Web Stream Processing with OntopStream

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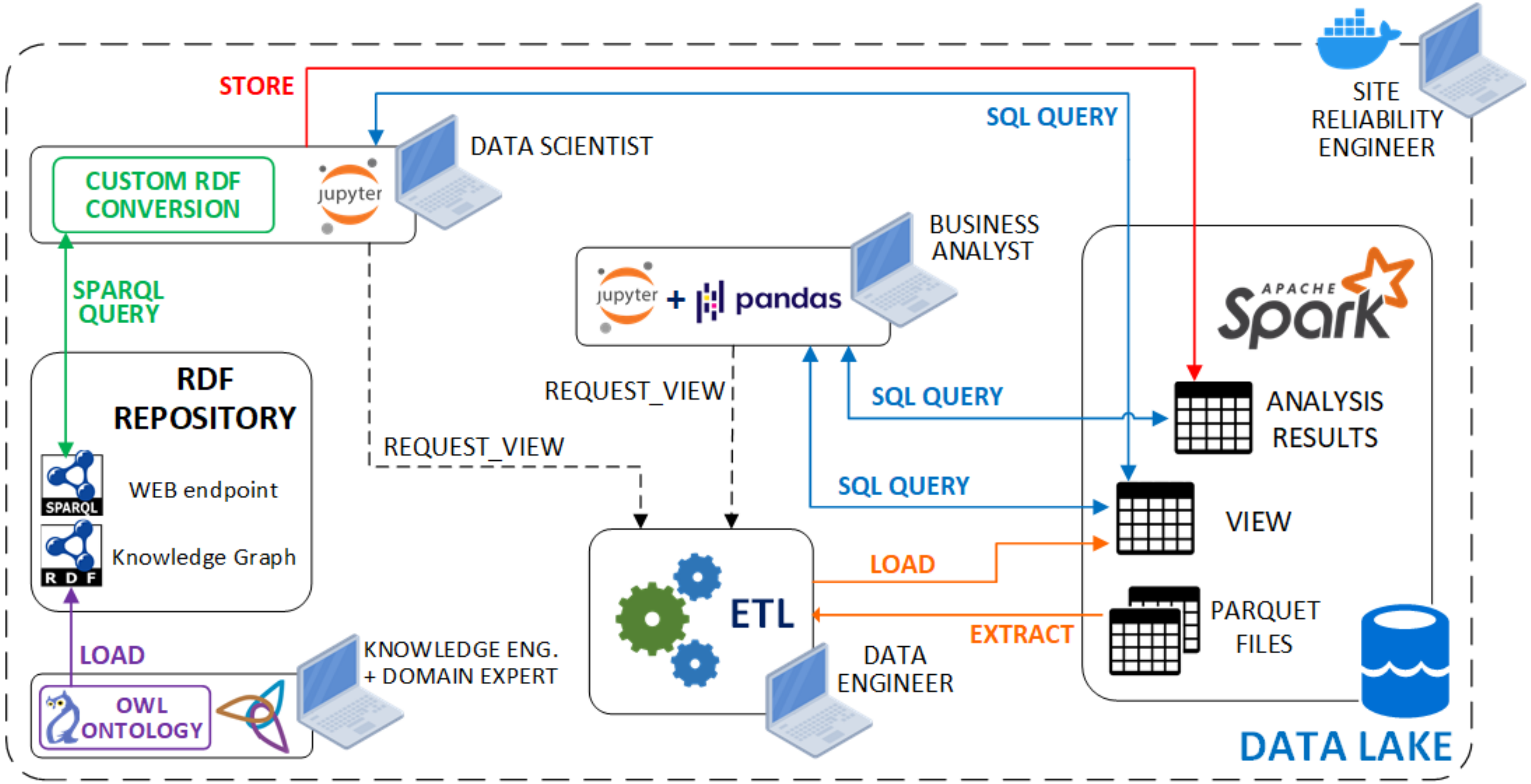
Business Scenario

Semantic and Big Data technologies are separated

- Data lakes : store the whole enterprise data. Analysts need custom **Extract Transform Load** (ETL) jobs to access the data
- Knowledge Graphs : queried with **SPARQL** to extract semantical information



Traditional Data Analysis - PROBLEMS

- Problem-dependent tasks:
    - new analytical query → new ETL task from scratch
    - ETLs require several days of work and meetings
    - requires a lot of Data Engineers workforce

- Semantical analyses persistence in the data lake, for later re-use, is difficult

Solvable using a combination of *multiple tools*, which *increase the required skills*

↓

need for ***single***, ***user-friendly***, ***straightforward*** tool

Ontology-Based Data Access

- **Ontology-Based Data Access (OBDA)** softwares aim to solve data integration problems…

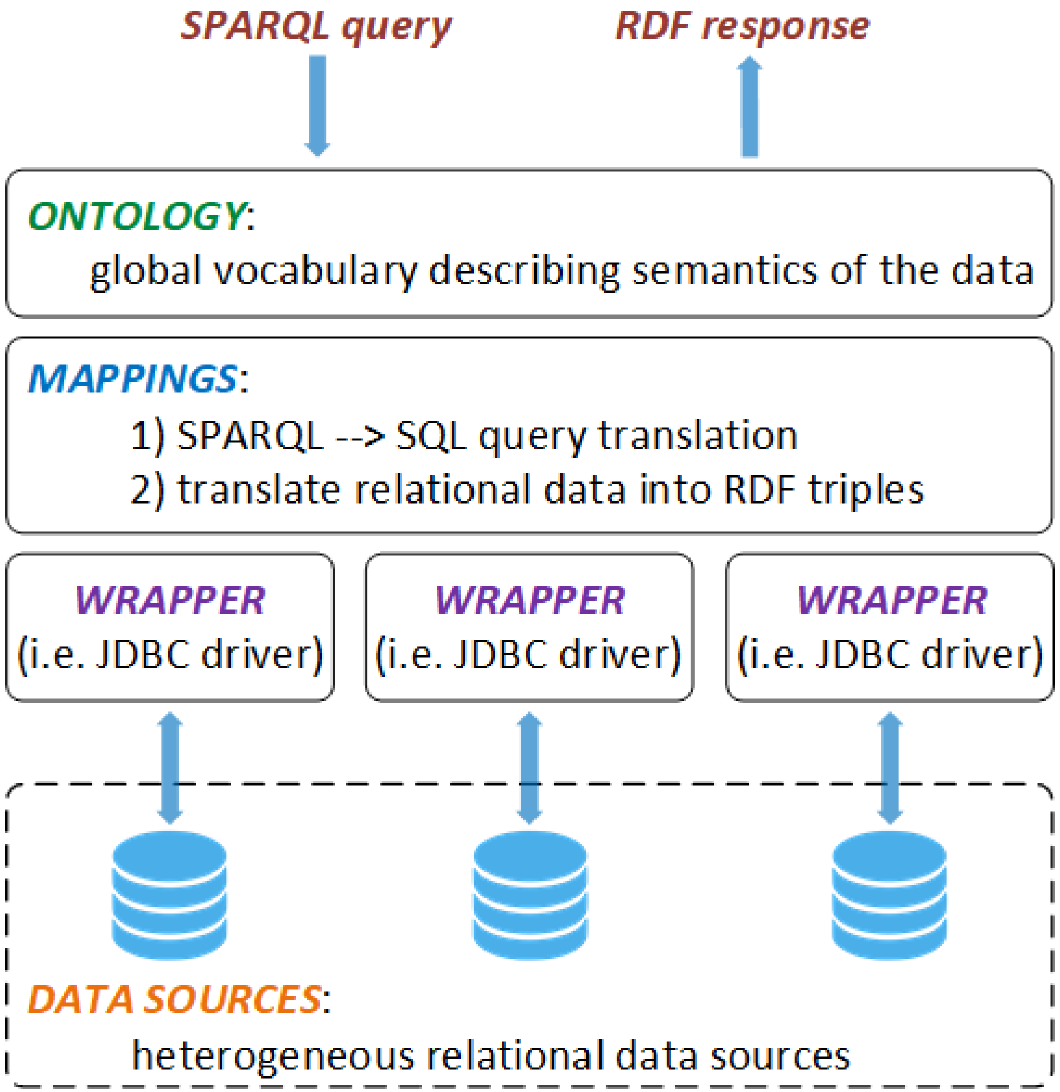
- **Virtual Knowledge Graph (VKG)** approach:
  - additional semantic layer on top of the data
  - relational data sources abstraction, exposed as RDF triples
  - SPARQL queries to access the data
  - automatic SPARQL → SQL query rewritings

Vitual Knowledge Graph approach

Data Analyst/Scientist

Knowledge Engineer

Data Engineer



Virtual Knowledge Graph engines

- “traditional” VKG engines (Mastro, Morph-RDB, UltraWrap)

- **Ontop** is considered the state-of-the-art reference VKG engine:
  - the only one offered as a commercial solution
  - active Github community (weekly-based issues)
  - relevant industrial-grade implementations
    - Statoil (Equinor)
    - Siemens Electric
    - Ricerca sul Sistema Energetico s.p.a

However, none of the tool is designed for supporting streams of data

Streaming Technologies

- Streaming technologies are becoming very popular…

- Data Streams can be:
  - continuously generated
  - incrementally processed
  - segmented by their time (window)

- Stream Processing engines enables real-time processing and querying of multiple data streams

State of the art streaming technologies…

OPEN-SOURCE

APACHE kafka®

Spark Streaming

Flink

APACHE nifi

ksqDB

APACHE calcite™

CLOUD-BASED (proprietary)

Cloud DataFlow

amazon Kinesis

Azure Stream Analytics

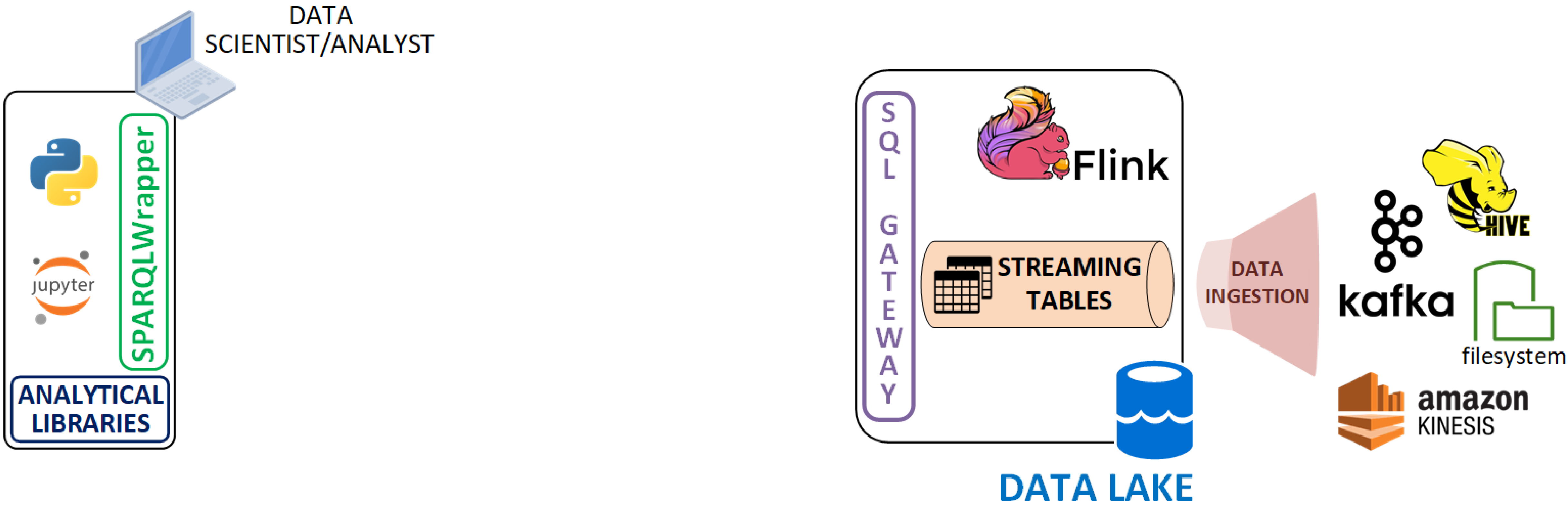
Towards real-time analytics

- Stream Processing engines enables real-time processing and querying of multiple data streams

- need for a real-time tool leveraging:
  - State-of-the-art open-source streaming technologies
    - Apache Flink, Apache Kafka, Apache Calcite
  - Streaming extensions of semantic technologies
    - RDF Stream Processing Query Language (RSP-QL)
    - Streaming-VKG

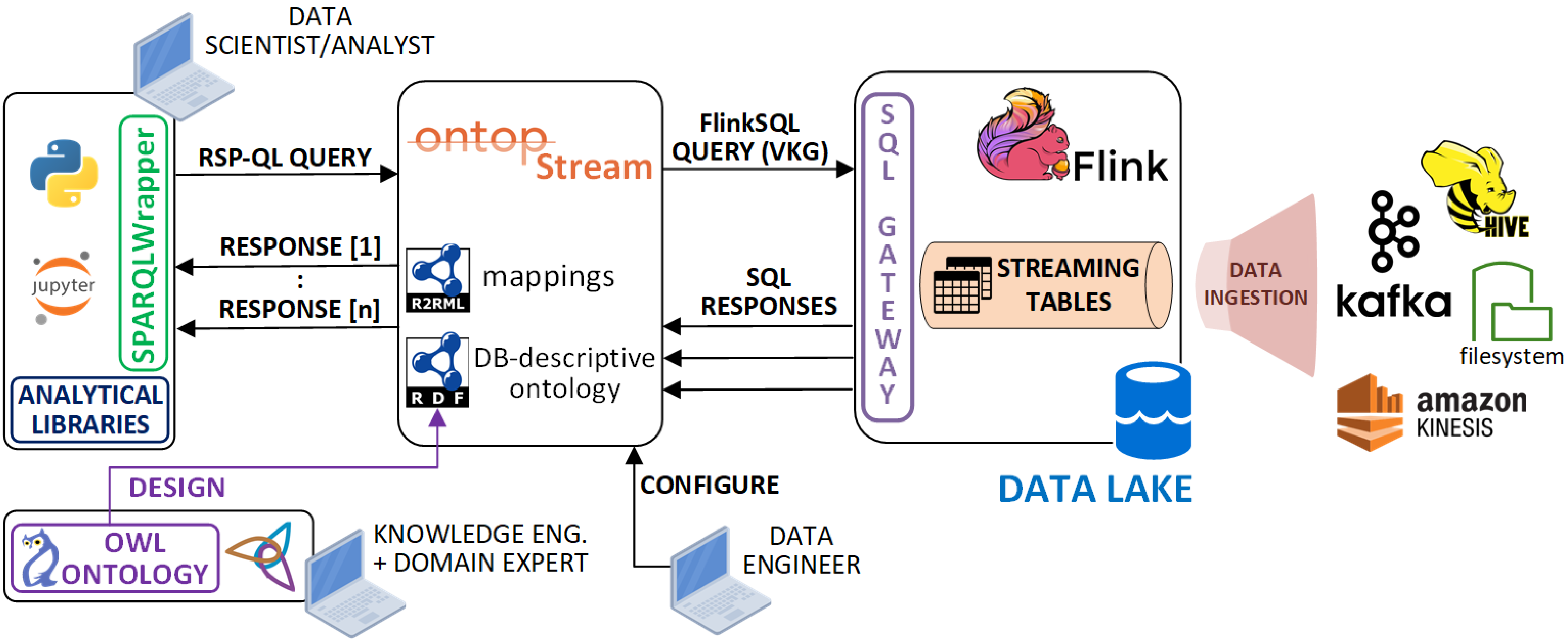
OntopStream

KG-Empowered Continuous Analytics



KG-Empowered Continuous Analytics

Streaming-VKGs as a bridge between Stream Processing and Semantic Techs



OntopStream

- Developed as an extension of the Ontop OBDA system (Java)

- Query relational data streams
  - stored and managed in Apache Flink dynamic tables
  - with RSP-QL continuous queries (windowed / not windowed)

- Get RDF streams of responses

- Two distributions:
  - OntopStream-CLI
  - OntopStream-Endpoint (only HTTP calls)

OntopStream: design decisions

- paradigm shift from traditional OBDA to Streaming-OBDA

- design decisions:

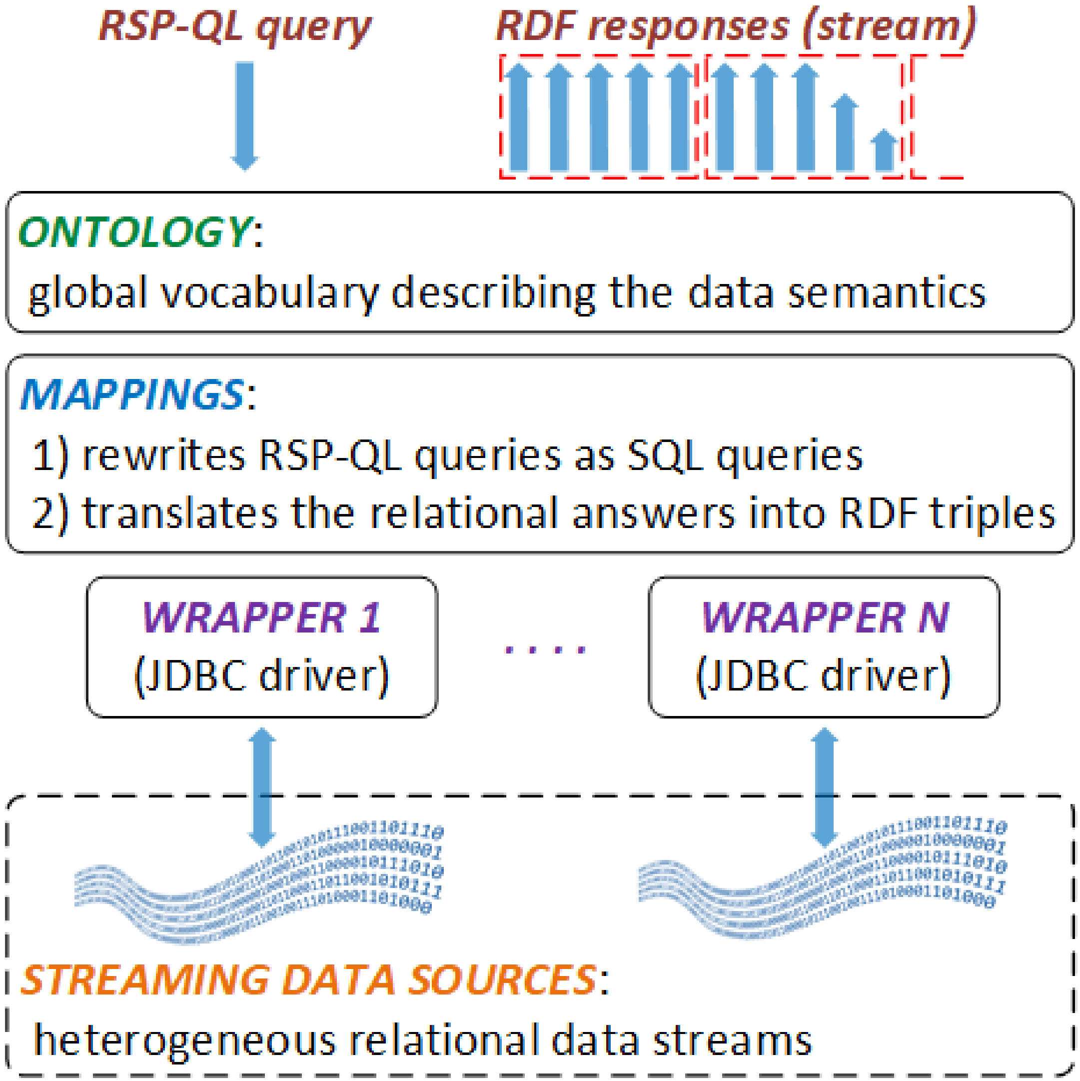
  1. extend the **`Flink JDBC driver`**
  2. re-design part of the **`ontop-engine`** to accept **`RSP-QL`** queries
  3. Streaming Virtual Knowledge Graph query rewriting approach
  4. include support for **`RDF streams`** of query outputs

Streaming Virtual Knowledge Graphs in OntopStream

Data Analyst/Scientist

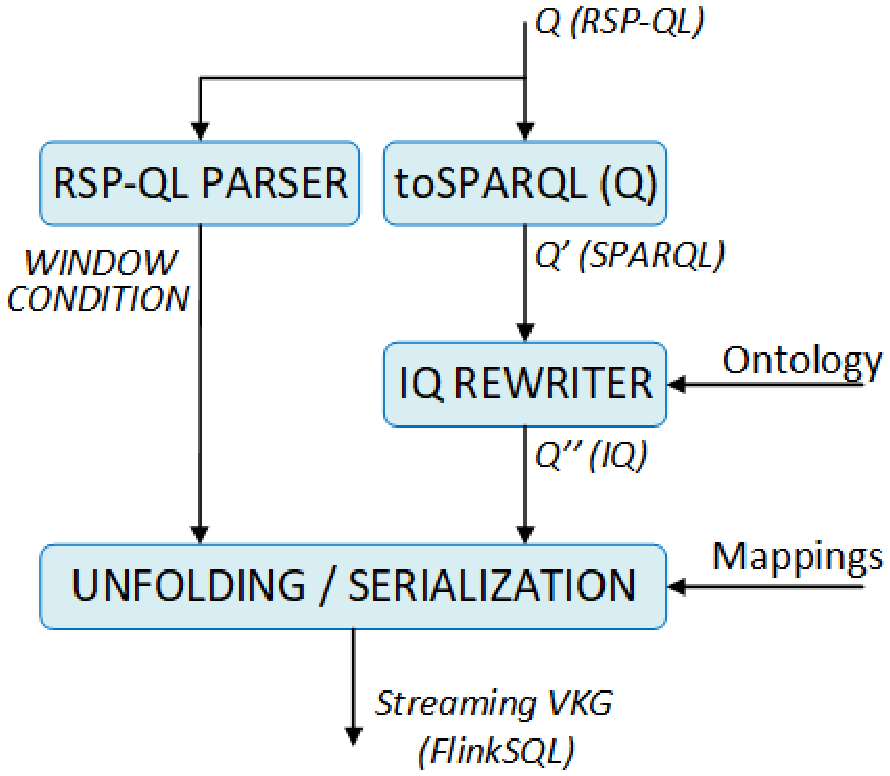
Knowledge Engineer

Data Engineer



Streaming Virtual Knowledge Graph query rewriter

- **`rsp4j`** parser to extract window conditions
- Intermediate Query rewriter unchanged
- **`IQ`** representation:
  - created w.r.t to the Ontology **`O`**
  - unfolded in a **`Streaming VKG`** tree
- Each tree node corresponds to a pseudo-SQL statement
- Streaming VKG serialization in a **`FlinkSQL query`**, add window condition **`W`** if existing



Tutorial

Business Scenario: Rental Company

- A car rental company has recently decided to **unify the information systems** of **two branches** using ontology-based data access techniques.

- Both the branches:
  - have a real-time data management infrastructure
  - store the rental records in Kafka topics

- However, they handles the data differently:
  - *Branch A* uses two separate Kafka topics for trucks and cars
  - *Branch B* stores all the rentals in a single topic, but the users' data are kept in a sperate topic

Business Requirements

The company is booming, and has in plan to acquire soon new branches.

Therefore, the company wants to make the integration process scalable, so that can be easily extended to all its new branches

They need a data integration solution that:

- provides an **unified logical view** of their data
- enables to **query in real-time** their data
- can be used with **python notebooks** for further analyses

Kafka topics: Branch A

user	rid	manufacturer	model	plate	status
Molly Davis	1	Fiat	Panda	FJ7PUJJ	START
Laura Baker	2	Tesla	Model S	JFGJ60A	START
William Diaz	3	Fiat	Tipo	FGL1X62	START
Molly Davis	1	Fiat	Panda	FJ7PUJJ	END
William Diaz	3	Fiat	Tipo	FGL1X62	END

DEALER1_CARS

user	rid	manufacturer	model	plate	status
Laura Baker	1	Iveco	Daily	HHST532	START
Wayne Flower	2	Fiat	Ducato	DM89JKD	START
Richard Tillman	5	Fiat	Ducato	JSDJFI3	START
Richard Tillman	5	Fiat	Ducato	JSDJFI3	END
Wayne Flower	2	Fiat	Ducato	DM89JKD	END

DEALER1_TRUCKS

Kafka topics: Branch B

DEALER2_VEHICLES

userID	rid	type	manufacturer	model	plate	status
3	1	Car	Audi	A3	DFU4HJF	START
4	2	Car	Mercedes	Classe C	784JD93	START
3	7	Truck	Mercedes	Vito	KD94KDS	START
3	1	Car	Audi	A3	DFU4HJF	END
6	8	Truck	Mercedes	Vito	012JKD0	START
3	7	Truck	Mercedes	Vito	KD94KDS	END

DEALER2_USERS

userID	name
1	Douglas Fitch
2	William Diaz
3	Kevin Rodriguez
4	Catherine Crandell
5	Richard Tillman

Kafka topics: Flink ingestion

- Data acquisition in Flink can be automated

- Design the topics ingestion in Flink:
  - Flink streaming tables
    - queried with FlinkSQL continuous queries, recorded in Flink
  - Kafka connector for Flink (Table & SQL API):
    - *files:*
      - ***sql-client-conf.yaml***: Kafka → Flink
      - ***sql-gateway-defaults.yaml***: Flink JDBC Gateway
    - **table schema**: topics fields, datatypes, watermarks, …
    - **connector properties**: Kafka address, schema registry, …

Example: DEALER2_VEHICLES topic

```
- name: D2_VEHICLES
  type: source
  update-mode: append
  schema:
  - name: userID
    type: BIGINT
  - name: rid
    type: BIGINT
  - name: type
    type: STRING
  - name: manufacturer
    type: STRING
  - name: model
    type: STRING
  - name: plate
    type: STRING
  - name: status
    type: STRING
  - name: ts
    type: STRING
```

TABLE NAME

data: SOURCE → FLINK

append new data, when is available from the source (Kafka)

TABLE SCHEMA

Reference: [Apache Kafka SQL Connector]

Example: DEALER2_VEHICLES topic

TABLE SCHEMA

SOURCE CONNECTOR

```
- name: parsed_timestamp
  type: TIMESTAMP
  rowtime:
    timestamps:
      type: "from-field"
      from: "ts"
    watermarks:
      type: "periodic-bounded"
      delay: "5"
connector:
  property-version: 1
  type: kafka
  version: universal
  topic: DEALER2_VEHICLES
  startup-mode: earliest-offset
  properties:
  - key: bootstrap.servers
    value: kafka:9092
 format:
  property-version: 1
  type: json
  schema: "ROW(userID BIGINT, rid BIGINT, type STRING, manufacturer STRING,
                model STRING, plate STRING, status STRING, ts STRING)"
```

reference field for time-based operations (WINDOWS)

source type

source address

topic schema

Relational Streaming Data Integration…

Now, we have a Flink streaming table for each Kafka topic

- *DEALER1_CARS* and *DEALER1_TRUCKS*
- *DEALER2_VEHICLES* and *DEALER2_USERS*

The data streams are still not integrated!!!

Relational Streaming Data Integration…

Now, we have a Flink streaming table for each Kafka topic

- *DEALER1_CARS* and *DEALER1_TRUCKS*
- *DEALER2_VEHICLES* and *DEALER2_USERS*

We can use **OntopStream** to create a **unified logical view** of the data streams…

Flink relational streams:

- exposed to OntopStream using the ***Flink JDBC Gateway***
- can be queried with ***FlinkSQL*** continuous queries

Relational Streaming Data Integration…

- Onpstream automates:
  - **RSP-QL → FlinkSQL** query rewriting
  - **relational → RDF** response streams translation

- To use OntopStream for the streaming data integration tasks we need:
  1. **Ontology**: provides the unified logical view to the user
     - Classes
     - Object Properties
     - Data Properties
  2. **Streaming-VKG mappings**: bridges the ontology with data streams (Kafka messages in Flink)
  3. **JDBC connection** configuration

1) Ontology Design

- Download Protégé from

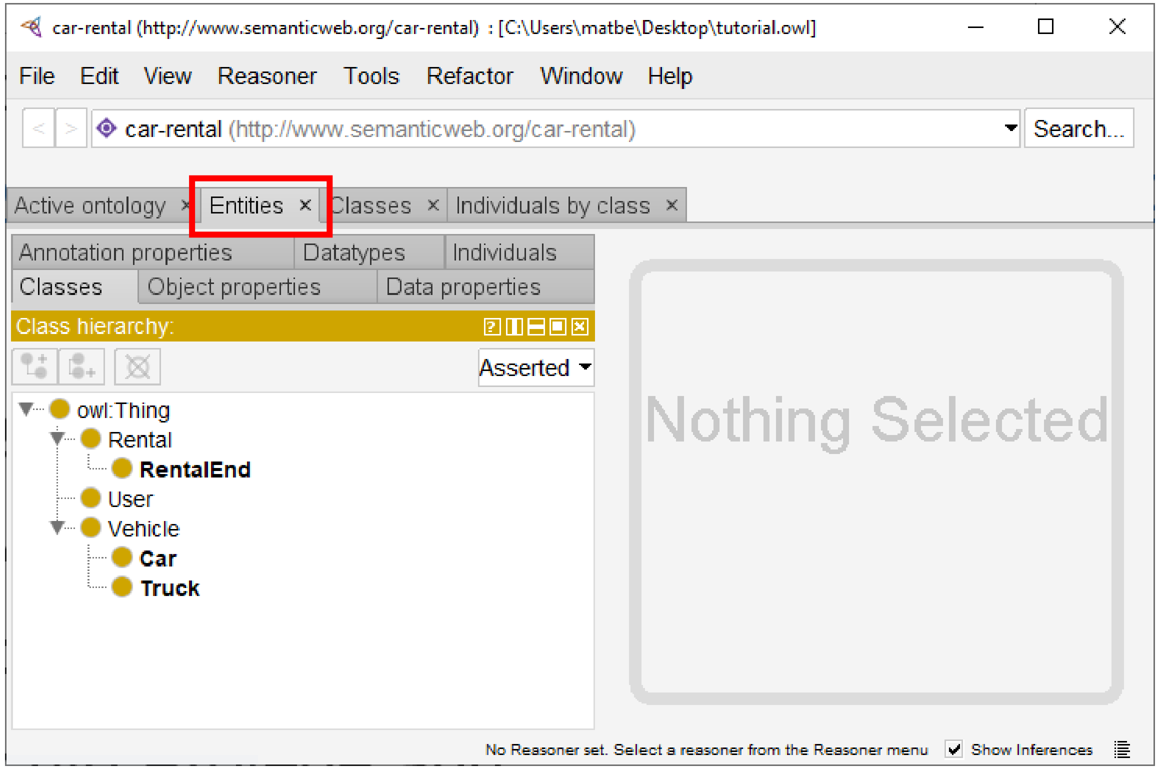
  https://protege.stanford.edu/products.php#desktop-protege

- Launch Protégé
  - Linux: *./run.sh* from the terminal
  - Windows: click on *Protégé.exe*
  - Mac: execute *Protégé.app*

- Change the ontology IRI in

  http://www.semanticweb.org/car-rental

- Open the Entities tab to start the ontology design



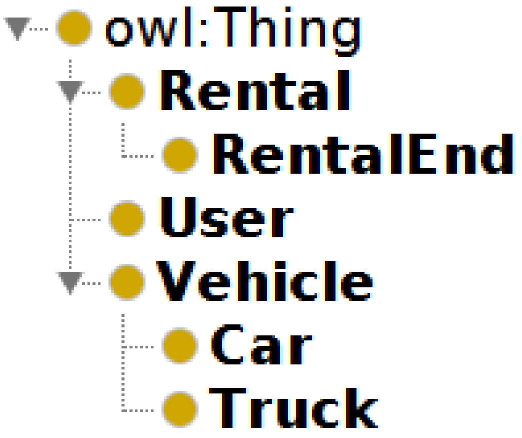
1) Ontology Design

Classes:

- express the **logical concepts** of the unified logical view
- The **Car** and **Truck** concepts are expressed as <u>subclasses</u> of **Vehicle**

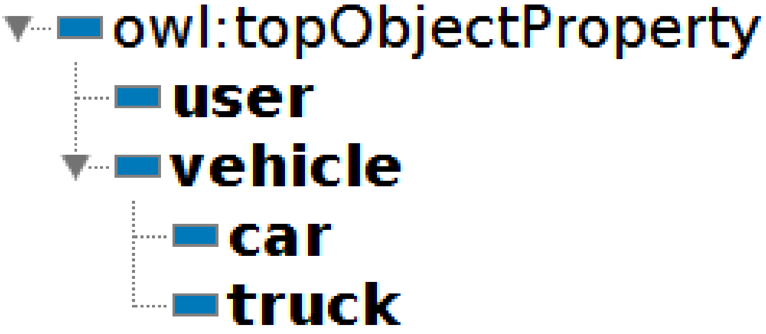
  i.e., a *Tesla Model X* is a Car, but also a transportation Vehicle
- **RentalEnd** is a specialization of (<u>subclass</u>) **Rental**

  it will be useful later for queries about ended rentals



Object Properties:

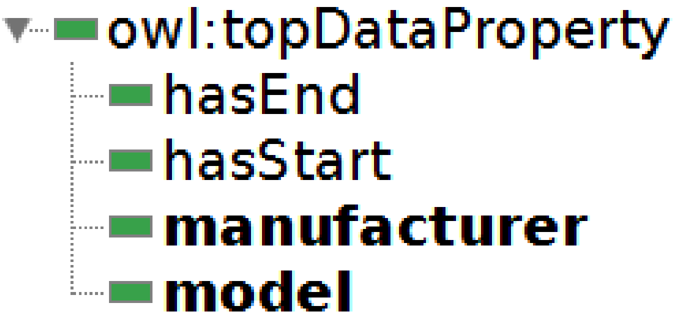
- ease the mapping process
- express implicit domain/range restrictions on Class istances:
  - the **user** property <u>range</u> is **User**
  - the **vehicle** property <u>range</u> is **Vehicle**



1) Ontology Design

Data Properties:

- expose the Kafka messages entries
  - Vehicle details (manufacturer, model)
  - Timestamps
  - Users personal information (name)



To save your ontology (OWL format) go to File > Save As

Name the file rentals.owl, and save it in the ontop/input folder

2) Streaming-VKG mappings

OntopStream answers **RSP-QL queries** with **RDF streams** of semantically-enriched responses based on:

- ontological concepts
- relational data streams: retrieved through **Streaming VKG queries** registered in Flink

Streaming-VKG mapping

- binding between a set of RDF statements and FlinkSQL selection query
- connects the ontological layer terms to data streams (in this tutorial, Kafka messages in Flink)
- consists of:
  - **MappingID**: friendly name to identify the mapping
  - **Source**: FlinkSQL query for the data extraction from the Flink streaming tables
  - **Target**: one or more RDF statements corresponding to the VKG generated by the single entry obtained from the data extracted with the Source query

2) Streaming-VKG mappings: Baranch A

Entities:

- **Rental:** each rental ID in the stream
- **Vehicle**: plate numbers
- **User:** client names

Kind of rented vehicle?

- **D1_CARS** table stores **Cars** data
- **D1_TRUCKS** table stores **Trucks** data

Start or ended lease?

- the **status** field refers to the rental state
- we can use a **WHERE** clause in the source query to filter out rentals by their status:
  - **status='START'** retrieves the starting rentals Kafka messages
  - **status='END'** retrieves the ended rentals Kafka messages

2) Streaming-VKG mappings: Baranch A

RentalEnd subclass of **Rental**:

- to ease the complexity of queries asking only for ended rentals, we use the subclass specialization

Started rentals [rentals.obda]

```
mappingId   DEALER1−CarRental
target      :D1_C{rid} a :Rental; :user :{user}; :hasStart {ts}^^xsd:dateTime; :car :{plate}. :{plate} a :Car; :manufacturer {manufacturer}; :model {model}.
source      SELECT rid, user, ts, plate, manufacturer, model FROM D1_CARS WHERE status='START'

mappingId   DEALER1−TruckRental
target      :D1_T{rid} a :Rental; :user :{user}; :hasStart {ts}^^xsd:dateTime; :truck :{plate}. :{plate} a :Truck; :manufacturer {manufacturer}; :model {model}.
source      SELECT rid, user, ts, plate, manufacturer, model FROM D1_TRUCKS WHERE status='START'
```

Ended rentals [rentals.obda]

```
mappingId   DEALER1−CarRentalEnd
target      :D1_C{rid} a :RentalEnd; :hasEnd {ts}^^xsd:dateTime; :car :{plate}.
source      SELECT rid,ts,plate FROM D1_CARS WHERE status='END'

mappingId   DEALER1−TruckRentalEnd
target      :D1_T{rid} a :RentalEnd; :hasEnd {ts}^^xsd:dateTime; :truck :{plate}.
source      SELECT rid,ts,plate FROM D1_TRUCKS WHERE status='END''
```

2) Streaming-VKG mappings: Branch B

Entities:

- **Rental:** each rental ID in the stream
- **Vehicle**: plate numbers
- **User:** client names

Kind of rented vehicle?

- the **type** field refers to the kind of vehicle in the **D2_VEHICLES** table
- for <u>starting rentals</u>, we can use a **WHERE** clause in the source query to determine the vehicle:
  - **type= 'Car'** retrieves **Car** rental entries
  - **type= 'Truck'** retrieves **Truck** rental entries
- for <u>ending rentals</u>, since the vehicle class is determined in the starting rental messages:
  - use the generic **vehicle** object property (property range is **Vehicle**)

Start or ended lease? (same as Branch A)

- use the **WHERE** clause in the source query to filter out rentals by their **status** field

2) Streaming-VKG mappings: Branch B

Users are kept in a separate topic:

- need to combine the Flink streaming tables **D2_VEHICLES** and **D2_USERS**
- FlinkSQL source query with a **JOIN** over the **userID** field

RentalEnd subclass of **Rental**: (same as Branch A)

- to ease the complexity of queries asking only for ended rentals, we use the subclass specialization

Started/Ended rentals [rentals.obda]

```
mappingId   DEALER2-CarRental
target      :D2_{rid} a :Rental; :user :{name}; :hasStart {ts}^^xsd:dateTime; :car :{plate}. :{plate} a :Car; :manufacturer {manufacturer}; :model {model}.
source      SELECT rid,name,ts,plate,manufacturer,model FROM D2_VEHICLES,D2_USERS WHERE D2_VEHICLES.userID=D2_USERS.userID
                AND type='Car' AND status='START'

mappingId   DEALER2-TruckRental
target      :D2_{rid} a :Rental; :user :{name}; :hasStart {ts}^^xsd:dateTime; :truck :{plate}. :{plate} a :Truck; :manufacturer {manufacturer}; :model {model}.
source      SELECT rid,name,ts,plate,manufacturer,model FROM D2_VEHICLES,D2_USERS WHERE D2_VEHICLES.userID=D2_USERS.userID
                AND type='Truck' AND status='START'

mappingId   DEALER2-RentalEnd
target      :D2_{rid} a :RentalEnd; :hasEnd {ts}^^xsd:dateTime; :vehicle :{plate}.
source      SELECT rid,ts,plate FROM D2_VEHICLES,D2_USERS WHERE D2_VEHICLES.userID=D2_USERS.userID AND status='END'
```

3) JDBC connection

- OntopStream interacts with Apache Flink:
  - through **JDBC calls**
  - using a **custom JDBC driver**

- Before starting OntopStream, we need to configure the connection to the **Flink JDBC Gateway**

- The configuration must be specified in a **property file**, passed as input to OntopStream on its startup

rentals.propery

```
jdbc.url=jdbc:flink://sql-client:8083?planner=blink
jdbc.driver=com.ververica.flink.table.jdbc.FlinkDriver
jdbc.user=
jdbc.name=test-RSE-streaming
jdbc.fetchSize=1
jdbc.password=
```

OntopStream startup

- The OntopStream docker image is available on DockerHub

  hub.docker.com/r/chimerasuite/ontop-stream

- We can now start the OntopStream endpoint using the command:

  docker-compose -f docker-compose-ontop.yml up -d

- If we look at the configuration in the **ontop.yml** file we can see the three input files:
  - **tutorial.owl**: contained the ontology describing the user unified logical view
  - **tutorial.obda**: the Streaming-VKG mappings we've designed
  - **tutorial.properties**: the JDBC connection properties

Tutorial practice

Starting-up the resources

- Requirements: *docker* and *docker-compose*

- Start the tutorial environment
  - Streaming resources (Flink, Kafka) and JupyterLab

```
sudo docker-compose -f flink-kafka.yml up -d
```

  - Flink JDBC Gateway:
    - **Note**: keep the JDBC endpoint alive until you need the service (don't close the terminal window)

```
sudo docker-compose -f flink-kafka.yml exec sql-client /opt/flink-sql-gateway-0.2-SNAPSHOT/bin/sql-gateway.sh --library /opt/sql-client/lib
```

  - OntopStream (new terminal window):

```
sudo docker-compose -f ontop.yml up -d
```