## Interpreting IoT Data with Sensor-based Linked Open Rules (S-LOR)

**Creator**

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Designed and implemented by Amélie Gyrard, she was a PhD student at Eurecom under the supervision of Prof. Christian Bonnet and Dr. Karima Boudaoud. She was also a post-doc researcher at Insight within the IoT unit led by Dr. Martin Serrano. She was highly involved in the FIESTA-IoT (Federated Interoperable Semantic IoT/Cloud Testbeds and Applications) H2020 project.


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<tr>
<th>Send Feedback</th>
<th>Do not hesitate to ask for help or give us feedback, advices to improve our tools or documentations, fix bugs and make them more user-friendly and convenient: <a href="mailto:amelie@knoesis.org">amelie@knoesis.org</a></th>
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<tr>
<td>Google Group</td>
<td><a href="https://groups.google.com/d/forum/m3-semantic-web-of-things">https://groups.google.com/d/forum/m3-semantic-web-of-things</a></td>
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Terms and acronyms

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<th>Acronym</th>
<th>Description</th>
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<td>IoT</td>
<td>Internet of Things (IoT)</td>
</tr>
<tr>
<td>LOV</td>
<td>Linked Open Vocabularies</td>
</tr>
<tr>
<td>LOV4IoT</td>
<td>Linked Open Vocabularies for Internet of Things</td>
</tr>
<tr>
<td>M3</td>
<td>Machine-to-Machine Measurement (M3) framework</td>
</tr>
<tr>
<td>S-LOR</td>
<td>Sensor-based Linked Open Rules</td>
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<tr>
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<tr>
<td>Jena</td>
<td>A framework to build Semantic Web Applications</td>
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### 1. SLOR Web Services

To contribute or understand the web services:

<table>
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<th>URL</th>
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<td>Getting all rules related to a specific sensor</td>
<td><code>http://linkedopenreasoning.appspot.com/slor/rule/{sensorType}</code></td>
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**Table 1. Existing S-LOR web services (much more must be referenced here)**

1. **Getting all rules related to a specific sensor**

   `http://linkedopenreasoning.appspot.com/slor/rule/{sensorType}`

   The parameter `sensorType` should be compliant with the classes referenced with M3 ontology.

   The web service returns all rules using this sensor type. It provides “IF THEN ELSE” rules readable for human and URLs for getting the Jena rule implementations.

   Example: `http://linkedopenreasoning.appspot.com/slor/rule/BodyThermometer`
2. Getting all projects employing a specific sensor

The web service returns all projects using this sensor type. The projects are those referenced within the LOV4IoT RDF dataset.

II. Example for Smart Home/Building (NEW: September 2020)

Demo URL: http://linkedopenreasoning.appspot.com/?p=slorv2

Figure 3. Sensor-based Linked Open Rules demo applied to smart home and building
Figure 4. Click on the drop-down list to select the domain that you are interested in (e.g., smart home or building)

Figure 5. When the domain is selected, the list of sensors relevant for this domain (e.g., home and building) is automatically retrieved (using the M3 ontology)
Figure 6. Click on the “Get Project button”, it will query our LOV4IoT knowledge base that references more than 600 ontology-based IoT projects, including energy and grid projects.

Figure 7. Click on the “Get rule button”, it will query our SLOR rule knowledge base that extracted the knowledge from the LOV4IoT knowledge base, including energy and grid projects.
III. Example for Smart Energy/ Grid
(NEW: September 2020)

Demo URL: http://linkedopenreasoning.appspot.com/?p=slorv2

Figure 8. Sensor-based Linked Open Rules demo applied to smart energy and grid

Figure 9. Click on the drop-down list to select the domain that you are interested in (e.g., smart energy or grid)
Figure 10. When the domain is selected, the list of sensors relevant for this domain (e.g., energy and grid) is automatically retrieved (using the M3 ontology)

Figure 11. Click on the “Get Project button”, it will query our LOV4IoT knowledge base that references more than 600 ontology-based IoT projects, including energy and grid projects
IV. **SLOR Architecture**


V. **Why SLOR?**

Sensor-based Linked Open Rules (S-LOR) is an approach to share and reuse the rules to interpret IoT data [2]. They provide interoperable datasets of rules compliant with the Jena framework and inference engine.

1. **Reusing domain knowledge from LOV4IoT**

The rules have been written manually but extracted from the Linked Open Vocabularies for Internet of Things (LOV4IoT) dataset, an ontology/dataset/rule catalogue designed by domain experts in various applicative domains relevant for IoT such as healthcare, agriculture, smart home, smart city, etc.
Figure 13. Interoperability issues regarding reasoning

TO DO: Explain owl restrictions, interoperability issues

### 2. Sharing and reusing based approach

S-LOR has a common vision with the following approaches:

- The **BASIL (Building APIs Simply)**\(^1\) framework combines REST principles and SPARQL endpoints in order to benefit from Web APIs and Linked Data approaches [1]. BASIL reduces the learning curve of data consumers since they query web services exploiting SPARQL endpoints. The main benefit is that data consumers do not need to learn the SPARQL language and related semantic web technologies.

- **Linked Edit Rules (LER)**\(^2\) [3] is a recent approach similar to the Sensor-based Linked Open Rules (S-LOR) to share and reuse the rules associated to the data. This work has been not applied to the context of IoT. LER is more focused on checking consistency of data (e.g., a person’s age cannot be negative, a man cannot be pregnant and an underage person cannot process a driving license). LER extends the RDF Data Cube data model by introducing the concept of EditRule. The implementation of LER is based on Stardog’s rule reasoning to check obvious consistency.

---

3. Dataset of interoperable rules

Data has been unified thanks to the M3 taxonomy, a cornerstone component for building a dataset of interoperable rules. The picture shows the implementation of the rule based on the M3 taxonomy: the hierarchy of quantity kinds and units.

```r
# Cloud Cover Rules
# Rule: IF m3:CloudCover greaterThan 5 AND lessThan 8 m3:Okta THEN MostlyCloudy
# MostlyCloudy:
#  (measurement rdf:type m3:CloudCover)
#  (measurement m3:hasValue ?v)
#  greaterThan(?v,5)
#  lessThan(?v,8) ->
#  (measurement rdf:type weather-dataset:MostlyCloudy)
```

**Figure 14. Rule example implemented for being compliant with the Jena framework**

Since we are using the Jena framework, within this project, intuitively we use the Jena inference engine and Jena rules for the implementation.

After the implementation, we realized that the same rules can be built using the SPARQL query language with the keyword “CONSTRUCT”.

Both methods have the same goal updating the knowledge graphs or triplestore with additional information (more triples).

SPARQL construct encourages interoperability since SPARQL is a W3C recommendation.

```sql
CONSTRUCT {?m naturopathy:hasDisease nat:Flu} WHERE {
  ?m rdf:type m3:BodyTemperature.
  ?m m3:hasValue ?v.
  FILTER ( ?v > 38 ).
}
```

**Figure 15. SPARQL CONSTRUCT RULE equivalent to Jena rules**
4. **Jena inference engine**

SWRL

Logic-based reasoning

https://jena.apache.org/documentation/inference/

5. **Algorithm**

Algo:

- Input: Dataset semantically annotated according to the FIESTA-IoT ontology including the M3-lite taxonomy
- Output: Dataset updated with more triples, High level abstraction
- Algo:
  - Load the dataset or triplestore
  - Load the rules of subset
  - Execute the reasoning engine
  - Update the dataset or triplestore with more triples

VI. **DEMOS & GUIs**

1. **Demo**

Go to this web page: [http://www.sensormeasurement.appspot.com/?p=swot_template](http://www.sensormeasurement.appspot.com/?p=swot_template)

- Select a sensor to find all rules interpreting sensor values as depicted in Figure 16 (e.g., Precipitation)
- The demonstration will show all rules related to the sensor chosen by the user to interpret sensor values. (e.g., if precipitation = 0 mm/h then NoPrecipitation)
- You have both the rule for humans and for machines (click on the LinkedOpenRules link)
Figure 16. Finding rules to interpret sensor data with S-LOR

The users can choose a device type from the drop-down list. This drop-down list queries in the back-end the M3 ontology (V1) or M3-lite taxonomy (V2).

Figure 17. S-LOR demo

The users can click on the URL to get access to the file with already implemented Jena rules. Figure 18 shows two rules:

- IF precipitation measurement >50 and < 100 mm/h THEN Extremely Heavy Rain
- IF precipitation measurement = 0 mm/h THEN No Precipitation.
Figure 18. Jena rules from the S-LOR Semantic Rule Repository

VII. S-LOR Code

S-LOR is a component of the M3 framework.
M3 on Github: https://github.com/gyrard/M3Framework

M3 documentation to set up the code:

1. WAR/RULES

You will find in this directory all the interoperable rules that we designed.

This is the Sensor-based Linked Open Rules (S-LOR) tool. The SWoT generator has predefined-templates to build semantic-based IoT application. The templates will referenced these pre-defined set of rules classified by domains.

VIII. **Code example: Interpreting IoT data and getting M3 suggestions**

Several steps need to be achieved to interpret IoT data (see Figure 21):

- Loading M3 ontologies, datasets which have been generated in the M3 template.
- Loading M3 data.= which has been generated by the M3 converter.
- Interpreting IoT data using the Jena reasoned
• Executing the M3 SPARQL query which has been generated in the M3 template
• Parse the result and build the user interface, control actuators or send notification, etc.

1. Getting a template
http://sensormeasurement.appspot.com/?p=m3api

See documentation (section Tutorial):
http://sensormeasurement.appspot.com/documentation/M3APIDocumentation.pdf

2. Loading M3 domain knowledge

Jena tutorial:
http://jena.apache.org/tutorials/rdf_api.html

Code example:

// STEP 1: Loading M3 domain knowledge and m3_data
Model model = ModelFactory.createDefaultModel();
InputStream in = new FileInputStream(PATH_FILE + m3_data);
// m3_data has been generated with the M3 converter
model.read(in, fileURL); // read all ontologies generated in the M3 template (.owl)
model.read(in, fileURL); // read all datasets generated in the M3 template (.rdf)
in.close();

3. Executing rules

Jena tutorial:
http://jena.apache.org/documentation/inference/

Code example:

// STEP 2: Interpreting M3 data
Reasoner reasoner = new GenericRuleReasoner(Rule.rulesFromURL(PATH_FILE + LinkedOpenRules*.txt));

// LinkedOpenRules*.txt: rules generated in the M3 template
reasoner.setDerivationLogging(true);

InfModel infModel = ModelFactory.createInfModel(reasoner, model); // apply the reasoner
// infModel has been updated with high-level abstraction

4. Executing SPARQL query

Jena tutorial:
http://jena.apache.org/tutorials/rdf_api.html

Code example:

// STEP 3: Getting M3 suggestions

// Executing the SPARQL query:
Query query = QueryFactory(m3_sparql); // m3_sparql has been generated in the M3 template
ResultSet results = QueryExecutionFactory.create(m3_sparql, model)
String m3_suggestions = ResultSetFormatter.asXMLString(results)

5. Finishing the application

The main task of the develop is to design a user-friendly interface or control actuators, etc.
according to the high-level abstractions deduce by M3 or the M3 suggestions provided by M3.

Code example:

// STEP 4: Parsing and displaying m3_suggestions to build the IoT application
// or control actuators, alerting, etc.
6. Code summary

```java
// STEP 1: Loading M3 domain knowledge and m3_data
Model model = ModelFactory.createDefaultModel();
InputStream in = new FileInputstream(PATH_FILE + m3_data);
// m3 data has been generated with the M3 converter
model.read(in, fileURL); // read all ontologies generated in the M3 template (.owl)
model.read(in, fileURL); // read all datasets generated in the M3 template (.rdf)
in.close();

// STEP 2: Interpreting M3 data
Reasoner reasoner = new GenericRuleReasoner(Rule.rulesFromURL(PATH_FILE + LinkedOpenRules*.txt));
// LinkedOpenRules*.txt: rules generated in the M3 template
reasoner.setDerivationLogging(true);
InfModel infModel = ModelFactory.createInfModel(reasoner, model); // apply the reasoner
infModel has been updated with high-level abstraction

// STEP 3: Getting M3 suggestions
// Executing the SPARQL query:
Query query = QueryFactory(m3_sparql); // m3_sparql has been generated in the M3 template
ResultSet results = QueryExecutionFactory.create(m3_sparql, model)
String m3_suggestions = ResultSetFormatter.asXMLString(results)

// STEP 4: Parsing and displaying m3_suggestions to build the IoT application
// or control actuators, alerting, etc.
```

Figure 21. Code example to interpret IoT data and get M3 suggestions

IX. S-LOR Limitations

S-LOR has some limitations:

- S-LOR works only with simple sensors such as thermometer, rainfall sensors. Some more complicated sensors such as camera provide images that cannot be proceed by S-LOR. For this reasoning, an objective is integrating the KAT toolkit based on machine leaning techniques to deal with more complicated sensors.

- How the Semantic Rule repository can be automatically updated with new rules provided by the experimenters (knowledge producers). Adding a new rule in the repository is easy. However, dealing with redundancy and overlapping rules is more complicated. For this, we need to check correctness and completeness of rules. Correctness and completeness have been checked manually.

- Redesign the Jena rules as SPARQL construct since SPARQL construct to encourage interoperability since SPARQL is a W3C recommendation.

TO DO:

Correctness and completeness have been checked manually.

Add table example:

X. **S-LOR Citations**

Please do not forget to cite S-LOR:


XI. **References**

