

Semantic Sensor Networks

The Internet of Things Needs
the Web of Data

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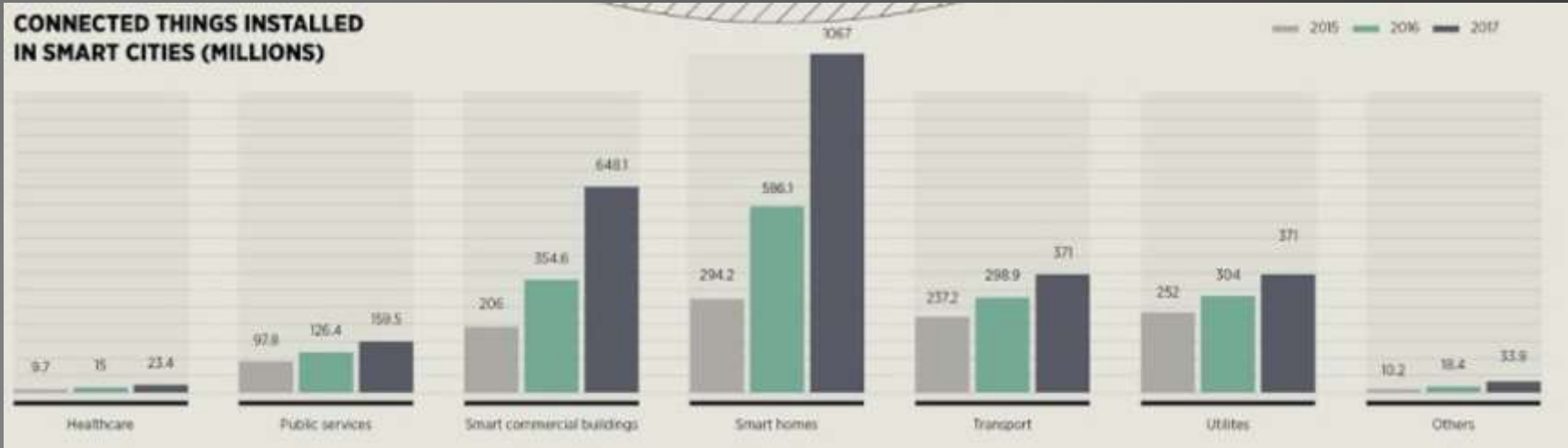


The Internet of Things does not need...

- Standards
- Object Identity
- Object linking
- Data Description
- Data models
- OLAP Cubes
- Domain independent reasoning
- Location and place
- Provenance
- Security



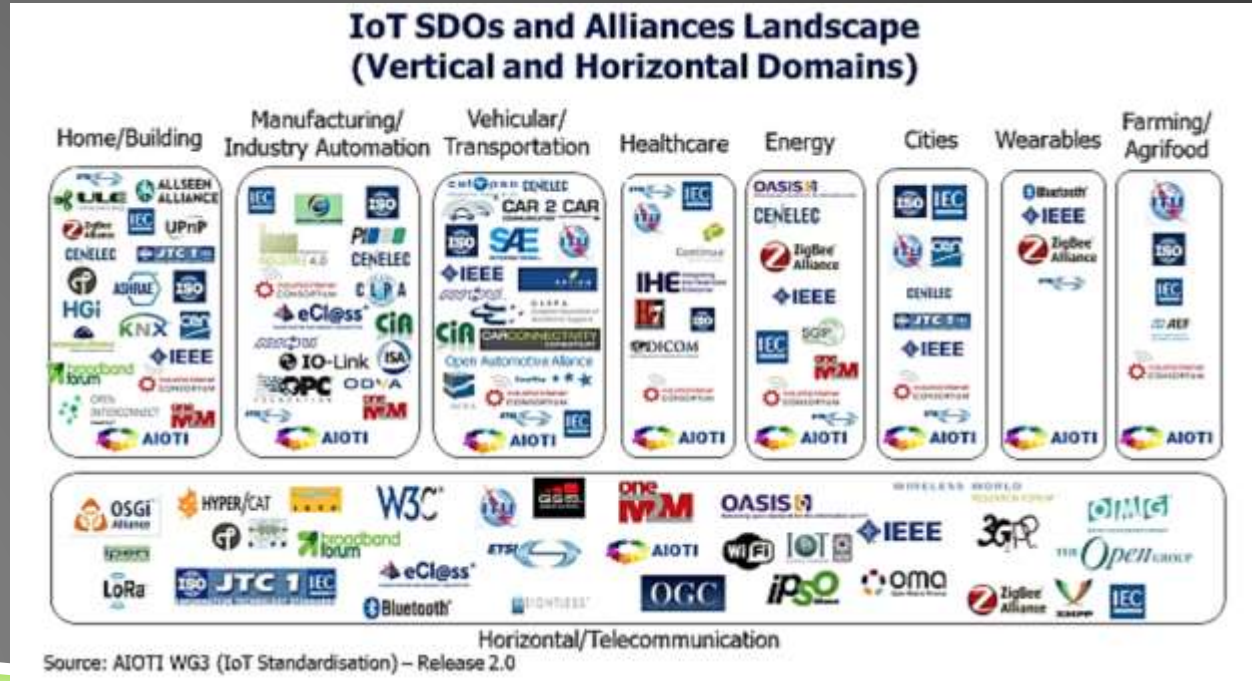
Growth of Smart Cities



Source: Gartner 2015 via raconteur.net

Standards and Architecture for the IoT

- EC Workshop on IoT Standardisation and Architecture
- IoT is developing rapidly through vertical silos
- Problems integrating sensors and devices within the Smart City infrastructure and vendor platforms due to lack of standardization.



How is a city smart?

- Citizens informed and in control
- Government informed and *just-enough* in control
- Environmentally and health-sensitive
- Safe
- Egalitarian access and participation
- Cost-efficient interactions

Adapted from P. Barnaghi, CityPulse



Source: city of Boston

- Continuous near-real-time localised data collection
- Linked and integrated data for integrated services
- Real-time intelligence and actionable information
- Services customised to context
- Public-private partnerships

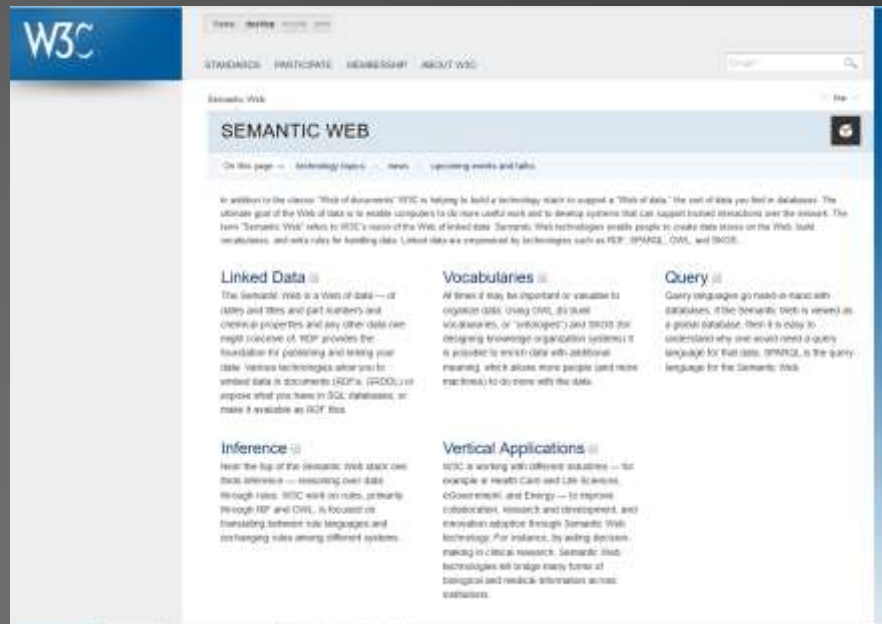
Internet of Things + Web of Data = Web of Things

- Addressing the “product silos”
- Open ecosystems and open standards
- Rich descriptions, shared data models
- Security, privacy, scalability and accessibility



Web of data

- Linked data
- Vocabularies
- Inference
- Vertical Applications
- Query
- Spatial Data on the Web



The image shows a screenshot of the W3C Semantic Web page. The page has a blue header with the W3C logo and navigation links: HOME, HELP, CONTACT, and NEWS. Below the header, there are links for STANDARDS, PARTICIPATE, MEMBERSHIP, and ABOUT W3C. The main content area is titled "SEMANTIC WEB" and includes a search bar. The page is divided into several sections: "Linked Data", "Vocabularies", "Query", "Inference", and "Vertical Applications". Each section contains a brief description of the concept and its application in the Semantic Web.

W3C HOME HELP CONTACT NEWS

STANDARDS PARTICIPATE MEMBERSHIP ABOUT W3C

Search

Semantic Web

SEMANTIC WEB

On this page — Technology topics — News — Upcoming events and talks

In addition to the classic "Web of documents" W3C is helping to build a technology stack to support a "Web of data," the web of data you find in databases. The ultimate goal of the Web of data is to enable computers to do more useful work and to develop systems that can suggest trusted interactions and the answer. The term "Semantic Web" refers to W3C's vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data. Linked data are represented by technologies such as RDF, SPARQL, OWL, and XSD.

Linked Data

All times it may be important or valuable to organize data. Using OWL, RDF, and XSD for vocabularies, or "ontologies," and SPARQL for designing knowledge organization systems, it is possible to work only with additional meaning, which allows more people (and more machines) to do more with the data.

Vocabularies

Query languages go hand-in-hand with databases. If the Semantic Web is viewed as a global database, then it is easy to understand why one would need a query language for that data. SPARQL is the query language for the Semantic Web.

Query

From the top of the Semantic Web stack one finds ontologies — meaning and data through rules. W3C work in this area will through RDF and OWL, is focused on translating between rule languages and exchanging rules among different systems.

Inference

W3C is working with different industries — for example in Health Care and Life Sciences, Coast Guard, and Energy — to explore collaboration, research and development, and innovation enabled through Semantic Web technology. For instance, by aiding decision-making in clinical research, Semantic Web technologies will bridge many forms of biological and medical information across institutions.

Vertical Applications

What is linked data?

A new data publishing and integration style influenced by successful Web principles and championed by Tim Berners-Lee



Why linked data?

Focuses community agreement on *what things are* and what to call them, not on how to encode them.

Realised as a *terminology*, or a *description* of concepts called an *ontology* or *vocabulary*

Formalised: founded on mathematical predicate logic theory

Uses sound and complete, domain-independent machine-interpreted reasoning services



Why linked data?

- Not tied to the lowest-common-denominator of the community
- Uses Web standards; URIs and links are everywhere inside and *outside*
- A Web-scale distributed database designed for in-situ data access by third party apps, mashups and web services

“We have lots of portals...what we haven't got to is to use my tool across a suite of resources” -

Ross Wilkinson, Australian National Data Service 2015



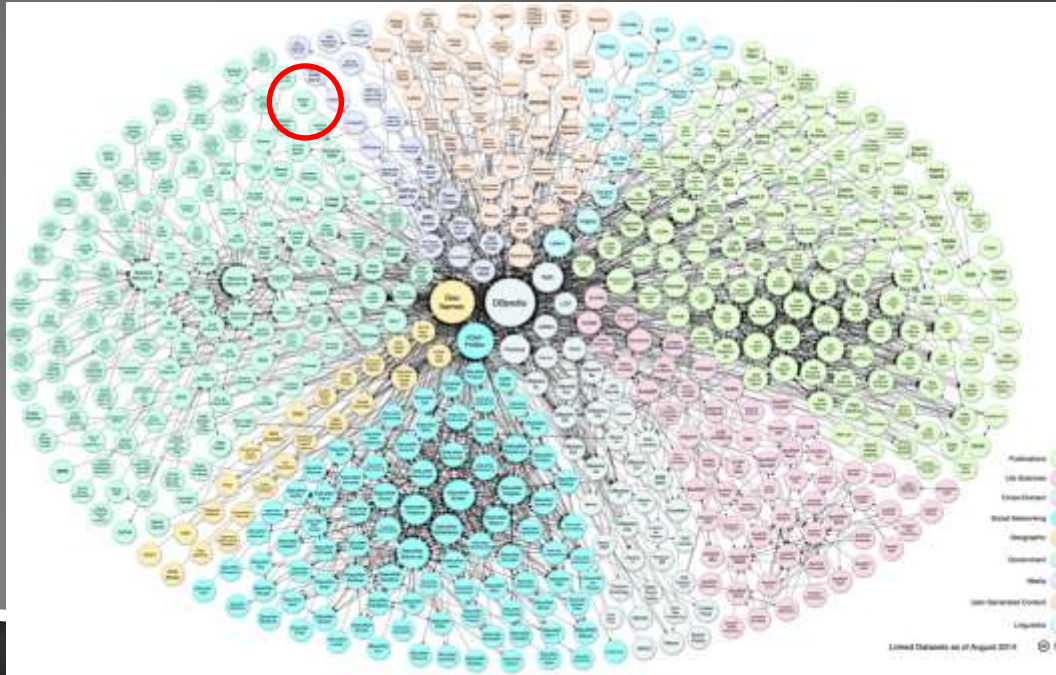
In Practice!

<http://smartfarm-ict.it.csiro.au/sparql-doc/compare-farm-and-archive-observations.html>

The screenshot shows a Mozilla Firefox browser window displaying a table of rainfall data. The browser's address bar shows the URL: lab.environment.data.gov.au/sparql?query=PREFIX+gn%3A+<http%3A%2F%2Fwww.geonames.org%2Fontology%23%3E%26APREFEX+asn%3A. The table below contains the following data:

rainfallDistrict	districtName	stationName	MaxEver	AvMax	smartfarmSite	day	month	year	daysMaxTemp
http://lab.environment.data.gov.au/id/raindist/56	New South Wales Northern Tablelands W	INVERELL (RAGLAN ST)	39.2	29.29	http://smartfarm-ict.it.csiro.au/id/site/40	12	1	2013	33.5
http://lab.environment.data.gov.au/id/raindist/56	New South Wales Northern Tablelands W	INVERELL (RAGLAN ST)	39.2	29.29	http://smartfarm-ict.it.csiro.au/id/site/88	12	1	2013	34.0

The LOD Cloud of public data

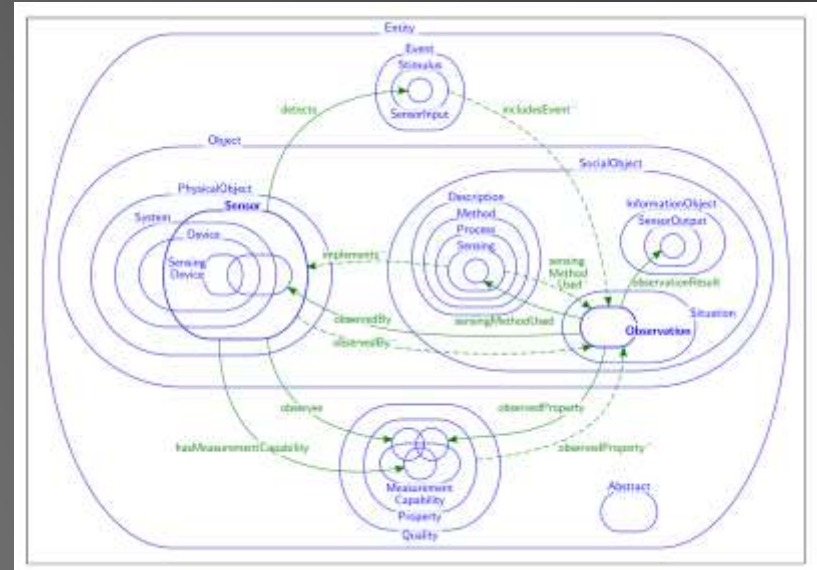


Linking Open
Data cloud
diagram 2014, by
Max
Schmachtenberg,
Christian Bizer,
Anja Jentzsch and
Richard Cyganiak.
[http://lod-
cloud.net/](http://lod-cloud.net/)



Semantic Sensor Networks

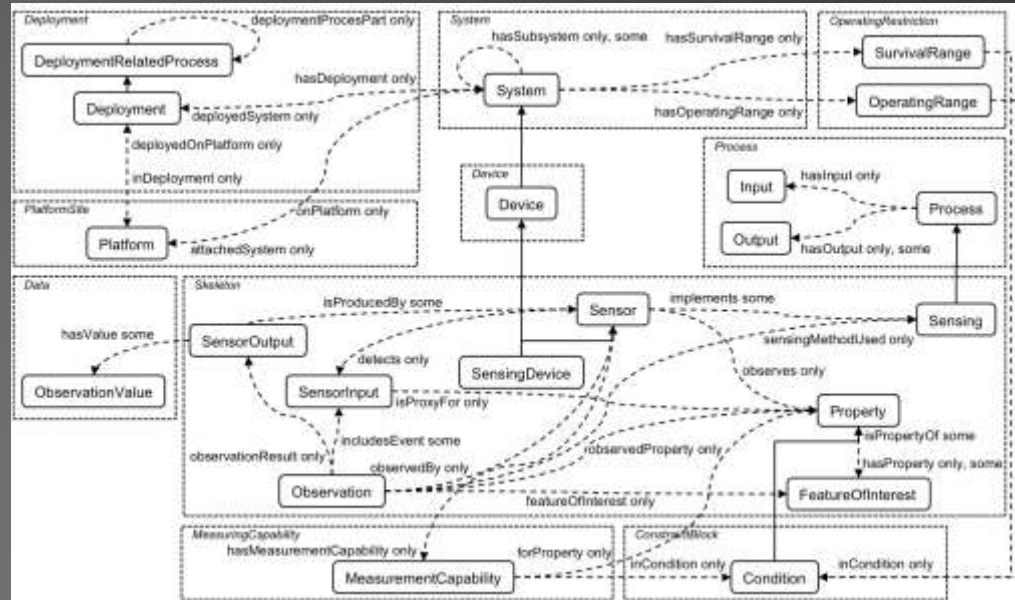
- Not just a list of words...
- OWL-DL ontology that is designed for use with machine-interpreted logical inference
- Meaning is explicit in the conceptual model
- Widely used for linked open data, together with spatial, temporal and rule-based inference
- See Compton et al 2012



source: Howse et al 2011

Semantic Sensor Networks

- Capabilities and properties of sensors
- Measuring capability, operating conditions, survival conditions
- Sensors in systems, including aspects of deployment
- The act and method of sensing
- The results of sensing



CityPulse EU FP7: Smart Cities and Smart Data Analytics

Collection, publication, annotation and query of smart city datastreams, addressing quality concerns.

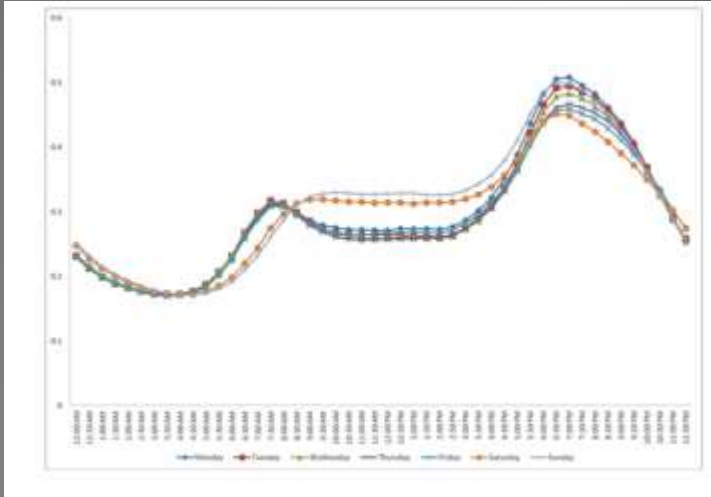
Adds social streams (Twitter) to cultural events, traffic, parking, pollution, weather,...

KAT: Knowledge Acquisition Toolkit



Source: Barnaghi et al, IEEE Intelligent Systems 28(6)

Australian Bureau of Statistics



source: data.gov.au

With the Australian Energy Market Operator (AEMO)

Aim to develop a strategic view of Electricity consumption in Australia to build a model for market planning and efficiency and government policy. e.g. consumption trends, dynamic charging models.

Using linked data methods for linking and analysing

- Smart-Grid Smart-City Customer Trial Data at unit record level
- Linked to meteorological data (now available as linked data, modelled with SSN, from Bureau of Meteorology)
- Socio-economic data (own data)

Contact: Ric Clarke (ABS)

Australian Bureau of Statistics



With Bureau of Infrastructure, Transport and Regional Economics

Aim to understand pattern of movement of freight and utilisation of infrastructure for planning (roads, warehousing, fuel), productivity analysis, regional development

Using linked data methods for linking and analysing

- In-vehicle telematics from 10-20 freight haulers (SSN)
- Freight transactional data
- Regional socio-economic data

Contact: Ric Clarke (ABS)

Spanish Smart Cities

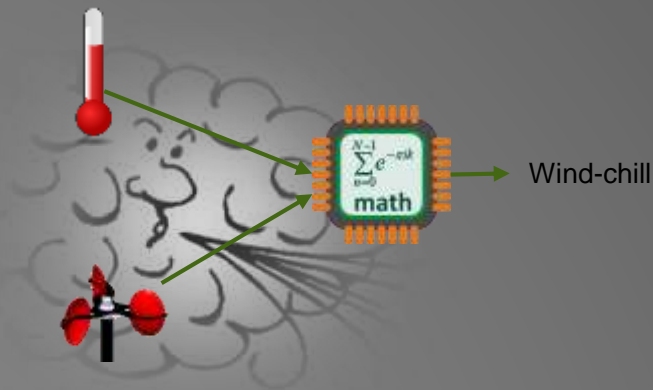
Spanish standard UNE178301:2015 *Smart Cities. Open Data*, proposes SSN for air quality data.

- SSN used for Zaragoza open data pollen counts and air pollution.
- SSN used by transport authority in Madrid for travel card validations.

And a startup in Madrid
Open data publishing for City Governments



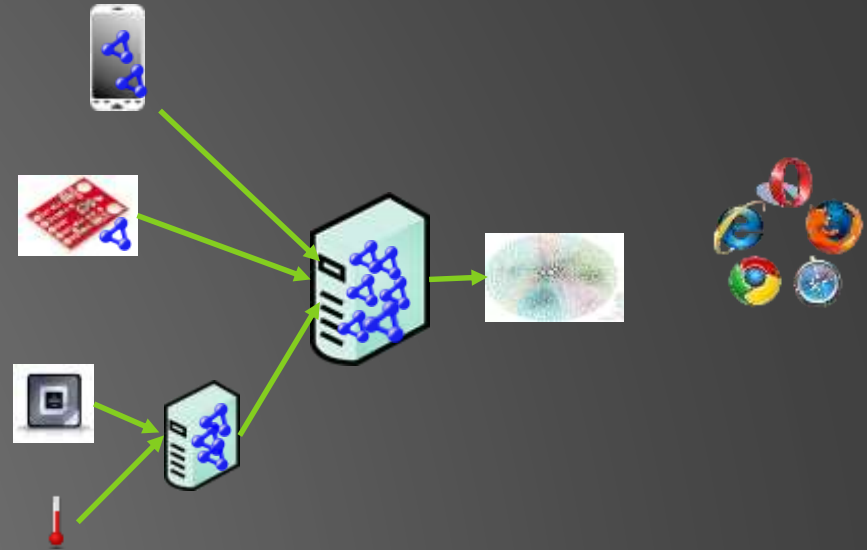
We don't need reasoning



- Composition of virtual sensors to make measurements not available in the raw.
- Some automated techniques require reasoning outside DL e.g. RCC, numeric, rules.
- See Compton, Neuhaus, Taylor, Tran 2009

IoT devices are too small for reasoning

- Classification of sensors into type hierarchies for discovery (by measured property, accuracy, location...)
- Integration of data about fragments into bigger models



Watch for IoT-lite, a Member Submission to W3C from Surrey

The data is too fast for reasoning

Stream Reasoning and Complex Event processing



Source: thecepblog.com

Describe/query for complex events in ontology languages
See Taylor & Leidinger 2011

The data is too big for semantics

Monitoring surface-atmosphere energy and gas flux for 5 months

- 326 million observations; 4.9 billion triples;
- Use observations of SSN, scales to billions, responds to SPARQL,
- Part-Cassandra (hashed observations) , part Sesame triple store (descriptive metadata)
- Constant query speed wrt size
- Stocker et al, 2015

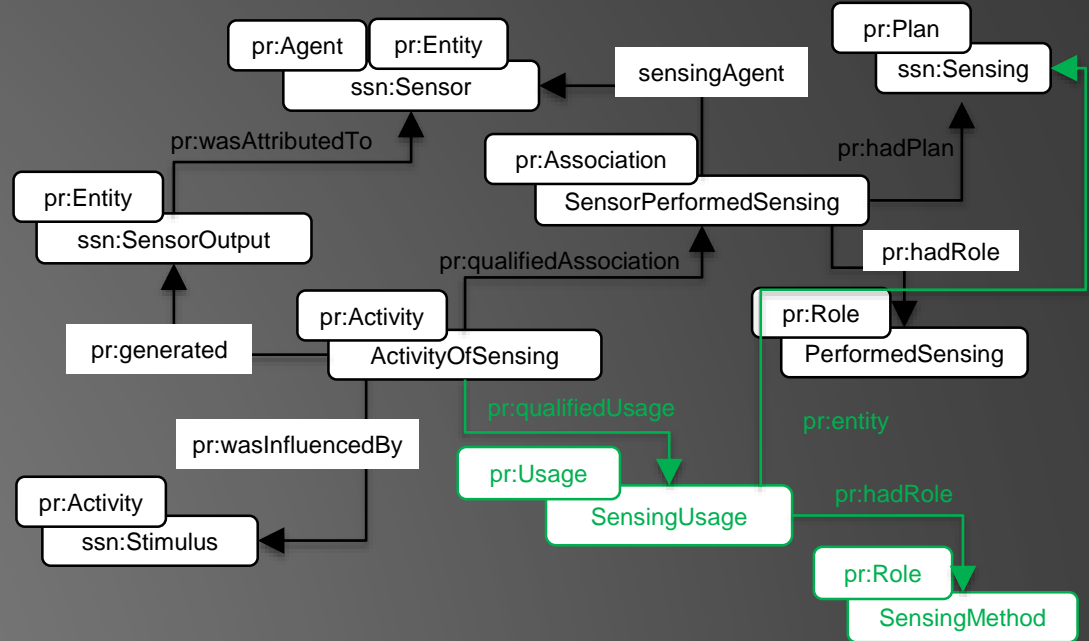


We don't care about where it comes from

SSN can be used for tracking provenance of measurements in concert with PROV-O standard

Shows which sensor and sensing method was used for a sensor measurement

PROV-O can also be used to enhance SSN deployment descriptions



You can't do IoT actuation with Semantics

- Various techniques emerging
- Rule languages e.g. SWRL-based
- Various examples of SSN extension
- You can use capability modelling (translated to templated native programming language)

Taylor & Penkala 2009



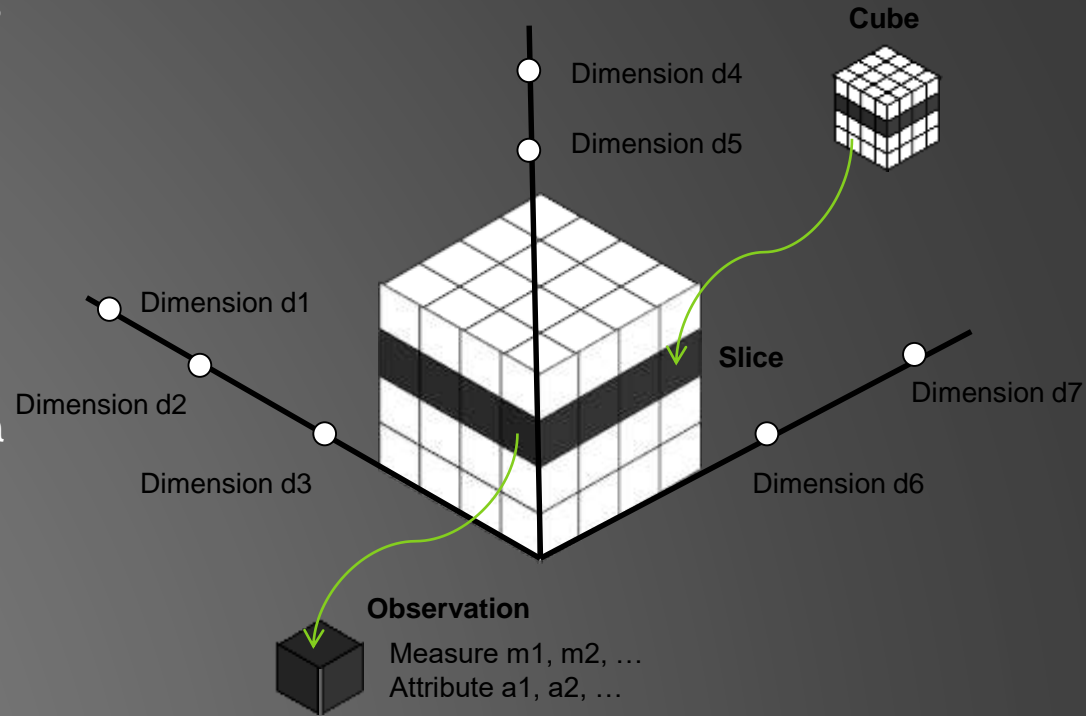
Image: extremetech.com

You can't do data analytics with ontologies

The RDF DataCube ontology can be used together with SSN for off-line analytics and summarisation (Lefort et al 2012)

Machine learning over semantic data for rich input and readable hypotheses e.g. Ratcliffe & Taylor 2014

Streaming analytics also developing Taylor et al 2013



source: Lefort et al 2012

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- Standards
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OGC/W3C Spatial Data on the Web

1 year & 13 days since the first meeting

87 people

45 organisations

50 use cases driving **57** requirements

6 months since first publishing draft UCR

14 days since first public working draft for BP

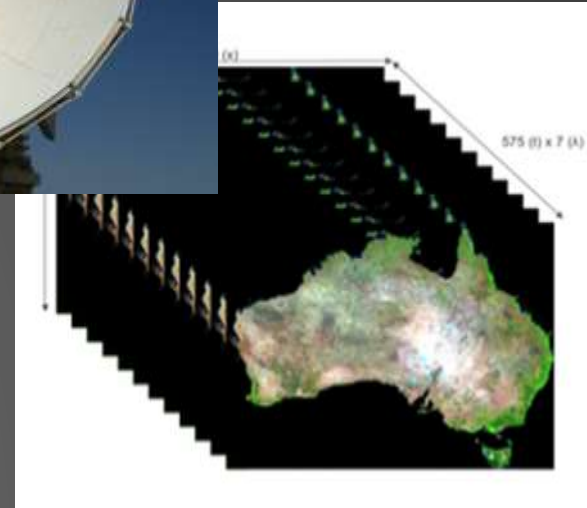
30 best practices so far

4 days to **3rd F2F** in Amersfoort

- **Use Cases and Requirements**
Consumer apps, crowdsourcing, discovery, IoT, e-science, provenance, remote sensing, govhack, agriculture, cultural heritage, transport, smart grids, taxation (intra-gov)...
- **Best Practices for Spatial Data**
Identifiers, semantics, linking, discovery, web services, large datasets, temporal aspects

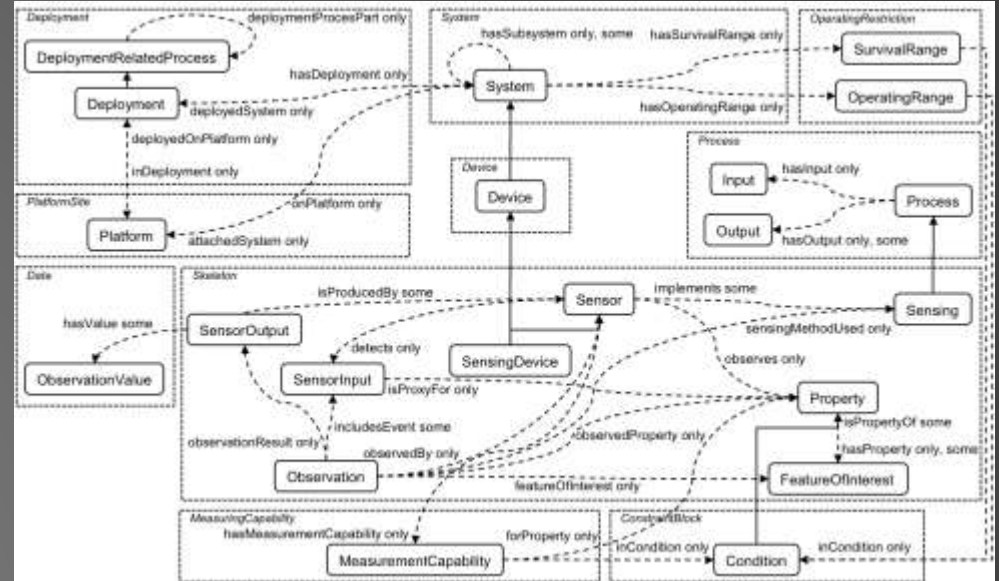
W3C/OGC Spatial Data on the Web Working Group

- Semantic Sensor Networks
- OWL-Time
- Coverage



Semantic Sensor Networks to do

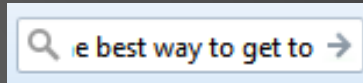
- Modularity
- Actuation
- Network topology
- Time Series data
- Citizen sensors
- Moving Features
- Mobile sensors
- Ex-situ sampling
- Uncertainty
- More...



What will it look like?

Search engines will understand it

What's the best way to get to London's Little Italy district from the airport at 2am on Saturday?



Clever IoT devices will use it

Your bus is running 10 minutes late. You still have time to finish that coffee before you go but I'll turn down the oven now so your dinner doesn't burn before you get home

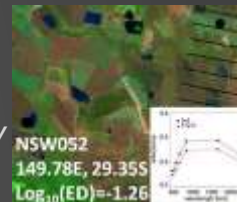


Smart Cities will use it

Which Melbourne suburbs had the highest electricity consumption per household in January 2015 and what is the most recent median household income for those suburbs and the sitting MLA for the electorates containing those suburbs?

Scientists will use it

Visualise the monthly fractional cover over Eastern Australia for the year to date correlated with the monthly maximum temperatures from the Bureau of Meteorology.



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Thanks for listening!

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