Deep Dive: Memory Management in Apache Spark

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```
students.select("name").orderBy("age").cache().show()
```

Memory Contention

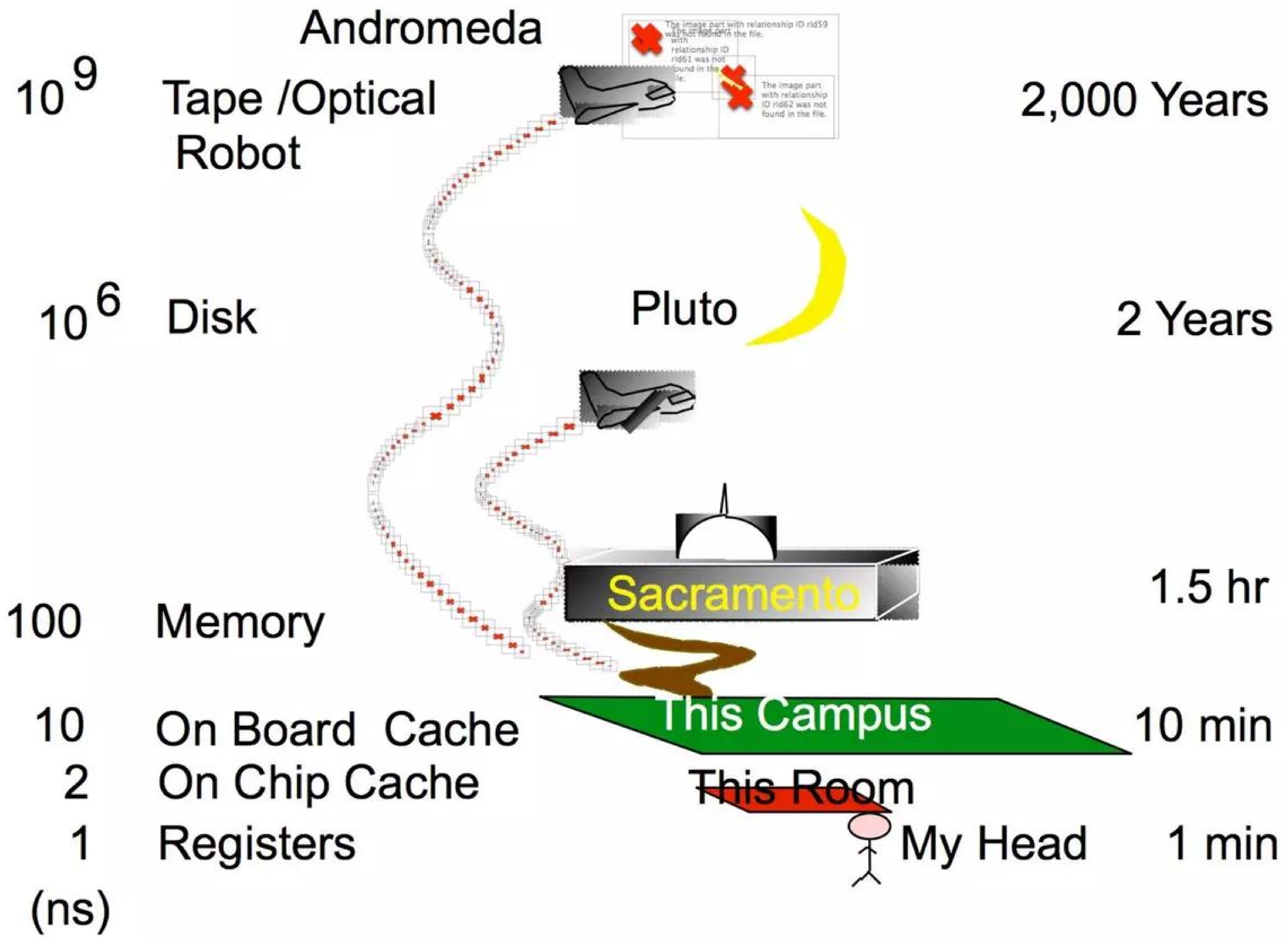
Off-heap

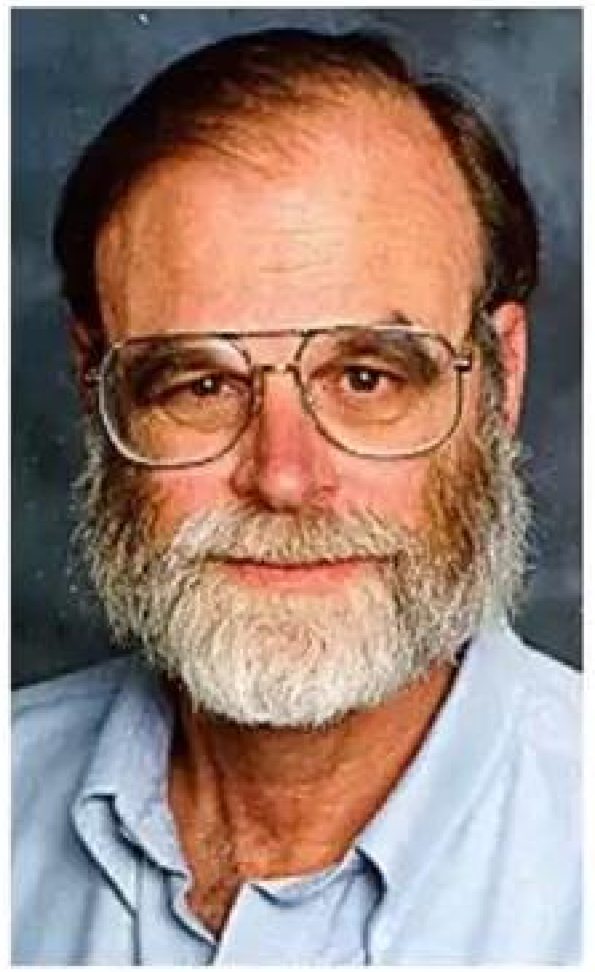
Caching

Tungsten

Efficient memory use is critical to *good performance*

Jim Gray's Storage Latency Analogy: How Far Away is the Data?





Jim Gray
Turing Award
B.S. Cal 1966
Ph.D. Cal 1969!

Memory contention poses three challenges for Apache Spark

How to arbitrate memory between execution and storage?

How to arbitrate memory across tasks running in parallel?

How to arbitrate memory across operators running within the same task?

Two usages of memory in Apache Spark

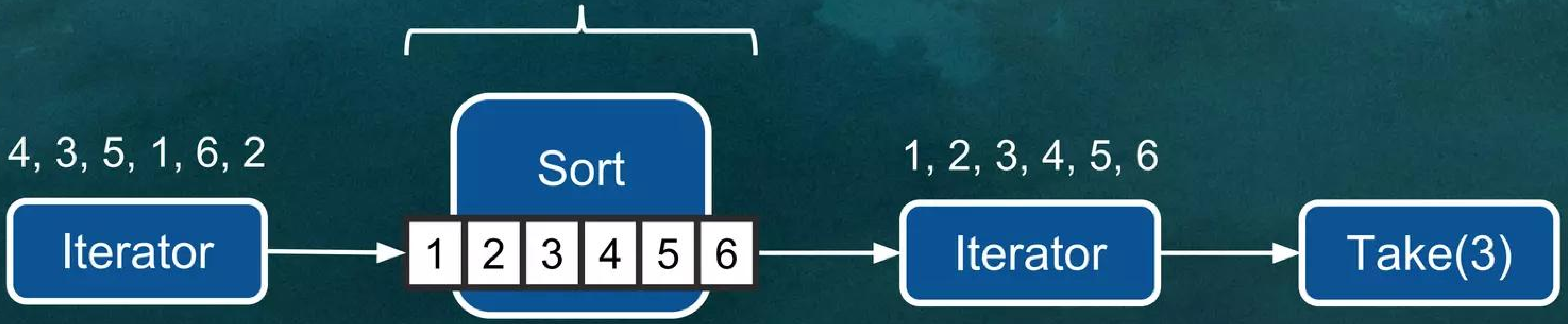
Execution

Memory used for shuffles, joins, sorts and aggregations

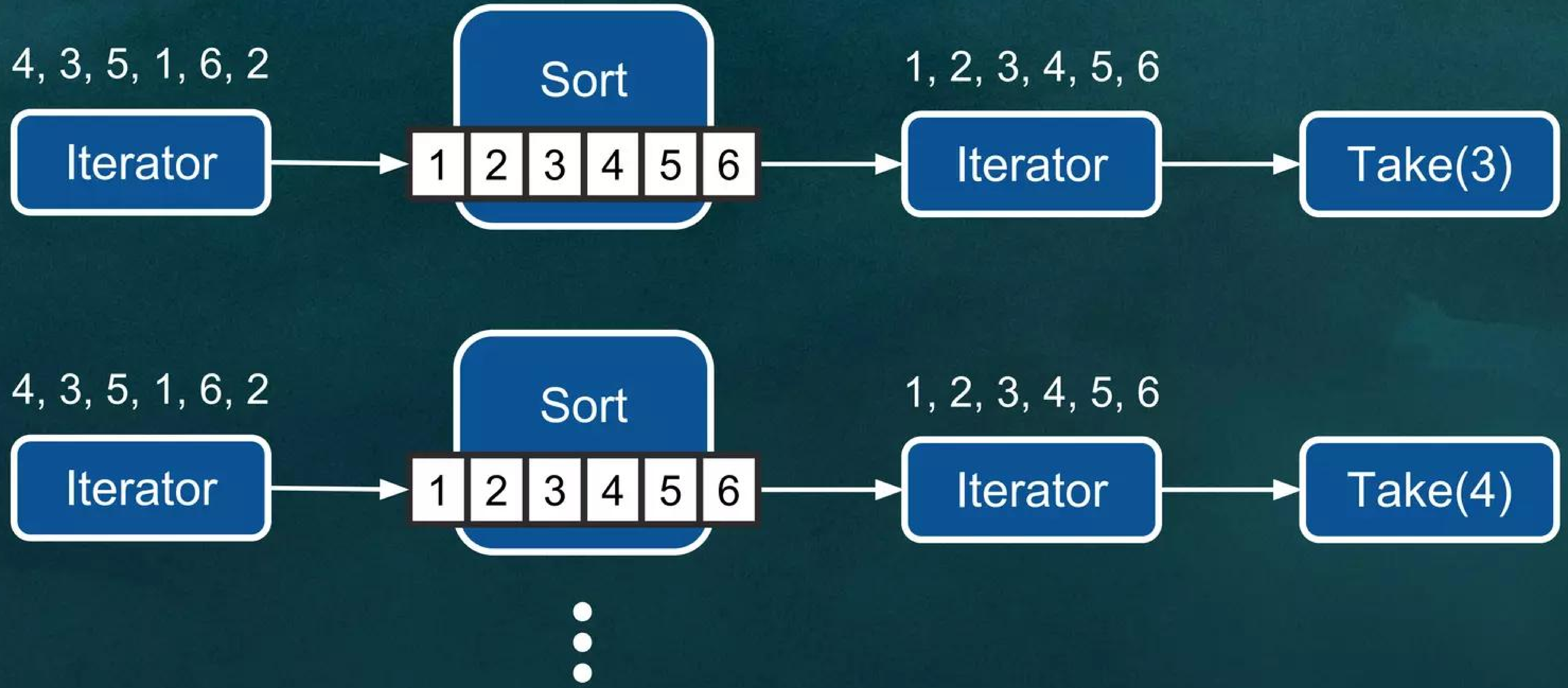
Storage

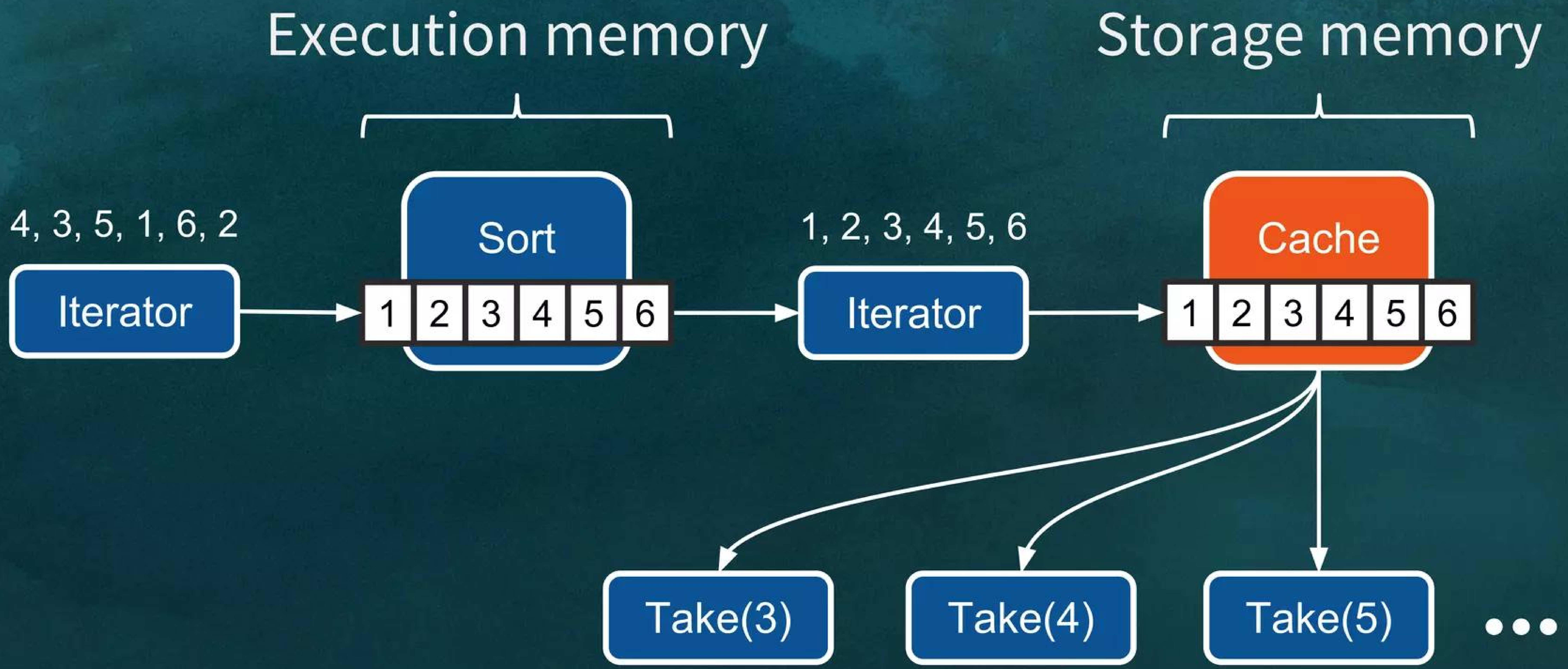
Memory used to cache data that will be reused later

Execution memory



What if I want the sorted values again?


4, 3, 5, 1, 6, 2
Iterator
Sort
1 2 3 4 5 6
1, 2, 3, 4, 5, 6
Iterator
Take(3)
4, 3, 5, 1, 6, 2
Iterator
Sort
1 2 3 4 5 6
1, 2, 3, 4, 5, 6
Iterator
Take(4)


Execution memory
Storage memory
4, 3, 5, 1, 6, 2
Iterator
Sort
1 2 3 4 5 6
1, 2, 3, 4, 5, 6
Iterator
Cache
1 2 3 4 5 6
Take(3)
Take(4)
Take(5)
...

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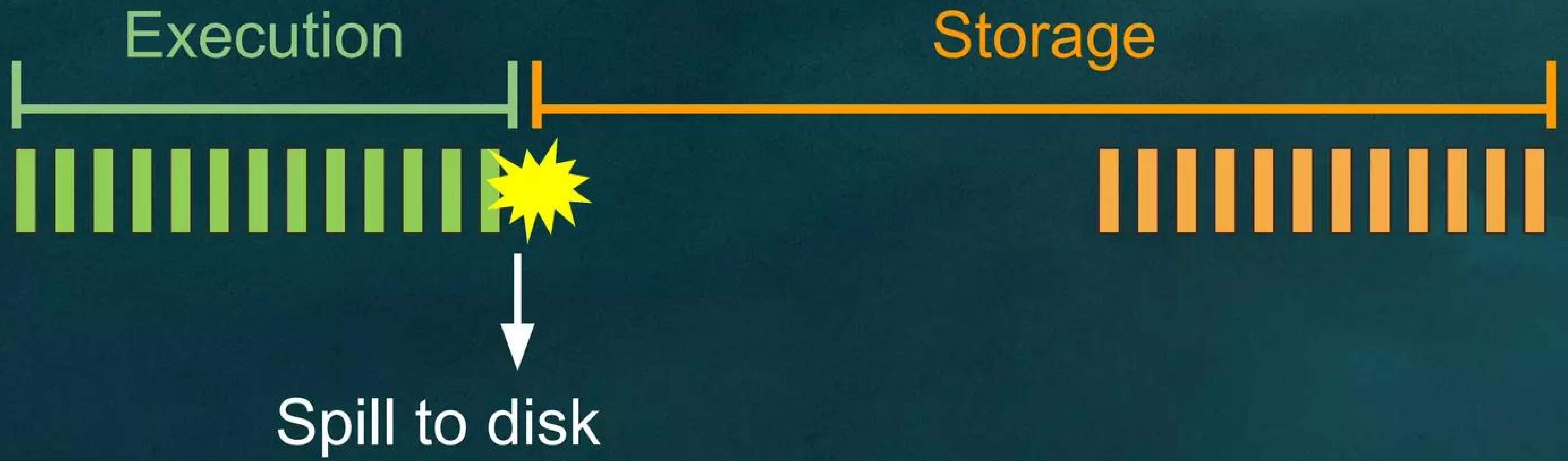
Challenge #1

How to arbitrate memory between execution and storage?

Easy, static assignment!

Spark 1.0
May 2014

Easy, static assignment!



Spark 1.0
May 2014

Easy, static assignment!

Spark 1.0
May 2014

Easy, static assignment!

Spark 1.0
May 2014

Inefficient memory use leads to *bad performance*

Easy, static assignment!

Spark 1.0
May 2014

Execution can only use a fraction of the memory, even when there is no storage!

Easy, static assignment!

Spark 1.0
May 2014

Efficient use of memory required user tuning

Fast forward to 2016…

How could we have done better?


Execution
Storage

Unified memory management

What happens if there is already storage?

Spark 1.6+
Jan 2016

Unified memory management

Spark 1.6+
Jan 2016

Unified memory management

What about the other way round?

Spark 1.6+
Jan 2016

Unified memory management

Spark 1.6+
Jan 2016

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Design considerations

Why evict storage, not execution?

Spilled execution data will always be read back from disk, whereas cached data may not.

What if the application relies on caching?

Allow the user to specify a minimum unevictable amount of cached data (not a reservation!).

Spark 1.6+
Jan 2016

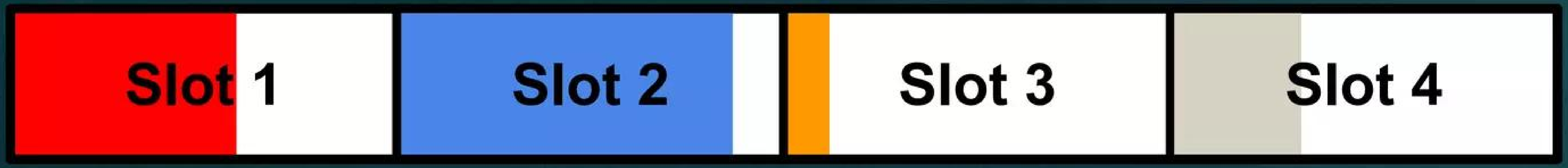
Challenge #2

How to arbitrate memory across tasks running in parallel?

Easy, static assignment!

Worker machine has 4 cores

Each task gets 1/4 of the total memory



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Alternative: Dynamic assignment

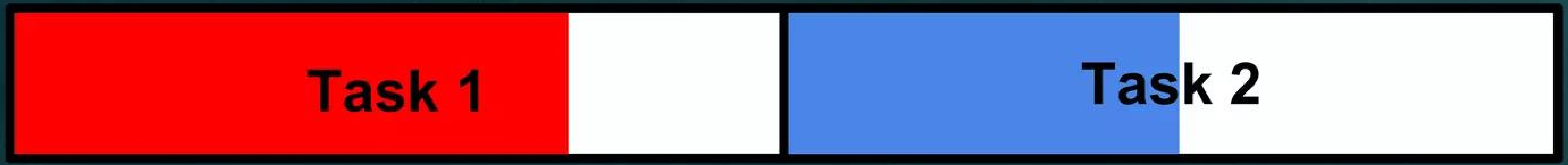
The share of each task depends on number of actively running tasks (N)

Alternative: Dynamic assignment

Now, another task comes along
so the first task will have to spill

Alternative: Dynamic assignment

Each task is now assigned 1/N of the memory, where N = 2



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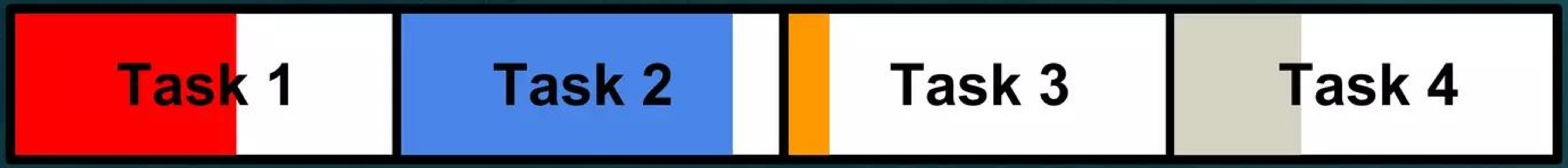
Alternative: Dynamic assignment

Each task is now assigned 1/N of the memory, where N = 4



Alternative: Dynamic assignment

Last remaining task gets all the memory because N = 1

Spark 1.0+
May 2014

Static vs dynamic assignment

Both are fair and starvation free

Static assignment is simpler

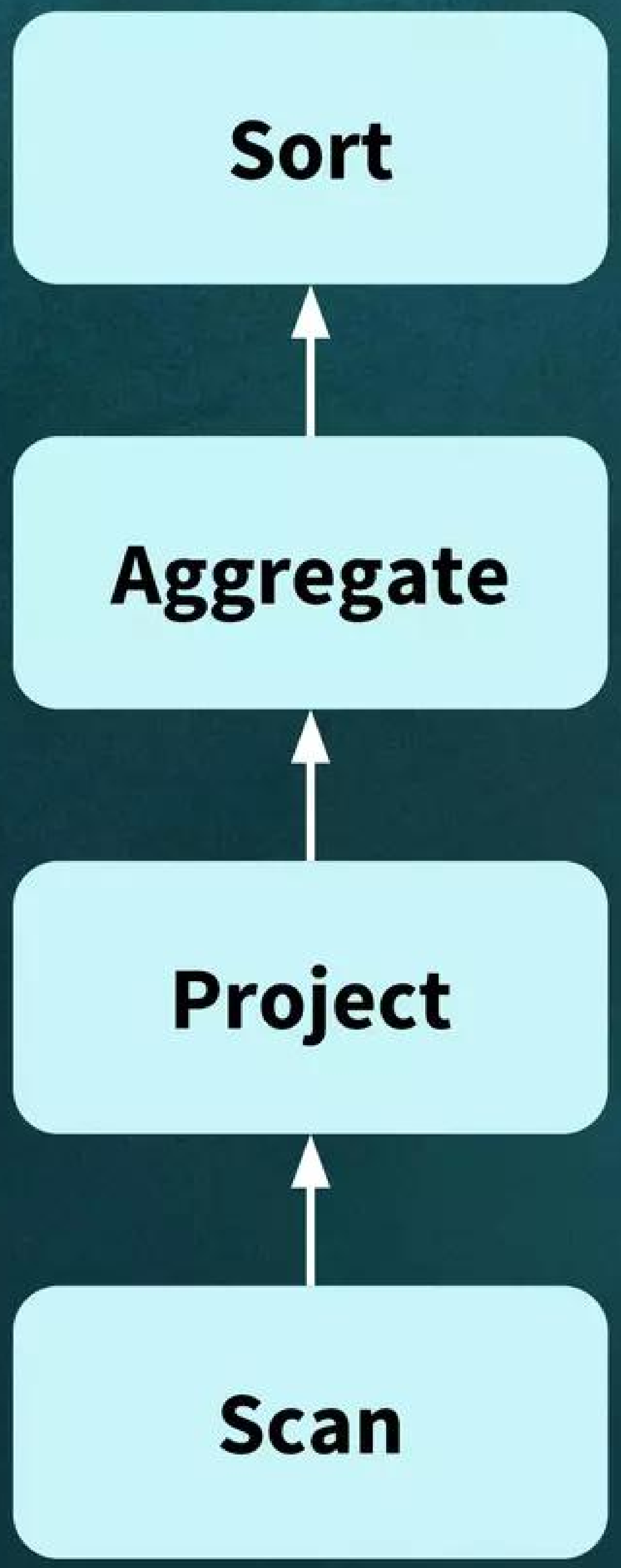
Dynamic assignment handles stragglers better

Challenge #3

How to arbitrate memory across operators running within the same task?

```
SELECT age, avg(height)
  FROM students
  GROUP BY age
  ORDER BY avg(height)
```

```
students.groupBy("age")
  .avg("height")
  .orderBy("avg(height)")
  .collect()
```



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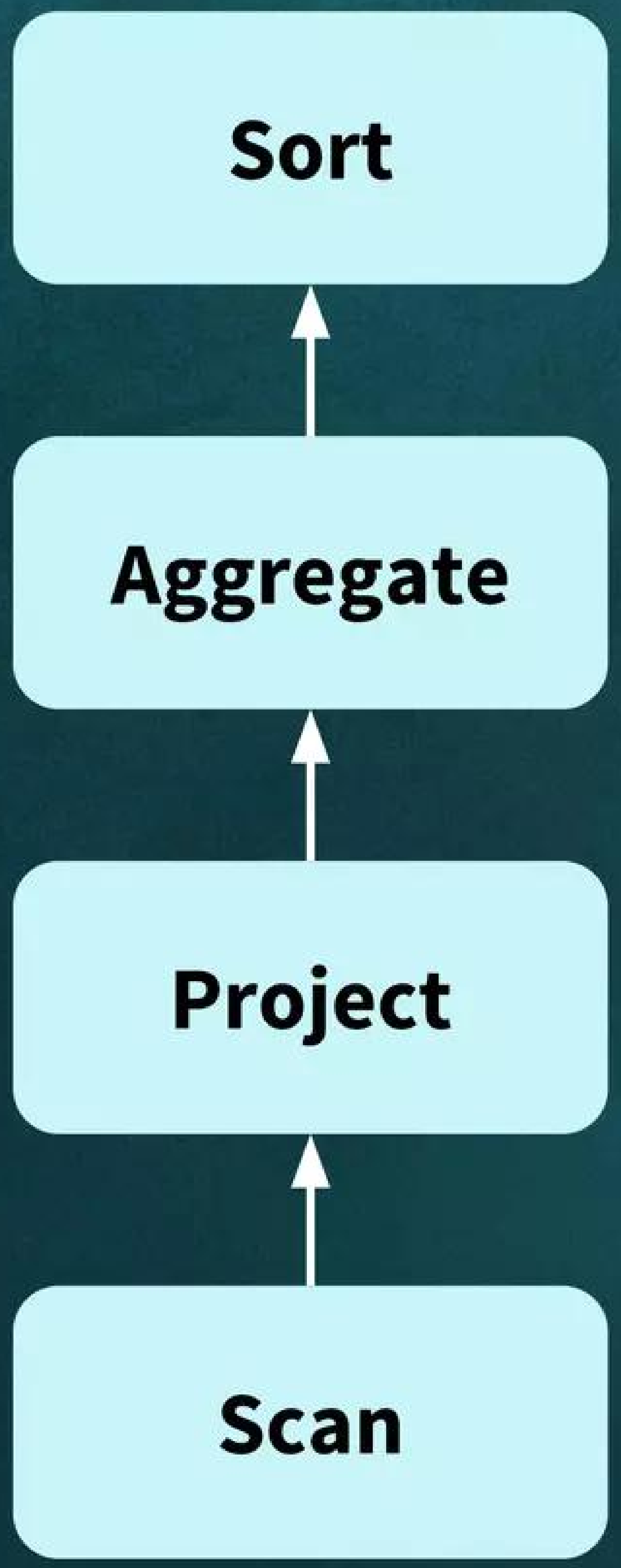
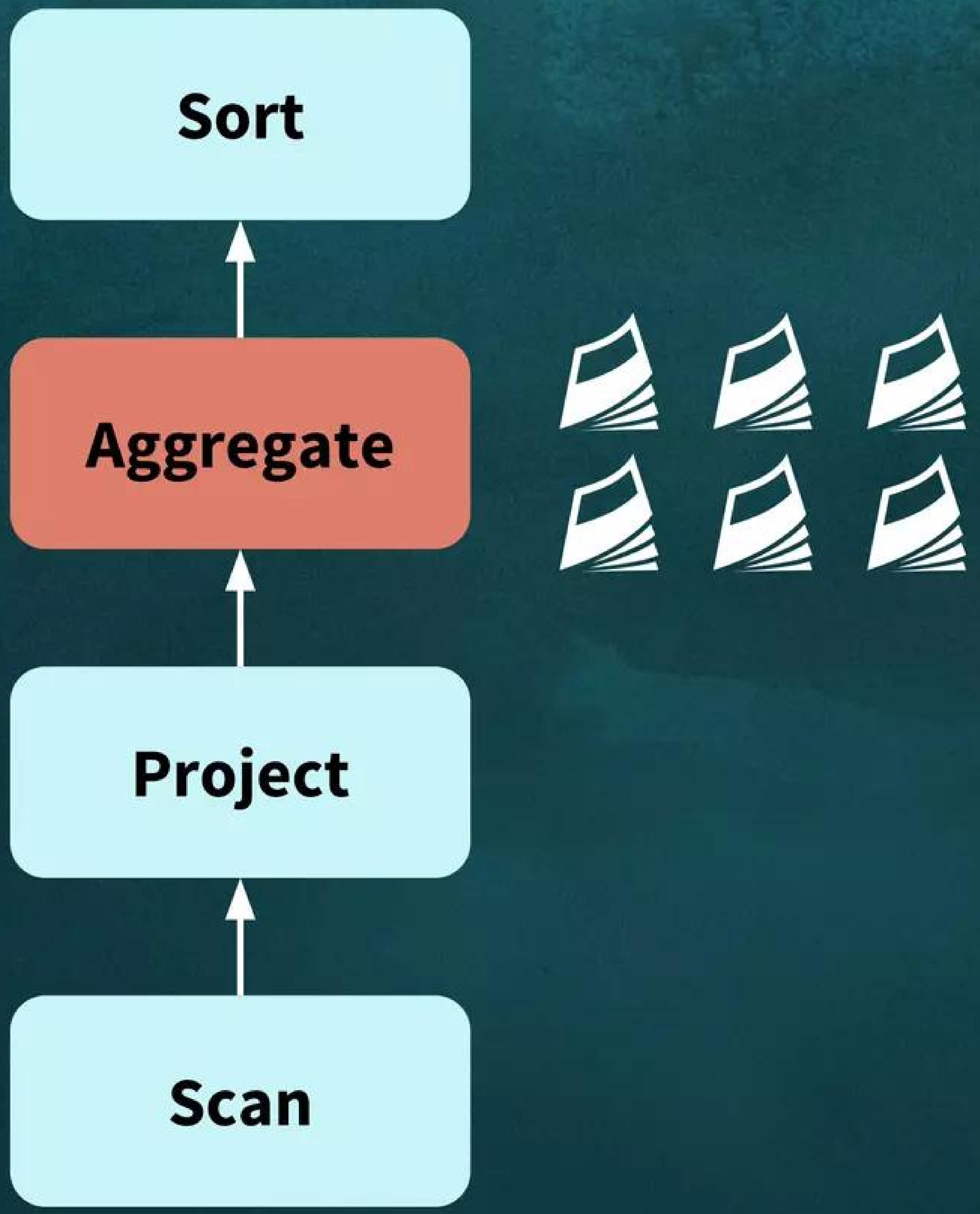
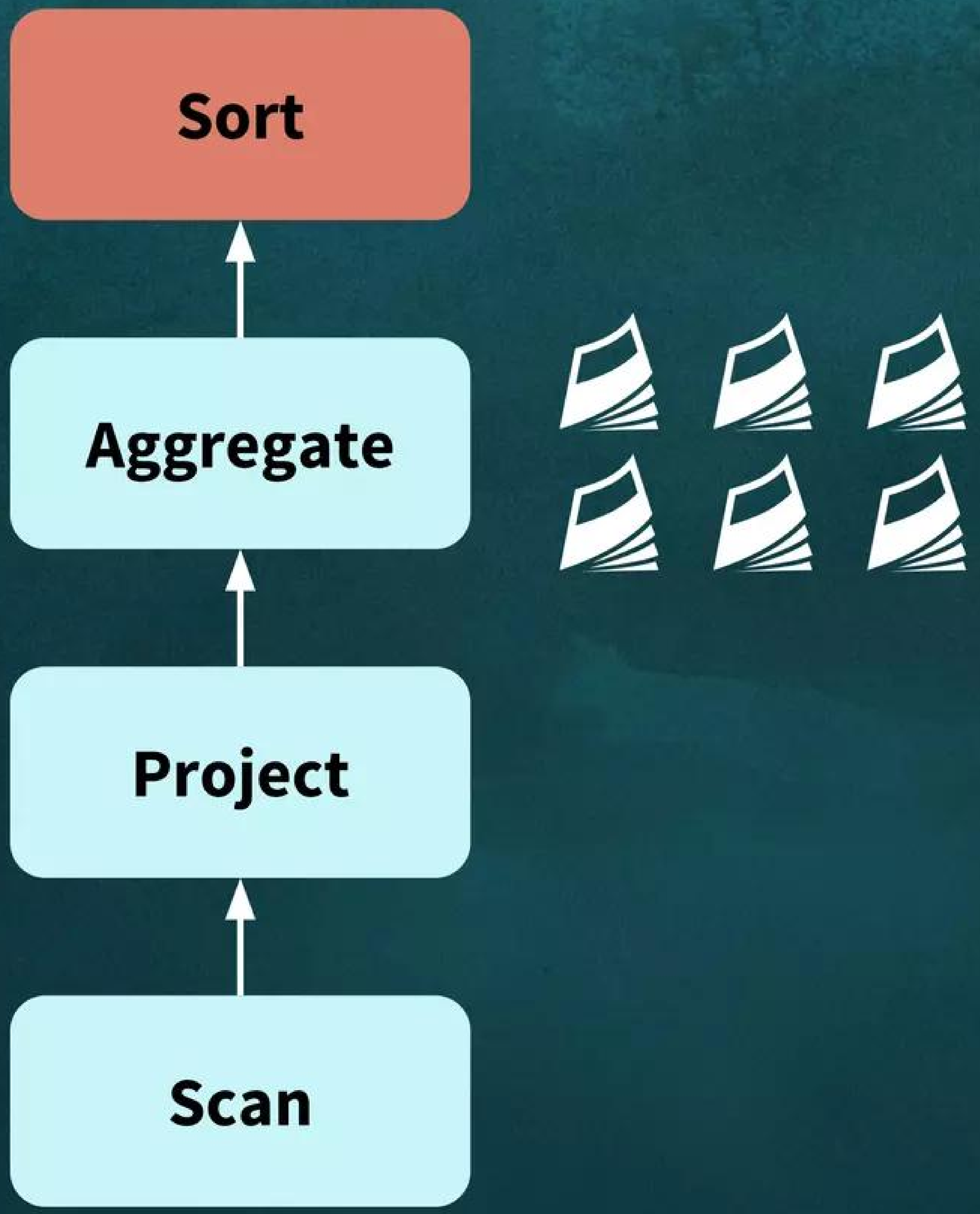
Worker has 6 pages of memory



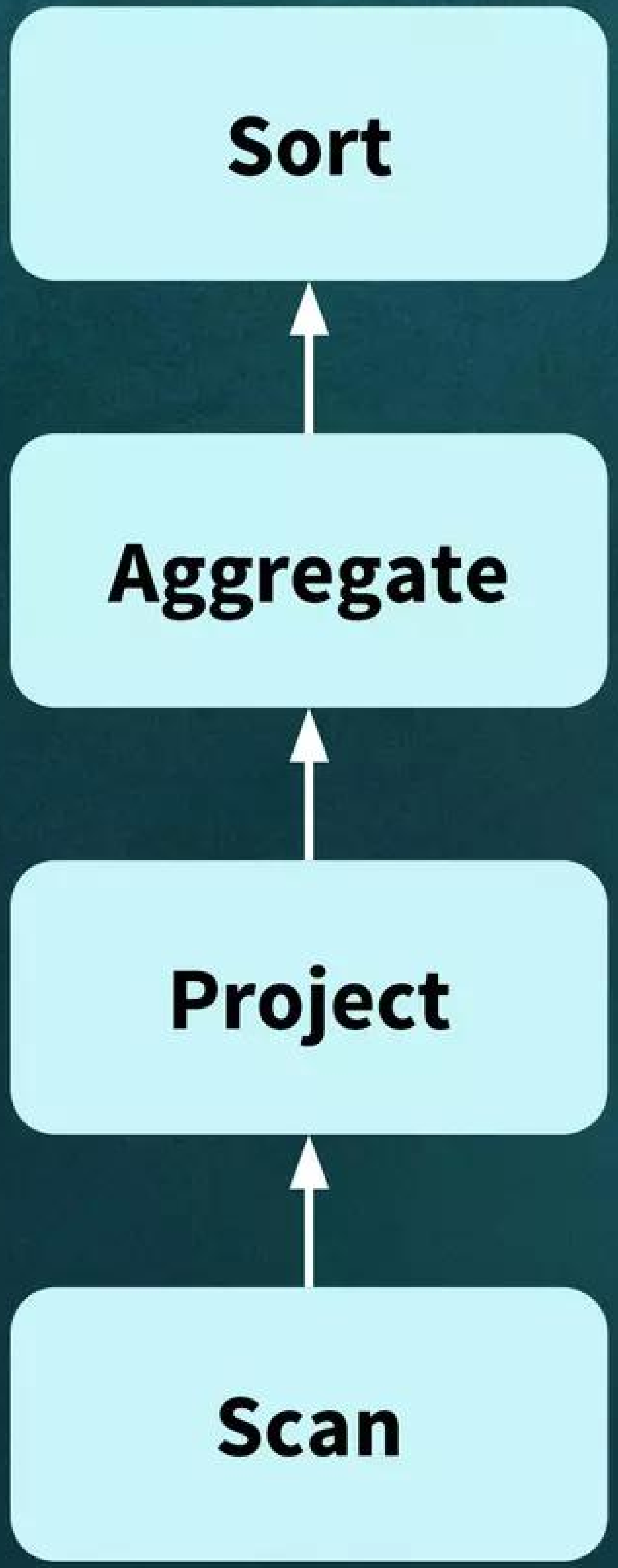
```
Map { // age → heights
  20 → [154, 174, 175]
  21 → [167, 168, 181]
  22 → [155, 166, 188]
  23 → [160, 168, 178, 183]
}
```



All 6 pages were used by *Aggregate*, leaving no memory for *Sort*!

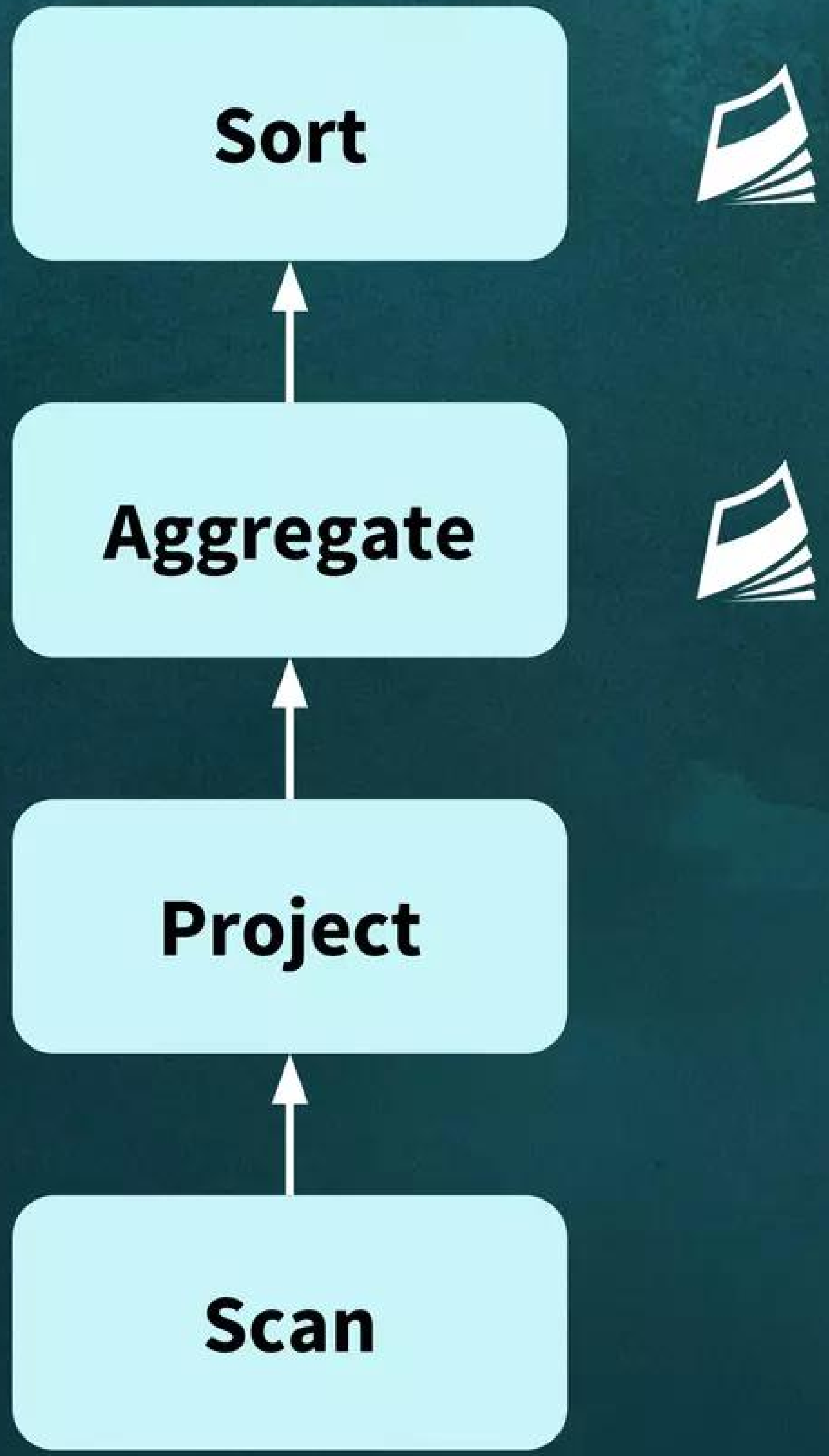


Solution #1:
Reserve a page for each operator



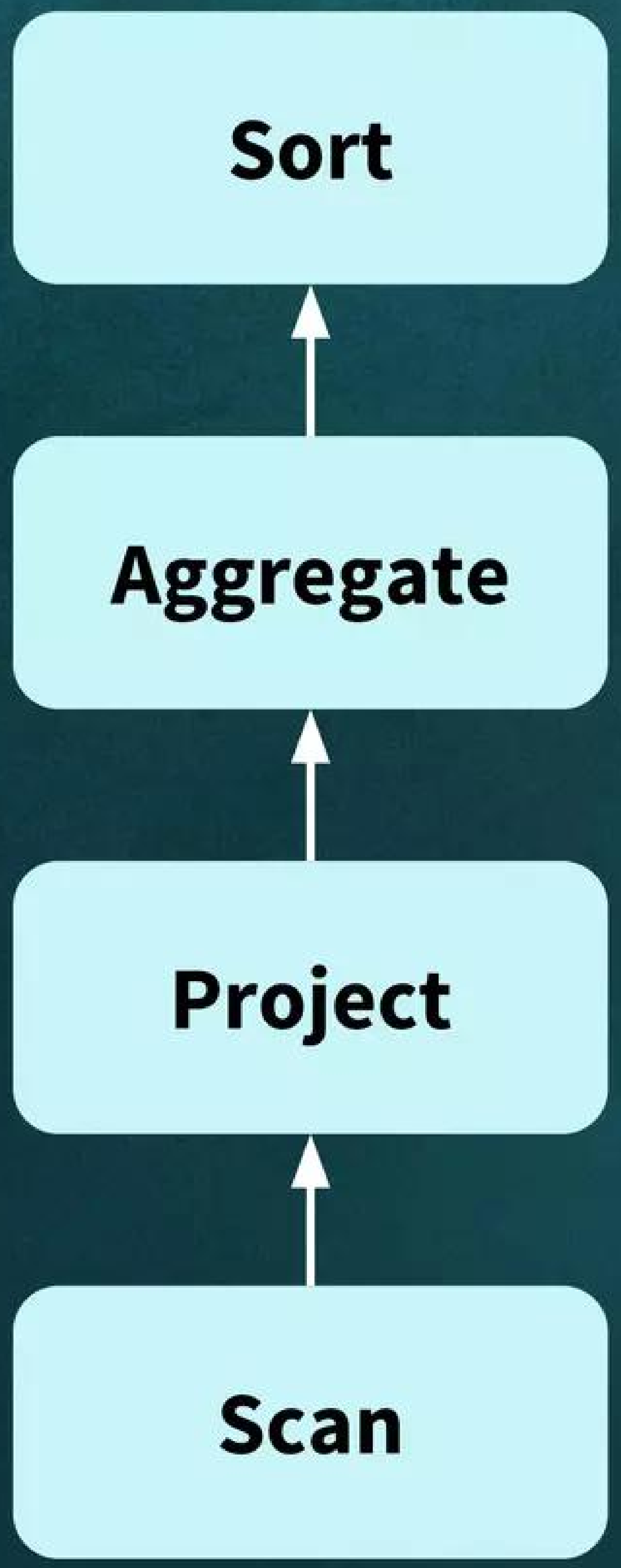
Solution #1:
Reserve a page for each operator

Starvation free, but still not fair…
What if there were more operators?

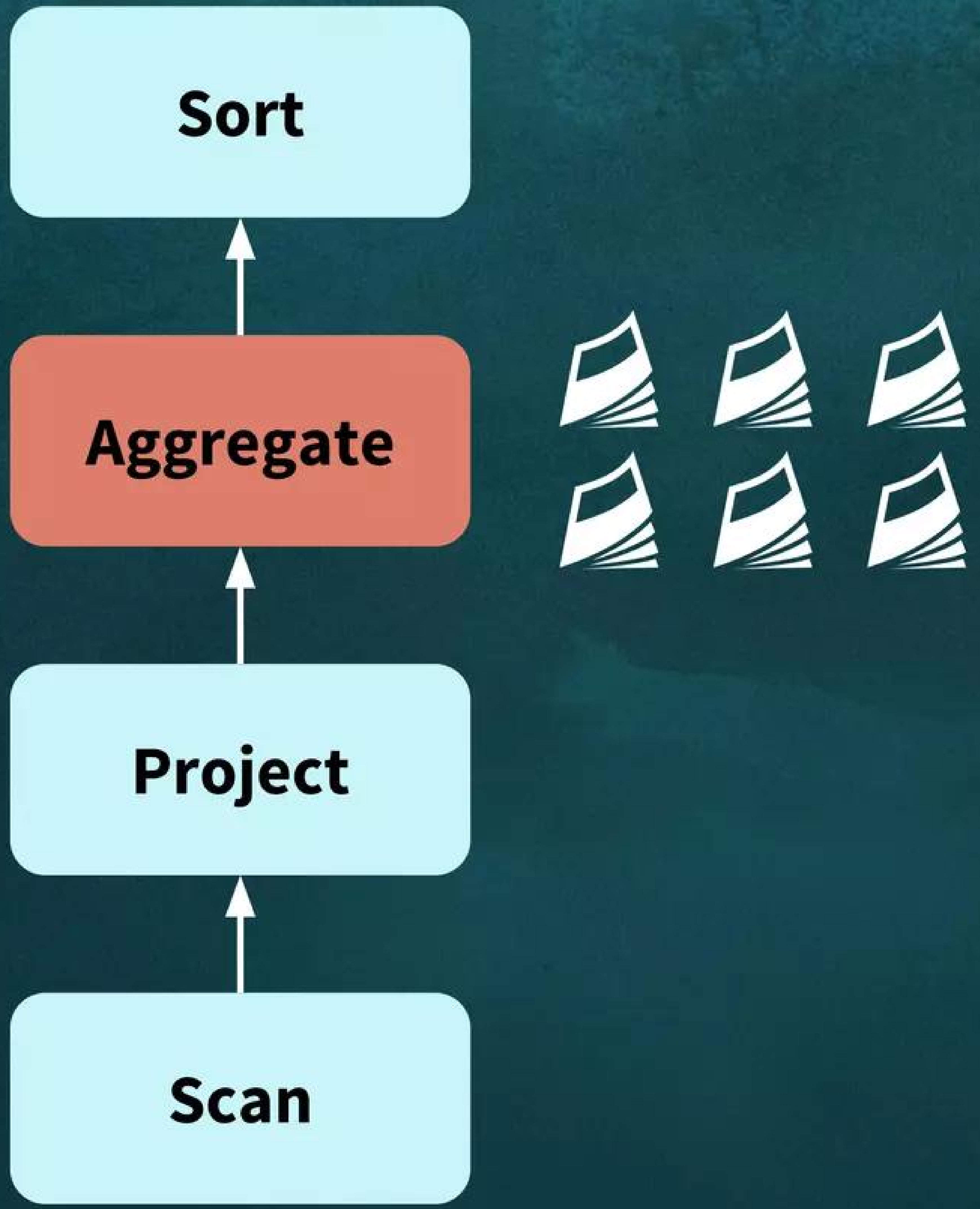


Solution #2:

Cooperative spilling



Solution #2:
Cooperative spilling



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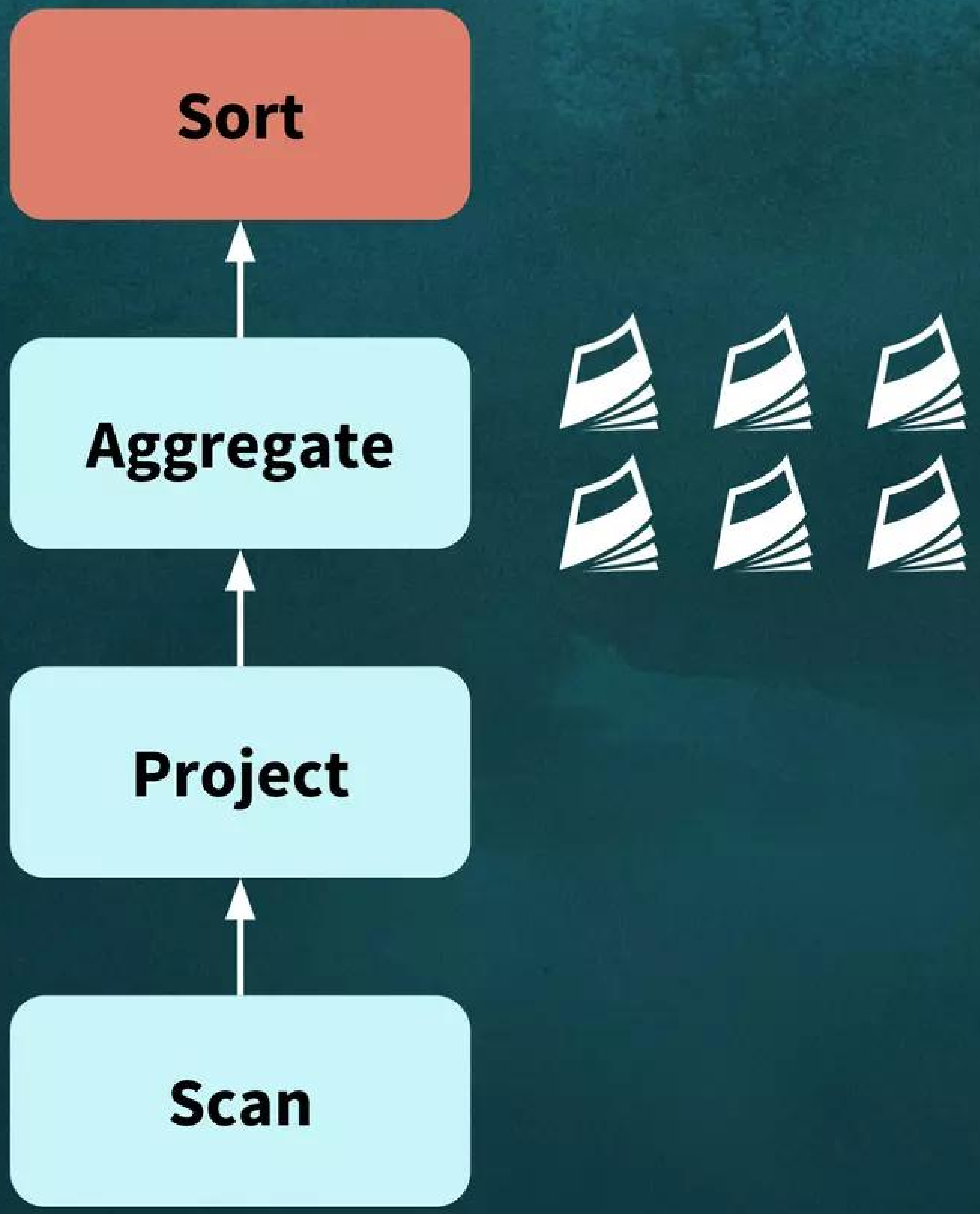
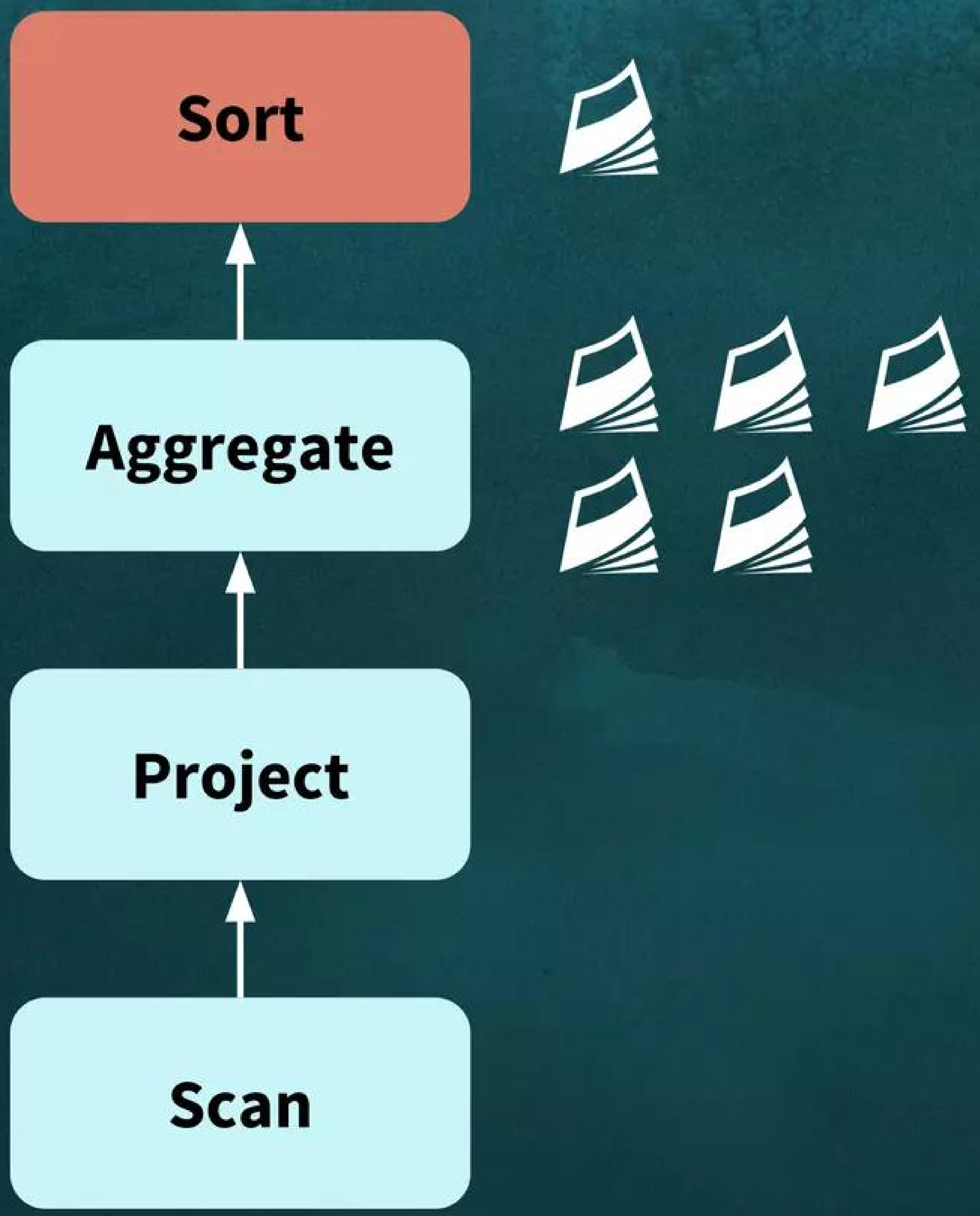
Solution #2: Cooperative spilling

Sort forces *Aggregate* to spill a page to free memory



Solution #2: Cooperative spilling

Sort needs more memory so it forces *Aggregate* to spill another page (and so on)



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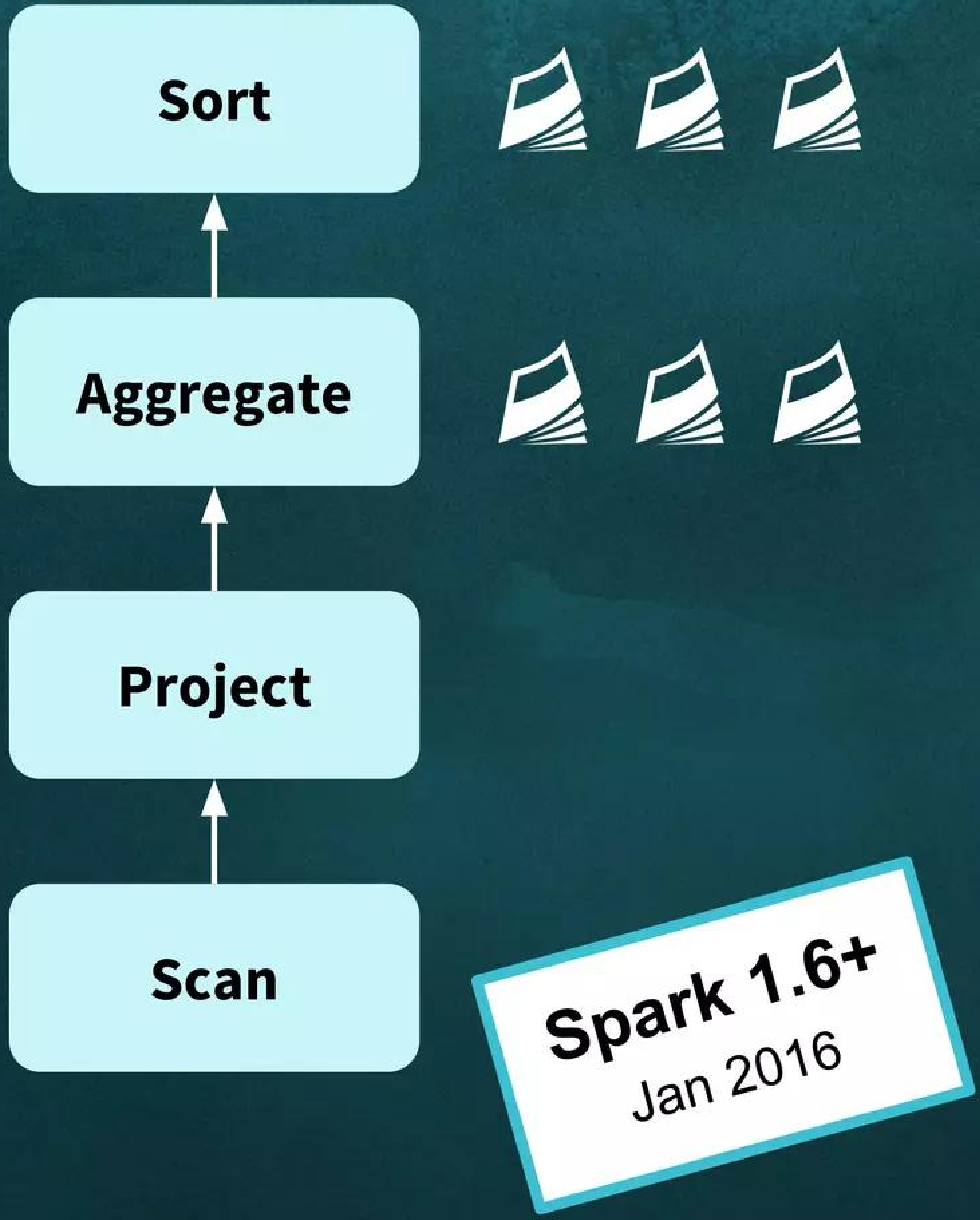
Solution #2: Cooperative spilling

Sort finishes with 3 pages

Aggregate does not have to spill its remaining pages



Recap: Three sources of contention

How to arbitrate memory …

- between execution and storage?
- across tasks running in parallel?
- across operators running within the same task?

Instead of avoid statically reserving memory in advance, deal with memory contention when it arises by forcing members to spill

Project Tungsten

Binary in-memory data representation

Cache-aware computation

Code generation (next time)

Spark 1.4+
Jun 2015

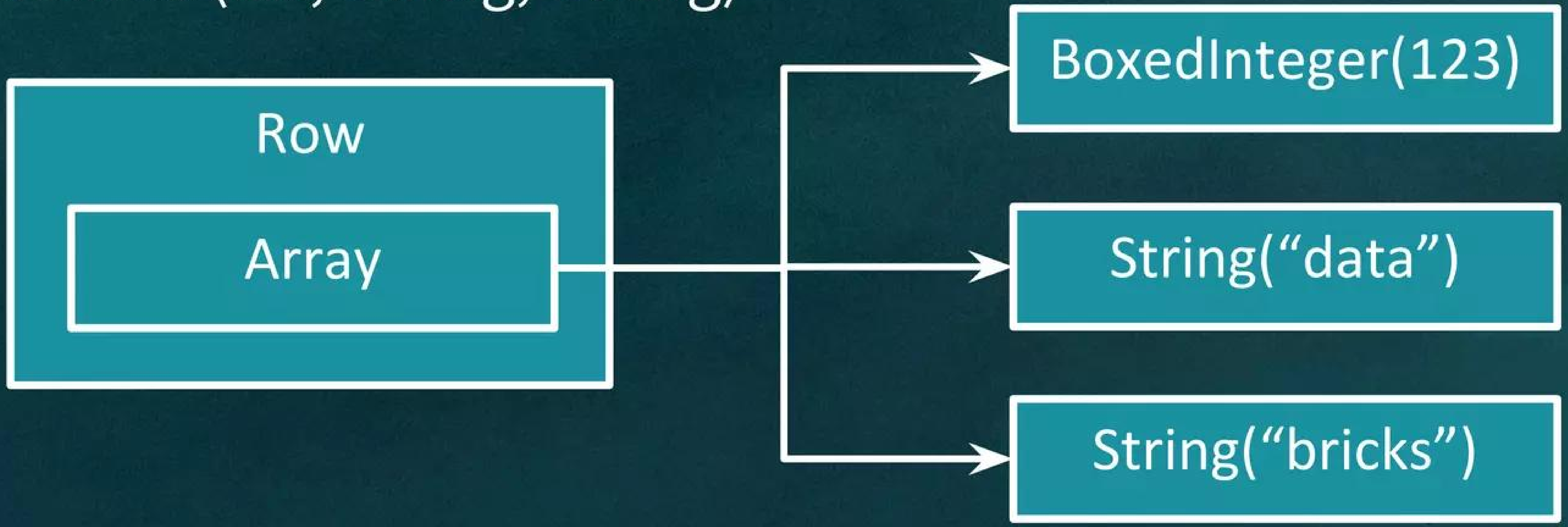
Java objects have large overheads

"abcd"

- Native: 4 bytes with UTF-8 encoding
- Java: 48 bytes
  - 12 byte header
  - 2 bytes per character (UTF-16 internal representation)
  - 20 bytes of additional overhead
  - 8 byte hash code

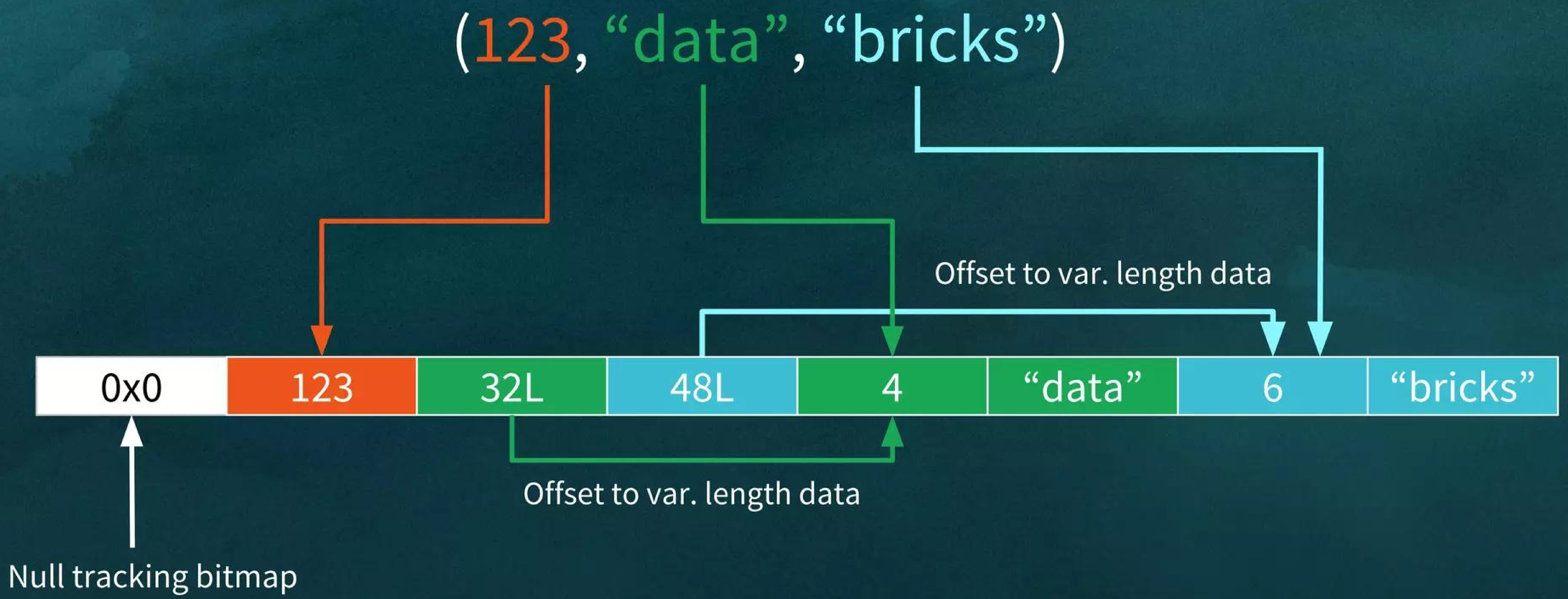
Java objects based row format

Schema: (Int, String, String)



5+ objects, high space overhead, expensive hashCode()

Tungsten row format



Cache-aware computation

E.g. sorting a list of records

Naive layout
Poor cache locality

Cache-aware layout
Good cache locality

Off-heap memory

Available for execution since Apache Spark 1.6

Available for storage since Apache Spark 2.0

Very important for large heaps

Many potential advantages: memory sharing, zero copy I/O, dynamic allocation

For more info...

Deep Dive into Project Tungsten: Bringing Spark Closer to Bare Metal
https://www.youtube.com/watch?v=5ajs8EIPWGI

Spark Performance: What's Next
https://www.youtube.com/watch?v=JX0CdOTWYX4

Unified Memory Management
https://issues.apache.org/jira/browse/SPARK-10000

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Thank you

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