Domain knowledge Interoperability to build the Semantic Web of Things

W3C Workshop on the Web of Things, 25–26 June 2014, Berlin, Germany

Amelie Gyrard, Christian Bonnet and Karima Boudaoud

Semantic Web of Things (SWoT) is a new field to combine Internet of Things (IoT) and semantic web technologies. We observe that the semantic web guidelines are generally not known by the IOT community which hinders automation or reuse of domain knowledge (ontologies, datasets and rules) whereas initially an ontology was designed to be easily shared and reused.

Keywords: Semantic Web, Domain Ontologies, Semantic Web of Things, Internet of Things (IoT), Machine-to-Machine (M2M), Linked Open Rules, Linked Open Data, Linked Open Vocabularies, Web of Things.

I. Introduction and problem definition

Increasingly, we are surrounded by sensor-based applications and recommender systems using semantic web technologies to represent knowledge in specific domains (tourism, healthcare, affective science, intelligent transport systems, smart home, agriculture, etc.). All of these domain knowledge are developed by domain experts and not by semantic web experts. Their domain knowledge is really interesting and should be reused, interlinked or extended by future works. Unfortunately, we cannot reuse these sensor-based ontologies since they are not published online or semantic web best practices are not followed. Furthermore, we underline that we could build cross-domain applications, since a specific domain (e.g., weather forecasting) can be reemployed in another domain (tourism, health, transport, etc.) as depicted in the Figure 1.

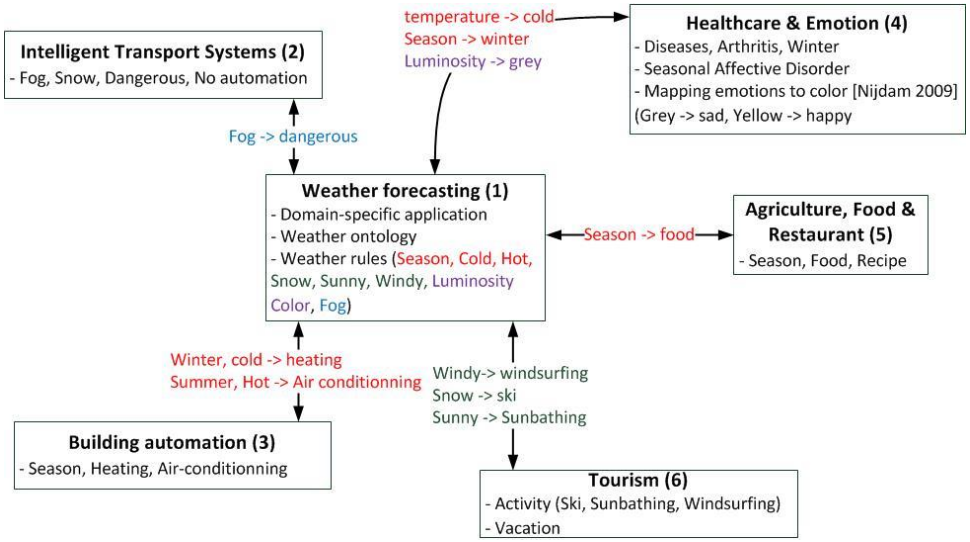

Figure 1. Reusing domain knowledge to build cross-domain ontology-based applications

II. Interlinking domains

We describe interoperability issues to interlink these domains. We are interested by domain ontologies, mostly related to sensors, actuators and RFID tags. These sensors are used in various domains. Today, most of these sensor-based ontologies are: (1) not published online, (2) do not follow semantic web best practices, and (3) are not interlinked. We referenced more than 180 ontology-based projects related to sensors which could be better reused if best practices regarding vocabulary publishing would have been enforced, as displayed in the Figure 2.

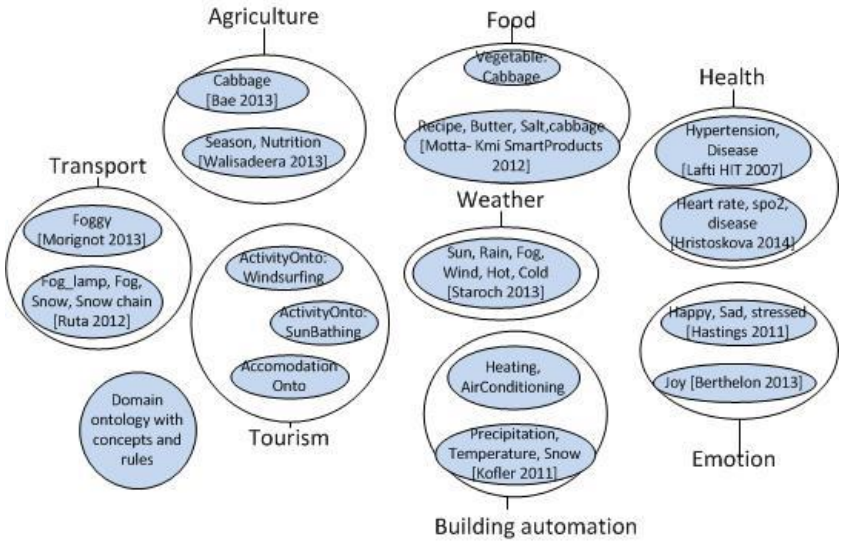

Figure 2. Domain ontologies are not interlinked

As depicted in the Figure 3, they are three layers to interlink domains:

- Link ontologies in a same domain since they have common concepts (in purple and bold)
- Cross-domain ontologies, for instance weather & transport (in green and light link)
- 'Linked Open Rules' to share and reuse domain rules (in orange and dashed link)

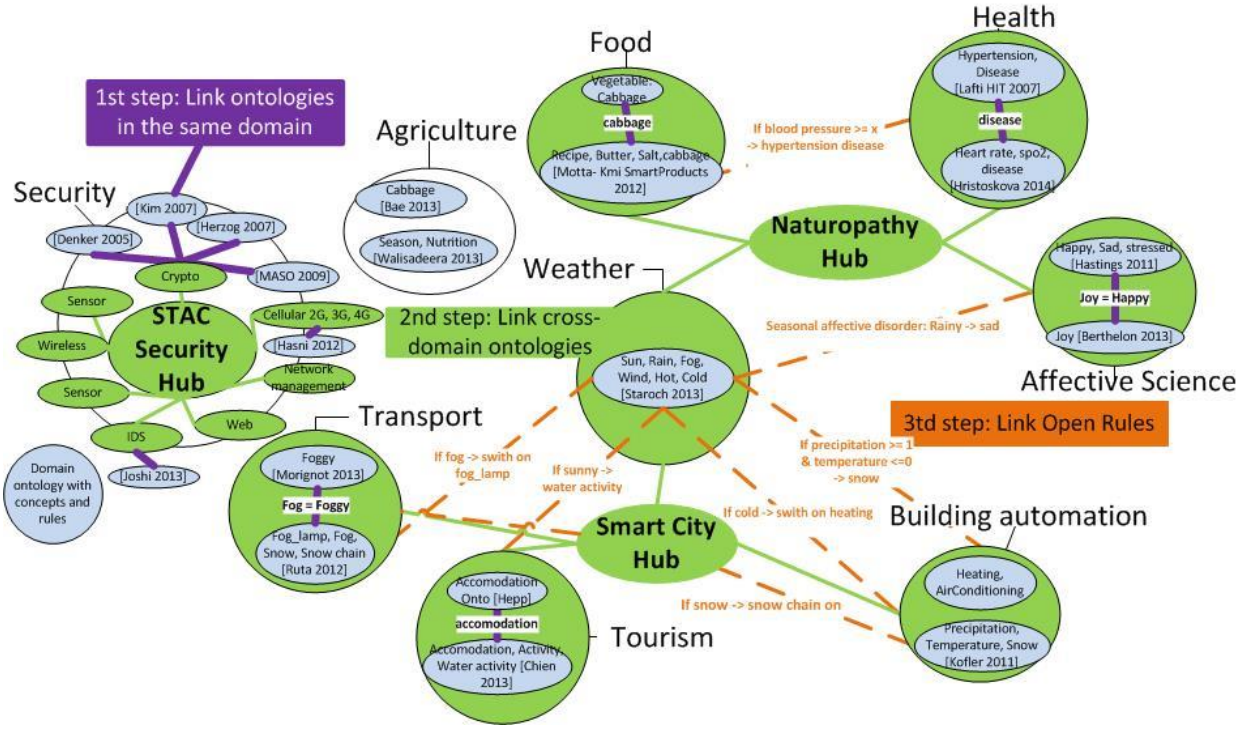

Figure 3. Domain interlinking (ontologies, datasets and rules)

III. Semantic guidelines not known by the Internet of Things community

1. Guidelines summary

We sum up some basic guidelines, more guidelines are referenced in the document OneM2M semantic Web best practices [3]:

- Publish online the domain knowledge (ontology, dataset and rules)
- Write labels or comments at least in English. Some of domain ontologies are only in German, English or Chinese which is not easily reusable.
- URI deferencable. For example, if you choose the namespace http://www.gdst.uqam.ca/Documents/Ontologies/HIT/Task_SH_Ontology.owl when you enter this URL on your browser, it is recommended to have the ontology file and not the 404 error "page not found".
- Suggest your ontology to the Linked Open Vocabularies (LOV)[1] catalogue which references more than 400 well-designed ontologies. Add the ontology metadata recommendation (rights, authors, title, etc.) in the ontology.
- Use semantic validators such as RDF validator[2], Triplechecker[3], Vapour[4], Oops[5] to validate your ontology and fix common errors.

2. First approach: send email to domain experts

Our first naïve approach was to send emails to authors to encourage them to publish online their ontologies and to spread as much as possible the semantic guidelines. We had a really good feedback from them, as you can see on the Figure 4:

- 11% cannot share their ontologies, since they are lost or confidential (colored in red in the Figure 5)
- 34% publish online the ontology thanks to our email (colored in green in the Figure 5)
- 13% answer that they will publish the ontology online soon (colored in purple in the Figure 5)
- 36% of authors do not answer to our email yet (colored in white in the Figure 5)
- Already 6% of the domain ontologies are online and referenced by LOV since the semantic web best practices are complied with. The process is still ongoing (colored in yellow)

3. Second approach: contribute to standards

Secondly, we contributed to the OneM2M[6] Working Group 5 (Management, Abstraction and Semantics), an international standard in the Internet of Things community. We describe in a draft document [3] all bad practices discovered while receiving domain ontologies and reference the recommended semantic web tools to improve the ontology or interoperability issues to interlink domain knowledge. Further, the Linked Open Vocabularies asked us to contribute to their ontology catalogue since most of the domains that we referenced are not referenced yet such as intelligent transportation system, affective science, healthcare, agriculture, food, smart home, security, etc.

4. Sensor-based popular domain ontologies

We encounter some difficulties to interlink domain knowledge. Indeed, domain experts do not use the same terms to represent the same idea or do not describe it in the same manner :

- Etymology (e.g., fog/foggy)
- Synonym (e.g., showering/bathering/washing). In IoT, these terms represent the same idea, it means that the water actuator is switched on and the current activity is deduced.
- Entity type (e.g., driver's state can be described as a concept or as a property in ontologies).

We try some user-friendly mapping tools such as LogMap[7] but such mappings are not detected. There is a need to become an expert in ontology matching to change the thresholds and find the best matching algorithm.

[1] http://lov.okfn.org/dataset/lov/
[2] http://www.w3.org/RDF/Validator/
[3] http://graphite.ecs.soton.ac.uk/checker/
[4] http://validator.linkeddata.org/vapour
[5] http://oeg-lia3.dia.fi.upm.es/webOOPS/index-content.jsp
[6] http://www.onem2m.org/
[7] http://csu6325.cs.ox.ac.uk/,

They are some popular ontologies such as FOAF[8] to describe persons. Our opinion is that we need such popular ontologies in the sensor-based domains.

Domain	#No ontologies	# No answer	# onto online	# onto lost	# onto in development	# ref by lov
Transport	26	11	5	5	4	1
Building Automation	29	9	7	4	8	1
Healthcare	34	10	12	7	5	0
Security	20	5	8	1	2	4
Tourism	26	10	10	4	1	1
Affective Science	5	1	2	0	0	2
Food, Beverage, Restaurant	22	9	9	0	3	1
Agriculture	7	5	1	1	0	0
Weather	9	2	5	0	0	2
Earthquake, pollution, environment	7	4	3	0	0	0
Total (to update)	185 (100%)	67 (36%)	63 (34%)	20 (11%)	24 (13%)	11 (6%)

Figure 4. Domain ontology status

IV. Related works

Sheth et al. [7] are the first to integrate semantics in sensor networks and called it "Semantic Sensor Web". The W3C SSN ontology[9] [2] describes sensors and observations, and related concepts but does not describe domain concepts, time, locations, etc. these are intended to be included from other ontologies via OWL imports.
The Spitfire [5] project proposes the new concept called "Semantic Web of Things". Barnaghi et al. [1] introduce the need to share and integrate information across different domains to infer new knowledge. Ruta et al. [6] propose the concept of SWOT framework and introduce the need of reasoning, but do not propose the idea to interlink domain ontologies and rules. Gyrard et al. [4] design the SWOT framework to automatically enrich sensor data with semantics and reason about them by reusing domain knowledge and to provide web services to developers who do not need to learn semantic web technologies. Their SWOT framework is based on the M3 ontology[10] which is focused on the ssn:ObservationValue concept from the W3C SSN ontology to describe in a uniform way sensors, measurement types and domains. For instance, rainfall or precipitation sensors represent the same sensor and 't', 'temp' or 'temperature' describe the same measurement.

V. Summary

There is a real need to spread semantic web best practices in the Internet of Things community to easily share and reuse domain knowledge to latter interlink them to build promising cross-domain Semantic Web of Things applications.

[8] http://xmlns.com/foaf/spec/
[9] http://www.w3.org/2005/Incubator/ssn/ssnx/ssn#
[10] http://www.sensormeasurement.appspot.com/?p=ontologies#m3

Intelligent Transport Systems

Authors	Year	Paper	Url onto	Technologies	Sensors	Rules
Stocker et al. (in red)	2012	Paper: Making sensor of sensor data using ontology: a discussion for road vehicle classification	Trivial ontology: few concepts (response), uses SSN Concepts: Vehicle, Light, Heavy, Dirving Side, Driving Speed.	Protege, Jena	Vibration, magnetometer, vehicle velocity	
Feld, Muller (in purple)	2011	Paper: The Automotive ontology: Managing knowledge inside the vehicle and sharing it between cars.	Work in progress (Response) Concepts: Road, Parking, Traffic Events, Emotional State, Driving Preferences, Mental State, Abilities, Characteristics, Personality		Speed, voice (microphone), ice sensor, heart beat, blood pressure, arousal, alcohol level	
Hulsen, Zollner, Weiss (in white)	2011	Paper: Traffic intersection situation description ontology for advanced driver assistance.	Concepts: Traffic Sign, Traffic Light, Road, Car, Crossing	RacerPro		
Ruta et al. (in green)	2010	Paper: A mobile knowlege-based system for on-board diagnostics and car driving assistance.	Ontology and Rules URL Concepts: Weather condictions (fog, windy, cloud, rain, snow, clear), road surface (unever, even), road condition (high/low speed), traffic (high/low density), driving style (even pace, imprudent) vehicle		GPS, accelerometer, speed, wind, esp, abs, fog lamp	fog -> low speed, fog lamp, abs (OWL restrictions)

Figure 5. Domain ontologies in the transportation domain (http://www.sensormeasurement.appspot.com/?p=ontologies)

References:

[1] Payam Barnaghi, Wei Wang, Cory Henson, and Kerry Taylor. Semantics for the internet of things: early progress and back to the future. *International Journal on Semantic Web and Information Systems (IJSWIS)*, 8(1):1–21, 2012.

[2] M. Compton, P. Barnaghi, L. Bermudez, R. Garcia-Castro, O. Corcho, S. Cox, J. Graybeal, M. Hauswirth, C. Henson, A. Herzog, et al. The ssn ontology of the w3c semantic sensor network incubator group. *Web Semantics: Science, Services and Agents on the World Wide Web*, 2012. http://www.w3.org/2005/Incubator/ssn/ssnx/ssn.

[3] Amélie Gyrard and Christian Bonnet. Semantic Web best practices: Semantic Web Guidelines for domain knowledge interoperability to build the Semantic Web of Things, 04 2014.

[4] Amélie Gyrard, Christian Bonnet, and Karima Boudaoud. Enrich machine-to-machine data with semantic web technologies for cross-domain applications. In *WF-IOT 2014, World Forum on Internet of Things, 6-8 March 2014, Seoul, Korea*, Seoul, KOREA, REPUBLIC OF, 03 2014.

[5] Dennis Pfisterer, Kay Romer, Daniel Bimschas, Oliver Kleine, Richard Mietz, Cuong Truong, Henning Hasemann, Alexander Kroller, Max Pagel, Manfred Hauswirth, et al. Spitfire: toward a semantic web of things. *Communications Magazine, IEEE*, 49(11):40–48, 2011.

[6] Michele Ruta, Floriano Scioscia, and Eugenio Di Sciascio. Enabling the semantic web of things: Framework and architecture. In *ICSC*, pages 345–347, 2012.

[7] A. Sheth, C. Henson, and S.S. Sahoo. Semantic sensor web. *Internet Computing, IEEE*, 12(4):78–83, 2008.