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Information Retrieval

Document Indexing

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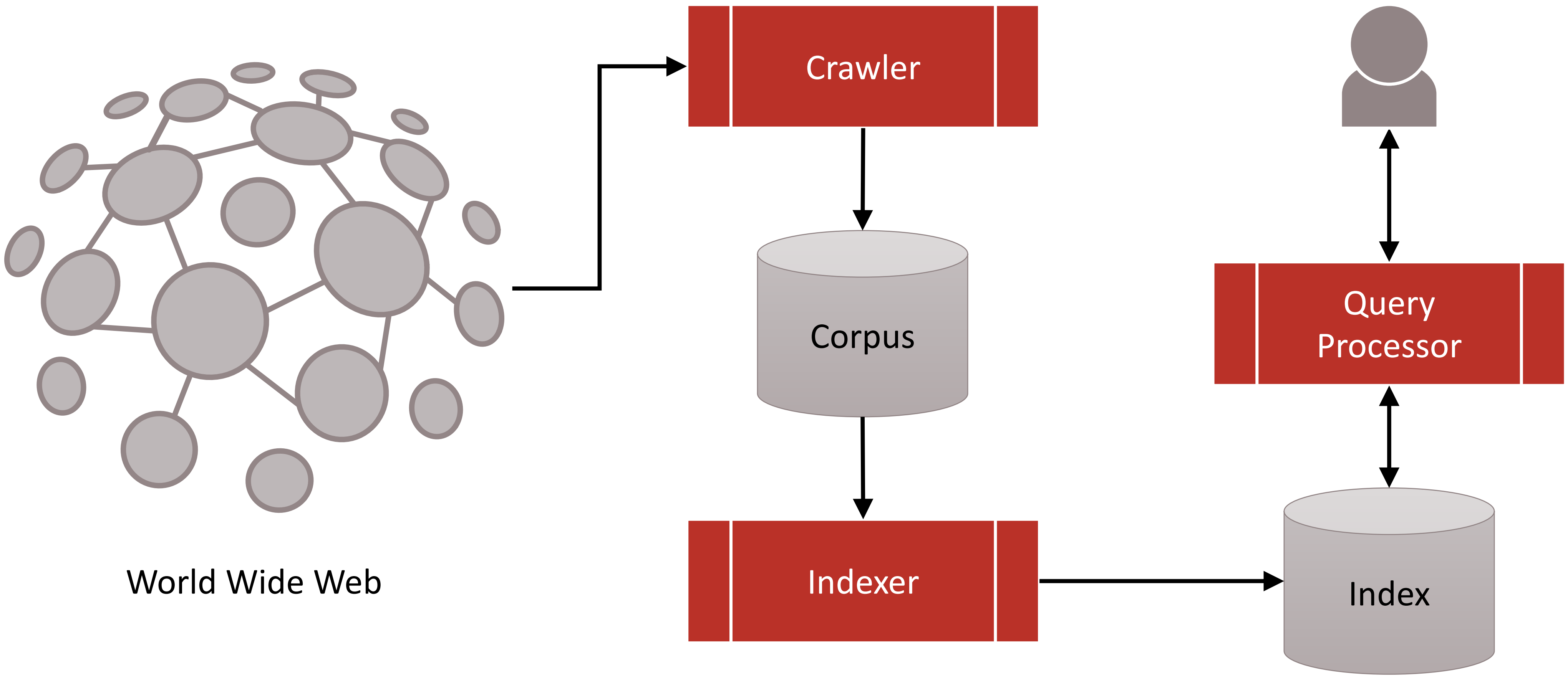
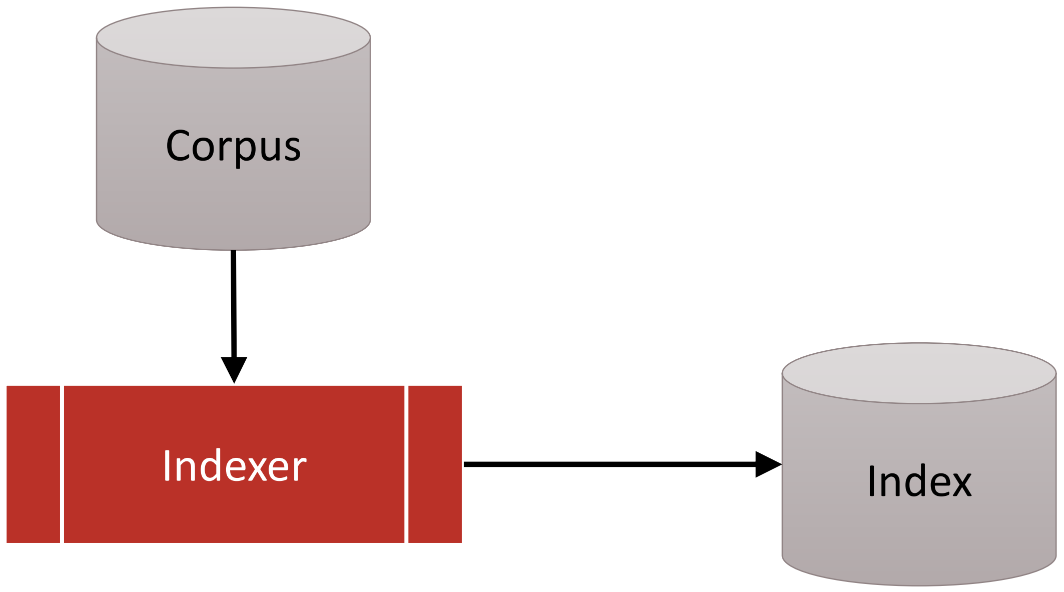
Search components



Search components



Key challenges

Support effective retrieval

- Extract meaningful document features
- Both topical and quality features

Support efficient retrieval

- Quick scoring of matched documents

Success metrics

Quality metrics

- Content utility: fraction of spam, exact/near dups
- Effectiveness: measured at ranking time

Performance metrics

- Compactness: size of the index in bytes
- Deployment cost: time to build / update index

Document prefiltering

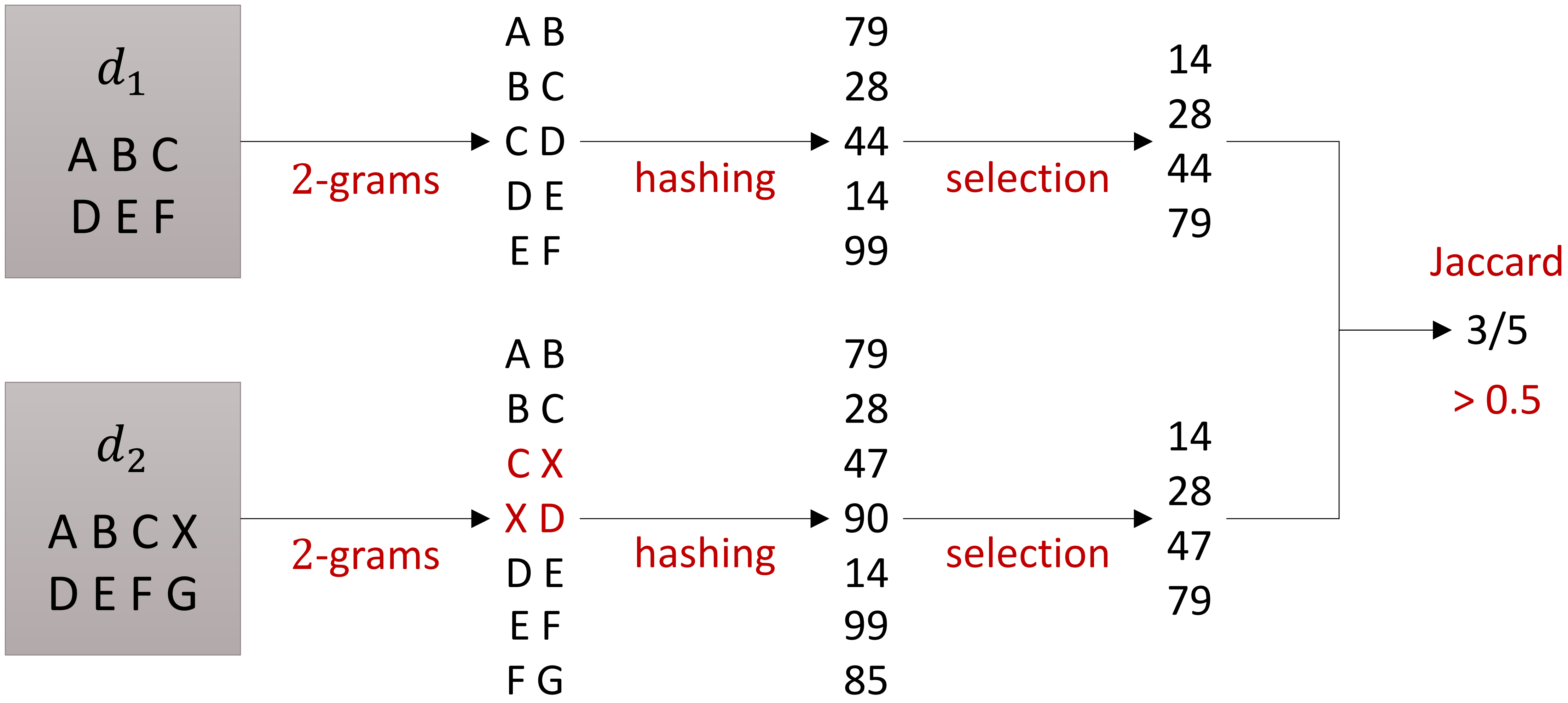
Detecting spam documents

- Term spamming → text classification
- Link spamming → trust propagation

Detecting documents with duplicate content

- Exact duplicates → compare hash values
- Near duplicates → compare *shingles* instead

Near duplicates via n-shingling



Document features

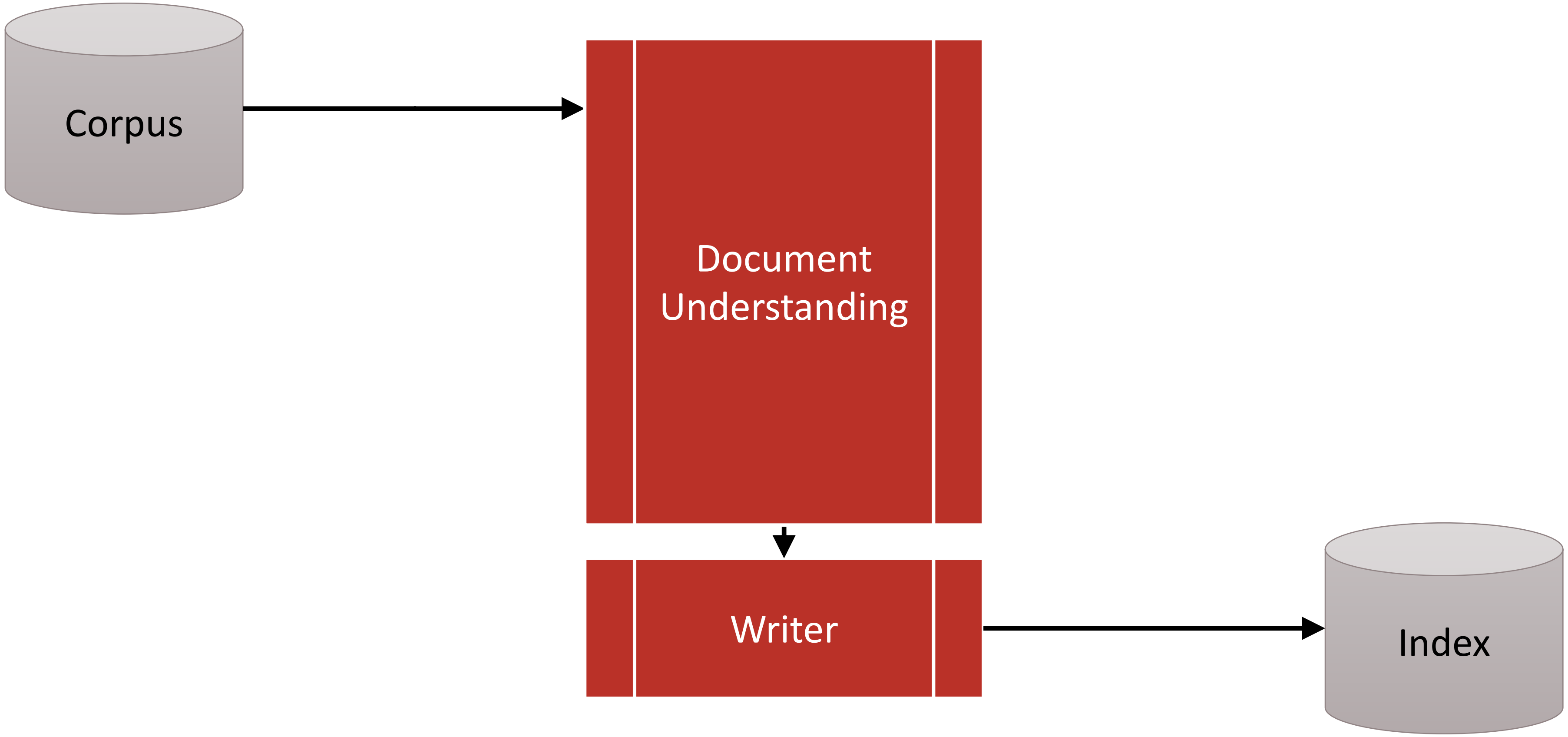
Features computed offline

- Content: spam score, domain quality score
- Web graph: PageRank, HostRank
- Usage: click count, CTR, dwell time

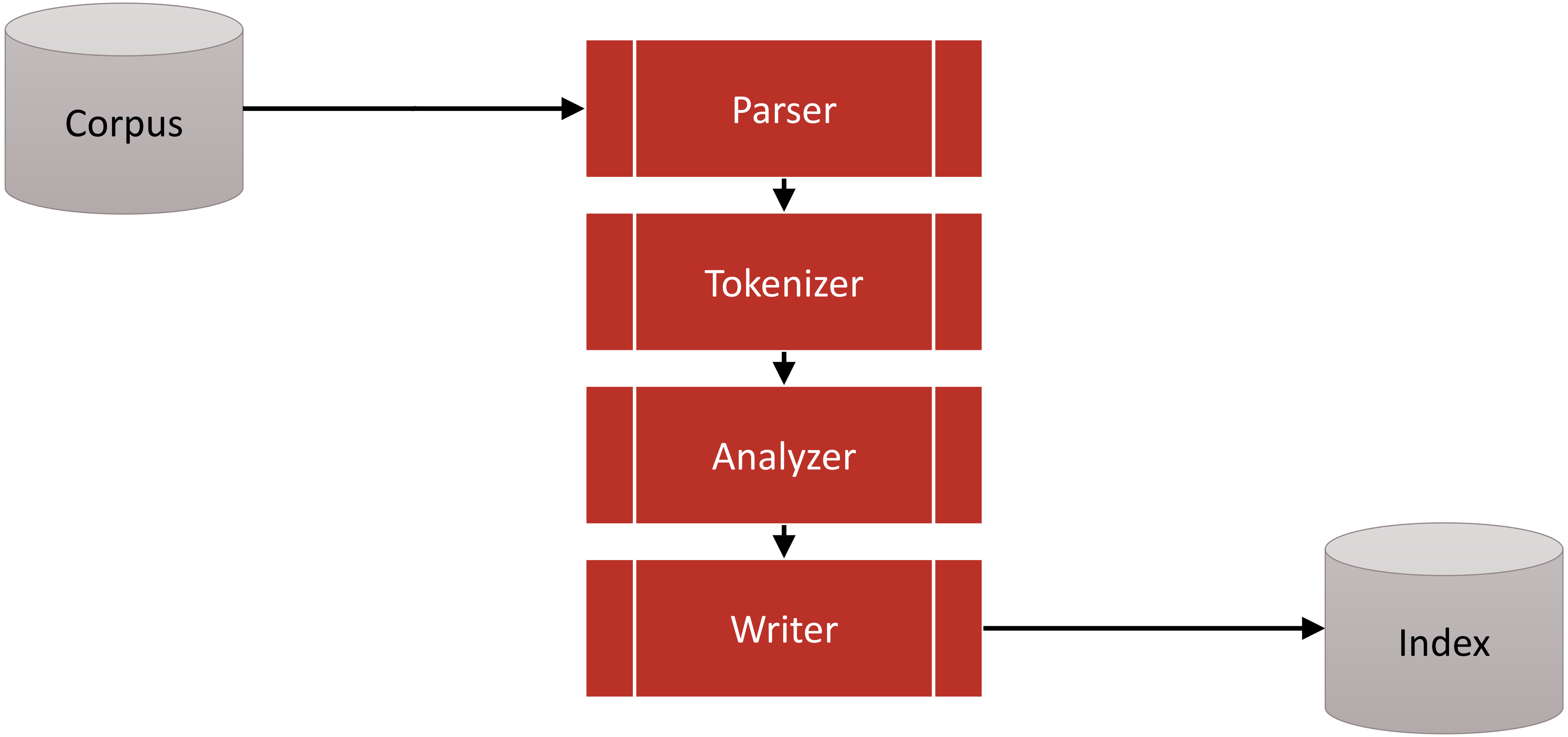
Features computed online

- Query-document similarity: TF-IDF, BM25, etc.

Indexing overview



Indexing overview



Document understanding

Parsing + tokenization

- Turn raw text into indexing terms

Token analysis

- Discriminative power
- Equivalence classing
- Phrasing, scoping

Document indexing

Indexing makes crawled documents searchable

- Efficient searching requires appropriate structures

Abandoned indexing data structures

- Suffix arrays, signature files

Currently used data structure

- Inverted index

Example “corpus”

d_1	Tropical fish include fish found in tropical environments around the world, including both freshwater and salt water species.
d_2	Fish keepers often use the term tropical fish to refer only those requiring fresh water, with saltwater tropical fish referred to as marine fish.
d_3	Tropical fish are popular aquarium fish, due to their often bright coloration.
d_4	In freshwater fish, this coloration typically derives from iridescence, while salt water fish are generally pigmented.

Incidence matrix

	d_1	d_2	d_3	d_4
and	■	□	□	□
aquarium	□	□	■	□
are	□	□	■	■
around	■	□	□	□
as	□	■	□	□
both	■	□	□	□
bright	□	□	■	□
coloration	□	□	■	■
derives	□	□	□	■
due	□	□	■	□
environments	■	□	□	□
fish	■	■	■	■

Inverted index: incidence

and	1			
aquarium	3			
are	3	4		
around	1			
as	2			
both	1			
bright	3			
coloration	3	4		
derives	4			
due	3			
environments	1			
fish	1	2	3	4

Inverted index: frequency

and	1:1			
aquarium	3:1			
are	3:1	4:1		
around	1:1			
as	2:1			
both	1:1			
bright	3:1			
coloration	3:1	4:1		
derives	4:1			
due	3:1			
environments	1:1			
fish	1:2	2:3	3:2	4:2

Inverted index: additional info

Term positions

- Exact phrases vs. proximity search

Document structure

- Field restrictions (e.g., date:, from:)
- Some fields more important (e.g., title, h1)

Inverted list compression

Key observation

- Standard representation wasteful

fish | 1:2 | 2:3 | 3:2 | 4:2

docid: 00000000000000000000000000000001 (32 bits)
frequency: 00000000000000000000000000000010 (32 bits)
$=$ 64 bits per posting
$\times$ 4 postings
$=$ 256 bits

Inverted list compression

Basic idea

- Lossless representation using fewer bits
- Several approaches [Catena et al., ECIR 2014]

Key benefits

- Reduced space and network / disk transfer costs

Cost: decompression overhead

Example: unary encoding

Consider encoding $k = 5_{10}$

$$5_{10} = 00000000000000000000000000000101_2 \text{ (32 bits)}$$

Unary encoding of k

- Write k 0's followed by one 1

$$5_{10} = 000001_2 \text{ (6 bits)}$$

Example: gamma encoding

Consider encoding $k = 5_{10}$

$$5_{10} = 00000000000000000000000000000101_2 \text{ (32 bits)}$$

Gamma encoding of k

- Let $l = \lfloor \log_2 k \rfloor$ (# binary digits of k minus 1)
- Let r be the binary repr. of k less most significant bit
- Write $unary(l)$ followed by r

$5_{10} = 00101_2$ (5 bits)

How about $k = 1{,}000{,}000$?

Uncompressed representation

$$1\mathrm{M}_{10} = 00000000000011110100001001000000_2$$ (32 bits)

Unary encoding

$$1\mathrm{M}_{10} = 00000000000000000000\ldots01_2$$ (1M+1 bits)

Gamma encoding

$$1\mathrm{M}_{10} = 000000000000000000011110100001001000000_2$$

(39 bits)

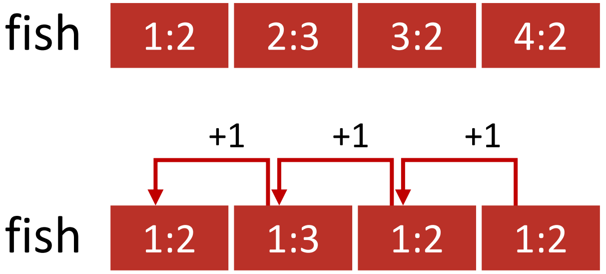
Inverted list compression

32 bit int cover -2,147,483,648 to +2,147,483,647

- Docids can get very large (~100B)

Large numbers require more bits

- Store delta gaps instead



Document identifier reordering

Goal: reassign document identifiers so that we obtain many small d-gaps, facilitating compression

old lists:	L1: 1 3 6 8 9	L2: 2 4 5 6 9	L3: 3 6 7 9
mapping:	1→1 2→9 3→2 4→7 5→8 6→3 7→5 8→6 9→4		
new lists:	L1: 1 2 3 4 6	L2: 3 4 7 8 9	L3: 2 3 4 5
old d-gaps:	2 3 2 1	2 1 1 3	3 1 2
new d-gaps:	1 1 1 2	1 3 1 1	1 1 1

Document identifier reordering

Key idea: assign similar documents close docids

- A term in one doc will likely be in similar docs

Clustering similar documents

- Assigns nearby IDs to documents in the same cluster

Sorting URLs alphabetically

- Pages from same site have high textual overlap

Index construction

```
function index(corpus)
  index = map()
  did = 0
  for document in corpus
    did += 1
    for (term, tf) in tokenize(document)
      if term not in index.keys()
         index[term] = list()
      index[term].append((did, tf))
  return index
```

Index construction

Equivalent to computing the transpose of a matrix

- Parse direct (document-term) occurrences
- Write out inverted (term-document) occurrences

Trivial in-memory implementation

- Does not scale even for moderately sized corpora
- On-disk processing typically needed

External indexing

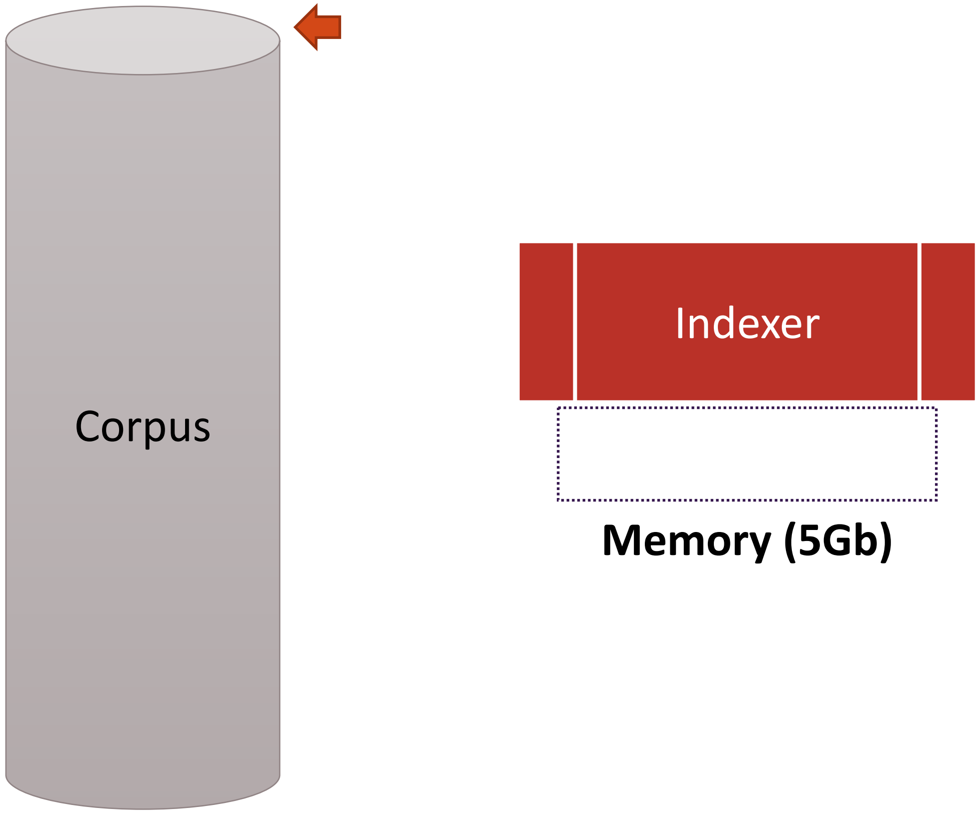
Merging addresses limited memory problem

- Build the inverted list structure until memory runs out
- Write partial index to disk, start making a new one

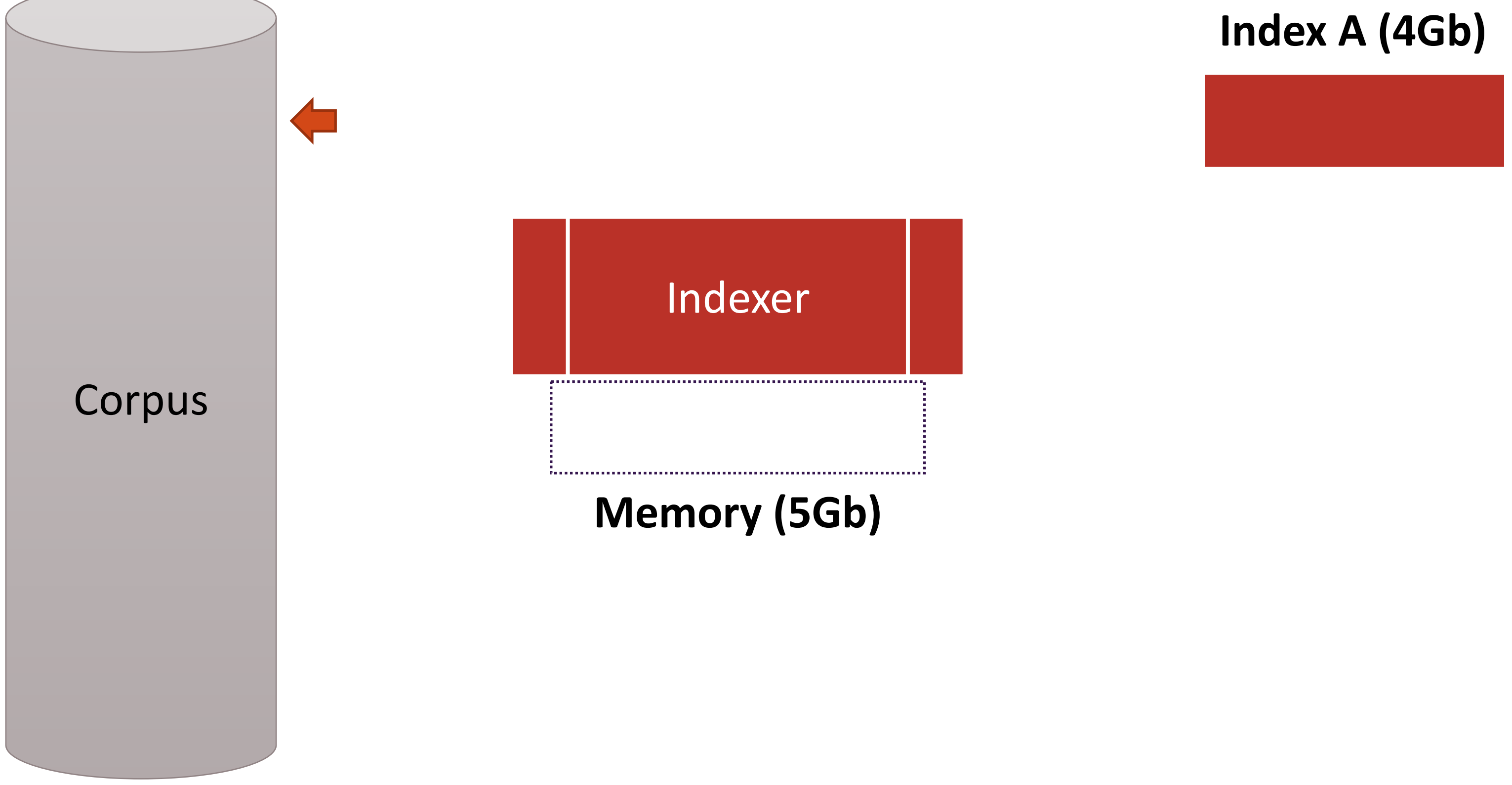
At the end of this process

- Merge many partial indexes in memory
- Equivalent to an external mergesort

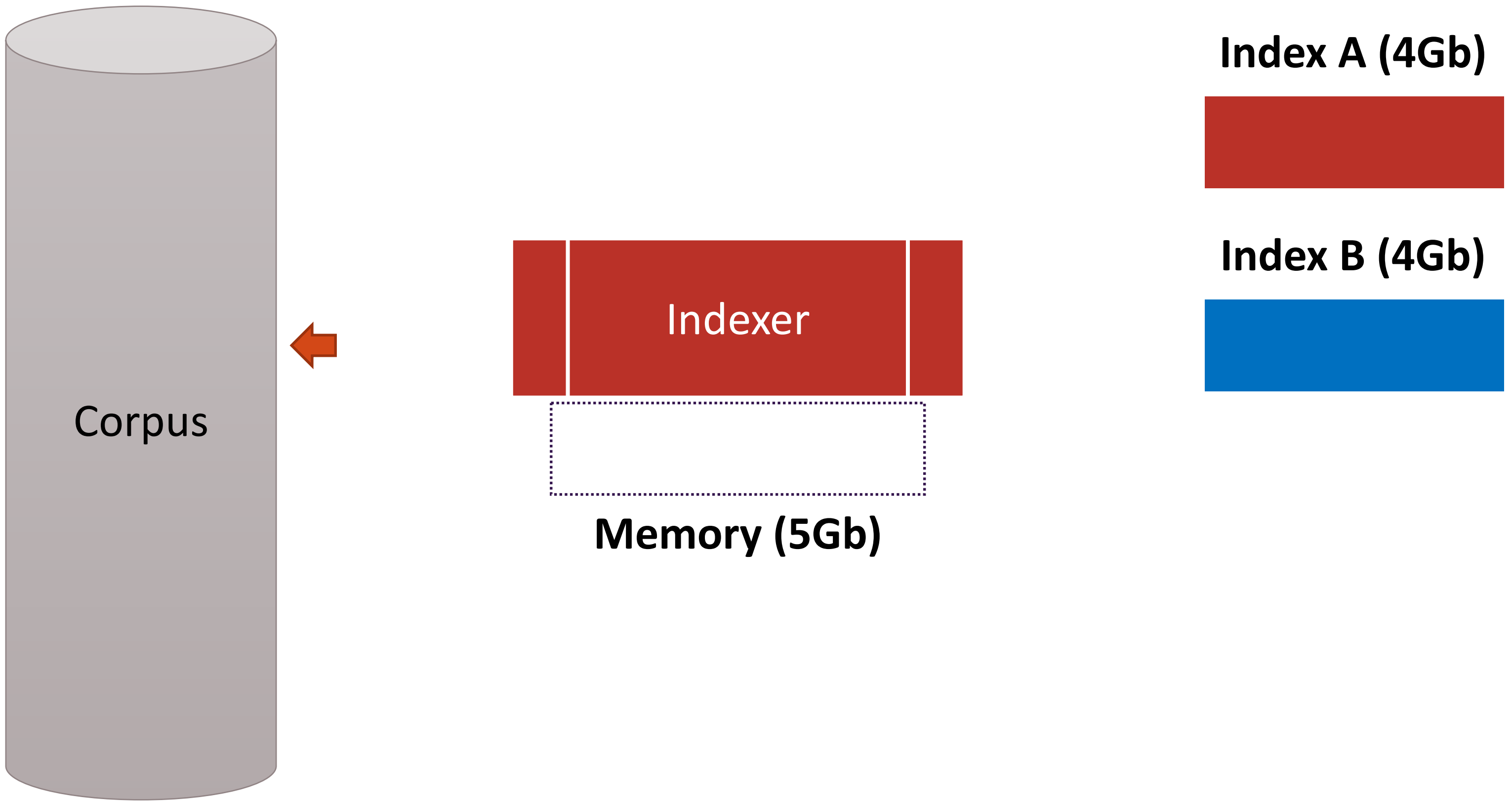
External indexing



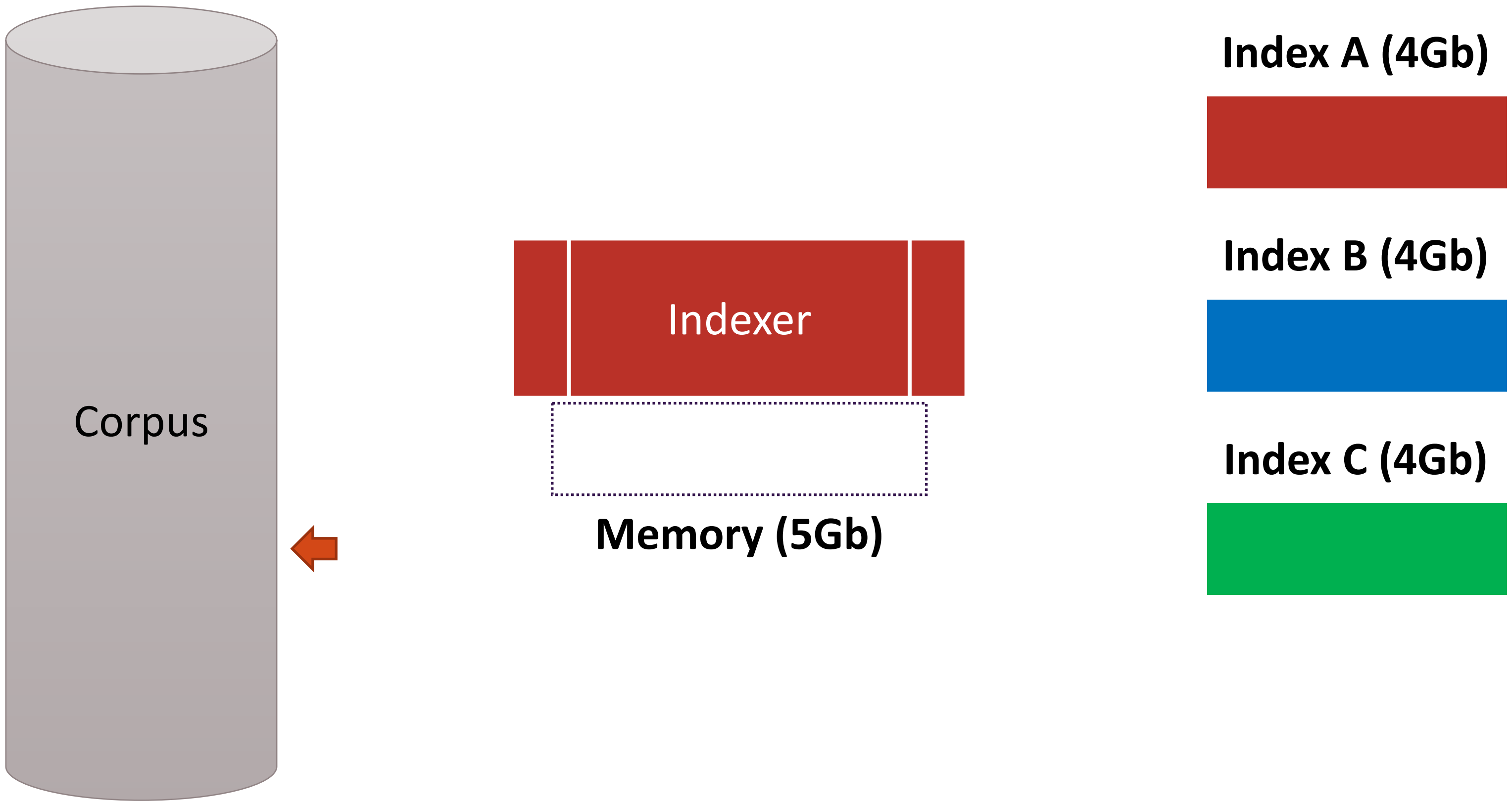
External indexing



External indexing



External indexing



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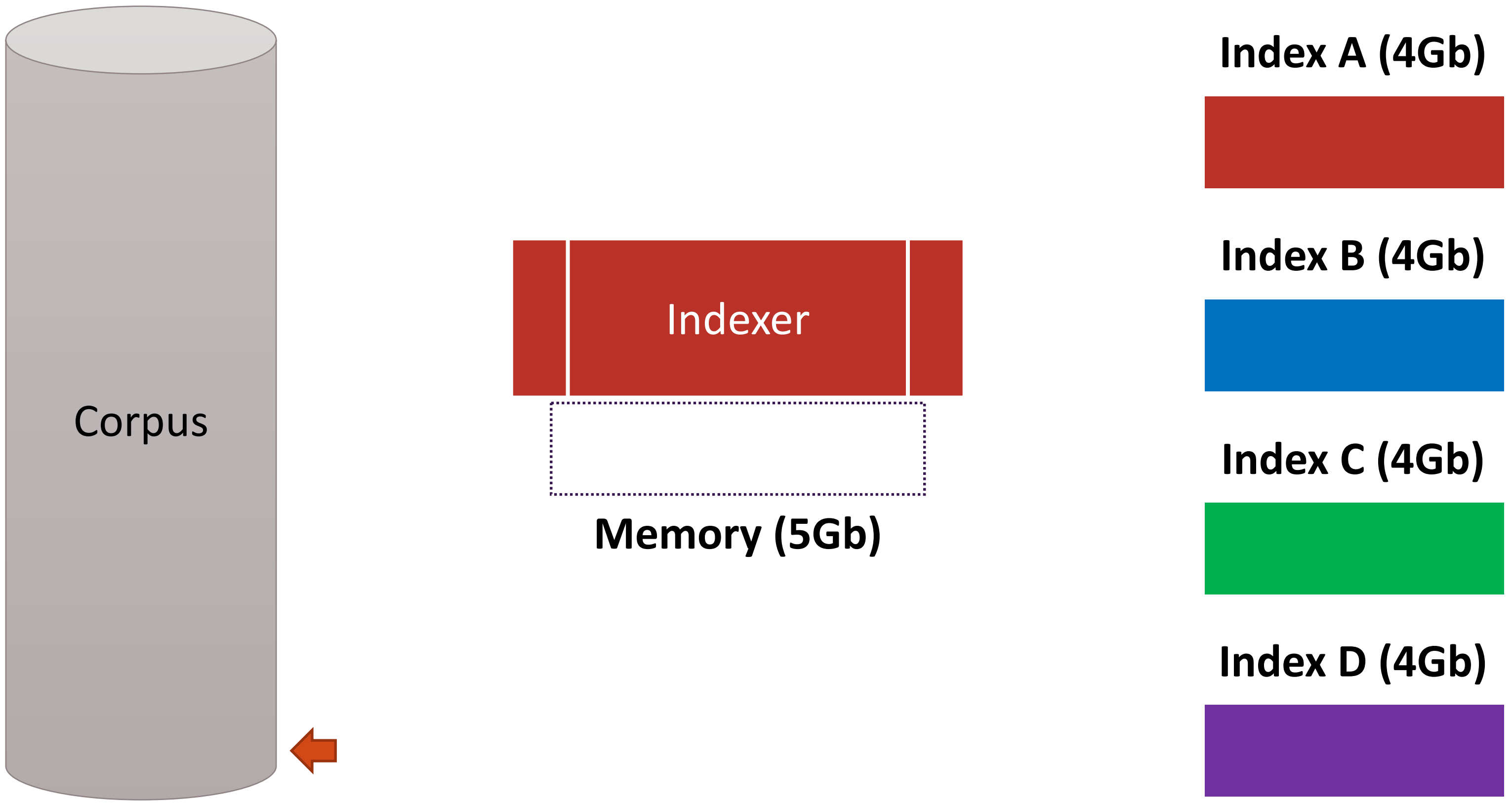
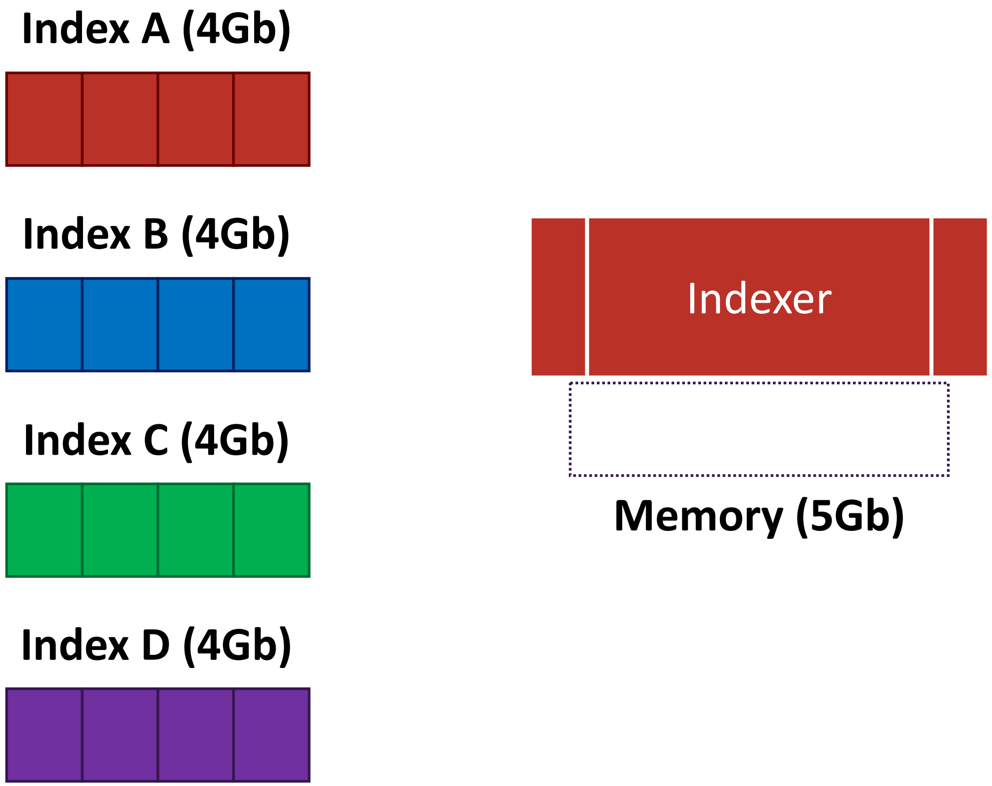


External merging



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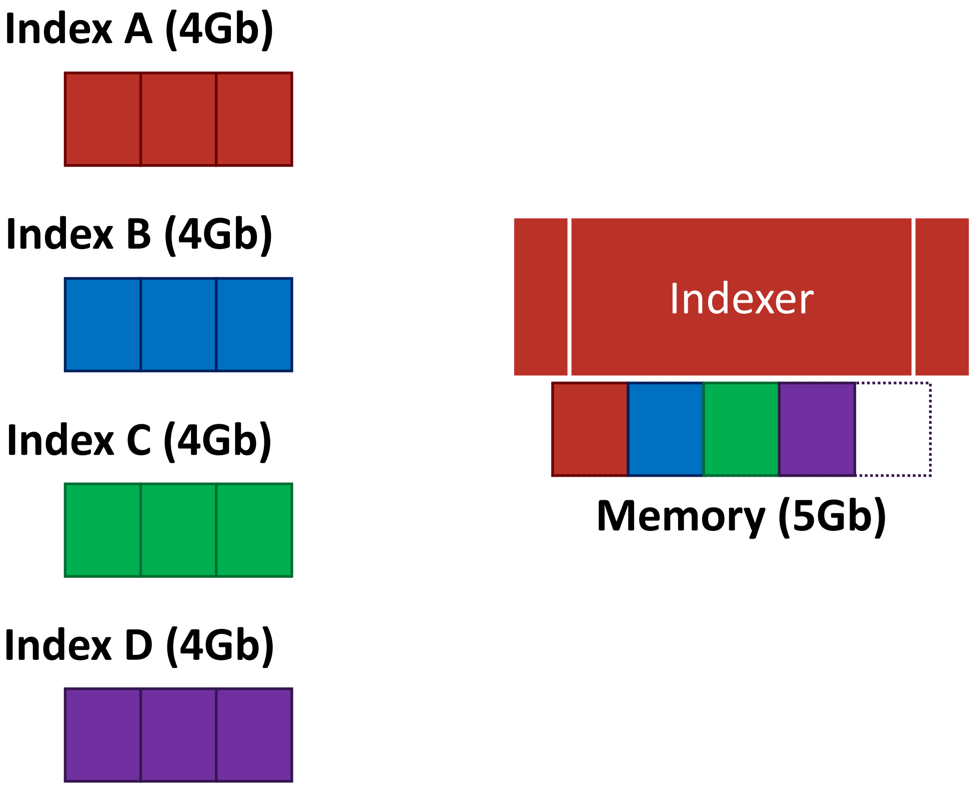
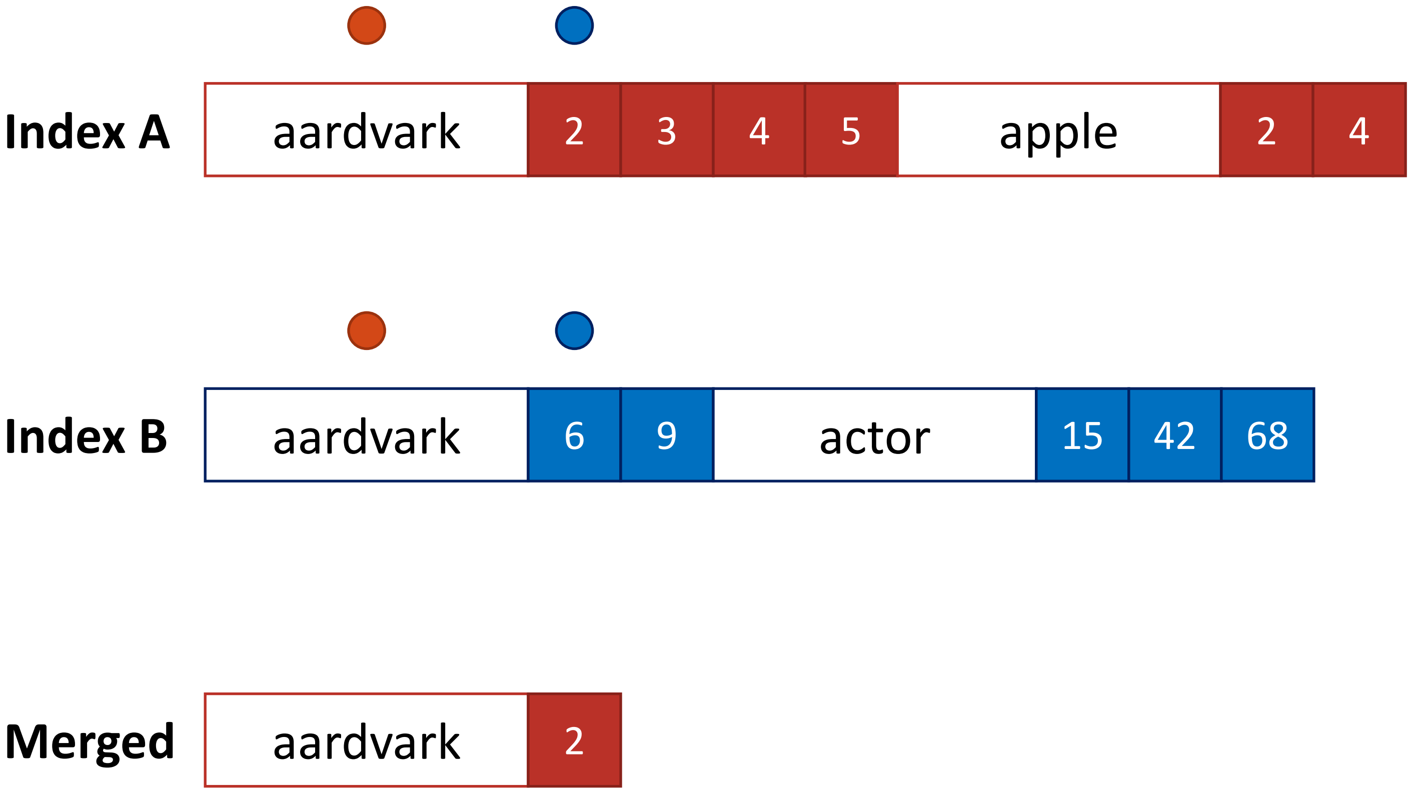


Internal merging



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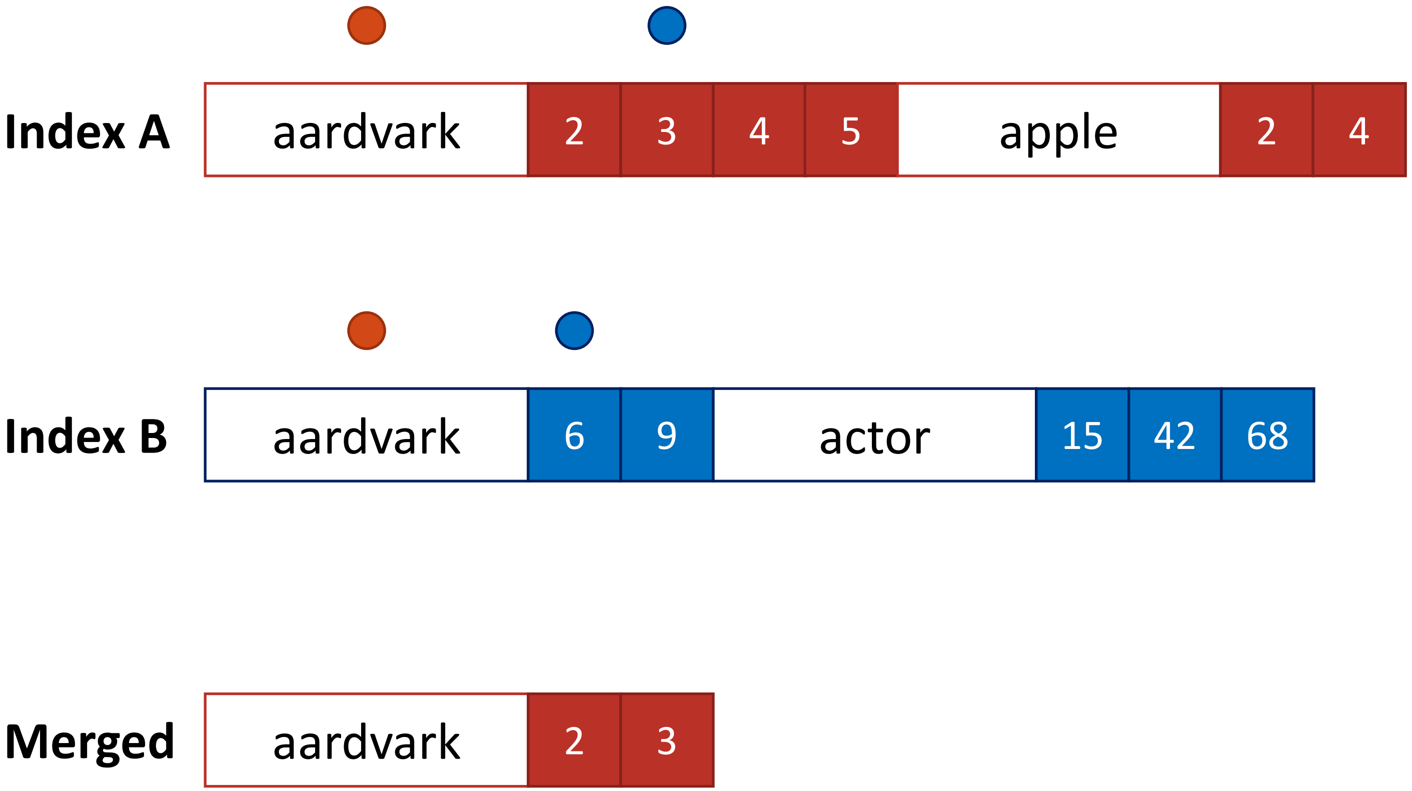

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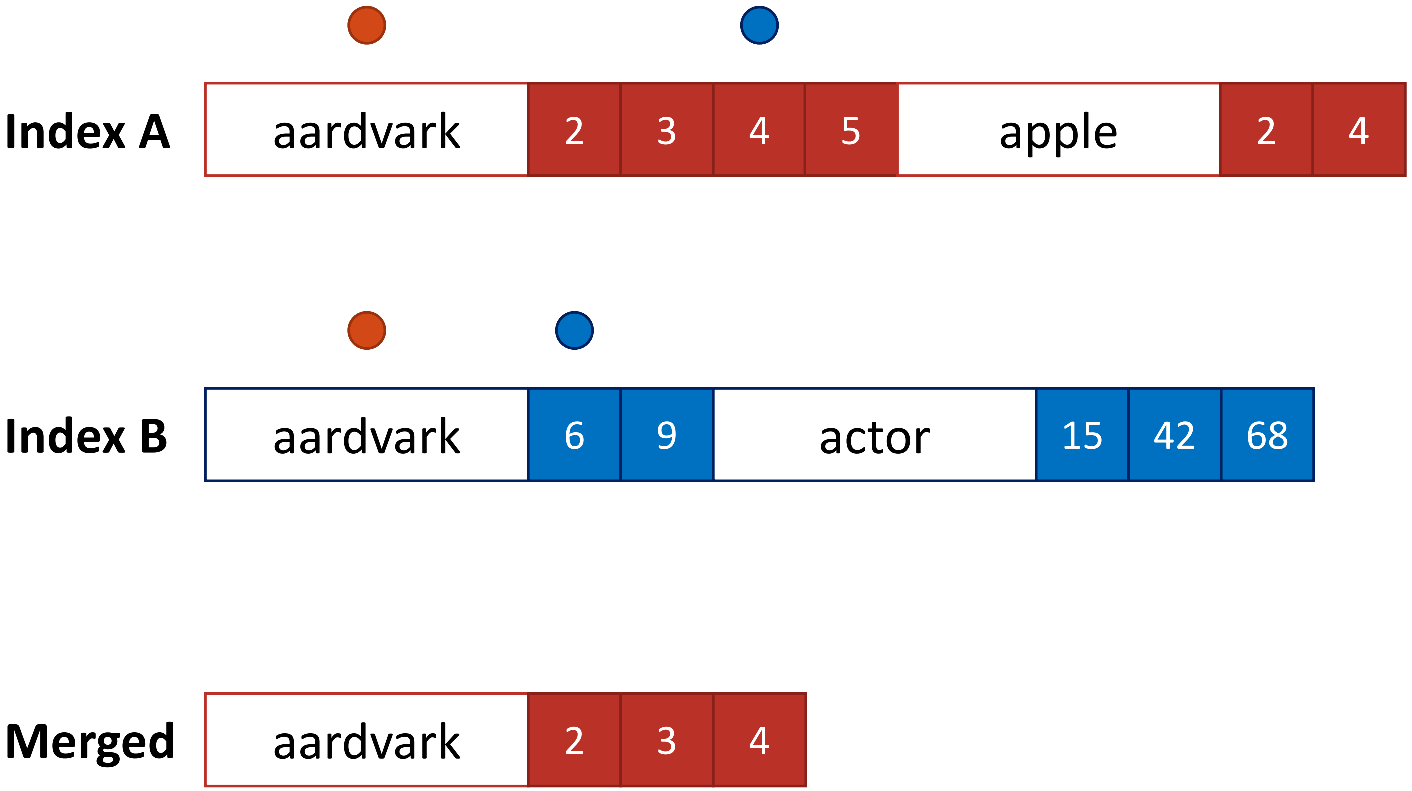

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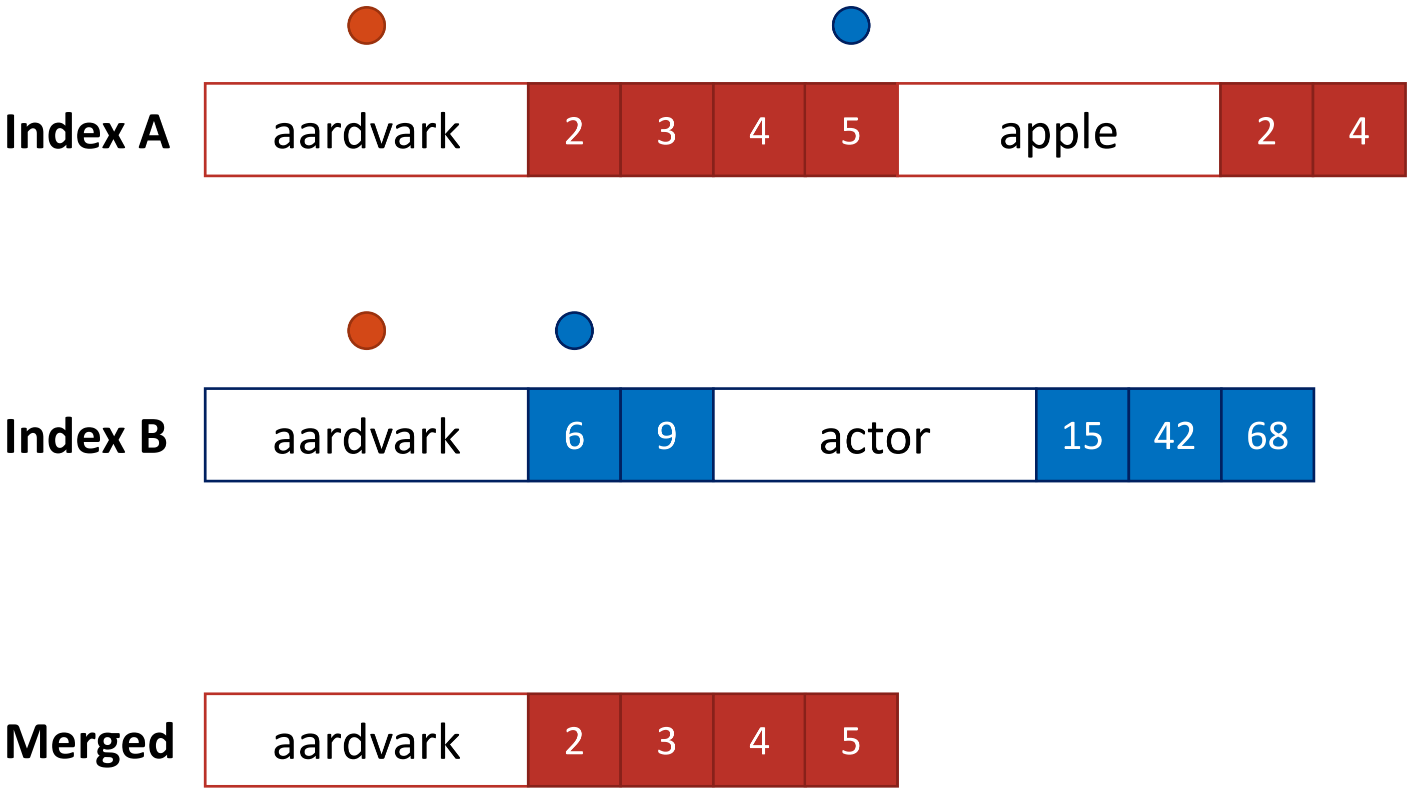

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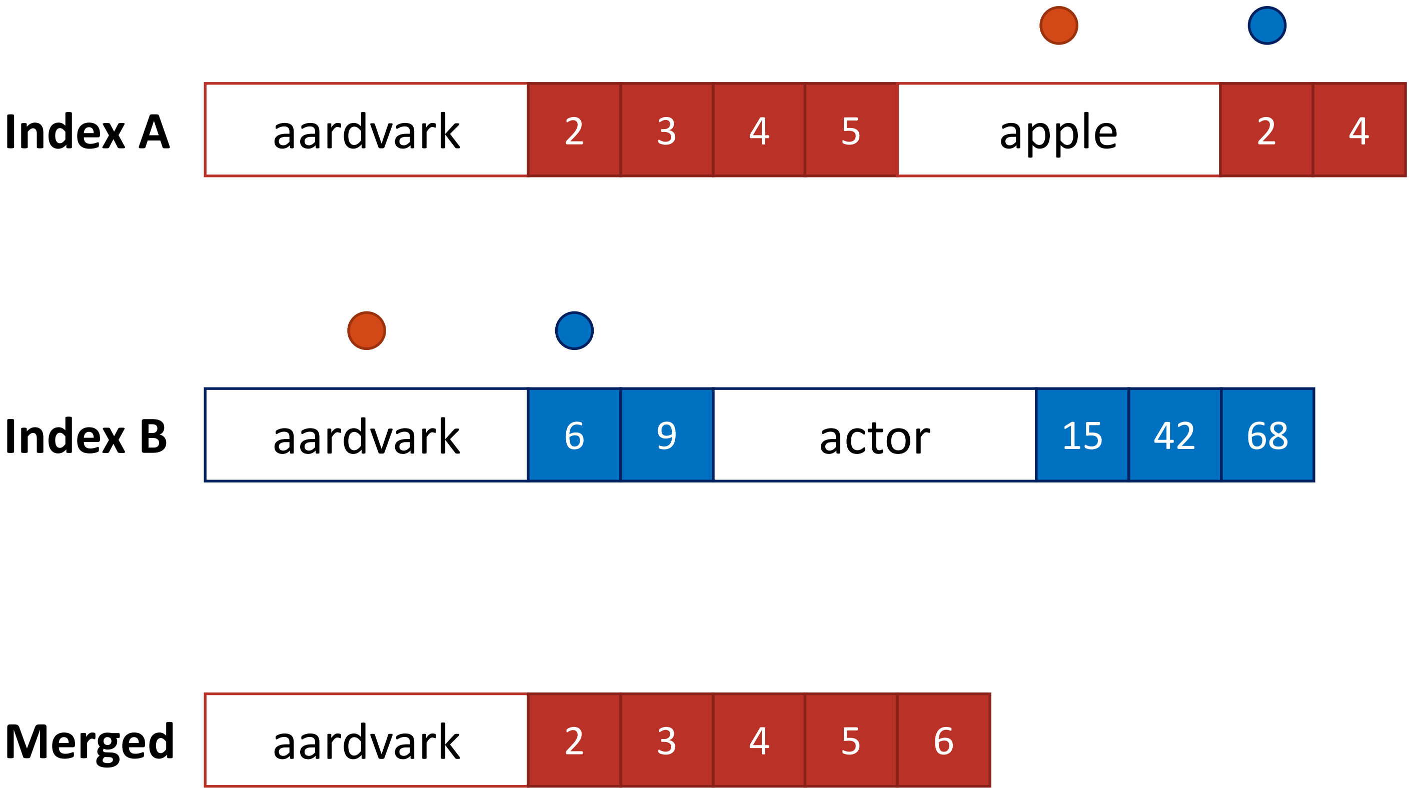

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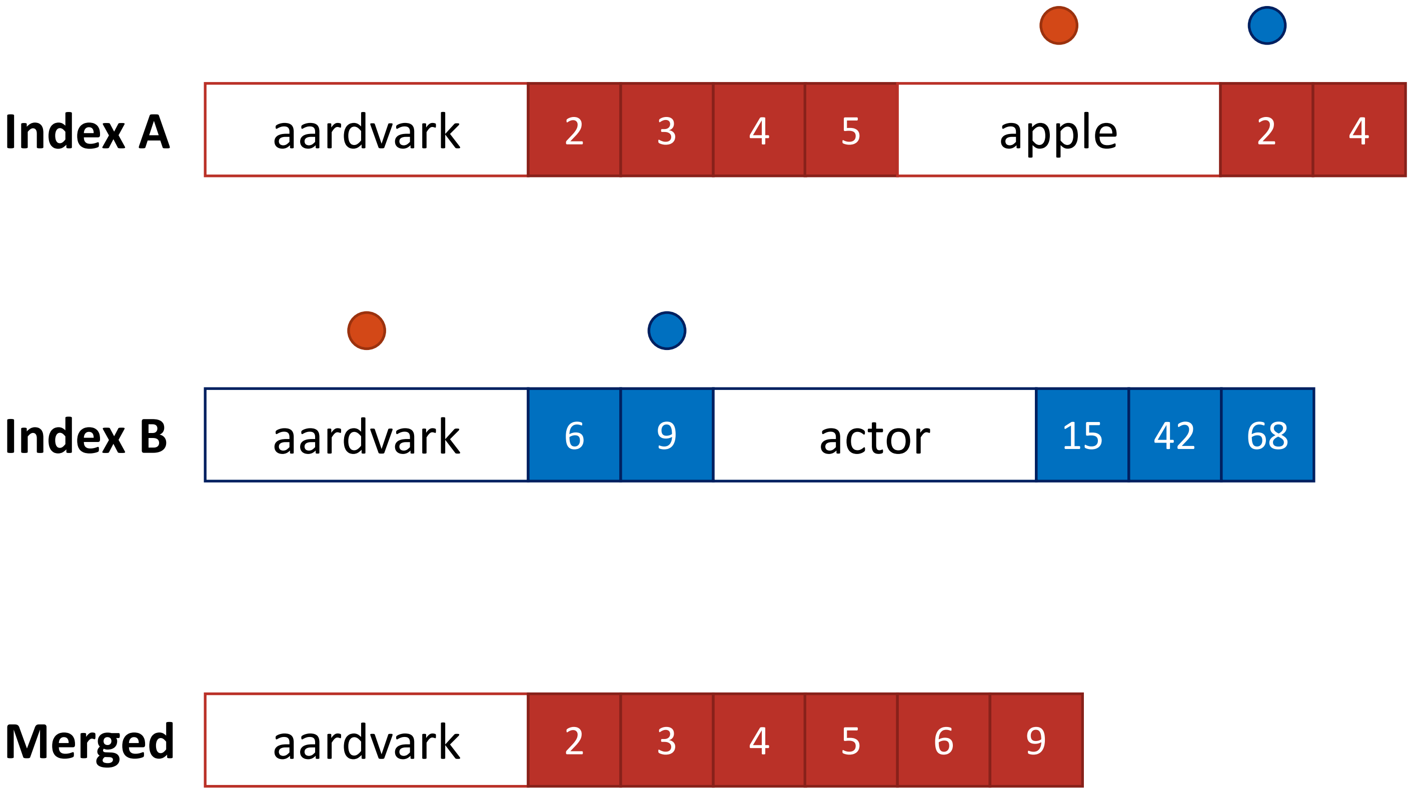

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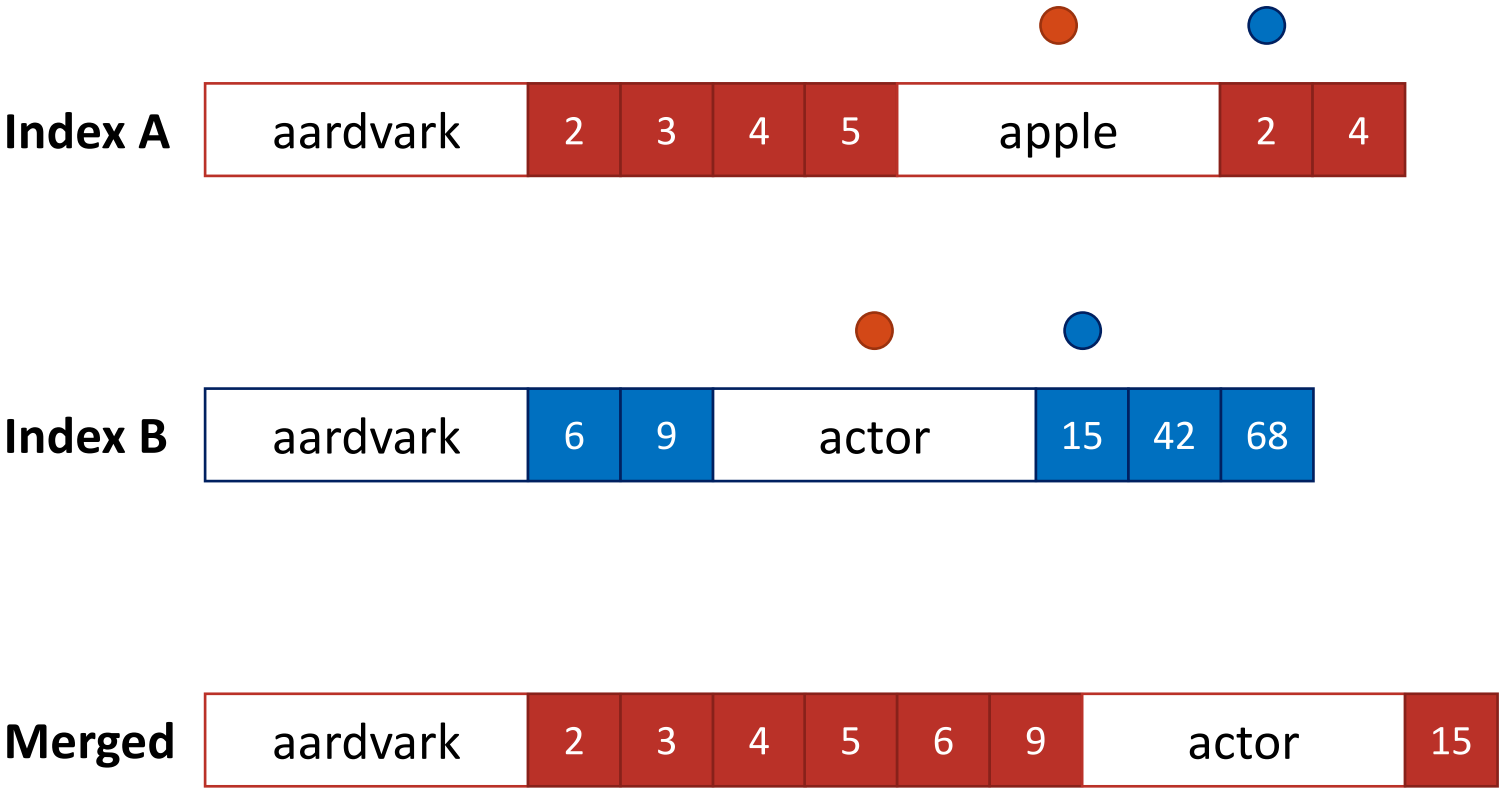

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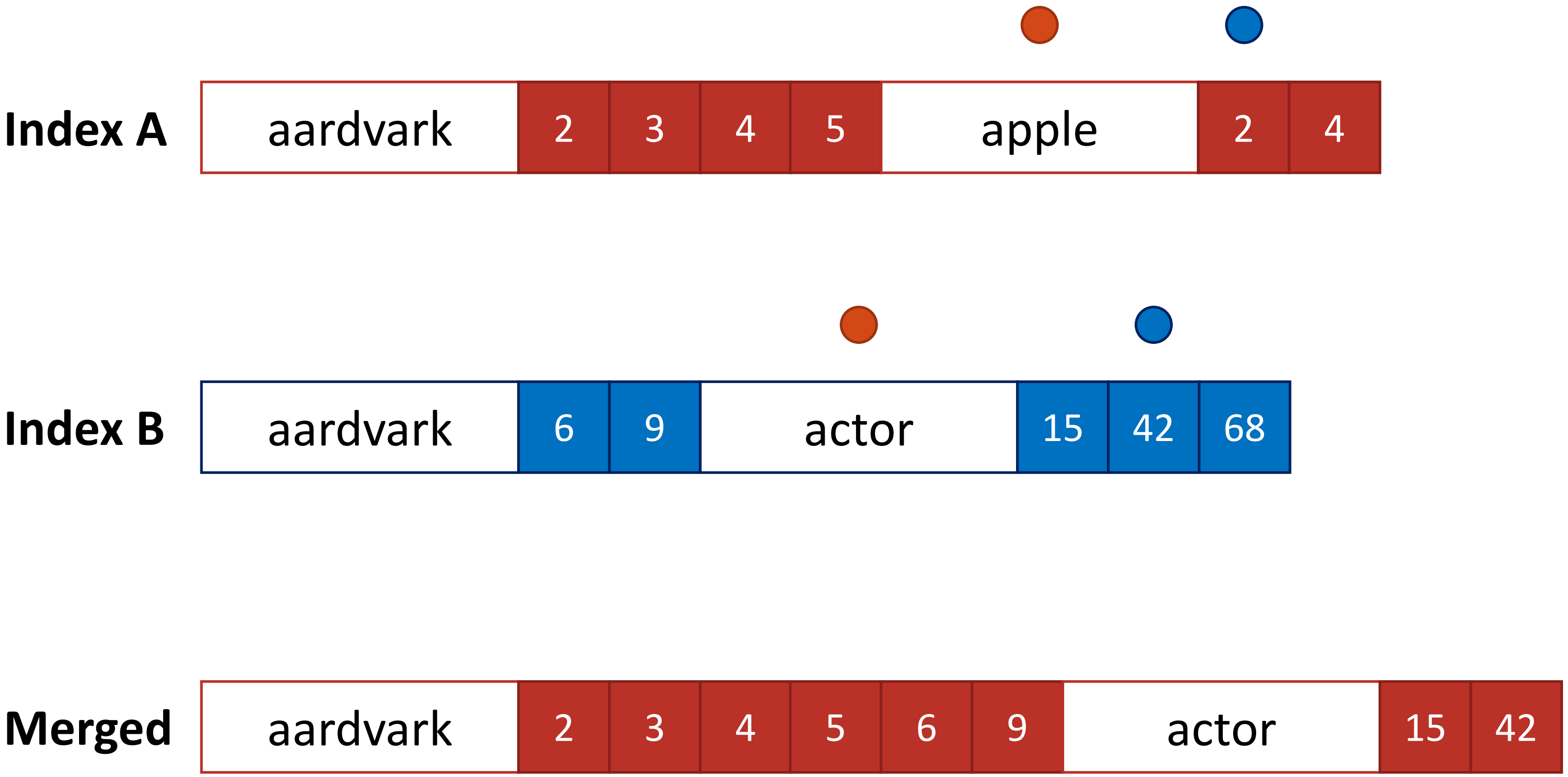

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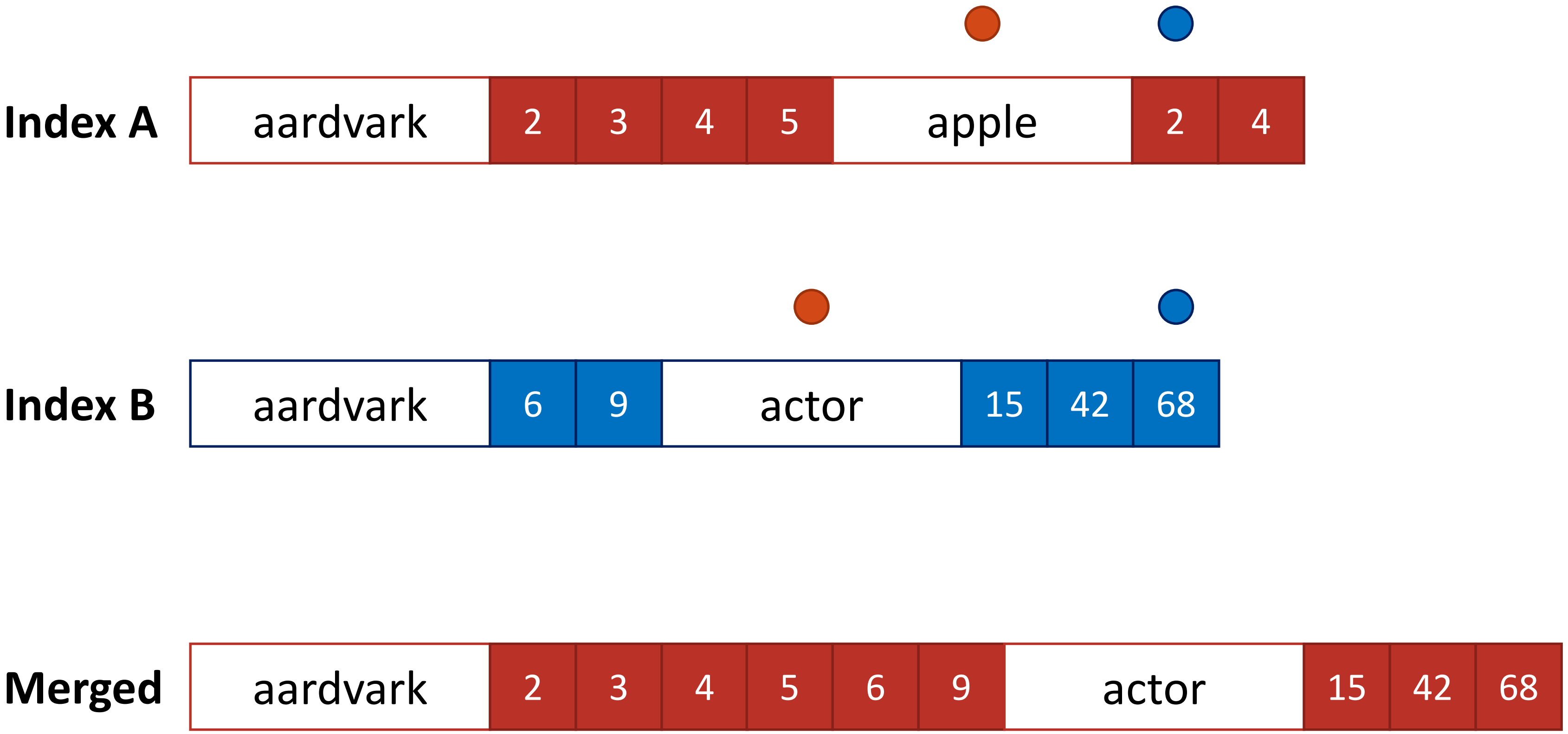

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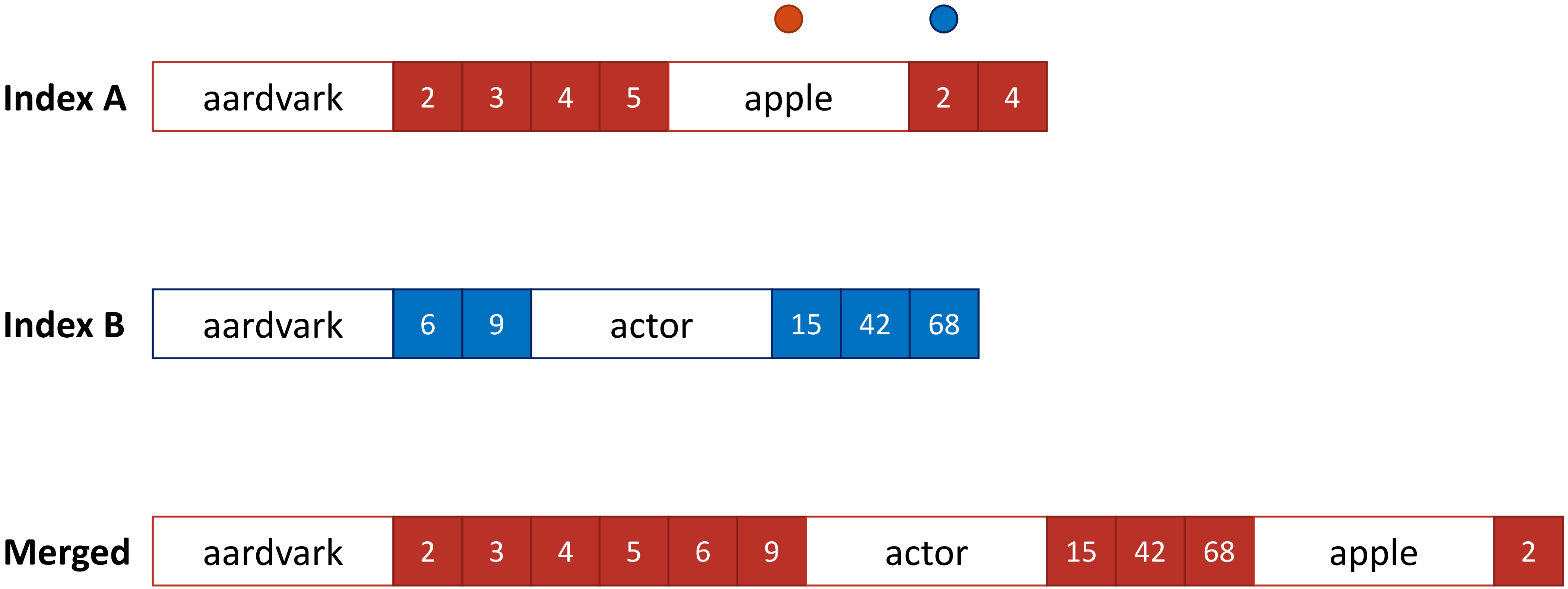

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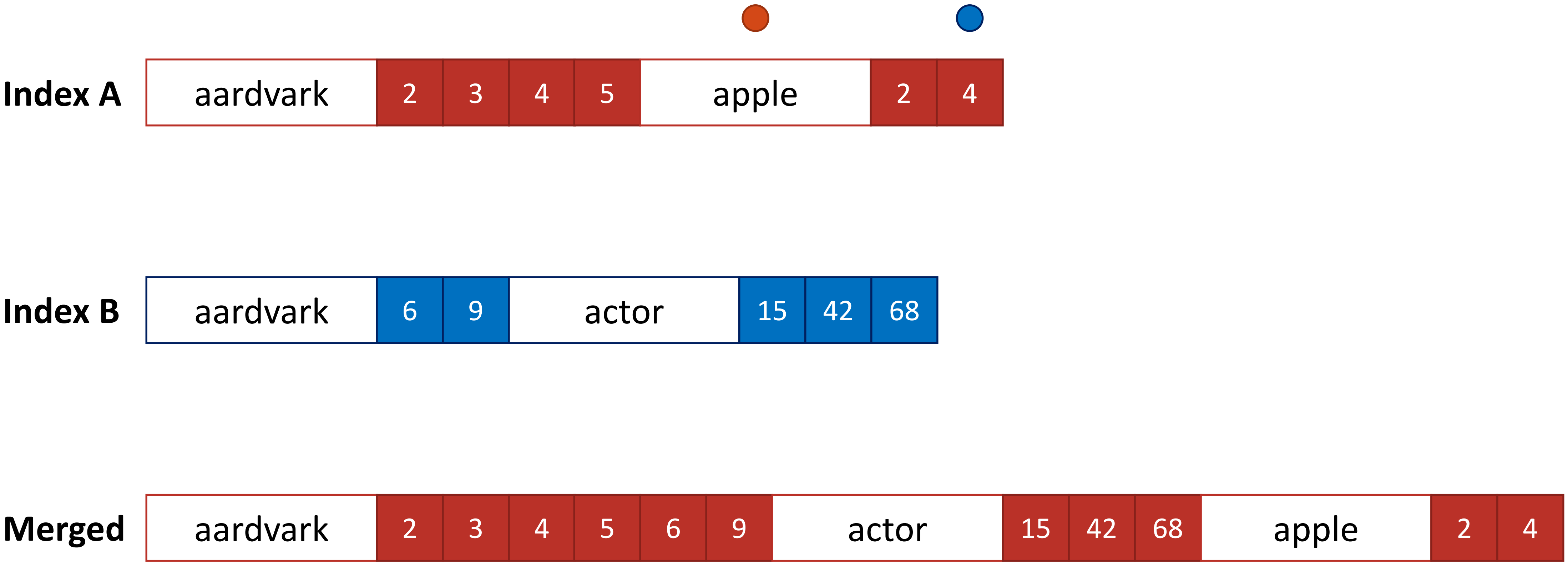

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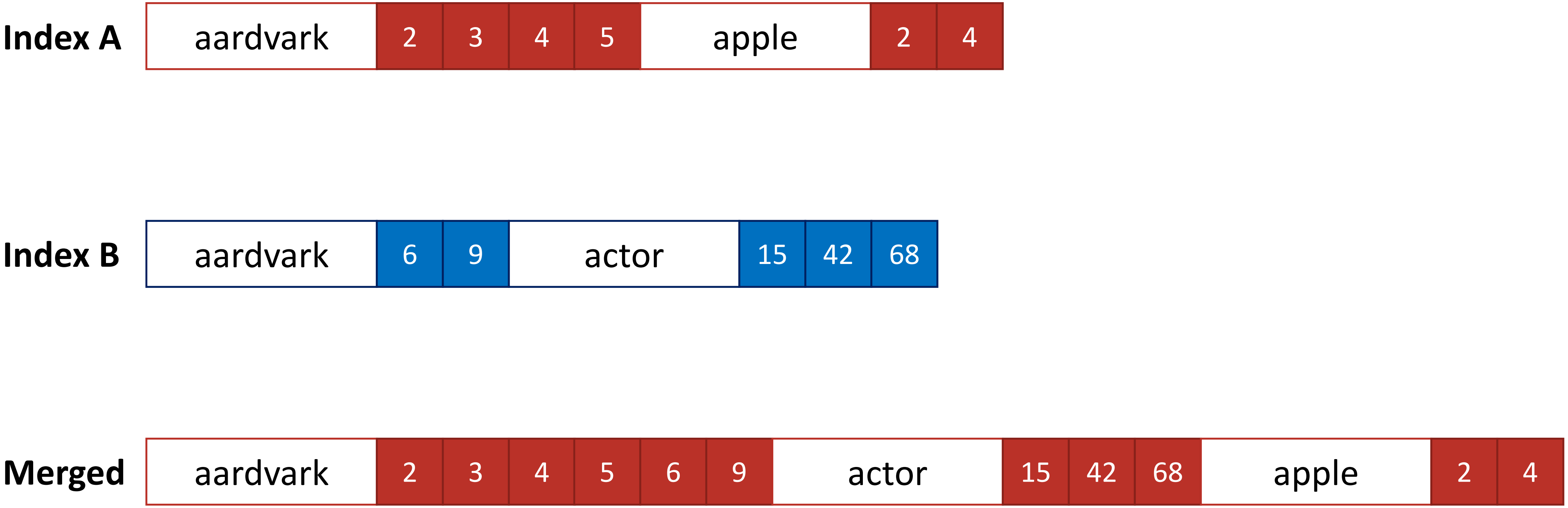

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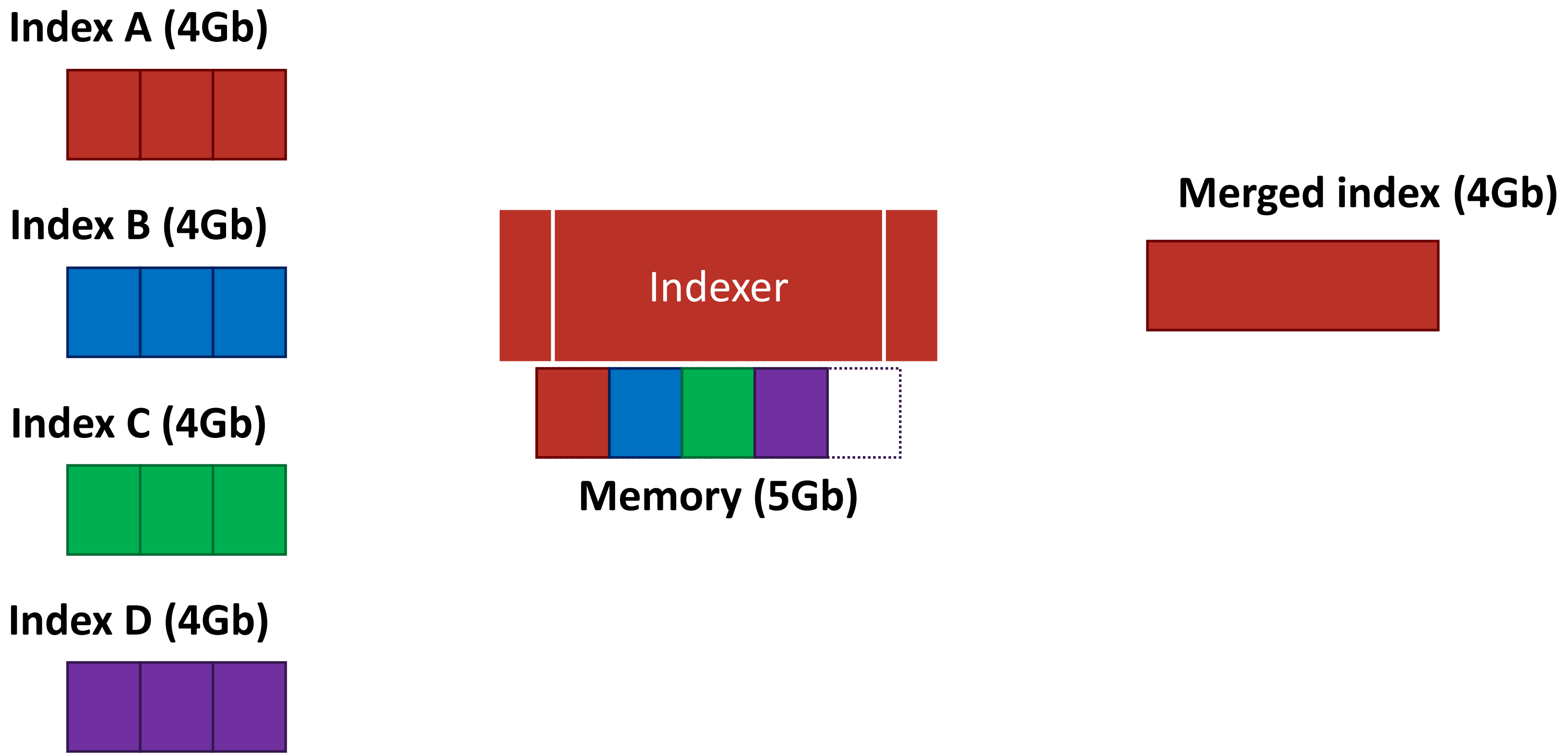

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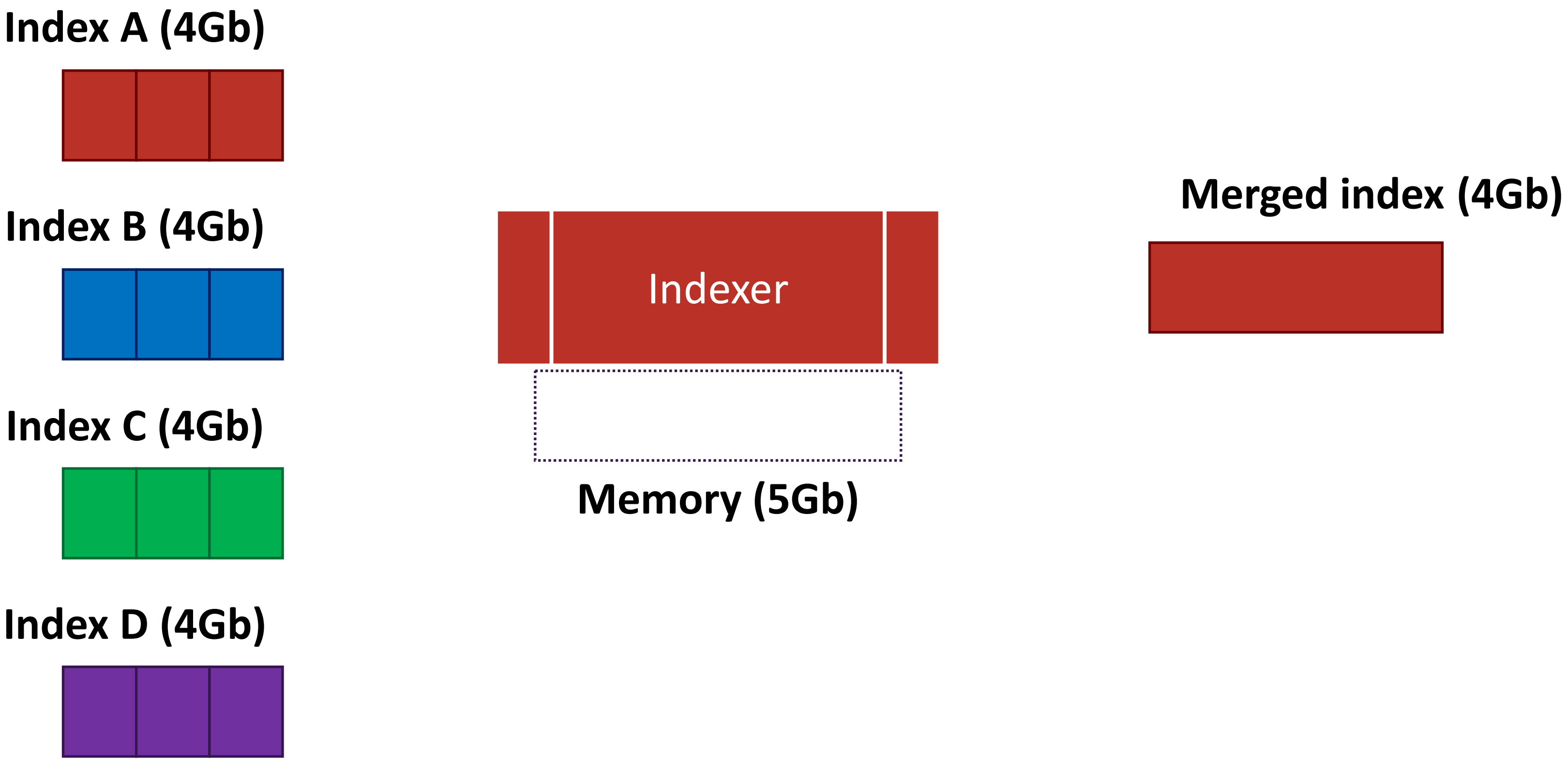

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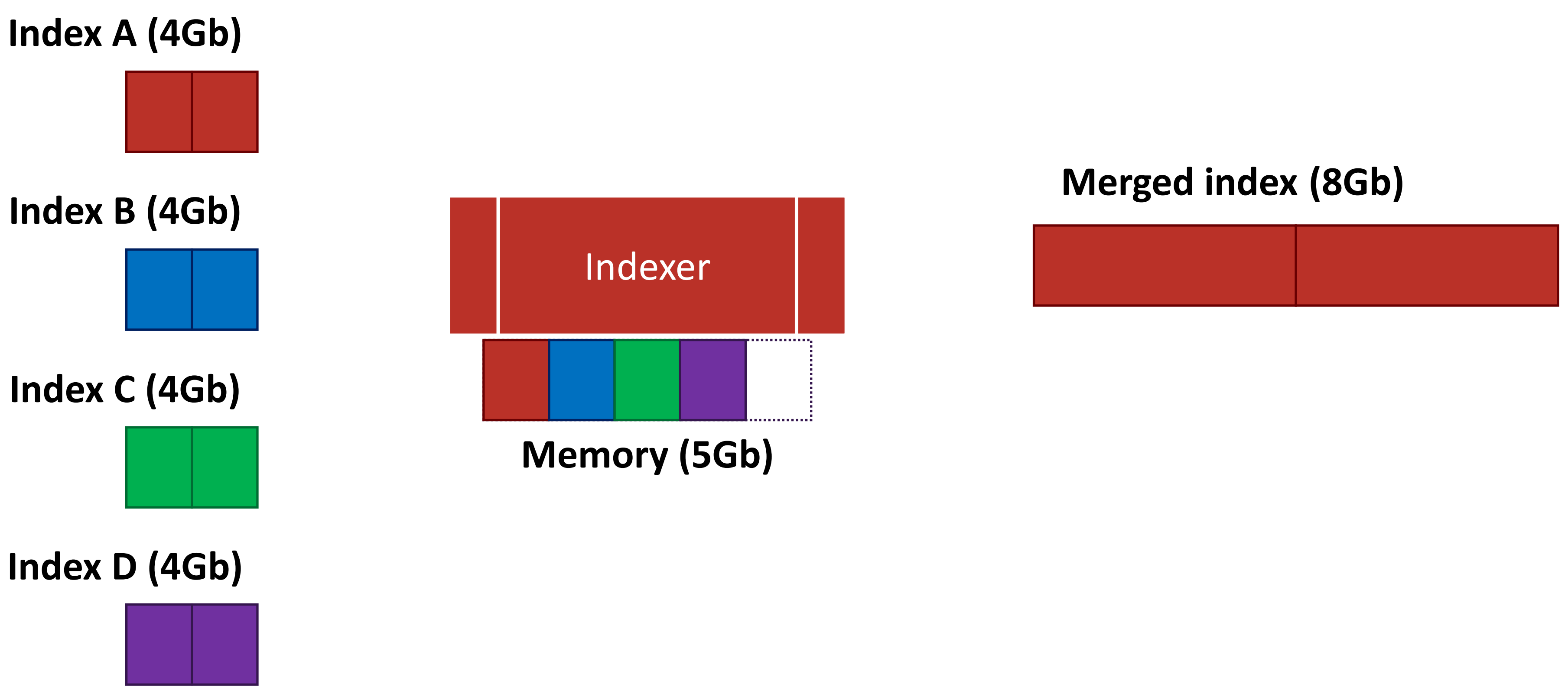

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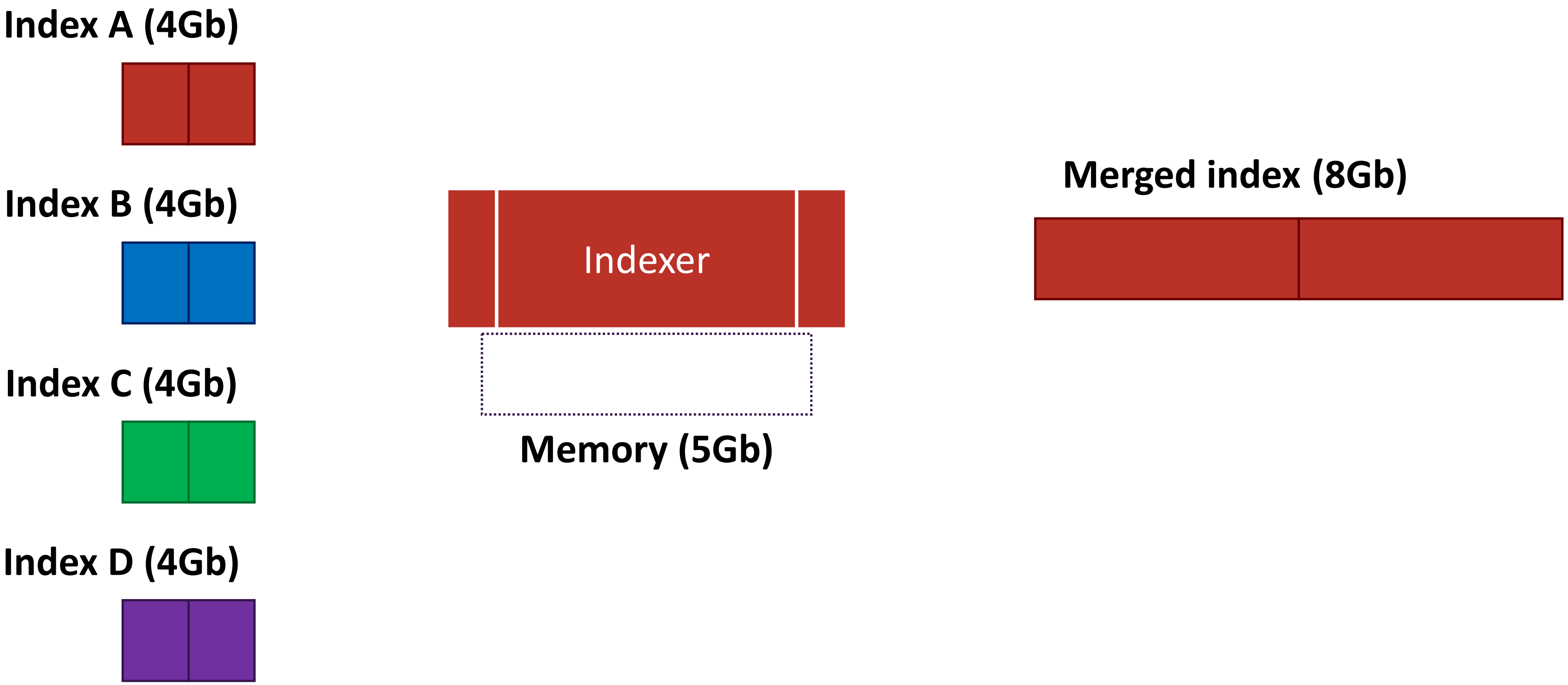

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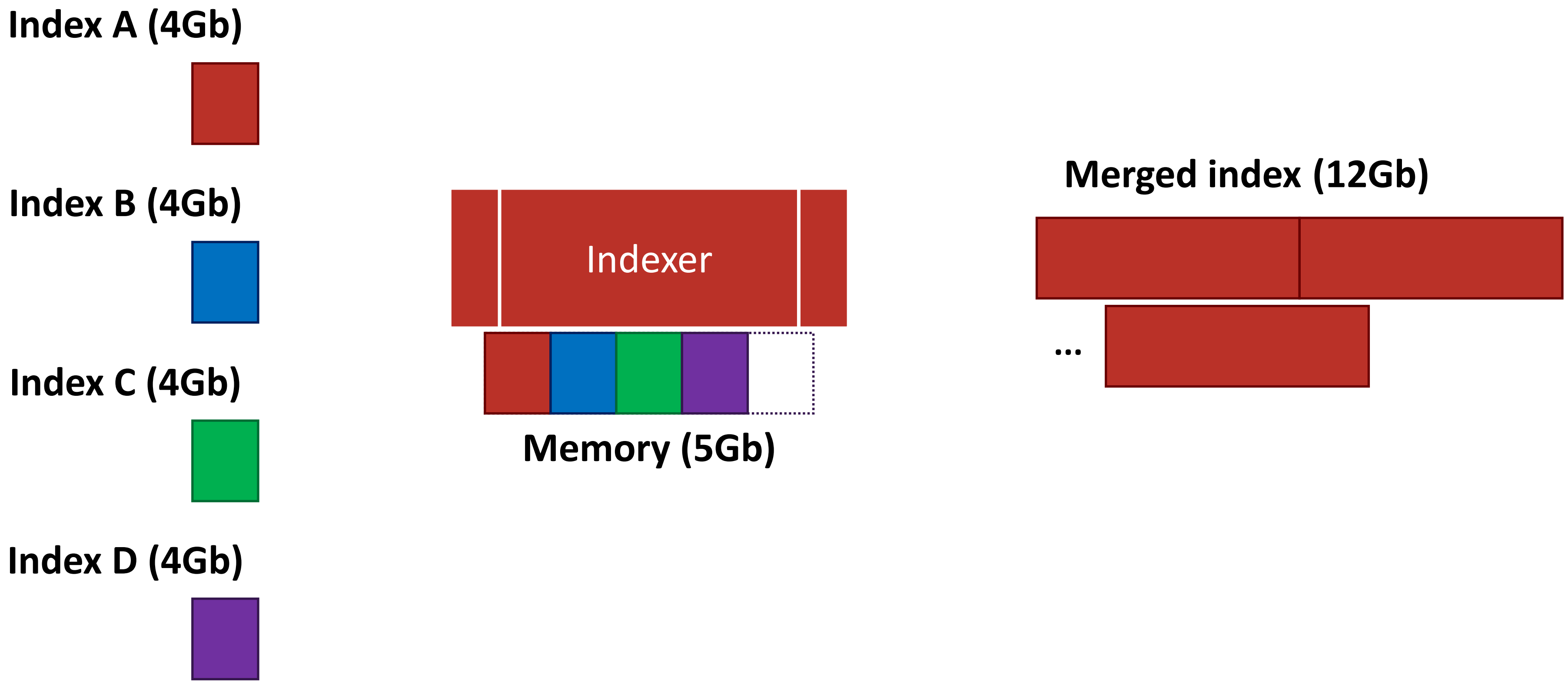

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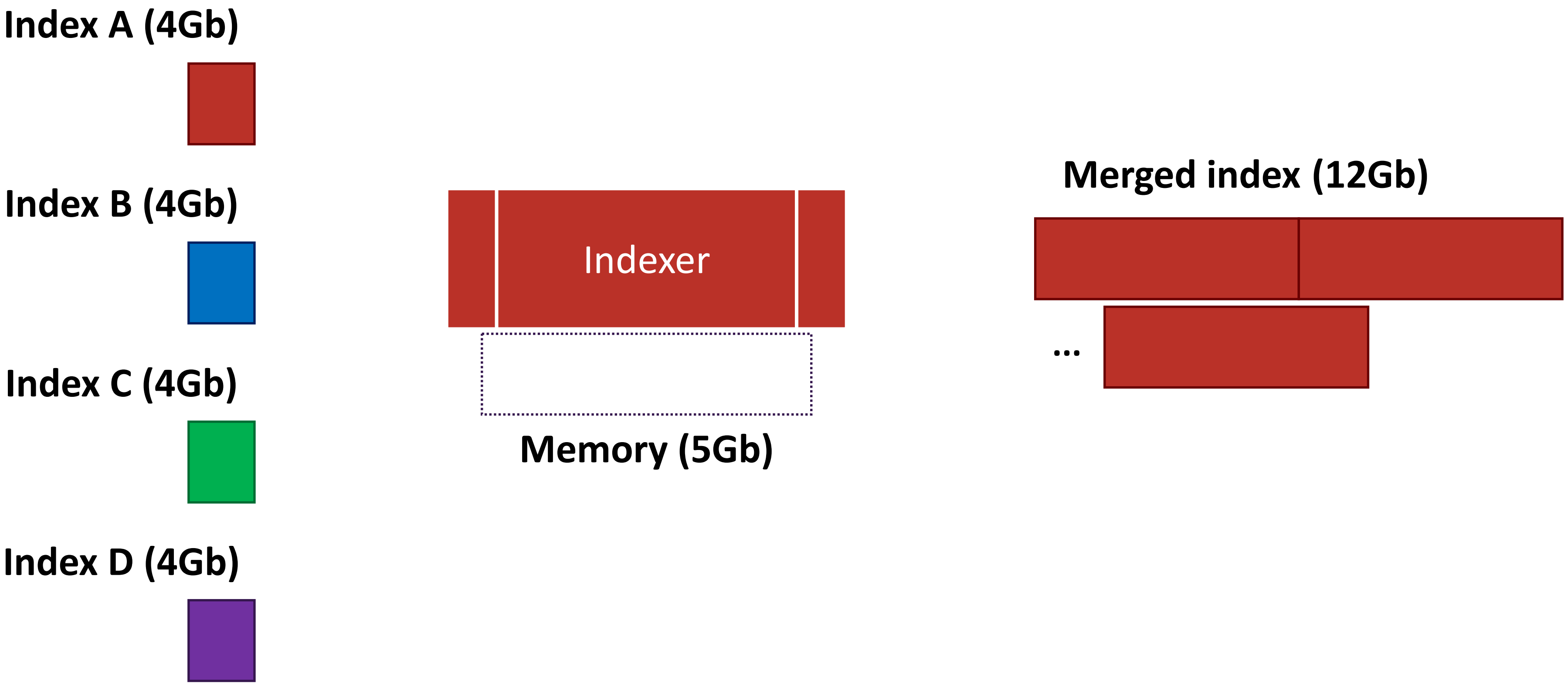


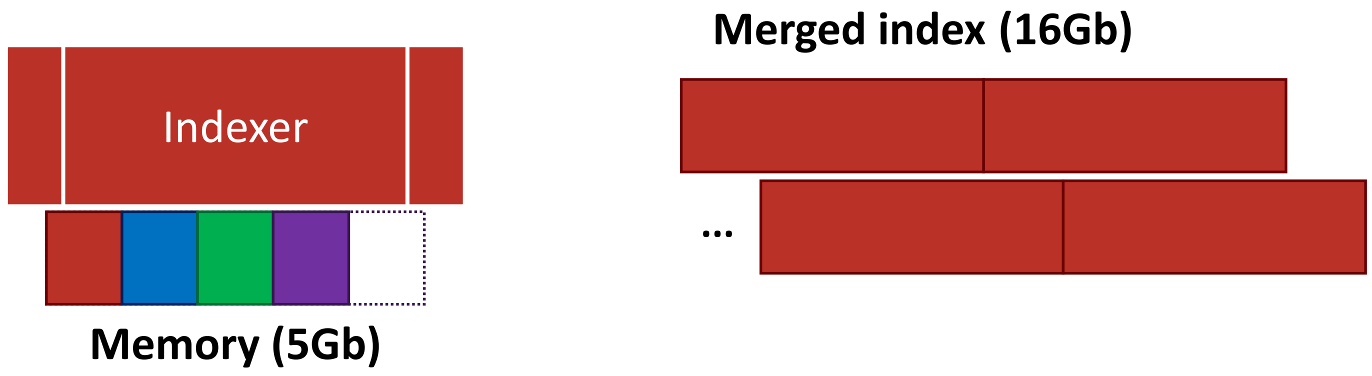
External merging

Index A (4Gb)

Index B (4Gb)

Index C (4Gb)

Index D (4Gb)



Index maintenance

Index merging efficient for large updates

- Overhead makes it inefficient for small updates

Instead, create separate index for new documents

- Merge *results* from both indexes

Could be in-memory, fast to update and search

- Also works for updates and deletions

Distributed indexing

Distributed processing driven by need to index and analyze huge amounts of data (i.e., the Web)

- Large numbers of inexpensive servers used rather than larger, more expensive machines

MapReduce is a distributed programming tool designed for indexing and analysis tasks

The MapReduce framework
[Dean and Ghemawat, USENIX 2004]

Key idea: keep data and processing together

- Bring code to data!

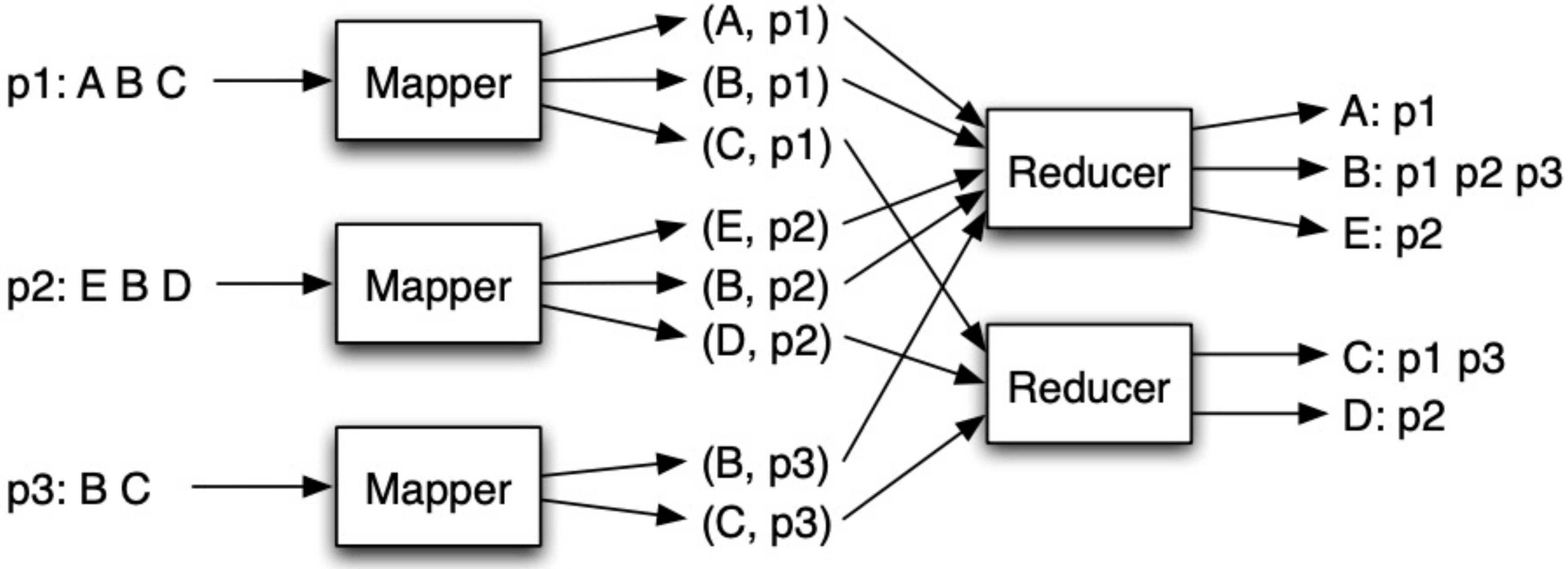
Map and reduce functions

- Inspired by functional programming

Constrained program structure

- But massive parallelization!

Distributed indexing with MapReduce
[McCreadie et al. IP&M 2012]



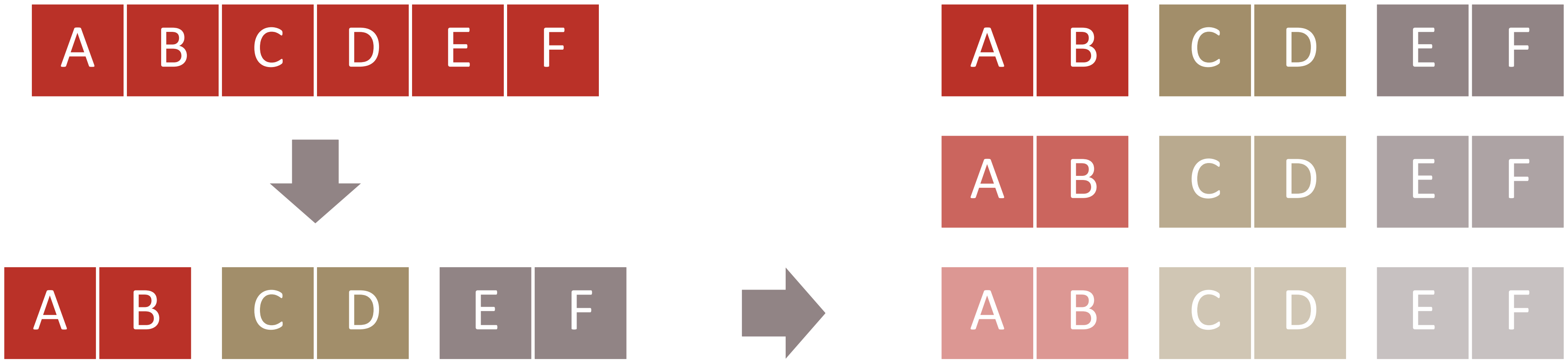
Index sharding and replication

Multiple index shards

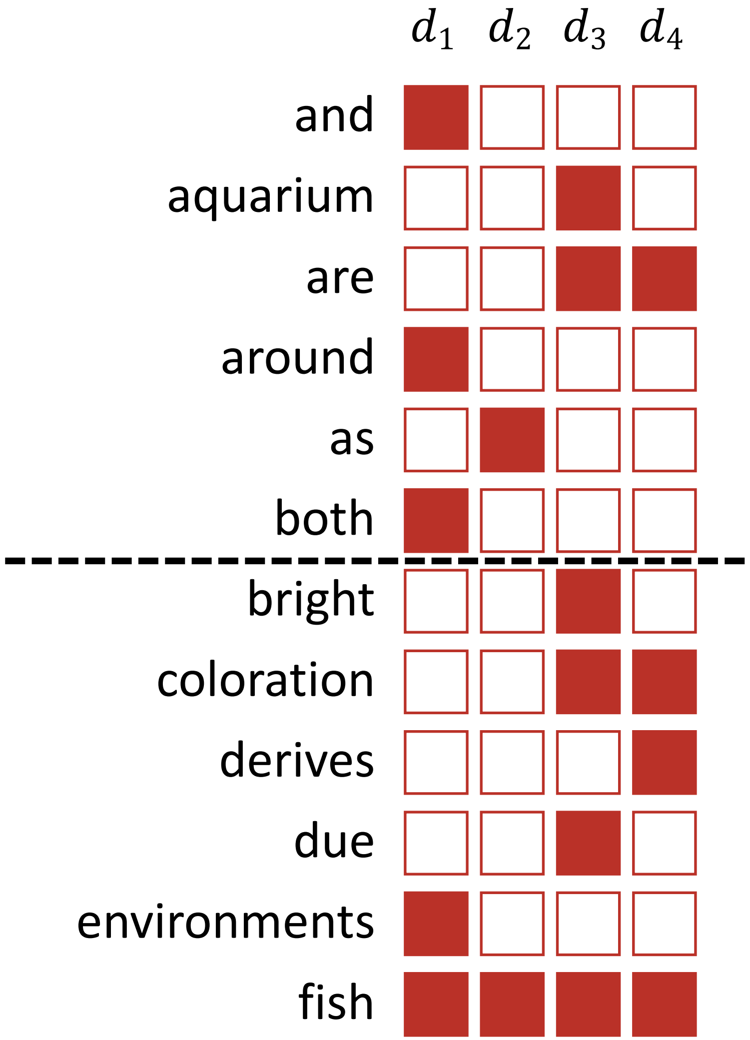
- Reduce query response times
- Scale with collection size

Multiple shard replicas

- Increase query throughput
- Scale with query volume
- Provide fault tolerance



Index sharding



Term-based sharding

- Disjoint terms in different nodes
- Single disk access per term

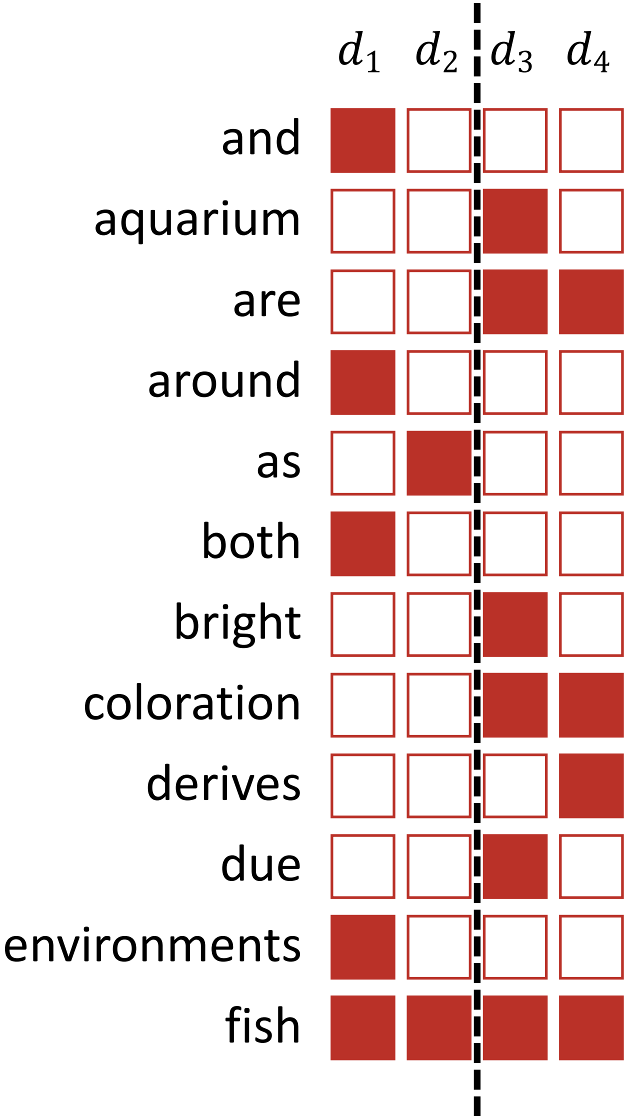
Good for inter-query parallelism

- Higher throughput (disjoint queries)

Bad for load balancing and resilience

- Nodes with popular terms overloaded
- Entire inverted lists missed on node failures

Index sharding



Document-based sharding

- Disjoint documents in different nodes
- Multiple (parallel) disk accesses per term

Good for intra-query parallelism

- Faster response (smaller indexes)
- Throughput increased via replication

Also good for load balancing and resilience

- Some documents missed on node failures

Summary

Indexing makes search feasible at a web-scale

- Effective search via carefully encoded postings
- Efficient search via carefully chosen structures

Several design choices

- Prefiltering, feature extraction, text understanding
- Posting design, ordering, compression, and more

Summary

Efficient management

- Memory-efficient, distributed construction
- Near-real time updates via clever merging
- Scalability via sharding and replication

References

Search Engines: Information Retrieval in Practice, Ch. 5
Croft et al., 2009

Scalability Challenges in Web Search Engines, Ch. 3
Cambazoglu and Baeza-Yates, 2015

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Coming next...

Query Understanding

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