An Extensible Semantic Data Fusion Framework for Autonomous Vehicles

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- PhD in Semantic Web Technologies
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- Catalink's areas of expertise
  - Knowledge-based Applications
  - Computer Vision
  - Machine Learning
- Strong presence in research projects
- Wide network of contacts with Universities, Research Institutes, Industry, Municipalities & Public Orgs

CPSoSaware

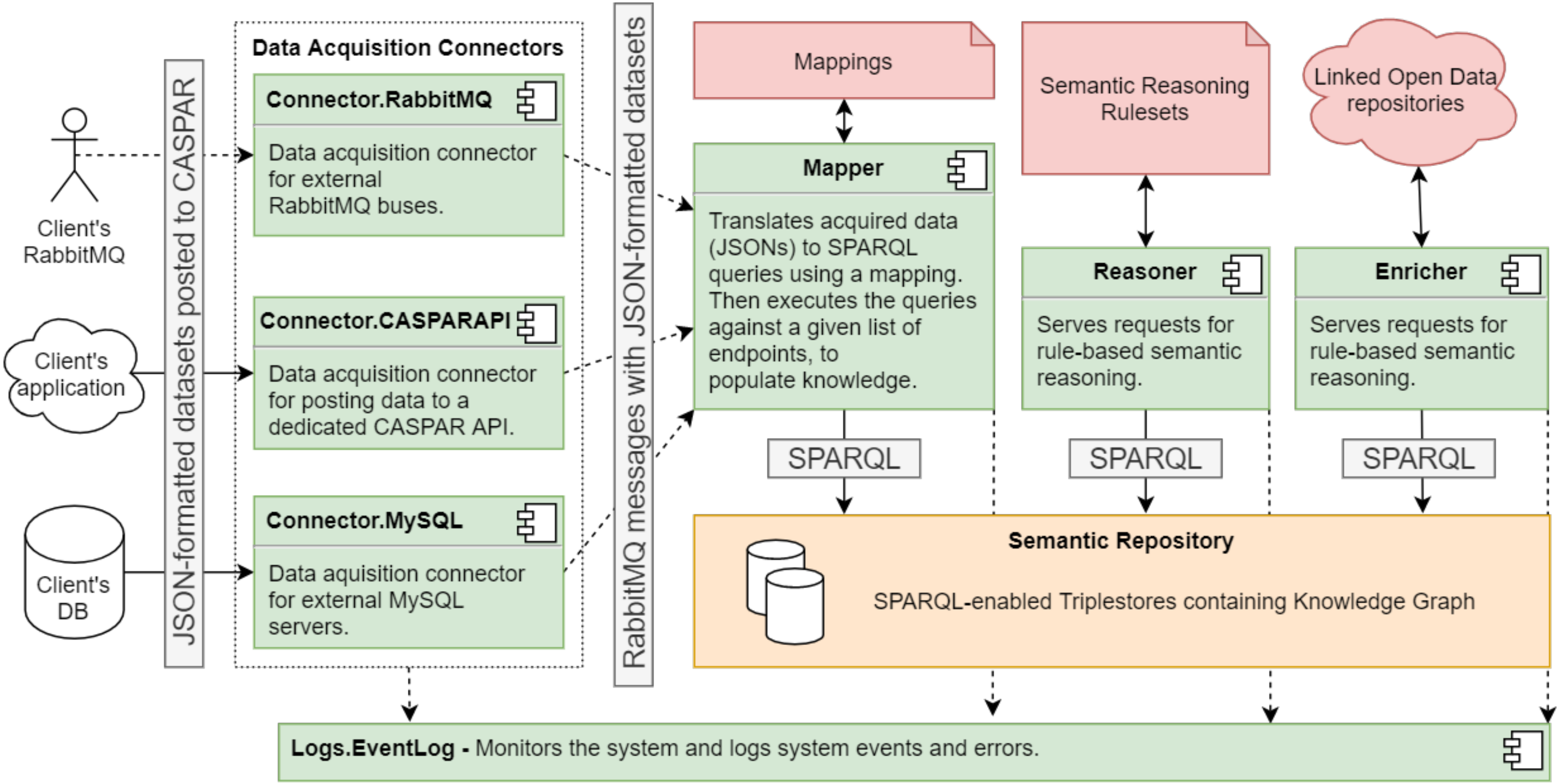
Motivation

- Rapidly increasing interest in (semi)autonomous connected vehicles
- Automotive AI market estimated at **$10.5 billion by 2025**
- Major automotive manufacturers increasingly investing in the field
- Key challenge: AI systems must deal with **large volumes of heterogeneous data** generated by sensors on the vehicle (e.g., camera, radar, LiDAR, GPS, etc.) & by the vehicle's environment (e.g., pervasive inputs, weather data, other vehicles, etc.)
- Semantic technologies are a natural fit for **semantically integrating** heterogeneous pieces of information into a uniform knowledge representation model, i.e., **a semantic KG**

Background – CPSoSaware H2020 Project

- CPSoS as a living organism:
  - Behaves autonomously
  - Is aware of its physical & cyber environment
  - Reacts to environment to match intended purpose
- Aims:
  - Develop models & tools for describing a CPSoS in a holistic & abstract way
  - Allocate computational power/resources to the CPS devices towards the overarching goal
  - AI for reliability, fault tolerance & security at system level
  - Increase human situational awareness for human-in-the-loop & consider human behavior in the CPSoS design & operation phase
- Two use cases:
  - **Connected semiautonomous vehicles**: Assess driver's state (DMS) + analysis of scene outside the vehicle
  - **Human – robot interaction in a manufacturing environment**: Operator's safety + design operation continuum support

CASPAR – Architecture



CASPAR – Data Acquisition Mechanisms

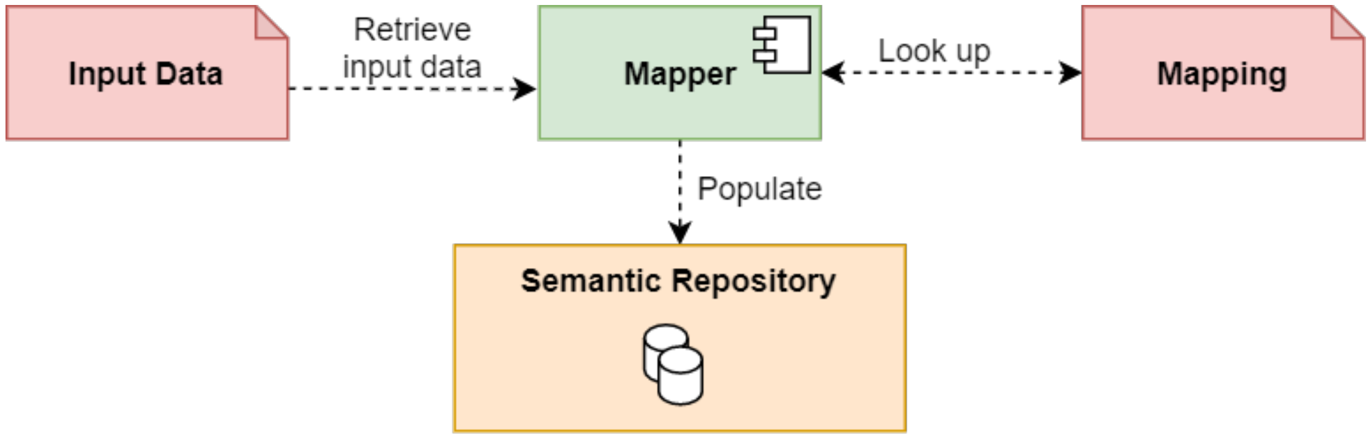
Aims:

- Heterogeneous input from multiple (diverse) sources
- Periodically retrieved & normalized into a common format
- Non-intrusive & seamlessly integrated to existing data-intensive systems

Modular data connectors:

- **API Connector**: RESTful API expecting HTTP requests with payload
- **MySQL Connector**: Definition of MySQL queries for extracting desired datasets from end user's DB
- **RabbitMQ Connector**: Directly consume messages from end user's RabbitMQ deployment
- **Future plans**: More query languages & DBs (SQL, SQLite, NoSQL, SPARQL); More message brokers (e.g. Apache Kafka); Periodically querying REST APIs on end-user side; Directly handling datasets in XML, CSV, Excel, JSON, etc.

Mapper – Mapping Definition & Semantic Data Integration



- Heterogeneous input from multiple (diverse) sources
- Transforms data into SPARQL queries & does the semantic data integration
- **Mappings** specify how input data is associated with concepts and relationships in the KG
  - **Template**: Mechanism for focusing on specific parts of the input (multiple templates per source input)
  - **Individuals**: Specify nodes to be created or updated in the KG
  - **Properties**: Specify object or data properties in the KG

So, where is the Novelty?!?

Other tools:

- Directly generate RDF triples from input source
- Insertion of duplicate nodes & branches

CASPAR:

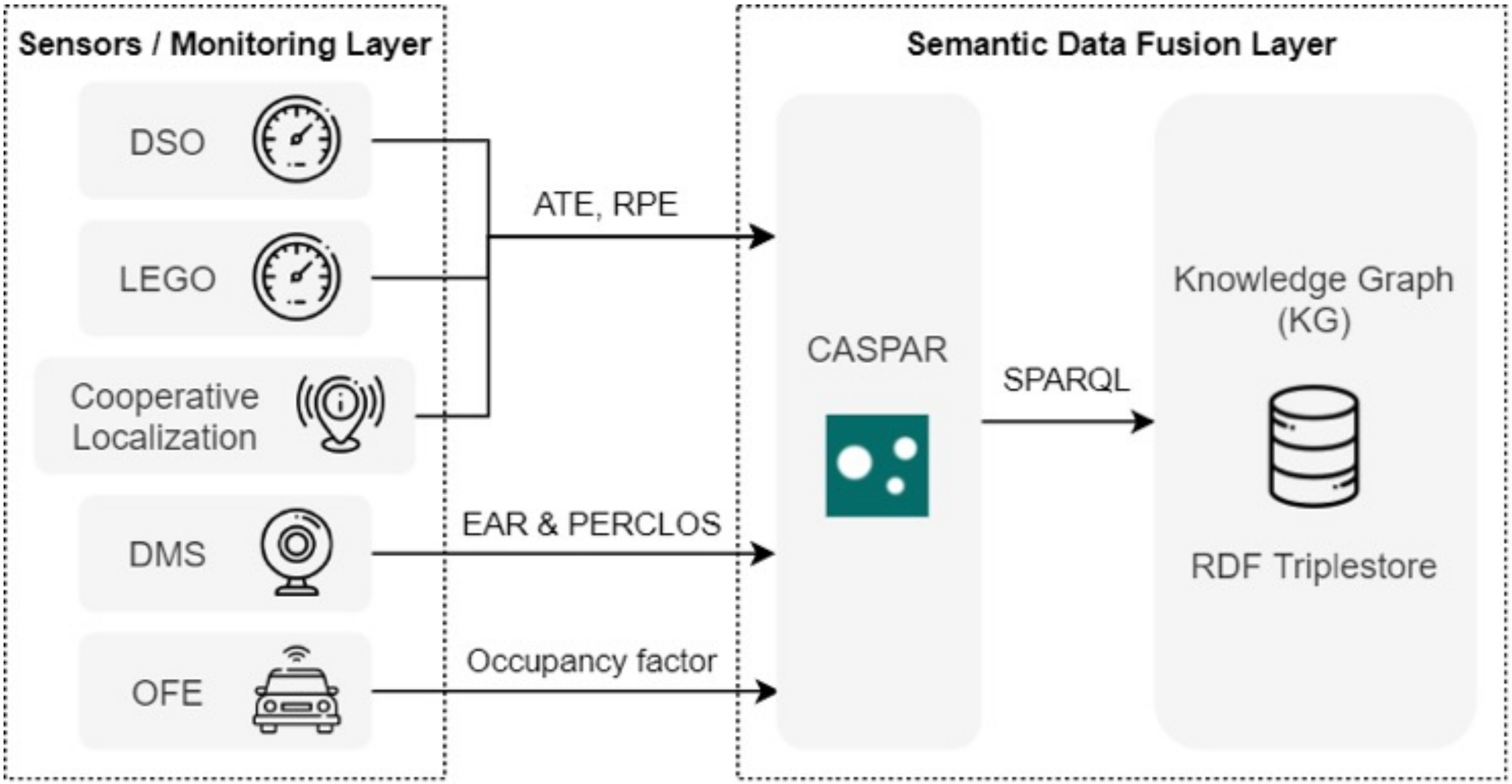
- Optional **update_on** field for each individual
- Takes advantage of SPARQL UPDATE

```
"individuals": [
  {
    "path": "customers.[*]",
    "namespace": "http://www.example.com/caspar#",
    "classes": [
      "ex:Customer"
    ],
    "properties": [
      {
        "predicates": [
          "ex:hasName",
          "rdfs:label"
        ],
        "object": {
          "path": "customers.[*].Name"
        }
      },
      {
        "predicates": [
          "ex:hasID"
        ],
        "object": {
          "path": "customers.[*].ID"
        }
      },
      {
        "predicates": [
          "ex:hasDietPreference"
        ],
        "object": {
          "path": "customers.[*].Dietary preferences.[*]"
        }
      }
    ],
    "update_on": [
      {
        "predicates": ["ex:hasID"],
        "object": {
          "path": "customers.[*].ID"
        }
      }
    ]
  },
```

Two Application Scenarios

- Semantic data integration from multiple diverse sources in the CPSoSaware autonomous driving use case
  - Populate a semantic model with data from other system components
- Monitor non time-critical parameters via offline reports
  - **Scenario #1**: Evaluate robustness of odometry algorithms
  - **Scenario #2**: Calculate risk levels for the driver

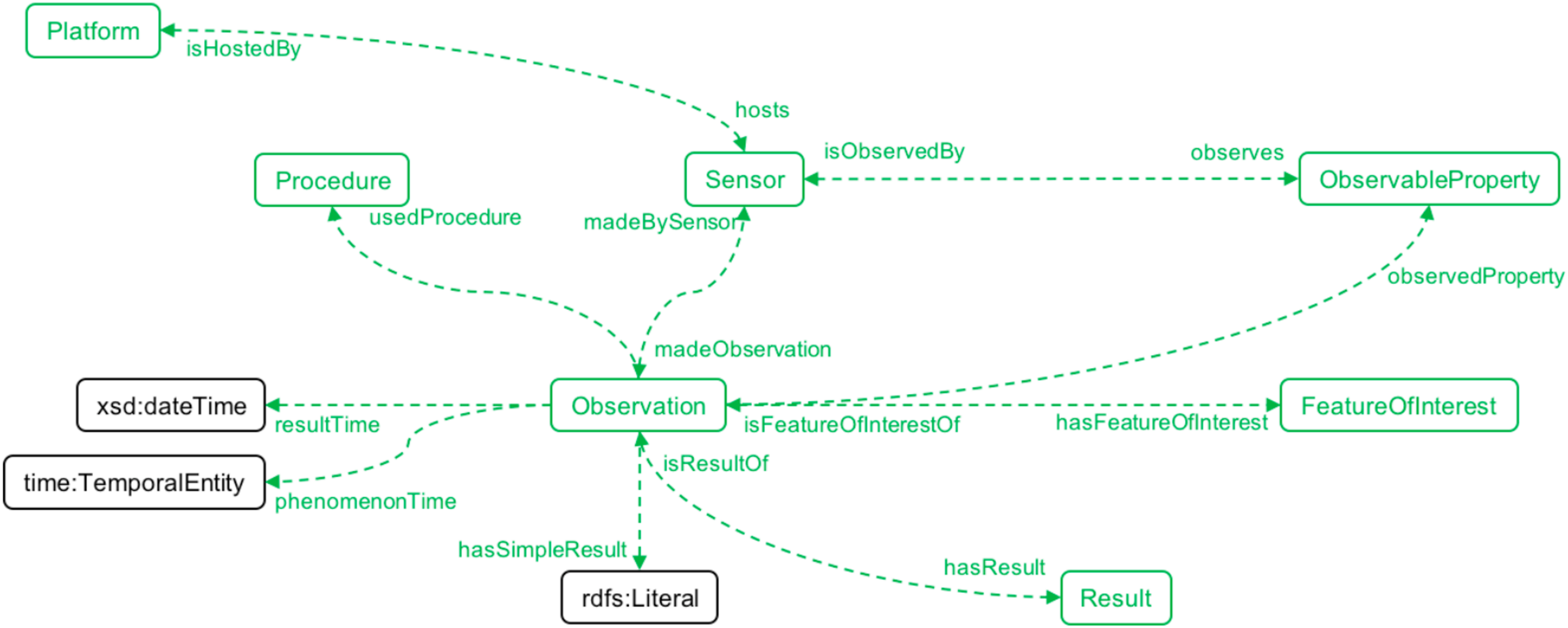
Overview



Sensors / Monitoring Layer
DSO
LEGO
Cooperative Localization
DMS
OFE
ATE, RPE
EAR & PERCLOS
Occupancy factor
Semantic Data Fusion Layer
CASPAR
SPARQL
Knowledge Graph (KG)
RDF Triplestore

Core Semantic Model

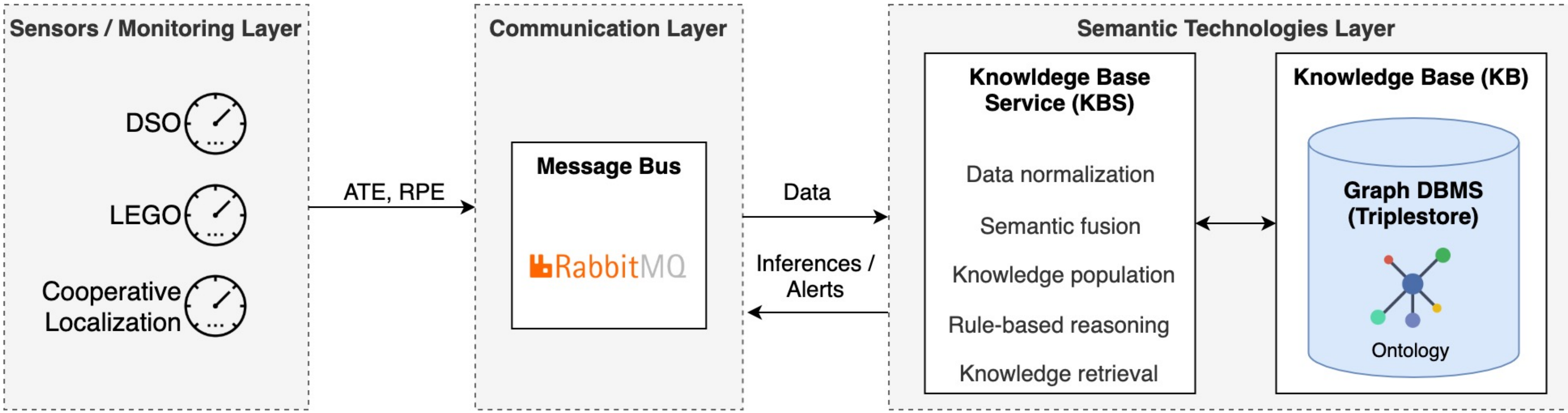
SOSA ontology (Sensor, Observation, Sample, & Actuator)*



*W3C Recommendation 19 October 2017: http://www.w3.org/ns/sosa/

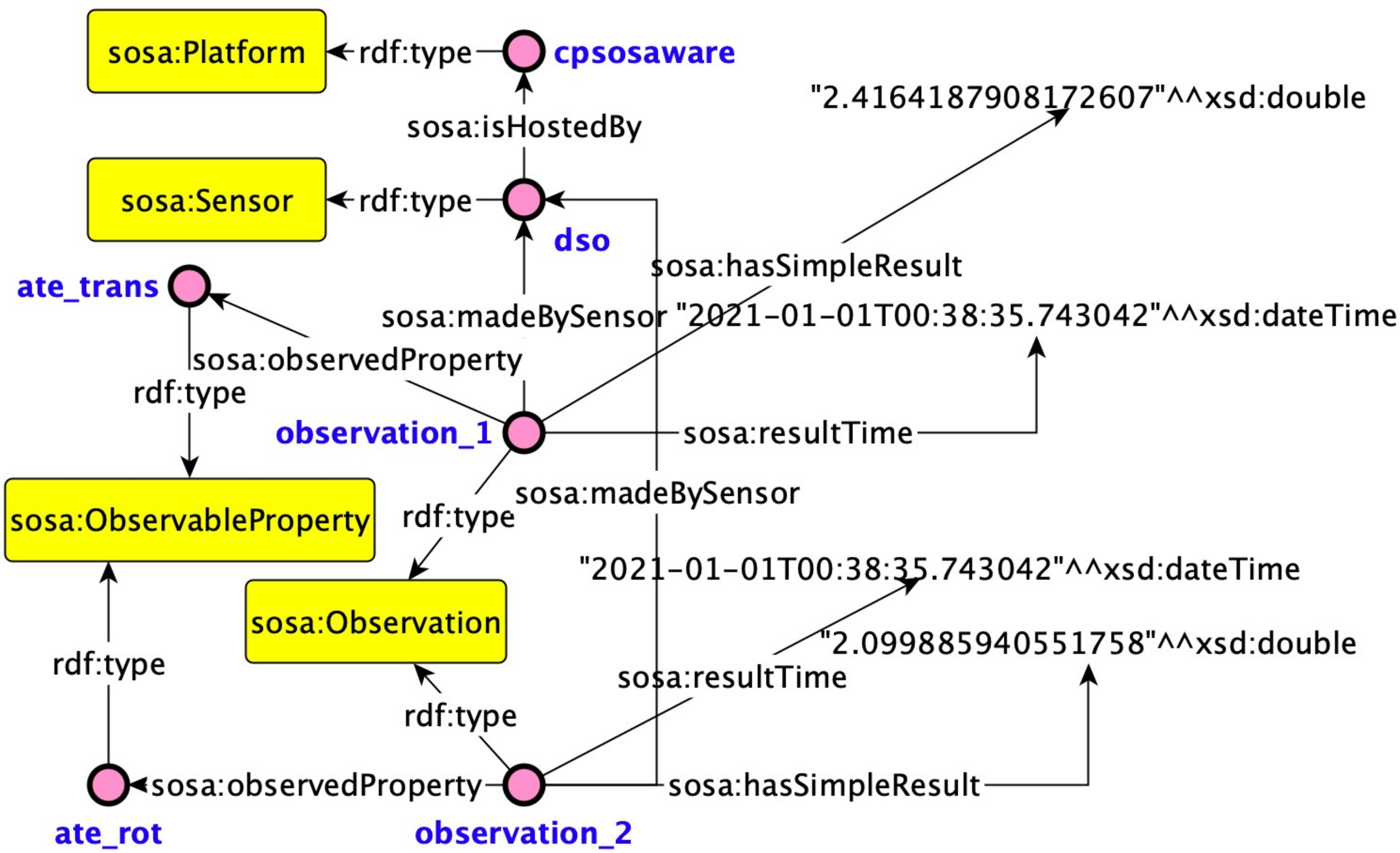
Scenario #1: Evaluate Robustness of Odometry Algorithms — Setup

ATE & **RPE** calculated for 3 algorithms (LegoLoam, DSO, cooperative localization) utilizing 3 different modalities (lidar, rgb, gnss)




```json
{
  "observations": [
    {
      "timestamp": "1970-01-01T00:38:35.743042",
      "property": "ate_trans",
      "result": 2.4164187908172607,
      "source": "dso"
    },
    {
      "timestamp": "1970-01-01T00:38:35.743042",
      "property": "rpe_trans",
      "result": 0.8676187992095947,
      "source": "dso"
    },
    ...
  ]
}
```

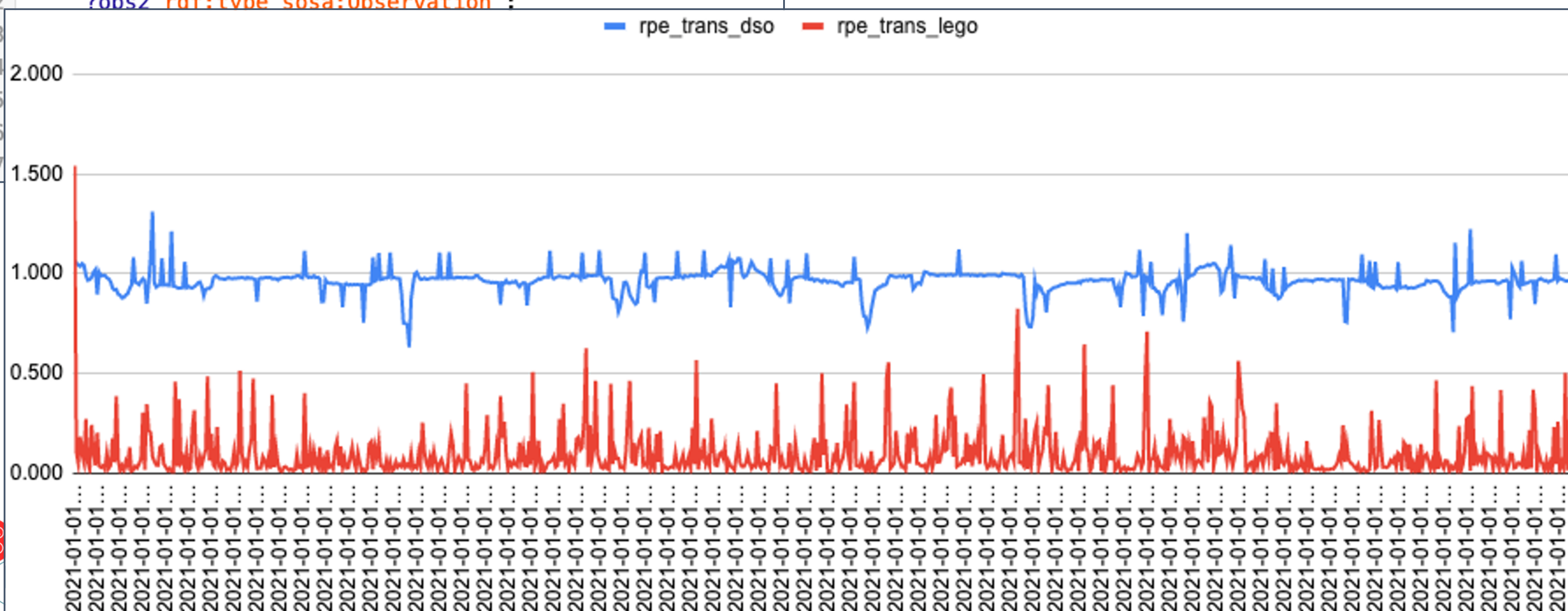
Scenario #1: Evaluate Robustness of Odometry Algorithms — Semantic KG



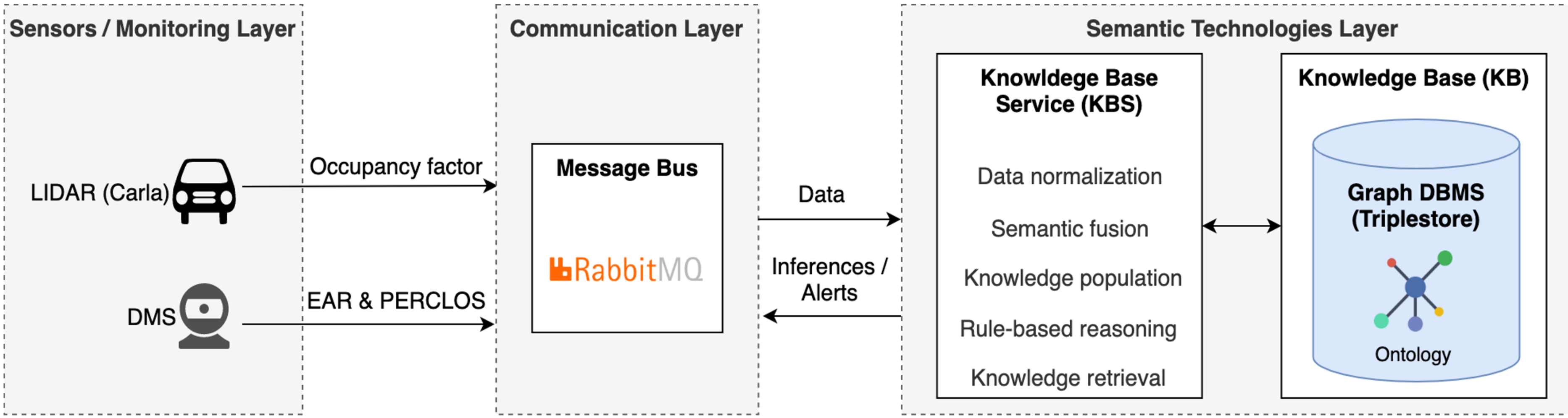
Scenario #1: Evaluate Robustness of Odometry Algorithms — Results

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX : <http://www.cpsosaware.eu/ontologies/kg#>

SELECT DISTINCT ?timestamp ?rpe_trans_dso ?rpe_trans_lego
WHERE {
    ?obs1 rdf:type sosa:Observation ;
        sosa:resultTime ?timestamp ;
        sosa:madeBySensor :dso ;
        sosa:hasSimpleResult ?rpe_trans_dso ;
        sosa:observedProperty :rpe_trans .
    ?obs2 rdf:type sosa:Observation ;
```



Scenario #2: Calculate Risk Levels — Setup



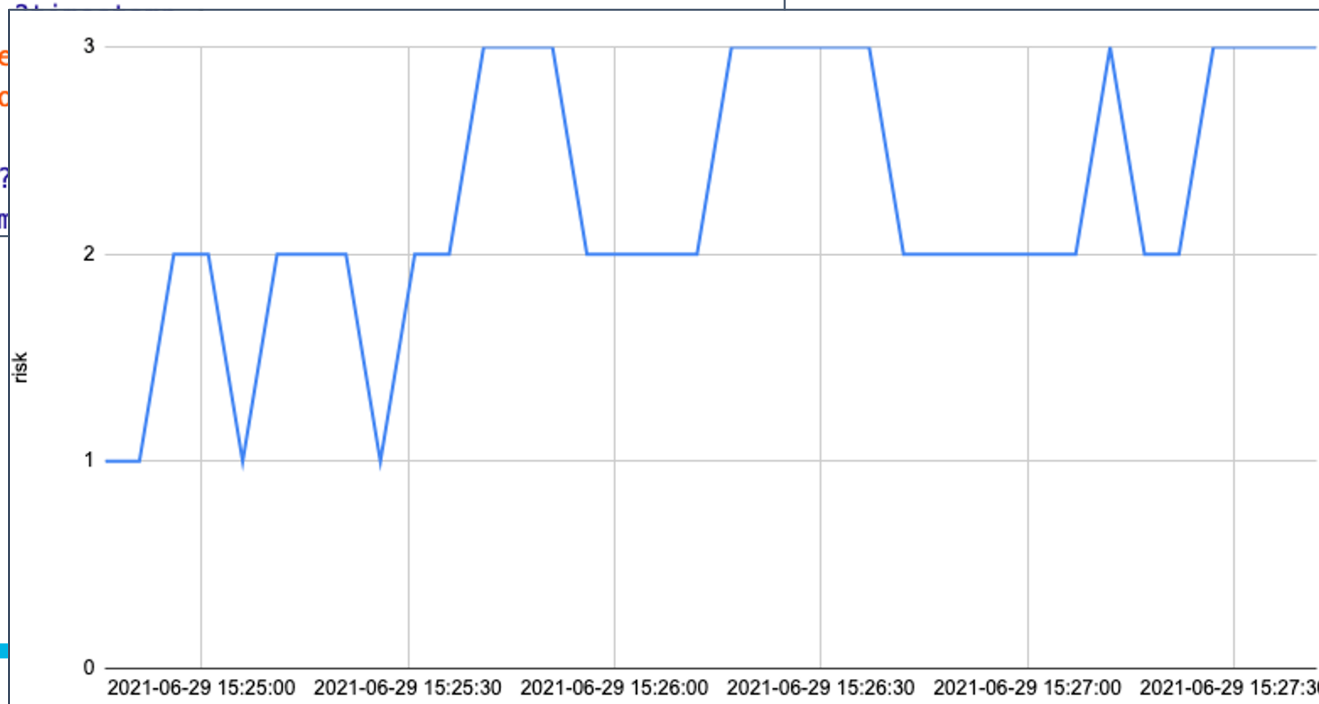

```json
{
  "observations": [
    {
      "timestamp": "2021-03-29T15:21:33.358+03:00",
      "result": 0,
      "property": "perclos",
      "source": "dsm_camera"
    },
    {
      "timestamp": "2021-03-29T15:21:33.358+03:00",
      "result": 319.435173411598,
      "property": "occupancy_factor",
      "source": "carla_lidar"
    },
    {
      "timestamp": "2021-03-29T15:21:33.358+03:00",
      "result": 0.32744966651627755,
      "property": "ear",
      "source": "dsm_camera"
    }
  ]
}
```


	PERCLOS < 0.25	PERCLOS >= 0.25 & < 0.7	PERCLOS >= 0.7
Occupancy factor > 280	Low risk	Be aware	High risk
Occupancy factor <= 280 & > 200	Low risk	Be aware	High risk
Occupancy factor <= 200	Be aware	High risk	High risk

Scenario #2: Calculate Risk Levels — Results

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX : <http://www.cpsosaware.eu/ontologies/kg#>

SELECT DISTINCT ?timestamp ?risk ?perclos ?of
WHERE {
    ?obs1 rdf:type sosa:Observation ;
        sosa:resultTime ?timestamp ;
        sosa:hasSimpleResult ?perclos ;
        sosa:observedProperty :perclos .
    ?obs2 rdf:type sosa:Observation ;
        sosa:resultTime
        sosa:hasSimpleRe
        sosa:observedPro
    BIND (IF(?perclos <
&& ?perclos < 0.7), IF(?
} ORDER BY ASC(?timestam
```



Next Steps

- Unified KG
- Run more complex simulation scenarios
  - Add more sources of information: steering frequency & biometrics (DMS), weather info
  - Dynamic objects, reduced visibility, sudden braking, etc.
  - Augment the rule-base accordingly
- Handle real-time semantic reasoning
- Deploy semantic data integration in the 2nd use case: manufacturing

Thank you for your attention!

CASPAR – Performance