Data Management for Data Science

Lecture 8: Reasoning about Scale

& The MapReduce Abstraction

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Today's Lecture

1. Scalability and Algorithmic Complexity

2. Data-Parallel Algorithms

3. The MapReduce Abstraction

1. Scalability and Algorithmic Complexity

What does scalable mean?

- Operationally:
  - Works even if the data does not fit in main memory
    - Use all available resources (cores/memory) on a single node (aka **scale up**)
  - Can make use of 1000s of cheap computers (cloud) – elastic (aka **scale out**)

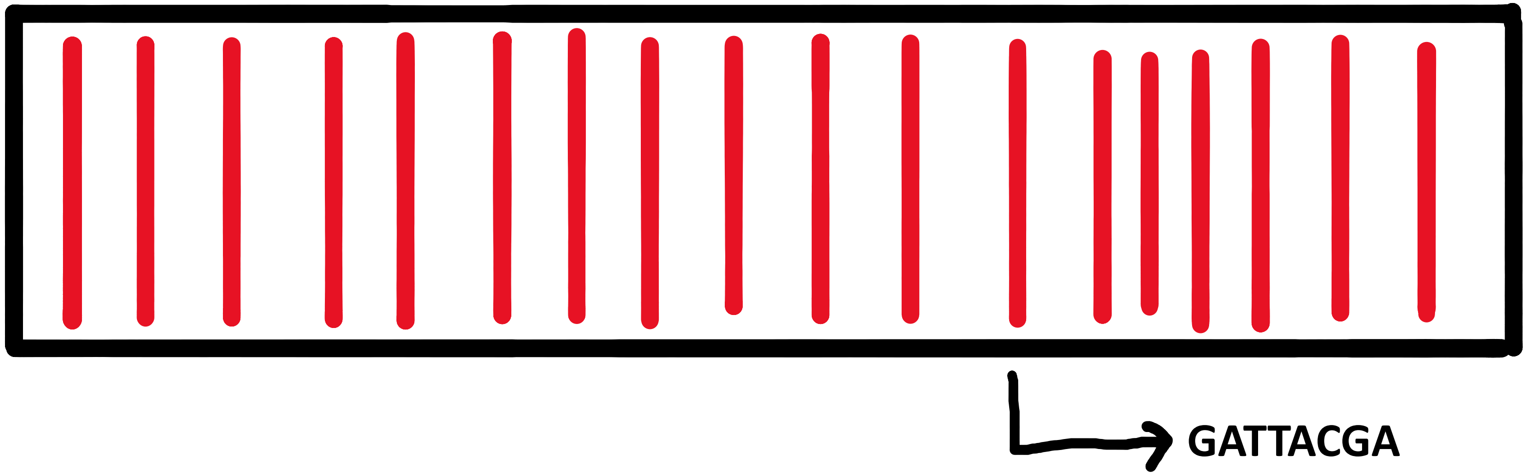
- Algorithmically:
  - If you have N data items you should not perform more than N^m operations (polynomial complexity)
  - In many cases it should be N*log(N) operations (streaming or too large data)
  - If you have N data items, you must do no more than N^m/k operations for some large k (k = number of cores/threads)

A sketch of algorithmic complexity

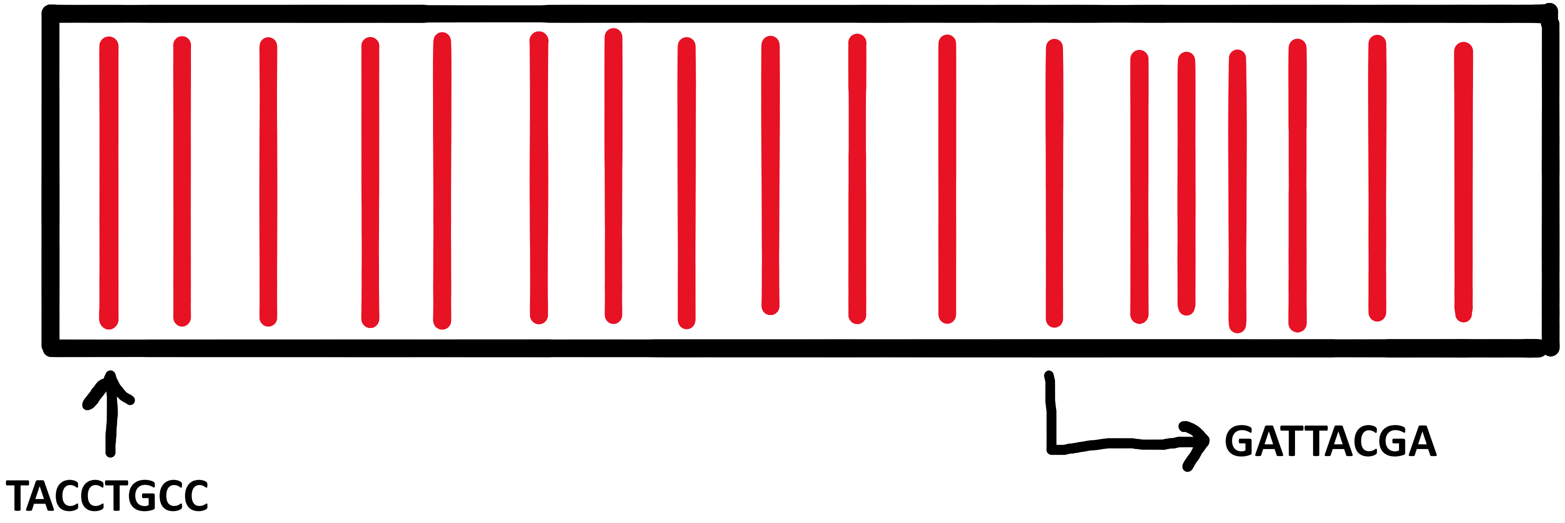
- Example: Find matching string sequences

- Given a set of string sequences
- Find all sequences equal to “GATTACGA”

Example: Find matching string sequences

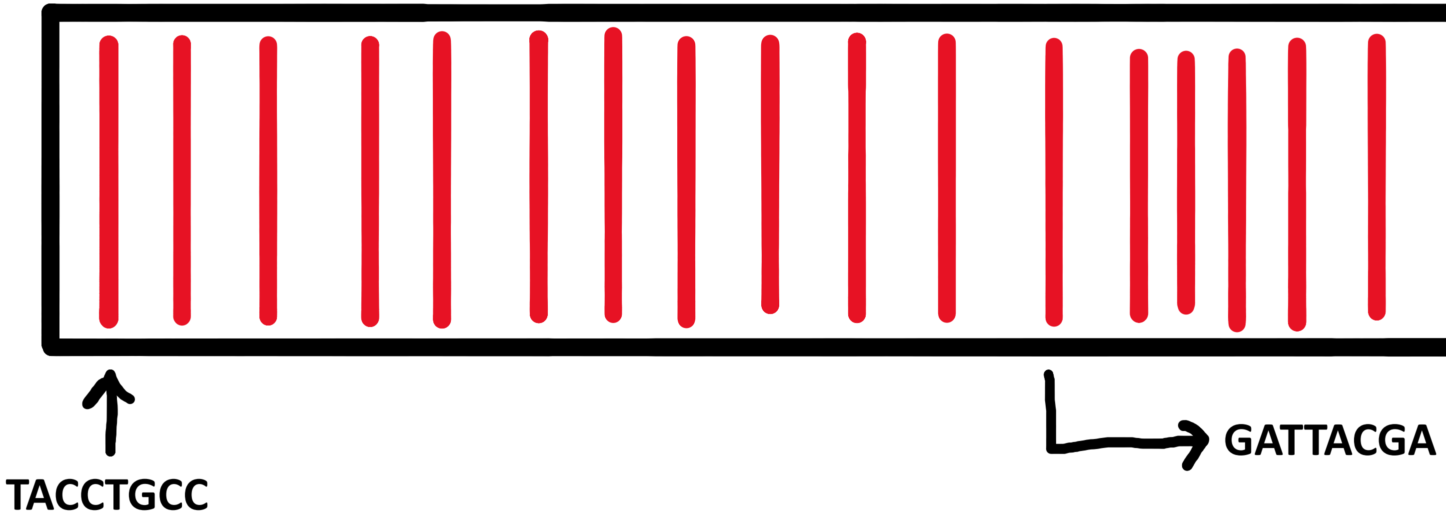


Example: Find matching string sequences



Time = 0: TACCTGCC ? GATTACGA

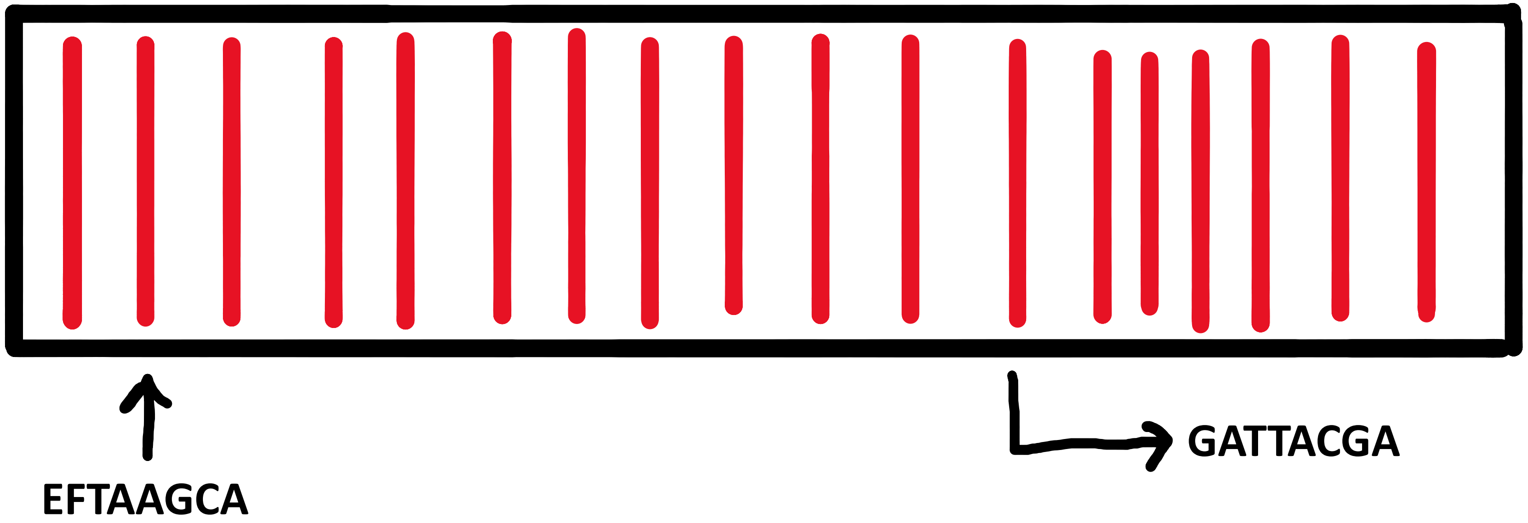
Example: Find matching string sequences



Time = 0: TACCTGCC ? GATTACGA

No move cursor to next data entry

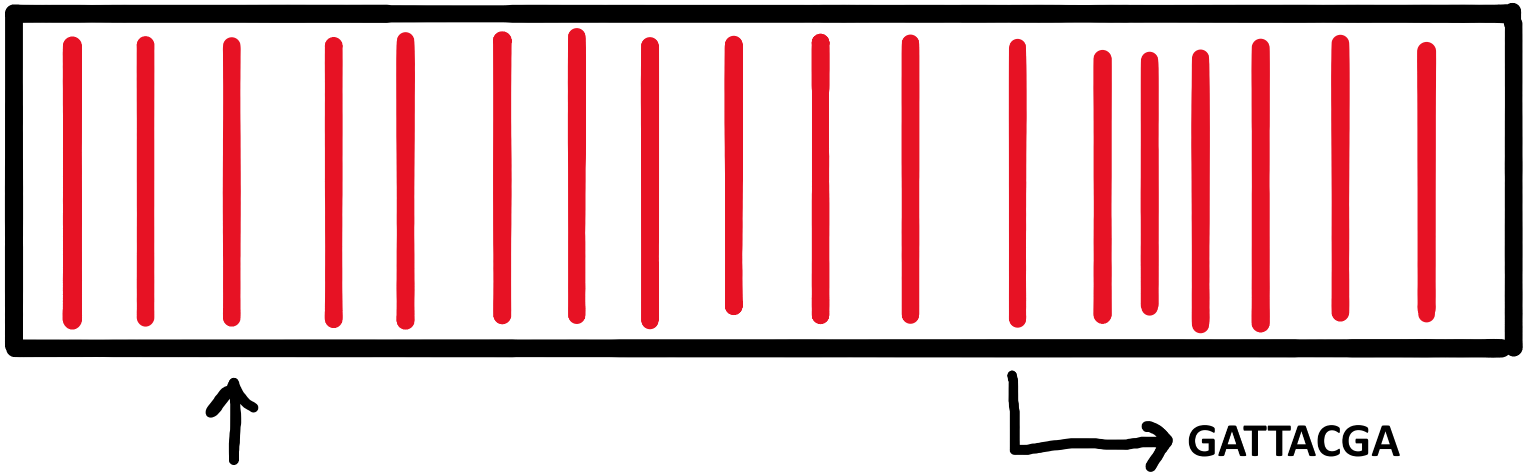
Example: Find matching string sequences



Time = 1: EFTAAGCA ? GATTACGA

No move cursor to next data entry

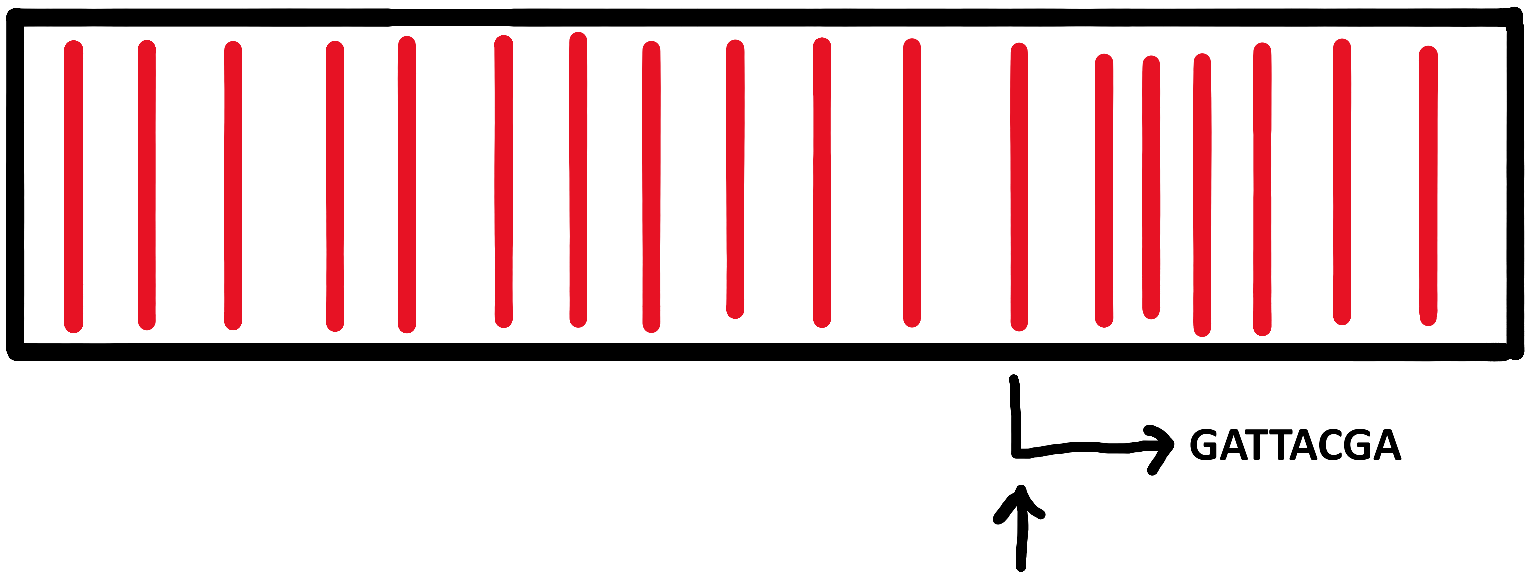
Example: Find matching string sequences



Time = 2: XXXXXXX ? GATTACGA

No move cursor to next data entry

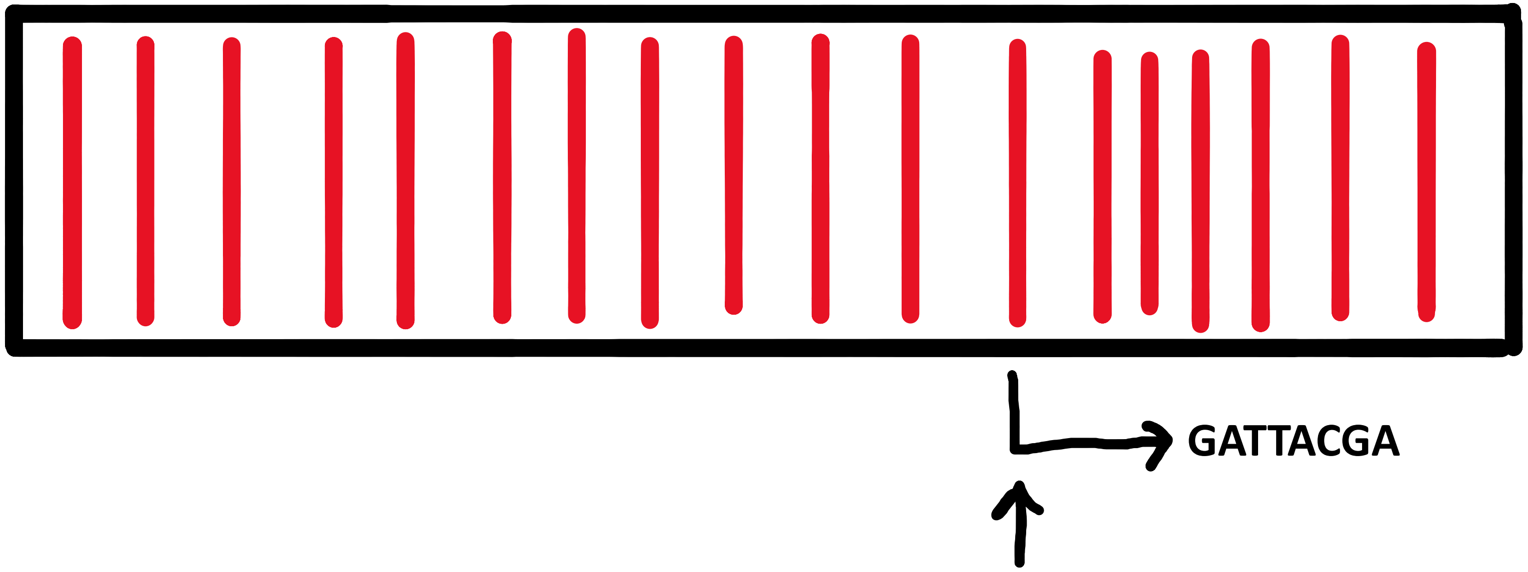
Example: Find matching string sequences



Time = n: GATTACGA ? GATTACGA

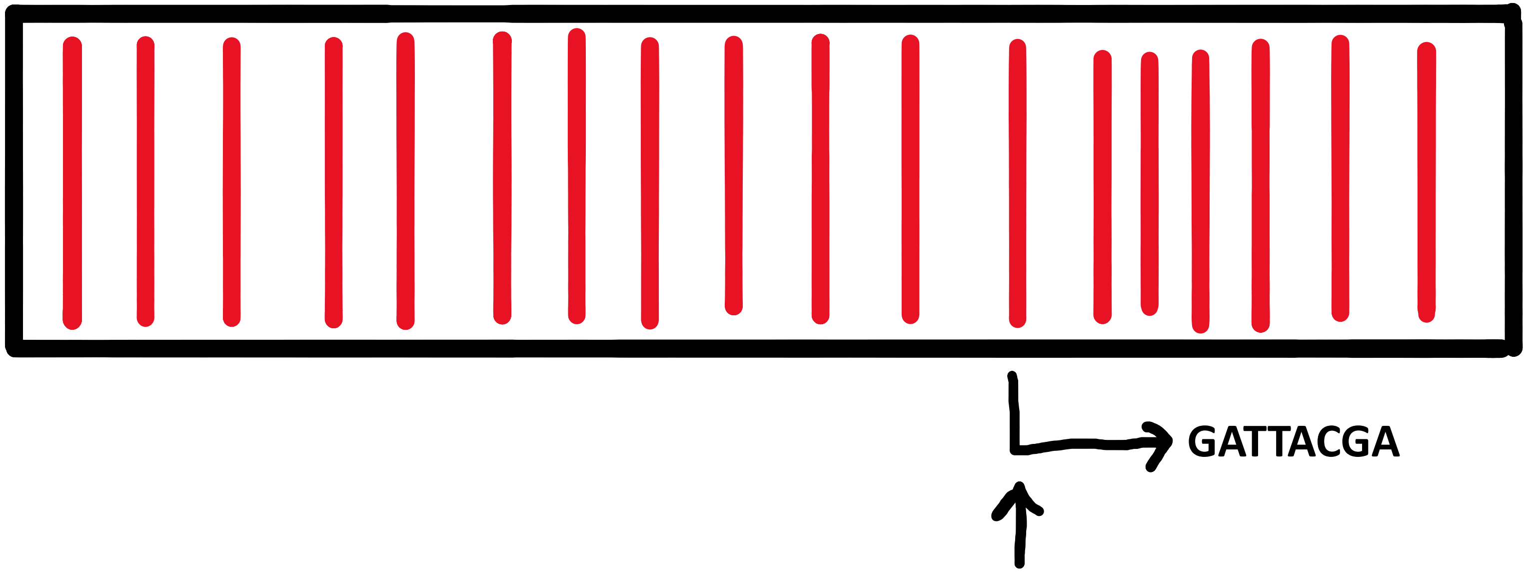
Yes! Output matching sequence

Example: Find matching string sequences



If we have 40 records we need to perform 40 comparisons

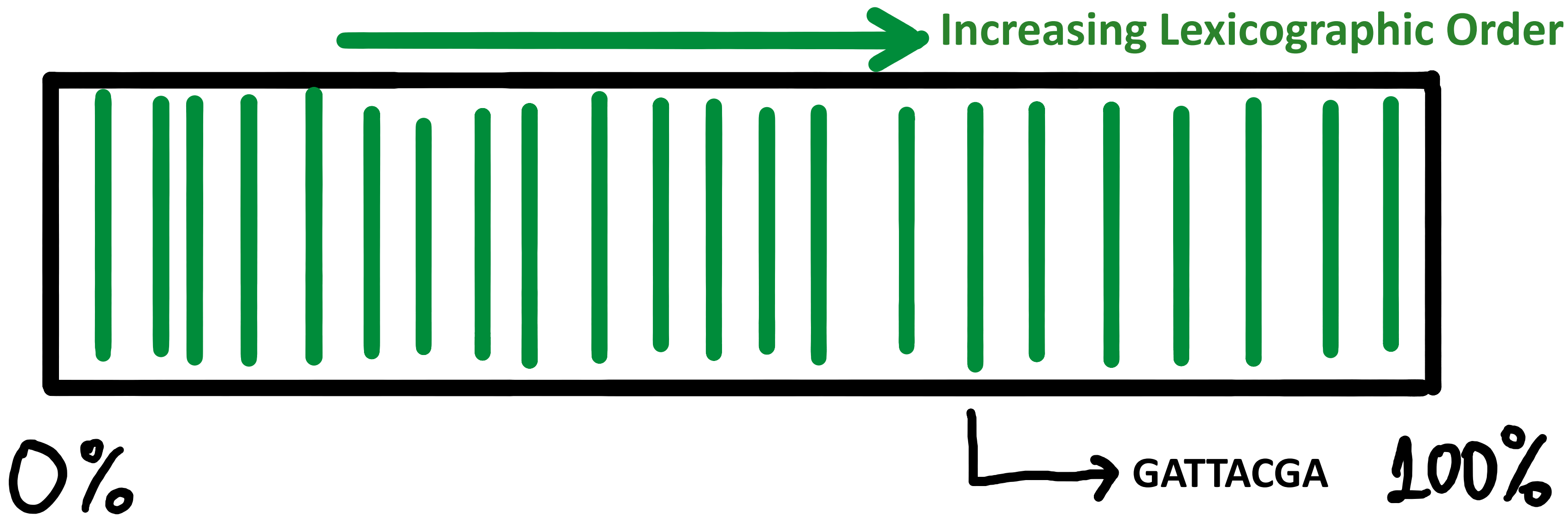
Example: Find matching string sequences



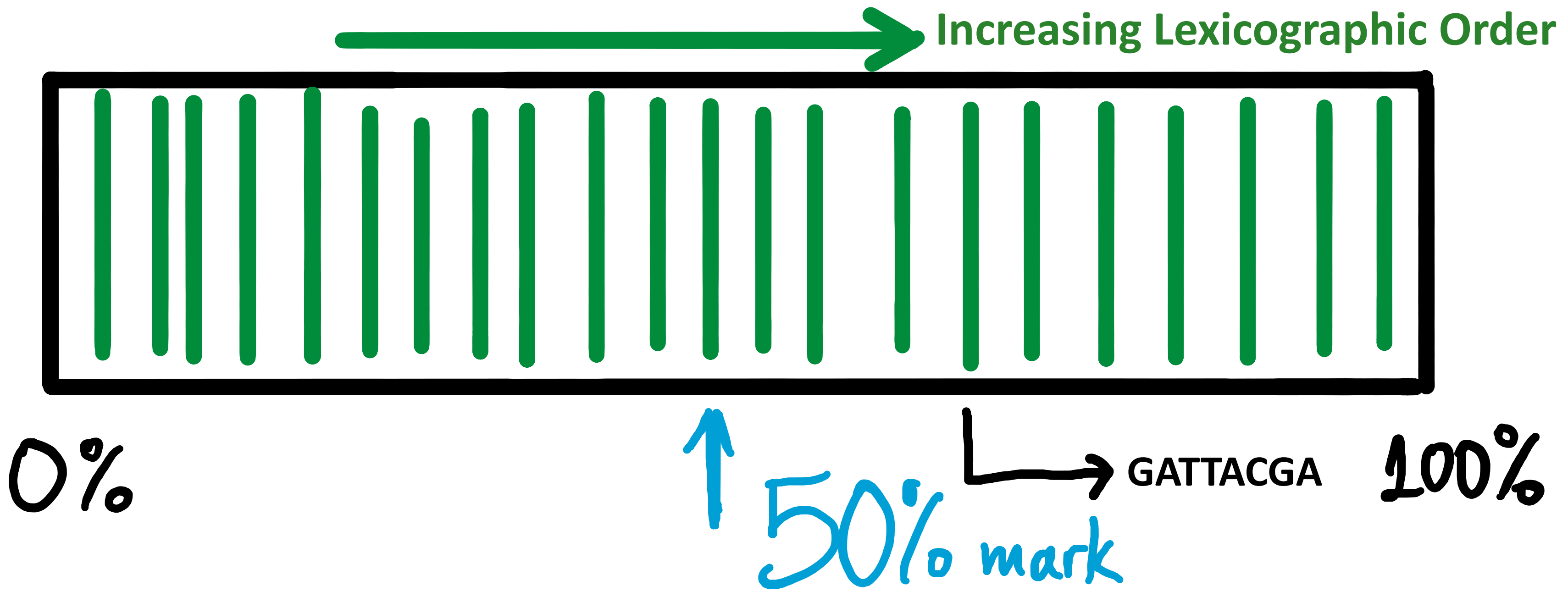
For N records we perform N comparisons

The algorithmic complexity is order N: O(N)

What if we knew the sequences are **sorted**

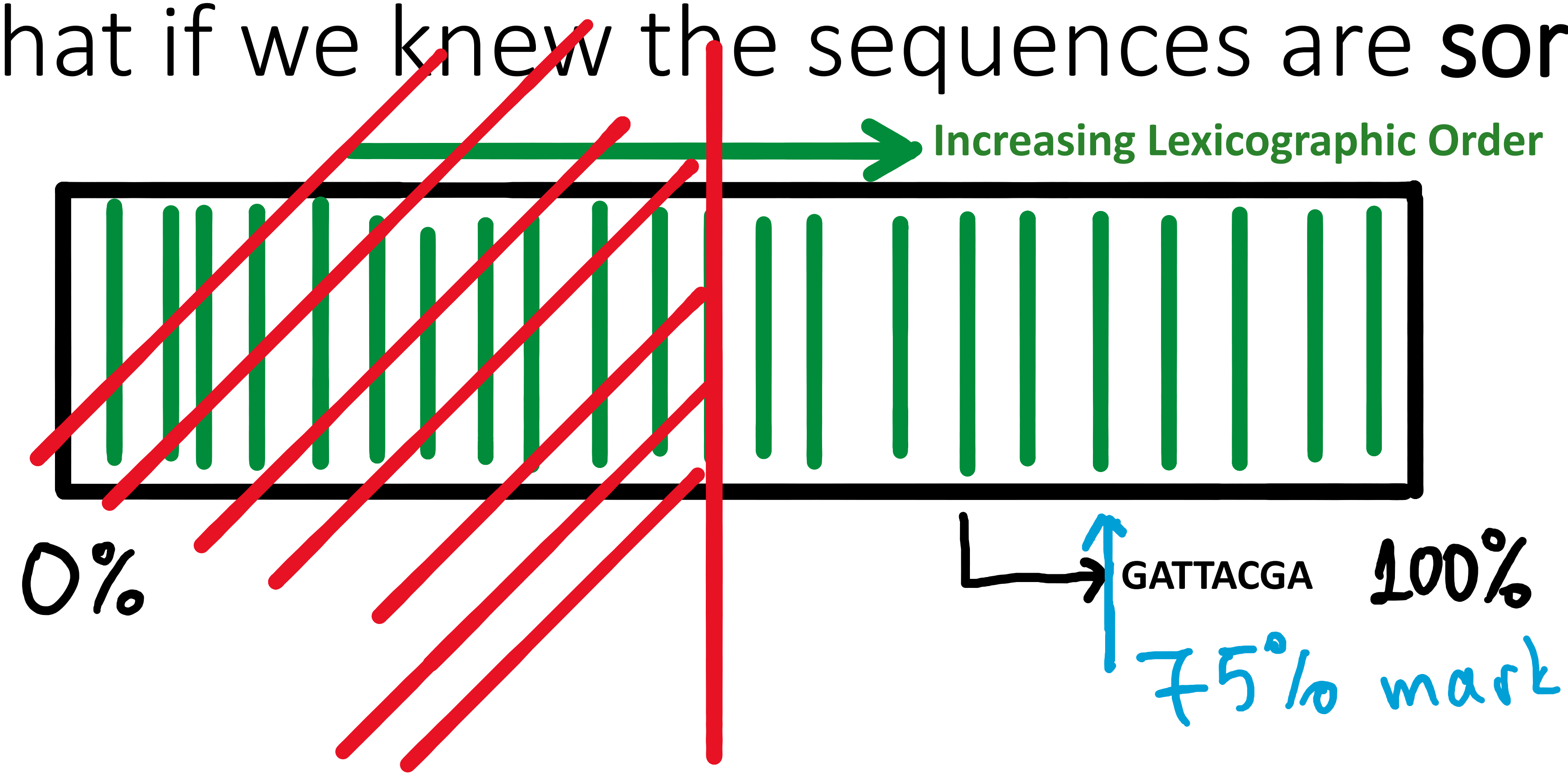


What if we knew the sequences are **sorted**



Time = 0: Start at 50% mark CTGTACA < GATTACGA

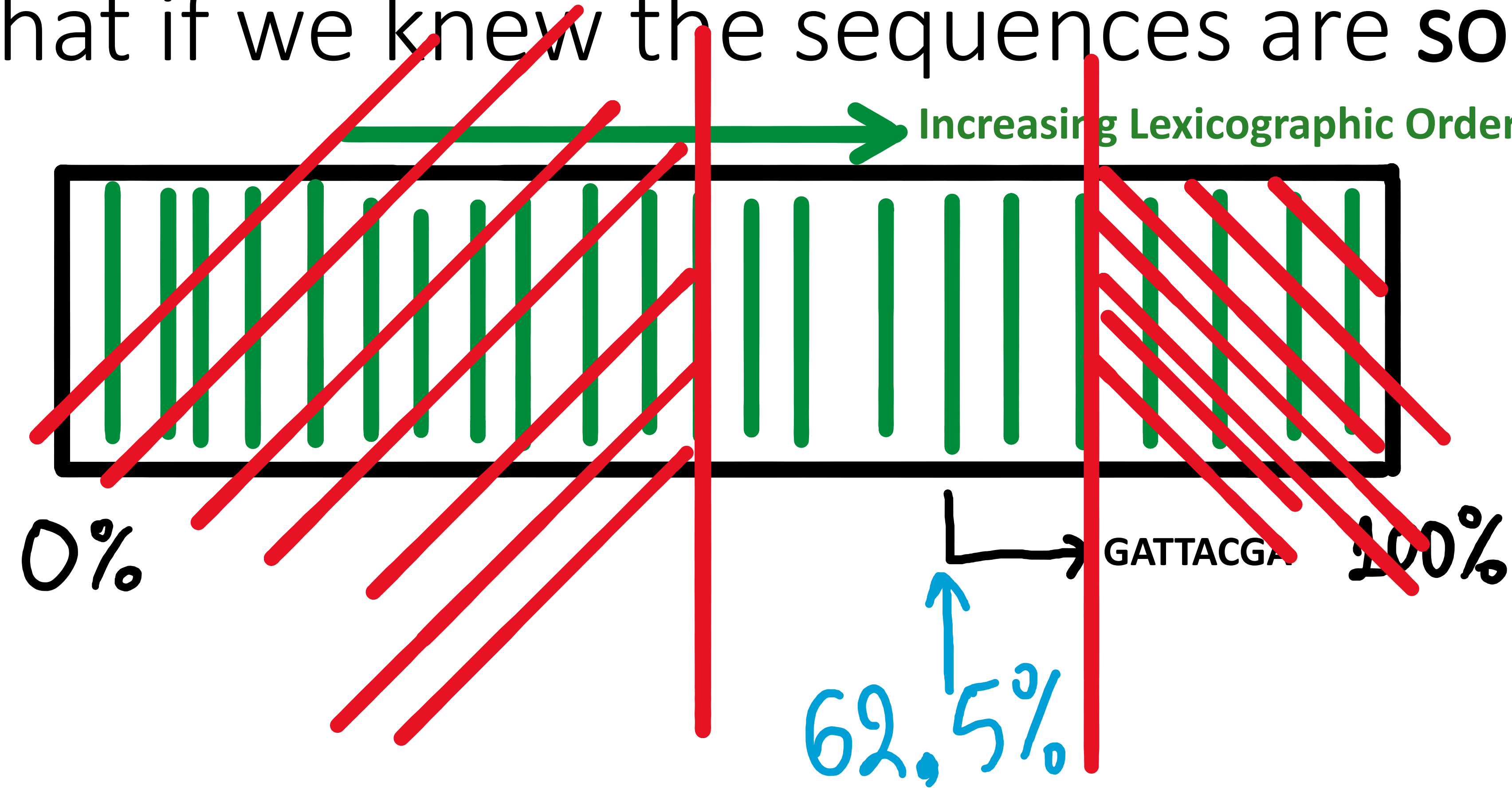
What if we knew the sequences are **sorted**



Time = 1: Start at 50% mark CTGTACA < GATTACGA

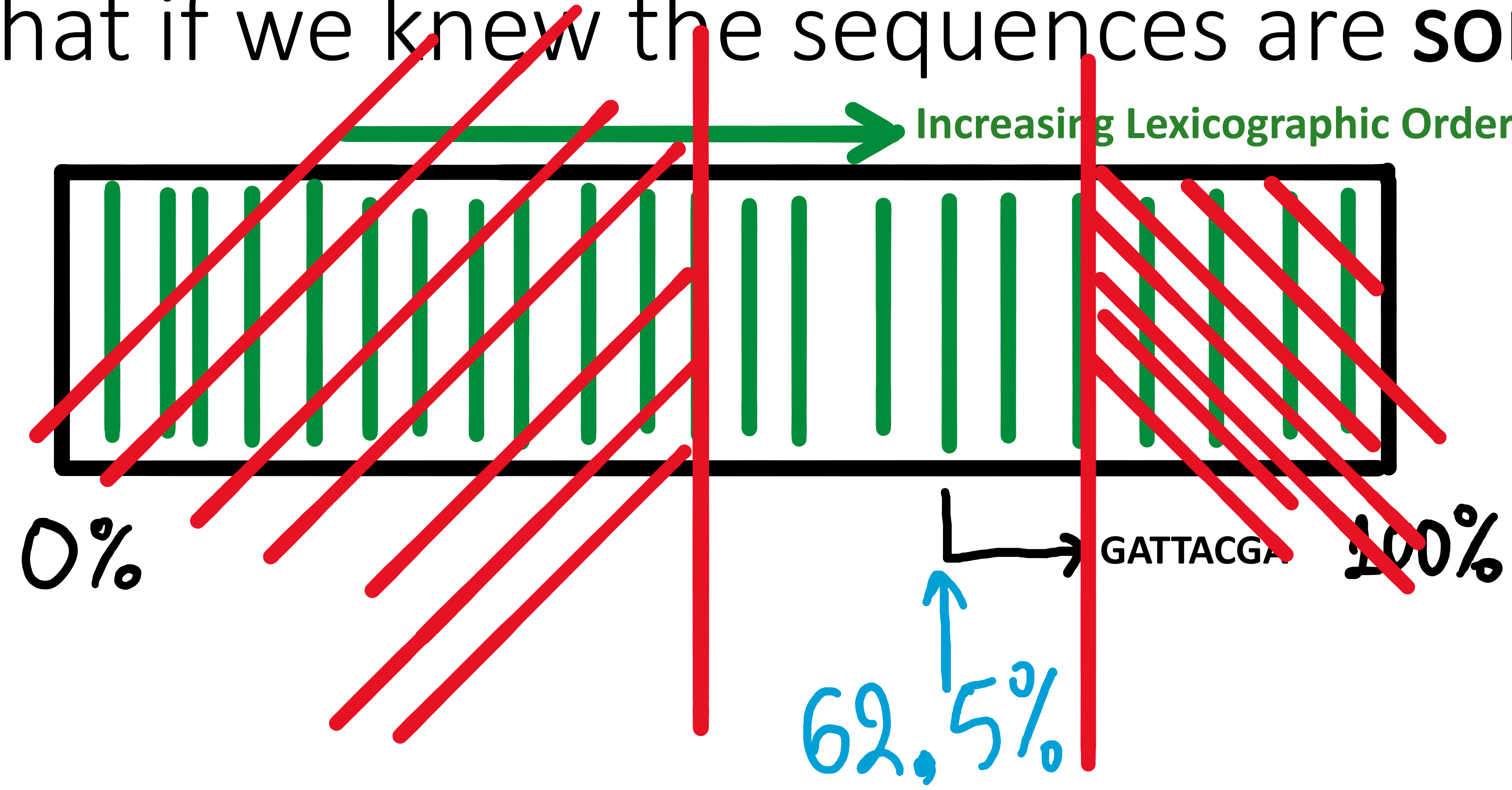
Skip to 75% mark (you know your sequence is in the second half)

What if we knew the sequences are **sorted**



Time = 2: We are at the 75% mark TTGTCCA > GATTACGA
Skip to 62.5% mark Match: GATTACGA = GATTACGA
We find our sequence in three steps. Now we can scan entries sequentially

What if we knew the sequences are **sorted**



How many comparisons?

For N records we did log(N) comparisons

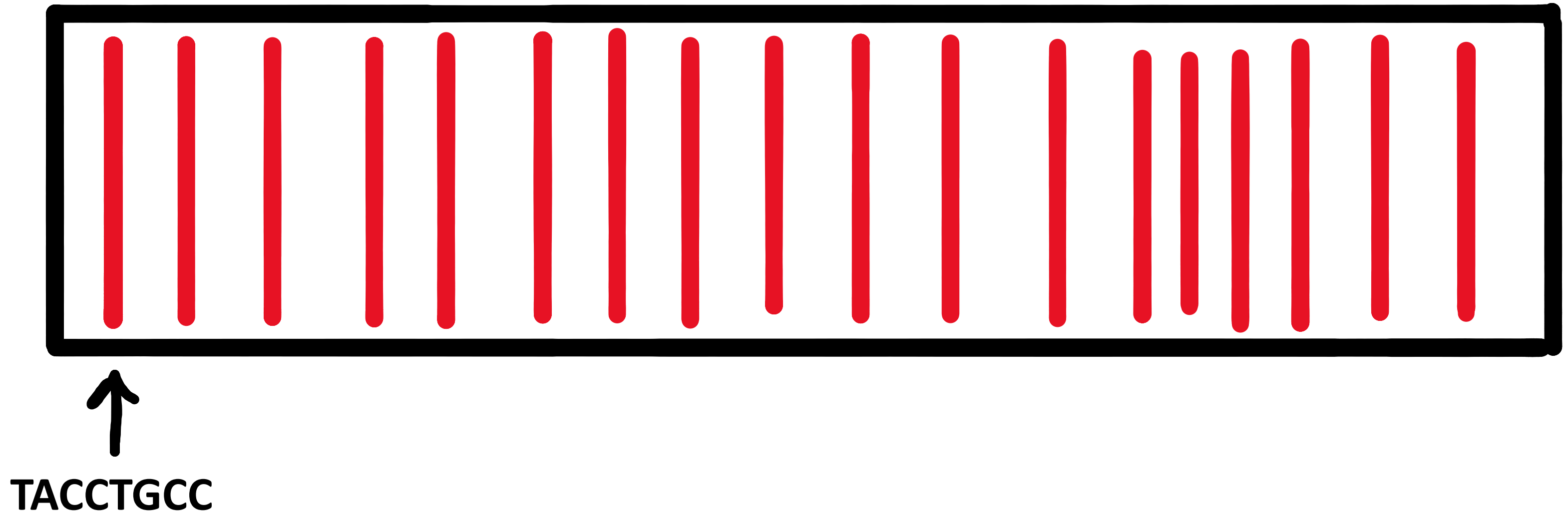
The algorithm has complexity O(log(N)) — much better scalability

2. Data-Parallel Algorithms

New task: Trim string sequences

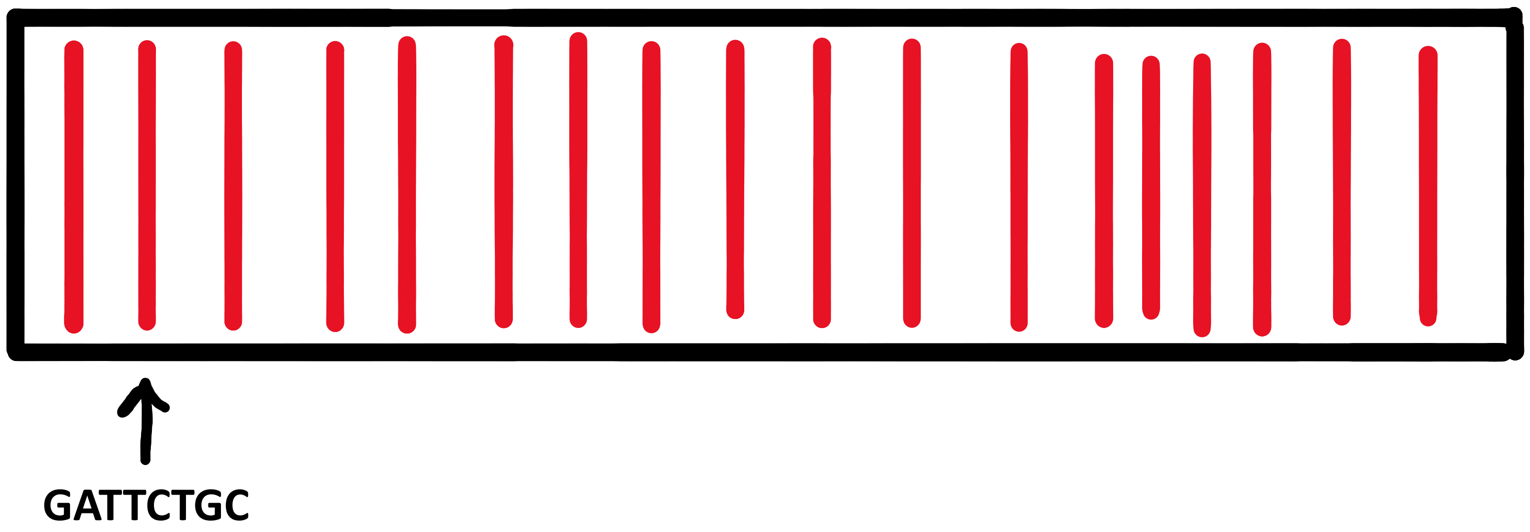
- Given a set of string sequences
- Trim the final *n* characters of each sequence
- Generate a new dataset

New task: Trim string sequences (last 3 chars)



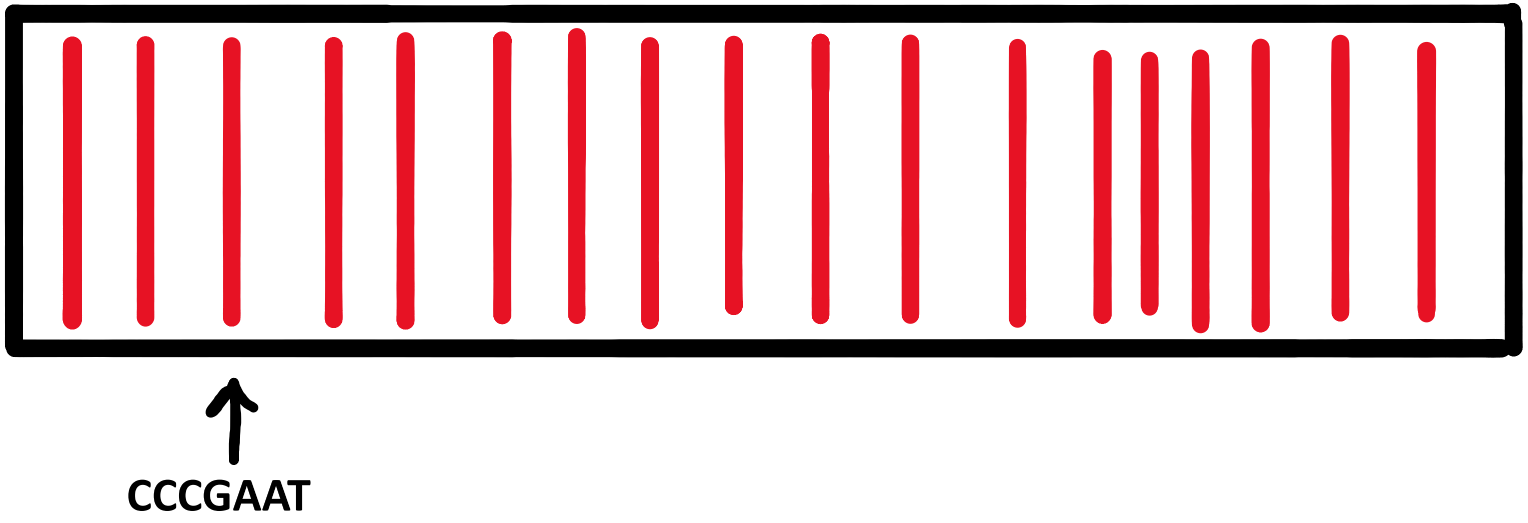
Time = 0: TACCTGCC -> TACCTG

New task: Trim string sequences (last 3 chars)



Time = 1: GATTCTGC -> GATTC

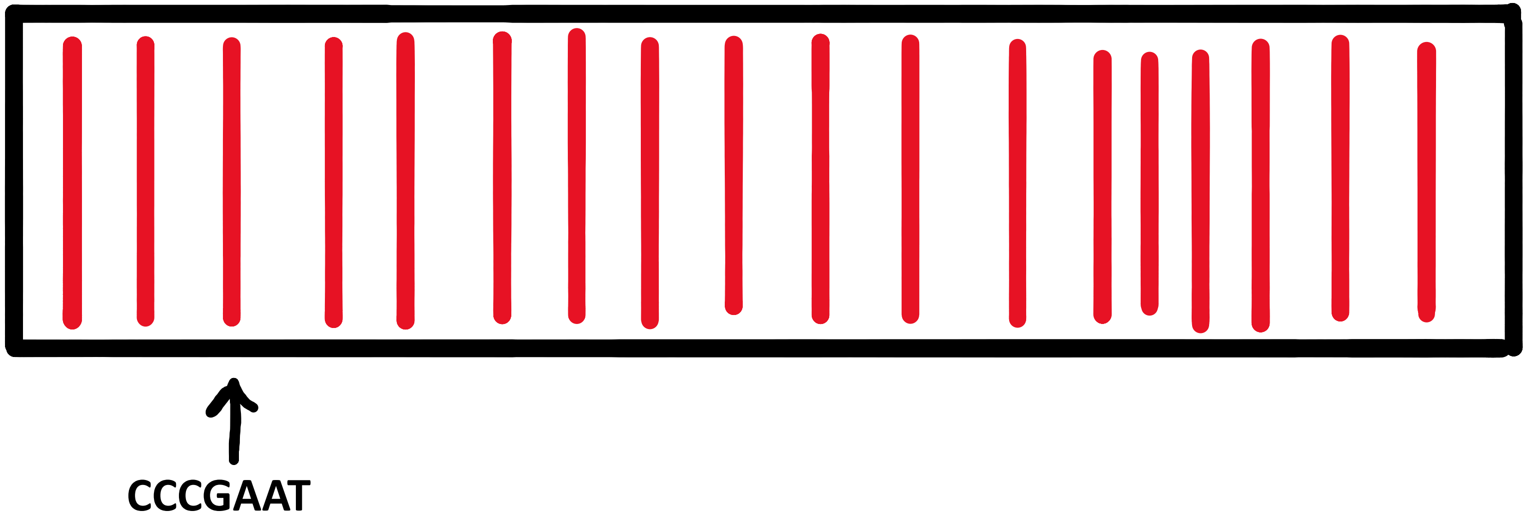
New task: Trim string sequences (last 3 chars)



Time = 2: CCCGAAT -> CCCG

Can we use a data structure to speed this operation?

New task: Trim string sequences (last 3 chars)

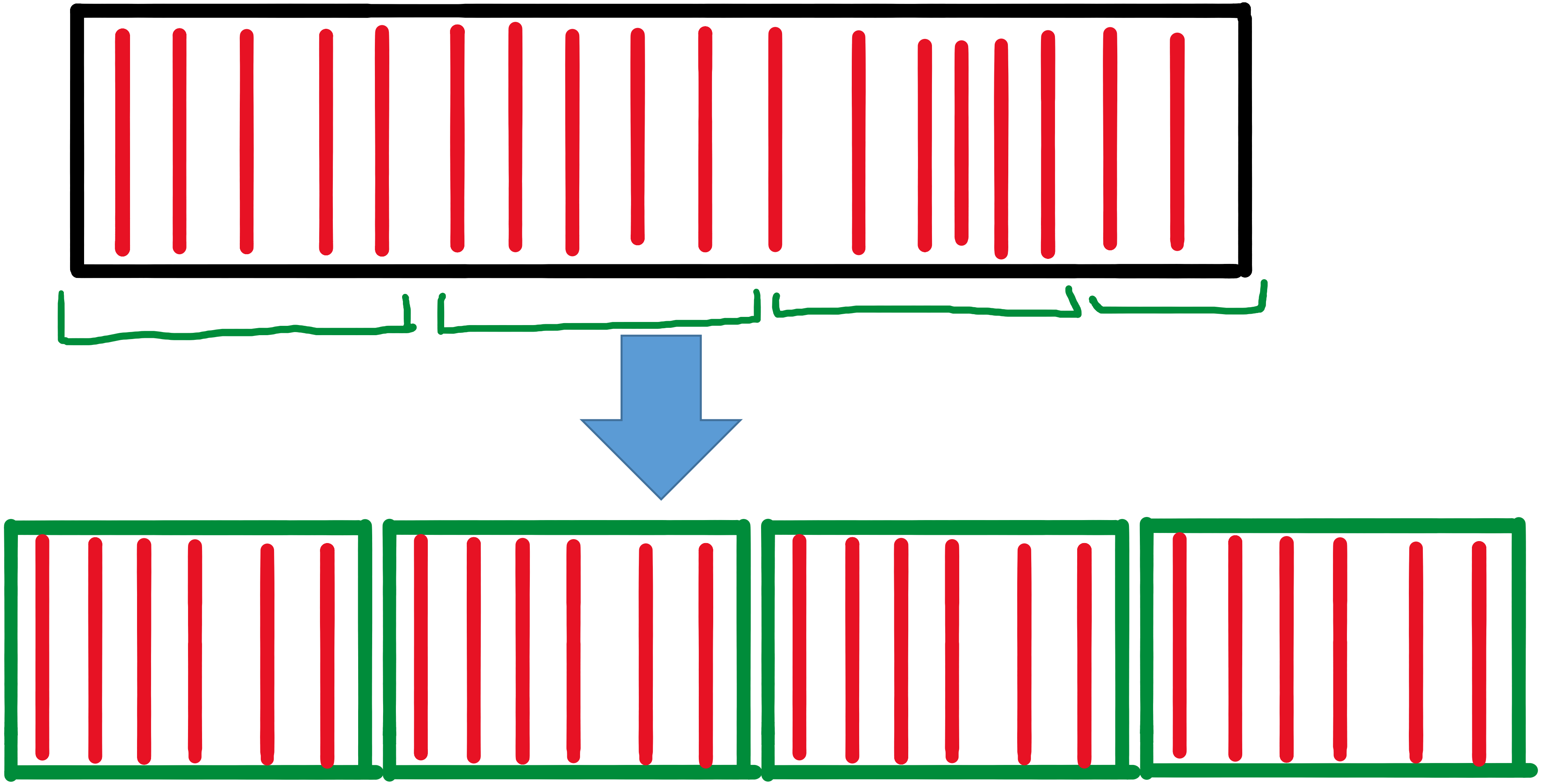


Time = 2: CCCGAAT -> CCCG

Can we use a data structure to speed this operation?

No. We have to touch every record! The task is O(N).

New task: Trim string sequences (last 3 chars)



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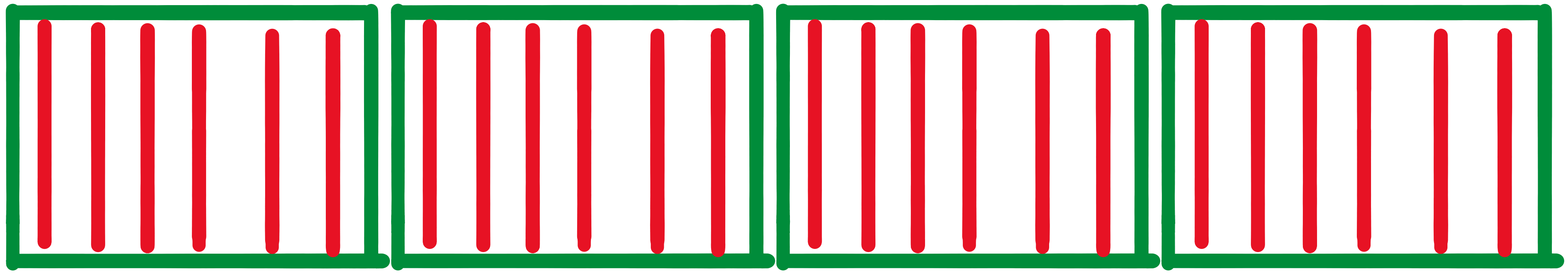

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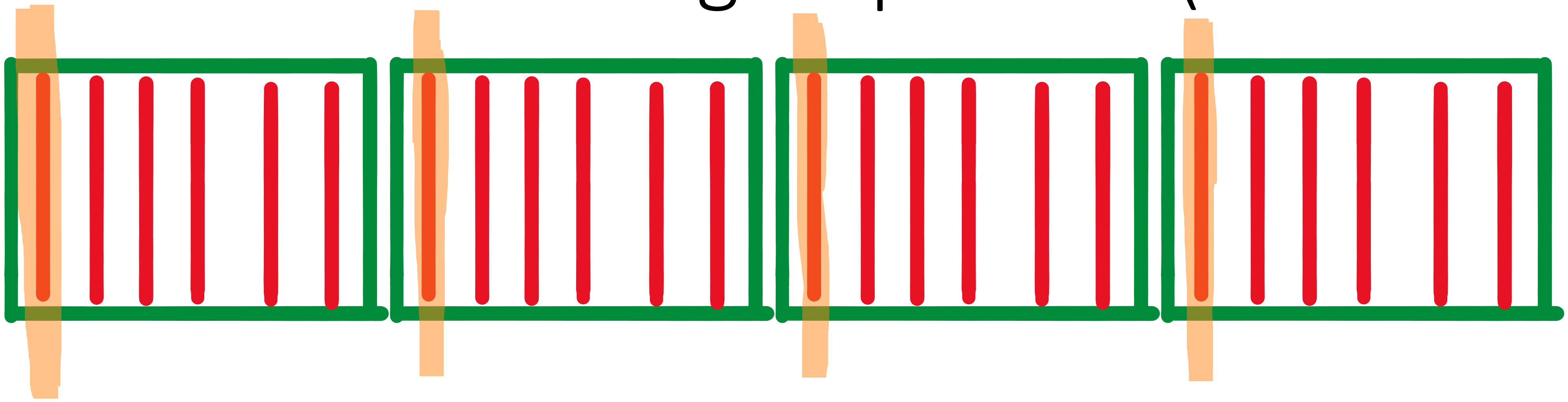
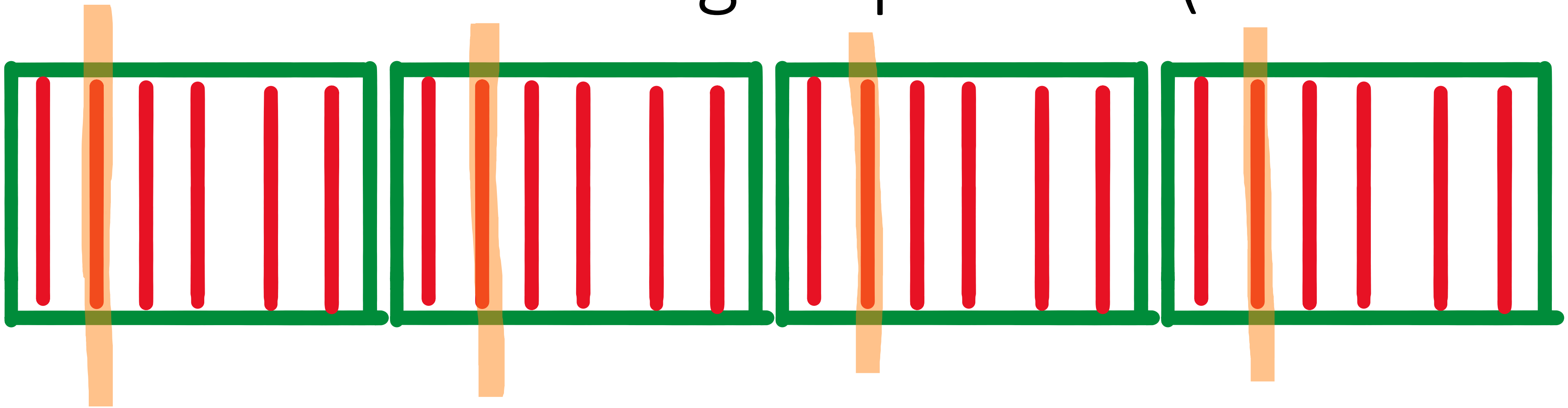


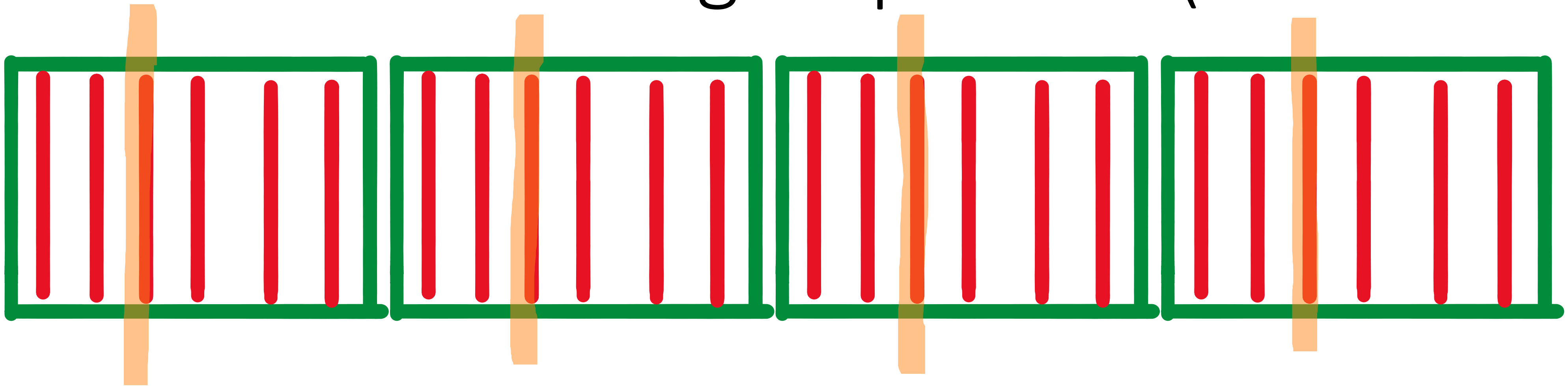
Time = 1: Process first element of each group

New task: Trim string sequences (last 3 chars)



Time = 2: Process second element of each group

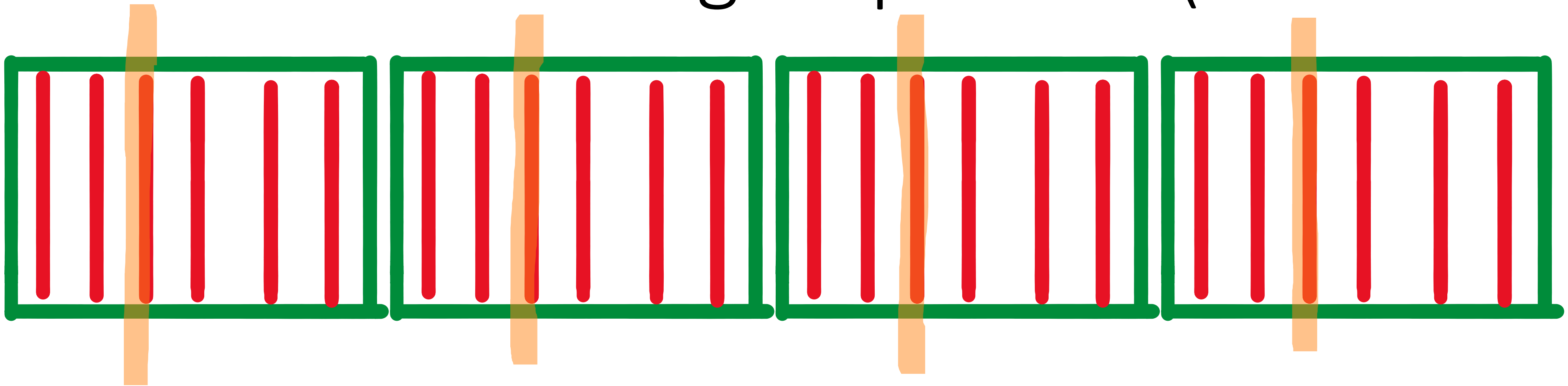
New task: Trim string sequences (last 3 chars)



Time = 3: Process third element of each group

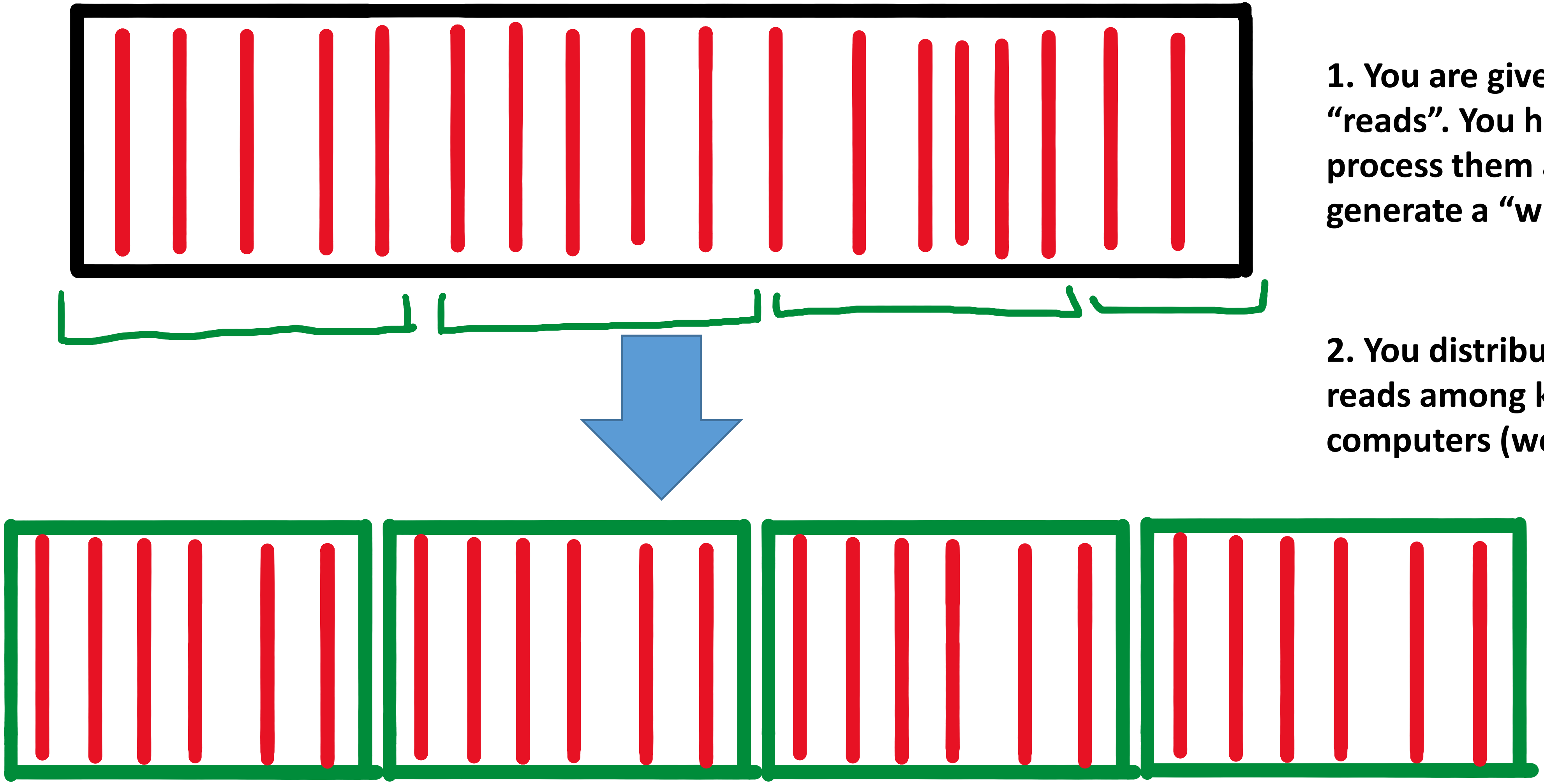
Etc.. How much time does this take?

New task: Trim string sequences (last 3 chars)



We only need O(N/k) operations where k is the number of groups (workers)

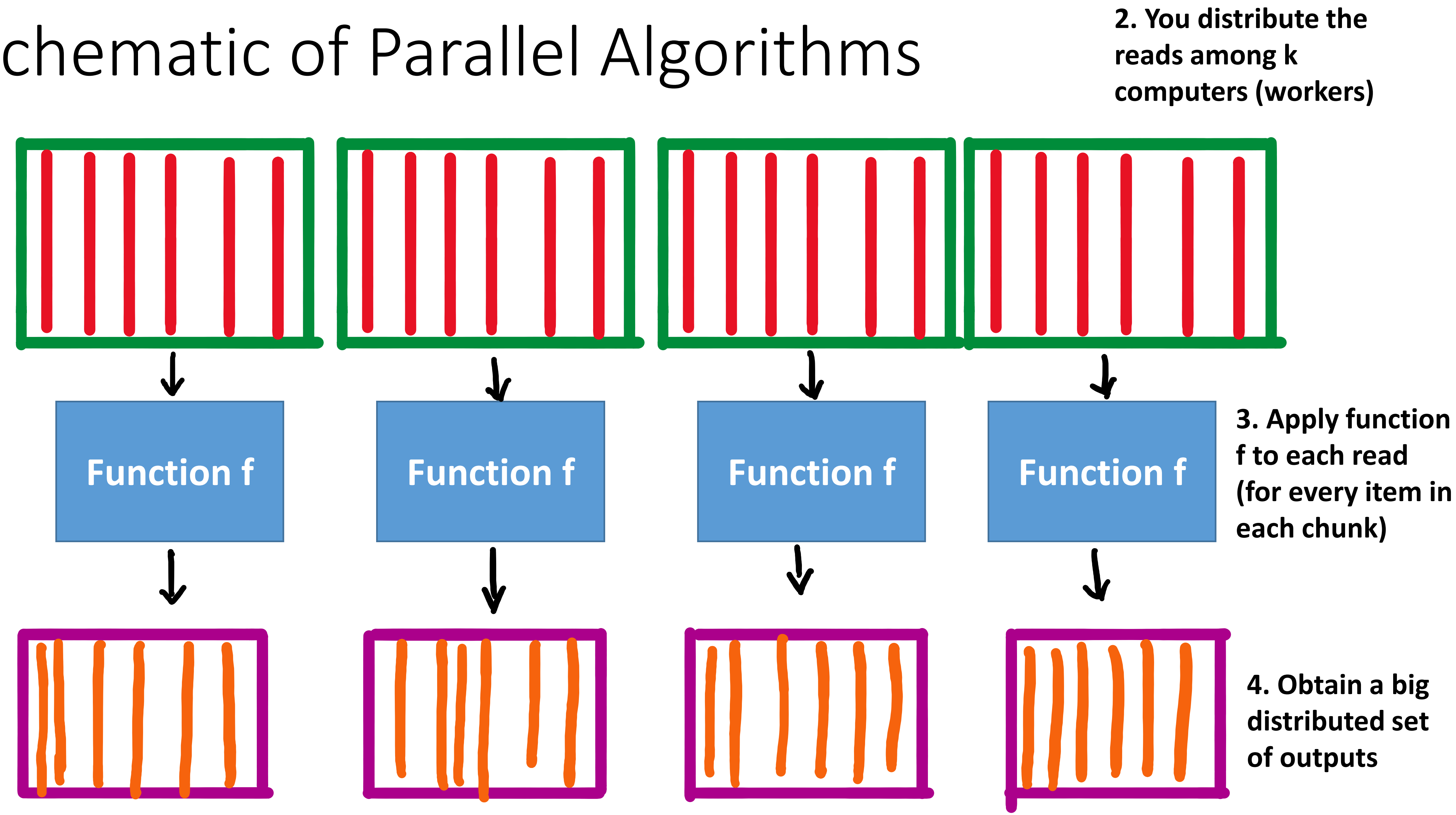
Schematic of Parallel Algorithms



1. You are given a set of "reads". You have to process them and generate a "write"

2. You distribute the reads among k computers (workers)

Schematic of Parallel Algorithms



Applications of parallel algorithms

- Convert TIFF images to PNG
- Run thousands of simulations for different model parameters
- Find the most common word in each document
- Compute the word frequency of every word in a single document
- Etc….

Applications of parallel algorithms

- Convert TIFF images to PNG
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- Compute the word frequency of every word in a single document
- Etc….

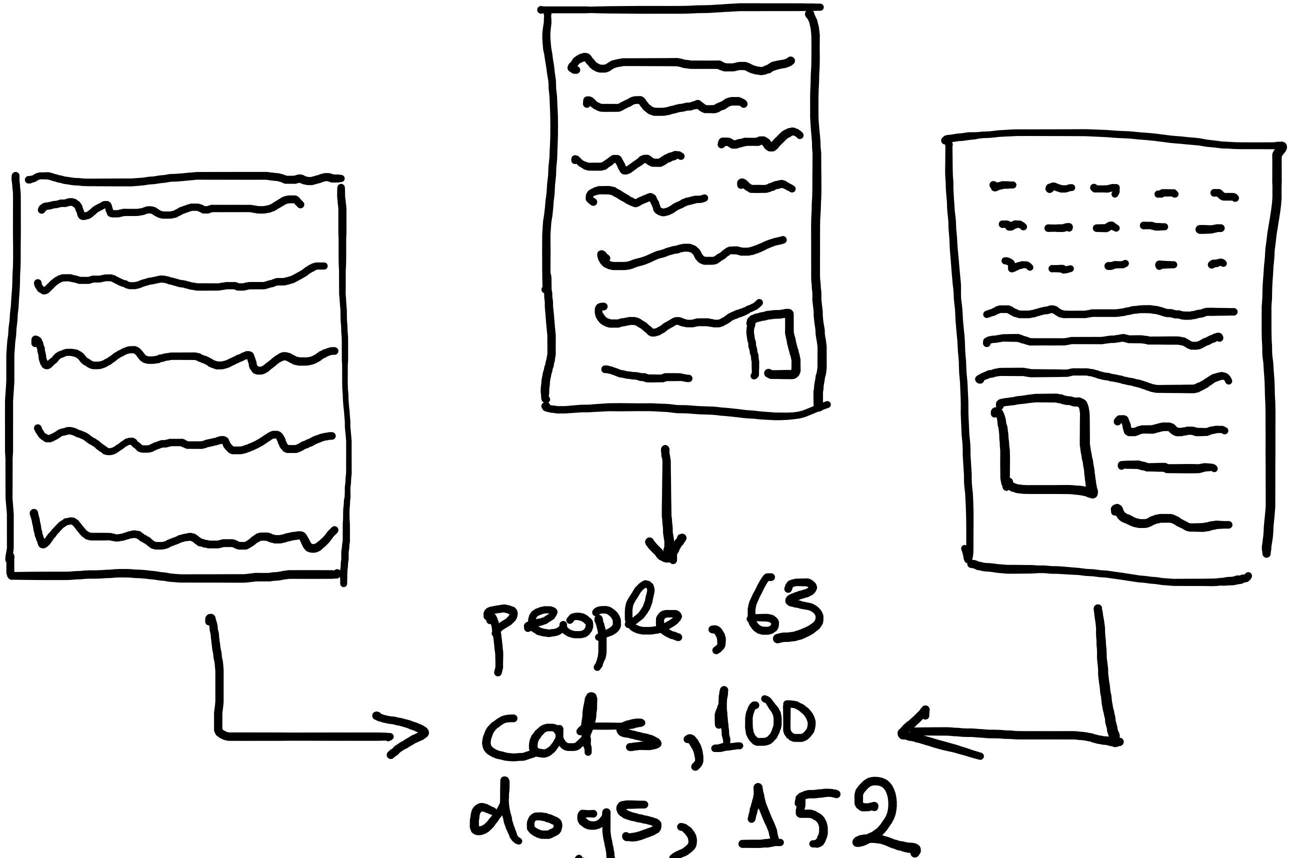
- There is a common pattern in all these applications

Applications of parallel algorithms

- A function that ***maps*** a string to a trimmed string
- A function that ***maps*** a TIFF images to a PNG image
- A function that ***maps*** a set of parameters to simulation results
- A function that ***maps*** a document to its most common word
- A function that ***maps*** a document to a histogram of word frequencies

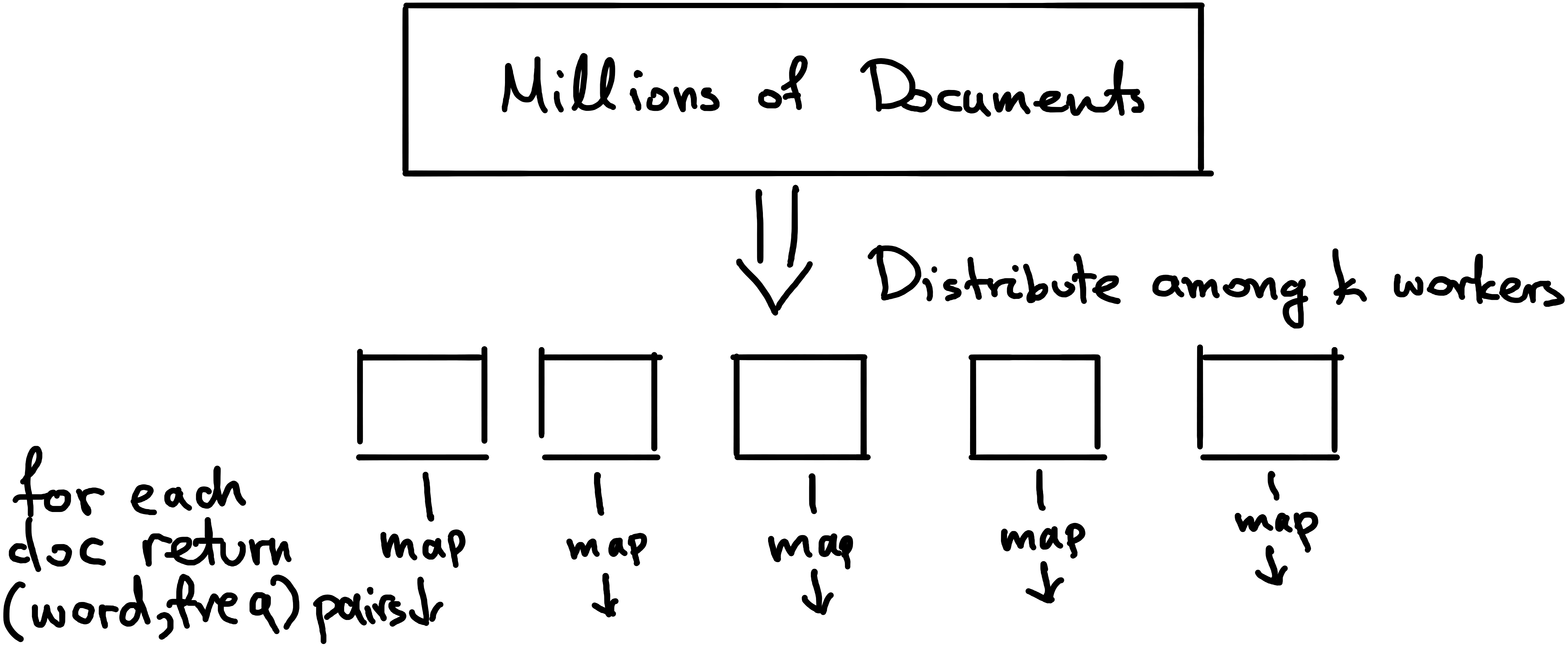
Applications of parallel algorithms

- What if we want to compute the word frequency across ***all*** documents?

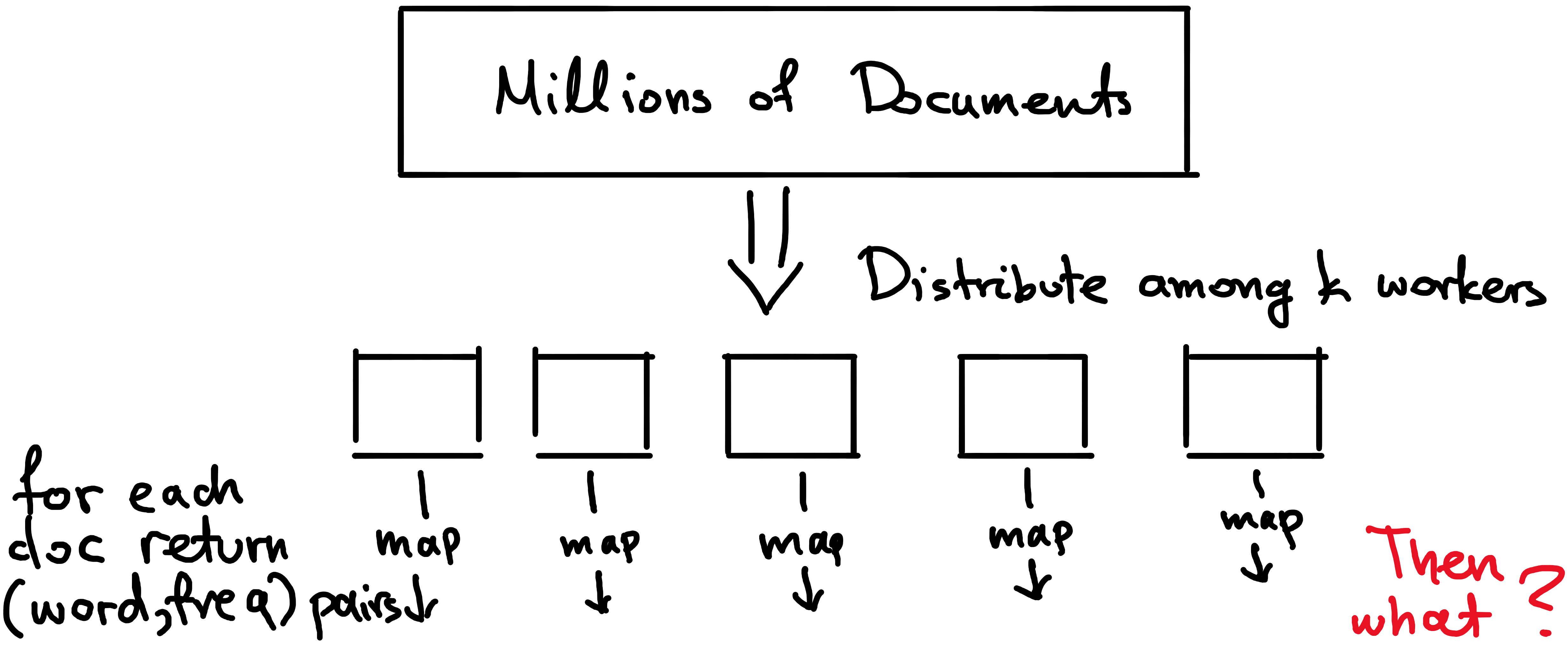


3. The MapReduce Abstraction

Compute the word frequency **across** 5M documents



Compute the word frequency **across** 5M documents

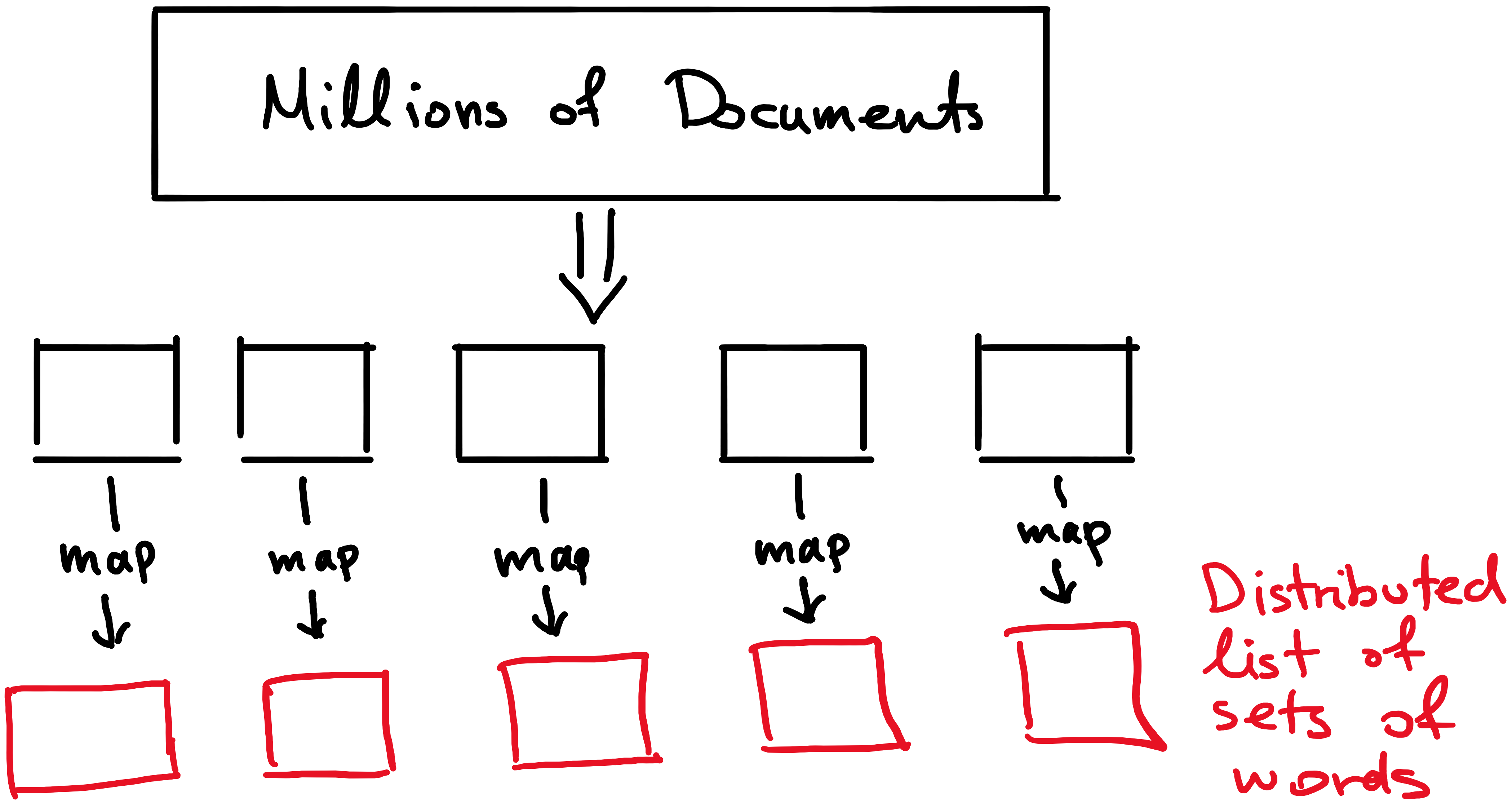


Challenge: in this task

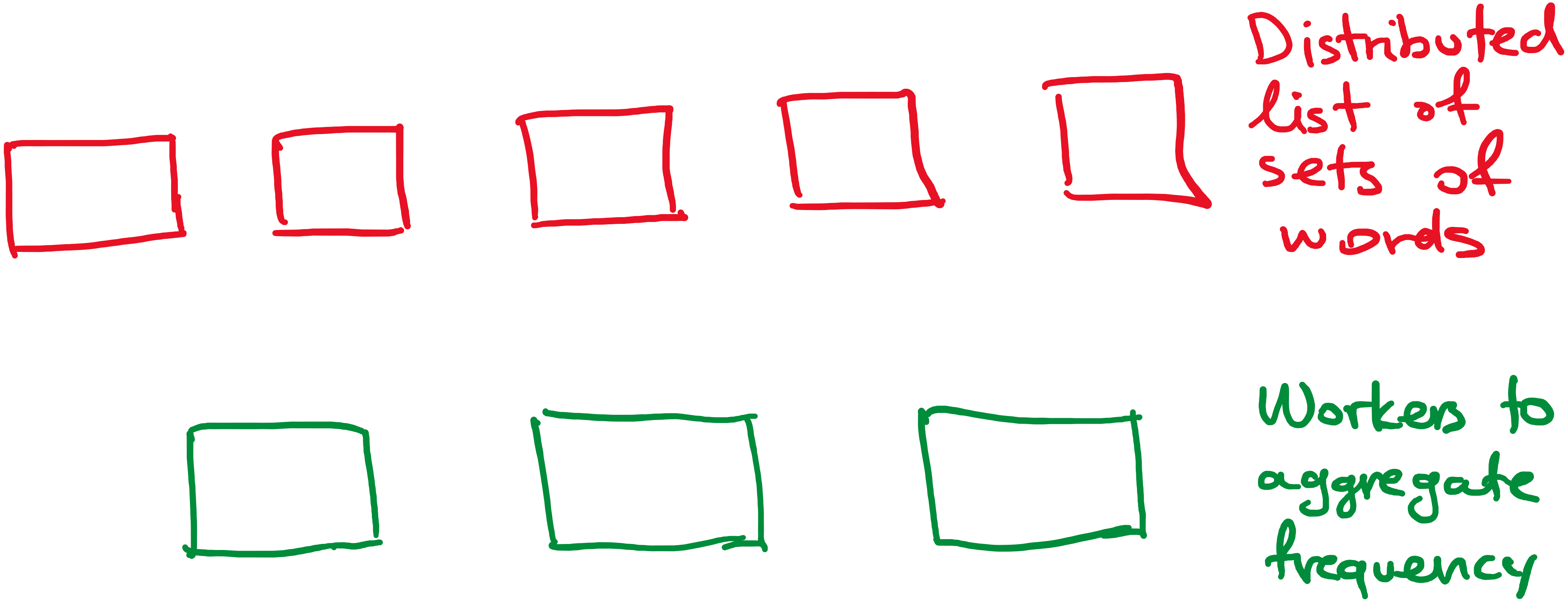
- How can we make sure that a single computer has access to every occurrence of a given word regardless of which document it appeared in?

- *Ideas?*

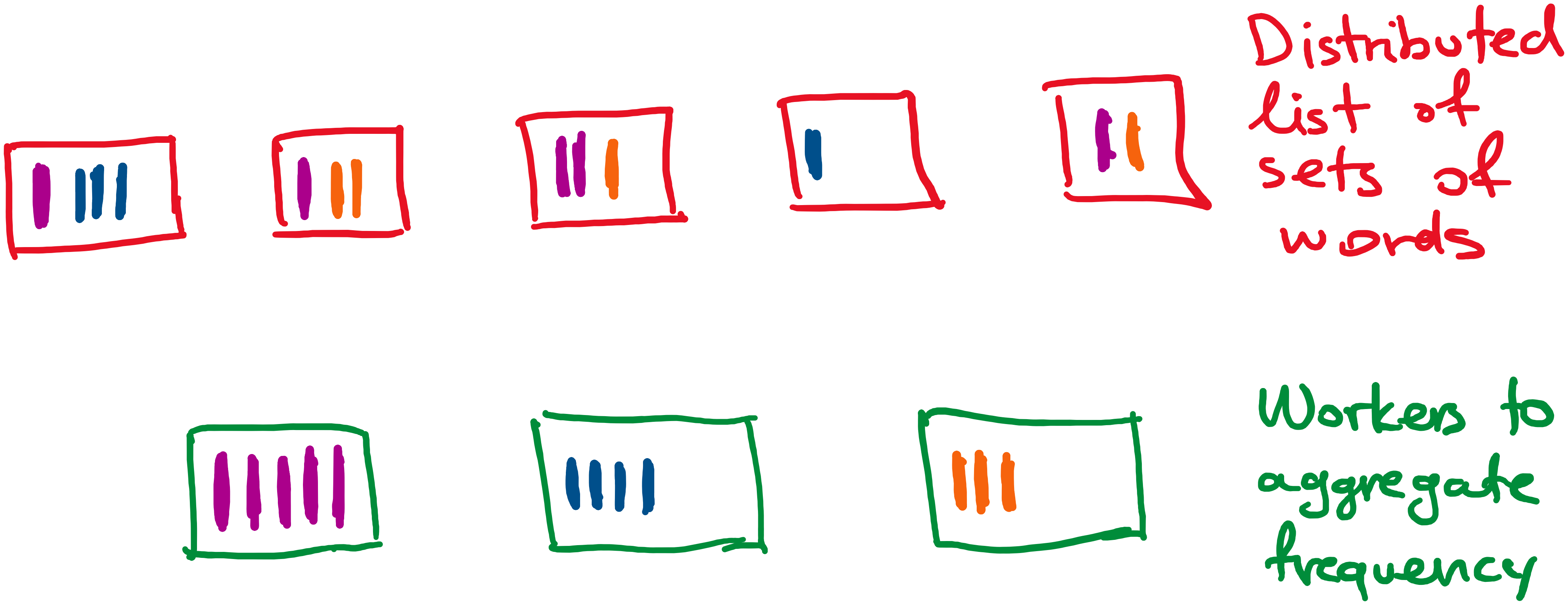
Compute the word frequency **across** 5M documents



Compute the word frequency **across** 5M documents



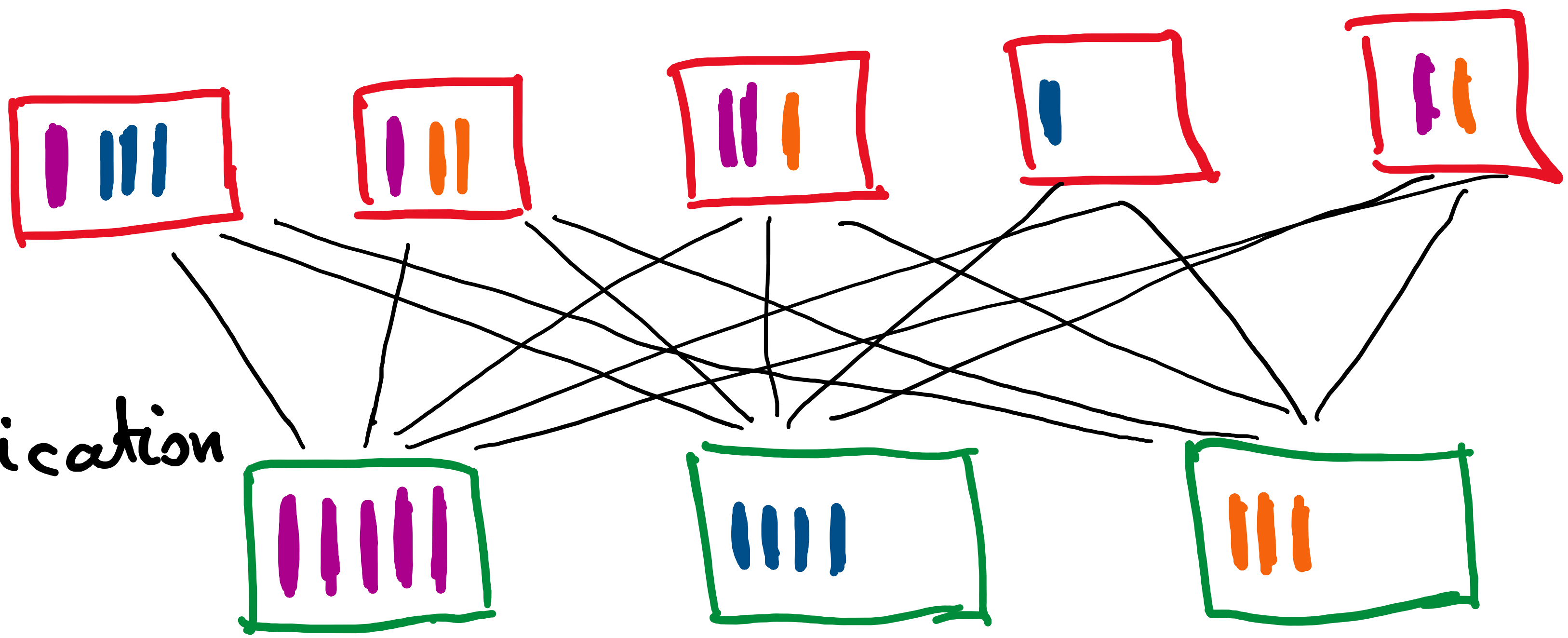
Compute the word frequency **across** 5M documents



Compute the word frequency **across** 5M documents

Distributed list of sets of words

Complex communication phase



Workers to aggregate frequency

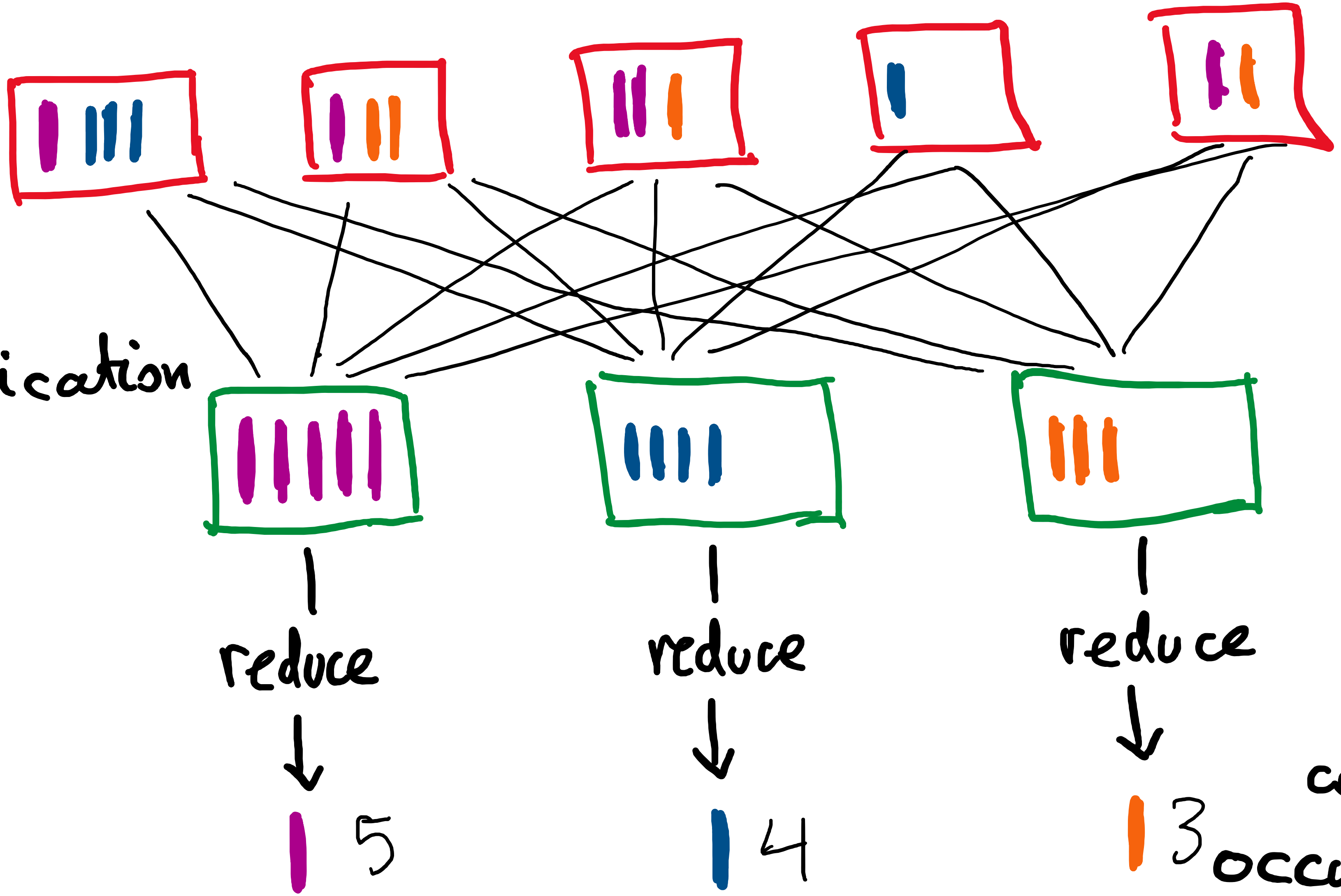
We use a hash function here!

A hash function is any function that can be used to map data of arbitrary size to a data of a fixed size

Compute the word frequency **across** 5M documents

Distributed list of sets of words

Complex communication phase



Workers to aggregate frequency

Now we just count the occurrences per word

The Map Reduce Abstraction for Distributed Algorithms