Introduction to Map/Reduce: From Hadoop to SPARK

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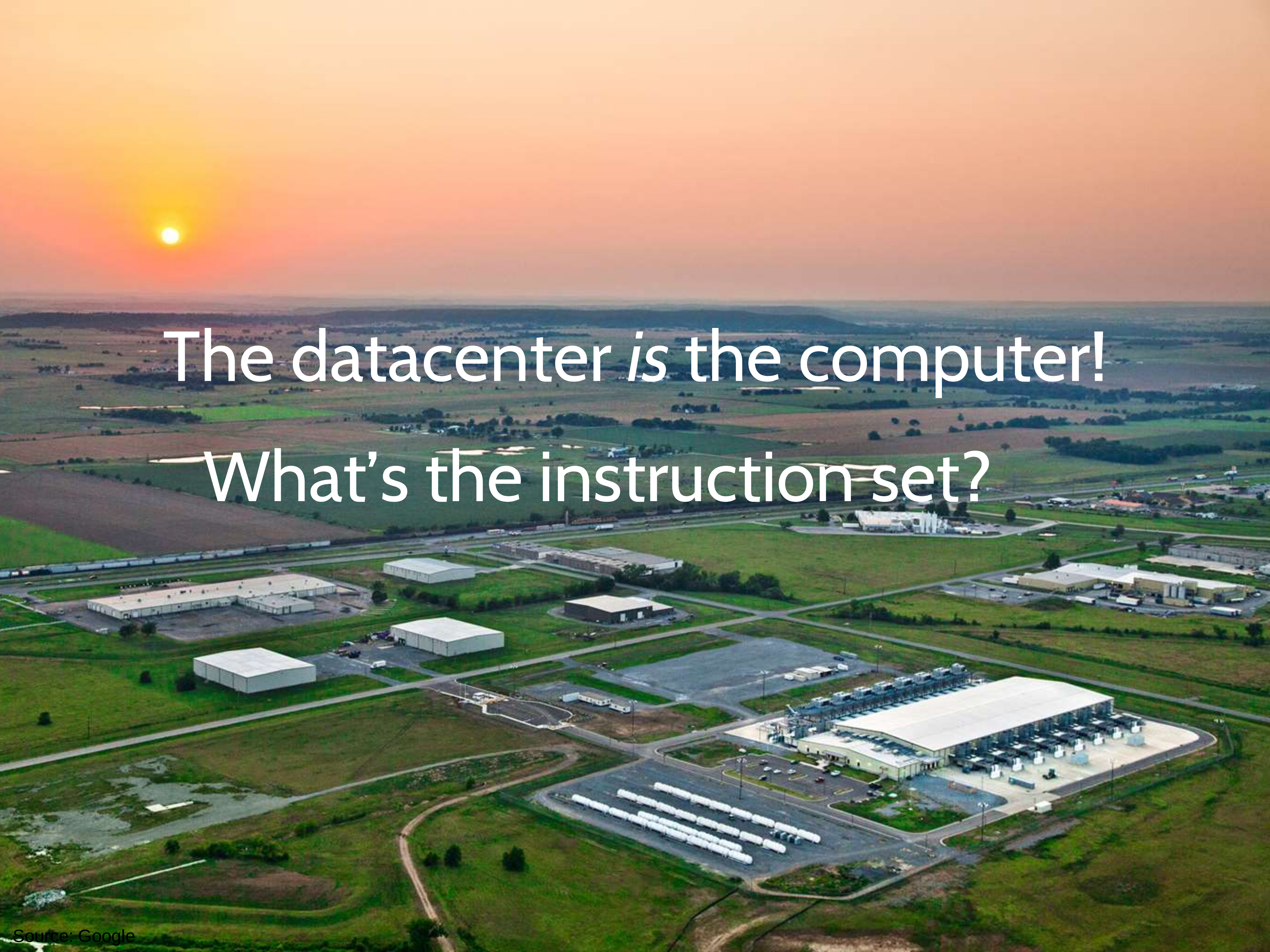
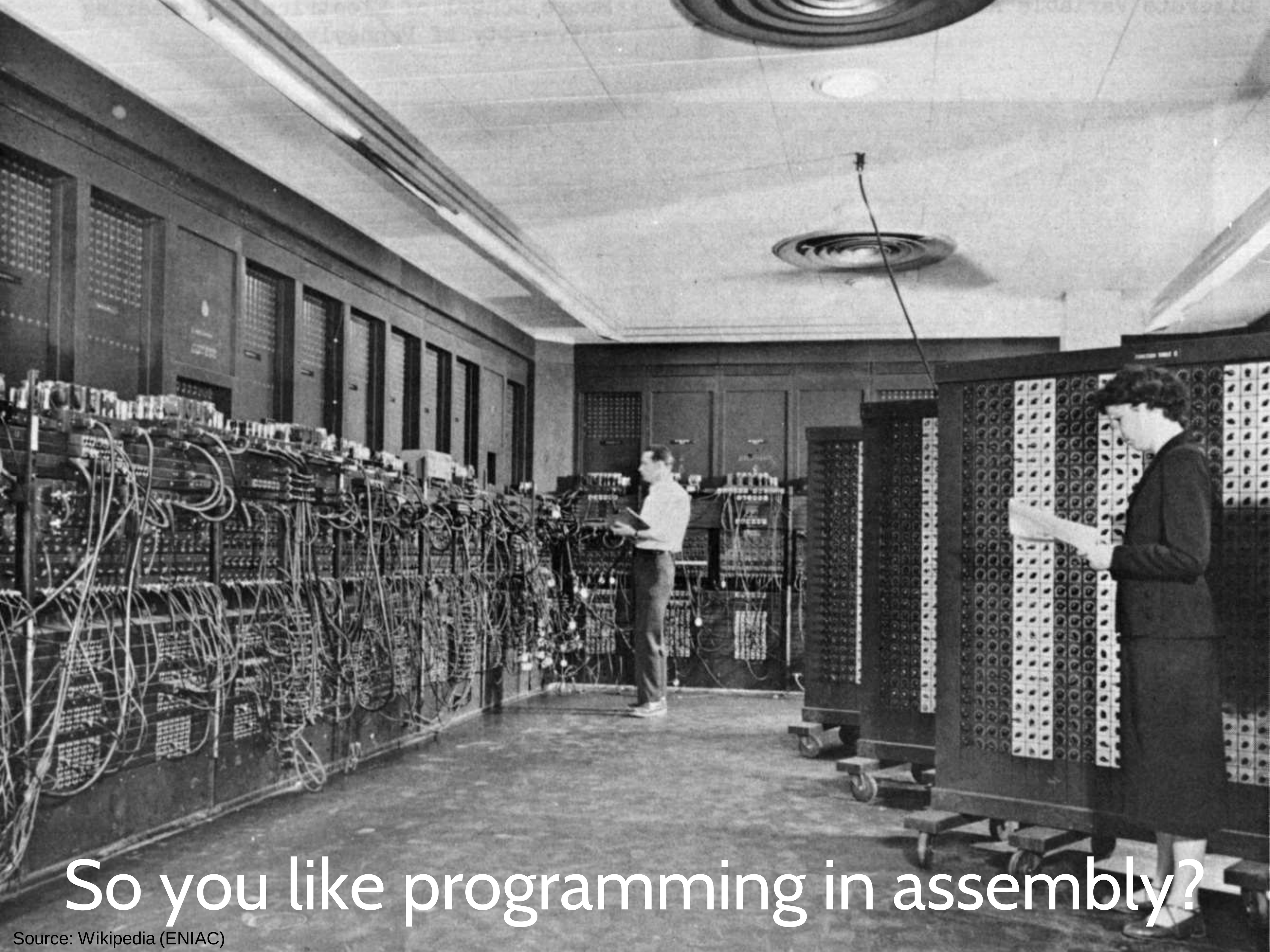
University of Crete, Greece

What we will cover...

- Dataflow Languages for Cluster Computing
- What is MapReduce?
- How does it work?
- A simple word count example
  - (the "Hello World!" of MapReduce)
- From MapReduce to Spark


The datacenter *is* the computer!
What's the instruction set?
Source: Google

So you like programming in assembly?



Source: Wikipedia (ENIAC)

Traditional Network Programming

Message-passing between nodes (e.g. MPI)

Very difficult to do at scale:

- How to split problem across nodes?
    - Must consider network & data locality

How to deal with failures? (inevitable at scale)

Even worse: stragglers (node not failed, but slow)

Ethernet networking not fast

- Have to write programs for each machine

Data Flow Models

Restrict the programming interface so that the system can do more automatically

Express jobs as graphs of high-level operators »System picks how to split each operator into tasks and where to run each task
• Run parts twice fault recovery

Biggest example: MapReduce

Why Use a Data Flow Engine?

Ease of programming

- High-level functions instead of message passing

Wide deployment

- More common than MPI, especially “near” data

Scalability to very largest clusters

- Even HPC world is now concerned about resilience

Examples: Pig, Hive, Scalding, Storm, Spark

Data-Parallel Dataflow Languages

We have a collection of records,
want to apply a bunch of operations
to compute some result

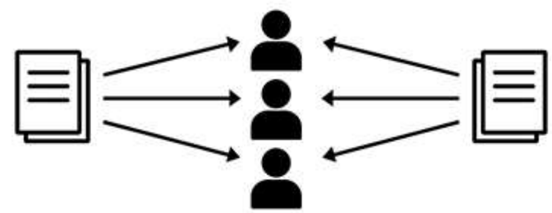
Assumption: static collection of records

(what's the limitation here?)

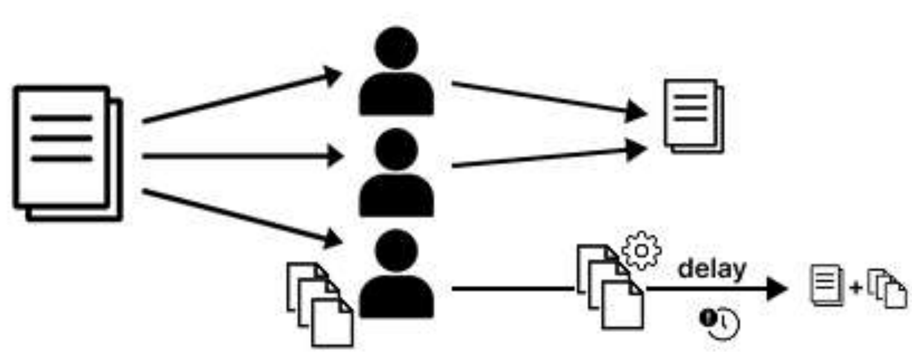
Example

- In a group project the teacher gives all students exactly 5 questions from a fixed worksheet

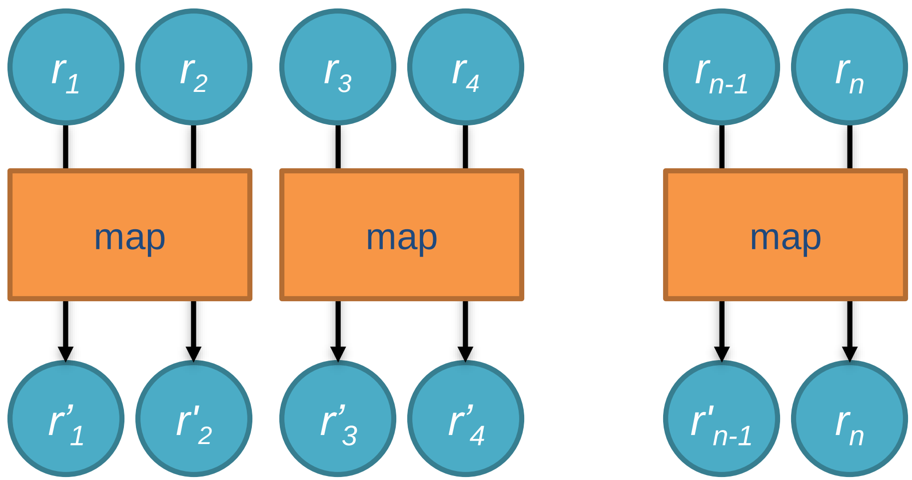
  Everyone can solve the questions in parallel, and at the end the answers are collected at the same time



What if the teacher suddenly adds 10 new questions in only 1 student?



We Need Per-record Processing



Remarks: Easy to parallelize maps,
record to "mapper" assignment is an implementation detail

What is MapReduce?

A programming model for processing large datasets in parallel on a cluster, by dividing the work into a set of independent tasks
(introduced by Google in 2005)

All we have to do is provide the implementation of two methods:

- map()
- reduce()

...but we can do much more...

← *even that, is optional!*

How does it work?

keys and **values**

- everything is expressed as (*key*, *value*) pairs
  - e.g. the information that the word "hello" appears 4 times in a text, could be expressed as: ("hello", 4)

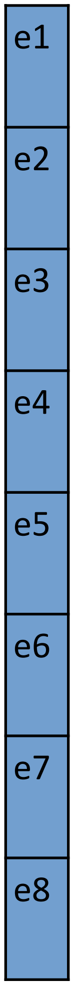
Each *map* method receives a list of (*key*, *value*) pairs and emits a list of (*key*, *value*) pairs

- the intermediate output of the program

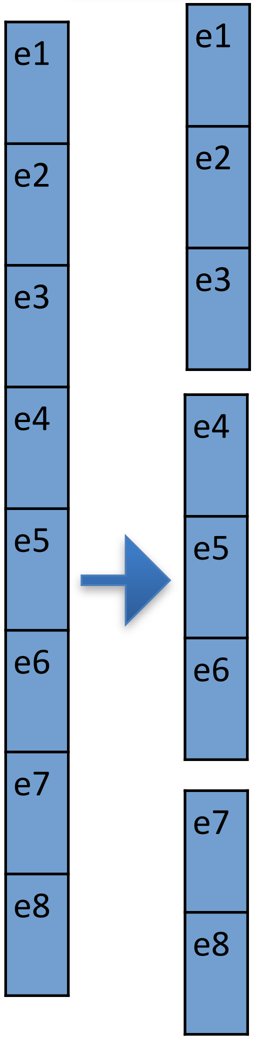
Each *reduce* method receives, for each unique intermediate key *k*, a **list** of all intermediate values that were emitted for *k*.
Then, it emits a list of (*key, value*) pairs

- the final output of the program

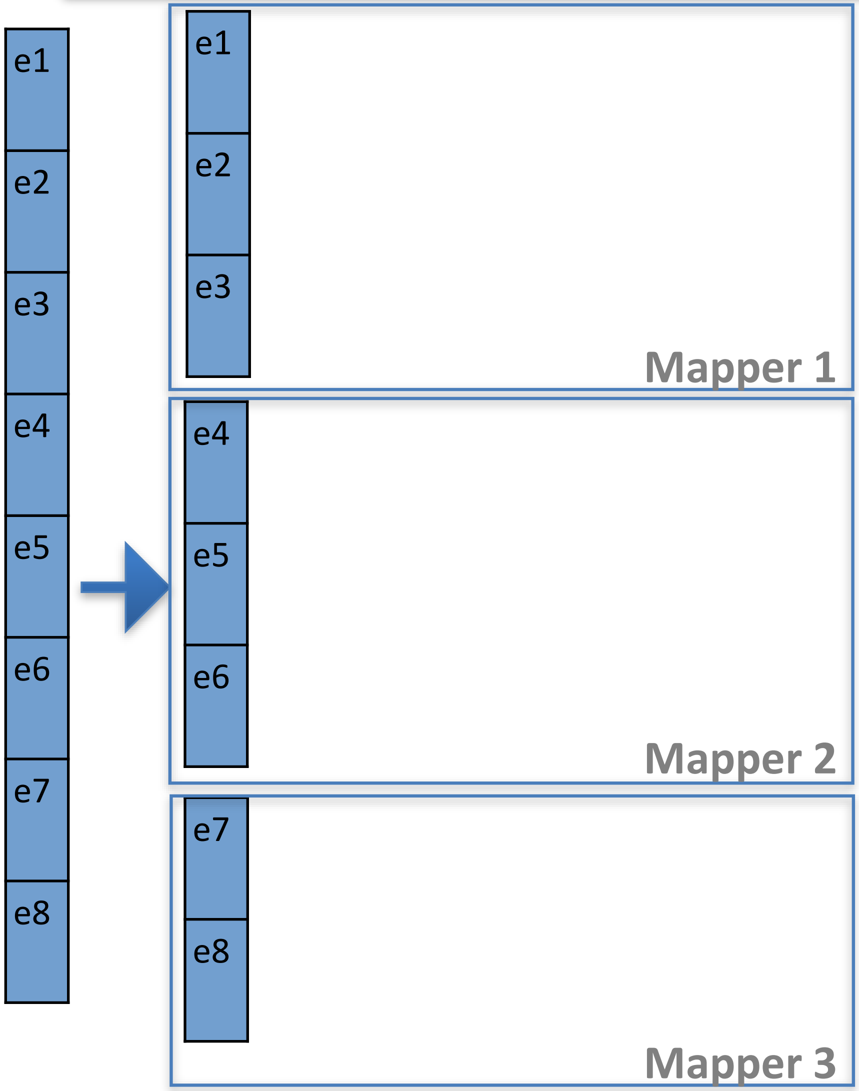
MapReduce – Input Data



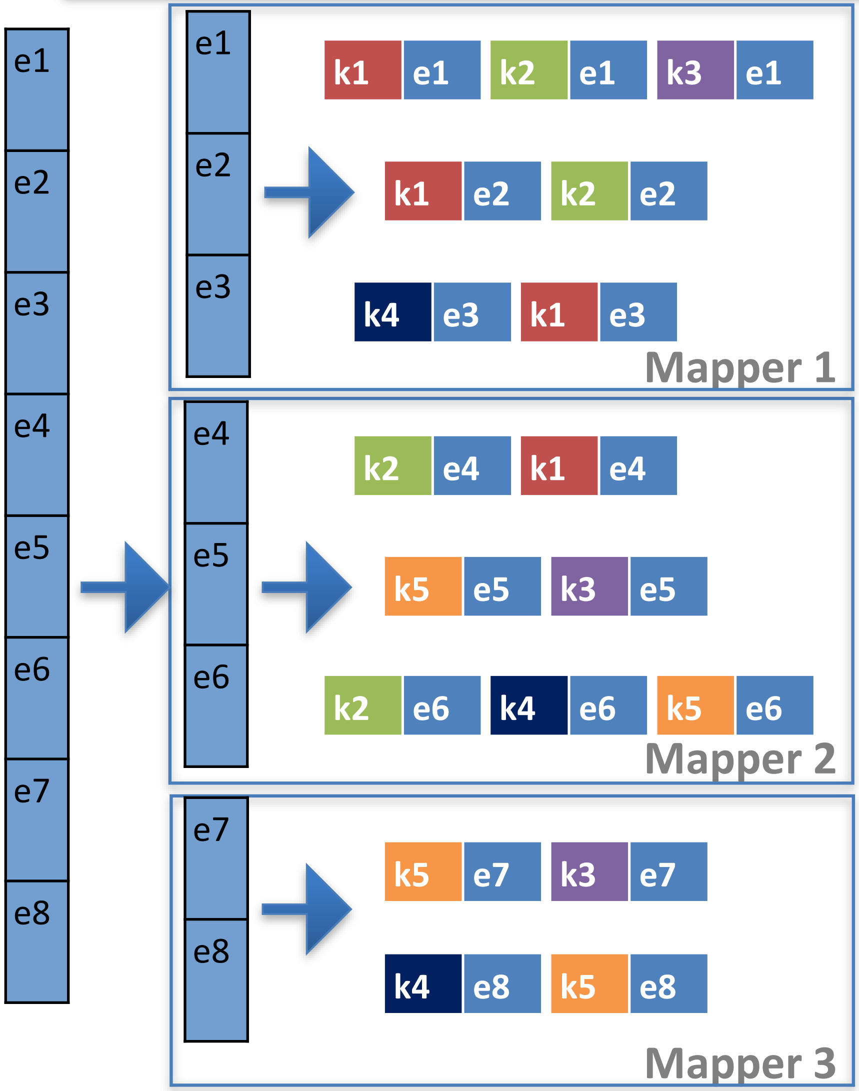
MapReduce – Input Data Splitting



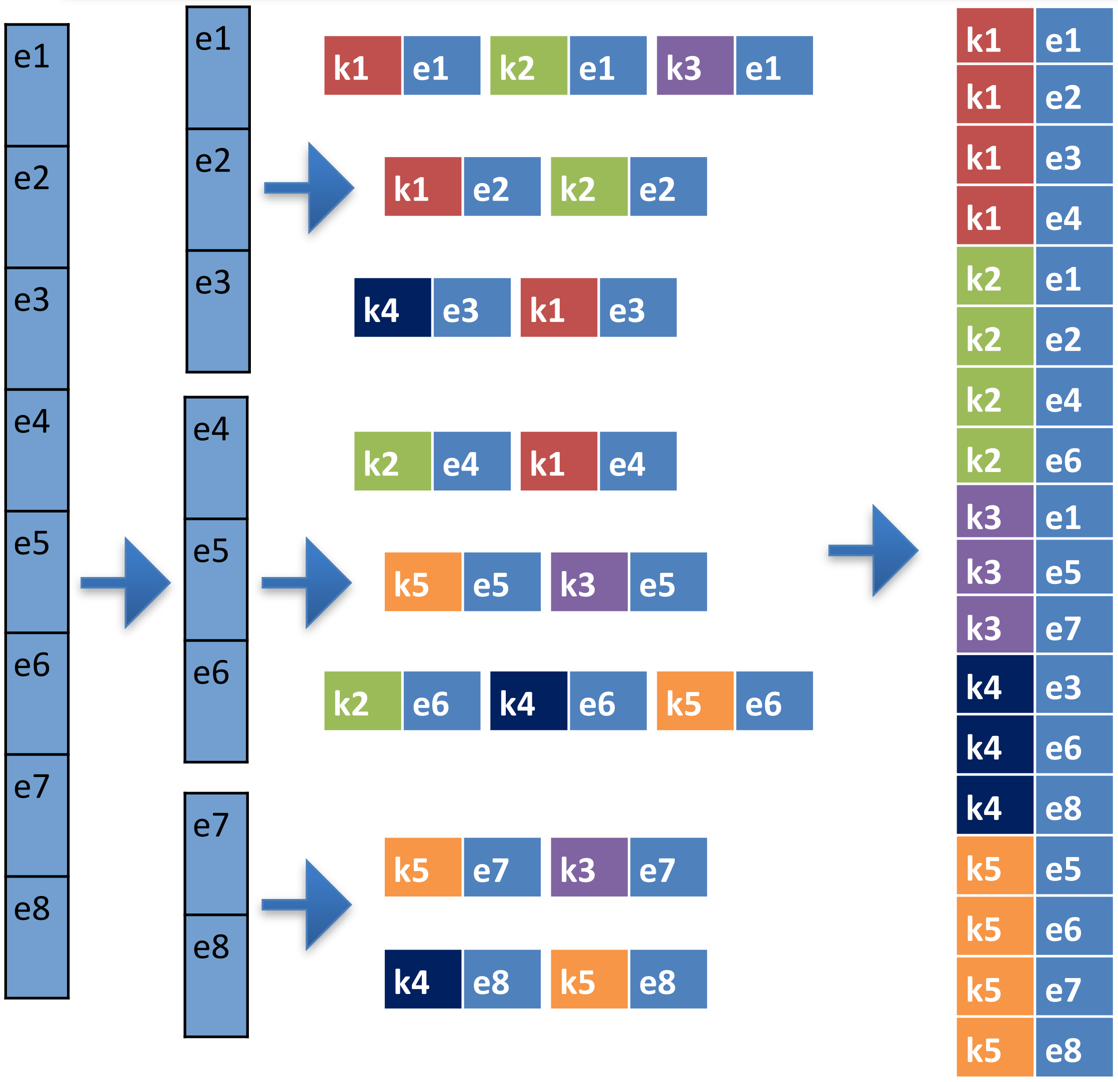
MapReduce – Mapper Input



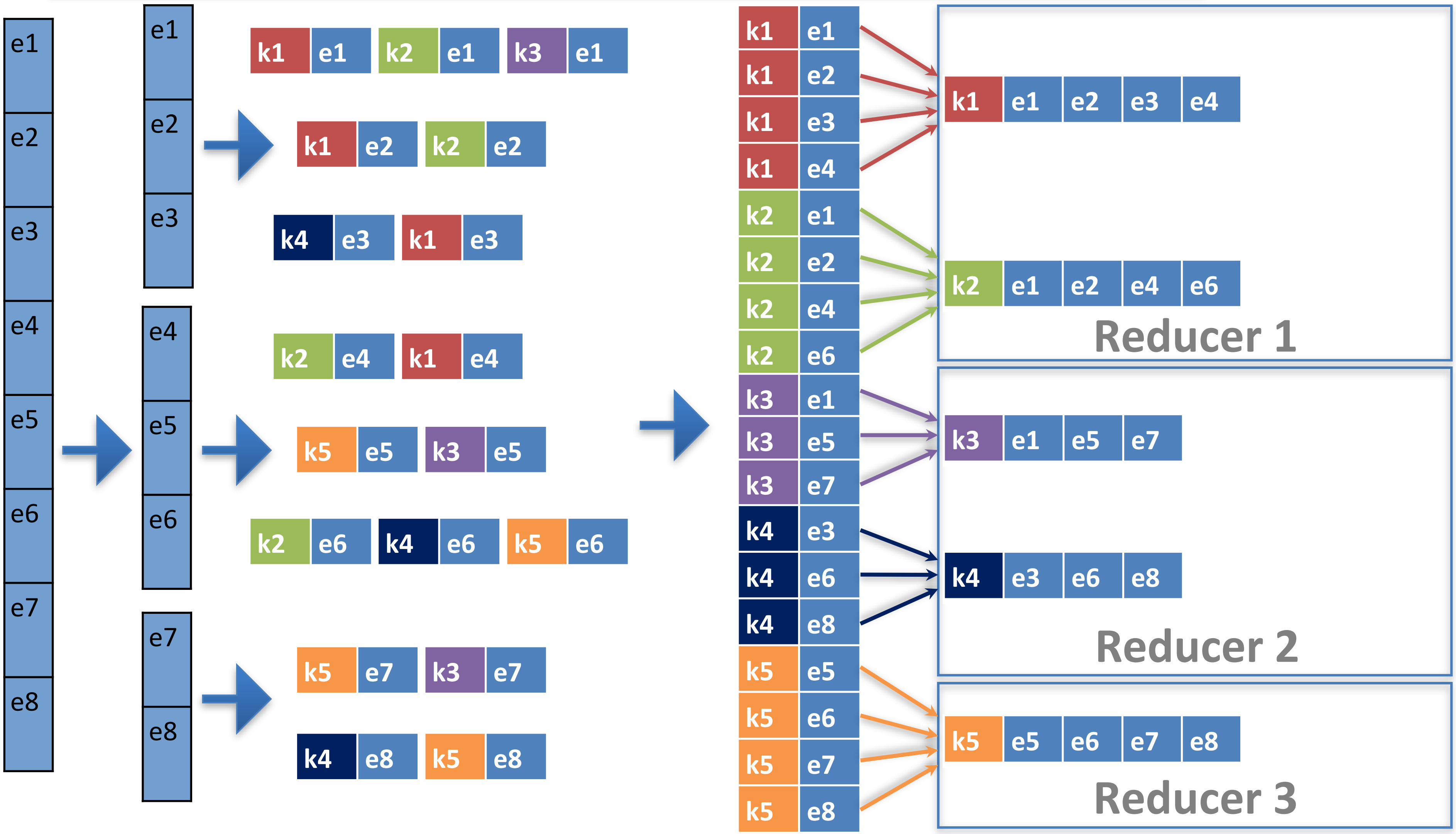
MapReduce – Mapper Output



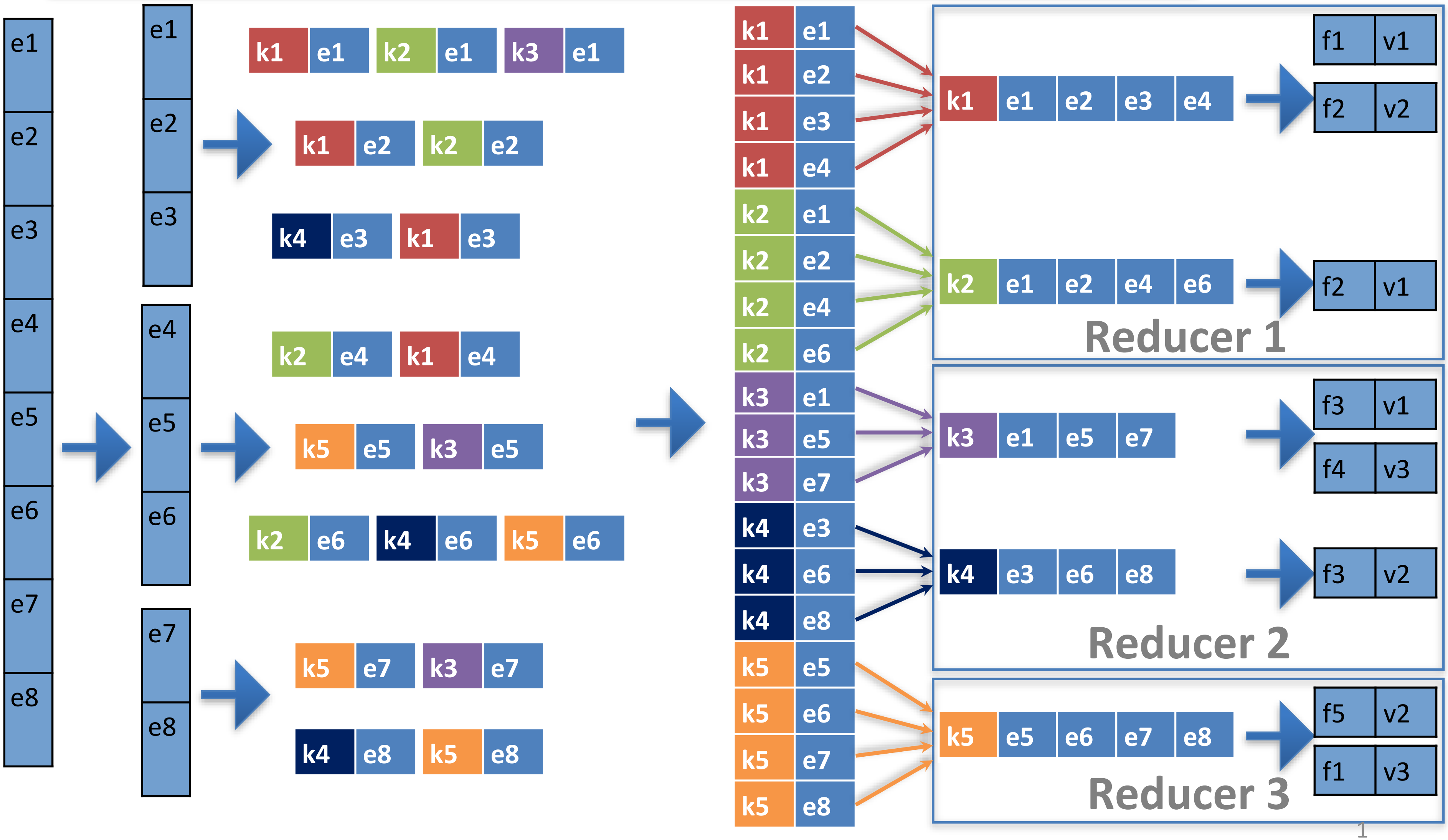
MapReduce – Shuffling & Sorting (simplified)



MapReduce – Reducing



MapReduce – Reducing



Example: WordCount

- **Input**: A list of (file-name, line) pairs
- **Output**: A list of (word, frequency) pairs for each unique word appearing in the input

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Idea:

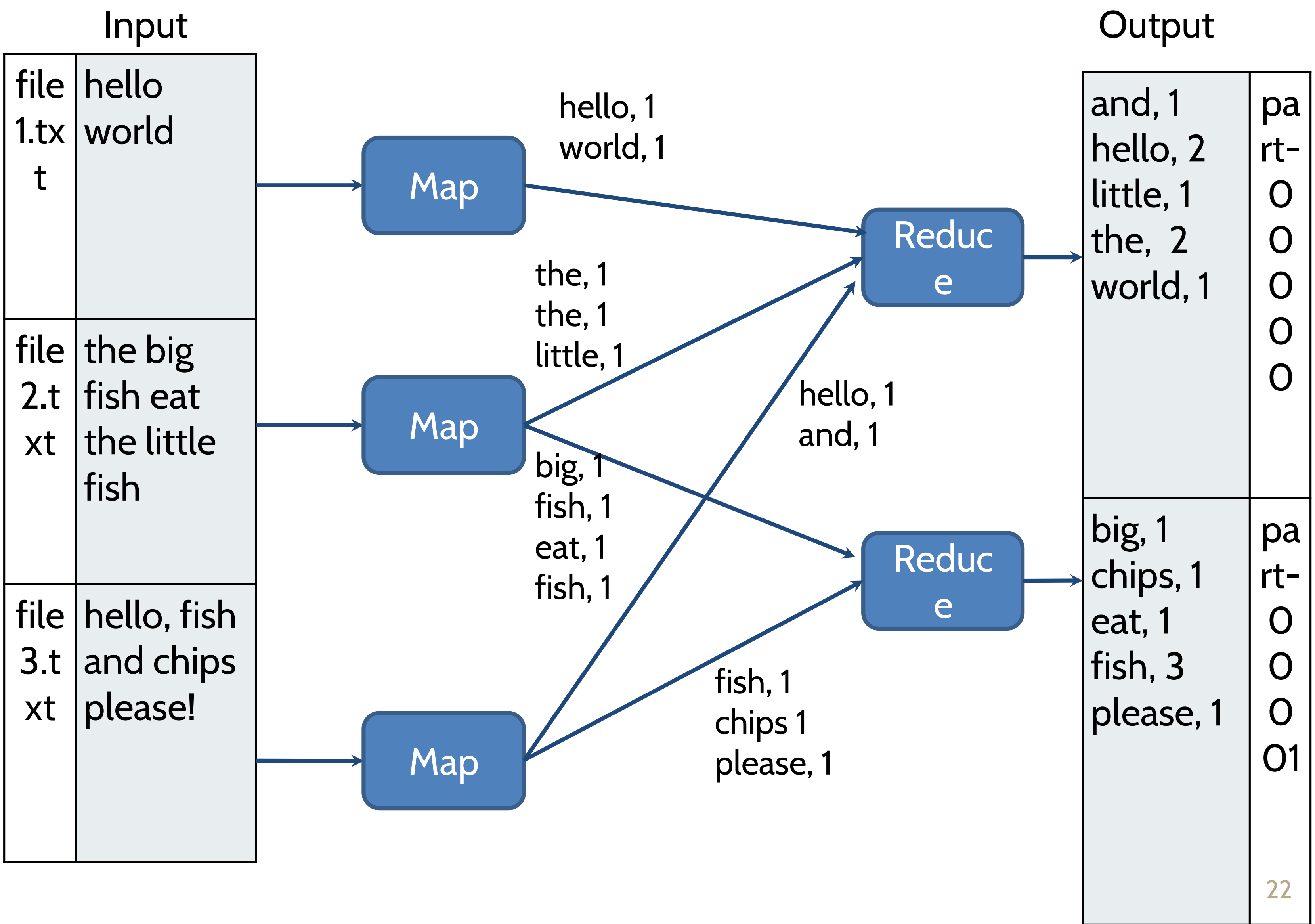
Map:

for each word w, emit a (w, 1) pair

Reduce:

for each (w, list(1,1,…,1)), sum up the 1’s and emit a (w, 1+1+…+1)) pair

Example: WordCount



WordCount Mapper

```
public static class Map extends Mapper<LongWritable, Text, Text,
   IntWritable> {
   private final static IntWritable one = new IntWritable(1);
   private Text word = new Text();

   public void map(LongWritable key, Text value, Context context)
   throws                                          IOException,
   InterruptedException {
         String line = value.toString();
         StringTokenizer tokenizer = new StringTokenizer(line);
         while (tokenizer.hasMoreTokens()) {
            word.set(tokenizer.nextToken());
            context.write(word, one);
         }
   }
}
```

WordCount Reducer

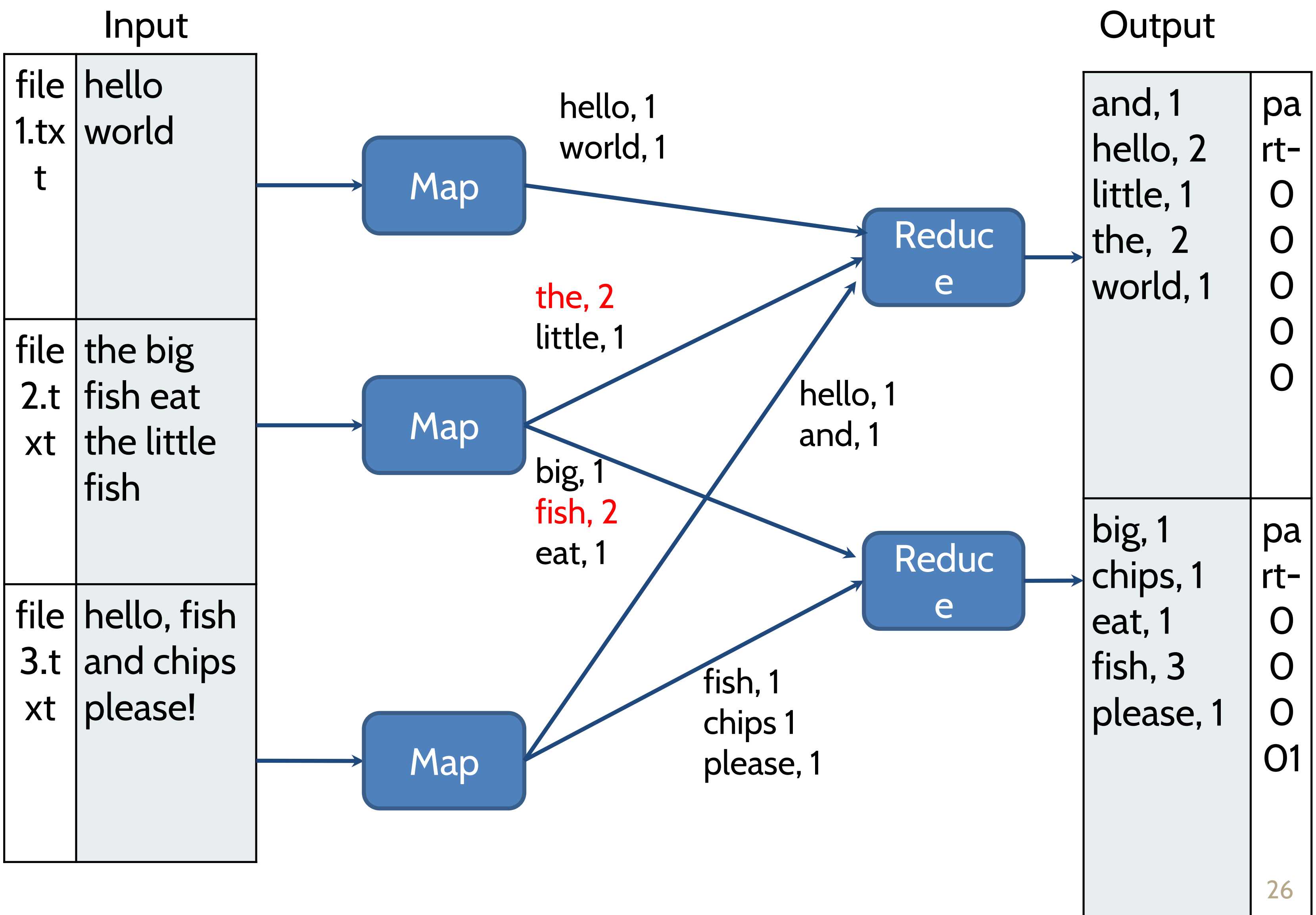
```
public static class Reduce extends Reducer<Text, IntWritable,
   Text, IntWritable>

   public void reduce(Text key, Iterable<IntWritable> values,
   Context context)
                                  throws IOException, InterruptedException {
          int sum = 0;
          for (IntWritable val : values) {
              sum += val.get();
          }
          context.write(key, new IntWritable(sum));
   }
}
```

Combiner: a local, mini-reducer

- An optional class that works like a reducer, run locally
  - for the output of each mapper
- Goal:
  - reduce the network traffic from mappers to reducers
    - could be a bottleneck
  - reduce the workload of the reducers

WordCount Example:
We could sum up the local 1's corresponding to the same key and emit a temporary word count to the reducer
  - fewer pairs are sent to the network
  - the reducers save some operations

WordCount with Combiner



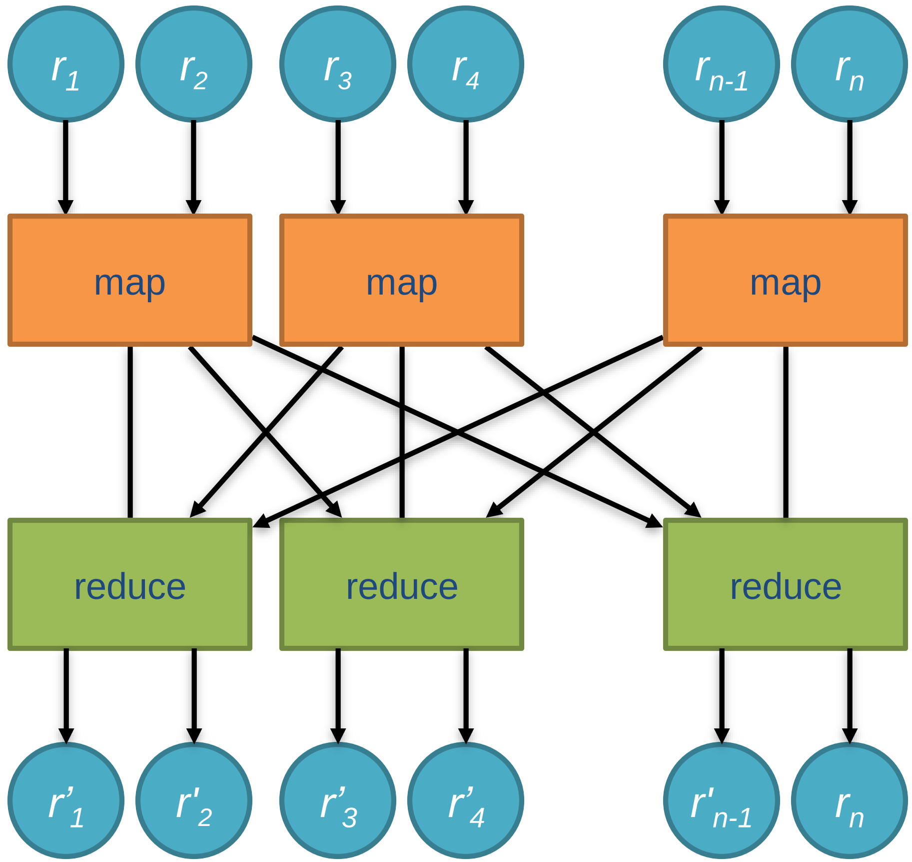
Map Alone Isn't Enough!

Where do intermediate results go?
We need an addressing mechanism!
What's the semantics of the group by?

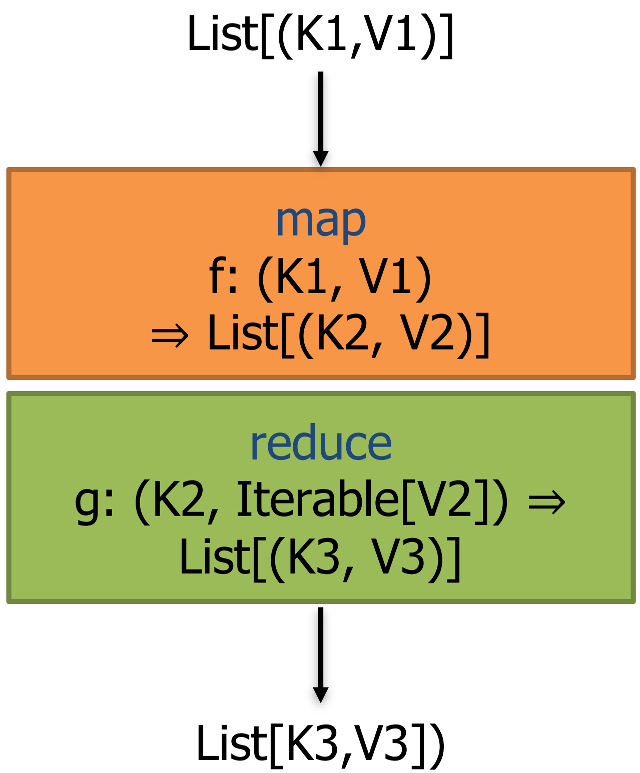
Once we resolve the addressing, apply another computation

That's what we call reduce!
(What's with the sorting then?)

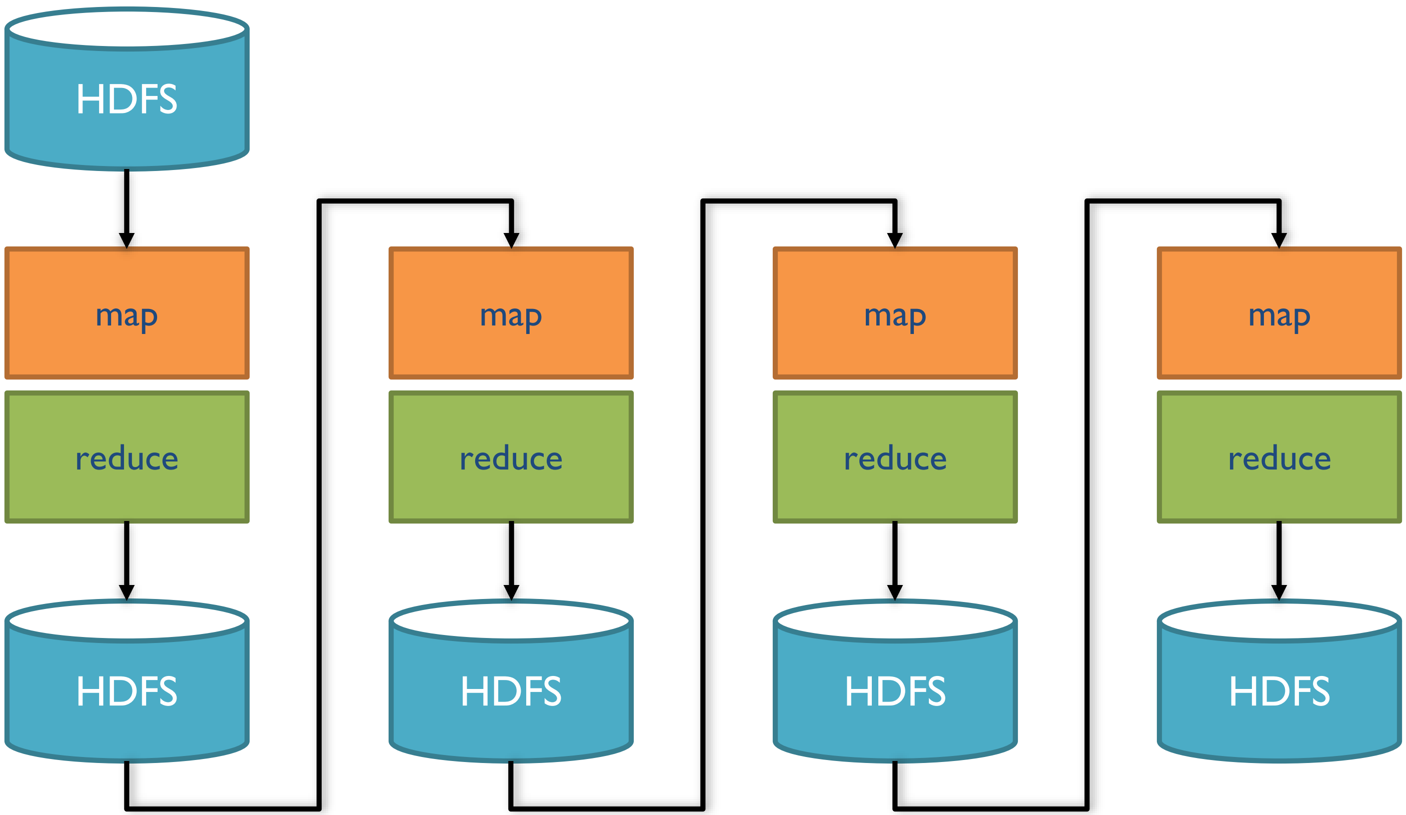
MapReduce


r_1
r_2
r_3
r_4
r_{n-1}
r_n
map
map
map
reduce
reduce
reduce
r'_1
r'_2
r'_3
r'_4
r'_{n-1}
r_n

MapReduce

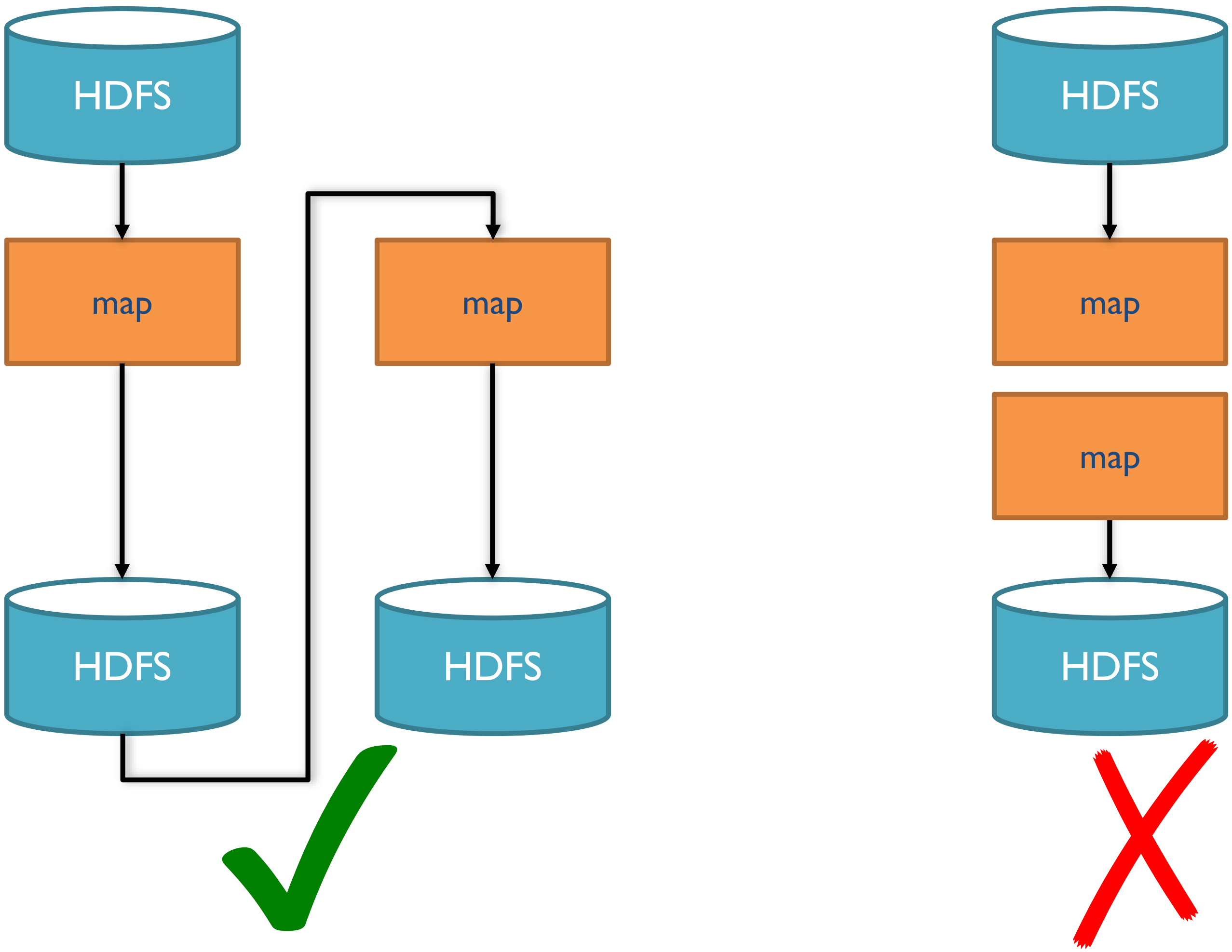

List[(K1,V1)]
map
f: (K1, V1)
⇒ List[(K2, V2)]
reduce
g: (K2, Iterable[V2]) ⇒
List[(K3, V3)]
List[K3,V3])

MapReduce Workflows

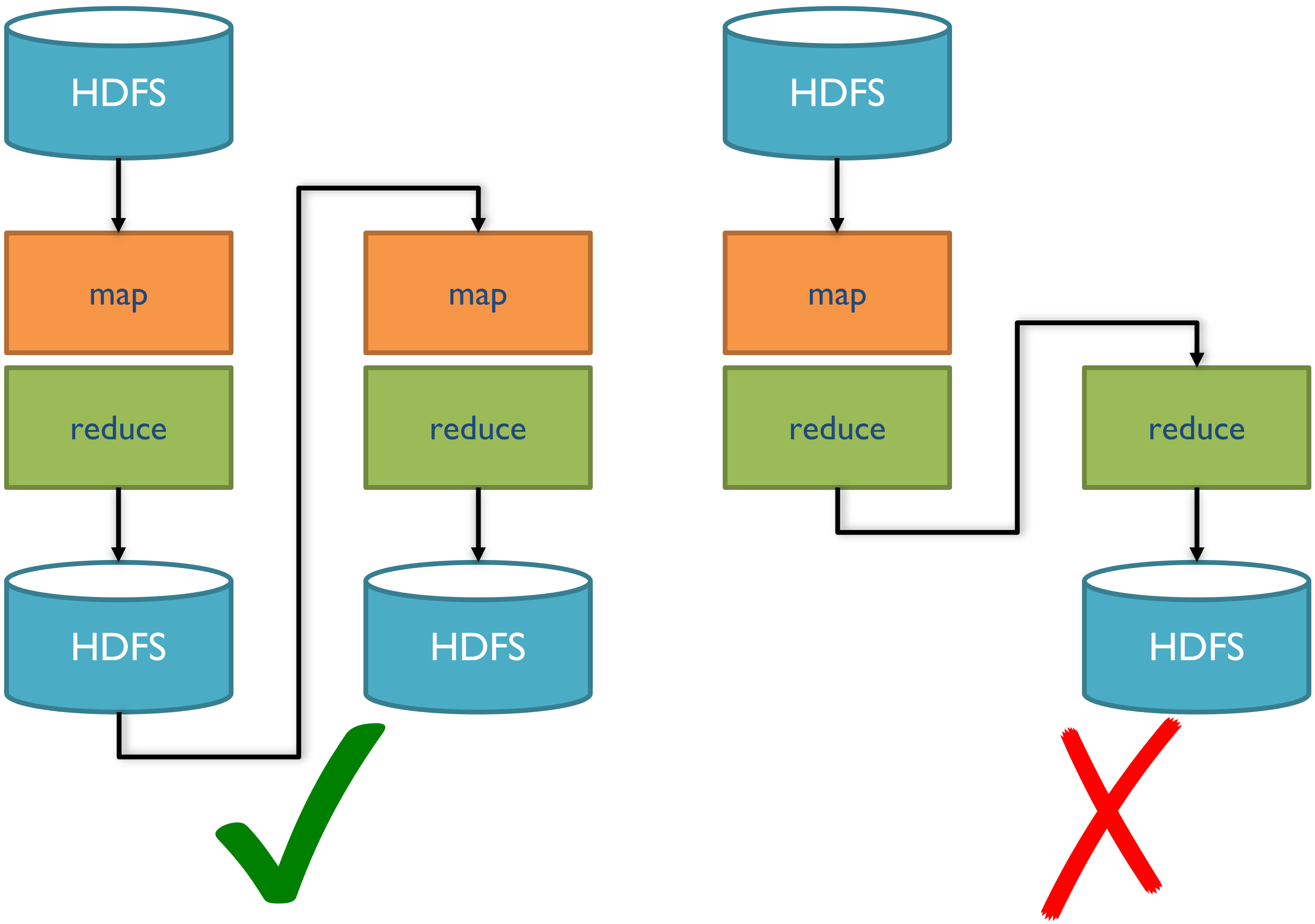


What's wrong?

Want MM?



Want MRR?

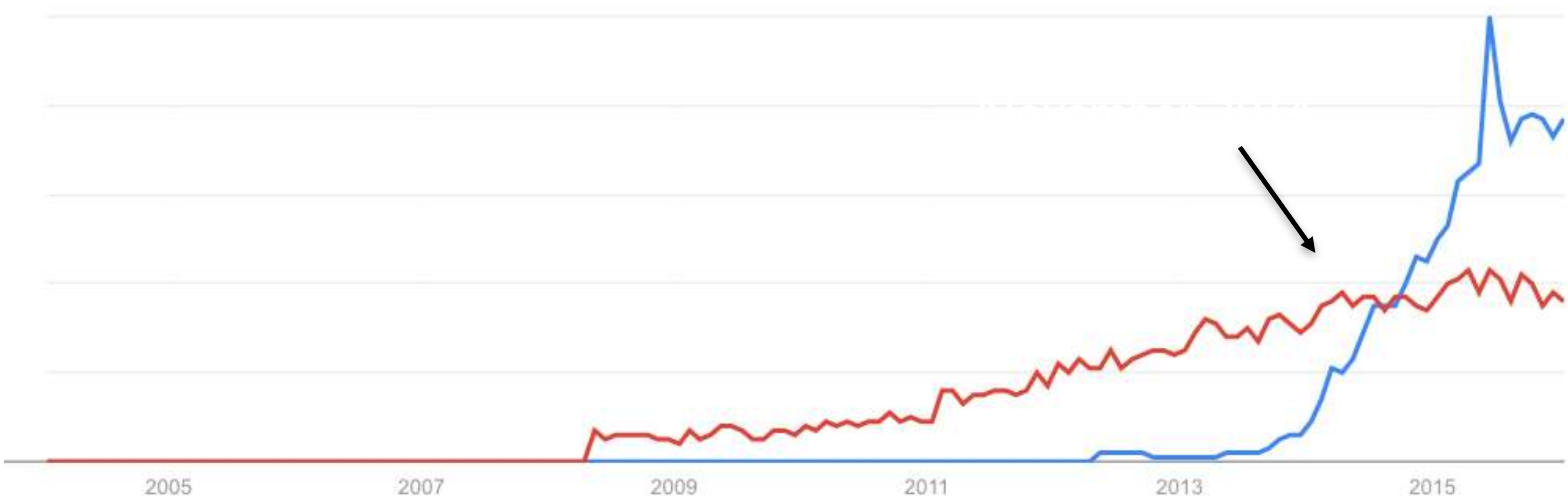

HDFS
map
reduce
HDFS
map
reduce
HDFS
HDFS
map
reduce
reduce
HDFS

Spark

Answer to “What’s beyond MapReduce?”

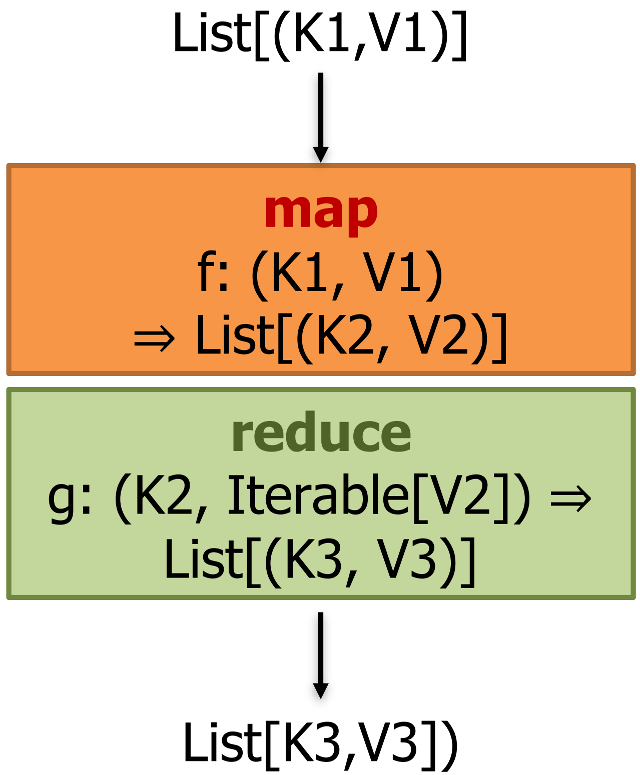
Brief history:
Developed at UC Berkeley AMPLab in 2009
Open-sourced in 2010
Became top-level Apache project in February 2014
Commercial support provided by DataBricks

Spark vs. Hadoop Popularity



Source: Datanan

MapReduce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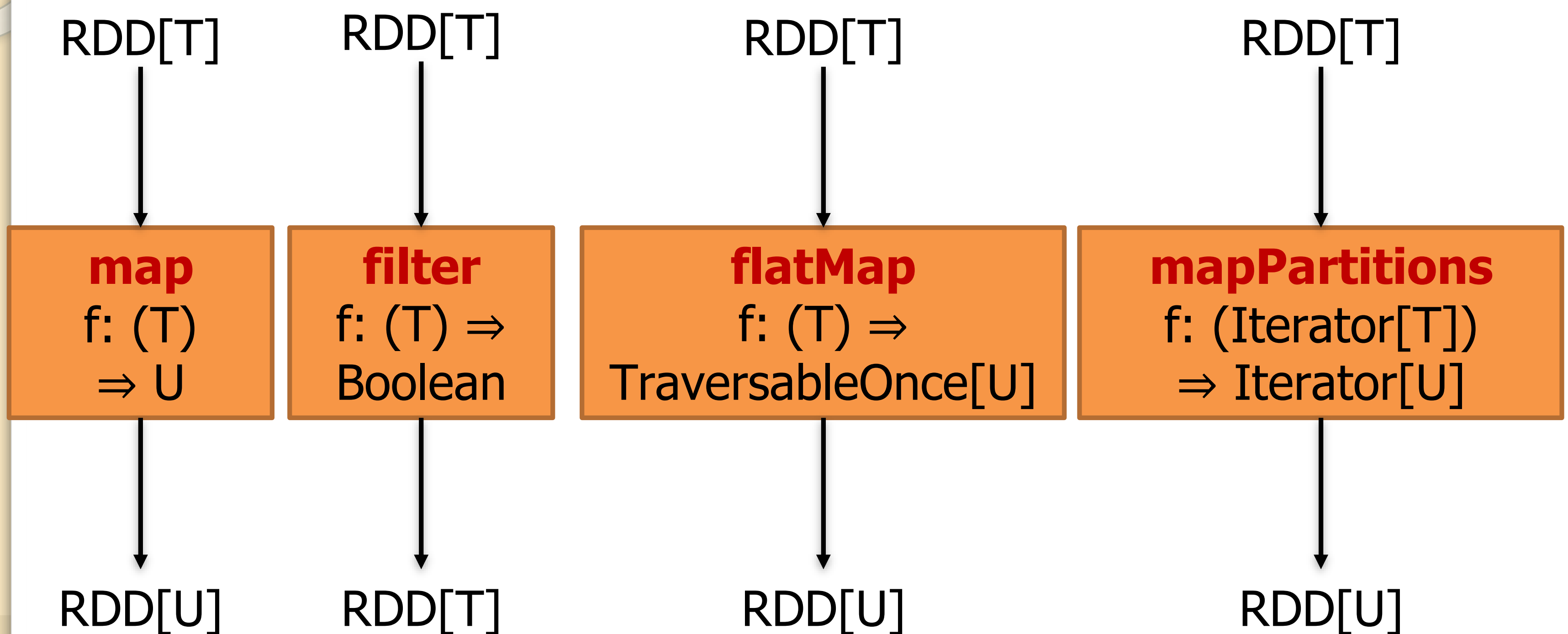
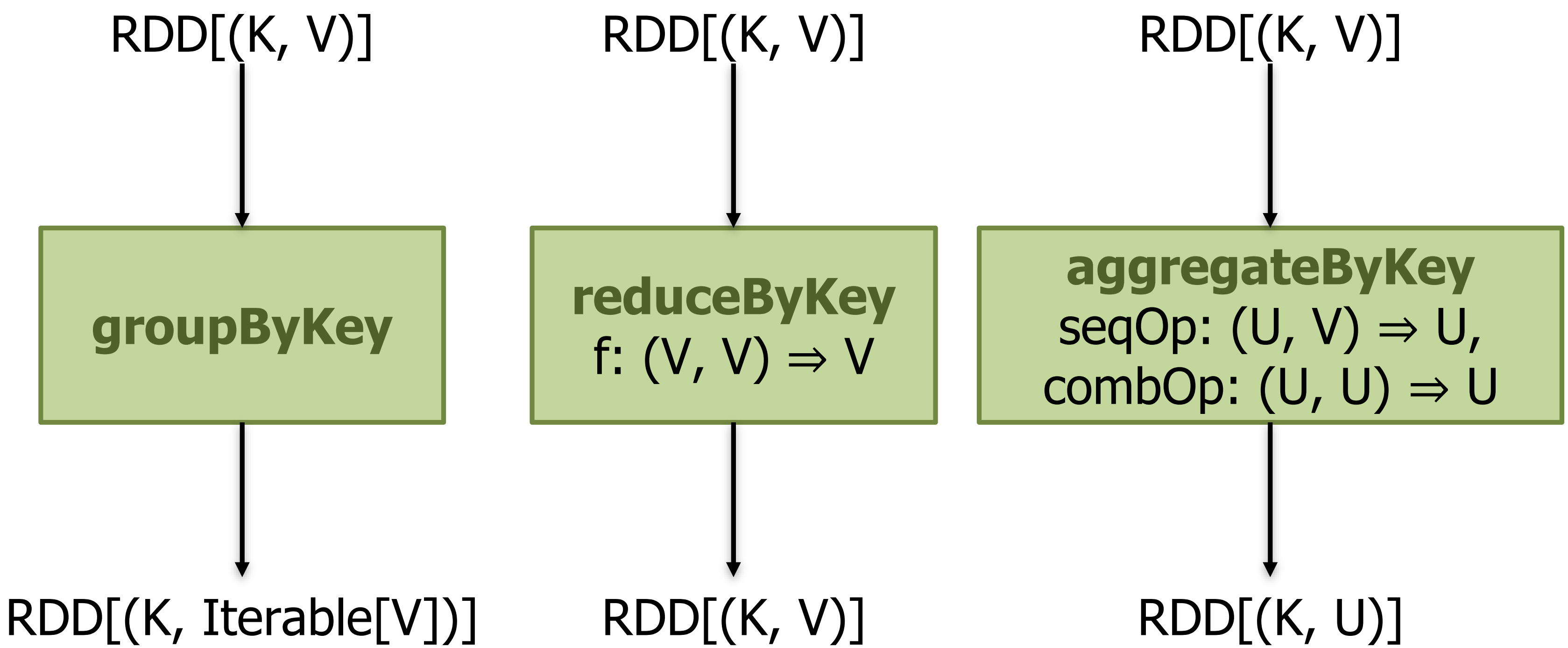
Map-like Operations



(Not meant to be exhaustive)

Reduce-like Operations



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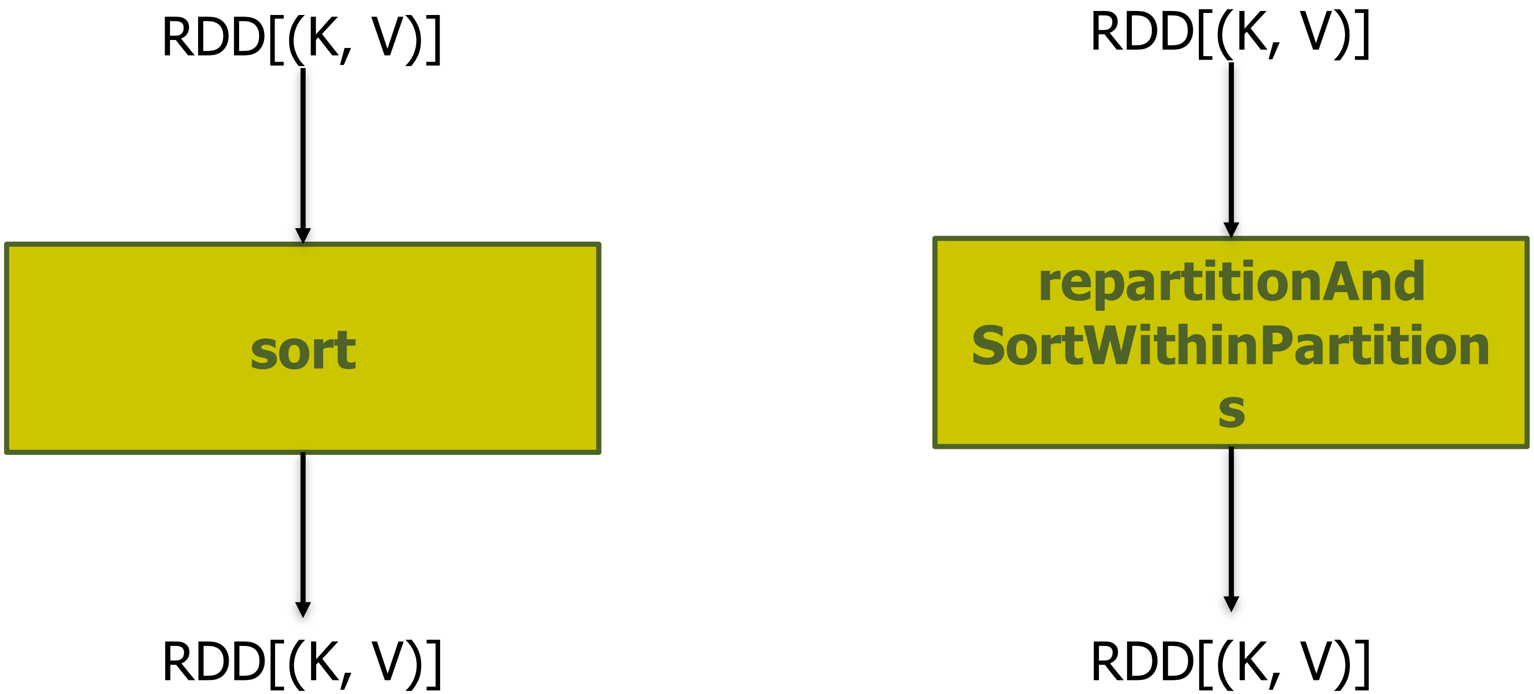
Sort Operations



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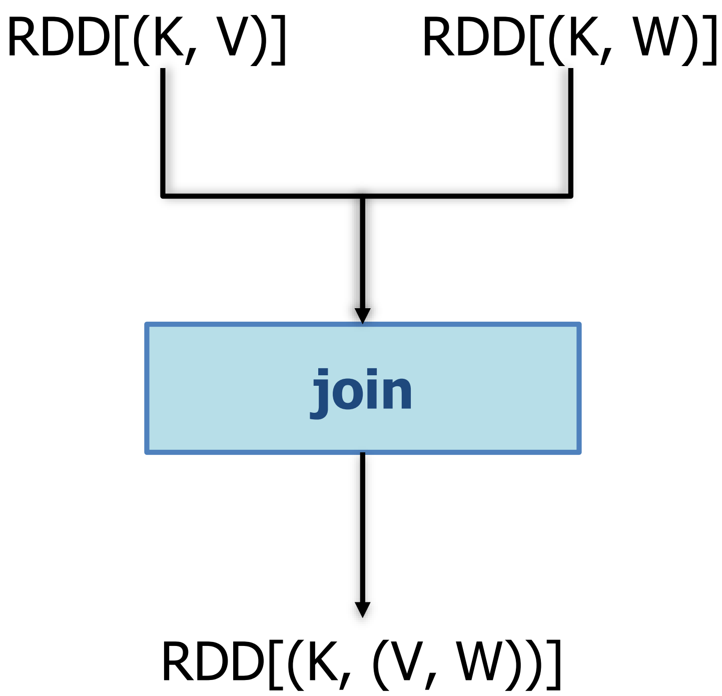
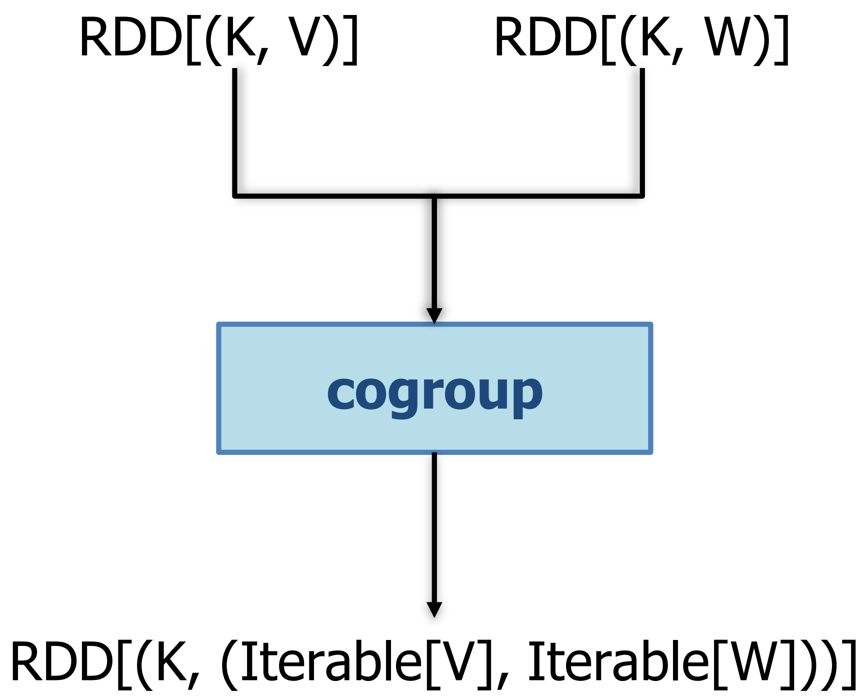
Join-like Operations





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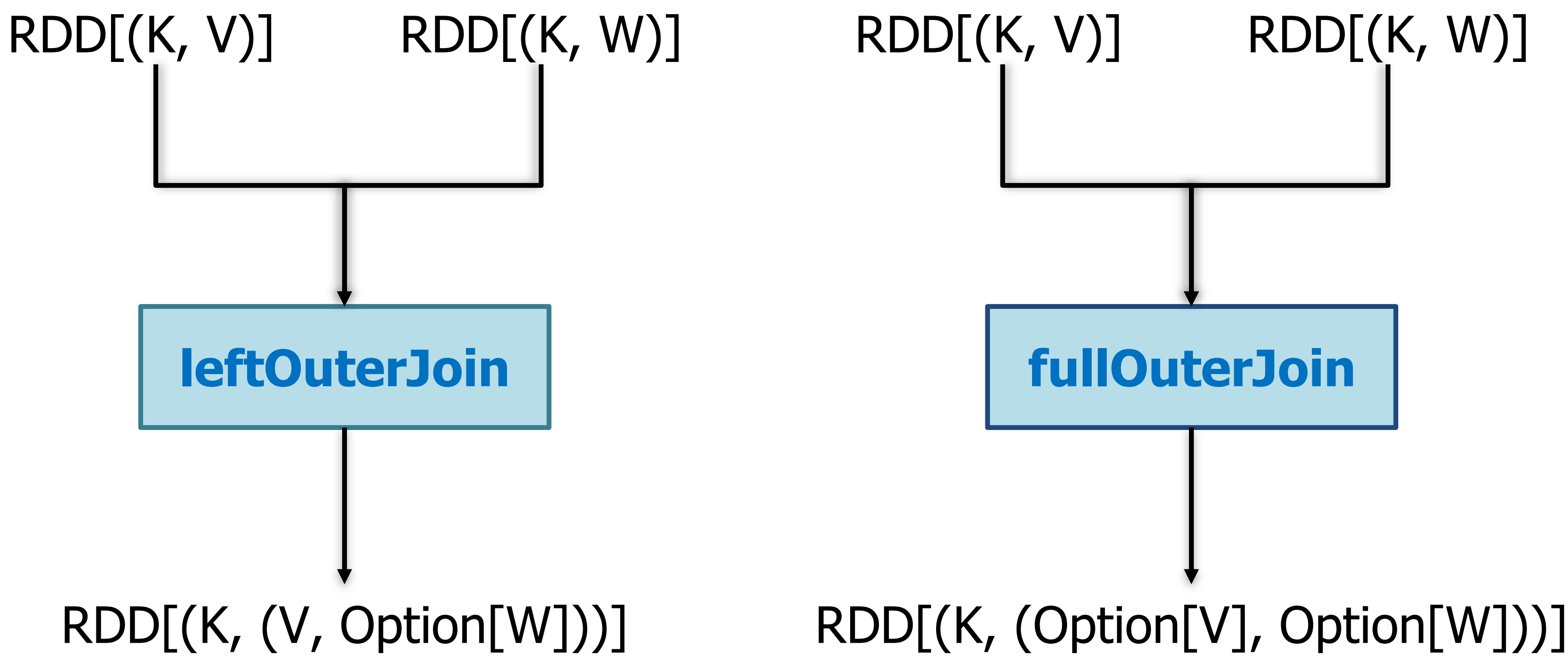
Join-like Operations



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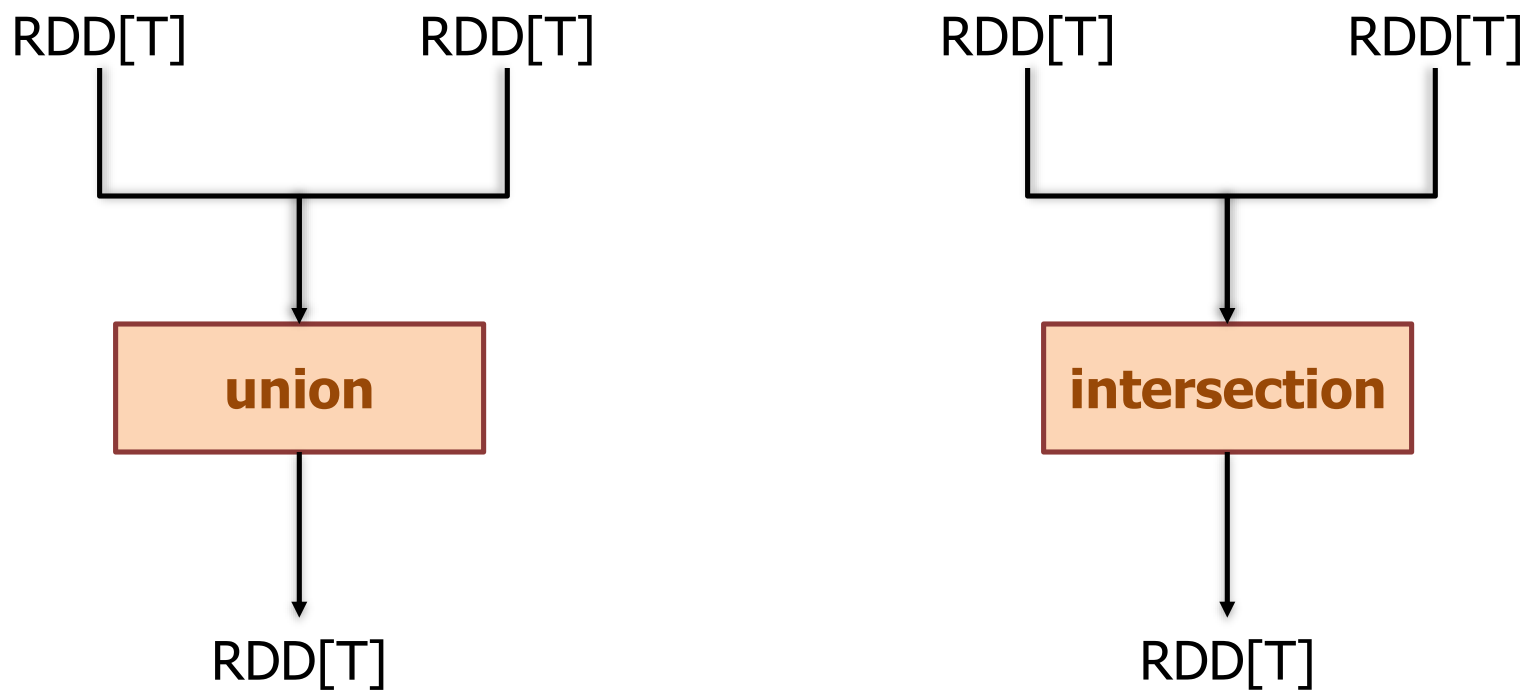
Set-ish Operations



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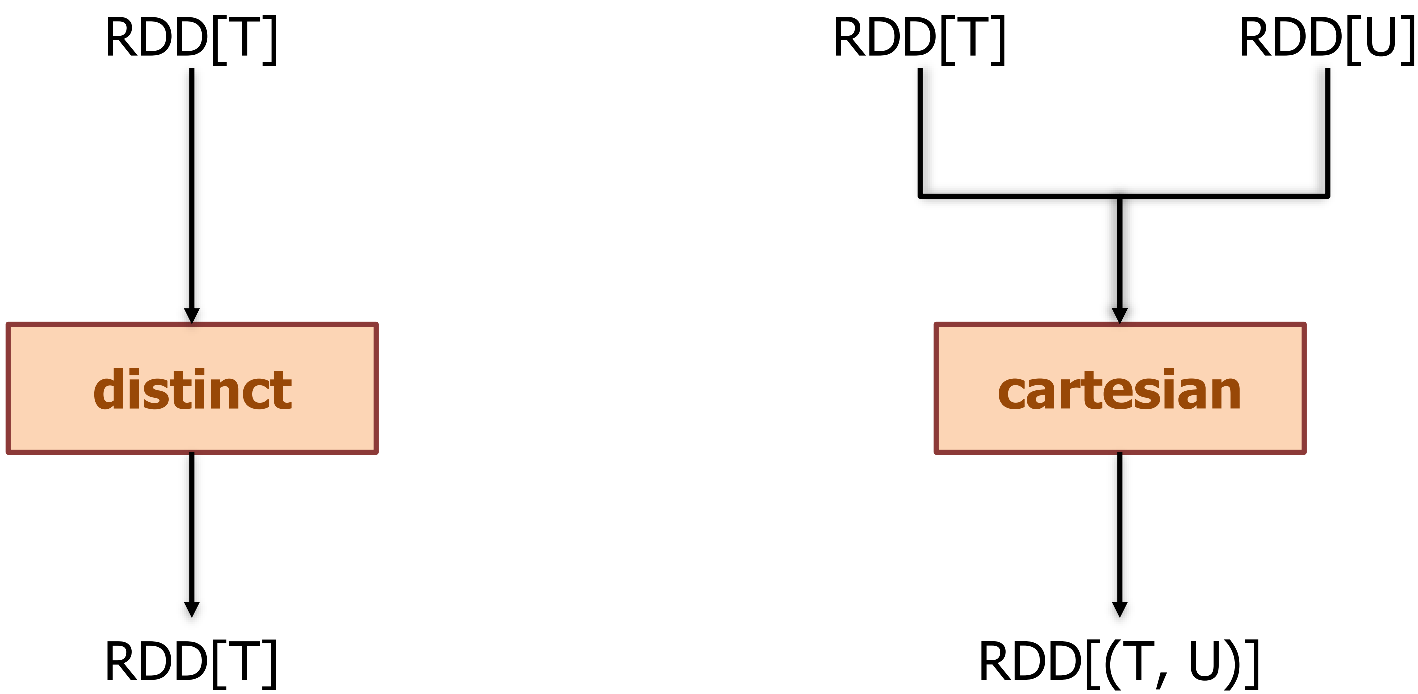
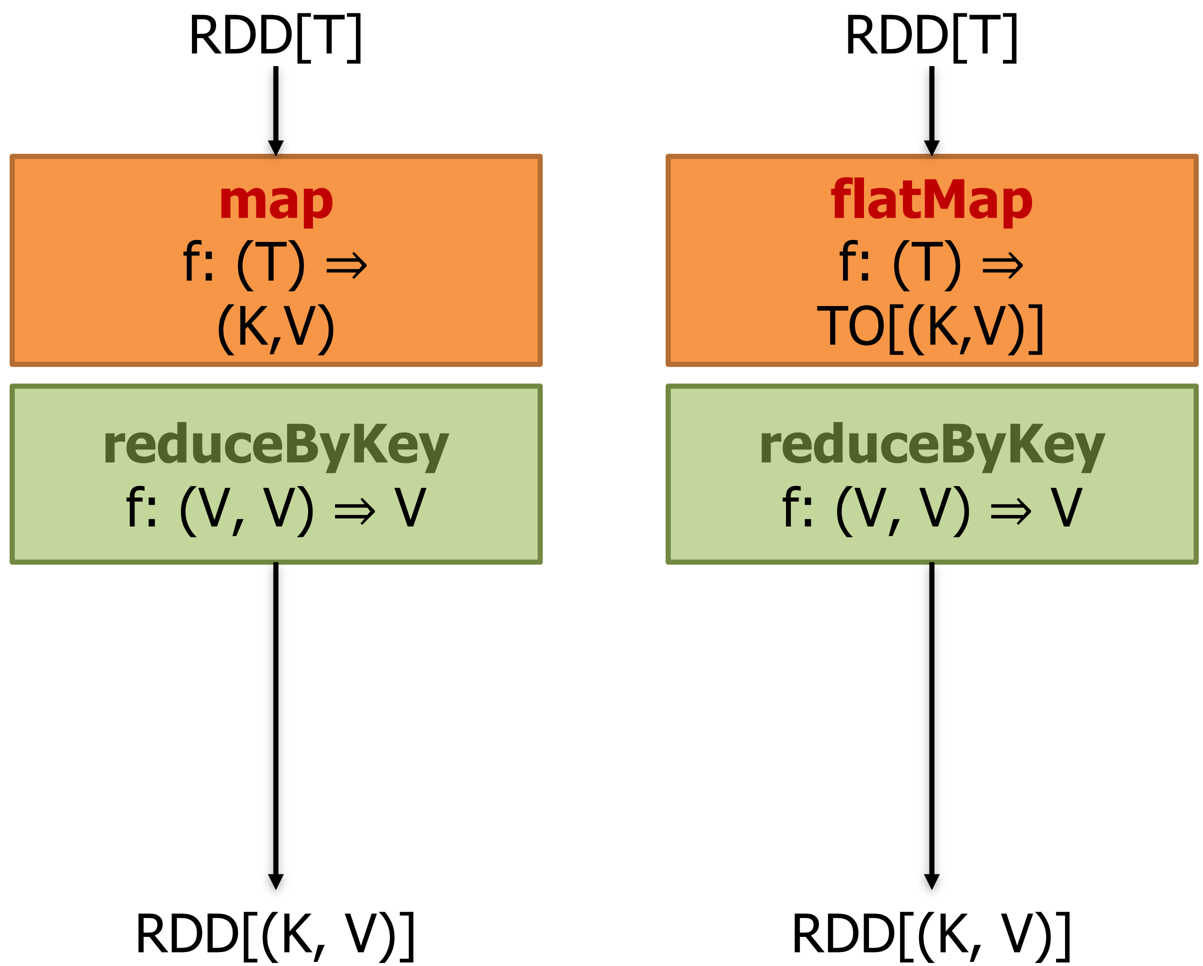
Set-ish Operations



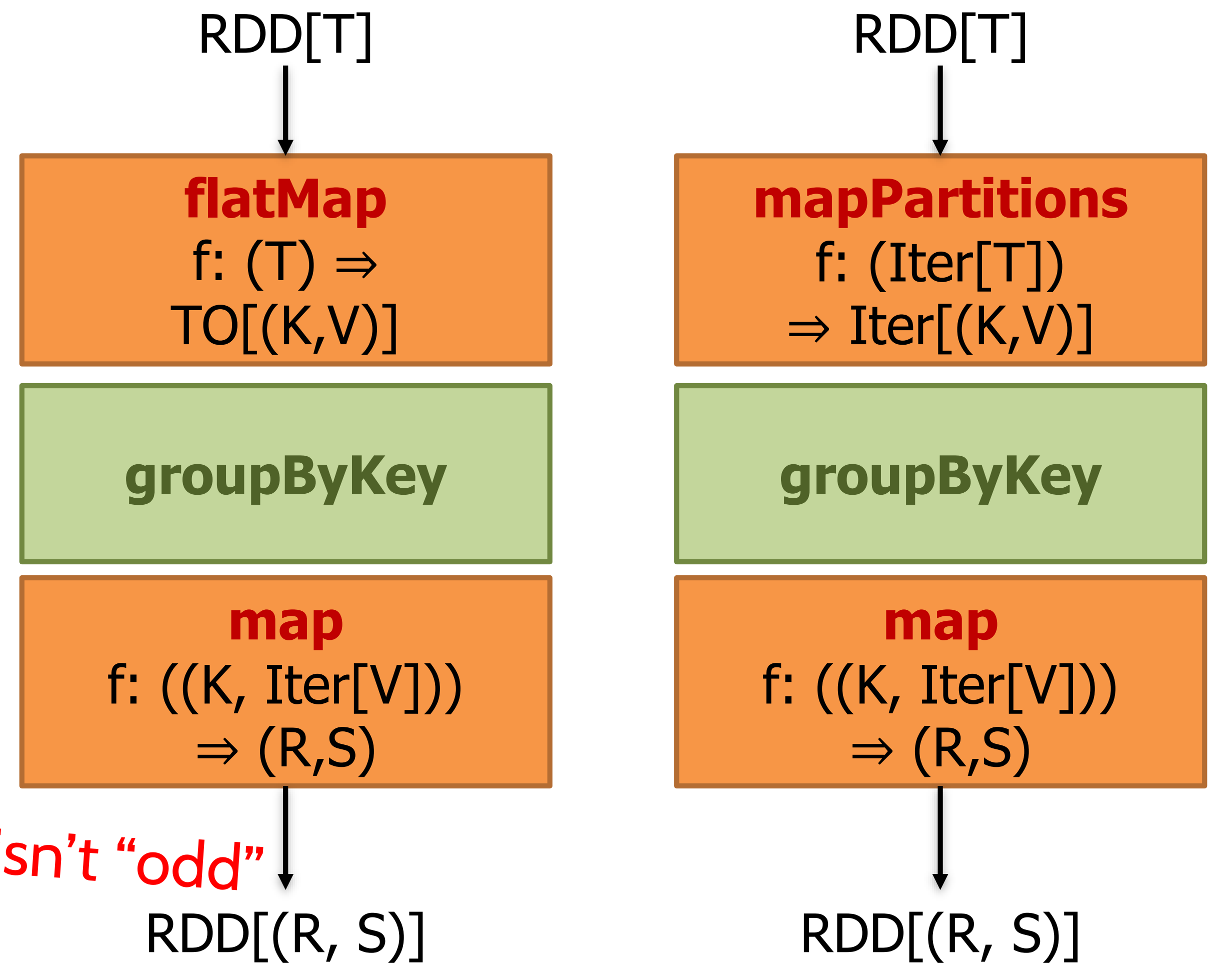
(Not meant to be exhaustive)

MapReduce in Spark?



Not quite…

MapReduce in Spark?



Nope, this isn't "odd"

Still not quite…

Don't focus on Java verbosity!

```
val textFile = sc.textFile(args.input())

textFile
  .map(object mapper {
    def map(key: Long, value: Text) =
      tokenize(value).foreach(word => write(word, 1))
    })
  .reduce(object reducer {
    def reduce(key: Text, values: Iterable[Int]) = {
      var sum = 0
      for (value <- values) sum += value
      write(key, sum)
    })
  .saveAsTextFile(args.output())
```

Spark Word Count

```
val textFile = sc.textFile(args.input())

textFile
  .flatMap(line => tokenize(line))
  .map(word => (word, 1))
  .reduceByKey(_ + _)
  .saveAsTextFile(args.output())
```

(x, y) => x + y

Aside: Scala tuple access notation, e.g., a._1

Install Spark

Let's get started using Apache Spark, in just four easy steps...
Step 1: Install Java JDK 6/7 on MacOSX or Windows
oracle.com/technetwork/java/javase/downloads/jdk7-downloads-1880260.html
follow the license agreement instructions
then click the download for your OS
need JDK instead of JRE (for Maven, etc.)
this is much simpler on Linux: sudo apt-get -y install openjdk-7-jdk
Step 2: Download the latest Spark version 2.4.4
open spark.apache.org/downloads.html with a browser
double click the archive file to open it
connect into the newly created directory

Run Spark with Shel

Step 3: Run Spark Shel
we'll run Spark's interactive shell...
```
./bin/spark-shell
```
then from the "scala>" REPL prompt,
let's create some data...
```
val data = 1 to 10000
```
Step 4: Create an RDD
create an RDD based on that data...
```
val distData = sc.parallelize(data)
```
then use a filter to select values less than 10...
```
distData.filter(_ < 10).collect()
```
Check your output : gist.github.com/ceteri/f2c3486062c9610eac1d#file-01-repl-txt

Run Spark with Scala

If using Scala, you can use metals for project management Download starter code here.
Install JDK 11+, sbt, and the Metals extension in VS Code and create a project.

You can either run the full project by running :
$ sbt run
or Press `Ctrl+Shift+B` and pick ****sbt: compile (watch)**** to auto-compile.

Optional Downloads

Python:
For Python 2.7, check out Anaconda by
Continuum Analytics for a full-featured platform:
store.continuum.io/cshop/anaconda/

Maven
Java builds later also require Maven, which you can download at:
maven.apache.org/download.cgi

Resources

- Jimmy Lin. CS 489/698 Big Data Infrastructure, Winter 2017. David R. Cheriton School of Computer Science, University of Waterloo http://lintool.github.io/bigdata-2017w/

- First part of this tutorial was adapted from https://developer.yahoo.com/hadoop/tutorial/index.html, under a Creative Commons Attribution 3.0 Unported License.