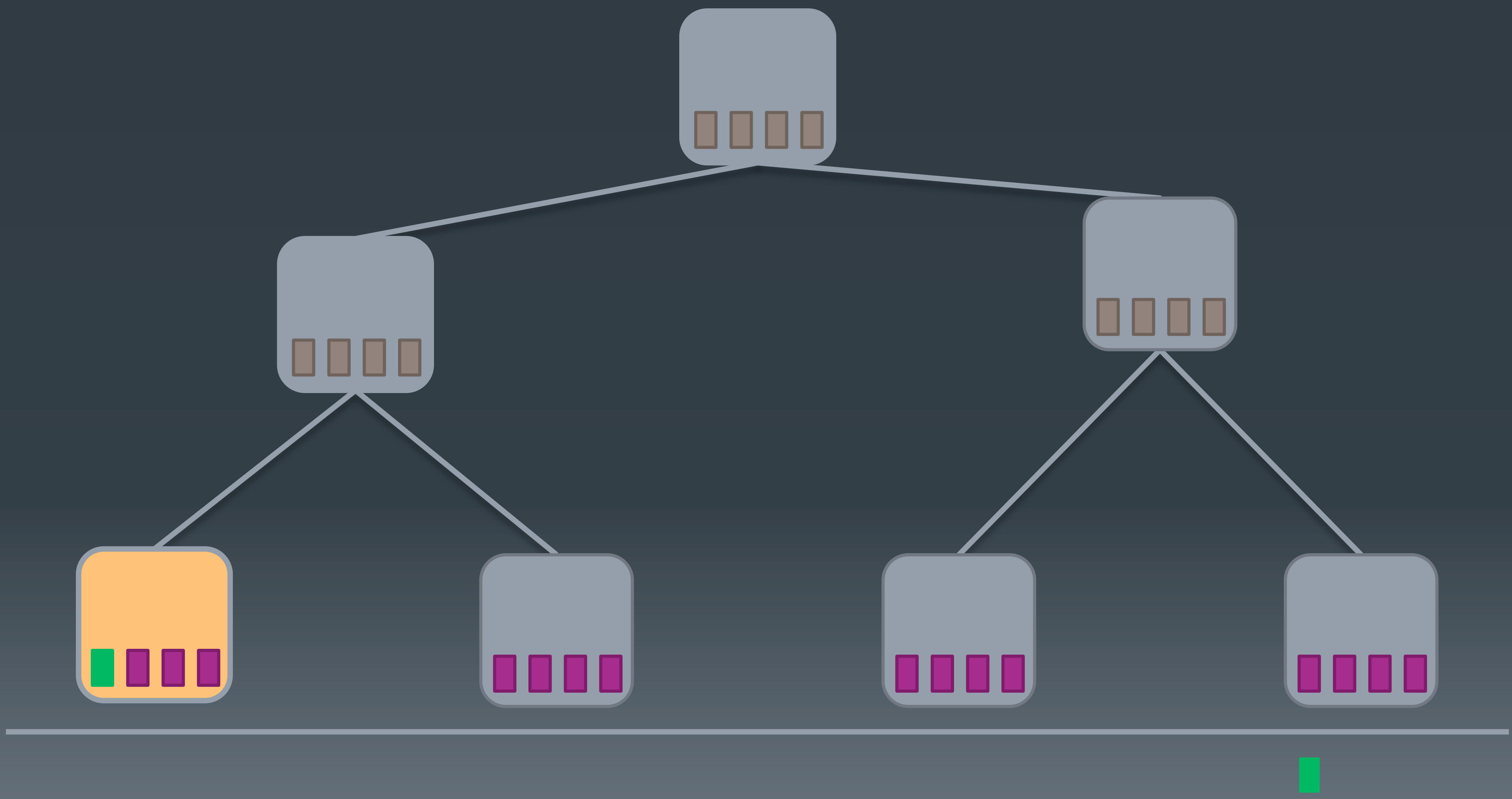

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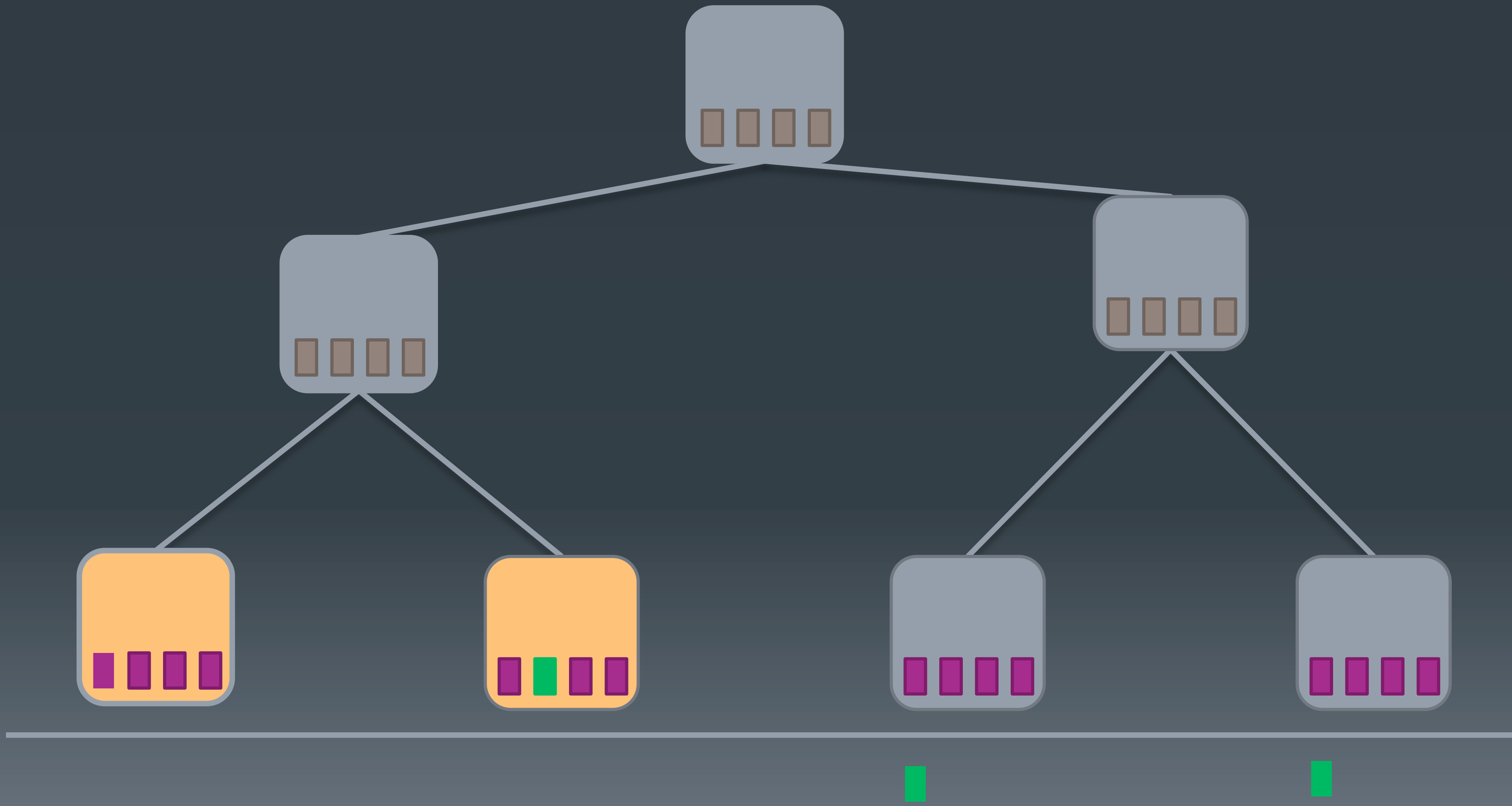
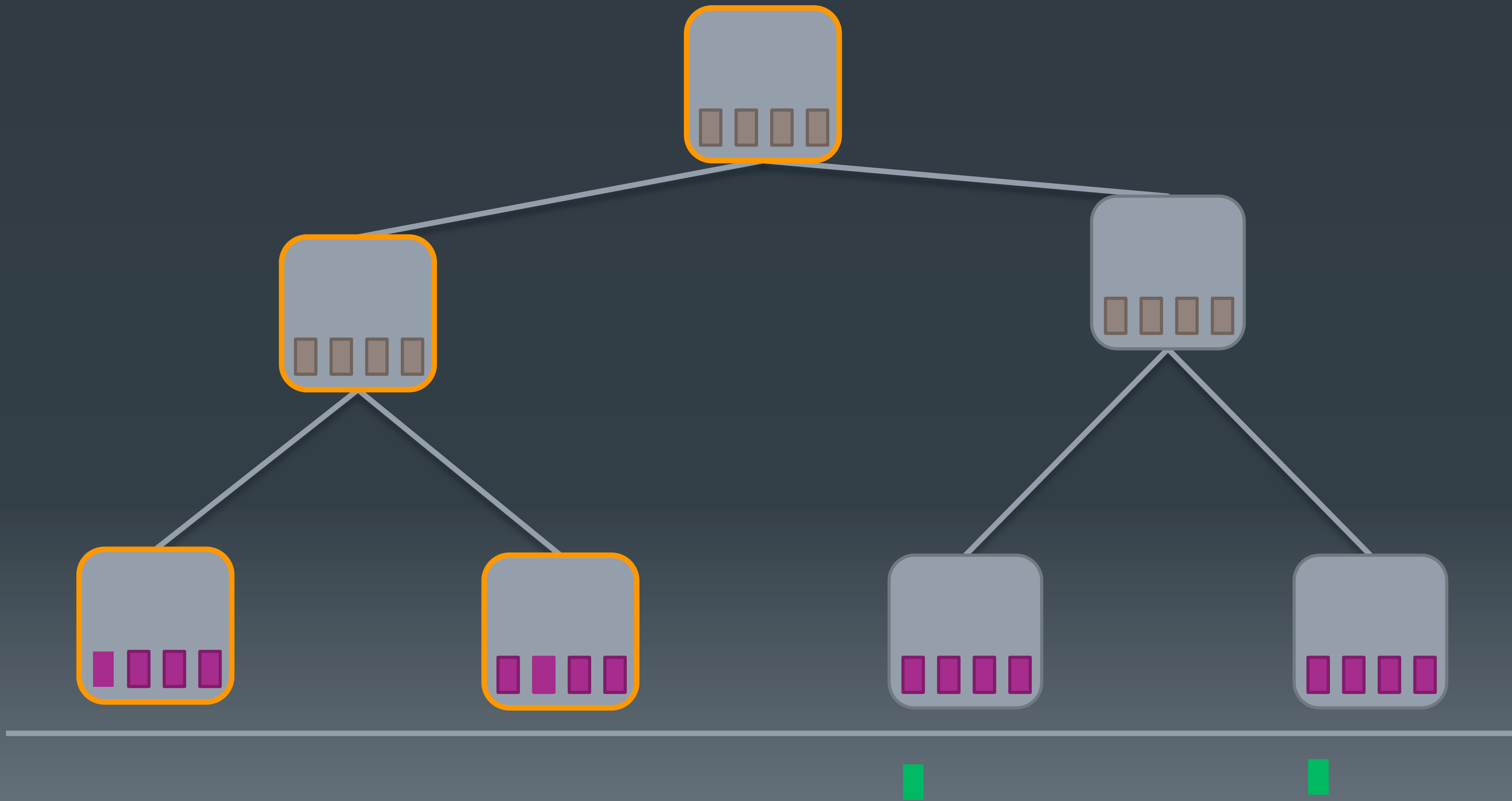
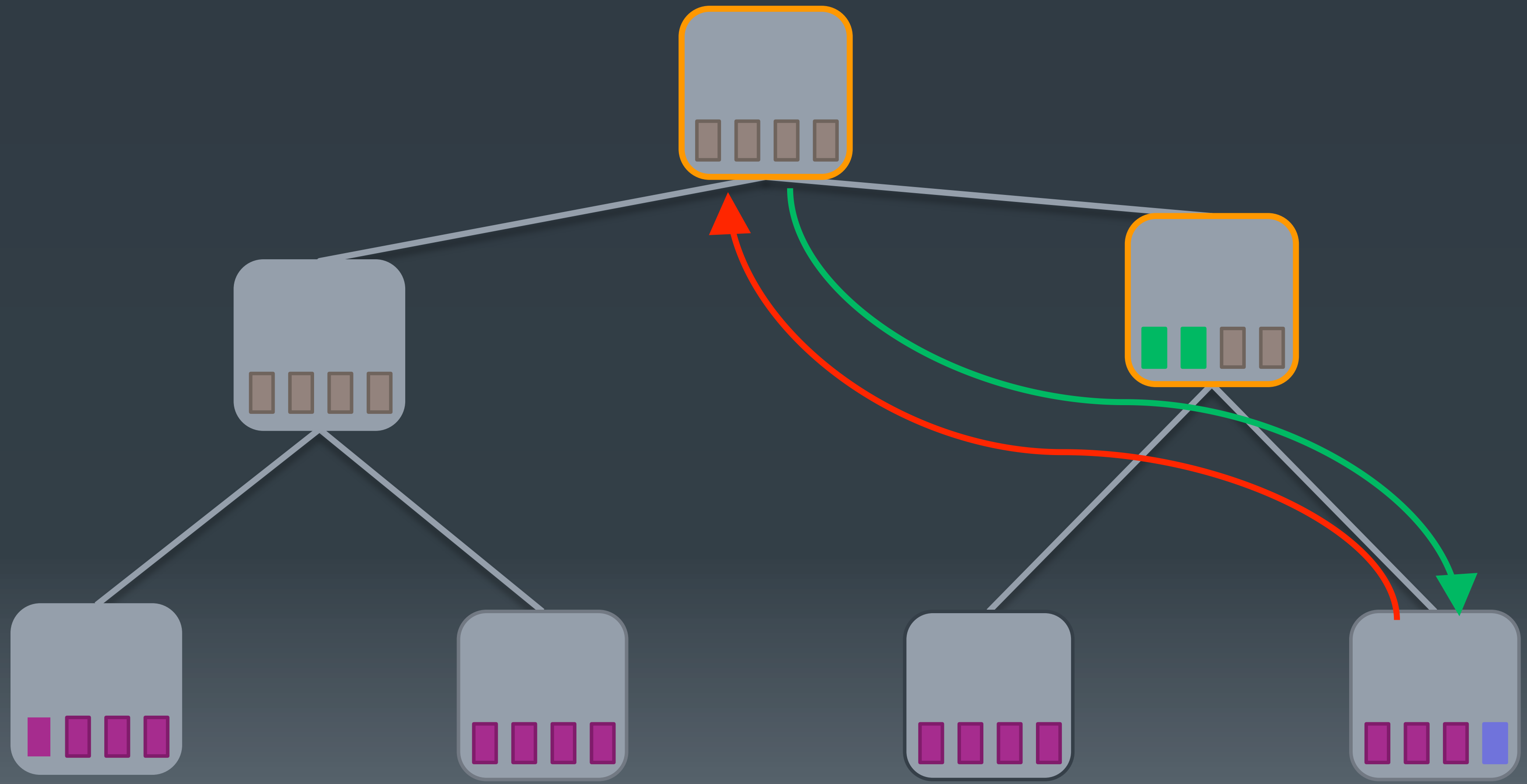


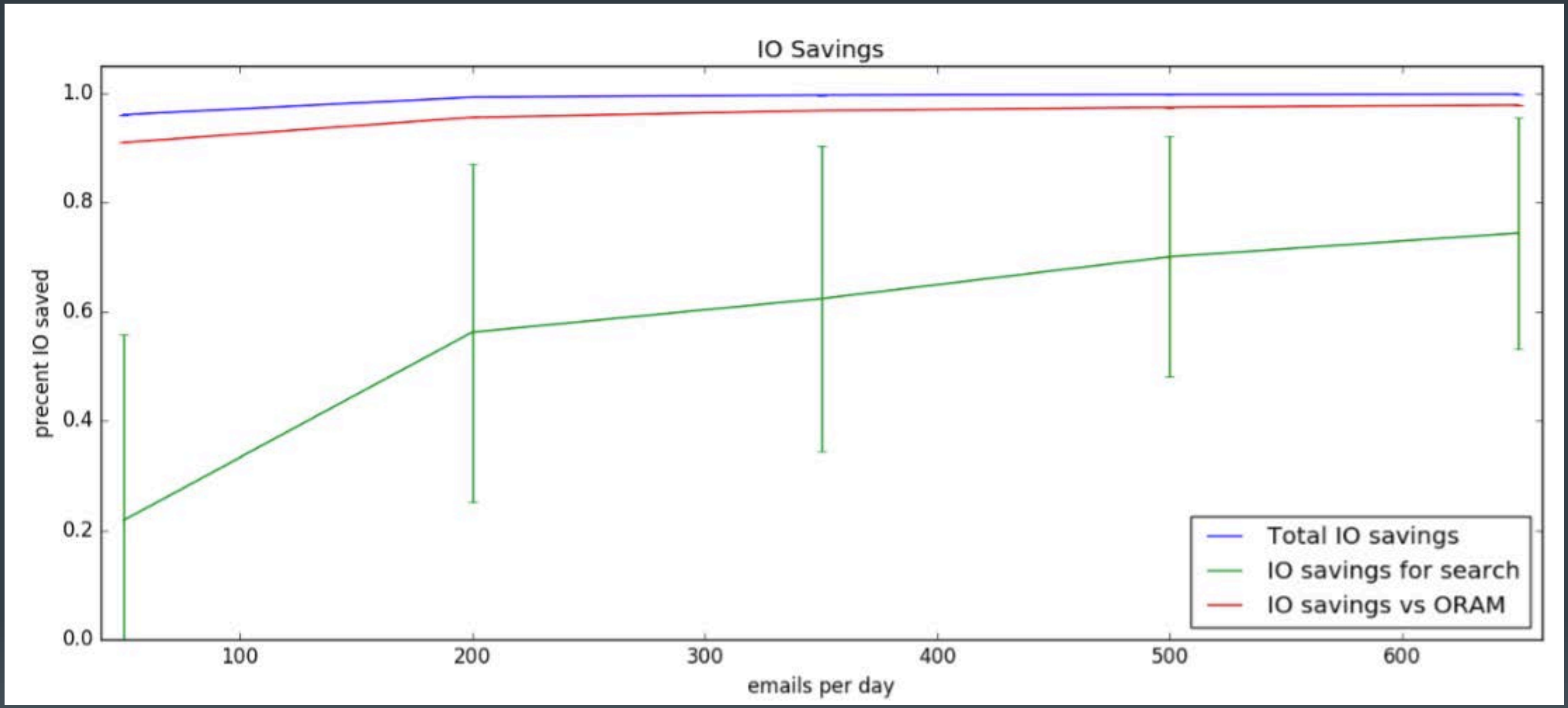
Deferred Reads + Batching



Batched update



Performance



IO Savings (percentage) vs

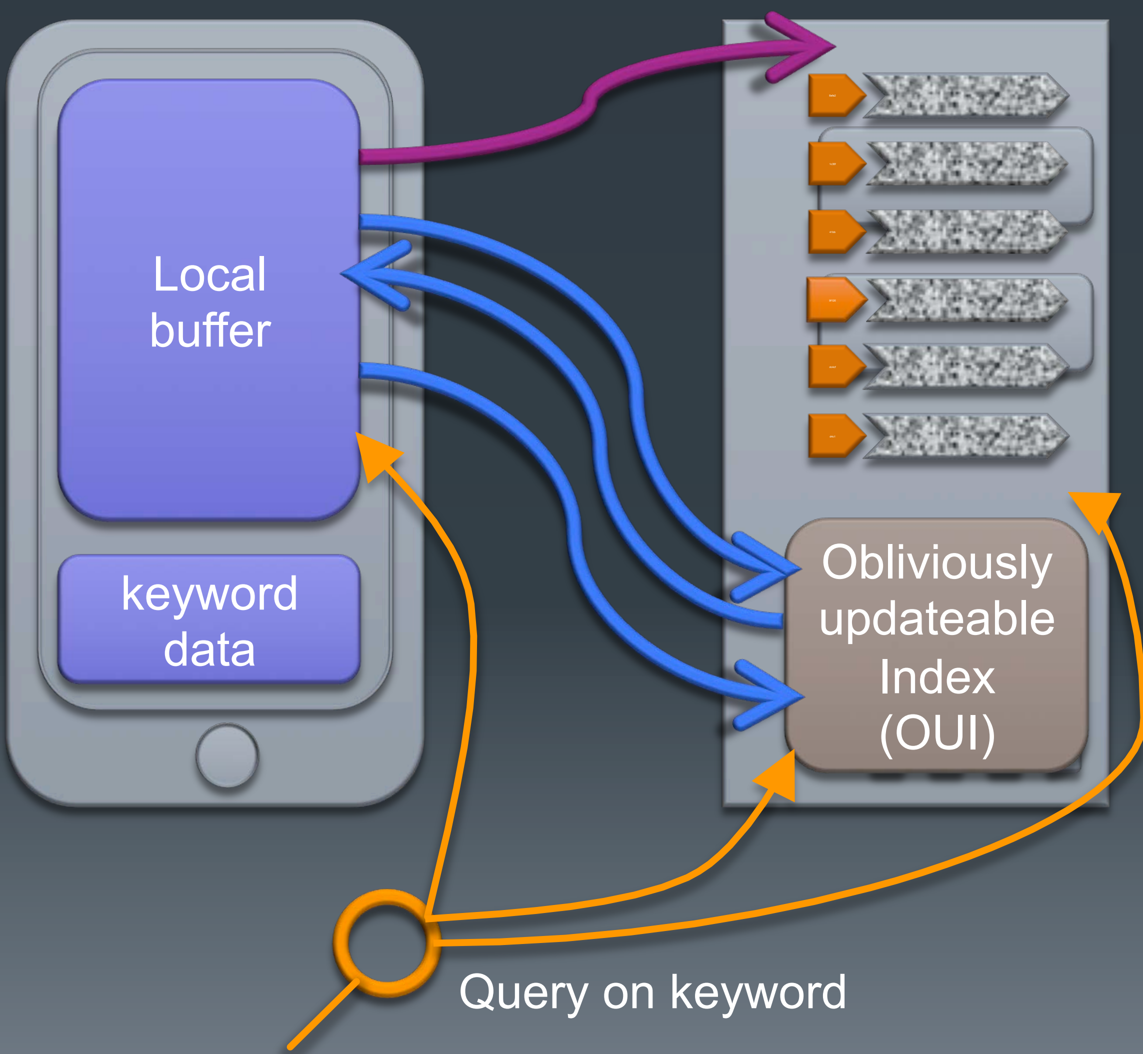
- Simple encrypted index(including all previous works under purely dynamic insertion)
- Savings just for search (ignoring updates)
- Oblivious index from path ORAM

Conclusion

- Searchable encryption might be feasible for cloud based messaging with effort
- It pays to examine problems in context
- You can always get better performance by relaxing security assumptions
- Sometimes the relaxation is inherent to the setting and free

Updates

- Query local, ORAM, and index with efficient access
- Update : Buffer locally, overflow to ORAM, then commit full chunks to index
- Defer ORAM I/O from queries until update period
- Requirements
  - 40 to 250mb of client storage to store a list of keywords
  - Client has fast internet sometimes
  - Ideally, client has large local buffer



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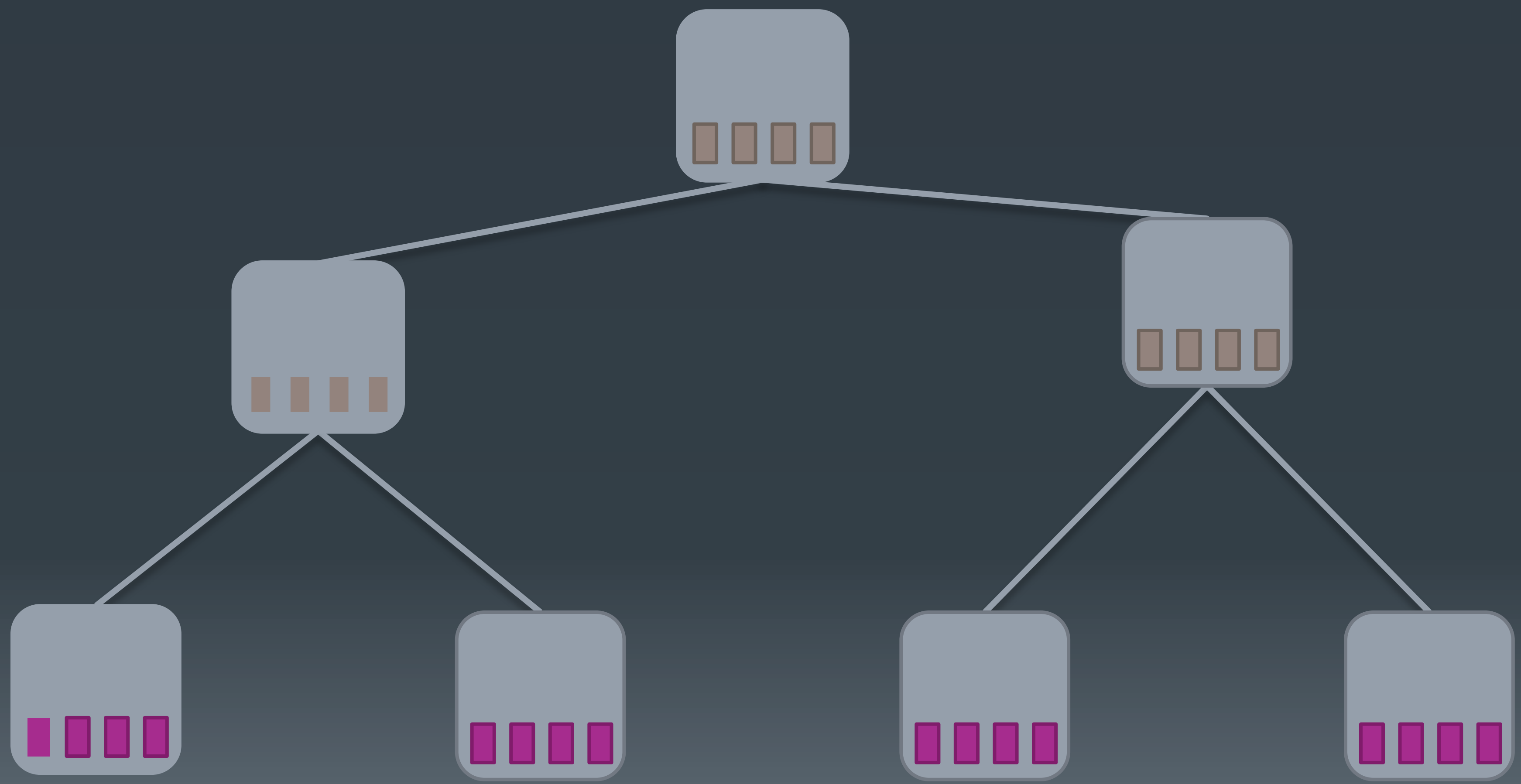

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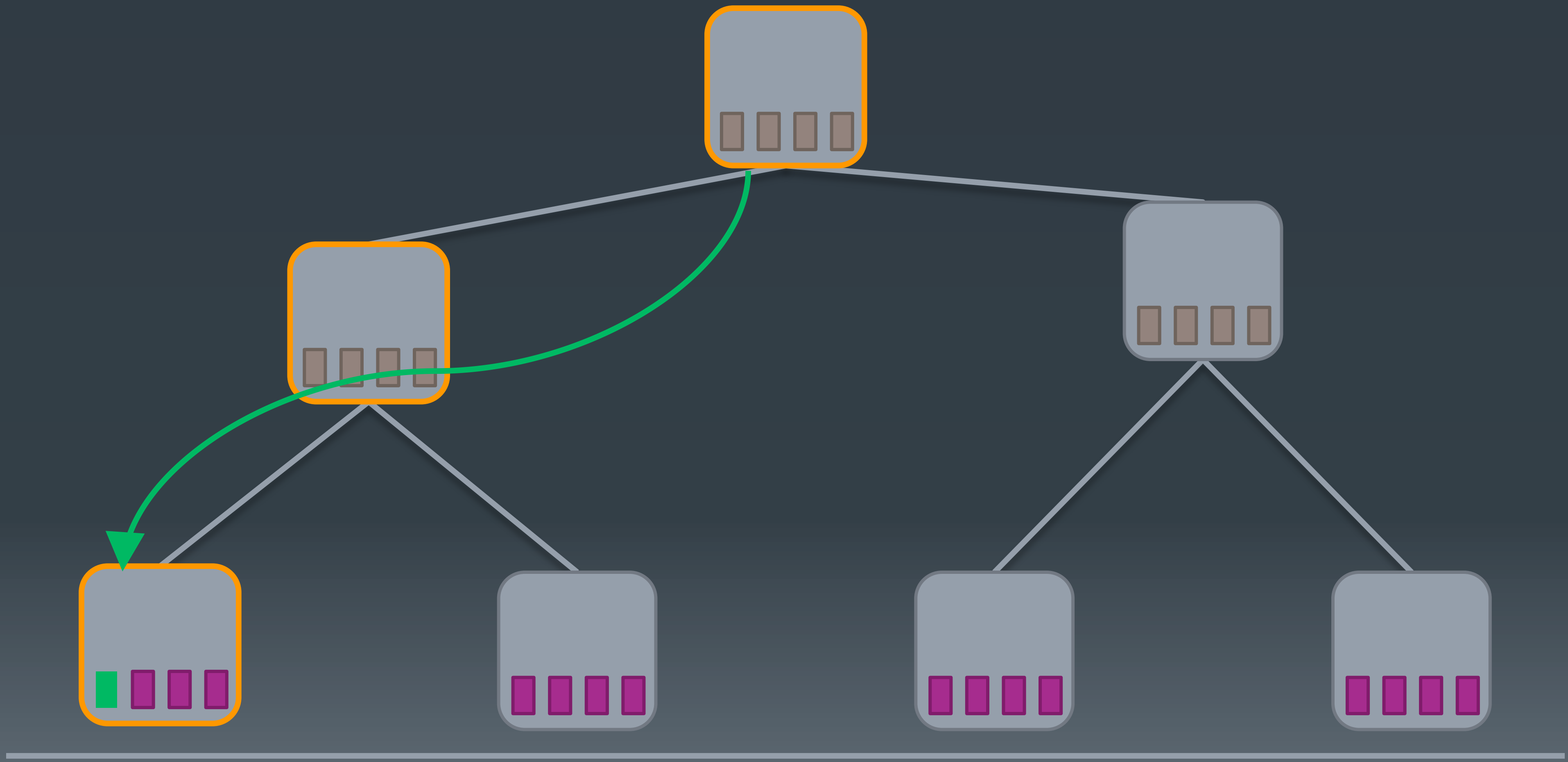

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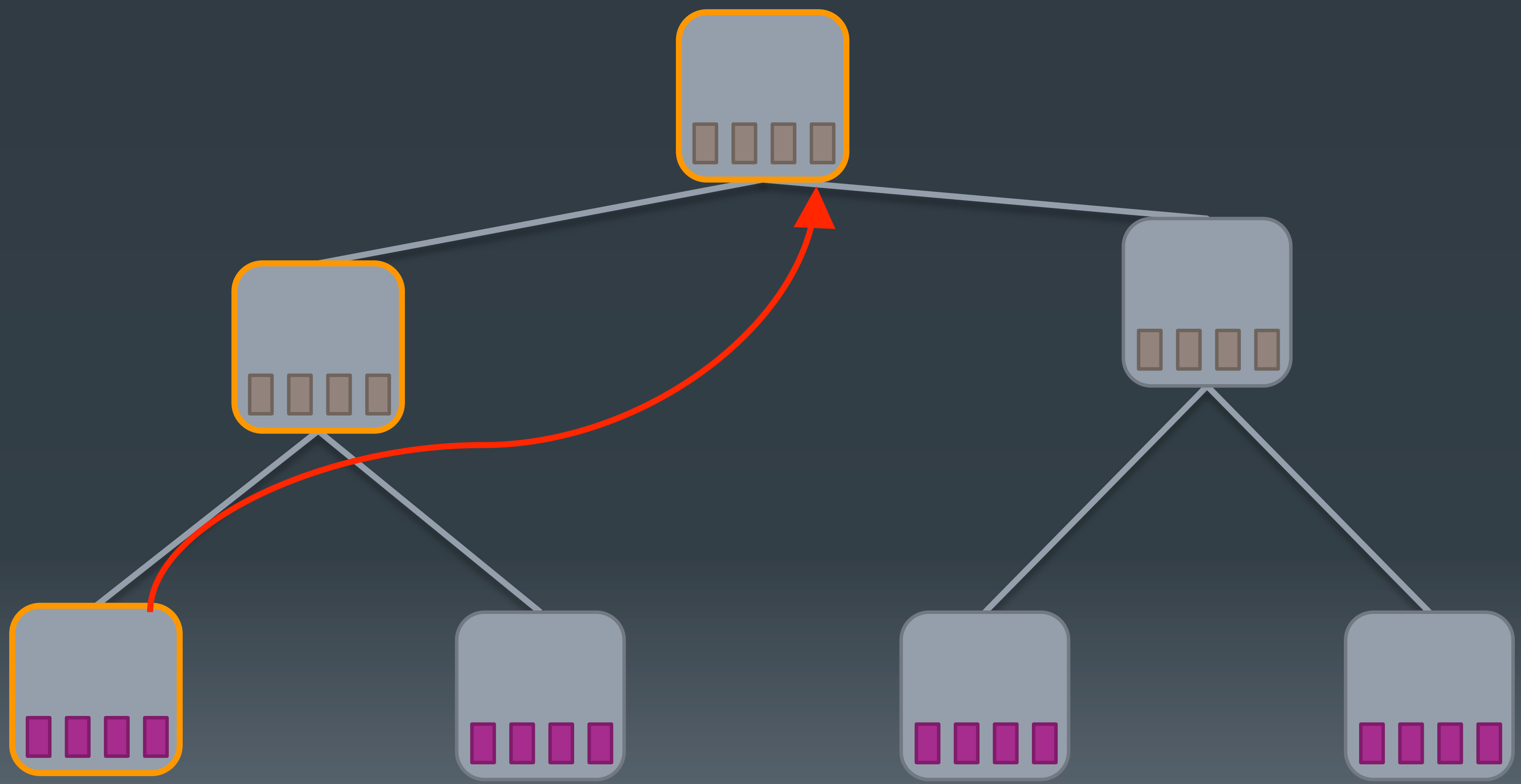

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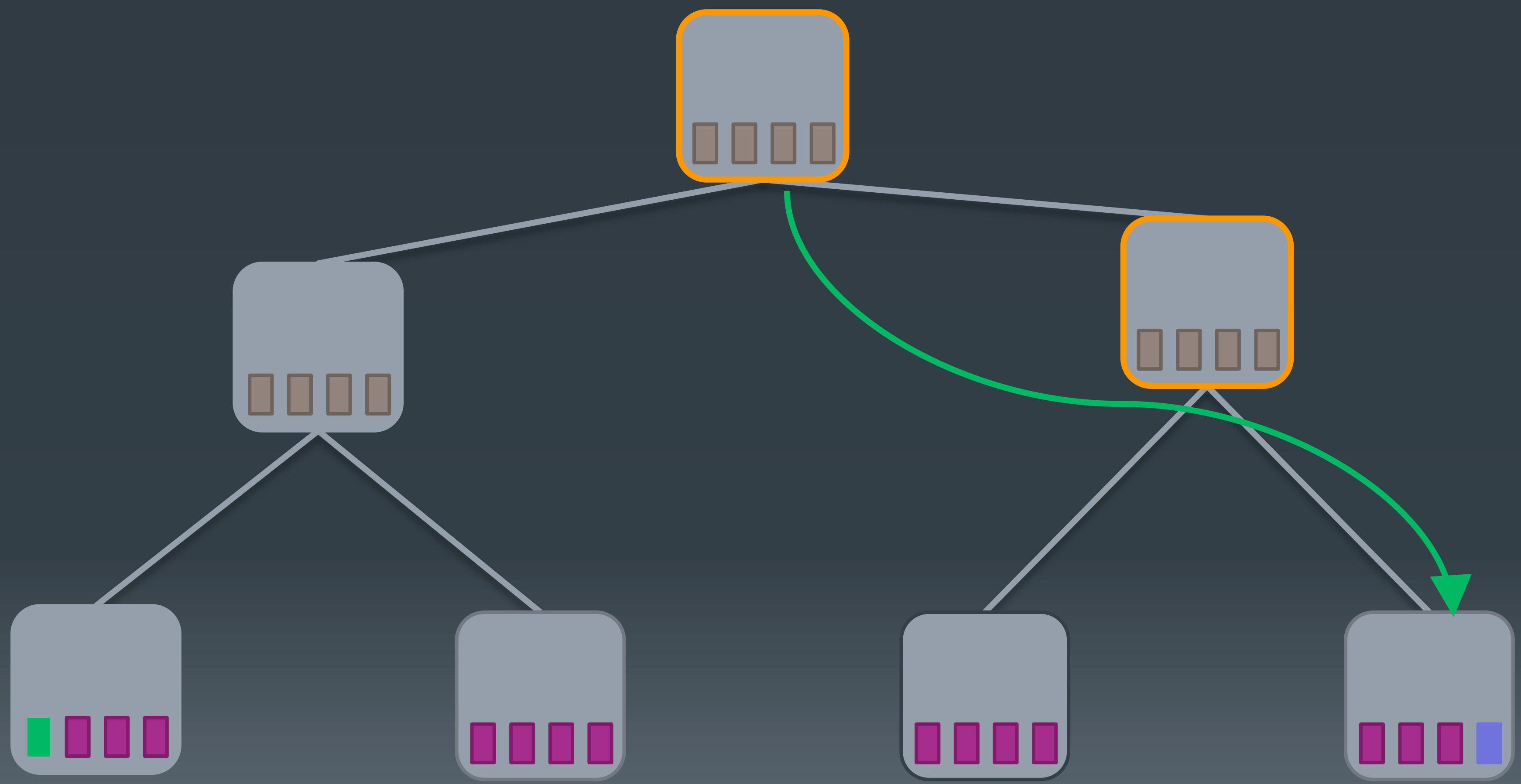

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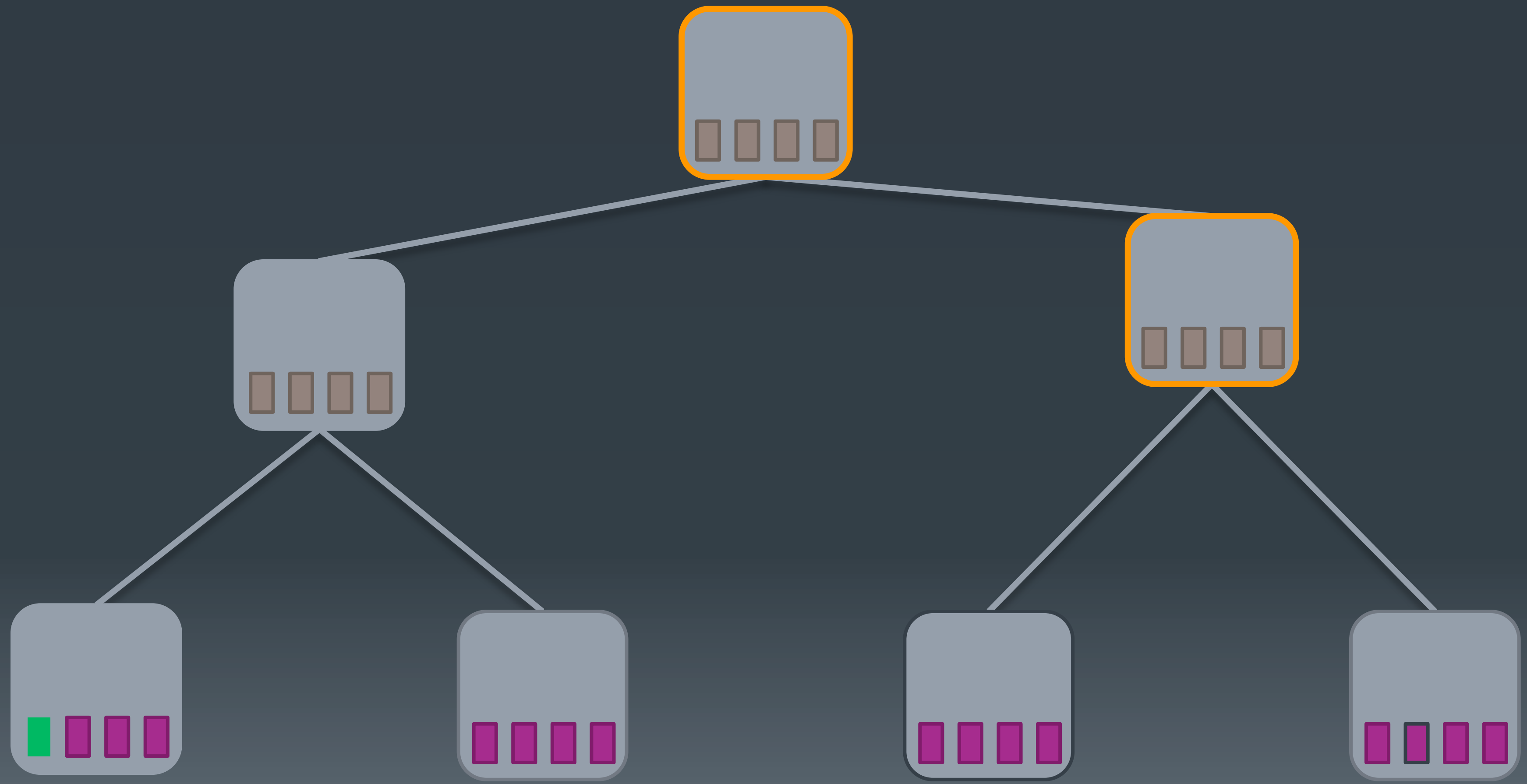

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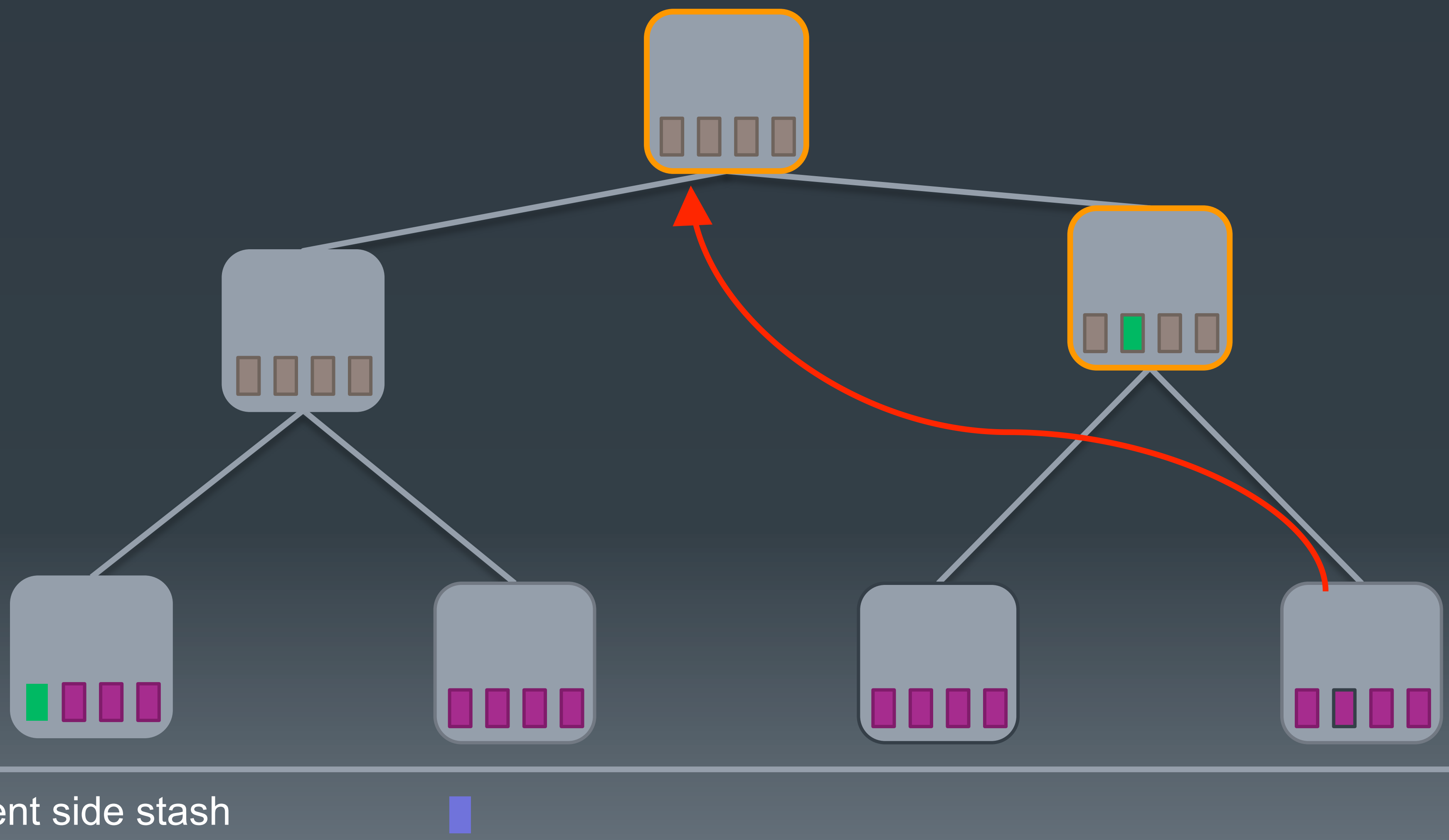

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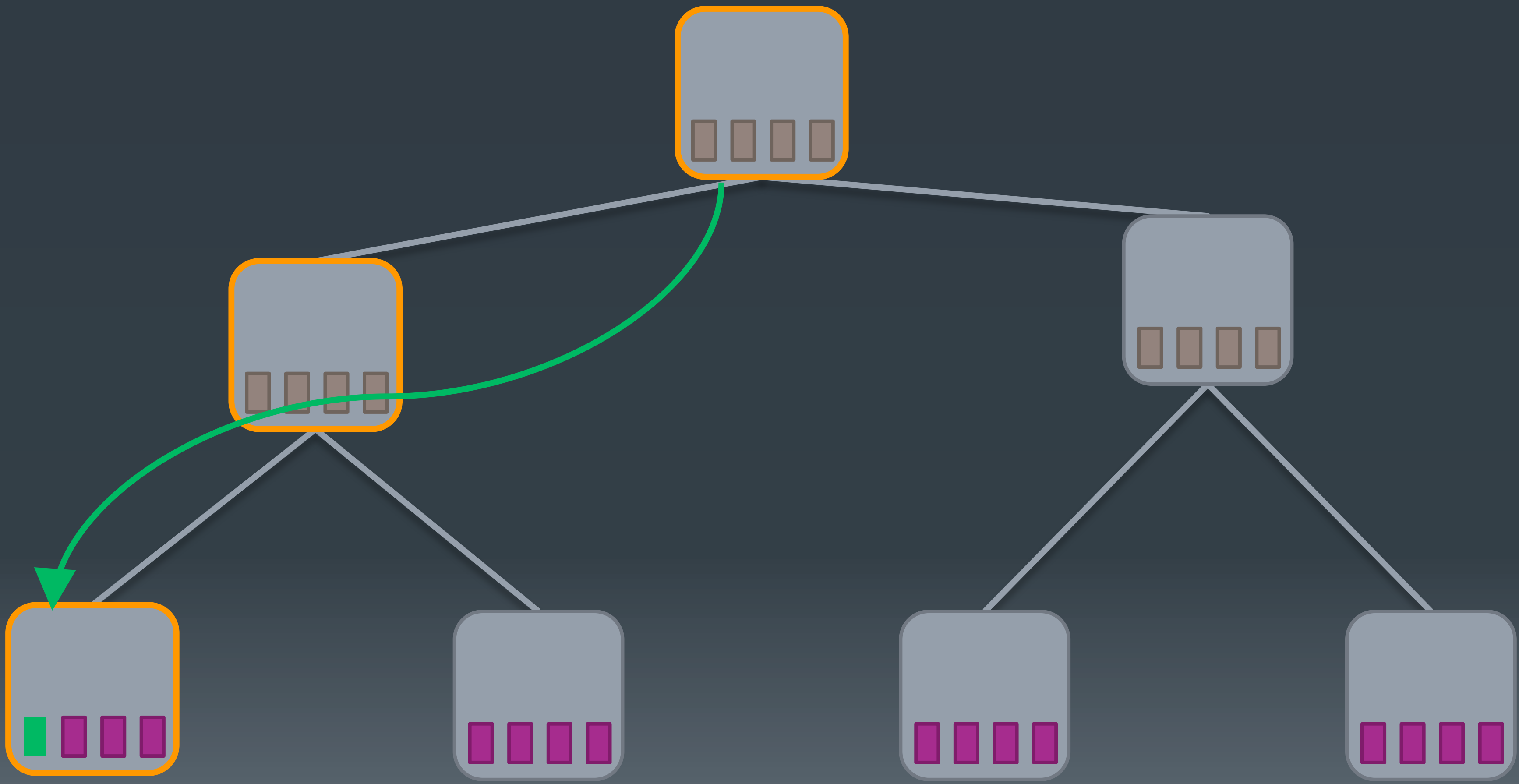

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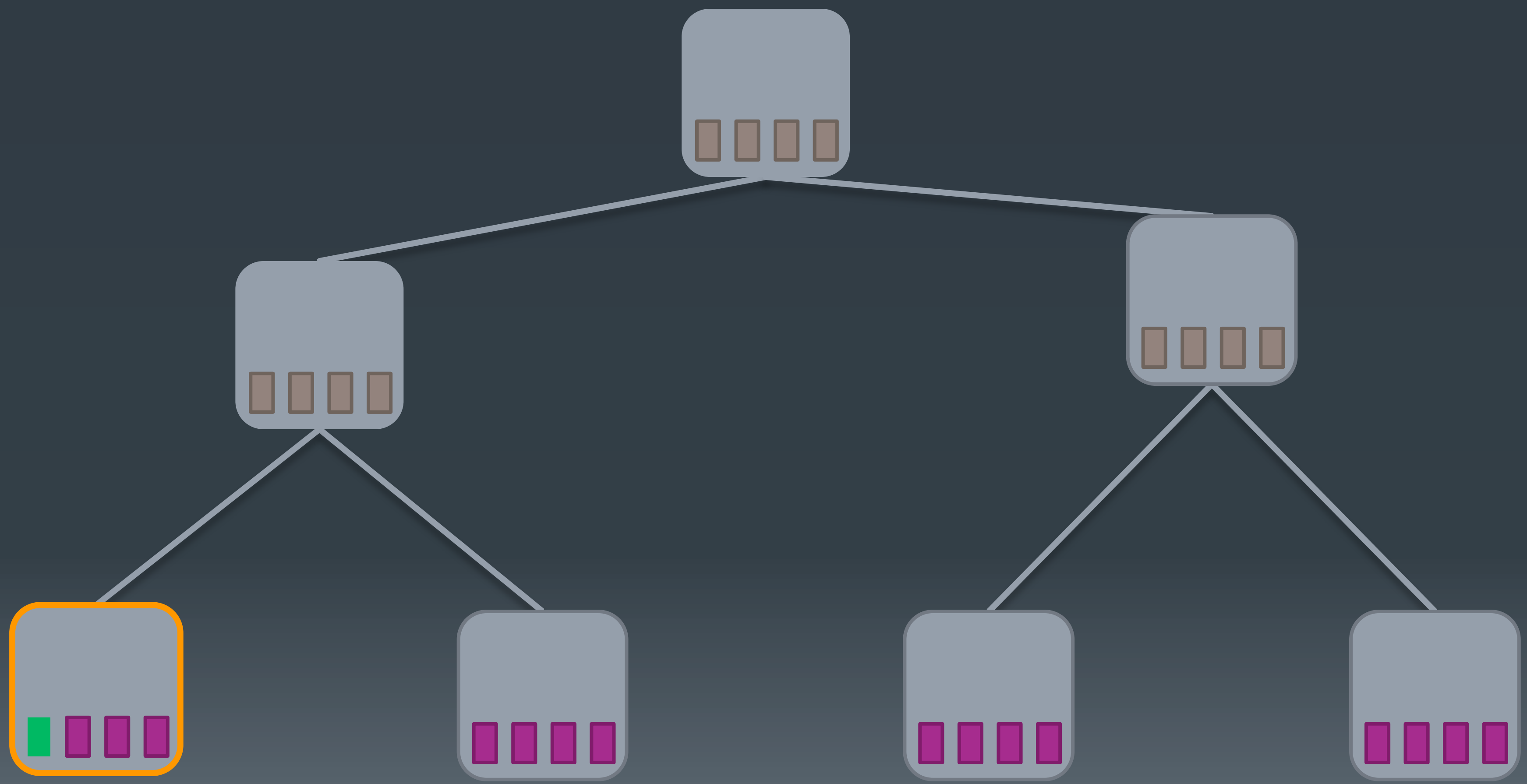
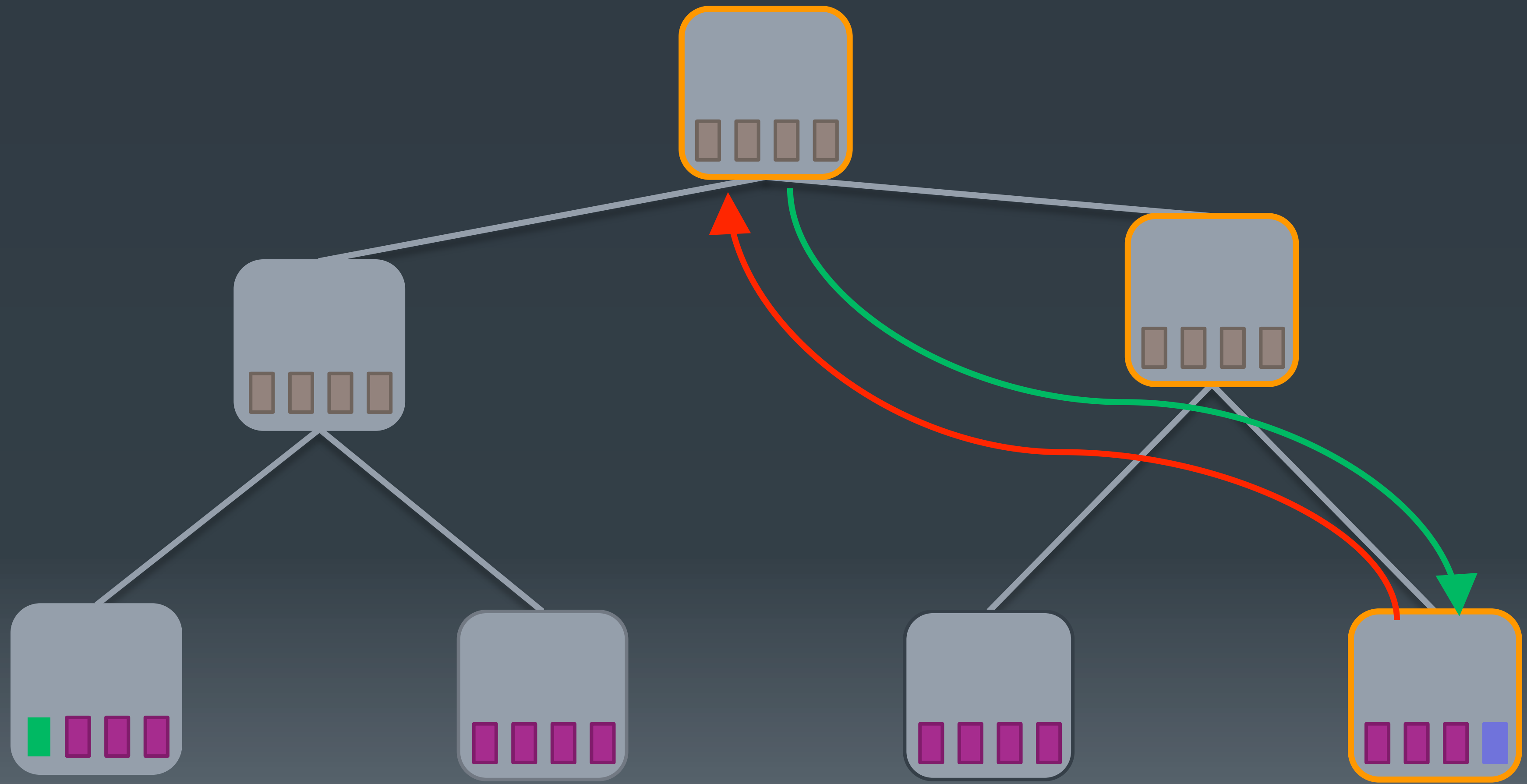


Leaks updates



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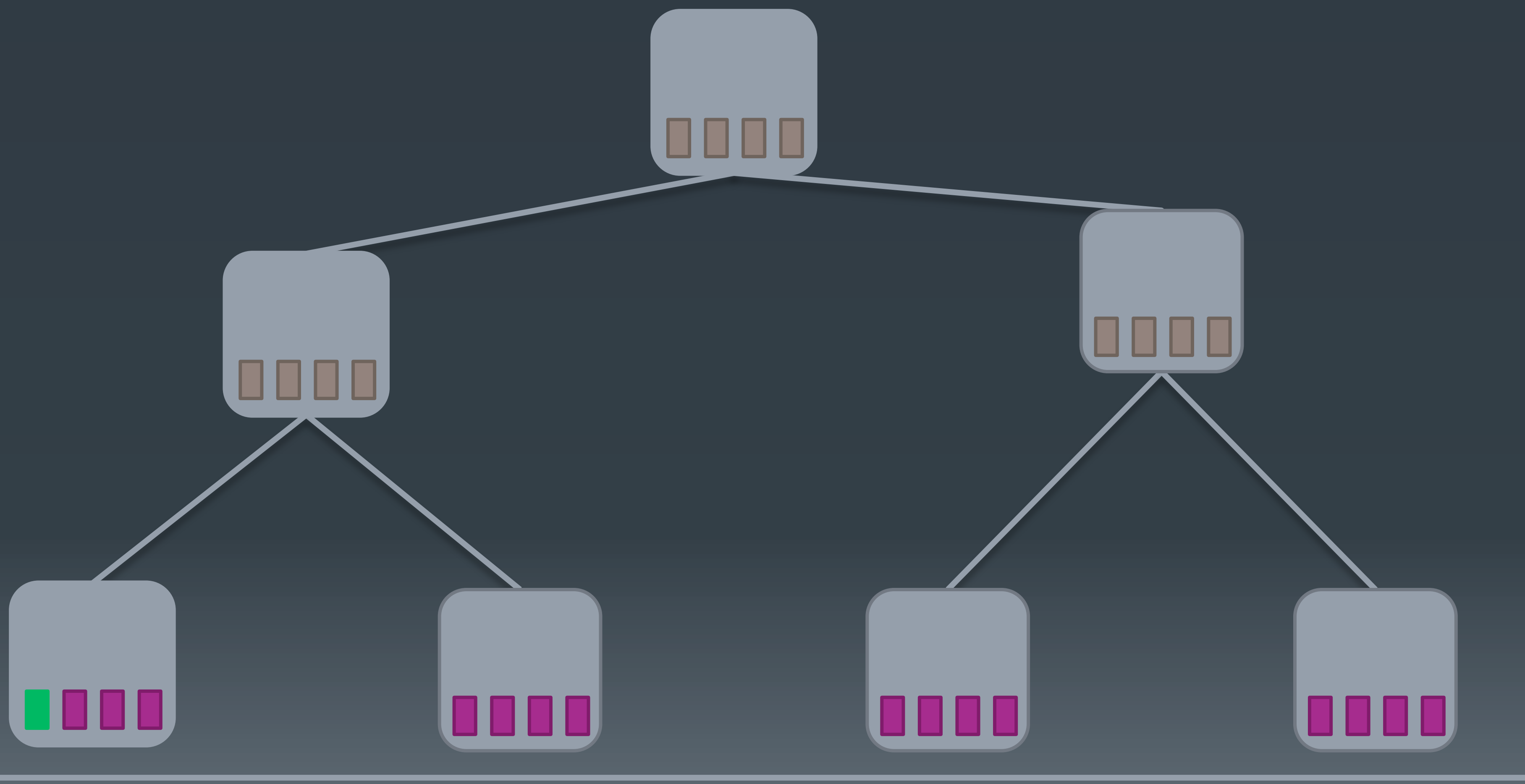

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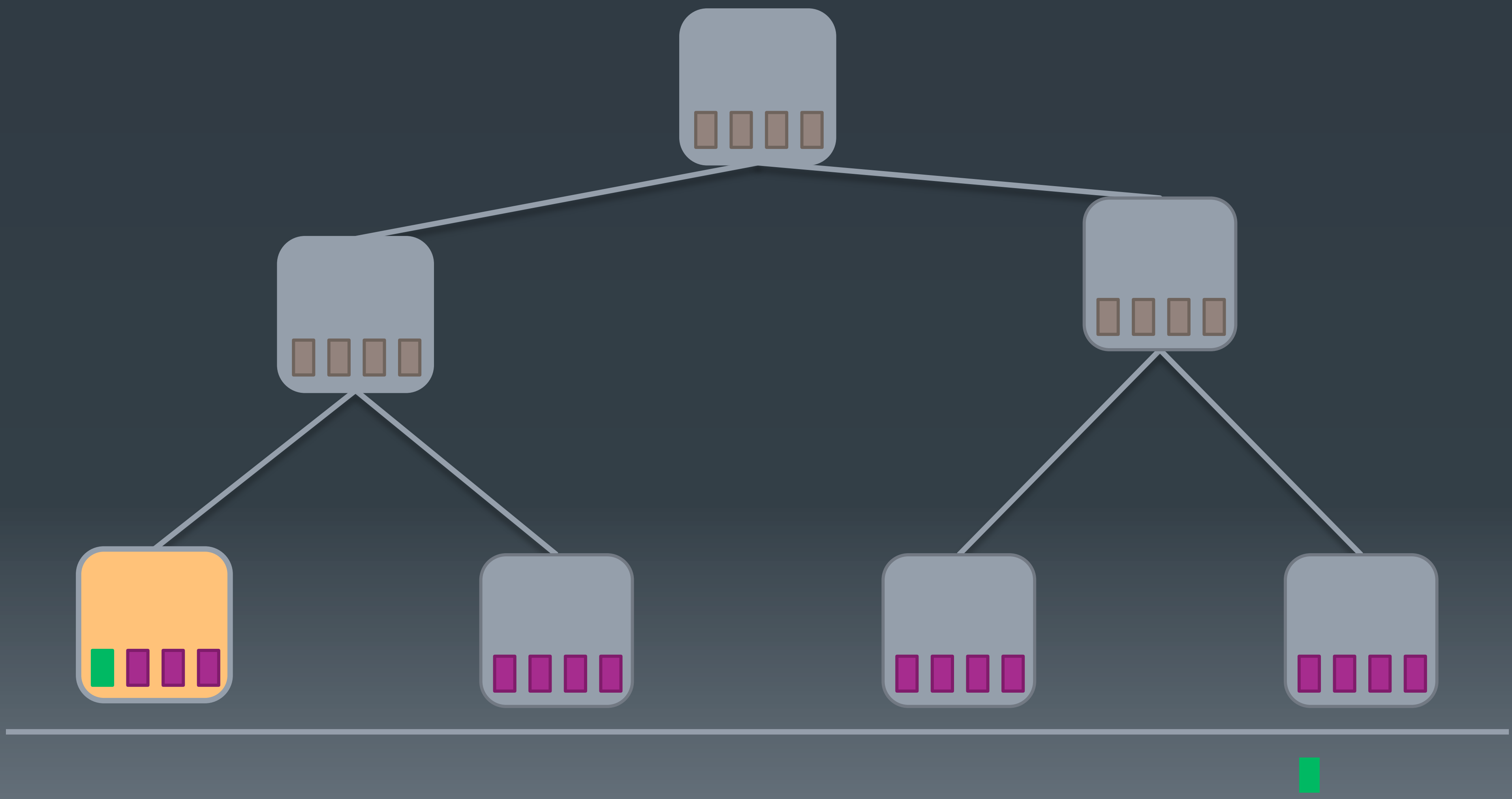

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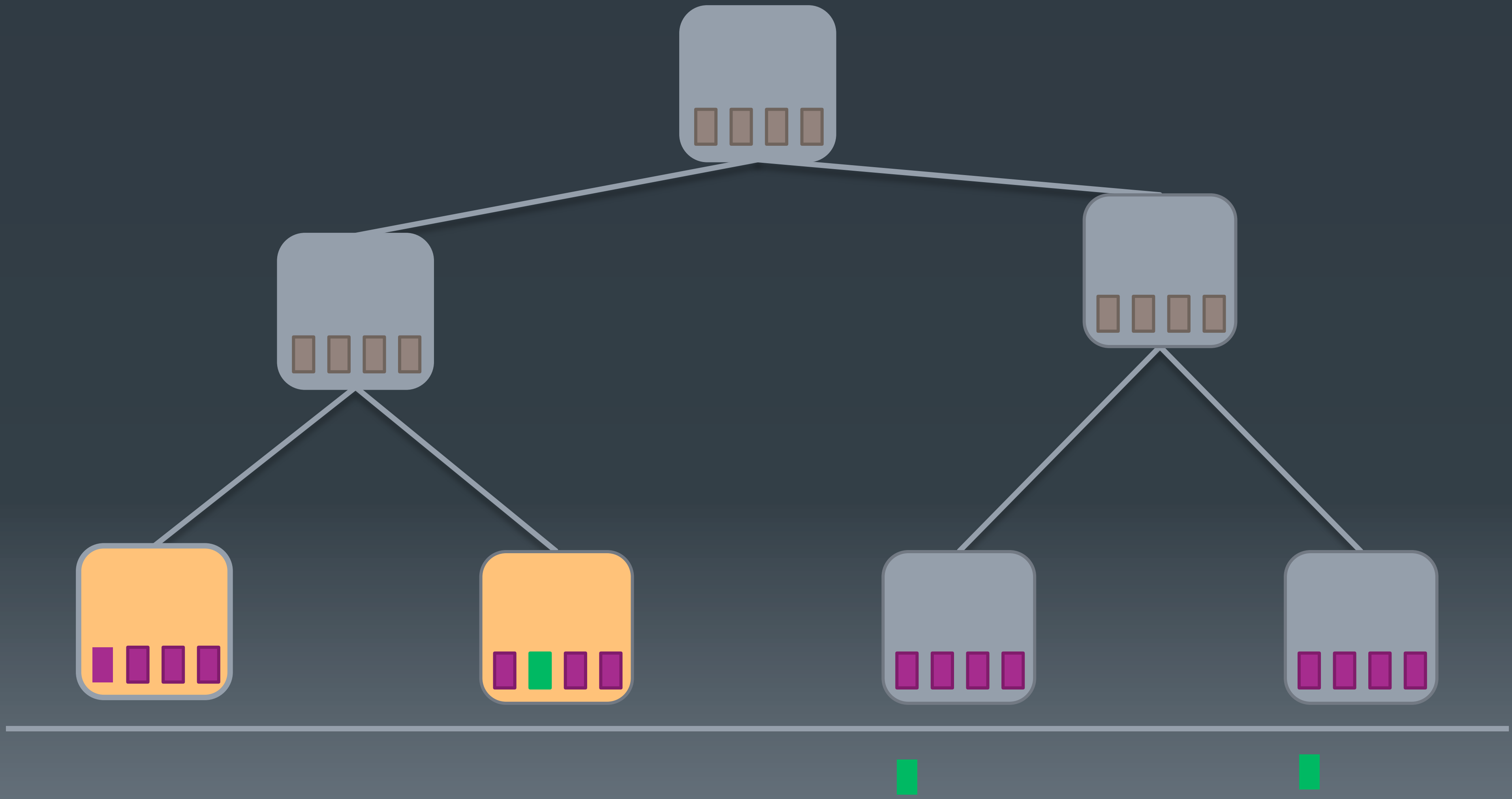
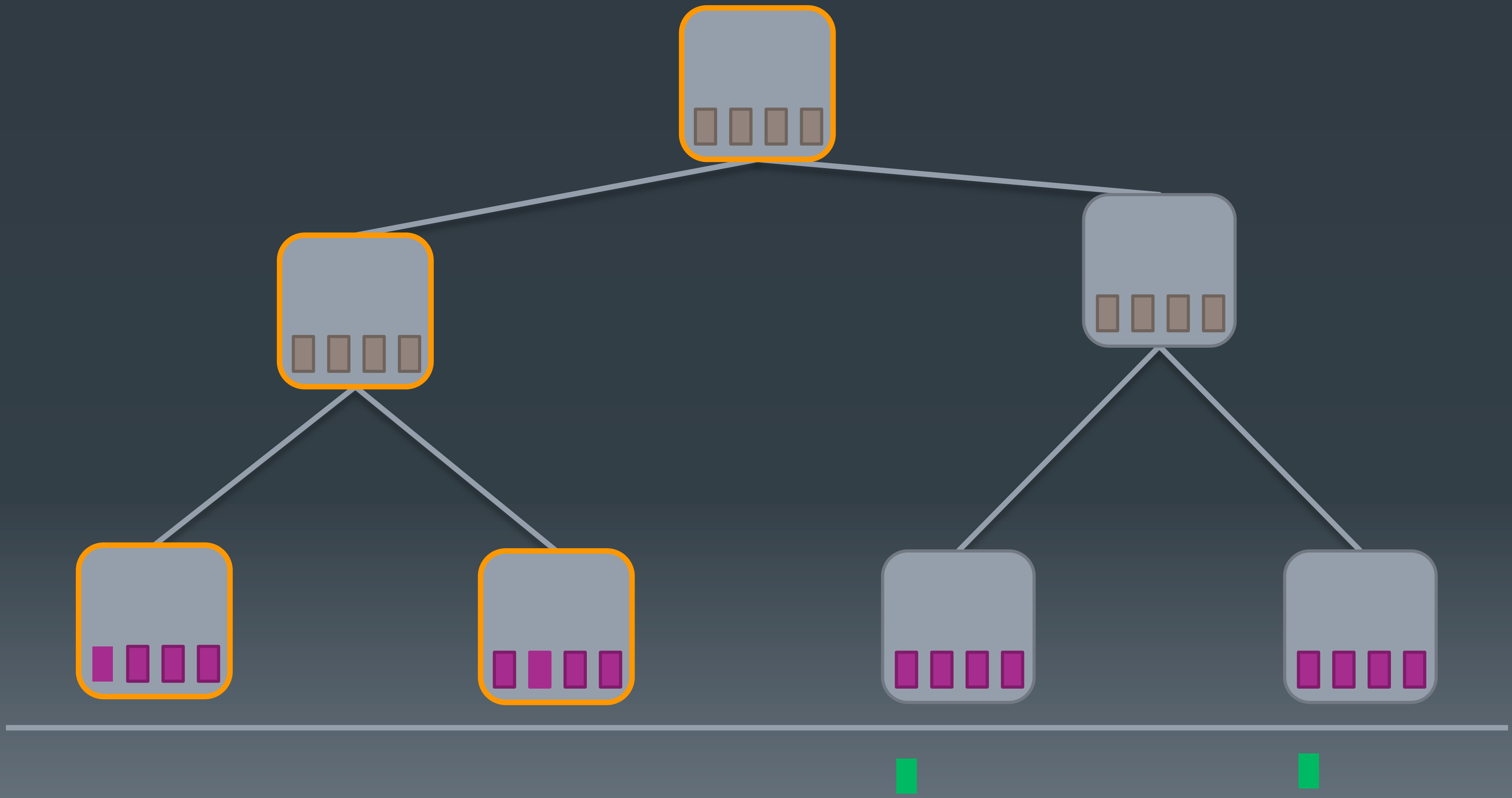


Deferred Reads + Batching



Batched update