From Internet of Things Platforms to Web of Things User Agents

Prof. Dr. Andreas Harth
Department Data Spaces and IoT Solutions, Fraunhofer IIS-SCS
Chair of Technical Information Systems, Friedrich-Alexander University Erlangen-Nuremberg

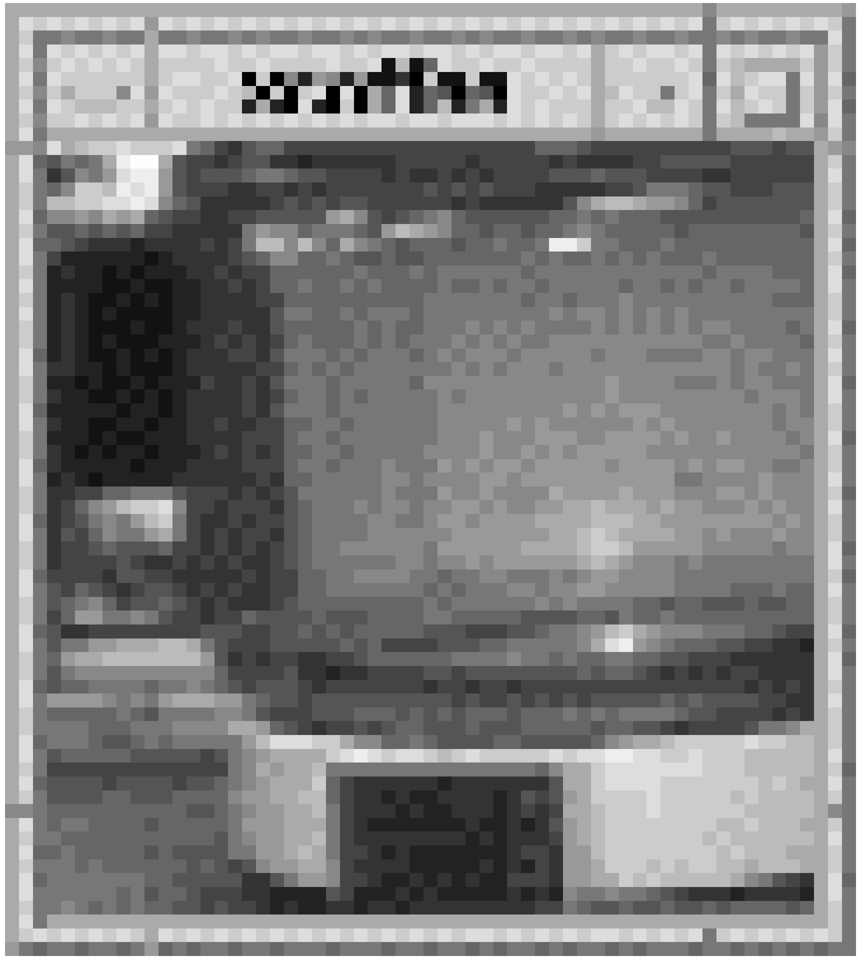
Fraunhofer IIS

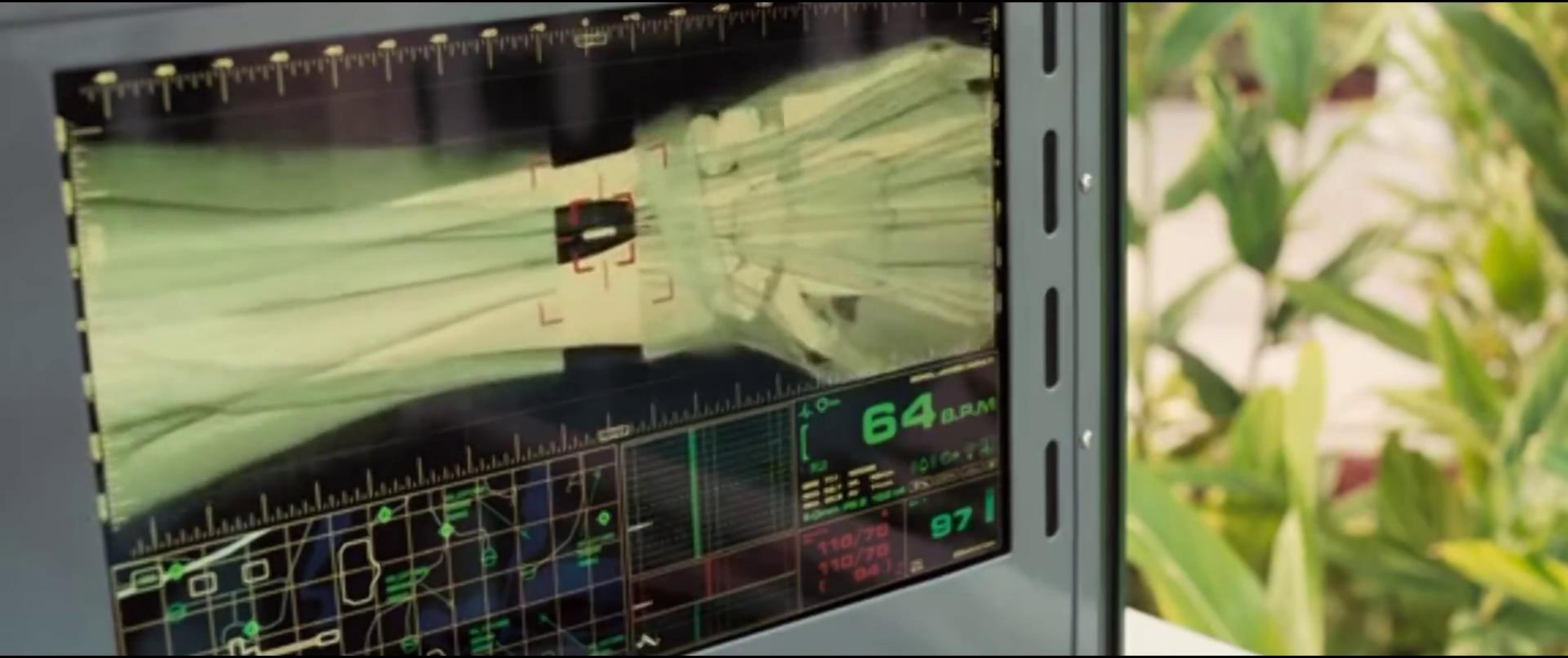
FRIEDRICH-ALEXANDER
UNIVERSITÄT
ERLANGEN-NÜRNBERG

Outline

- **The Internet of Things**
- Internet of Things Platforms
- Uniform Data Access with Linked Data
- Specifying and Executing Behaviour
- Conclusion

Trojan Room Coffee Pot (1991)




64 B.P.M
110/70
110/70
97

Things

- Networked computers with sensors and actuators
- Computers
  - AtMEGA 32u4 (Arduino), ESP8266, ESP32, ARM Cortex M0-M4…
- Sensors and actuators
  - Button, temperature, humidity, barometric pressure, CO2, gyroscope/accelometer, Earth magnetic field…
  - LEDs, beepers, relais, servos/motors...
- Network
  - Passive or active wireless data transmission technologies

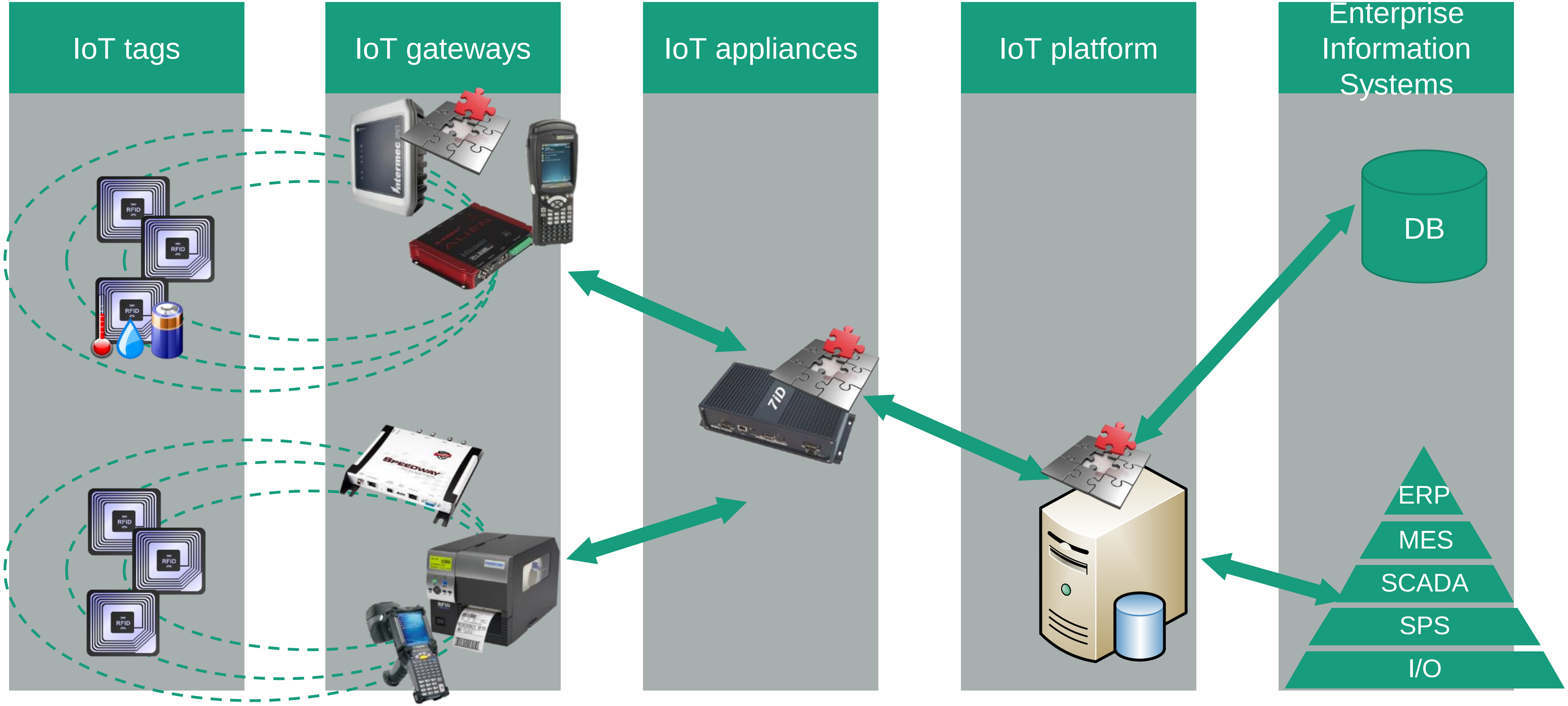

Basic Use Cases Internet of Things

- Alerts
- Tracing
- Condition Monitoring
- Tracking
- Identification

Outline

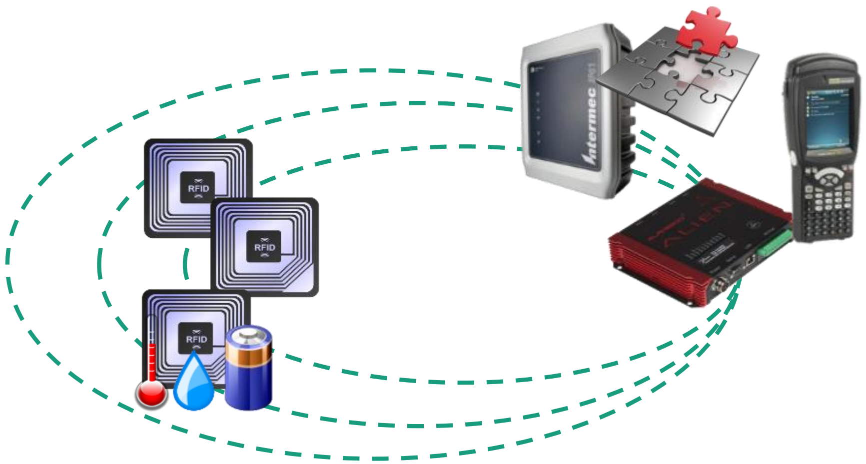
- The Internet of Things
- **Internet of Things Platforms**
- Uniform Data Access with Linked Data
- Specifying and Executing Behaviour
- Conclusion

Internet of Things (IoT) System Architecture



Lempert, S., 2015. *RFID-Middleware. Metastudie und Marktübersicht: Grundlagen, Anbieter und Produkte aus dem proprietären und Open Source-Umfeld*. Stuttgart: Fraunhofer Verlag. ISBN 978-3-8396-0915-6.

From Devices to IoT Gateways



- The device either sends (pushes) data to the gateway or
- The gateway accesses (pulls) data from the device
- Gateways have to speak the physical wireless communication protocol

Rfid.automobile (Wikipedia)

Which Physical Wireless Communication Protocol?

Wireless Radio Communication Technologies

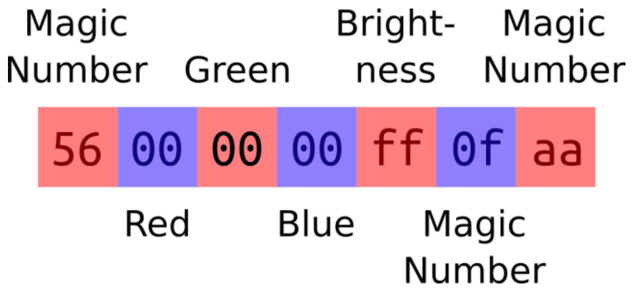
Technology	Frequency	Range	Market Entry	Price of Device (approx.)
Radio-frequency Identification (RFID)	120–150 kHz	~ 10 cm (passive), 100 m (active)	<2000	1 Euro (passive), 5 Euro (active)
Bluetooth Low Energy (BLE)	2.4 GHz	~ 30 m (indoors)	<2010	20 Euro
Zigbee	868 MHz, 2.4 GHz	~ 20 m (indoors)	<2010	20 Euro
Wireless LAN (WLAN)	2.4 GHz, 5 GHz	~ 20 m (indoors)	<2000	20 Euro
Low-power Wide-area Network (LPWAN)	868 MHz	1-2 km	~2017	60 Euro

…and there are also mobile cellular networks und satellite communication.

A BLE Advertisement (Read) Message

Manufacturer ID	04 99
Data format	05
Temperature in 0.005 degrees	12 fc
Humidity in 0.0025%	53 94
Pressure in 1 Pa (-50 000 Pa Offset)	c3 7c
X-axis acceleration in mG	00 04
Y-axis acceleration in mG	ff fc
Z-axis acceleration in mG	04 0c
Battery and Tx power	ac 36
Movement Counter	42
Measurement Sequence Counter	00 cd
MAC address	cb b8 33 4c 88 4f

A BLE Write Message

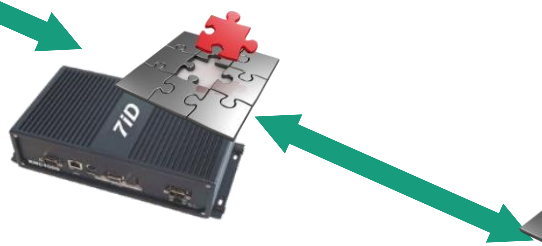



thomann

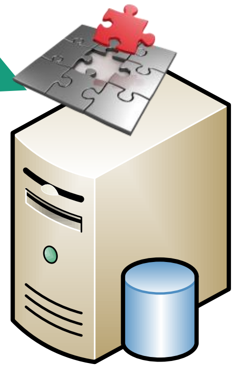

thomann

From IoT Gateways and IoT Appliances to the IoT Platform

- IoT Gateways and IoT Appliances typically push data to the IoT Platform



- IoT Gatways and IoT Appliances have to speak the protocol of the IoT Platform



- Communication happens using standardised internet technologies, such as TCP/IP, DNS…
- But what specific network protocol?
- But which data model? Which data format?

Which Network Protocol?

ROS

UPnP™

MQTT.ORG

http://

SIP
Session Initiation Protocol

WAMP

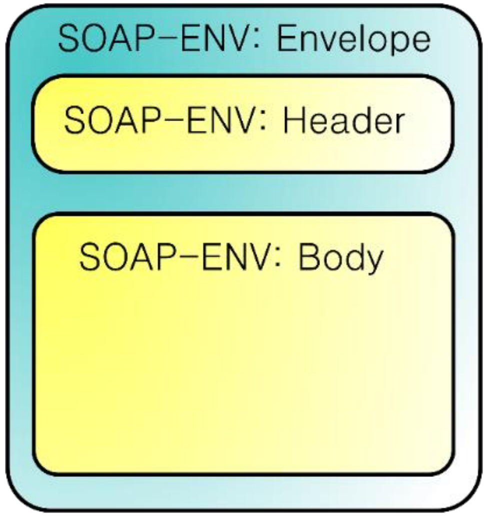
DDS

XMPP

CoAP

AMQP
Advanced Message Queuing Protocol

Stomp



CORBA®

Which Data Model? Which Data Format?

CSV

{JSON}

protobuf
Protocol Buffers

AVRO™

Microsoft .net™

RDF

Java

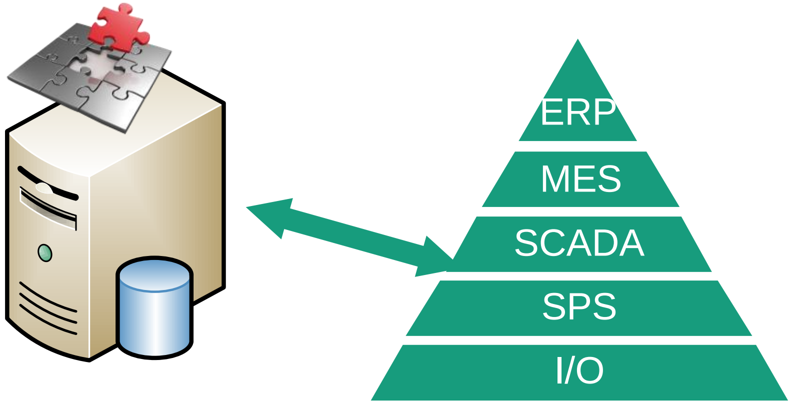
RMI

<xml />

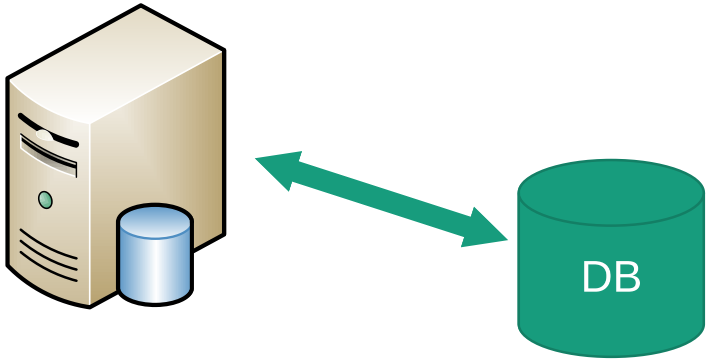
CAP'N PROTO
cerealization protocol

From the IoT Platform to the Enterprise Information Systems

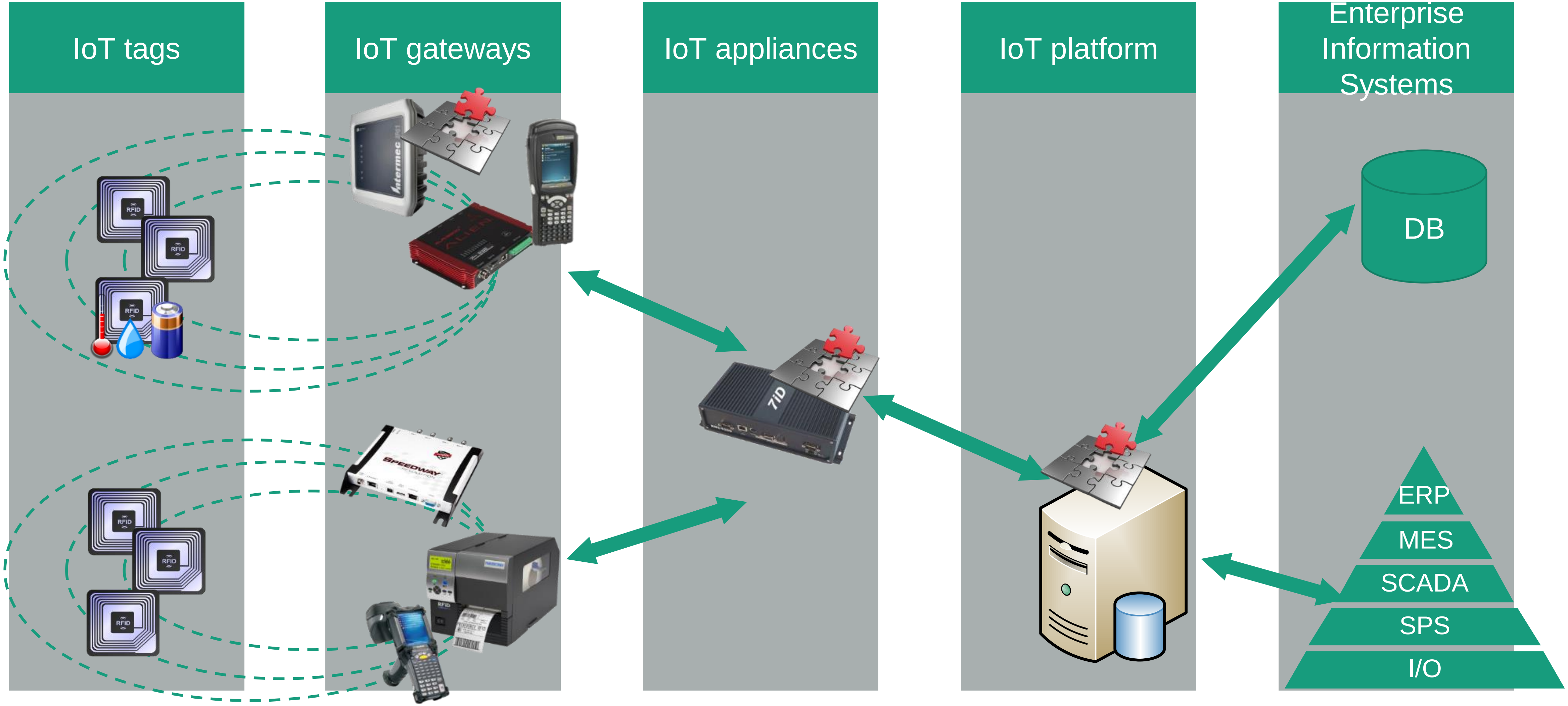
- Pre-processed data from sensors needs to be fed into the Enterprise Resource Planning (ERP) system, into the Manufacturing Execution System (MES)…



- Pre-processed data from sensors needs to be stored in some sort of database (for tracing)



Internet of Things (IoT) System Architecture



Lempert, S., 2015. *RFID-Middleware. Metastudie und Marktübersicht: Grundlagen, Anbieter und Produkte aus dem proprietären und Open Source-Umfeld*. Stuttgart: Fraunhofer Verlag. ISBN 978-3-8396-0915-6.


salesforce
Microsoft
SAP
Commercial
IoT
Platform
A0078
NORDICID
accent
conbee
LoRa
Hybrid-TAG L500 Series

IoT Platform Business Models

- A centralised platform yields a killer business model (Apple's app store: 30 % of each transaction) with vendor lock-in
- As a result, many players (Microsoft, IBM, SAP, Bosch, Siemens…) want to establish platforms for IoT
- Building such a platform is very difficult from a technological point of view due to heterogeneity of network protocols, data models, data formats…
- Let's say Microsoft, IBM, SAP, Bosch, Siemens… achieve to build an IoT platform
- While the business model is very tempting, becoming the one platform that everybody uses is difficult
- If we end up with ten (or n) platforms, we have the integration problem again
- So: go for a decentralised architecture

Outline

- The Internet of Things
- Internet of Things Platforms
- **Uniform Data Access with Linked Data**
- Specifying and Executing Behaviour
- Conclusion

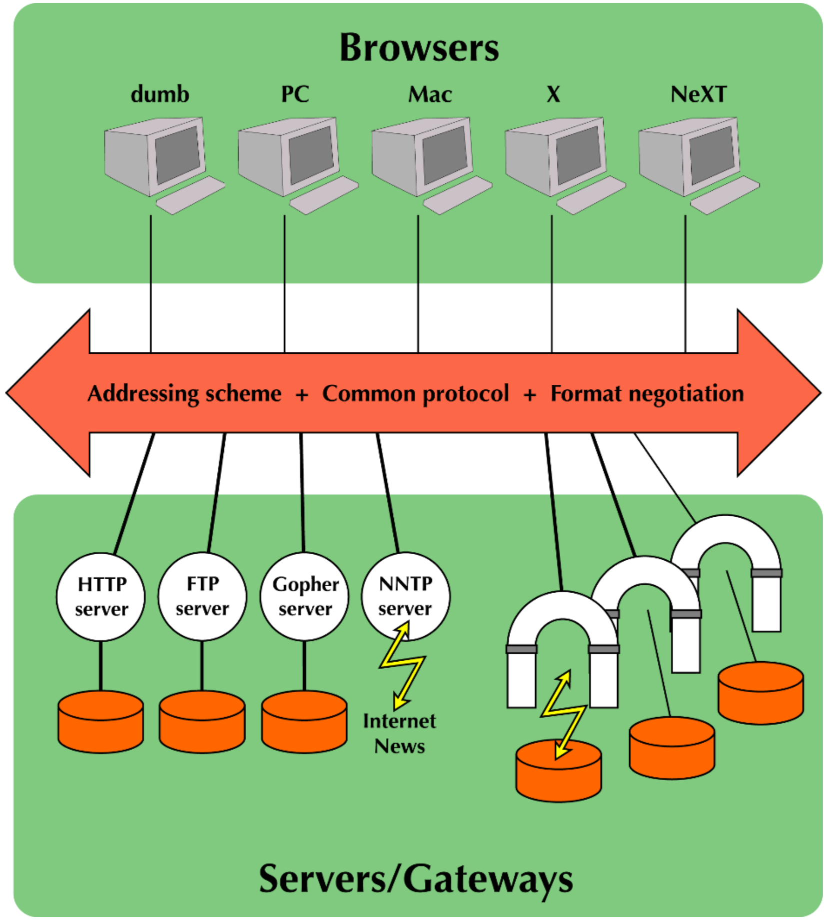
The World Wide Web

- Anybody with an Internet connection can participate, both consume and publish information
  - Decentralised architecture via hyperlinking
  - Open standards, royalty-free via W3C
- Users can jump from one server to another, anywhere in the world
- Users can look under the hood via “view source”
- No business model for the Web as information exchange platform

Web Architecture

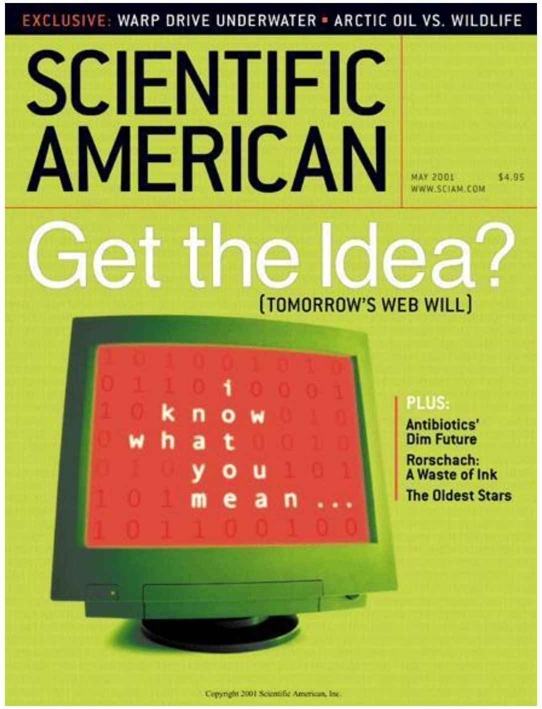
- URI: RFC 1630 (1994), now RFC 3986
- HTTP: RFC 1945 (1996), now RFC 7230, 7231, 7232, 7234, 7235

- HTTP assumes a strict separation between user agents and servers
- User agents emit requests, receive response
- Servers answer to incoming requests with a response



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.

May
2001



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

Linked Data Principles

1. Use URIs as names for things
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards (RDF*, SPARQL)
4. Include links to other URIs. so that they can discover more things.

http://www.w3.org/DesignIssues/LinkedData.html

Which Network Protocol?

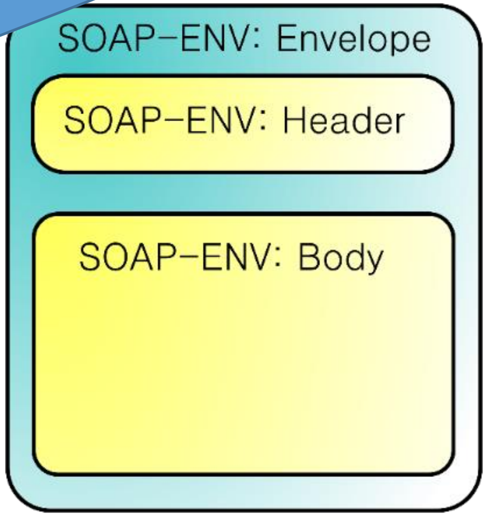
ROS

UPnP™

WAMP

Queuing Protocol

Stomp



CoAP

CORBA®

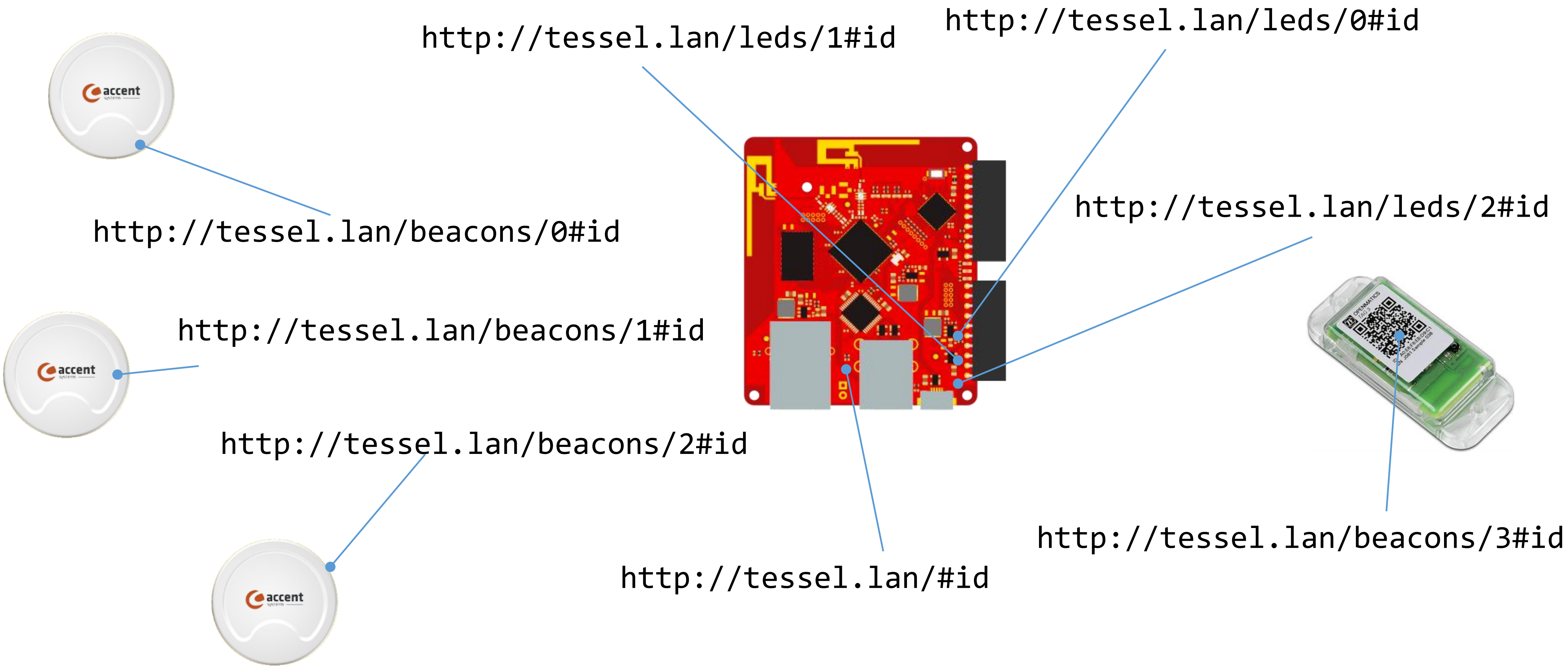
Solved, it's HTTP

Which Data Model? Which Data Format?

Solved, it's RDF

RMI

HTTP URIs for Sensors and Actuators



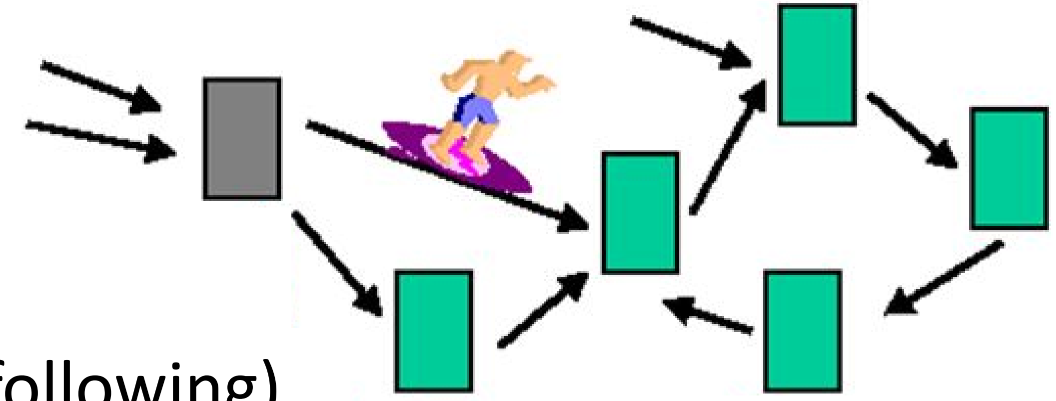
Use Linked Data for Data Access

- HTTP for data access (read) and manipulation (write)
- Data providers are HTTP servers, data consumers are HTTP user agents
- Semantic Web languages (RDF, RDFS, a bit of OWL) for data representation and integration
- SPARQL for querying

Semantic “Web” Today

Jul
2020

- 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)



http://slideplayer.com/slide/8080871/

Future Scenarios Today

Jul
2020

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

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

Reading a BLE Advertisement Message via HTTP

Manufacturer ID	04 99
Data format	05
Temperature in 0.005 degrees	12 fc
Humidity in 0.0025%	53 94
Pressure in 1 Pa (-50 000 Pa Offset)	c3 7c
X-axis acceleration in mG	00 04
Y-axis acceleration in mG	ff fc
Z-axis acceleration in mG	04 0c
Battery and Tx power	ac 36
Movement Counter	42
Measurement Sequence Counter	00 cd
MAC address	cb b8 33 4c 88 4f

↓ ble-adapter (HTTP GET http://131.188.245.49/history?mac=c4eb72373fe8&limit=1)

```
[] rdf:type ble:Advertisement ;
    ble:peripheral </devices/c4eb72373fe8> ;
    ble:timestamp "2020-07-24T10:32:51.93+01:00"^^xsd:dateTimeStamp ;
    ble:manufacturerId "0499" ;
    ble:manufacturerData ( 5 18 252 83 148 195 124 0 4 255 252 04 12 172 54 66 0 205 ) .
```

Mapping a ble:Advertisment to a sosa:Observation

```
[] rdf:type ble:Advertisement ;
    ble:peripheral </devices/c4eb72373fe8> ;
    ble:timestamp "2020-07-24T10:32:51.93+01:00"^^xsd:dateTimeStamp ;
    ble:manufacturerId "0499" ;
    ble:manufacturerData ( 5 18 252 83 148 195 124 0 4 255 252 04 12 172 54 66 0 205 ) .
```

observation.n3 (ldfu)

```
[] a sosa:Observation ;
    sosa:hasSimpleResult 1036 ;
    sosa:resultTime "2020-07-24T10:32:51.93+01:00"^^xsd:dateTimeStamp ;
    sosa:madeBySensor </devices/c4eb72373fe8> ;
    sosa:observedProperty ble:acceleration_z .
```

Mapping a sosa:Actuation to a HTTP POST Request

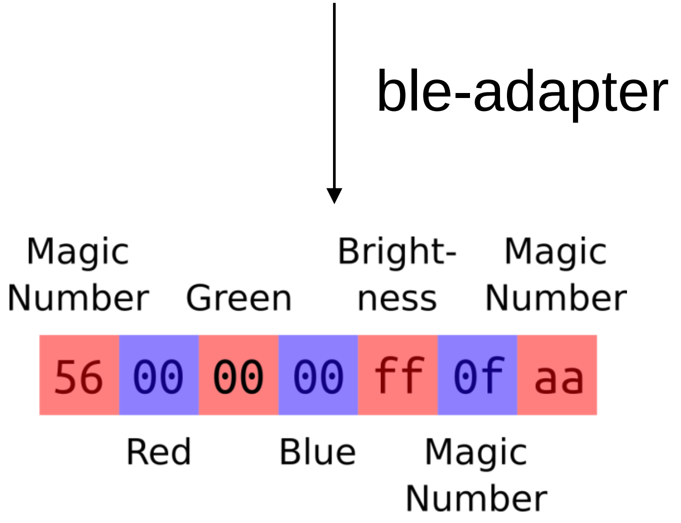
```
[] a sosa:Actuation ;
    sosa:hasSimpleResult 255 ;
    sosa:madeByActuator </devices/ffff8001c9c4> ;
    sosa:actsOnProperty ble:brightness .
```

↓ actuation.n3 (ldfu)

```
[]  http:mthd httpm:POST ;
    http:requestURI <http://131.188.245.49/devices/ffff8001c9c4/char/0017> ;
    http:fieldName "Content-Type" ;
    http:fieldValue "application/json" ;
    http:body "{
                    \"type\": \"WriteWithoutResponse\",
                    \"data\": \"56000000ff0faa\"
                 }" .
```

Writing a BLE Messages via HTTP

```
[]  http:mthd httpm:POST ;
    http:requestURI <http://131.188.245.49/devices/ffff8001c9c4/char/0017> ;
    http:fieldName "Content-Type" ;
    http:fieldValue "application/json" ;
    http:body "{
                    \"type\": \"WriteWithoutResponse\",
                    \"data\": \"56000000ff0faa\"
                 }" .
```



Outline

- The Internet of Things
- Internet of Things Platforms
- Uniform Data Access with Linked Data
- **Specifying and Executing Behaviour**
- Conclusion

How to Specify and Run Applications?

JS

Lua

Samsung ARTIK™

IFTTT

Google Cloud Platform

Microsoft Azure
IoT Hub

AWS IoT

BOSCH
Invented for life
Bosch IoT Suite as Platform as a Service
One open IoT platform for all domains

BPEL

BPMN

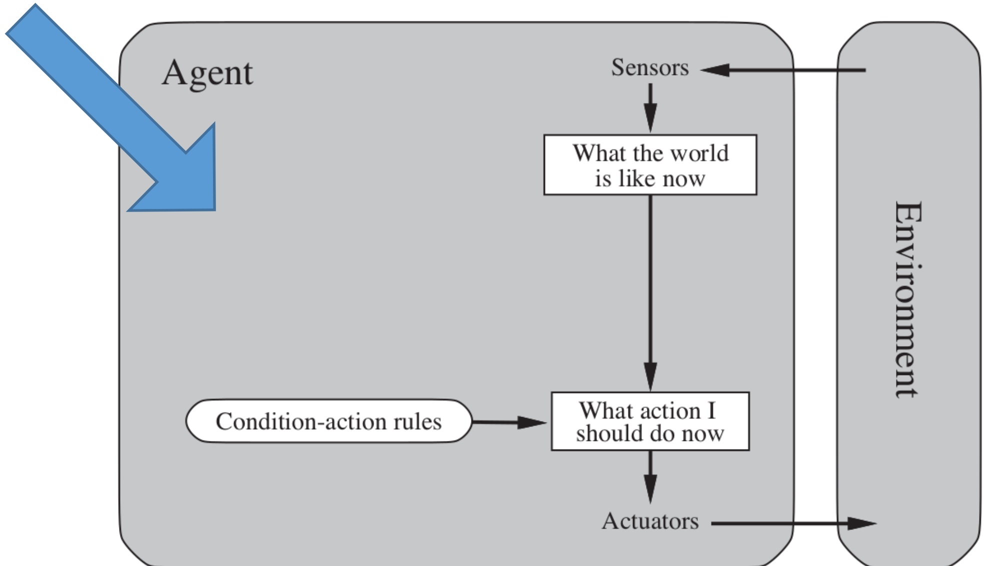
ASM

ECA

Cognitive Architectures

- SOAR (initially: State, Operator, Apply, Result),
- ACT-R (Adaptive Control of Though – Rational)
- Goal: to create „intelligent agents“
- For starters we only consider user agents that are
  - „simple reflex agents“ (Russel & Norvig, see figure),
  - aka „tropistic agents“ (Genesereth & Nilson)
- Use condition-action rules to control the agent‘s behaviour

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



Specify Application Behaviour Declaratively

- Using rules
  - IF condition THEN assertion (derivation rules)
  - IF condition THEN request (request rules, a variant of production rule)
- Using workflows (layered on top of the rules layer)
  - Using Sequence, Parallel, Conditional
- Can be also run in decentralised settings, i.e., without the need for a centralised platform

Specifying Behaviour

If

04 99	05	12 fc	53 94	c3 7c	00 04	ff fc	04 0c	ac 36	42	00 cd	cb b8 33 4c 88 4f
Manufacturer ID	Data format	Temperature in 0.005 degrees	Humidity in 0.0025%	Pressure in 1 Pa (-50 000 Pa Offset)	X-axis acceleration in mG	Y-axis acceleration in mG	Z-axis acceleration in mG	Battery and Tx power	Movement Counter	Measurement Sequence Counter	MAC address

then

56	00	00	00	ff	0f	aa
Magic Number	Red	Green	Blue	Bright-ness	Magic Number	Magic Number

Mapping a sosa:Observation to a sosa:Actuation

```
[] a sosa:Observation ;
    sosa:hasSimpleResult 1036 ;
    sosa:resultTime "2020-07-24T10:32:51.93+01:00"^^xsd:dateTimeStamp ;
    sosa:madeBySensor </devices/c4eb72373fe8> ;
    sosa:observedProperty ble:acceleration_z .
```

↓ magic.n3 (ldfu)

```
[] a sosa:Actuation ;
    sosa:hasSimpleResult 255 ;
    sosa:madeByActuator </devices/ffff8001c9c4> ;
    sosa:actsOnProperty ble:brightness .
```

Keep It Simple

- 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

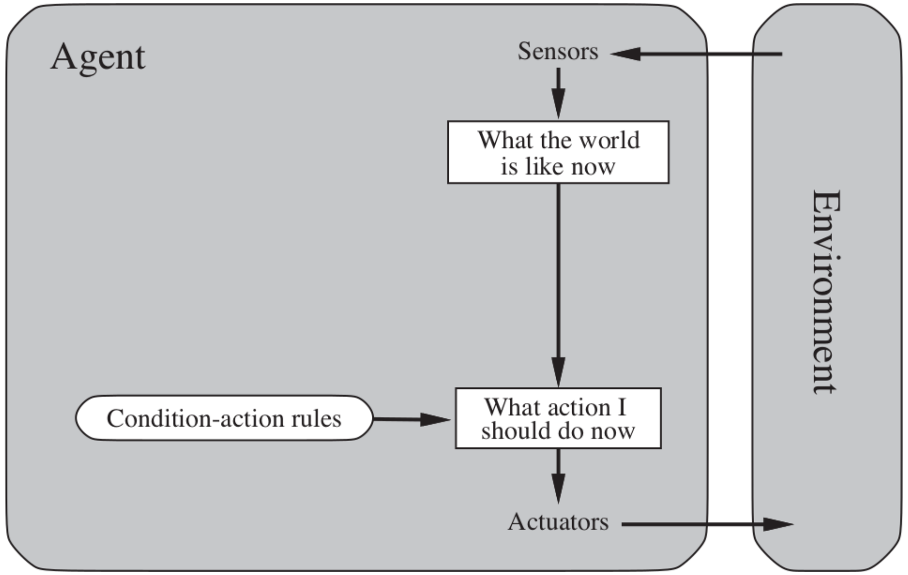
- Operational agent-oriented programming…
  - Yoav Shoham, Agent-Oriented Programming. Artificial Intelligence, 1993
- …instead of Situation Calculus
  - J. McCarthy and P. Hayes. Some philosophical problems from the standpoint of artificial intelligence. In: Machine Intelligence, 4:463–502. Edinburgh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

- If you want, layer more complex things on top later

Towards Simple Agents On The Web

- Can we start with a simple "Hello World" scenario for agents on the web?
- Agents: Query processing on live data
- 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

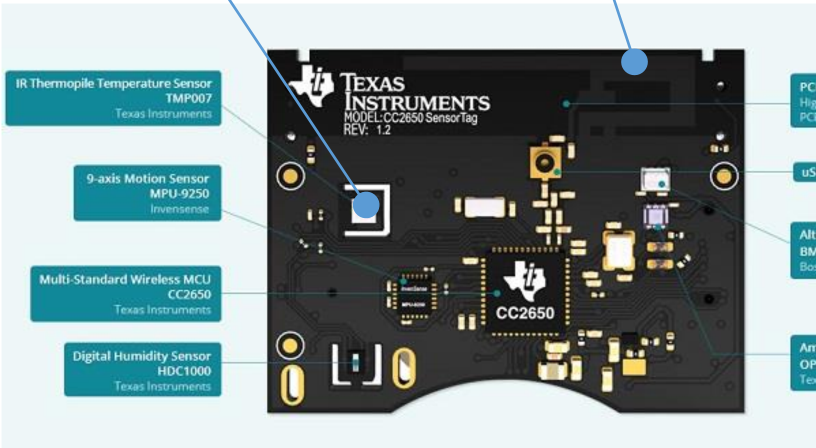
Server: Thermometer Sensor as Linked Data

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 .
}
```

Query User Agent and Sensor as Linked Data

User Agent Loop

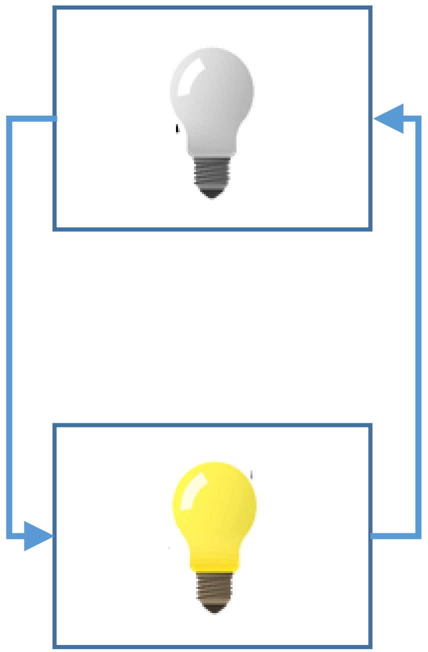
```
while true:
  execute SPARQL query with FROM
  output results
  wait 1 second
```

Server Loop

```
every second:
  read and store temperature

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

Read-Write Linked Data User Agent: Blinker

```
GET <led.ttl>

{
  <led.ttl#id> :state :off .
}  => {
  PUT </led.ttl> { <led.ttl#id> :state :on . }
} .

{
  <led.ttl#id> :state :on .
}  => {
  PUT </led.ttl> { <led.ttl#id> :state :off . }
} .
```



Simple Agents Layer Cakes

Read/Write Linked Data User Agents

Link-Following User Agents

Query User Agents

Adding Unsafe HTTP Methods Read-Write Linked Data

URI + HTTP + RDF (read-only) Linked Data

Scenario: Behaviour of Smart Buildings

- 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)

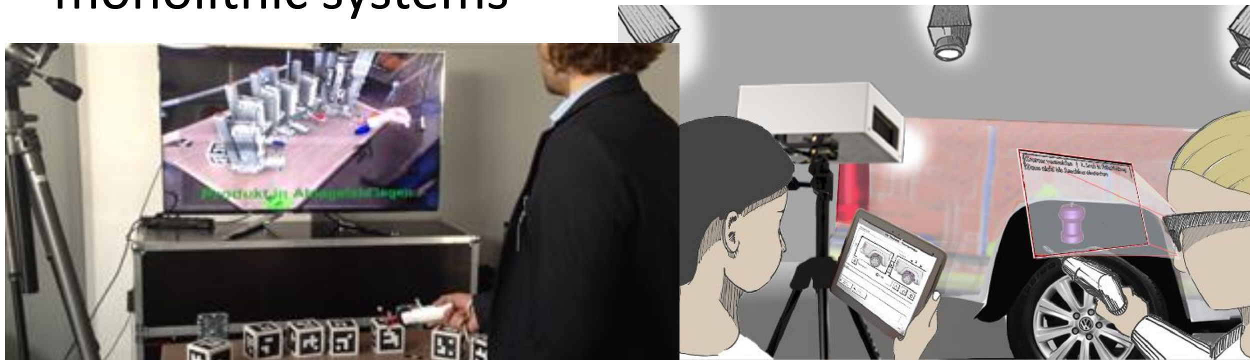
i-VISION

- 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

- ARVIDA: Reference Architecture for Virtual Services and Applications
- 23 partners incl. 17 industry partners from German industry (Daimler, Volkswagen,...)
- Flexible, open and interoperable virtual technology systems, breaking up current monolithic systems

Bundesministerium für Bildung und Forschung



Outline

- The Internet of Things
- Internet of Things Platforms
- Uniform Data Access with Linked Data
- Specifying and Executing Behaviour
- **Conclusion**

Summary

- Uniform data representation helps when reading sensor state
- Uniform data representation helps when writing actuator state
- Integration of message formats can be done via RDF
- A uniform communication protocol helps when accessing different sensors and actuators
- Commercial IoT platforms aim at hiding differences in communication protocols and data representation
- Web technologies offer a vendor-neutral path to accessing sensor data and effecting change in actuators
- Rule-based and workflow-based methods allow for the declarative specification of application behaviour

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: single machine agents
- 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
  - Multiple agents and agent communities
  - Supporting users to specify agent behaviour
- But let’s start with building simple agents!

Acknowledgements

- My old colleagues at KIT, in particular Sebastian Speiser, Steffen Stadtmueller, Felix Keppmann and Tobias Kaefer, and my colleagues at Fraunhofer SCS and FAU, in particular Victor Charpenay, Matthias Farnbauer-Schmidt and Daniel Schraudner

- BMBF: ARVIDA (FKZ 01IM13001G, 2013 – 2016) and MOSAIK (01IS18070A, 2019 – 2022) projects
- 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).
- Screenshots from Dredd and James Bond movie