The Web of Things
Bridging the IoT Silos
Interoperability across IoT platforms

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The Internet of Things – Bridging the Silos

Still very immature, but with massive potential

Lack of interoperability at the application level

Many platforms and associated standards

- Addressing broad range of different requirements
- End to end security challenging across platforms

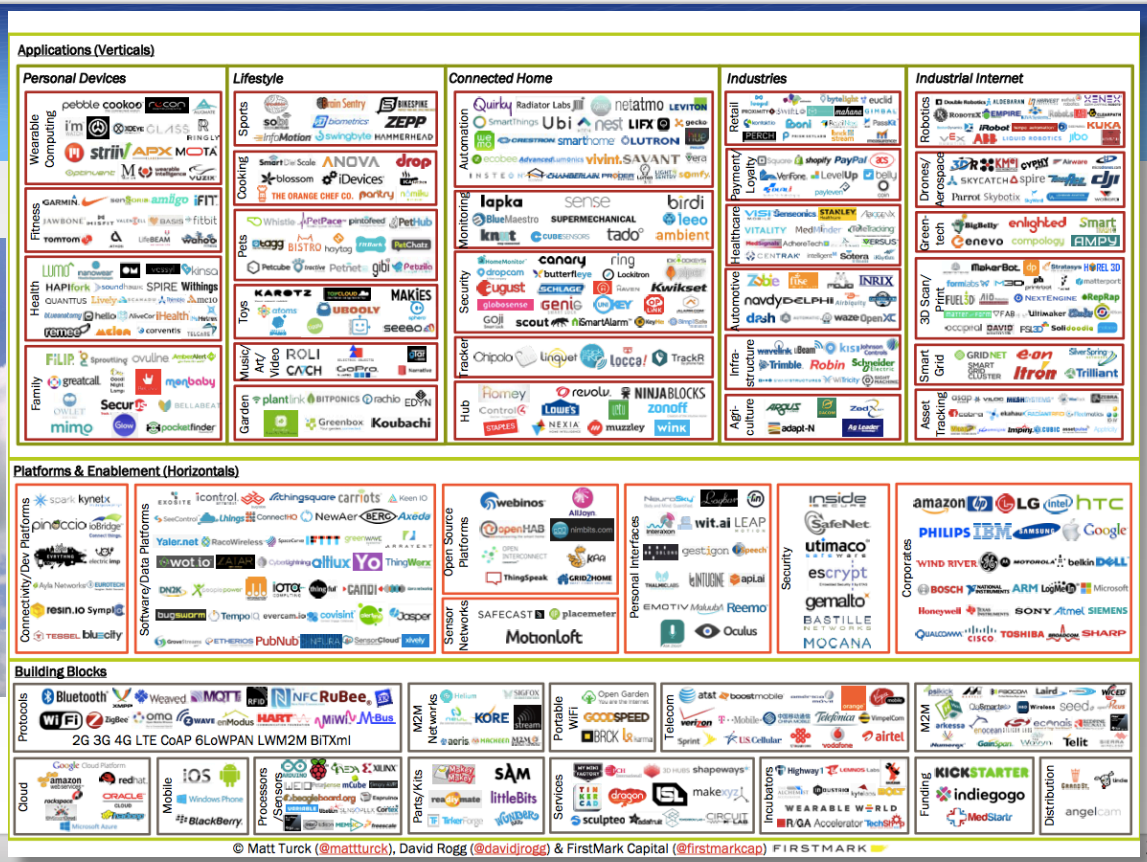
Fragmentation and Silos are holding back the potential

Open or closed system?

- Closed systems incentive: control
- Open systems prompt: reduced costs and increased market size

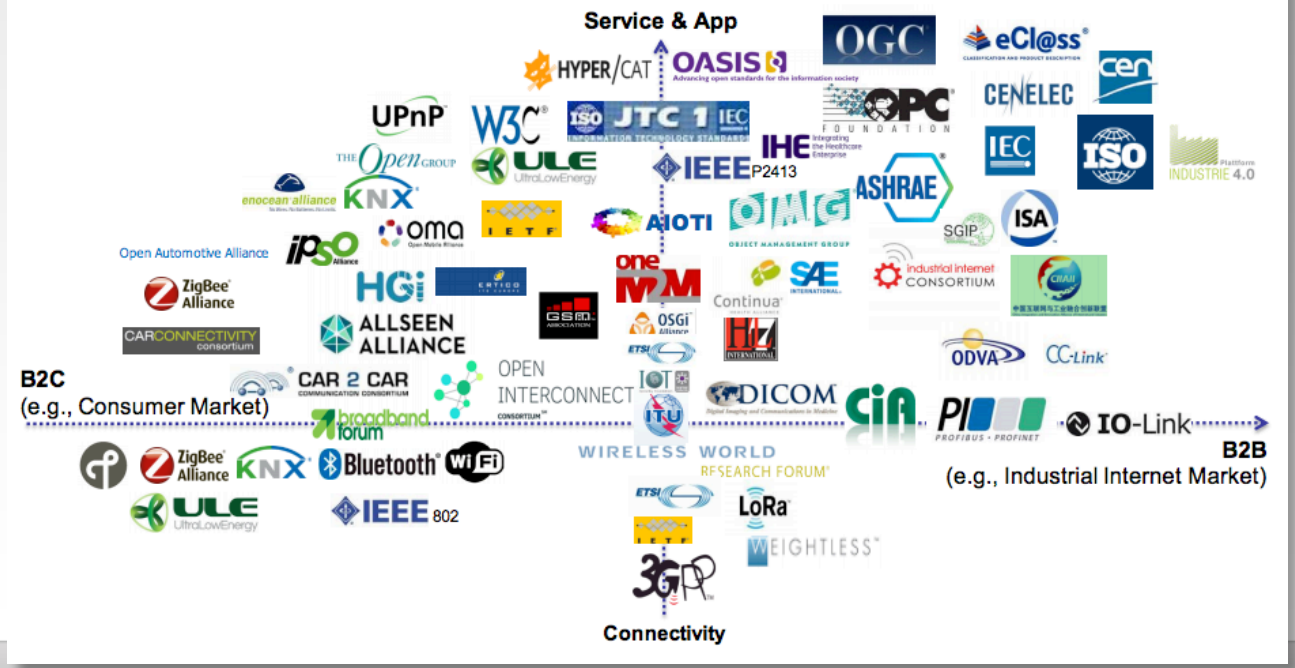
- Need for wide adoption of shared open standards

IoT Landscape

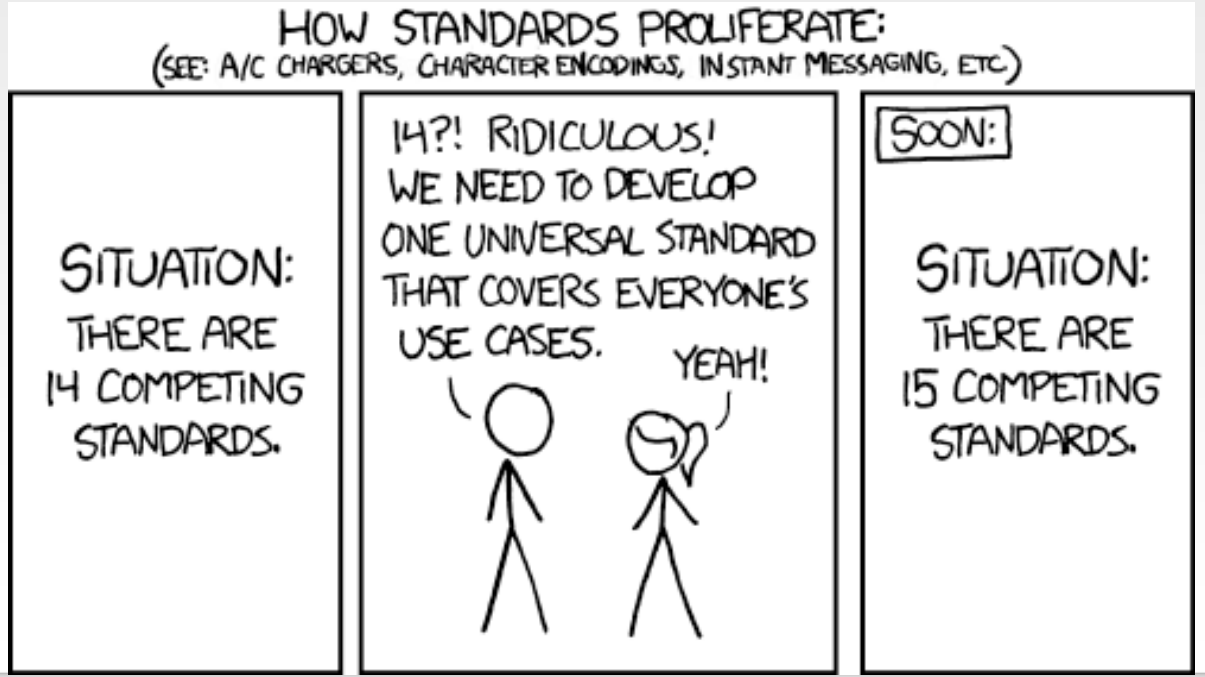


The IoT Standardisation Challenge

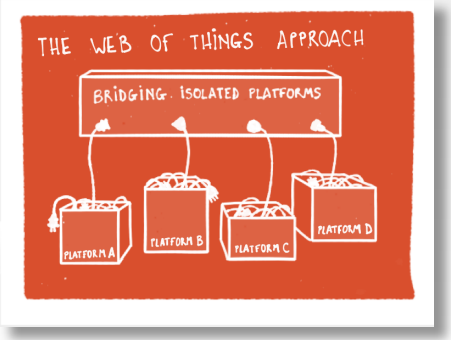
- AIOTI WG03 IoT Standardization landscape (and still extending)

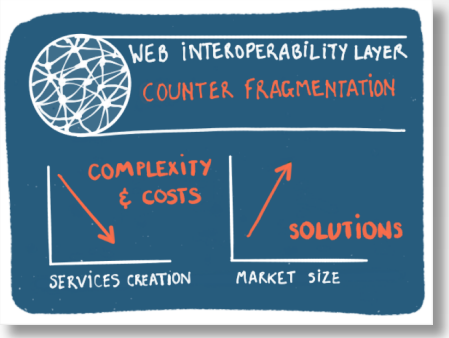


What we want to avoid …



Web of Things – Inter-Platform standards for interoperability





The Web will enable a transition from costly monolithic software to open markets of apps

Analogy with early days of networking

Before the Internet, there were many non-interoperable network technologies

- IP made it simple to interconnect networks and create interoperable services independent of the network technologies
- The Internet grew exponentially as the opportunities were realised
- Likewise for the Web which took over from isolated information services

Direct analogy with today's IoT silos and their lack of interoperability

- The Web of Things is the equivalent of IP for semantic interoperability and end to end security
- The Web of Things will enable explosive growth as the barriers to interoperability are torn down

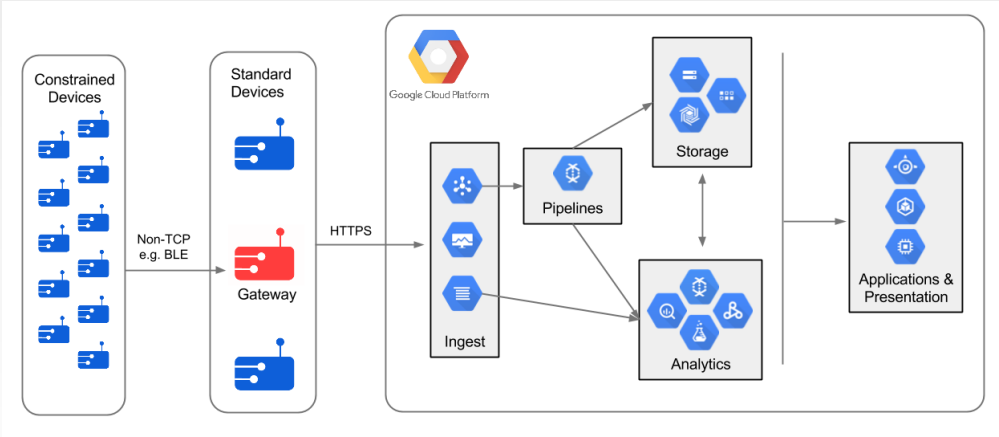
Sensor Data Streams

- A time sequence of tuples where the time interval is non-negative (wikipedia)
- Many application areas
  - Wind direction and speed
  - Healthcare, e.g. electrocardiogram
  - Racing car engine data
  - Rocketry
  - Oil and gas industry
  - Smart cities
  - . . . .
- Metadata describing what is being measured and how it is buffered and encoded for transmission

Telemetry for remote sensors

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



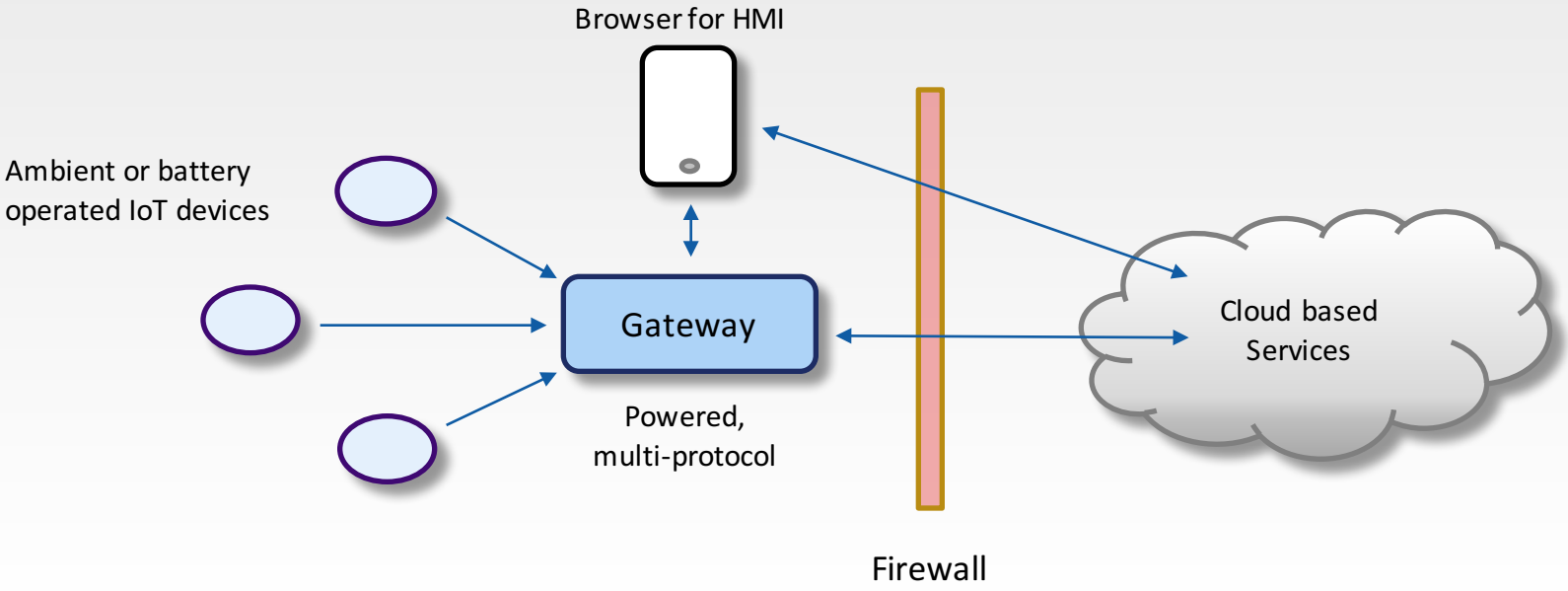
Google's Cloud Platform for the IoT

Home Hubs as Platforms for Smart Home Apps

- Web standards can create opportunities for vendor neutral platforms for a market for apps you can install 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

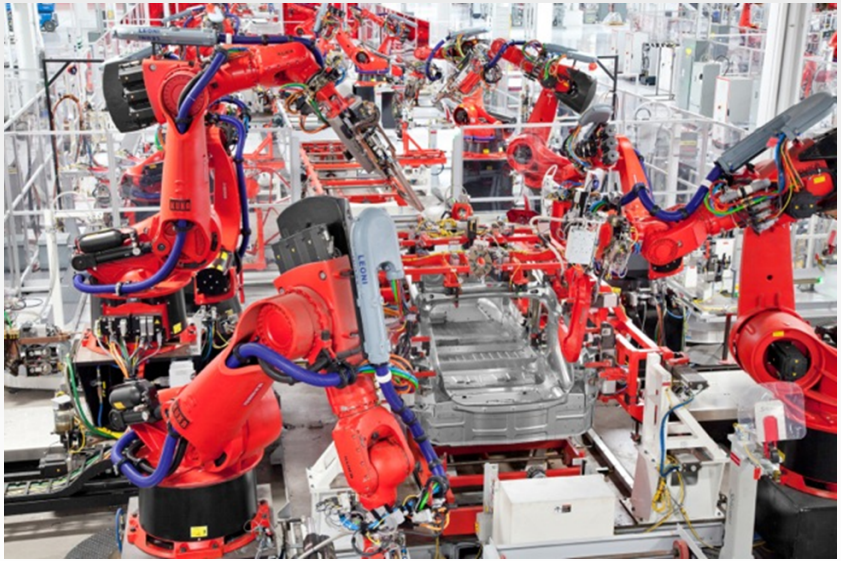
Samsung's Smart Things

The Web of Things in the Home



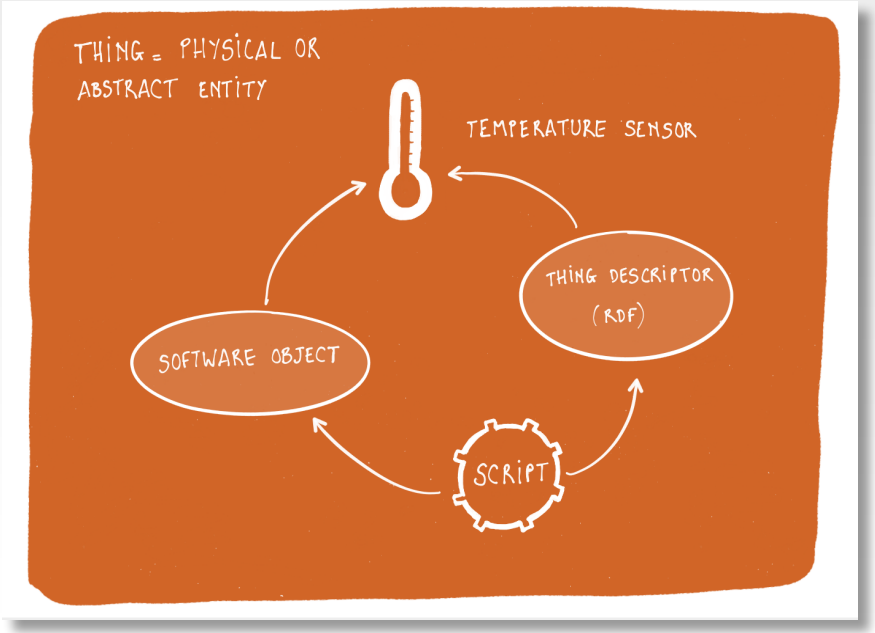
Smart Manufacturing

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



Robots manufacturing Tesla's electric cars

Web of Things



Applications act on software objects that stand for physical or abstract things

- Local “things”
- Remote “things

Rich descriptions for every “thing”

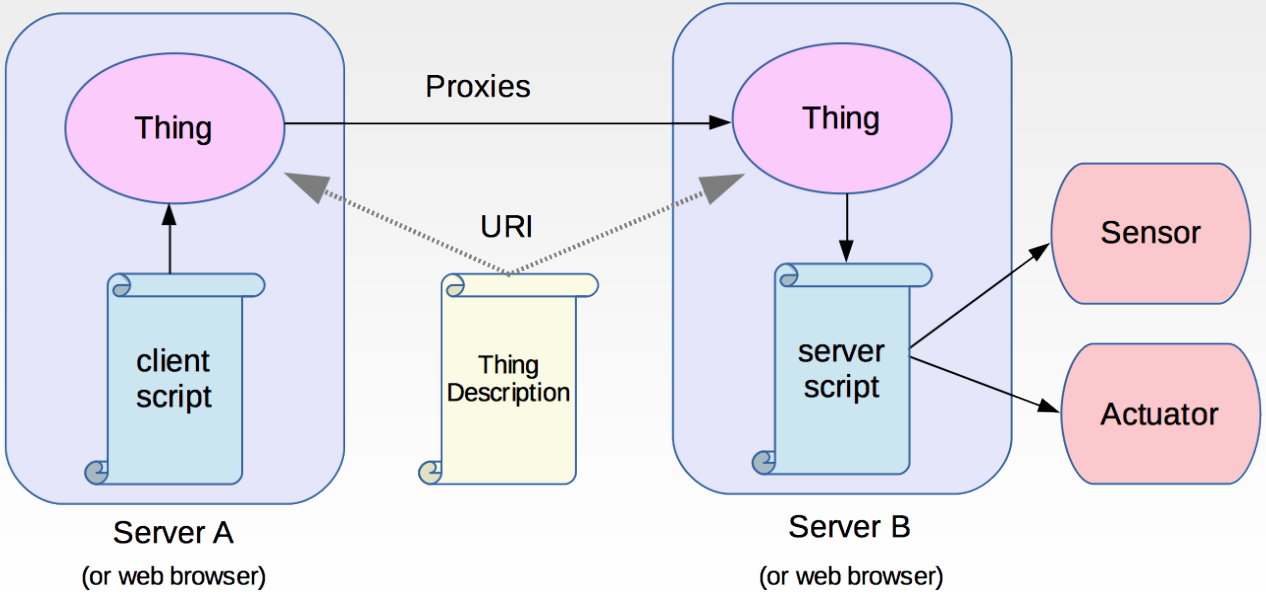
- Data models, semantics, metadata
- Ontologies that describe “things”

Things don’t need to be connected

- Abstract entities and unconnected physical objects

Distributed Web of Things where every thing has a URI

- 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



Communications Stack – Clean separation of concerns

Application Developer (WoT focus)

Platform Developer (IoT 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
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, AMQP 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

Scalability

Web of Things servers can be realised at many scales from microcontrollers to clouds

Home Hub: home/office server for access to smart home and wearables, running behind firewall

Micro-controller: resource constrained, IoT devices or gateways, CoAP, running behind firewall

Smart Phone: personal server for access to smart home and wearables

Cloud-Based: highly scalable server for many users, devices and working with big data

Web of Things for the Maker Community

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

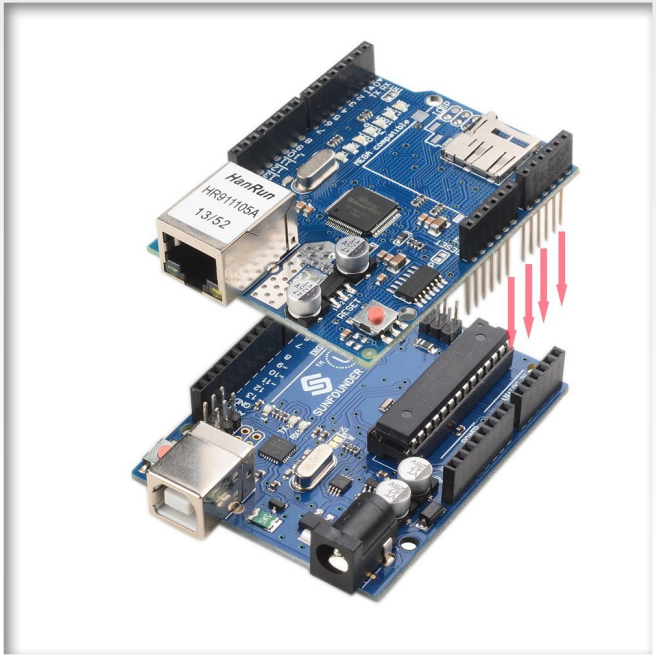
Arduino Ethernet Shield

- 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



What kinds of metadata do we need for this?

- Thing lifecycles, data and interaction models
  - As exposed to the applications
- How to interoperate with another platform?
  - Mapping from thing descriptions to platform specific protocols
    - IP address and port for IP based protocols
    - Paths for REST based protocols such as CoAP & HTTP
- What communication patterns to use?
  - Push, pull, pub-sub, peer to peer
  - Real-time requirements
  - Transactional robustness & rollbacks
  - Multiplexing and buffering
  - Sleepy ambient & battery powered devices
- Semantic models of things and their constraints

Data & Interaction Models

Must be rich enough to cover broad range of use cases and platforms

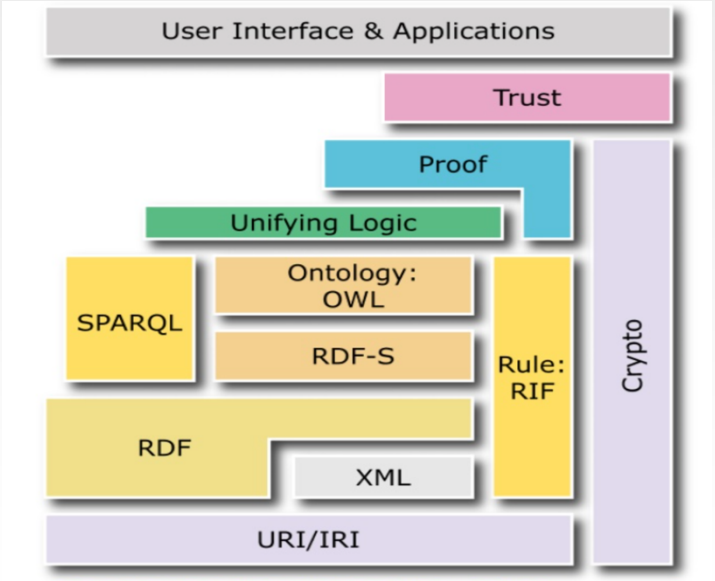
- Properties, actions and events carry values
  - Actions are asynchronous and can be passed a value, and may return a sequence of values
- Values as basic types
  - Null, true, false, numbers, strings
- Compound values
  - Arrays
  - Sets of name/value pairs
  - Things (a web of related things)
  - Streams (e.g. wind speed and direction)
- Integrity constraints
  - On single values, e.g.
    - min/max, integer/float
  - Across multiple values
  - Cardinality constraints
  - Need for path expressions
- Complications
  - Proxy chains
  - Early and late binding
    - Partially defined types
  - Cyclic dependencies across things
  - Software dependencies
    - Metadata constraints (versioning)

Semantics

- Needed to ensure that platforms share the same meaning for the data they exchange
- Simple approach is to define semantics as part of the system specifications
- Better approach is to tag data as belonging to an ontology that describes the relationships between concepts in a machine interpretable way
  - What kind of a thing is it?
    - e.g. a temperature sensor
  - What are the domain constraints?
    - temperature sensors must describe their physical units, which must be from the set {Kelvin, Celsius, Fahrenheit}
    - Other ontologies could describe the location of the sensor and what it is measuring

Semantics

- Ontologies allow information to be exchanged meaningfully in a way that is independent of the data formats used for its transmission
- Ontologies further allow for checks that the information is consistent with the domain models
- This can cover richer constraints, e.g. temporal constraints across actions and properties
- W3C has a suite of standards for the Semantic Web and Linked Data
  - RDF, XML, SPARQL, RDF-S, OWL, RIF, JSON-LD, RDF in CSV, . . .
- Enable semantic based search and composition of services
  - Ensure that compositions will use interoperable services



Web of Things

Activity

W3C Web of Things Interest Group

Workshop in Berlin (June 2014)

- Launch of Web of Things IG in 2015
- Chaired by Jörg Heuer, Siemens
- Task forces
  - Thing descriptions
  - APIs and protocols
  - Discovery and provisioning
  - Security, privacy and resilience
  - Communications and collaboration

Strong emphasis on implementation experience

- Demos and plug-fests
- Helps to build a shared understanding

Montreal Face to Face, 11-13 April 2016

Members of the Web of Things Interest Group

Joint White Paper on Semantic Interoperability

- Contributors are individuals from a range of industry alliances and standards development organisations
  - Editors from W3C, oneM2M, IEEE P2413
- Inspiration from many of the papers on semantic interoperability
- Illustrate the concept in terms of some use cases, along with the requirements, and views on how to enable semantic interoperability within and across IoT platforms
- Discuss best practices for ontology design and distinguish cross domain (horizontal) metadata and domain specific (vertical) metadata
- Once we have a stable version we will invite wider expert review and update the document accordingly
- We will seek broad dissemination of the document and will publish under a Creative Commons License
- We hope that the development process will help shape a common perspective across contributors and that the white paper will influence the agendas of working groups across the industry

Liaisons and Collaborations

Reaching out to industry alliances and SDO's to drive convergence to unleash the potential

- Plattform Industrie 4.0
  - Especially the "semantics" subgroup
- Industrial Internet Consortium
- Open Connectivity Foundation
- OPC Foundation
- IETF/IRTF
- oneM2M
- AIOTI

Web of Things Working Group

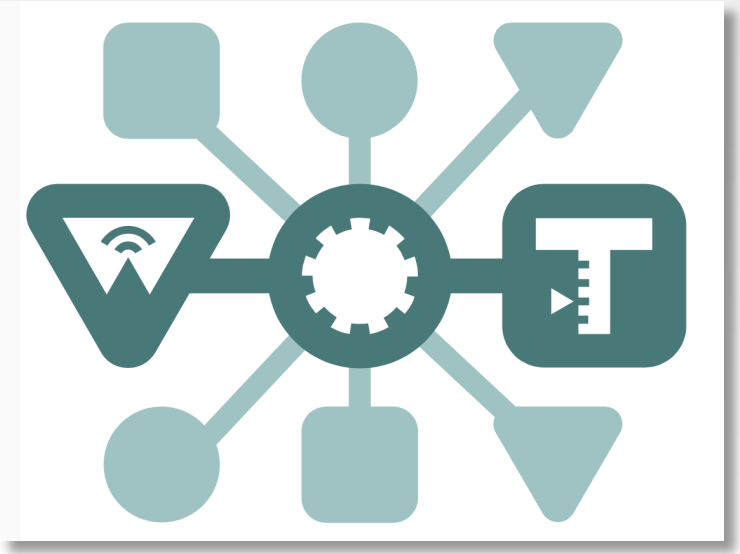
The Interest Group (IG) is working on

- Use cases, requirements, technology landscape and plans for launching working groups (WG)
- IGs prepare the ground for standards but don't develop standards
- WGs are chartered to develop standards (W3C Recommendations)

We're collecting ideas for a Working Group including

- Horizontal metadata vocabularies (things, security, communications)
- Serialisations of metadata, e.g., as JSON-LD
- APIs and bindings to specific protocols and platforms in collaboration with the platform owners

Web of Things Working Group to be launched in 2016



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

World Wide Web Consortium

Mission: lead the Web to its full potential

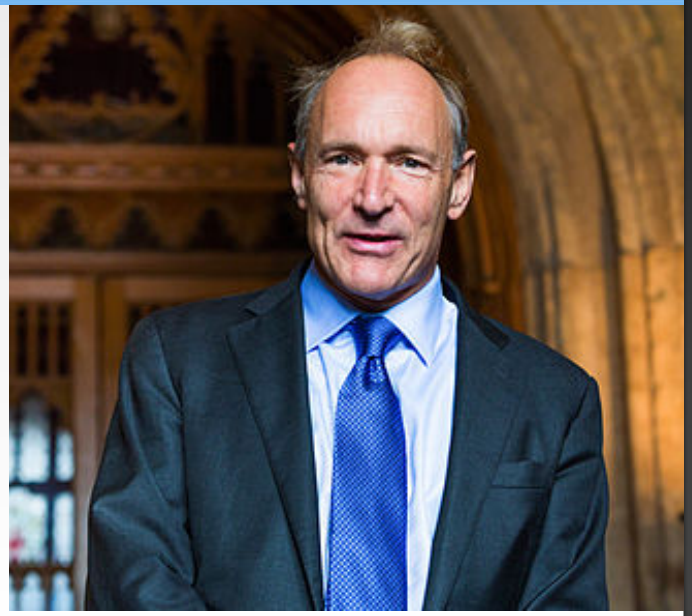
- The Web is the world's largest vendor-neutral distributed application platform

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



Work with us to build the Web of Things!

For more information on W3C see:

www.w3.org

Thank you!