Upravljanje i analiza velikih skupova podataka

Projekat 1 - Apache Spark & HDFS

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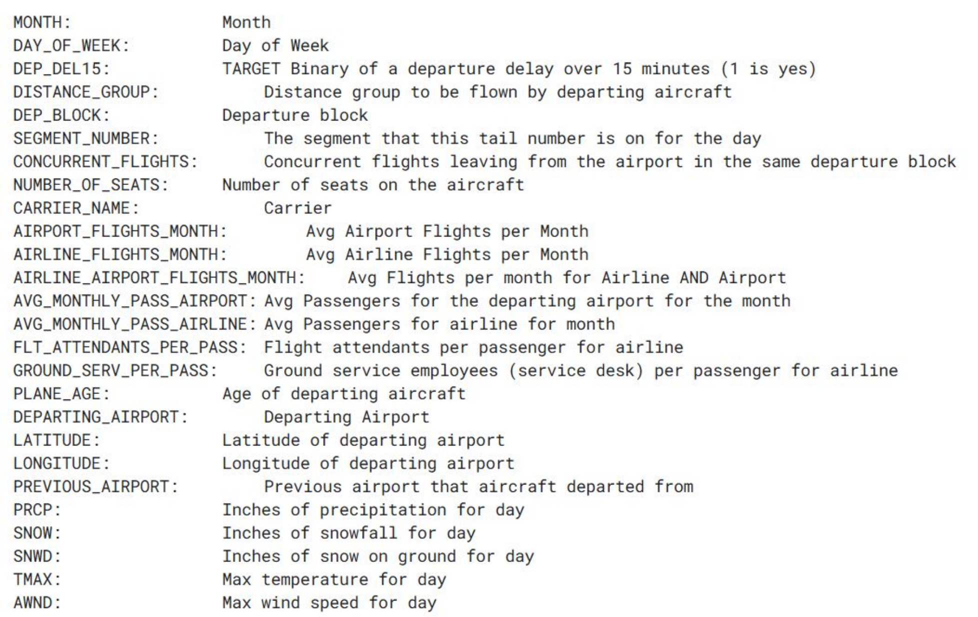
Projekat 1

- Analiza kašnjenja letova korišćenjem Apache Spark-a:
  - Batch obrada velikog skupa podataka
  - Python API (PySpark) + Spark na Docker klasteru (BDE/Bitnami)
  - HDFS za skladištenje podataka

- Funkcionalnosti aplikacije:
  - Brojanje i filtriranje podataka po zadatim kriterijumima (npr. mesec, aviokompanija)
  - Statistička analiza atributa (min, max, avg, stddev) grupisanih po kolonama (npr. aviokompanija, aerodrom)

Skup podataka

- 2019 Airline Delays w/Weather and Airport Detail (≈1.37GB)
- https://www.kaggle.com/datasets/threnjen/2019-airline-delays-and-cancellations?select=full_data_flightdelay.csv
- Skup podataka sa detaljnim informacijama o avio-kompanijama, aerodromima i vremenskim uslovima



```
MONTH:                  Month
DAY_OF_WEEK:            Day of Week
DEP_DEL15:              TARGET Binary of a departure delay over 15 minutes (1 is yes)
DISTANCE_GROUP:             Distance group to be flown by departing aircraft
DEP_BLOCK:              Departure block
SEGMENT_NUMBER:             The segment that this tail number is on for the day
CONCURRENT_FLIGHTS:         Concurrent flights leaving from the airport in the same departure block
NUMBER_OF_SEATS:        Number of seats on the aircraft
CARRIER_NAME:               Carrier
AIRPORT_FLIGHTS_MONTH:          Avg Airport Flights per Month
AIRLINE_FLIGHTS_MONTH:          Avg Airline Flights per Month
AIRLINE_AIRPORT_FLIGHTS_MONTH:      Avg Flights per month for Airline AND Airport
AVG_MONTHLY_PASS_AIRPORT: Avg Passengers for the departing airport for the month
AVG_MONTHLY_PASS_AIRLINE: Avg Passengers for airline for month
FLT_ATTENDANTS_PER_PASS:  Flight attendants per passenger for airline
GROUND_SERV_PER_PASS:     Ground service employees (service desk) per passenger for airline
PLANE_AGE:              Age of departing aircraft
DEPARTING_AIRPORT:          Departing Airport
LATITUDE:               Latitude of departing airport
LONGITUDE:              Longitude of departing airport
PREVIOUS_AIRPORT:           Previous airport that aircraft departed from
PRCP:                   Inches of precipitation for day
SNOW:                   Inches of snowfall for day
SNWD:                   Inches of snow on ground for day
TMAX:                   Max temperature for day
AWND:                   Max wind speed for day
```

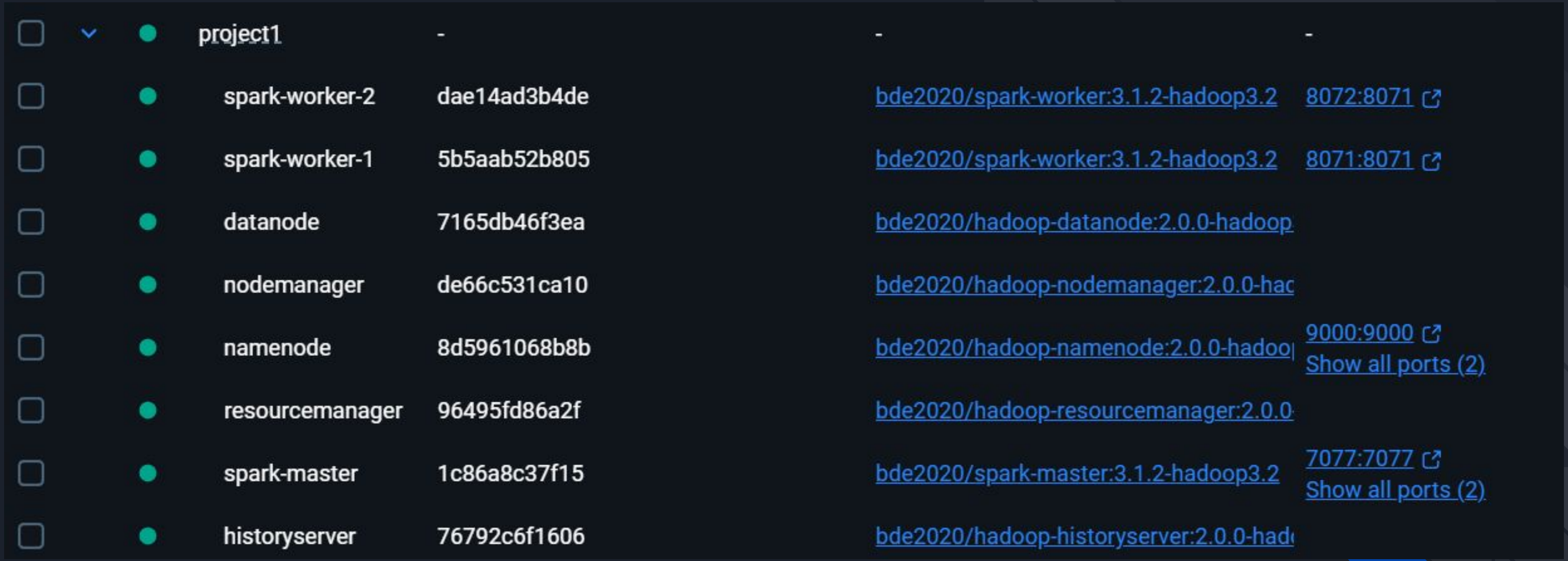
Docker i klaster kontejnera

- Dockerfile za Spark aplikaciju
- `docker-compose.yml`klaster konfiguracija:
  - Spark klaster (Spark master + 2 workera)
  - Hadoop klaster (namenode, datanode, resourcemanager, nodemanager, historyserver)

- Docker konfiguracija koristi BDE (Big Data Europe) slike, standardne za ovakve projekte.
- Spark aplikacija pokreće se unutar mreže bde

- Pokretanje infrastrukture:
  - `docker network create bde`
  - pozicioniranje u folder gde se nalazi `docker-compose.yml`
  - `docker-compose up --build -d`

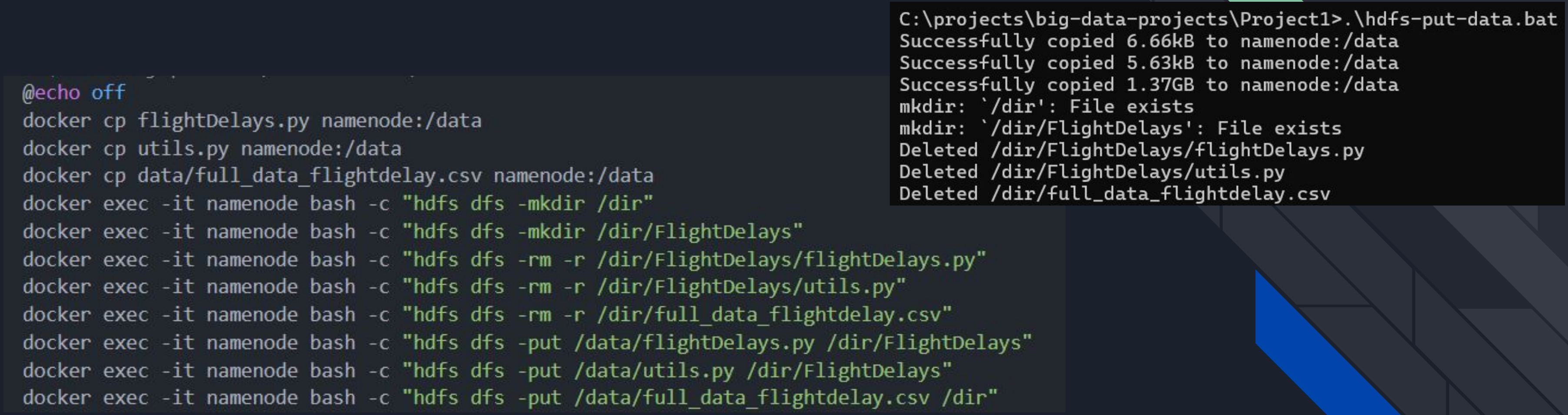
Docker i klaster kontejnera



□	⌄	●	project1	-	-	-
□		●	spark-worker-2	dae14ad3b4de	bde2020/spark-worker:3.1.2-hadoop3.2	8072:8071
□		●	spark-worker-1	5b5aab52b805	bde2020/spark-worker:3.1.2-hadoop3.2	8071:8071
□		●	datanode	7165db46f3ea	bde2020/hadoop-datanode:2.0.0-hadoop	
□		●	nodemanager	de66c531ca10	bde2020/hadoop-nodemanager:2.0.0-hac	
□		●	namenode	8d5961068b8b	bde2020/hadoop-namenode:2.0.0-hadoo	9000:9000 Show all ports (2)
□		●	resourcemanager	96495fd86a2f	bde2020/hadoop-resourcemanager:2.0.0	
□		●	spark-master	1c86a8c37f15	bde2020/spark-master:3.1.2-hadoop3.2	7077:7077 Show all ports (2)
□		●	historyserver	76792c6f1606	bde2020/hadoop-historyserver:2.0.0-had	

Postavljanje podataka na HDFS

- Pokretanje skripte:
  - Pozicioniranje u folder u kome se nalazi skripta `hdfs-put-data.bat`
  - `./hdfs-put-data.bat`
- Nakon pokretanja, svi neophodni podaci će biti kopirani na HDFS

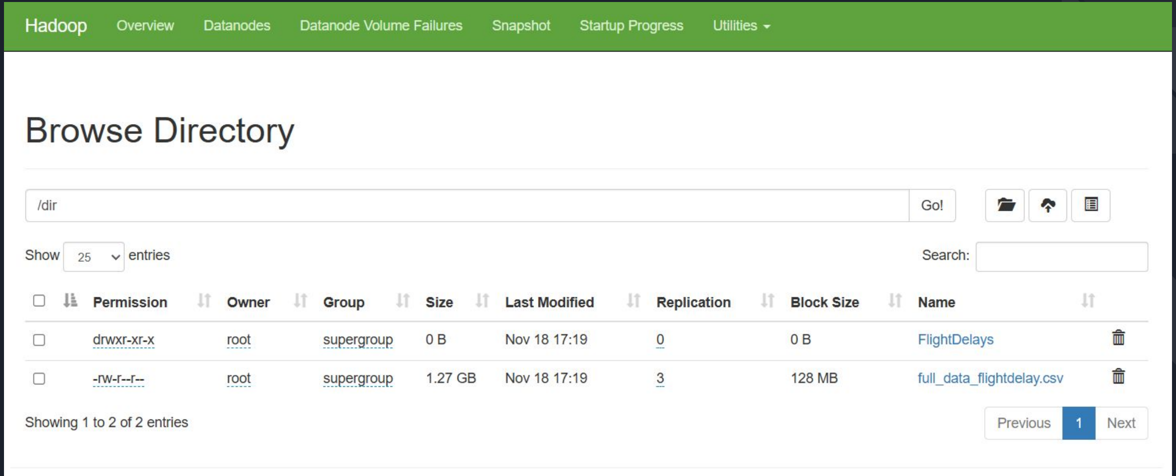


```
@echo off
docker cp flightDelays.py namenode:/data
docker cp utils.py namenode:/data
docker cp data/full_data_flightdelay.csv namenode:/data
docker exec -it namenode bash -c "hdfs dfs -mkdir /dir"
docker exec -it namenode bash -c "hdfs dfs -mkdir /dir/FlightDelays"
docker exec -it namenode bash -c "hdfs dfs -rm -r /dir/FlightDelays/flightDelays.py"
docker exec -it namenode bash -c "hdfs dfs -rm -r /dir/FlightDelays/utils.py"
docker exec -it namenode bash -c "hdfs dfs -rm -r /dir/full_data_flightdelay.csv"
docker exec -it namenode bash -c "hdfs dfs -put /data/flightDelays.py /dir/FlightDelays"
docker exec -it namenode bash -c "hdfs dfs -put /data/utils.py /dir/FlightDelays"
docker exec -it namenode bash -c "hdfs dfs -put /data/full_data_flightdelay.csv /dir"
```

```
C:\projects\big-data-projects\Project1>.\hdfs-put-data.bat
Successfully copied 6.66kB to namenode:/data
Successfully copied 5.63kB to namenode:/data
Successfully copied 1.37GB to namenode:/data
mkdir: `/dir': File exists
mkdir: `/dir/FlightDelays': File exists
Deleted /dir/FlightDelays/flightDelays.py
Deleted /dir/FlightDelays/utils.py
Deleted /dir/full_data_flightdelay.csv
```

Pregled podataka

- Hadoop namenode: http://localhost:9870/



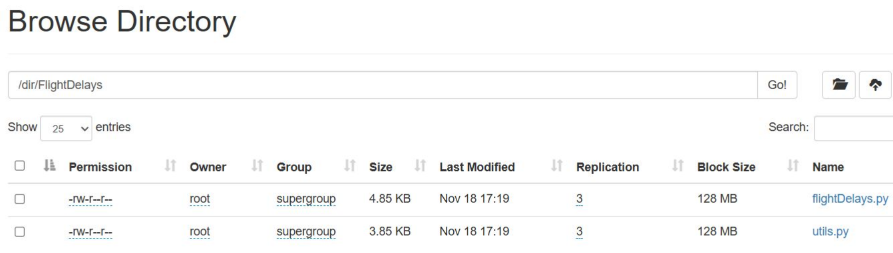
Browse Directory

/dir

☐	Permission	Owner	Group	Size	Last Modified	Replication	Block Size	Name
☐	drwxr-xr-x	root	supergroup	0 B	Nov 18 17:19	0	0 B	FlightDelays
☐	-rw-r--r--	root	supergroup	1.27 GB	Nov 18 17:19	3	128 MB	full_data_flightdelay.csv

Showing 1 to 2 of 2 entries

Hadoop, 2019.



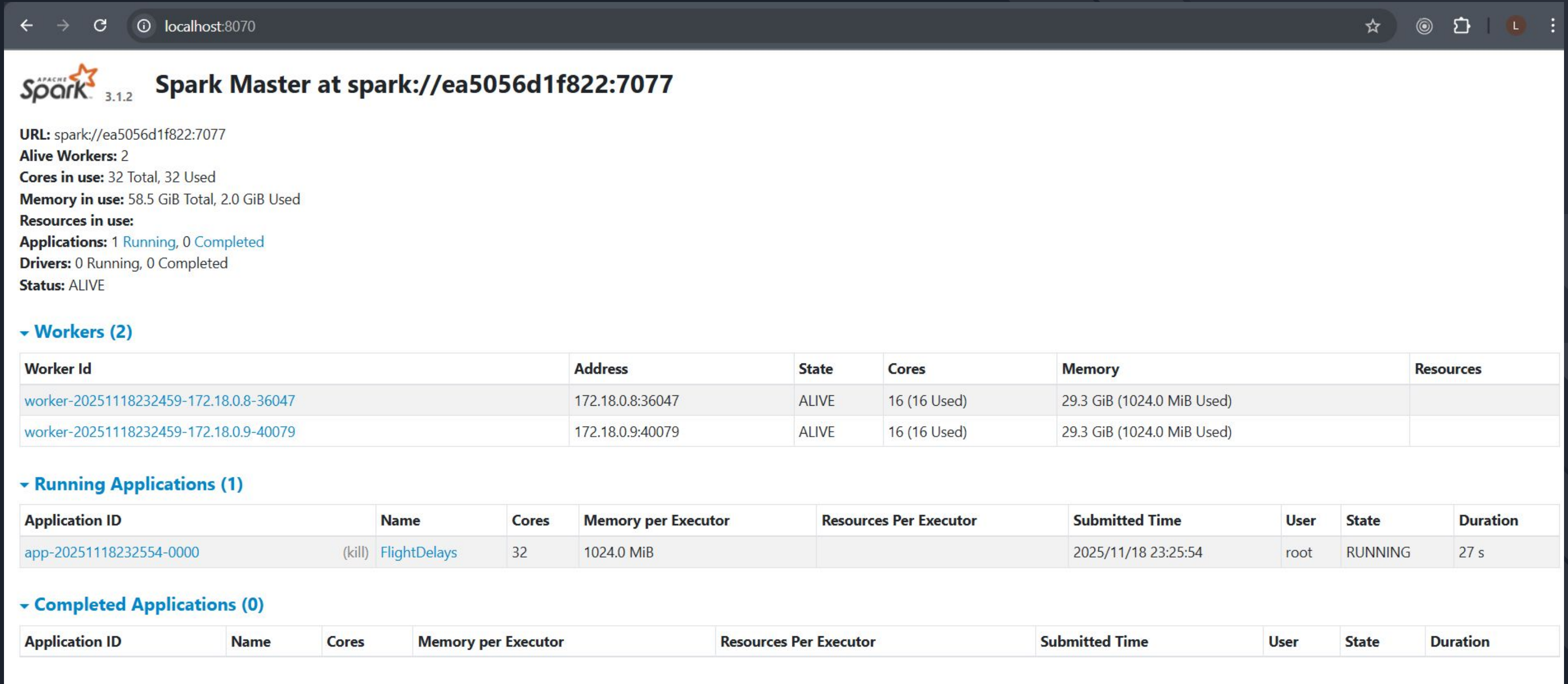
Browse Directory

/dir/FlightDelays

☐	Permission	Owner	Group	Size	Last Modified	Replication	Block Size	Name
☐	-rw-r--r--	root	supergroup	4.85 KB	Nov 18 17:19	3	128 MB	flightDelays.py
☐	-rw-r--r--	root	supergroup	3.85 KB	Nov 18 17:19	3	128 MB	utils.py

Spark master

- Dostupan na: http://localhost:8070/
- Na ovom prozoru moguće je praćenje aktivnosti workera, dostupne memorije, statuse aplikacija, vremena izvršavanja, itd.



Spark Master at spark://ea5056d1f822:7077

3.1.2

URL: spark://ea5056d1f822:7077
Alive Workers: 2
Cores in use: 32 Total, 32 Used
Memory in use: 58.5 GiB Total, 2.0 GiB Used
Resources in use:
Applications: 1 Running, 0 Completed
Drivers: 0 Running, 0 Completed
Status: ALIVE

Workers (2)

Worker Id	Address	State	Cores	Memory	Resources
worker-20251118232459-172.18.0.8-36047	172.18.0.8:36047	ALIVE	16 (16 Used)	29.3 GiB (1024.0 MiB Used)	
worker-20251118232459-172.18.0.9-40079	172.18.0.9:40079	ALIVE	16 (16 Used)	29.3 GiB (1024.0 MiB Used)	

Running Applications (1)

Application ID	Name	Cores	Memory per Executor	Resources Per Executor	Submitted Time	User	State	Duration
app-20251118232554-0000 (kill)	FlightDelays	32	1024.0 MiB		2025/11/18 23:25:54	root	RUNNING	27 s

Completed Applications (0)

Application ID	Name	Cores	Memory per Executor	Resources Per Executor	Submitted Time	User	State	Duration

Pokretanje aplikacije - I način

1. Manuelno pokretanje

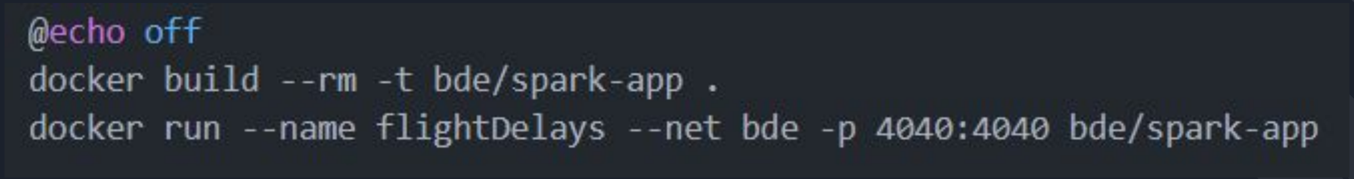
-
  ```
  docker run -it --network bde --env-file hadoop.env -p 4040:4040 --name
  spark bde2020/spark-base:3.1.2-hadoop3.2 bash
  ```

-
  ```
  /spark/bin/spark-submit --master spark://spark-master:7077 --py-files
  hdfs://namenode:9000/dir/FlightDelays/utils.py
  hdfs://namenode:9000/dir/FlightDelays/flightDelays.py --input
  hdfs://namenode:9000/dir/full_data_flightdelay.csv --month 7 --carrier
  "United Air Lines Inc." --stats_col PLANE_AGE --group_by_col CARRIER_NAME
  ```

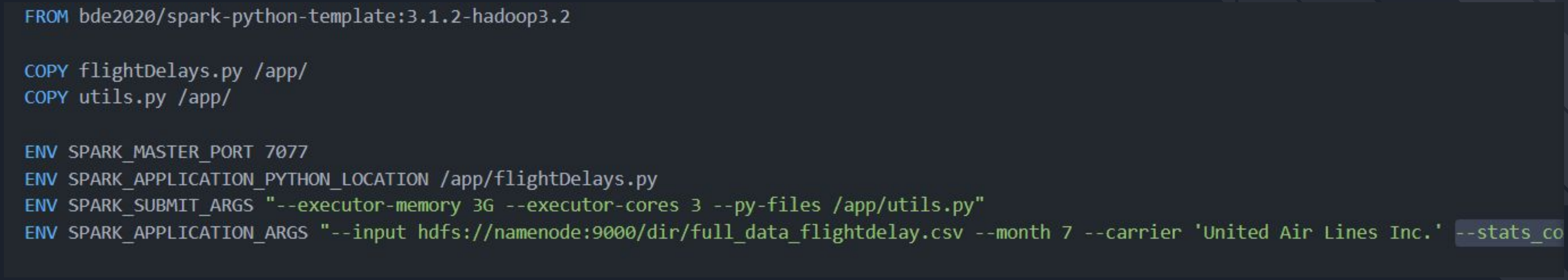
Pokretanje aplikacije - II način

2. Korišćenjem Spark Python template-a

- Pozicionirati se u folder koji sadrži `run.bat` skriptu
- Pokrenuti `run.bat` skriptu: `.\run.bat`



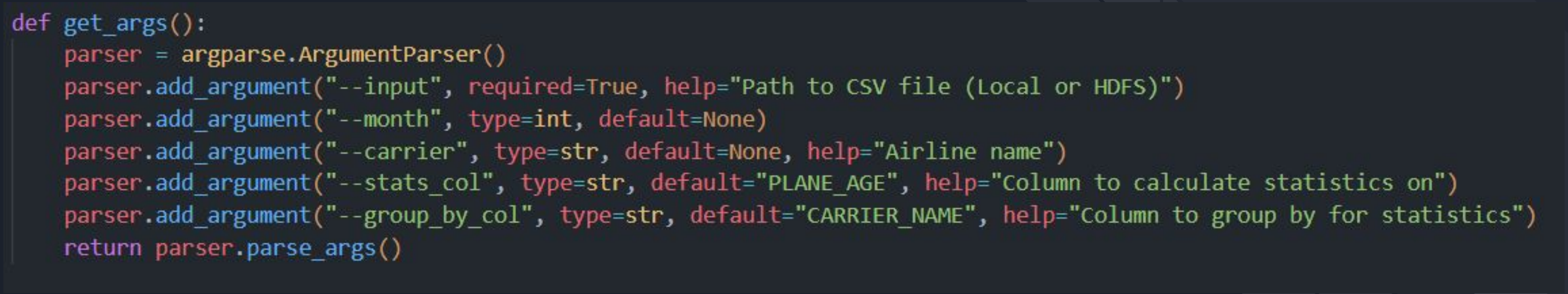
```
@echo off
docker build --rm -t bde/spark-app .
docker run --name flightDelays --net bde -p 4040:4040 bde/spark-app
```



```
FROM bde2020/spark-python-template:3.1.2-hadoop3.2

COPY flightDelays.py /app/
COPY utils.py /app/

ENV SPARK_MASTER_PORT 7077
ENV SPARK_APPLICATION_PYTHON_LOCATION /app/flightDelays.py
ENV SPARK_SUBMIT_ARGS "--executor-memory 3G --executor-cores 3 --py-files /app/utils.py"
ENV SPARK_APPLICATION_ARGS "--input hdfs://namenode:9000/dir/full_data_flightdelay.csv --month 7 --carrier 'United Air Lines Inc.' --stats_co
```

Aplikacija

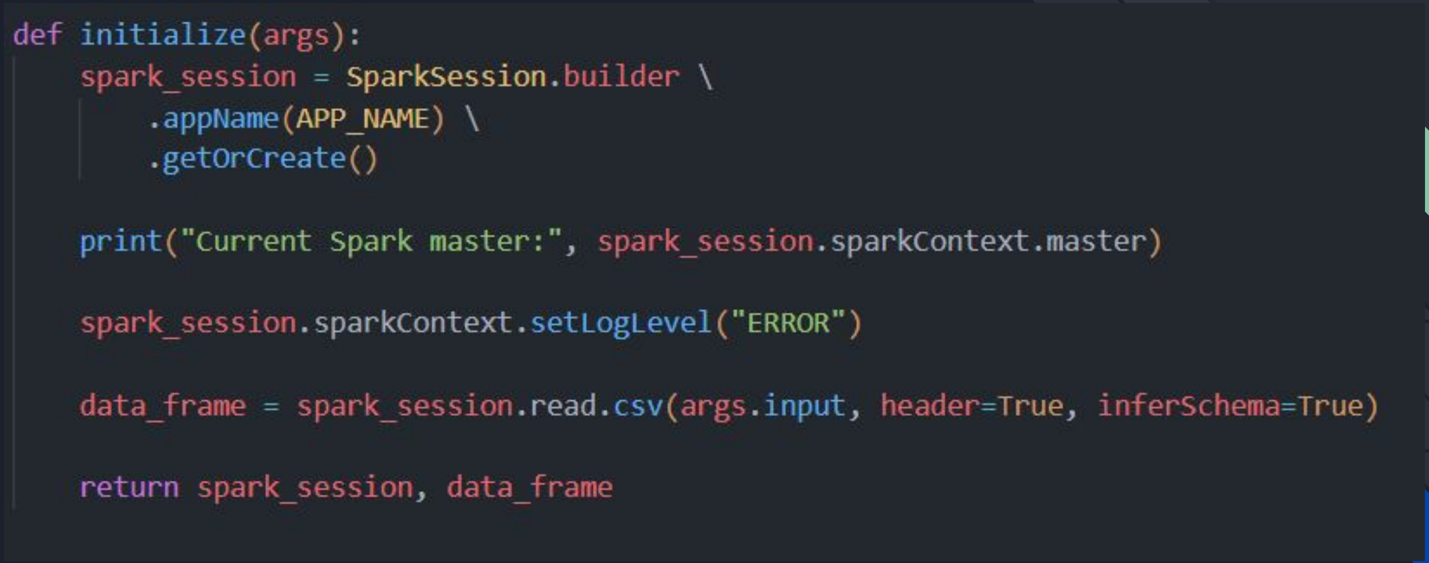
- Argumenti aplikacije



```python
def get_args():
    parser = argparse.ArgumentParser()
    parser.add_argument("--input", required=True, help="Path to CSV file (Local or HDFS)")
    parser.add_argument("--month", type=int, default=None)
    parser.add_argument("--carrier", type=str, default=None, help="Airline name")
    parser.add_argument("--stats_col", type=str, default="PLANE_AGE", help="Column to calculate statistics on")
    parser.add_argument("--group_by_col", type=str, default="CARRIER_NAME", help="Column to group by for statistics")
    return parser.parse_args()
```

Aplikacija

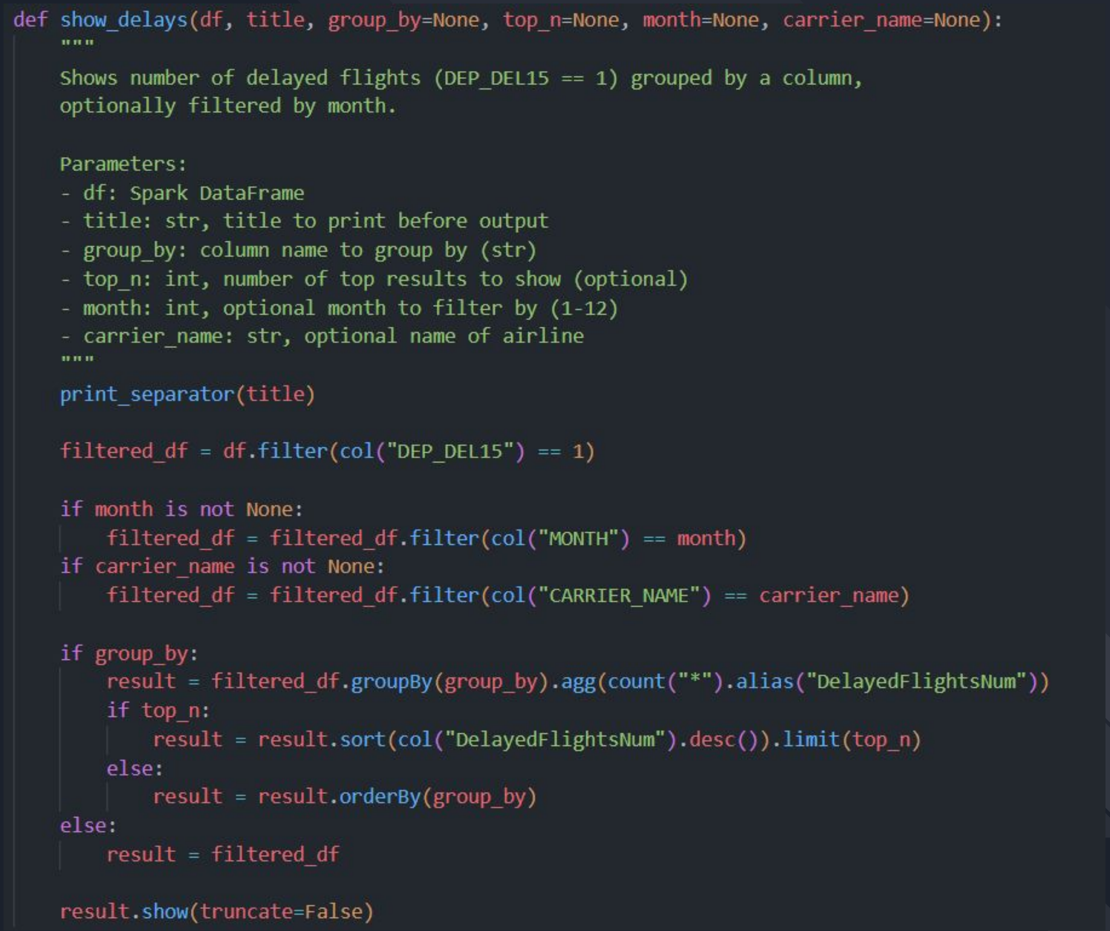
- Spark inicijalizacija i učitavanje dataset-a



```python
def initialize(args):
    spark_session = SparkSession.builder \
        .appName(APP_NAME) \
        .getOrCreate()

    print("Current Spark master:", spark_session.sparkContext.master)

    spark_session.sparkContext.setLogLevel("ERROR")

    data_frame = spark_session.read.csv(args.input, header=True, inferSchema=True)

    return spark_session, data_frame
```

Aplikacija

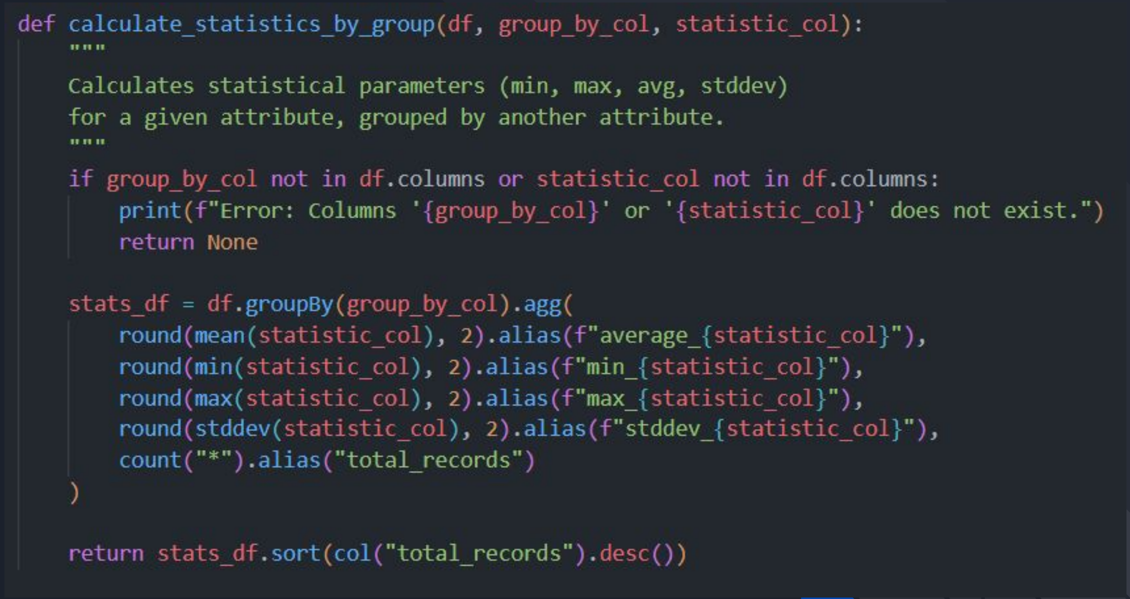
- Funkcija za određivanje broja letova sa kašnjenjem ≥ 15 minuta na osnovu na osnovu zadatih argumenata (--month, --carrier)



```python
def show_delays(df, title, group_by=None, top_n=None, month=None, carrier_name=None):
    """
    Shows number of delayed flights (DEP_DEL15 == 1) grouped by a column,
    optionally filtered by month.

    Parameters:
    - df: Spark DataFrame
    - title: str, title to print before output
    - group_by: column name to group by (str)
    - top_n: int, number of top results to show (optional)
    - month: int, optional month to filter by (1-12)
    - carrier_name: str, optional name of airline
    """
    print_separator(title)

    filtered_df = df.filter(col("DEP_DEL15") == 1)

    if month is not None:
        filtered_df = filtered_df.filter(col("MONTH") == month)
    if carrier_name is not None:
        filtered_df = filtered_df.filter(col("CARRIER_NAME") == carrier_name)

    if group_by:
        result = filtered_df.groupBy(group_by).agg(count("*").alias("DelayedFlightsNum"))
        if top_n:
            result = result.sort(col("DelayedFlightsNum").desc()).limit(top_n)
        else:
            result = result.orderBy(group_by)
    else:
        result = filtered_df

    result.show(truncate=False)
```

Aplikacija

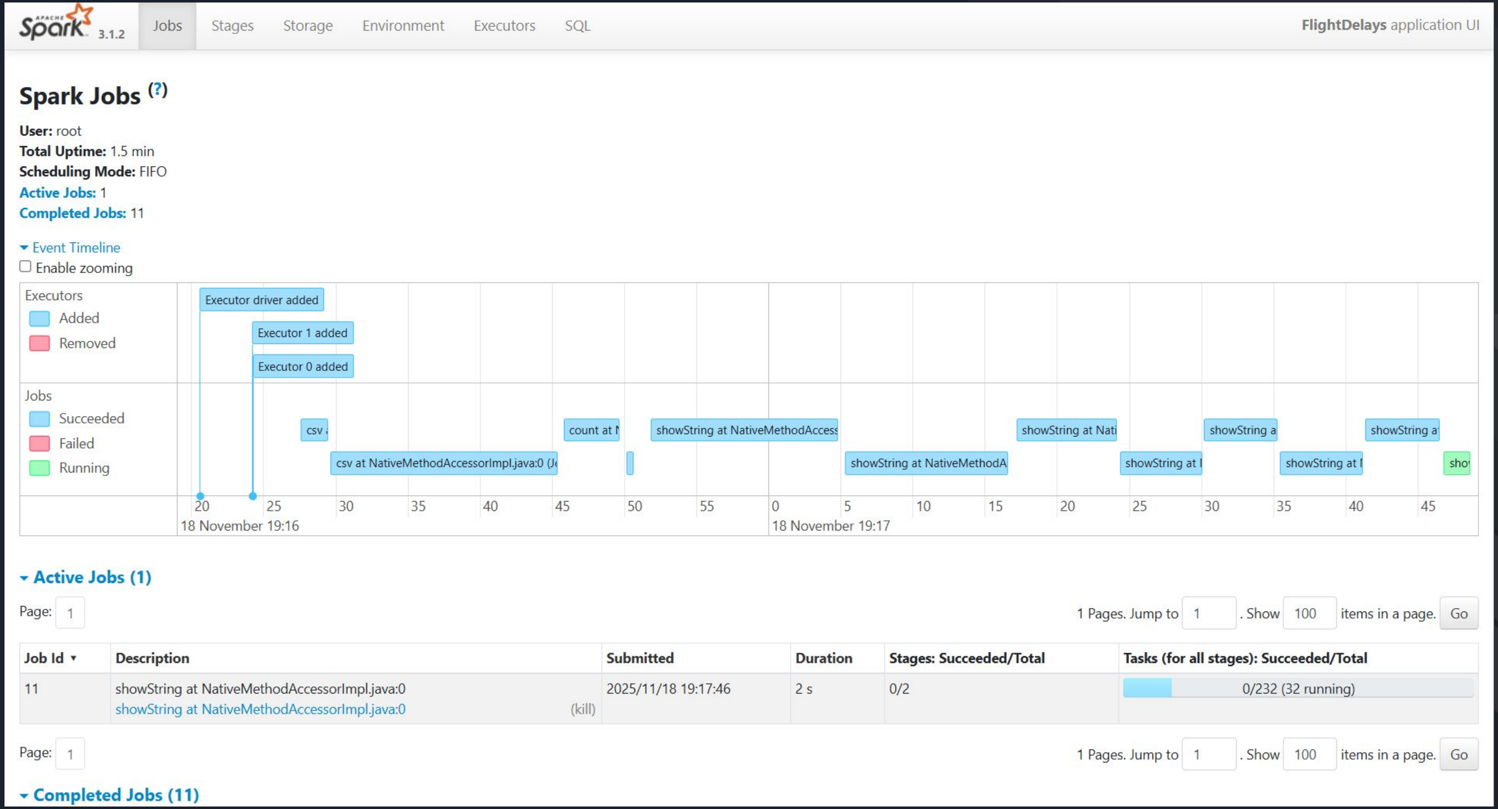
- Funkcija koja računa statističke parametre (minimalne, maksimalne, srednje vrednosti, standardne devijacije) i broj zapisa za zadati atribut (--stats_col) grupisane po drugom atributu (--group_by_col)
- Koristi agregacione funkcije PySpark-a



```python
def calculate_statistics_by_group(df, group_by_col, statistic_col):
    """
    Calculates statistical parameters (min, max, avg, stddev)
    for a given attribute, grouped by another attribute.
    """
    if group_by_col not in df.columns or statistic_col not in df.columns:
        print(f"Error: Columns '{group_by_col}' or '{statistic_col}' does not exist.")
        return None

    stats_df = df.groupBy(group_by_col).agg(
        round(mean(statistic_col), 2).alias(f"average_{statistic_col}"),
        round(min(statistic_col), 2).alias(f"min_{statistic_col}"),
        round(max(statistic_col), 2).alias(f"max_{statistic_col}"),
        round(stddev(statistic_col), 2).alias(f"stddev_{statistic_col}"),
        count("*").alias("total_records")
    )

    return stats_df.sort(col("total_records").desc())
```

Praćenje rada Spark aplikacije

- http://localhost:4040/



Spark Jobs (?)

User: root
Total Uptime: 1.5 min
Scheduling Mode: FIFO
Active Jobs: 1
Completed Jobs: 11

▾ Event Timeline
□ Enable zooming

▾ Active Jobs (1)

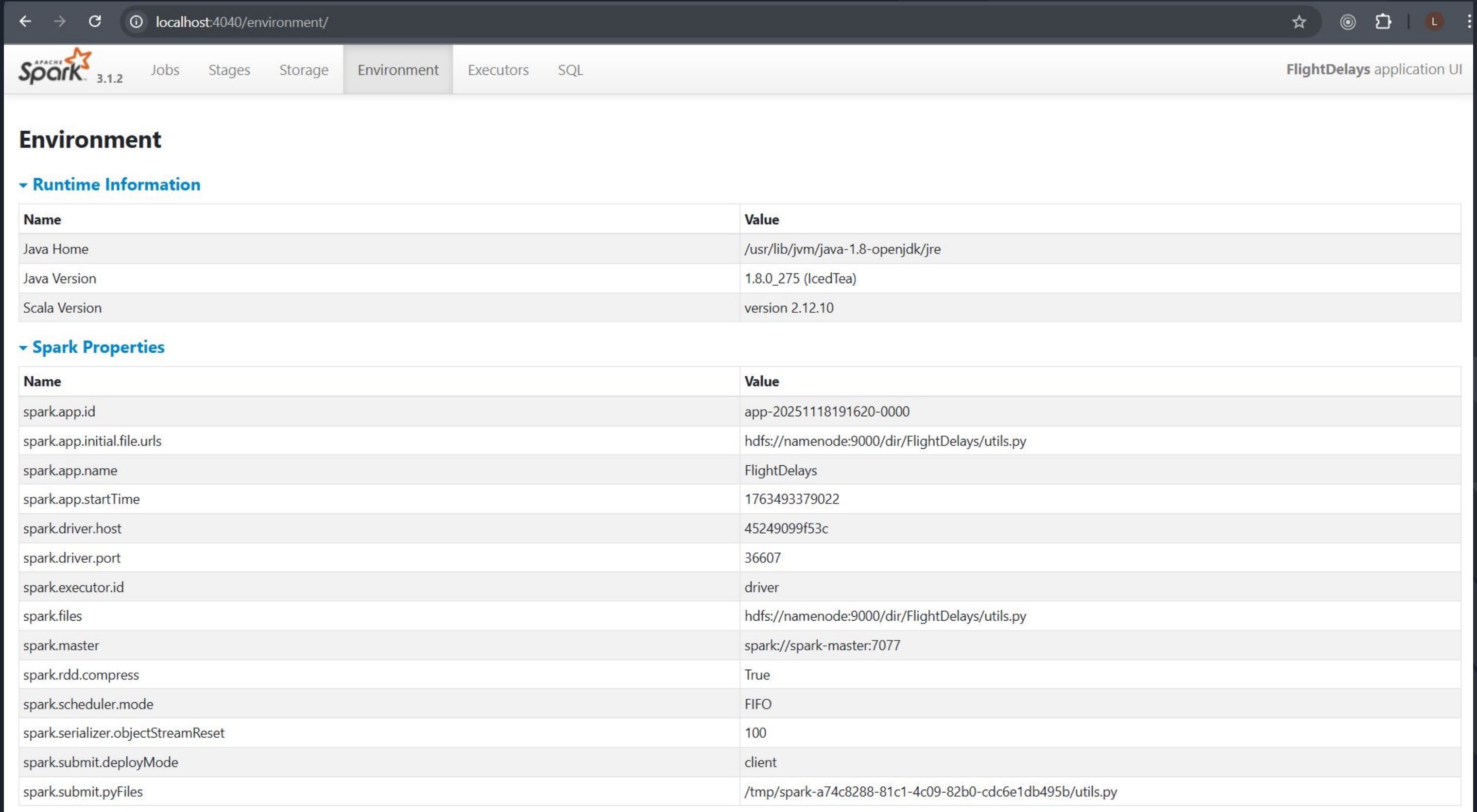
Page: 1   1 Pages. Jump to 1 . Show 100 items in a page. Go

Job Id ▾	Description	Submitted	Duration	Stages: Succeeded/Total	Tasks (for all stages): Succeeded/Total
11	showString at NativeMethodAccessorImpl.java:0 showString at NativeMethodAccessorImpl.java:0 (kill)	2025/11/18 19:17:46	2 s	0/2	0/232 (32 running)

Page: 1   1 Pages. Jump to 1 . Show 100 items in a page. Go

▾ Completed Jobs (11)

Konfiguracije i promenljive okruženja



Environment

Runtime Information

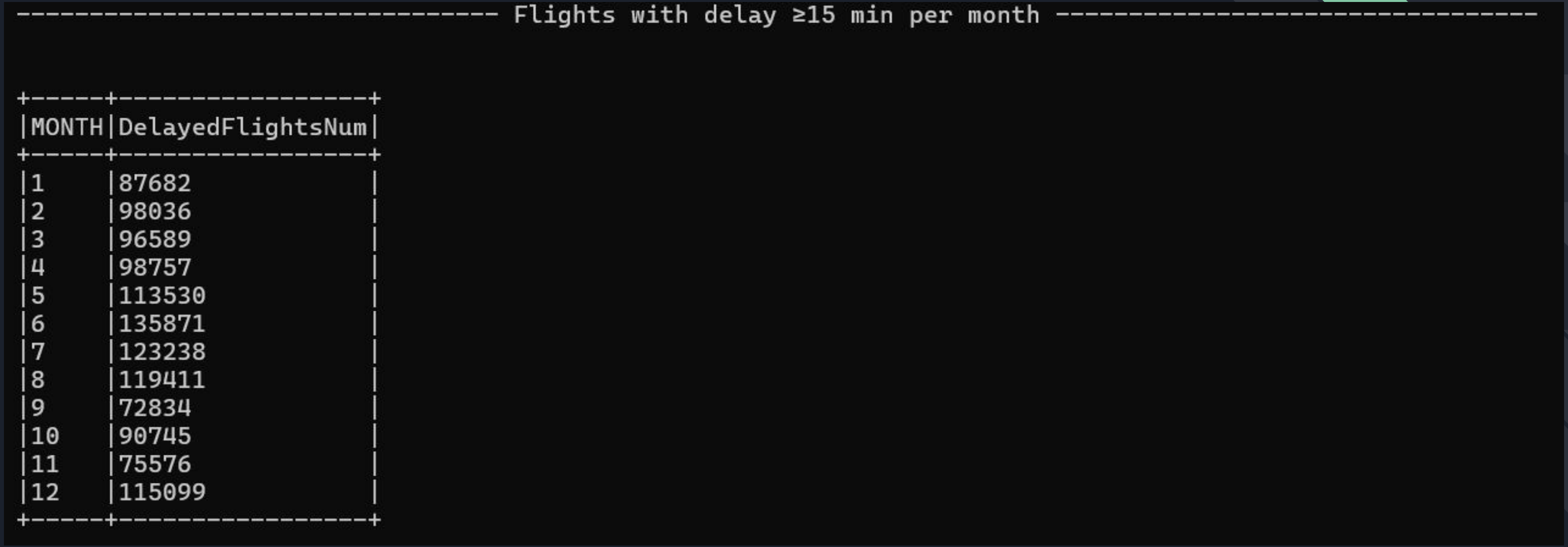
Name	Value
Java Home	/usr/lib/jvm/java-1.8-openjdk/jre
Java Version	1.8.0_275 (IcedTea)
Scala Version	version 2.12.10

Spark Properties

Name	Value
spark.app.id	app-20251118191620-0000
spark.app.initial.file.urls	hdfs://namenode:9000/dir/FlightDelays/utils.py
spark.app.name	FlightDelays
spark.app.startTime	1763493379022
spark.driver.host	45249099f53c
spark.driver.port	36607
spark.executor.id	driver
spark.files	hdfs://namenode:9000/dir/FlightDelays/utils.py
spark.master	spark://spark-master:7077
spark.rdd.compress	True
spark.scheduler.mode	FIFO
spark.serializer.objectStreamReset	100
spark.submit.deployMode	client
spark.submit.pyFiles	/tmp/spark-a74c8288-81c1-4c09-82b0-cdc6e1db495b/utils.py

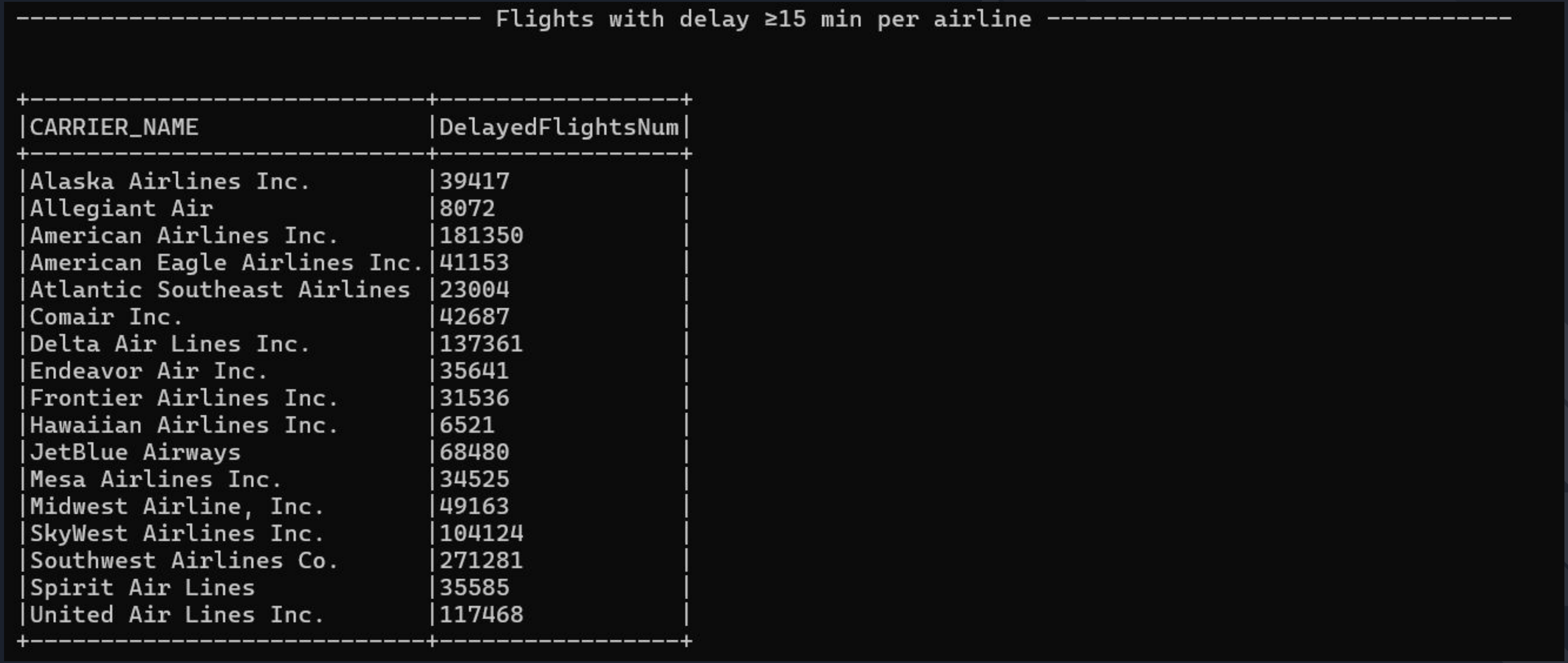
Prikaz rezultata

- --input hdfs://namenode:9000/dir/full_data_flightdelay.csv
- --month 7
- --carrier "United Air Lines Inc."
- --stats_col PLANE_AGE
- --group_by_col CARRIER_NAME



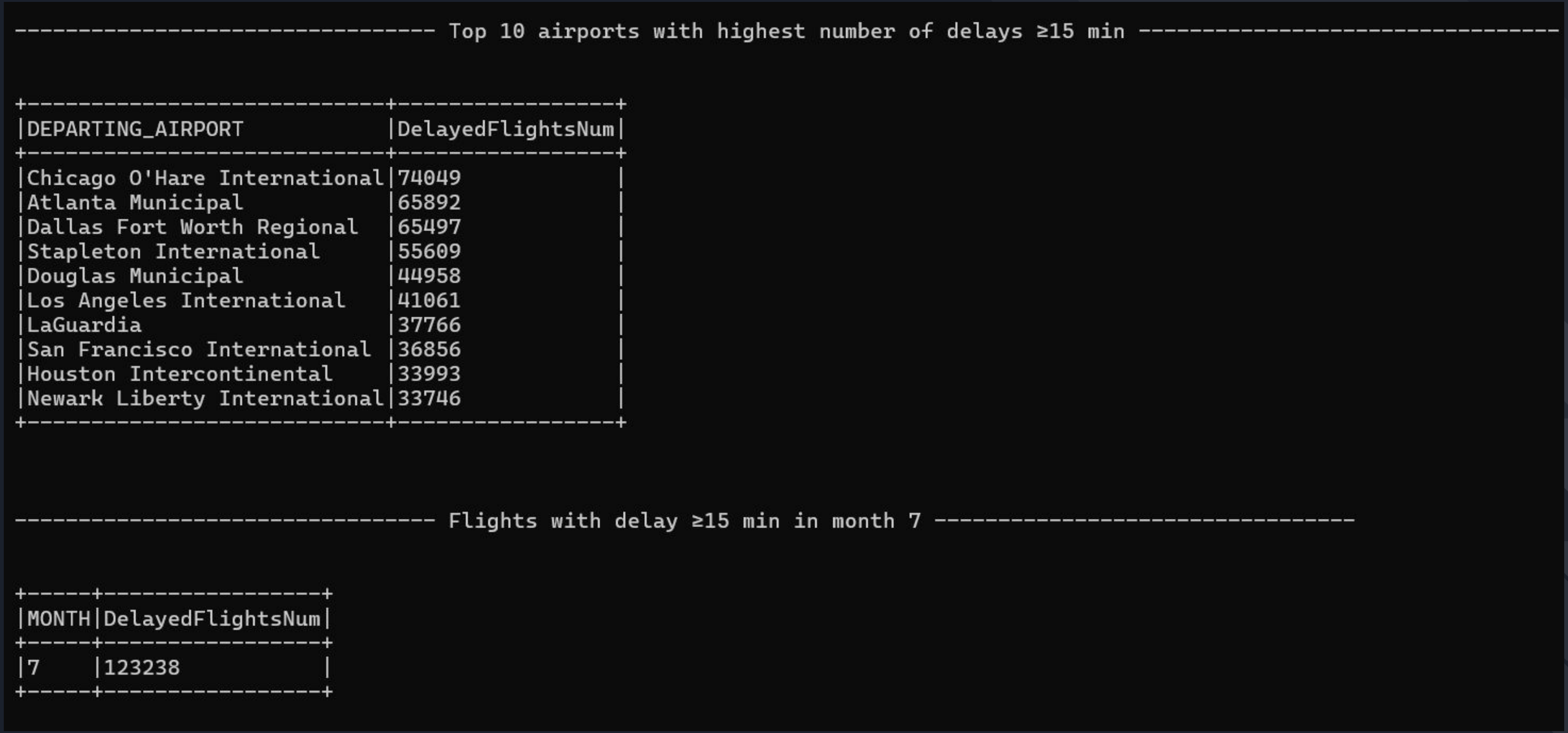
```
--------------------------------- Flights with delay ≥15 min per month ---------------------------------


+-----+-----------------+
|MONTH|DelayedFlightsNum|
+-----+-----------------+
|1    |87682            |
|2    |98036            |
|3    |96589            |
|4    |98757            |
|5    |113530           |
|6    |135871           |
|7    |123238           |
|8    |119411           |
|9    |72834            |
|10   |90745            |
|11   |75576            |
|12   |115099           |
+-----+-----------------+
```

Prikaz rezultata



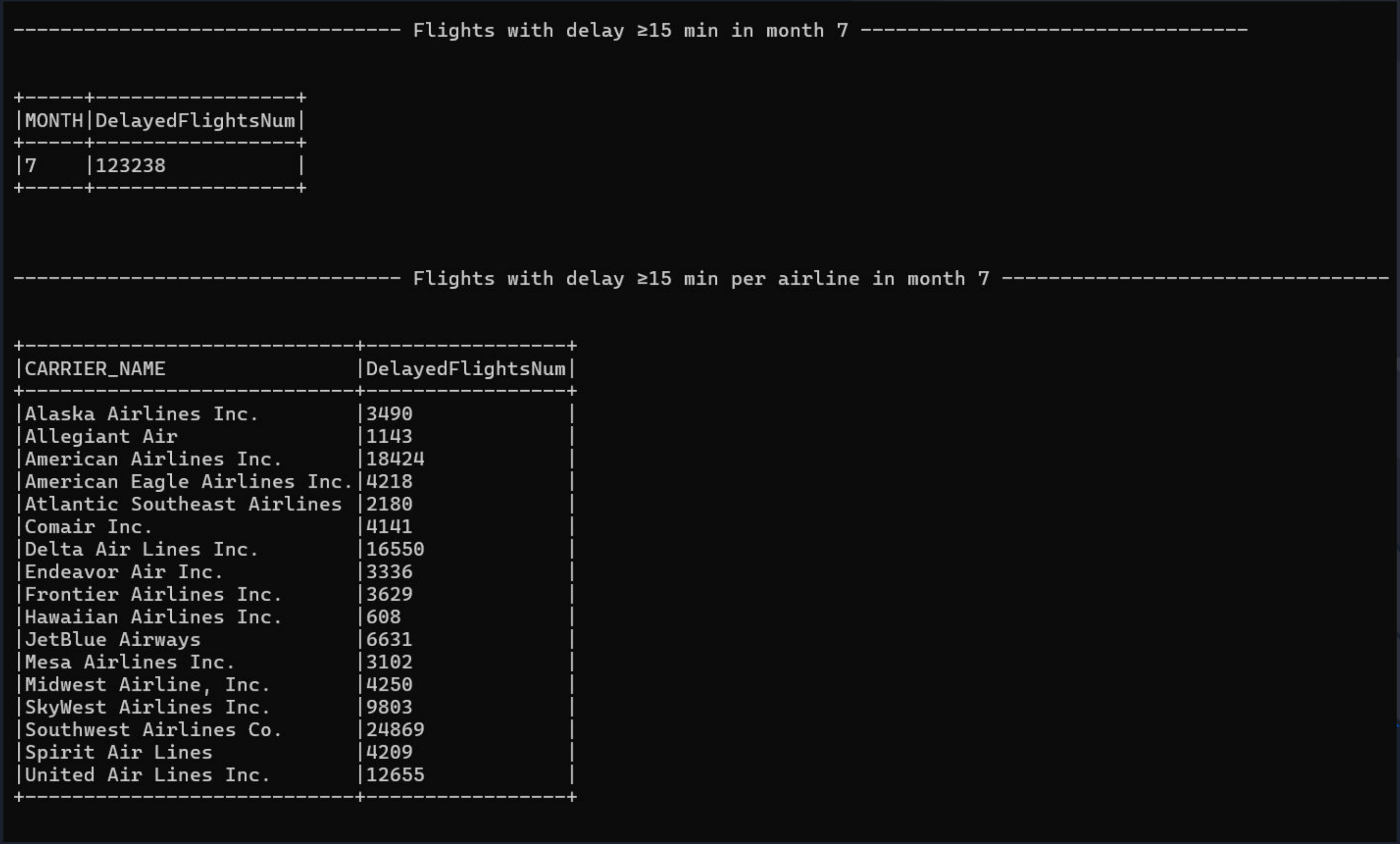
```
--------------------------------- Flights with delay ≥15 min per airline ---------------------------------


+----------------------------+-----------------+
|CARRIER_NAME                |DelayedFlightsNum|
+----------------------------+-----------------+
|Alaska Airlines Inc.        |39417            |
|Allegiant Air               |8072             |
|American Airlines Inc.      |181350           |
|American Eagle Airlines Inc.|41153            |
|Atlantic Southeast Airlines |23004            |
|Comair Inc.                 |42687            |
|Delta Air Lines Inc.        |137361           |
|Endeavor Air Inc.           |35641            |
|Frontier Airlines Inc.      |31536            |
|Hawaiian Airlines Inc.      |6521             |
|JetBlue Airways             |68480            |
|Mesa Airlines Inc.          |34525            |
|Midwest Airline, Inc.       |49163            |
|SkyWest Airlines Inc.       |104124           |
|Southwest Airlines Co.      |271281           |
|Spirit Air Lines            |35585            |
|United Air Lines Inc.       |117468           |
+----------------------------+-----------------+
```

Prikaz rezultata



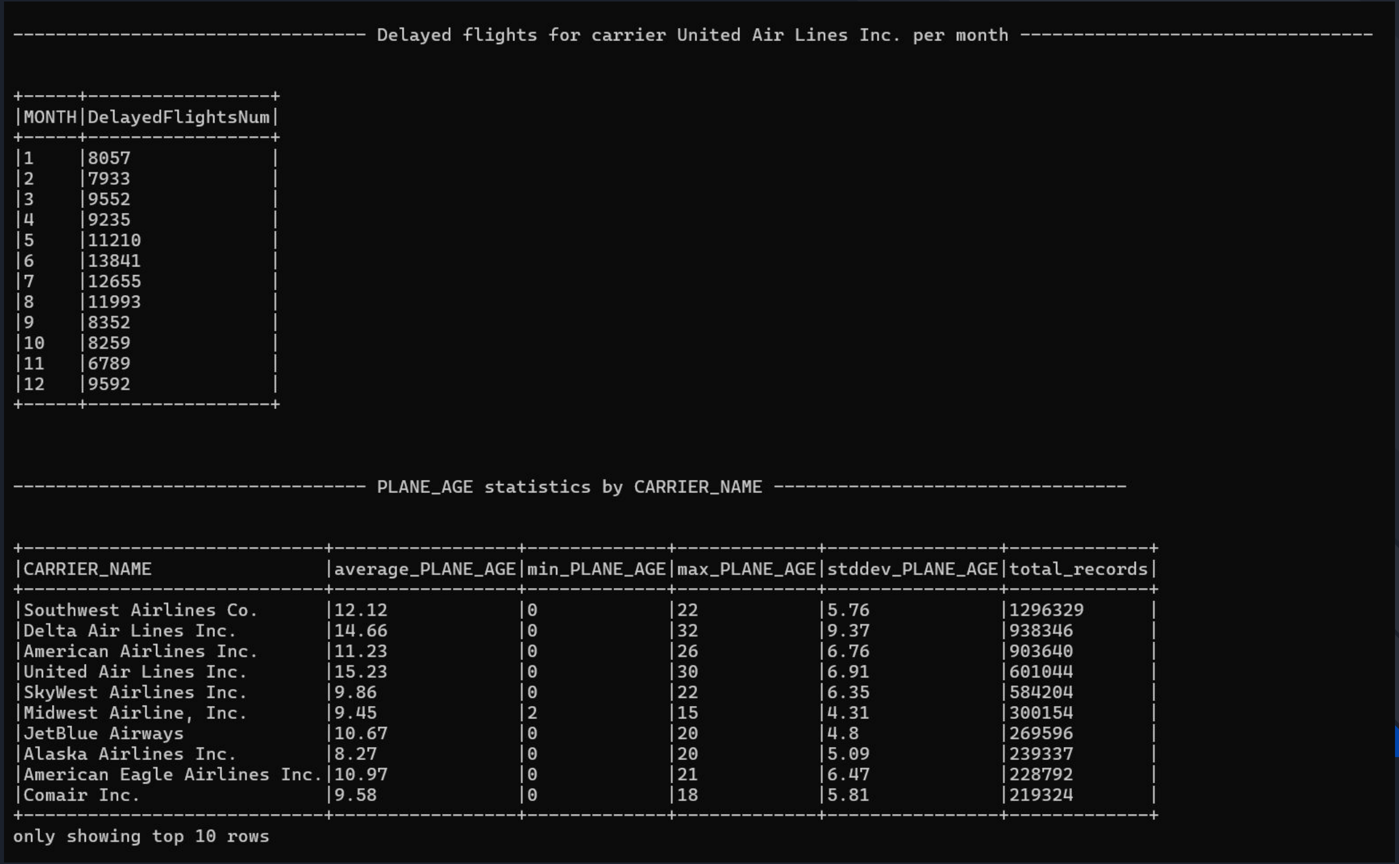
```
--------------------------------- Top 10 airports with highest number of delays ≥15 min ---------------------------------


+----------------------------+-----------------+
|DEPARTING_AIRPORT           |DelayedFlightsNum|
+----------------------------+-----------------+
|Chicago O'Hare International|74049            |
|Atlanta Municipal           |65892            |
|Dallas Fort Worth Regional  |65497            |
|Stapleton International     |55609            |
|Douglas Municipal           |44958            |
|Los Angeles International   |41061            |
|LaGuardia                   |37766            |
|San Francisco International |36856            |
|Houston Intercontinental    |33993            |
|Newark Liberty International|33746            |
+----------------------------+-----------------+



--------------------------------- Flights with delay ≥15 min in month 7 ---------------------------------


+-----+-----------------+
|MONTH|DelayedFlightsNum|
+-----+-----------------+
|7    |123238           |
+-----+-----------------+
```

Prikaz rezultata



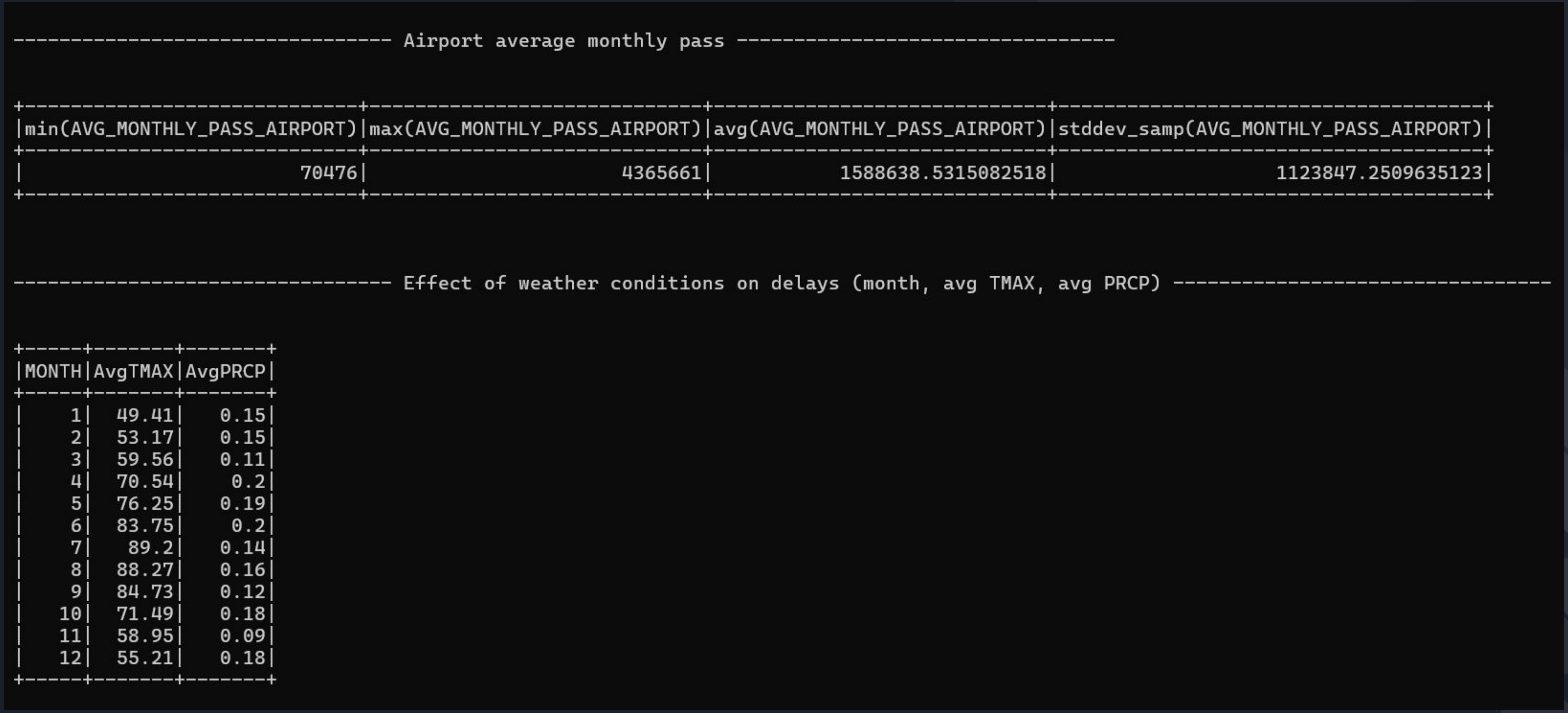
```
--------------------------------- Flights with delay ≥15 min in month 7 ---------------------------------


+-----+-----------------+
|MONTH|DelayedFlightsNum|
+-----+-----------------+
|7    |123238           |
+-----+-----------------+




--------------------------------- Flights with delay ≥15 min per airline in month 7 ---------------------------------


+----------------------------+-----------------+
|CARRIER_NAME                |DelayedFlightsNum|
+----------------------------+-----------------+
|Alaska Airlines Inc.        |3490             |
|Allegiant Air               |1143             |
|American Airlines Inc.      |18424            |
|American Eagle Airlines Inc.|4218             |
|Atlantic Southeast Airlines |2180             |
|Comair Inc.                 |4141             |
|Delta Air Lines Inc.        |16550            |
|Endeavor Air Inc.           |3336             |
|Frontier Airlines Inc.      |3629             |
|Hawaiian Airlines Inc.      |608              |
|JetBlue Airways             |6631             |
|Mesa Airlines Inc.          |3102             |
|Midwest Airline, Inc.       |4250             |
|SkyWest Airlines Inc.       |9803             |
|Southwest Airlines Co.      |24869            |
|Spirit Air Lines            |4209             |
|United Air Lines Inc.       |12655            |
+----------------------------+-----------------+
```

Prikaz rezultata



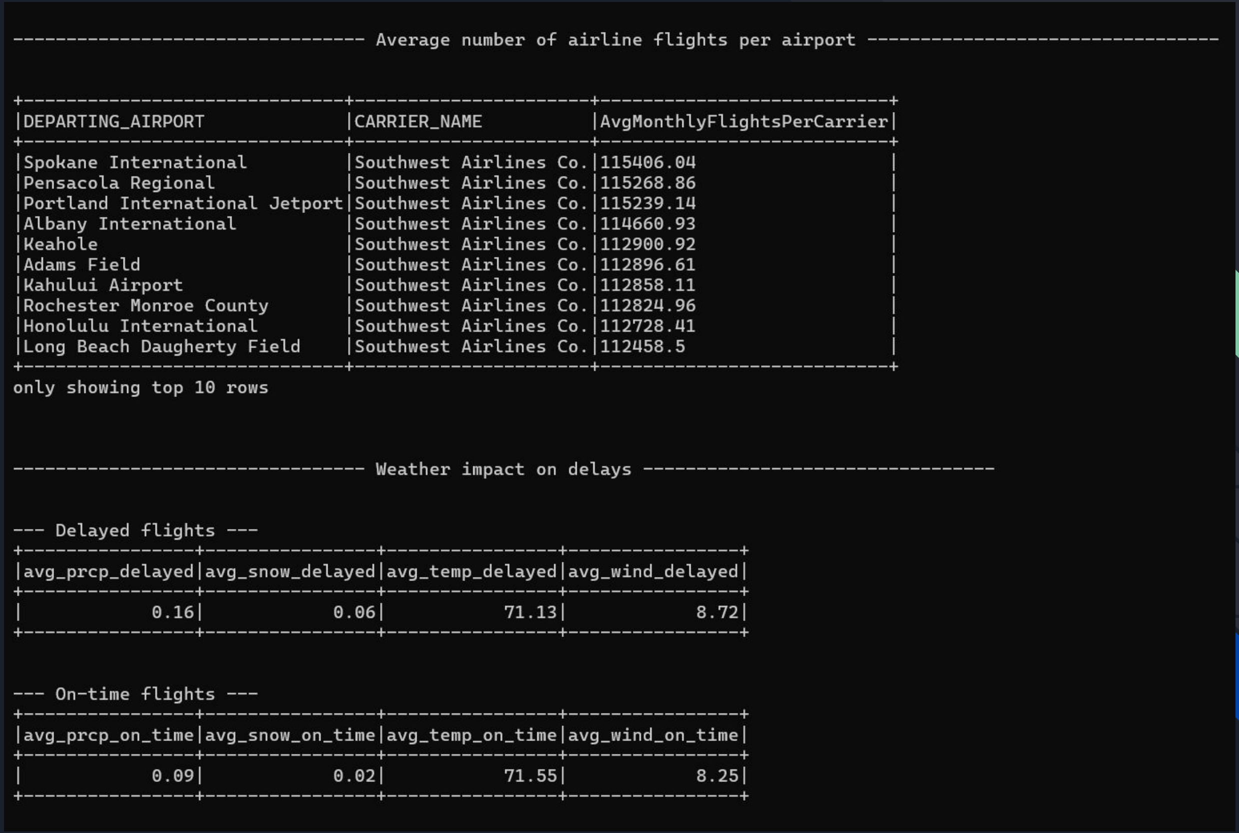
```
--------------------------------- Delayed flights for carrier United Air Lines Inc. per month ---------------------------------


+-----+-----------------+
|MONTH|DelayedFlightsNum|
+-----+-----------------+
|1    |8057             |
|2    |7933             |
|3    |9552             |
|4    |9235             |
|5    |11210            |
|6    |13841            |
|7    |12655            |
|8    |11993            |
|9    |8352             |
|10   |8259             |
|11   |6789             |
|12   |9592             |
+-----+-----------------+



--------------------------------- PLANE_AGE statistics by CARRIER_NAME ---------------------------------


+----------------------------+-----------------+-------------+-------------+----------------+-------------+
|CARRIER_NAME                |average_PLANE_AGE|min_PLANE_AGE|max_PLANE_AGE|stddev_PLANE_AGE|total_records|
+----------------------------+-----------------+-------------+-------------+----------------+-------------+
|Southwest Airlines Co.      |12.12            |0            |22           |5.76            |1296329      |
|Delta Air Lines Inc.        |14.66            |0            |32           |9.37            |938346       |
|American Airlines Inc.      |11.23            |0            |26           |6.76            |903640       |
|United Air Lines Inc.       |15.23            |0            |30           |6.91            |601044       |
|SkyWest Airlines Inc.       |9.86             |0            |22           |6.35            |584204       |
|Midwest Airline, Inc.       |9.45             |2            |15           |4.31            |300154       |
|JetBlue Airways             |10.67            |0            |20           |4.8             |269596       |
|Alaska Airlines Inc.        |8.27             |0            |20           |5.09            |239337       |
|American Eagle Airlines Inc.|10.97            |0            |21           |6.47            |228792       |
|Comair Inc.                 |9.58             |0            |18           |5.81            |219324       |
+----------------------------+-----------------+-------------+-------------+----------------+-------------+
only showing top 10 rows
```

Prikaz rezultata



```
--------------------------------- Airport average monthly pass ---------------------------------


+-----------------------------+-----------------------------+-----------------------------+-------------------------------------+
|min(AVG_MONTHLY_PASS_AIRPORT)|max(AVG_MONTHLY_PASS_AIRPORT)|avg(AVG_MONTHLY_PASS_AIRPORT)|stddev_samp(AVG_MONTHLY_PASS_AIRPORT)|
+-----------------------------+-----------------------------+-----------------------------+-------------------------------------+
|                        70476|                      4365661|           1588638.5315082518|                   1123847.2509635123|
+-----------------------------+-----------------------------+-----------------------------+-------------------------------------+



--------------------------------- Effect of weather conditions on delays (month, avg TMAX, avg PRCP) ---------------------------------


+-----+-------+-------+
|MONTH|AvgTMAX|AvgPRCP|
+-----+-------+-------+
|    1|  49.41|   0.15|
|    2|  53.17|   0.15|
|    3|  59.56|   0.11|
|    4|  70.54|    0.2|
|    5|  76.25|   0.19|
|    6|  83.75|    0.2|
|    7|   89.2|   0.14|
|    8|  88.27|   0.16|
|    9|  84.73|   0.12|
|   10|  71.49|   0.18|
|   11|  58.95|   0.09|
|   12|  55.21|   0.18|
+-----+-------+-------+
```

Prikaz rezultata



```
--------------------------------- Average number of airline flights per airport ---------------------------------


+------------------------------+----------------------+---------------------------+
|DEPARTING_AIRPORT             |CARRIER_NAME          |AvgMonthlyFlightsPerCarrier|
+------------------------------+----------------------+---------------------------+
|Spokane International         |Southwest Airlines Co.|115406.04                  |
|Pensacola Regional            |Southwest Airlines Co.|115268.86                  |
|Portland International Jetport|Southwest Airlines Co.|115239.14                  |
|Albany International          |Southwest Airlines Co.|114660.93                  |
|Keahole                       |Southwest Airlines Co.|112900.92                  |
|Adams Field                   |Southwest Airlines Co.|112896.61                  |
|Kahului Airport               |Southwest Airlines Co.|112858.11                  |
|Rochester Monroe County       |Southwest Airlines Co.|112824.96                  |
|Honolulu International        |Southwest Airlines Co.|112728.41                  |
|Long Beach Daugherty Field    |Southwest Airlines Co.|112458.5                   |
+------------------------------+----------------------+---------------------------+
only showing top 10 rows



--------------------------------- Weather impact on delays ---------------------------------


--- Delayed flights ---
+----------------+----------------+----------------+----------------+
|avg_prcp_delayed|avg_snow_delayed|avg_temp_delayed|avg_wind_delayed|
+----------------+----------------+----------------+----------------+
|            0.16|            0.06|           71.13|            8.72|
+----------------+----------------+----------------+----------------+


--- On-time flights ---
+----------------+----------------+----------------+----------------+
|avg_prcp_on_time|avg_snow_on_time|avg_temp_on_time|avg_wind_on_time|
+----------------+----------------+----------------+----------------+
|            0.09|            0.02|           71.55|            8.25|
+----------------+----------------+----------------+----------------+
```

HVALA NA PAŽNJI!