Hadoop MapReduce

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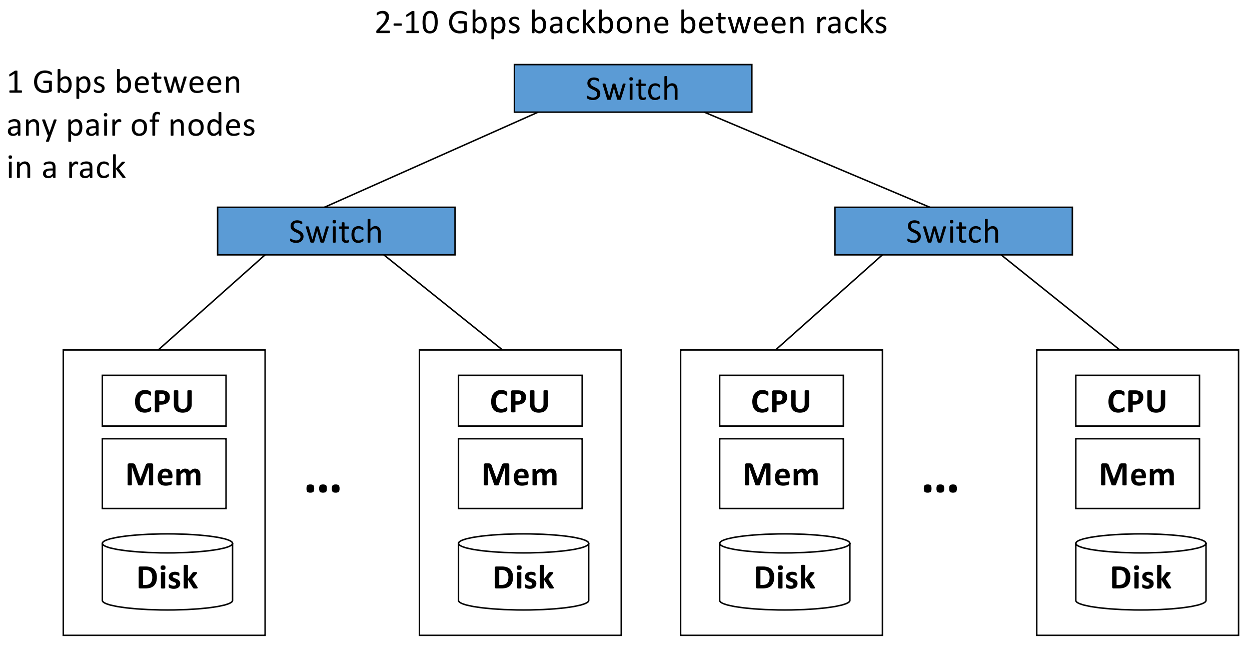
Hadoop Distributed File System (HDFS)

- HDFS has multi-node architecture.
- Each of the data nodes have storage and processing capacity.
- Need a model of data processing that is parallel, distributed, fault-tolerant, and efficient.
- Want to minimize communication between nodes as it costs network bandwidth.
- Let's look at a real example on the next page

Cluster Architecture


2-10 Gbps backbone between racks
1 Gbps between any pair of nodes in a rack
Switch
Switch
Switch
CPU
Mem
Disk
…
CPU
Mem
Disk
CPU
Mem
Disk
…
CPU
Mem
Disk

Each rack contains 16-64 nodes

In 2011 it was guestimated that Google had 1M machines, http://bit.ly/Shh0RO

Large-scale Computing

- Problems with using commodity hardware
- **Challenges:**
  - **How do you distribute computation?**
  - **How can we make it easy to write distributed programs?**
  - **Machines fail:**
    - One server may stay up 3 years (1,000 days)
    - If you have 1,000 servers, expect to loose 1/day
    - People estimated Google had ~1M machines in 2011
      - 1,000 machines fail every day!

MapReduce in HDFS

- MR is the processing engine of HDFS.
- Helps with the concept of "moving computation" rather than "moving data".
  => locality of computation
- Cluster consists of nodes, that have storage and processing power.
- We need to have multiple nodes perform computation in parallel.

MapReduce

- **Design Considerations:**
  - process vast amounts of data (multi-terabyte data-sets)
  - parallel processing
  - large clusters (thousands of nodes) of commodity hardware
  - reliable
  - fault-tolerant
  - should be able to increase processing power by adding more nodes
    - -> "scale-out" and not "scale-up".
  - sharing data or processing between nodes is bad
    - -> ideally want "shared-nothing" architecture.
  - want batch processing
    - -> process entire dataset and not random seeks

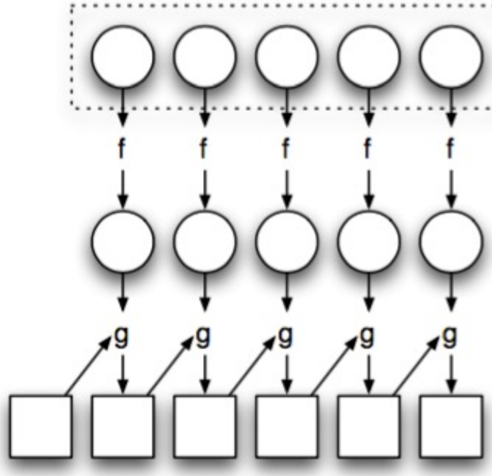
MapReduce Basics

MR has origins in Functional Programming

- Map is a higher order function that applies a function element-wise to a list of elements.
- Map transform **lists** of input data elements into **lists** of output data elements by applying a function to each element of the list.
- Reduce (also called Fold) is a higher order function that processes a list of elements by applying a function pairwise and finally returning a scalar.
- Reduce compacts a list into a scalar by applying a function pairwise.

Functional Programming

- **Key feature: higher order functions**
  - Functions that accept other functions as arguments
  - **Map** and **Fold (Reduce)**



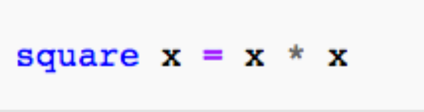
f is applied to every element and it results in a new list

g starts with an initial value and reduces every element
i.e. compacts list to a scalar

Figure: Illustration of *map* and *fold*.

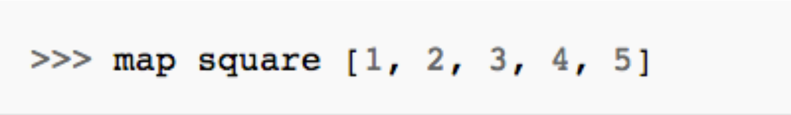
Map Operation

- Define a function:



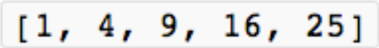
```
square x = x * x
```

- Apply on a list:



```
>>> map square [1, 2, 3, 4, 5]
```

- Get another list:

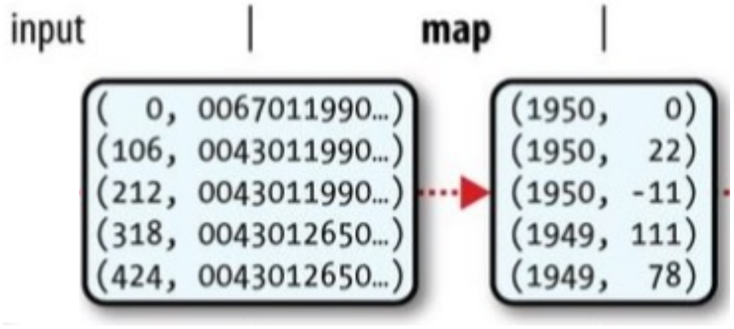


```
[1, 4, 9, 16, 25]
```

,

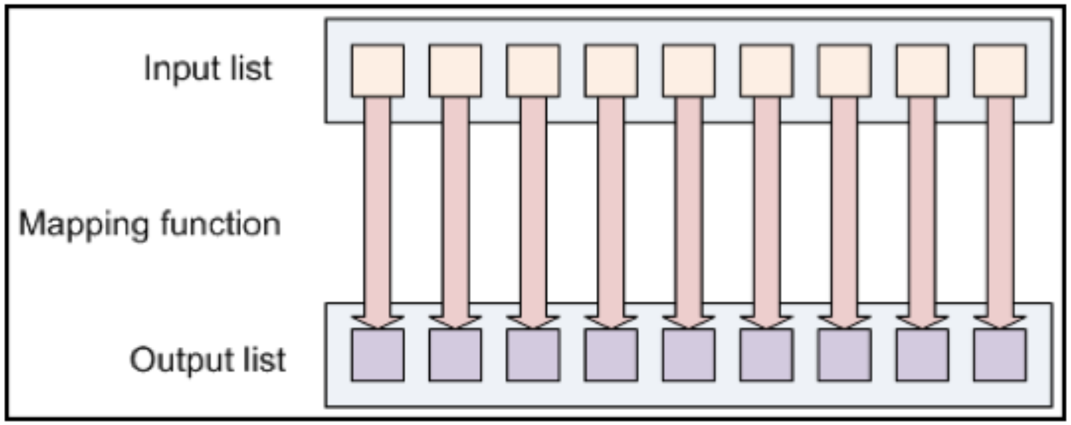
Map function

- Takes input (k, v) and outputs (k', v')
  => Generally input k has little meaning, but we try to find a meaningful output k'
- Example: You have input file with line number as key and text as value. A map function could extract and output year as key and temperature as value.



```
(  0, 0067011990...)          (1950,   0)
(106, 0043011990...)          (1950,  22)
(212, 0043011990...)  ---->   (1950, -11)
(318, 0043012650...)          (1949, 111)
(424, 0043012650...)          (1949,  78)
```

Mapping



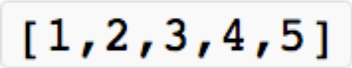
Mapper Process

Reduce (Fold) Operation

- Define an operator: +

- Initial value = 0

- Apply on a list:



```
[1,2,3,4,5]
```

- Get a scalar: 15

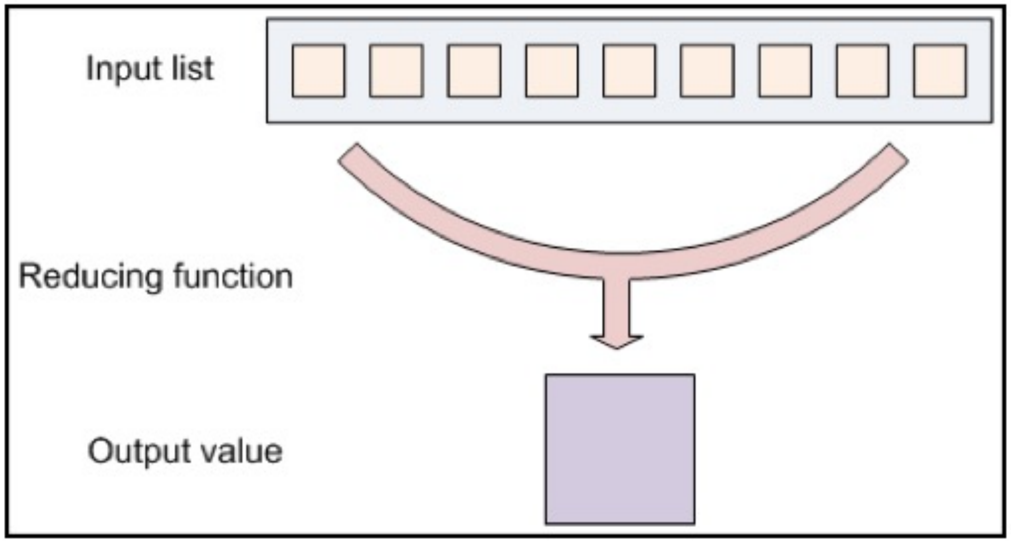
Reduce function

- Reduce function generally receives a key and a list of values.
- It compacts the list to a single (generally) value.
- For example, input key is year and value is list of temperatures. Output could be key and maximum temperature.

  (1950, [30, 70, 50, 72, 18]) -> (1950, 72)

- A key point is that reduce is generally run on data from same key value.
  => Eg. Find average time spent by each visitor on a website
  Key = userID, Value = Time spent during each visit
  It makes sense to aggregate (reduce) for each key separately

Reducing

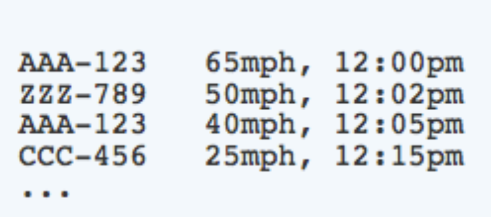


Reducer Process

MapReduce Data Structures

Key-Value Structure

- Each data element needs to have a **key** associated with it.
- Uniquely identifies the data item.
- Example: Log of cars passing by.
  What's the key?
          Could be the license plate number.



```
AAA-123   65mph, 12:00pm
ZZZ-789   50mph, 12:02pm
AAA-123   40mph, 12:05pm
CCC-456   25mph, 12:15pm
...
```

- Does it have to be unique in entire dataset? No

K-V pairs

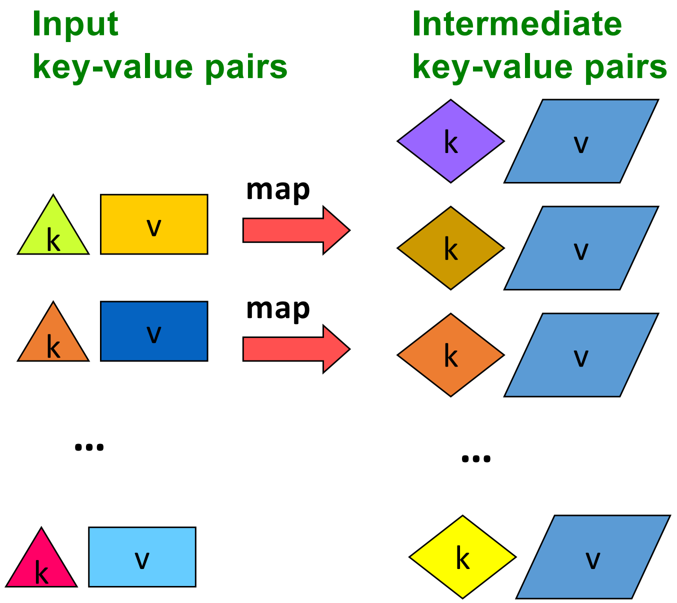
- Key-Value (K-V) pairs are one of the basic data structures for BD.
- Please keep this in mind for future discussion also.

K-V pairs

- A mapper is presented data that contains multiple keys.
- It transforms this data in a 1-1 fashion and outputs a meaningful K-V pair.
- The reducer is presented with data containing only a single key.
- It compacts (or aggregates) the values of the key.
- How does each reducer get data from only one key?
- Someone has to do the sorting and shuffling of data from mappers to reducers.
- That's the job of the Hadoop framework

MapReduce in Hadoop

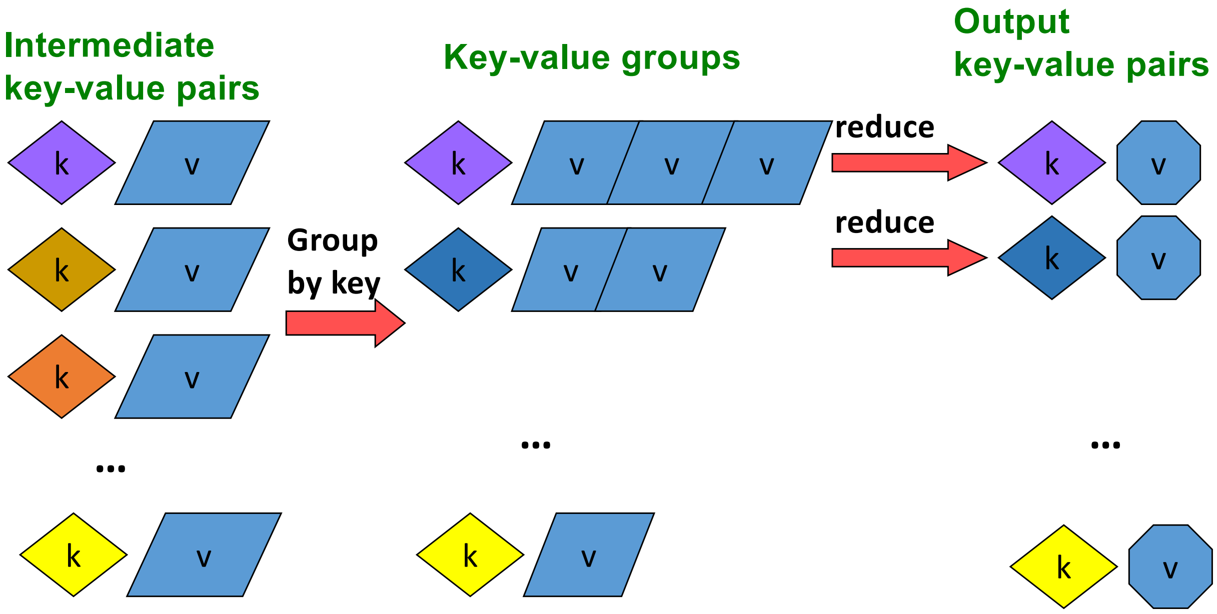
MapReduce: The Map Step



Input
key-value pairs

Intermediate
key-value pairs

MapReduce: The Reduce Step



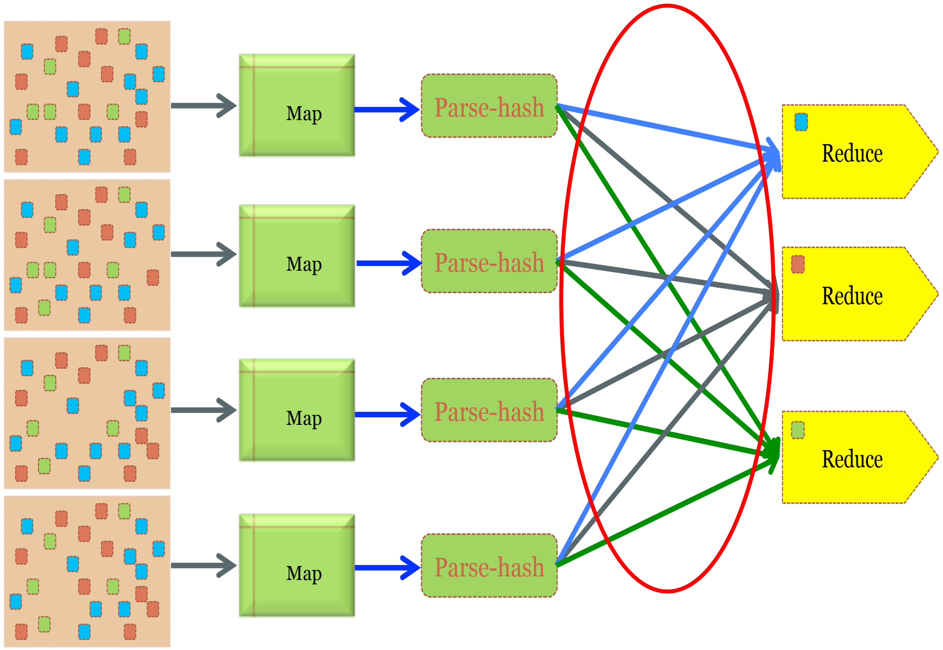
Key-Value Pairs

- Mappers and Reducers are users’ code (provided functions)
- Just need to obey the Key-Value pairs interface
- **Mappers:**
  - Consume <key, value> pairs
  - Produce <key, value> pairs
- **Reducers:**
  - Consume <key, <list of values>>
  - Produce <key, value>
- **Shuffling and Sorting:**
  - Hidden phase between mappers and reducers
  - Groups all similar keys from all mappers, sorts and passes them to a certain reducer in the form of <key, <list of values>>

Example 1 – Color Count

MapReduce Execution in Hadoop

- Suppose you are given a dataset where each item is keyed with a color – Red, Blue, or Green
- Aim is to compute the count of each colors.



Dataset is divided into 4 blocks.

The map-reduce job consists of 4 map tasks and 3 reduce tasks

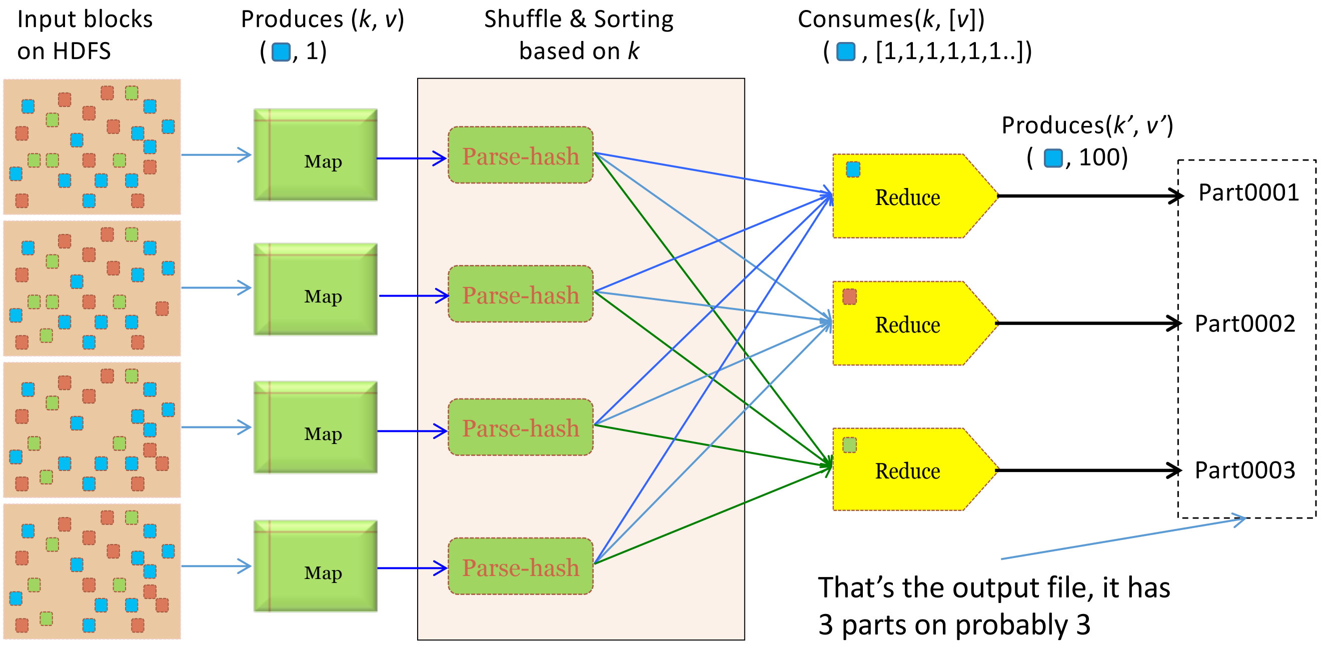
Map task takes each data item and applies a transformation to it. Could be as simple as output (key, 1) e.g. (Red, 1)

Reduce task needs to get data of a single key.

Framework does the sorting and shuffling

Color Count Example

Job: Count the number of each color in a data set



Input blocks on HDFS

Produces (*k*, *v*)
(🟦, 1)

Shuffle & Sorting based on *k*

Consumes(*k*, [*v*])
(🟦 , [1,1,1,1,1,1..])

Produces(*k'*, *v'*)
(🟦, 100)

That's the output file, it has 3 parts on probably 3 different machines

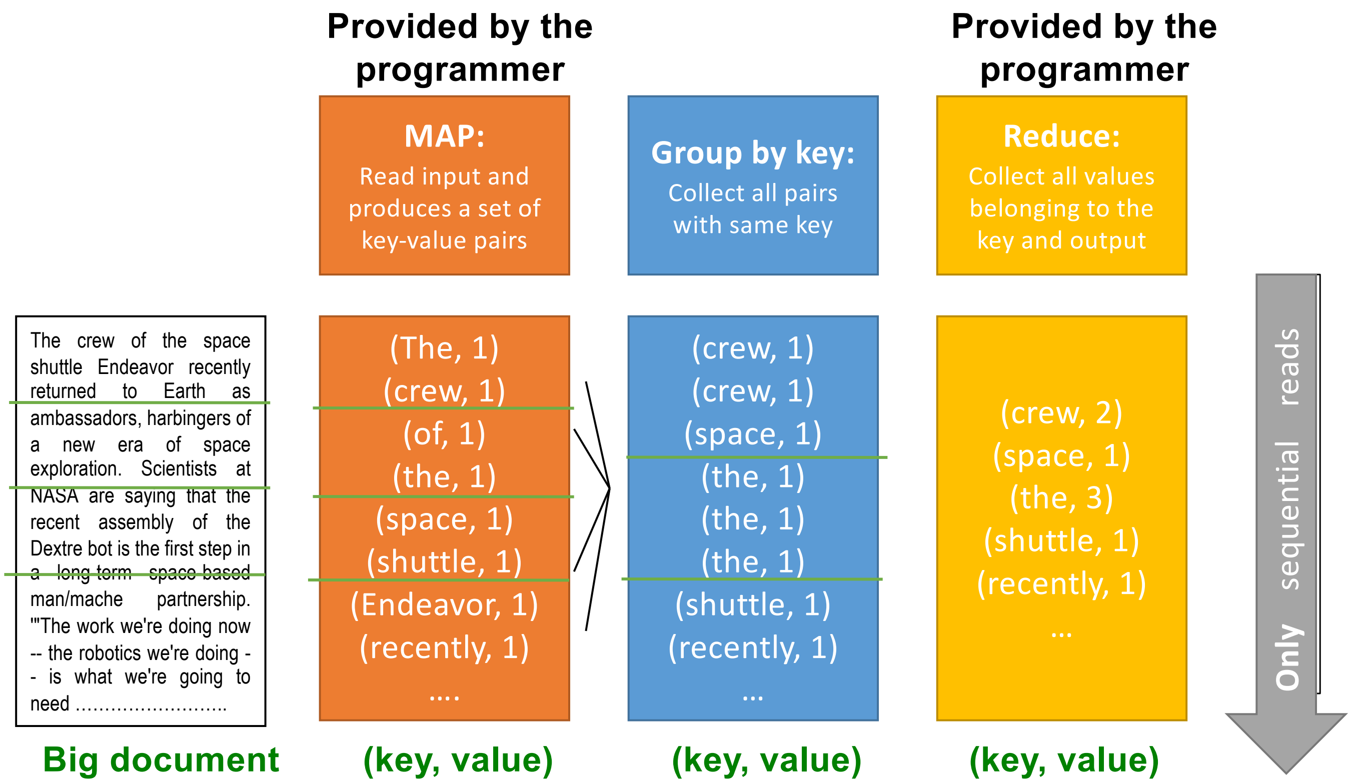
Example 2 – Word Count

Programming Model: MapReduce

Warm-up task:

- We have a huge text document
- Count the number of times each distinct word appears in the file
- **Sample application:**
  - Analyze web server logs to find popular URLs

MapReduce: Word Counting



Provided by the programmer

MAP:
Read input and produces a set of key-value pairs

Group by key:
Collect all pairs with same key

Provided by the programmer

Reduce:
Collect all values belonging to the key and output

The crew of the space shuttle Endeavor recently returned to Earth as ambassadors, harbingers of a new era of space exploration. Scientists at NASA are saying that the recent assembly of the Dextre bot is the first step in a long-term space based man/mache partnership. '"The work we're doing now -- the robotics we're doing -- is what we're going to need ……………………..

Big document

(The, 1)
(crew, 1)
(of, 1)
(the, 1)
(space, 1)
(shuttle, 1)
(Endeavor, 1)
(recently, 1)
….

(key, value)

(crew, 1)
(crew, 1)
(space, 1)
(the, 1)
(the, 1)
(the, 1)
(shuttle, 1)
(recently, 1)
…

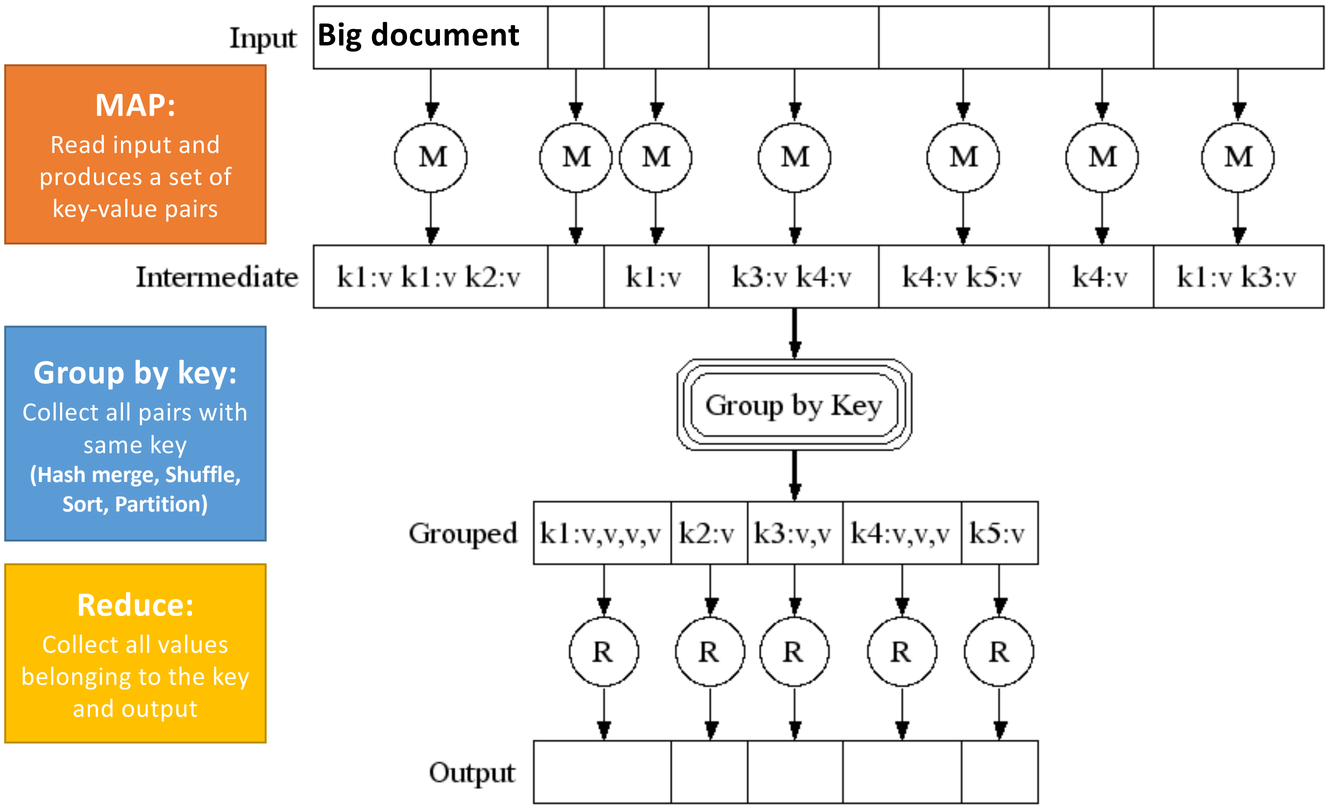
(key, value)

(crew, 2)
(space, 1)
(the, 3)
(shuttle, 1)
(recently, 1)
…

(key, value)

Only sequential reads

Map-Reduce: A diagram



MAP:
Read input and produces a set of key-value pairs

Group by key:
Collect all pairs with same key
(Hash merge, Shuffle, Sort, Partition)

Reduce:
Collect all values belonging to the key and output

Word Count Using MapReduce

```
map(key, value):
// key: document name; value: text of the document
  for each word w in value:
      emit(w, 1)

reduce(key, values):
// key: a word; value: an iterator over counts
      result = 0
      for each count v in values:
            result += v
      emit(key, result)
```

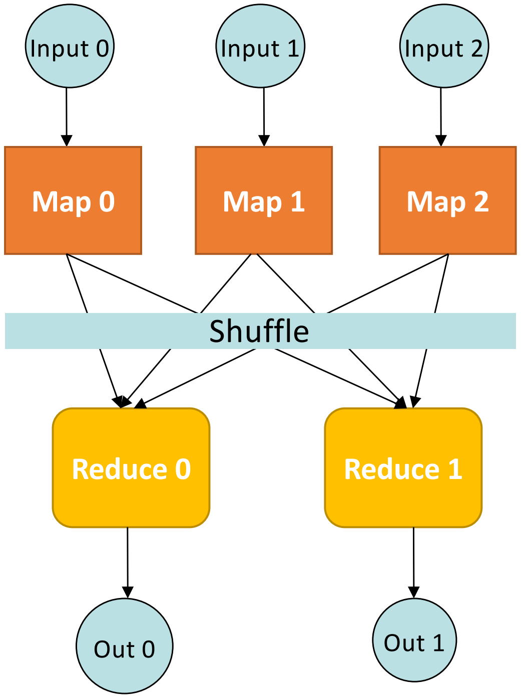
Map-Reduce: Environment

Map-Reduce environment takes care of:

- Partitioning the input data (input splits)
- Scheduling the program's execution across a set of machines
- Performing the **group by key** step
- Handling machine failures
- Managing required inter-machine communication

Map-Reduce

- Programmer specifies:
  - Map and Reduce and input files
- **Workflow:**
  - Read inputs as a set of key-value-pairs
  - **Map** transforms input kv-pairs into a new set of k'v'-pairs
  - Sorts & Shuffles the k'v'-pairs to output nodes
  - All k’v’-pairs with a given k’ are sent to the same **reduce**
  - **Reduce** processes all k'v'-pairs grouped by key into new k''v''-pairs
  - Write the resulting pairs to files
- All phases are distributed with many tasks doing the work


Input 0
Input 1
Input 2
Map 0
Map 1
Map 2
Shuffle
Reduce 0
Reduce 1
Out 0
Out 1