# Documentation for Precision Beekeeping Ontology (PBO)

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## 1 Introduction

This documentation contains technical information about the Precision Beekeeping Ontology (PBO) developed to represent knowledge in beekeeping domain, particularly precision beekeeping (PB). The PBO ontology targets the researchers, agriculturalists particularly beekeepers, software developers and ontology engineering community. The PBO ontology covers the following areas in hive and colony health management in precision beekeeping: observation such as temperature, weight and humidity observations that represent actual measurement events and its results. It covers observable property such as temperature, weight and humidity that represents what can be measured. It covers devices used in PB such as smart devices, hives, power supply system and network router. Also, it covers the monitoring system and alert

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about connectivity and power. It covers hive and monitoring system status. It covers about bee and their roles.

This documentation is organized as follows: Section 2 contains PBO ontology metadata; Section 3 gives information about reused external thesauri and ontologies; Section 4 is about PBO ontology structure; Section 5 explains about constraints on properties in PBO ontology; Section 6 talks about SPARQL queries and results of PBO ontology; Section 7 concludes the documentation and there is appendices in the end of this document.

# 2 PBO ontology metadata

- *Ontology name*: The name given to the developed ontology is Precision Beekeeping Ontology (PBO).
- *Version*: This is the first version (V1.0) of the PBO ontology.
- *Ontology availability*: The PBO ontology is available at `https://github.com/paulmushi0018/Precision-Beekeeping-Ontology-PBO-`
- *License*: The PBO ontology is released under Creative Commons licenses (CC BY-SA)[1]
- *Language and tools used*: The tool used to develop ontology is Protégé[2] 5.6.5, which supports OWL 2 (Web Ontology Language), Resource Description Framework (RDF) and Description Logic (DL). The SPARQL[3] queries were done in Apache Jena Fuseki Server 5.4.0 and Logical consistency was checked using HermiT 1.4.3.456 reasoner in Protégé. Visualization tool, WebVOWL[4] was used.

# 3 Reused external thesauri and ontologies

The PBO ontology reused the concepts and relations from DOLCE+DnS Ultralite (DUL) upper ontology[5], SOSA Module (Sensors, Observations, Samples and Actuations) in Semantic Sensor network ontology (SSN)[6], AGROVOC[7]

[1] `https://creativecommons.org/licenses/by-sa/4.0/`
[2] `https://protege.stanford.edu/software.php#desktop-protege`
[3] `https://sparql.dev/article/SPARQL_and_ontology_development.html`
[4] `https://service.tib.eu/webvowl/`
[5] `http://www.ontologydesignpatterns.org/ont/dul/DUL.owl`
[6] `https://w3c.github.io/sdw-sosa-ssn/ssn/`
[7] `https://agrovoc.fao.org/browse/agrovoc/en/page/c_529`

Multilingual Thesaurus and the General Multilingual Environmental Thesaurus (GEMET[8]), for example "c_8872" for "Apiary_" and all other classes defined in Protégé with URI in external vocabulary were annotated by *rdfs:label* for readability. This can be seen in Figure 1 for the term Apiary_ and BeeColony_ that they have external link to AGROVOC thesaurus.

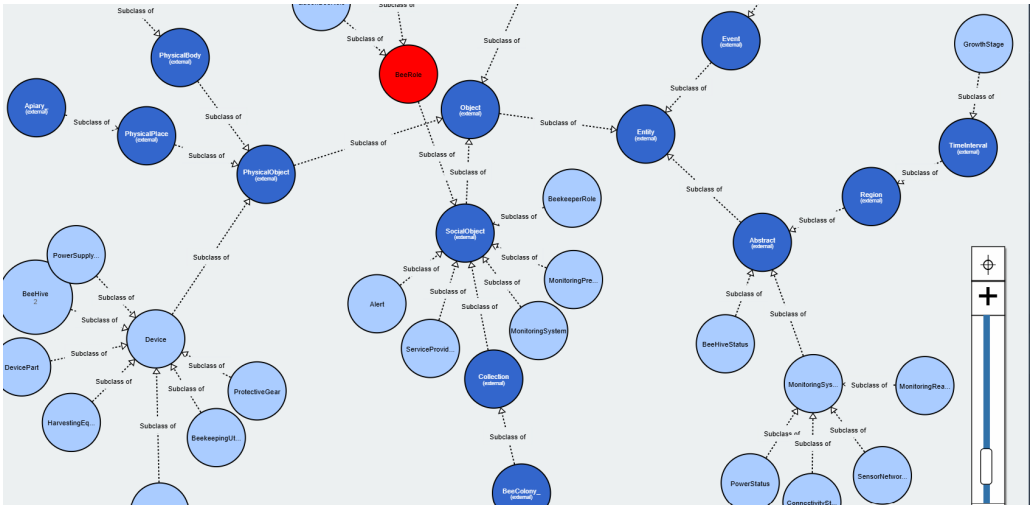


Figure 1: Class hierarchy and visualization of the PBO ontology using the WebVOWL tool

# 4 PBO ontology structure

As depicted in Figure 2, metrics of PBO ontology in Protégé are axioms, logical axioms count, declarative axioms count, class count, object property count, data property count, individual count and annotation property count.

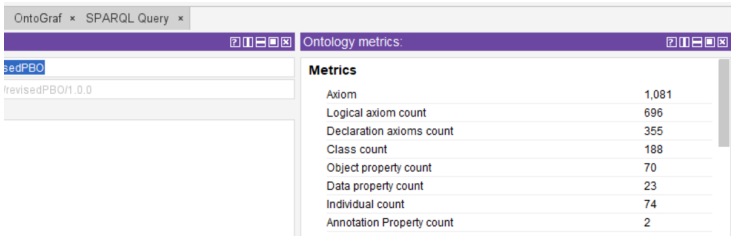


Figure 2: Metrics of the PBO ontology from the Protégé

[8] https://www.eionet.europa.eu/gemet/en/themes/

- PBO ontology has 1081 axioms, whereby 696 axioms are logical and 355 axioms are declarative.
- PBO ontology has 188 concepts or terms that appear as classes in Protégé, which indicates the concepts that have been covered in the PB domain.
- The object property count in PBO ontology is 70, which defines the relationship between classes. For example, the object property that links the "Observation" class and the "BeeHive" class is shown in Figure 3 "hasFeatureOfInterest" which was reused from SSN/SOSA. Also, some of object properties are seen in Figure 4 as defined in the Protégé.

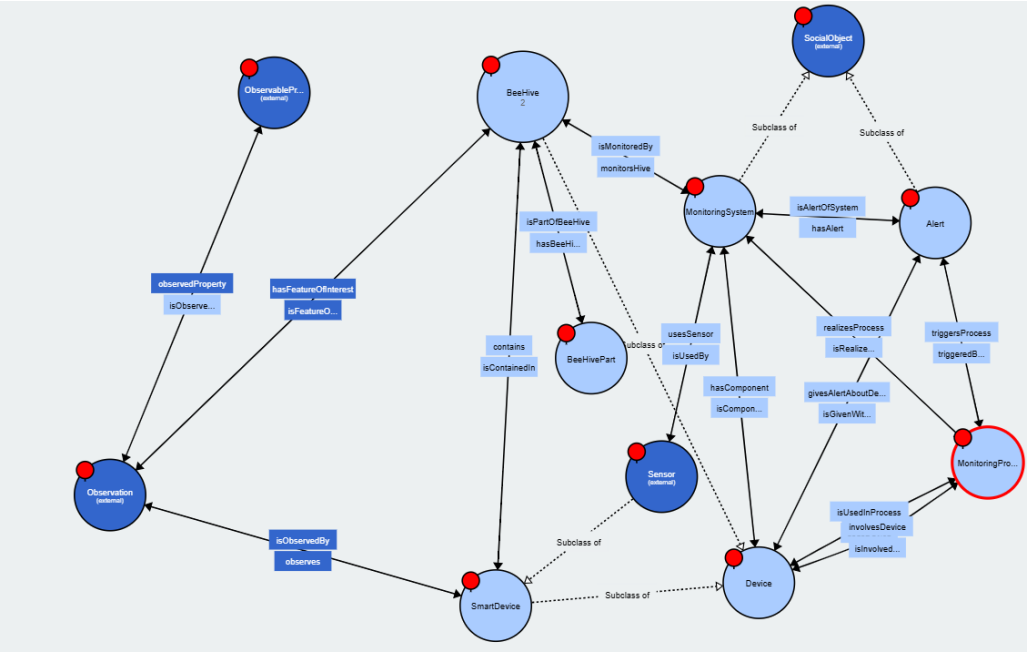


Figure 3: Visualization in WebVOWL tool of the object properties such as hasFeatureOfInterest between the Observation class and the BeeHive class.

- The data property count is 23 in the PBO ontology and some of them are seen in Figure 5.
- The individual count is 74 in PBO ontology as seen in Table 1 and Table 2, which contains about beehive metrics that include 2 hives (Schwartau and Wurzburg), 48 internal temperature readings of Schwartau hive

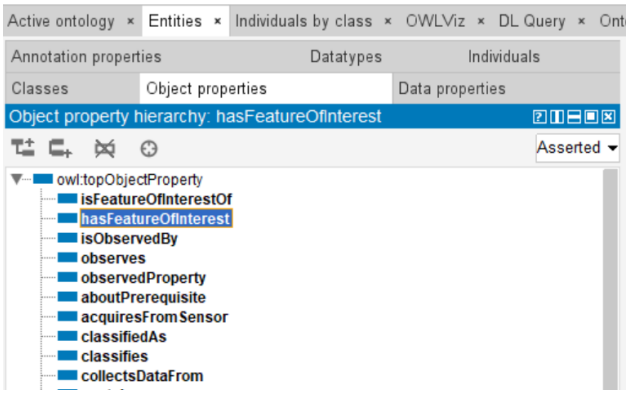


Figure 4: Snippet of Object Property Hierarchy in Protégé for PBO Ontology

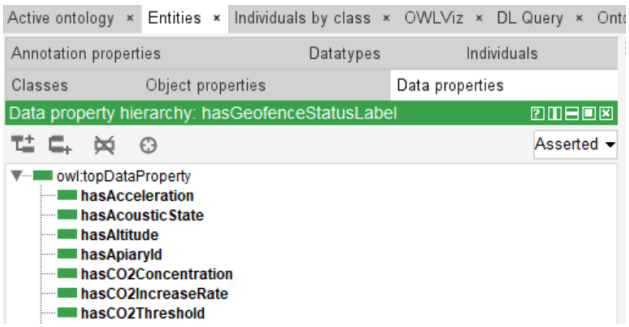


Figure 5: Snippet of Data Property Hierarchy in Protégé for PBO Ontology

and 24 hive weight readings of Schwartau and Wurzburg hives from Kaggle dataset repository[9] as seen in Figure 6.

# 5 Constraints on properties in PBO ontology

To ensure the correct reasoning of the PBO ontology, we specified constraints on the properties For example, the value datatype constraints show that the *WeightObservation* class can contain individual *WeightObs1* specified under the data property *hasWeight* with value *50.55* as double datatype and not otherwise as seen in Figure 7.

We also specified the domain and range restrictions on the object properties for example hasFeatureOfInterest object property with the domain Observation class and the range BeeHive class.

In specifying restrictions on data properties, we specified value datatypes,

[9] `https://www.kaggle.com/datasets/se18m502/bee-hive-metrics/data`

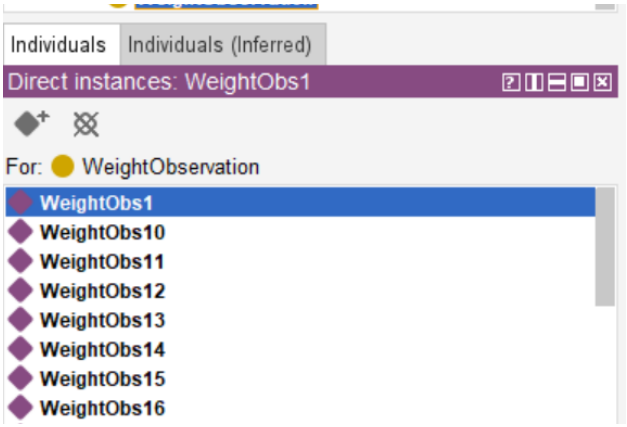


Figure 6: Snippet of individuals (instances) in Protégé for PBO Ontology


Figure 7: Snippet of data Property restrictions in Protégé for PBO Ontology

domain and range restrictions such as hasWeight data property link between BeeHive class as domain and xsd:double as range.

# 6 SPARQL queries and results of PBO ontology

The PBO ontology was evaluated based on the pre-defined competence questions (CQs) that were 6 based on the internal temperature and hive weight data. Using SPARQL queries in the Apache Jena Fuseki server after being set locally as shown in Figure 8, we successfully evaluated the ontology based on 6 CQs. Figure 9 shows the total number of triples uploaded 1082, from the PBO ontology, from which CQ1 (For each hive, what is its most recent recorded weight?) is illustrated in Figure 10.

Figure 11 illustrates instances of the results for CQ1 for corresponding query in Figure 10 which gives the latest recorded weight per hive which are 50.55 and 52.38 for Schwartau and Wurzburg respectively . The other CQs 2 to 6 for SPARQL queries and results are available in Appendices A to J.

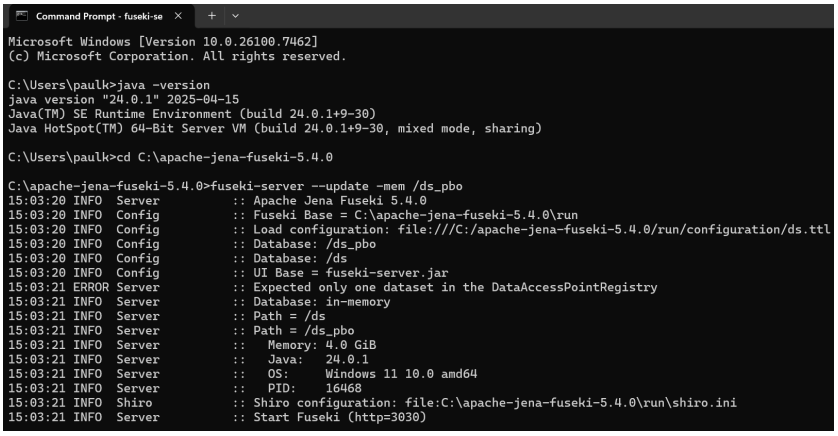


Figure 8: Setting the Apache Jena Fuseki Server for Ontology Evaluation

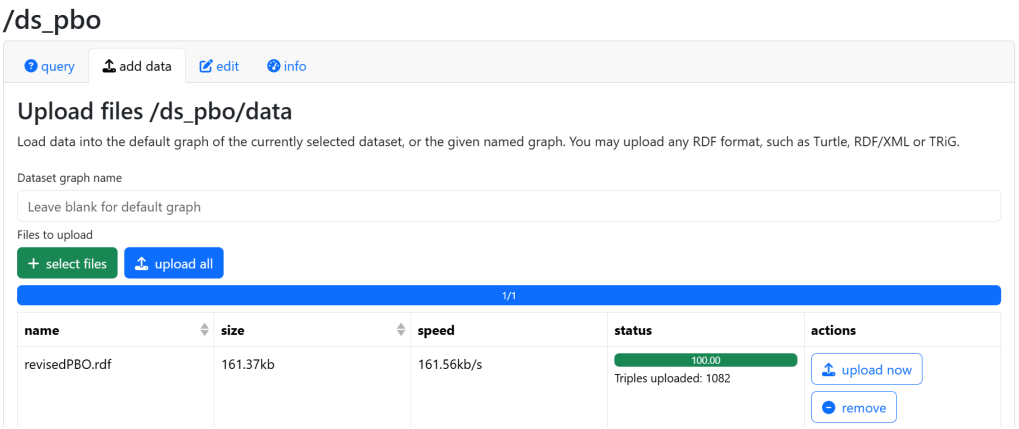


Figure 9: Triples uploaded in Apache Jena Fuseki server for running SPARQL queries

Table 1: Sample weight observations for Wurzburg and Schwartau hives

| Instance | Hive | Hive ID | Recorded Timestamp | Weight (kg) |
|---|---|---|---|---|
| WeightObs1 | Wurzburg | Wurzburg1 | 2017-01-01T13:00:00 | 52.63 |
| WeightObs2 | Wurzburg | Wurzburg1 | 2017-01-02T01:00:00 | 52.67 |
| WeightObs3 | Wurzburg | Wurzburg1 | 2017-01-02T13:00:00 | 52.70 |
| WeightObs4 | Wurzburg | Wurzburg1 | 2017-01-03T01:00:00 | 52.70 |
| WeightObs5 | Wurzburg | Wurzburg1 | 2017-01-03T13:00:00 | 52.63 |
| WeightObs6 | Wurzburg | Wurzburg1 | 2017-01-04T01:00:00 | 52.63 |
| WeightObs7 | Wurzburg | Wurzburg1 | 2017-01-04T13:00:00 | 52.67 |
| WeightObs8 | Wurzburg | Wurzburg1 | 2017-01-05T01:00:00 | 52.60 |
| WeightObs9 | Wurzburg | Wurzburg1 | 2017-01-05T13:00:00 | 52.57 |
| WeightObs10 | Wurzburg | Wurzburg1 | 2017-01-06T01:00:00 | 52.67 |
| WeightObs11 | Wurzburg | Wurzburg1 | 2017-01-06T13:00:00 | 52.89 |
| WeightObs12 | Wurzburg | Wurzburg1 | 2017-01-07T01:00:00 | 52.38 |
| WeightObs13 | Schwartau | Schwartau1 | 2017-01-01T13:00:00 | 50.74 |
| WeightObs14 | Schwartau | Schwartau1 | 2017-01-02T01:00:00 | 50.70 |
| WeightObs15 | Schwartau | Schwartau1 | 2017-01-02T13:00:00 | 50.61 |
| WeightObs16 | Schwartau | Schwartau1 | 2017-01-03T01:00:00 | 50.74 |
| WeightObs17 | Schwartau | Schwartau1 | 2017-01-03T13:00:00 | 50.80 |
| WeightObs18 | Schwartau | Schwartau1 | 2017-01-04T01:00:00 | 50.65 |
| WeightObs19 | Schwartau | Schwartau1 | 2017-01-04T13:00:00 | 50.41 |
| WeightObs20 | Schwartau | Schwartau1 | 2017-01-05T01:00:00 | 50.17 |
| WeightObs21 | Schwartau | Schwartau1 | 2017-01-05T13:00:00 | 50.05 |
| WeightObs22 | Schwartau | Schwartau1 | 2017-01-06T01:00:00 | 49.88 |
| WeightObs23 | Schwartau | Schwartau1 | 2017-01-06T13:00:00 | 50.46 |
| WeightObs24 | Schwartau | Schwartau1 | 2017-01-07T01:00:00 | 50.55 |

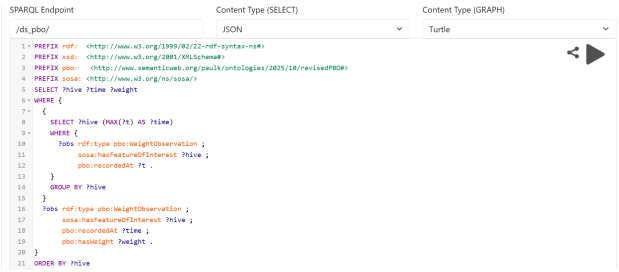


Figure 10: SPARQL query for Competence Question 1 (CQ1) in Jena Fuseki Server for Ontology Evaluation

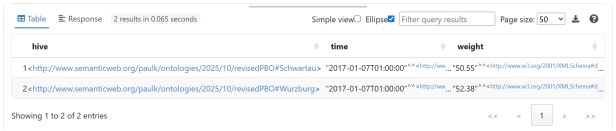


Figure 11: SPARQL query results for Competence Question 1 (CQ1) in Jena Fuseki Server for Ontology Evaluation

Table 2: Sample internal temperature observations for the Schwartau hive

| Instance | Hive | Hive ID | Recorded Timestamp | Internal Temperature (°C) |
|---|---|---|---|---|
| InTemperatureObs1 | Schwartau | Schwartau1 | 2017-01-01T14:15:00 | 12.34 |
| InTemperatureObs2 | Schwartau | Schwartau1 | 2017-01-01T15:15:00 | 12.38 |
| InTemperatureObs3 | Schwartau | Schwartau1 | 2017-01-01T16:15:00 | 15.73 |
| InTemperatureObs4 | Schwartau | Schwartau1 | 2017-01-01T17:15:00 | 17.63 |
| InTemperatureObs5 | Schwartau | Schwartau1 | 2017-01-01T18:15:00 | 13.35 |
| InTemperatureObs6 | Schwartau | Schwartau1 | 2017-01-01T19:15:00 | 13.93 |
| InTemperatureObs7 | Schwartau | Schwartau1 | 2017-01-01T20:15:00 | 12.52 |
| InTemperatureObs8 | Schwartau | Schwartau1 | 2017-01-01T21:15:00 | 20.56 |
| InTemperatureObs9 | Schwartau | Schwartau1 | 2017-01-01T22:15:00 | 19.91 |
| InTemperatureObs10 | Schwartau | Schwartau1 | 2017-01-01T23:15:00 | 19.99 |
| InTemperatureObs11 | Schwartau | Schwartau1 | 2017-01-02T00:15:00 | 18.24 |
| InTemperatureObs12 | Schwartau | Schwartau1 | 2017-01-02T01:15:00 | 13.47 |
| InTemperatureObs13 | Schwartau | Schwartau1 | 2017-01-02T02:15:00 | 13.20 |
| InTemperatureObs14 | Schwartau | Schwartau1 | 2017-01-02T03:15:00 | 14.86 |
| InTemperatureObs15 | Schwartau | Schwartau1 | 2017-01-02T04:15:00 | 12.34 |

*Continued on next page*

| Instance | Hive | Hive ID | Recorded Timestamp | Internal Temperature (°C) |
|---|---|---|---|---|
| InTemperatureObs16 | Schwartau | Schwartau1 | 2017-01-02T05:15:00 | 12.77 |
| InTemperatureObs17 | Schwartau | Schwartau1 | 2017-01-02T06:15:00 | 13.90 |
| InTemperatureObs18 | Schwartau | Schwartau1 | 2017-01-02T07:15:00 | 15.16 |
| InTemperatureObs19 | Schwartau | Schwartau1 | 2017-01-02T08:15:00 | 11.72 |
| InTemperatureObs20 | Schwartau | Schwartau1 | 2017-01-02T09:15:00 | 12.75 |
| InTemperatureObs21 | Schwartau | Schwartau1 | 2017-01-02T10:15:00 | 12.52 |
| InTemperatureObs22 | Schwartau | Schwartau1 | 2017-01-02T11:15:00 | 11.50 |
| InTemperatureObs23 | Schwartau | Schwartau1 | 2017-01-02T12:15:00 | 12.92 |
| InTemperatureObs24 | Schwartau | Schwartau1 | 2017-01-02T13:15:00 | 14.60 |
| InTemperatureObs25 | Schwartau | Schwartau1 | 2017-01-02T14:15:00 | 11.91 |
| InTemperatureObs26 | Schwartau | Schwartau1 | 2017-01-02T15:15:00 | 12.16 |
| InTemperatureObs27 | Schwartau | Schwartau1 | 2017-01-02T16:15:00 | 11.63 |
| InTemperatureObs28 | Schwartau | Schwartau1 | 2017-01-02T17:15:00 | 11.43 |
| InTemperatureObs29 | Schwartau | Schwartau1 | 2017-01-02T18:15:00 | 11.03 |
| InTemperatureObs30 | Schwartau | Schwartau1 | 2017-01-02T19:15:00 | 10.60 |
| InTemperatureObs31 | Schwartau | Schwartau1 | 2017-01-02T20:15:00 | 11.67 |
| InTemperatureObs32 | Schwartau | Schwartau1 | 2017-01-02T21:15:00 | 13.48 |
| InTemperatureObs33 | Schwartau | Schwartau1 | 2017-01-02T22:15:00 | 20.08 |
| InTemperatureObs34 | Schwartau | Schwartau1 | 2017-01-02T23:15:00 | 15.84 |
| InTemperatureObs35 | Schwartau | Schwartau1 | 2017-01-03T00:15:00 | 16.57 |
| InTemperatureObs36 | Schwartau | Schwartau1 | 2017-01-03T01:15:00 | 15.75 |
| InTemperatureObs37 | Schwartau | Schwartau1 | 2017-01-03T02:15:00 | 19.50 |
| InTemperatureObs38 | Schwartau | Schwartau1 | 2017-01-03T03:15:00 | 12.33 |
| InTemperatureObs39 | Schwartau | Schwartau1 | 2017-01-03T04:15:00 | 12.67 |
| InTemperatureObs40 | Schwartau | Schwartau1 | 2017-01-03T05:15:00 | 11.43 |
| InTemperatureObs41 | Schwartau | Schwartau1 | 2017-01-03T06:15:00 | 14.14 |
| InTemperatureObs42 | Schwartau | Schwartau1 | 2017-01-03T07:15:00 | 11.00 |
| InTemperatureObs43 | Schwartau | Schwartau1 | 2017-01-03T08:15:00 | 15.28 |
| InTemperatureObs44 | Schwartau | Schwartau1 | 2017-01-03T09:15:00 | 15.49 |
| InTemperatureObs45 | Schwartau | Schwartau1 | 2017-01-03T10:15:00 | 15.24 |
| InTemperatureObs46 | Schwartau | Schwartau1 | 2017-01-02T11:15:00 | 15.62 |
| InTemperatureObs47 | Schwartau | Schwartau1 | 2017-01-02T12:15:00 | 20.91 |
| InTemperatureObs48 | Schwartau | Schwartau1 | 2017-01-02T13:15:00 | 15.63 |

# 7 Conclusion

This documentation gives the technical details of the PBO ontology about metadata, reused external links, the structure of the ontology, constraints specified in PBO ontology and SPARQL queries and results during evaluation. The PBO ontology can be extended to improve interoperability by including external links to the concepts and object properties from other ontologies. Also, PBO ontology can be extended by considering more parameters such as acoustic sound, humidity, CO2 concentration and geo position as the real-world data from hives connected with sensors in the apiary.

# Appendices

## A : CQ 2: On which days did each hive experience strong daily nectar intake, defined as a daily weight increase above a threshold?

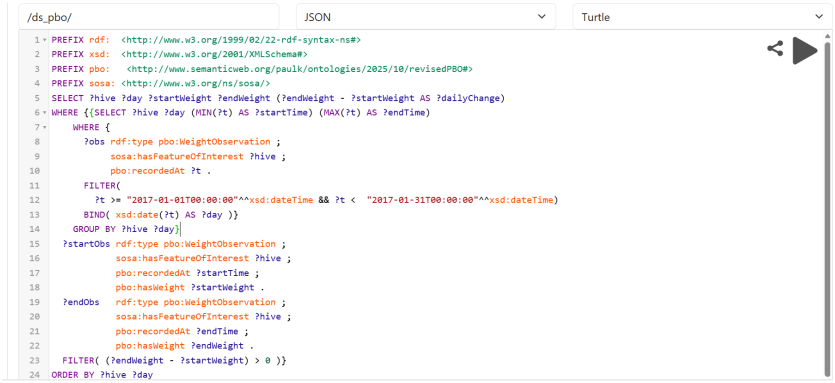


Figure 12: SPARQL query for CQ 2 in Apache Jena Fuseki Server

## B : SPARQL query results for CQ 2

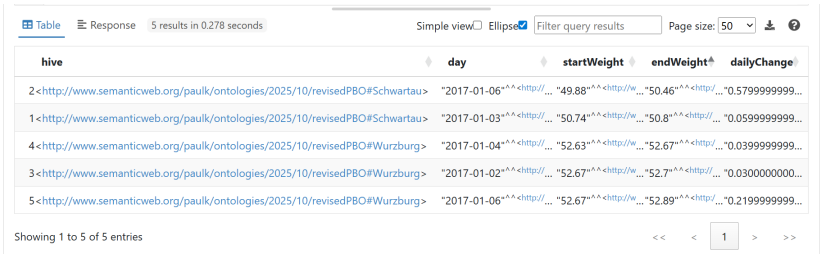


Figure 13: SPARQL query results for CQ 2 in Apache Jena Fuseki Server

## C : CQ 3: On which days did each hive experience a significant daily weight loss below a given threshold?

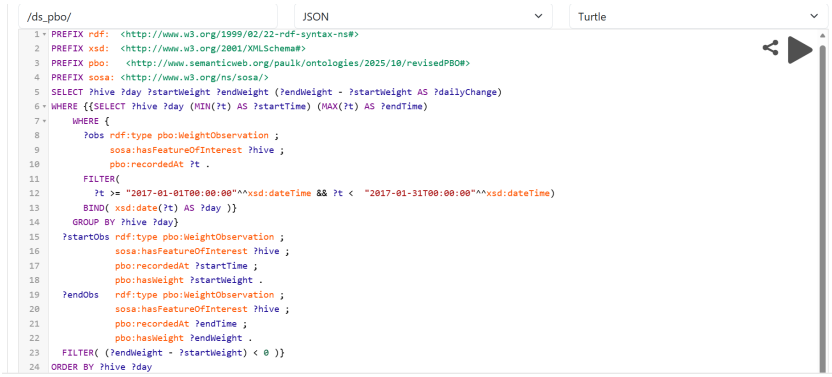


Figure 14: SPARQL query for CQ 3 in Apache Jena Fuseki Server

## D : SPARQL query results for CQ 3

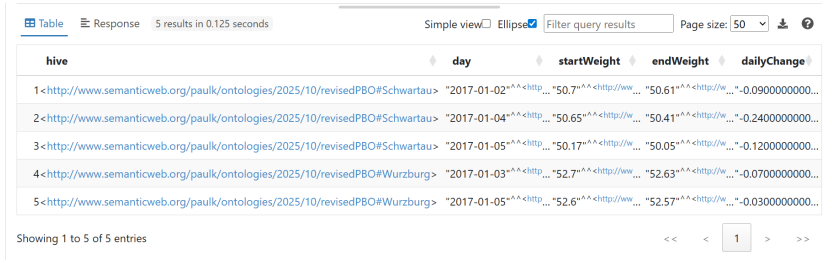


Figure 15: SPARQL query results for CQ 3 in Apache Jena Fuseki Server

## E : CQ 4: Is the Schwartau hive maintaining stable internal hive temperature?

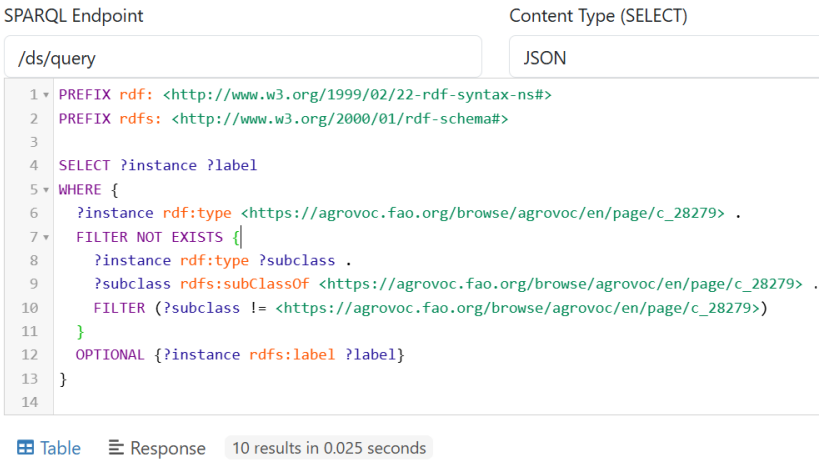


Figure 16: SPARQL query for CQ 4 in Apache Jena Fuseki Server

## F : SPARQL query results for CQ 4

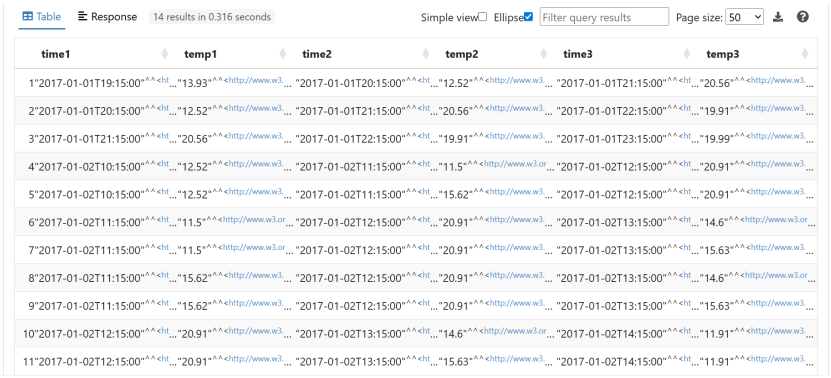


Figure 17: SPARQL query results for CQ 4 in Apache Jena Fuseki Server

## G : CQ 5: Did the Schwartau hive experience rapid temperature drops (less than 2°C per hour), indicating weakening thermoregulation or disturbance?

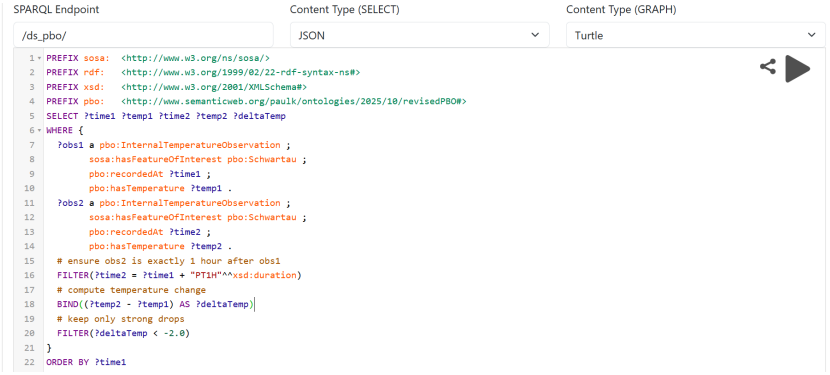


Figure 18: SPARQL query for CQ 5 in Apache Jena Fuseki Server

## H : SPARQL query results for CQ 5

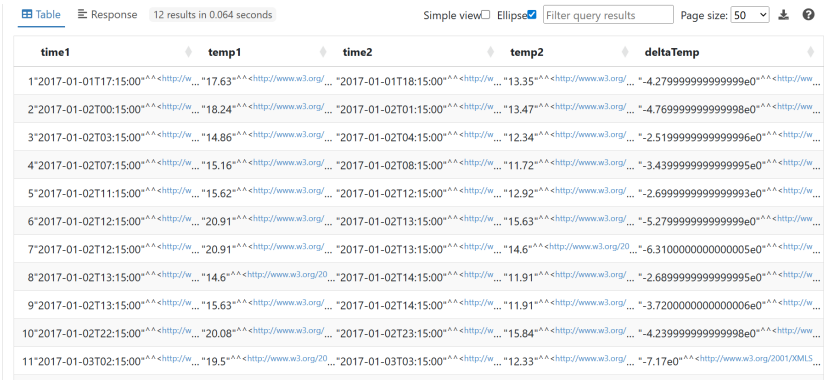


Figure 19: SPARQL query results for CQ 5 in Apache Jena Fuseki Server

## I : CQ 6: Is the internal temperature showing a consistent upward or downward trend indicating cluster migration?

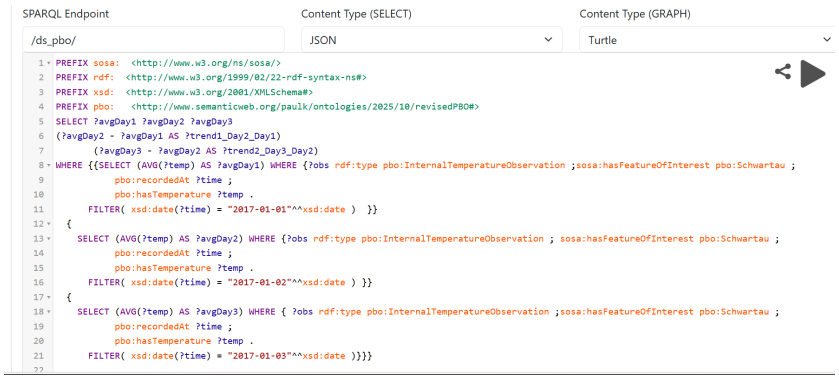


Figure 20: SPARQL query for CQ 6 in Apache Jena Fuseki Server

## J : SPARQL query results for CQ 6

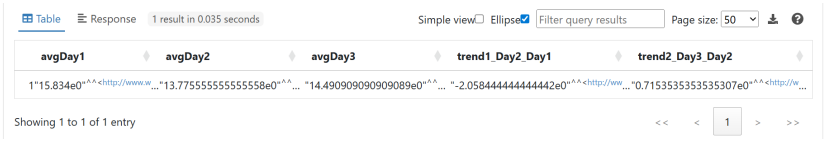


Figure 21: SPARQL query results for CQ 6 in Apache Jena Fuseki Server