




Linked Open Vocabularies for Internet of Things (LOV4IoT)

<p>WARNING!</p> 	<p>Check our dedicated web site to stay updated with the latest news, documentations, etc. http://lov4iot.appspot.com/</p> <p>Documentation updated: http://lov4iot.appspot.com/documentation/LOV4IoTDocumentation.pdf</p>
Version 2	http://lov4iot.appspot.com/documentation/LOV4IoTDocumentation.pdf
Version 1	<p>DEPRECATED→</p> <p>http://sensormeasurement.appspot.com/documentation/LOV4IoTDocumentation.pdf</p>
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Google Group	https://groups.google.com/d/forum/m3-semantic-web-of-things
Last updated	<p>November:</p> <ul style="list-style-type: none"> Recommendations for the new web site and up-to-date documentations <p>October 2017</p> <ul style="list-style-type: none"> Query all health ontologies (to get their URL) with the LOV4IoT web service All web services are now hosted on http://lov4iot.appspot.com/, documentation updated <p>August 2017</p> <ul style="list-style-type: none"> LOV4IoT web services for PerfectO LOV4IoT web services summary table and description LOV4IoT more automatic with more web services Refinement between IoT, WoT, Smart City and Sensor ontologies Methodology to update the ontology catalogue – V1 <p>September, June 2016</p> <ul style="list-style-type: none"> Add section web services/APIs (already explained in the M3 documentation)


	<ul style="list-style-type: none"> • Restructuration of the document • Update LOV4IoT citations • Suggestion new web services – improvement idea <p>April 2016</p> <ul style="list-style-type: none"> • Errors with LOV, LOV community Google + • Suggesting a vocab to LOVIoT <p>March 2016</p> <ul style="list-style-type: none"> • Suggesting a vocab to LOV
Created	February 2016
Status	 Work in progress
Goal	<p>This documentation enables understanding the LOV4IoT tool:</p> <ul style="list-style-type: none"> • Use the Graphical User interface (GUI) • Use the web services • Contribute to the LOV4IoT knowledge base <p>Linked Open Vocabularies for Internet of Things (LOV4IoT) is an extension of Linked Open Vocabularies (LOV) for Internet of Things</p>
Useful links	<p>M3 ontology OWL code: http://sensormeasurement.appspot.com/m3#</p> <p>M3 ontology documentation: http://sensormeasurement.appspot.com/documentation/NomenclatureSensorData.pdf</p> <p>M3 documentation with Parrot: http://ontorule-project.eu/parrot/parrot?documentUri=http%3A%2F%2Fwww.sensormeasurement.appspot.com%2Fm3%23&mimetype=application%2Frd%2Fxml&profile=technical&language=en&customizeCssUrl=</p>

Table of contents

I.	LOV4IoT Web services hosted on LOV4IoT	8
1.	Summary	8
2.	Web service: Get the total number of ontologies	8
3.	Web service: Get the number of ontologies by domains	9
4.	Web service: Get the number of ontology by ontology status	10
5.	Web Service: Get all domains referenced within LOV4IoT.....	11
6.	Web Service: Get all ontologies referenced within LOV4IoT	11
7.	Web Service: Get all ontologies for a specific domain	12
8.	Web Service: Get all health ontologies useful information.....	12
II.	Adding a new domain to LOV4IoT Methodology.....	13
III.	Refinement between IoT, WoT, Smart City and Sensor ontologies.....	14
IV.	LOV4IoT Citations.....	15
V.	Introduction: From LOV to LOV4IoT	15
9.	Suggesting a vocabulary to LOV	16
10.	Errors encountered when suggesting a vocabulary on LOV	20
11.	Suggesting a vocabulary to LOV4IoT	22
VI.	Reusing domain knowledge with LOV4IoT	23
VII.	LOV4IoT web services/APIs.....	25
1.	LOV4IoTWS Java class	25
2.	Web service: Get the total number of ontologies	26
3.	Web service: Get the number of ontologies by domains.....	27
4.	Web service: Get the number of ontology by ontology status	28
5.	Use Case: LO4IoT HTML user interface using web services	29
VIII.	HTML web page	31
1.	Adding a new ontology in LOV4IoT HTML web page.....	31
IX.	LOV4IoT ontology.....	32
1.	Visualizing LOV4IoT with WEBVOWL	32
X.	LOV4IoT RDF dataset	33
1.	Adding a new instance in the LOV4IoT RDF dataset.....	34
XI.	LOV4IoT Bot	34
1.	LOV Bot user interface	34

2.	LOV Bot explanations.....	35
XII.	LOV4IoT Architecture.....	36
XIII.	Repository purl with Ghis.....	36
XIV.	LOV4IoT Use Cases.....	36
I.	LOV4IoT sequence diagram	36
1.	Machine-to-Machine Measurement (M3) framework.....	36
2.	Domain experts.....	37
3.	Knowledge extraction experts	37
4.	Ontology matching tool experts	37
5.	IoT/SWoT developers and projects	37
6.	Ontology matching tool experts	38
II.	Lessons Learnt: Best Practices	38
1.	Ontology Documentation	38
III.	Improvement ideas	39
1.	Improving the user interface	39
2.	Checking best practices	41
3.	Automatically updating LOV4IoT	42
4.	New web service	43
IV.	References	43

Table of figures

FIGURE 1. LOV4IoT WEB SERVICE TO COUNT THE TOTAL NUMBER OF ONTOLOGIES	9
FIGURE 2. LOV4IoT WEB SERVICE TO COUNT THE NUMBER OF ONTOLOGIES BY DOMAIN	10
FIGURE 3. LOV4IoT WEB SERVICE TO COUNT THE NUMBER OF ONTOLOGIES BY ONTOLOGY STATUS	10
FIGURE 4. RESULT RETURNED BY THE WEB SERVICE GETALLDOMAINFROMLOV4IoT	11
FIGURE 5. RESULT RETURNED BY THE WEB SERVICE GETONTO.....	11
FIGURE 6. RESULT RETURNED BY THE WEB SERVICE /GETONTODOMAIN/?DOMAIN=CITY.....	12
FIGURE 7. RESULT RETURNED BY THE WEB SERVICE /GETONTODOMAIN/?DOMAIN= HEALTH	13
FIGURE 8. IOT, WOT, WIRELESS SENSOR NETWORKS ARE COMPLIMENTARY	15
FIGURE 9. LINKED OPEN VOCABULARIES (LOV).....	16
FIGURE 10. SUGGEST A VOCABULARY ON LOV	17
FIGURE 11. SUGGEST YOUR ONTOLOGY ON LOV	17
FIGURE 12. SUGGEST YOUR ONTOLOGY ON LOV WITHOUT ERRORS.....	18
FIGURE 13. LOV RECOMMENDATIONS	19
FIGURE 14. ERRORS ENCOUNTERING WHEN SUGGESTING ONTOLOGIES ON LOV	20
FIGURE 15. LOV COMMUNITY ON GOOGLE +	21
FIGURE 16. THE REACTIVE LOV COMMUNITY GUIDES US TO FIX ISSUES REGARDING ONTOLOGIES	21
FIGURE 17. ALMOST 300 ONTOLOGY-BASED PROJECTS REFERENCED IN LOV4IoT.....	22
FIGURE 18. ONTOLOGIES CLASSIFIED IN VARIOUS DOMAINS	23
FIGURE 19. CLASSIFICATION OF PROJECTS ACCORDING TO THE REUSABILITY	23
FIGURE 20. SCREENSHOT OF LOV4IoT	24
FIGURE 21. LOV4IoTWS JAVA CLASS LOCATION.....	25
FIGURE 22. EXAMPLE OF THE LOV4IoT/TOTALONTO: WEB SERVICE	26
FIGURE 23. LOV4IoT WEB SERVICE TO COUNT THE TOTAL NUMBER OF ONTOLOGIES	27
FIGURE 24. LOV4IoT WEB SERVICE TO COUNT THE NUMBER OF ONTOLOGIES BY DOMAIN	28
FIGURE 25. LOV4IoT WEB SERVICE TO COUNT THE NUMBER OF ONTOLOGIES BY ONTOLOGY STATUS	29
FIGURE 26. LOV4IoT WEB SERVICES.....	30
FIGURE 27. LOV4IoT HTML FILE LOCATION	31
FIGURE 28. LOV4IoT ONTOLOGY FILE LOCATION.....	32
FIGURE 29. VISUALIZING LOV4IoT ONTOLOGY WITH WEBVOWL	33
FIGURE 30. LOV4IoT RDF FILE LOCATION.....	33
FIGURE 31. AN ONTOLOGY-BASED IOT PROJECT REFERENCED IN THE LOV4IoT RDF DATASET	34
FIGURE 32. LOV4IoT BOT USER INTERFACE.....	35
FIGURE 33. CODE TO SEND EMAILS TO CONVINCE AUTHORS TO SHARE THEIR ONTOLOGIES WITH LOV4IoT BOT.....	35
FIGURE 34. BUBBLE VIEW TO CLASSIFY ONTOLOGIES ACCORDING TO THE SENSOR TYPE	40
FIGURE 35. BUBBLE VIEW TO CLASSIFY ONTOLOGIES ACCORDING TO THE IOT APPLICATIVE DOMAIN	41
FIGURE 36. BEST PRACTICES TOOLS INTEGRATED WITH LOV.....	42
FIGURE 37. INTEGRATING LOV4IoT WITH SEMANTIC SEARCH ENGINES AND CATALOGUES.....	43

Terms and acronyms

IoT	Internet of Things (IoT)
LOV	Linked Open Vocabularies
LOV4IoT	Linked Open Vocabularies for Internet of Things
M3 framework	Machine-to-Machine Measurement (M3) framework

I. LOV4IoT Web services hosted on LOV4IoT

1. Summary

Table 1. Summary LOV4IoT Web serviced hosted on PerfectO

Get number total of ontologies	E.g., http://lov4iot.appspot.com/lov4iot/totalOnto/
Get the number of ontologies by domains	E.g., http://lov4iot.appspot.com/lov4iot/nbOntoDomain/?domain=BuildingAutomation
Get the number of ontology by ontology status	E.g., http://lov4iot.appspot.com/lov4iot/ontoStatus/?status=Online
Get all domains referenced within LOV4IoT	http://lov4iot.appspot.com/perfectoOnto/getAllDomainFromLOV4IoT
Get all ontology links referenced within LOV4IoT	http://lov4iot.appspot.com/perfectoOnto/getOnto/
Get all ontologies for a specific domain	http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain={domain} Generic web service, domain must be replaced by a domain referenced within the M3 taxonomy. E.g., http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain=City
Get all health ontologies	http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain=Health

2. Web service: Get the total number of ontologies

Query:

<http://lov4iot.appspot.com/lov4iot/totalOnto/>

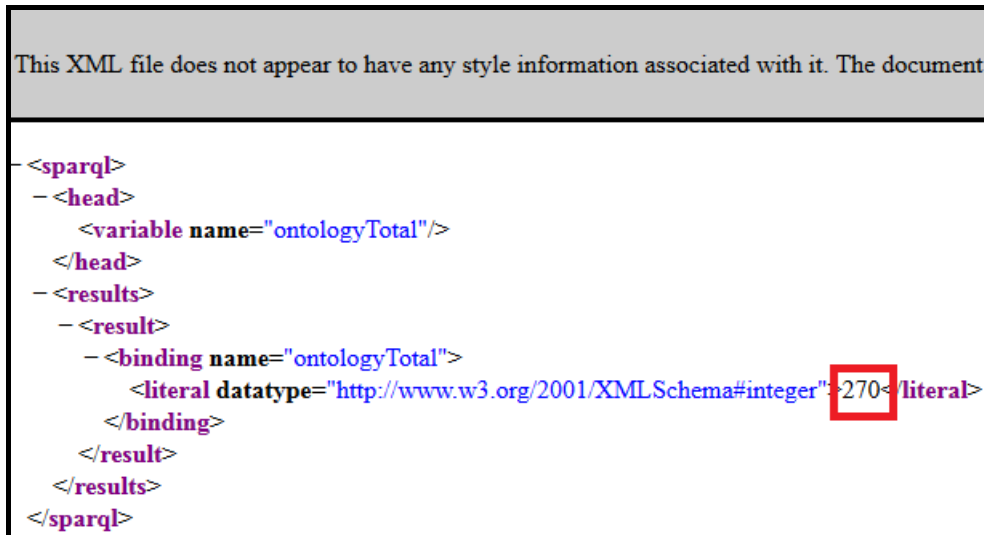


Figure 1. LOV4IoT Web service to count the total number of ontologies

In the picture, 270 is the total number of ontologies referenced in the LOV4IoT RDF dataset.

3. Web service: Get the number of ontologies by domains

Query: <http://lov4iot.appspot.com/lov4iot/nbOntoDomain/?domain=BuildingAutomation>

For instance domain is: BuildingAutomation, Weather, Emotion, Agriculture, Health, Tourism, Transportation, City, Energy, Environment, TrackingFood, Activity, Fire, TrackingCD, TrackingDVD, SensorNetworks, Security.

The domain is referenced in the M3 nomenclature which is implemented in the M3 ontology (subclassOf FeatureOfInterest).



Figure 2. LOV4IoT Web service to count the number of ontologies by domain

4. Web service: Get the number of ontology by ontology status

Query:

<http://lov4iot.appspot.com/lov4iot/ontoStatus/?status=Online>

For instance, status is: Confidential, OngoingProcessOnline, WaitForAnswer, Online, OnelinLOV, AlreadyLOV.

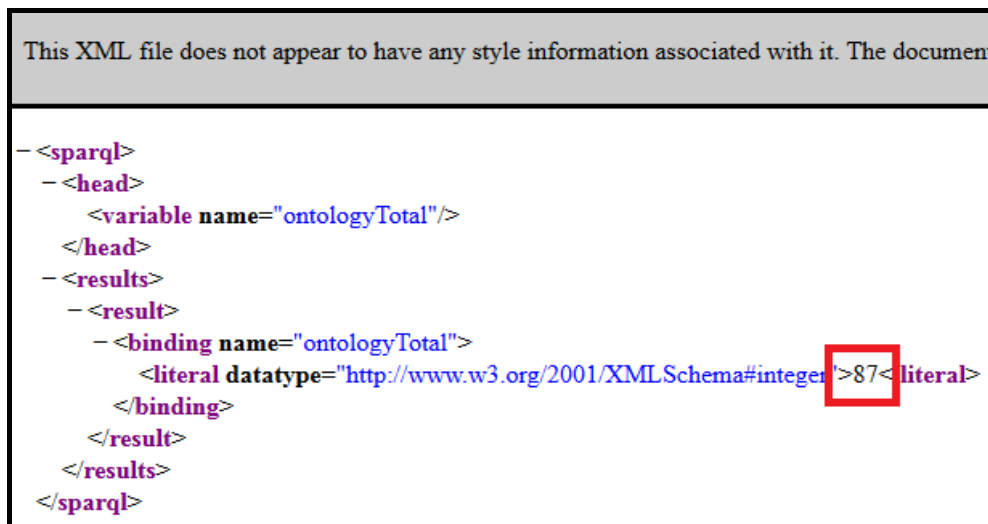


Figure 3. LOV4IoT Web service to count the number of ontologies by ontology status

The web service returns that 87 ontologies referenced in the LOV4IoT RDF dataset are online.

5. Web Service: Get all domains referenced within LOV4IoT

Result returned by the web service:

<http://lov4iot.appspot.com/perfectoOnto/getAllDomainFromLOV4IoT>

Web service Output: Domains URL, labels and comments are returned by the web service.

```
<?xml version="1.0" encoding="UTF-8"?>
<sparql xmlns="http://www.w3.org/2005/sparql-results#">
  <head>
    <variable name="domainURL"/>
    <variable name="domainLabel"/>
    <variable name="domainComment"/>
  </head>
  <results>
    <result>
      <binding name="domainURL">
        <uri>
          http://sensormeasurement.appspot.com/m3#Agriculture
        </uri>
      </binding>
      <binding name="domainLabel">
        <literal xml:lang="en">Agriculture - Smart farm</literal>
      </binding>
      <binding name="domainComment">
        <literal xml:lang="en">
          Agriculture or Smart farm as an Internet of Things (IoT) applicative domain. Useful to classify projects and ontologies within the LOV4IoT Project.
        </literal>
      </binding>
    </result>
  </results>
</sparql>
```

Figure 4. Result returned by the web service getAllDomainFromLOV4IoT

6. Web Service: Get all ontologies referenced within LOV4IoT

Result returned by the web service:

[http://lov4iot.appspot.com/perfectoOnto/](http://lov4iot.appspot.com/perfectoOnto/getOnto/)

Web service Output: Project URL, Ontology URL, project labels and comments (including the research paper) are returned by the web service.

```
<?xml version="1.0" encoding="UTF-8"?>
<result>
  <binding name="projectOntology">
    <uri>
      http://sensormeasurement.appspot.com/ont/m3/CityPulse
    </uri>
  </binding>
  <binding name="ontologyURL">
    <uri>http://purl.oclc.org/NET/UNIS/sao/sao#</uri>
  </binding>
  <binding name="projectLabel">
    <literal xml:lang="en">
      Stream Annotation ontology (SAO) ontology and dataset
    </literal>
  </binding>
  <binding name="projectComment">
    <literal xml:lang="en">
      CityPulse project A knowledge-based approach for real-time IoT data stream annotation and processing [Kolozalet al. iThings 2014]
    </literal>
  </binding>
</result>
<binding name="domainComment">
  <literal xml:lang="en">
    Smart City as an Internet of Things (IoT) applicative domain. Useful to classify projects and ontologies within the LOV4IoT Project.
  </literal>
</binding>
</result>
```

Figure 5. Result returned by the web service getOnto

7. Web Service: Get all ontologies for a specific domain

Result returned by the web service:

<http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain=City>

?domain is the parameter of the web service and should be compliant with the domains referenced within M3 ontology.

Web service Output: Project URL, project labels and comments (including the research paper) are returned by the web service.

```
<?xml version="1.0"?>
<result>
  <binding name="projectOntology">
    <uri>
      http://sensormeasurement.appspot.com/ont/m3/Consoli2015
    </uri>
  </binding>
  <binding name="ontologyURL">
    <uri>
      http://www.ontologydesignpatterns.org/ont/prisma/ontology.owl
    </uri>
  </binding>
  <binding name="projectLabel">
    <literal xml:lang="en">Smart City PRISMA ontology</literal>
  </binding>
  <binding name="projectComment">
    <literal xml:lang="en">
      A Smart City Data Model based on Semantics Best Practice and Principles [Consoli et al. WM Companion 2015]
    </literal>
  </binding>
  <binding name="domainLabel">
    <literal xml:lang="en">Smart City</literal>
  </binding>
  <binding name="domainComment">
    <literal xml:lang="en">
      Smart City as an Internet of Things (IoT) applicative domain. Useful to classify projects and ontologies within the LOV4IoT Project.
    </literal>
  </binding>
</result>
```

Figure 6. Result returned by the web service /getOntoDomain/?domain=City

8. Web Service: Get all health ontologies useful information

Result returned by the web service:

<http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain=Health>

?domain is the parameter of the web service and should be compliant with the domains referenced within M3 ontology.

Web service Output: Ontology URL, project labels and comments (including the research paper) are returned by the web service.

We suggest to retrieve all <uri> from OntologyURL parameter.

```

<binding name="projectOntology">
  <uri>
    http://sensormeasurement.appspot.com/ont/m3/DemaCare
  </uri>
</binding>
<binding name="ontologyURL">
  <uri>
    http://sensormeasurement.appspot.com/ont/home/demcare/lab.owl
  </uri>
</binding>
<binding name="projectLabel">
  <literal xml:lang="en">DemaCare Ontology - Lab</literal>
</binding>
<binding name="projectComment">
  <literal xml:lang="en">
    Knowledge-driven activity recognition and segmentation using context connections [DemaCare 2006-2014, ISWC 2014]
  </literal>
</binding>
<binding name="domainLabel">
  <literal xml:lang="en">Healthcare</literal>
</binding>
<binding name="domainComment">
  <literal xml:lang="en">
    Healthcare as an Internet of Things (IoT) applicative domain. Useful to classify projects and ontologies within the LOV4IoT Project.
  </literal>
</binding>
</result>

```

Figure 7. Result returned by the web service /getOntoDomain/?domain= Health

II. Adding a new domain to LOV4IoT Methodology

We developed the following methodology when we need to add a new domain to LOV4IoT.

Algo:

- Does the M3 ontology already referenced the domain
 - IF YES -> perfect, retrieve the URL
 - IF not add a new concept (Subclassof `ssn:FeatureOfInterest`)
 - Appropriate for some domains like water management, home
 - Less appropriate for generic domain like WoT, IoT -> how to improve?
- STEP: Enrich the LOV4IoT RDF dataset with the new ontology-based project
- STEP: Check the LOV4IoT web service support this new domain
 - add it manually
 - IMPROVEMENT TO DO: make the web service more generic by automatically replacing the SPARQL query with the `featureofinterest` parameter?
- STEP: LOV4IoT HTML web page
 - add a new picture to represent the domain
 - call the web service to automatically retrieve ontologies and compute the number
 - create the table with the links to papers, ontologies, best practices, and other relevant information not explained within the RDF dataset.

Code Example:

```

<owl:Class rdf:ID="WebofThings">
  <rdfs:label xml:lang="en">WoT (Web of Things)</rdfs:label>
  <rdfs:comment xml:lang="en">WoT (Web of Things). Useful to classify
projects and ontologies within the LOV4IoT Project.</rdfs:comment>
  <rdfs:subClassOf rdf:resource="#FeatureOfInterest"/>

```

```

    <dcterms:issued
rdf:datatype="http://www.w3.org/2001/XMLSchema#date">2017-08-22</dcterms:issued>
</owl:Class>

```

M3 FeatureOfInterest concept has been linked to similar concepts from other ontologies:

```

<owl:Class rdf:ID="FeatureOfInterest">
    <rdfs:label xml:lang="en">Feature of Interest</rdfs:label>
    <rdfs:comment xml:lang="en">A Feature of Interest is for us a
concept to classify IoT domains such as smart home, healthcare,
etc.</rdfs:comment>
    <rdfs:domain rdf:resource="#Sensor"/>
    <rdfs:range rdf:resource="<u>xsd:string</u>">
    <owl:equivalentClass rdf:resource="<u>ssn:FeatureOfInterest</u>">
    <owl:equivalentClass rdf:resource="<u>sensor weather:Observation</u>">
    <owl:equivalentClass rdf:resource="<u>m3-lite:DomainOfInterest</u>">
    <owl:equivalentClass rdf:resource="<u>sosa:FeatureOfInterest</u>">
</owl:Class>

```

STEP: Enrich the LOV4IoT RDF dataset with the new ontology-based project:

```

<m3:M2MApplication rdf:about="Spitfire">
    <m3:hasContext rdf:resource="<u>m3:WebOfThings</u>">
    <rdfs:label xml:lang="en">SPITFIRE ontology and LD4Sensor
dataset</rdfs:label>
    <rdfs:comment xml:lang="en">SPITFIRE project: Towards a Semantic Web
of Things [Pfisterer et al. 2011]</rdfs:comment>
    <lov4iot:hasOntologyStatus rdf:resource="<u>lov4iot:AlreadyLOV</u>">
    <m3:hasUrlDataset rdf:resource="http://datahub.io/dataset/ld4s-linked-
sensor-data"/>
    <m3:hasUrlOntology
rdf:resource="http://sensormeasurement.appspot.com/ont/sensor/spitfire.owl"/>
    <dcterms:modified
rdf:datatype="http://www.w3.org/2001/XMLSchema#date">2017-08-22</dcterms:modified>
</m3:M2MApplication>

```

III. Refinement between IoT, WoT, Smart City and Sensor ontologies

Sometimes a same project could be referenced within several sections. For instance, domains such as IoT, WoT, Smart City and Sensor ontologies are really close and complementary.

According to the term mainly employed by the authors within their paper, we classify accordingly the ontology.

We encourage you to browse the different domains (see Figure 8).


							
Nb onto: 35	Nb onto: 21	Nb onto: 7	Nb onto: 18	Nb onto: 55	Nb onto: 59	Nb onto: 10	Nb onto: 30
							
Nb onto: 35	Nb onto: 20	Nb onto: 17	Nb onto: 5	Nb onto: 16	Nb onto: 14	Nb onto: 30	Nb onto: 7
							
Nb onto: 6	Nb onto: 7	Nb onto: 32	Nb onto: 5	Nb onto: 4			

Figure 8. IoT, WoT, Wireless Sensor networks are complimentary

IV. LOV4IoT Citations

Please do not forget to cite our LOV4IoT work:

- Reusing and Unifying Background Knowledge for Internet of Things with LOV4IoT. 4rd International Conference on Future Internet of Things and Cloud (FiCloud 2016), 22-24 August 2016, Vienna, Austria. Amelie Gyrard, Ghislain Atemezing, Christian Bonnet, Karima Boudaoud and Martin Serrano
- LOV4IoT: A second life for ontology-based domain knowledge to build Semantic Web of Things applications. 4rd International Conference on Future Internet of Things and Cloud (FiCloud 2016), 22-24 August 2016, Vienna, Austria. Amelie Gyrard, Christian Bonnet, Karima Boudaoud and Martin Serrano
- Semantic Web Methodologies, Best Practices and Ontology Engineering Applied to Internet of Things IEEE World Forum on Internet of Things (WF-IoT), Milan, Italy, December 14-16, 2015 Amelie Gyrard, Martin Serrano, Ghislain Atemezing
- Domain knowledge Interoperability to build the Semantic Web of Things W3C Web of Things, 25-26 June 2014, Berlin, Germany Amelie Gyrard, Christian Bonnet and Karima Boudaoud
- Semantic Web Guidelines for domain knowledge interoperability to build the Semantic Web of Things OneM2M International standard, Management, Abstraction and Semantics (MAS) Working Group 5, April 2014 Amelie Gyrard, Christian Bonnet

V. Introduction: From LOV to LOV4IoT

Linked Open Vocabularies (LOV) [10] is an ontology catalogue designed by semantic web experts.

New ontologies should follow some best practices to be referenced. In Internet of Things, we classified almost 300 ontologies that cannot be referenced on LOV because of the “bad practices”.

For those reasons, we designed Linked Open Vocabularies for Internet of Things (LOV4IoT).

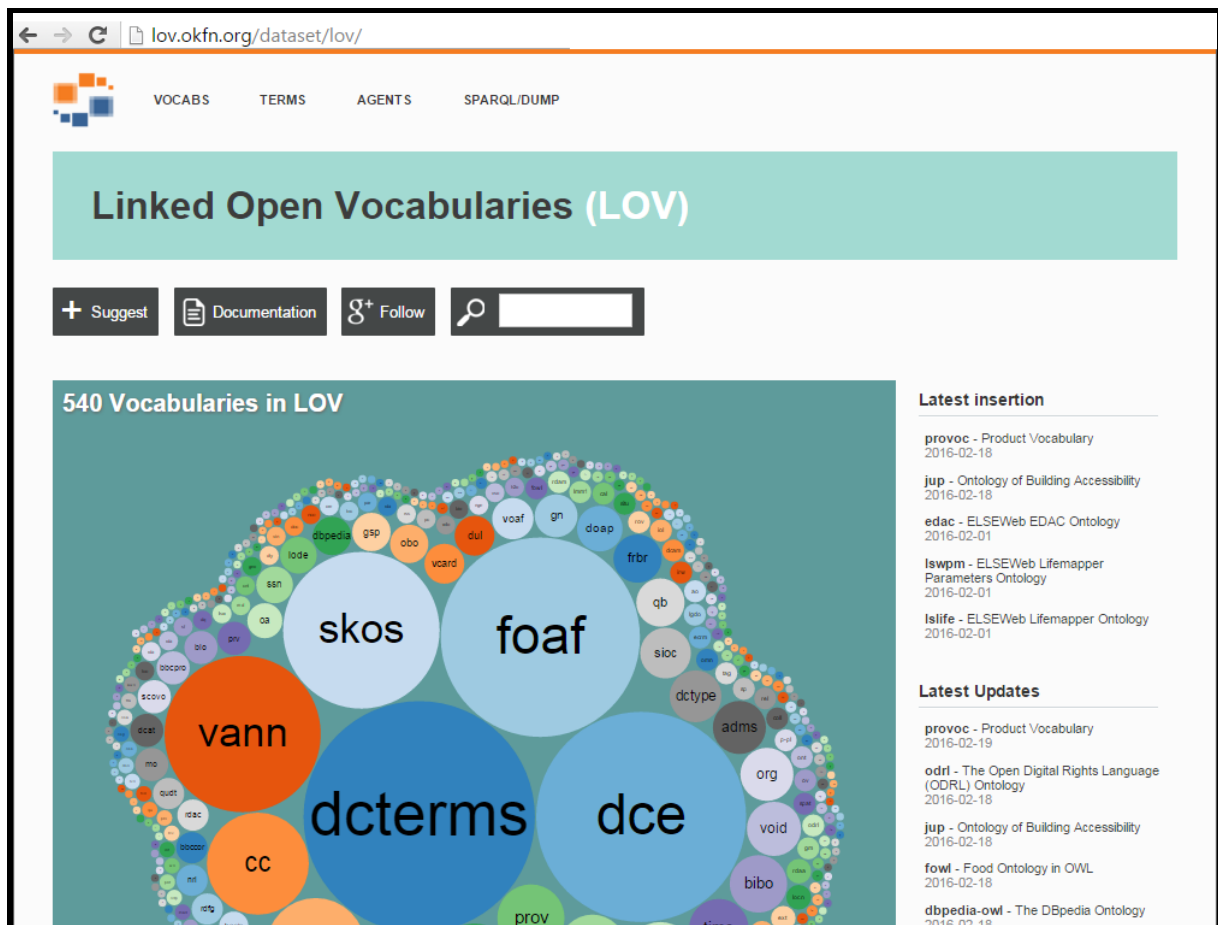


Figure 9. Linked Open Vocabularies (LOV)

9. Suggesting a vocabulary to LOV

- Step 1: Go to the LOV web page: <http://lov.okfn.org/dataset/lov/>
- Step 2: Click on Suggest
- Step 3: Enter the URL of the ontology
- Step 4: Does your ontology contain ontology metadata as recommended by LOV? [11]

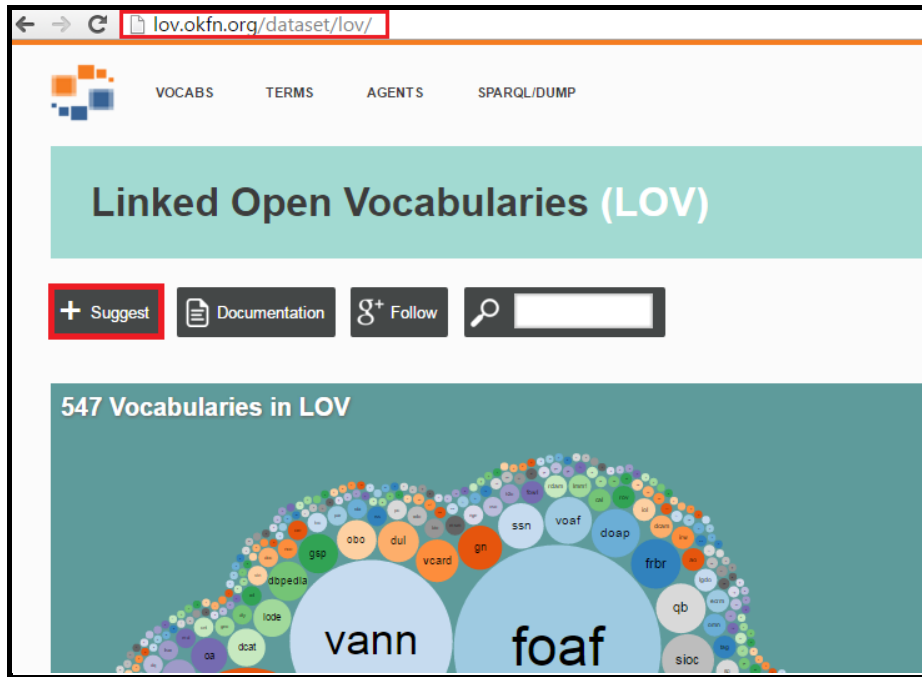


Figure 10. Suggest a vocabulary on LOV



Figure 11. Suggest your ontology on LOV

lov.okfn.org/dataset/lov/suggest?q=https%3A%2F%2Fmimove-apps.paris.inria.fr%2Fontology%2Ffiesta-iot.owl

VOCABS TERMS AGENTS SPARQL/DUMP

SUGGEST

Recommendations for vocabulary metadata description

Metadata

Please check the metadata below and confirm the suggestion using your email for further communication

Enter you email address that will contact you in case of issues regarding the ontology submitted

URI	http://purl.org/lot/fiesta-iot#
Namespace	http://purl.org/lot/vocab/m3-lite#
Prefix	m3-lite
Title	FIESTA-IoT, FIESTA-IoT Ontology @en
Description	FIESTA-IoT Ontology is a merge of various ontologies such as IoT-lite, M3-lite Taxonomy, SSN and DUL. Please report any errors to support@fiesta-iot.eu @en. The FIESTA-IoT Ontology is an unified ontology. FIESTA-IoT Ontology is a merge of various ontologies such as IoT-lite, M3-lite Taxonomy, SSN and DUL. @en
Language	English Italian
First Issued	2016-04-28
Last Modified	2016-04-28
Uses Metadata from (8)	http://lod.taxonconcept.org/ontology/bn.owl (bn) http://purl.org/dc/elements/1.1/ (dce) http://purl.org/dc/terms/ (dcterms) http://purl.org/vocab/vann/ (vann) http://www.w3.org/1999/02/22-rdf-syntax-ns# (rdf) http://www.w3.org/2000/01/rdf-schema# (rdfs) http://www.w3.org/2002/07/owl (owl) http://www.w3.org/2003/06/sw-vocab-status/ns (vs) http://data.qudt.org/qudt/owl/1.0.0/unit.owl# http://purl.okfn.org/NET/UNIS/ware/lot-lite#

Statistics

Classes	378
Properties	1
Datatypes	0
Instances	0

Figure 12. Suggest your ontology on LOV without errors

Metadata Recommendations For Linked Open Data Vocabularies

Authors	Pierre-Yves Vandenbussche Bernard Vatant
---------	---

Version	1.1
---------	-----

Date	2012-08-19
------	------------

Modifications	VOAF namespace updated
---------------	------------------------

Abstract

This document describes metadata recommendations for vocabulary description on the Web (in RDFS or OWL). We document the properties and classes used to describe metadata about the vocabulary itself and about vocabulary elements.

Introduction

As the Web of data is growing, emerging initiatives try to organize it [Heath and Bizer, 2011]. A particular project, the Linked Open Data¹ (LOD), helps to improve the quality of data shared by promoting their links and reuse [Bizer et al., 2009]. The data published on the Semantic Web is based on the use of shared vocabularies and ontologies that allow to structure and describe data. These vocabularies act as tools for building formalized reusable data. To facilitate the reuse, we propose some recommendations about metadata for such vocabularies.

Scope

We must first clarify the meaning of "Vocabulary" in the context of this document. We do not stick to the definition of vocabulary in linguistics meaning but approach it in terms of its use in the Semantic Web. In this context, a vocabulary is basically synonymous² of ontology. However, we differentiate vocabulary from an ontology by characteristics enabling reuse and integration by other vocabularies:

Figure 13. LOV recommendations

10. Errors encountered when suggesting a vocabulary on LOV

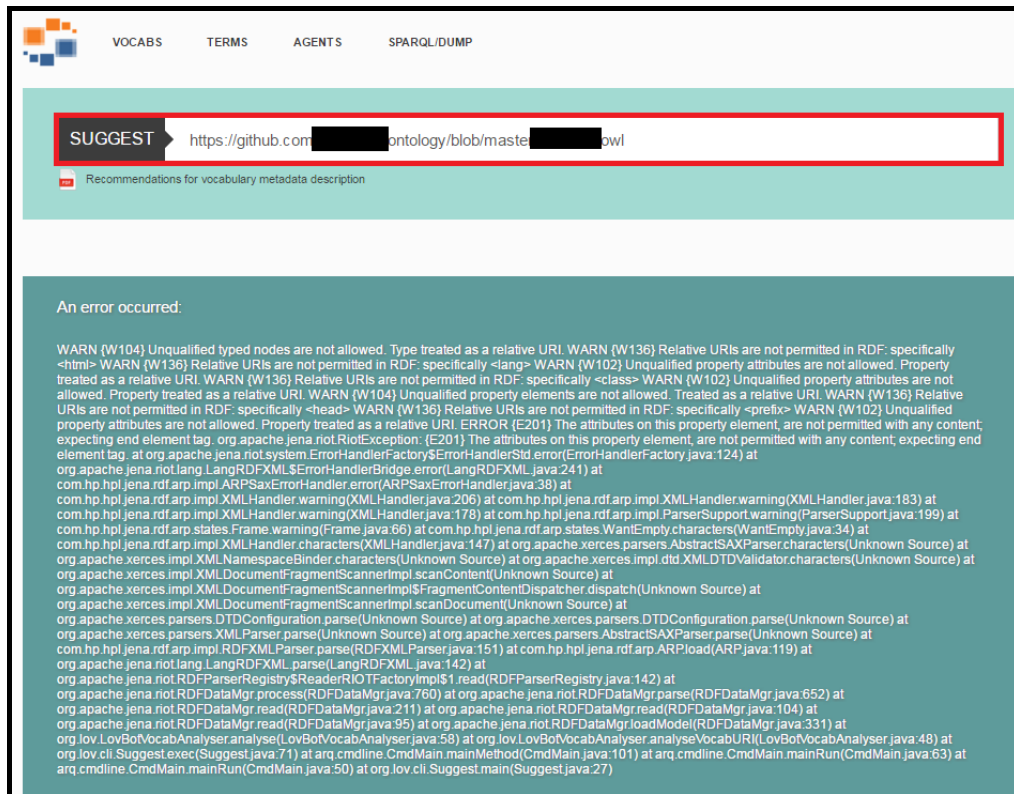


Figure 14. Errors encountering when suggesting ontologies on LOV

In case you cannot fix the error, you can ask to the reactive LOV community on Google +¹

¹ <https://plus.google.com/u/1/communities/108509791366293651606>

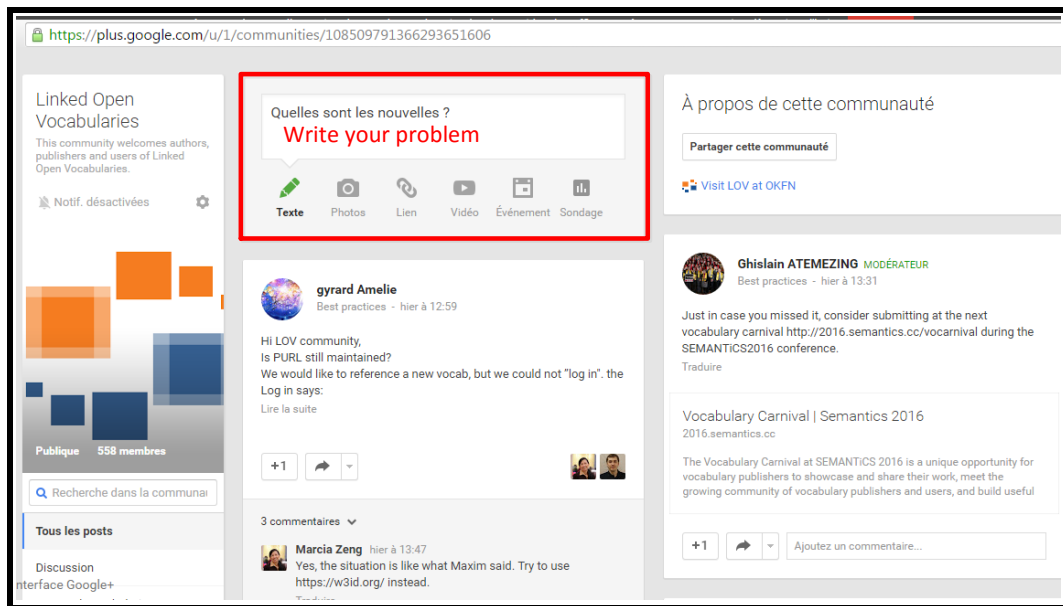


Figure 15. LOV community on Google +

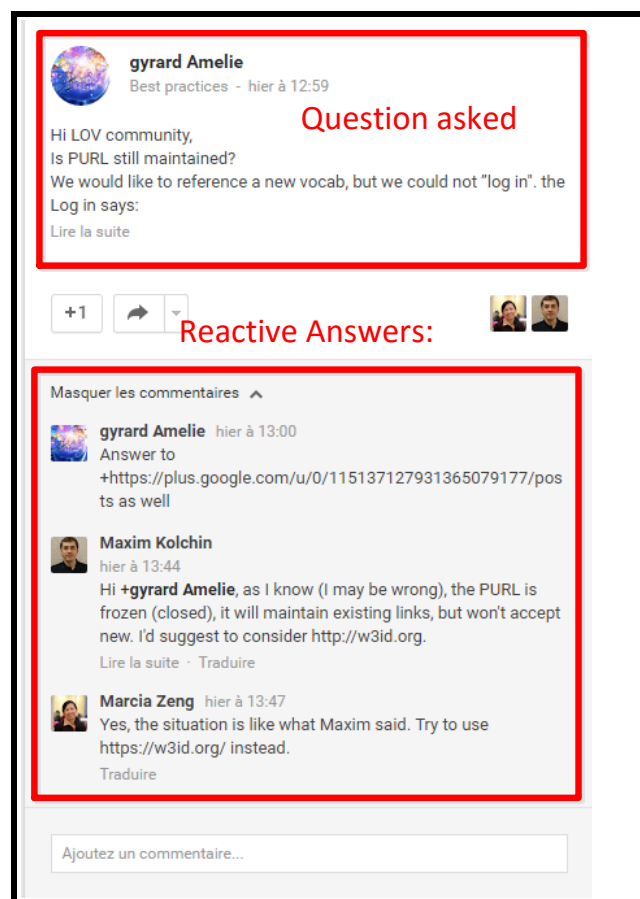


Figure 16. The reactive LOV community guides us to fix issues regarding ontologies

11. Suggesting a vocabulary to LOV4IoT

We are thinking about a web page to submit a new ontology.

The current solution is to send us a message and we will update the LOV4IoT dataset.

amelie.gyrard@insight-centre.org

Thanks for your help for referencing more ontologies ☺ We have almost 300 ontology-based projects referenced in LOV4IoT.

sensormeasurement.appspot.com/?p=ontologies

Linked Open Vocabularies for Internet of Things (LOV4IoT)

Reusing domain knowledge expertise

Before to reinvent the wheel, maybe you can reuse the following existing ontologies with minor modifications.

We have referenced in this web page **297** ontology-based projects relevant for IoT. These domain ontologies, although very interesting, are not referenced on the [Linked Open Vocabularies \(LOV\)](#) since the [Semantic Web best practices](#) are not followed.


									
Nb onto: 46	Nb onto:	Nb onto:	Nb onto: 30	Nb onto: 32	Nb onto: 17	Nb onto: 16	Nb onto:	Nb onto:	Nb onto:
									
Nb onto: 55	Nb onto:	Nb onto:	Nb onto:	Nb onto:	Nb onto:	Nb onto:	Nb onto:		

Figure 17. Almost 300 ontology-based projects referenced in LOV4IoT

VI. Reusing domain knowledge with LOV4IoT

- ➔ Go to the Linked Open Vocabularies for Internet of Things (LOV4IoT) web page (see Figure 18): <http://www.sensormeasurement.appspot.com/?p=ontologies>
- ➔ Choose 1 domain by clicking on the image (e.g., transportation) as depicted in Figure 18.

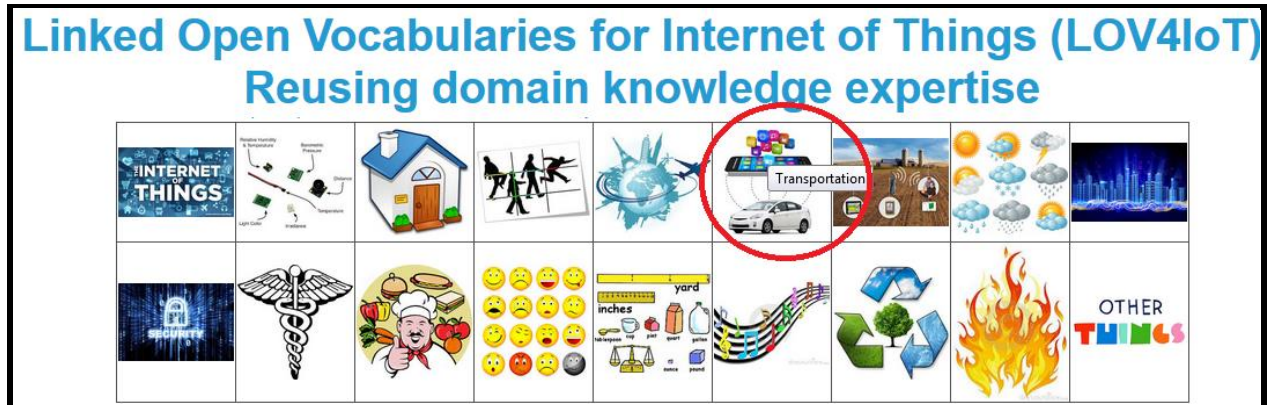


Figure 18. Ontologies classified in various domains

- ➔ You will find a table with the following information as depicted in Figure 20:
 - Domain experts names (authors)
 - Year of publication
 - Research articles
 - Ontology URL of available
 - Technologies used in their project
 - Sensors used in their project
 - Rules designed

-Ontologies and projects have been classified according to different colors (see Figure 19):

- Red: the ontology is not available
- White: we do not have any links to get the ontology
- Orange: we contacted authors to get their ontologies. They answered us they will share ontologies and rules soon.
- Yellow: we retrieve the ontology URL or get a copy
- Green: Ontologies published online, cannot be referenced on the Linked Open Vocabularies (LOV)² project due to a lack of best practices.
- Dark green: The ontology is referenced on the Linked Open Vocabularies project. It checks best practices.

The ontology will never be available (lost, confidential, etc.) :-(We are waiting the response of the authors to publish the ontology online	Authors are publishing online the ontology (ongoing work)	Ontology published online but the Semantic Web best practices are not complied with.	Ontology published online and referenced by LOV since Semantic Web best practices are adopted! :-)))	Already on LOV - No email sent
---	---	---	--	--	--------------------------------

Figure 19. Classification of projects according to the reusability

² <http://lov.okfn.org/dataset/lov/>

Intelligent Transport Systems								
Authors	Year	Paper	Url onto	Technologies	Sensors	Rules	LOV status	Security
Bermejo, Astrain Escola Mail: 14/02/14, Response: 18/02/14	2014	Paper: Ontology based road traffic management	No server (response), but sent us the OWL ontology copy URL Application ? Concepts: 24 classes, 12 properties, 77 rules. Vehicle	SWRL (DLSafeRule), Jess reasoner, extension of A3ME ontology, OWL API 3.4.2	LastBeforeGap, FirstAfterGap, NotOvertaker, Overtaker), distance sensor -> Space (Lateral, Ahead, Behind, NoSpace), Acceleration sensor (BigSpeedDifference, SpeedWith,	77 rules/actions (swrl dlsafe rule in the ontology) change line, decelerate, accelerate, maintain distance with car in front, maintain speed	Priority 1, responsive, ongoing, lov metadata, uri deferencable 26/03/14, ask for label and comment	
Morignot, Pollard et al.	2013	Paper: An ontology-based Model to determine the automation level of an automated vehicle for co-driving Paper: An ontology-based approach to relax traffic regulation for autonomous vehicle assistance	Ontology URL Ontology URL Concepts: emotion driver, Weather Conditions (foggy, cloudy, snowy, sunny, rainy), lighting conditions (day, night, setting sun), road (highway, campaing, urban, mountain), obstacles	Pellet, SWRL (DLSafeRule), Protege, SWOOPS (ontology editor)	Position, velocity, acceleration/braking and steering actuators	foggy -> mode manual, search for parking place, stopped, hasNextMotion	content negociation, uri def error, vapour rdf/xml	

Figure 20. Screenshot of LOV4IoT

VII. LOV4IoT web services/APIs

12. LOV4IoTWS Java class

This Java class contains all web services related to LOV4IoT.

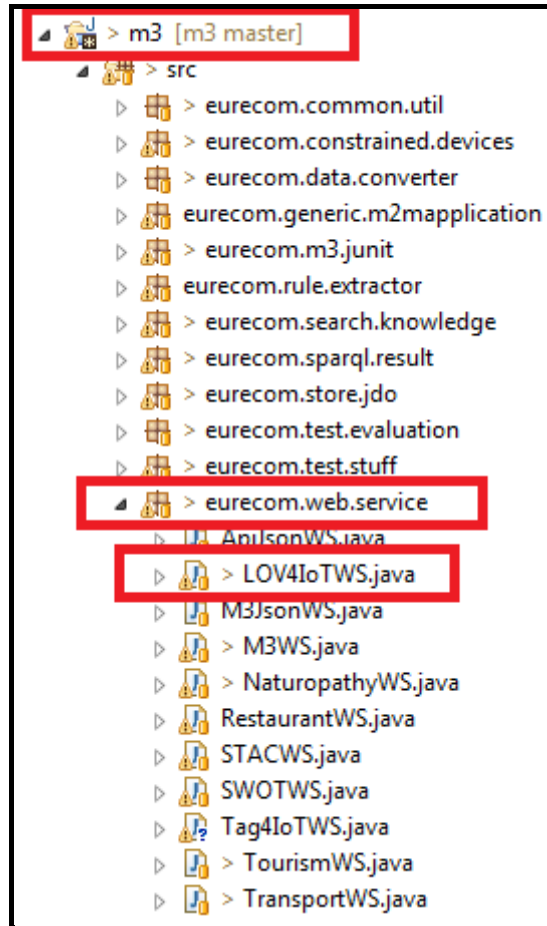


Figure 21. LOV4IoTWS Java Class location

All web services related to the Linked Open Vocabularies for Internet of Things (LOV4IoT) dataset³ to automatically count the number of ontologies in this dataset (e.g., by domains, by ontology status, etc.):

- lov4iot/totalOnto/ which executes a SPARQL query to count the total number of ontology-based project referenced in the LOV4IoT RDF dataset.
E.g., <http://sensormeasurement.appspot.com/lov4iot/totalOnto/>
- /lov4iot/ontoStatus/{status} which executes a SPARQL query to count the different status of ontologies
 - Status can be: Online, Confidential, OngoingProcessOnline, WaitForAnswer, Online, OnlineLOV, AlreadyLOVE.g., <http://sensormeasurement.appspot.com/lov4iot/ontoStatus/?status=Online>

³ <http://www.sensormeasurement.appspot.com/?p=ontologies>

- /lov4iot/nbOntoDomain/{domain} which executes a SPARQL query to count the different ontologies in all domains
 - Domain can be: BuildingAutomation, Weather, Emotion, Agriculture, Health, Tourism, Transportation, City, EnergyFOI, Environment, TrackingFood, Activity, Fire, TrackingCD, TrackingDVD, SensorNetworks, IoT, Security

E.g.,

<http://sensormeasurement.appspot.com/lov4iot/nbOntoDomain/?domain=BuildingAutomation>

- /lov4iot/sendEmail/{recipient,paper} which sends email to encourage people to share their domain knowledge (ontologies, datasets, and rules)

```
@GET
@Path("/totalOnto/")
@Produces(MediaType.APPLICATION_XML)
public Response getTotalNumberOntology() {
    //load the LOV4IoT dataset into the model
    Model model = ModelFactory.createDefaultModel();
    ReadFile.enrichJenaModelOntologyDataset(model, Var.LOV4IOT_DATASET_PATH);
    M2MAppGeneric m2mappli = new M2MAppGeneric(model);

    //SPARQL query
    ExecuteSparql sparqlQuery = new ExecuteSparql(model, Var.ROOT_SPARQL_LOV4IoT + "countTotalOntology.sparql");

    //no variable to replace in the SPARQL query
    ArrayList<VariableSparql> var = new ArrayList<VariableSparql>();
    String resultSparqlsenml = sparqlQuery.getSelectResultAsXML(var);

    return Response.status(200).entity(resultSparqlsenml).build();
}
```

Figure 22. Example of the lov4iot/totalOnto: web service

Yan can download the LOV4IoT RDF dataset⁴ and write your own SPARQL queries.

Otherwise, we designed some web services:

13. Web service: Get the total number of ontologies

Query:

<http://www.sensormeasurement.appspot.com/lov4iot/totalOnto/>

⁴ <http://www.sensormeasurement.appspot.com/dataset/lov4iot-dataset>



```
- <sparql>
- <head>
  <variable name="ontologyTotal"/>
</head>
- <results>
  - <result>
    - <binding name="ontologyTotal">
      <literal datatype="http://www.w3.org/2001/XMLSchema#integer">270</literal>
    </binding>
  </result>
</results>
</sparql>
```

Figure 23. LOV4IoT Web service to count the total number of ontologies

In the picture, 270 is the total number of ontologies referenced in the LOV4IoT RDF dataset.

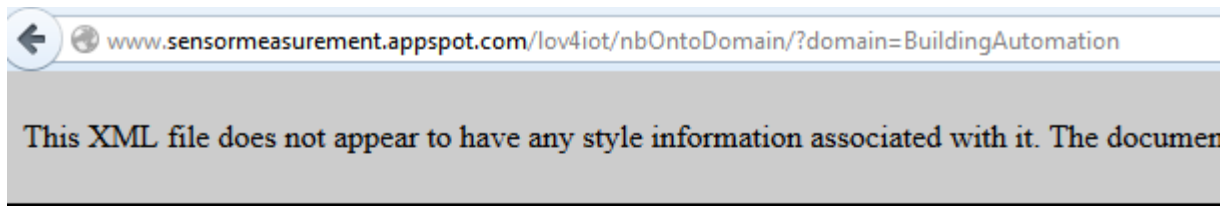
14. Web service: Get the number of ontologies by domains

Query:

<http://www.sensormeasurement.appspot.com/lov4iot/nbOntoDomain/?domain=BuildingAutomation>

For instance domain is: BuildingAutomation, Weather, Emotion, Agriculture, Health, Tourism, Transportation, City, Energy, Environment, TrackingFood, Activity, Fire, TrackingCD, TrackingDVD, SensorNetworks, Security.

The domain is referenced in the M3 nomenclature which is implemented in the M3 ontology (subclassOf FeatureOfInterest).



```
-<sparql>
  -<head>
    <variable name="nbOntoDomain"/>
  </head>
  -<results>
    -<result>
      -<binding name="nbOntoDomain">
        <literal datatype="http://www.w3.org/2001/XMLSchema#integer">45</literal>
      </binding>
    </result>
  </results>
</sparql>
```

Figure 24. LOV4IoT Web service to count the number of ontologies by domain

15. Web service: Get the number of ontology by ontology status

Query:

<http://www.sensormeasurement.appspot.com/lov4iot/ontoStatus/?status=Online>

For instance, status is: Confidential, OngoingProcessOnline, WaitForAnswer, Online, OnelinLOV, AlreadyLOV.



```
-<sparql>
-  <head>
    <variable name="ontologyTotal"/>
  </head>
-  <results>
    <result>
      <binding name="ontologyTotal">
        <literal datatype="http://www.w3.org/2001/XMLSchema#integer">87</literal>
      </binding>
    </result>
  </results>
</sparql>
```

Figure 25. LOV4IoT Web service to count the number of ontologies by ontology status

The web service returns that 87 ontologies referenced in the LOV4IoT RDF dataset are online.

16. Use Case: LO4IoT HTML user interface using web services

All of these web services have been used in the HTML LOV4IoT web page⁵ to automatically count the number of ontologies in the dataset (e.g., by domains, by ontology status, etc.)

⁵ <http://www.sensormeasurement.appspot.com/?p=ontologies>

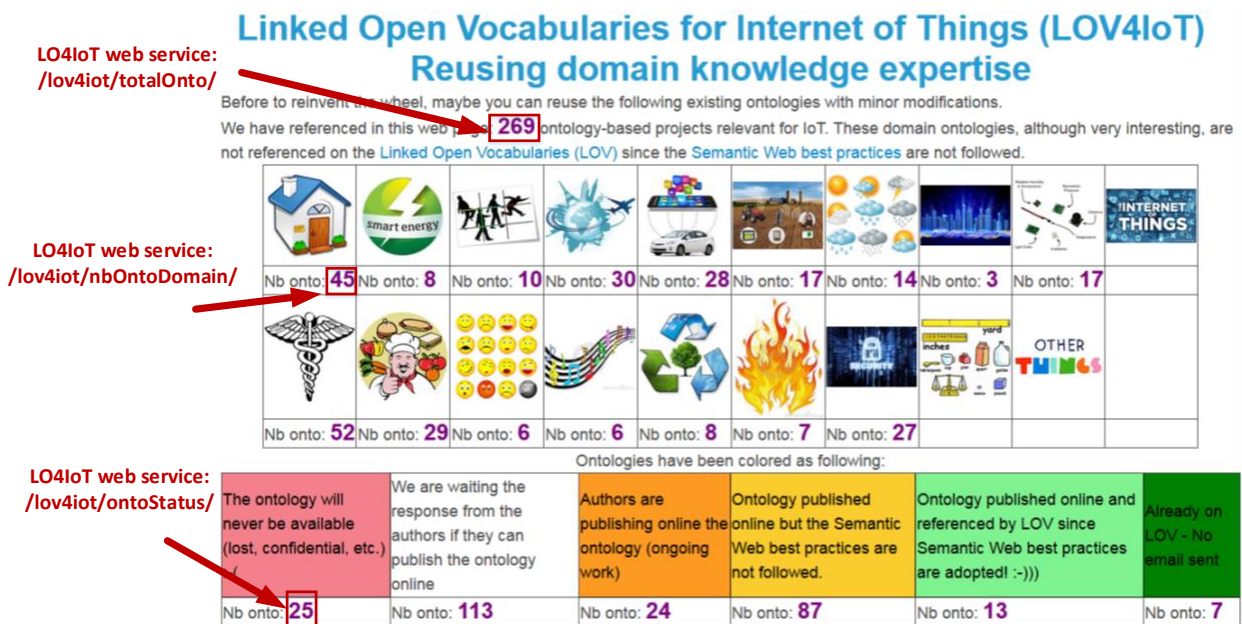


Figure 26. LOV4IoT web services

VIII. HTML web page



In the future, we will automatically build the HTML web page according to the LOV4IoT RDF dataset. This work is ongoing. Currently, we have to update the HTML web page and the RDF dataset when we want to reference a new ontology-based project.

17. Adding a new ontology in LOV4IoT HTML web page

Go to m3/WAR/html/lov4iot.html

Look for the table related to the domain, add a new line with all columns required.

<http://sensormeasurement.appspot.com/?p=ontologies>

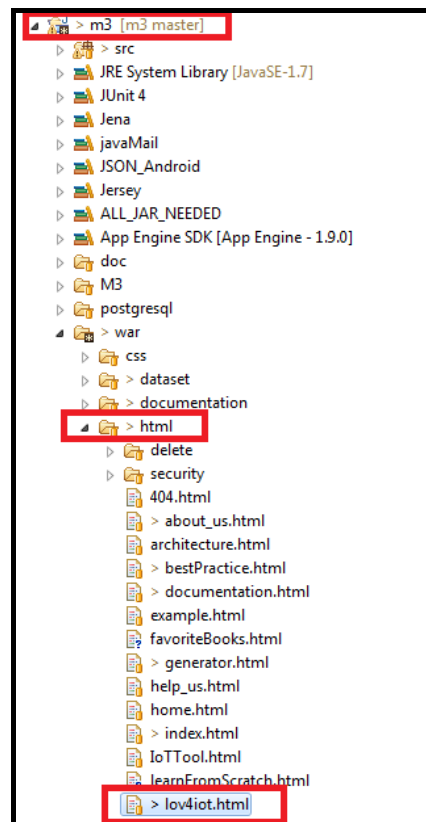


Figure 27. LOV4IoT HTML file location

IX. LOV4IoT ontology

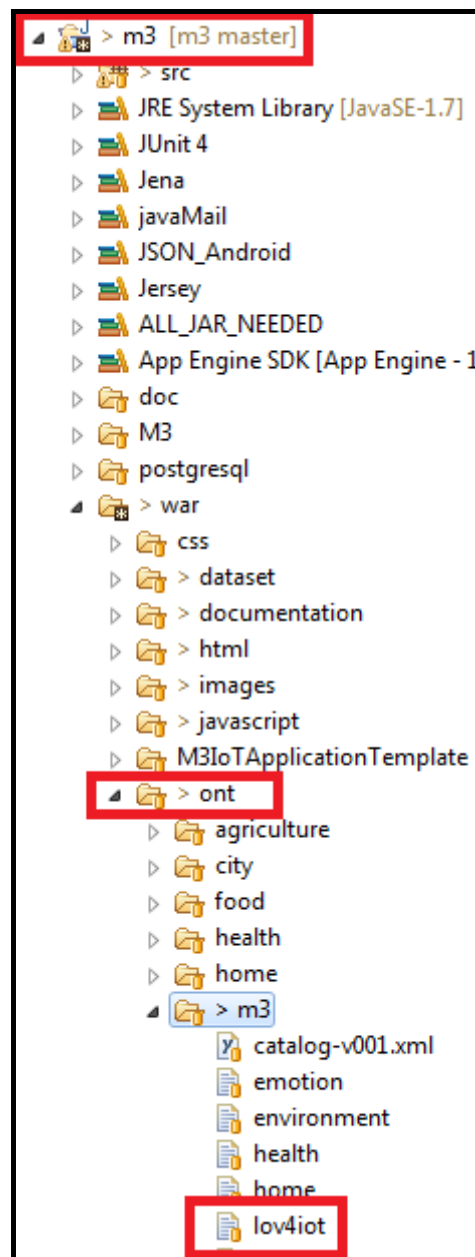


Figure 28. LOV4IoT ontology file location

18. Visualizing LOV4IoT with WEBVOWL

<http://vowl.visualdataweb.org/webvowl/#iri=http://sensormeasurement.appspot.com/ontology/m3/lov4iot#>

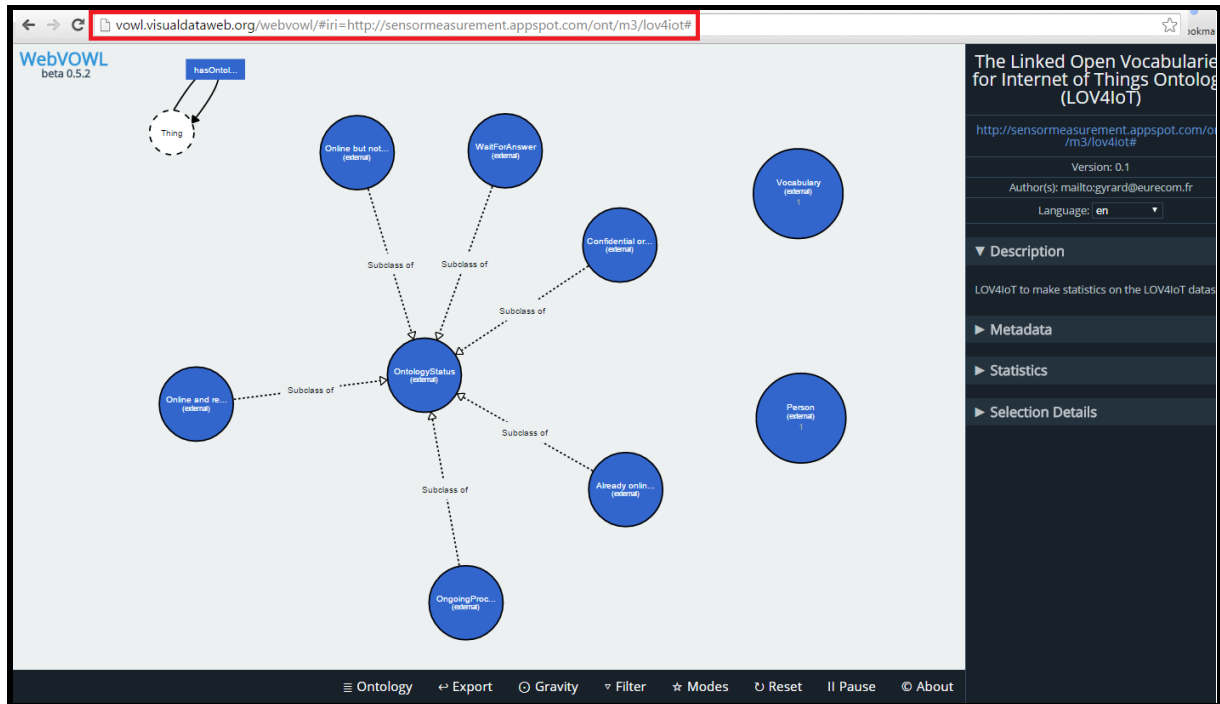


Figure 29. Visualizing LOV4IoT ontology with WEBVOWL

X. LOV4IoT RDF dataset

You can download the LOV4IoT RDF dataset⁶ and write your own SPARQL queries.

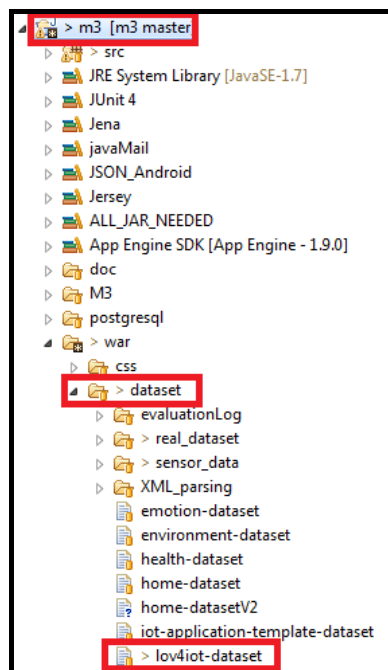


Figure 30. LOV4IoT RDF file location

⁶ <http://www.sensormeasurement.appspot.com/dataset/lov4iot-dataset>

In the LOV4IoT RDF dataset⁷, add a new ontology-based project.

19. Adding a new instance in the LOV4IoT RDF dataset

Figure below shows an instance of the LOV4IoT dataset. An instance is based on the LOV4IoT and M2 ontologies.

```
<m3:M2MApplication rdf:about="PaulStaroch">
  <m3:hasContext rdf:resource="&m3;Weather"/>
  <m3:hasContext rdf:resource="&m3;BuildingAutomation"/>
  <rdfs:label xml:lang="en">[Paul Staroch 2013]. See LOV4IoT for more details.</rdfs:label>
  <rdfs:comment xml:lang="en">Master's Thesis: A weather ontology for predictive control
  <m3:hasM2MDevice rdf:resource="&m3;Thermometer"/>          in smart homes. 2013</rdfs:comment>
  <m3:hasM2MDevice rdf:resource="&m3;PrecipitationSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;HumiditySensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;AtmosphericPressureSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;SolarRadiationSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;WindDirectionSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;WindSpeedSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;SunPositionDirectionSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;SunPositionElevationSensor"/>
  <m3:hasM2MDevice rdf:resource="&m3;CloudCoverSensor"/>
  <m3:hasUrlOntology rdf:resource="http://paul.staroch.name/thesis/SmartHomeWeather.owl"/>
  <m3:hasUrlRule rdf:resource="http://paul.staroch.name/thesis/SmartHomeWeather.owl"/>
  <lov4iot:hasOntologyStatus rdf:resource="&lov4iot;OnlineLOV"/>
  <dcterms:creator>
    <foaf:Person rdf:about="mailto:paul@staroch.name">
      <foaf:name>Paul Staroch</foaf:name>
    </foaf:Person>
  </dcterms:creator>
</m3:M2MApplication>
```

Figure 31. An ontology-based IoT project referenced in the LOV4IoT RDF dataset

XI. LOV4IoT Bot

20. LOV Bot user interface

To encourage people to share their ontologies you can use the LOV4IoT bot⁸.

⁷ <http://www.sensormeasurement.appspot.com/dataset/lov4iot-dataset>

⁸ <http://sensormeasurement.appspot.com/?p=lov4iot>

LOV4IoT-bot

LOV4IoT-bot encourages domain experts to share their domain knowledge (ontologies, datasets and rules) by sending emails:

To (domain expert):

Paper:

Figure 32. LOV4IoT bot user interface

21. LOV Bot explanations

LOV4IoT-bot

LOV4IoT-bot encourages domain experts to share their domain knowledge

To (domain expert): (ontologies, datasets and rules) by sending emails:

=> To replace by the author's email

Paper:

=> To replace by the title of the research article
describing ontologies, datasets or rules relevant for IoT

Use our web service to automatically send email
to encourage domain experts
to share their domain knowledge

```
@GET
@Path("/sendEmail/")
@Consumes(MediaType.APPLICATION_FORM_URLENCODED)
@Produces(MediaType.TEXT_PLAIN)
public static Response sendEmail(@QueryParam(value = "recipient") String recipient, @QueryParam(value = "paper") String paper) {
    try {
        System.out.println("Paper: " + paper);
        System.out.println("Recipient: " + recipient);
        Properties props = new Properties();
        Session session = Session.getDefaultInstance(props, null);
        String message = "";
        Message msg = new MimeMessage(session);
        msg.setFrom(new InternetAddress("ameliegyrard@gmail.com", "gyrard@eurecom.fr"));
        msg.addRecipient(Message.RecipientType.TO,
            new InternetAddress(recipient, ""));
        msg.addRecipient(Message.RecipientType.CC,
            new InternetAddress("gyrard@eurecom", "Amelie Gyrard"));
        msg.setSubject("ontology and rule");
        msg.setText(message);
        Transport.send(msg);
    }
}
```

Figure 33. Code to send emails to convince authors to share their ontologies with LOV4IoT bot

XII. LOV4IoT Architecture

TO DO: Take inspiration from LOV paper?

XIII. Repository purl with Ghis

Some ontologies very relevant for IoT are kept in silos by the owners and do not follow some best practices in their design. LOV4IoT platform references almost 300 ontologies that fall into that category. To overcome the issue, we propose to use a collaborative approach using Github for modeling the ontologies and publish them using PURL system under the URI http://purl.org/iot/vocab/{name_ontology}. For instance, name ontology is m3-lite with the following namespace <http://purl.org/iot/vocab/m3-lite#>. PURL enables keeping always the same namespace whatever where the ontology is hosted. The work has already started at <https://github.com/LOV4IoT/vocabs>. The goal is to republish all the legacy ontologies under the PURL.org namespace using redirection to the Github location.

XIV. LOV4IoT Use Cases

In this section, we demonstrate that the LOV4IoT dataset has been used in two uses cases: the Machine-to-Machine Measurement (M3) framework to build interoperable Semantic Web of Things applications and the LOV4IoT analyzer to detect the most popular terms used in ontologies. Moreover, we explain that different stakeholders can benefit from or exploit the LOV4IoT dataset such as domain experts, ontology matching tool experts, knowledge extraction experts, Semantic Web of Things developers and projects as depicted in Figure :

XV. LOV4IoT sequence diagram

TO DO

22. Machine-to-Machine Measurement (M3) framework

Machine-to-Machine Measurement (M3) framework employs the LOV4IoT dataset to redesign interoperable domain ontologies, rules and datasets to assist IoT developers in designing semantic-based IoT applications without having to learn semantic web technologies thanks to the Machine-to-Machine Measurement (M3) framework \cite{gyrard2015m3}.

LOV4IoT analyzer exploits the LOV4IoT dataset to load all ontologies in the same domain and extract the most popular concepts and properties. An essential step to later automatically build interoperable background knowledge.

This functionality will be exploited within the EU FIESTA-IoT project\footnote{\a href="http://www.fiesta-iot.eu/"}.

23. Domain experts

Domain experts can use this dataset for their state of the art and to reuse existing ontologies or before designing their own ontologies, etc. For instance, a security expert used the LOV4IoT user interface to analyze existing ontologies in the security domain.

24. Knowledge extraction experts

Knowledge extraction experts can benefit from the LOV4IoT dataset since the domain knowledge expertise is referenced and classified. There is a need of innovative tools to extract rules, etc. and redesign ontologies, datasets and rules in an unified way and having the same structure to facilitate interoperability in future architectures and systems.

25. Ontology matching tool experts

Ontology matching tool experts can reuse this dataset to later standardized the most popular and well-designed ontologies. They benefit from LOV4IoT by analyzing interoperability issues explained in [5] [4], exiting tools need to be improved to ease interoperability. Ontology editor tools such as Protege could preconize the re-use of existing ontologies based on the LOV and LOV4IoT dataset. When the user designd a new concept or property, some recommendations could be provided to reuse existing ontologies. This task is under development within ProtegeLOV⁹. Such extensions could be improved to recommend to integrate labels, comments, ontology metadata, etc. as preconized by LOV.

26. IoT/SWoT developers and projects

IoT/SWoT developers and projects can surf on the LOV4IoT web page to search domain ontologies according to a specific domain. For instance, the developer is looking for smart home ontologies, he goes on this section and finds more than 45 projects describing sensors and rules employed to build smart homes applications. Some scenarios such as air pollution or real-time traffic monitoring among the 101 scenarios proposed by CityPulse can reuse the ontologies referenced in LOV4IoT by searching these keywords or the related sections.

A table is available on the web¹⁰ to match the scenarios proposed by CityPulse and how the LOV4IoT tool can assist in building the applications by reusing domain knowledge. A concrete example if the chronic disease scenario proposed by CityPulse, they want to build an application to monitor food consumption according to user's diseases deduced from physiological data. We have referenced the naturopathy ontology and dataset which can be reused to build this application.

⁹ <http://boris.villazon.terrazas.name/projects/prolov/index.html>

¹⁰ http://www.sensormeasurement.appspot.com/?p=m3_scenario

27. Ontology matching tool experts

Usually, ontology matching tools are evaluated with the Ontology Alignment Evaluation Initiative (OAEI)¹¹ benchmark. Current ontology matching tools are not adapted to ontologies referenced in the LOV4IoT dataset. A main challenge would be to have ontology matching tools adapted to both datasets (OAEI and LOV4IoT) meeting these main requirements: (1) heterogeneous languages, (2) syntactic heterogeneity, (3) conceptual heterogeneity, (4) terminological heterogeneity, and (5) semiotic heterogeneity. For instance, concepts or properties do not have labels or comments whereas ontology matching tool algorithms are based on labels to compare them. The ontologies from the OAEI benchmark differ in their structure compared to the domain ontologies from the ones found in LOV4IoT. Regarding ontologies relevant for IoT, concepts are linked with each other through owl:Restriction, and properties associated to concepts are not frequently used. For instance, snow is linked to temperature and precipitation through owl:Restriction. In the OAEI benchmark, concepts have properties which are mostly used by ontology matching tools. For instance, a person or a patient have both properties such as family name and birth date.

As explained above, the LOV4IoT dataset is relevant for various communities.

XVI. Lessons Learnt: Best Practices

We have learnt a set of best practices. More explanations can be found in [6] [4].

Reminder List of tools:

- Vapour [1]
- See this web page¹² for more tools
- ProtegeLOV¹³ [3]
- LOV ontology metadata [11]

28. Ontology Documentation

Tools:

- WebVOWL [7]
 - Easy to use
- LODE [8]
 - Nice documentation
- Parrot [9]
 - Easy to use
 - Cannot integrate picture

¹¹ <http://oei.ontologymatching.org/>

¹² <http://localhost:50101/?p=bestPractice>

¹³ <http://data.semanticweb.org/conference/eswc/2015/paper/demo/2>

- OWL DOC protege plugin¹⁴
- Neologism [2]

XVII. Improvement ideas

We have in mind the following improvements:

- Improving the user interface
- Automatically updating the LOV4IoT database
- Creation of an automatic workflow to check the best practices
- Interconnecting LOV4IoT with LOV
- Encouraging best practices with some tools (e.g., ProtegeLOV extension)
- Integrating LOV4IoT with semantic search engines, ontology and dataset catalogues.

Feel free to join the LOV4IoT community to help us! You are more than welcome 😊

29. Improving the user interface

- TO DO: Take inspiration from LOV user interface¹⁵ and adapt it to IoT domain:
- Technology used: D3.js javascript library for visualizations.

¹⁴ <http://protegewiki.stanford.edu/wiki/OWLDoc>

¹⁵ <http://lov.okfn.org/dataset/lov/>

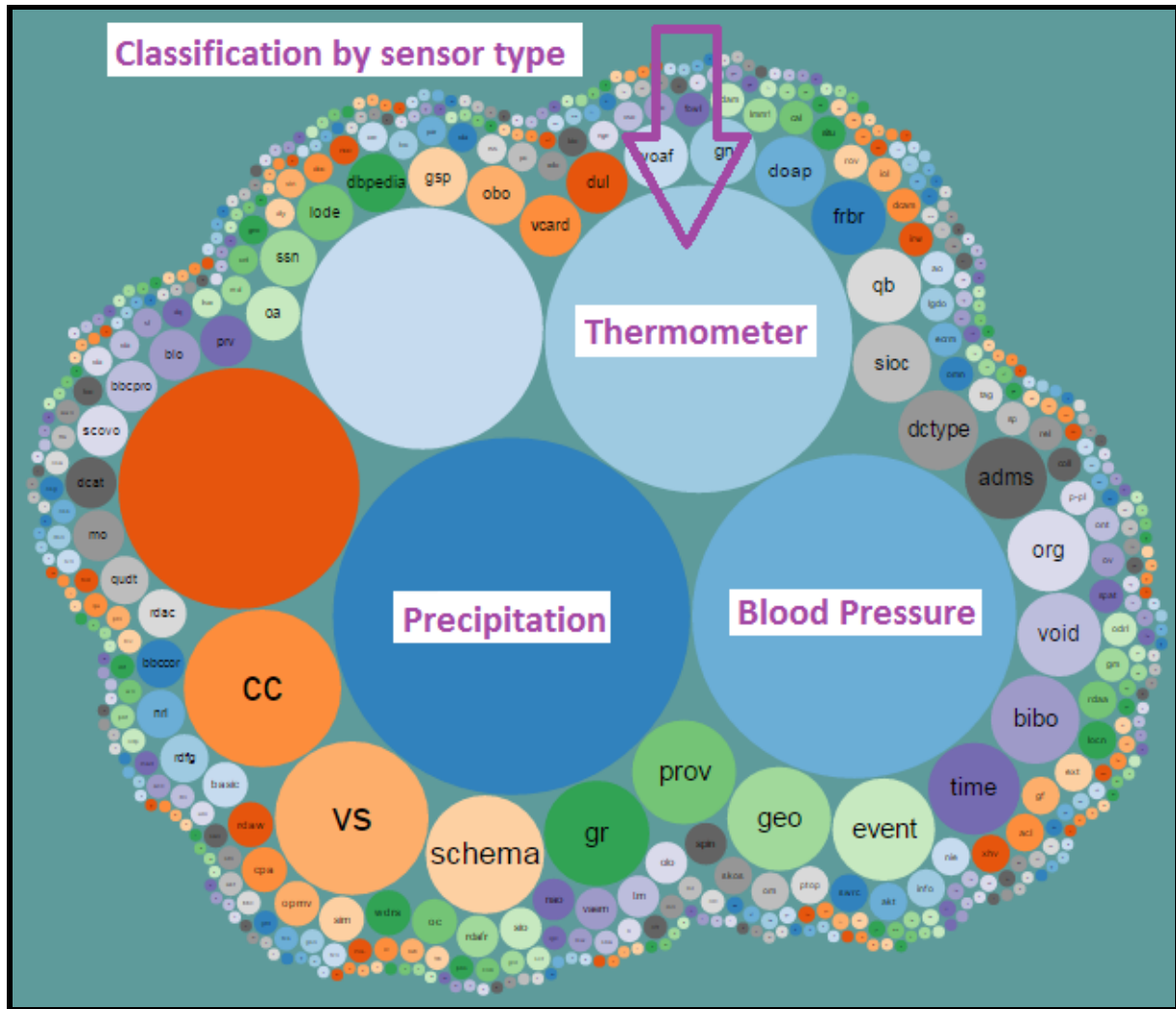


Figure 34. Bubble view to classify ontologies according to the sensor type

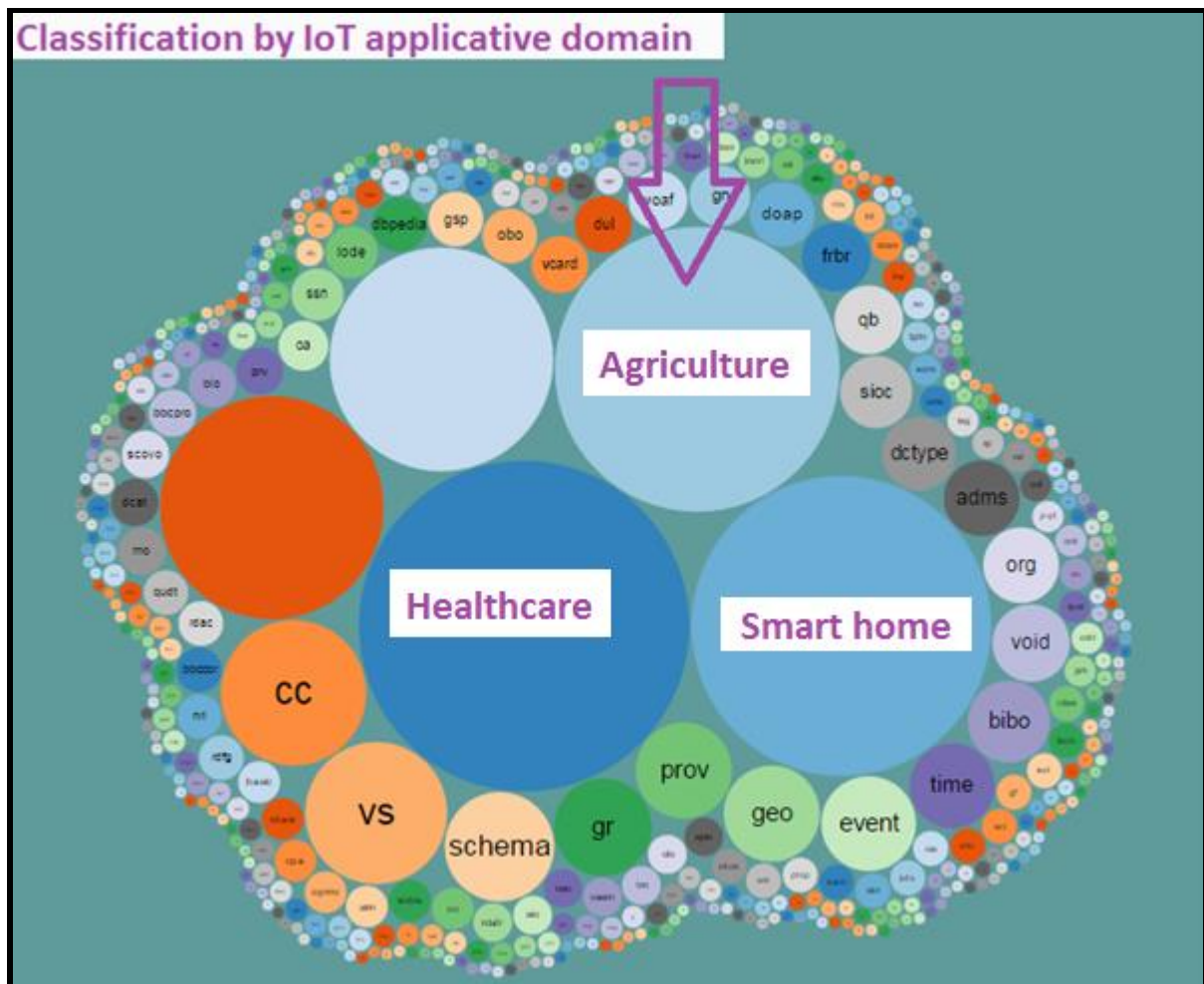


Figure 35. Bubble view to classify ontologies according to the IoT applicative domain

30. Checking best practices

LOV provides an interface for each ontology to use some tools such as:

- **WebVOWL** to visualize the ontology
- **Oops** to detect common ontology pitfalls
- **Parrot** to see the documentation of the ontology
- **Vapour** to check that the ONTOLOGY URL is deferencable (content negotiation)
- **RDF Triple-Checker** to check some typos or syntax issues.

TO DO:

- Something similar with LOV4IoT
- Integration with more tools referenced in [6].
- Creating the entire workflow of validation.

The screenshot shows the Semantic Sensor Network Ontology (ssn) page. At the top, there are navigation links: VOCABS, TERMS, AGENTS, and SPARQL/DUMP. The main title is "Semantic Sensor Network Ontology (ssn)". Below the title, there is a row of icons for various tools: a magnifying glass, a person, a gear, a checkmark, and a checkmark. To the right of these icons, there is a red box with the text "Tools to check best practices, visualizations, etc.". Below this, there is a "Metadata" section with a table of information.

Metadata	
URI	http://www.w3.org/2005/Incubator/ssn/ssnx/ssn
Namespace	http://purl.oclc.org/NET/ssnx/ssn#
Description	This ontology describes sensors and observations, and related concepts. It does not describe domain concepts, time, locations, etc. these are intended to be included from other ontologies via OWL imports. @en
Language	
Creator	W3C Semantic Sensor Network Incubator Group http://www.w3.org/2005/Incubator/ssn/
Comment	(2014-07-29) Bernard Vatant : Annual review - no change (2013-08-04) Bernard Vatant : Imports an obsolete version of DUL http://www.loa-cnr.it/ontologies/DUL.owl# (2015-04-03) Bernard Vatant : Added creator

Figure 36. Best practices tools integrated with LOV

31. Automatically updating LOV4IoT

Updating the LOV4IoT dataset is simple, it is adding a new row in the HTML web page or a new instance in the RDF LOV4IoT dataset. If required, we could find additional background knowledge by connecting LOV4IoT to semantic search engines and ontology or dataset catalogue as depicted in Figure 37.

At the beginning of this work, we started to use ontology catalogues such as Linked Open Vocabulary (LOV) since it provides web services. Unfortunately, when we were experimenting this, we realized that most of the ontologies designed for IoT were not referenced on such tools yet.

As a long-term vision, LOV4IoT should be interconnecting with existing ontology/dataset catalogues and semantic search engines.

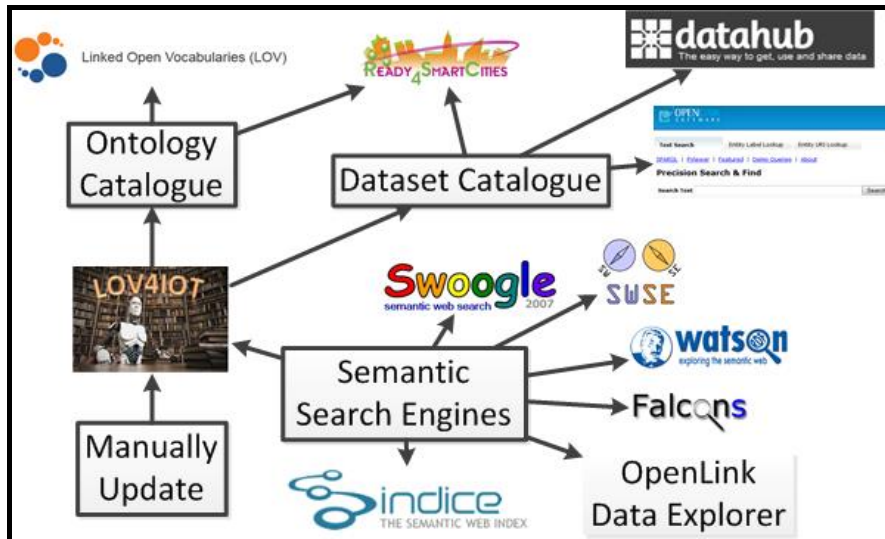


Figure 37. Integrating LOV4IoT with semantic search engines and catalogues

32. New web service

TO DO: Create web services (Suggested by Ali June 2016):

- Get all ontologies URL and research papers in IoT
- Get all ontologies URL and research papers in Sensor Networks
- Get all ontologies URL and research papers in IoT and in Sensor Networks

XVIII. References

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