From Representing Knowledge To**wards** Representing Behaviour **On The Web**

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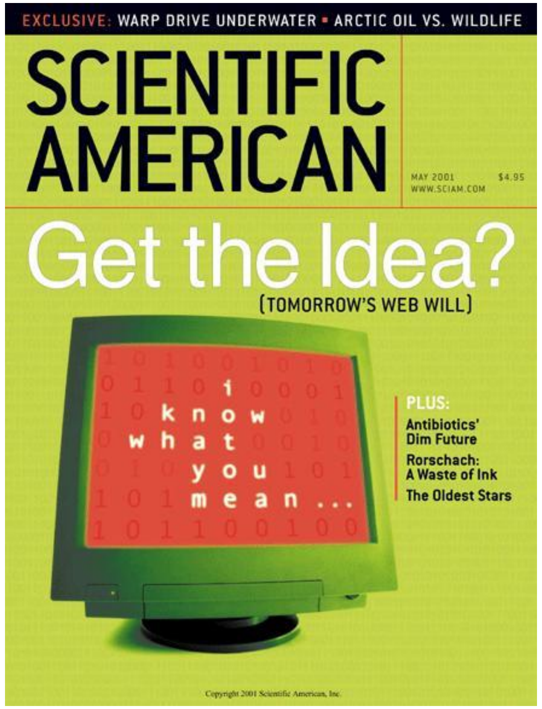
The Semantic Web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users.

Tim Berners-Lee, James Hendler, Ora Lassila (May 17, 2001). "The Semantic Web". Scientific American.



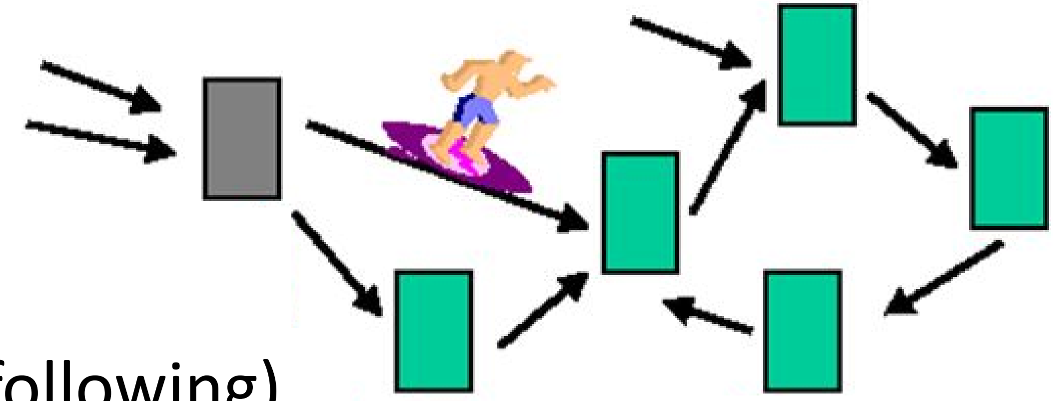
There was a nice scenario in the Berners-Lee, Hendler and Lassila Scientific American article, but I have not seen it actually demonstrated. That scenario is quite ambitious, and depends too much on resources that do not exist today.

Gio Wiederhold

Gio Wiederhold, Rudi Studer, Mark Musen, Stefan Decker and Steffen Staab. Final report: ONTO-AGENTS-ENABLING INTELLIGENT AGENTS ON THE WEB, May 2005.

Semantic “Web” Today

- Standards for knowledge representation languages (RDF, RDFS, OWL) that work in conjunction with a query language (SPARQL)
- Deployed as centrally curated knowledge graphs, either by the large internet companies, large websites or in an enterprise setting
- Most systems look like databases
- Even with Linked Data, tenets of web architecture are insufficiently used (hyperlinking) or not used at all (link-following)



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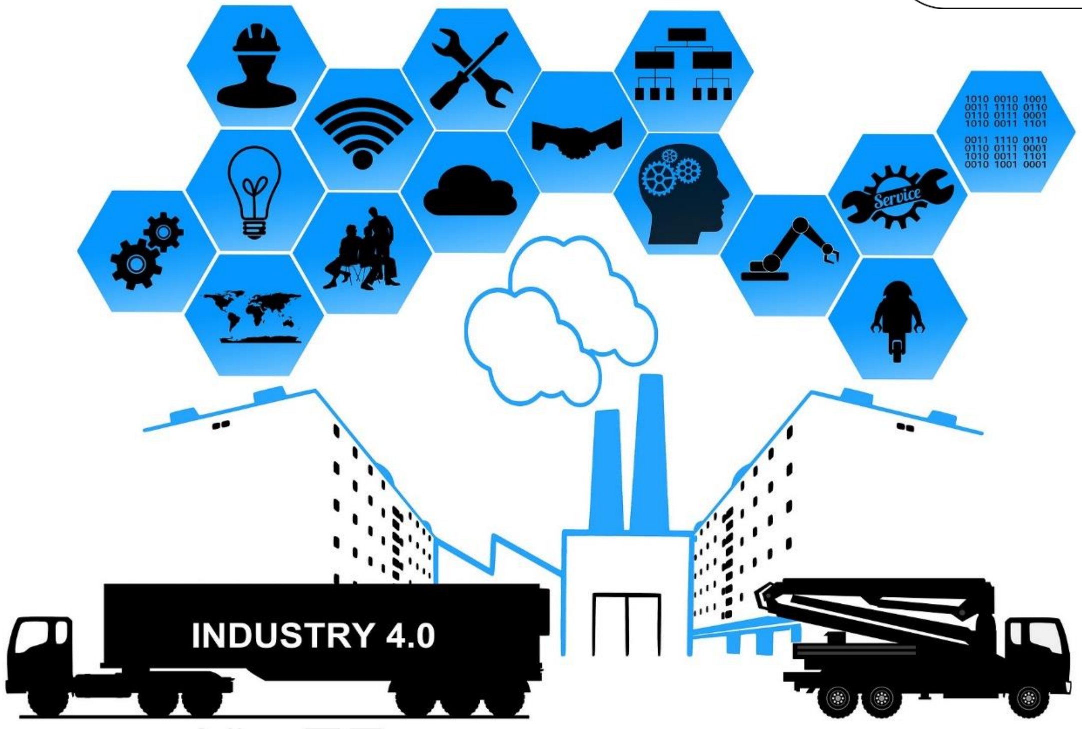
Future Scenarios Today

Sep
2019



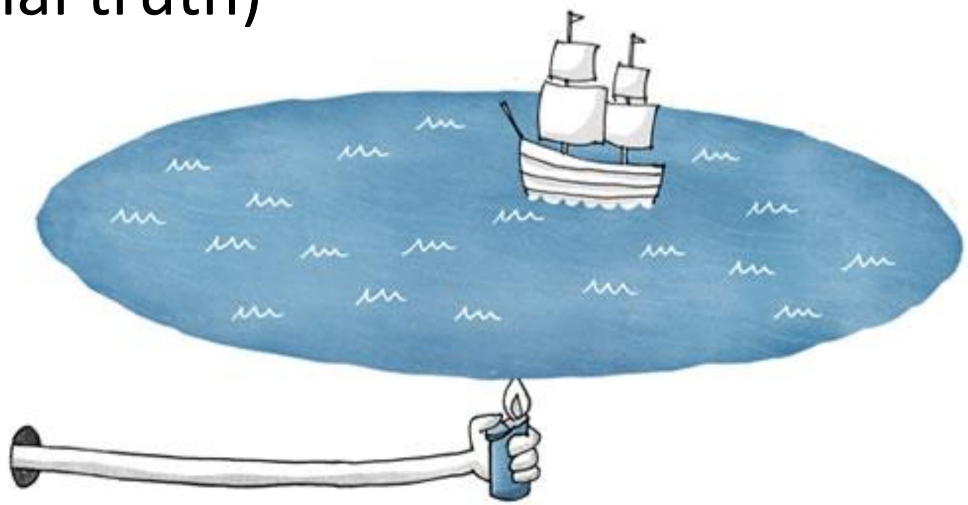
Can we solve scenarios around the Internet of Things and Industry 4.0 with “Semantic-Web-as-a-Database” technology?

Back To Square One

What Went Wrong? Where Are The Agents?

My top-three reasons:

3. Operational aspects underspecified for accessing formally represented knowledge (no communication architecture; no network protocol)
2. Semantics defined exclusively based on model theory (disembodied; representing global, eternal truth)
1. Trying to solve all problems at once (trying to „boil the ocean“)



3. Operational Aspects

- Linked Data: brings partitioning (via different RDF documents), brings time (via different representations of resources at different points in time)
- Linked Data principles mix data publishing (on servers) with data consumption (on user agents)
- Read-Write Linked Data (e.g., the W3C Linked Data Platform) brings in changing state

Linked Data Principles: Two Perspectives

Data Consumer (User Agent)

1. Assume URIs as names for things. ✓
2. User agents look up HTTP URIs. ✓
3. User agents process RDF/RDFS documents containing useful information and provide the ability to evaluate SPARQL queries. ✗
4. User agents can discover more things via accessing links to other URIs. ✗

Data Publisher (Server)

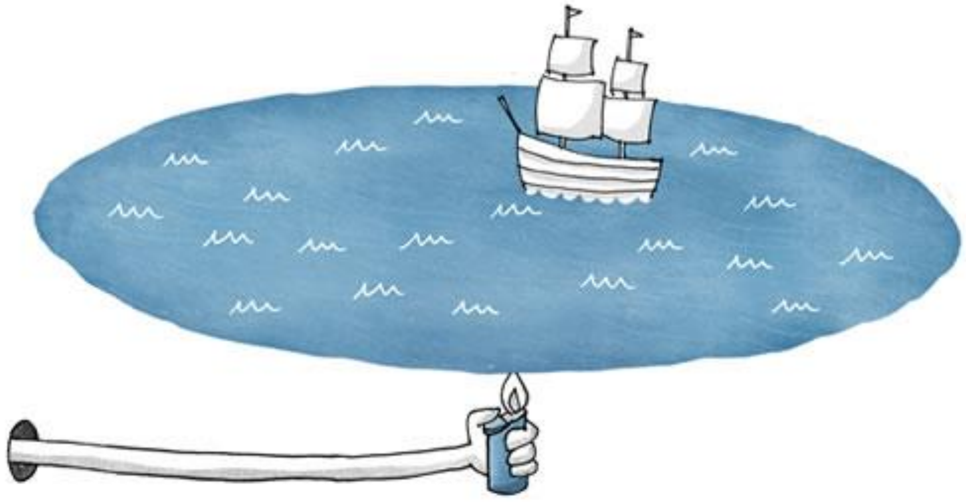
1. Coin URIs to name things. ✓
2. Use a HTTP server to provide access to documents. ✓
3. Upon receiving a request for a URI, the server returns useful information (about the URI in the request) in RDF and RDF Schema. ✓
4. The “useful information” the server returns in the RDF document includes links to other URIs (on other servers). ✓

Adapted from https://www.w3.org/DesignIssues/LinkedData.html

2. Semantics Based On Model Theory

- Model theory represents the state of the art in mathematics circa 1950 (Tarski)
- Proper fully logical characterisation of Linked Data still open
- Could be based on modal logic (modalities could be resources, time and agents) or Gurevich's abstract state machines
- But maybe not needed
- Just keep in mind: model theory characterises a limited view on semantics of Linked Data

1. Boiling The Ocean



- Avoid, obviously
- Also avoid: reinventing the wheel
- Read the classics
  - Yoav Shoham, Agent-Oriented Programming. Artificial Intelligence, 1993
- Start small

Not Boiling The Ocean: Examples

- The web is a very simple hypertext system
  - Tim Berners-Lee's paper to a hypertext conference was only accepted as a poster
- RDF is a very simple knowledge representation language
- RDFS provides only very few modelling primitives
- Schema.org provides a fixed vocabulary

- Operational agent-oriented programming…
  - Yoav Shoham, Agent-Oriented Programming. Artificial Intelligence, 1993
- …instead of Situation Calculus
  - J. McCarthy and P. Hayes. Some philosophical problems from the standpoint of artificial intelligence. In: Machine Intelligence, 4:463–502. Edinburgh University Press, 1969.)

- Layer more complex things on top if you want

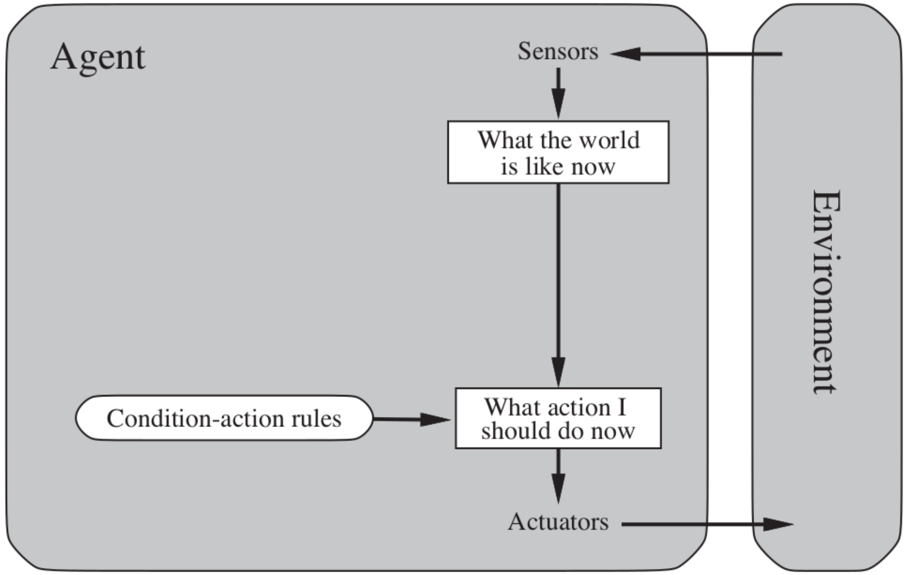
Towards Simple Agents On The Web

- Agents: Can we start with a simple “Hello World” scenario for agents on the web?
- Server: Based on a (read-only) Linked Data interface to sensors

- Agents: Then, add condition-(read)action rules to specify link traversal

- Server: Next, provide a Read-Write interface to sensors and actuators
- Agents: And add condition-(read-write) action rules

Simple Reflex Agent



Russel and Norvig, Artificial Intelligence – A Modern Approach, Third Edition, 2010

Server: Thermometer Sensor

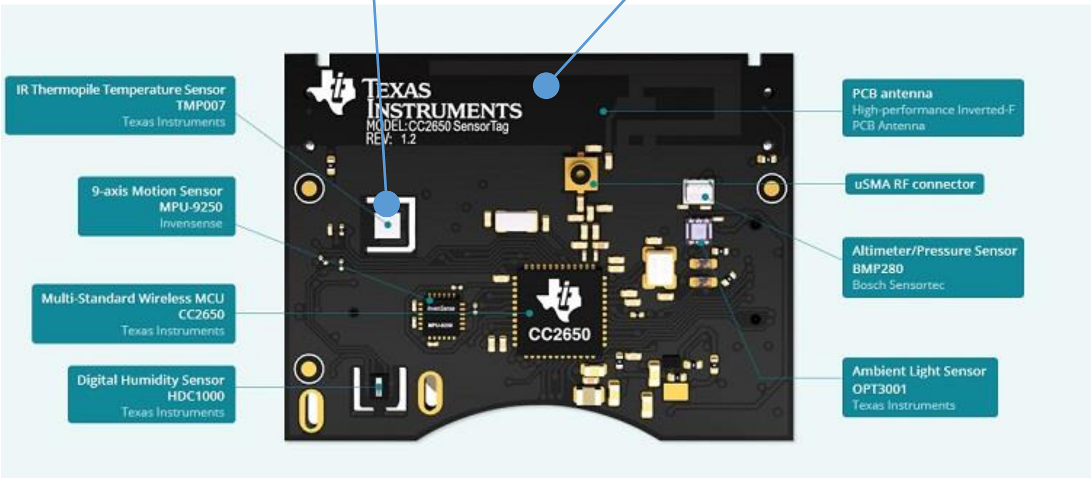
http://localhost/thermometer represented as Content-Type: text/turtle

```
@prefix sosa: <http://www.w3.org/ns/sosa/> .
@prefix ssn: <http://www.w3.org/ns/ssn/> .
@prefix : <vocab#> .

[] a sosa:Observation ;
    ssn:hasProperty :Temperature ;
    sosa:FeatureOfInterest :Hall4 ;
    sosa:hasSimpleResult 23 ; :time 4 .
```

http://localhost/

http://localhost/thermometer



User Agent: Query Current Temperature

```
PREFIX sosa: <http://www.w3.org/ns/sosa/>
PREFIX ssn: <http://www.w3.org/ns/ssn/>
PREFIX : <vocab#>

SELECT ?temp ?time
FROM <thermometer>
WHERE {
  ?x ssn:hasProperty :Temperature ;
     sosa:FeatureOfInterest :Hall4 ;
     sosa:hasSimpleResult ?temp ;
     :time ?time .
}
```

Loops

User Agent Loop

```
while true:
  execute SPARQL query
  output results
  wait 1 second
```

Server Loop

```
every second:
  read and store temperature

while true:
  wait for request
  if request uri = ‘thermometer’:
    return temperature in RDF
```

Simple Agents Layer Cakes

Read/Write Linked Data User Agents	Adding Unsafe HTTP Methods Read-Write Linked Data
Link-Following User Agents	URI + HTTP + RDF Linked Data (read-only)
Query User Agents	

Scenario: Building Behaviour

- Sensors and actuators with a Read-Write Linked Data interface, user agent workloads with increasing complexity (W1 – W5)

- W1: Baseline (3 sense rules, 2 act rules): Turn on all lights.
- W2: Working hours (5 sense rules, 12 act rules): Turn on the lights per default during working hours.
- W3: Sun hours report (5 sense rules, 11 act rules): Turn on the lights based on the sun hours report.
- W4: Luminance sensor (7 sense rules, 8 act rules): Turn on the lights based on luminance sensor values in the rooms.
- W5: Luminance sensor w/room-individual thresholds (7 sense rules, 8 act rules): Turn light on based on an individual light threshold per room.

Building 3 of IBM Dublin

Rooms	281
Floors	2
Wings	3
Lights w/ occupancy sensors	156
Lights w/ luminance sensors	126
Triples, ~2.4MB	24947
Resources in the LDP container	3281
Sensor resources	551

Tobias Käfer, Andreas Harth. "Rule-based Programming of User Agents for Linked Data". WWW2018 Workshop on Linked Data on the Web (LDOW2018), April 23, 2018. Lyon, France.

Scenarios 2016: Interactive Linked Systems

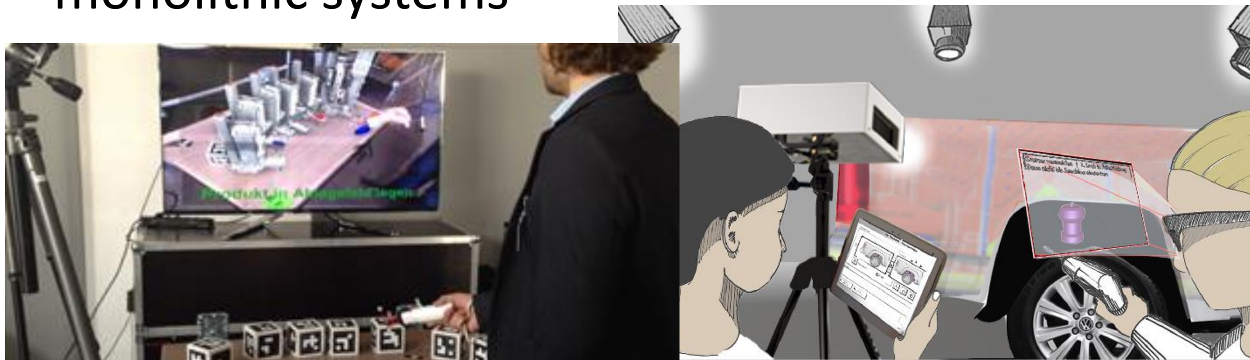
- Rule-based language to specify data integration and system interoperation
- Access to components via web standards (REST, Read-Write Linked Data)

- i-VISION: Immersive Semantics-based Virtual Environments for the Design and Validation of Human-centred Aircraft Cockpits
- EU project with Airbus DE/FR
- Query, interpret, evaluate and manipulate the virtual cockpit in an immersive and interactive environment

- ARVIDA: Reference Architecture for Virtual Services and Applications
- 23 partners incl. 17 industry partners from German industry (Daimler, Volkswagen,...)

Bundesministerium für Bildung und Forschung

- Flexible, open and interoperable virtual technology systems, breaking up current monolithic systems



Conclusion

- The agent metaphor is attractive for deployment on the (Semantic) Web, also in scenarios around Internet of Things and Industry 4.0
- Before we move on to sophisticated model-based and goal-based agents, we should get the foundations right, starting with the Web and the Semantic Web
- Many exciting research challenges for behaviour representation
  - “Service descriptions” for Read-Write Linked Data
  - Reasoning about the behaviour of single agents and groups of agents
  - Planning and model checking
  - Supporting users to specify agent behaviour
- But let’s start with building simple agents!

Acknowledgements

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- EU: i-VISION project (GA #605550, 2013 – 2016)

Image Credits

- Tim Berners-Lee in 2001: https://www.nature.com/articles/35074206
- Digital transformation and Industry 4.0: Gerd Altmann on pixabay.com
- Internet of Things: Wilgengebroed on Flickr, image originally via Gary Stevens of Hosting Canada. Licensed under the Creative Commons Attribution 2.0 Generic license (Wikimedia Commons).
- Back to square one: http://search.coolclips.com/m/vector/cart0298/Back-to-square-one/
- Boiling the ocean: http://alwaysinfo.co.uk/images/i/don-39t-boil-the/5 via https://medialabamsterdam.com/workspaces2020-nl/2015/02/26/translate-session-1-dont-try-to-boil-the-ocean/

Behavior

Behavior or behaviour is the range of actions and mannerisms made by individuals, organisms, systems, or artificial entities in conjunction with themselves or their environment, which includes the other systems or organisms around as well as the physical environment.

https://en.wikipedia.org/wiki/Behavior

Knowledge Graphs

Development

May 13, 2019
Volume 17, issue 2

PDF

Industry-scale Knowledge Graphs: Lessons and Challenges

Five diverse technology companies show how it's done

Natasha Noy, Google; Yuqing Gao, Microsoft; Anshu Jain, IBM Watson; Anant Narayanan, Facebook; Alan Patterson, eBay; Jamie Taylor, Google

"I haven't seen anything that is different from the many versions of semantic networks that have been designed and implemented for the past 60+ years."
– John Sowa, 2019-07-25

Serving Representations For *t* And *t-1*

http://localhost/thermometer represented as Content-Type: text/turtle

```
@prefix sosa: <http://www.w3.org/ns/sosa/> .
@prefix ssn: <http://www.w3.org/ns/ssn/> .
@prefix : </vocab#> .

[] a sosa:Observation ; ssn:hasProperty :Temperature ;
sosa:FeatureOfInterest :Hall4 ;
sosa:hasSimpleResult 31 ; :time 4 .

[] a sosa:Observation ; ssn:hasProperty :Temperature ;
sosa:FeatureOfInterest :Hall4 ;
sosa:hasSimpleResult 30 ; :time 3 .
```

Detecting An Event: Comparing *t-1* With *t*

```
ASK
FROM <thermometer>
WHERE {
  ?x ssn:hasProperty :Temperature ; sosa:FeatureOfInterest :Hall4 ;
  sosa:hasSimpleResult ?tempx ; :time ?timex .

  ?y ssn:hasProperty :Temperature ; sosa:FeatureOfInterest :Hall4 ;
  sosa:hasSimpleResult ?tempy ; :time ?timey .

  FILTER (?tempy > ?tempx && ?tempx <= 30)
  FILTER (?timey > ?timex)
}
```