Real-time Streaming Bus Data with Kafka and Spark

by Andrea Zhang

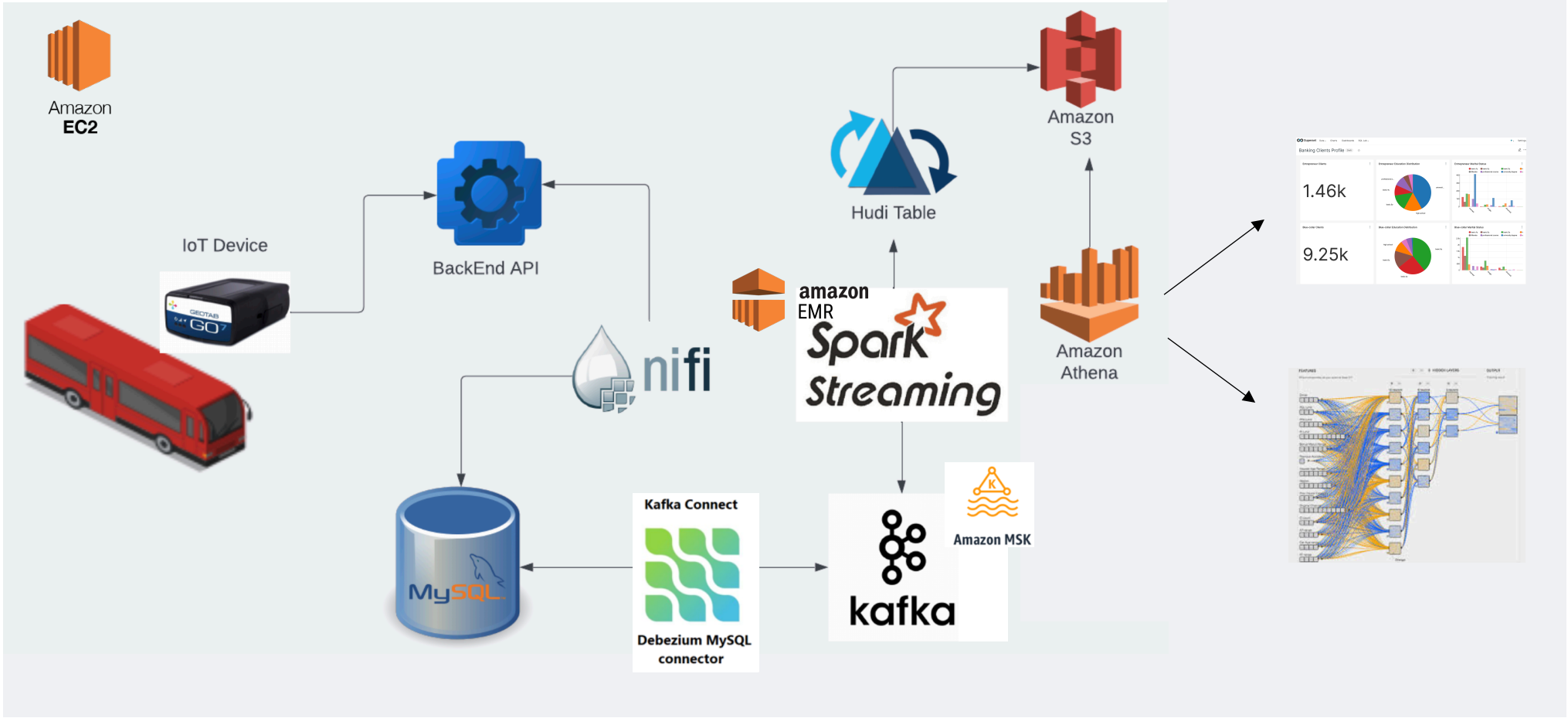
Project Motivation

Objective: The primary focus of this project is to build a real-time application that collects GPS data steamed by IoT devices located on Toronto TTC buses.

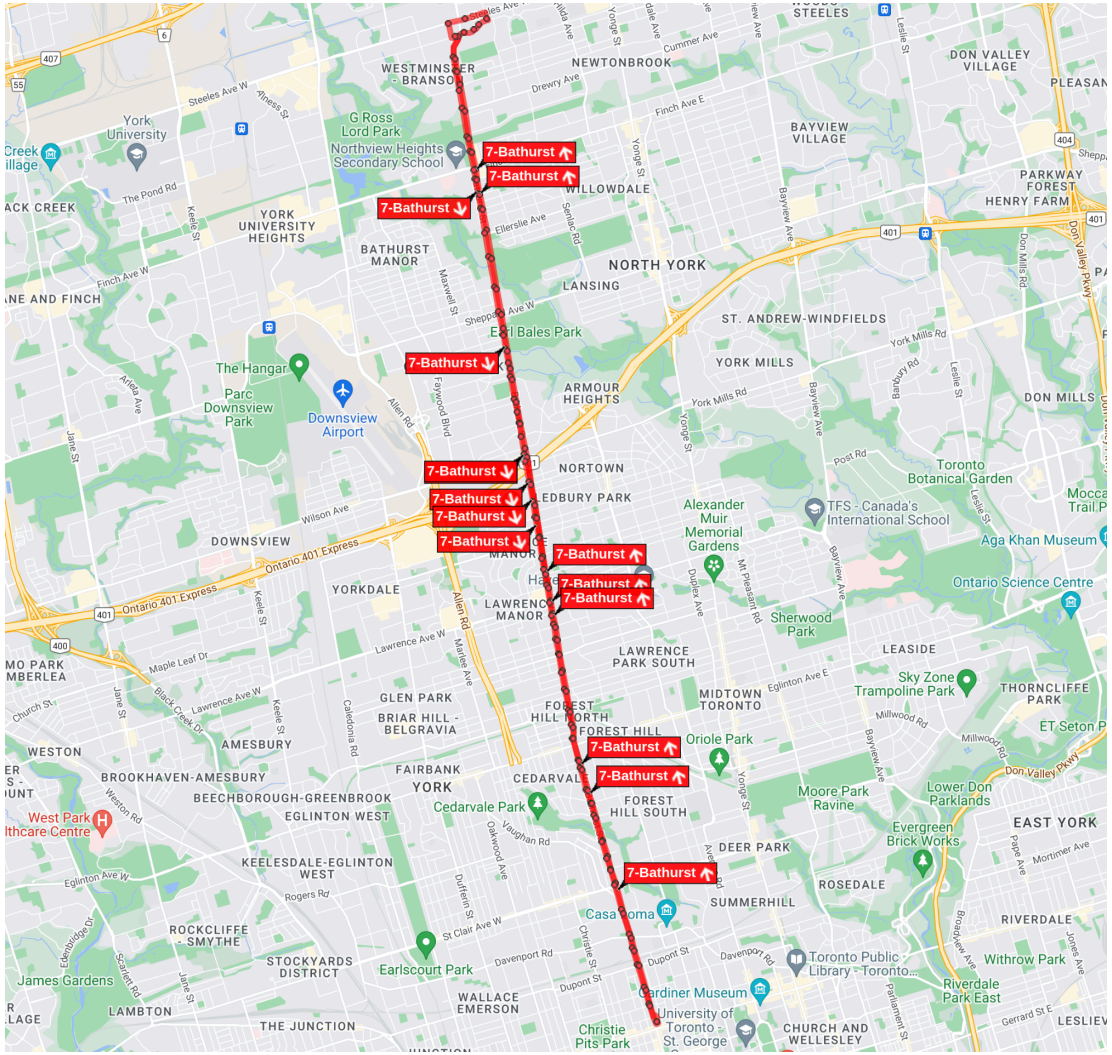
For this project, multiple big data applications were used, including Apache NiFi, CDC(Debezium), Kafka (MSK), Spark Structural Streaming, Docker, MySQL and the analytics layer using Amazon Athena.

Conceptual Data Streaming Architecture

Data Collection | Transformation | Storage | Analytics/ML



Data Collection – RestBus API



In order to collect the public bus data in real time, an open API called [Rest Bus](#) is used to import the XML Feed data using URLs with parameters specified in the query string.

Data output is in a JSON format. This data need to be transferred to an analytical database for further consumption.

Sample Data


```
[{"id":"7","title":"7-
Bathurst","_links":{"self":{"href":"http://restbus.info/api/agencies/ttc
/routes/7","type":"application/json","rel":"http://restbus.info/_links/r
el/full","rt":"route","title":"Full configuration for ttc route 7-
Bathurst."},"to":[{"href":"http://restbus.info/api/agencies/ttc/routes/7
","type":"application/json","rel":"http://restbus.info/_links/rel/full",
"rt":"route","title":"Full configuration for ttc route 7-
Bathurst."}],"from":[{"href":"http://restbus.info/api/agencies/ttc","typ
e":"application/json","rel":"via","rt":"agency","title":"Transit agency
ttc details."}
```

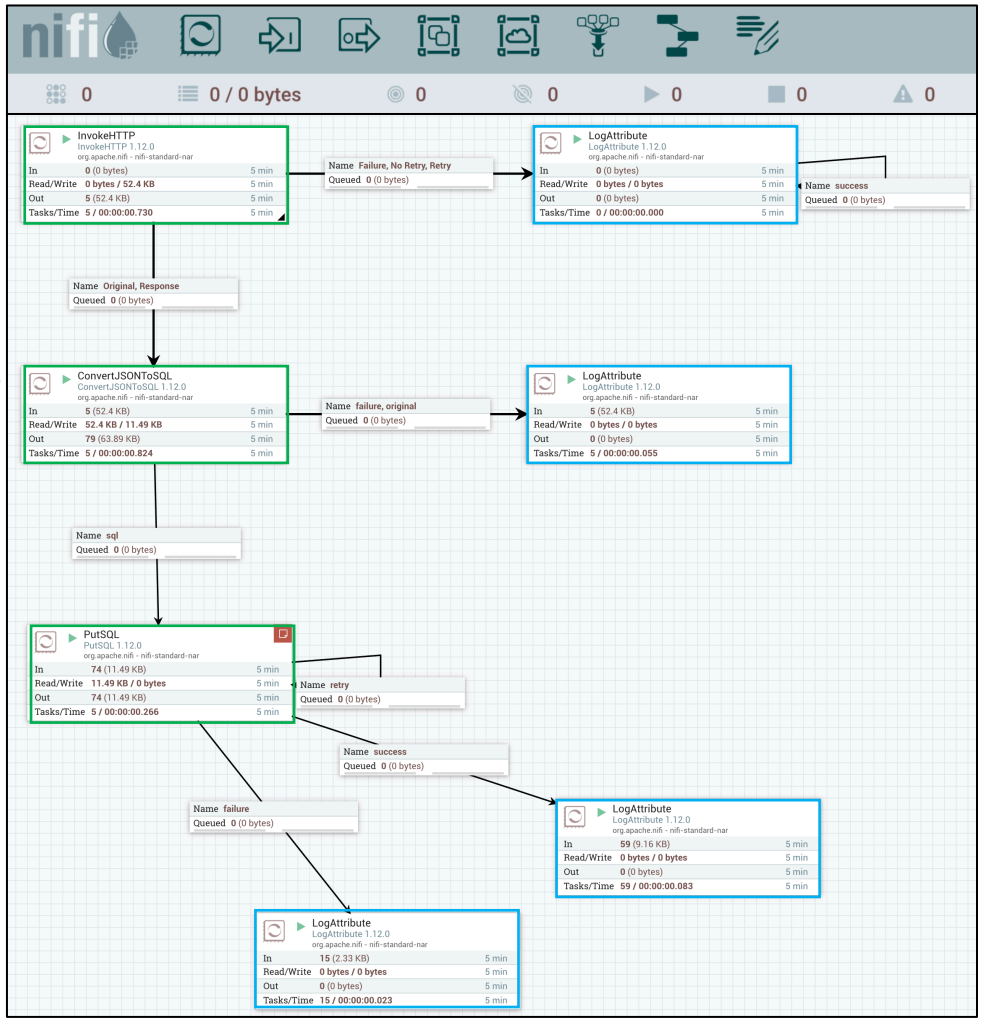
Data Transformation - Apache NiFi

InvokeHTTP collects data in JSON blobs with a scheduler of every 30s.

ConvertJSONToSQL converts data from JSON blobs into SQL insert statements.

PutSQL executes SQL insert statements.

LogAttribute Retry upon failure.



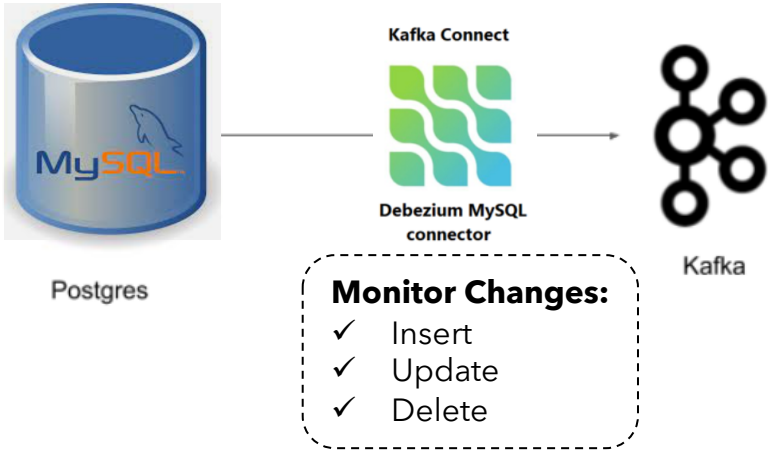
Apache NiFi is the selected solution for the data transformation problem because it provides a drag-and-drop tool that creates a data flow framework to extract the large amount of data from the bus API and send it to an analytical database with lightning speed effortlessly.

Similar to Apache Kafka, but different.

Pros	Cons
• Easy to use • Scalability • Security – pull out the queued data at any instance • Processor group – better organization of different pipelines • Template pipeline – quick creation of multiple pipelines processing different bus routes using a template	• Once the node is detached from the cluster, it's difficult to fetch the data from that node. Although you can manually copy the data from that node, it will occupy your time and energy. However, if you are on the receiver end, you cannot find the data from the detached node until the admin follows the above procedure. • Another limitation is the state persistence issue of the Apache NiFi. The issue makes it difficult for the source to fetch the data. If you experience an issue in the first node, you can expect the impact in other nodes, n as well.

Data Distribution – MySQL with Debezium

The data from Bus API will be stored in MySQL tables, constantly updated, and sent over the changes to the Kafka topic via Debezium's Kafka Connect.



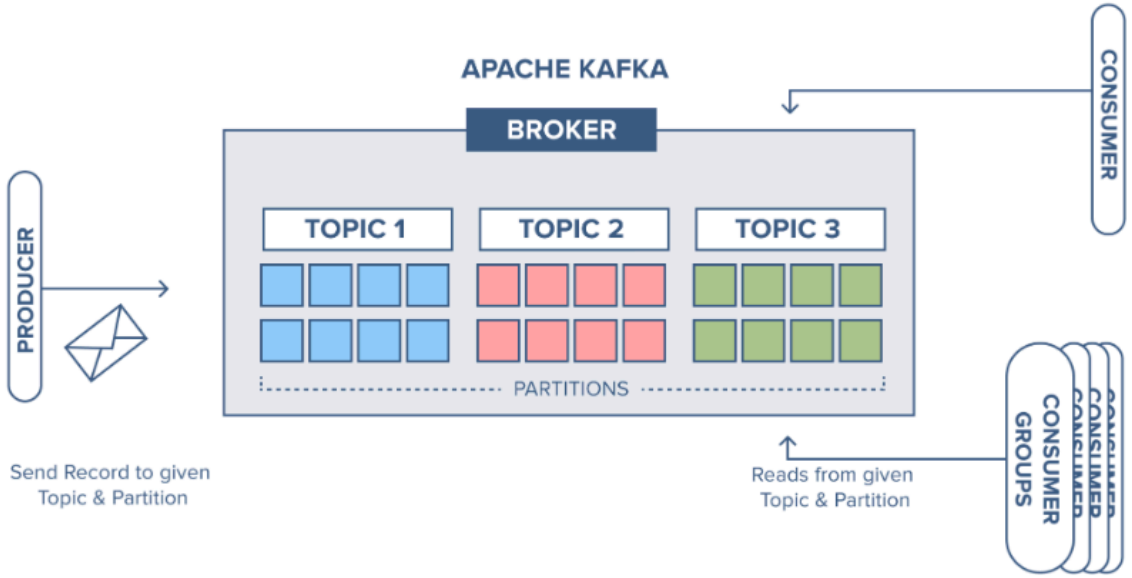
Set up MySQL with Debezium as an extra layer to help to capture each row-level changes in the database and send it over to Kafka.

```
mysql> select * from bus_status;
+-----------+------+---------+-------------+-------------+-----------------+-----+---------+-------------+-------------+------------------+---------------------+
| record_id | id   | routeId | directionId | predictable | secsSinceReport | kph | heading | lat         | lon         | leadingVehicleId | event_time          |
+-----------+------+---------+-------------+-------------+-----------------+-----+---------+-------------+-------------+------------------+---------------------+
|         1 | 8156 |       7 | 7_1_7       |           1 |              28 |  18 |     348 | 43.73719140 | -79.43381820 |             NULL | 2022-07-24 18:13:55 |
|         2 | 8178 |       7 | 7_0_7       |           1 |              28 |   0 |     168 | 43.70559560 | -79.42656040 |             NULL | 2022-07-24 18:13:55 |
|         3 | 8132 |       7 | 7_1_7       |           1 |              28 |  33 |      73 | 43.79323970 | -79.44185970 |             NULL | 2022-07-24 18:13:55 |
|         4 | 8138 |       7 | 7_1_7       |           1 |              28 |  28 |     349 | 43.77753710 | -79.44385090 |             NULL | 2022-07-24 18:13:55 |
|         5 | 8358 |       7 | 7_1_7       |           1 |              28 |  24 |     344 | 43.68229960 | -79.41795270 |             NULL | 2022-07-24 18:13:55 |
|         6 | 8389 |       7 | 7_0_7       |           1 |              28 |   0 |     181 | 43.70171730 | -79.42577360 |             NULL | 2022-07-24 18:13:55 |
|         7 | 8130 |       7 | 7_0_7       |           1 |              28 |   0 |     181 | 43.70195440 | -79.42571090 |             NULL | 2022-07-24 18:13:55 |
|         8 | 8384 |       7 | 7_1_7       |           1 |              28 |   0 |     230 | 43.79187920 | -79.44193110 |             NULL | 2022-07-24 18:13:55 |
|         9 | 8150 |       7 | 7_1_7       |           1 |              28 |   0 |     342 | 43.69939040 | -79.42483870 |             NULL | 2022-07-24 18:13:55 |
|        10 | 8360 |       7 | 7_0_7       |           1 |              28 |   0 |     263 | 43.79083100 | -79.44400010 |             NULL | 2022-07-24 18:13:55 |
|        11 | 8195 |       7 | 7_0_7       |           1 |              28 |   6 |     167 | 43.70161430 | -79.42572780 |             NULL | 2022-07-24 18:13:55 |
|        12 | 8382 |       7 | 7_0_7       |           1 |              28 |   5 |      75 | 43.73743050 | -79.43408200 |             NULL | 2022-07-24 18:13:55 |
|        13 | 8119 |       7 | 7_1_7       |           1 |              29 |  41 |     350 | 43.77991930 | -79.44451140 |             NULL | 2022-07-24 18:13:55 |
|        14 | 8156 |       7 | 7_1_7       |           1 |              28 |   3 |     251 | 43.73764020 | -79.43405470 |             NULL | 2022-07-24 18:14:25 |
```

Data Distribution – Apache Kafka (Amazon MSK)

Kafka was used to transfer the Bus data from MySQL to Spark Streaming in a fast, fault-tolerance and high scalable way.

- ✓ The Kafka topic receives incoming messages in JSON blobs.
- ✓ Built-in partitioning
- ✓ Replication



Kafka Topics

```
__amazon_msk_canary
__consumer_offsets
dbhistory.demo
dbserver1
dbserver1.demo.bus_status
my_connect_config
my_connect_offsets
my_connect_statuses
```

Topic Description

```
]$ bin/kafka-topics.sh --describe my_connect_config --boots
mp3s.1qo03c.c23.kafka.us-east-1.amazonaws.com:9092
fig        PartitionCount: 1       ReplicationFactor: 2
nect_config        Partition: 0    Leader: 2       Replicas
tuses      PartitionCount: 5       ReplicationFactor: 2
nect_statuses      Partition: 0    Leader: 2       Replicas
nect_statuses      Partition: 1    Leader: 1       Replicas
nect_statuses      Partition: 2    Leader: 3       Replicas
nect_statuses      Partition: 3    Leader: 2       Replicas
nect_statuses      Partition: 4    Leader: 1       Replicas
```

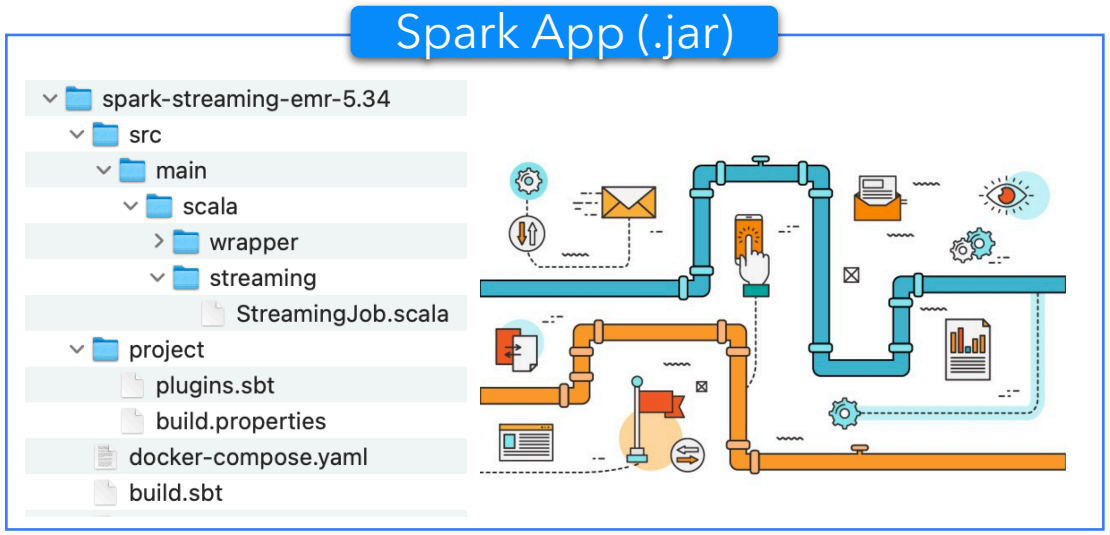
Data in Topic

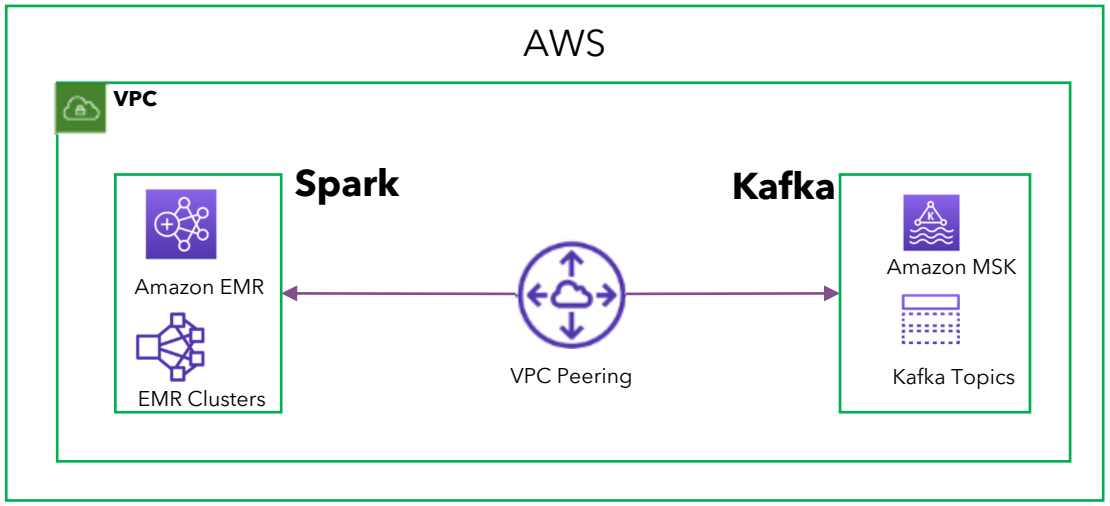

```
{"schema":{"type":"struct","fields":[{"type":"struct","fields":[{"type":"int32","optional":false,"field":"recor
ptional":true,"field":"directionId"},{"type":"int16","optional":true,"field":"predictable"},{"type":"int32","op
ld":"heading"},{"type":"bytes","optional":false,"name":"org.apache.kafka.connect.data.Decimal","version":1,"par
fka.connect.data.Decimal","version":1,"parameters":{"scale":"8","connect.decimal.precision":"10"},"field":"lon
amp","version":1,"default":0,"field":"event_time"}],"optional":true,"name":"dbserver1.demo.bus_status.Value","
alse,"field":"id"},{"type":"int32","optional":false,"field":"routeId"},{"type":"string","optional":true,"field
ort"},{"type":"int32","optional":false,"field":"kph"},{"type":"int32","optional":true,"field":"heading"},{"type
nal.precision":"10"},"field":"lat"},{"type":"bytes","optional":false,"name":"org.apache.kafka.connect.data.Dec
field":"leadingVehicleId"},{"type":"int64","optional":true,"name":"io.debezium.time.Timestamp","version":1,"de
elds":[{"type":"string","optional":false,"field":"version"},{"type":"string","optional":false,"field":"connecto
ional":true,"name":"io.debezium.data.Enum","version":1,"parameters":{"allowed":"true,last,false,incremental"},"
:"sequence"},{"type":"string","optional":true,"field":"table"},{"type":"int64","optional":false,"field":"server
ional":false,"field":"pos"},{"type":"int32","optional":false,"field":"row"},{"type":"int64","optional":true,"fi
","field":"source"},{"type":"string","optional":false,"field":"op"},{"type":"int64","optional":true,"field":"ts
tal_order"},{"type":"int64","optional":false,"field":"data_collection_order"}],"optional":true,"field":"transac
:8119,"routeId":7,"directionId":"7_1_7","predictable":1,"secsSinceReport":2,"kph":0,"heading":172,"lat":"AQRFHz
","name":"dbserver1","ts_ms":1657981766000,"snapshot":"false","db":"demo","sequence":null,"table":"bus_status"
57981766377,"transaction":null}}
```

Data Streaming – Spark Streaming

Ingesting Data From Kafka with Spark Streaming

- Create an AWS EMR for Spark and enable EMR and MSK communication through CPV Perring.
- Compiling Spark Streaming Jobs Built in Scala. Upload .jar file to an S3 bucket.
- Spark-submit using the .jar file to the Spark (EMR cluster) master node.
- The Spark application ingests data from Kafka, transform the data according to a predefined schema and produces parquet files in a S3 bucket.





Data Streaming – Spark Streaming

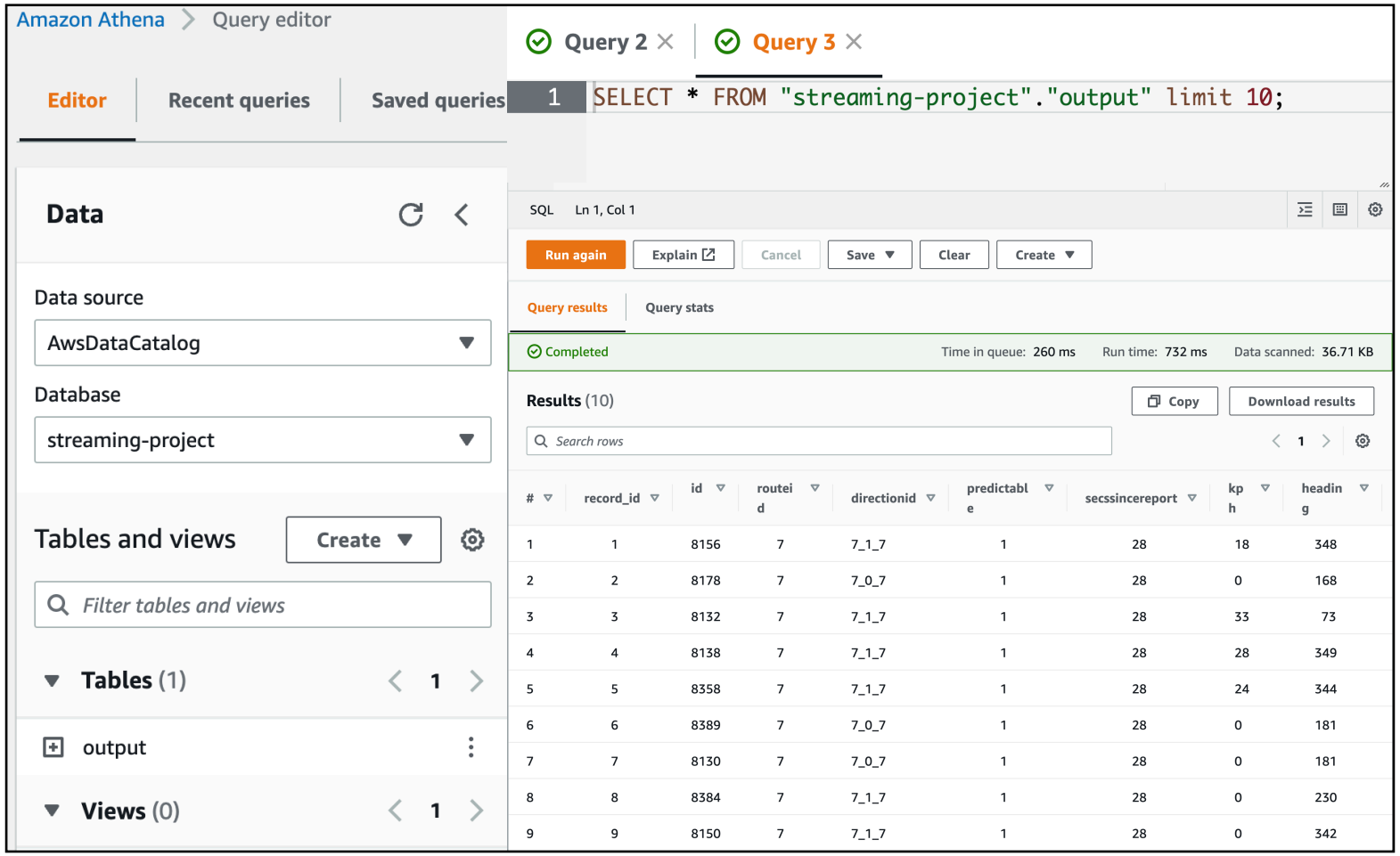
Micro batches of data coming from the Kafka topic.

Micro-batch processing: divides incoming streams into small batches for processing.

```
-------------------------------------------
Batch: 189
-------------------------------------------
+-----------+-------------+-------+----+---+---------+---------------+----------+-----------+---------+-------+---------------+
|directionId|event_time   |heading|id  |kph|lat      |leadingVehicleId|lon       |predictable|record_id|routeId|secsSinceReport|
+-----------+-------------+-------+----+---+---------+---------------+----------+-----------+---------+-------+---------------+
|7_0_7      |1656546597000|281    |9004|0  |43.790825|null           |-79.444496|true       |4706     |7      |26             |
|7_1_7      |1656546597000|349    |9002|1  |43.76817 |null           |-79.441475|true       |4707     |7      |26             |
|7_1_7      |1656546597000|172    |9006|0  |43.66606 |null           |-79.411064|true       |4708     |7      |27             |
|7_0_7      |1656546597000|169    |8313|0  |43.737576|null           |-79.434235|true       |4709     |7      |26             |
|7_1_7      |1656546597000|349    |8395|31 |43.7115  |null           |-79.42788 |true       |4710     |7      |26             |
|7_0_7      |1656546597000|173    |9000|24 |43.719265|null           |-79.4298  |true       |4711     |7      |26             |
|null       |1656546597000|142    |8309|14 |43.741898|null           |-79.45461 |false      |4712     |7      |27             |
|7_0_7      |1656546597000|172    |8102|0  |43.666378|null           |-79.411125|true       |4713     |7      |26             |
|7_1_7      |1656546597000|349    |9012|0  |43.73826 |null           |-79.43412 |true       |4714     |7      |26             |
|7_0_7      |1656546597000|216    |8165|0  |43.790855|null           |-79.44464 |true       |4715     |7      |26             |
|7_1_7      |1656546597000|337    |9018|16 |43.68691 |null           |-79.419716|true       |4716     |7      |25             |
|7_0_7      |1656546597000|163    |9016|22 |43.768547|null           |-79.44178 |true       |4717     |7      |26             |
|7_0_7      |1656546597000|169    |8302|25 |43.70999 |null           |-79.42762 |true       |4718     |7      |26             |
|7_1_7      |1656546597000|349    |1370|39 |43.77536 |null           |-79.443245|true       |4719     |7      |26             |
|7_0_7      |1656546627000|281    |9004|0  |43.790825|null           |-79.444496|true       |4720     |7      |22             |
|7_1_7      |1656546627000|349    |9002|34 |43.770443|null           |-79.44208 |true       |4721     |7      |22             |
|7_1_7      |1656546627000|172    |9006|0  |43.66606 |null           |-79.411064|true       |4722     |7      |23             |
|7_0_7      |1656546627000|167    |8313|46 |43.736576|null           |-79.43387 |true       |4723     |7      |22             |
|7_1_7      |1656546627000|350    |8395|0  |43.71225 |null           |-79.42798 |true       |4724     |7      |22             |
|7_0_7      |1656546627000|169    |9000|4  |43.71797 |null           |-79.42948 |true       |4725     |7      |23             |
+-----------+-------------+-------+----+---+---------+---------------+----------+-----------+---------+-------+---------------+
only showing top 20 rows
```

Data Analytics – AWS Athena

Spark streaming app point to Athena table and enable querying the bus data instantly.



Use Cases

Monitoring

Optimization

Trip Planner

ML predictions