Ontology Summit 2015:
Internet of Things: Toward Smart Networked Systems and Societies
Synthesis II – March 26, 2015

Track A: Ontology Integration in the Internet of Things: Synthesis II

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Track A: Ontology Integration in the Internet of Things: **Goal** & **Mission**

- ***Goal of Track:***
  - To discuss the various approaches being taken to address the integration and interoperability issues
- ***Mission:***
  - Present case studies of IoT
  - Discuss current approaches in integration and interoperability
  - Discuss gaps in current approaches
  - Discuss issues of vertical integration and interoperability across layers of the IoT, including granularity
  - Propose methods for achieving integration and interoperability through ontologies
  - Propose a unified framework for integration and interoperability for multimodal (audio, text, video, etc.) interfaces

Terminology: From Internet of Things to Smart Networked Systems and Societies

- ***Internet of Things.*** The Internet of Things (IoT) is a term that is being used to denote a network – typically the Internet -- of devices that constantly monitor the environment and can result in "intelligent actions." These devices can range from simple sensors to complex systems such as automobiles and buildings. There are several views of IoT in vogue. For example, ITU (International Telecommunication Union) and IERC (IoT-European Research Cluster) define IoT as "a global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes and virtual personalities, use intelligent interfaces and are seamlessly integrated into the information network." (See Internet of Things – From Research and Innovation to Market Deployment, Vermesan, O. and Friess, P. (editors), 2014, River Publishers, Aalborg, Denmark).
- ***Cyber-Physical Systems.*** Cyber-physical systems (CPSs) extend IoT and will play an increasingly important role in the next generation industrial systems. These systems extend IoT by adding a control and decision making layer. Again, several views of CPSs exist. One commonly used definition is provided in http://varma.ece.cmu.edu/summit/index.html, which places an emphasis on embedded systems and the tight coupling between hardware and software.
- ***Cyber-Physical Human Systems.*** When humans take an active role in CPSs we have Cyber-physical Human Systems (CPHSs). These systems can be viewed as socio-technical systems, with a symbiotic relationship between the human and the physical device.
- ***Cyber-physical Social Systems*** *or* ***Smart Networked Systems and Societies****.* Social networks, such as Facebook and Twitter, primarily connect people to one another. These networks have played a very important role in various democratic uprisings in the recent past. Social networks have been used both to curtail and to propagate freedom of speech. When these networks are combined with CPSs, we have *Smart Networked Systems and Societies (SNSS)*, which are also known as *Cyber-physical Social Systems (CPSS)* or *Internet of Everything (IoE)*.

The Technical Challenge

- The development of a trusted, secure, reliable, and interoperable net-centric computing environment will need technologies that can assure a flexible and scalable system allowing the application of diverse and robust privacy requirements, thus enabling the trusted and meaningful growth of net-centric infrastructures for the benefit of all societies.
- One such technical challenge is that the network consists of things (both devices and humans) which are heterogeneous, yet need to have seamless interoperability.
- This requires the development of standard terminologies which capture objects and events.
- Creating and testing such terminologies will aid in effective recognition and reaction in a network-centric situation awareness environment.

Strategy for Addressing the Technical Challenge in Track A

- Present case studies of IoT/IoE
- Discuss current approaches in integration and interoperability
- Discuss gaps in current approaches
- Propose methods for achieving integration and interoperability through ontologies
- Propose a unified framework for integration and interoperability for multimodal (audio, text, video, etc.) interfaces

Track A Speakers

- **Dr. Steve Ray (Carnegie Mellon University, USA)**: An Ontology-Driven Integration Framework for Smart Communities
  - Describes a neutral, abstract ontology and framework that supports the vision and diverse contexts of a smart community, supporting IoT and ontology mapping
- **Dr. Payam Barnaghi (University of Surrey, UK):** Dynamic Semantics for the Internet of Things
  - Provides an overview of the use-case and requirements for semantic interoperability in the IoT with a focus on annotation, processing and information extraction and dynamicity in the IoT environment
- **Dr. Jack Hodges (Web of Things (WOT) Research Group, Siemens Berkeley Laboratory, USA)**: Semantic Integration Prototype for Wearable Devices in Health Care
  - Describes a prototype using curated biomedical ontologies to assist health care professionals in selecting appropriate wearable devices to monitor diagnosed disorders
- **Dr. Ram D. Sriram (NIST):** Toward Internet of Everything: IoT, CPS, and SNSS
  - Provides definitions of IoT, CPS, and SNSS. Discusses challenges for making a netcentric society a reality. Emphasis the need to develop event ontologies. Discusses an example in the health care domain.
- **Drs. Spencer Breiner (NIST) and Eswaran Subrahmanian (CMU):** Category Theory for Modular Design: An IoT Example
  - Discusses Category theory (CT) is the mathematical study of structure and, as such, provides a rich formal language for the specification and analysis of ontologies, broadly construed as structured representations of information.
- **Dr. Krzystof Janowicz (University of California, Santa Barbara):** Ontology Virtualization for Smart Environments
  - Discusses ontology design patterns. Introduces notion of ontology virtualization, which provides a flexible plug and play-style reconfiguration of patterns with purpose-driven “semantic views.”

Case Studes of IoT/IoE

- Sensor Integration (Steve Ray)
- Smart Grid (Steve Ray)
- Smart Health Care (Jack Hodges, Ram D. Sriram)
- Framework for Internet of Things (Payam Barnaghi)

Current Approaches to Integration and Interoperability

- **The Hyer/CAT approach** (see http://www.hypercat.io/standard.html): This a simple approach, where servers provide catalogues – an array of URIs -- of resources, annotated with metadata -- to clients [Barnaghi]
- **Simple Mapping:** Manually map JSON entities to target ontologies [Ray]
- **Inference-based Mapping:** Mappings between ontologies can be achieved using an inference engine (or AI theorem provers) [Ray]. This may involve making data smart [Janowicz]
- **Combine existing ontologies:** There are well defined ontologies in various domains. Use these ontologies to integrate systems [e.g., Quantities, Units, Dimensions; Semantic Sensor Networks; Foundation Model of Anatomy; Symptom Ontology; Human Disease Ontology]

Gaps

- Most systems in prototype stage
- Lack of semantic annotation tools
- Lack of tools for validation of ontologies
- Need more work on representing events
- IoT ontologies need to deal with dynamic time varying data vs. the often static Semantic Web
- Privacy and security issues
- Mostly manual methods for integration
- For some promising approaches the mathematics may be solid but there is lack of implementaions.

Methods for Integration and Interoperability

- **Encode dynamic semantics**, which includes incorporating time semantics [Barnaghi]
- **Develop event ontologies** with above dynamic semantics [Barnaghi, Sriram]
- **Explore category theory**, which reveals deep connections between formal logic, computer science and theoretical physics. Approach would involve the following:
  1) Begin with two or more models;
  2) Identify the overlap between these;
  3) Map the overlap into each piece;
  4) Define aggregates semantically (using category theory); and
  5) Push out, [Breiner and Subrahmanian]
- **Use design patterns** toward ontology virtualization: Given a set of ontology design patterns and their combination into micro-ontologies, one can abstract the underlying axiomatization by: dynamically reconfiguring patterns in a plug and play style; bridging between different patters as micro-theories; providing ontological views and semantic shortcuts that suit particular provide, user, and use case needs by highlighting or hiding certain aspects of the underlying ontological model; and mapping between major modeling styles [Janowicz]
- **Expand on techniques presented by Ray and Hodges.**

Verification and Validation (abstracted from various talks)

- Interconnect algorithms and hardware for two existing networks (example: a medical network and a transportation network that provides traffic data) with respect to algorithms and hardware
- Select an existing ontology to bridge the networks
- Create evaluation metrics based on strengths and weaknesses of the ontology bridge
- Test evaluation metrics by interconnecting two other networks and run the same questions/metrics. Expand metrics as needed

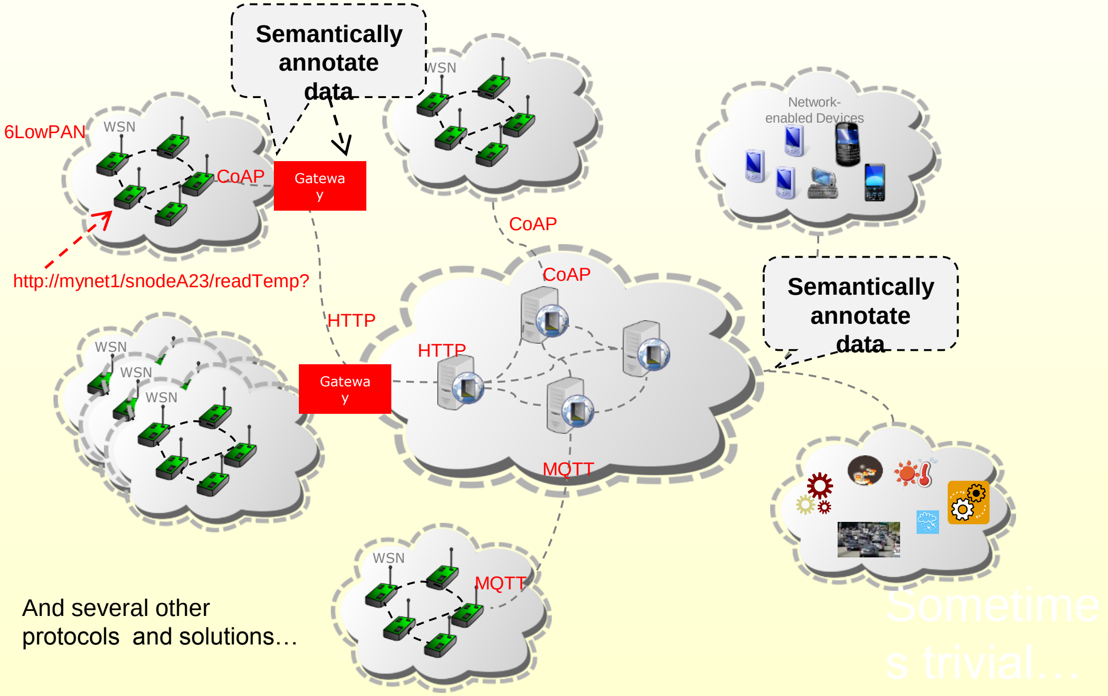
Some Process Insights (Barnaghi)

1. Design for large-scale and provide tools and APIs.
2. Think of who will use the semantics and how when you design your models.
3. Provide means to update and change the semantic annotations.
4. Create tools for validation and interoperability testing.
5. Create taxonomies and vocabularies.
6. Try to re-use existing ones as much as you can.
7. Link your data and descriptions to other existing resources.
8. Define rules and/or best practices for providing the values for each attribute.
9. Remember the widely used semantic descriptions on the Web are simple ones like FOAF.
10. Semantics are only one part of the solution and often not the end-product so the focus of the design should be on creating effective methods, tools and APIs to handle and process the semantics. Query methods, machine learning, reasoning and data analysis techniques and methods should be able to effectively use these semantics.

Backup

Some approaches for Integration and Interoperability (1)

- Simple approaches (e.g., Hyper/CAT, slides 14, 17, Payam Barnaghi) to Semantic approaches:

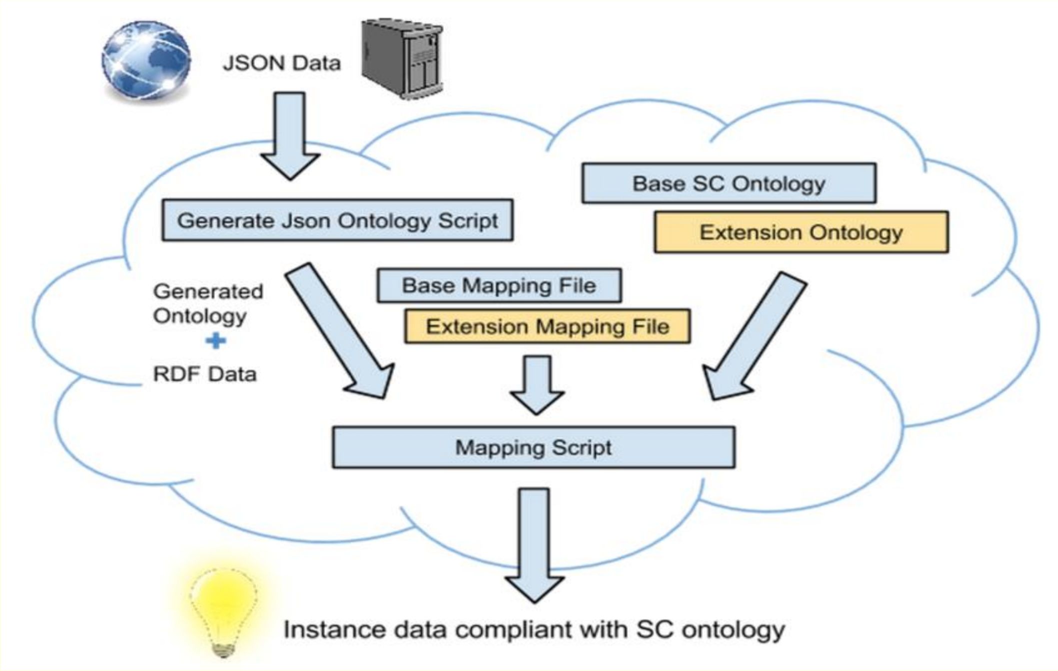


  - Servers provide catalogues of resources to clients.
  - A catalogue is an array of URIs.
  - Each resource in the catalogue is annotated with metadata (RDF-like triples).

Some approaches for Integration and Interoperability (2)

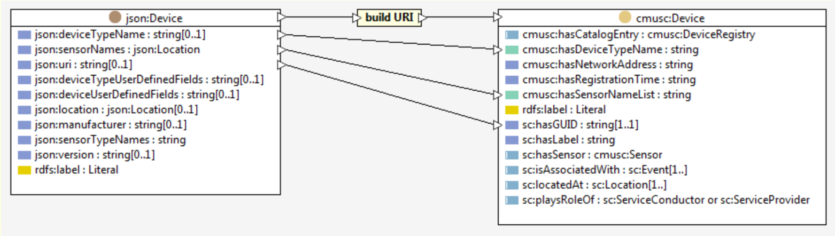
- Simple manual mapping to inference-based ontology mapping (see Steve Ray, slides 3, but 8-9)

High-Level System Design

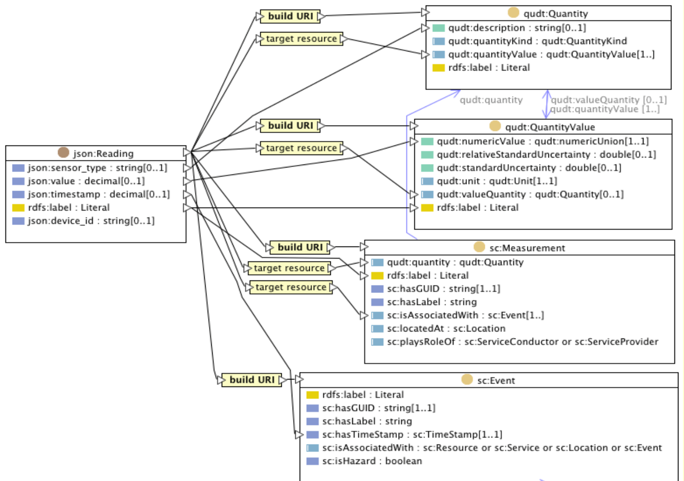


Manually Map JSON Entities to Target Ontology (the one manual step)

Sometimes trivial…



…sometimes more complex



Some approaches for Integration and Interoperability (3)

- Combine existing ontologies (Jack Hodges, slide 11):
  - Automatic ontology matching/mapping not attempted
    - No existing/proposed approach is 100%
    - For usefulness generated mappings would have to be checked manually by SMEs anyway
  - So, bridge ontologies and mappings (slides 13, 15):

DOID ←→ SYMP ←→ FMA bridge ontologies