Semantics for the IoT:

Early progress and back to the future

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Extending the Internet

- Smart homes, e-health, transport, ...
- Create situation awareness
  - Enable apps, machines, and users to understand environments
  - Understanding situations / contexts $\longrightarrow$ intelligent decisions

Challenges

- Diverse, volatile and ubiquitous
  - 90% of world’s data generated last 2 years (IBM)
  - How to process, integrate and interpret real world data?

- Knowledge hierarchy
  - Lower layer: Produced by IoT resources
  - Upper layer: Structured, machine-readable, enhanced interoperability
  - High-level abstraction → meanings and insights of the underlying data
  - IoT data must be structured, annotated, and shared

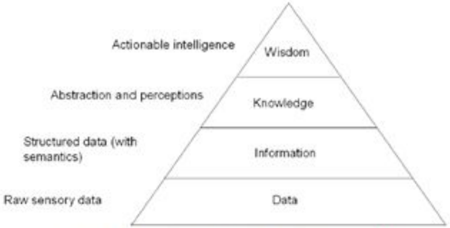

Figure 1. “Knowledge Hierarchy” in the context of IoT

Importance of semantics

- 25 billion by 2015
- 50 billion by 2020
  - 55 ZB data
- Semantics ⟶ increased interoperability ⟶ fundamental requirement
  - Object addressing, tracking, and discovery
  - Information representation, storage, and exchange
- Principal solutions in realizing IoT
  - Ontologies, semantic annotation, Linked Data, semantic Web services, ...

Interoperability

- Data from devices or humans
  - Attributes of phenomenon / entity from the physical world
  - Combinable to create abstractions of the environment
- Semantic interoperability ⟶ greater access to data
- I.e. annotation of data ⟶ machine-interpretable descriptions of data
  - Origin, provider, quality, …

Ontologies

- Common ontology → greater interoperability
  - Benefits users and shareholders alike
- Agreed-upon ontological definitions
  - Requirement for stakeholders to work together
- Global scale semantic interoperability is achievable through ...
  - Common semantic annotation frameworks
  - Ontology definitions
  - Adaptations

Semantic tech in IoT and semantic annotations

- Machine-readable & machine-interpretable metadata
  - Describes IoT resources and data
- Machine-interpretable data != machine-understandable data
  - RDF, OWL, SPARQL lacks the ability to process and interpret data

- Semantic descriptions and annotations
  - Devices, real-world objects and events, and services and business process models
- Supports the automated management and interaction of IoT systems

Semantic modeling and ontology development

- Ontologies in IoT
  - Descriptions of sensor and sensor networks, IoT resources and services, smart “Things”, etc
- W3C Semantic Sensor Networks Incubator Group
  - SSN Ontology - describes sensors and sensor network resources
    - High-level schemas for sensor devices, operation & management, observation & measurement data, …

Semantic descriptions in IoT domain ⟶ key to achieving autonomous and seamless integration of the IoT data in business applications and services

Linked sensor data pt. 1

- Semantic annotation lacks description of IoT data
- Resources need to be associated with each other
- Effective reasoning and processing mechanism for IoT data?
    - Access to domain knowledge
    - Relating semantically enriched descriptions to other entities
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Linked sensor data pt. 2

- Linked data relates different resources
- Adopted on the Web
- Four principles:
    - URI’s as names for things; unique URI’s for everything
    - HTTP URI’s to enable name-lookup, accessible through HTTP interfaces
    - RDF information related to URI’s looked up by machines or people
    - Linking the URI’s to other URI’s
- Linked Data in IoT?
    - Semantic data linked to other domain dependent resources
        - i.e. location information
    - SensorMasher

Data abstractions and knowledge extraction

- We need …
  - Effective querying, analysis, processing of the semantic data, and links between the resources
- Now: SPARQL
  - Data streams
  - Distributed over different networks with diverse types of data
  - Problem: Data is real-time, and data attributes can change over time
    - Dynamicity and agility
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Goals for the Internet of Things

- Dynamic and universal network
- Context-aware
- Intelligent decision-making algorithm

Reality?

- Not anytime soon
- We need …
    - Common frameworks
- Simply too much data
    - No available scalable methods

Dynamicity and complexity, security and privacy

- Dynamicity and complexity
    - Real world data
        - Environment changes, time and location dependent
    - Semantic technologies
        - Describe meaning behind data
        - Enables description of different attributes of resources and networks
            - Pervasiveness and volatility
        - Difficult to scale, high diversity, network/resource constraints, continuous changes, …
- Security and privacy
    - IoT data is often personal
        - Our environment, status of homes, personal health, …
        - Semantics can help by providing verification measures, requirements, …
        - We need reliable and efficient solutions