Semantic Web meets Internet of Things (IoT) and Web of Things (WoT)

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Abstract. An ever growing interest and wide adoption of Internet of Things (IoT) technologies unleash a true potential of designing a broad range of high-quality consumer applications. Smart cities, smart buildings, and e-health are among various application domains which are benefited from IoT technologies. Diversity, dynamicity and heterogeneity of devices, networks and data are among major challenges hindering the wide adoption of IoT technologies. Semantic technologies have been effectively used in various domains, particularly, to address the heterogeneity challenge to (i) ease the interconnection of such data, (ii) deduce new knowledge to build smart applications and (iii) maintain interoperability at data processing, management and storage. We will familiarize our audience with the "evolution" of IoT called Web of things (WoT) which is based on existing Web standards. Combining Semantic Web and Web of Things technologies pave the way for the Semantic Web of Things. This tutorial will introduce the basics of Internet of Things and Web of Things in order to enable the rapid development of semantics-based Web of Things applications. Towards that goal, the tutorial will also demonstrate how semantic web technologies are employed for semantic annotation and reasoning on data to build interoperable IoT/WoT applications. One key aspect is helping IoT developers in dealing with semantic web technologies by reducing the learning curve as much as possible. We will showcase real-world use case scenarios which are designed using semantically enabled IoT frameworks (e.g. CityPulse, FIESTA-IoT).

1 Motivation

In recent years, we have been witnessing a growing number of sensors embedded in smart devices or everyday objects. Applications exploiting sensors and producing data are more and more popular. More than 100 scenarios[4] have been referenced by IoT projects such as continuous health care, smart home, smart orchard,

[4] http://www.ict-citypulse.eu/scenarios/scenarios

detecting road conditions or air pollution countermeasures. However, one of the challenging problem with the existing IoT applications is that devices are not/or little interoperable with each other since their data is based on proprietary formats and they do not use common terms or vocabulary to describe interoperable IoT data. Semantic web technologies have already shown their benefits in other domains than IoT. IoT interoperability is still in its infancy phase. Semantic web technologies can be employed in IoT to overcome the challenge in dealing with interoperability of data produced by devices already employed in real-life.

Through this tutorial, we aim to bridge this gap between IoT and Semantic worlds by providing the participants with an overview of the existing IoT approaches with their pros and cons and how the limitations of existing IoT platforms can be overcome with semantic web technologies. Moreover, we aim to provide the participants hands-on experience that will guide them to choose a right approach for their needs to develop their semantics-based IoT applications.

The main benefit of this tutorial is helping developers in dealing with semantic web technologies by reducing the learning curve as much as possible. We are expecting that the tutorial will encourage semantic web experts to spread our approach of easing the integration of semantic web technologies in other domains than IoT.

2 Audience

The same people attending the following (previous) workshop editions or research tracks would be interested in our tutorial:

- ISWC 2016 Main track: Data streams and the Internet of Things
- International Workshop on Semantic Sensor Networks and Terra Cognita[5].
- Semantics for Smart Cities (S4SC)[6] workshop.
- Semantics and Data Analytics for Smart City Applications[7] tutorial.

This tutorial should be of interest to the semantic professionals and the academic community as it straddles the line between applied research and that which is reasonably achievable for a customer. Participants with all levels of ontology modeling experience are encouraged to attend. There is much information to be absorbed and enjoyed on all levels of semantic expertise and all levels are most welcome. Ideal preparation would be to have some basics regarding Internet of Things, Web of Things, etc. Overall the tutorial is expected to attract a large audience comprising of academia, industry, engineers and other stakeholders in IoT, SWoT and smart city initiatives.

3 Detailed Description

In this section, we describe the tutorial content, aims and learning objectives, tutorial material, and the prior knowledge required by the attendees.

[5] http://event.cwi.nl/ssn-tc-2015/
[6] http://kat.ee.surrey.ac.uk/wssc/index.html
[7] http://ict-citypulse.eu/page/tutorial/smartcity-tutorial-eswc2015.htm

3.1 Content Overview

Our tutorial will consist of five sessions:

PART I: Internet of Things (IoT). The tutorial will start with an introduction aimed at setting a common context between the IoT and SWoT for all participants. It will provide an understanding of commonly used terminology by presenting a domain model [1] [2] [3]. This is followed by a discussion on Common Service Functions (CSFs) to build IoT ecosystems including uniform metadata exchange [4], device registration [5], resource discovery [6], device management [7], data management and repository [8]. The entire ecosystem is highly fragmented due to individualized implementations of these CSFs as well as data-silos arising due to non-uniform treatment of IoT data originating at heterogeneous domains. To mitigate these issues, oneM2M partnership project[8] (an initiative to standardize IoT by standard development organizations around the world) is exploiting semantic web technologies. Techniques for rapid application development will then be discussed which are based on (i) such architecture, (ii) model-based development [9], (iii) macro-programming languages and compilers (iv) node-centric programming such as Node-RED[9].

These concepts will be delivered using examples with code snippets. We will present hands-on tips to start with the IoT application development immediately and demonstrate our current project – IoTSuite [10], a toolkit for prototyping IoT applications[10].

PART II: Moving from IoT to WoT. Utilizing the RESTful web services, standards and best practices can bring harmony and interoperability among the IoT platforms and ecosystems. In this session, we will leverage the IoT concepts described previously and combine it with the Web, thus preparing foundation for the next session on – "Semantic Web of Things". We will start this session by some motivation scenarios for the WoT [11], [12]. The session will highlight semantics for thing description such as JSON-LD[11], RDFa[12]; and standardization efforts by W3C WoT Interest Group (IG)[13]. The WoT IG activities are split into four Task Forces (TFs). Among them the TF on Thing Description is looking into semantic-based representation of things while TF of Discovery examines semantic-based discovery. Benefits of utilizing the semantic web technologies will be thoroughly highlighted. We will discuss how the presented WoT and Semantic Web concepts can be integrated in real-world WoT applications.

PART III: Semantic Web of Things (SWoT) platforms. While the previous sessions outline the benefits of integrating semantic web technologies to IoT and WoT, this session dives deeper into semantics. It explains the way to semantically annotate data produced by IoT devices by using the W3C Semantic

[8] http://www.onem2m.org/
[9] http://nodered.org/
[10] https://github.com/pankeshlinux/IoTSuite
[11] json-ld.org/
[12] https://rdfa.info/
[13] https://www.w3.org/WoT/IG/

Sensor Networks (SSN) ontology [13] and the Machine-to-Machine Measurement (M3) ontology [14] to unify terms to describe sensor data. M3 Framework has been designed to assist developers in developing semantics-based WoT applications [15]. M3 enables enriching IoT data with meaningful information using logic-based inference engine (e.g., deducing hot from an outdoor temperature) but also enables combining IoT application domains [16] [17]. The design of the M3 semantic engine is flexible enough to be deployed at a cloud[14] or a Gateway or even an Android powered device. This section will extend and improve the tutorial online exploiting the semantic engine[15]. The M3 semantic engine will be explained in this context and the hands-on session will enable to use it in practice.

PART IV: Semantics-based Smart City Demos. Realizing the true potential of semantic technologies, various IoT frameworks have been proposed which address the data interoperability issues using the Semantic Web technologies and standards [18, 19]. In this session, we will demonstrate practical scenarios designed in the context of smart cities projects [19,20], which leverage the benefits of semantic interoperability and provide real-time data analytics solutions for large-scale IoT data streams [21]. We will showcase a real-time data analytics and decision support applications (City Route Planner and Parking Space Finder) developed for the City of Aarhus, Denmark using the CityPulse Framework [22, 23]. Both applications process real-time IoT data streams and perform real-time data analytics using semantic technologies and user-centric decision support. We will also demonstrate a second related to the FIESTA-IoT[16] EU project ensuring semantic interoperability of IoT data, testbeds and experiments/applications. It reuses the semantic engine presented in the previous section. Sensor data produced by smart cities such as Santander in Spain is exploited and combined with other data coming from others cities such as Galway in Ireland and Guildford in United Kingdom. A set of FIESTA-IoT tools[17] can be used to register and discover testbeds and experiments to later run the experiment to provide smart IoT applications to end-users. CityPulse[18] is another EU project aiming at analyzing data provided by other smart cites such as Ahruus in Denmark and are mainly focused on scalability issues. CityPulse develops semantics-based IoT applications.

PART V: Semantic Web of Things in Practice. The last section is for practitioning the different tools presented previously: IoT tools, WoT tools, SWoT tools and data analytics tools to be able to design semantics-based IoT/WoT applications.

[14] http://sensormeasurement.appspot.com/
[15] http://sensormeasurement.appspot.com/documentation/M3APIDocumentation.pdf
[16] http://fiesta-iot.eu/
[17] http://fiesta-iot-tools.appspot.com/
[18] http://www.ict-citypulse.eu/page/

3.2 Aims and Learning Objectives

Through this tutorial, our aim is to bring together the Software Engineering, Internet of Things, Semantic Web, and Web of Things communities together for developing future Internet applications via Semantic Web of Things (SWoT).

The learning objectives of the tutorial are the following:

1. For beginners, it will create an understanding of what SWoT means, common terminology, and use cases.
2. For practitioners, it will provide a solid foundation to compare and evaluate existing approaches for building SWoT applications.
3. It will provide a discussion forum for researchers working in these areas, concerning all aspects of designing and developing an ecosystem for SWoT applications.
4. For semantic web experts, it will demonstrate the need to design tools to assist non experts in integrating semantic web technologies and reduce as much as possible the learning curve.

3.3 Tutorial Material

Our presentations will be mostly based on Powerpoint slides, animations, small code snippets to illustrate the concepts. We will interleave live demonstration of existing systems with the presentations of the material throughout the tutorial to make it more attractive. This will provide audiences with the opportunities to study the technology in action. We will make the tutorial interactive while delivering the contents. Small and quick exercises will be asked to make the tutorial interactive and ensure that the core concepts are delivered.

The tutorial will have the following five parts with hands-on exercises relevant to each session:

1. Internet of Things (IoT) - 30 mins
   Presenters: Pankesh Patel & Soumya Kanti Datta
   Slides will be presented and followed by demos recorded.
2. Web of Things (WoT) - 30 mins
   Presenters: Pankesh Patel & Soumya Kanti Datta
   Slides will be presented and followed by demos recorded illustrating the IoT suite tool.
3. Semantic Web of Things (SWoT) - 30 mins
   Presenters: Amelie Gyrard, Soumya Kanti Datta & Ali Intizar
   Slides will be presented and followed by demos recorded illustrating the M3 framework.
4. Semantics-based Smart City Demos - 30 mins
   Presenters: Amelie Gyrard & Ali Intizar
   Slides will be presented and followed by demos recorded from FIESTA-IoT and CityPulse EU projects.
5. Hands-on sessions - 90 mins
   - Running IoTSuite, WoTKit and IBM IoT Foundation.

- Running M3 framework on the Cloud and embedded on Android-powered devices.
- Data Analytics with CityPulse.
- Semantic interoperability with FIESTA-IoT.

The tutorial will wrap up with a focused discussion on specific learning of the audience and open questions.

3.4 Required Prior Knowledge

Since this tutorial is for ISWC, we assume that attendees have some basics regarding semantic web languages and ontologies. The knowledge of a semantic web framework such as Jena [24] and the set up of the Eclipse environment and Java 1.7 already done would be appreciated. We will provide basics to understand IoT and WoT in our presentations. Our step-by-step tutorial will guide people to use both WoT and semantic web to develop Semantic Web of Things applications.

4 Length

We intend to deliver a half day tutorial.

5 Technical Requirements

The tutorial presenters need access to the Internet and standard equipment e.g. projector, audio system, microphone and power plugs. Participants must bring their own laptop with the software (to be announced later) installed.

6 Presenters

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She is a post-doc researcher at Insight/National University of Ireland, Galway (NUIG). She is actively working in the scientific development and coordination of the FIESTA-IoT (Federated Interoperable Semantic IoT/Cloud Testbeds and Applications) EU H2020 project. Her research interests are on Software engineering for Semantic Web of Things and Internet of Things (IoT), semantic web best practices and methodologies, ontology engineering, reasoning and interoperability of IoT data. She is interested in semantic-based IoT related research fields such as Ubiquitous Computing (UbiComp), Pervasive Computing, Ambient Intelligence (AmI), Context-Awareness, Ambient Assisted Living (AAL), Smart Homes, Semantic Sensor Networks (SSN), Machine-to-Machine (M2M), Internet of Things (IoT), Web of Things (WoT), Smart Cities and Physical-Cyber-Social Computing

(PCS). She holds a Ph.D. from Eurecom since April 2015 where she designed and implemented the Machine-to-Machine Measurement (M3) framework [25]. The title of her dissertation is 'Designing Cross-Domain Semantic Web of Things Applications'. She also disseminated her work in standardizations such as ETSI M2M, oneM2M (working group on management, abstraction and semantics) and W3C Web of Things. She is a reviewer for international conferences and journals (IJSWIS Journal, Sensors Journal, IoT Journal, ICCCT).

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He is a Research Engineer in EURECOM, France and is working on many French research projects and technology transfer to industry. His research focuses on innovation, standardization and development of next-generation technologies in Internet of Things, Machine-to-Machine Communications, Smart Cities and Mobile computing. He is an active member of IEEE Communication Society and IEEE Consumer Electronics (CE) Society. He leads the activities of IEEE CE Society Future Directions on IoT. He has published more than 35 research papers in top IEEE Conferences and Journals. He regularly serves the IEEE conferences in many capacities. He is a frequent participant of ETSI events and regularly gives presentations and tutorials on IoT at various events including ETSI and IEEE Conferences. Currently he is involved in oneM2M partnership project and W3C Web of Things Interest Group and is actively contributing to their standard development activities. Soumya holds an M.Sc in Communications and Computer Security from Telecom ParisTech (EURECOM), France.

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