Memory-Efficient GroupBy-Aggregate with Compressed Buffer Trees

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Carnegie Mellon

Michael Kaminsky
Intel Labs.

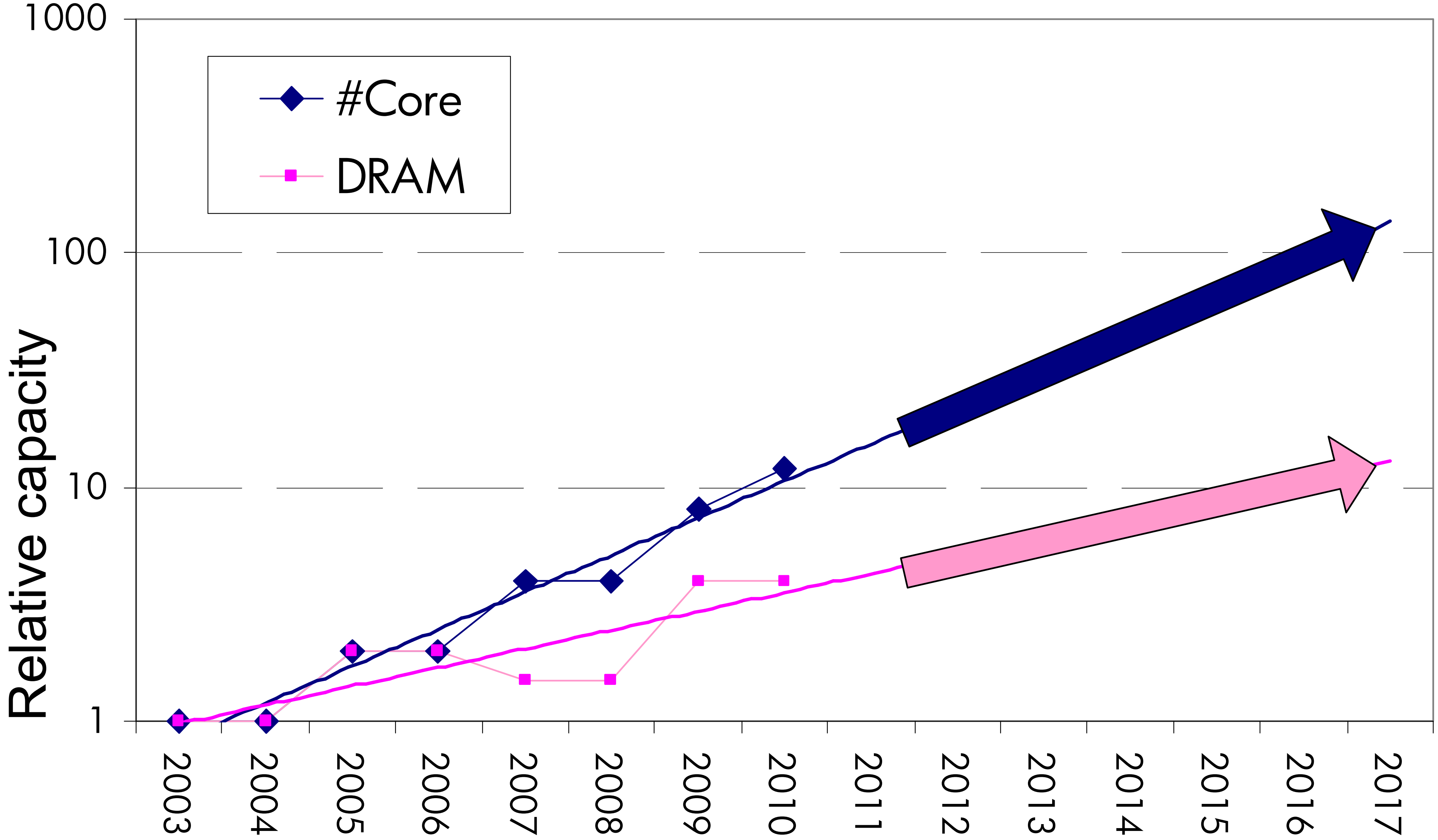
Motivation

Increasing cost of memory

Importance of GroupBy-Aggregate

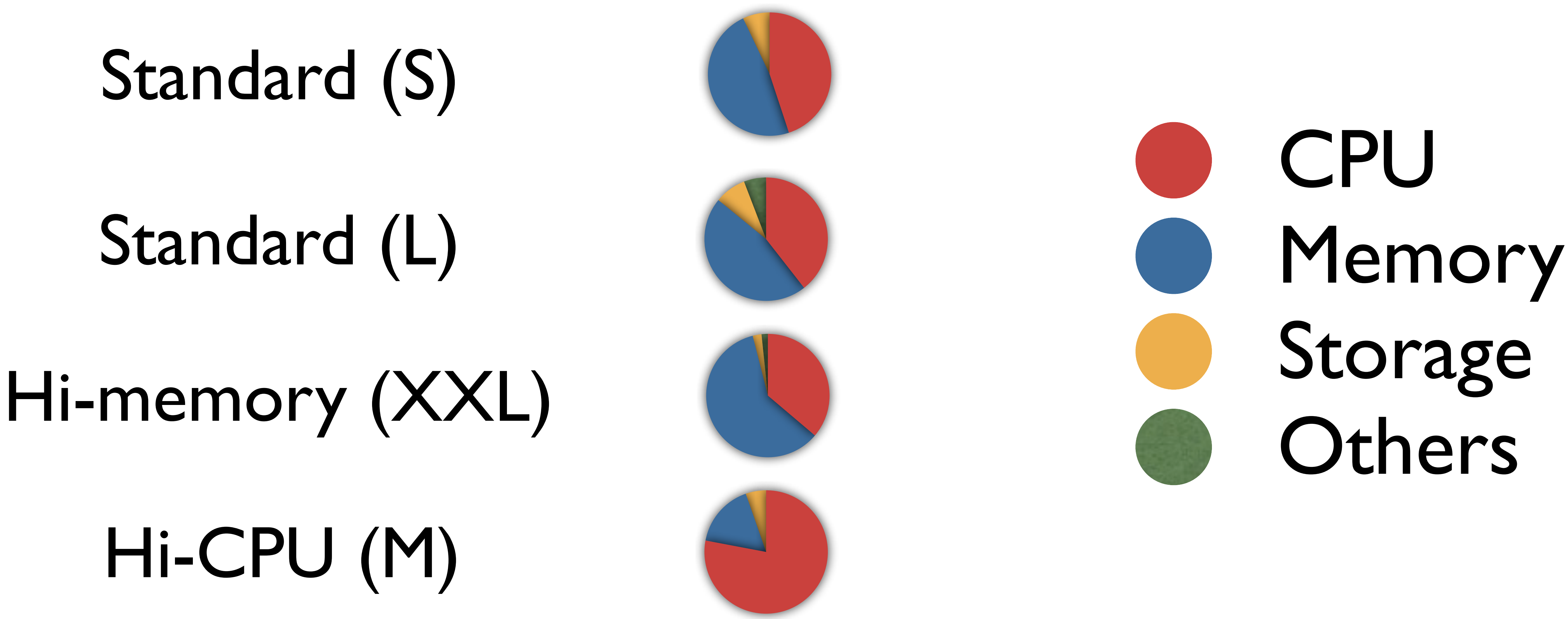
Need for Memory Efficiency

Decreasing memory capacity per core



1. Disaggregated Memory for Expansion and Sharing in Blade Servers, Lim et al., ISCA'09

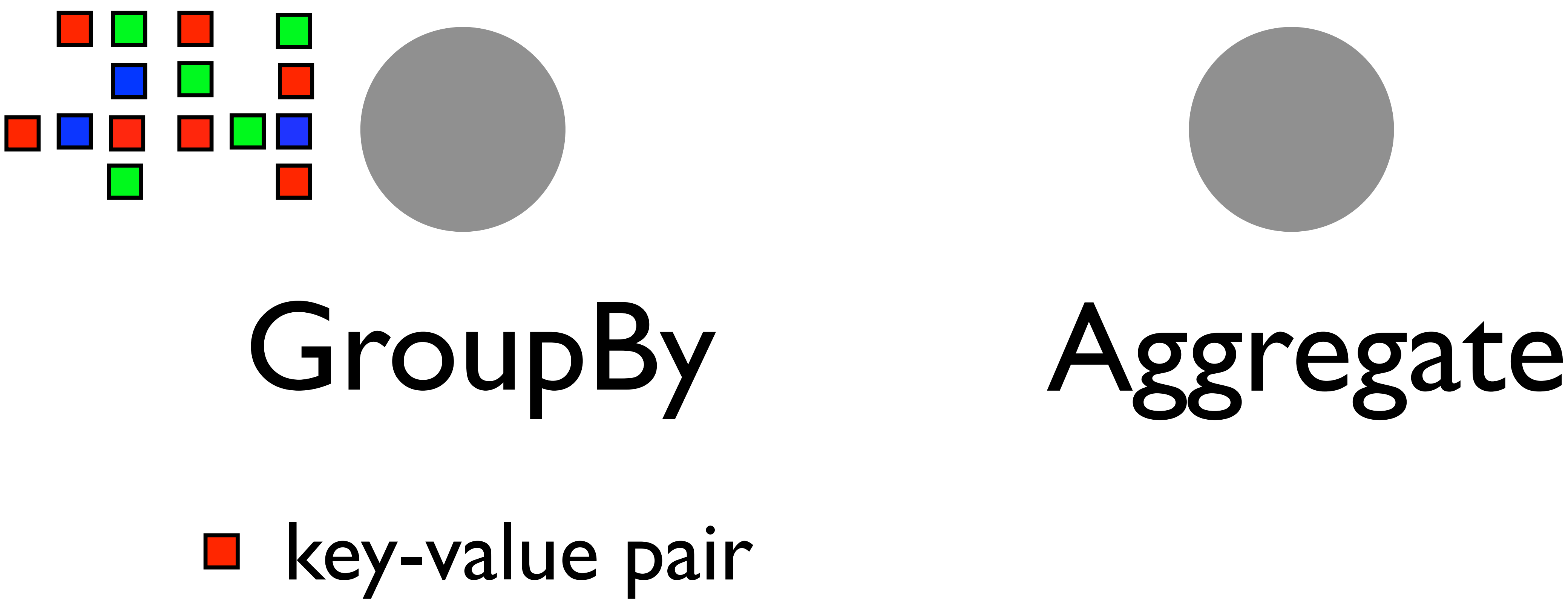
DRAM is expensive



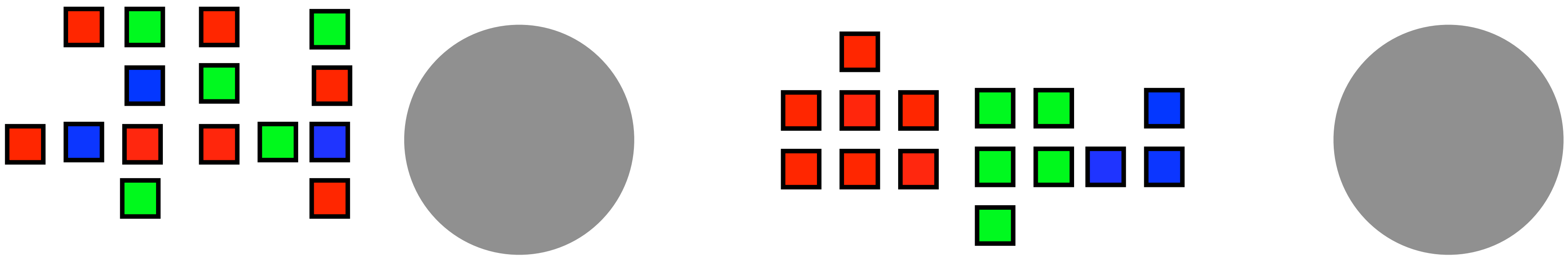
Amazon EC2 proportional resource cost

GroupBy-Aggregate

GroupBy-Aggregate



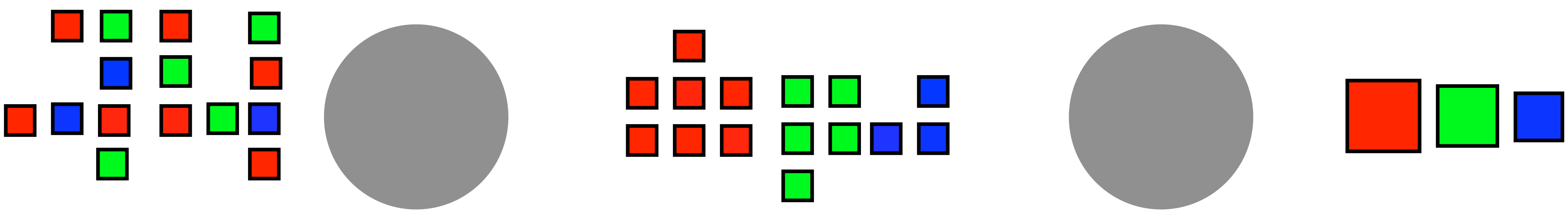
GroupBy-Aggregate



GroupBy Aggregate

■ key-value pair

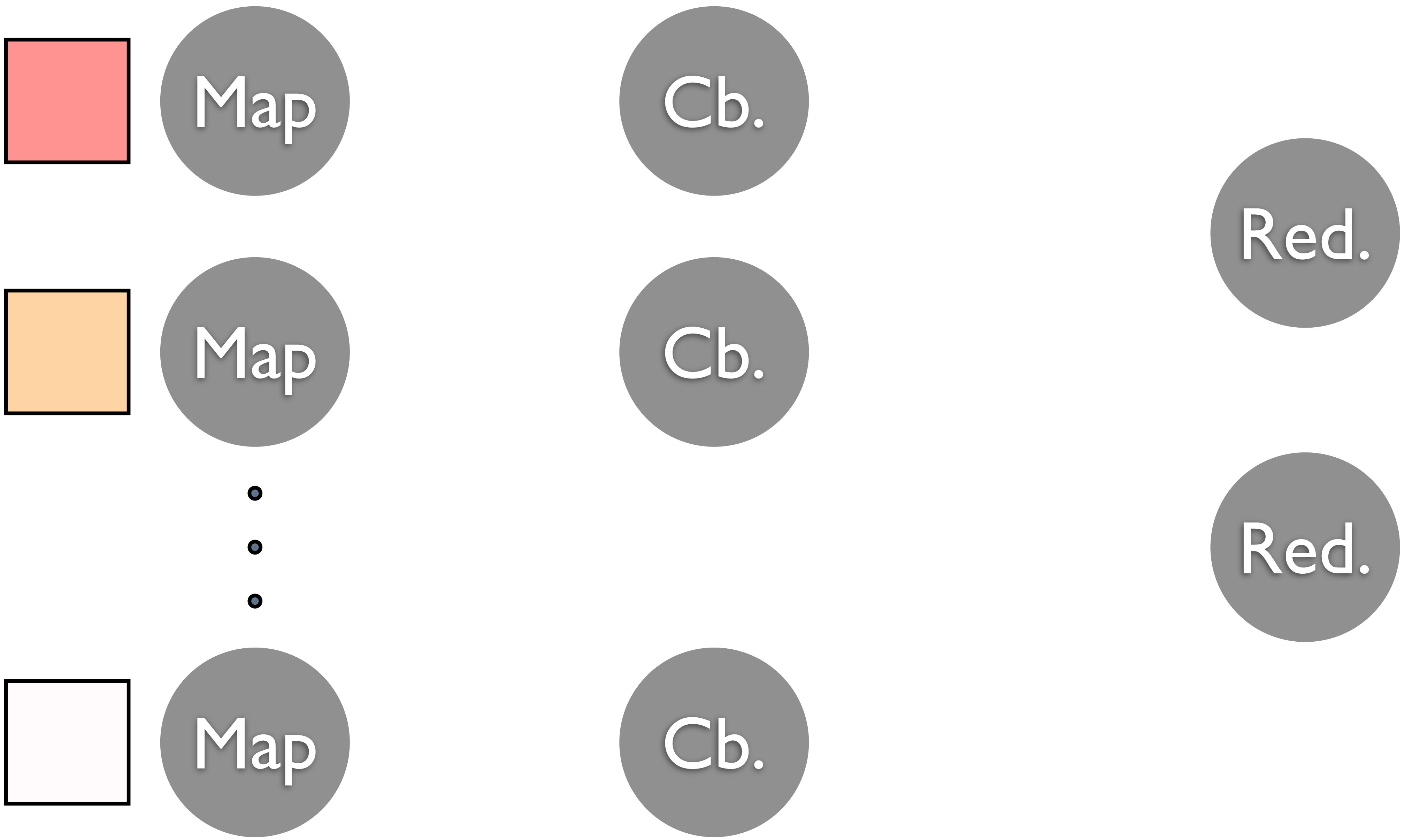
GroupBy-Aggregate



GroupBy Aggregate

■ key-value pair

MapReduce



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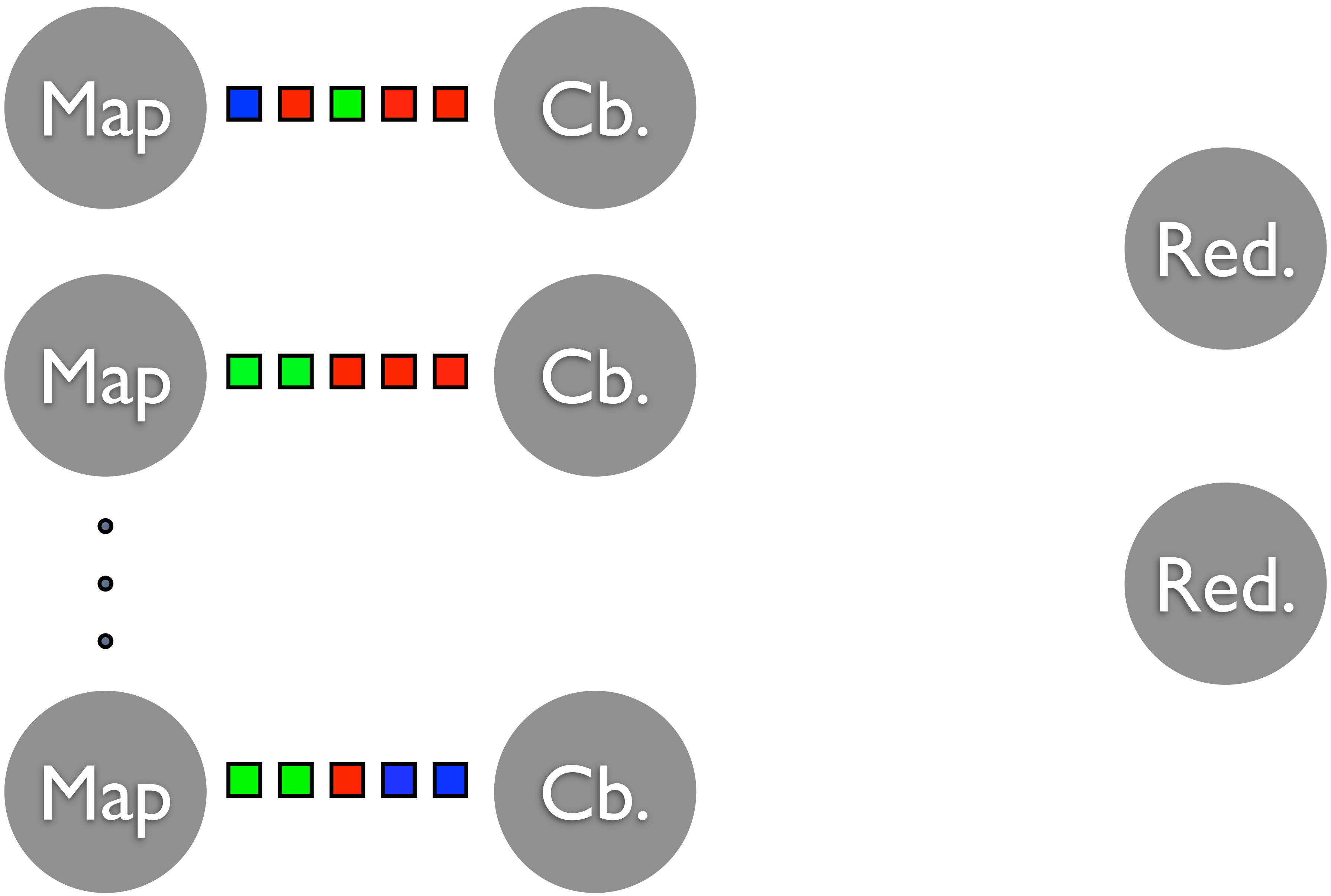

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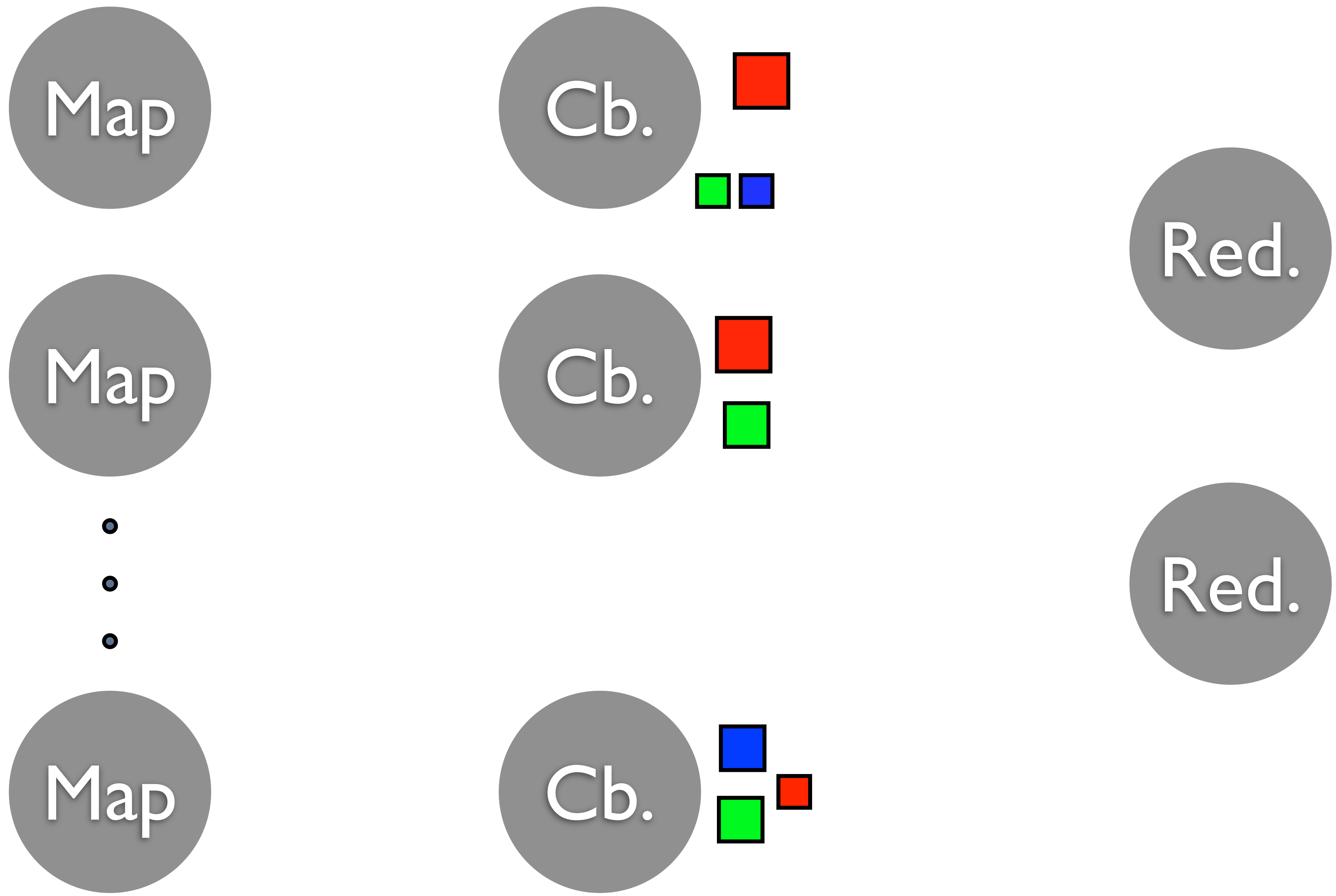

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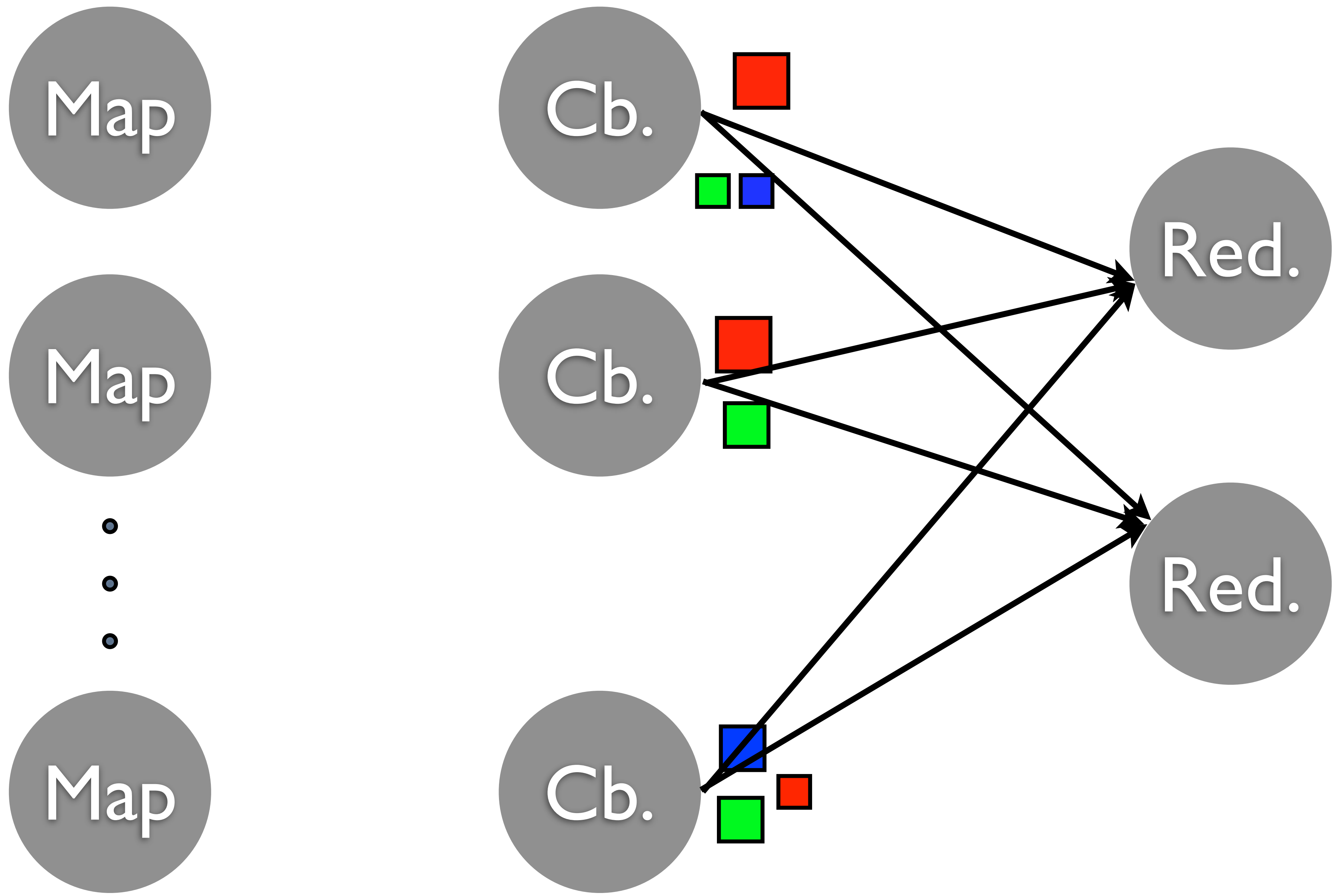

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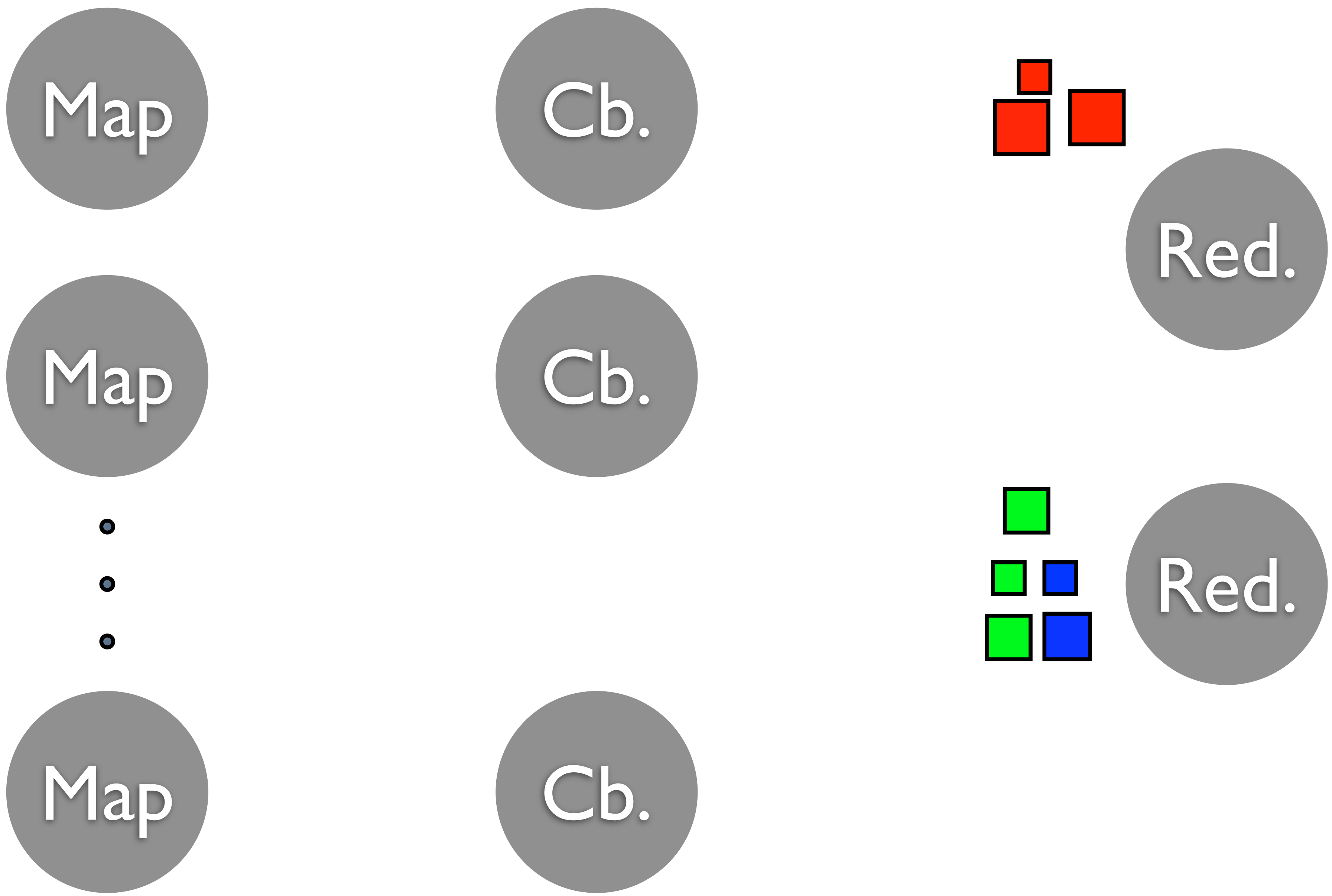

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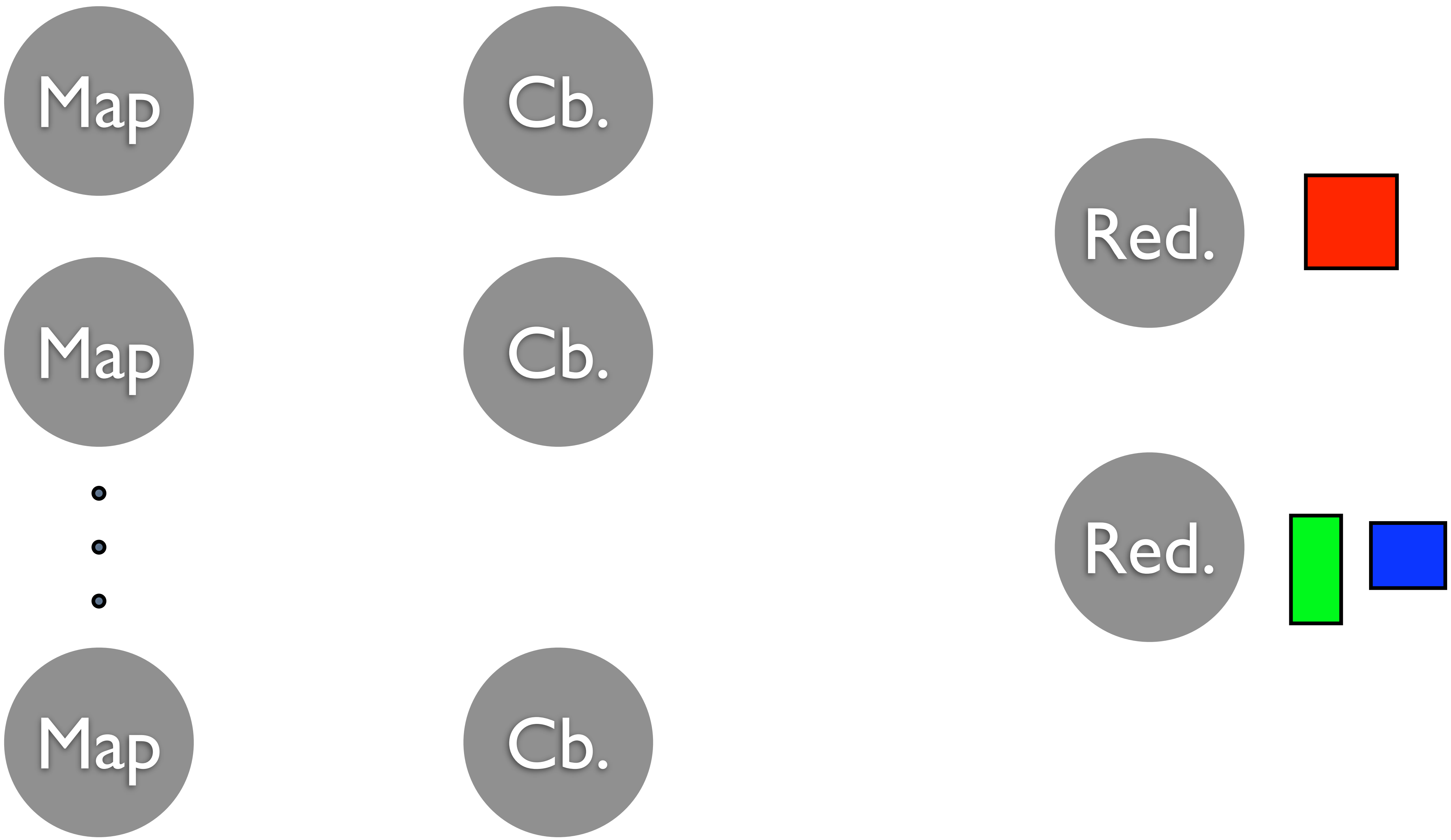

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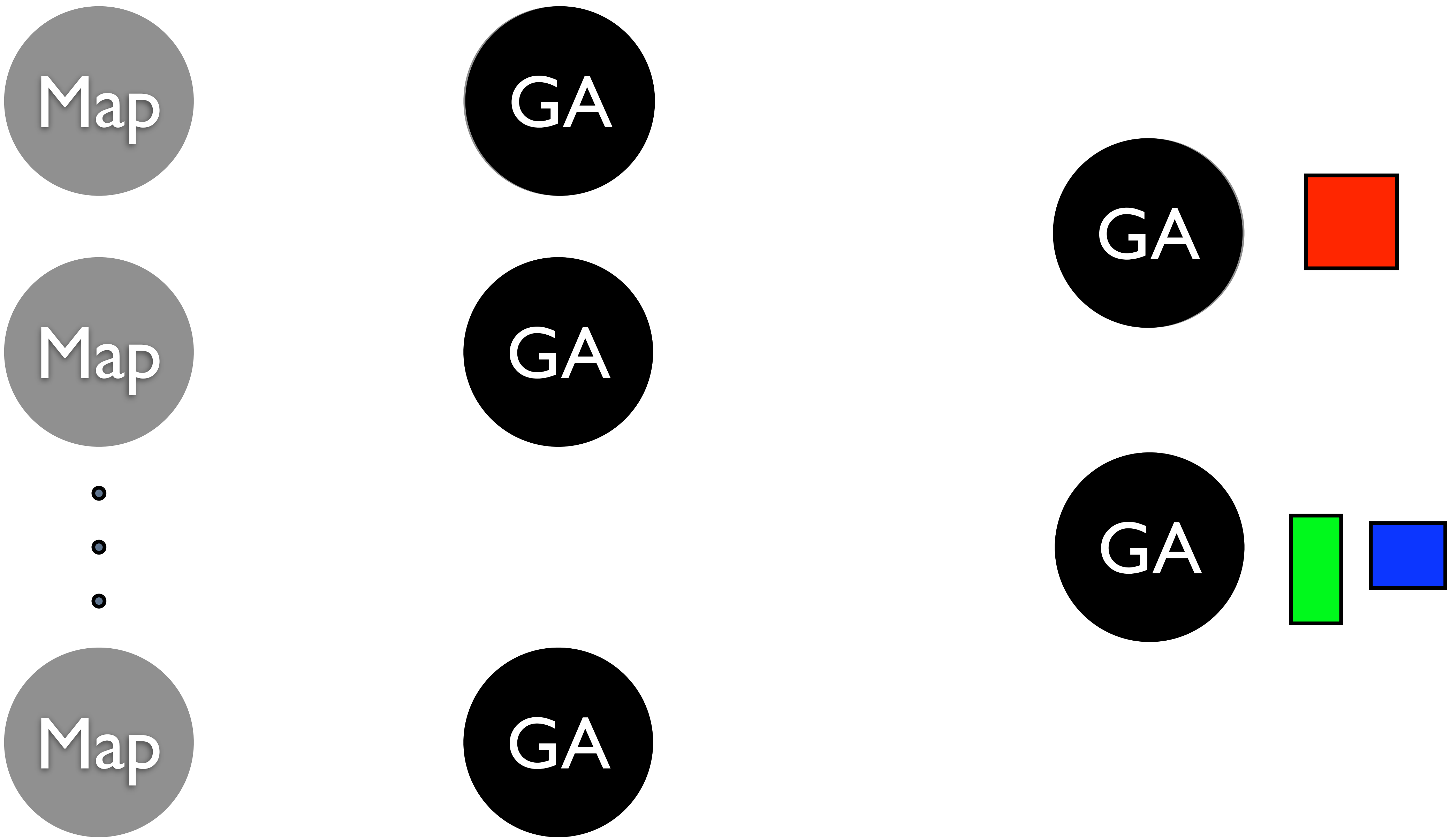
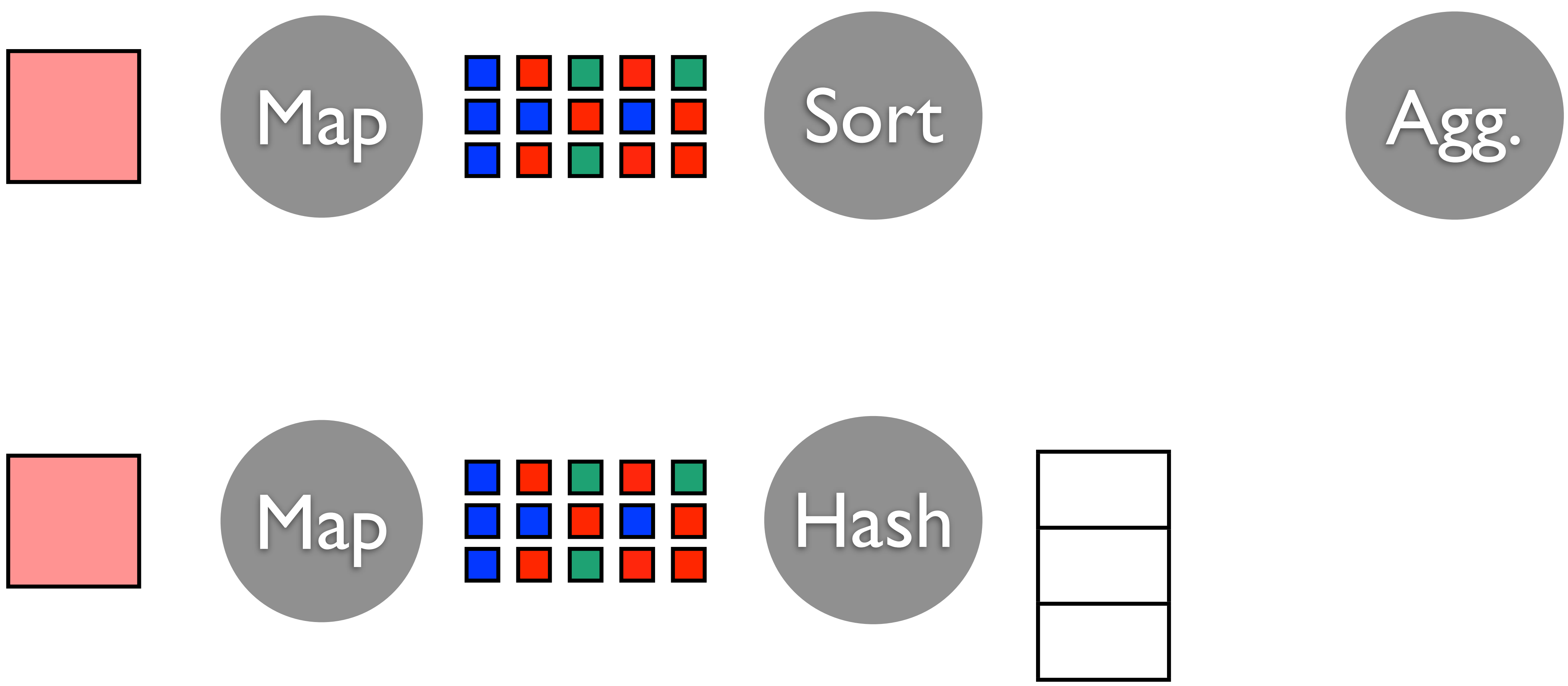


Implementation of G-A



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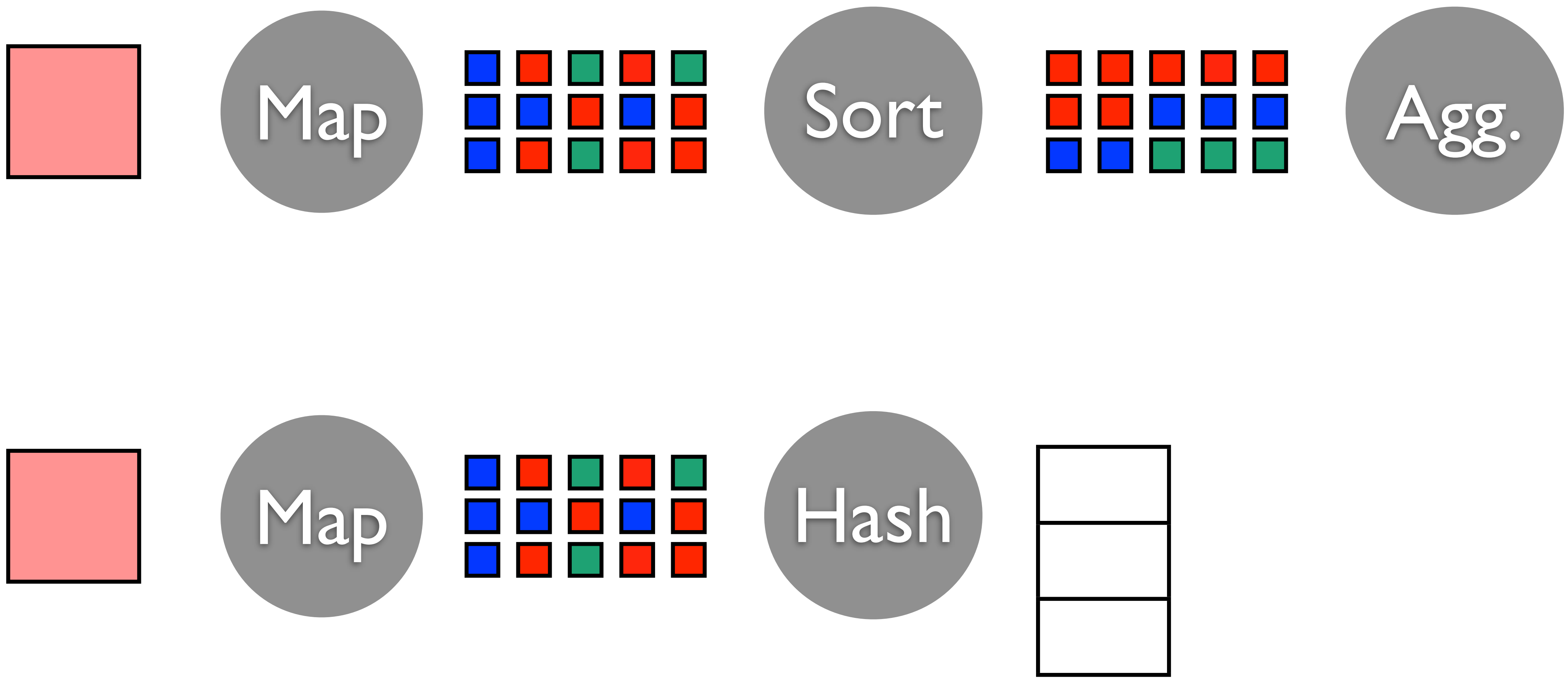

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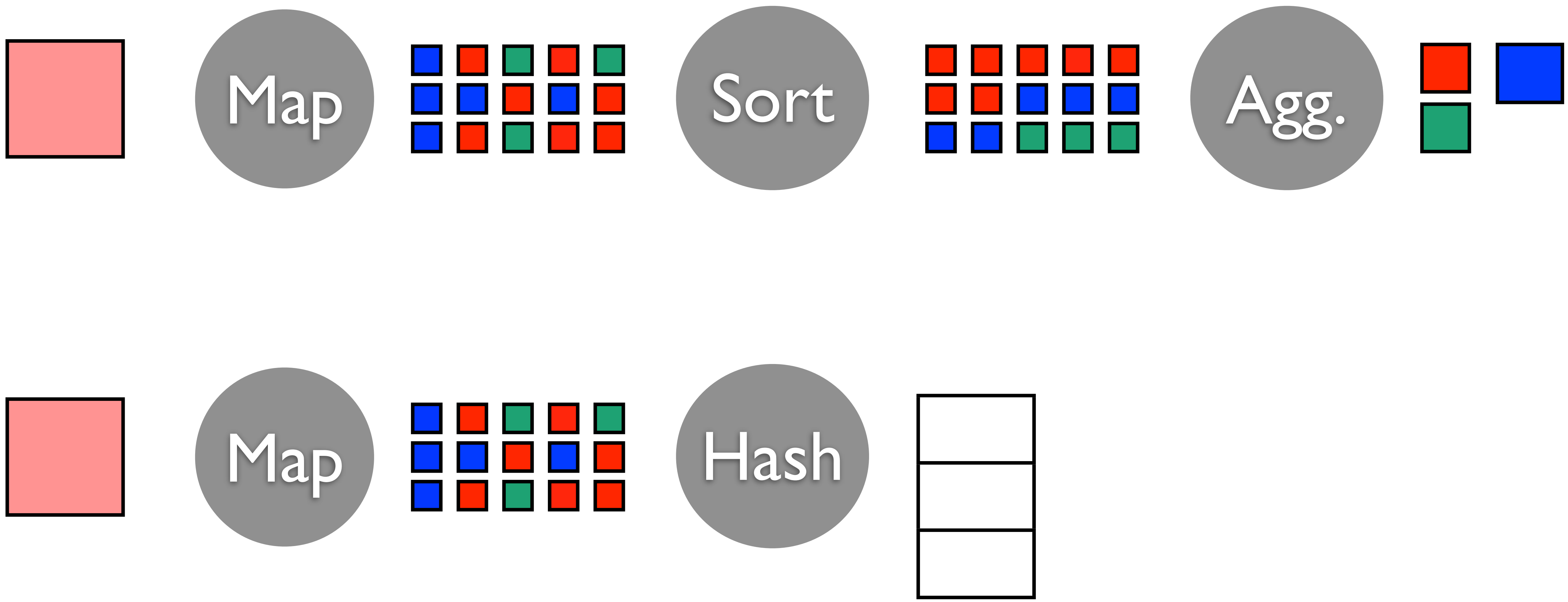

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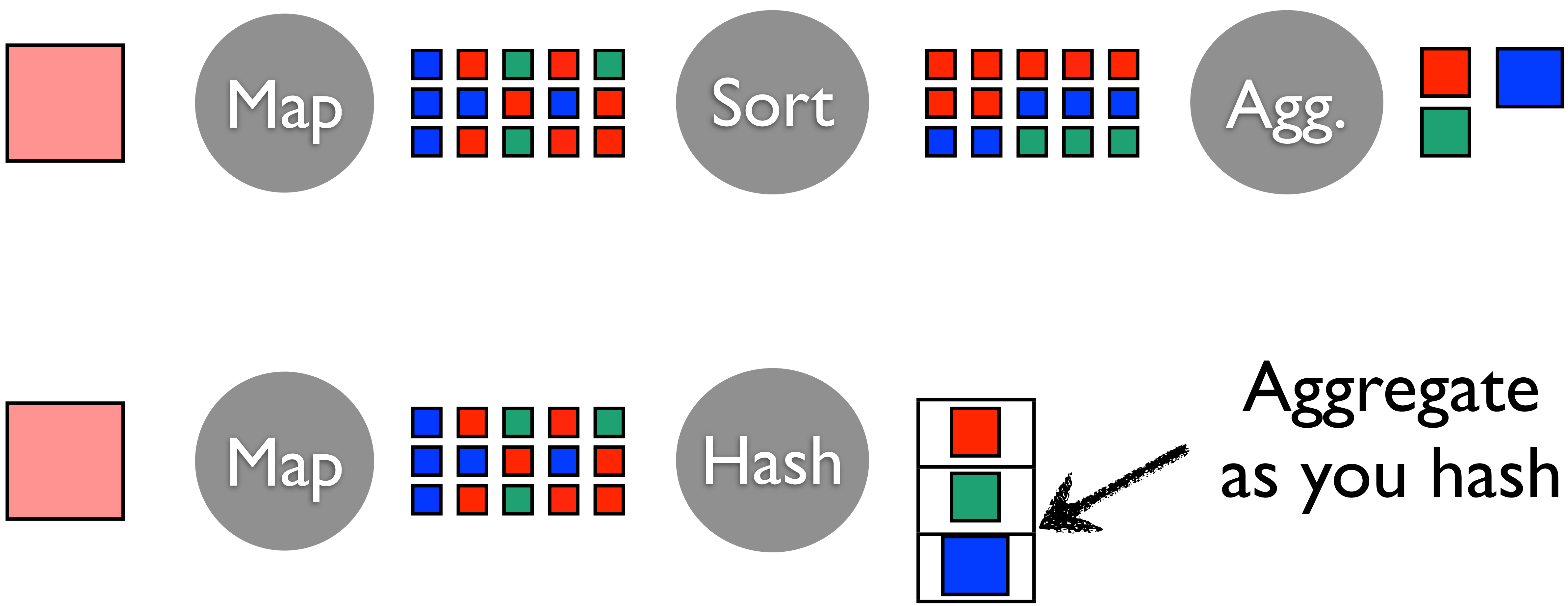

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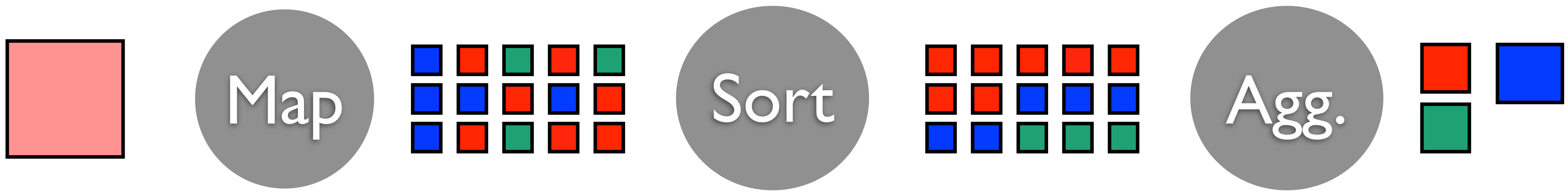

Sort *orders* keys along with *grouping* them

Sort vs. Hash-based GA

Hash typically outperforms Sort for aggregation workloads[1,2,3]

1. Distributed Aggregation for Data-Parallel Computing:Interfaces and Implementations, Yu et. al., SOSP'09
2. Tenzing: A SQL Implementation On The MapReduce Framework, Chattopadhyaya et al., VLDB'11
3. A Platform for Scalable One-Pass Analytics using MapReduce, Li et al., SIGMOD'11

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Hash-based G-A requires lots of memory

Hashtable Overheads

Allocator	Per-entry memory (B)	
	`std::unordered_map`	`sparse_hash_map`
hoard [9]	64.9	67.8
tcmalloc [21]	57.2	43
jemalloc [20]	58.1	**41**

Dataset:

Key: 8B char array

Value: 4B integer

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Sources of Memory Overhead

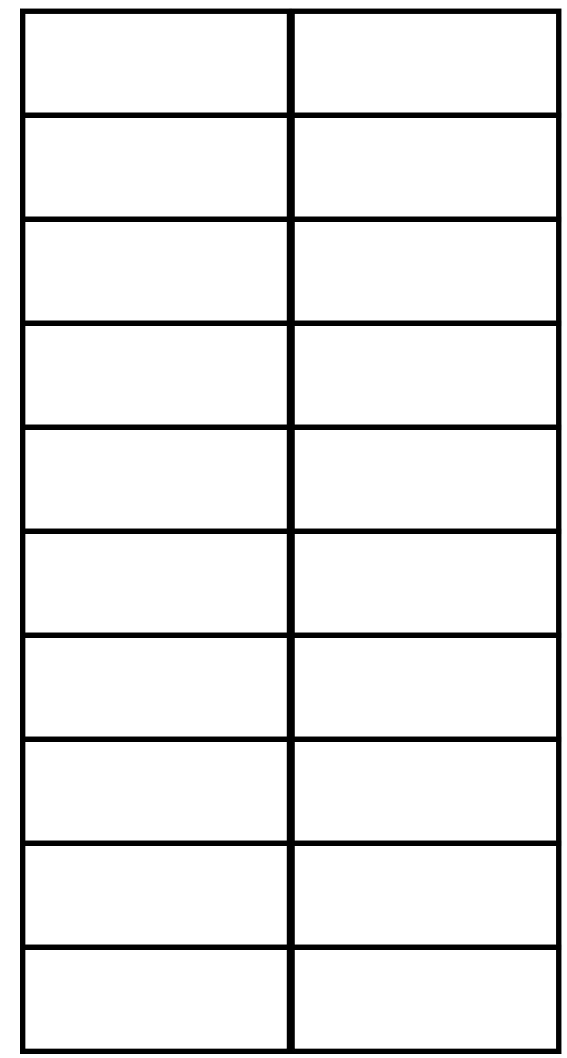
- Allocator overhead for small heap objects
- Indirection overhead (64bit)
- Empty slots in hashtable

How to build a **memory-efficient** and **fast** GroupBy-Aggregate?

Approach

Use Compression for
Memory Efficiency

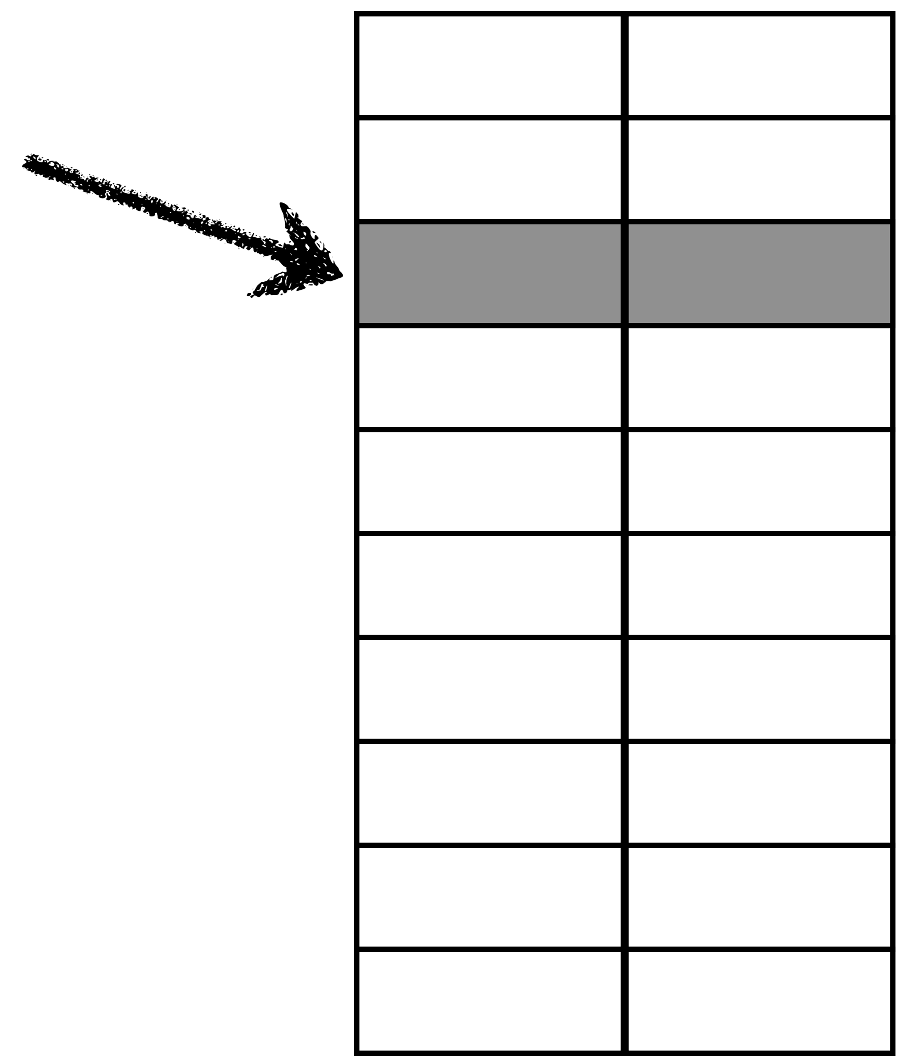
Can we compress hashtables?



Can we compress hashtables?

Strawman 1

Compress each entry



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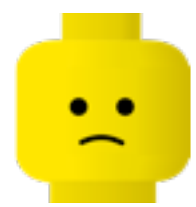
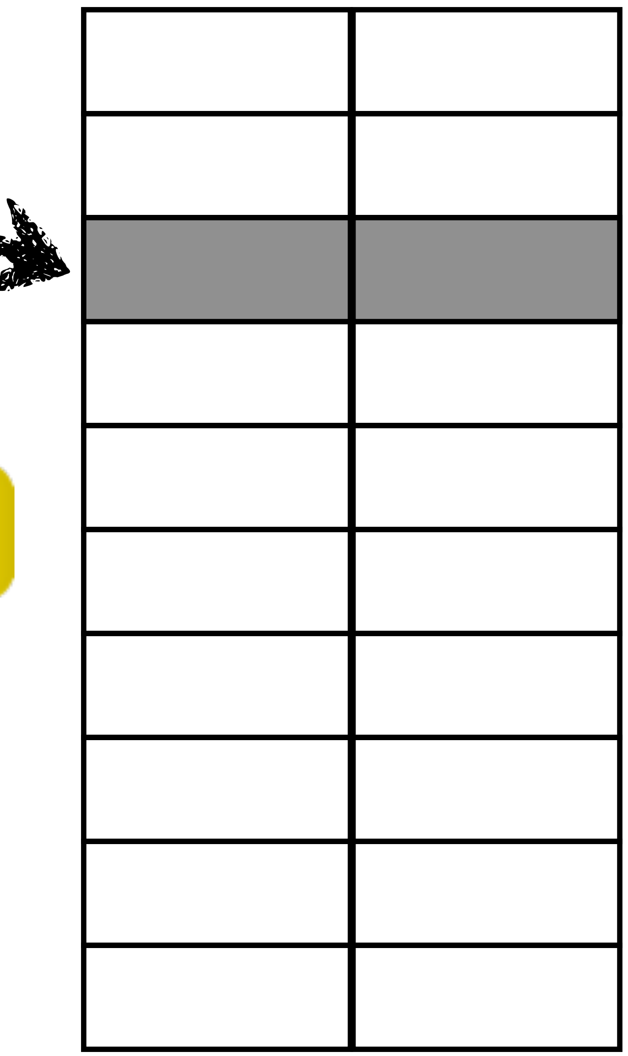
Strawman 1

Compress each entry

Ineffective compression





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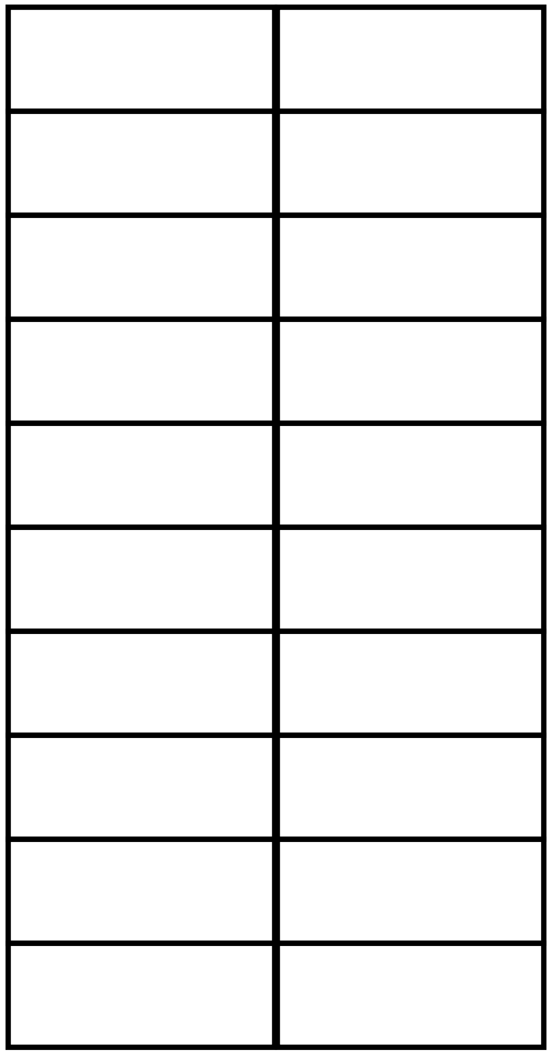
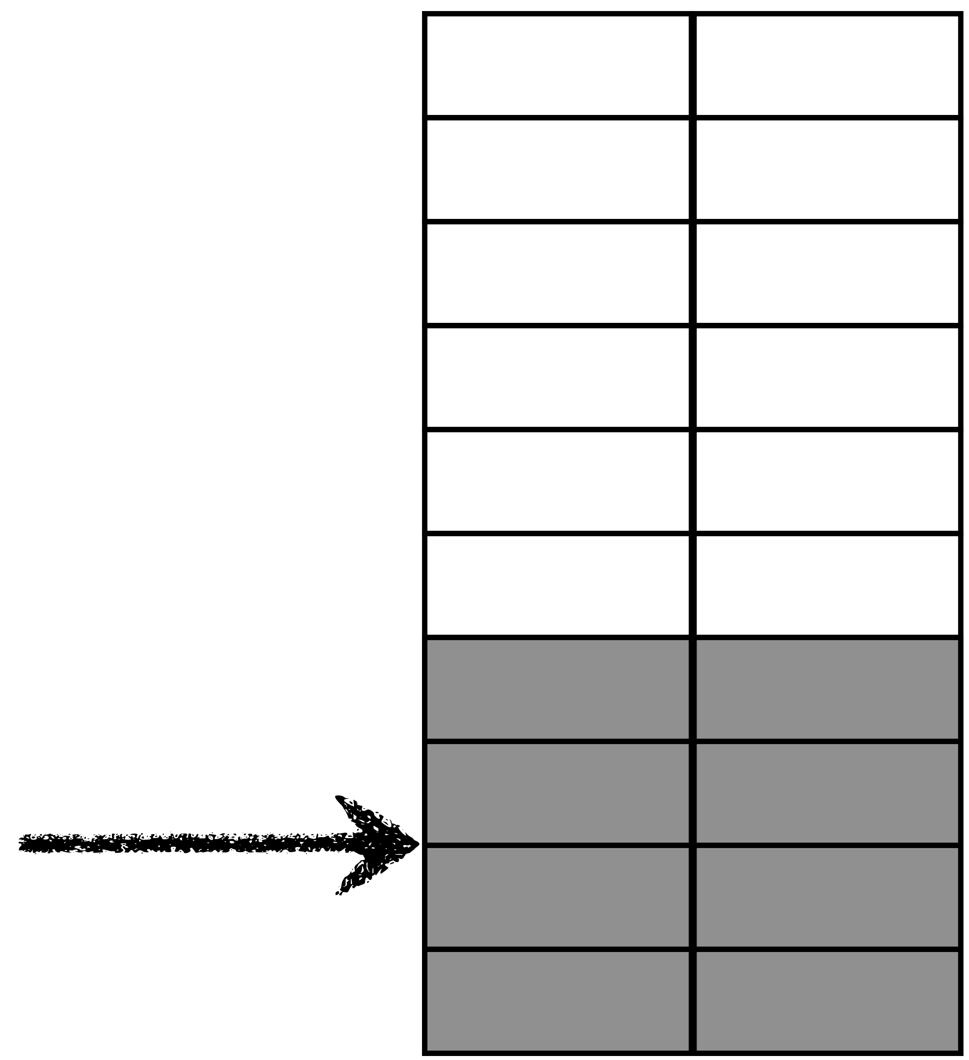


Can we compress hashtables?

Strawman 2

Compress a block



Can we compress hashtables?

Strawman 2

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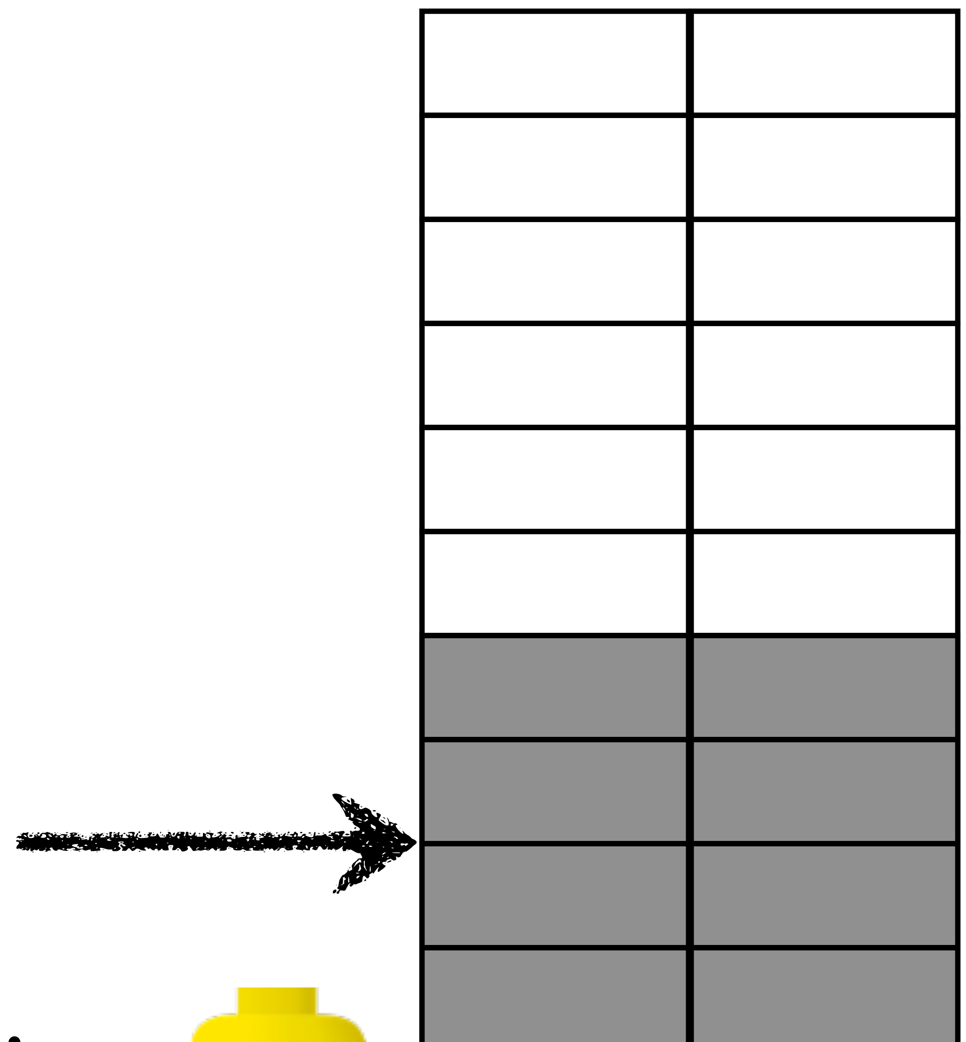
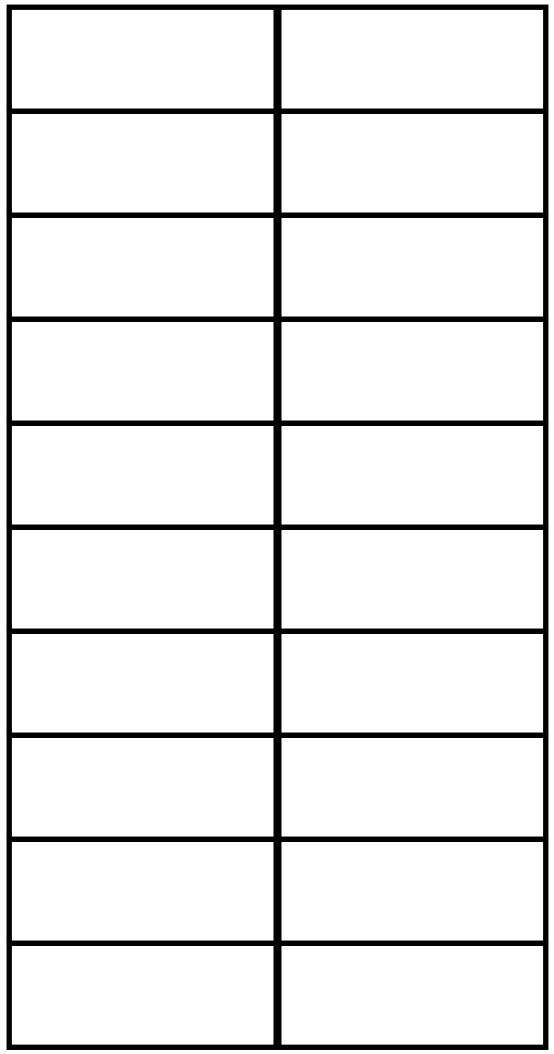


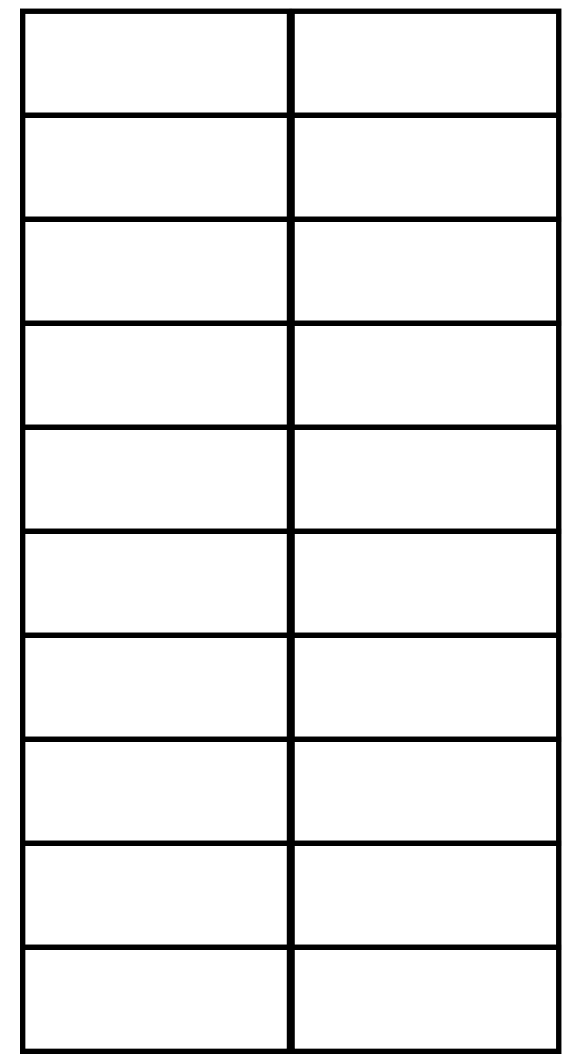
Frequent compression

Can we compress hashtables?



Can we compress hashtables?

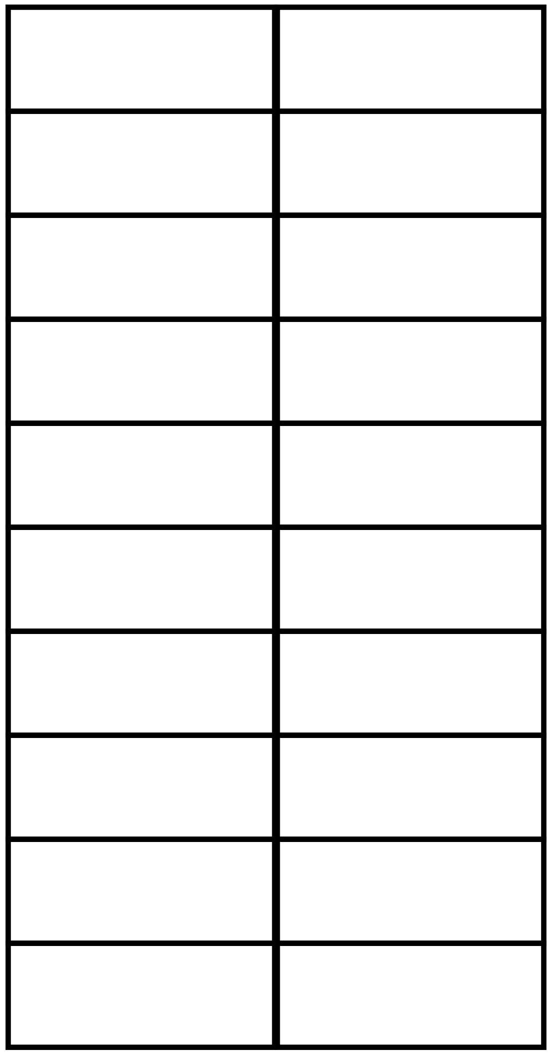
Tension between efficiency of compression and performance



Can we compress hashtables?

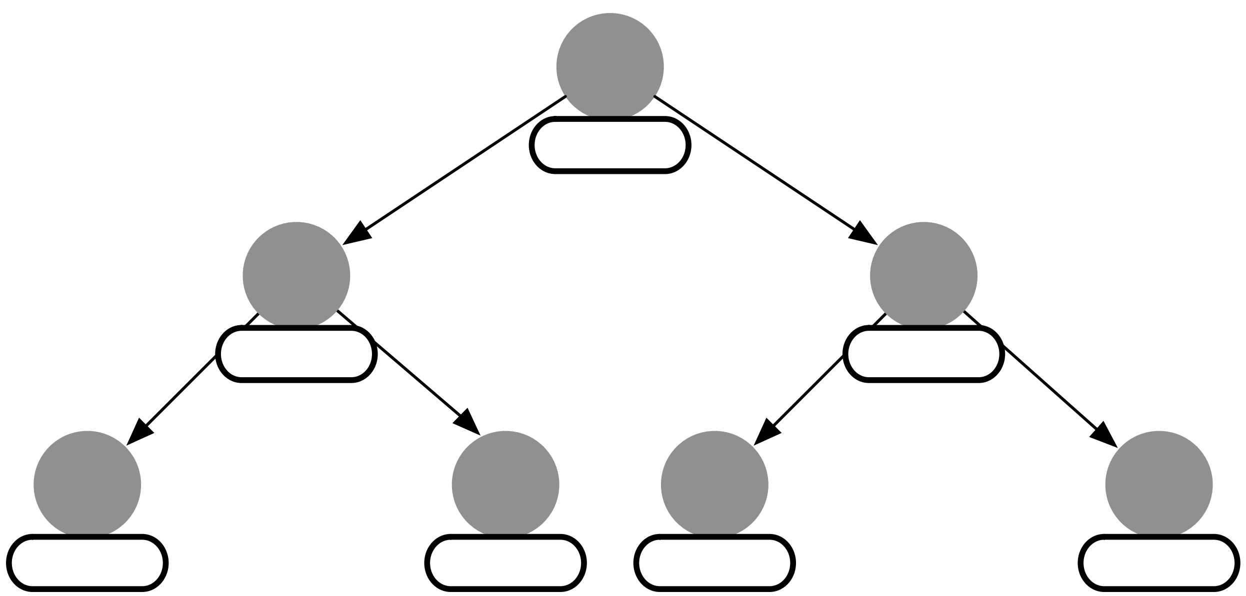
Tension between efficiency of compression and performance

But we want both!



Compressed Buffer Trees

Compressed Buffer Trees (CBT)



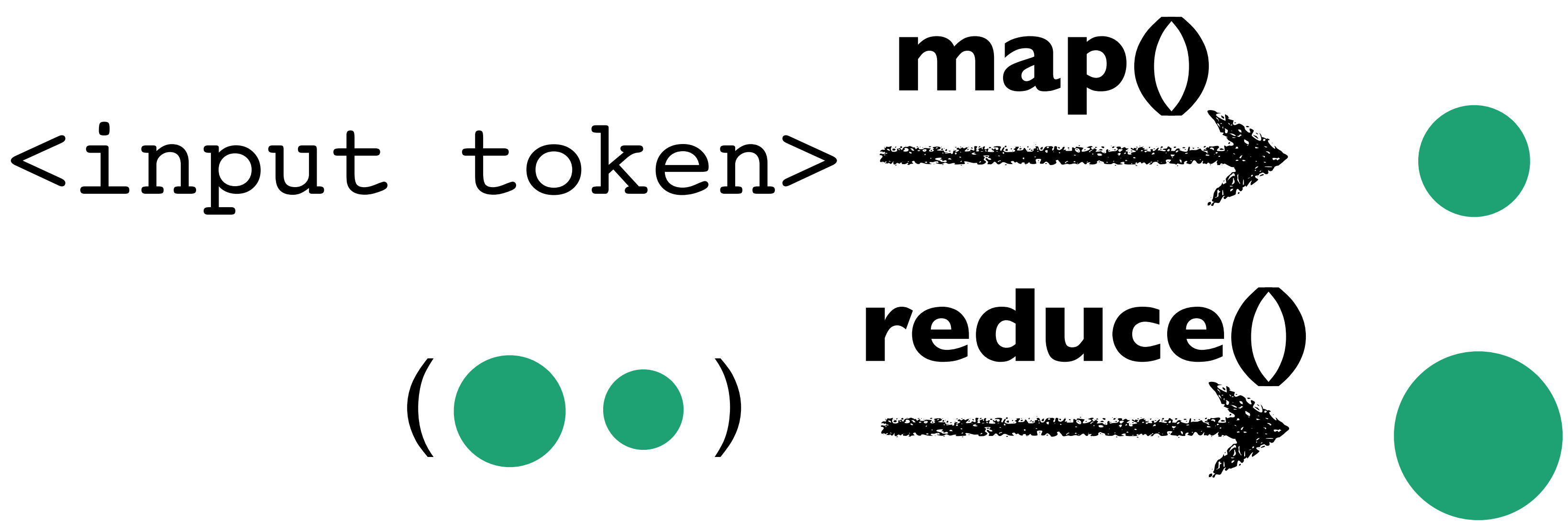
- In-memory B-tree with each node augmented with a memory buffer
- Inspired by the buffer tree[1]

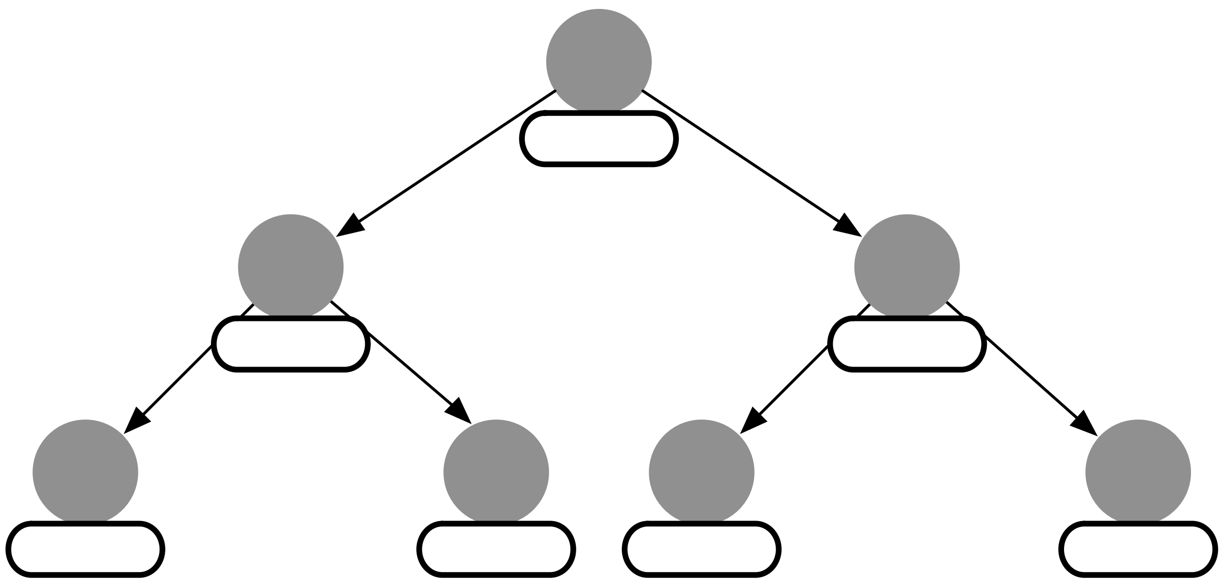
1. The Buffer Tree: A New Technique for Optimal I/O Algorithms, Arge.

Terminology

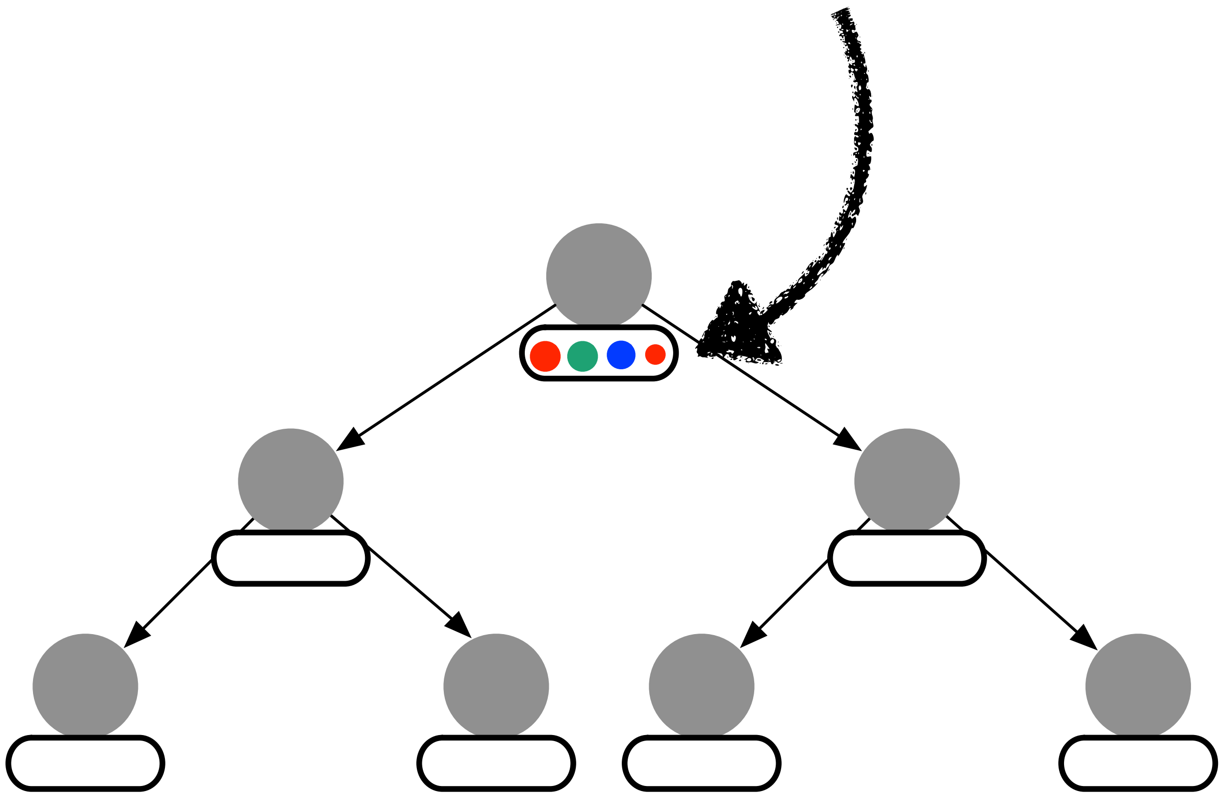
Partial Aggregation Object (PAO)

- User-defined key and value
- Eg. (char*, uint32) for wordcount, (char*, vector<T>) for k-Nearest-Neighbor

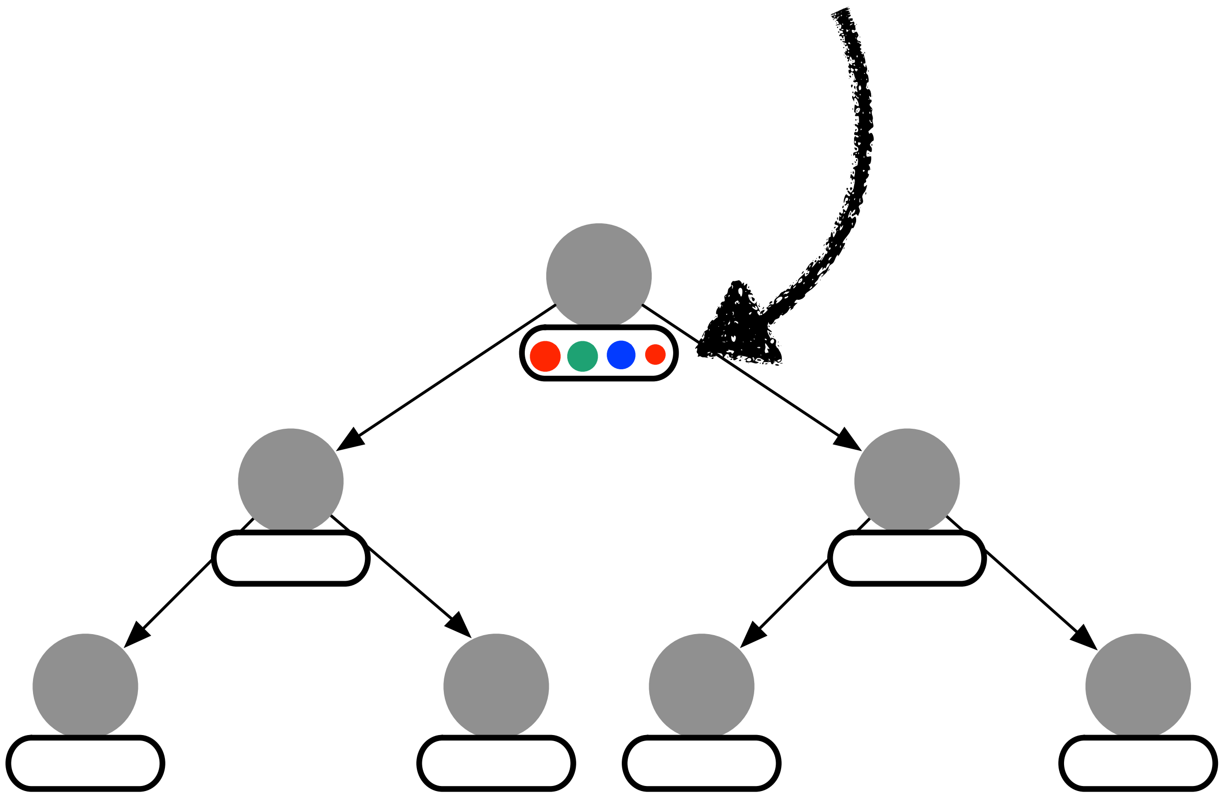




① Insert **PAO**



① Insert **PAO** ② Full root:



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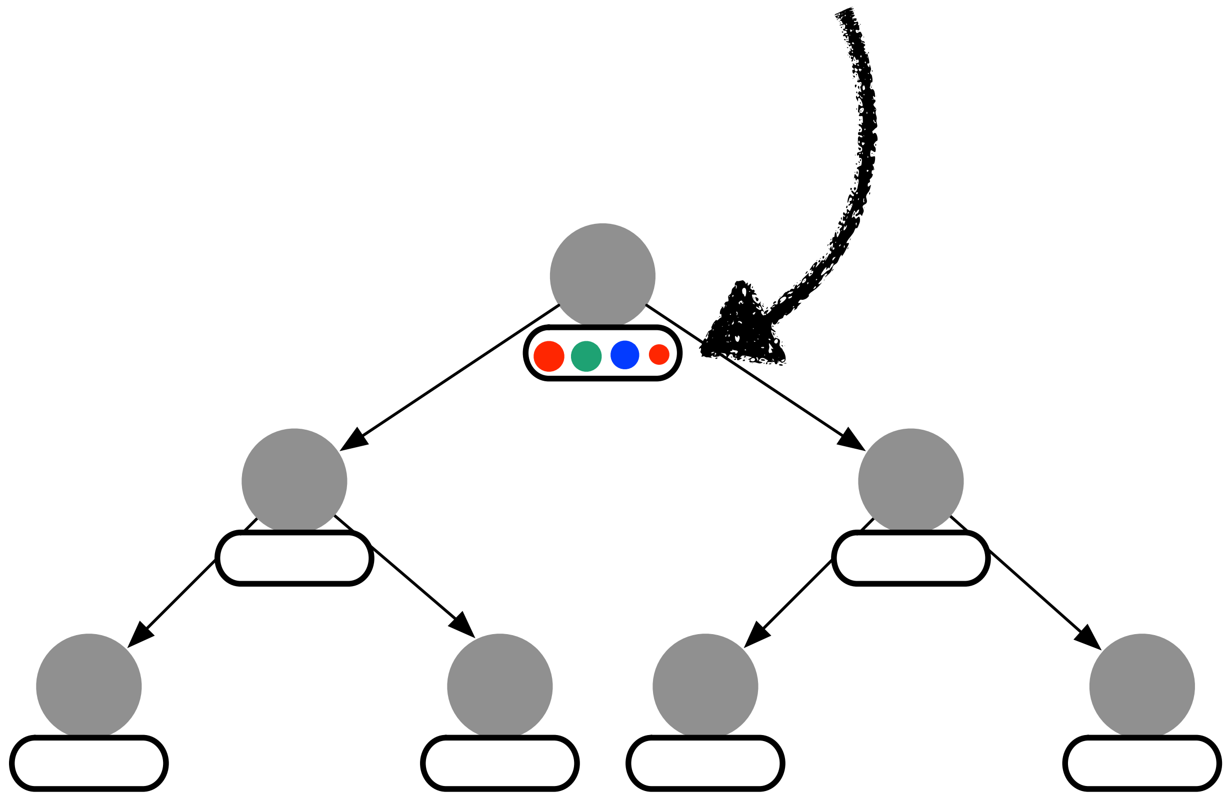
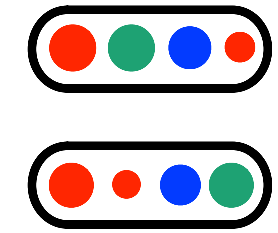


② Full root:

a. sorted



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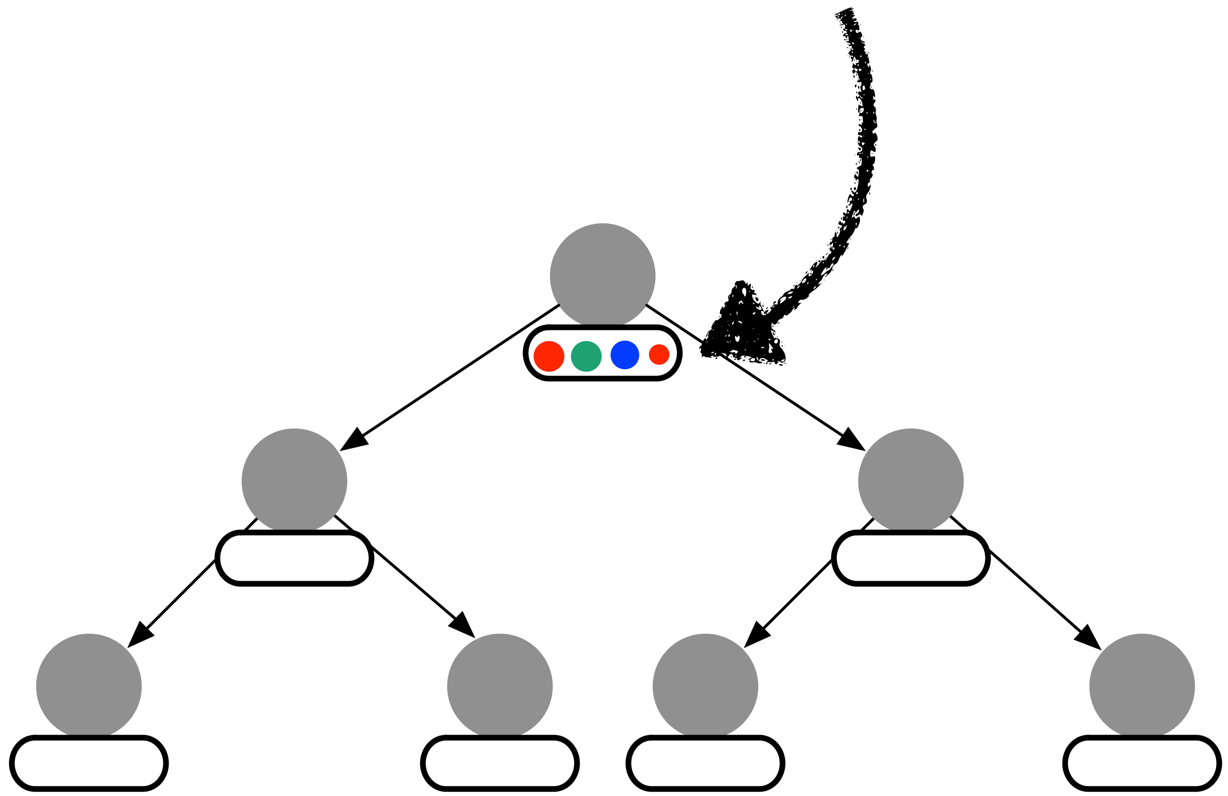

② Full root:

a. sorted

b. aggregated

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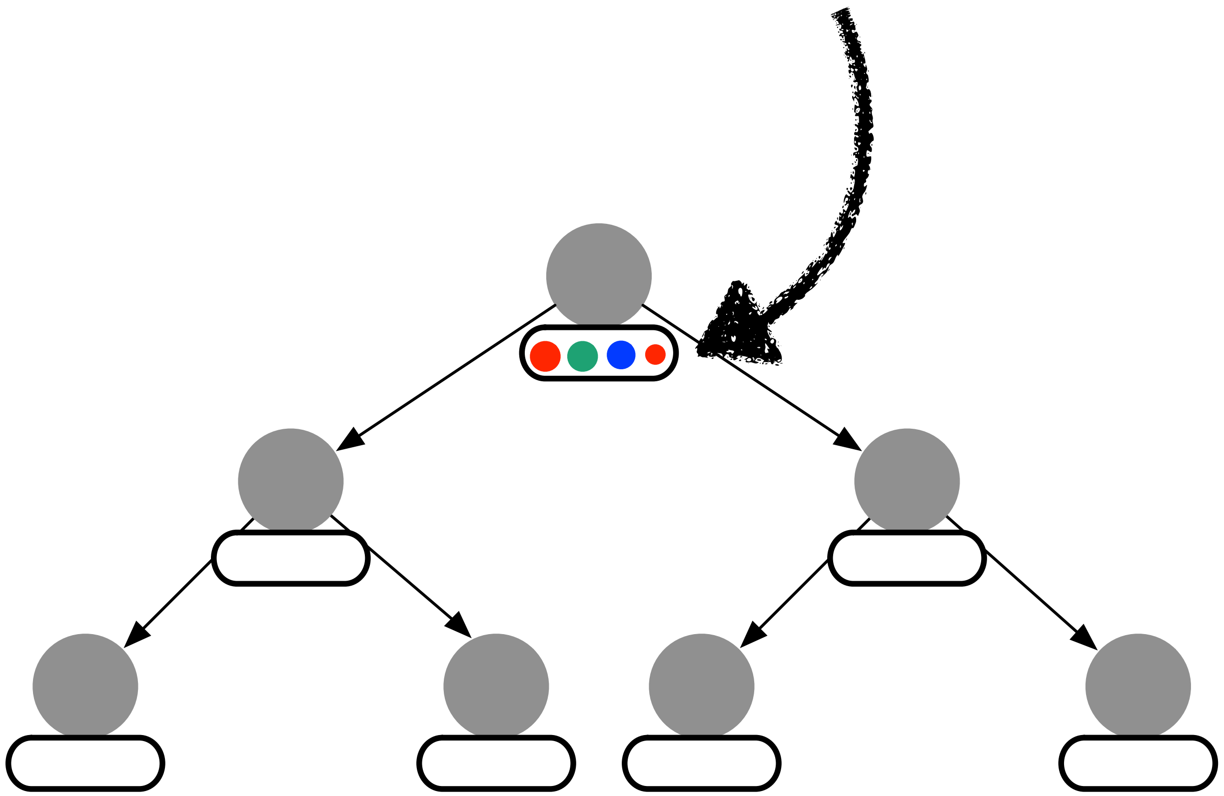

② Full root:

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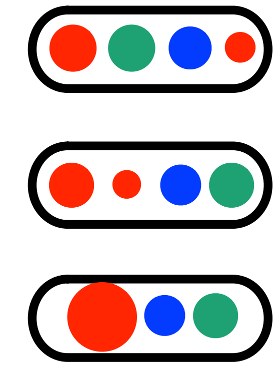

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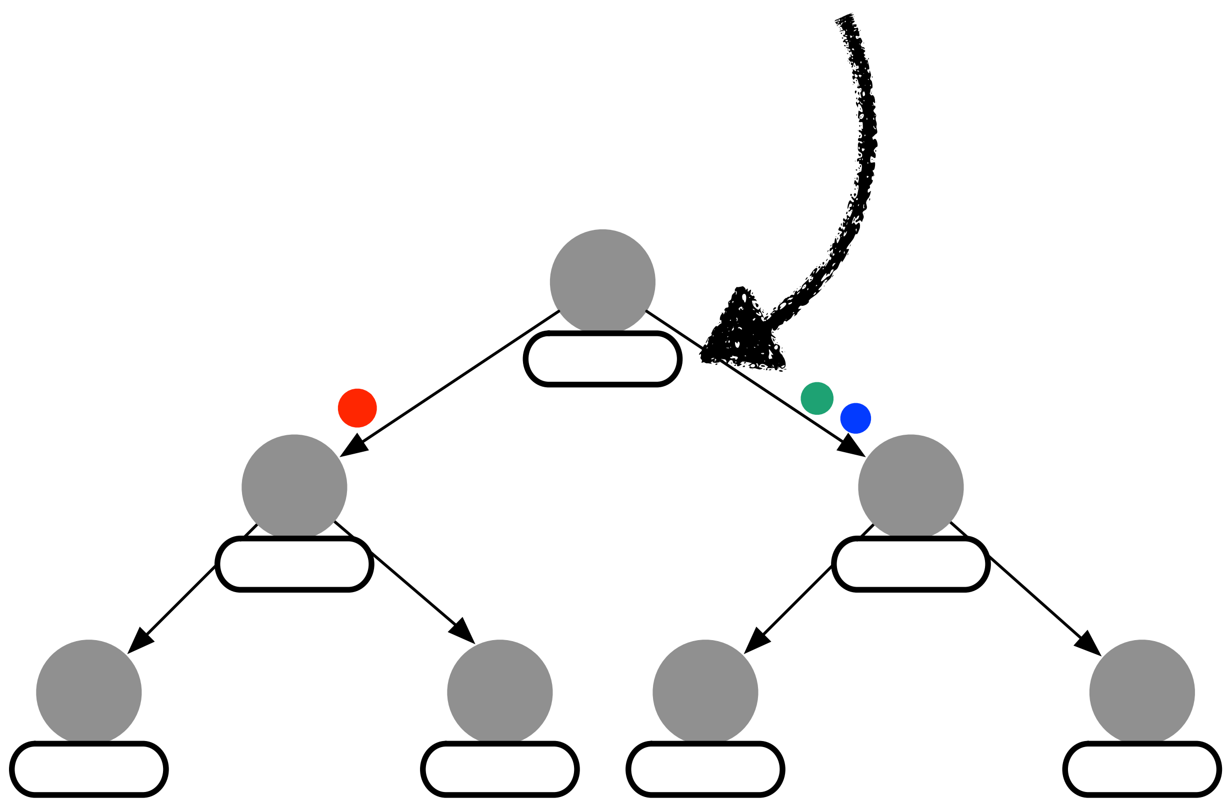

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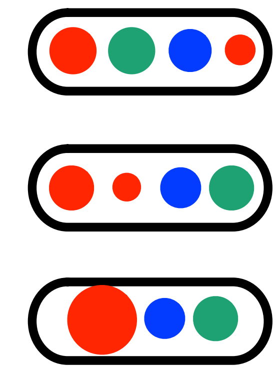

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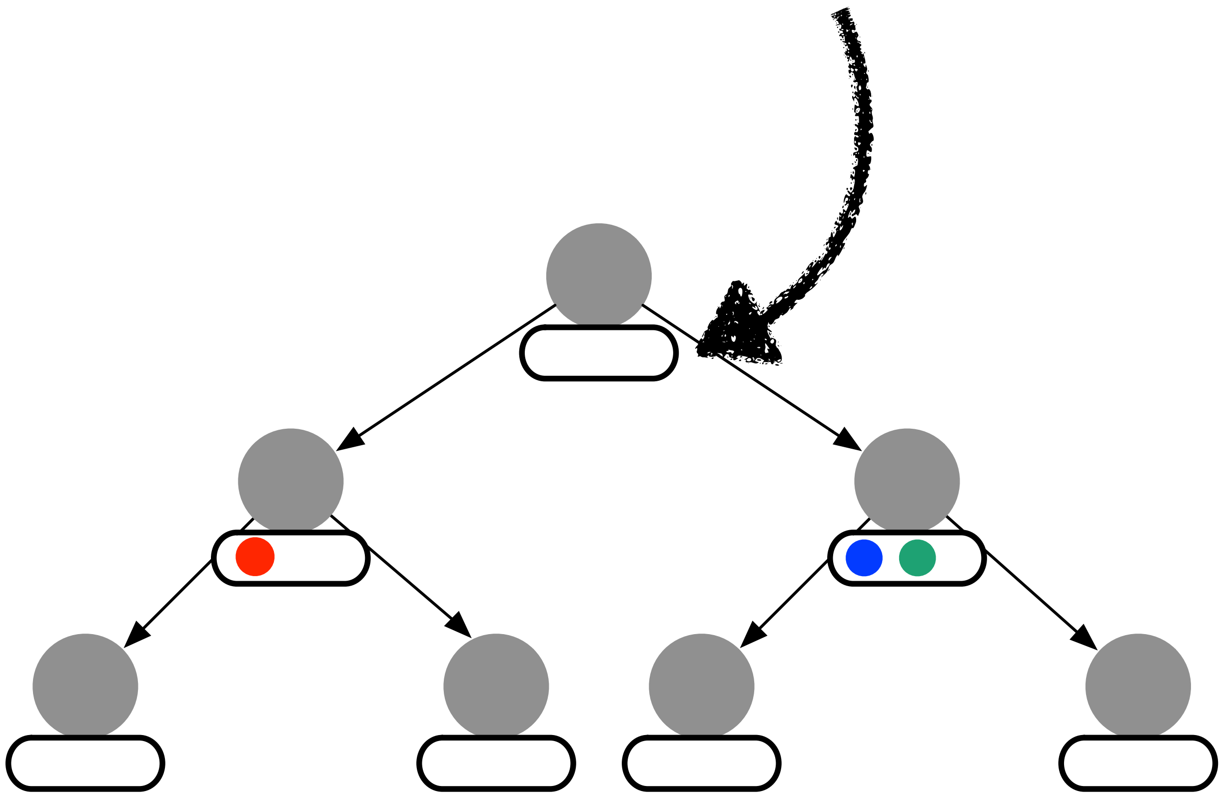

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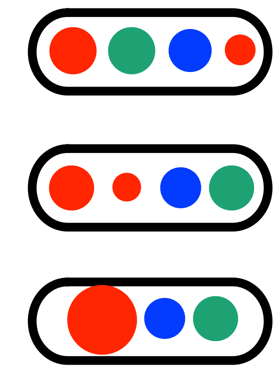

① Insert **PAO**

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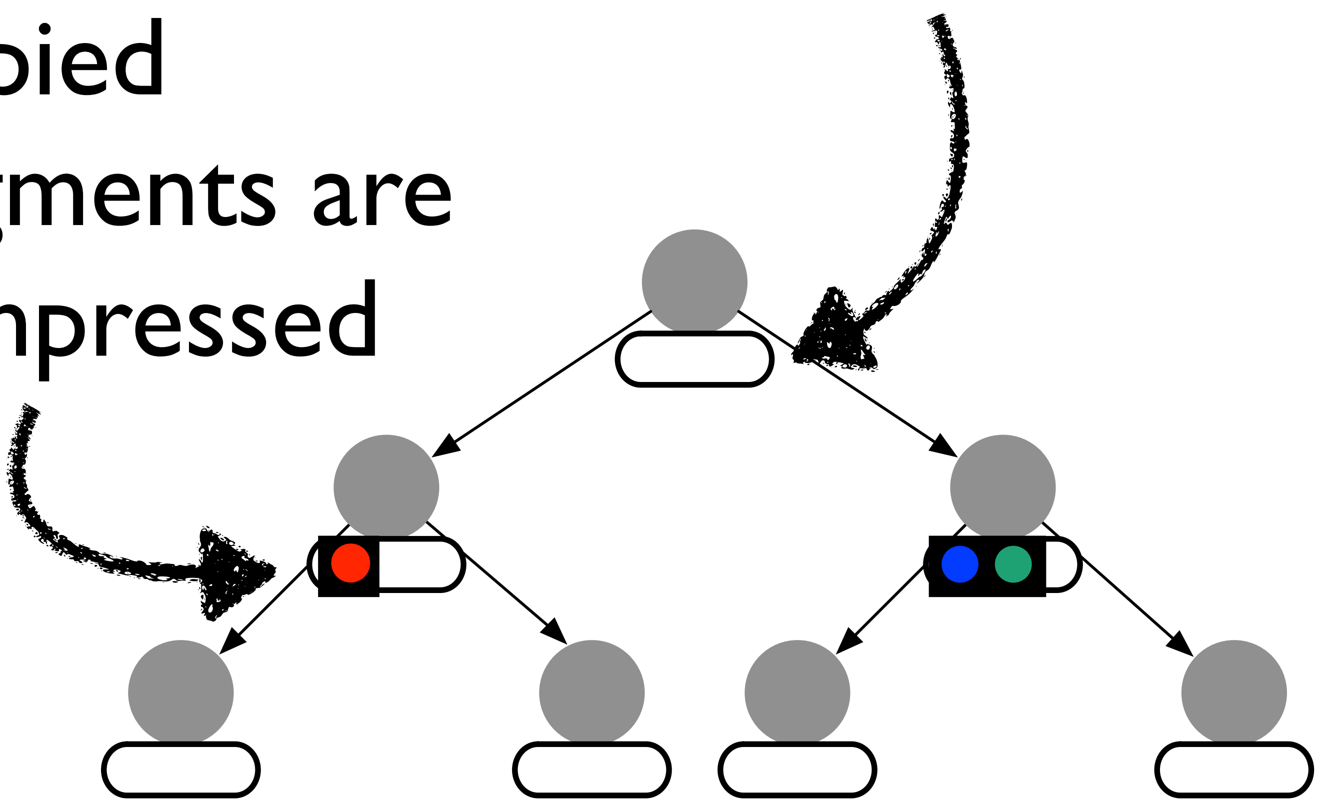
③ Copied fragments are compressed



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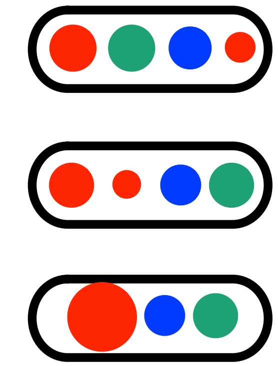

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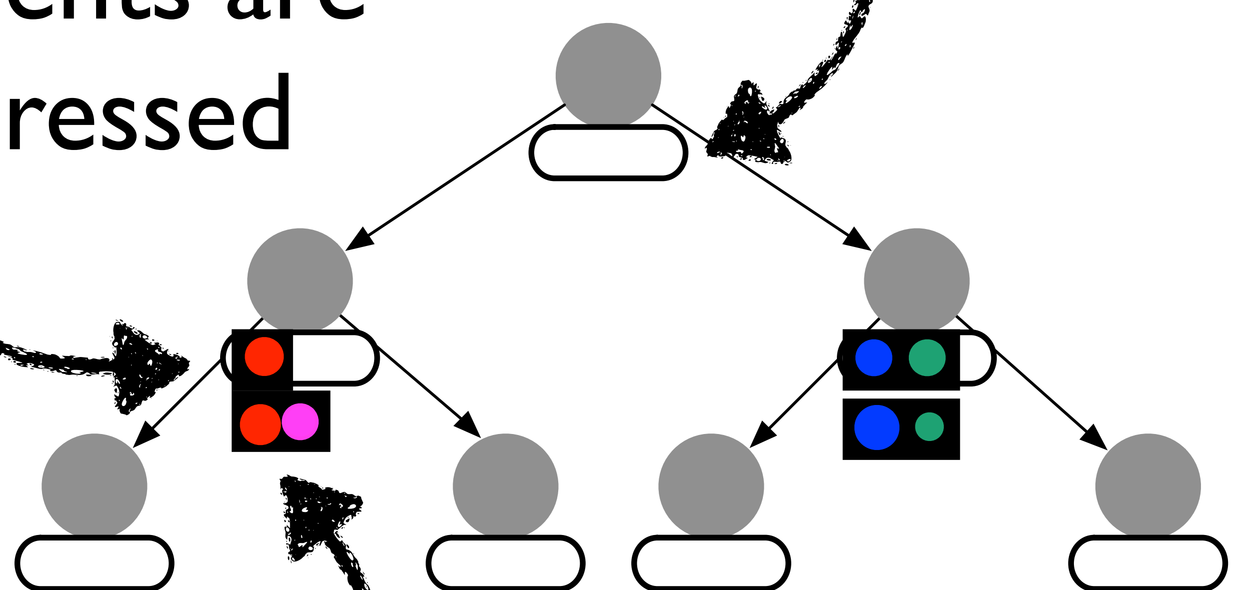

④ Further spills create more fragments

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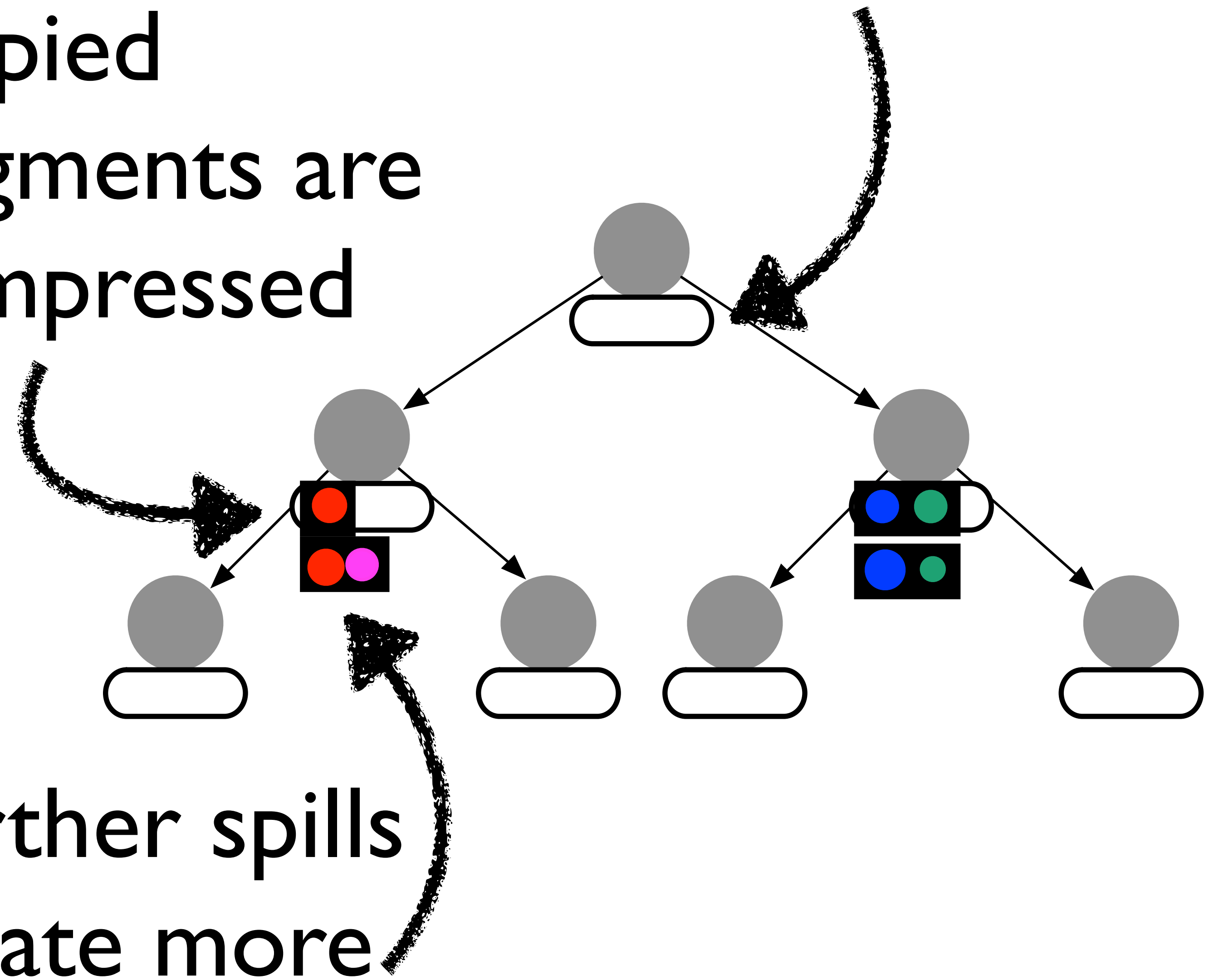

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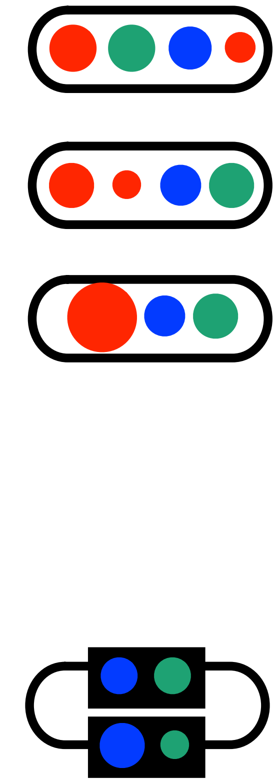
⑤ Full node:



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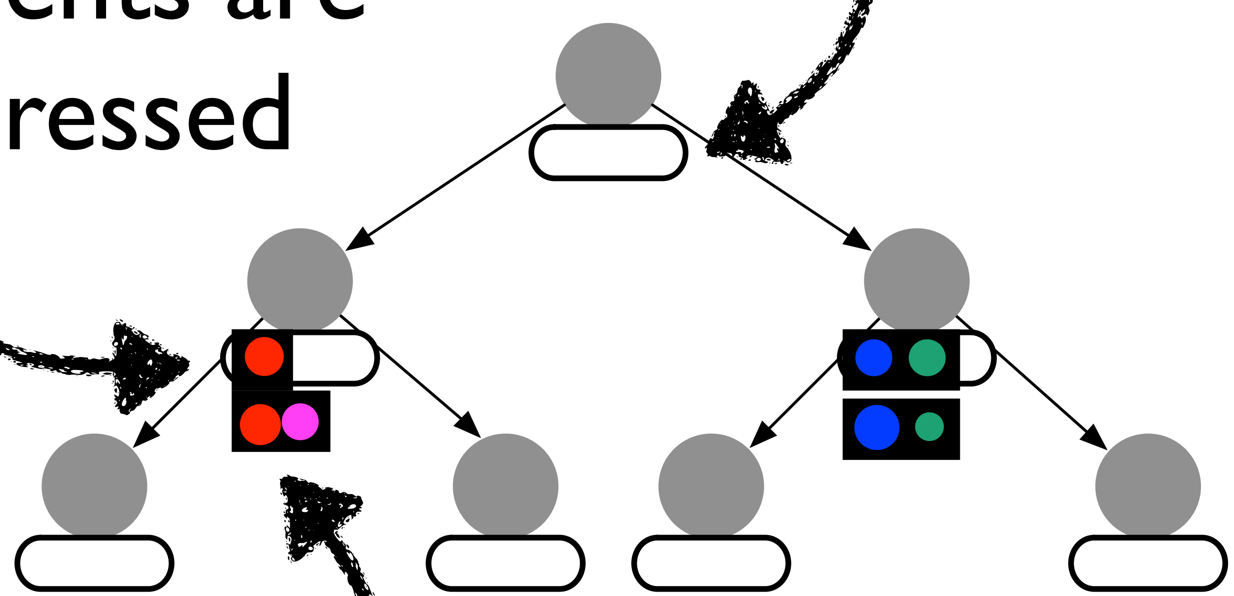

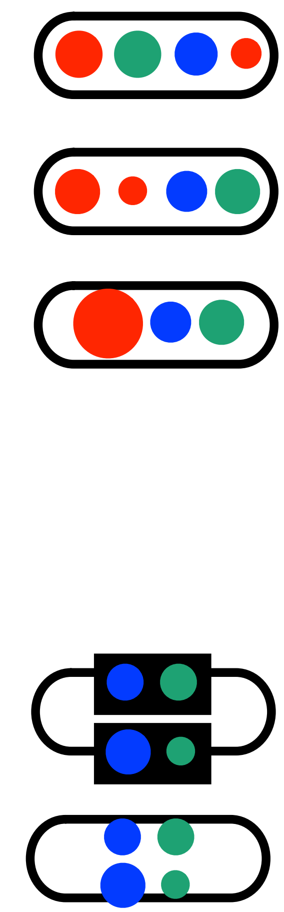

④ Further spills create more fragments

⑤ Full node:

a. decomp.

① Insert **PAO**

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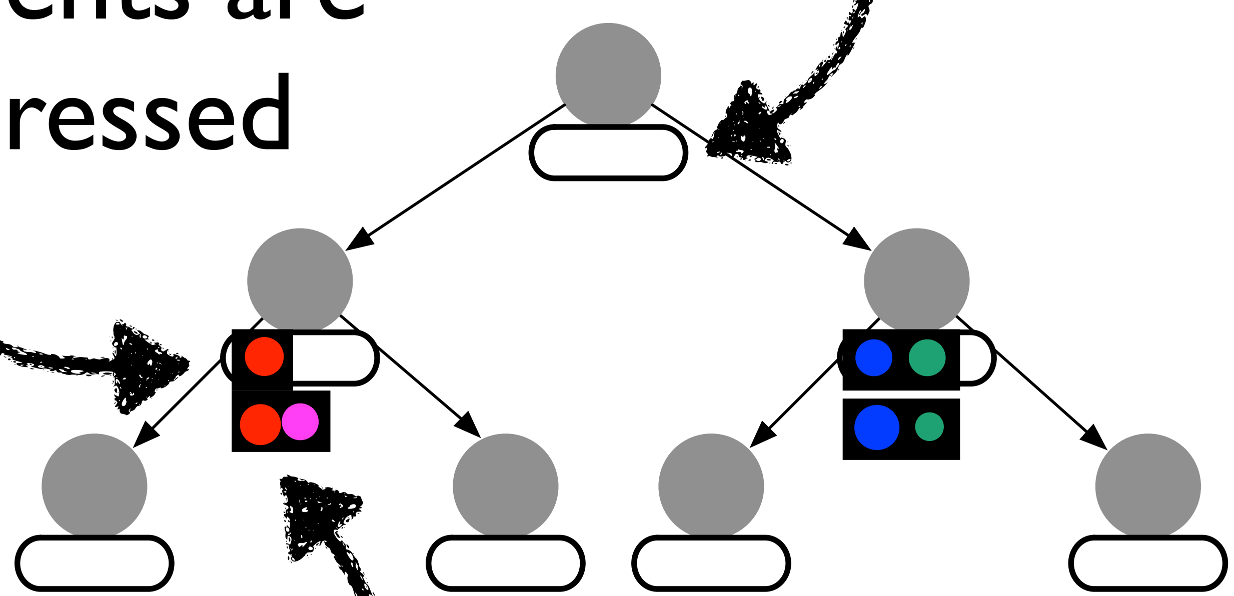
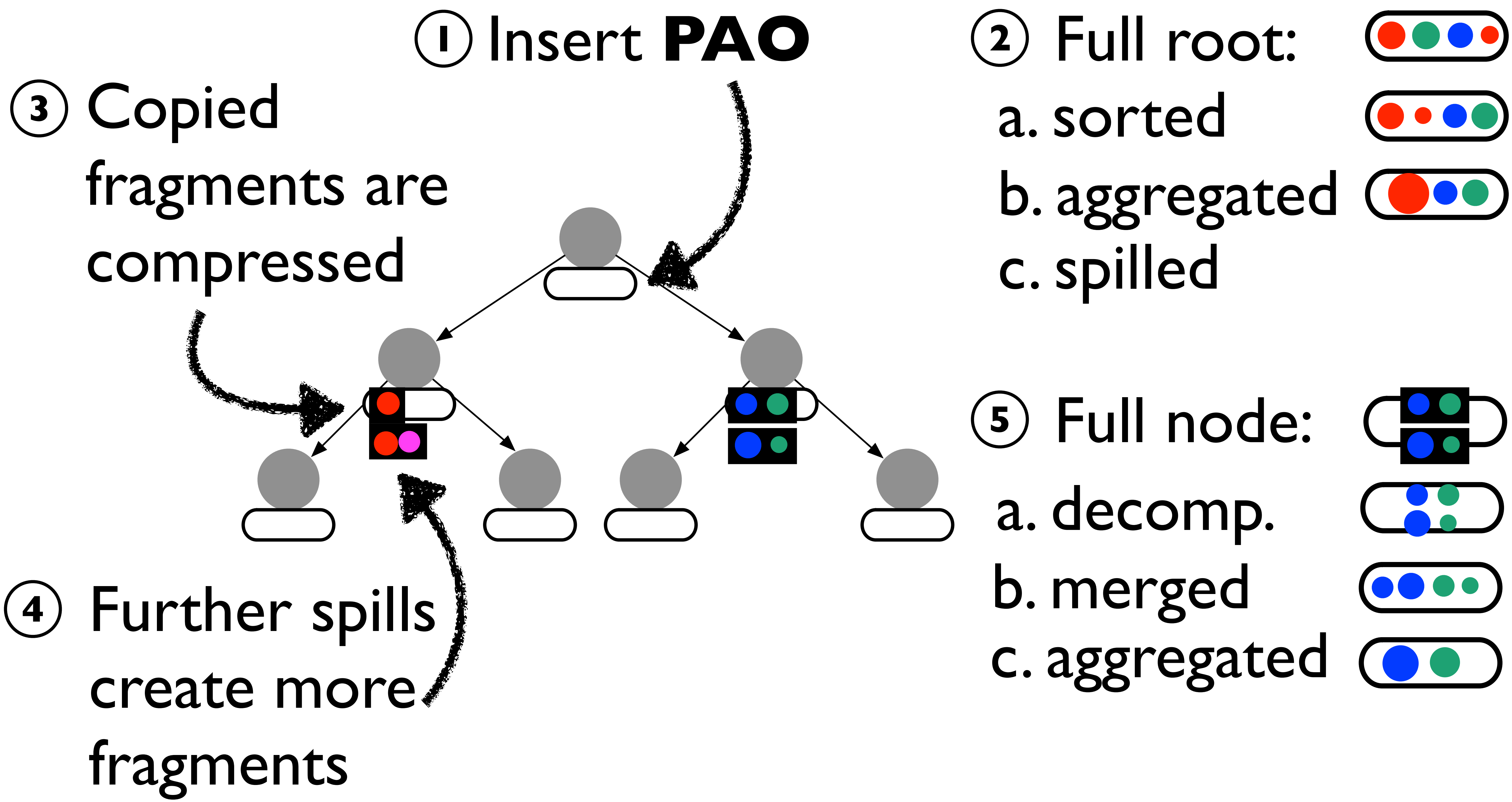


④ Further spills create more fragments

⑤ Full node:

a. decomp.

b. merged



1 Insert PAO
2 Full root:
a. sorted
b. aggregated
c. spilled
3 Copied fragments are compressed
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① Insert **PAO**

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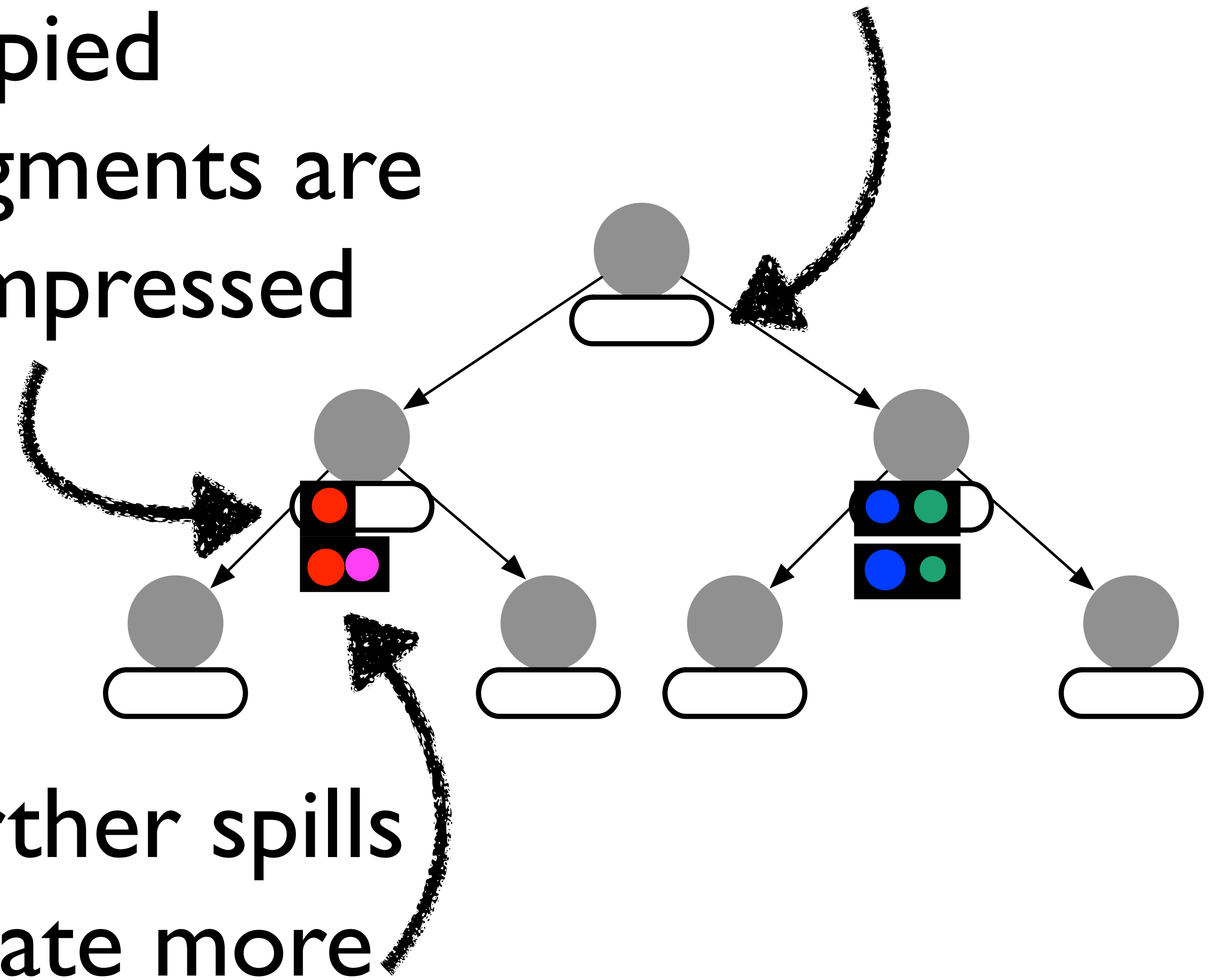

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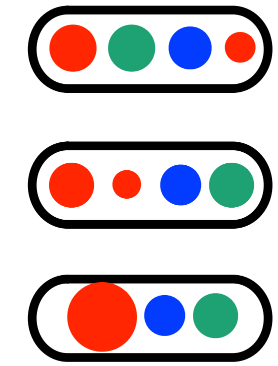

⑤ Full node:

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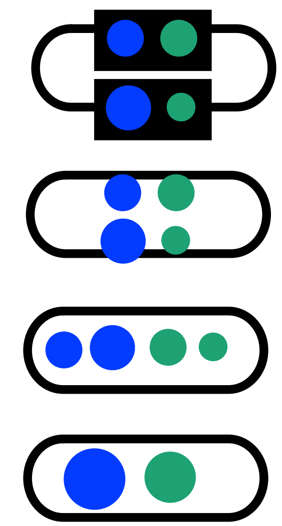

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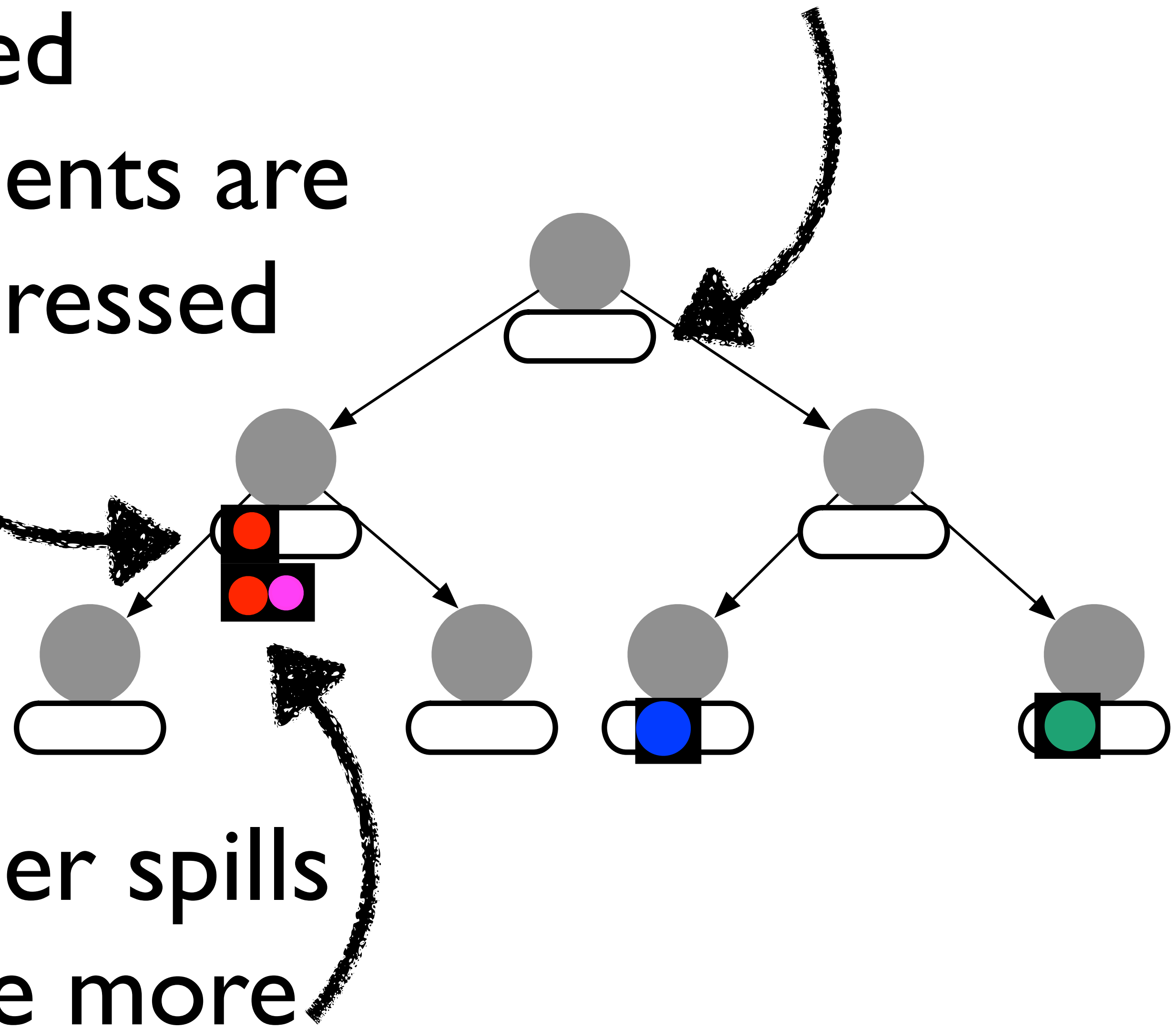

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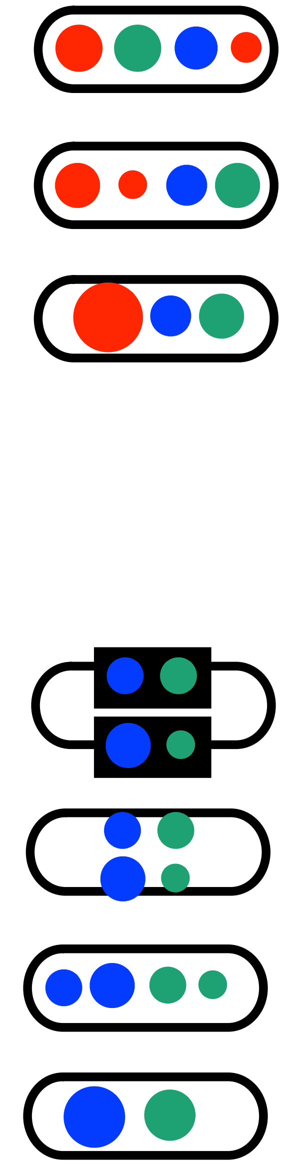
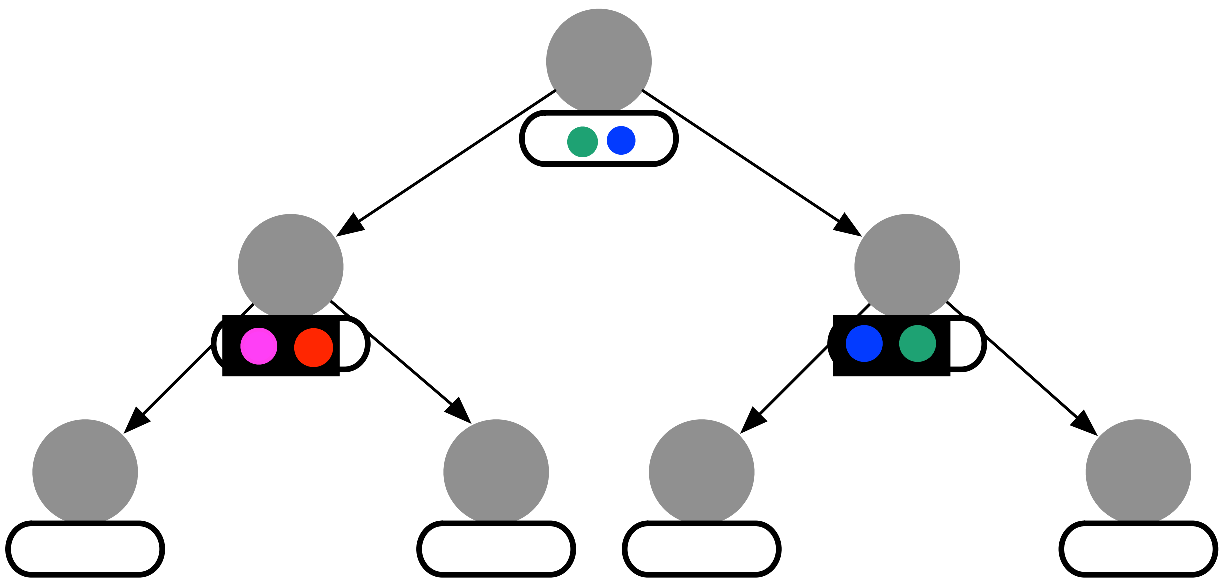
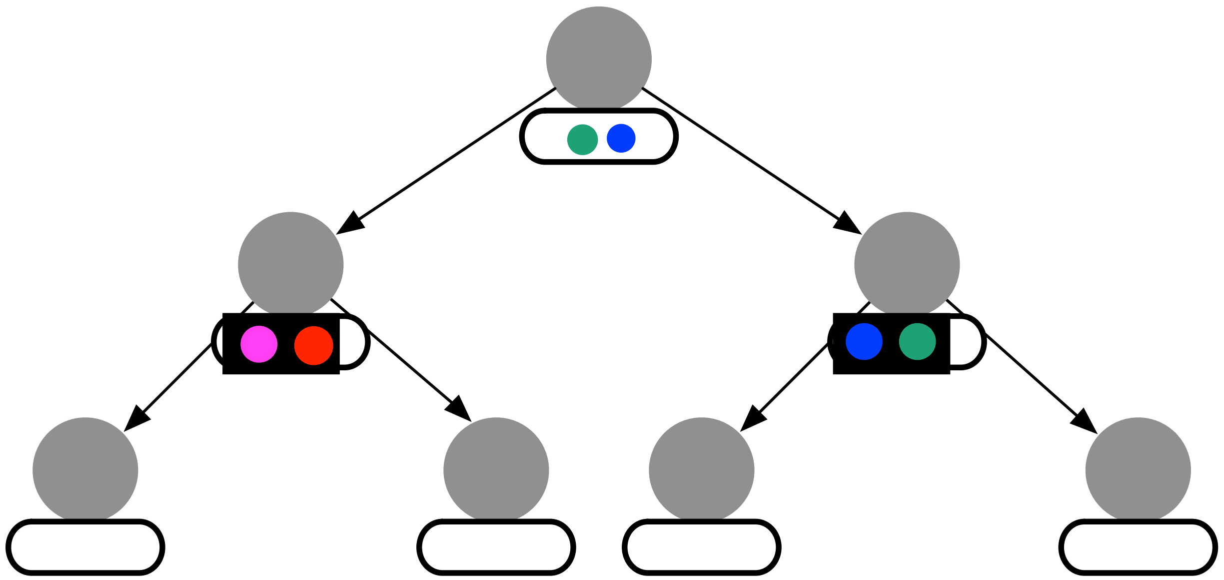
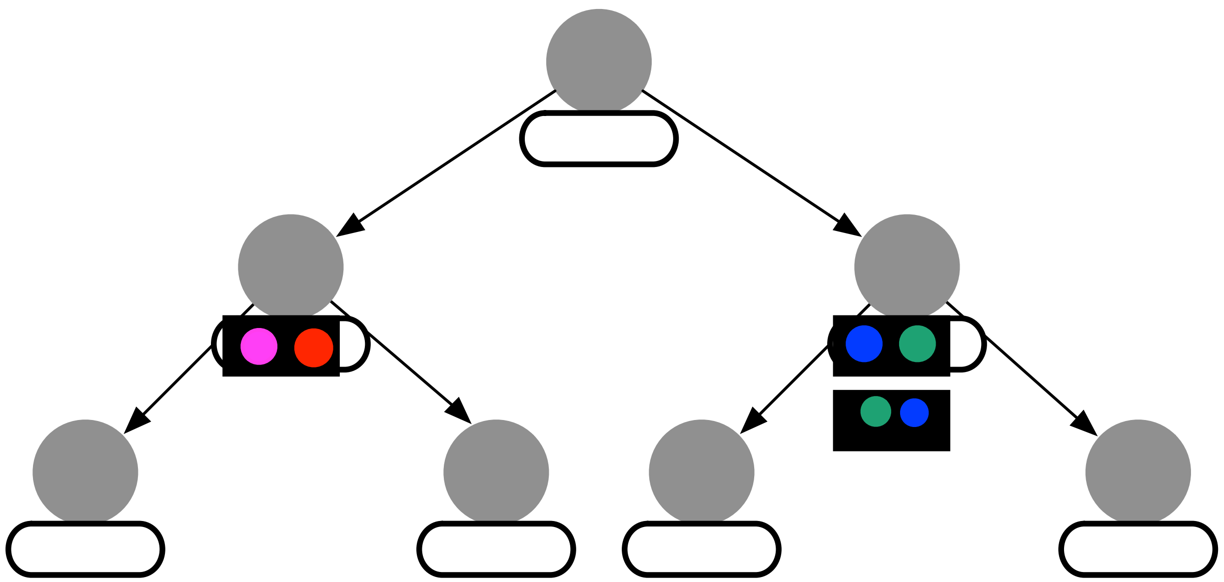




⑥ After all inserts, tree is flushed





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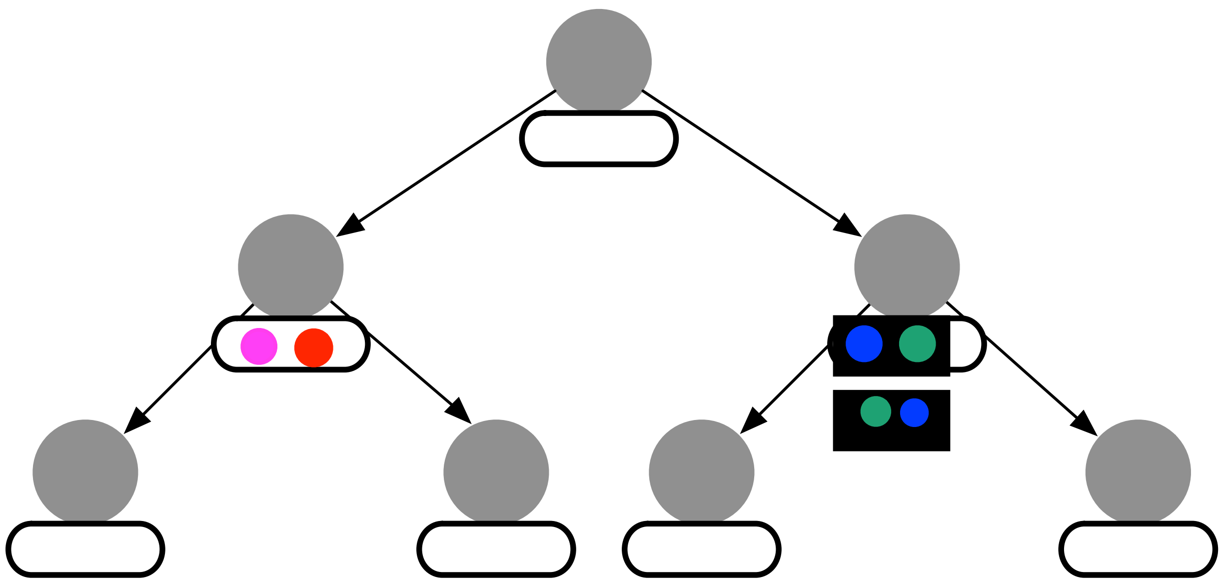

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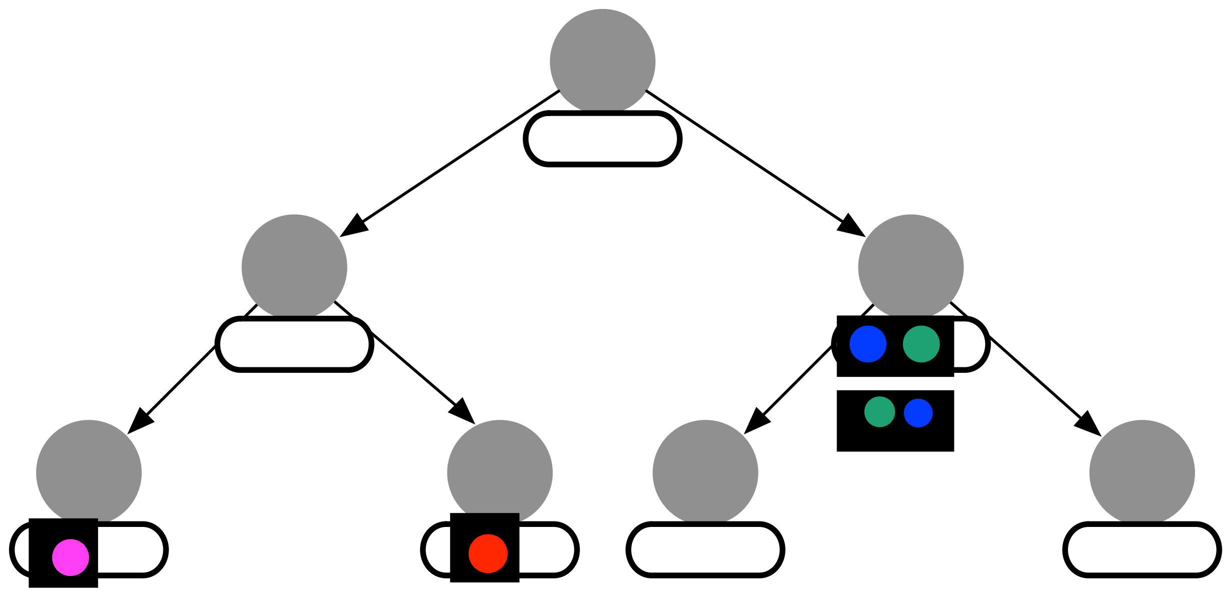
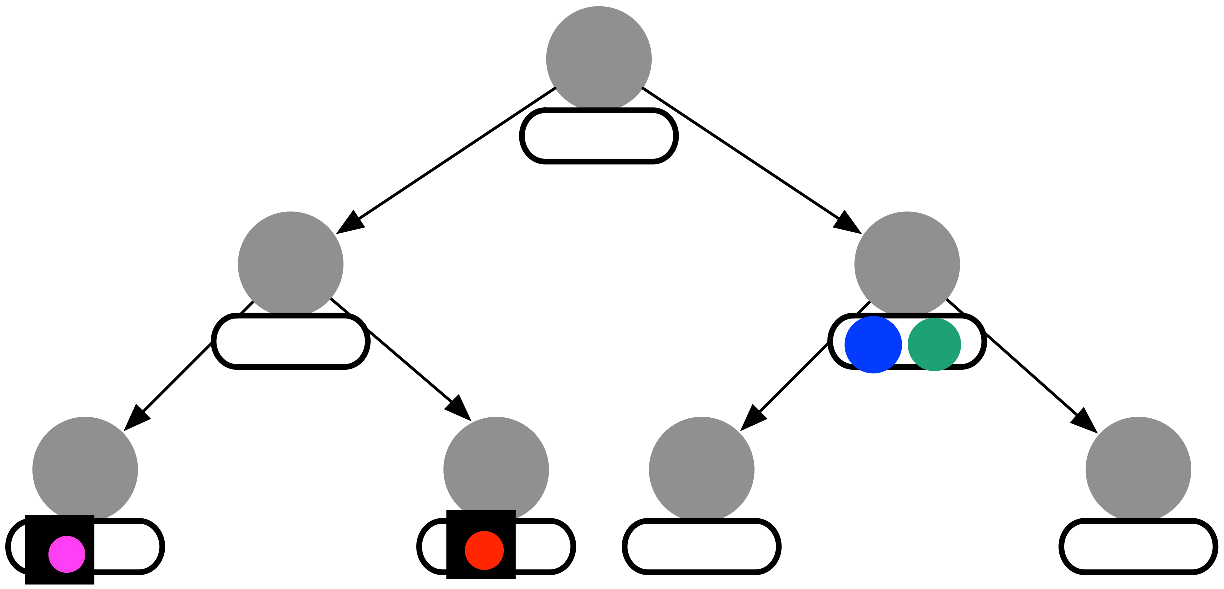
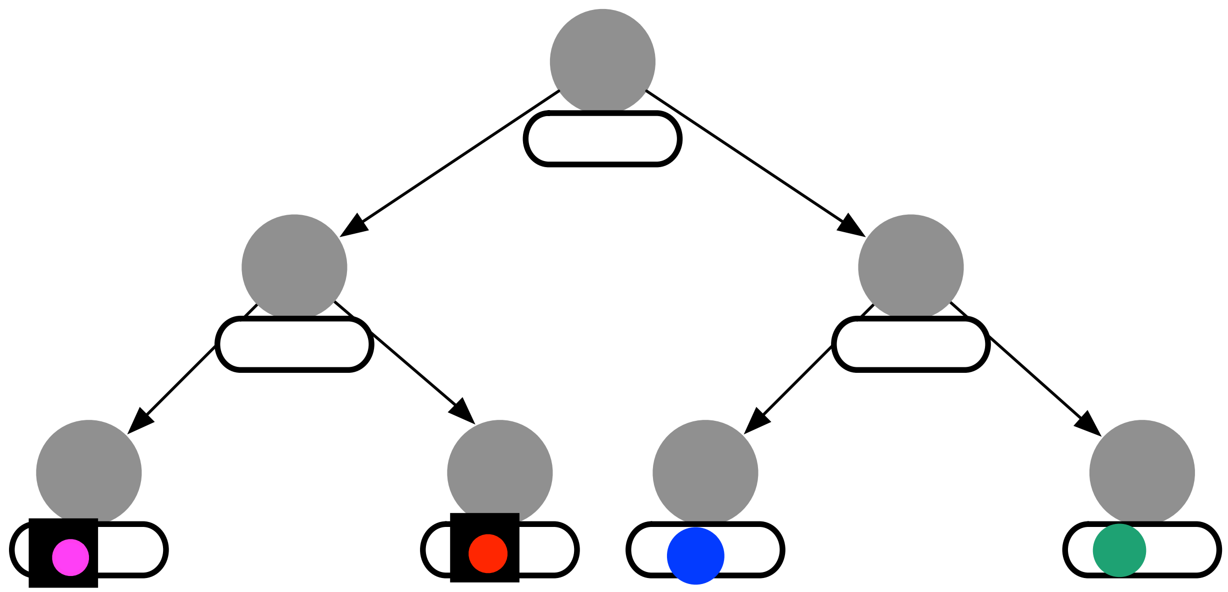


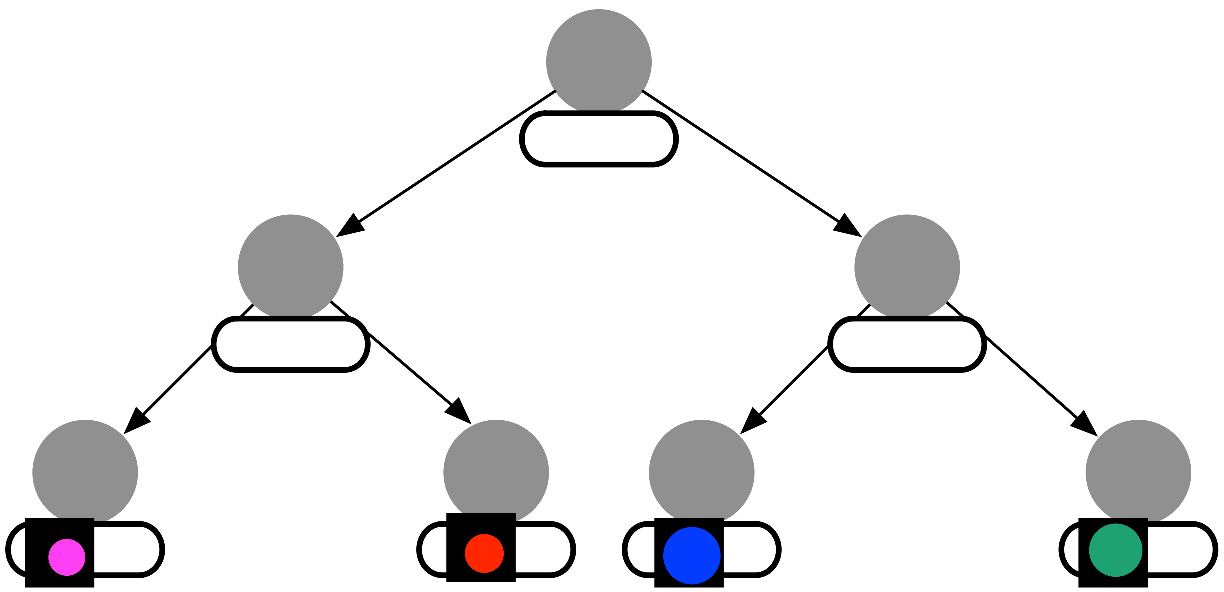
⑥ After all inserts, tree is flushed



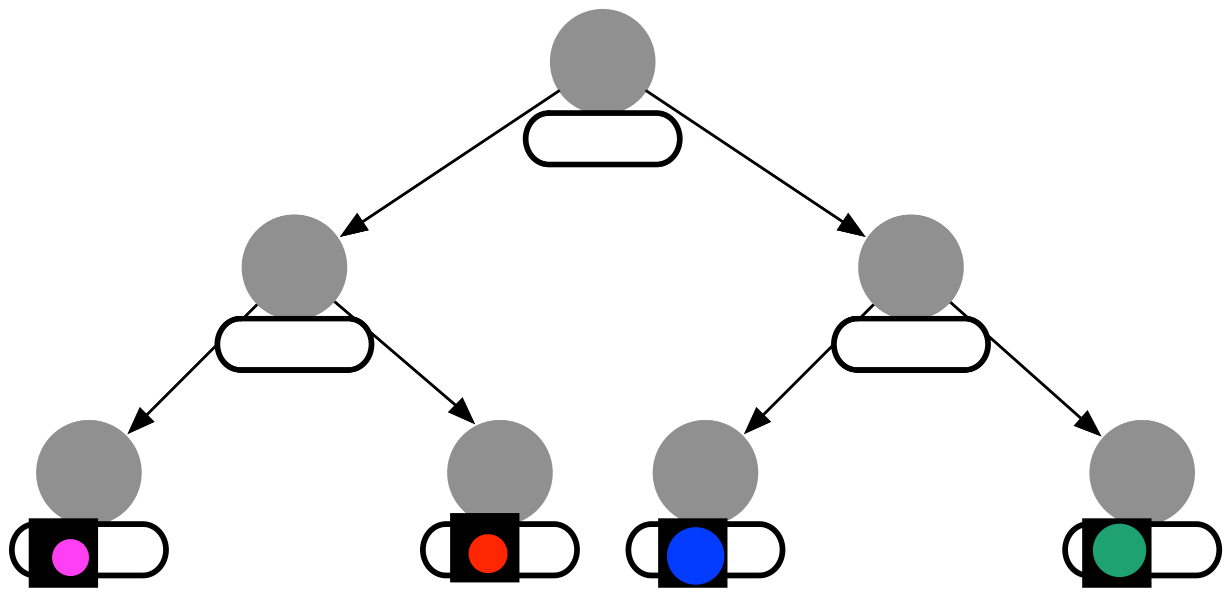
⑥ After all inserts, tree is flushed



⑥ After all inserts, tree is flushed



⑥ After all inserts, tree is flushed



⑦ Aggregated results available in leaves

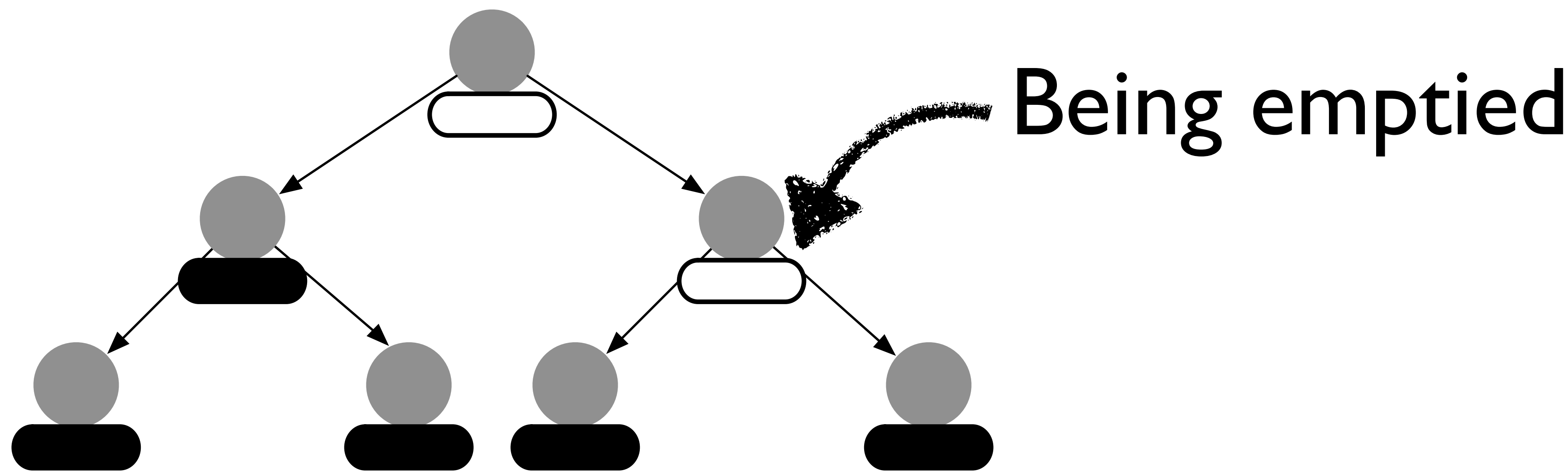
CBT Operation (recap)

- **PAO**s always inserted into root buffer
- If root full, sort **PAO**s, aggregate and spill
- Spilled buffer fragments are compressed in memory
- If child is full, decompress fragments, merge and spill recursively
- Flush tree at the end

Compressed Buffer Tree

Compressed Buffer Tree

Memory efficiency through compression



Compressed Buffer Tree

Memory efficiency through compression

Compressed Buffer Tree

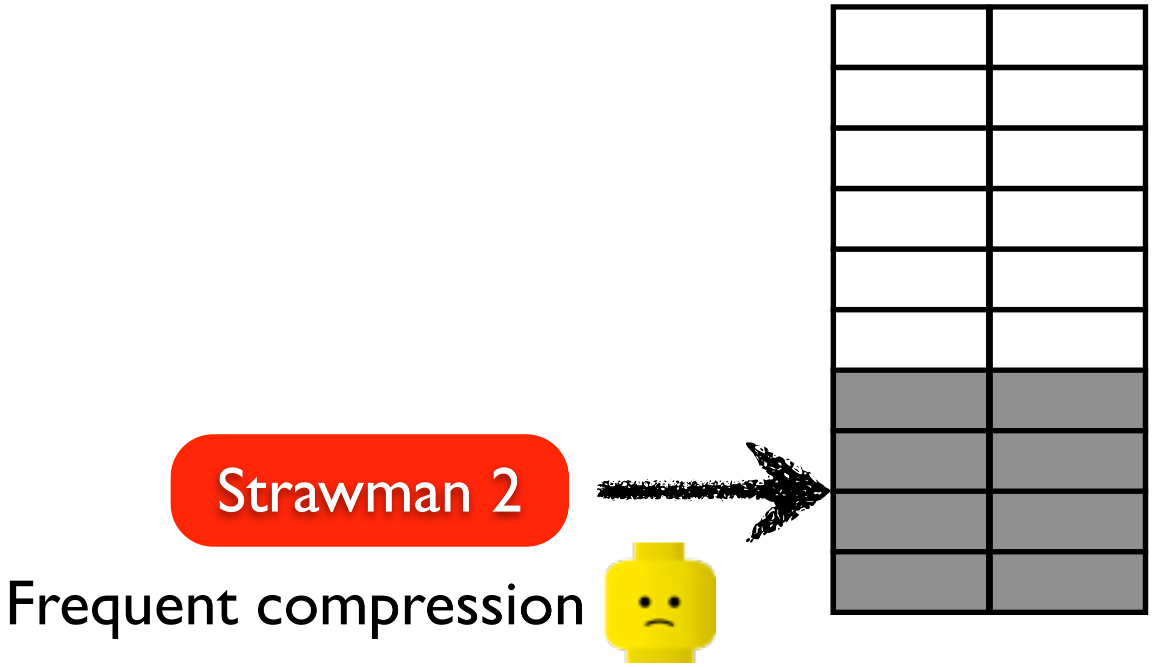
Memory efficiency through compression

Effective compression through use of large buffers

Compressed Buffer Tree

Memory efficiency through compression

Effective compression through use of large buffers



Compressed Buffer Tree

Memory efficiency through compression

Effective compression through use of large buffers

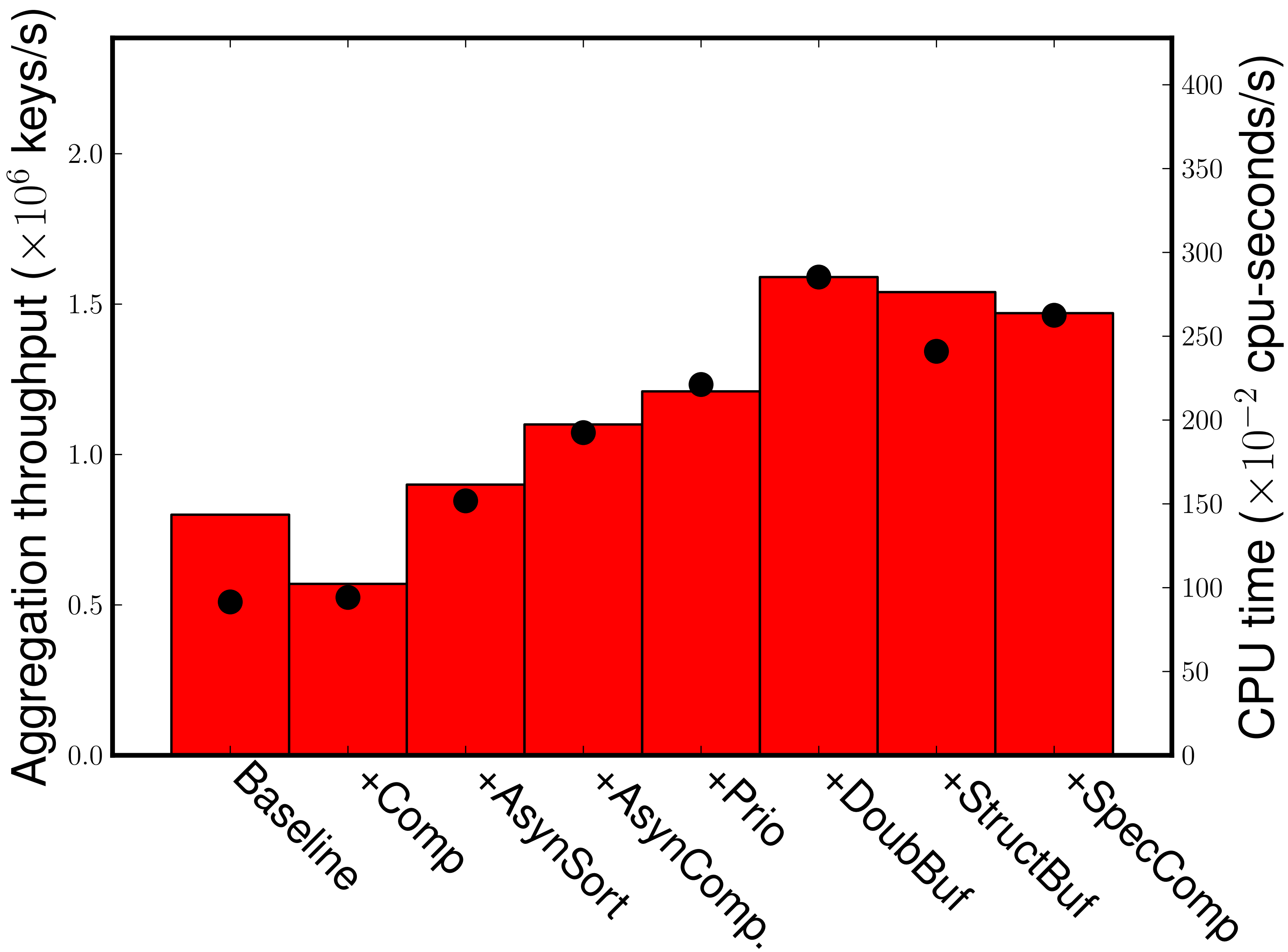
Compressed Buffer Tree

Memory efficiency through compression

Effective compression through use of large buffers

High performance through buffering

Implementation



Performance

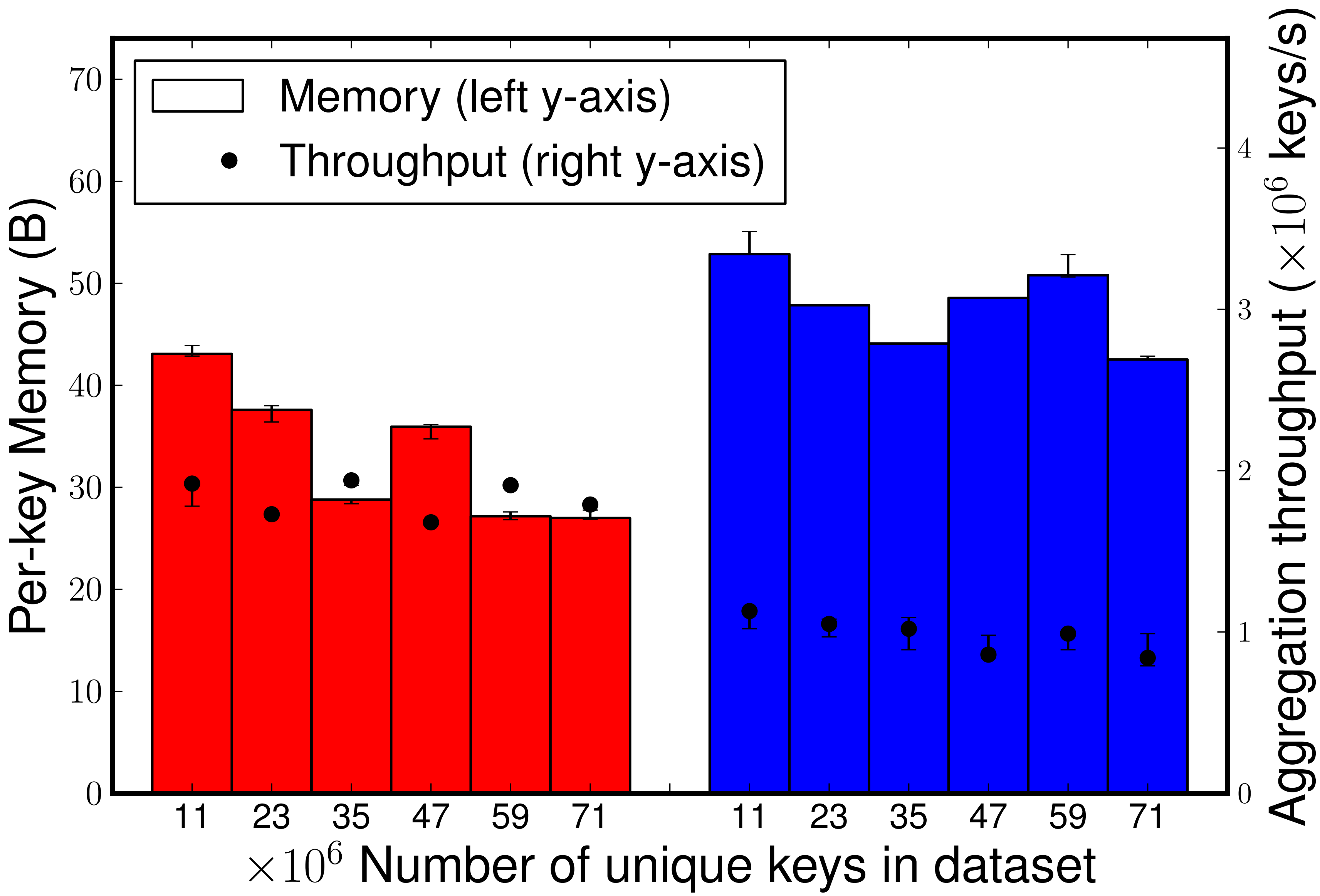
Microbenchmark

Application	Dataset
Wordcount	Key: Random 8B char array Value: 4B uint

Applications:

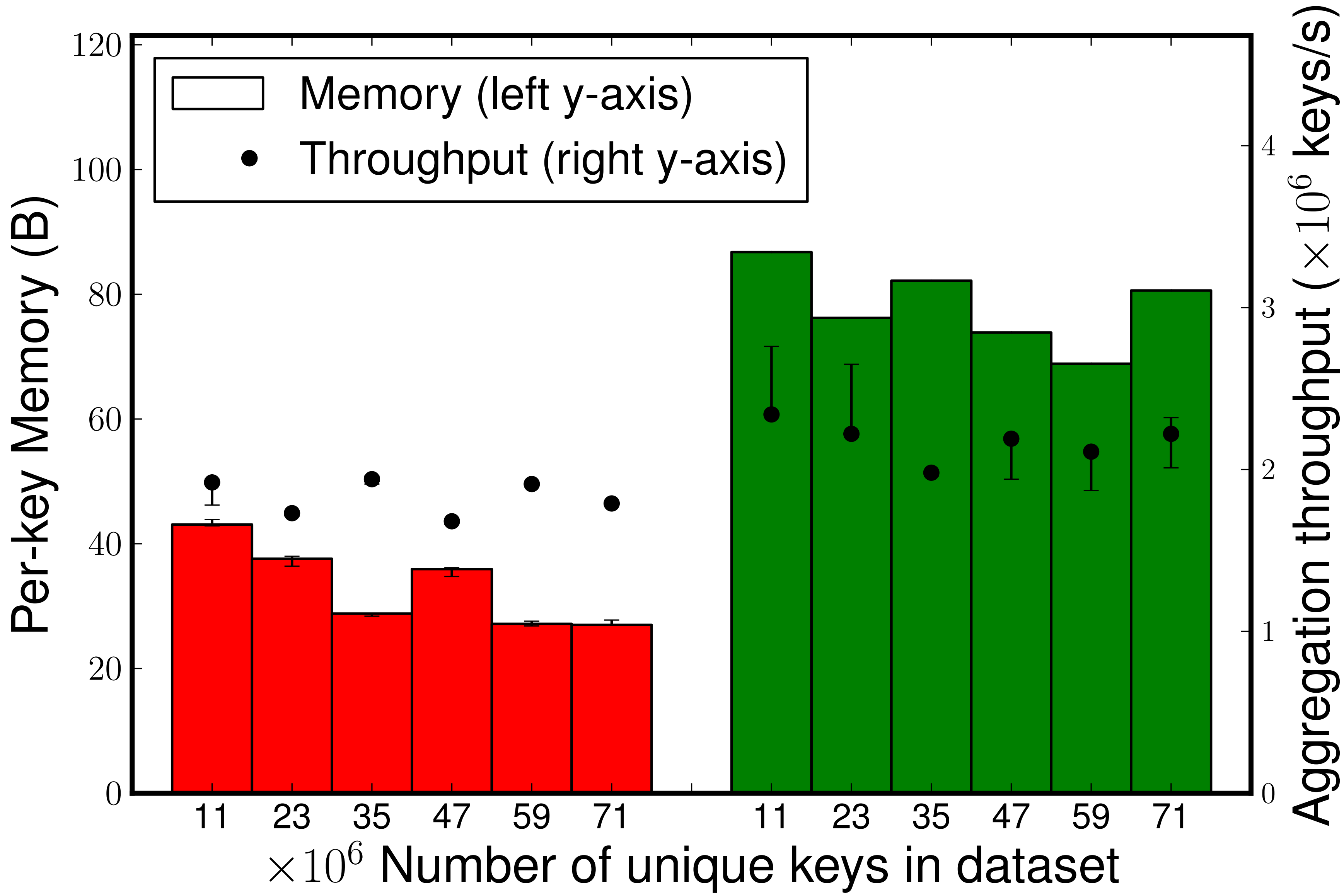
Application	Dataset
Tri-gram count	Project Gutenberg ebooks
Clustering	MIT Tiny Image Dataset
Pagerank	Twitter follower network

Memory Usage: CBT vs. HT



(red)	CBT	Compressed Buffer Tree
(blue)	HT	Google sparse_hash_map

Throughput: CBT vs. HT-C



Application: Wordcount

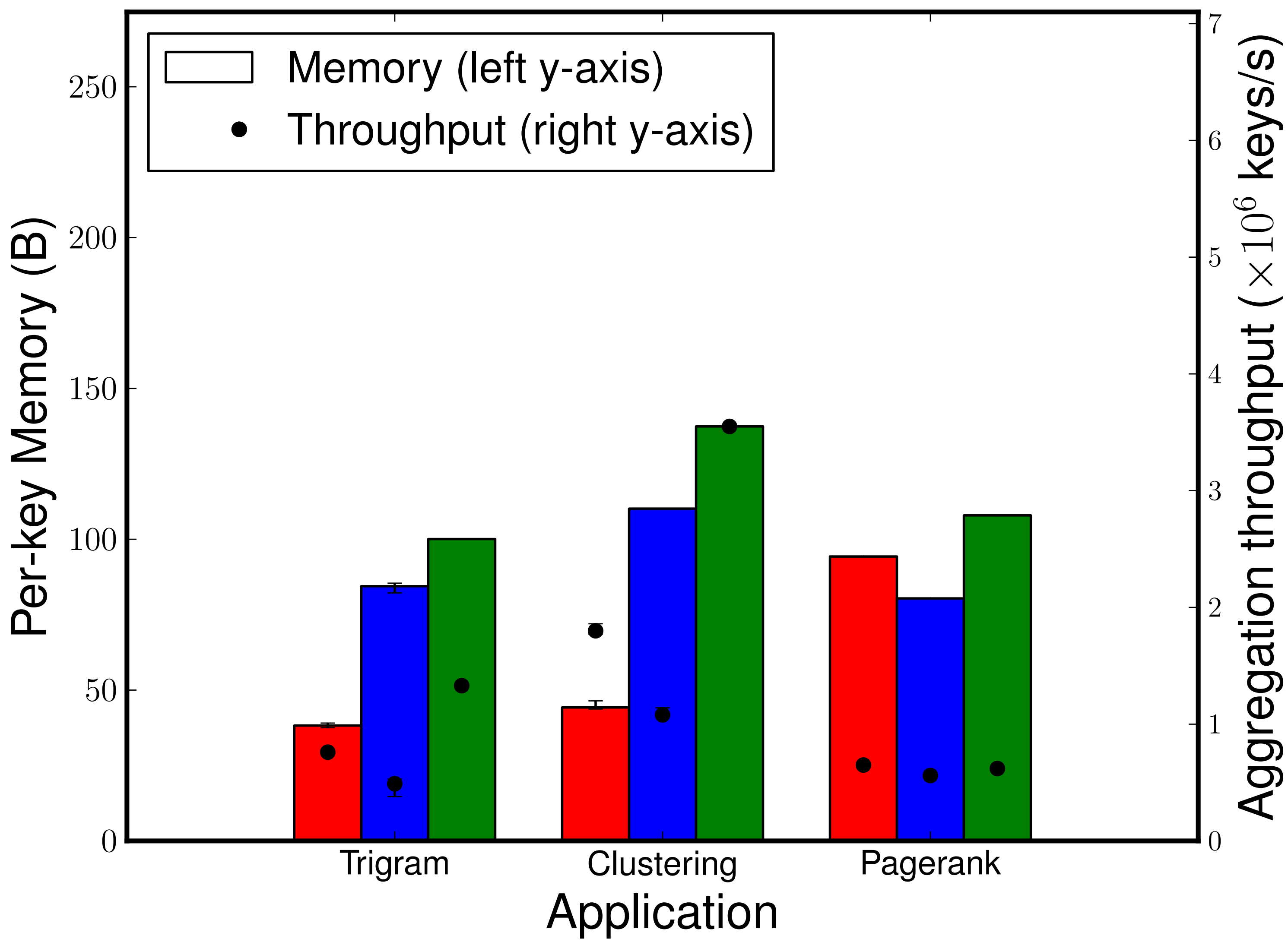
Dataset:

Key: 8B char array

Value: 4B uint

	CBT	Compressed Buffer Tree
	HT-C	TBB concurrent_hash_map

Performance



(red)	CBT	Compressed Buffer Tree
(blue)	HT	Google sparse_hash_map
(green)	HT-C	TBB concurrent_hash_map

CBT: Summary

Memory efficiency through compression

Effective compression through use of large buffers

High performance through buffering

Thanks!