Introduction to Apache Spark

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Agenda

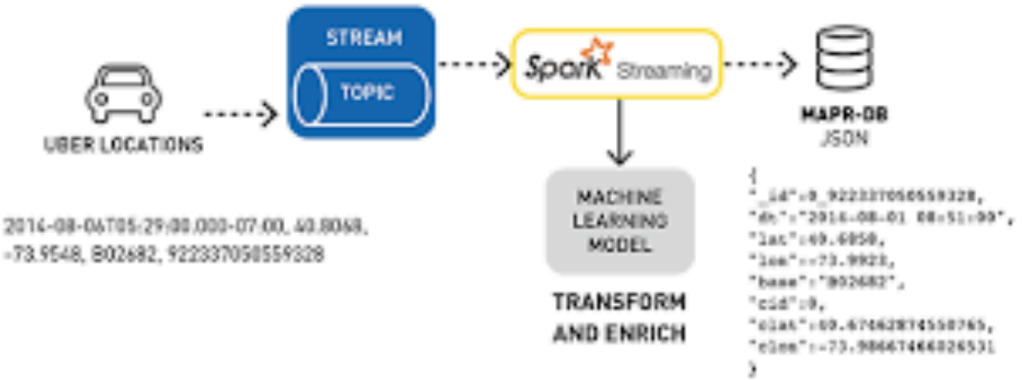
- About Apache Spark
- Spark execution modes
- Basic Spark data structures (RDDs)
- Hands-on tutorial
  - RDDs and operations
  - DataFrames, User defined functions and SparkSQL
- Hands-on lab exercises – Jupyter notebooks
- Hands-on lab exercise – Spark on an HPC
  - Apache Spark deployment using Slurm
- Challenge exercises (independent work) & debug session

About Apache Spark

- Fast, expressive, general-purpose in-memory cluster computing framework compatible with Apache Hadoop and built around speed, ease of use and streaming analytics
- Faster and easier than Hadoop MapReduce*
- Large community and 3rd party libraries
- Provides high-level APIs (Java, Scala, Python, R)
- Supports variety of workloads
  - interactive queries, streaming, machine learning and graph processing

Apache Spark Use cases

- Logs processing (Uber)
- Event detection and real-time analysis
- Interactive analysis
- Latency reduction
- Advanced ad-targeting (Yahoo!)
- Recommendation systems (Netflix, Pinterest)
- Fraud detection
- Sentiment analysis (Twitter)
- ...



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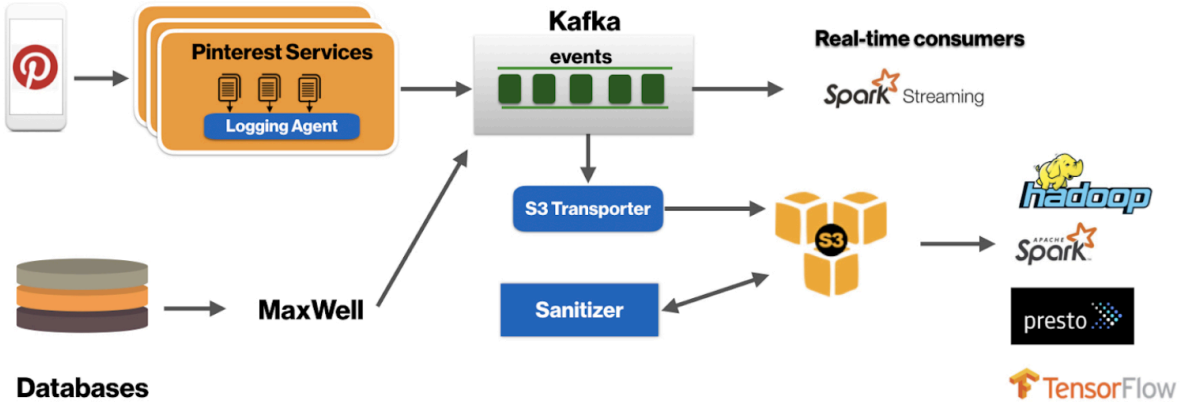

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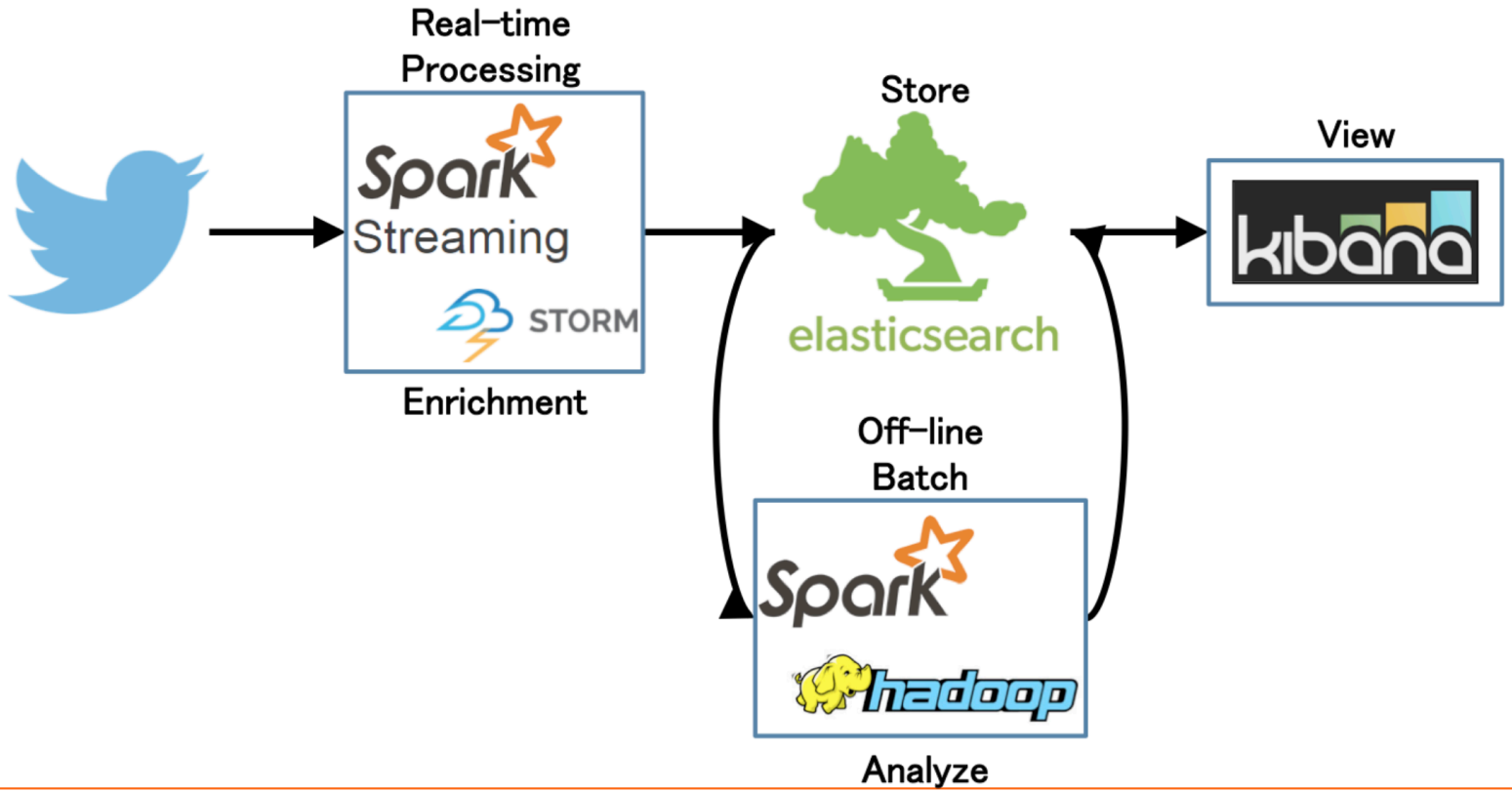
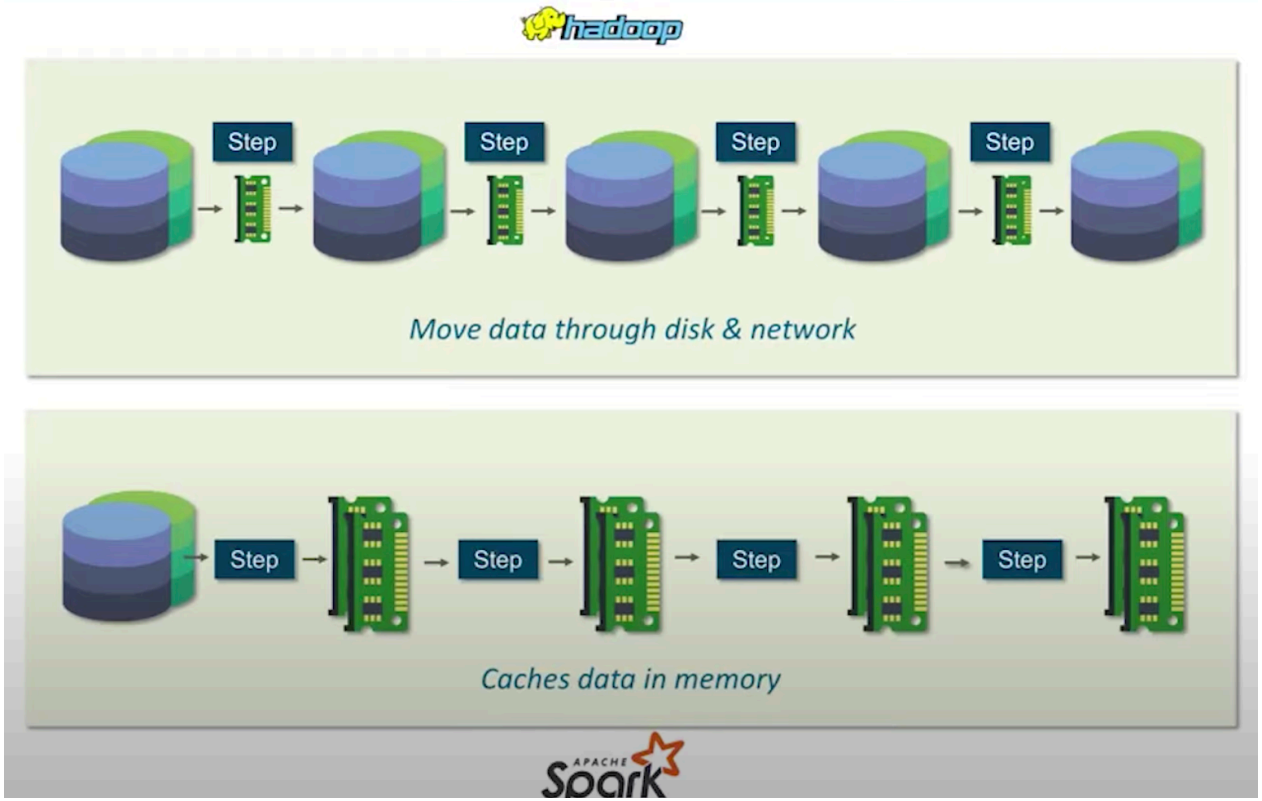
Apache Spark general setup: Twitter sentiment analysis



Hadoop MapReduce vs. Apache Spark

- Big data frameworks
  - Performance
  - Ease of use
  - Costs
  - Data processing
  - Fault tolerance
  - Security
- Hadoop
  - Archival data analysis
- Spark
  - Real-time data analysis



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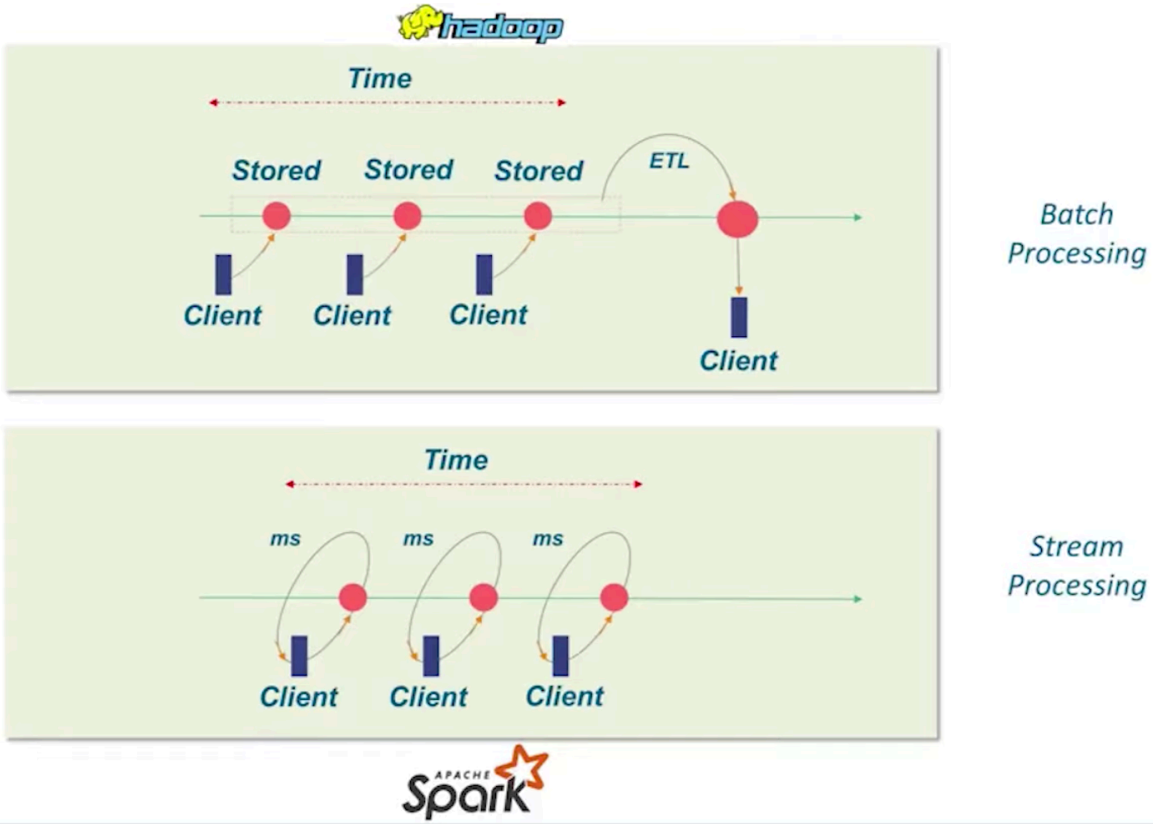

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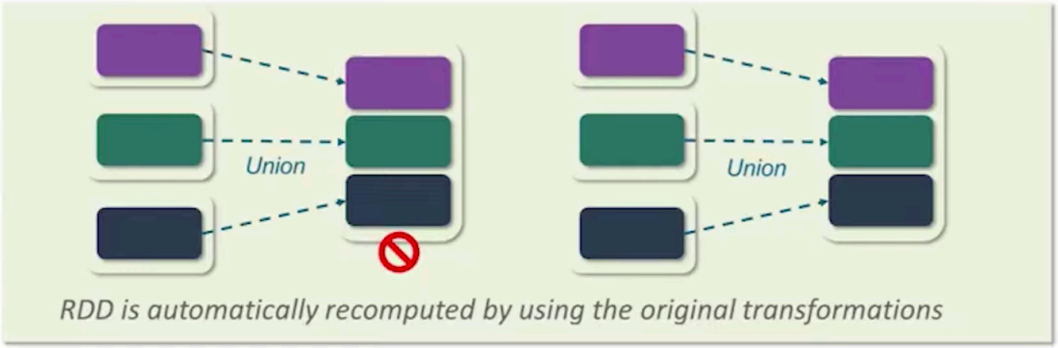
hadoop



Apache Spark

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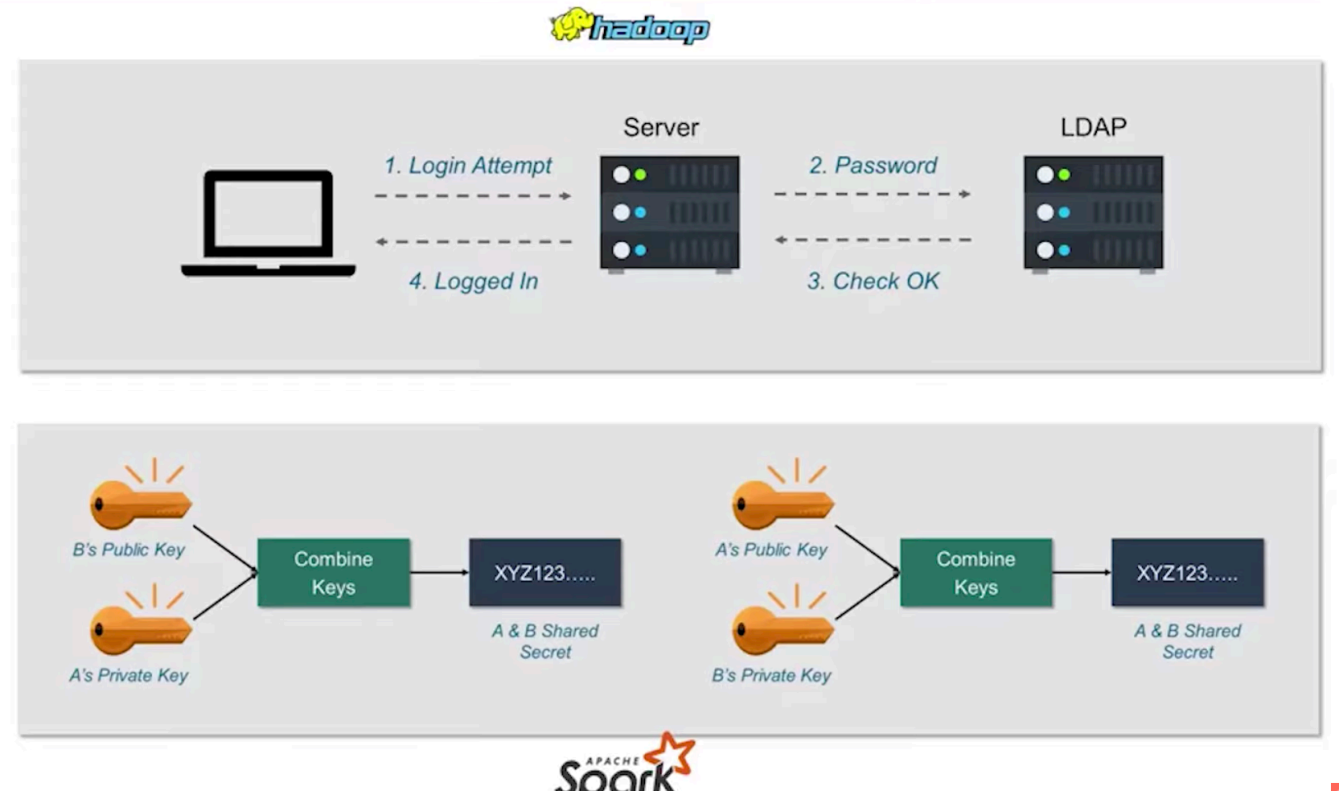
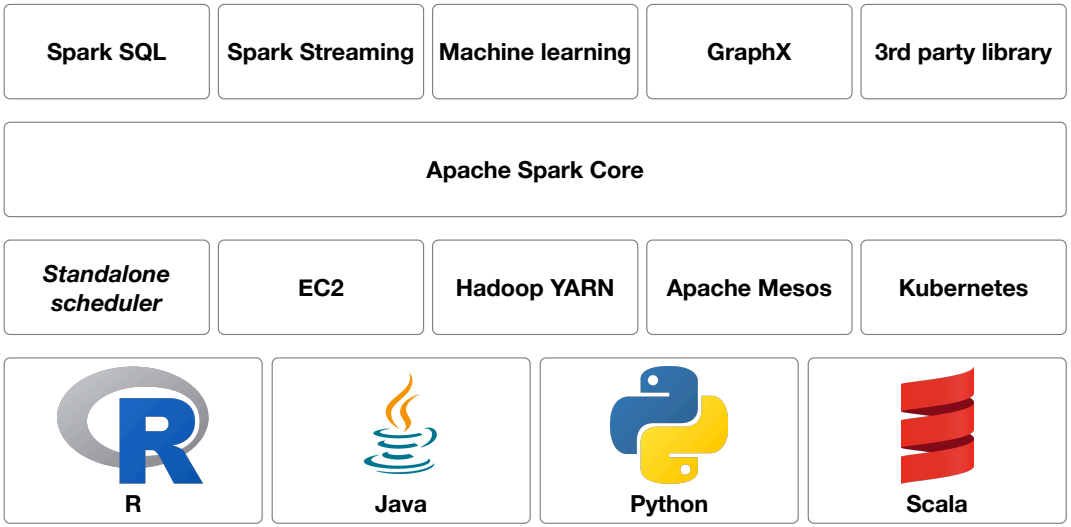


Apacke Spark ecosystem

Spark SQL	**Spark Streaming**	**Machine learning**	**GraphX**	**3rd party library**
Apache Spark Core				
Standalone scheduler	**EC2**	**Hadoop YARN**	**Apache Mesos**	**Kubernetes**
 **R**	 **Java**	 **Python**	 **Scala**	

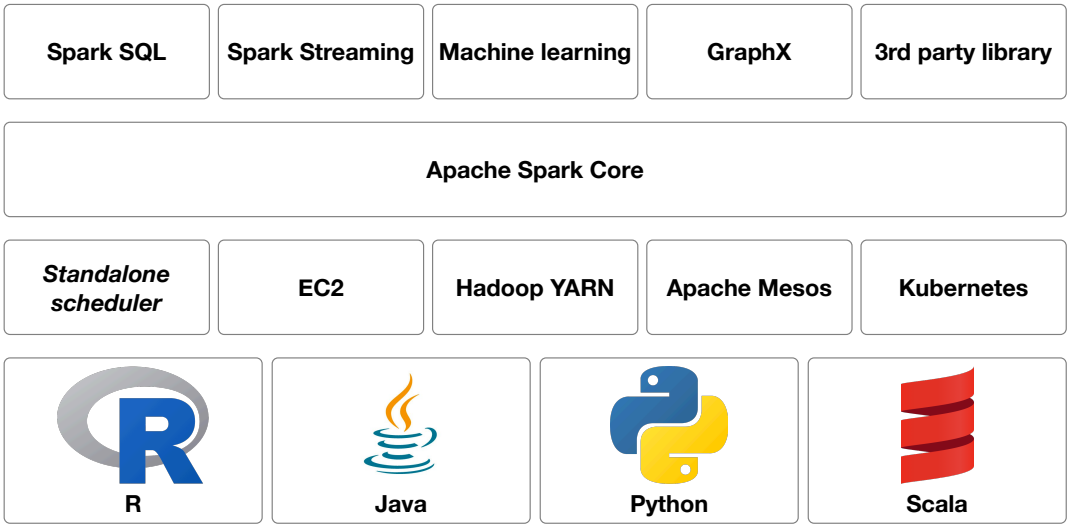
Spark ecosystem: Spark core



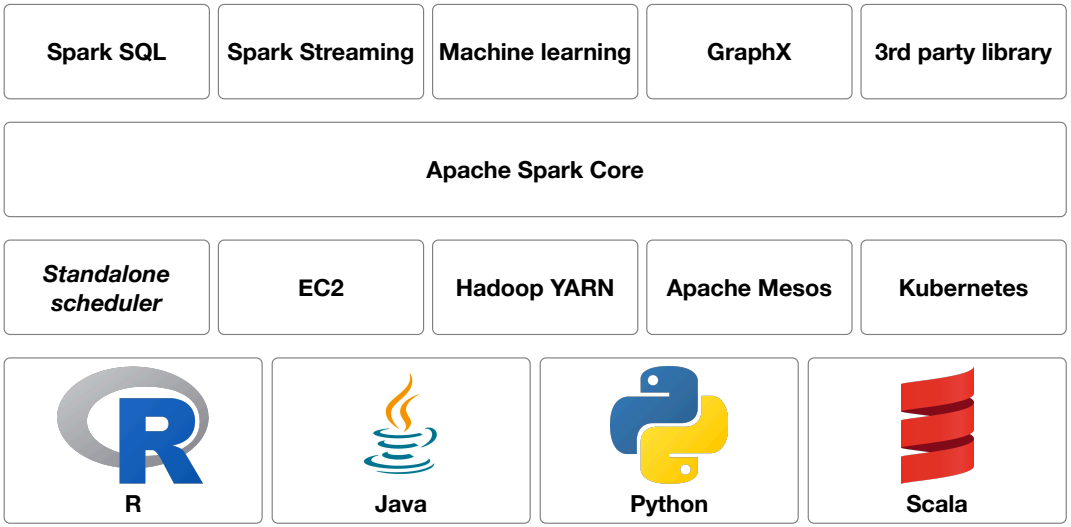
- Core functionalities
  - task scheduling
  - memory management
  - fault recovery
  - storage systems interaction
  - etc.
- Basic data structure definitions/abstractions
  - Resilient Distributed Data sets (RDDs)
    - main Spark data structure
  - Directed Acyclic Graph (DAG)

Spark ecosystem: Spark SQL

- Structured data manipulation
  - Data Frames definition
- Table-like data representation
  - RDDs extension
  - Schema definition
- SQL queries execution
- Native support for schema-based data
  - Hive, Paquet, JSON, CSV

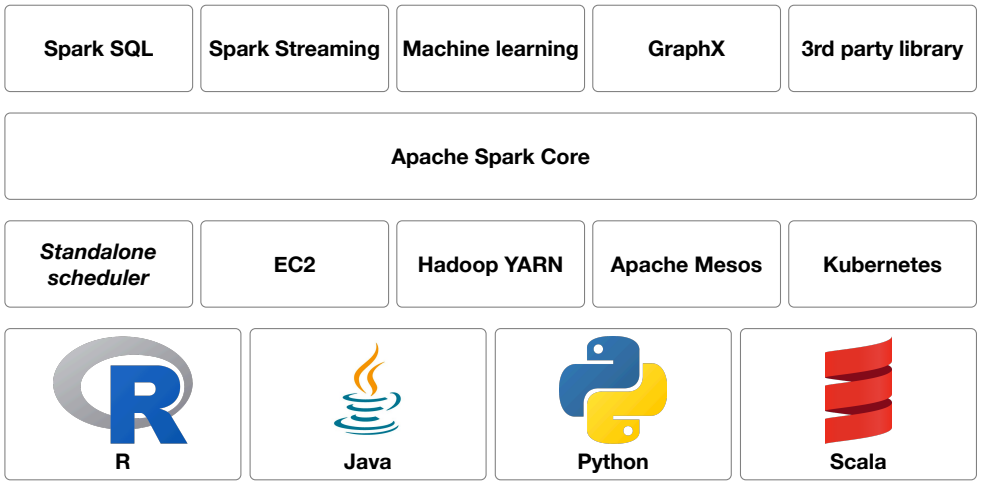


Spark ecosystem: Streaming



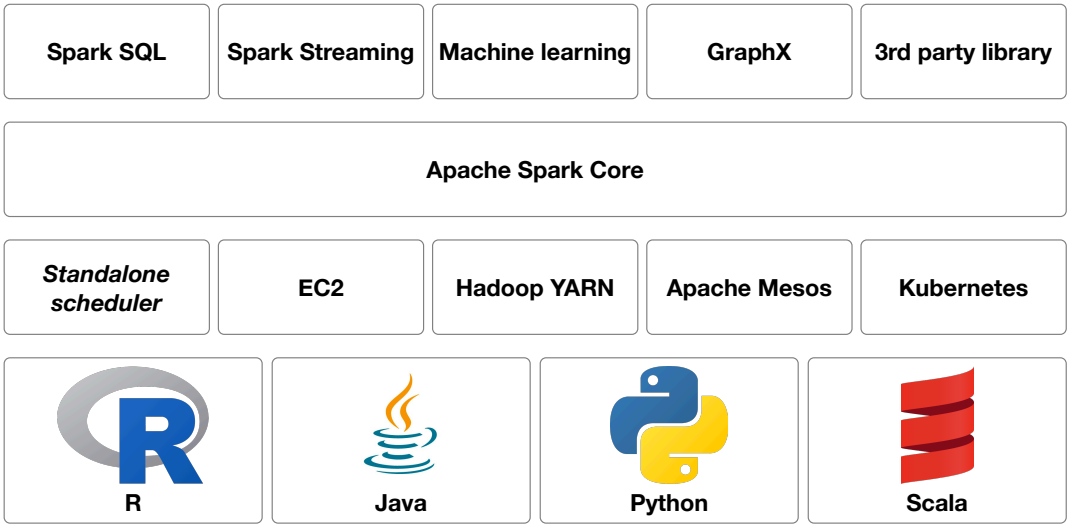
- Data analysis of streaming data
  - e.g. tweets, log messages
- Features of stream processing
  - High-troughput
  - Fault-tolerant
  - End-to-end
  - Exactly-once
- High-level abstraction of a discretized stream
  - Dstream represented as a sequence of RDDs
- Spark 2.3+ , Continuous Processing
  - end-to-end latencies as low as 1ms

Spark ecosystem: MLlib

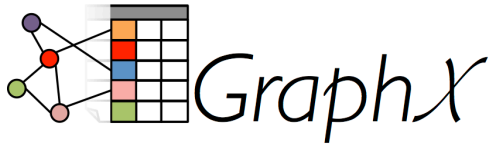


- Common ML functionalities
  - ML Algorithms
    - common learning algorithms such as classification, regression, clustering, and collaborative filtering
  - Featurization
    - feature extraction, transformation, dimensionality reduction, and selection
  - Pipelines
    - tools for constructing, evaluating, and tuning ML Pipelines
  - Persistence
    - saving and load algorithms, models, and Pipelines
  - Utilities
    - linear algebra, statistics, data handling, etc.
- Two APIs
  - RDD-based API (*spark.mllib package*)
  - Spark 2.0+, DataFrame-based API (*spark.ml package*)
- Methods scale out across the cluster by default

Spark ecosystem: GraphX



- Support for graphs and graph-parallel computation
  - Extension of RDDs (Graph)
    - directed multigraph with properties on vertices and edges
- Graph computation operators
  - subgraph, joinVertices, and aggregateMessages, etc.
  - PregelAPI support

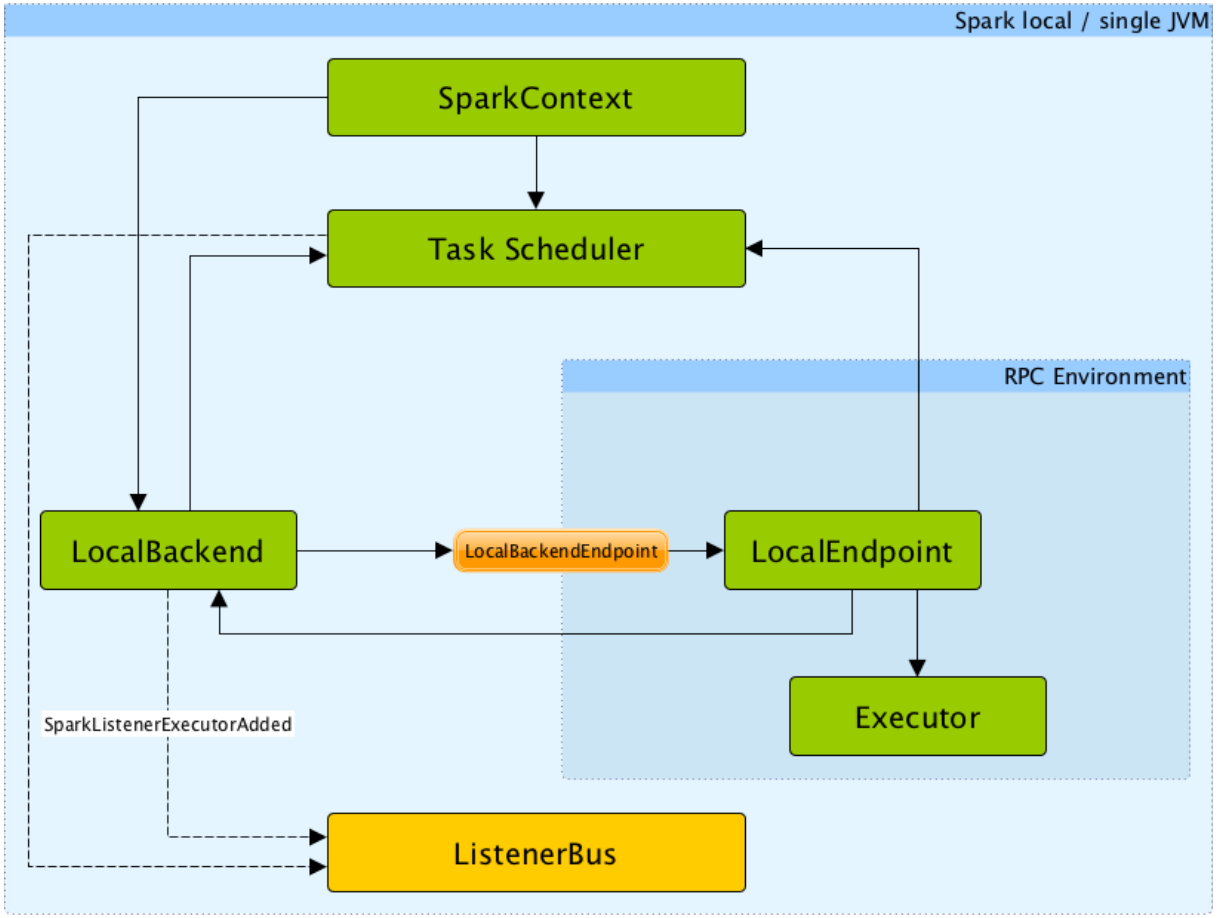


Spark Execution modes

- Local mode
  - „Pseudo-cluster“ ad-hoc setup using script
- Cluster mode
  - Running via cluster manager
- Interactive mode
  - Direct manipulation in a shell (*pyspark*, *spark-shell*)

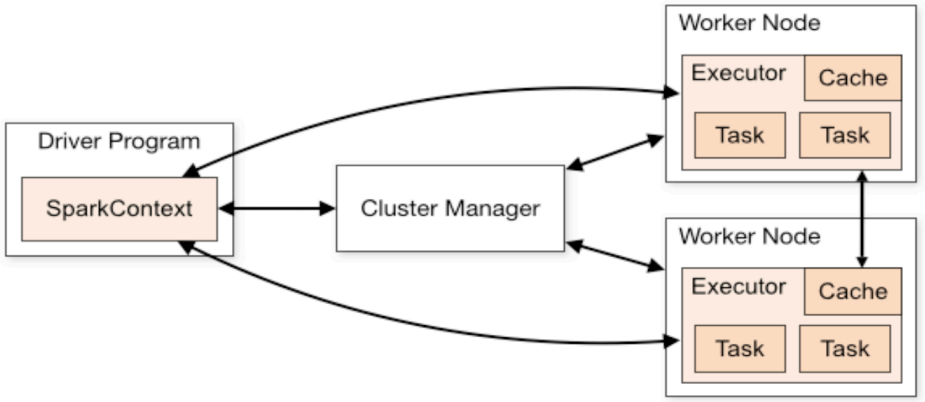
Spark execution modes Local mode

- Non-distributed single-JVM deployment mode
- Spark library spawns (in a JVM)
  - driver
  - scheduler
  - master
  - executor
- Parallelism is the number of threads defined by a parameter N in a spark master URL
  - *local[N]*

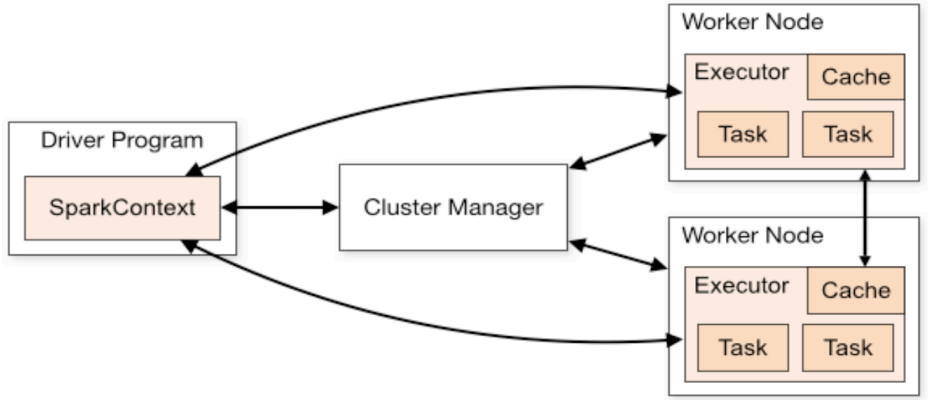


Spark execution modes Cluster mode

- Deployment on a private cluster
  - Apache Mesos
  - Hadoop YARN
  - Kubernetes
  - Standalone mode, ...

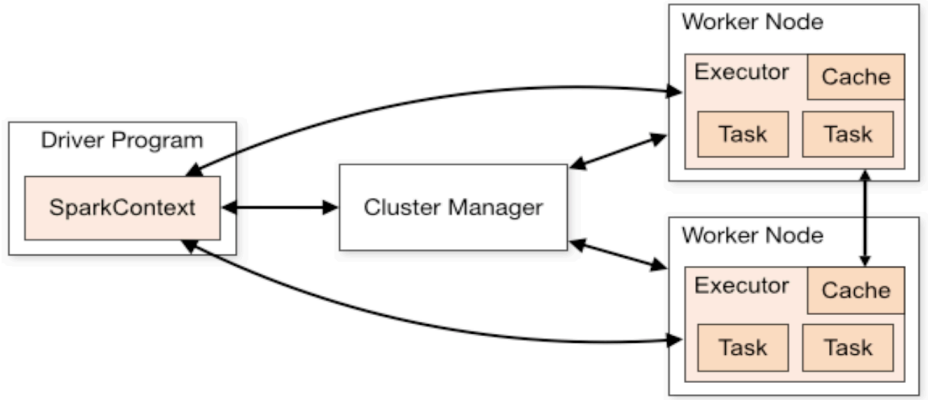


Spark execution modes Cluster mode



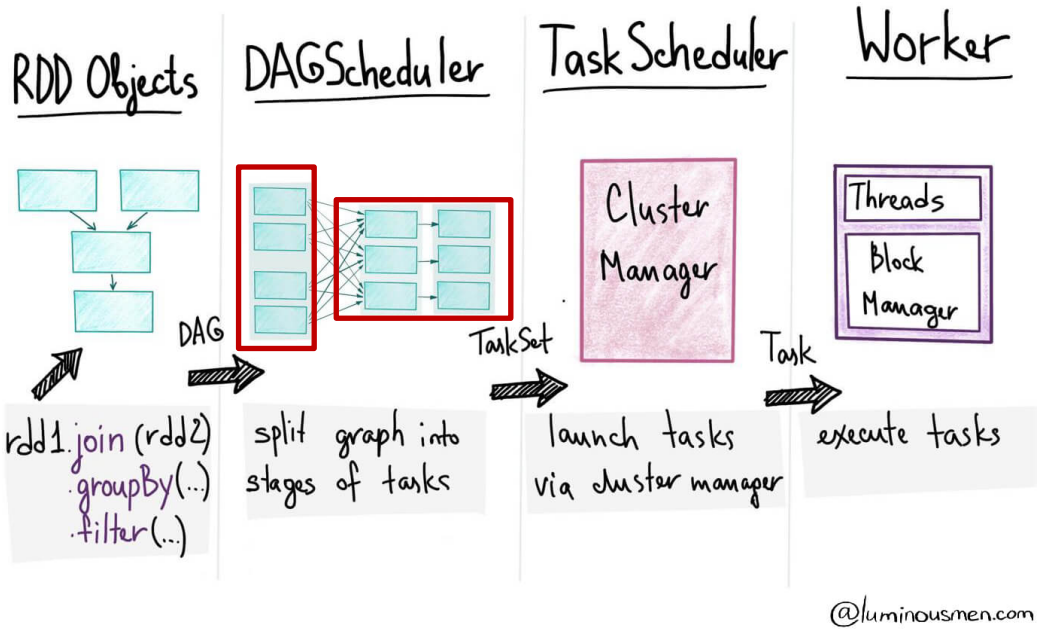
- Components
  - Worker
    - Node in a cluster, managed by an executor
    - Executor manages computation, storage and caching
  - Cluster manager
    - Allocates resources via SparkContext with Driver program
  - Driver program
    - A program holding SparkContext and main code to execute in Spark
    - Sends application code to executors to execute
    - Listens to incoming connections from executors

Spark execution modes Cluster mode



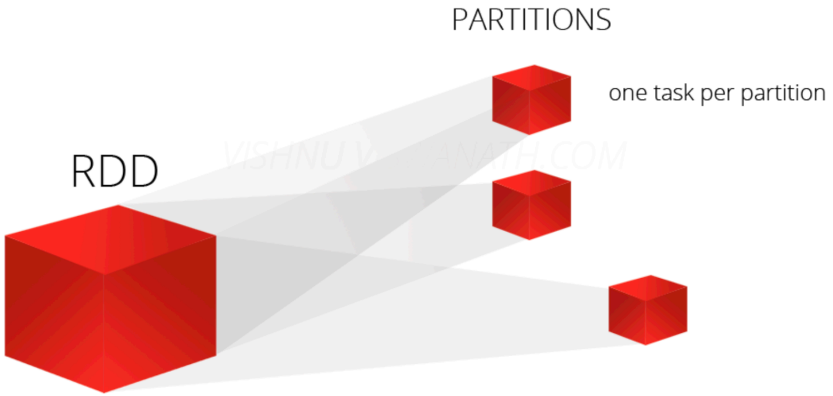
- Deploy modes (*standalone clusters*)
  - Client mode (default)
    - Driver runs in the same process as client that submits the app
  - Cluster mode
    - Driver launched from a worker process
    - Client process exits immediately after application submission

Spark Execution process



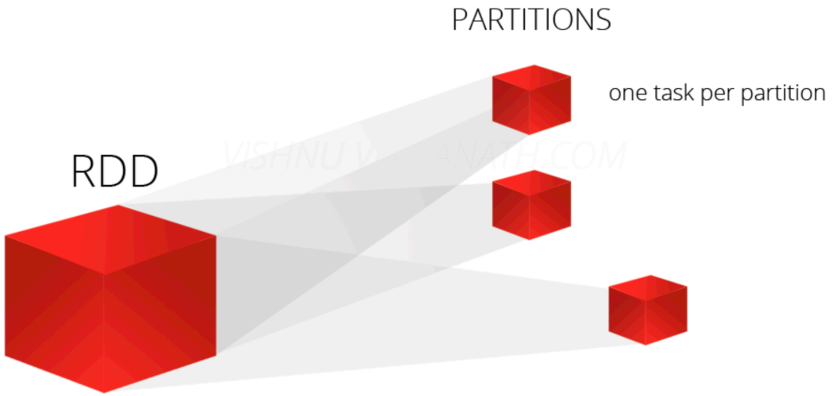
1. Data preparation/import
   - RDDs creation – i.e. parallel dataset with partitions
2. Transformations/actions definition*
   - Creation of tasks (units of work) sent to one executor
   - Job is a set of tasks executed by an action*
3. Creation of a directed acyclic graph (DAG)
   - Contains a graph of RDD operations
   - Defition of stages – set of tasks to be executed in parallel (i.e. at a partition level)
4. Execution of a program

Spark Programming concepts (Resilient distributed datasets - RDDs)

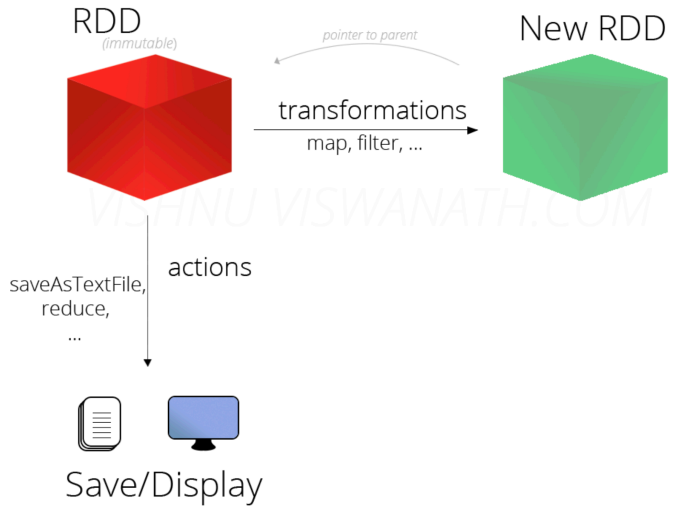


- Basic data representation in Spark
- A distributed collection of items – *partitions*
  - Enables operations to be performed in parallel
- Immutable (read-only)
- Fault tolerant
  - "Recipe" of data transformations is preserved, so a partition can be re-created at any time
- Caching
  - Different storage levels possible
- Supports a set of Spark transformations and actions

Spark Programming concepts (Resilient distributed datasets - RDDs)

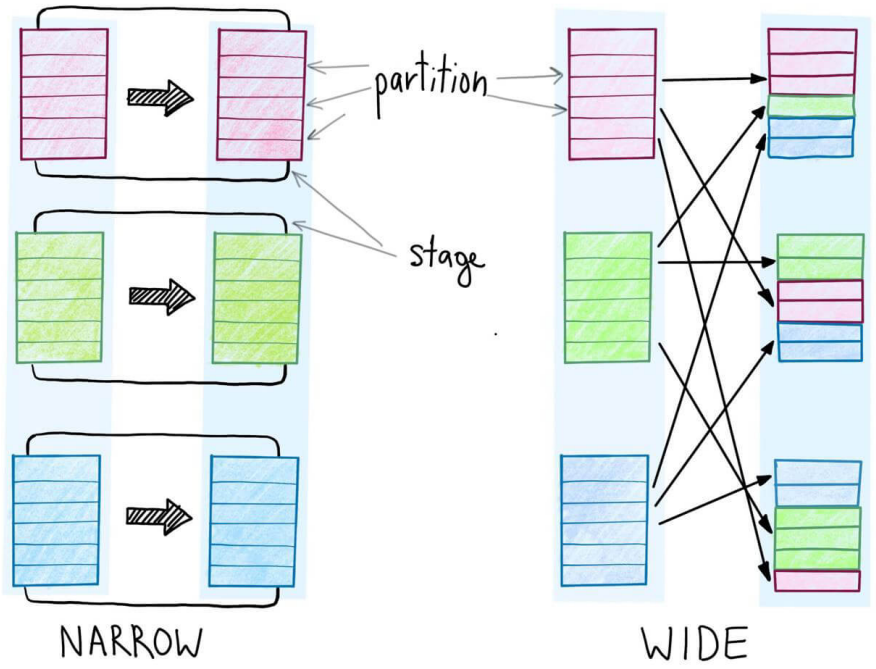


- Computations are expressed using
  - creation of new RDDs
  - transforming existing RDDs
  - operations on RDDs to compute results (actions)
- Distributes the data within RDDs across nodes (executors) in the cluster and parallelizes calculations



RDD Operations

- RDDs enable following operations
  - **transformations**
    - lazy operations that return a new RDD from input RDDs
    - narrow or wide types
    - examples: map, filter, join, groupByKey...
  - **actions**
    - return a result or write to storage, execute transformations
    - examples: count, collect, save



RDD Transformations vs. actions

 = easy  = medium

Essential Core & Intermediate Spark Operations

General

- map
- filter
- flatMap
- mapPartitions
- mapPartitionsWithIndex
- groupBy
- sortBy

Math / Statistical

- sample
- randomSplit

Set Theory / Relational

- union
- intersection
- subtract
- distinct
- cartesian
- zip

Data Structure / I/O

- keyBy
- zipWithIndex
- zipWithUniqueID
- zipPartitions
- coalesce
- repartition
- repartitionAndSortWithinPartitions
- pipe

- reduce
- collect
- aggregate
- fold
- first
- take
- forEach
- top
- treeAggregate
- treeReduce
- forEachPartition
- collectAsMap

- count
- takeSample
- max
- min
- sum
- histogram
- mean
- variance
- stdev
- sampleVariance
- countApprox
- countApproxDistinct

- takeOrdered

- saveAsTextFile
- saveAsSequenceFile
- saveAsObjectFile
- saveAsHadoopDataset
- saveAsHadoopFile
- saveAsNewAPIHadoopDataset
- saveAsNewAPIHadoopFile

Hands On

1. Use NoMachine to login to UL FS‘s HPC
2. Open Terminal/Console/“Konzola“
3. Clone Workshop Git repository and enter its folder

```
git clone https://github.com/szitnik/Apache-Spark-Workshop.git
cd Apache-Spark-Workshop
```

4. Enter the following commands

```
module load Spark/2.4.0-Hadoop-2.7-Java-1.8
python3 -m venv spark-workshop-env
. spark-workshop-env/bin/activate
```

```
(spark-workshop-env) [campus02@viz Apache-Spark-Workshop]$
```

```
pip install --upgrade pip
pip install pyspark jupyter
python
```

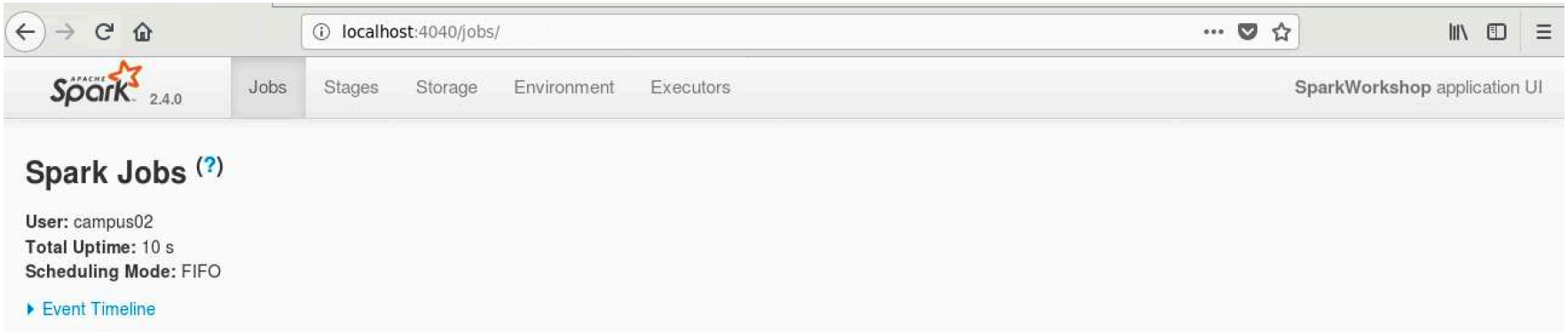
```
Python 3.6.8 (default, Apr 25 2019, 21:02:35)
[GCC 4.8.5 20150623 (Red Hat 4.8.5-36)] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

RDDs in Spark

- We will use pySpark library interactively

```
import pyspark
sc = pyspark.SparkContext(appName='SparkWorkshop', master='local[1]')
```

```
2020-09-15 16:28:01 WARN  NativeCodeLoader:62 - Unable to load native-hadoop library for your platform... using builtin-java clas
ses where applicable
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newLevel).
2020-09-15 16:28:02 WARN  Utils:66 - Service 'SparkUI' could not bind on port 4040. Attempting port 4041.
>>>
```



RDDs in Spark

- Creation of RDDs
  - From a collection

```
rdd1 = sc.parallelize([('John', 23), ('Mark', 11), ('Jenna', 44),
('Sandra', 61)])
```

  - From a file

```
rdd2 = sc.textFile('data/IMDB Dataset.csv')
```

- Basic transformations map(), filter(), flatMap()

```
older = rdd1.filter(lambda x: x[1] > 18)
anonymized = older.map(lambda x: (x[0][0], x[1]))

birthdays = rdd1.map(lambda x: list(range(1, x[1]+1)))
birthdays = rdd1.flatMap(lambda x: list(range(1, x[1]+1)))
```

RDDs in Spark

- Further actions, transformations

```
rdd2.take(2)


def organize(line):
    data = line.split('",')
    data = data if len(data) == 2 else line.split(',')
    return (data[1], data[0][1:51] + ' ...')
movies = rdd2.filter(lambda x: x != 'review,sentiment').map(organize)


movies.count() // 50.000
movies = movies.filter(lambda x: x[0] in ['positive', 'negative'])
movies.count() // 45.936
movieCounts = movies.groupByKey().map(lambda x: (x[0], len(x[1])))
```

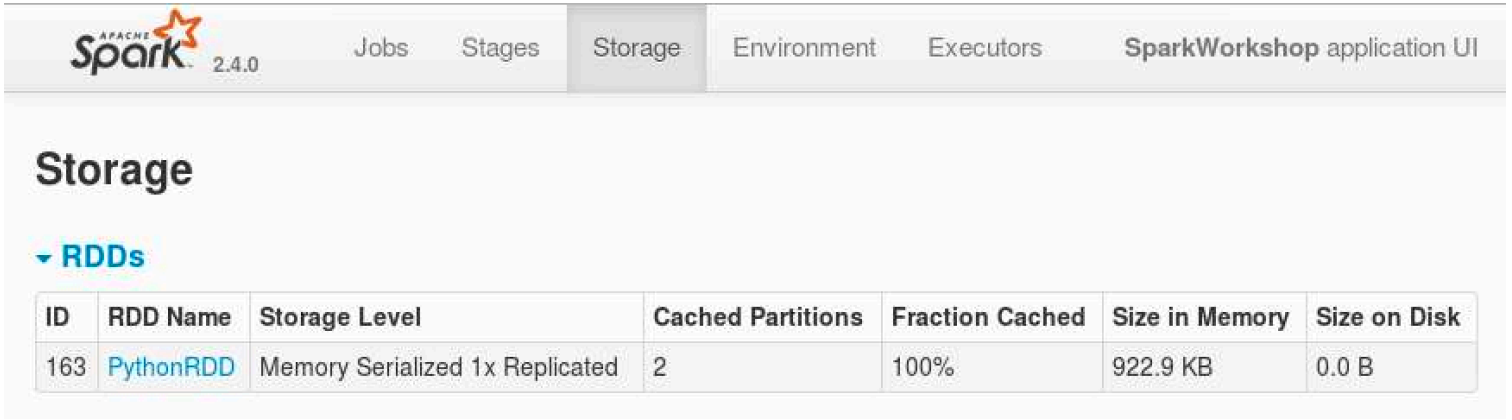
RDDs in Spark

- Caching

```
movies.take(2)

posReviews = movies.filter(lambda x: x[0] == 'positive').map(lambda x: x[1])
negReviews = movies.filter(lambda x: x[0] == 'negative').map(lambda x: x[1])

posReviews.cache().collect()
```

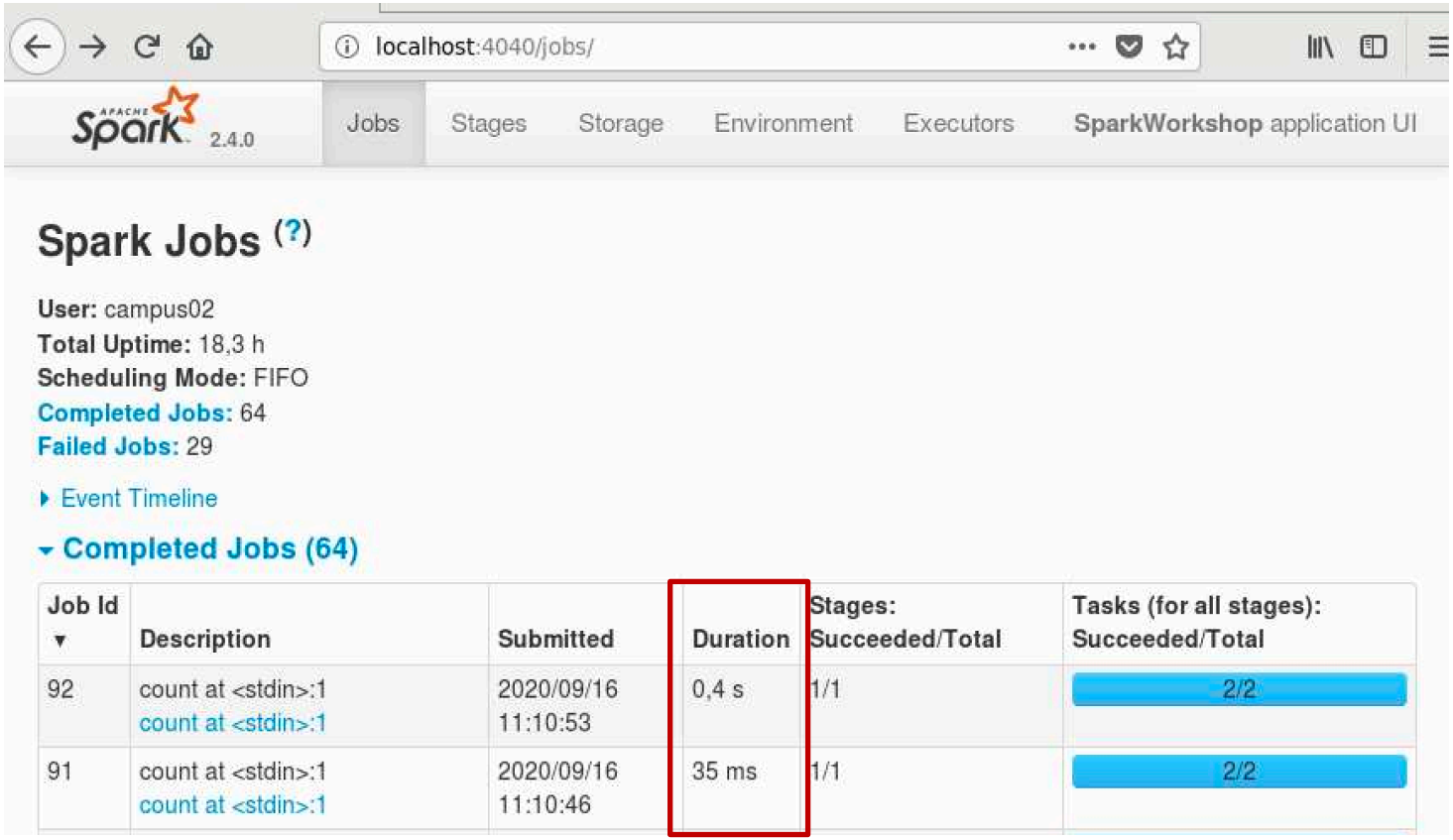


ID	RDD Name	Storage Level	Cached Partitions	Fraction Cached	Size in Memory	Size on Disk
163	PythonRDD	Memory Serialized 1x Replicated	2	100%	922.9 KB	0.0 B

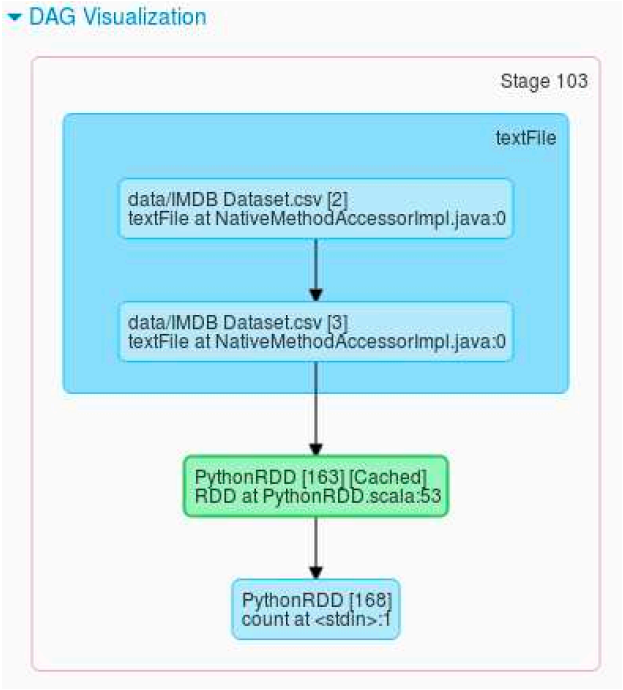
RDDs in Spark

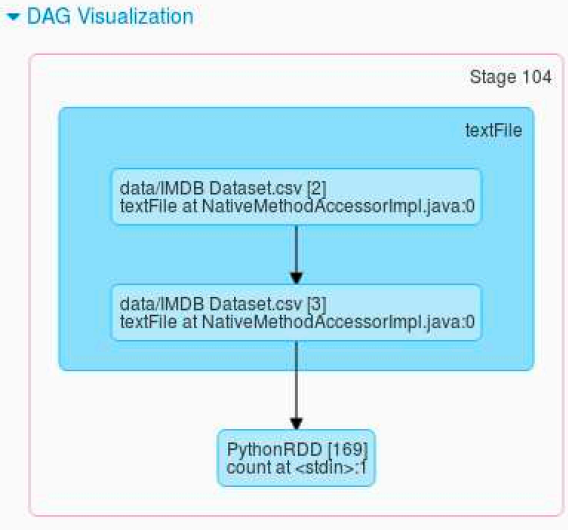
- Caching

```
posReviews.filter(lambda x: 'good' in x).count() //605
negReviews.filter(lambda x: 'bad' in x).count() //788
```



RDDs in Spark





Tasks (2)

Index ▲	ID	Attempt	Status	Locality Level	Executor ID	Host	Launch Time	Duration	GC Time	Input Size / Records	Errors
0	138	0	SUCCESS	PROCESS_LOCAL	driver	localhost	2020/09/16 11:10:53	0,2 s	4 ms	32.1 MB / 25311	
1	139	0	SUCCESS	PROCESS_LOCAL	driver	localhost	2020/09/16 11:10:53	0,2 s	4 ms	31.1 MB / 24690	

Tasks (2)

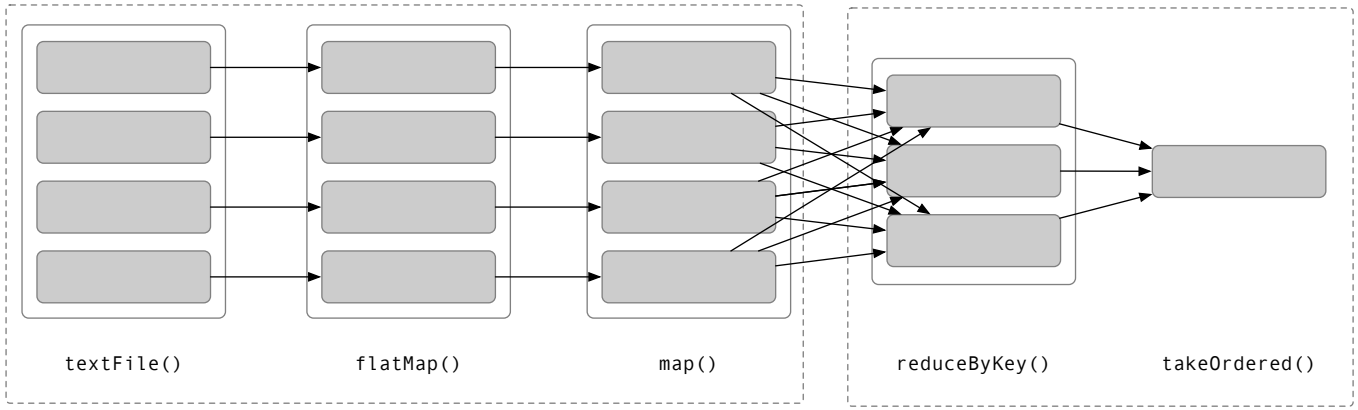
Index ▲	ID	Attempt	Status	Locality Level	Executor ID	Host	Launch Time	Duration	GC Time	Input Size / Records	Errors
0	136	0	SUCCESS	PROCESS_LOCAL	driver	localhost	2020/09/16 11:10:46	18 ms		469.2 KB / 16	
1	137	0	SUCCESS	PROCESS_LOCAL	driver	localhost	2020/09/16 11:10:46	12 ms		453.7 KB / 16	

RDDs in Spark

- DAG exploration

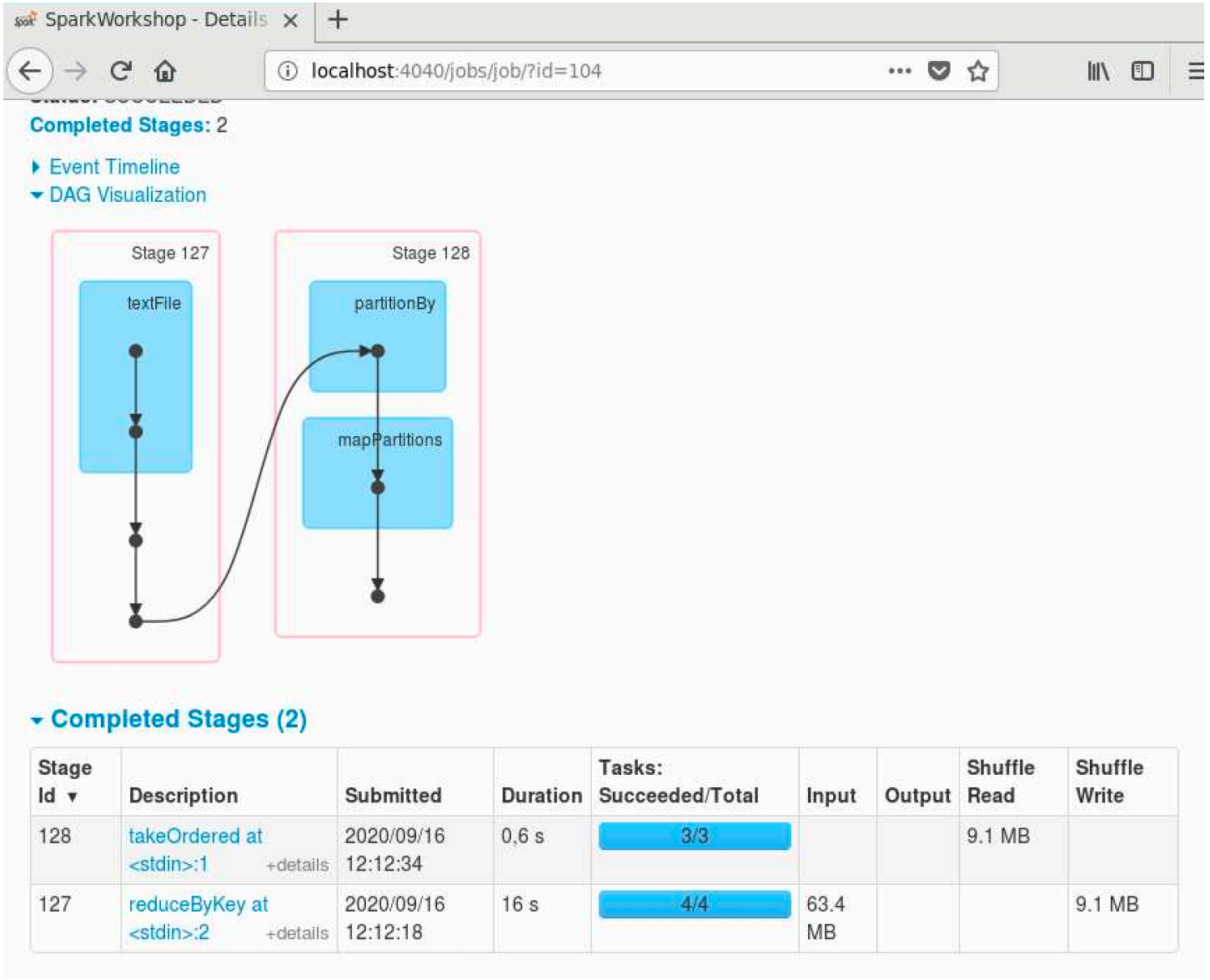
```
def splitLine(line):
    return line.replace(',', ' ').replace('"', ' ').replace('.', ' ').split()


rdd2 = sc.textFile('data/IMDB Dataset.csv', 4)
wordCounts = rdd2.flatMap(splitLine).map(lambda word: (word, 1)). \
                        reduceByKey(lambda a,b: a+b, 3)
wordCounts.takeOrdered(10, key = lambda x: -x[1])
```



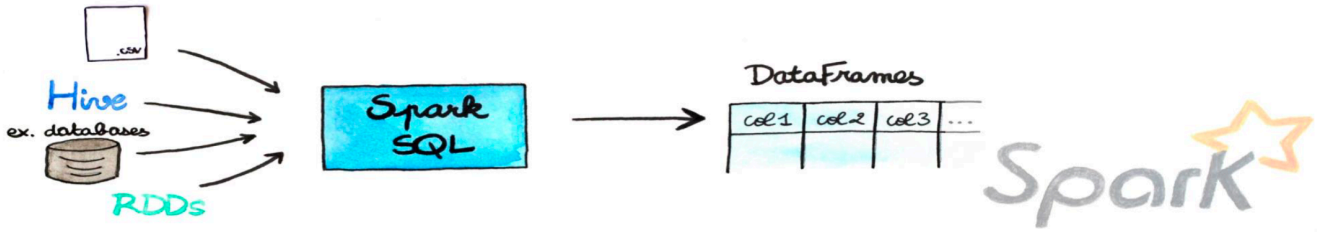
RDDs in Spark

- DAG exploration (admin console result)



DataFrames (= RDDs + schema) in Spark

- Spark SQL enables read/write from/to files, JSON, databases, etc.

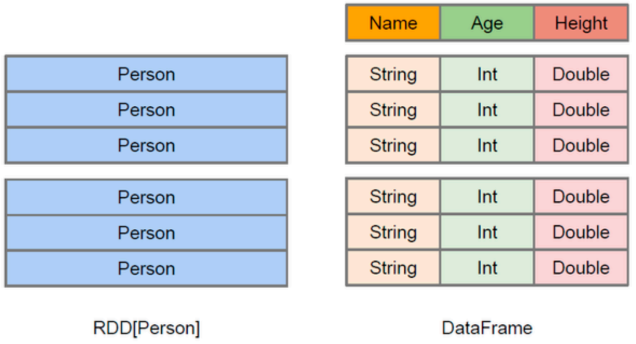


- DataFrames interoperable with Pandas dataframe
- DataFrames creation ...

```
from pyspark.sql import SQLContext, Row
from pyspark.sql.types import StructType, IntegerType, StringType, StructField
sqlContext = SQLContext(sc)

df1 = sqlContext.createDataFrame(rdd1, ["name", "age"])

ExampleRow = Row("name", "age")
rdd1a = rdd1.map(lambda x: ExampleRow(x[0], x[1]))
df1 = sqlContext.createDataFrame(rdd1a)
```



DataFrames (= RDDs + schema) in Spark

- ... DataFrames creation ...

```
schema = StructType([StructField("name", StringType(), False), \
            StructField("age", IntegerType(), True)])
df1 = sqlContext.createDataFrame(rdd1, schema)
```

```
df1.show() +------+---+
           |  name|age|
           +------+---+
           |  John| 23|
           |  Mark| 11|
           | Jenna| 44|
           |Sandra| 61|
           +------+---+
```

```
df1.printSchema()
           root
            |-- name: string (nullable = false)
            |-- age: integer (nullable = true)
```

DataFrames (= RDDs + schema) in Spark

- ... DataFrames creation

```
df2 = sqlContext.read.format('csv').option('header', 'true'). \
            option('mode', 'DROPMALFORMED').load('data/IMDB Dataset.csv')
```

```
df2.show(5)
```

```
+--------------------+---------+
|              review|sentiment|
+--------------------+---------+
|One of the other ...| positive|
|Basically there's...| negative|
|I sure would like...| positive|
|This show was an ...| negative|
|Encouraged by the...| negative|
+--------------------+---------+
only showing top 5 rows
```

```
df2.printSchema()
```

```
root
 |-- review: string (nullable = true)
 |-- sentiment: string (nullable = true)
```

DataFrames and User Defined Functions (UDF) in Spark

- User defined functions are custom functions to run against the "database" directly
- Caveats
  - Optimization problems (especially in pySpark!)
  - Special values handling by the programmer (e.g. null values)
- Approaches to use UDFs
  - *df = df.withColumn*
  - *df = sqlContext.sql("SELECT * FROM <UDF>")*
  - *rdd.map(UDF())*

DataFrames and User Defined Functions (UDF) in Spark

- Examples

```
from pyspark.sql.functions import udf


reviewLen = udf(lambda r: len(r), IntegerType())
reviewSnippet = udf(lambda r: r[0:50] + ' ...', StringType())


df2 = df2.withColumn('reviewLength', reviewLen('review'))
df2 = df2.withColumn('reviewSnippet', reviewSnippet('review'))
```

DataFrames and User Defined Functions (UDF) in Spark

- Examples

```
def words(review, type = 'positive'):
  sentimentWords = ['good', 'great', 'nice', 'awesome']
  if type == 'negative':
    sentimentWords = ['bad', 'worst', 'ugly', 'scary']
  return sum(map(lambda w: review.count(w), sentimentWords))

positiveWords = udf(lambda r: words(r), IntegerType())
negativeWords = udf(lambda r: words(r, 'negative'), IntegerType())

df2 = df2.withColumn('positiveWords', positiveWords('review'))
df2 = df2.withColumn('negativeWords', positiveWords('review'))

df2 = df2.drop('review')
```

DataFrames and User Defined Functions (UDF) in Spark

- Examples

```
df2.cache().show()
```

```
+---------+--------------------+------------+------------+------------+
|sentiment|       reviewSnippet|reviewLength|positiveWords|negativeWords|
+---------+--------------------+------------+------------+------------+
| positive|One of the other ...|        1761|           0|           0|
| negative|Basically there's...|         748|           0|           0|
| positive|I sure would like...|         726|           1|           1|
| negative|This show was an ...|         934|           0|           0|
| negative|Encouraged by the...|         681|           0|           0|
| positive|If you like origi...|         176|           0|           0|
| negative|"Phil the Alien i...|         582|           0|           0|
| negative|I saw this movie ...|         937|           0|           0|
| negative|The cast played S...|         662|           1|           1|
| positive|This a fantastic ...|         275|           1|           1|
| negative|Kind of drawn in ...|         830|           0|           0|
| positive|Some films just s...|         720|           0|           0|
| negative|This movie made i...|        1322|           0|           0|
| positive|I remember this f...|         639|           0|           0|
| negative|An awful film! It...|         741|           1|           1|
| positive|After the success...|        1813|           1|           1|
| positive|What an absolutel...|         346|           0|           0|
| negative|This was the wors...|         808|           2|           2|
| positive|The Karen Carpent...|         680|           3|           3|
| negative|This film tried t...|         836|           0|           0|
+---------+--------------------+------------+------------+------------+
only showing top 20 rows
```

Spark SQL DataFrame operations

- Examples

```
df2.select('sentiment', 'positiveWords').show(3)
```

```
+---------+-------------+
|sentiment|positiveWords|
+---------+-------------+
| positive|            0|
| negative|            0|
| positive|            1|
+---------+-------------+
only showing top 3 rows
```

```
df2.select(df2['sentiment'], df2['positiveWords']).show(3)
```

```
+---------+-------------+
|sentiment|positiveWords|
+---------+-------------+
| positive|            0|
| negative|            0|
| positive|            1|
+---------+-------------+
only showing top 3 rows
```

```
df2.select(df2['sentiment'], df2['positiveWords']). \
    filter(df2['positiveWords'] > 10).show(3)
```

```
+---------+-------------+
|sentiment|positiveWords|
+---------+-------------+
| positive|           18|
| negative|           11|
| positive|           11|
+---------+-------------+
only showing top 3 rows
```

```
df2.groupBy('sentiment').count().show()
```

```
+---------+-----+
|sentiment|count|
+---------+-----+
| positive|14897|
|,positive|    2|
| negative|13792|
+---------+-----+
```

```
df2.summary().show()
```

```
+-------+---------+------------------+----------------+----------------+
|summary|sentiment|       reviewSnippet|   positiveWords|   negativeWords|
+-------+---------+------------------+----------------+----------------+
|  count|    28691|             28691|           28691|           28691|
|   mean|     null|              null|1.002474643616465|1.002474643616465|
| stddev|     null|              null|1.351616569521083|1.351616569521083|
|    min|,positive|!!! Spoiler alert...|               0|               0|
|    25%|     null|              null|               0|               0|
|    50%|     null|              null|               1|               1|
|    75%|     null|              null|               1|               1|
|    max| positive|ý thýnk uzak ýs t...|              24|              24|
+-------+---------+------------------+----------------+----------------+
```

Spark SQL SQL operations

- Examples

```
df2.createOrReplaceTempView('imdb')
```

```
sqlContext.sql('SELECT * FROM imdb WHERE positiveWords > 10 LIMIT 5').show()
```

```
+---------+--------------------+-------------+-------------+
|sentiment|       reviewSnippet|positiveWords|negativeWords|
+---------+--------------------+-------------+-------------+
| positive|This is a great G...|           18|           18|
| negative|I just watched th...|           11|           11|
| positive|I bought this a w...|           11|           11|
| positive|I can't say too m...|           11|           11|
| positive|"First an explana...|           14|           14|
+---------+--------------------+-------------+-------------+
```

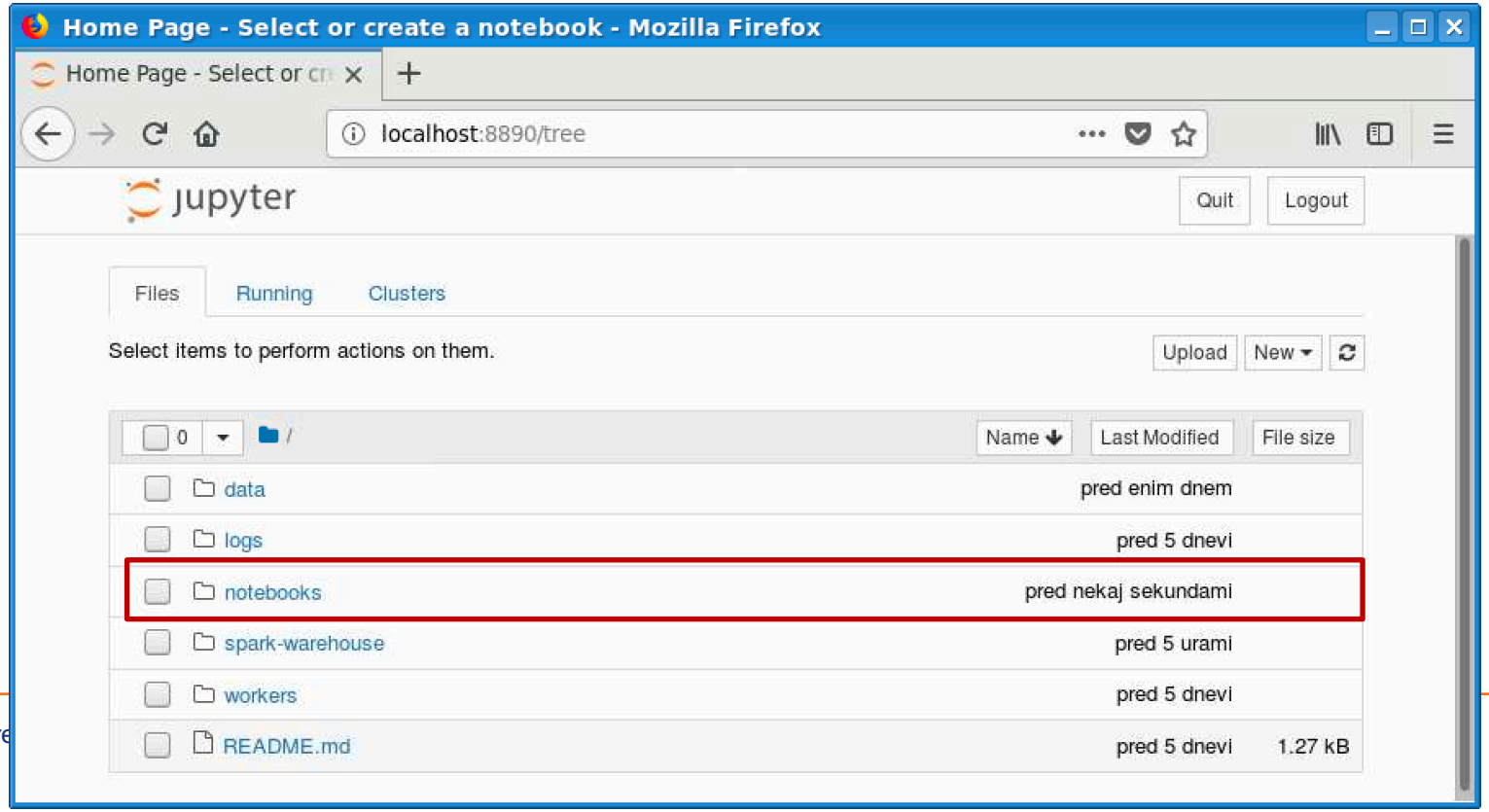
```
sqlContext.sql('SELECT sentiment, count(*) FROM imdb GROUP BY sentiment').show()
```

```
+---------+--------+
|sentiment|count(1)|
+---------+--------+
| positive|   14897|
|,positive|       2|
| negative|   13792|
+---------+--------+
```

Lab exercises - Jupyter

- Run jupyter notebook command in the project folder and run notebooks from notebooks folder

```
(spark-workshop-env) [campus02@viz Apache-Spark-Workshop]$ jupyter notebook
```



Lab exercise – Spark on an HPC

- Move to `spark-hpc` folder:
  - `00_clean.sh`
    - Script to clean logs, data generated by running scripts
  - `01_run-sbatch.sh`
    - Prepare and submit scripts with a Spark job
  - `conf/spark-env.sh`
    - Env variables for worker folder and log folder set
  - `job.py`
    - Pyspark source code (i.e. simple pi calculation script)
  - `logs/`
    - Spark and slurm log folder
  - `NOTES.txt`
    - Short Slurm commands reference
  - `spark-job-TEMPLATE.sh`
    - Slurm script for job submission
  - `workers/`
    - Workers working directories

```
00_clean.sh
01_run-sbatch.sh
conf
job.py
logs
NOTES.txt
spark-job-TEMPLATE.sh
workers
```

Lab exercise – Spark on an HPC

- job.py

```
from pyspark import SparkContext, SparkConf
from random import random
from operator import add

spark_conf = SparkConf()
sc = SparkContext(appName='SparkWorkshop Python Pi', conf = spark_conf)

n = 10000000

def f(_):
  x = random() * 2 - 1
  y = random() * 2 - 1
  return 1 if x ** 2 + y ** 2 <= 1 else 0

count = sc.parallelize(range(1, n + 1), 2).map(f).reduce(add)

print("\n\n##########################")
print("Pi is roughly %f" % (4.0 * count / n))
print("##########################\n\n")
```

Lab exercise – Spark on an HPC

- spark-job-TEMPLATE.sh

```
#!/bin/bash
#SBATCH -N 1
#SBATCH -t 00:10:00
#SBATCH --ntasks-per-node 3
#SBATCH --cpus-per-task 2
#SBATCH --output=logs/slurm_stdout_err__%j.log

module purge
module load Spark/2.4.0-Hadoop-2.7-Java-1.8

# MAIN DIR
export JOB_SPARK_DIR="CURRENT_DIR"

export JOB_SPARK_LOG_DIR="${JOB_SPARK_DIR}/logs"
export JOB_SPARK_WORKER_DIR="${JOB_SPARK_DIR}/workers"
export SPARK_CONF_DIR="${JOB_SPARK_DIR}/conf"

# Start Master
start-master.sh

# Start Workers
start-slave.sh spark://`hostname`:7077

# Spark cluster running to submit jobs
# via driver from login node
#sleep infinity

# Run driver on an HPC node
spark-submit --master spark://`hostname`:7077 "${JOB_SPARK_DIR}/job.py"
```

Lab exercise – Spark on an HPC

- 01_run-sbatch.sh

```
#!/bin/bash

cp spark-job-TEMPLATE.sh spark-job.sh

sed -i "s#CURRENT_DIR#${PWD}#g" spark-job.sh
sbatch spark-job.sh

rm -rf spark-job.sh
```

Lab exercise – Spark on an HPC

- Run spark application on an HPC (commands):

```
./01_run-sbatch.sh
```

```
(spark-workshop-env) [campus02@viz spark-hpc]$ ./01_run-sbatch.sh
Submitted batch job 51438
```

```
squeue -u campus02
```

```
JOBID PARTITION     NAME     USER ST       TIME  NODES NODELIST(REASON)
51438  westmere spark-jo campus02  R       0:17      1 cn17
```

```
sacct -j 51438
```

```
       JobID    JobName  Partition    Account  AllocCPUS      State ExitCode
------------ ---------- ---------- ---------- ---------- ---------- --------
51438        spark-job+   westmere                    12  COMPLETED      0:0
51438.batch       batch                              12  COMPLETED      0:0
51438.extern     extern                              12  COMPLETED      0:0
```

Lab exercise – Spark on an HPC

- Check the output log:

```
cat logs/slurm_stdout_err__51438.log
```

```
....
2020-09-16 21:42:51 INFO  DAGScheduler:54 - Job 0 finished: reduce at ...

##########################
Pi is roughly 3.141645
##########################

2020-09-16 21:42:51 INFO  SparkContext:54 - Invoking stop() from shutdown hook
...
```

Challenge exercises

- Check Lab 1 and Lab 2 Jupyter notebooks and solve challenges at the end
- Train a classifier to predict movie review sentiment
  - Use the provided *IMBD reviews.csv* data an split it to train and test set
  - Extract features (e.g. TF-IDF), train model (e.g. SVM) and test it
  - See MLlib documentation at https://spark.apache.org/docs/latest/ml-guide.html
- Use more nodes with workers on an HPC
  - Adapt HPC lab exercise to be run on multiple nodes
  - Hint: https://info.gwdg.de/wiki/doku.php?id=wiki:hpc:slurm_sbatch_script_for_spark_applications
- Viewing event logs in the SparkUI after Slurm job is finished
  - Replicate the HPC exercise from before, retrieve logs and run history server to explore SparkUI
  - Hints: https://researchcomputing.princeton.edu/faq/spark-via-slurm

References

- https://training.databricks.com/visualapi.pdf
- https://events.prace-ri.eu/event/896/
- https://luminousmen.com/post/spark-core-concepts-explained
- https://info.gwdg.de/wiki/doku.php?id=wiki:hpc:slurm_sbatch_script_for_spark_applications
- https://researchcomputing.princeton.edu/faq/spark-via-slurm

THANK YOU FOR YOUR ATTENTION

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