The Web of Things

Enabling exponential growth of IoT services

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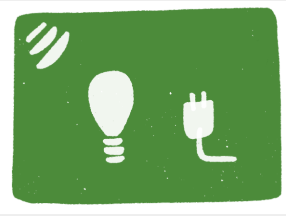
Sao Paulo, 13th October 2016

Massive Potential for the Internet of Things

Smart Homes

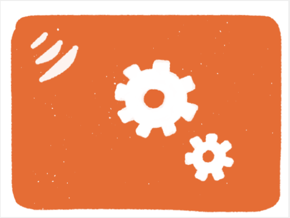
Wearables

Healthcare



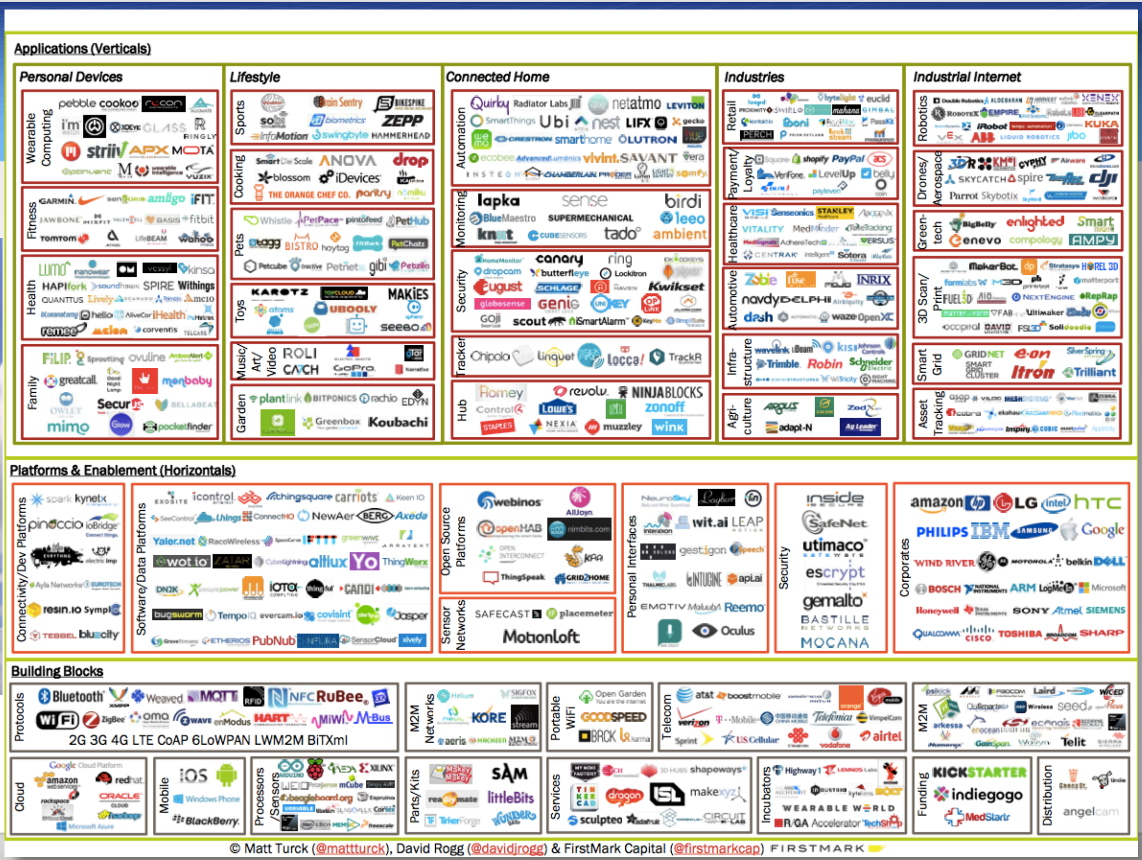
Power & Environment

Smart Cities



Manufacturing

IoT Landscape



A Rapidly Evolving Suite of Protocols and Technologies

- **Internet Protocols**
  - HTTP
    - Client requests, server responds
  - WebSockets
    - Asynchronous bidirectional messaging
  - Pub-Sub protocols
    - MQTT
    - XMPP
    - AMQP
  - Peer to peer
    - WebRTC

- **IoT Communication technologies**
  - LPWAN
  - WiFi
  - Bluetooth
  - ZigBee
  - KNX
  - EnOcean
  - Body Area Networks
  - NFC and RFID
  - *Barcodes*

This is just a sampling of available technologies

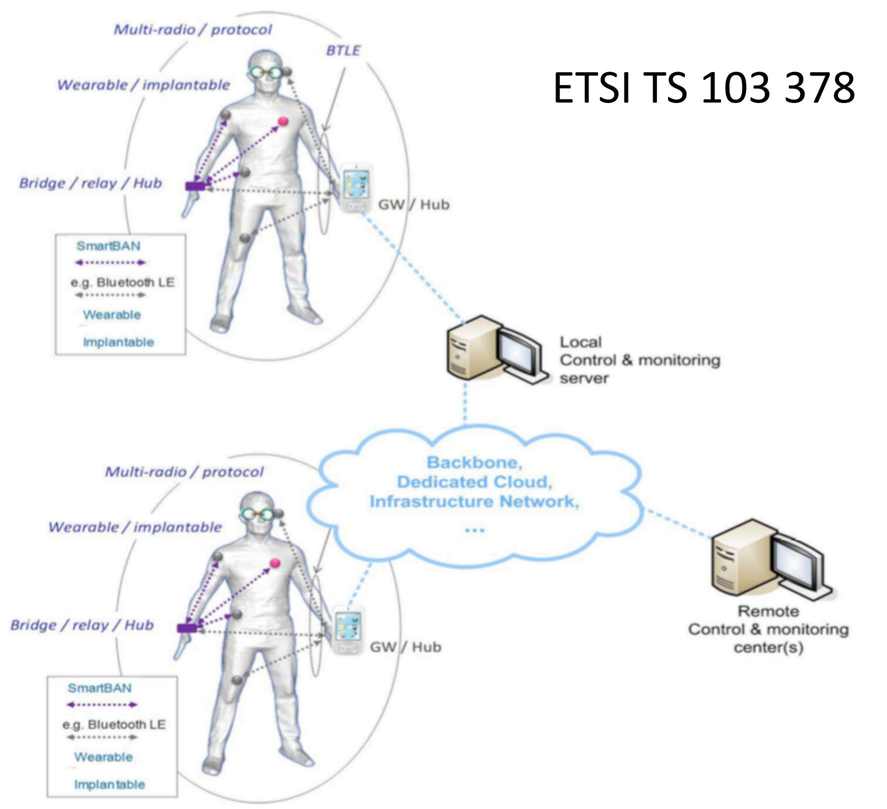
Communication Patterns

- Huge variation in requirements across application domains necessitate use of different communication patterns
  - Real-time requirements on the factory floor
  - Data streams versus the occasional update
  - In some cases, losing the odd reading doesn't matter
  - In other cases it is critical to store all sensor readings
  - It is sometimes necessary to buffer and send blocks of readings to save power or improve network usage
  - For devices that are ambient powered or which need to run for years on the same battery, it is essential for the devices to spend most of the time asleep
  - Push vs Pull vs Pub-Sub vs Peer to Peer

Body Area Networks

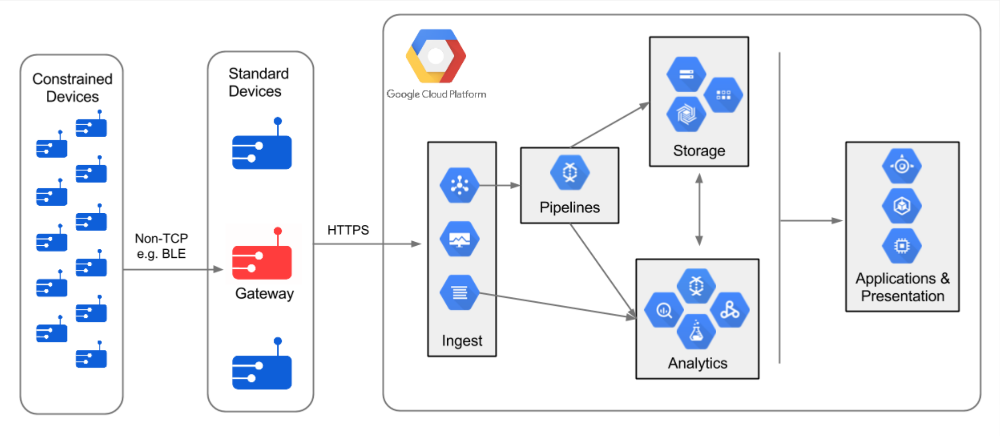
- Devices you wear or are part of your clothes, shoes, or even inside your body
- Applications to healthcare, fitness, and even tracking criminals released into the community
  - Smart healthcare – improving outcomes and reducing costs, especially with the elderly
- ETSI work on Smart Body Area Networks
- Need for unified data representations, semantic and open data models

ETSI TS 103 378



Sensor Data Streams and the Cloud

- Device – Gateway – Cloud
  - IoT devices with local connectivity
  - Gateways that stream sensor data to the cloud
  - Powerful scalable cloud based platforms
- Opportunities for services across many application domains
- Big data, stream analytics and advanced AI
  - Machine learning and personalised services
- Need for open standards to create open markets of services that span cloud platforms operated by different vendors



Google's Cloud Platform for the IoT

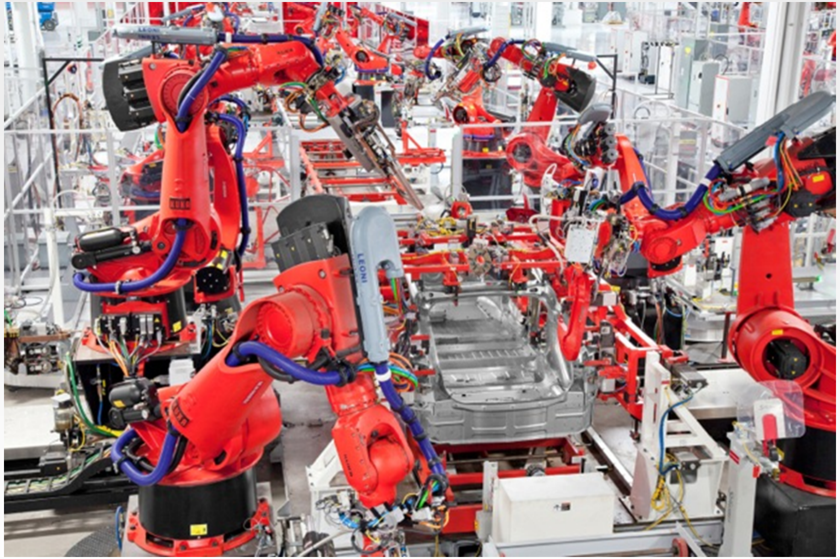
Hubs as Platforms for Smart Home Apps

- Web standards can create opportunities for vendor neutral platforms for a market of apps for installation on your home hub
- Your smart phone provides the human machine interface for these apps
- Improved sense of privacy compared with having your personal data being sent to the cloud
- Apps based upon your social connections
  - Peer to peer with your friend's home hubs

Samsung's Smart Things

Smart Manufacturing

- Greater flexibility to address the trend to highly personalised products
- Reacting faster to changing market conditions
- Vertical integration from production cells to the board room
- Horizontal integration across both the supply chain and the value chain within a business



Robots manufacturing Tesla's electric cars

Cyber-Physical Systems

- Network of interacting elements with physical input and output
  - Seamless integration of computational algorithms and physical components
  - Expressing control at different levels of abstraction and distributed across a network of devices
- Examples
  - Wireless sensor networks that collectively relay processed information to the cloud
  - Automotive systems including engine management, and self-driving cars
  - City wide control over traffic lights
  - Smart grids that signal devices to reduce demand during peak periods, as well as storing and releasing energy held in smart homes, e.g. in electric car batteries, and dedicated storage devices
  - Smart medical systems, e.g. for insulin delivery for diabetics
  - Process control and smart manufacturing

Levels of Abstraction	Level Attributes
Configuration	• Self configure for resilience • Self adjust for variation • Self optimise for disturbance
Cognition	• Integrated simulation and synthesis • Remote visualisation • Collaborative diagnostics and decision making
Cyber	• Digital avatars for devices and components • Time machine for variation identification and memory • Clustering for similarity in data mining
From Data to Information	• Smart analytics for device health, with multi-dimensional data correlation • Degradation and performance prediction
Smart Connection	• Plug & play • Tether-free communication • Sensor network

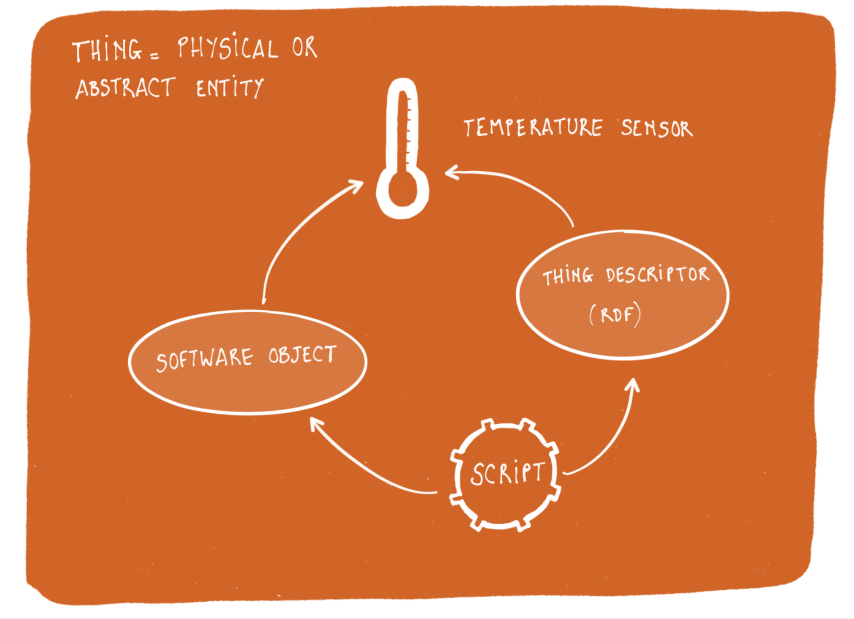
With thanks to IMS Center for Cyber-Physical Systems in Manufacturing

Overcoming Fragmentation

Analogy with the introduction of the Internet

- Before the Internet, there were many non-interoperable network technologies
- The Internet introduced an abstraction layer across network technologies
  - Enabled end to end messaging, stimulating exponential growth in services
- Direct analogy with today's IoT silos and their lack of interoperability
  - The IoT is still immature and very fragmented
- We need an abstraction layer for the IoT to counter fragmentation and bridge the silos

Web of Things – abstraction layer above the IoT



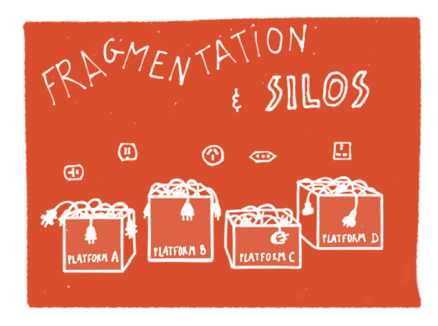
Applications act on software objects that stand for things

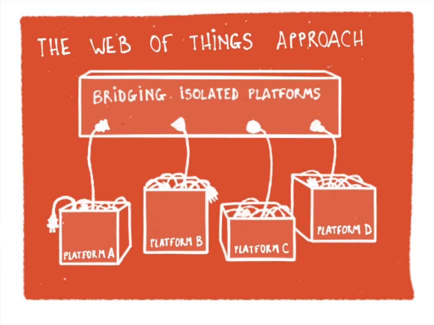
- Digital avatars on behalf of physical or abstract entities
- Things with properties, actions and events
- Local and remote "things"

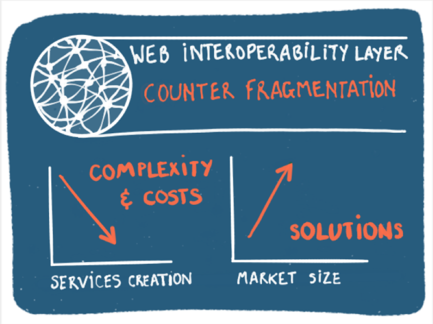
Rich descriptions for every "thing"

- Each thing has a URI for its name
- This provides access to its description
- Ontologies that describe "things" and their relationships
- Using W3C's Linked Data framework

Web of Things – enabling interoperability across platforms



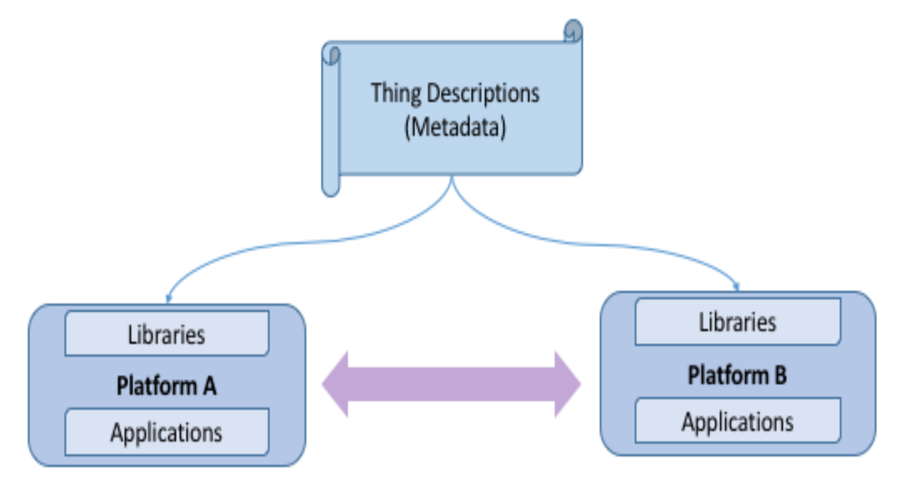




The Web will enable exponential growth for open markets of services

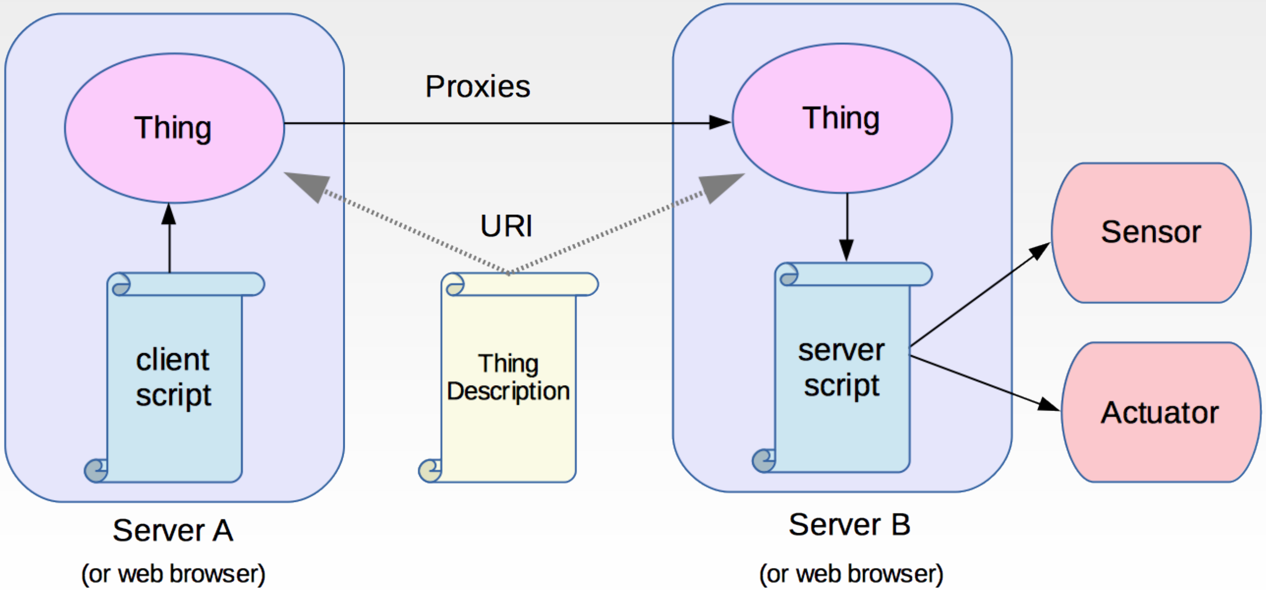
The Web of Things – countering fragmentation with standardised metadata and APIs

- **Simplifying application development by decoupling the underlying protocols**
  - Essential for scaling across the huge range of requirements across application domains
- **Enabling interoperability across different platforms with standardised metadata**
  - Describing the interfaces exposed to applications
  - Describing the communication and security requirements for accessing things
  - Describing the semantic models and domain constraints



Distributed Web of Things

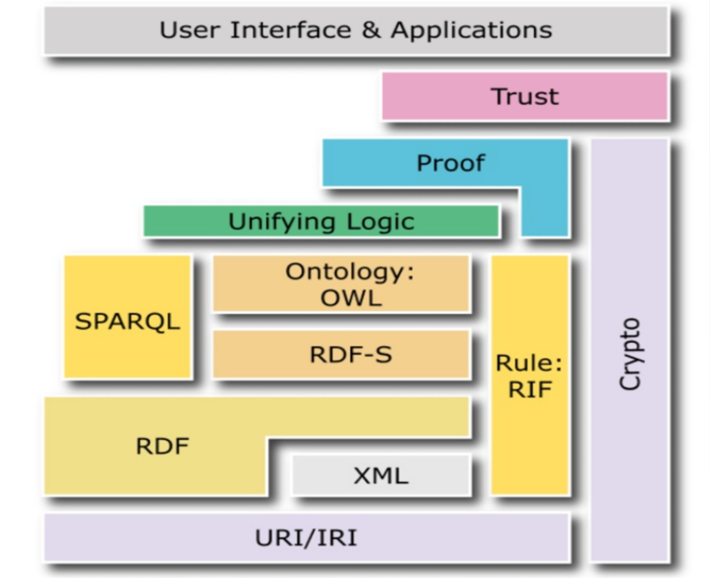
- Thing descriptions can be used to create proxies for a thing, allowing scripts to interact with a local proxy for a remote entity
- Scripts can run on servers or as part of Web pages in Web browser for human machine interface
- Thing topologies
  - Peer to Peer, Peer to Peer via Cloud, Star, Device to Cloud, Star to Cloud
  - Proxy chains from the edge through the cloud to the browser



Linked Data and Semantic Models

Essential for enabling web scale open markets of services

- Semantic Descriptions ensure that platforms share the same meaning for the data they exchange
- Discovery based upon properties and relationships
  - Search engines that can index the Web of Things
- For verifying that a thing is consistent with given models
- For designing service compositions based upon the knowledge of which services are compatible



RDF = semantic network with nodes connected by labelled arcs

W3C has a rich suite of related standards

Communications Stack – Clean separation of concerns

Application Developer (WoT focus)	**Application**	Scripts that define thing behaviour in terms of their properties, actions and events, using APIs for control of sensor and actuator hardware
	Things	Software objects that hold their state Abstract thing to thing messages Semantics and Metadata, Data models and Data
Platform Developer (IoT focus)	**Transfer**	Bindings of abstract messages to mechanisms provided by each protocol, including choice of communication pattern, e.g. pull, push, pub-sub, peer to peer, etc.
	Transport	REST based protocols, e.g. HTTP, CoAP Pub-Sub protocols, e.g. MQTT, XMPP Others, including non IP transports, e.g. Bluetooth
	Network	Underlying communication technology with support for exchange of simple messages (packets) Many technologies designed for different requirements

W3C Web of Things Activity

World Wide Web Consortium

Mission: lead the Web to its full potential

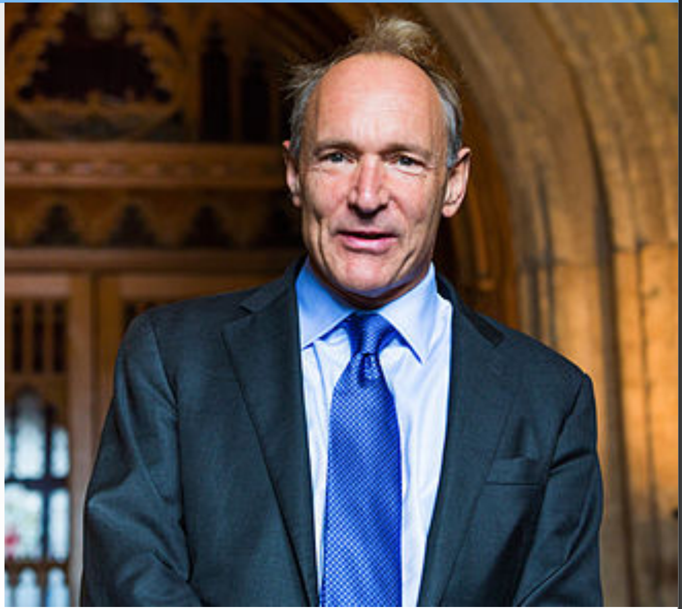
- The Web is the world's largest vendor-neutral distributed application platform

Founded by Sir Tim Berners-Lee, inventor of the Web

- 400+ Members
- Member-funded international organisation

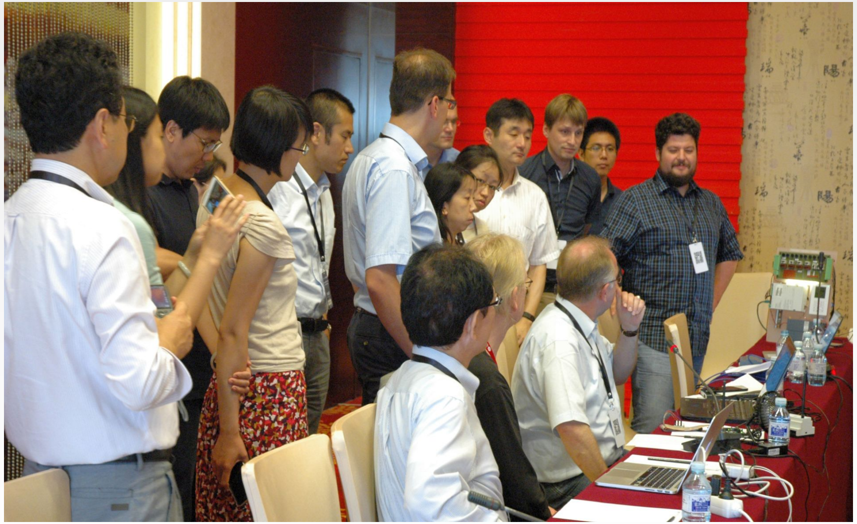
Develops standards for Web and semantic technologies

- HTML, CSS, scripting APIs, XML, SVG, VoiceXML, Semantic Web and Linked Data etc.
- Developer oriented, enabling cooperation between organisations with very different backgrounds
- W3C patent policy for royalty free standards
- W3C staff of engineers actively participating in standardisation
- Increasingly involved in verticals: Mobile, TV, Automotive, Digital publishing



W3C Web of Things Activity

- W3C is chartering a Web of Things Working Group to develop initial standards
  - Charter currently under review by W3C Members
- W3C Web of Things Interest Group
  - Interoperability tests across platforms using open source implementations
  - Further work on semantics, security and privacy
- Plans for an IoT on the Web Business Group
  - Focus on business level requirements across domains
  - Building a shared understanding through collaboration with external groups including Hypercat and BSI

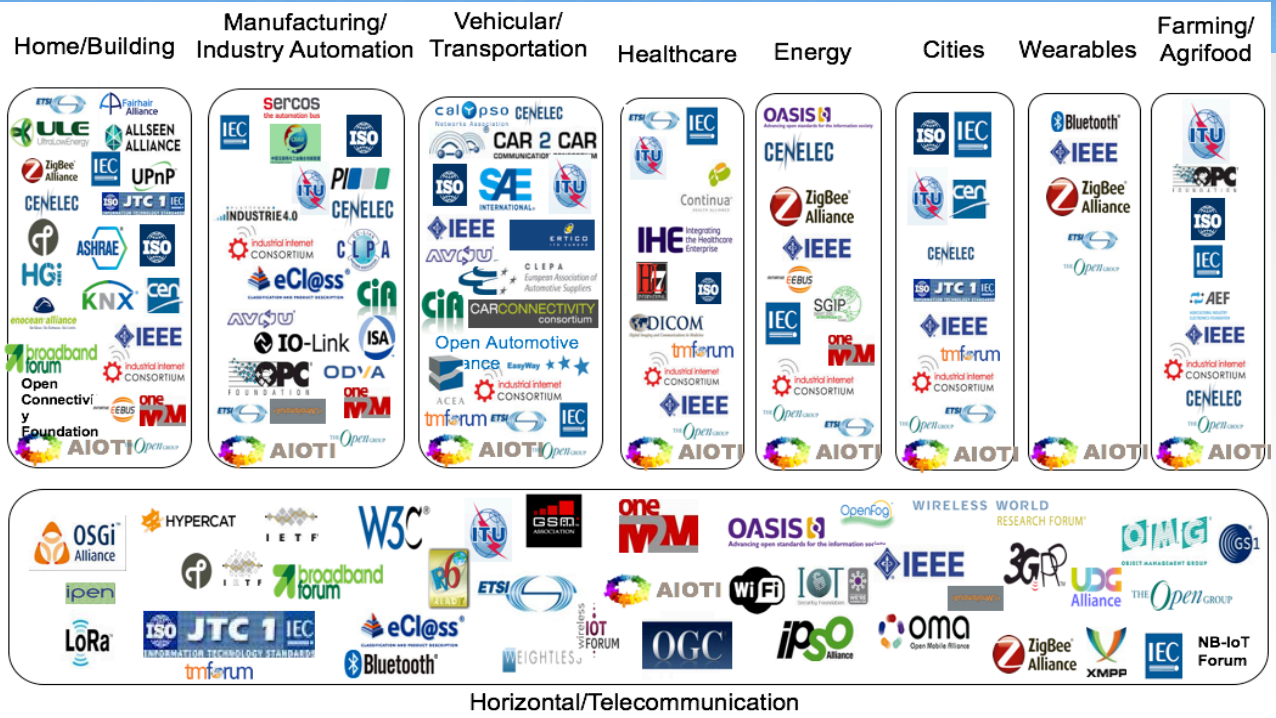


Web of Things Plugfest, Beijing 2016

Members of the Web of Things Interest Group

The Need for Coordination

IoT Alliances and Standards Development Organisations



Source: AIOTI IoT Standardisation report release 2.6

Liaisons and Collaborations

Reaching out to industry alliances and SDO's to drive convergence to unleash the potential, e.g.

- Plattform Industrie 4.0
  - Especially the "semantics" subgroup
- Proposed German Smart Home Initiative
- Industrial Internet Consortium
- Open Connectivity Foundation
- OPC Foundation
- IETF/IRTF
- IoT-SF
- BSI & Hypercat
- oneM2M
- GSMA
- AIOTI

Agile Processes for Standardisation

- Today, several IoT alliances and standards development organisations are working on models as descriptions of devices and services
- Organisations are working on this in isolation with risk of fragmentation
- Joint white paper on semantic interoperability to counter this
  - Building a shared understanding of the role of semantic interoperability
  - See http://dx.doi.org/10.13140/RG.2.2.25758.13122
- Discussion underway on next steps to keep the momentum flowing
- We need agile processes for vocabulary development that meets the timescales and business realities facing SMEs
  - Experimental, early commercial use, widespread use
  - Encouraging re-use where practical

IoT Security Should Worry Us All

- Breaches of privacy
- Cybercrime
- Physical safety in the home, across the city and within businesses
- Threats to national infrastructure
- Looming risks of cyberwar

Need for joint work on best practices and technical standards

- Plan for joint white paper on end to end security, trust and privacy

The Challenges for IoT and Big Data

- Lots of sensors will generate a vast amount of data
  - API Research estimated 200 exabytes in 2014 and 1.6 zettabytes in 2020
  - 90% is currently processed locally, although this varies by domain
- This creates a greater volume of sensitive data, increasing the risk of
  - Data and identity theft,
  - Device manipulation,
  - Data falsification
  - IP theft, server/network manipulation, etc.
- Impact of introduction of data consolidation and analytics at network edge
  - Cisco, HPE and others
  - App platforms in the cloud or at the network edge will be targets for attacks

Security, Trust, Safety, and Resilience

- Strong security relies on understanding and adherence to best practices
- Trust prior agreements and attestation by trusted third parties
- Bootstrapping trust and security, and ways this can unravel
- Mutual authentication of communicating parties
- Authorisation – determining who can do what
  - ACLs, Rules and Capabilities
- Ensuring that IoT systems are safe to use even when things go wrong
- Resilience – maintaining control in the presence of faults and attacks
  - Defense in depth, monitoring, machine learning, policies

Privacy and the Internet of Things

- The IoT has the potential to gather huge and unprecedented amounts of personal information
  - This information may last indefinitely
  - Risk of abuse by individuals, criminals, companies and governments
  - Sense of intrusion into your personal space
  - Fear of harm due to disclosure of personal information
- Strongly identifying information
  - Your address, data of birth, sexual orientation, …
  - Principle of data minimisation – high cost to companies for handling personal data securely
  - Privacy policies determining what purposes data can be used for, and for how long
- Weakly identifying information
  - When sufficient such data is combined this can uniquely characterise you
  - Companies need to provide privacy policies on how they handle such data
- Need for adhering to best practices to avoid reputational damage to companies
  - Including regulatory requirements

Building the Communities

Open Source, Maker movements, Digital Accelerators

Web of Things for the Maker Community

Open source projects are underway, e.g. for the Arduino and more powerful MCUs

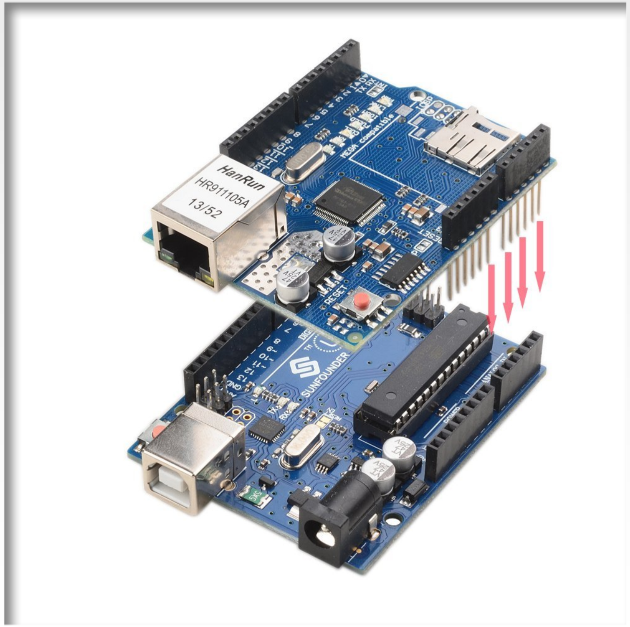
Arduino Ethernet Shield

- 16 KB RAM
- MicroSD card slot
- Controlled through SPI bus
- Polling or H/W interrupt
- Cost: 4.75 GBP on eBay

Arduino Uno with ATmega328P MCU

- 2 KB RAM
- 1 KB EEPROM
- 32 KB FLASH
- Lots of I/O pins
- Cost: 2.33 GBP on eBay

https://github.com/w3c/wot-arduino



Web of Things for the Maker Community

- Microduino m-cookies
- Arduino compatible with none of the wiring hassles
- Family of small boards
- Boards snap together magnetically
- Can be combined with Lego
- See https://www.microduino.cc

Web of Things for the Maker Community

- Web of Things Gateway
- Based upon NodeJS (i.e. JavaScript)
- Support for multiple protocols
- Runs on relatively powerful devices, e.g. Raspberry Pi
- Further work planned on installable apps
  - Install apps onto SD card
- More details at
  - https://github.com/w3c/web-of-things-framework

Wrapping Up

The Bottom Line

The Web is essential for realizing the full potential of the IoT

The Web provides a unifying framework for semantic interoperability

The Web acts as a global marketplace for suppliers and consumers of services

Work with us to build the Web of Things!

For more information on W3C see:

www.w3.org