Semantic Technologies for the Internet of Things

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The rapid increase in number of network-enabled devices and sensors deployed in the physical environments is changing the information communication networks, and services and applications in various domains. It is predicted that within the next decade billions of devices (Cisco predicts that the number of the Internet connected devices will be around 50 Billion by 2020 [1]) will generate large volumes of real world data for many applications and services in a variety of areas such as smart grids, smart homes, healthcare, automotive, transport, logistics and environmental monitoring [2]. The related technologies and solutions that enable integration of real world data and services into the current information networking technologies are often described under the umbrella term of the Internet of Things (IoT) [3].

A primary goal of interconnecting devices (e.g., sensors) and collecting/processing data from them is to create situation awareness and enable applications, machines, and human users to better understand their surrounding environments. The understanding of a situation, an occurrence and event, and also relationships between different patterns and occurrences potentially enables services and applications to make intelligent decisions and to respond to the dynamics of their environments. Data collected by different sensors and devices is usually multi-modal (temperature, light, sound, video, etc.) and diverse in nature (quality of data can vary with different devices through time and it is mostly location and time dependent; the data can be also noisy and incomplete). The diversity, volatility, and ubiquity make the task of processing, integrating, and interpreting the real world data a challenging task. The volume of data on the Internet and the Web has already been overwhelming and is still growing at stunning pace: everyday around 2.5 quintillion bytes of data is created and it is estimated that 90% of the data today was generated in the past two years [4]. Sensory data (including crowed sourced sensory data) related to different events and occurrences can be analyzed and turned into actionable information to give us better understanding about our physical world and to create more value-added products and services; for example, readings from smart energy meters can be used to better predict and balance power consumption in smart grids; analyzing combination of traffic, pollution, weather and congestion sensory data records can provide better traffic control and management; monitoring and processing health signals collected by sensory devices can provide better healthcare services.

The IoT data, however, is not only limited to sensor device data. Information available from social media and user submitted physical world observations and measurements also provide a wealth of data [5]. Integration of data from various physical, cyber, and social resources enables developing applications and services that can incorporate situation and context-awareness into the decision making mechanisms and can create smarter applications and enhanced services [6].

In dealing with large volumes of distributed and heterogeneous IoT data, issues related to interoperability, automation, and data analytics will require common description and data representation frameworks and machine-readable and machine-interpretable data descriptions. Applying semantic technologies to the IoT promotes interoperability among various resources and data providers and consumers [7], and facilitates effective data access and integration, resource discovery, semantic reasoning, and knowledge extraction [8]. Data annotations and semantic descriptions can be used at different levels and semantic annotations can be applied to various resources in the IoT. Figure 1 shows some of the key areas in the IoT that semantic technologies can be used.

Large number of highly distributed and heterogeneous devices in the IoT need to be interconnected and communicate in different scenarios autonomously. This implies that providing interoperability among the "Things" on the IoT is one of the most fundamental requirements to support object addressing, tracking, and discovery as well as information representation, storage, and exchange. The suite of technologies developed in the Semantic Web [9], such as ontologies, semantic annotation, Linked Data [10] and semantic Web services [11], can be uses as principal solutions for the purpose of realising the IoT.

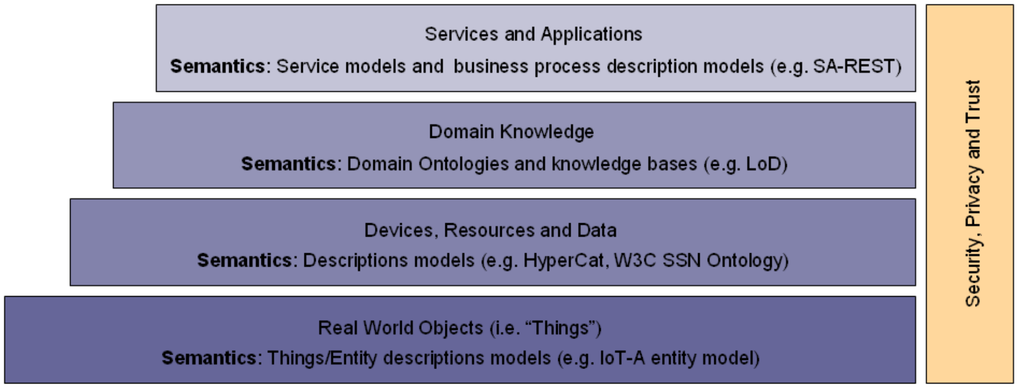

Figure 1: Semantics in the IoT

Semantic technologies and annotation models

The main description models for the Semantic Web include the Resource Description Framework (RDF)[1], and the Web Ontology Language (OWL)[2] is based on description logic and facilitates construction of ontologies for different domains. Semantic data can be accessed by software agents for query, reasoning and analysis purposes to derive additional knowledge from the represented data. There are also common software tools and open libraries such as Jena [12] and Sesame [13] to work with semantic data.

The W3C Incubator group on Semantic Sensor Networks has developed an ontology for describing sensors and sensor network resources that is SSN ontology [14], [15]. The ontology provides a high-level schema to describe sensor devices, their operation and management, observation and measurement data, and process related attributes of sensors. It has received consensus of the community and has been adopted in several projects [8]. To model the observation and measurement data produced by the sensors, the SSN ontology can be used along with other ontologies such as the Quantity Kinds and Units ontology[3] and the SWEET ontology[4]. The SSN ontology has also been used with domain ontologies to develop various smart Things ontologies [14]. Semantic annotations can describe IoT resources, services and related processes. However, often there is no direct association to the domain knowledge in the core models that describe the IoT data. Different resources, including observation and measurement data, also need to be associated with each other to add meaning to the IoT data. Effective reasoning and processing mechanisms for the IoT data, and making it interoperable through different domains, requires accessing domain knowledge and relating semantically enriched descriptions to other entities and/or existing data (on the Web). Linked Data is an approach to relate different resources and is currently adopted on the Web. The four principles, or best practices, of publishing data as linked data includes [10]:

- Using URI's as names for things; everything is addressed using unique URI's.
- Using HTTP URI's to enable people to look up those names; all the URI's are accessible via HTTP interfaces.
- Providing useful RDF information related to URI's that are looked up by machine or people;
- Linking the URI's to other URI's.

The current linked open data[5] effort on the Web provides a large of number of interlinked data represented in RDF accessible via common standard interfaces. The linked data approach is also applied to the IoT domain by providing semantic data and linking it to other domain dependent resources such as location information and semantic tags; e.g. the work described in [16]. The linked data approach enables resources described via different models and

[1] http://www.w3.org/RDF/
[2] http://www.w3.org/2001/sw/wiki/OWL
[3] http://www.w3.org/2005/Incubator/ssn/ssnx/qu/qu-rec20.html
[4] http://sweet.jpl.nasa.gov/ontology/
[5] http://linkeddata.org/

ontologies to be interconnected. Linking the data to existing domain knowledge and resources also makes the descriptions more interoperable. Providing automated mechanisms for semantic tagging of the resources using the concepts available as linked data and defining automated association mechanisms between different resources (e.g. based on location, theme, provider and other common properties) make the IoT data usable across different domains. It is important to note that providing semantic descriptions alone will not create semantic interoperability and will not solve all the issues regarding discovery, management of data, and supporting autonomous interactions. The semantic descriptions will still need to be shared, processed, and interpreted by various methods and services across different domains [8].

This lecture will provide an overview of the recent developments in applying semantic technologies to the IoT. The discussion will be also extended to the Web of Things and data analysis and related issues in the IoT.

Acknowledgement

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