2016

Internet of Things to Smart IoT Through Semantic, Cognitive, and Perceptual Computing

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Publication Info

Postprint version. Published in *IEEE Intelligent Systems*, Volume 31, Issue 2, 2016, pages 108-112.

A. Sheth, "Internet of Things to Smart IoT Through Semantic, Cognitive, and Perceptual Computing," in IEEE Intelligent Systems, vol. 31, no. 2, pp. 108-112, Mar.-Apr. 2016, doi: 10.1109/MIS.2016.34.   Access online at: https://ieeexplore.ieee.org/document/7435181

IoT to Smart IoT powered by Semantic, Cognitive and Perceptual computing

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Anytime a technology enters a hype cycle, there are promises of massive growth and visions of immediate impact. But time and again it takes 10-15 years as the technology makes its way slowly through different stages of a hype cycle before it matures and we figure out the broad based market presence of the technology. In my own experience, the gap between the time from when I worked on federated databases, distributed workflow management, and a semantic search engine to the time a credible and mature product or service came took 12-15 years—the example semantic search is discussed at http://j.mp/15yrsSS.

One may argue, however, that the Internet of Things (IoT) is seeing a much more rapid adoption. Depending on estimates we believe, there were 5 to 9 billion connected devices with a market size around 700 billion in 2015. With the estimates of over 25 to 50 billion IoTs deployed and 17 to 32% annual growth, IoT could be over a trillion dollar market before this decade is over (see: http://j.mp/ForbesIoT and http://j.mp/IronIoT).

From a scientific and technological viewpoint, the more important number is related to the amount of data IoT already generates. In 2008, social (or Web 2.0) data overtook all other types of data on internet, and sometime in recent past, IoT data became the largest type of data on the internet. It is estimated that they are already generating 2.5 quintillion bytes of new data daily (http://j.mp/IBMCIoT). Now, put this in the context that around 2008, we generated more data than it was possible to store, and around the turn of the last decade, less than 1% of all data was being analyzed. This means that the data that is not analyzed in real-time or soon after it was generated, is never looked at. In this context, we will look at the needs to progress along the DIKW (data, information, knowledge, wisdom) path to support more intelligent processing of IoT data.

Targeted and limited use of IoT Data: the current state of affair

Much of the current use of IoT is point-to-point, for expected, targeted or predetermined use of data. This is the case with most of the use cases where IoT deployments are finding extensive applications (http://j.mp/M2MIoT): energy control and HVAC maintenance in commercial buildings, maintenance and field service, manufacturing, transportation logistics, insurance telematics, and in-store contextual marketing are currently the leaders in IoT deployments. Here, the types of sensors utilized in the given applications are of limited types and the use of data they supply is well defined and targeted (http://j.mp/20IoTApp).

Integrated and knowledge-enhanced analytics of IoT Data: a medium term scenario

The next state of the evolution of IoT data will involve integration of a wider variety of IoT data with more advanced analytics of the data. Example applications that are likely to deploy such use of IoT data include smart buildings and connected vehicles. IoT data has found its use in fleet health monitoring of aircrafts and to maximize the operational efficiency (http://onforb.es/1OxqJuF). Achieving efficiency required the knowledge of the process (e.g., scheduling, demand, pricing, logistics) and access to near real-time data facilitated through IoT.

Physical, Cyber, Social (PCS) Data: IoT as component for nextgen applications

Some of the more advanced applications in consumers, smart city, and healthcare (including personalized digital health), require broader variety of (i.e., multimodal) sensors for collecting data of interest. Furthermore, the IoT data will be complemented by social data and data on the Web (Cyber), such as event information, collective intelligence (e.g., Wikipedia), a broad variety of open data, and curated knowledge (in the form of taxonomies, knowledge graphs, or ontologies).

With such a progress in IoT applications, we will face all the classic big data challenges in more extreme forms—increasing volume, broader variety and increasing complexity, rapid changes (velocity), and more veracity challenges encompassing trust, security and privacy. This would then imply a need to move from raw data processing to more intelligent processing of data. Applications would simply not be able to deal with data, we will have to work hard at sifting data to identify higher quality data, what data is more relevant and why (context and personalization), and look at the data through layers of abstractions. The real opportunity as well as challenge related to IoT is not with the devices and wearable, nor the networking and infrastructure, and not even collecting and storing the data—it is, instead, in making sense of the data. Let's explore.

IoT Big Data to Smart IoT

The advancement of IoT usage will likely be along the following dimensions:

- from single modality or of a few types of sensors to a broad variety of multimodal sensors as well as physical-cyber-social data
- from simple, pre-defined and expected events, with even specific solutions to unexpected events and situations not defined or planned for a priori, further on to event agnostic solutions
- from monitoring and data analysis to predictive and intelligent processing, shifting from rules-based maintenance to more prediction driven intervention
- from aggregating IoT data on cloud for intelligent processing to help make decisions and take actions, divest or downscaling computation to the edge of the network, gateways and devices (a.k.a. intelligence at the edge [HTS12, PCS]).

An IoT ecosystem that supports making sense of all the IoT big data is what we call smart IoT (see an exposition of the term in [S15], *Video*). A smart IoT enables intelligent applications that enable good and timely decision making and actions. What does this mean? Here is a rough analogy: "The human body sends 11 million bits per second to the brain for processing, yet the conscious mind seems to be able to process only 50 bits per second." (http://j.mp/Brain101), of the 400 billion bits of information per second that reach the brain, we are aware of only 2,000 bits [D2007] (possibly for situational awareness or conscious decision making). Whether or not the level of information compression can be very accurately measured (as estimated), intelligent processing implies converting a massive amount of raw data into something contextually relevant or meaningful for situational awareness, decision making or taking actions. Let us explain this with an example shown in Figure 1. The lowest level shows "150" which is a blood pressure reading (sensor/device data). The next level shows labeled (semantically annotated) data or information. The third level represents knowledge that is based on the latest NIH guidance used by clinicians, this information represents a medical condition of "elevated blood pressure". And yet this knowledge is not actionable—the clinician needs to decide whether this is due to hyperthyroidism or hypertension, which is needed before a proper medication can be prescribed.

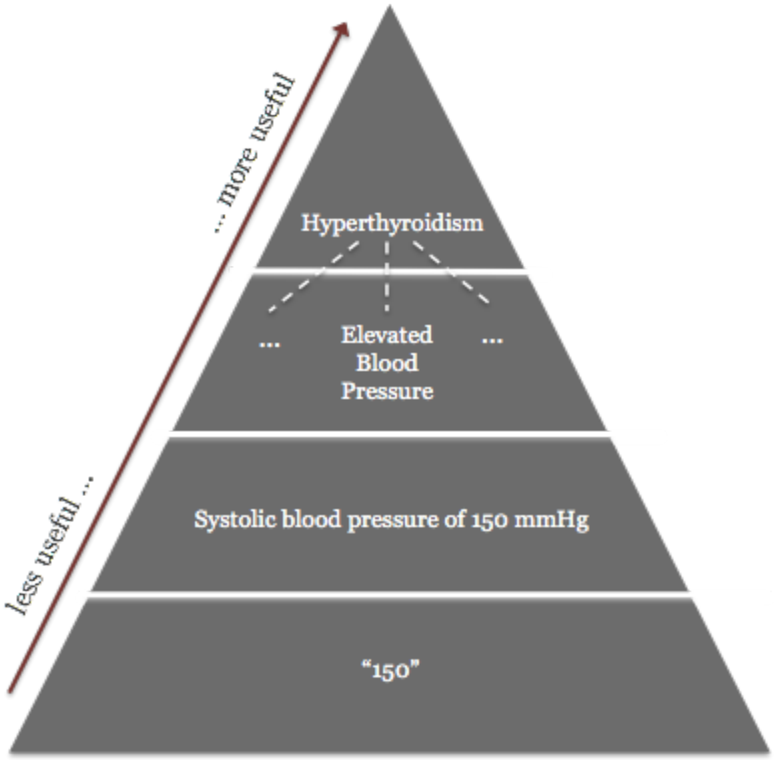

Figure 1. From Data to Decisions and Actions, climbing the DIKW ladder.

Making sense of physical (including IoT), cyber and social big data will involve an intertwined trio or a braid of three computing paradigms. We take a pedagogic view for conceptual clarity- for example, what we characterize as a feature of cognitive computing based on the our interpresentation of contemporary dominant view might have been considered to be aspects of semantic computing in some literature. If these three forms of computing are seen as key to intelligent computing, then the distinction of one form to another at their respective interactions are going to be somewhat arbitrary.

Acquisition and processing of IoT data offers various challenges such as (a) heterogeneity: multiple sensors, devices, textual reports, (b) incompleteness: sensors may fail or there may be a partial coverage due to factors such as communication or network limitations resulting in incomplete data, (c) uncertainty: veracity is a major issue in a distributed setting like IoT, and (d) dynamism (or velocity): observations arrive continuously reflecting changes in the physical world. Addressing these challenges is crucial for a deeper understanding of the physical world with numerous applications including manufacturing, healthcare, sustainability, public safety, and mobility. Next we will describe the role of semantic, cognitive, and perceptual computing in dealing with these IoT challenges and define the notion of Smart IoT.

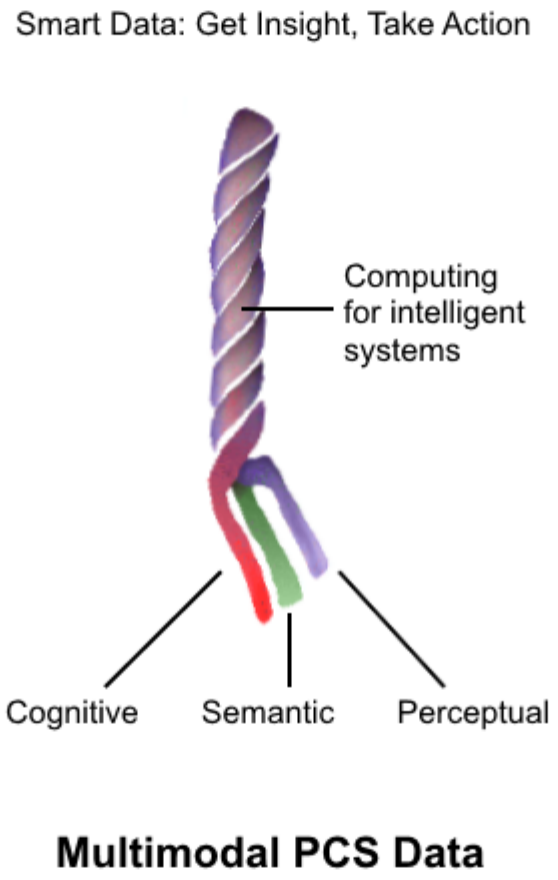

Figure 2. Semantic, Cognitive and Perceptual Computing: converting PCS big data into smart data

Role of Semantic Computing

Semantics is about associating meaning with data. It allows us to deal with data so that we can interpret data in context, in spite of differences in syntax and representation or structure. Semantic computing encompasses technologies for representing concepts and their relations that loosely mimics the interrelation of concepts in the human mind. This conceptual knowledge, represented formally in an ontology or as part of a structured knowledge base, increasingly identified as a knowledge graph, can be used to annotate data and infer new knowledge from interpreted data. Additionally, semantic computing plays a crucial role in supporting interoperability at various levels of system architecture and in sensor/IoT data fusion that includes integrating multisensory and multimodal observations from diverse sources. Semantic computing deals with the heterogeneity challenge of IoT and further enhance interpretation of IoT data.

Some near-term challenges that semantic computing can address can support interoperability at the device, networking, and data exchange levels. These issues can be addressed based on our experiences with similar challenges from the past. For example, Samsung and Google’s collaborat---ion on a low-power wireless network called Thread uses Bluetooth Smart to connect one device to another. Samsung, Dell, and Intel’s effort on the Open Interconnect Consortium is working to connect any device with one another, regardless of the operating system, connection provider, or form factor.

To make data meaningful, semantic techniques are needed at various levels in a system architecture. On a lower level, one effort called Semantic Gateway as Service (SGS) [DSA15] allows for the translation between a variety of IoT messaging protocols in current use, such as XMPP, CoAP and MQTT. At a somewhat higher level, an important interoperability standard is provided by W3C's Semantic Sensor Network [C+12] (SSN) ontology and annotation framework, pioneered in the SemSOS semantic sensor service conceived in the semantic sensor web framework (http://knoesis.org/projects/ssw). It is useful to describe any sensor/device and its data in a standard form and support semantic annotations of sensor data, making that data more meaningful. In essence, this provides semantic interoperability between messages carrying IoT data. W3C has paired up with the Open Geospatial Consortium to make an international standard on Spatial Data on the Web with SSN as the primary input, whose outcomes will further aid semantic computing.

Role of Cognitive Computing

In 2002, DARPA, defined cognitive computing as “reason[ing], [the] use [of] represented knowledge, learn[ing] from experience, accumulat[ing] knowledge, explain[ing] itself, accept[ing] direction, be[ing] aware of its own behavior and capabilities as well as respond[ing] in a robust manner to surprises.” Cognitive algorithms interpret data by learning and matching patterns in a way that loosely mimics the process of cognition in the human mind. Cognitive systems learn from their experiences and then get better when performing repeated tasks. Through data mining, pattern recognition, and natural language processing, cognitive computing is rapidly progressing towards developing technology to support our ability to answer complex questions. Cognitive computing acts as prosthetics for human cognition by analyzing a massive amount of data and being able to answer questions humans may have when making certain decisions.

With the success of IBM Watson in defeating human champions on Jeopardy! in 2011, IBM has used the term cognitive computing for a system that can ingest multimodal data, understand natural language, generate and evaluate hypothesis, and learn through interactions with humans. With IoT being pervasive across various domains and its potential to deliver value to businesses, cognitive IoT extends the idea of cognitive computing to IoT. Cognitive IoT (http://j.mp/IBMCIoT) aspires to add additional ‘senses’ comprised of various sensors, devices, and unstructured data on the IoT to IBM Watson to facilitate leveraging value from IoT data. Cognitive IoT is explored by scenarios in fitness and well-being IBM and its partners.

While semantic computing addresses interoperability and integration aspects of heterogeneity, cognitive computing can address complementary aspects , such as hypothesizing correlations and validating them through evidence. Combining multiple data sources may support dealing with *incompleteness*. The degree of confidence the cognitive computing system has in its observations quantifies *uncertainty*. The *dynamism* challenge of IoT is not addressed explicitly by the cognitive computing system. Specifically, with IoT, the changes in the physical world reflect in the observations being collected from the physical world. Understanding the current state of the world, a.k.a situational awareness, plays a crucial role in deriving value from data. Some, including IBM, consider natural language based interaction with IoT data as a key feature of CIoT.

Role of Perceptual Computing

Socrates taught that knowledge is attained through the careful and deliberate process of asking and answering questions. Through data mining, pattern recognition, and natural language processing, cognitive computing is rapidly progressing towards developing technology to support our ability to answer complex questions. In our view, perceptual computing provides an important complementary capability for deriving intelligence from data by providing a technology to support our ability to ask *contextually* relevant and *personalized* questions . Making sense of observations from the physical world is formulated as an iterative abductive-deductive reasoning process [HST12], focusing and explaining based on the observed data, is also critical in ascending the abstraction levels such as the one shown in Figure 1.

Context is better captured through continuous observations from sensors around us. For example, our mobile phones have an accelerometer, microphone, temperature, and location sensors providing contextual information. Personalization deals with learning preferences and choices by people while interacting with the physical world. Utilizing contextualization and personalization for asking the right questions in various scenarios is an important aspect of perceptual computing.

The dynamism challenge of IoT is addressed by contextual and personalized exploration of the physical world by a perceptual computing system. Understanding contextual information is mostly bottom-up process. Based on the contextual understanding, applying personalized recommendation is mostly top-down. This interleaving top-down and bottom-up processing complements cognitive IoT systems.

A personalized digital medicine example of SmartIoT that is empowered by complementary capabilities of semantic, cognitive, and perceptual computing is exemplified with the use case of asthma in children in [SAH16].

Acknowledgements: This article has benefited from brainstorming with my PhD students Pramod Anantharam and Cory Henson, and captures some of the broad themes that are carried out by them in further depth in their papers and dissertations.

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