Dynamic Local Searchable Symmetric Encryption

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Roadmap Crypto’22

Searchable Symmetric Encryption

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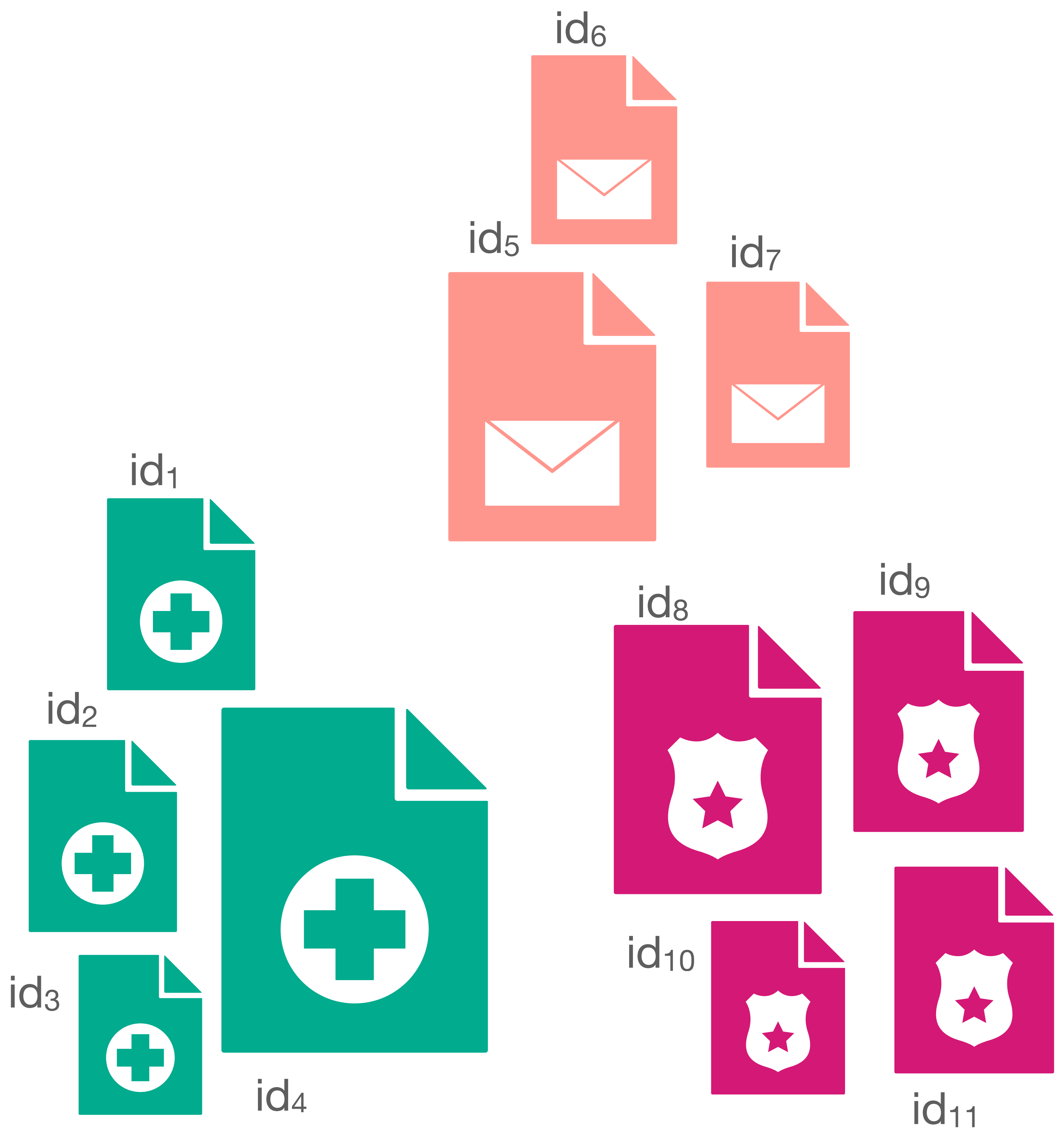
Motivation

Outsource confidential information



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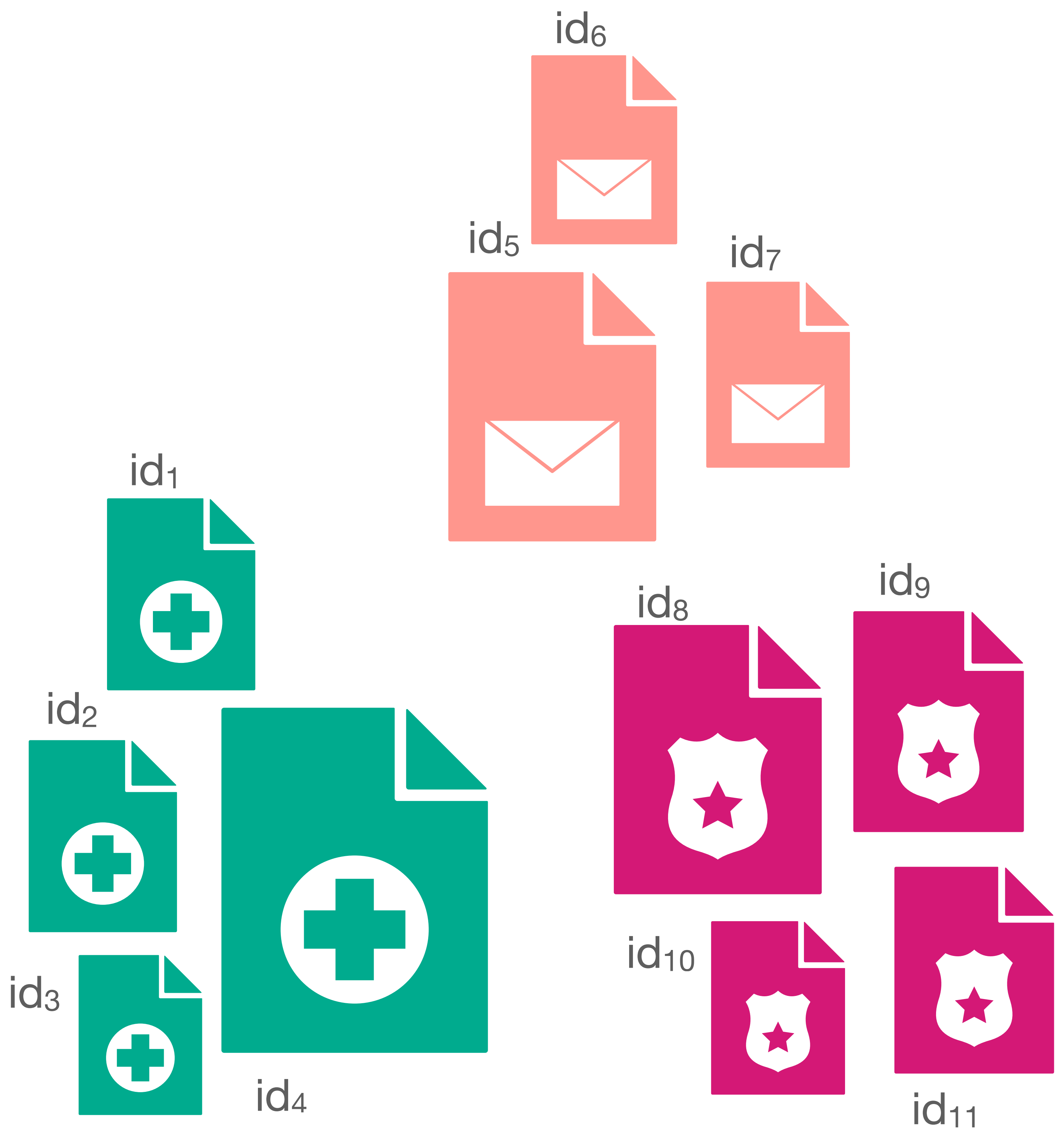
Reverse Index:

“covid” ↦ id_1, id_3

“fire” ↦ id_2, id_3, id_6

…



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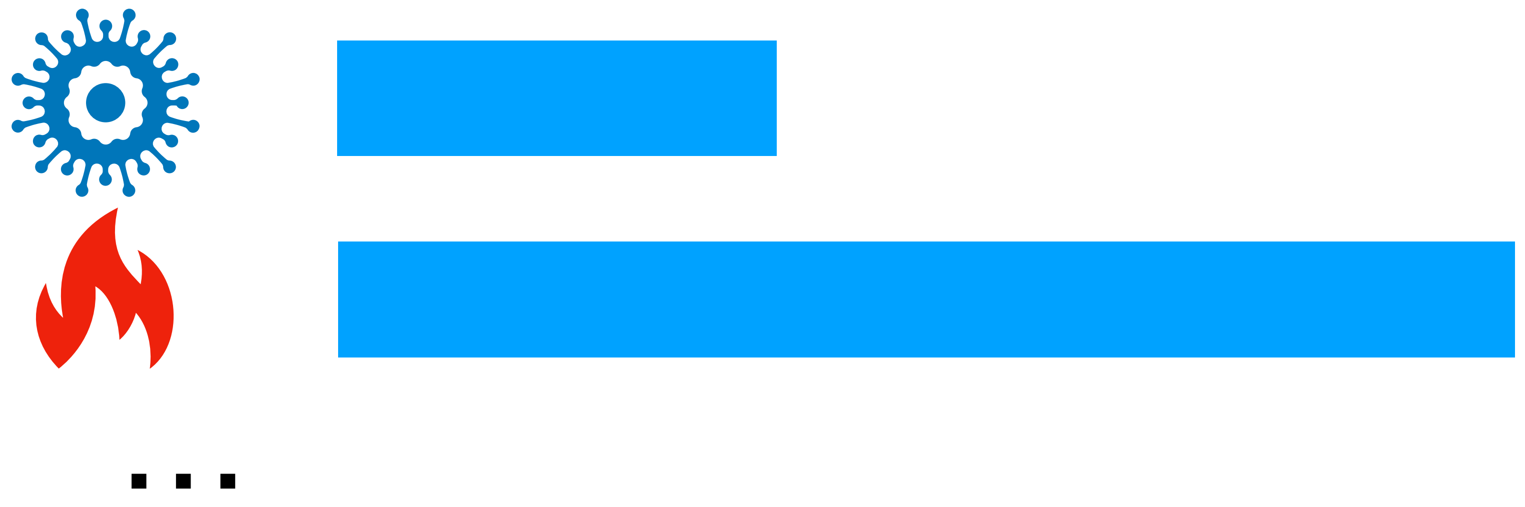

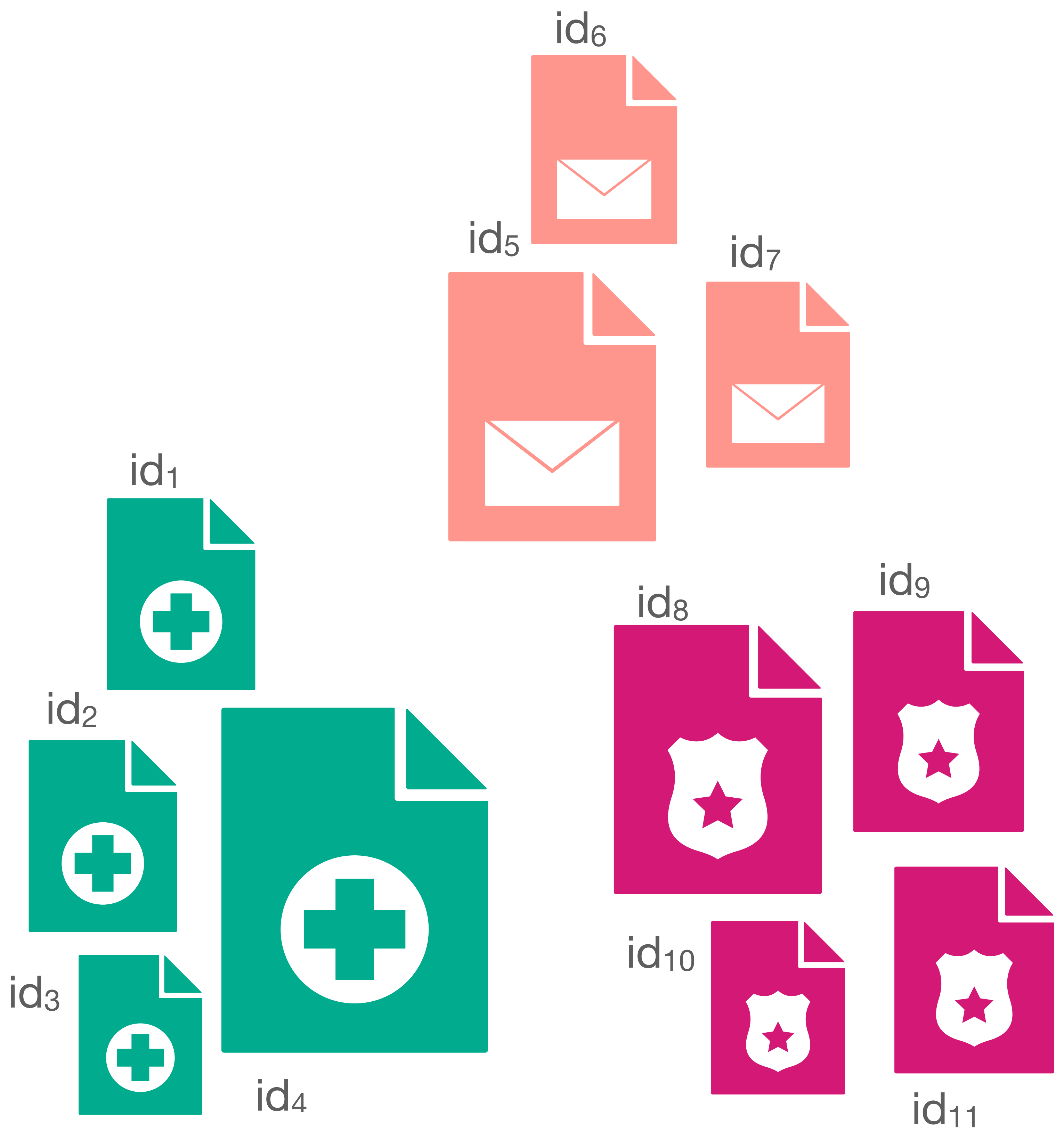

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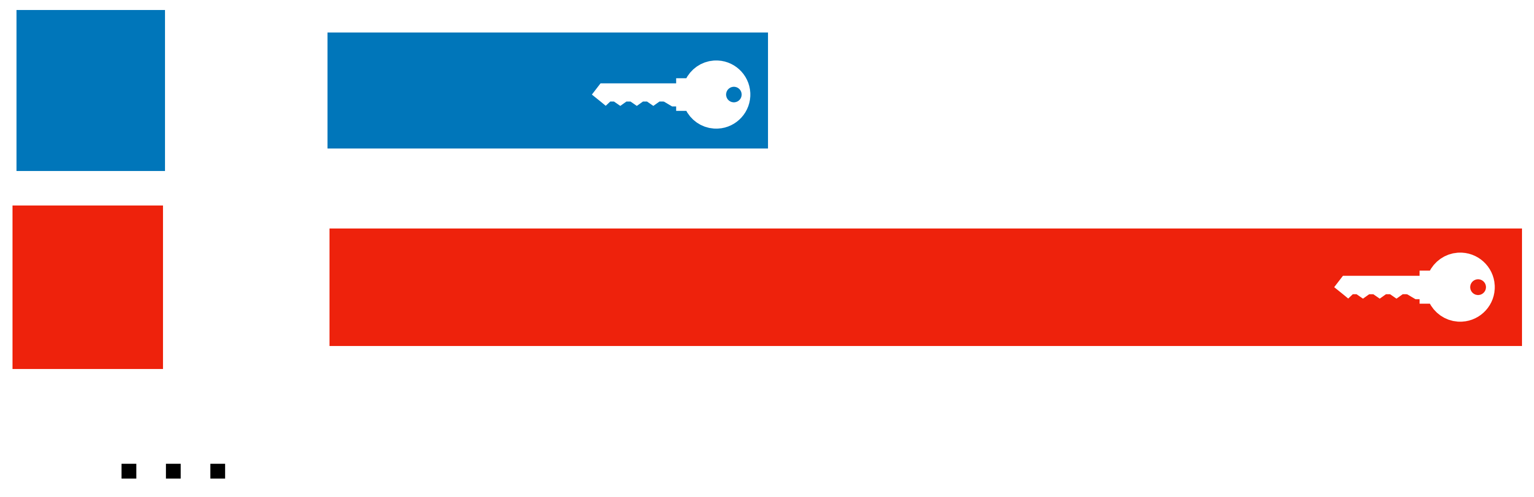

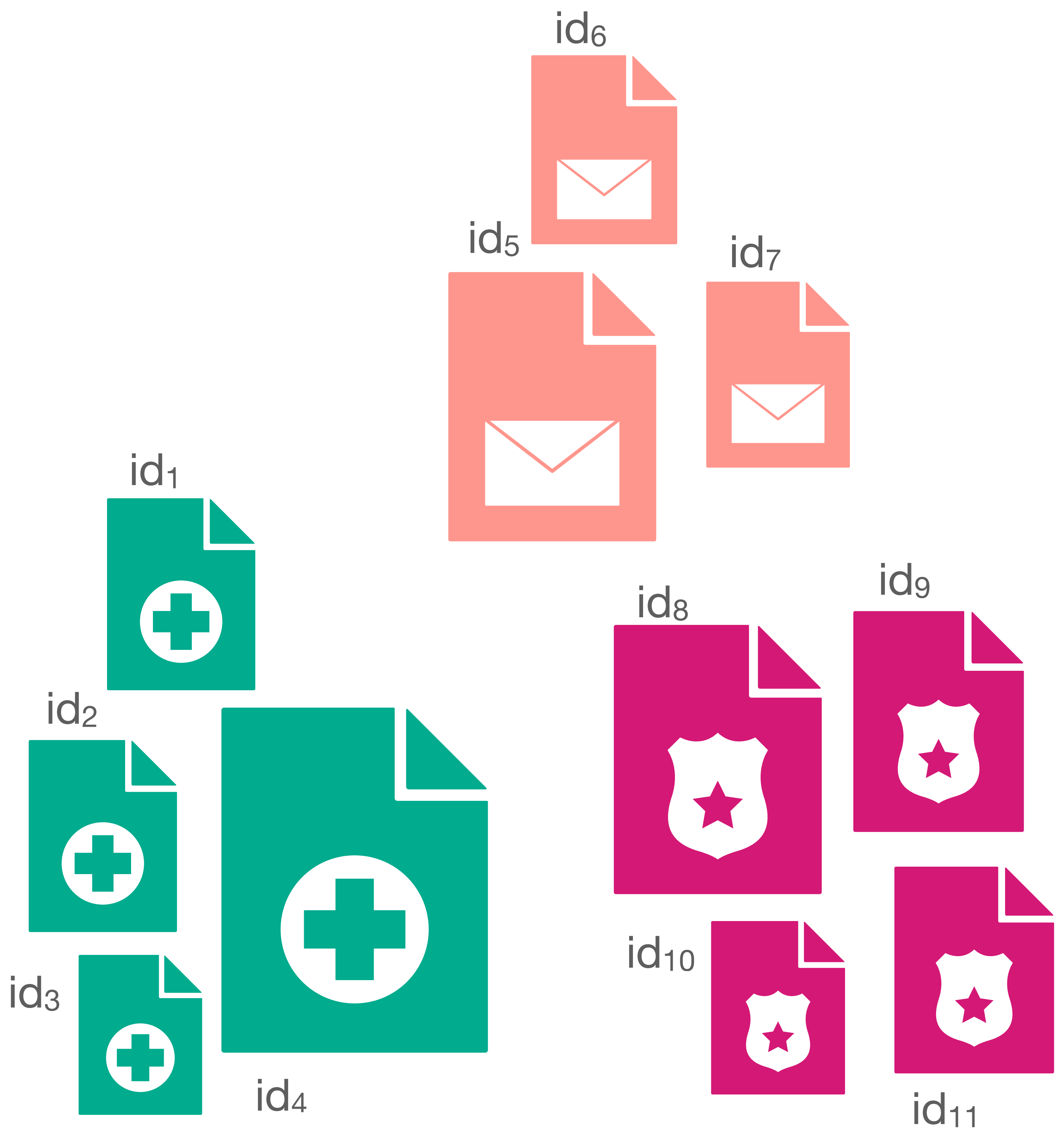

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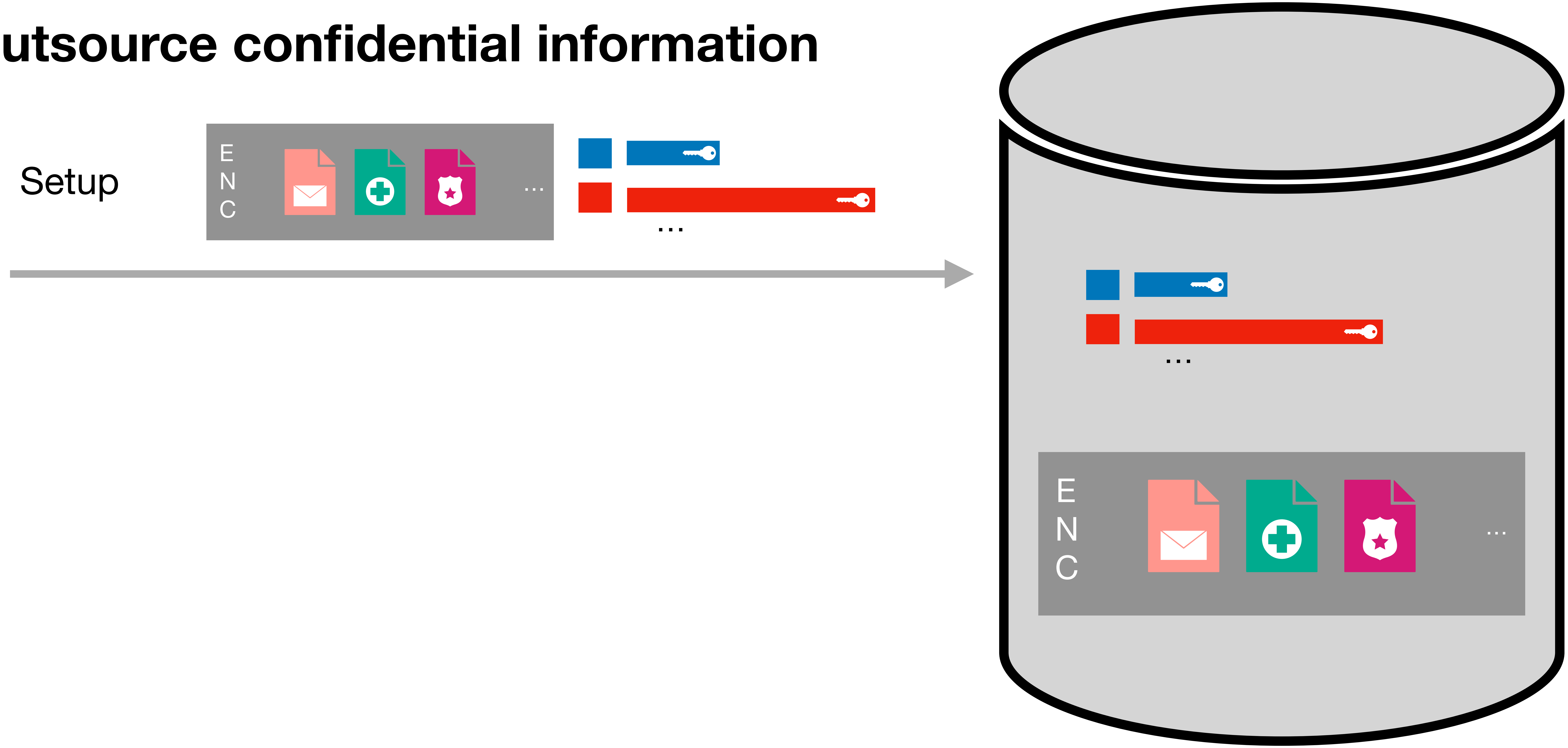

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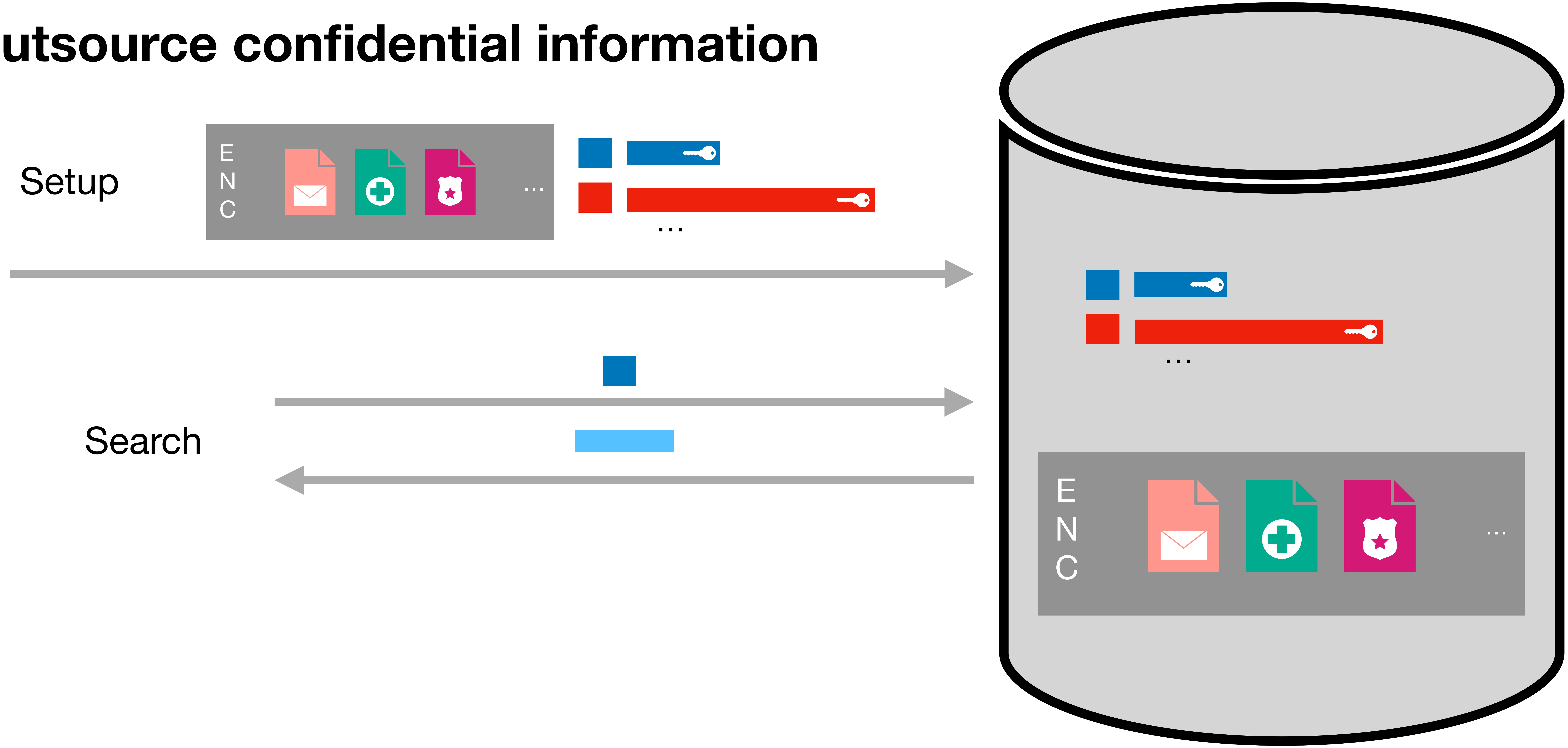

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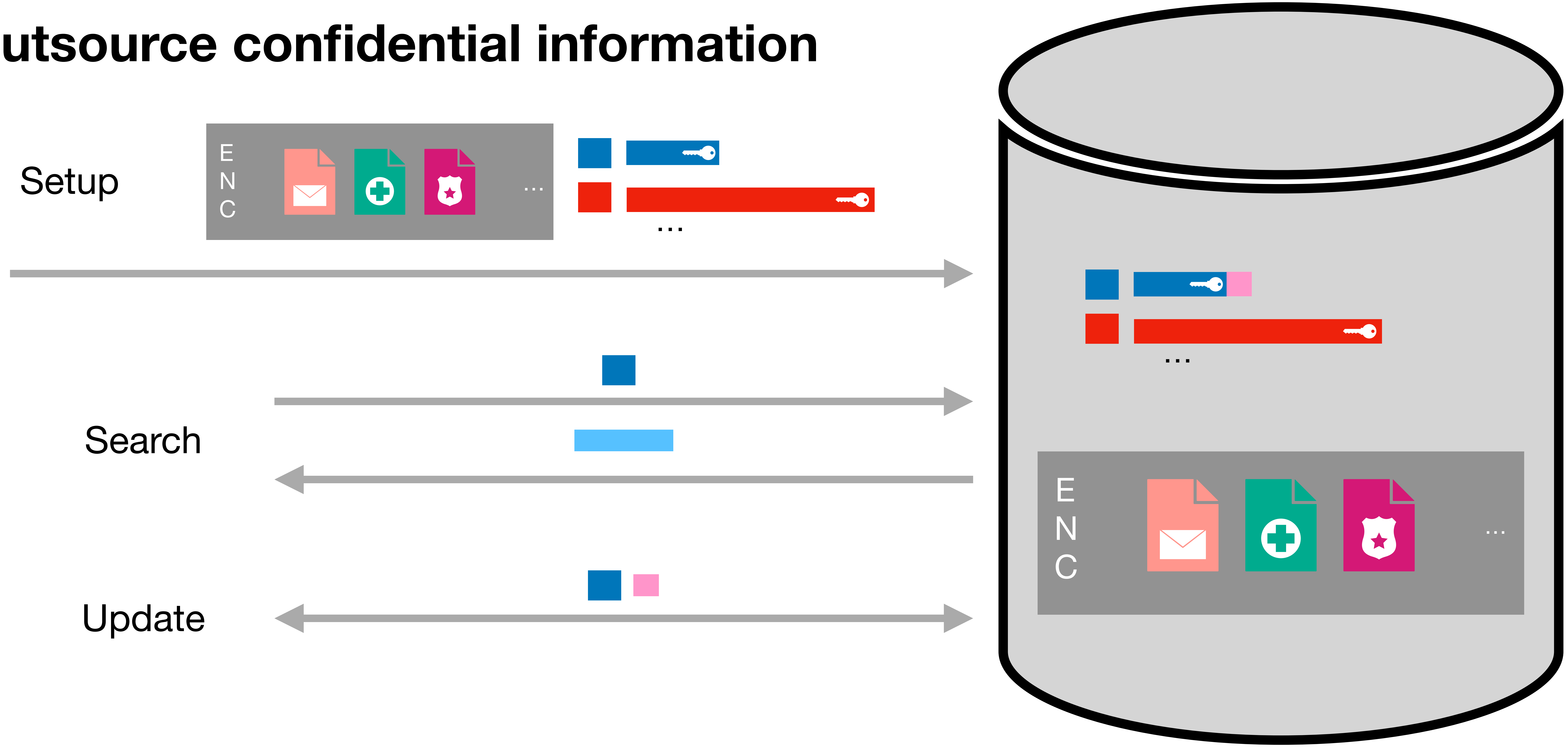

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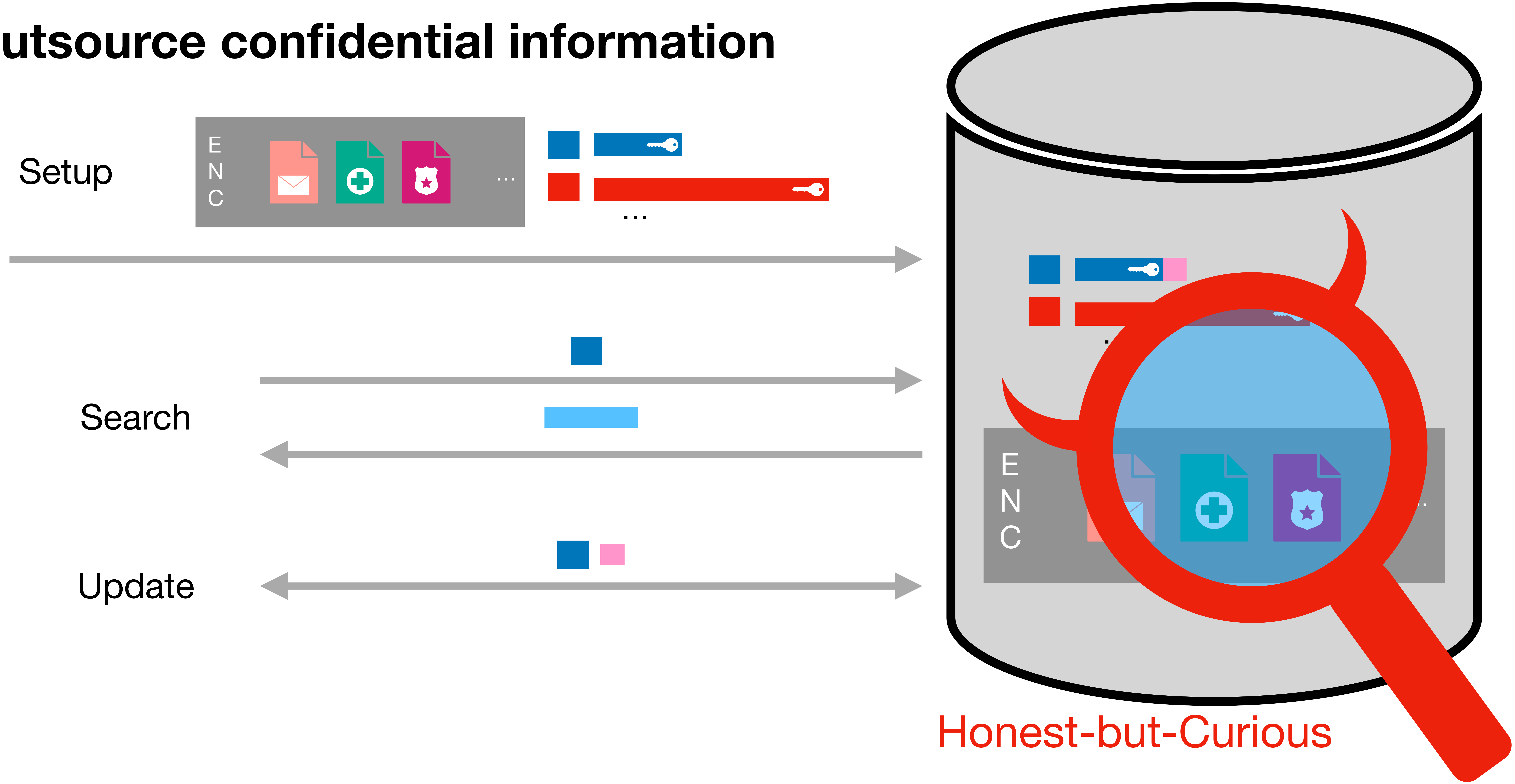

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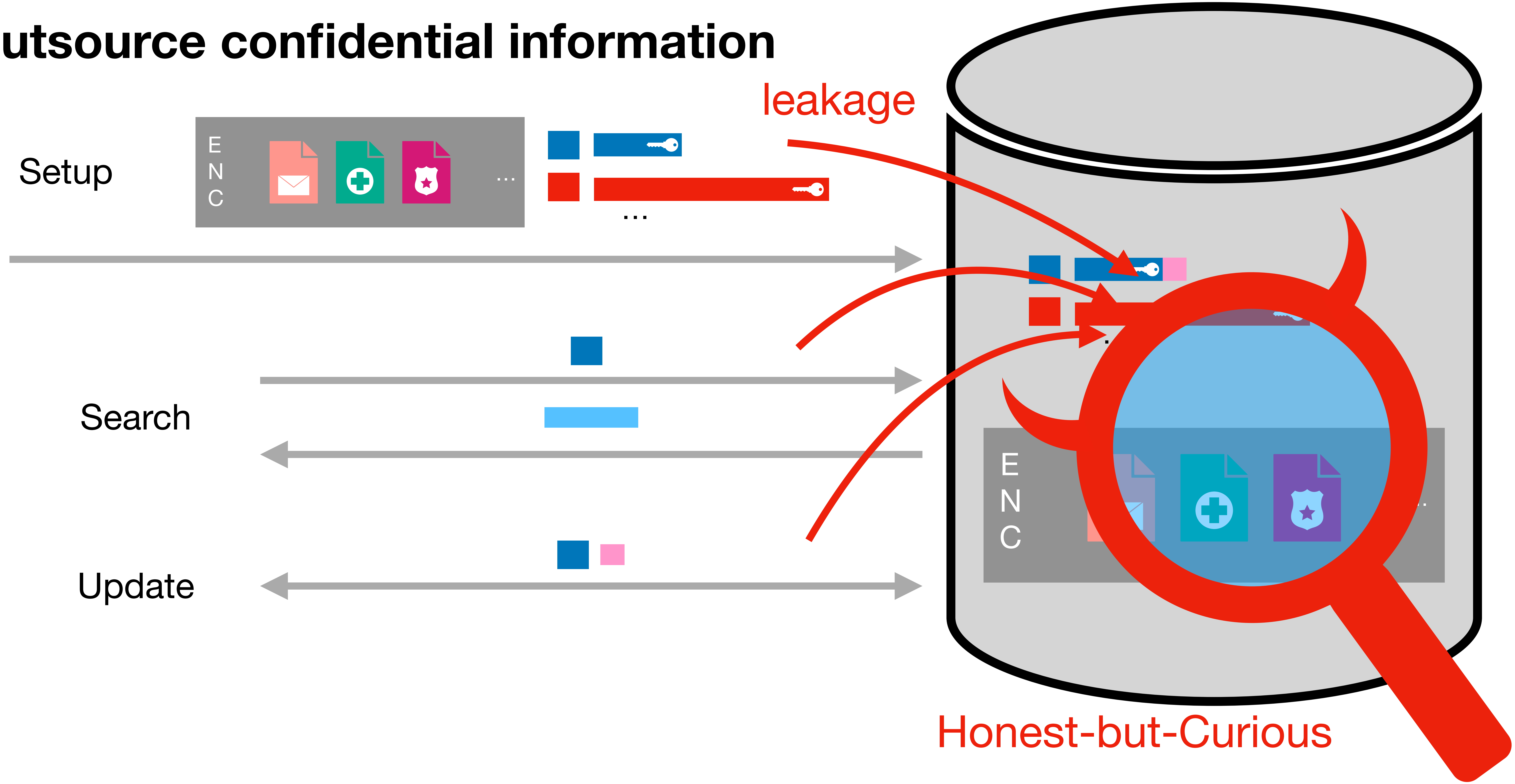
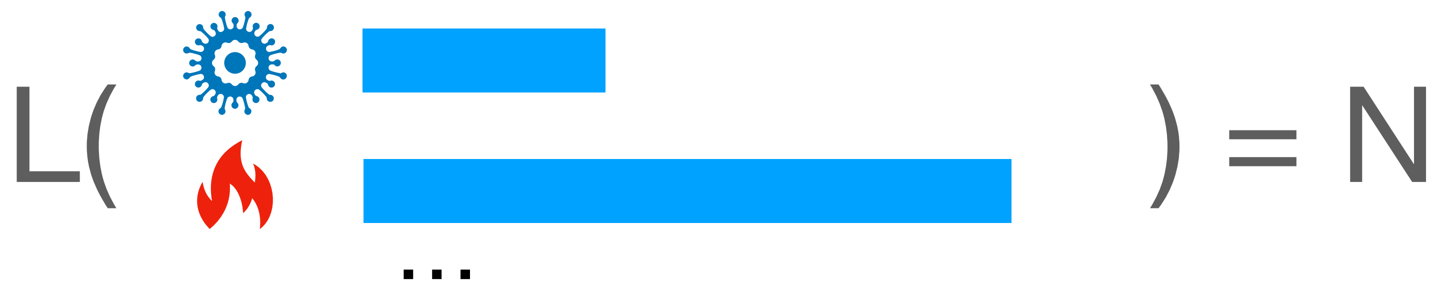


Leakage

Forward Security

- **Security model:** Server learns nothing except leakage
- Allows for tradeoffs: efficiency / security
- Common leakage:
  - **Setup:** database size
  - **Search:** query pattern, access pattern, number of matching IDs
  - **Update:**



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Non-Forward Secure SSE

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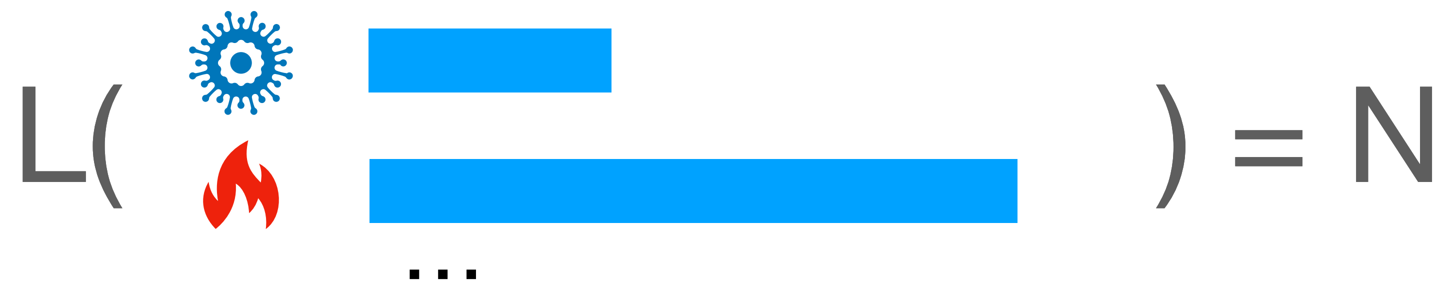

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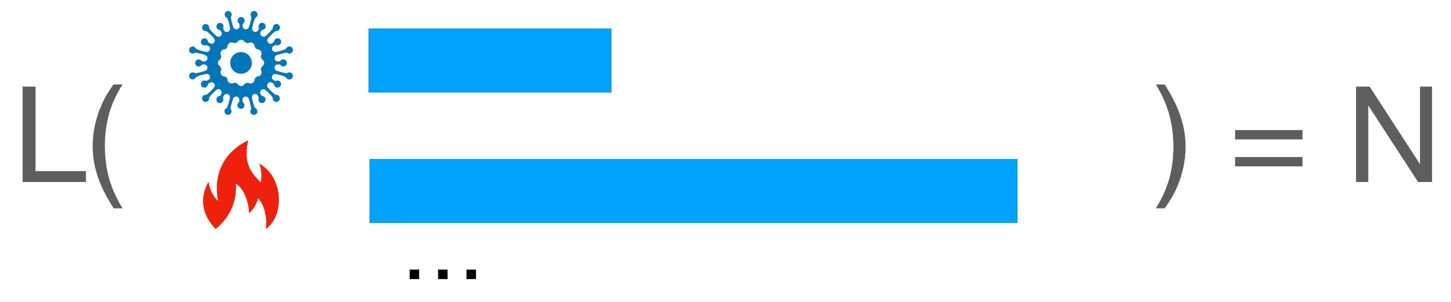

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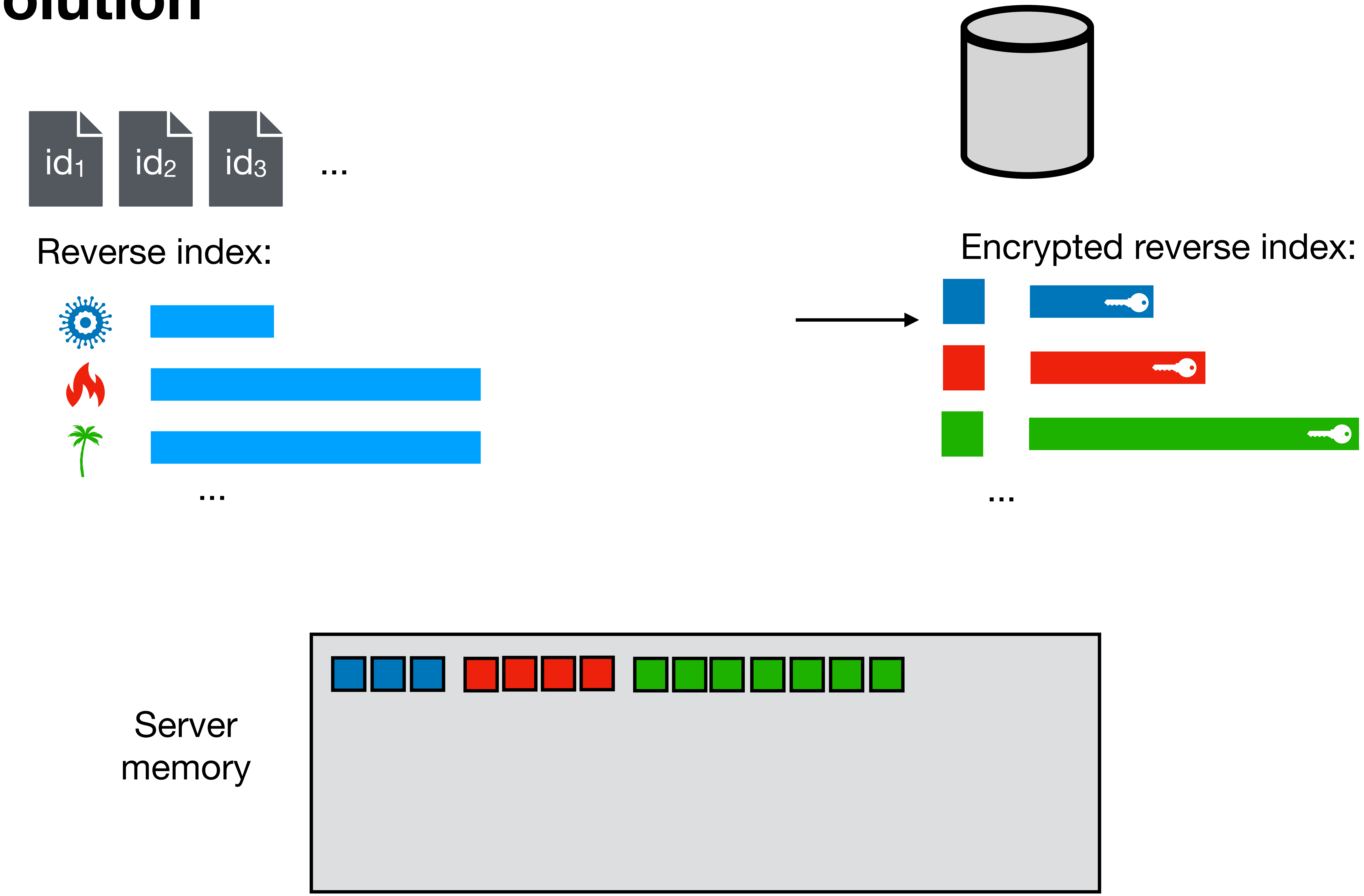
  - **Update:** query pattern, number of matching IDs

No leakage about **unqueried** keywords

SSE

Non-Solution



SSE

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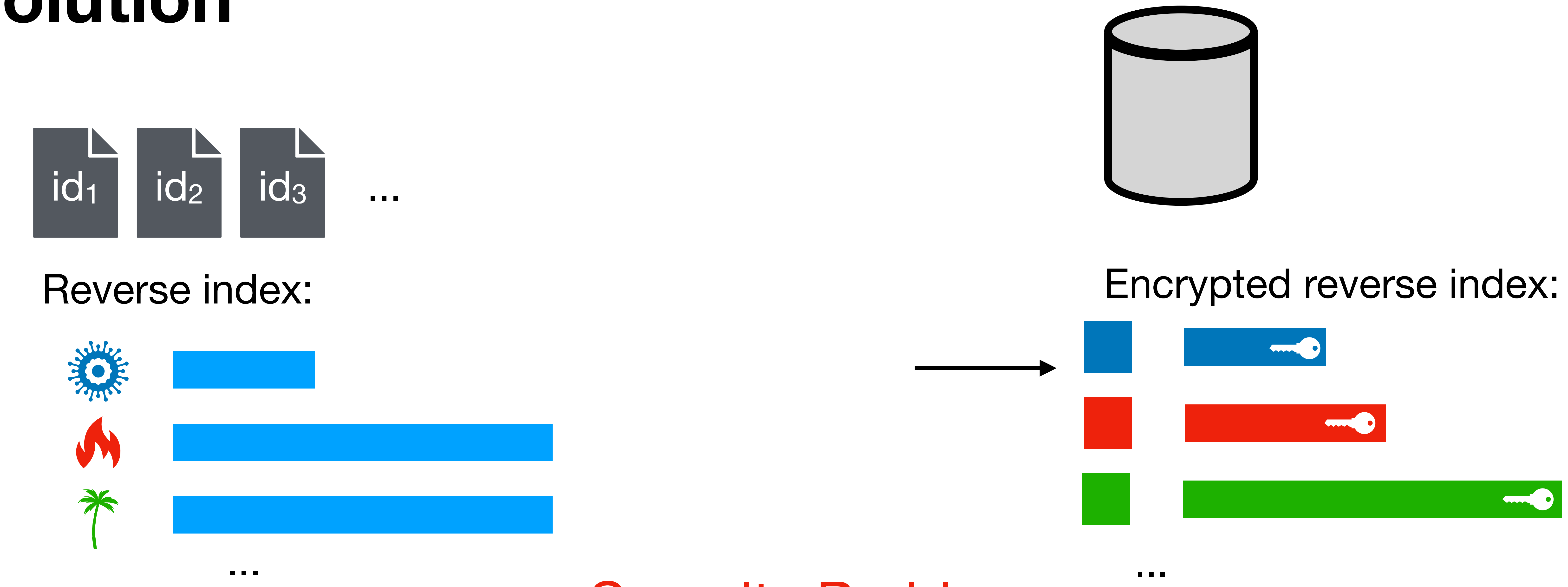
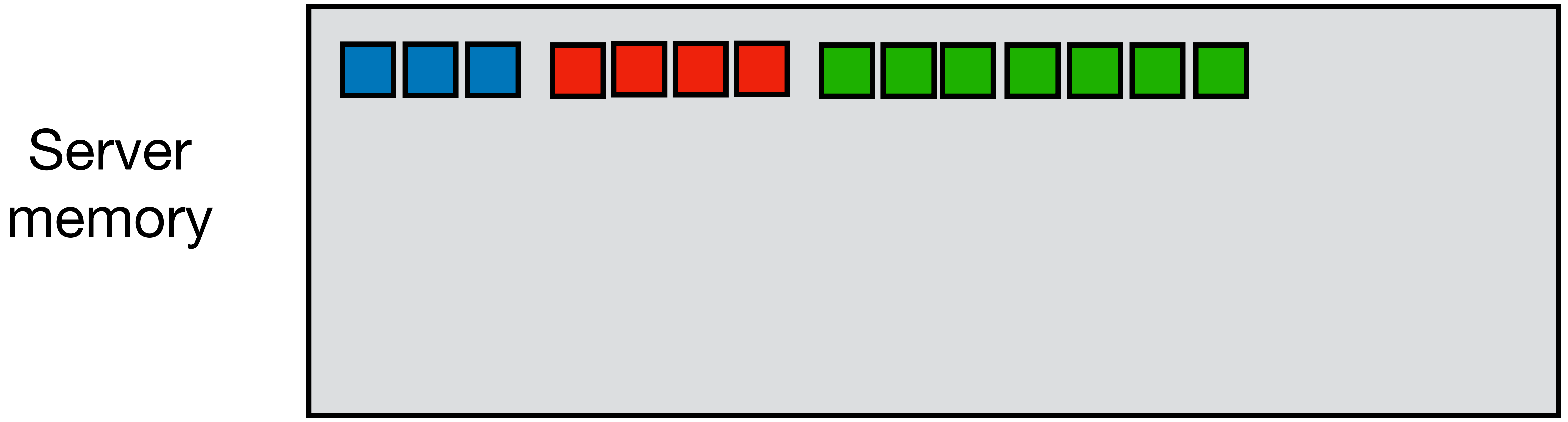


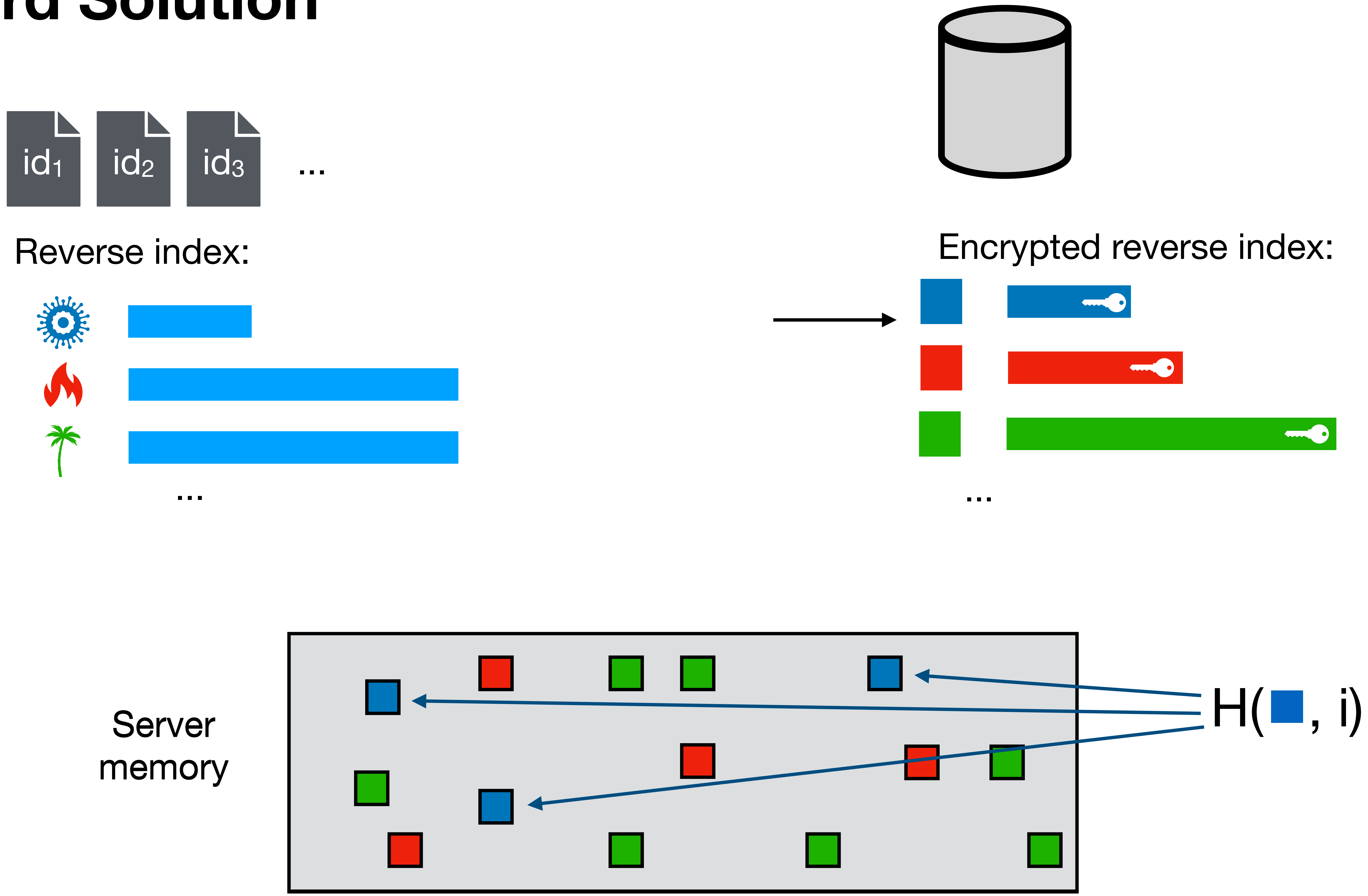
Security Problem

Here, list locations depend on other lists



SSE

Standard Solution



id_1 id_2 id_3 …

Reverse index:

…

Encrypted reverse index:

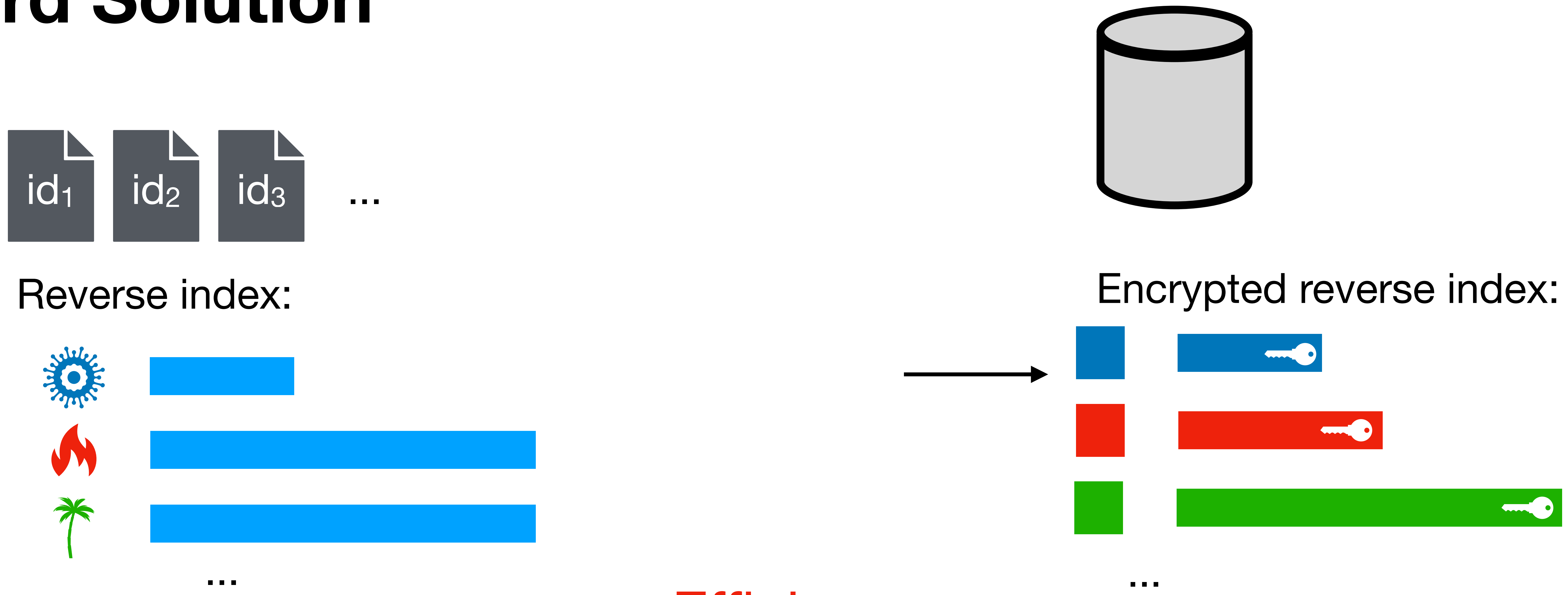
…

Server memory

H(■, i)

SSE

Standard Solution



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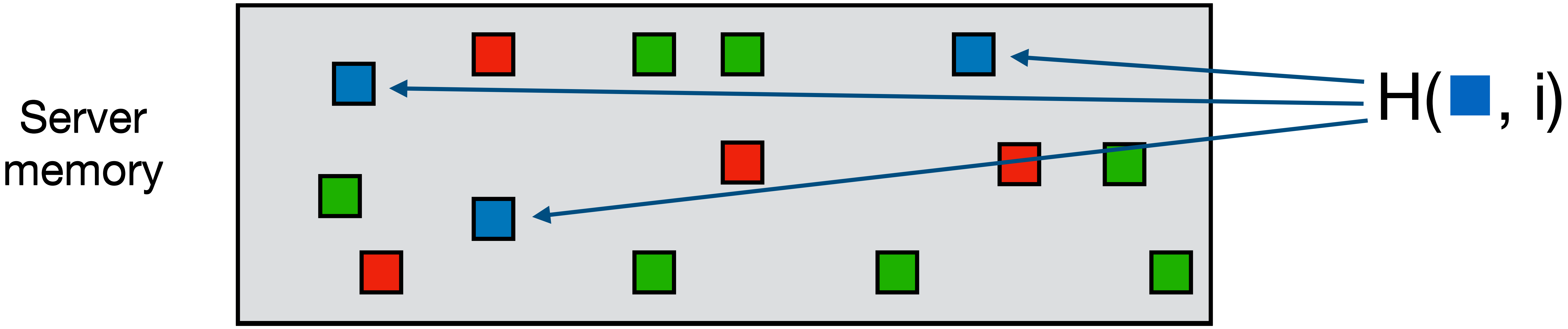
Efficiency

Retrieval induces many random memory accesses



Server memory

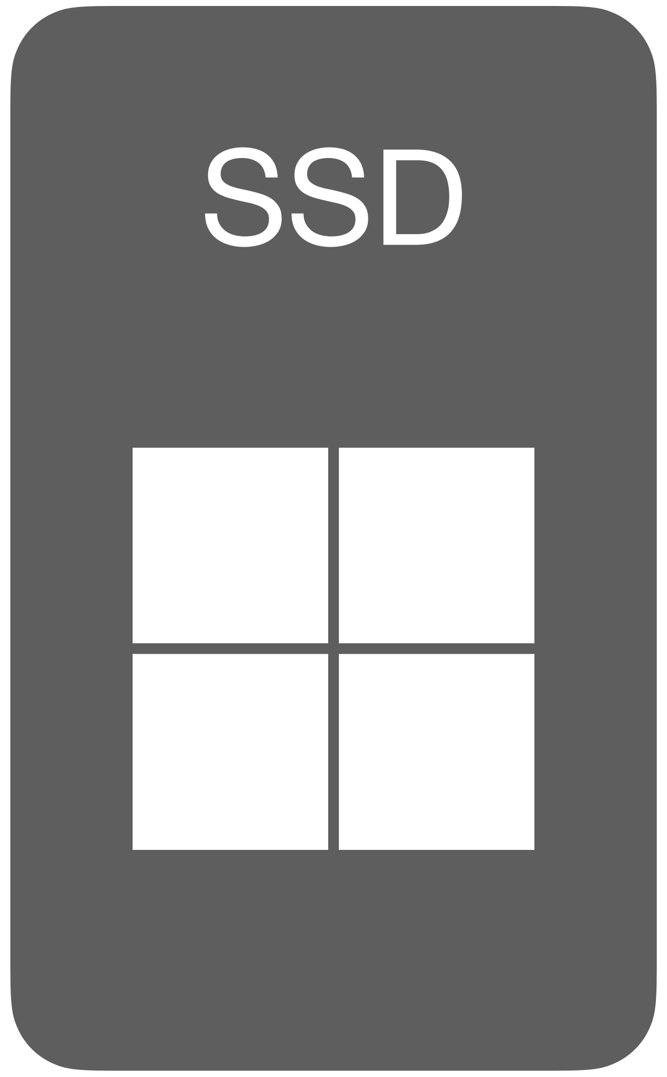
H(🟦, i)

Memory Efficiency

HDDs vs SSDs

Locality:

Number of Read
(non-adjacent)
Memory Locations

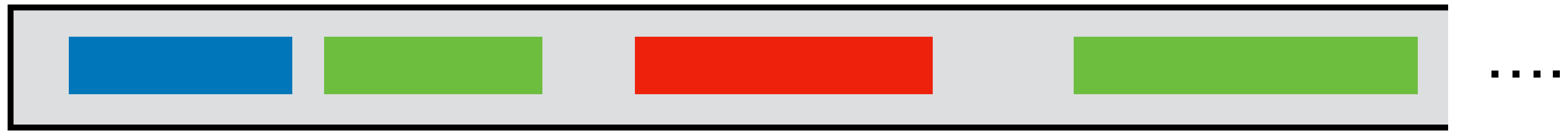


Page Efficiency:

Number of Read
Pages per Query

Locality

Look at server memory as array



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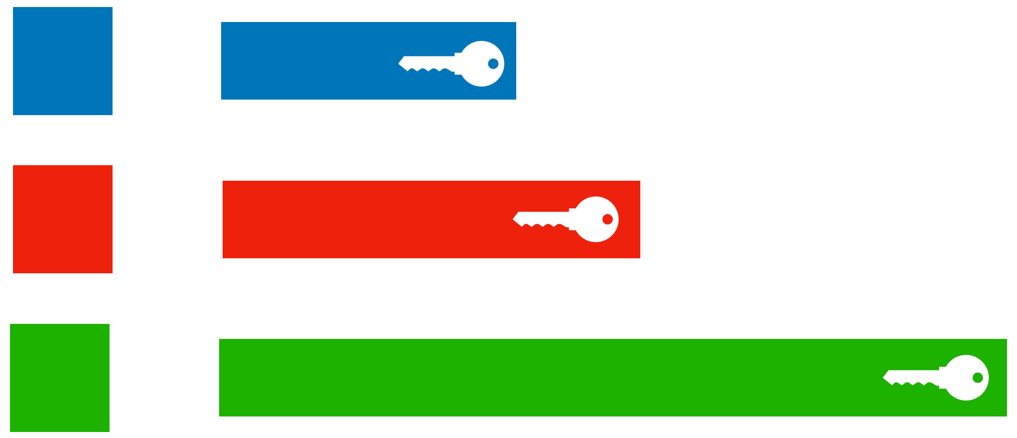
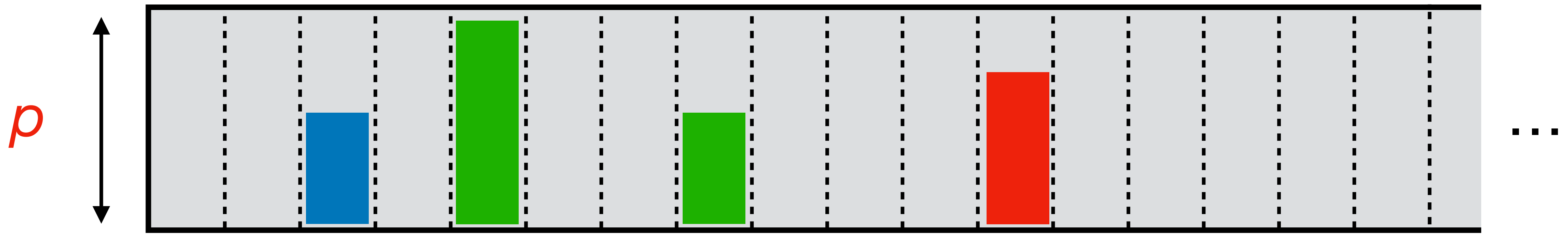


- Goal:
  - Locality: read at most constant disjoint intervals
  - Read Efficiency: read **as little extra data** as possible
  - Storage Efficiency: At most constant blow-up of server memory

Page Efficiency

Look at server memory as pages



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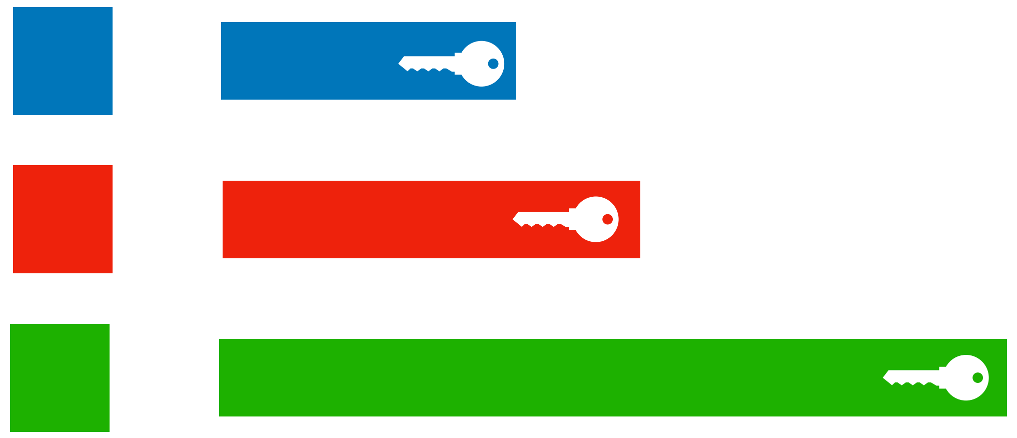

- Goal:
  - Page Efficiency: Store identifier lists in **as little pages** as possible
  - Storage Efficiency: At most constant blow-up of server memory

Current State of the Art

Constant Storage Efficiency (and Locality)

Read Efficiency:

- **[ANSS16]:** $\tilde{O}(\log \log N)$ *
- **[ASS18]:** $\tilde{O}(\log \log \log N)$ **
- **[DPP18]:** $O(\log^{2/3+\varepsilon} N)$

* restriction on longest list
** even stronger restriction on longest list

Page Efficiency:

- **[BBFMR21]:** $O(1)$ +

+ logarithmic client storage

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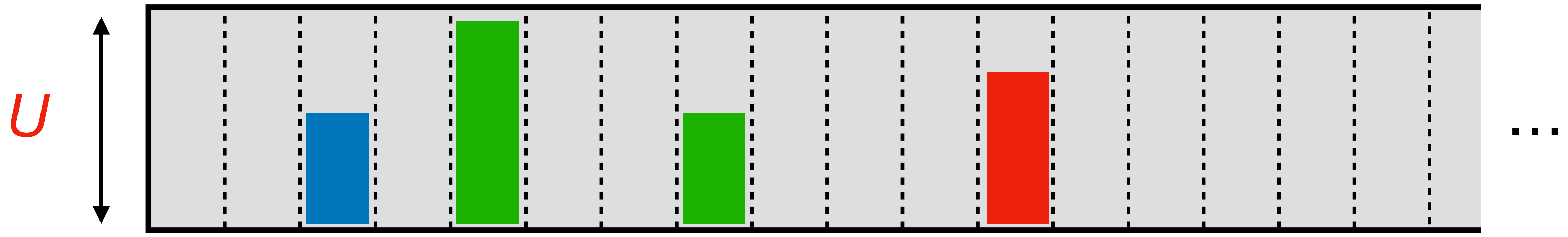
Exclusively static constructions

Framework

Balls-into-Bins

Look at server memory as bins



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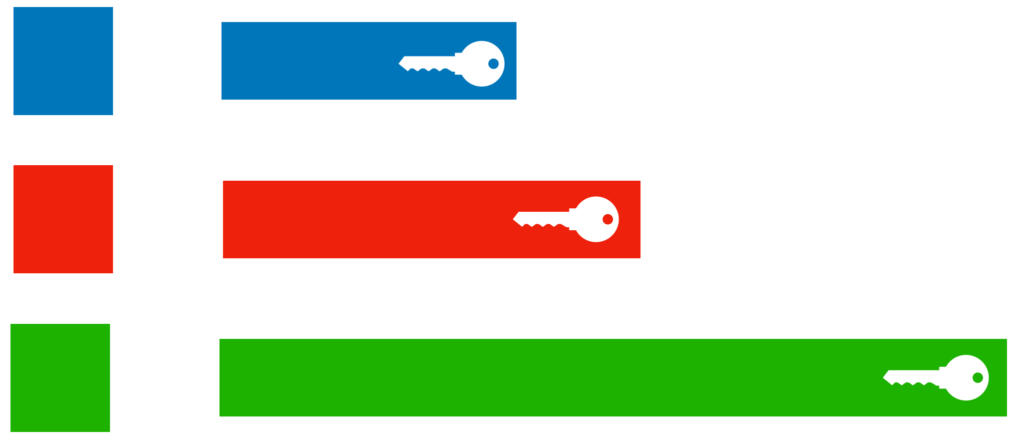

- Approach: throw *weighted* balls into bins via hash function
- Goal: upper bound *U* on maximal bin load

Framework

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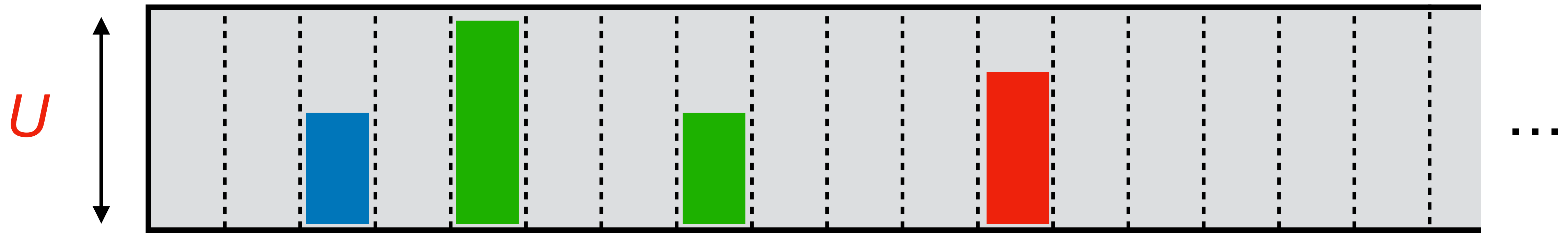

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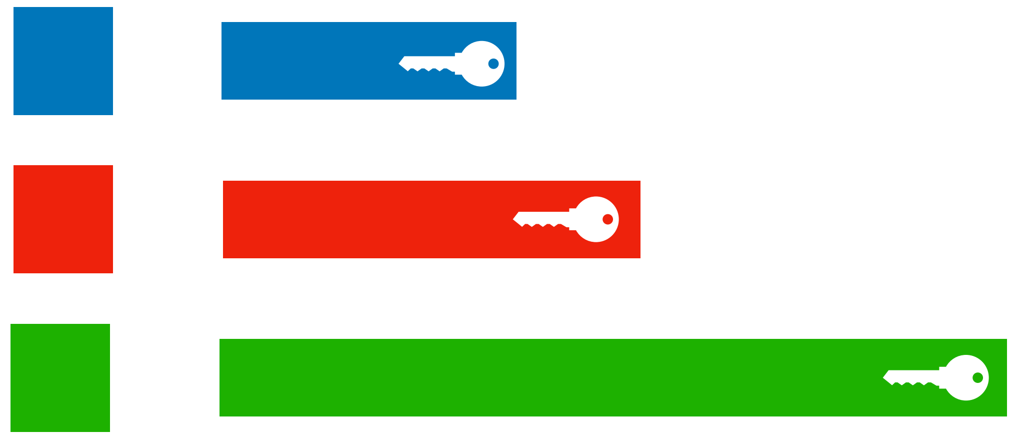

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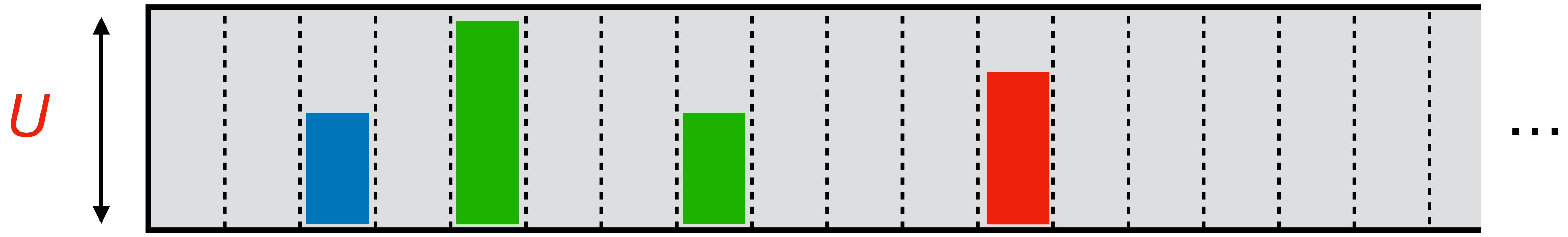

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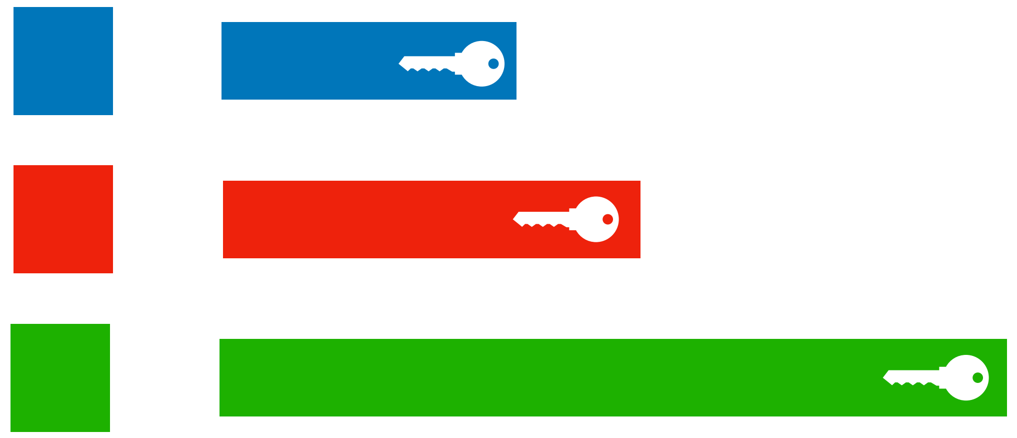

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→ SSE with $O(U)$ page efficiency

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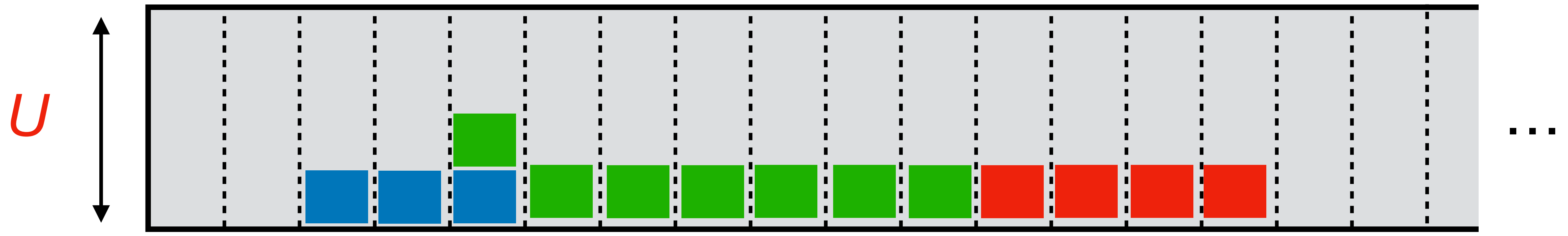

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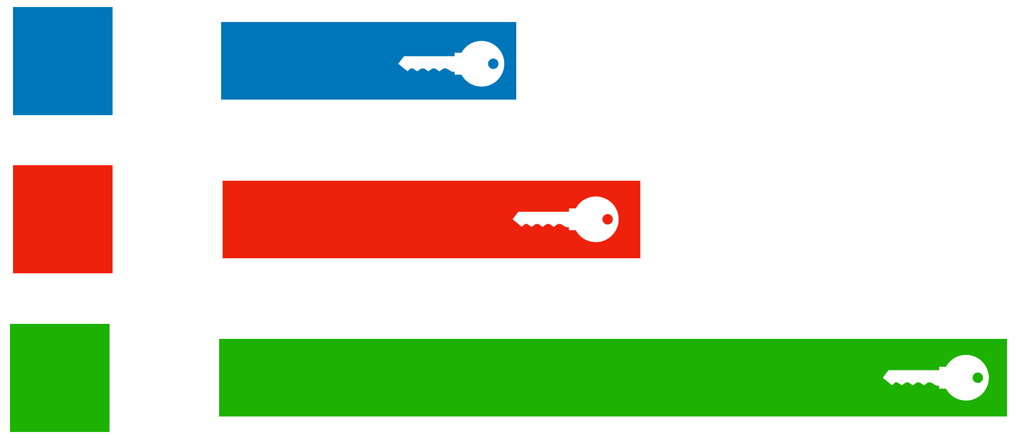

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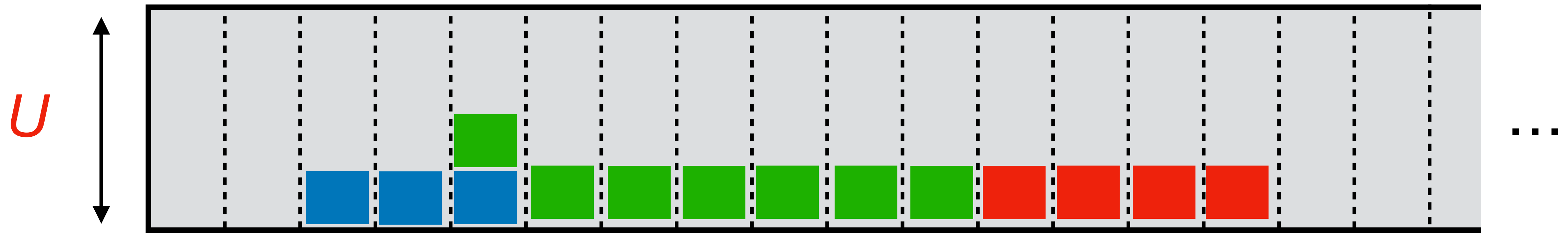

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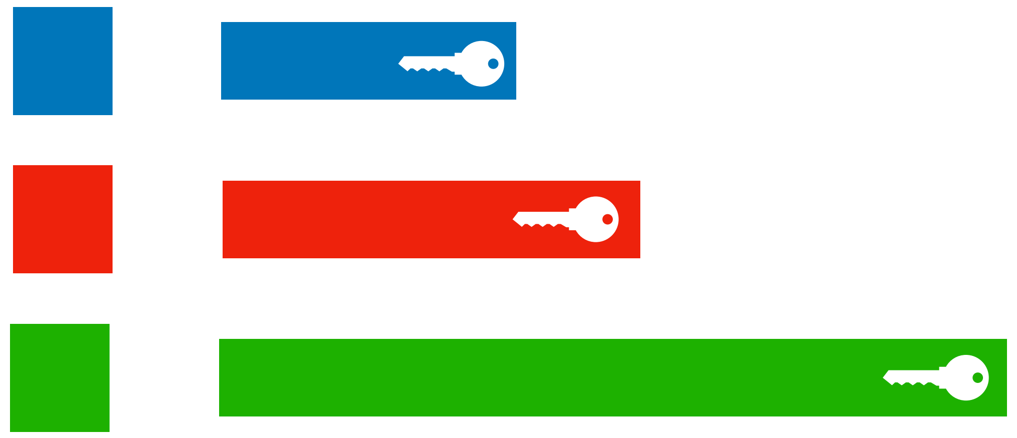

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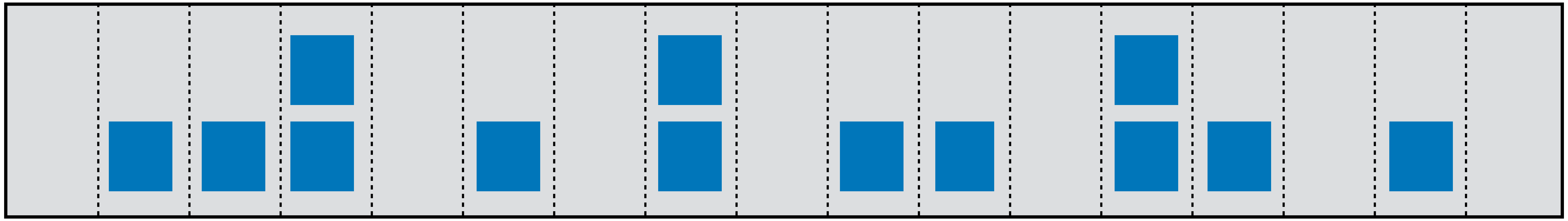
→ SSE with *O*(*U*) read efficiency, *O(1)* locality

Two-Choice

Throw n balls into $m = O(n)$ bins at random



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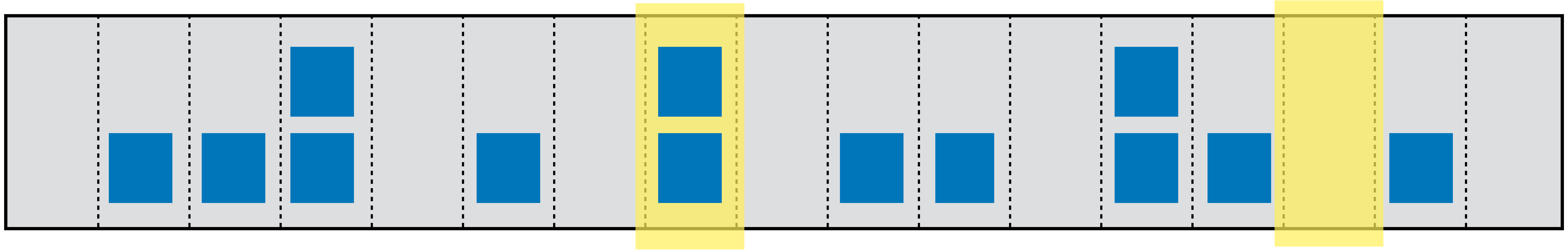

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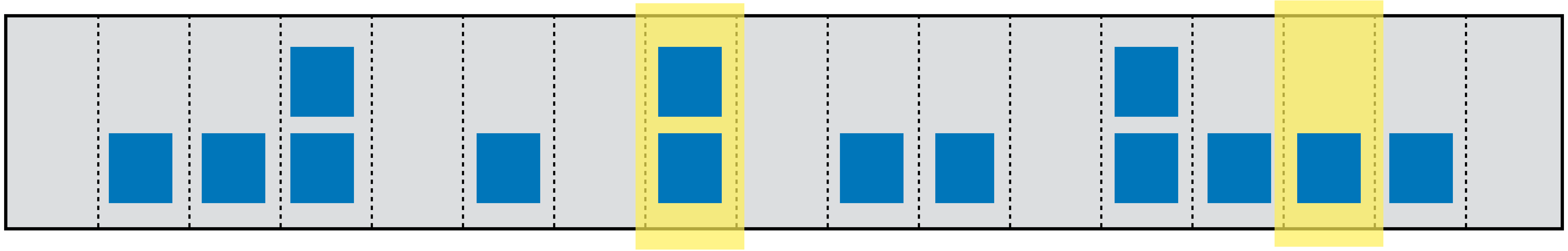

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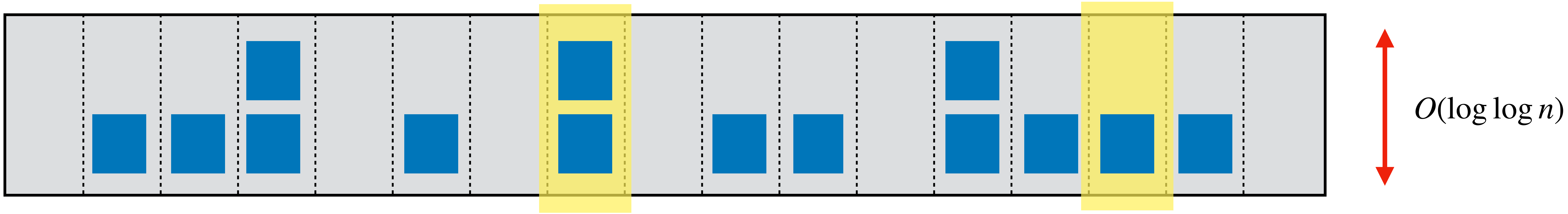

Weighted Two-Choice

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- **Layered2C: modify comparison**
  - behaves "almost" like standard two-choice
  - no distributional assumption or presorting
  - Tight upper bound *U*
- **LayeredSSE:** DSSE with $\tilde{O}(\log \log N/p)$ page efficiency

Generic Local Transform

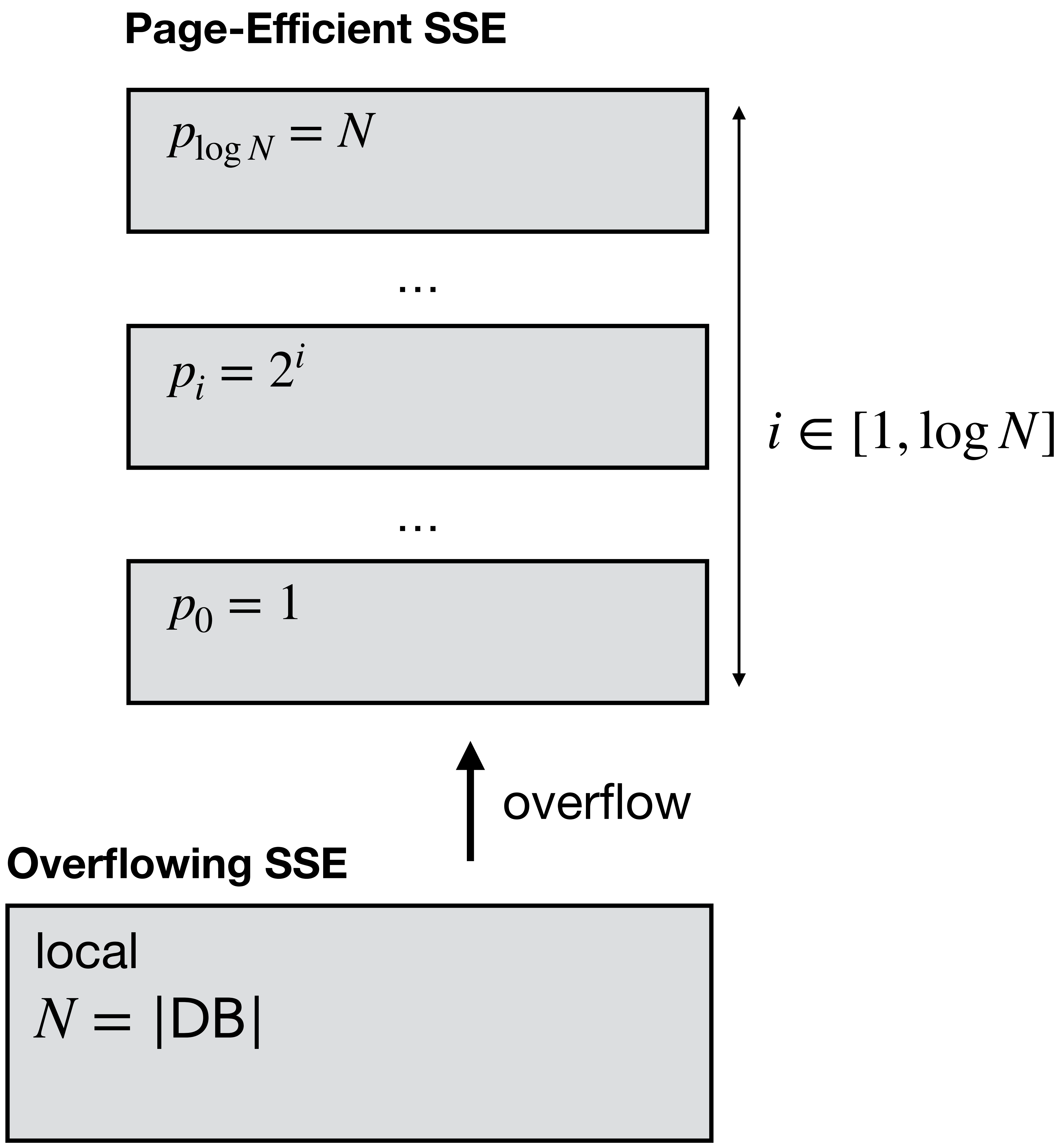
Page-Efficient DSSE → Local DSSE

Overflowing SSE:

- local SSE with **overflow**
- instantiation: variant of 2D-1C [ANSS16]

Page-Efficient SSE:

- deals with overflowing items
- instantiation: LayeredSSE



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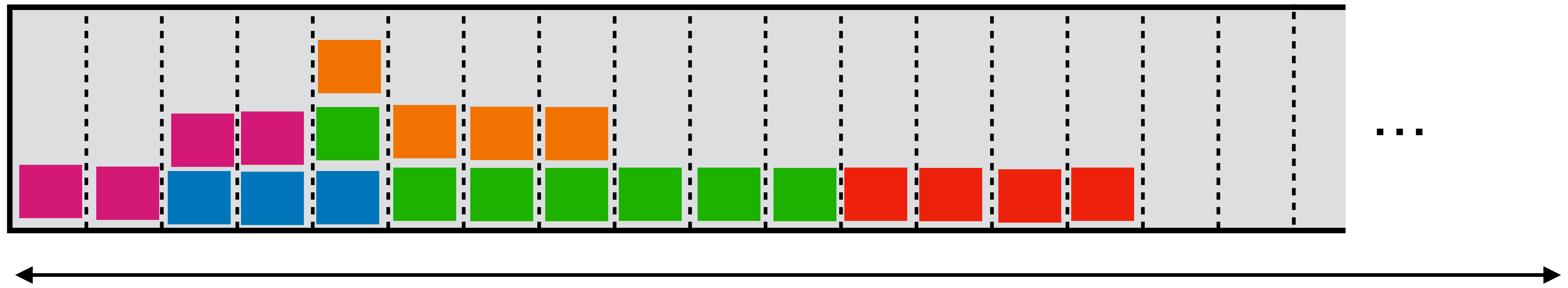
Overflowing SSE: 2D-1C [ANSS16] with cut-off



$O(N/\log\log N)$

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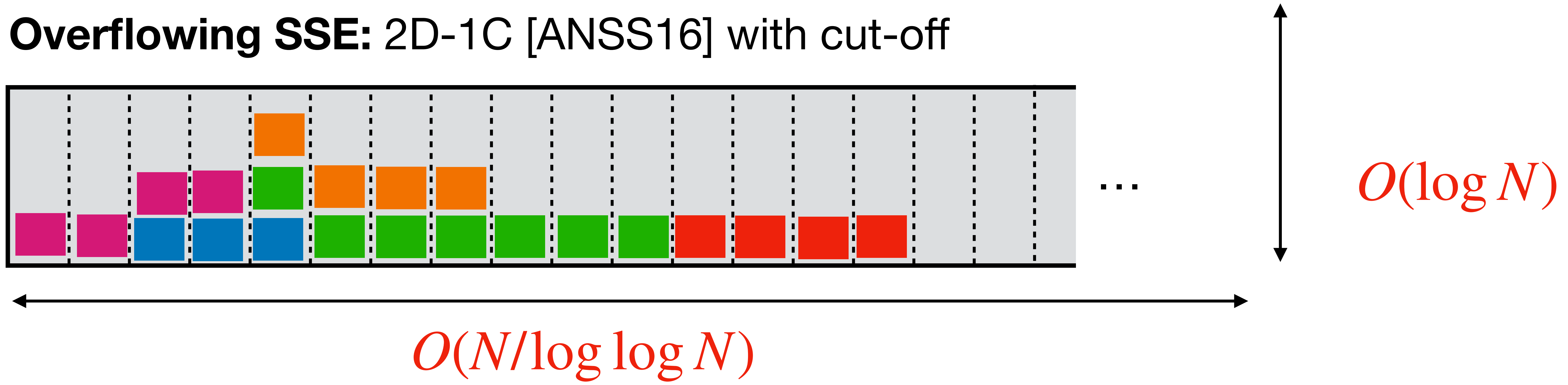

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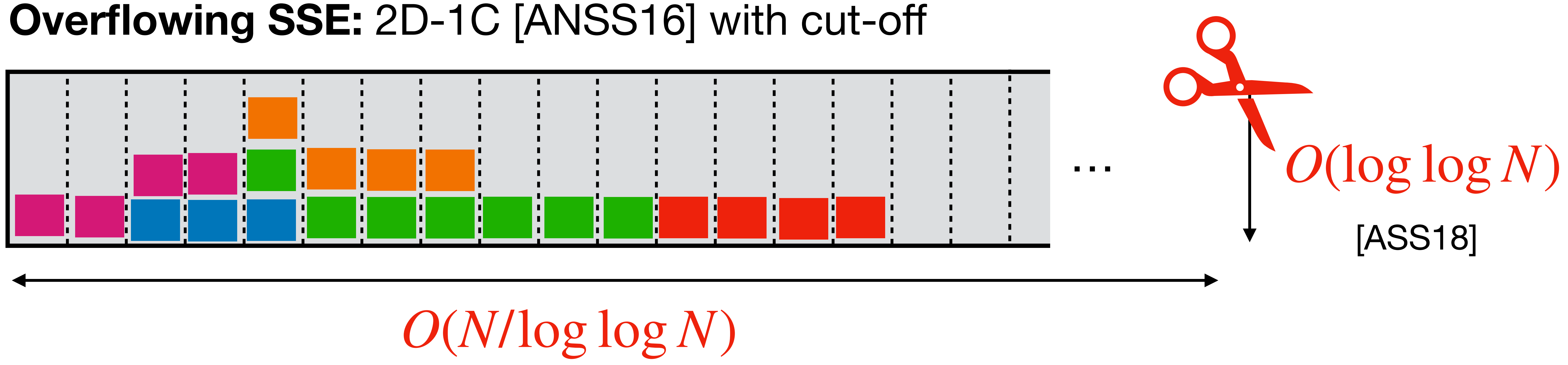

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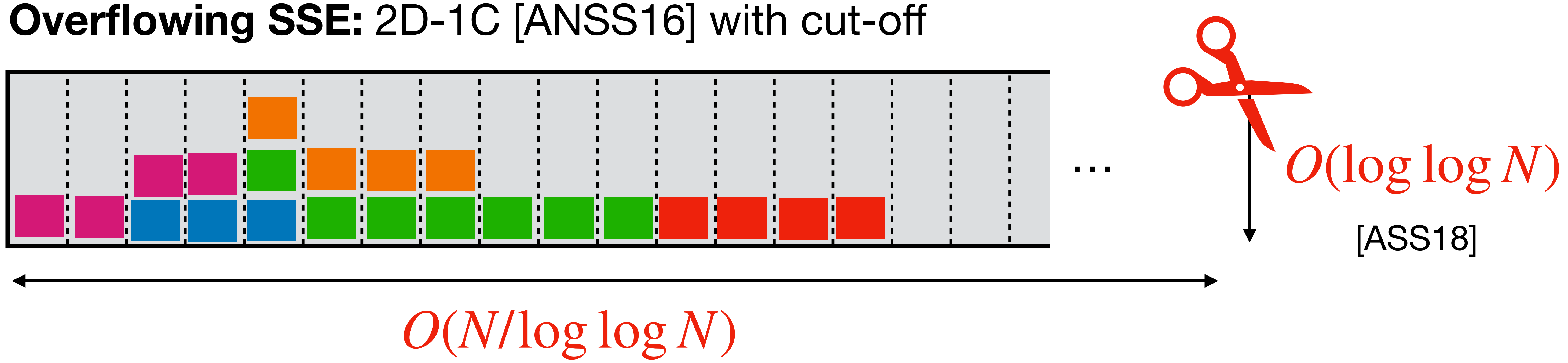
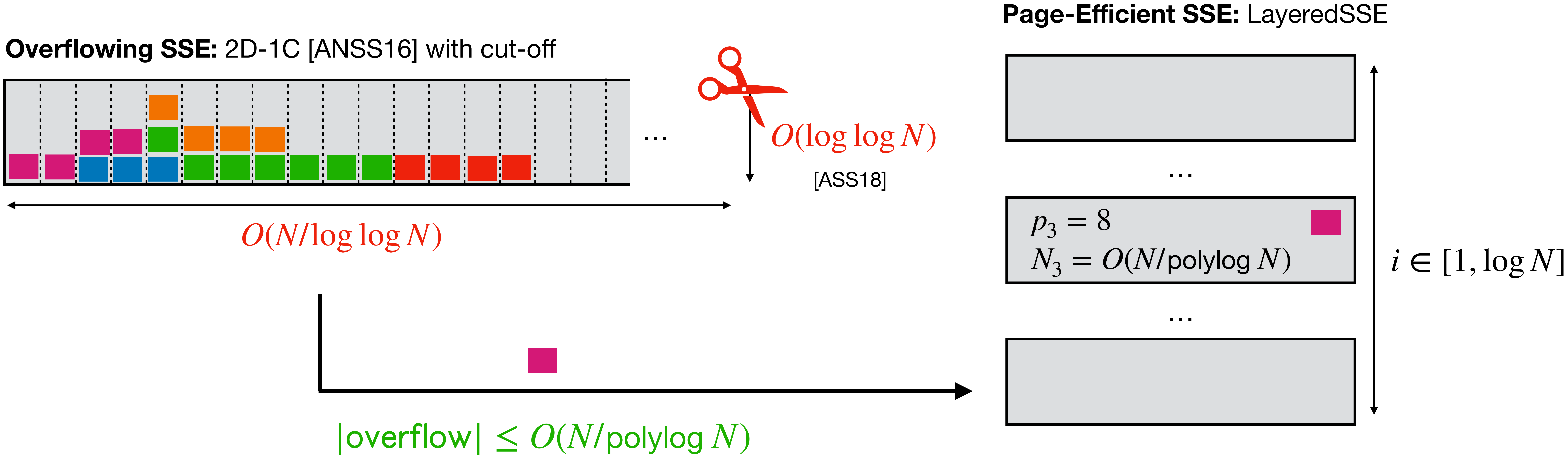


$|\text{overflow}| \leq O(N/\text{polylog } N)$

Generic Local Transform

Instantiation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Page-Efficient SSE: LayeredSSE
…
$p_3 = 8$
$N_3 = O(N/\text{polylog } N)$
…
$i \in [1, \log N]$

Generic Local Transform

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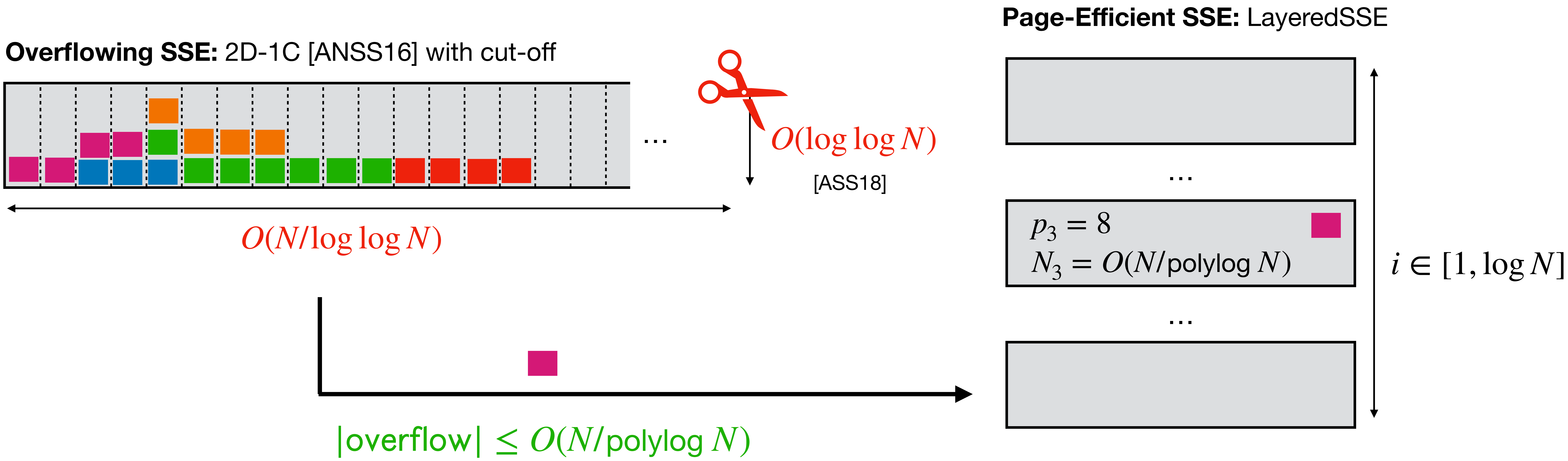

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Page-Efficient SSE: LayeredSSE

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$\tilde{O}(\log \log N)$ read efficiency *

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Unconditional Local SSE

- **Goal:** unconditional SSE
- **State of the art:** $O(\log^{2/3+\varepsilon} N)$ read efficiency [DPP18]

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Remove bottleneck from [DPP18] via GLT:

1. Generalize the local ORAM of [DPP18]
2. Handle lists with different sizes via different SSE schemes
    - Small, Medium, Large, Huge

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$O(\log^{\varepsilon} N)$ read efficiency

Recap

- Weighted 2C variant
- First dynamic memory-efficient schemes
- New connection between locality and page efficiency
- Best “unconditional” scheme

Open Problems

- Analysis of “pure” weighted 2C
- Forward secure memory-efficient SSE
- Lower bounds?