Aalto University
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Big Data Processing with MapReduce/Spark Programming Models

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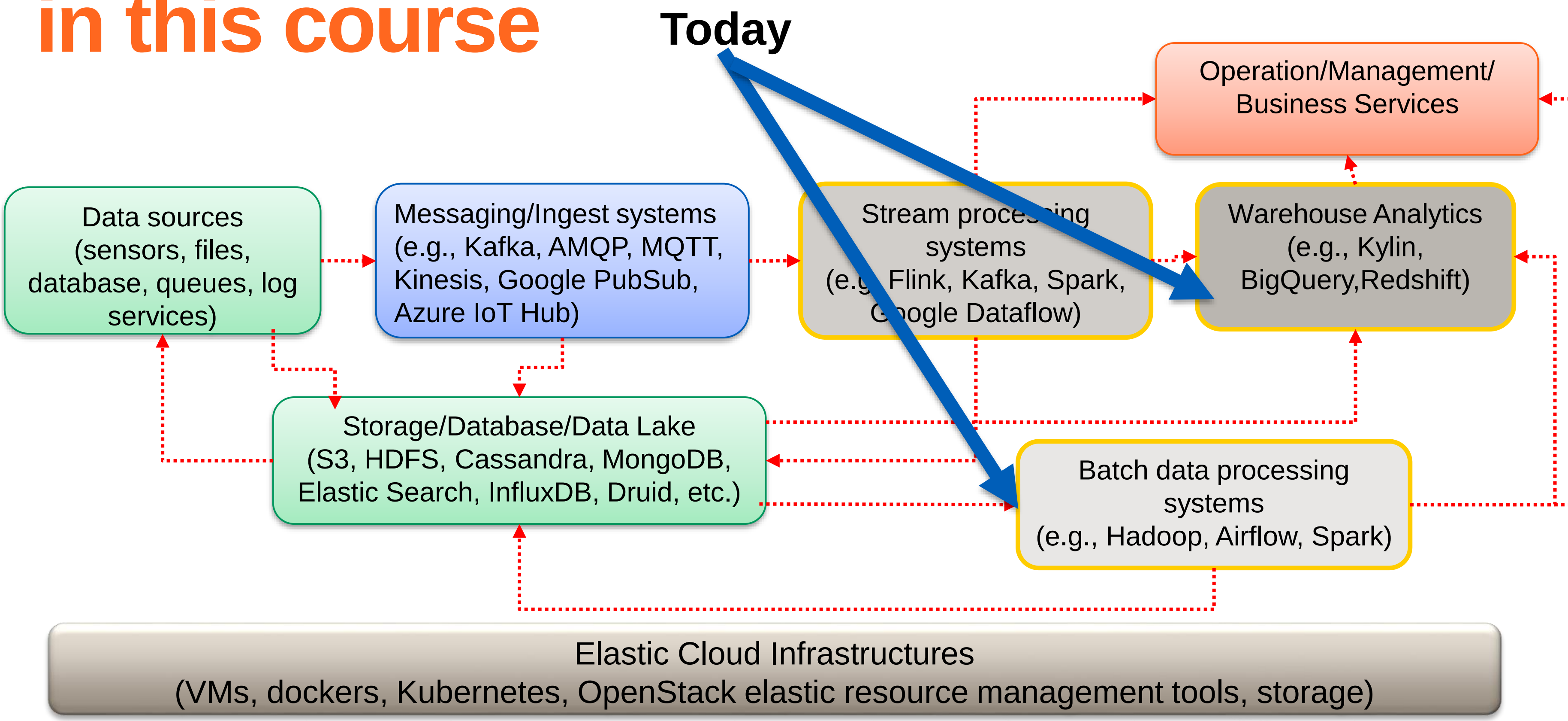
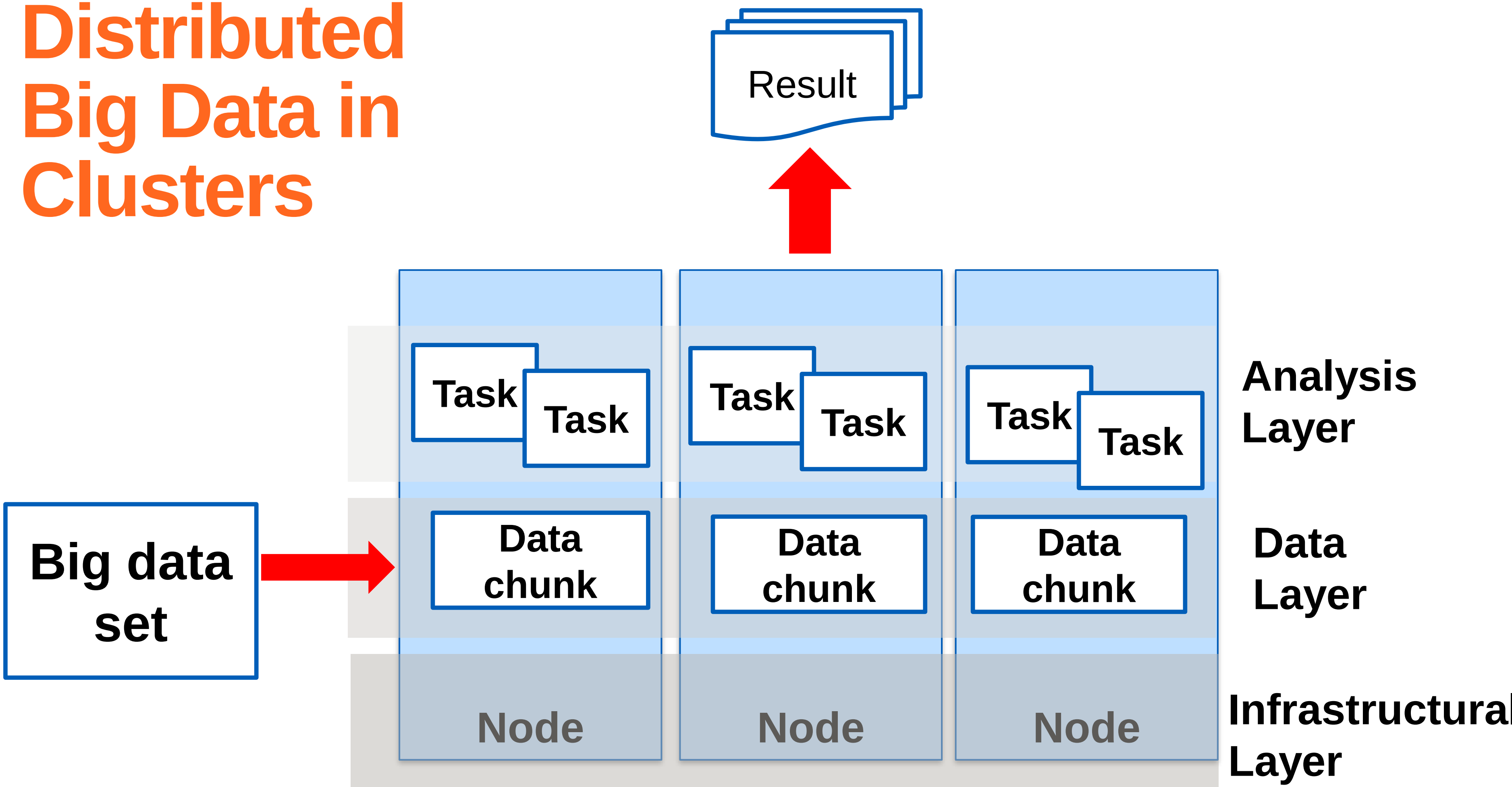
Learning objectives

- **Be familiar with big data processing models using multiple nodes/clusters**
- **Understand MapReduce/Spark programming models for big data processing**
- **Able to perform practical programming features with MapReduce/Spark**
- **Able to design and apply MapReduce/Spark data processing with Hadoop and other frameworks**

Big data at large-scale: the big picture in this course



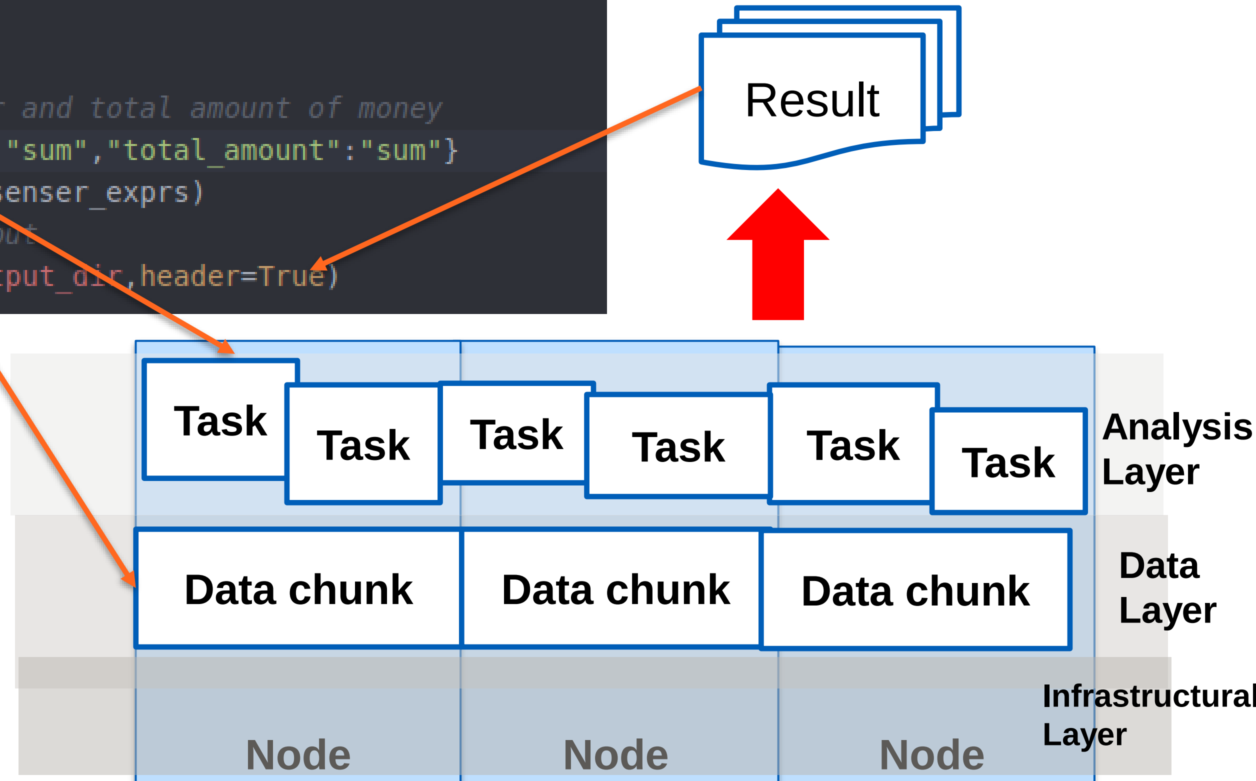
Distributed Big Data in Clusters



```
inputFile =args.input_file
## hadoop inputFile="hdfs://"
df =spark.read.csv(inputFile,header=True,inferSchema=True)
#df.show()
print("Number of trips", df.count())
#number of passenger count per vendor and total amount of money
passenser_exprs = {"passenger_count":"sum","total_amount":"sum"}
df2 = df.groupBy('VendorID').agg(passenser_exprs)
# Where do you want to write the output
df2.repartition(1).write.csv(args.output_dir,header=True)
```

Remember HIVE SQL statements?

What we need when we develop analysis programs for big data



Big data processing techniques in our focus

- **Programming models**
  - MapReduce/Spark
  - Stream Data Processing
  - Workflows
- **Studied frameworks**
  - Apache Hadoop/Spark
  - Apache Flink
  - Apache Airflow

MapReduce

https://hadoop.apache.org

MapReduce programming model

- **MapReduce is a programming model orignal from from Google**
  - Various implementations/frameworks support MapReduce
  - Apache Hadoop (originally from Yahoo!) is the most famous one
  - **https://hadoop.apache.org**
- **Support batch data processing for very large datasets**
- **Suitable for batch jobs in big data, e.g.,**
  - Web search, document processing, ecommerce information
  - Extract, transform, data wrangling, and data cleansing tasks

Map & Reduce

- **Map: map data into (key, value)**
  - Receives <key,value>
  - Outputs <key,value> - new set of <key,value>
- **Reducer: sum results from the same key**
  - Receives <key, Iterable[value]>
  - Outputs <key,value>

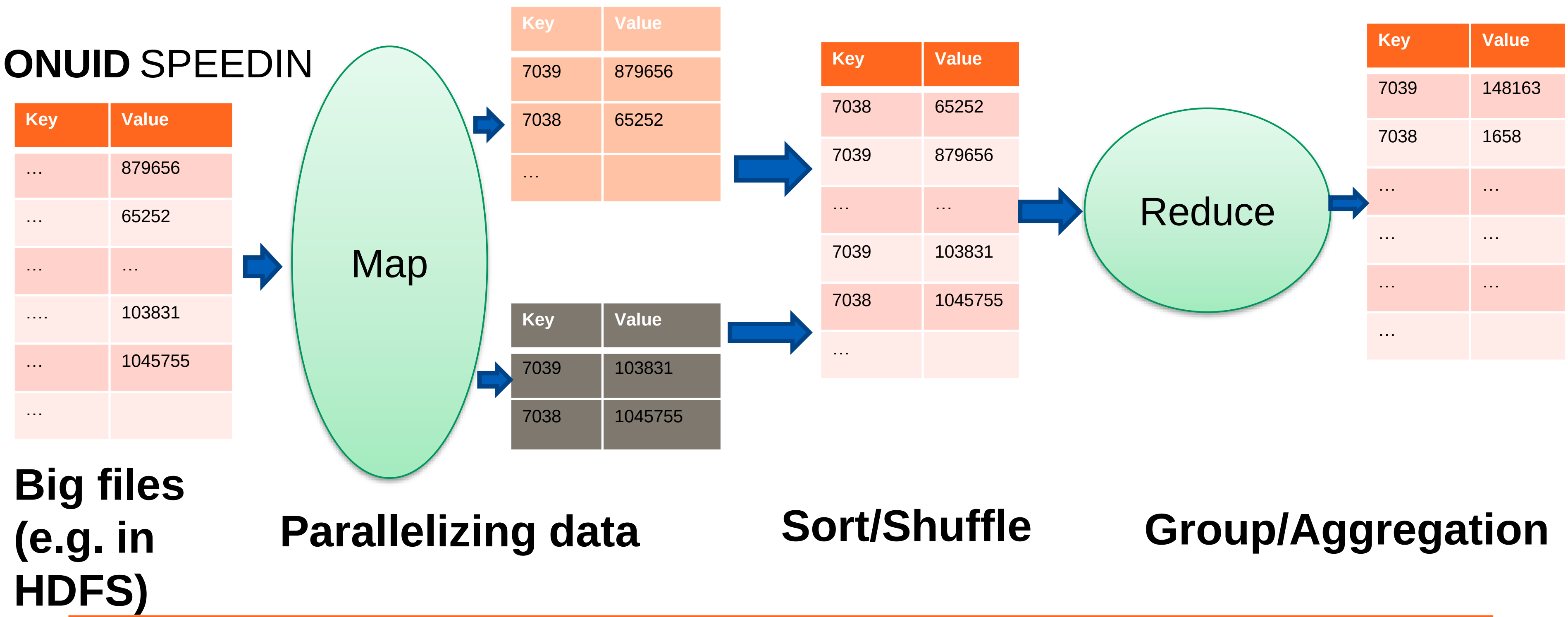
Example of a real data

Look at the network monitoring data

PROVINCECODE,DEVICEID,IFINDEX,FRAME,SLOT,PORT,ONUINDEX,ONUID,TIME,SPEEDIN,SPEEDOUT
XXN,10XXXXXX023,26XXXXXX8,1,2,7,39,100XXXXXX2310207039,01/08/2019 00:04:07,148163,49018
XXN,10XXXXXX023,26XXXXXX8,1,2,7,38,100XXXXXX2310207038,01/08/2019 00:04:07,1658,1362
XXN,10XXXXXX023,26XXXXXX8,1,2,7,9,100XXXXXX2310207009,01/08/2019 00:04:07,6693,5185

Sample: https://version.aalto.fi/gitlab/bigdataplatforms/cs-e4640/-/tree/master/data/onudata

Understand the MapReduce programming model



Key ideas of MapReduce

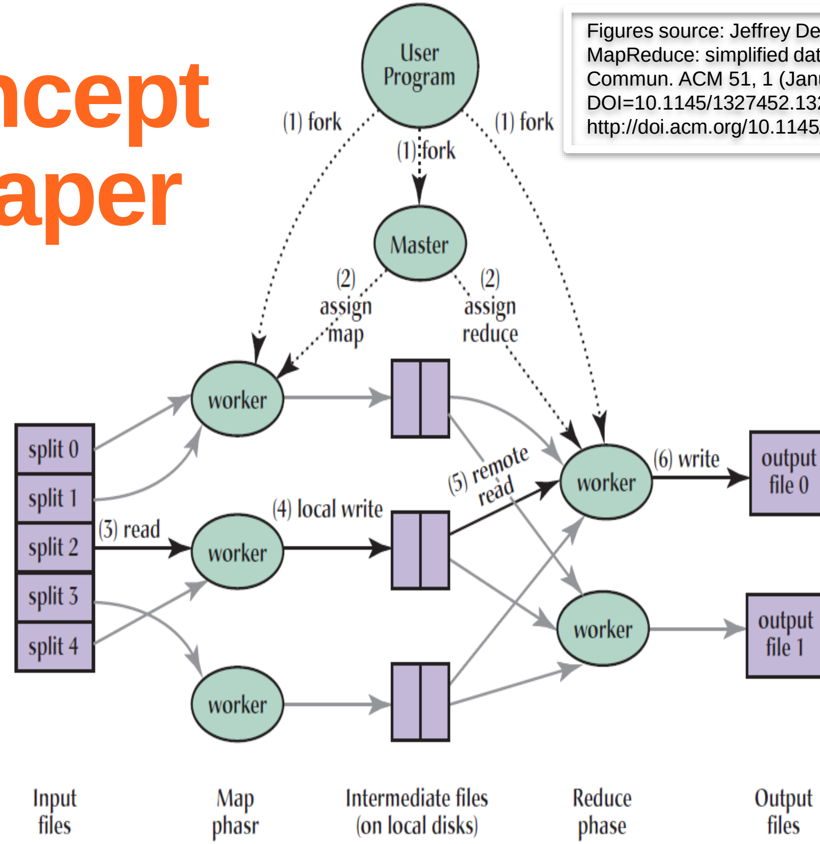
- **Data can be divided by “Map” operators**
  - data processing tasks extract “intermediate results”
- **Intermediate results can be aggregated through “Reduce” operators**
  - data processing tasks produce a result from “intermediate results”
- **We can glue “Map” and “Reduce” operators into a multi-stage data flow model**
- **Other possible operators:**
  - `Combiner`: performs “Reduce” at local nodes
  - `Partitioner`: decides key/value for Reduce

Key ideas of MapReduce

- **Key points for the developers**
  - should write only the main "logic": Map and Reduce operators
- **The runtime framework will**
  - handle data movement and input/output management for Map/Reduce tasks
  - parallelizing tasks in multiple nodes

MapReduce concept in the original paper

```
map(String key, String value):
    // key: document name
    // value: document contents
    for each word w in value:
        EmitIntermediate(w, "1");

reduce(String key, Iterator values):
    // key: a word
    // values: a list of counts
    int result = 0;
    for each v in values:
        result += ParseInt(v);
    Emit(AsString(result));
```



Figures source: Jeffrey Dean and Sanjay Ghemawat. 2008. MapReduce: simplified data processing on large clusters. Commun. ACM 51, 1 (January 2008), 107-113. DOI=10.1145/1327452.1327492 http://doi.acm.org/10.1145/1327452.1327492

Key point: parallelize workers to process a lot of input files and produce a lot of output files

Hadoop MapReduce

- **Hadoop supports the MapReduce programming model**
  - Use cluster nodes for data processing tasks
  - Access data in HDFS and data partitioned in different nodes
  - Hadoop runtime automatically creates parallel tasks
  - YARN is used to run jobs of MapReduce applications
- **Data management (HDFS) and data processing (MapReduce) is aligned nicely**
  - Run in the same nodes → data locality optimization

Map/Reduce tasks and data/node partitions

- **A Map task can handle a data partition in the same node**
  - E.g., a Map task handles a HDFS data block → local data optimization: no data movement - local processing
  - Results from a Map task are intermediate → to where a task will store them?
  - *What if a Map task fails?*
- **Reduce Task**
  - Need to deal with data produced from different Map tasks → *where to run the Reduce tasks?*

Examples - Map

Input

Output

```
public static class SpeedInMapper
    extends Mapper<Object, Text, LongWritable , AverageWritable>{
  private LongWritable id =new LongWritable();
  private AverageWritable averagecount = new AverageWritable();
  public void map(Object key, Text value, Context output)
      throws IOException, InterruptedException {

      String valueString = value.toString();
      String[] record = valueString.split(",");
      id.set(Long.parseLong(record[7]));
      averagecount.setAverage(Float.parseFloat(record[9]));
      averagecount.setCount(1);
      output.write(id,averagecount);
  }
}
```

Parse the data to get ONUID and SPEEDIN

Map (ONUID,(SPEEDIN, count))

Example - Reduce

Input

Output

```
public static class SpeedInAverageReducer
      extends Reducer<LongWritable,AverageWritable,LongWritable,FloatWritable> {
  private FloatWritable new_result = new FloatWritable();


  public void reduce(LongWritable key, Iterable<AverageWritable> values,
                     Context context
                     ) throws IOException, InterruptedException {
    float avg = 0;
    int count = 0;
    for (AverageWritable val : values) {
        float current_avg =val.getAverage();
        int current_count =val.getCount();
        avg = avg + (current_avg*current_count);
        count = count + current_count;
    }

   new_result.set(avg/count);
   context.write(key, new_result);
  }
}
```

Simple way to determine the average as "Reduce" operator

Reduce (ONUID,AVG)

Driver: connect Map and Reduce operators

```
public static void main(String[] args) throws Exception {
  Configuration conf = new Configuration();
  Job job = Job.getInstance(conf, "simpleonuaverage");
  job.setJarByClass(SimpleAverage.class);
  job.setMapperClass(SpeedInMapper.class);
  job.setCombinerClass(SpeedInAverageCombiner.class);
  job.setReducerClass(SpeedInAverageReducer.class);
  job.setMapOutputKeyClass(LongWritable.class);
  job.setMapOutputValueClass(AverageWritable.class);
  job.setOutputKeyClass(LongWritable.class);
  job.setOutputValueClass(FloatWritable.class);
  FileInputFormat.addInputPath(job, new Path(args[0]));
  FileOutputFormat.setOutputPath(job, new Path(args[1]));
  System.exit(job.waitForCompletion(true) ? 0 : 1);
}
```

Combiner

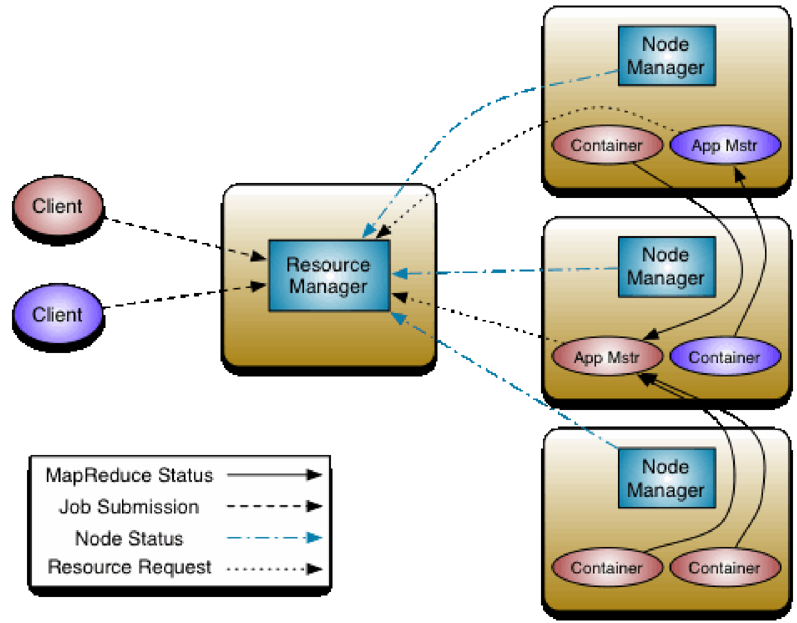
Example with Python using MRJob

```
class ONUSpeedinAverage(MRJob):
    def mapper(self, _, entry):
        provincecode,deviceid,ifindex,frame,slot,port,onuindex,onuid,timestamp,speedin,speedout= entry.split(",")
        #average speed its speedin with count = 1
        yield (onuid, (float(speedin),1))

   ## recalculate the new speedin average through an array of speedin average values
    def _recalculate_avg(self, onuid, speedin_avg_values):
        current_speedin_total = 0
        new_avg_count = 0
        for speedin_avg, avg_count  in speedin_avg_values:
            current_speedin_total = current_speedin_total +(speedin_avg*avg_count)
            new_avg_count = new_avg_count + avg_count
        new_speedin_avg = current_speedin_total/new_avg_count
        return (onuid, (new_speedin_avg, new_avg_count))

    def combiner(self, onuid, speedin_avg_values):
        yield self._recalculate_avg(onuid, speedin_avg_values)

    def reducer(self, onuid,speedin_avg_values):
        onuid, (speedin_avg, avg_count) = self._recalculate_avg(onuid,speedin_avg_values)
        yield (onuid, speedin_avg)

if __name__ == '__main__':
    ONUSpeedinAverage.run()
```

Note: see code examples in our GIT

Resource management and execution for MapReduce in clusters

A cluster of computing nodes can be managed by YARN
 or Mesos



Source: http://hadoop.apache.org/docs/current/hadoop-yarn/hadoop-yarn-site/YARN.html

Schedule and monitoring for MapReduce

- **A MapReduce program runs → MapReduce Job**
  - includes many tasks (Map and Reduce processes + others)
- **JobTracker**
  - monitors the whole job (all tasks of a MapReduce program)
- **TaskTracker**
  - performs a task of the MapReduce applications
  - informs JobTracker about the state of the tasks

Monitoring MapReduce Jobs

Logged in as: dr.who

Application application_1570429323498_0008

- Cluster
  - About
  - Nodes
  - Node Labels
  - Applications
    - NEW
    - NEW_SAVING
    - SUBMITTED
    - ACCEPTED
    - RUNNING
    - FINISHED
    - FAILED
    - KILLED
  - Scheduler
- Tools

Application Overview

User:	mybdp
Name:	cse4640-nytaxicount
Application Type:	SPARK
Application Tags:	
Application Priority:	0 (Higher Integer value indicates higher priority)
YarnApplicationState:	FINISHED
Queue:	default
FinalStatus Reported by AM:	SUCCEEDED
Started:	Fri Oct 25 19:22:08 +0000 2019
Elapsed:	3mins, 6sec
Tracking URL:	History
Log Aggregation Status:	DISABLED
Application Timeout (Remaining Time):	Unlimited
Diagnostics:	
Unmanaged Application:	false
Application Node Label expression:	<Not set>
AM container Node Label expression:	<DEFAULT_PARTITION>

Application Metrics

Total Resource Preempted:	<memory:0, vCores:0>
Total Number of Non-AM Containers Preempted:	0
Total Number of AM Containers Preempted:	0
Resource Preempted from Current Attempt:	<memory:0, vCores:0>
Number of Non-AM Containers Preempted from Current Attempt:	0
Aggregate Resource Allocation:	5039065 MB-seconds, 973 vcore-seconds
Aggregate Preempted Resource Allocation:	0 MB-seconds, 0 vcore-seconds

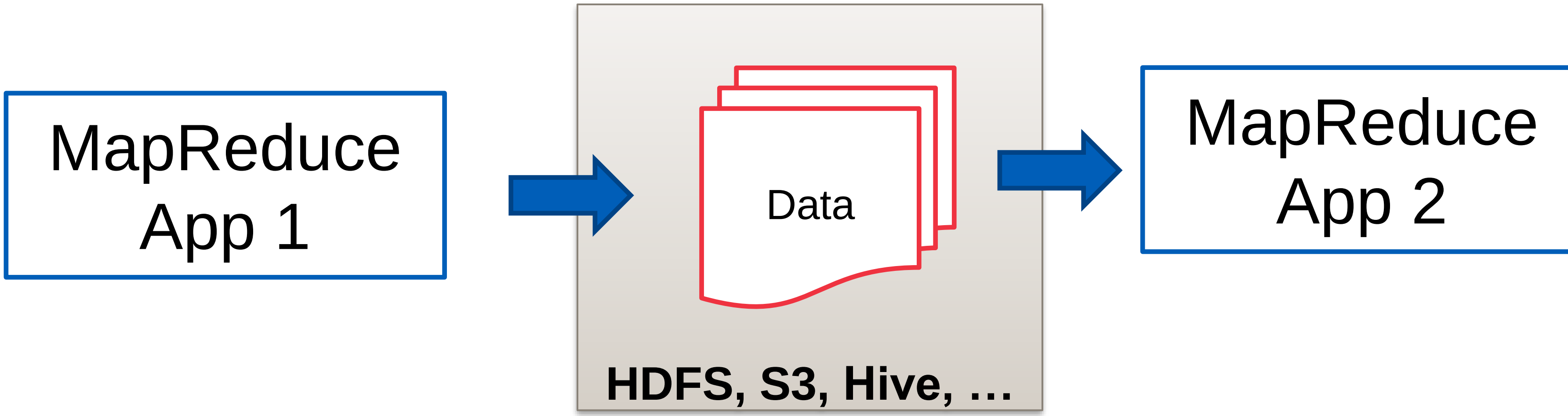
Show 20 entries Search:

Attempt ID	Started	Node	Logs	Nodes blacklisted by the app	Nodes blacklisted by the system
appattempt_1570429323498_0008_000001	Fri Oct 25 22:22:08 +0300 2019	http://cluster-bdp-w-3.c.bigmultidatstore.internal:8042	Logs	0	0

Showing 1 to 1 of 1 entries First Previous 1 Next Last

Connecting MapReduce applications

Build complex MapReduce pipelines



Using big data storage/database as data exchange

We can use workflows to coordinate different MapReduce apps

Problems with MapReduce

- **Strict Map & Reduce tasks connection → limitation**
- **Need more flexible in processing big data workloads**
  - Batch data flows and streaming data flows
- **Programming diversity support**
  - Software engineering productivity

Apache Spark

https://spark.apache.org/

Apache Spark

- **Cluster-based high-level computing framework**
- **“unified engine” for different types of big data processing**
  - SQL/structured data processing
  - Machine learning
  - Graph processing
  - (Microbatching)streaming processing
- **It is a powerful computing framework and system → an important service that a big data platform should support**

Apache Spark

Can be run a top

- **Hadoop (using HDFS and YARN)**
- **Mesos cluster**
  - http://mesos.apache.org/
- **Kubernetes**
- **Standalone machines**

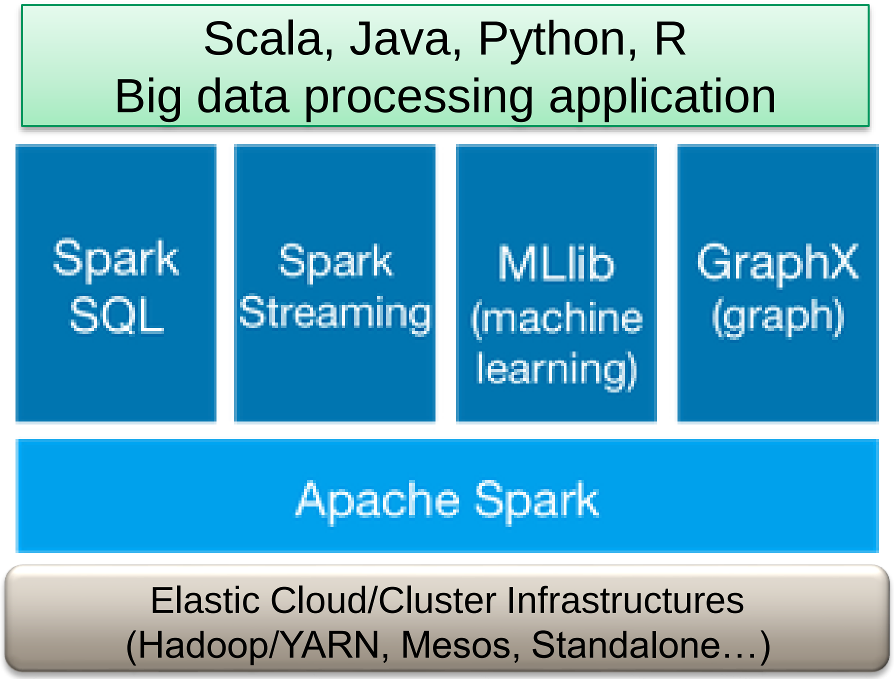


Figure source: http://spark.apache.org/

Key features

- **Data is distributed in different nodes for processing**
  - Like data distributed in different nodes in big storage/database
- **Leverage parallel computing concepts to run multiple tasks**
  - Parallel tasks, task pipeline, DAG of processing stages
- **Employ in-memory big data processing**
- **Program driver steers the execution of parallel tasks**
  - Tasks are paralleled automatically and are scheduled with different underlying schedulers
- **Key data operators**
  - Transformations and actions on data

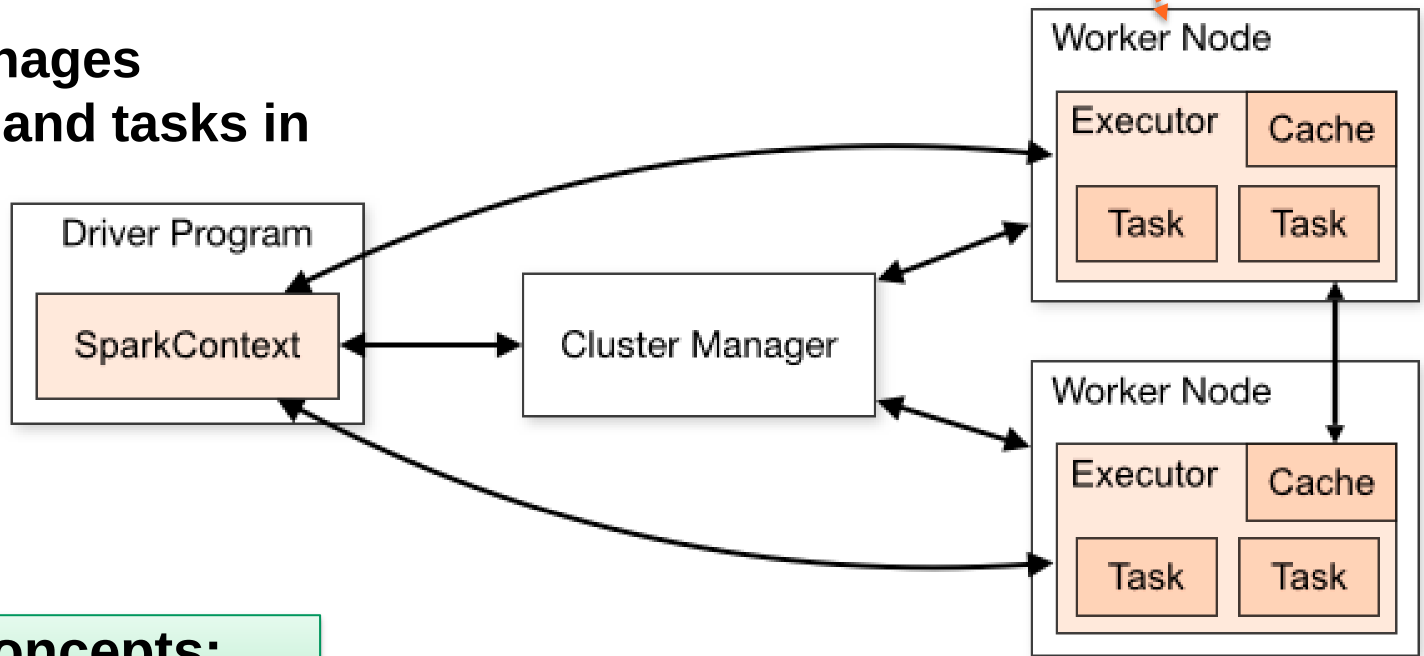
Spark Program: programming elements

- **SparkSession**
  - Act as a program driver to manage the execution of tasks
  - SparkContext: manages connection to cluster, manage internal services
- **Data APIs**
  - Low-level Resilient Distributed Dataset (RDD)
  - High-level DataFrames/DataSets
  - Load and hold distributed data
  - Transformation and action functions
- **ML, Graph and Streaming functions and pipelines**

Execution Model

Map into a resource in a cluster node

Driver manages operators and tasks in nodes



Common concepts: Driver, Nodes, Tasks

Figure source: http://spark.apache.org/docs/latest/cluster-overview.html

Spark application management: high-level view

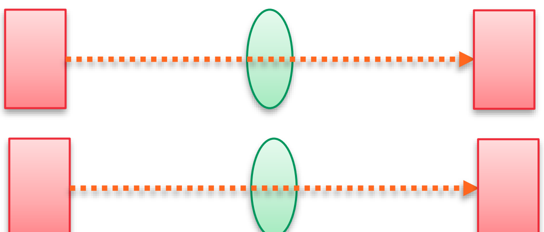
- **Submission/Request**
  - Submit the Spark application for running
  - Resource is provided for running the Driver
- **Launch**
  - The Driver requests resources for executors (through SparkContext)
  - Establish executors across worker nodes
- **Execution**
  - The driver starts to execute code and move data
- **Finish/Completion:**
  - Finish, release executors

Spark program logic: typical steps

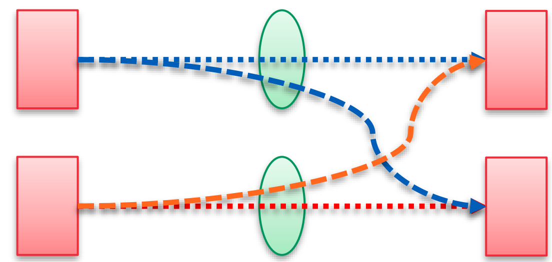
- **Load data and distribute data**
  - Data is immutable after created
  - Data partition in Spark: a partition is allocated in a node
- **Perform transformation and action operators**
  - *Transformations:* build plans for transforming data models
  - *Actions:* perform computation on data
- **The developer mostly focuses on loading data and performing operators**

Transformation operators

- **Transformation:**
  - Instructions about how to transform a data in a form to another form → it will not change the original data (immutability)
- **Only tell what to do: to build a DAG (direct acyclic graph): a lineage of what to do**
- **lazy approach → real transformation will be done at action operators**



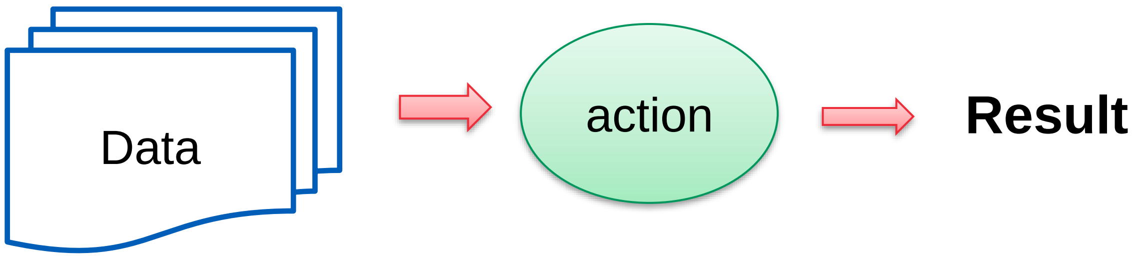
Narrow transformation, no data shuffle



Wide transformation, cross data partitions, require shuffles

Action operators

- **Compute the results for a set of transformations**
  - Examples: count or average
- **Actions: view, collect, write, calculation**



Lazy approach: an action triggers execution of transformation operators → enable various types of optimization

Resilient distributed dataset (RDD)

- **Low-level data structure**
  - Collection of data elements partitioned across nodes in the cluster
- **Create RDD**
  - Created by loading data from files (text, sequence file) including local file systems, HDFS, Cassandra, HBase, Amazon S3, etc.
- **Persist RDD**
  - In memory or to files

RDD transformations and actions

Transformations

- map
- filter
- sample
- intersection
- groupByKey

Actions

- reduce()
- collect()
- count()
- saveAs…File()

Example with RDD

```
VendorID,tpep_pickup_datetime,tpep_dropoff_datetime,passenger_count,trip_distance,RatecodeID,store_and_fwd_flag,PULocationID,DOLocationID,payment_type,fare_amount,extra,mta_tax,tip_amount,tolls_amount,improvement_surcharge,total_amount
2,11/04/2084 12:32:24 PM,11/04/2084 12:47:41 PM,1,1.34,1,N,238,236,2,10,0,0.5,0,0,0.3,10.8
2,11/04/2084 12:32:24 PM,11/04/2084 12:47:41 PM,1,1.34,1,N,238,236,2,10,0,0.5,0,0,0.3,10.8
2,11/04/2084 12:25:53 PM,11/04/2084 12:29:00 PM,1,0.32,1,N,238,238,2,4,0,0.5,0,0,0.3,4.8
```

as a text file

```
conf = SparkConf().setAppName("cse4640-rddshow").setMaster(args.master)
sc = SparkContext(conf=conf)
##modify the input data
rdd=sc.textFile(args.input_file)
## if there is a header we can filter it otherwise comment two lines
csvheader = rdd.first()
rdd =  rdd.filter(lambda csventry: csventry != csvheader)
## using map to parse csv text entry
rdd=rdd.map(lambda csventry: csventry.split(","))
rdd.repartition(1)
rdd.saveAsTextFile(args.output_dir)
```

Shared variables

- **Implement common patterns in parallel computing:**
  - broadcast and global counter
- **Variables used in parallel operations**
  - variables are copied among parallel tasks
  - shared among tasks or between tasks and the driver
- **Types of variables**
  - broadcast variables: cache a value in all nodes
  - accumulators: a global counter shared across processes

Examples

```
conf = SparkConf().setAppName("cse4640-broadcast").setMaster(args.master)
sc = SparkContext(conf=conf)
bVar = sc.broadcast([5,10])
print("The value of the broadcast",bVar.value,sep=" ")
counter = sc.accumulator(0)
sc.parallelize([1, 2, 3, 4]).foreach(lambda x: counter.add(bVar.value[0]))
print("The value of the counter is ",counter.value,sep=" ")
```

Use cases:

- **Broadcast variables: lookup tables**
- **Accumulators: monitoring/checkpoint counters**

Spark SQL and DataFrames

- **High-level APIs**
- **SparkSQL: enable dealing with structured data**
  - SQL query execution, Hive, JDBC/ODBC

- **DataFrame**
  - Distributed data organized into named columns, similar to a table in relational database
  - Pandas and Spark DataFrames have similar concepts
    - *But single machine versus multiple machines*

DataFrame

```
inputFile =args.input_file
df =spark.read.csv(inputFile,header=True,inferSchema=True)
print("Number of partition",df.rdd.getNumPartitions())
df.show()
```

PROVINCECODE	DEVICEID	IFINDEX	FRAME	SLOT	PORT	ONUINDEX	ONUID	TIME	SPEEDIN	SPEEDOUT
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	39	10[redacted]07039	01/08/2019 00:04:07	148163	49018
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	38	10[redacted]07038	01/08/2019 00:04:07	1658	1362
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	9	10[redacted]07009	01/08/2019 00:04:07	6693	5185
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	8	10[redacted]07008	01/08/2019 00:04:07	640	544
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	11	10[redacted]07011	01/08/2019 00:04:07	118	114
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	10	10[redacted]07010	01/08/2019 00:04:07	28514	12495
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	13	10[redacted]07013	01/08/2019 00:04:07	868699	23400
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	15	10[redacted]07015	01/08/2019 00:04:07	1822	1120
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	17	10[redacted]07017	01/08/2019 00:04:07	998069	117345
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	16	10[redacted]07016	01/08/2019 00:04:07	22402	1804
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	19	10[redacted]07019	01/08/2019 00:04:07	640	791
[redacted]YN	[redacted]3023	[redacted]760	1	1	10	49	10[redacted]10049	01/08/2019 00:04:07	662	494
[redacted]YN	[redacted]3023	[redacted]760	1	1	10	48	10[redacted]10048	01/08/2019 00:04:07	2158	759
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	21	10[redacted]07021	01/08/2019 00:04:07	0	0
[redacted]YN	[redacted]3023	[redacted]760	1	1	10	51	10[redacted]10051	01/08/2019 00:04:07	2600890	54153
[redacted]YN	[redacted]3023	[redacted]528	1	2	7	20	10[redacted]07020	01/08/2019 00:04:07	330	184

Create DataFrame

DataFrames can be created from a Hive table, from Spark data sources, or another DataFrame

Load and save

- From Hive, JSON, CSV
- HDFS, local file, etc

Formats and Sources supported by DataFrames

Source: https://databricks.com/blog/2015/02/17/introducing-dataframes-in-spark-for-large-scale-data-science.html

DataFrame Transformations

- **Several transformations can be done**
  - *Think transformation for relational database or matrix*
- **Select**
  - *df.select(“PROVINCECODE").show()*
- **Filter**
  - *df.filter(df[‘DEVICEID]).show()*
- **Groupby**
  - *df.groupBy(“ONUID").count().show()*
- **Handle missing data**
  - *Drop duplicate rows, drop rows with NA/null data*
  - *Fill NA/null data*

Actions with DataFrame

Actions

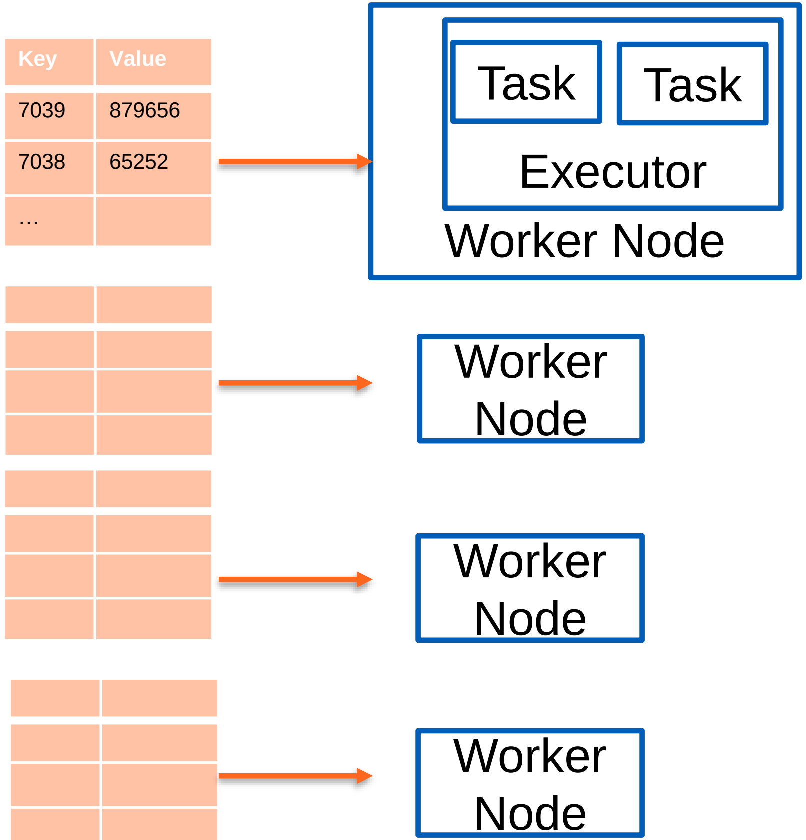
- Return values calculated from DataFrame

Examples

- reduce, max, min, sum, variance and stdev

→Distributed and parallel processing but it is done by the framework

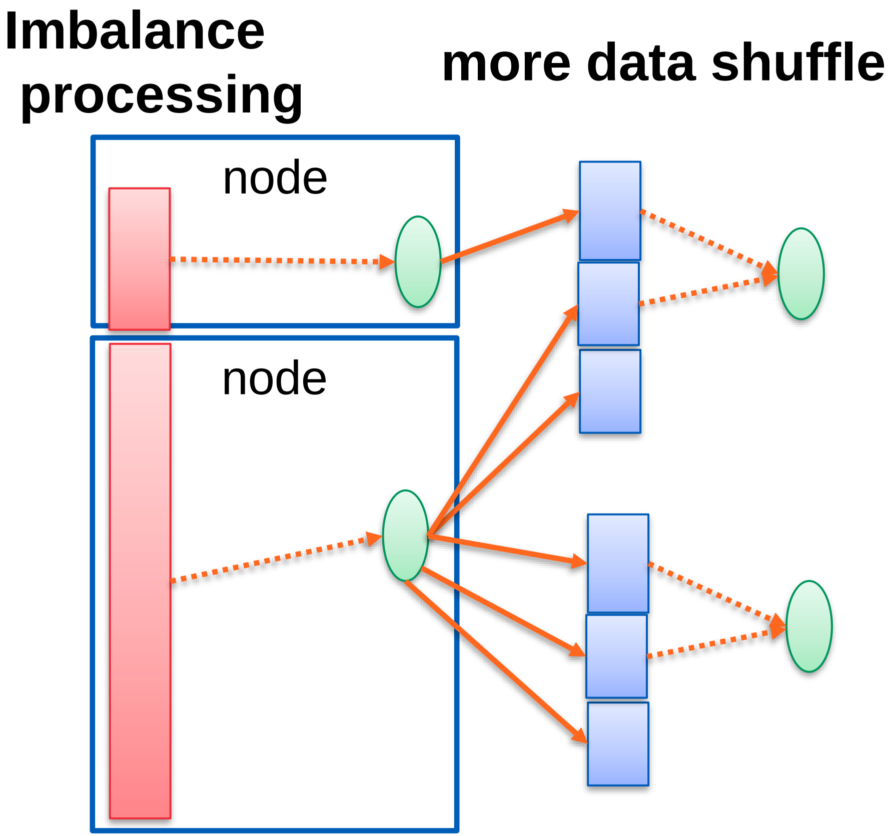
Data Distribution



One task works on a partition at a time

→ Parallelism and performance are strongly dependent on number of partitions, tasks, CPU cores

Data Distribution: Load balance



- **It is important to have well-balanced data distribution across nodes**
- **Detection:**
  - look at runtime execution time to see problems or check your data
- **Examples of solution:**
  - Repartition
  - Broadcast
  - Change group keys

Example of a Spark program

```
#!/usr/bin/env python2
#encoding: UTF-8
# CS-E4640
import csv
import sys
from datetime import datetime
from pyspark.sql import SparkSession
import numpy as np
from pyspark.sql import functions as F
import argparse
parser = argparse.ArgumentParser()
parser.add_argument('--input_file', help='input data file')
parser.add_argument('--output_dir',help='output dir')
args = parser.parse_args()

##define a context
spark = SparkSession.builder.appName("cse4640-onu").getOrCreate()
#NOTE: using hdfs:///..... for HDFS file or file:///
inputFile =args.input_file
df =spark.read.csv(inputFile,header=True,inferSchema=True)
#df.show()
print("Number of records", df.count())
exprs = {"SPEEDIN":"avg"}
df2 = df.groupBy('ONUID').agg(exprs)
df2.repartition(1).write.csv(args.output_file,header=True)
```

Session/Driver

Read data

Apply operators

Spark application runtime view

- **Tasks:**
  - A unit of work executed in an executor: e.g., set of transformations for a data partition
- **Stage**
  - A set of tasks executed in many nodes for computing the same operation
  - Move to a new stage: through shuffle operations
- **Job**
  - Runtime view of an action operator (produce a result), includes many stages

Pipelining, Shuffle and DAG

- **Operations work in a pipeline without moving data across nodes**
  - E.g., map->filter, select->filter
- **Shuffle persistent**
  - Shuffle needs move data across nodes
  - Source tasks save shuffle files into local disks for data shuffle, then the target tasks will read data from source nodes
    - *Save time, recovery, fault tolerance*

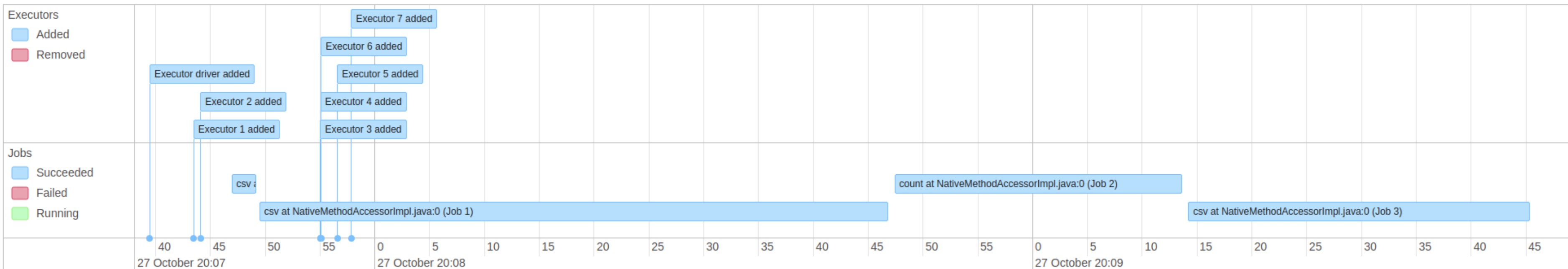
Monitoring Spark: Executors and tasks

Spark 2.3.3 | Jobs | Stages | Storage | Environment | Executors | SQL | **cse4640-nytaxicount** application UI

Spark Jobs (?)

User: truong
Total Uptime: 2.1 min
Scheduling Mode: FAIR
Completed Jobs: 4

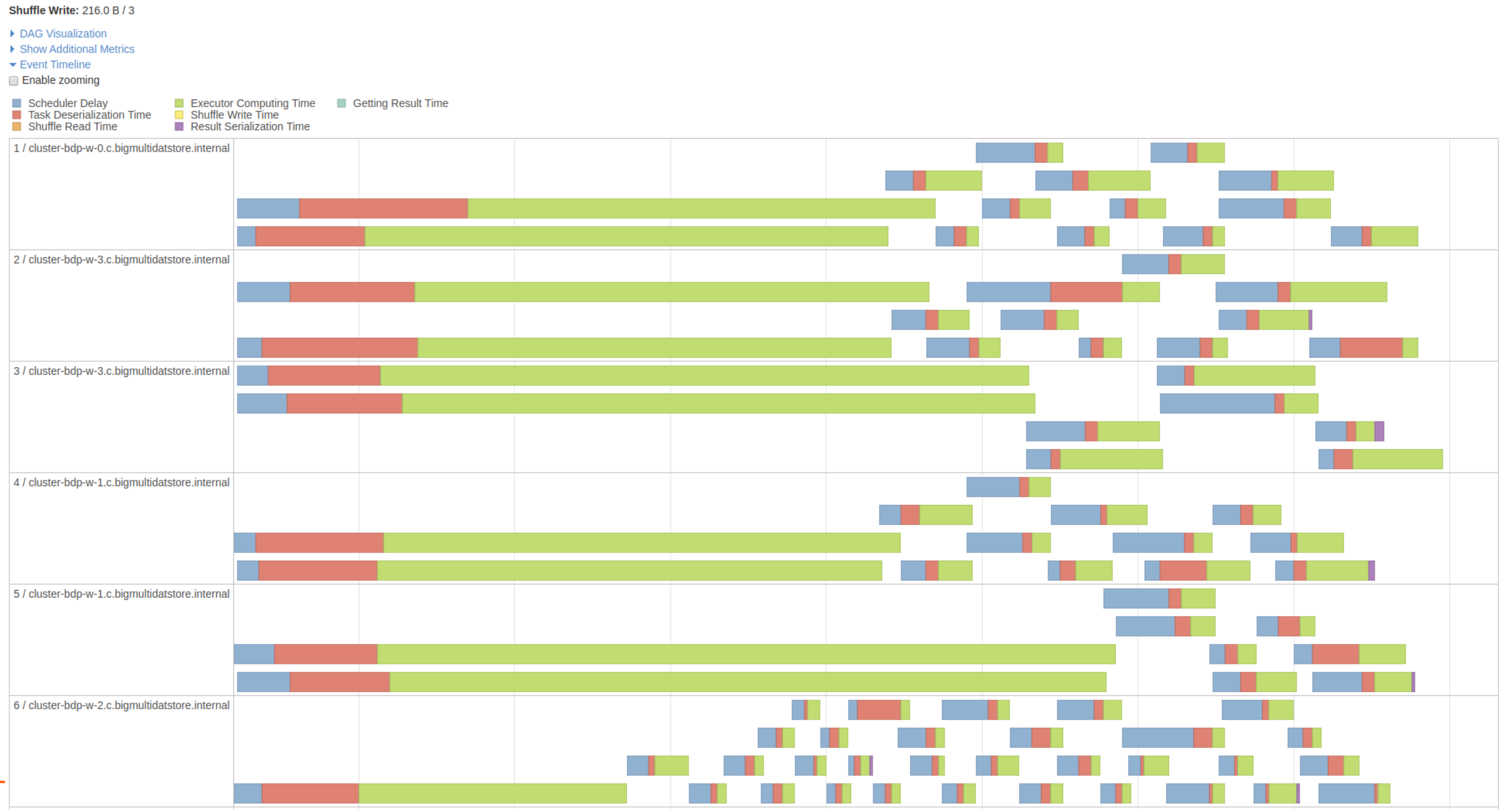
▾ Event Timeline
☐ Enable zooming



Completed Jobs (4)

Job Id ▾	Description	Submitted	Duration	Stages: Succeeded/Total	Tasks (for all stages): Succeeded/Total
3	csv at NativeMethodAccessorImpl.java:0 csv at NativeMethodAccessorImpl.java:0	2019/10/27 20:09:14	31 s	3/3	279/279
2	count at NativeMethodAccessorImpl.java:0 count at NativeMethodAccessorImpl.java:0	2019/10/27 20:08:47	26 s	2/2	79/79
1	csv at NativeMethodAccessorImpl.java:0 csv at NativeMethodAccessorImpl.java:0	2019/10/27 20:07:49	57 s	1/1	78/78
0	csv at NativeMethodAccessorImpl.java:0 csv at NativeMethodAccessorImpl.java:0	2019/10/27 20:07:46	2 s	1/1	1/1

Executors and tasks



Other important support of Spark

- **Mlib - Machine learning**
  - Distributed and parallel machine learning algorithms with big data and clusters
    - *You might run many ML algorithms, but many of them are sequential*
- **Streaming**
  - Microbatching data processing in near-realtime
- **Graph Processing**
  - Parallel computation for graphs

Summary

- **Facts:**
  - MapReduce and Spark are important frameworks
  - A user/developer needs to learn to develop MapReduce/Spark applications
  - A platform operator/provider offer services for managing resources, processing and monitoring
- **Thoughts:**
  - Think about the success of Apache Spark: rich ecosystems!
  - Think if you combine data, different distributed programming supports for your big data platform

Thanks!

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rdsea.github.io