Lecture 2

Big Data Processing Techniques (MapReduce)

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Agenda

- MapReduce Definition
- MapReduce Algorithm
- MapReduce Examples

MapReduce Definition

MapReduce Definition

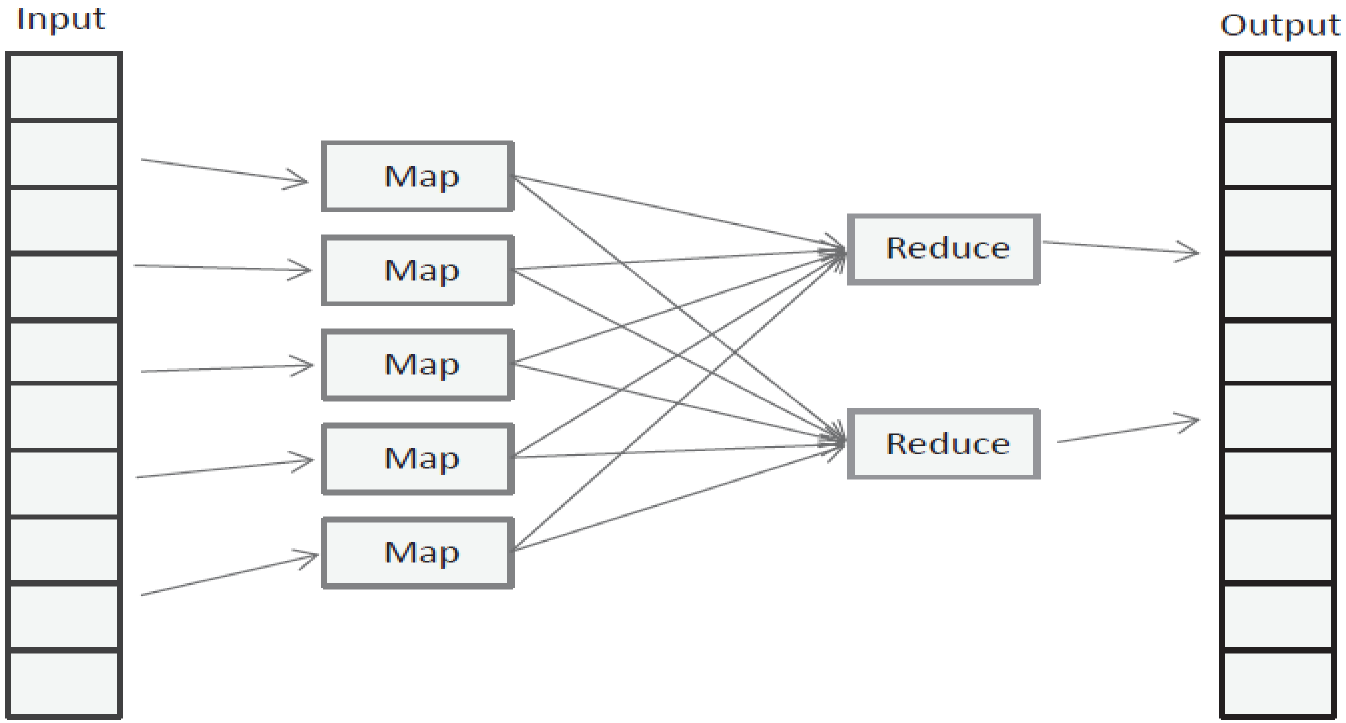
- MapReduce is a widely used Big data processing technique.
- It processes large datasets using **parallel processing** deployed over clusters of hardware.
- It is based on the principle of **divide-and-conquer**. It divides a big problem into a collection of smaller problems that can each be solved quickly.
- A **dataset is broken down** into multiple smaller parts, and operations are performed on each part independently and in parallel.
- The results from all operations are then **combined** to arrive at the result of the whole dataset.

MapReduce Definition

- Each MapReduce job is composed of a **map phase** and a **reduce phase** and each phase consists of multiple stages.
- The Map and Reduce phases run **sequentially** in a cluster.
- The Map phase is executed first then the Reduce phase.
- The output of the Map phase becomes the input of the Reduce phase.
- MapReduce does not require that the input data conform to any particular data model.

MapReduce Definition

- The following figure shows the data flow in MapReduce:



MapReduce Definition

- In MapReduce, all map and reduce tasks run in parallel.

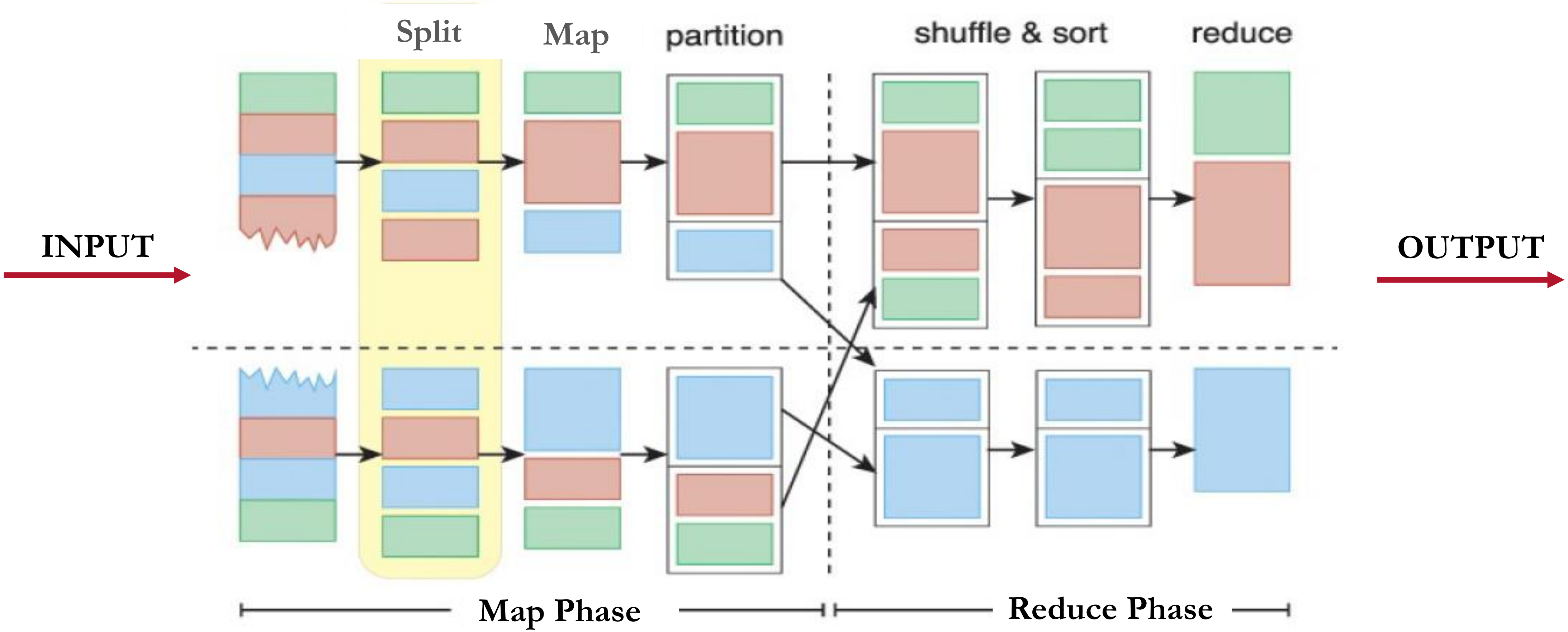
- First of all, all map tasks are independently run.

- Meanwhile, reduce tasks wait until their respective maps are finished.

- Then, reduce tasks process their data concurrently and independently.

MapReduce Algorithm

MapReduce Algorithm

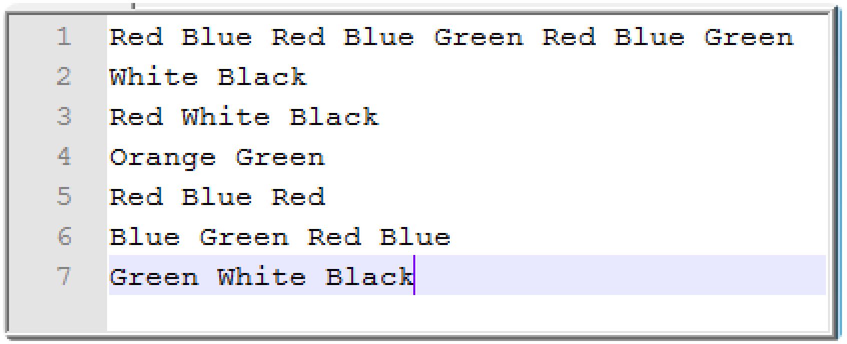


MapReduce Algorithm

➢ We will now apply and explain each stage on the following example:

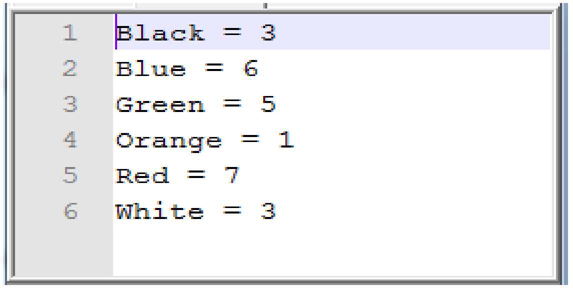
- **Problem Statement:**
  Count the number of occurrences of each word available in a DataSet.

Input Dataset



```
Red Blue Red Blue Green Red Blue Green
White Black
Red White Black
Orange Green
Red Blue Red
Blue Green Red Blue
Green White Black
```

Required Output



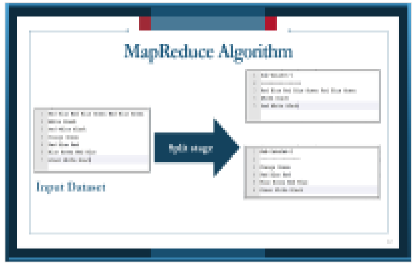
```
Black = 3
Blue = 6
Green = 5
Orange = 1
Red = 7
White = 3
```

MapReduce Algorithm

➢Split stage:

- Takes input DataSet and divides it into smaller Sub-DataSets called splits.
- Each split is parsed into its constituent records as a key-value pair. The key is usually the ordinal position of the record, and the value is the actual record.
- A common example will read a directory full of text files and return each line as a record.
- The key-value pairs for each split are then sent to a map function (or mapper).

➢By applying this stage on our example, we get the following:

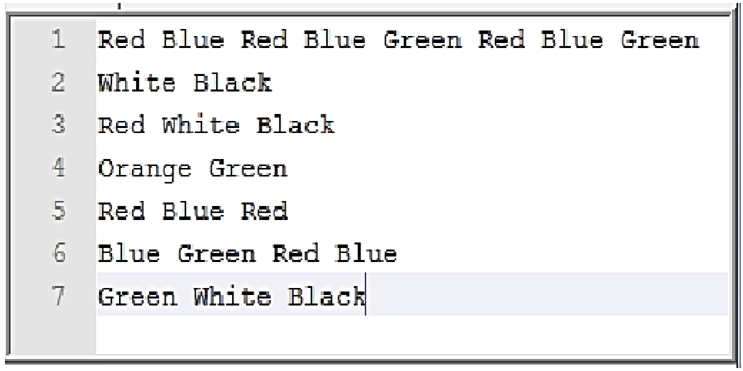


MapReduce Algorithm

Split stage

Input Dataset

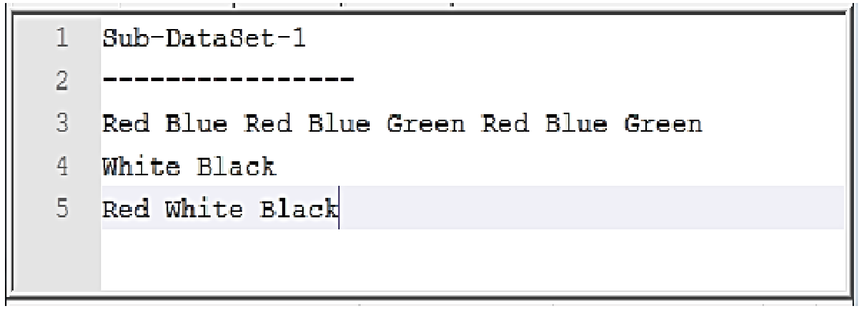
MapReduce Algorithm



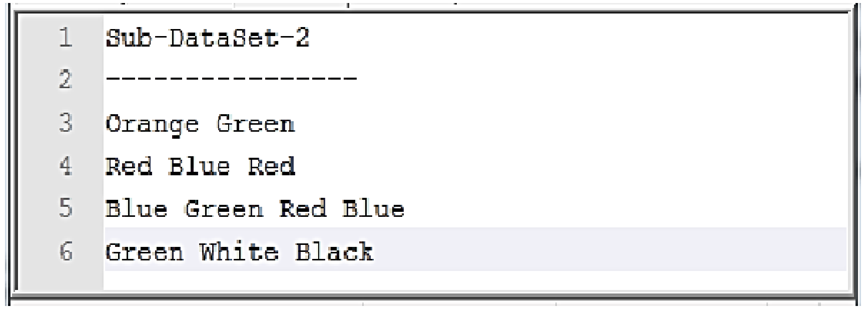
```
Red Blue Red Blue Green Red Blue Green
White Black
Red White Black
Orange Green
Red Blue Red
Blue Green Red Blue
Green White Black
```

Input Dataset

Split stage



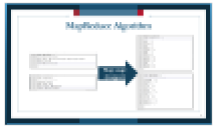
```
Sub-DataSet-1
----------------
Red Blue Red Blue Green Red Blue Green
White Black
Red White Black
```



```
Sub-DataSet-2
----------------
Orange Green
Red Blue Red
Blue Green Red Blue
Green White Black
```

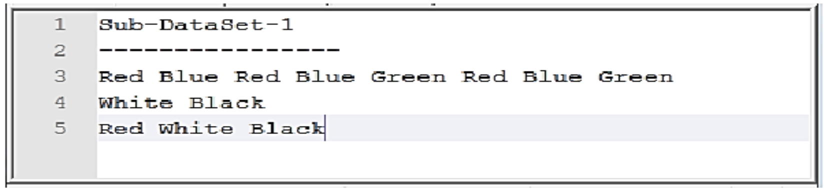
MapReduce Algorithm

- Map stage:
  - This is the **map function** or **mapper** that executes **user-defined logic**.
  - The mapper processes each key-value pair as per the user-defined logic and further generates a key-value pair as its output.
  - The output key can either be the same as the input key or a substring value from the input value, or another user-defined object.
  - Similarly, the output value can either be the same as the input value or a substring value from the input value, or another user-defined object.
  - When all records of the split have been processed, the output is a list of key-value pairs where multiple key-value pairs can exist for the same key.
- By applying this stage on our example, we get the following:

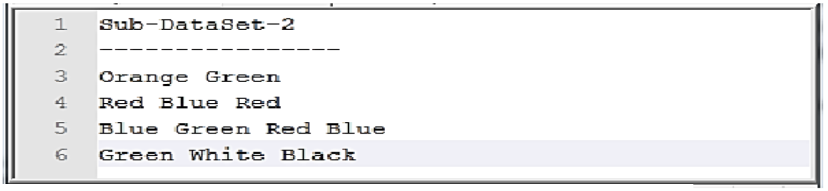


MapReduce Algorithm

MapReduce Algorithm

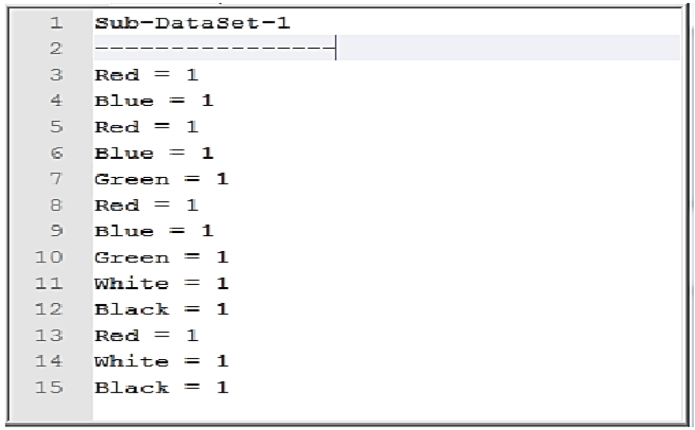


```
Sub-DataSet-1
----------------
Red Blue Red Blue Green Red Blue Green
White Black
Red White Black
```

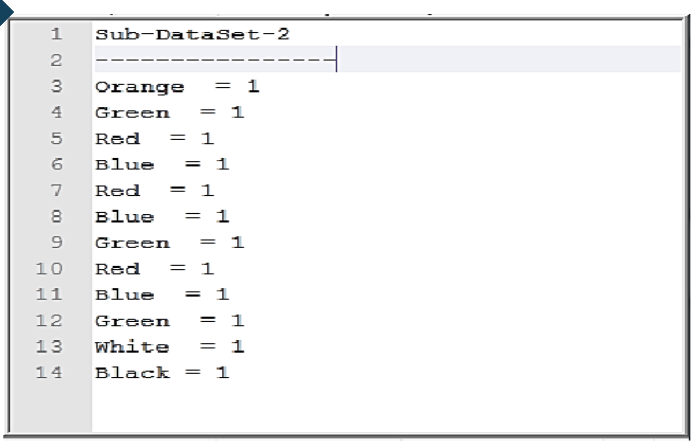


```
Sub-DataSet-2
----------------
Orange Green
Red Blue Red
Blue Green Red Blue
Green White Black
```

Map stage
(mapper)



```
Sub-DataSet-1
----------------
Red = 1
Blue = 1
Red = 1
Blue = 1
Green = 1
Red = 1
Blue = 1
Green = 1
White = 1
Black = 1
Red = 1
White = 1
Black = 1
```



```
Sub-DataSet-2
----------------
Orange   = 1
Green   = 1
Red   = 1
Blue   = 1
Red   = 1
Blue   = 1
Green   = 1
Red   = 1
Blue   = 1
Green   = 1
White   = 1
Black = 1
```

MapReduce Algorithm

- Partition stage:
  - During the partition stage, if more than one reducer is involved, a partitioner divides the output from the mapper into partitions between reducer instances.
  - **All records for a particular key are assigned to the same reducer**.
  - The MapReduce algorithm guarantees a random and fair distribution between reducers while making sure that all of the same keys across multiple mappers end up with the same reducer.
- Assume here in our example, that we have only one reducer.

MapReduce Algorithm

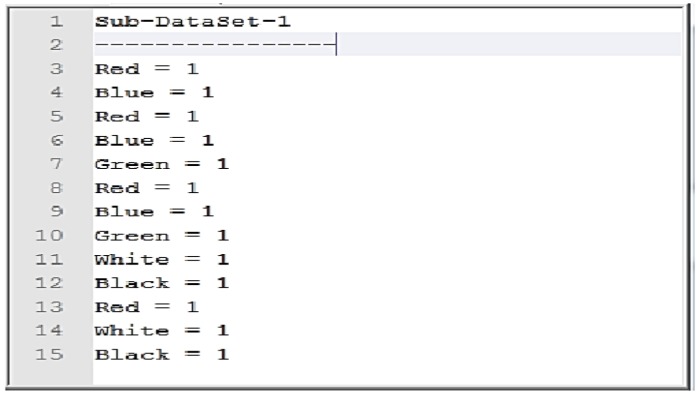
➢ Shuffle and Sort stage:

- During the first stage of the reduce task, output from all partitioners is copied across the network to the nodes running the reduce task. This is known as **shuffling**.
- The output list of key-value pairs from each partitioner can contain the same key multiple times, so **sorting and merging** of the key-value pairs is done according to the keys so that the output contains a sorted list of all input keys and their values with the same keys appearing together.
- This merge creates a single key-value pair per group, where key is the group key and the value is the list of all group values.
- The way in which keys are sorted and merged can be *customized*.

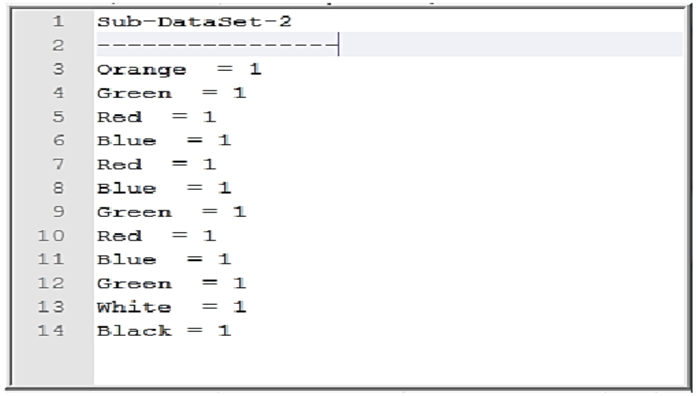
➢ By applying this stage on our example, we get the following:

MapReduce Algorithm

MapReduce Algorithm

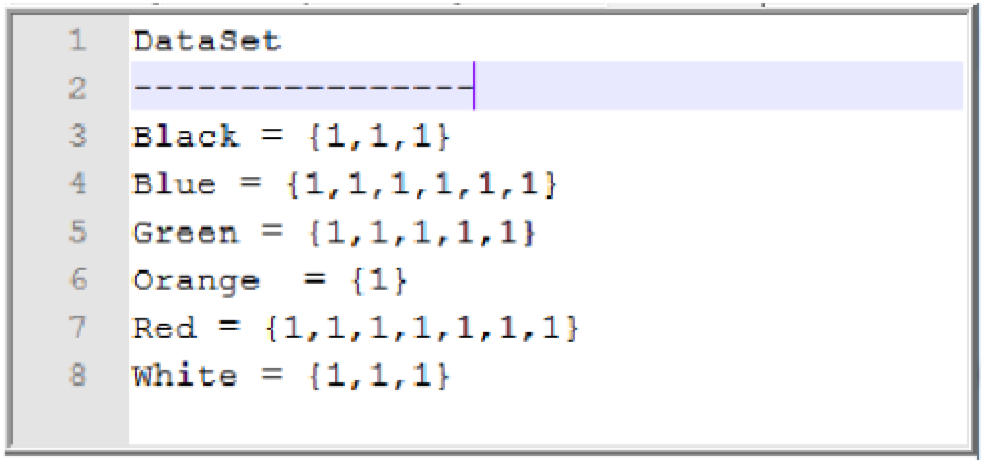


```
Sub-DataSet-1
----------------
Red = 1
Blue = 1
Red = 1
Blue = 1
Green = 1
Red = 1
Blue = 1
Green = 1
White = 1
Black = 1
Red = 1
White = 1
Black = 1
```



```
Sub-DataSet-2
----------------
Orange   = 1
Green   = 1
Red   = 1
Blue   = 1
Red   = 1
Blue   = 1
Green   = 1
Red   = 1
Blue   = 1
Green   = 1
White   = 1
Black = 1
```

Shuffling and Sorting stage

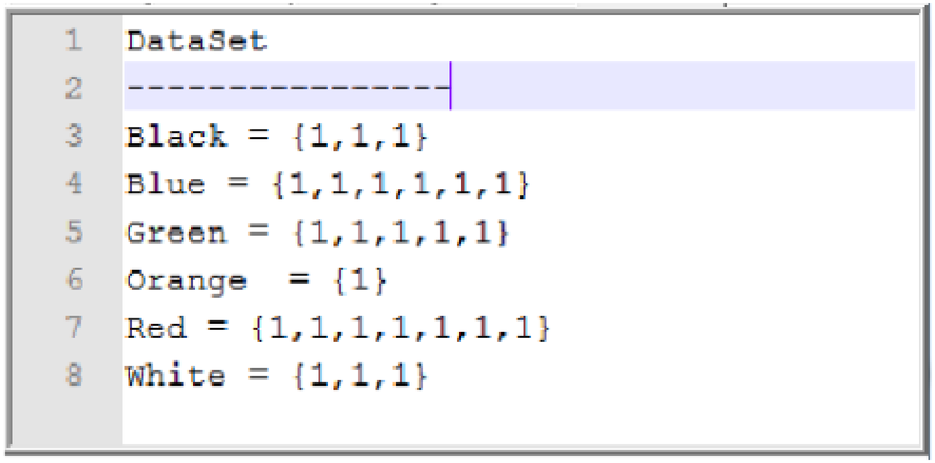


```
DataSet
----------------
Black = {1,1,1}
Blue = {1,1,1,1,1,1}
Green = {1,1,1,1,1}
Orange   = {1}
Red = {1,1,1,1,1,1,1}
White = {1,1,1}
```

MapReduce Algorithm

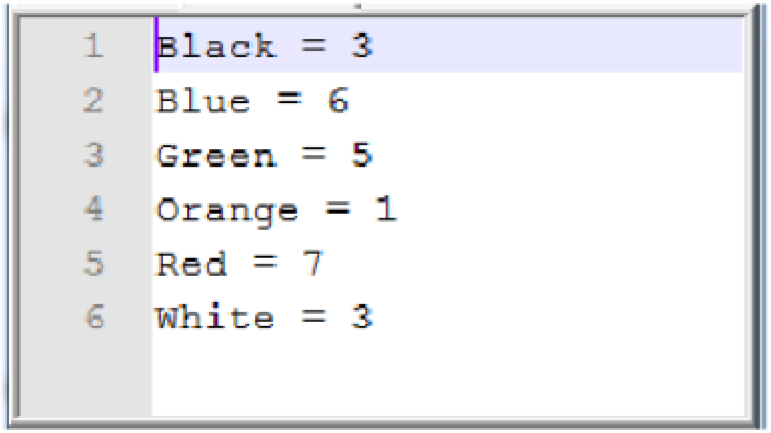
- Reduce stage:
  - Reduce is the final stage of the reduce phase.
  - Depending on the **user-defined logic** specified in the **reduce function** or **reducer**, the reducer will either further summarize its input or will emit the output without making any changes.
  - The output key can either be the same as the input key or a substring value from the input value, or another user-defined object.
  - The output value can either be the same as the input value or a substring value from the input value, or another user-defined object.
- By applying this stage on our example, we get the following:

MapReduce Algorithm



```
DataSet
----------------
Black = {1,1,1}
Blue = {1,1,1,1,1,1}
Green = {1,1,1,1,1}
Orange  = {1}
Red = {1,1,1,1,1,1,1}
White = {1,1,1}
```

Reduce stage (reducer)



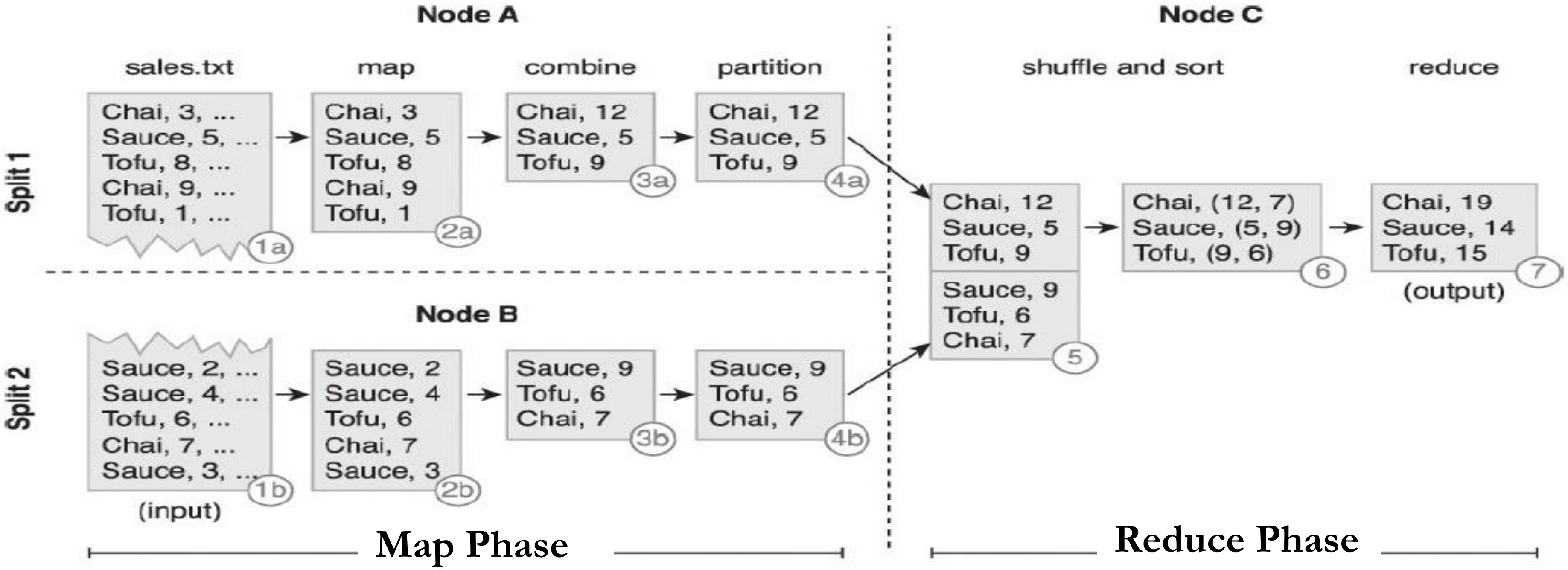
```
Black = 3
Blue = 6
Green = 5
Orange = 1
Red = 7
White = 3
```

Final Output

MapReduce Algorithm

➢ Consider another example as follows:

- We have products information as input and we need as output the quantity of each product.



Node A

sales.txt | map | combine | partition

Split 1

Chai, 3, ...
Sauce, 5, ...
Tofu, 8, ...
Chai, 9, ...
Tofu, 1, ...
(1a)

Chai, 3
Sauce, 5
Tofu, 8
Chai, 9
Tofu, 1
(2a)

Chai, 12
Sauce, 5
Tofu, 9
(3a)

Chai, 12
Sauce, 5
Tofu, 9
(4a)

Node B

Split 2

Sauce, 2, ...
Sauce, 4, ...
Tofu, 6, ...
Chai, 7, ...
Sauce, 3, ...
(1b)

(input)

Sauce, 2
Sauce, 4
Tofu, 6
Chai, 7
Sauce, 3
(2b)

Sauce, 9
Tofu, 6
Chai, 7
(3b)

Sauce, 9
Tofu, 6
Chai, 7
(4b)

Node C

shuffle and sort | reduce

Chai, 12
Sauce, 5
Tofu, 9
Sauce, 9
Tofu, 6
Chai, 7
(5)

Chai, (12, 7)
Sauce, (5, 9)
Tofu, (9, 6)
(6)

Chai, 19
Sauce, 14
Tofu, 15
(7)

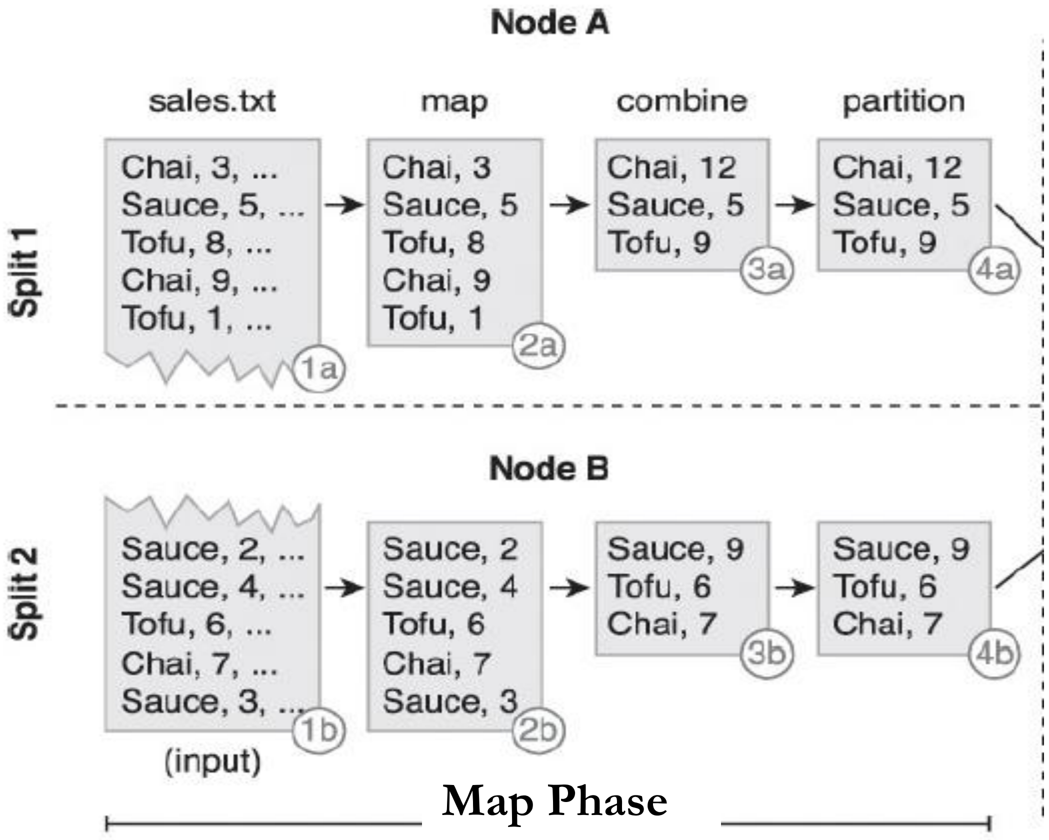
(output)

Map Phase

Reduce Phase

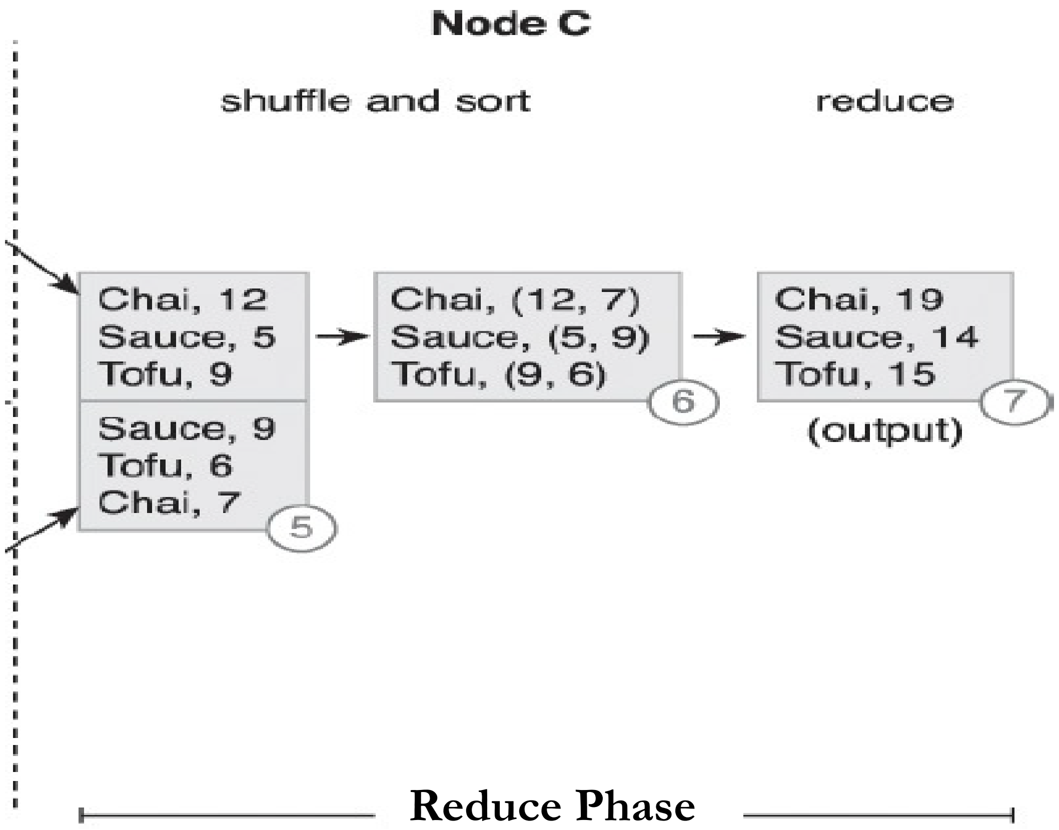
MapReduce Algorithm

1. The input (sales.txt) is divided into two splits.
2. Two map tasks running on two different nodes, Node A and Node B, extract product and quantity from the respective split's records in parallel. The output from each map function is a key-value pair where product is the key while quantity is the value.
3. The **combiner** then performs local summation of product quantities. (A combiner is essentially a reducer function that locally groups a mapper's output on the same node as the mapper.)
4. As there is only one reduce task, no partitioning is performed.



MapReduce Algorithm

5. The output from the two map tasks is then copied to a third node, Node C, that runs the shuffle stage as part of the reduce task.
6. The sort stage then groups all quantities of the same product together as a list.
7. The reduce function then sums up the quantities of each unique product in order to create the output.



MapReduce Examples

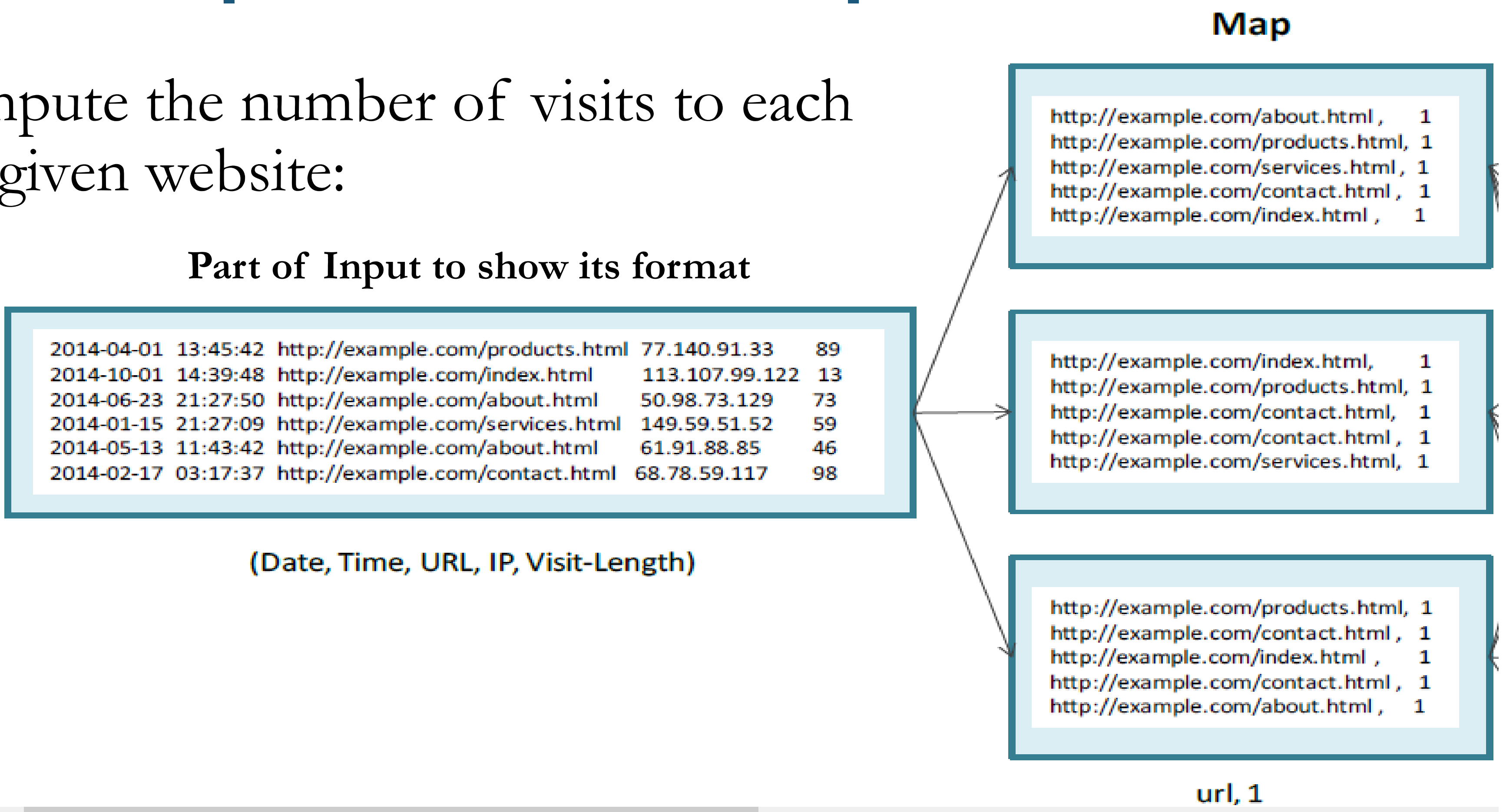
MapReduce Examples

- For the examples in this section, we will use data similar to the data collected by a web analytics service that shows various statistics for page visits for a website.
- Each page has some tracking code which sends the visitor's IP address along with a timestamp to the web analytics service. The web analytics service keeps a record of all page visits and the visitor IP addresses and uses MapReduce programs for computing various statistics.
- Each visit to a page is logged as one row in the log. The log file contains the following columns:

  Date (YYYY-MM-DD), Time (HH:MM:SS), URL, IP, Visit-Length.

MapReduce Examples

1. **Count:** Compute the number of visits to each page of the given website:



Part of Input to show its format

```
2014-04-01  13:45:42  http://example.com/products.html  77.140.91.33     89
2014-10-01  14:39:48  http://example.com/index.html      113.107.99.122  13
2014-06-23  21:27:50  http://example.com/about.html      50.98.73.129     73
2014-01-15  21:27:09  http://example.com/services.html   149.59.51.52     59
2014-05-13  11:43:42  http://example.com/about.html      61.91.88.85      46
2014-02-17  03:17:37  http://example.com/contact.html   68.78.59.117     98
```

(Date, Time, URL, IP, Visit-Length)

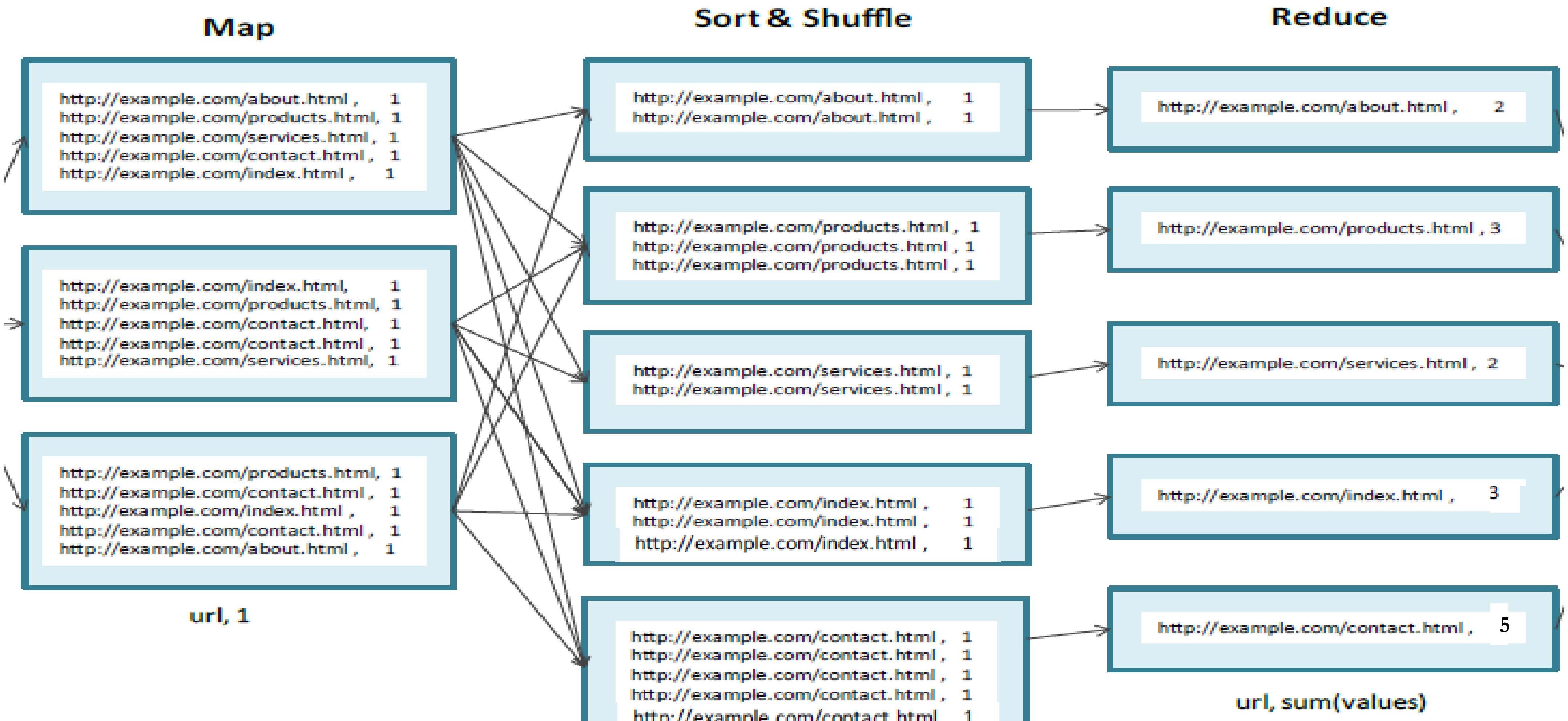
Map

```
http://example.com/about.html ,     1
http://example.com/products.html,  1
http://example.com/services.html ,  1
http://example.com/contact.html ,   1
http://example.com/index.html ,     1
```

```
http://example.com/index.html,      1
http://example.com/products.html,  1
http://example.com/contact.html,    1
http://example.com/contact.html ,   1
http://example.com/services.html,  1
```

```
http://example.com/products.html,  1
http://example.com/contact.html ,   1
http://example.com/index.html ,      1
http://example.com/contact.html ,   1
http://example.com/about.html ,     1
```

url, 1



Map

http://example.com/about.html , 1
http://example.com/products.html, 1
http://example.com/services.html, 1
http://example.com/contact.html , 1
http://example.com/index.html , 1

http://example.com/index.html, 1
http://example.com/products.html, 1
http://example.com/contact.html, 1
http://example.com/contact.html , 1
http://example.com/services.html, 1

http://example.com/products.html, 1
http://example.com/contact.html , 1
http://example.com/index.html , 1
http://example.com/contact.html , 1
http://example.com/about.html , 1

url, 1

Sort & Shuffle

http://example.com/about.html , 1
http://example.com/about.html , 1

http://example.com/products.html , 1
http://example.com/products.html , 1
http://example.com/products.html , 1

http://example.com/services.html , 1
http://example.com/services.html , 1

http://example.com/index.html , 1
http://example.com/index.html , 1
http://example.com/index.html , 1

http://example.com/contact.html , 1
http://example.com/contact.html , 1
http://example.com/contact.html , 1
http://example.com/contact.html , 1
http://example.com/contact.html , 1

Reduce

http://example.com/about.html , 2

http://example.com/products.html , 3

http://example.com/services.html , 2

http://example.com/index.html , 3

http://example.com/contact.html , 5

url, sum(values)

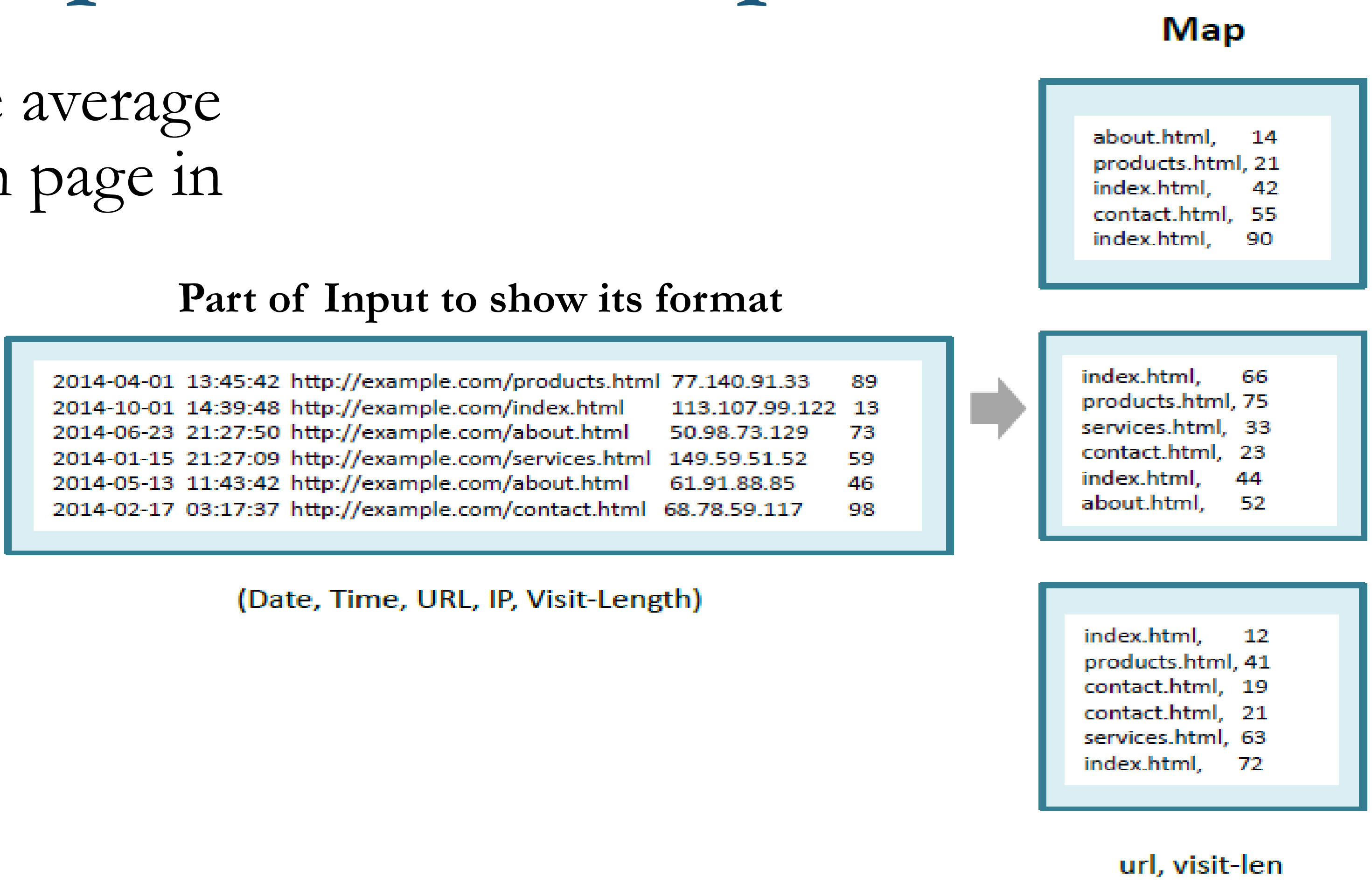
MapReduce Examples

1. **Count computation Explanation:**
   - To compute count, the mapper function emits key-value pairs where the key is the field to group-by.
   - The mapper function in this example parses each line of the input and emits key-value pairs where the key is the URL and value is ‘1’.
   - The reducer function receives the key-value pairs grouped by the same key and adds up the values for each group to compute count.

MapReduce Examples

2. **Average:** Find the average time spent on each page in the given website:

Part of Input to show its format



```
2014-04-01  13:45:42  http://example.com/products.html  77.140.91.33     89
2014-10-01  14:39:48  http://example.com/index.html      113.107.99.122   13
2014-06-23  21:27:50  http://example.com/about.html      50.98.73.129     73
2014-01-15  21:27:09  http://example.com/services.html  149.59.51.52     59
2014-05-13  11:43:42  http://example.com/about.html      61.91.88.85      46
2014-02-17  03:17:37  http://example.com/contact.html   68.78.59.117     98
```

(Date, Time, URL, IP, Visit-Length)

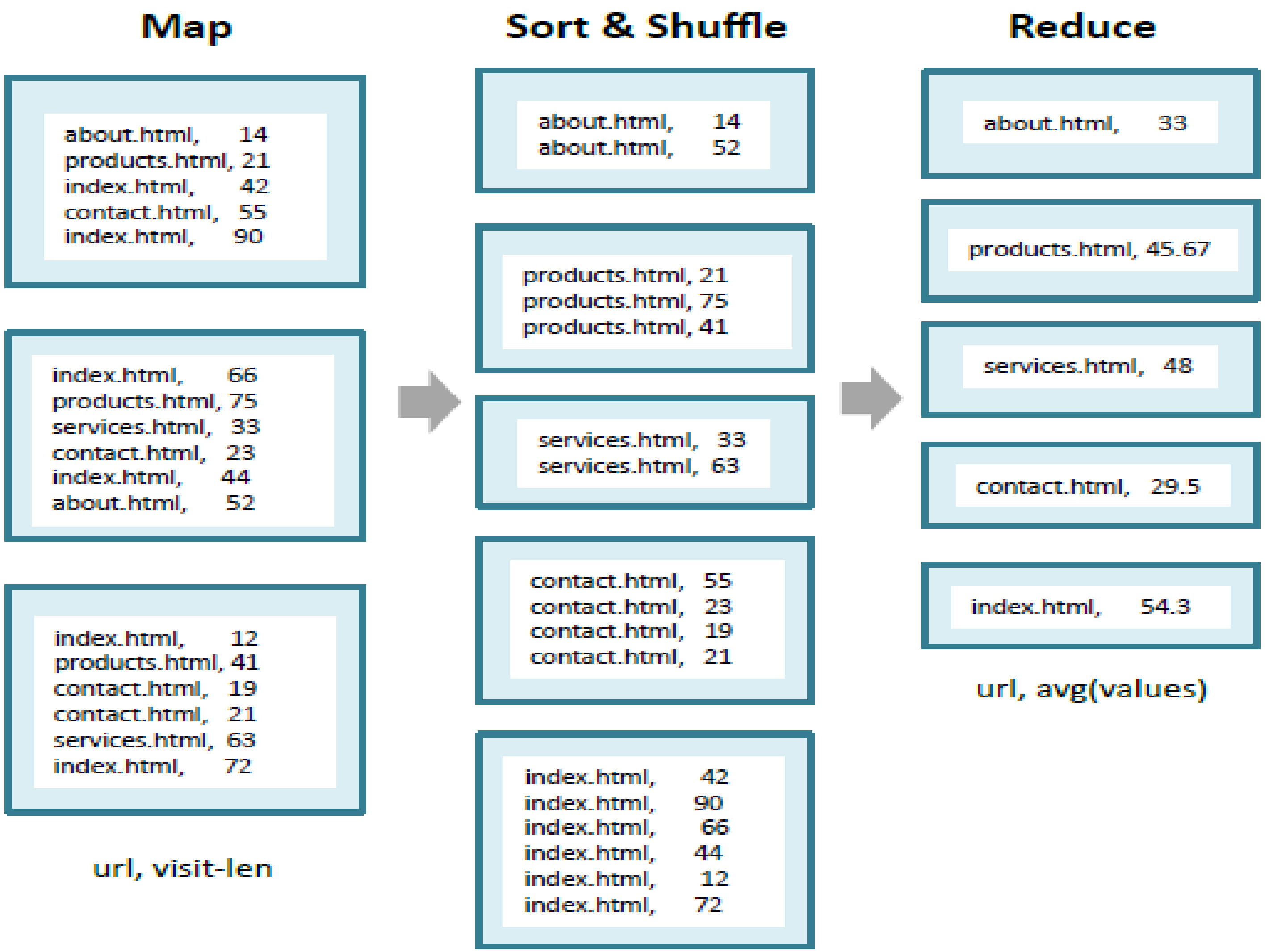
Map

```
about.html,     14
products.html, 21
index.html,     42
contact.html,   55
index.html,     90
```

```
index.html,     66
products.html, 75
services.html,  33
contact.html,   23
index.html,     44
about.html,     52
```

```
index.html,     12
products.html, 41
contact.html,   19
contact.html,   21
services.html,  63
index.html,     72
```

url, visit-len



Map

about.html, 14
products.html, 21
index.html, 42
contact.html, 55
index.html, 90

index.html, 66
products.html, 75
services.html, 33
contact.html, 23
index.html, 44
about.html, 52

index.html, 12
products.html, 41
contact.html, 19
contact.html, 21
services.html, 63
index.html, 72

url, visit-len

Sort & Shuffle

about.html, 14
about.html, 52

products.html, 21
products.html, 75
products.html, 41

services.html, 33
services.html, 63

contact.html, 55
contact.html, 23
contact.html, 19
contact.html, 21

index.html, 42
index.html, 90
index.html, 66
index.html, 44
index.html, 12
index.html, 72

Reduce

about.html, 33

products.html, 45.67

services.html, 48

contact.html, 29.5

index.html, 54.3

url, avg(values)

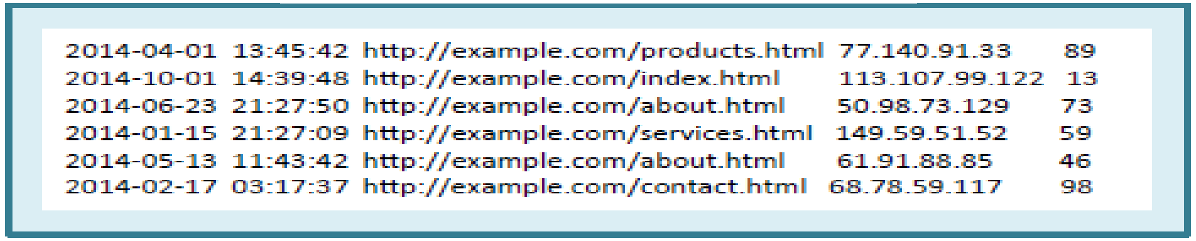
MapReduce Examples

2. **Average computation Explanation:**
   - To compute the average, the mapper function emits key-value pairs where the key is the field to group-by and value contains related items required to compute the average.
   - The mapper function in this example parses each line of the input and emits key-value pairs where the key is the URL and value is the visit length.
   - The reducer receives the list of values grouped by the key (which is the URL) and finds the average of these values.

MapReduce Examples

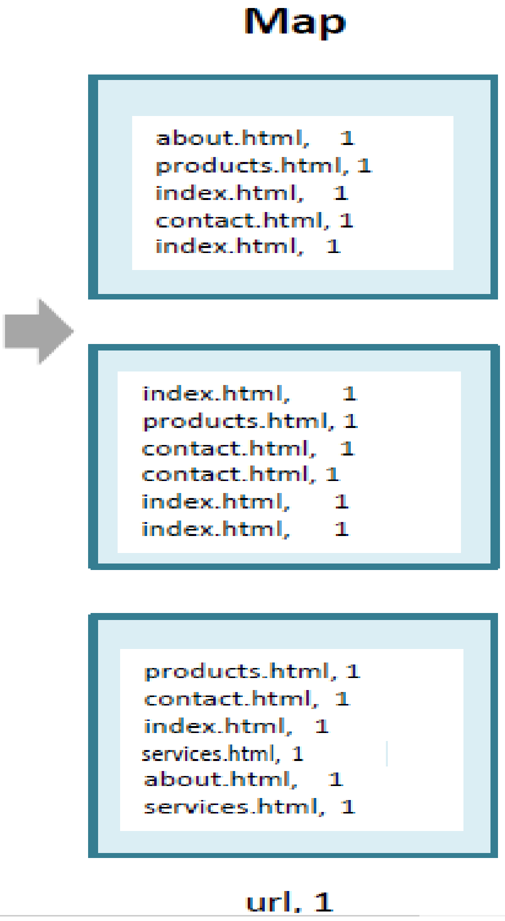
3. **Top-N:** Find the top 3 most visited pages in the given website:

Part of Input to show its format



```
2014-04-01  13:45:42  http://example.com/products.html  77.140.91.33     89
2014-10-01  14:39:48  http://example.com/index.html      113.107.99.122  13
2014-06-23  21:27:50  http://example.com/about.html      50.98.73.129     73
2014-01-15  21:27:09  http://example.com/services.html  149.59.51.52     59
2014-05-13  11:43:42  http://example.com/about.html      61.91.88.85      46
2014-02-17  03:17:37  http://example.com/contact.html  68.78.59.117      98
```

(Date, Time, URL, IP, Visit-Length)



Map

```
about.html,    1
products.html, 1
index.html,    1
contact.html, 1
index.html,   1
```

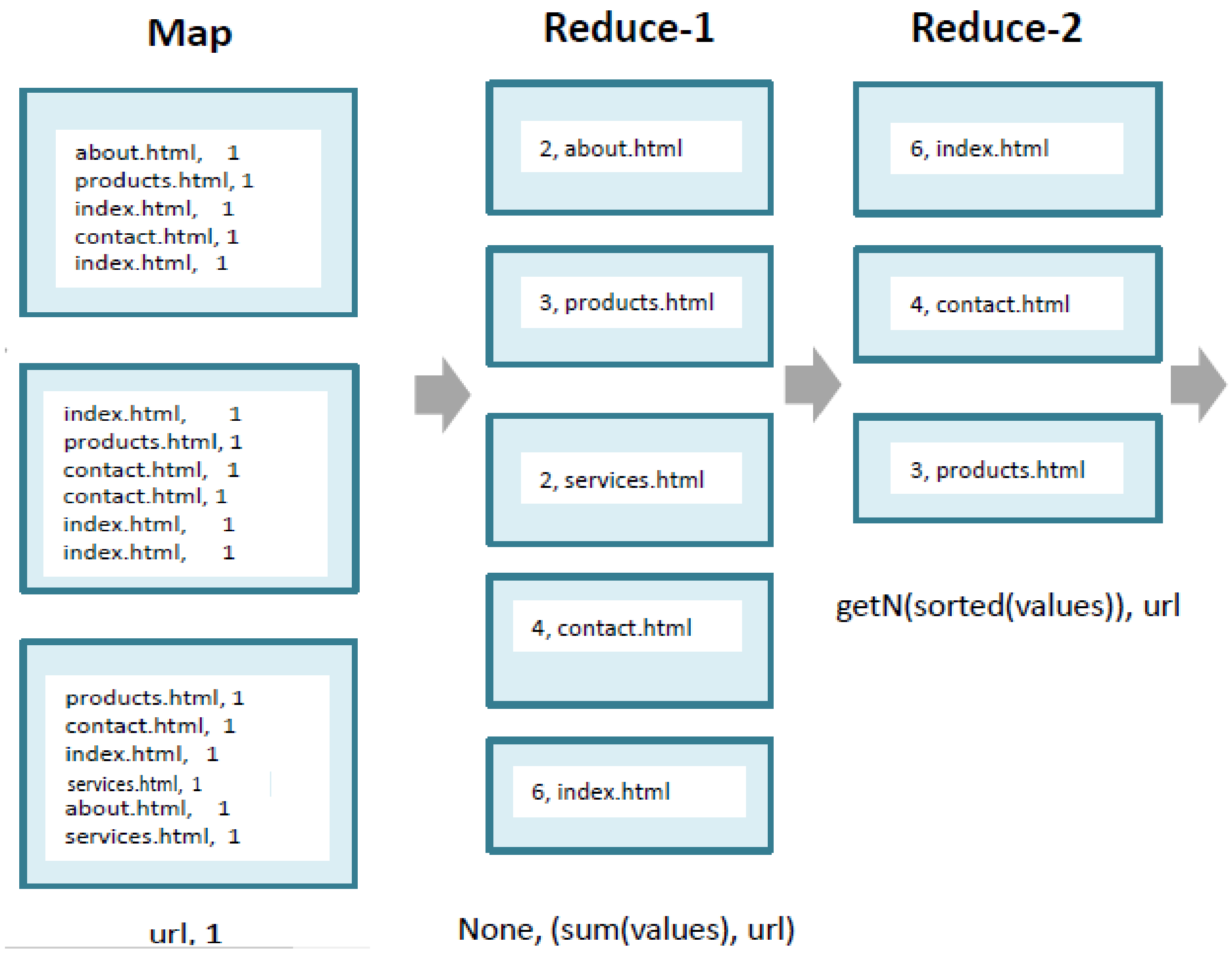
```
index.html,      1
products.html, 1
contact.html,    1
contact.html, 1
index.html,      1
index.html,      1
```

```
products.html, 1
contact.html,  1
index.html,   1
services.html, 1
about.html,    1
services.html,  1
```

url, 1

a. What will be the output of the shuffle and sort stage?

b. In Reduce-2, how many reducers do we have?



Map

about.html, 1
products.html, 1
index.html, 1
contact.html, 1
index.html, 1

index.html, 1
products.html, 1
contact.html, 1
contact.html, 1
index.html, 1
index.html, 1

products.html, 1
contact.html, 1
index.html, 1
services.html, 1
about.html, 1
services.html, 1

url, 1

Reduce-1

2, about.html

3, products.html

2, services.html

4, contact.html

6, index.html

None, (sum(values), url)

Reduce-2

6, index.html

4, contact.html

3, products.html

getN(sorted(values)), url

MapReduce Examples

3. **Top-N computation Explanation:**
   - The mapper function in this example parses each line of the input and emits key-value pairs where the key is the URL and value is ‘1’.
   - The reducer receives the list of values grouped by the key and sums up the values to count the visits for each page.
   - The first reducer emits None as the key and a tuple comprising of page visit count and page URL and the value.
   - The second reducer receives a list of (visit count, URL) pairs all grouped together (as the key is None). The reducer sorts the visit counts and emits top 3 visit counts along with the page URLs.
   - In this example, a two-step job was required because we need to compute the page visit counts first before finding the top 3 visited pages.

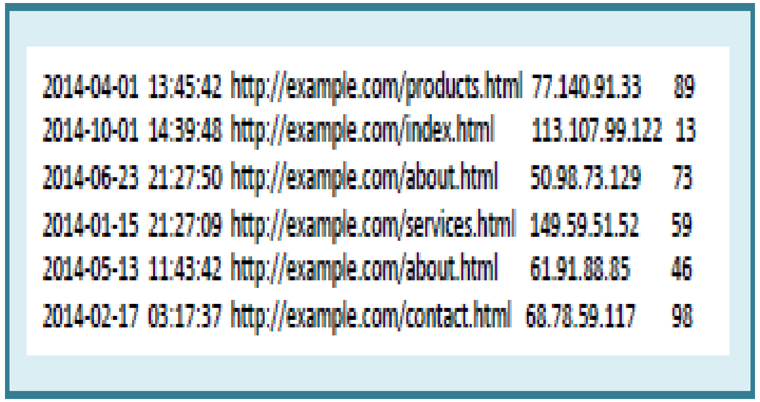
MapReduce Examples

4. **Filtering:**
    - Filter out a subset of the records based on a filtering criteria.
    - For example: filtering all page visits for the page ‘contact.html’ in the month of Dec 2014.

MapReduce Examples

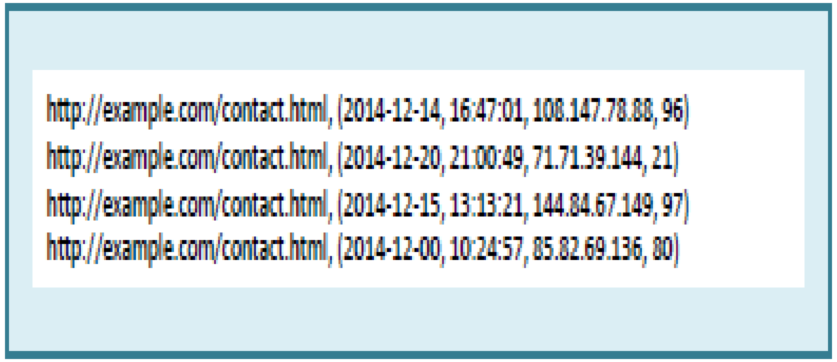
Map

Part of Input to show its format

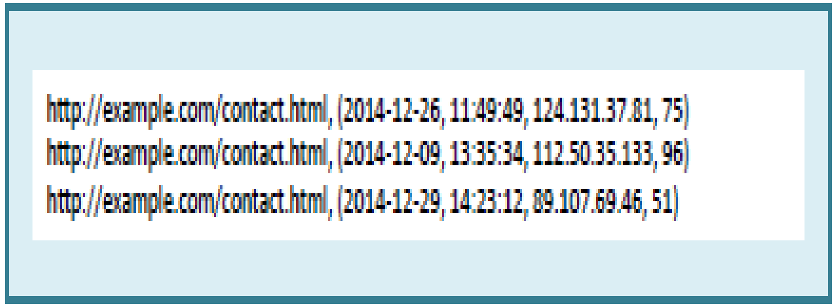


```
2014-04-01  13:45:42  http://example.com/products.html  77.140.91.33    89
2014-10-01  14:39:48  http://example.com/index.html     113.107.99.122  13
2014-06-23  21:27:50  http://example.com/about.html     50.98.73.129    73
2014-01-15  21:27:09  http://example.com/services.html  149.59.51.52    59
2014-05-13  11:43:42  http://example.com/about.html     61.91.88.85     46
2014-02-17  03:17:37  http://example.com/contact.html   68.78.59.117    98
```

(Date, Time, URL, IP, Visit-Length)



```
http://example.com/contact.html, (2014-12-14, 16:47:01, 108.147.78.88, 96)
http://example.com/contact.html, (2014-12-20, 21:00:49, 71.71.39.144, 21)
http://example.com/contact.html, (2014-12-15, 13:13:21, 144.84.67.149, 97)
http://example.com/contact.html, (2014-12-00, 10:24:57, 85.82.69.136, 80)
```



```
http://example.com/contact.html, (2014-12-26, 11:49:49, 124.131.37.81, 75)
http://example.com/contact.html, (2014-12-09, 13:35:34, 112.50.35.133, 96)
http://example.com/contact.html, (2014-12-29, 14:23:12, 89.107.69.46, 51)
```

URL, (Date, Time, IP, Visit-Length)

MapReduce Examples

4. **Filtering computation Explanation:**
   - Filtering is useful when you want to get a subset of the data for further processing.
   - Filtering requires only a Map task.
   - Each mapper filters out its local records based on the filtering criteria in the map function.
   - The mapper function in this example parses each line of the input, extracts the month, year and page URL and emits key-value pairs if the month and year are Dec 2014 and the page URL is 'http://example.com/contact.html'.
   - The key is the URL, and the value is a tuple containing the rest of the parsed fields.

Thank You