Systems and Architectures for Big Data AY 2017/2018
University of Rome Tor Vergata

Batch processing for smart plugs sensor data with Apache Spark on Google DataProc

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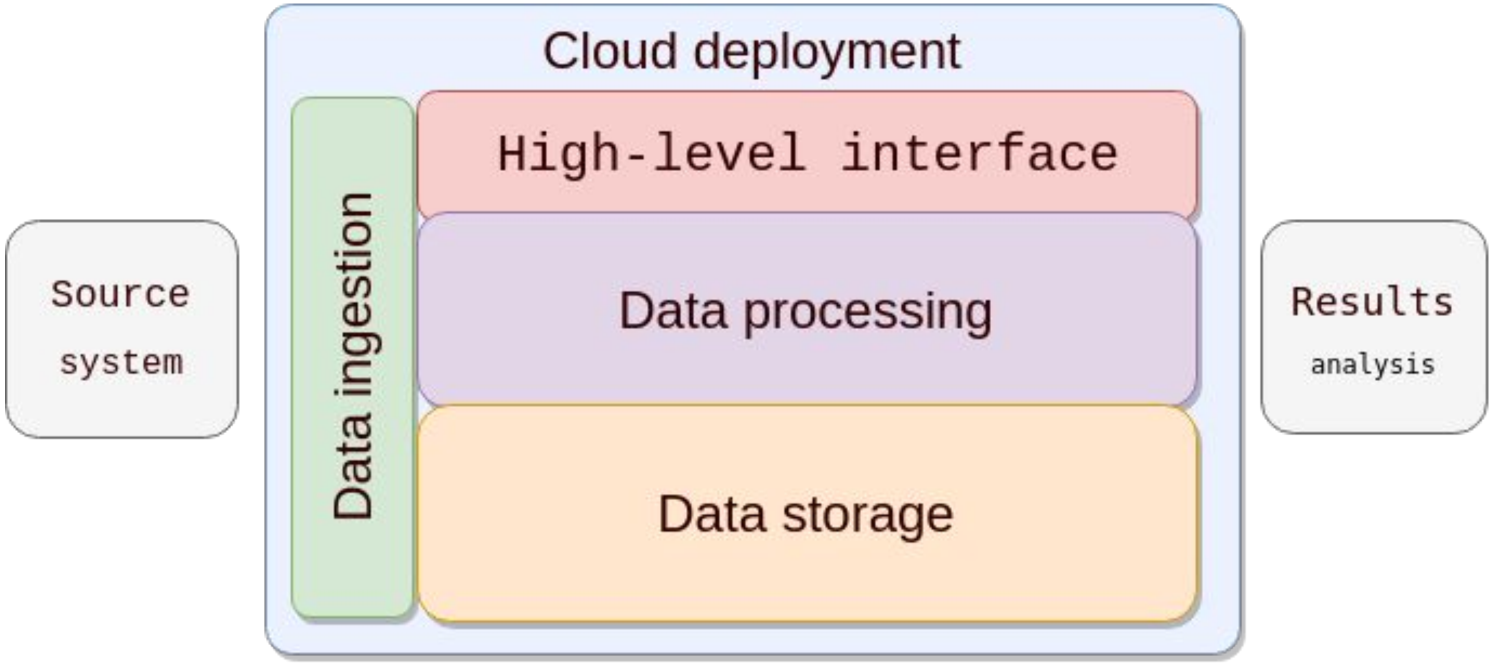
1.

System Architecture

High Level Overview

System Layers



Data Processing Layer

- Basic RDD API
- Scala as the programming language
  a. Spark written in Scala
  b. Functional Programming Functions similar with RDD API

High Level Interface

SQL

- Support for structured and semi-structured data using DataFrame API
- SQL-like query language
- Our own UDF (User Defined Functions)

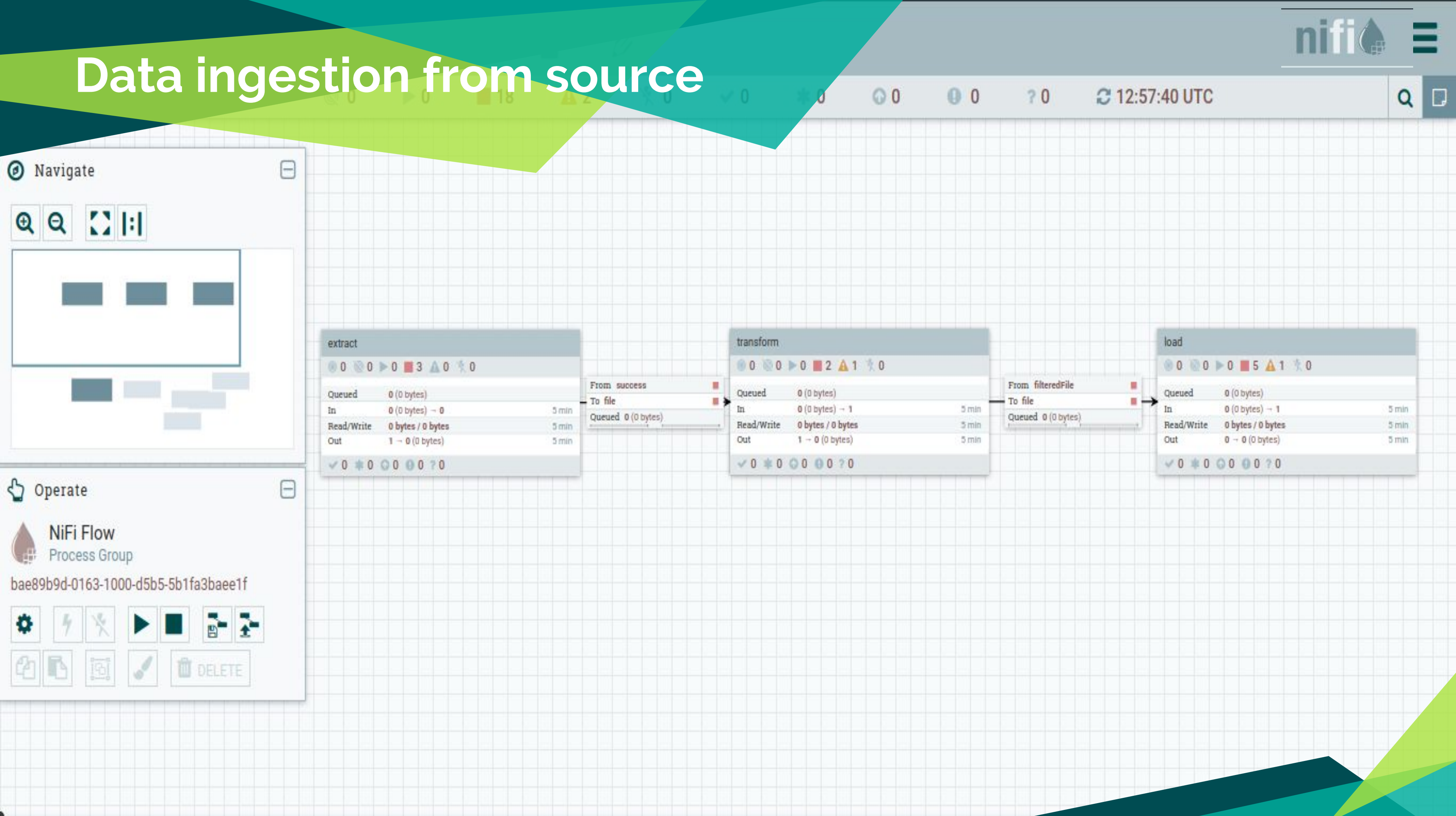
Data Storage

- HDFS stores and serves input, results and benchmark files
- Alluxio handles all data read, write and cache operations on HDFS theoretically improving performance up to 10x

Data Ingestion

- Inject data from external sources to data storage layer
- Transfer data between components in storage layer
- Data filtering

Data ingestion from source



NiFi Flow
Process Group
bae89b9d-0163-1000-d5b5-5b1fa3baee1f

extract
0 0 0 3 0 0

Queued	0 (0 bytes)	
In	0 (0 bytes) → 0	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	1 → 0 (0 bytes)	5 min

0 0 0 0 ? 0

From success
To file
Queued 0 (0 bytes)

transform
0 0 0 2 1 0

Queued	0 (0 bytes)	
In	0 (0 bytes) → 1	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	1 → 0 (0 bytes)	5 min

0 0 0 0 ? 0

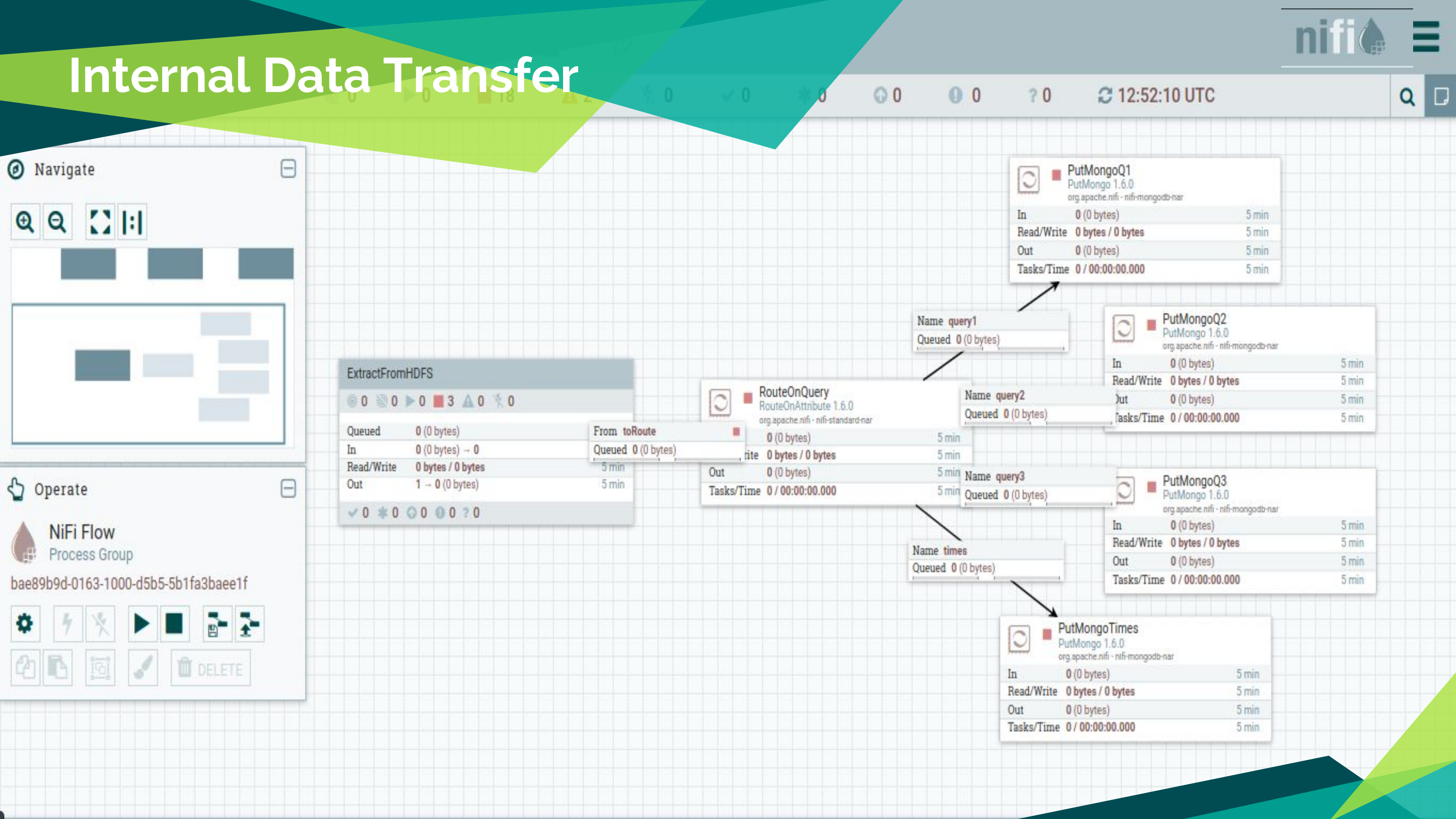
From filteredFile
To file
Queued 0 (0 bytes)

load
0 0 0 5 1 0

Queued	0 (0 bytes)	
In	0 (0 bytes) → 1	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	0 → 0 (0 bytes)	5 min

0 0 0 0 ? 0

Internal Data Transfer



ExtractFromHDFS

0 0 0 3 0 0

Queued	0 (0 bytes)	
In	0 (0 bytes) → 0	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	1 → 0 (0 bytes)	5 min

0 0 0 0 ? 0

From toRoute
Queued 0 (0 bytes)

RouteOnQuery
RouteOnAttribute 1.6.0
org.apache.nifi - nifi-standard-nar

	0 (0 bytes)	5 min
rite	0 bytes / 0 bytes	5 min
Out	0 (0 bytes)	5 min
Tasks/Time	0 / 00:00:00.000	5 min

Name query1
Queued 0 (0 bytes)

Name query2
Queued 0 (0 bytes)

Name query3
Queued 0 (0 bytes)

Name times
Queued 0 (0 bytes)

PutMongoQ1
PutMongo 1.6.0
org.apache.nifi - nifi-mongodb-nar

In	0 (0 bytes)	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	0 (0 bytes)	5 min
Tasks/Time	0 / 00:00:00.000	5 min

PutMongoQ2
PutMongo 1.6.0
org.apache.nifi - nifi-mongodb-nar

In	0 (0 bytes)	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	0 (0 bytes)	5 min
Tasks/Time	0 / 00:00:00.000	5 min

PutMongoQ3
PutMongo 1.6.0
org.apache.nifi - nifi-mongodb-nar

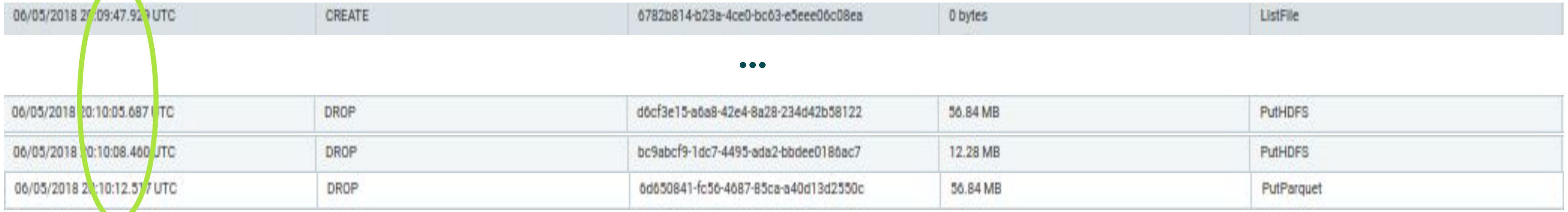
In	0 (0 bytes)	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	0 (0 bytes)	5 min
Tasks/Time	0 / 00:00:00.000	5 min

PutMongoTimes
PutMongo 1.6.0
org.apache.nifi - nifi-mongodb-nar

In	0 (0 bytes)	5 min
Read/Write	0 bytes / 0 bytes	5 min
Out	0 (0 bytes)	5 min
Tasks/Time	0 / 00:00:00.000	5 min

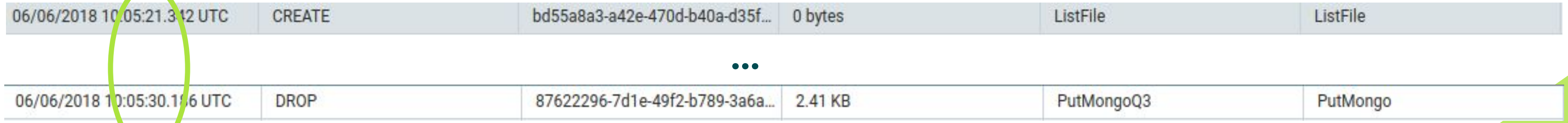
Data provenance lineage

Data ingestion from local to HDFS < 30 sec



06/05/2018 20:09:47.929 UTC	CREATE	6782b814-b23a-4ce0-bc63-e5eee06c08ea	0 bytes	ListFile
		…		
06/05/2018 20:10:05.687 UTC	DROP	d6cf3e15-a6a8-42e4-8a28-234d42b58122	56.84 MB	PutHDFS
06/05/2018 20:10:08.460 UTC	DROP	bc9abcf9-1dc7-4495-ada2-bbdee0186ac7	12.28 MB	PutHDFS
06/05/2018 20:10:12.517 UTC	DROP	6d650841-fc56-4687-85ca-a40d13d2550c	56.84 MB	PutParquet

Results collection from HDFS to MongoDB < 10 sec



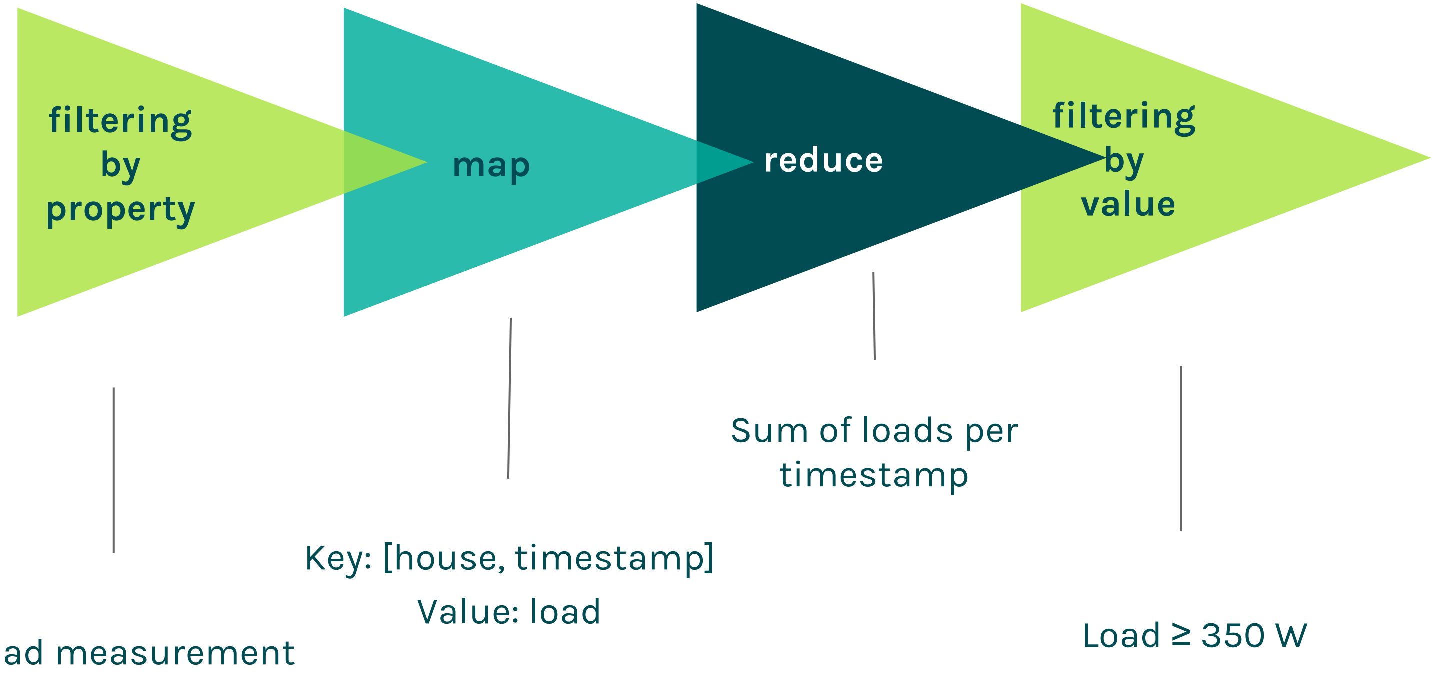
06/06/2018 10:05:21.342 UTC	CREATE	bd55a8a3-a42e-470d-b40a-d35f...	0 bytes	ListFile	ListFile
		…			
06/06/2018 10:05:30.186 UTC	DROP	87622296-7d1e-49f2-b789-3a6a...	2.41 KB	PutMongoQ3	PutMongo

2.

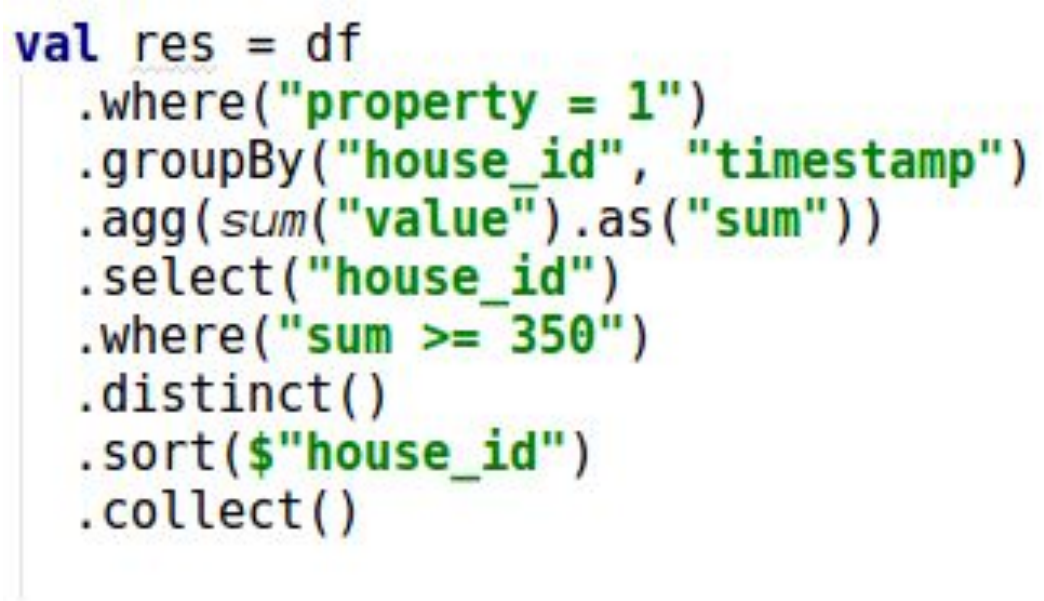
Queries

Detailed queries description

Query 1

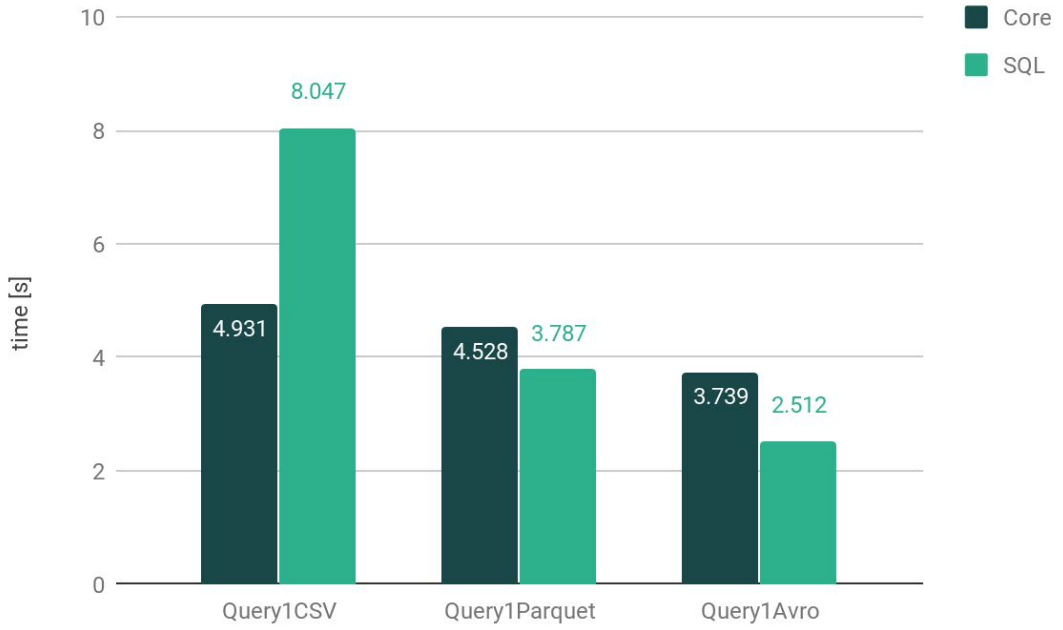

filtering by property
map
reduce
filtering by value
Load measurement
Key: [house, timestamp]
Value: load
Sum of loads per timestamp
Load ≥ 350 W

Query 1 Spark SQL



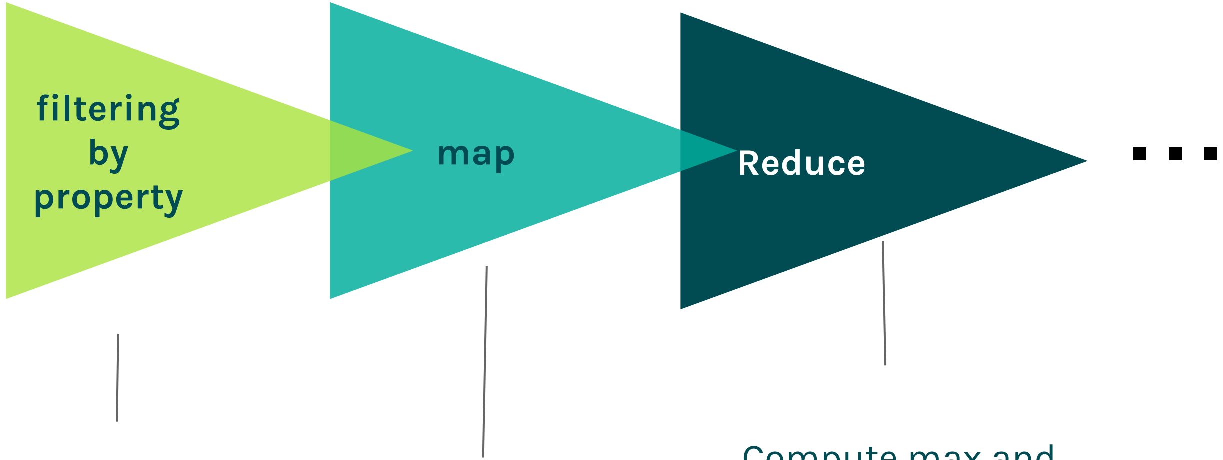
```
val res = df
    .where("property = 1")
    .groupBy("house_id", "timestamp")
    .agg(sum("value").as("sum"))
    .select("house_id")
    .where("sum >= 350")
    .distinct()
    .sort($"house_id")
    .collect()
```

Query 1 performances



Spark Core and Spark SQL implementations performances.

Query 2



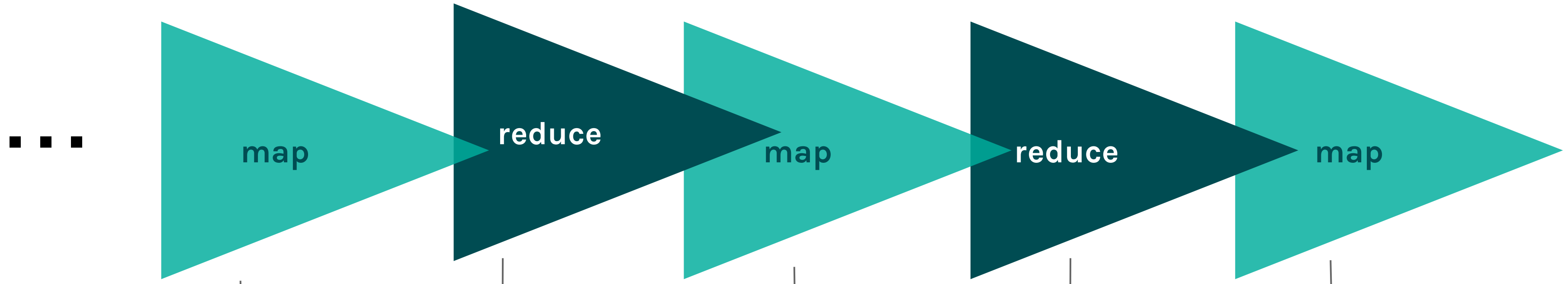
Work measurement

Key:
[house, household, plug, time slot, day, month]

Value: *MaxMinHolder* init by work

Compute max and min value per slot

Query 2



Sum of increments

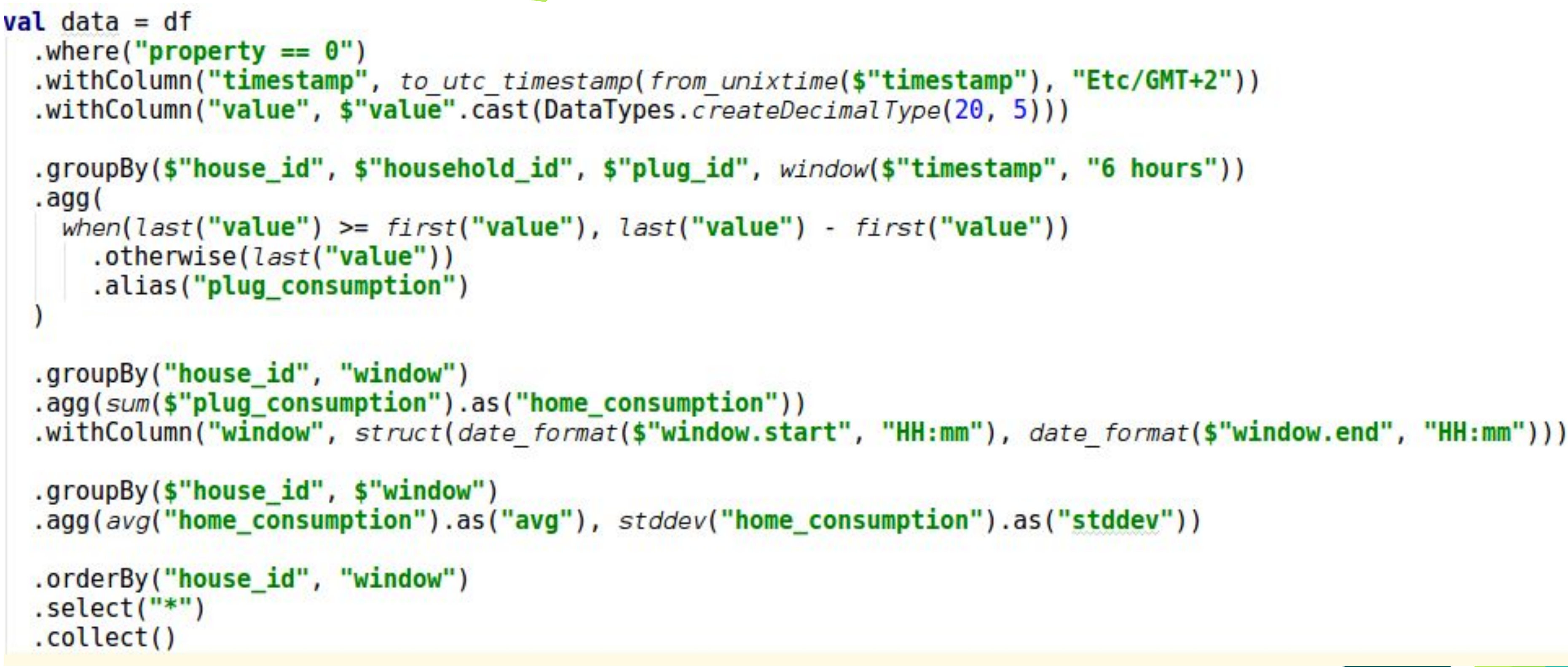
Sum of consumption, count of items, sum of consumption^2

Key:
[house, time slot, day, month]
Value: [consumption per slot]

Key:
[house, time slot]
Value: [consumption, 1, consumption^2]

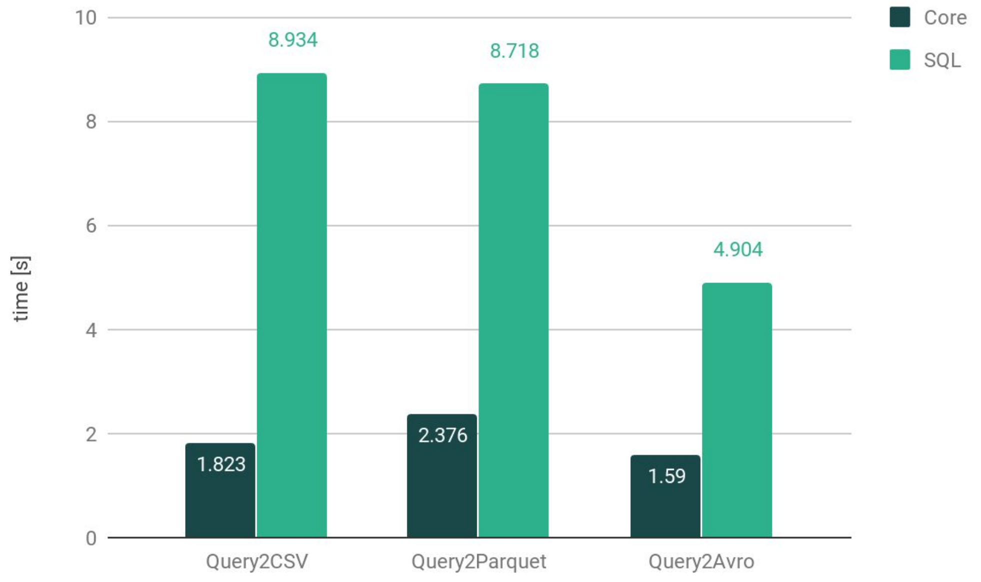
Key:
[house, time slot]
Value: [mean, standard deviation]

Query 2 Spark SQL



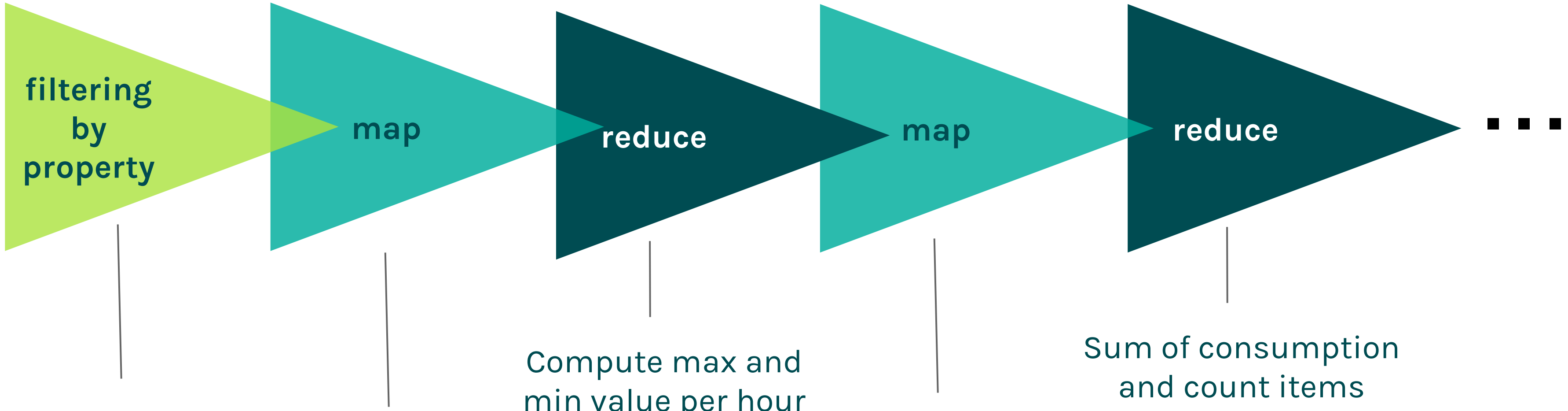
```
val data = df
  .where("property == 0")
  .withColumn("timestamp", to_utc_timestamp(from_unixtime($"timestamp"), "Etc/GMT+2"))
  .withColumn("value", $"value".cast(DataTypes.createDecimalType(20, 5)))

  .groupBy($"house_id", $"household_id", $"plug_id", window($"timestamp", "6 hours"))
  .agg(
    when(last("value") >= first("value"), last("value") - first("value"))
      .otherwise(last("value"))
      .alias("plug_consumption")
  )

  .groupBy("house_id", "window")
  .agg(sum($"plug_consumption").as("home_consumption"))
  .withColumn("window", struct(date_format($"window.start", "HH:mm"), date_format($"window.end", "HH:mm")))

  .groupBy($"house_id", $"window")
  .agg(avg("home_consumption").as("avg"), stddev("home_consumption").as("stddev"))

  .orderBy("house_id", "window")
  .select("*")
  .collect()
```

Query 2 performances



Spark Core and Spark SQL implementations performances.

Query 3



Load measurement

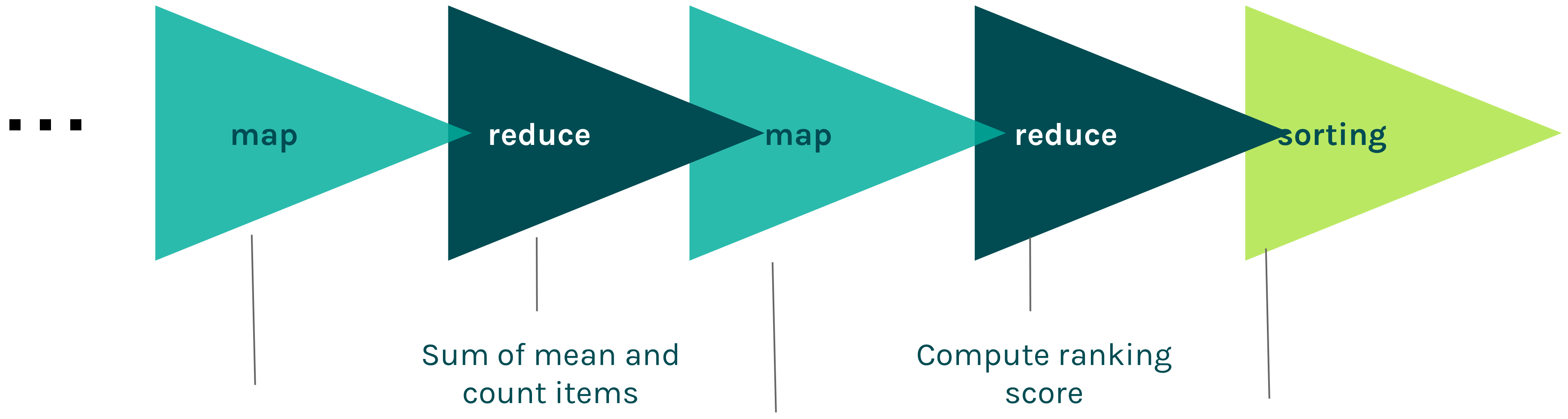
Key:
[house, household, plug, rate, hour, day, month]
Value: *MaxMinHolder* init by work]

Compute max and min value per hour

Key:
[house, houseold, plug,rate, day]
Value: [consumption, 1]

Sum of consumption and count items

Query 3



Key:
[house, household, plug, rate]
Value: [mean, 1]

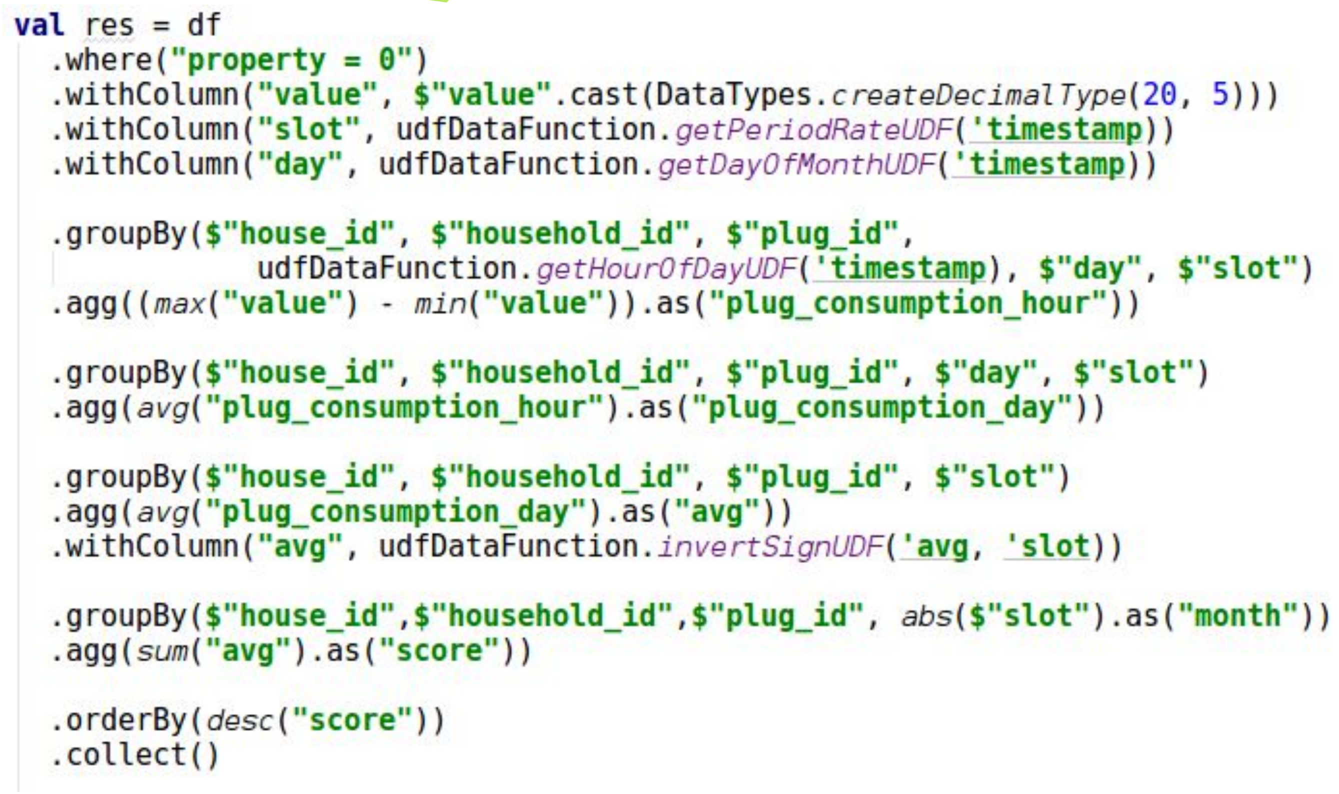
Sum of mean and count items

Key:
[house, household, plug, |rate|]
Value: [±mean]

Compute ranking score

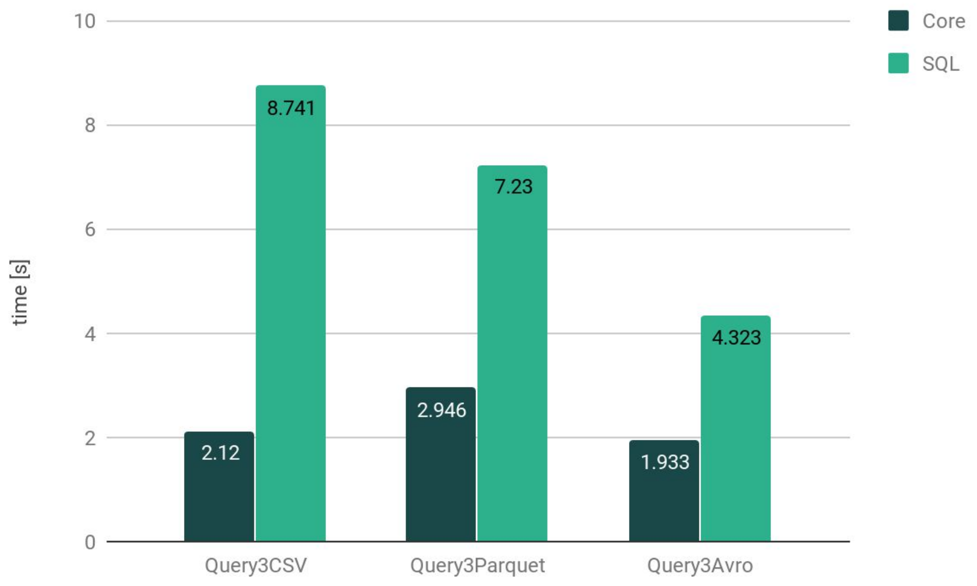
Sort by score

Query 3 Spark SQL



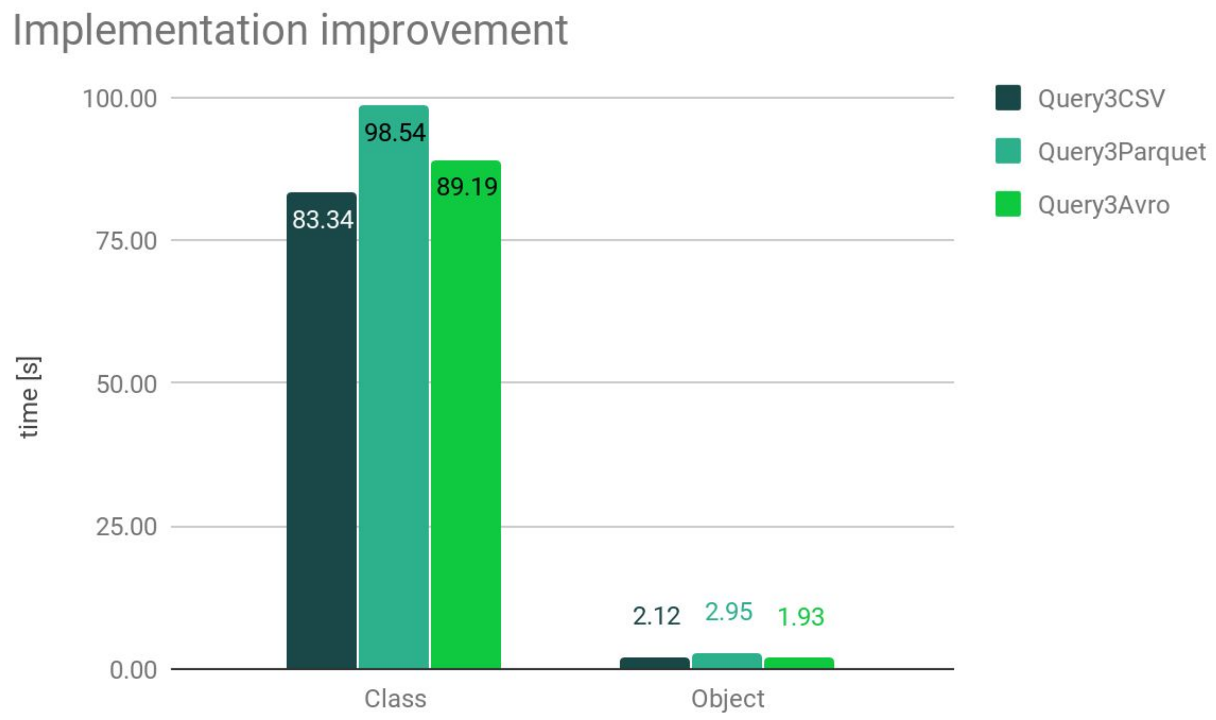
```
val res = df
    .where("property = 0")
    .withColumn("value", $"value".cast(DataTypes.createDecimalType(20, 5)))
    .withColumn("slot", udfDataFunction.getPeriodRateUDF('timestamp))
    .withColumn("day", udfDataFunction.getDayOfMonthUDF('timestamp))

    .groupBy($"house_id", $"household_id", $"plug_id",
                udfDataFunction.getHourOfDayUDF('timestamp), $"day", $"slot")
    .agg((max("value") - min("value")).as("plug_consumption_hour"))

    .groupBy($"house_id", $"household_id", $"plug_id", $"day", $"slot")
    .agg(avg("plug_consumption_hour").as("plug_consumption_day"))

    .groupBy($"house_id", $"household_id", $"plug_id", $"slot")
    .agg(avg("plug_consumption_day").as("avg"))
    .withColumn("avg", udfDataFunction.invertSignUDF('avg, 'slot))

    .groupBy($"house_id",$"household_id",$"plug_id", abs($"slot").as("month"))
    .agg(sum("avg").as("score"))

    .orderBy(desc("score"))
    .collect()
```

Query 3 performances



Spark Core and Spark SQL implementations performances.

Query 3 improvement



3.

Results

Queries output on given dataset

Query 1 results

House ID	0	1	2	3	4	5	6	7	8	9

Query 2 (partial) results

House ID	0	0	0	0	1	1	1	1	2	2	2	2
Time slot	00:00-5:59	6:00-11:59	12:00-17:59	18:00-23:59	00:00-5:59	6:00-11:59	12:00-17:59	18:00-23:59	00:00-5:59	6:00-11:59	12:00-17:59	18:00-23:59
Mean	0.14	0.41	0.19	0.25	0.37	0.69	0.79	0.68	0.30	0.30	0.31	0.33
Standard deviation	0.11	1.04	0.14	0.14	0.36	0.48	0.49	0.40	0.31	0.32	0.30	0.33

...

Query 3 (partial) results

Ranking	Plug	Month	Score
1°	(8,0,1)	9	0.115
2°	(8,0,0)	9	0.080
3°	(0,0,2)	9	0.077
4°	(1,0,1)	9	0.042
5°	(5,0,1)	9	0.011
6°	(7,0,1)	9	0.008

...

4.

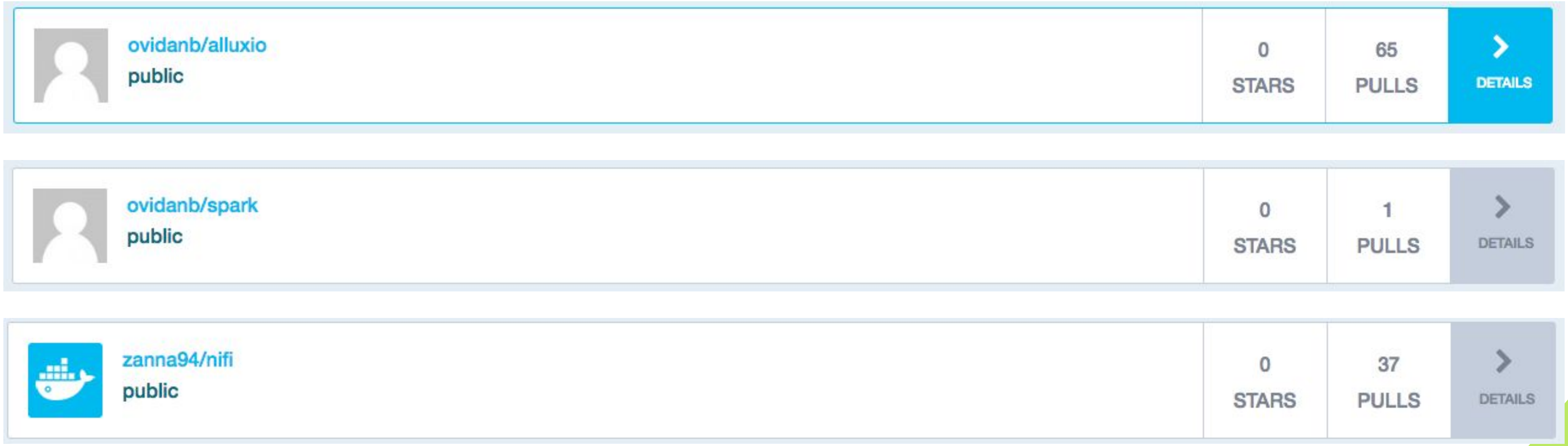
Deployment

Local and Cloud deployment

Local Deploy

- Every system component is built as a Docker Image
- Made from scratch (Spark, NiFi, Alluxio) or from existing images (HDFS, MongoDB)
- Some run in pseudo-distributed mode (HDFS, Spark and Alluxio) with 1 Master and N Workers
- All components run on same network

Docker Images



ovidanb/alluxio	public	0 STARS	65 PULLS	DETAILS
ovidanb/spark	public	0 STARS	1 PULLS	DETAILS
zanna94/nifi	public	0 STARS	37 PULLS	DETAILS

Cloud Deploy

Google Cloud Platform

Google Cloud Platform was used as the deploy environment.

In particular the DataProc and Kubernetes Engine services.

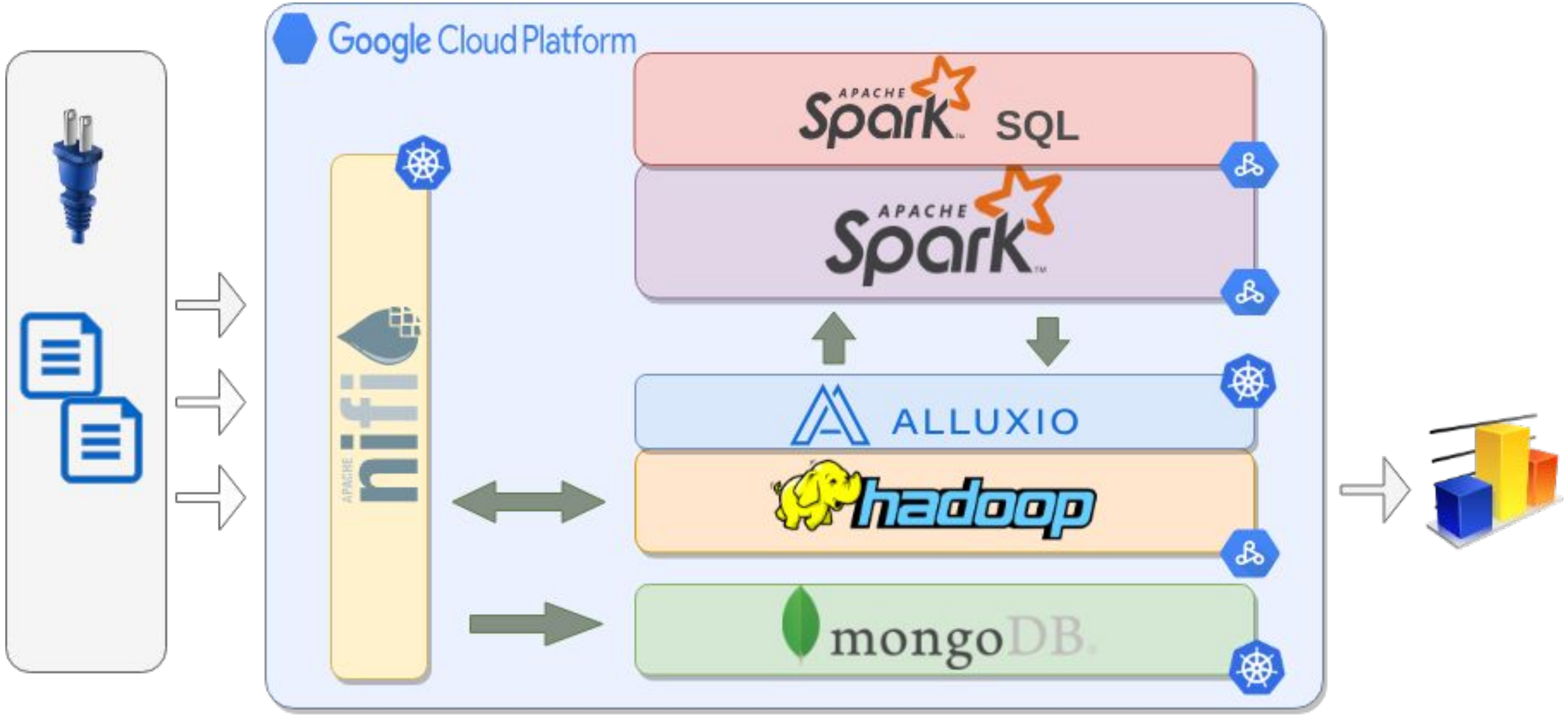
DataProc

- Fully-managed cloud service for running Spark and Hadoop Clusters
- Ready with Hadoop Ecosystem frameworks (HDFS, Hive, Pig and YARN)
- 3 or 5 node cluster configurations (1 Master only)

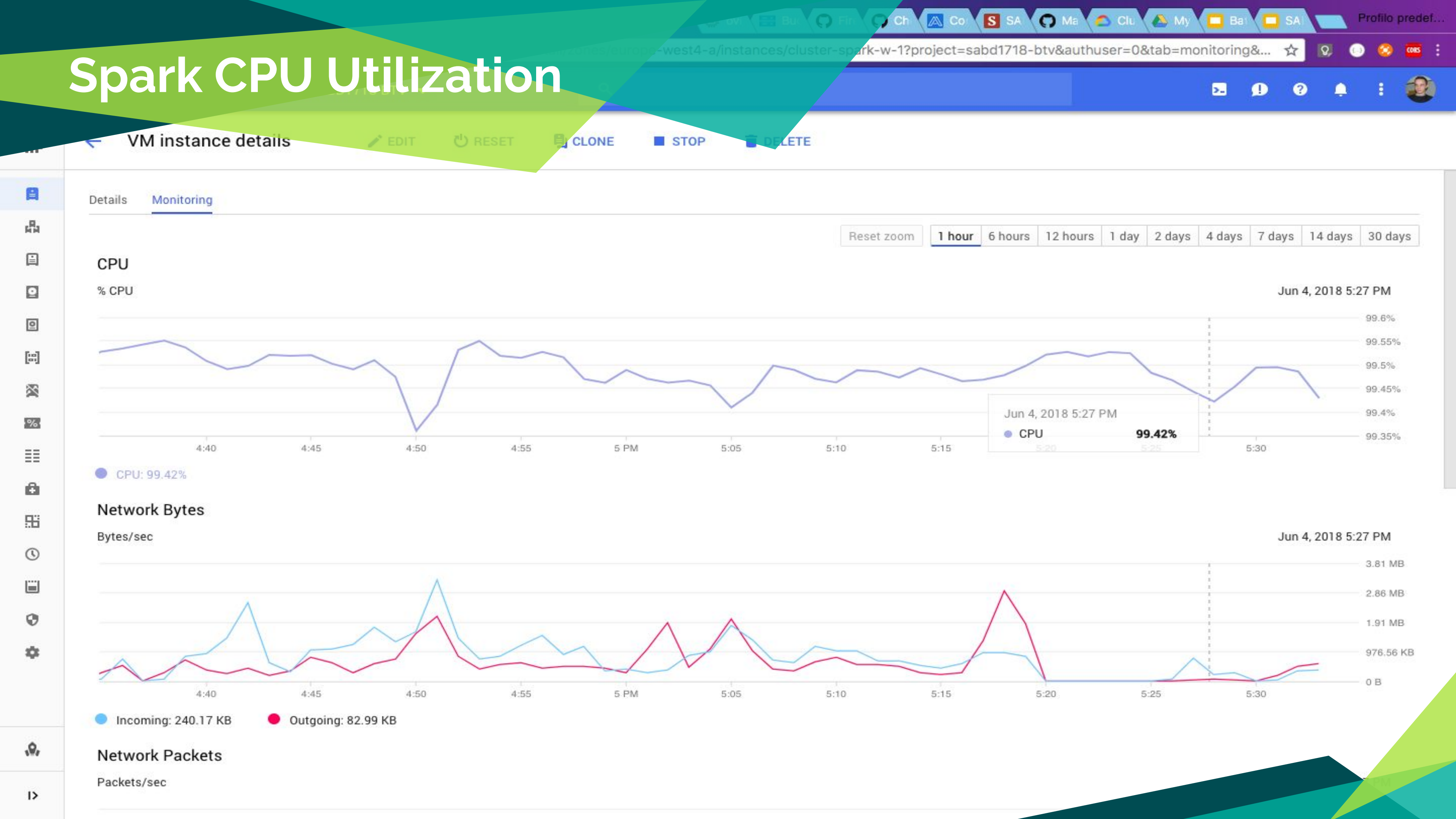
Kubernetes

- Used to deploy remaining System components (MongoDB, NiFi and Alluxio) as Docker containers
- 3-node Cluster (1 Master and 2 Slaves)
- On the same VPC network as DataProc cluster

Cloud Deployment



Spark CPU Utilization


VM instance details

EDIT RESET CLONE STOP DELETE

Details Monitoring

Reset zoom 1 hour 6 hours 12 hours 1 day 2 days 4 days 7 days 14 days 30 days

CPU

% CPU Jun 4, 2018 5:27 PM

Jun 4, 2018 5:27 PM
CPU 99.42%

● CPU: 99.42%

Network Bytes

Bytes/sec Jun 4, 2018 5:27 PM

● Incoming: 240.17 KB ● Outgoing: 82.99 KB

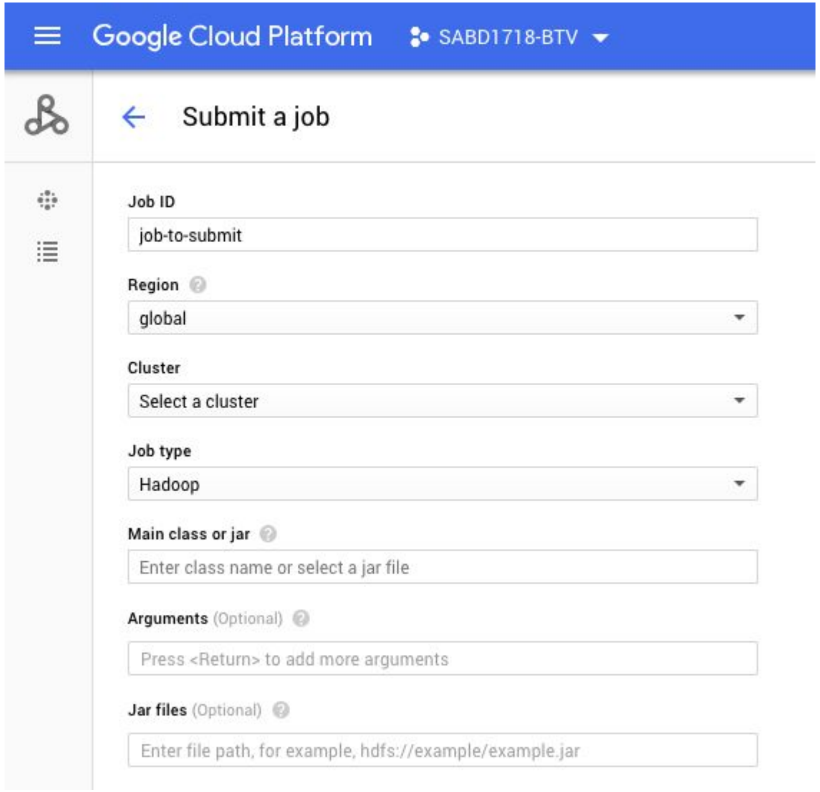
Network Packets

Packets/sec

DataProc Submit Job

Job Type:

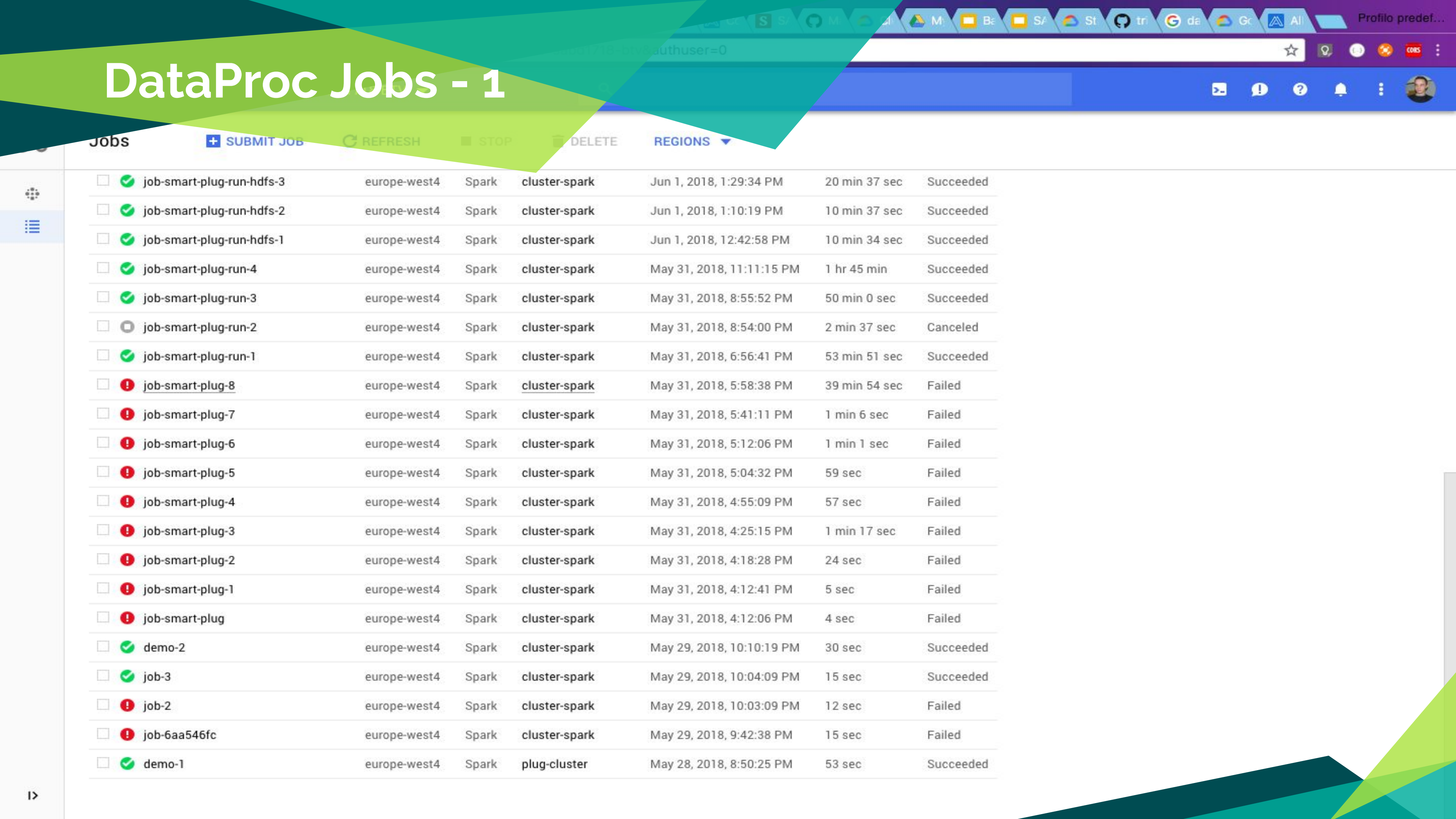
- Hadoop
- Spark
- PySpark
- Hive
- SparkSQL
- Pig



Submit a job

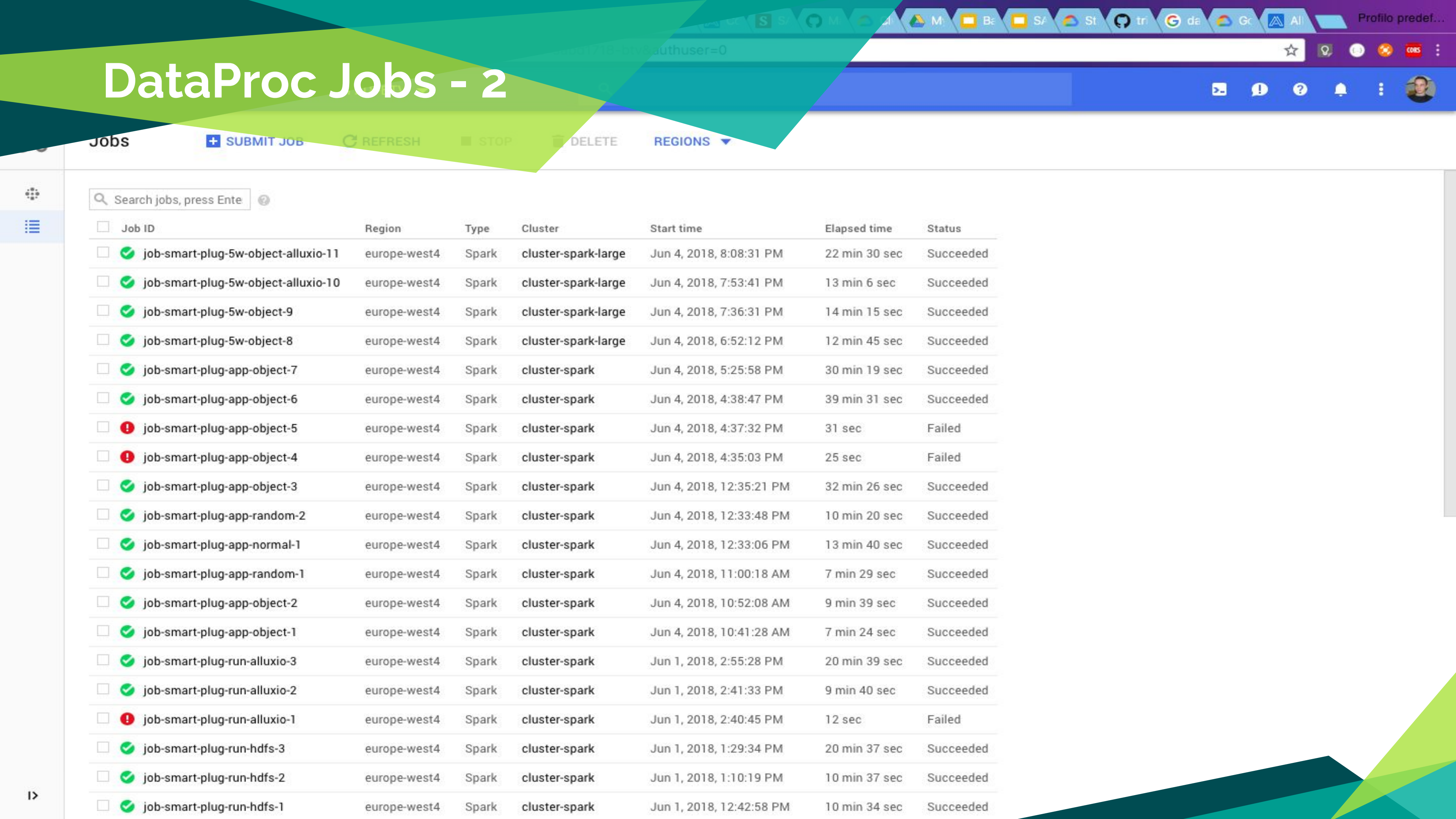
Job ID	job-to-submit
Region	global
Cluster	Select a cluster
Job type	Hadoop
Main class or jar	Enter class name or select a jar file
Arguments (Optional)	Press <Return> to add more arguments
Jar files (Optional)	Enter file path, for example, hdfs://example/example.jar

DataProc Jobs - 1



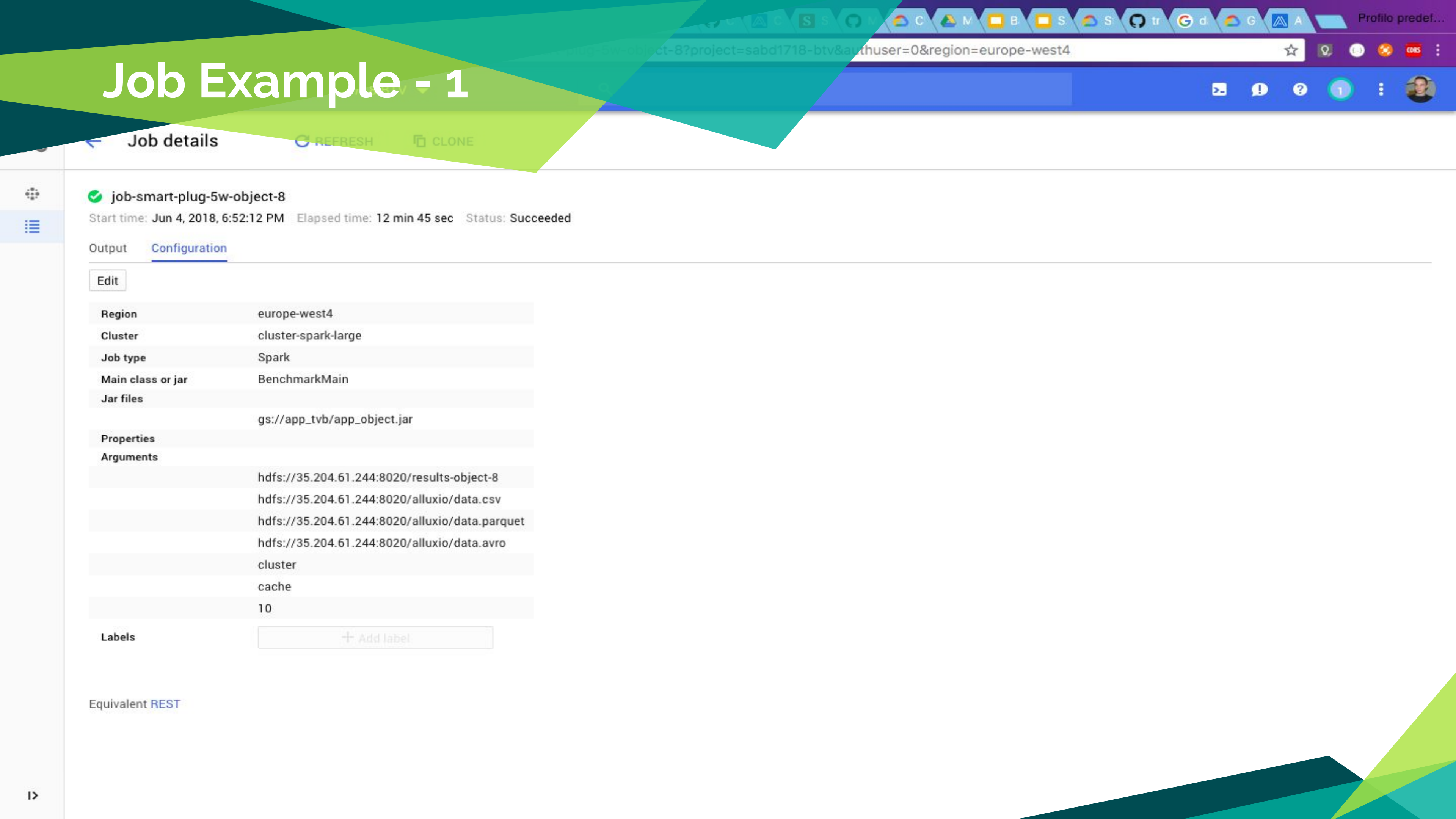
✓	job-smart-plug-run-hdfs-3	europe-west4	Spark	cluster-spark	Jun 1, 2018, 1:29:34 PM	20 min 37 sec	Succeeded
✓	job-smart-plug-run-hdfs-2	europe-west4	Spark	cluster-spark	Jun 1, 2018, 1:10:19 PM	10 min 37 sec	Succeeded
✓	job-smart-plug-run-hdfs-1	europe-west4	Spark	cluster-spark	Jun 1, 2018, 12:42:58 PM	10 min 34 sec	Succeeded
✓	job-smart-plug-run-4	europe-west4	Spark	cluster-spark	May 31, 2018, 11:11:15 PM	1 hr 45 min	Succeeded
✓	job-smart-plug-run-3	europe-west4	Spark	cluster-spark	May 31, 2018, 8:55:52 PM	50 min 0 sec	Succeeded
■	job-smart-plug-run-2	europe-west4	Spark	cluster-spark	May 31, 2018, 8:54:00 PM	2 min 37 sec	Canceled
✓	job-smart-plug-run-1	europe-west4	Spark	cluster-spark	May 31, 2018, 6:56:41 PM	53 min 51 sec	Succeeded
!	job-smart-plug-8	europe-west4	Spark	cluster-spark	May 31, 2018, 5:58:38 PM	39 min 54 sec	Failed
!	job-smart-plug-7	europe-west4	Spark	cluster-spark	May 31, 2018, 5:41:11 PM	1 min 6 sec	Failed
!	job-smart-plug-6	europe-west4	Spark	cluster-spark	May 31, 2018, 5:12:06 PM	1 min 1 sec	Failed
!	job-smart-plug-5	europe-west4	Spark	cluster-spark	May 31, 2018, 5:04:32 PM	59 sec	Failed
!	job-smart-plug-4	europe-west4	Spark	cluster-spark	May 31, 2018, 4:55:09 PM	57 sec	Failed
!	job-smart-plug-3	europe-west4	Spark	cluster-spark	May 31, 2018, 4:25:15 PM	1 min 17 sec	Failed
!	job-smart-plug-2	europe-west4	Spark	cluster-spark	May 31, 2018, 4:18:28 PM	24 sec	Failed
!	job-smart-plug-1	europe-west4	Spark	cluster-spark	May 31, 2018, 4:12:41 PM	5 sec	Failed
!	job-smart-plug	europe-west4	Spark	cluster-spark	May 31, 2018, 4:12:06 PM	4 sec	Failed
✓	demo-2	europe-west4	Spark	cluster-spark	May 29, 2018, 10:10:19 PM	30 sec	Succeeded
✓	job-3	europe-west4	Spark	cluster-spark	May 29, 2018, 10:04:09 PM	15 sec	Succeeded
!	job-2	europe-west4	Spark	cluster-spark	May 29, 2018, 10:03:09 PM	12 sec	Failed
!	job-6aa546fc	europe-west4	Spark	cluster-spark	May 29, 2018, 9:42:38 PM	15 sec	Failed
✓	demo-1	europe-west4	Spark	plug-cluster	May 28, 2018, 8:50:25 PM	53 sec	Succeeded

DataProc Jobs - 2



	Job ID	Region	Type	Cluster	Start time	Elapsed time	Status
✓	job-smart-plug-5w-object-alluxio-11	europe-west4	Spark	cluster-spark-large	Jun 4, 2018, 8:08:31 PM	22 min 30 sec	Succeeded
✓	job-smart-plug-5w-object-alluxio-10	europe-west4	Spark	cluster-spark-large	Jun 4, 2018, 7:53:41 PM	13 min 6 sec	Succeeded
✓	job-smart-plug-5w-object-9	europe-west4	Spark	cluster-spark-large	Jun 4, 2018, 7:36:31 PM	14 min 15 sec	Succeeded
✓	job-smart-plug-5w-object-8	europe-west4	Spark	cluster-spark-large	Jun 4, 2018, 6:52:12 PM	12 min 45 sec	Succeeded
✓	job-smart-plug-app-object-7	europe-west4	Spark	cluster-spark	Jun 4, 2018, 5:25:58 PM	30 min 19 sec	Succeeded
✓	job-smart-plug-app-object-6	europe-west4	Spark	cluster-spark	Jun 4, 2018, 4:38:47 PM	39 min 31 sec	Succeeded
!	job-smart-plug-app-object-5	europe-west4	Spark	cluster-spark	Jun 4, 2018, 4:37:32 PM	31 sec	Failed
!	job-smart-plug-app-object-4	europe-west4	Spark	cluster-spark	Jun 4, 2018, 4:35:03 PM	25 sec	Failed
✓	job-smart-plug-app-object-3	europe-west4	Spark	cluster-spark	Jun 4, 2018, 12:35:21 PM	32 min 26 sec	Succeeded
✓	job-smart-plug-app-random-2	europe-west4	Spark	cluster-spark	Jun 4, 2018, 12:33:48 PM	10 min 20 sec	Succeeded
✓	job-smart-plug-app-normal-1	europe-west4	Spark	cluster-spark	Jun 4, 2018, 12:33:06 PM	13 min 40 sec	Succeeded
✓	job-smart-plug-app-random-1	europe-west4	Spark	cluster-spark	Jun 4, 2018, 11:00:18 AM	7 min 29 sec	Succeeded
✓	job-smart-plug-app-object-2	europe-west4	Spark	cluster-spark	Jun 4, 2018, 10:52:08 AM	9 min 39 sec	Succeeded
✓	job-smart-plug-app-object-1	europe-west4	Spark	cluster-spark	Jun 4, 2018, 10:41:28 AM	7 min 24 sec	Succeeded
✓	job-smart-plug-run-alluxio-3	europe-west4	Spark	cluster-spark	Jun 1, 2018, 2:55:28 PM	20 min 39 sec	Succeeded
✓	job-smart-plug-run-alluxio-2	europe-west4	Spark	cluster-spark	Jun 1, 2018, 2:41:33 PM	9 min 40 sec	Succeeded
!	job-smart-plug-run-alluxio-1	europe-west4	Spark	cluster-spark	Jun 1, 2018, 2:40:45 PM	12 sec	Failed
✓	job-smart-plug-run-hdfs-3	europe-west4	Spark	cluster-spark	Jun 1, 2018, 1:29:34 PM	20 min 37 sec	Succeeded
✓	job-smart-plug-run-hdfs-2	europe-west4	Spark	cluster-spark	Jun 1, 2018, 1:10:19 PM	10 min 37 sec	Succeeded
✓	job-smart-plug-run-hdfs-1	europe-west4	Spark	cluster-spark	Jun 1, 2018, 12:42:58 PM	10 min 34 sec	Succeeded

Job Example - 1



Job details

REFRESH CLONE

job-smart-plug-5w-object-8

Start time: Jun 4, 2018, 6:52:12 PM Elapsed time: 12 min 45 sec Status: Succeeded

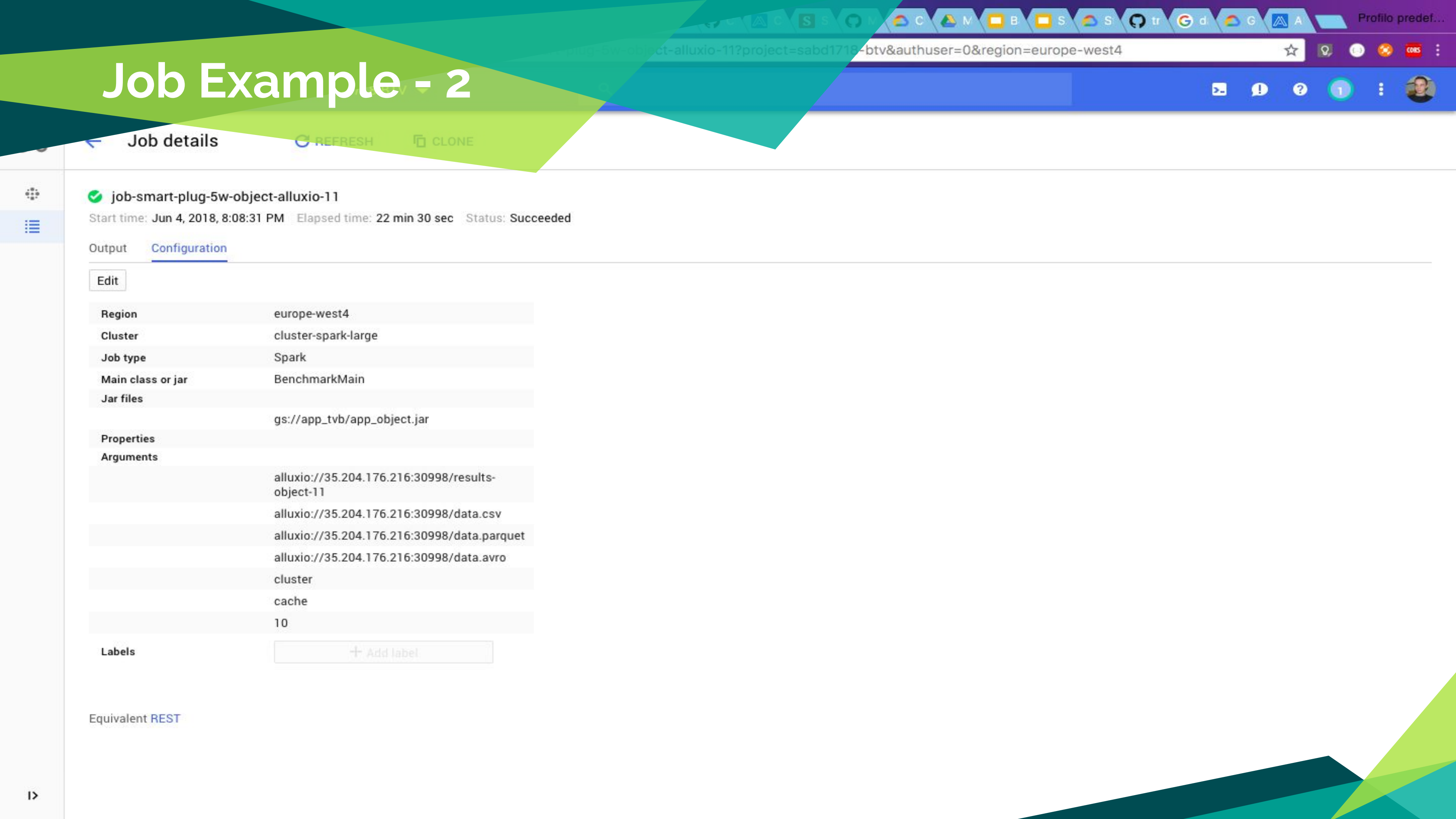
Output Configuration

Edit

Region	europe-west4
Cluster	cluster-spark-large
Job type	Spark
Main class or jar	BenchmarkMain
Jar files	
	gs://app_tvb/app_object.jar
Properties	
Arguments	
	hdfs://35.204.61.244:8020/results-object-8
	hdfs://35.204.61.244:8020/alluxio/data.csv
	hdfs://35.204.61.244:8020/alluxio/data.parquet
	hdfs://35.204.61.244:8020/alluxio/data.avro
	cluster
	cache
	10
Labels	+ Add label

Equivalent REST

Job Example - 2



job-smart-plug-5w-object-alluxio-11

Start time: Jun 4, 2018, 8:08:31 PM Elapsed time: 22 min 30 sec Status: Succeeded

Region	europe-west4
Cluster	cluster-spark-large
Job type	Spark
Main class or jar	BenchmarkMain
Jar files	
	gs://app_tvb/app_object.jar
Properties	
Arguments	
	alluxio://35.204.176.216:30998/results-object-11
	alluxio://35.204.176.216:30998/data.csv
	alluxio://35.204.176.216:30998/data.parquet
	alluxio://35.204.176.216:30998/data.avro
	cluster
	cache
	10
Labels	

Equivalent REST

5.

Queries Performance

Execution time with different formats on different architectures

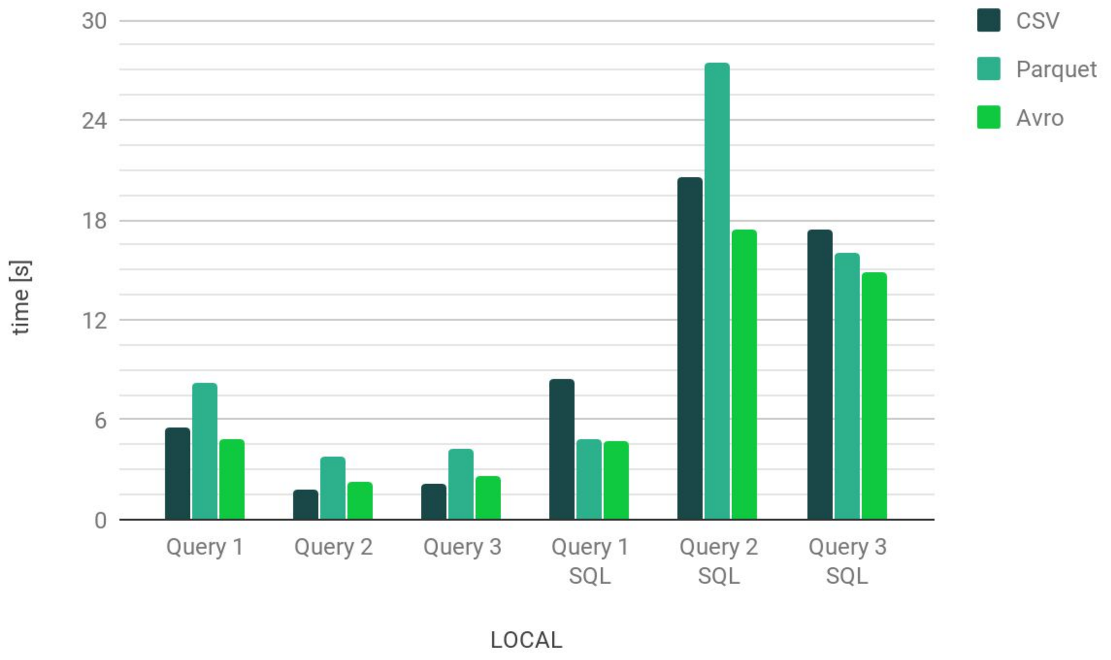
Local Deployment Performance

Specs :

- Macbook Air 2014
- 4 GB RAM
- 1,4 GHz Intel Core i5

Docker (same network):

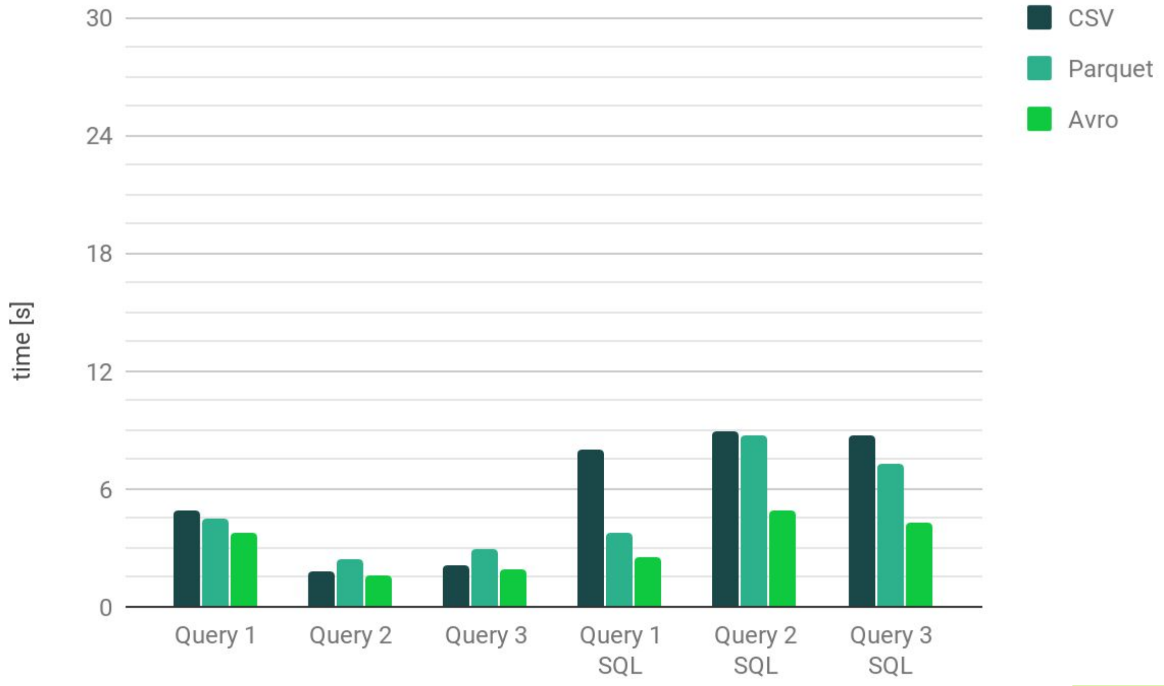
- 4 HDFS nodes
- 3 Spark nodes
- 2 Alluxio nodes



Cloud deployment using HDFS

DataProc :

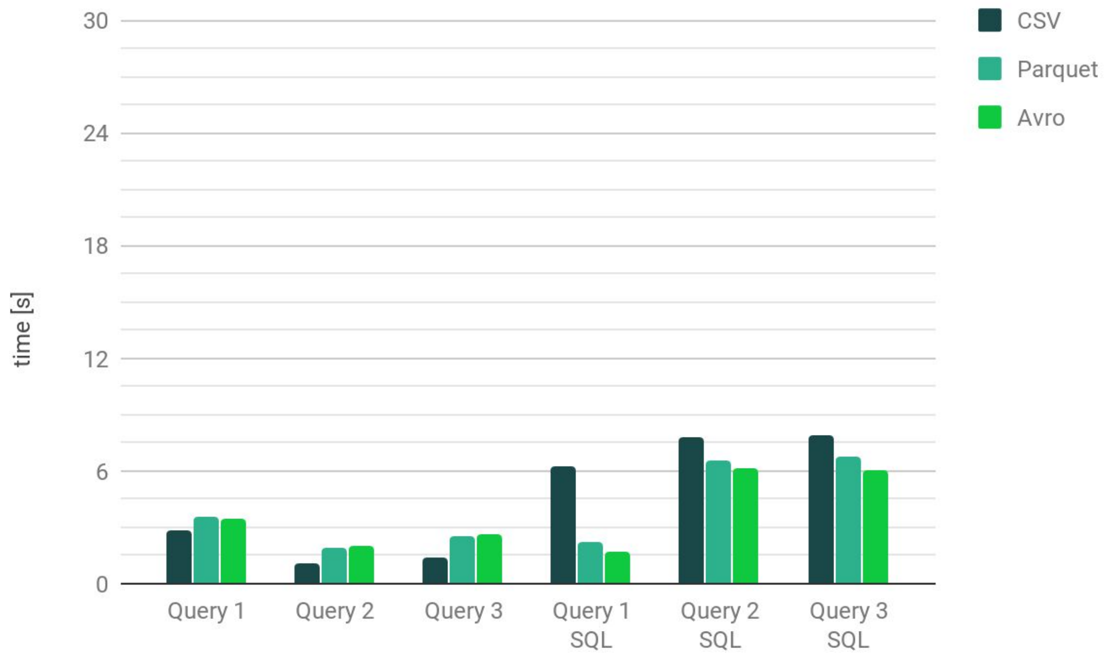
- 5 worker node cluster
- 1 master node
- node: n1-standard-2 (2 vCPUs with 7.5 GB RAM)



Cloud deployment using HDFS and cache

DataProc :

- 5 worker node cluster
- 1 master node
- node: n1-standard-2 (2 vCPUs with 7.5 GB RAM)



Cloud deployment using Alluxio

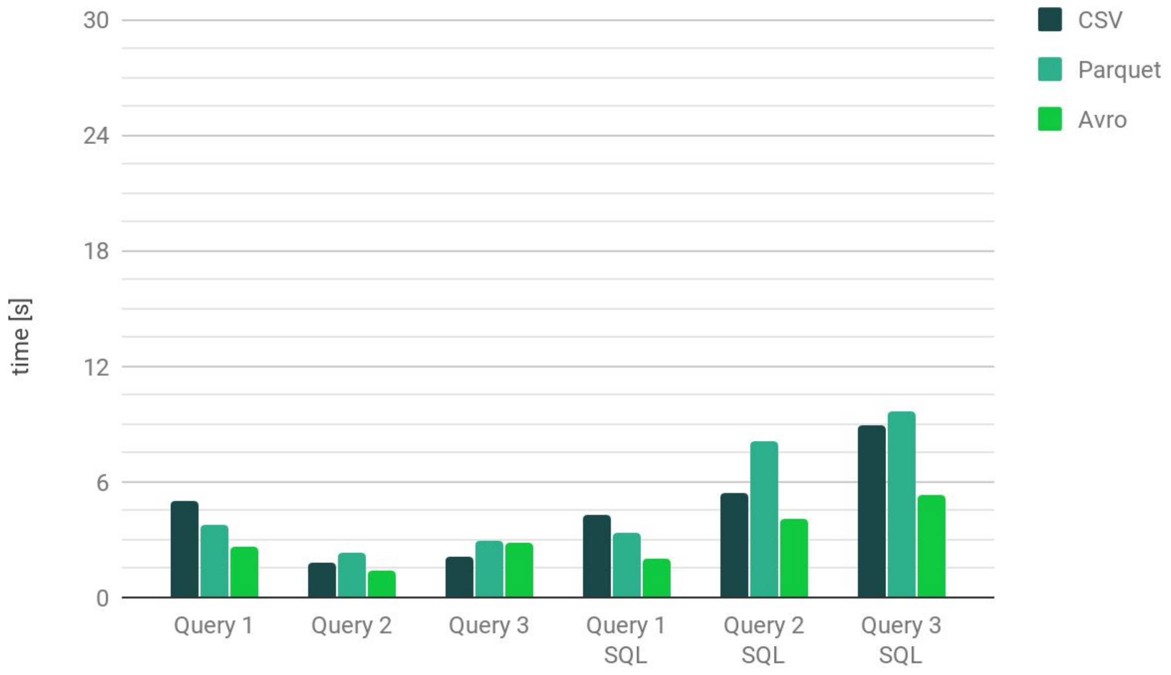
DataProc :

- 5 worker node cluster & 1 master
- node: n1-standard-2 (2 vCPUs with 7.5 GB RAM)

Kubernetes:

- 3 node n1-standard-2 cluster (each with Alluxio agent)

Both clusters on same VPC network



Best Performance

- Avro as dataset format
- Alluxio (on top of HDFS) as distributed file system
- No Spark caching

Best Performance

	Core	SQL
Query 1	2.37 s	2,01 s
Query 2	1.39 s	4.12 s
Query 3	2.84 s	5.31 s

Thank you for listening!