MapReduce

A Framework for Big Data Processing

The Big Data Challenge

We can store Big Data in distributed file systems...

- Handle **volume** (large amounts of data)
- Handle **velocity** (fast data ingestion)

But how do we analyze it?

- Deal with **variety** (unstructured data)
- Extract meaningful insights

The Brute Force Approach: Full Scan

Example: Searching for a log entry in AWS S3

- Problem: Find a particular request's log entry
- Solution: Full scan of all logs
- Result: **Ran overnight!** 😴

Can we do better?

Speeding Up: Parallel Processing

Idea: Use multiple processes scanning different data shards

- Each process scans a file block on a data node
- Minutes instead of hours/days! ⚡

Use cases:

- Searching for particular data
- Filtering data

But: Need infrastructure to:

- Set up multiple processes
- Coordinate data sharding

What About More Complex Operations?

Examples of aggregate operations:

- Total number of requests per day for each customer
- Total units sold for each product on invoices

Traditional approach:

- Write a custom distributed program for each problem
- Complicated, time-consuming, and error-prone

There must be a better way!

The Analogy: Filesystems vs DBMS

Filesystem:

- Extract information → write custom program for each use case
- Tedious and repetitive

DBMS:

- Provides general infrastructure
- Supports different use cases with minimal effort
- SQL queries instead of custom programs

We need something similar for Big Data!

Introducing MapReduce

> **MapReduce** provides a general-purpose infrastructure and programming framework to process large data sets with minimal effort

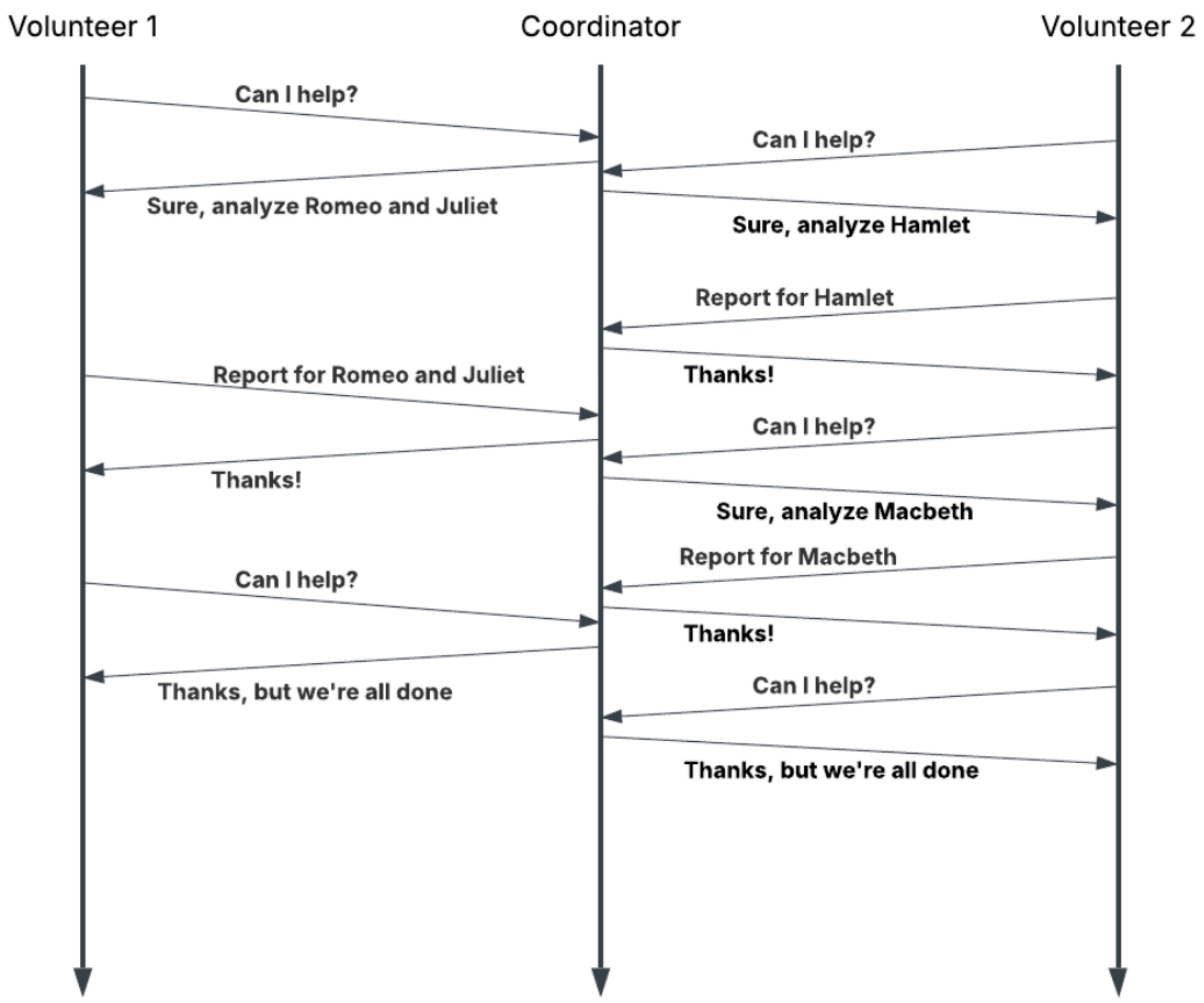
Key Benefits:

- Write simple Map and Reduce functions
- Infrastructure handles distribution, coordination, fault tolerance
- Focus on **what** to compute, not **how** to distribute

Case Study: Word Count

Real-world project: Distributed word-frequency counter for Shakespeare's plays

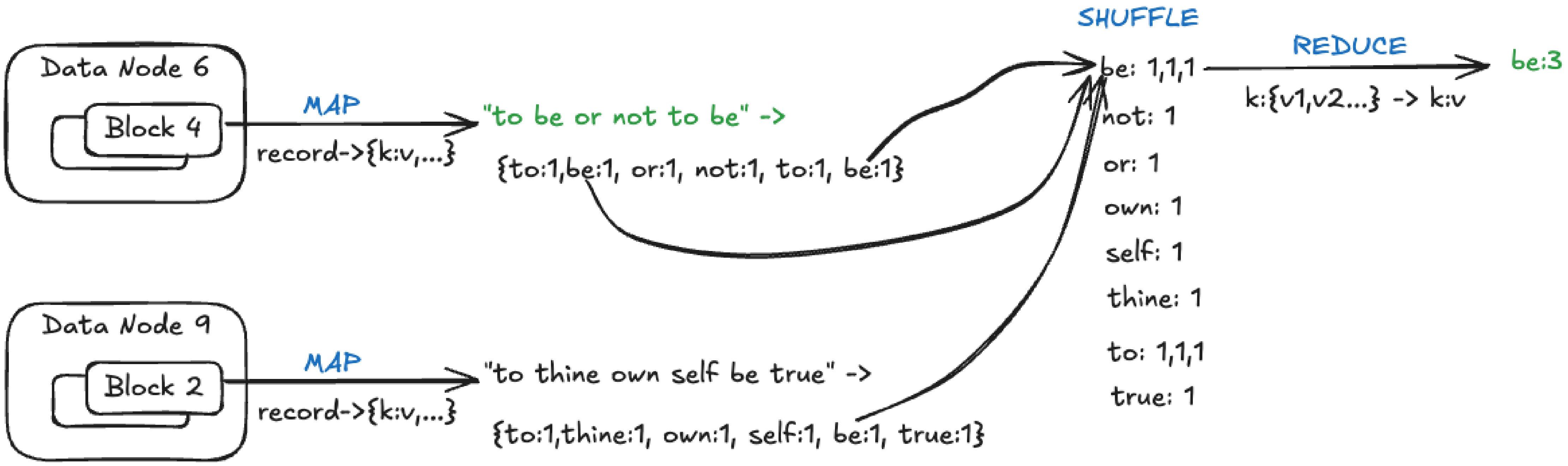
- Students build coordinator-volunteers system
- Count word frequencies across all plays
- Requires significant implementation effort


Volunteer 1
Coordinator
Volunteer 2
Can I help?
Can I help?
Sure, analyze Romeo and Juliet
Sure, analyze Hamlet
Report for Hamlet
Thanks!
Report for Romeo and Juliet
Can I help?
Thanks!
Sure, analyze Macbeth
Report for Macbeth
Can I help?
Thanks!
Thanks, but we're all done
Can I help?
Thanks, but we're all done

Question: Can MapReduce simplify this?

Answer: Yes! Dramatically!

Word Count with MapReduce



Your job: Code the Map function and Reduce function

MapReduce infrastructure handles: Everything else!

MapReduce Word Count: The Code

```java
public class Main {
    public static void main(String[] args) {
        Mapper<String, Integer> mapper = (String line, Consumer<Entry<String, Integer>> consumer) -> {
            for (String word : line.split(" ")) {
                word = word.toLowerCase();
                consumer.accept(Map.entry(word, 1));
            }
        };

        Reducer<String, Integer> reducer = (String key, Collection<Integer> values, Consumer<String> consumer) -> {
            int sum = 0;
            for (int v : values) {
                sum += v;
            }
            consumer.accept(key + ": " + sum);
        };

        Spec<String, Integer> spec = new Spec<>("java/src/examples/data",
                mapper, reducer, "java/src/examples/wordcount");
        Runner<String, Integer> runner = new Runner<>(spec);
        runner.run();
    }
}
```

Breaking Down the Map Function

```java
Mapper<String, Integer> mapper = (line, consumer) -> {
    for (String word : line.split(" ")) {
        word = word.toLowerCase();
        consumer.accept(Map.entry(word, 1));
    }
};
```

What it does:

1. Takes a line of text as input
2. Splits into individual words
3. Converts to lowercase (normalization)
4. Emits each word with count of 1: `(word, 1)`

Breaking Down the Reduce Function

```
Reducer<String, Integer> reducer = (key, values, consumer) -> {
    int sum = 0;
    for (int v : values) {
        sum += v;
    }
    consumer.accept(key + ": " + sum);
};
```

What it does:

1. Receives a word (key) and all its counts (values)
2. Sums up all the counts
3. Outputs: `word: total_count`

💡 Active Learning: Trace the Execution (3 minutes)

Input text:

```
The quick brown fox
The lazy dog
```

Task: Work through what the Map and Reduce functions produce

1. What key-value pairs does the Mapper emit?
2. How are they grouped before Reduce?
3. What does the Reducer output?

Solution: Trace the Execution

Mapper output:

```
(the, 1), (quick, 1), (brown, 1), (fox, 1)
(the, 1), (lazy, 1), (dog, 1)
```

After grouping (by key):

```
the: [1, 1]
quick: [1]
brown: [1]
fox: [1]
lazy: [1]
dog: [1]
```

Reducer output:

```
the: 2, quick: 1, brown: 1, fox: 1, lazy: 1, dog: 1
```

MapReduce Playground

Example Code

Available for experimentation:

- Java-based MapReduce framework
- Runs on a single machine
- No distributed infrastructure needed

Purpose:

- Learn MapReduce concepts
- Experiment without setup complexity
- Focus on Map/Reduce logic

For production: Use Hadoop MapReduce

Use Cases: One-Off Jobs

Ad-hoc analysis tasks:

Example: Grep across logs

- Service handling millions of queries per second (qps)
- Search for specific patterns across all request logs
- Quick insights without building custom tools

Other examples:

- Find all errors in the last 24 hours
- Extract user behavior patterns
- Identify anomalies in system metrics

Use Cases: Production Systems

Google Maps Generation

- **Input:** Geo features (roads, buildings, restaurants)
- **Output:** Vector drawing instructions for map tiles
    - Zoom 0: one tile for the entire world
    - Zoom 1: divide into 4 tiles
    - Each zoom level multiplies tiles by 4

SaaS Billing System

- **Input:** Request logs from all customers
- **Output:** Per-customer bills based on API usage
- Process millions of requests to generate accurate invoices

Key Takeaways

1. **Problem:** Analyzing Big Data requires custom distributed programs
2. **Solution:** MapReduce provides reusable infrastructure
3. **Your job:** Write Map and Reduce functions
4. **Framework handles:** Distribution, coordination, fault tolerance
5. **Result:** Focus on logic, not infrastructure