A.I. GROUP
Semantic Web &Multi-agent Systems

UNIVERSITY OF PIRAEUS
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Semantic Interoperability on the Internet of Things

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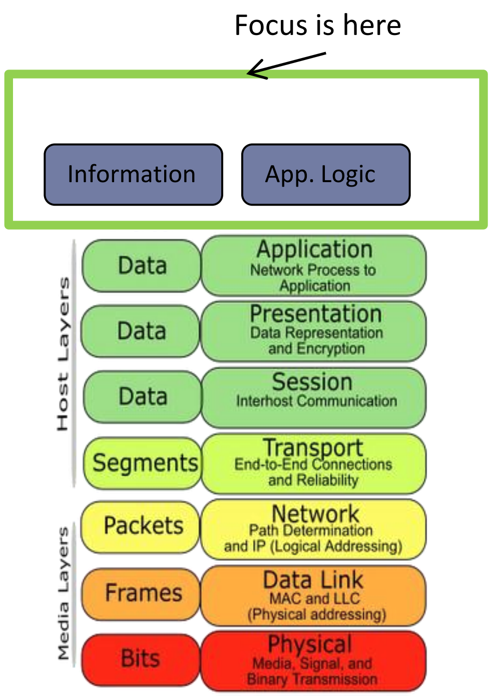
Outline

- IoT interoperability at present
  (what companies showed at CES 2012, USA)
- A vision of the future of IoT
  (interoperable)
- Web of Things
  (reliance on the Web architecture as key enabler of interoperability on IoT)
- Semantic technology
  (for interoperability and openness at the information-level)
- SSGF and Smart Proxy approach
  (at VTT/ERCIM funded work)
- Related Trends/Efforts



Interoperability at present

(in IoT-related systems)

material is borrowed by Artem Katasonov, VTT

UPnP / DLNA

- UPnP: “Universal Plug and Play”
- DLNA: “Digital Living Network Alliance”

- Not a new thing: An industry standard.

- At home, we have a Windows PC, a Sony PS3, two Samsung Android smartphones.

- All these devices can share their media (images/videos/audio) over WiFi, so that they can be played on any of these devices.

- Windows Media Player on PC can also be remotely controlled. So, I can push a video from my smartphone to be played there.

CES 2012: “Screen-to-screen” sharing is everywhere

- Some solutions are based on video-streaming
- Some are based on data exchange
- Focus on ease: just swipe a finger.

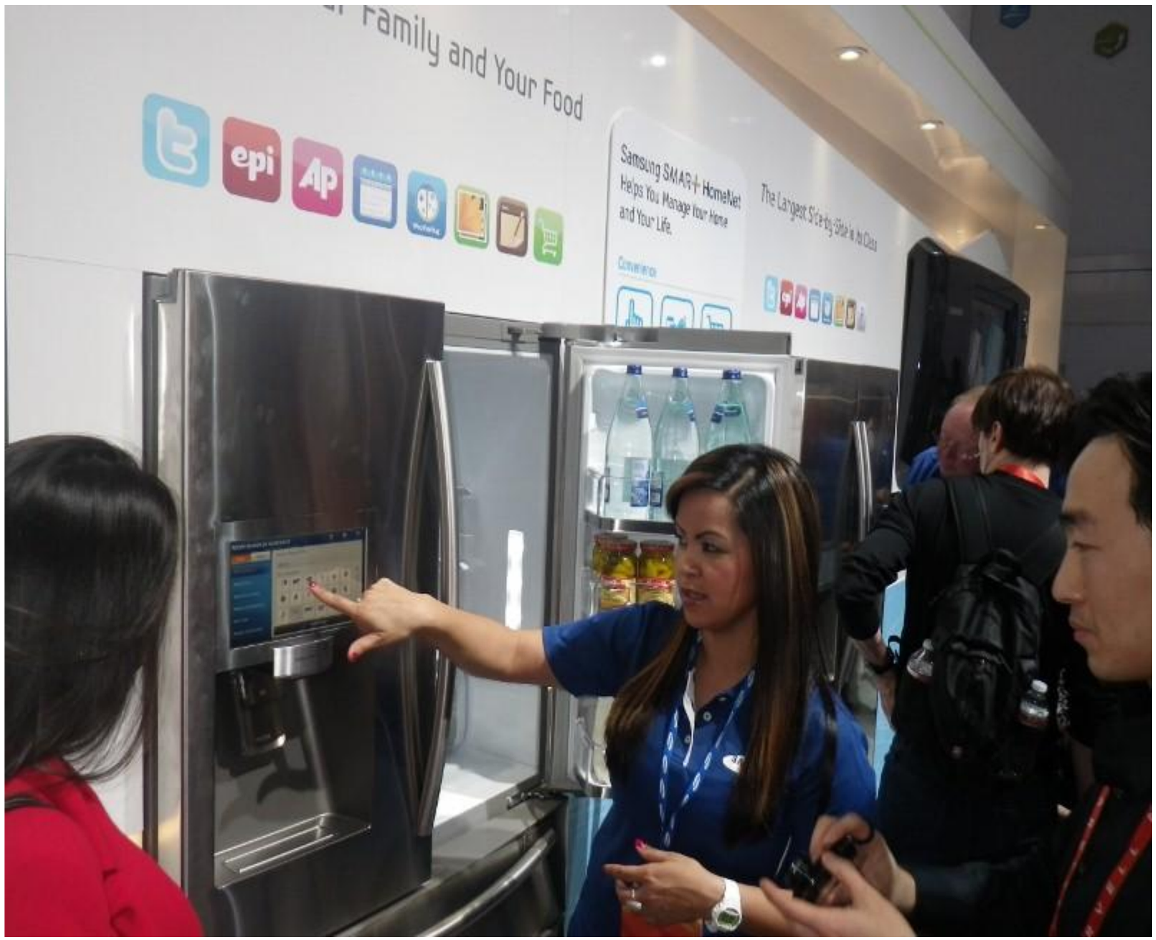
@ Panasonic

CES 2012: "Screen-to-screen" sharing is everywhere (2).

- Not just image/video, but a set of popular applications like Email, Facebook, Google Maps, PowerPoint, etc.
- Special client app for different devices.

@ Eureka park

CES 2012: “Smart” fridges



- Can check your Facebook
- Can send a picture from smartphone
- Fridge can push to a smartphone alarms about expiring goods

@ Samsung

CES 2012: “Smart” washing machines

@ LG

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CES 2012: Fridge communicating with an oven

- Fridge can have food recipes stored
- A recipe can be sent to the oven
- Oven will set the cooking temperature and other settings according to the recipe

@ LG

CES 2012: Phones are connected to everything

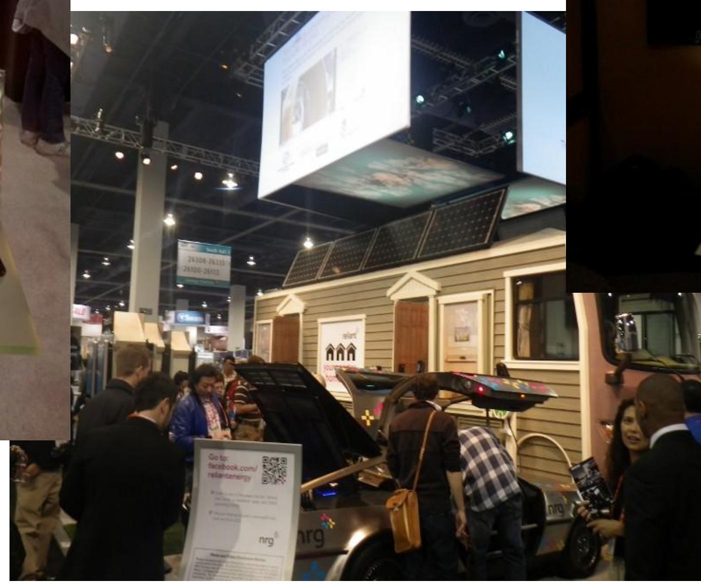
@ LG

@ Intel

@ Panasonic

CES 2012: Home Automation focus is on energy saving

@ Z-Wave Alliance



@ Eureka park

- All is about:
  - Gateway “boxes” to access data from and control devices.
  - Interfaces for users

CES 2012: Home Automation: Lights, locks, alarms

- Can define rules, e.g.:
  - WHEN: front door is locked from outside (leaving house)
  - THEN: all light off, blinds close, etc.

CES 2012: Home Automation: + phone/tablet, again

One of the most visible trends at CES:

Smartphone as a "remote control for life" (mobile apps used for controlling home automation, home appliances, etc.)

So, interoperability?

- Except for UPnP and DLNA-based media sharing, today one **MUST**:
  - Buy all the devices from one vendor, **OR**
  - Connect "smart" devices (phones, TVs) from different vendors through installing a particular software client (from one vendor) on each of them (limited list of supported platforms), **OR**
  - Use a particular gateway box, then can connect devices from different vendors (from a limited list of supported by the gateway)
- **In all three cases, a single vendor is responsible for all of the "interoperability"**

CES 2012: IoT-related panels

3 panels on “smart home”:

1. Mostly appliance manufacturers (Panasonic, GE, Whirlpool, etc.)
2. Home automation companies (Control4, Clare Controls, etc.)
3. Mostly networking companies and operators (Netgear, Verizon, etc.)

Openness?

- 3rd panel (especially Netgear representative) explicitly spoke of a need for the openness: cross-vendor interoperability, open APIs.
- In both 1st and 2nd, this topic was raised during Q&A. The answer was “yes, probably” in both cases. Not sure how much they actually support this.

Connectivity gateways? (special boxes resolving interoperability issues).

The 3rd panel:

- Opinion was that it is an important first step.
- The second step would be to do it gateway-free, based on intelligence spread in devices and applications.

A vision of the future of IoT

(interoperable IoT and an IoT for supporting innovation)

The scenario

1. **Mary** has at her home a remotely-controlled **heater**, an **indoor temperature sensor** in the **living room**, and a **control software** that adjusts the heater's power based on the temperature and Mary's preference settings. All devices and software are from **Vendor A**.

2. Mary buys another **temperature sensor**, from a **Vendor B**, and it is installed in the **bedroom**:
   - **Control software** is able to work with more than one sensor (e.g. to keep the temperature in both rooms close to Mary's preferences).
   - There is no common standard on how temperature measurements are encoded and transmitted. Vendor A and Vendor B use different approaches.

Problem: How to enable "Plug-n-Play", i.e. that **software of Vendor A** is able to utilize the **sensor of Vendor B** (mostly) automatically?

A simple (yet difficult) scenario cntd.

3. Mary learns that there exists a **software application** from some **Vendor C** that is capable of **energy-saving predictive heating control** that takes into account not only the **indoor temperature** but also the changes in the **outdoor temperature**:
   - Mary wants to use this application instead of the control software she has in place. She downloads it from a Web-based store, or runs a service instance in the Cloud
   - The new application discovers the heater and the two indoor temperature sensors Mary has at home
   - It then fails to find an outdoor temperature sensor in Mary's home network and opts to use an appropriate Web-service (current data or a forecast) for that e.g. Pachube/COSM

Problem:
How such a **decoupling of hardware (and other data providers) from software applications** can be possible?
How generic applications are able to '**configure**' themselves to work with various sensors / devices / services?

Vision (what need to be done)

- Ability to develop **gradually growing IoT environments**, contrasted to a need to install and interconnect all IoT devices and software at once.

- Ability to **interconnect devices from different vendors**.

- Ability of **3rd parties to develop software applications for IoT environments**, contrasted to applications coming only from the devices' vendors.

- Ability to **develop applications that are generic** in the sense of running on various IoT device sets (different vendors, same purpose), contrasted to developing applications for a very particular configuration of devices

In summary: ***"App store for smart environments***

e.g. smart home, smart city, smart island

3 IoT worlds interoperable

- ***Attached devices***: Identifiers such as RFID tags or barcodes are attached to things to enable their automatic identification and tracking. Based on a thing's identifier, the information about the thing is then retrieved from a database or from the Web.

- ***Sensing and Actuating devices***: These devices are placed in the close vicinity of 'things' and provide a "second-hand" access (from outside) to their properties or functions. Examples are temperature and other sensors, cameras for cars' register plate recognition, and actuators like remotely-controlled door locks or window blind controls.

- ***Embedded devices***: Some 'things', such as industrial machinery, home electronics, smart phones, wearable devices, have embedded processors, data storages, sensors and actuators, enabling "first hand" access (from inside) to them, often over IP and without special gateways.

Two interoperability approaches

- *Standardize everything*

(difficult to reach agreements, difficult to cover everything in an evolving world)

- *Some level of standardization + some intelligence*
  - *E.g. Web protocols and formats (W3C recommendations)*
  - *Plus intelligence through semantic technology*
    - *Requiring formats/languages for encoding metadata and ontologies (W3C recommendations)*

Web of Things

Web of Things

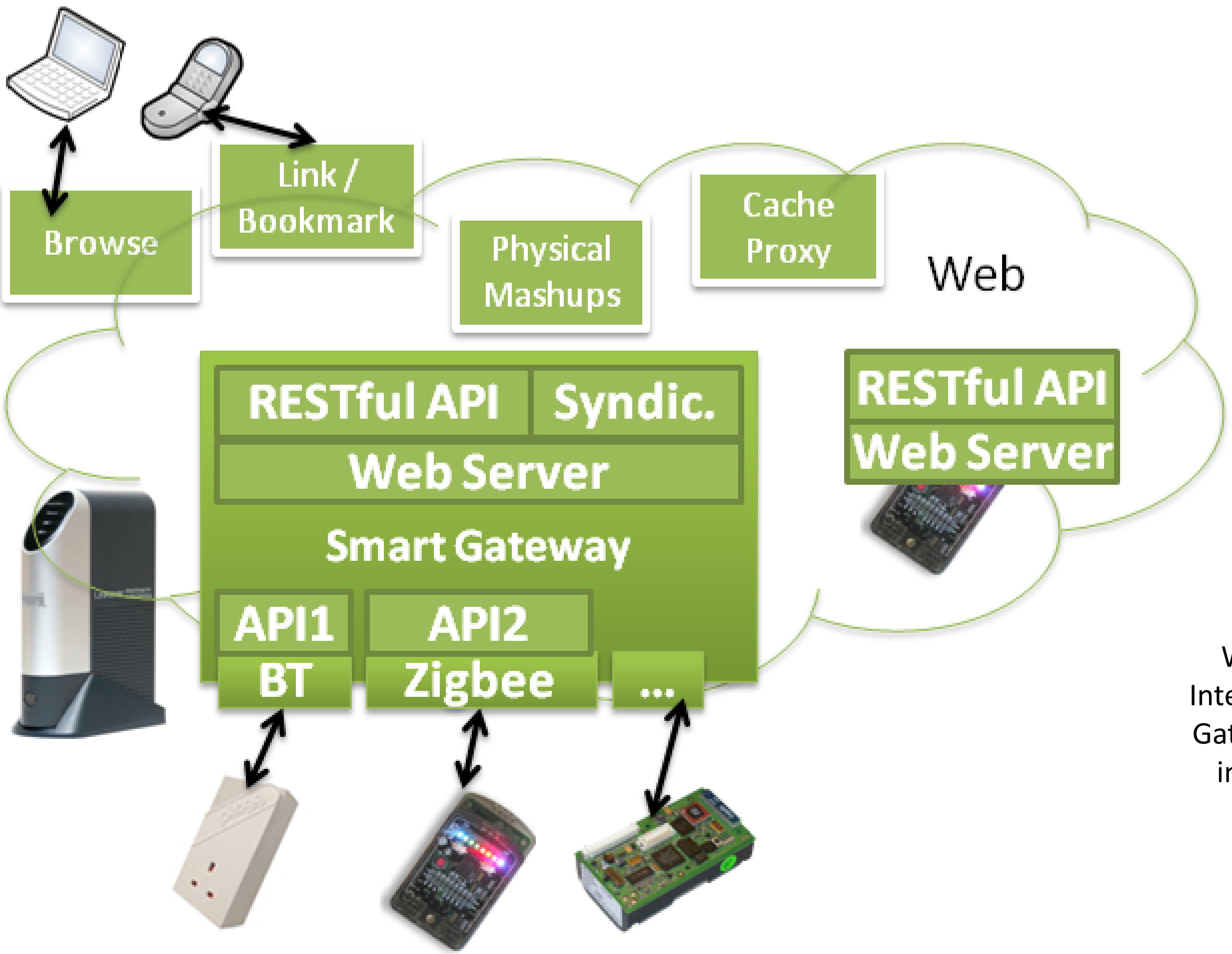
- A trend in IoT area is to **attempt to integrate 'things' seamlessly with the *existing Web infrastructure*** and to **expose connected 'things' uniformly as Web resources**, resulting in what is called the Web of Things (WoT).

- The aim is to **reuse *the architectural principles of the Web*** and **apply them to the connection with the real world**, i.e. with smart entities e.g.
  - smart fridges (with embedded computers),
  - smart packages (with RFIDs),
  - smart rooms (with sensors and actuators),

  thereby making them **first-class citizens of the Web**.

Integrating ‘things’ into the Web:

the RESTful approach



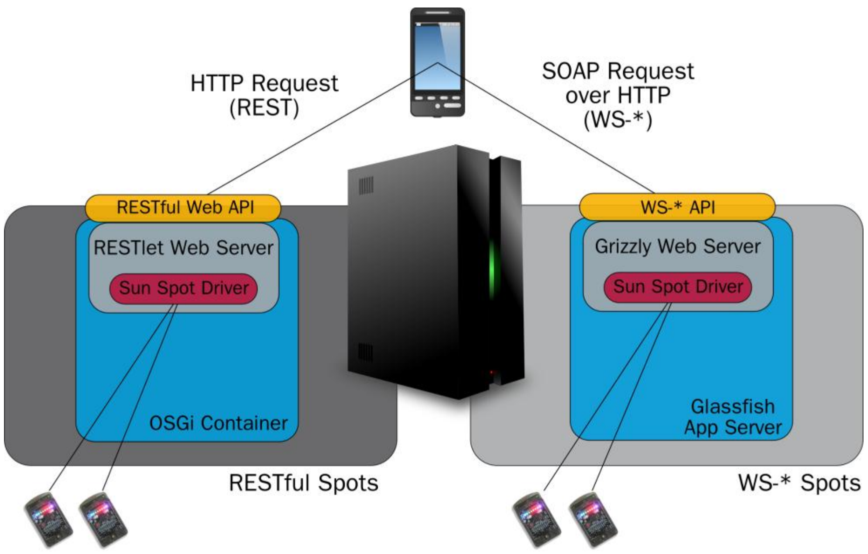
Web and Internet Integration with Smart Gateways (left), direct integration (right).

Paper of D. Guinard et al, “Architecting a Mashable Open WWW of Things”, Technical Report No. 663, Department of Computer Science, ETH Zurich, February 2010

WS-* vs. RESTful experiment

2 types of service-oriented architectures (SOA):

- REST: Representational State Transfer
- WS-* : declare services' functionality and interfaces in WSDL

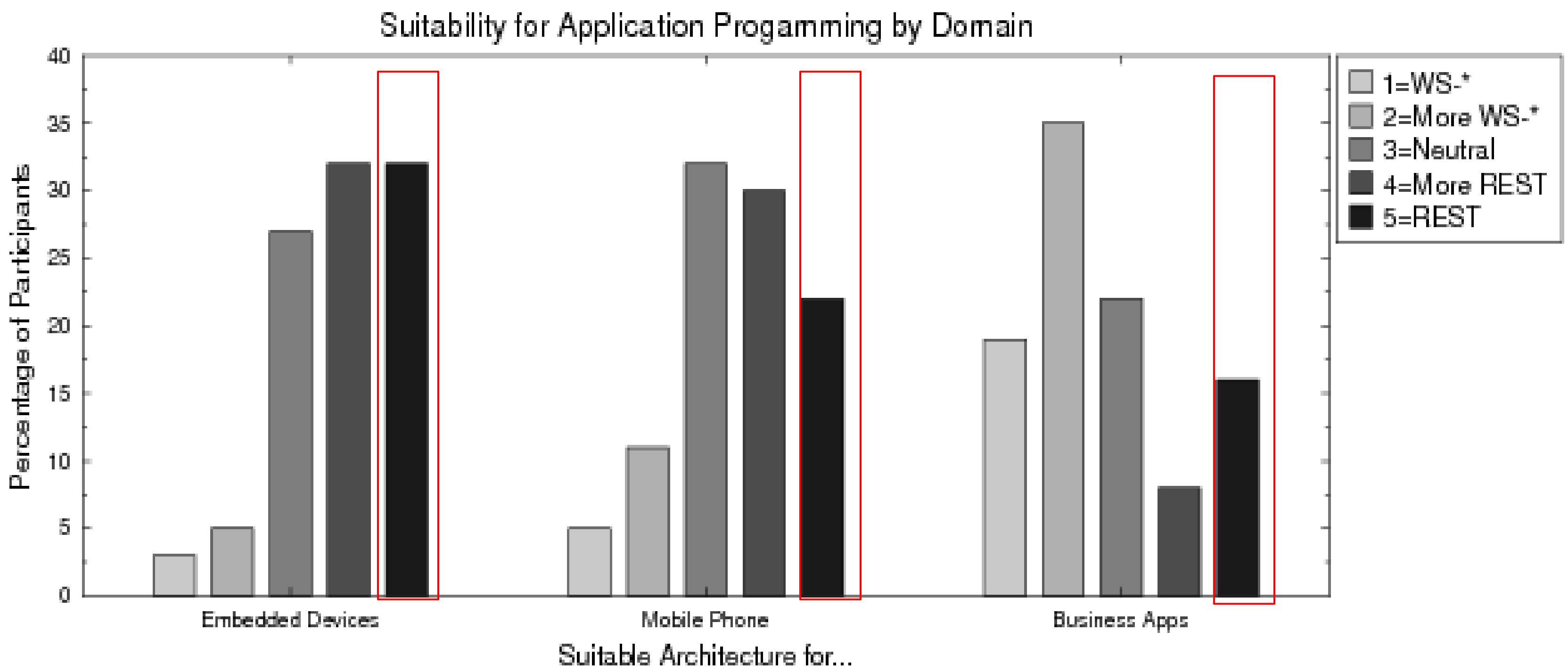


Experiment's Data:

- 69 novice developers learned both technologies
- They Implemented mobile phone applications that retrieve sensor data both through a RESTful and through a WS-* service architecture.
- Developers found REST easier to learn than WS-*
- They consider it more suitable for programming smart things.
- For applications with advanced security and Quality of Service requirements, WS-*Web services are perceived to be better suited.

Developers' opinion survey in Ph.D. Thesis of D. Guinard

WS-* vs. RESTful experiment

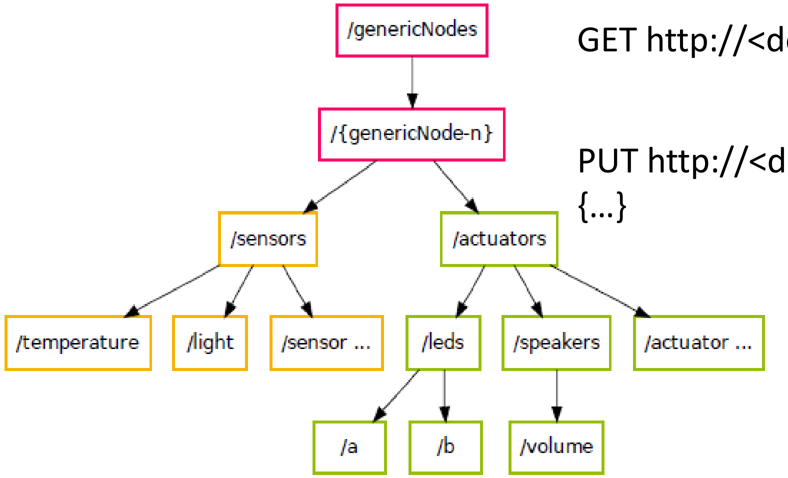


Developers' opinion survey in Ph.D. Thesis of D. Guinard

So, What is a REST request…?

*REST: "*Representational state transfer"
RESTful: stateless, the server does not have to keep the history of past requests to process and answer a request.

- **GET** is used to retrieve the representation of a resource (since we talk about Resource Oriented Architecture of Things).
- **POST** creates a new resource (includes payload).
- **PUT** is used to update the state of an existing resource or to create a resource by providing its identifier (includes payload).
- **DELETE** is used to remove a resource.



GET http://<domain>:<port>/generic-nodes/1/sensors/temperature

PUT http://<domain>:<port>/generic-nodes/1/sensors/temperature/value
{…}

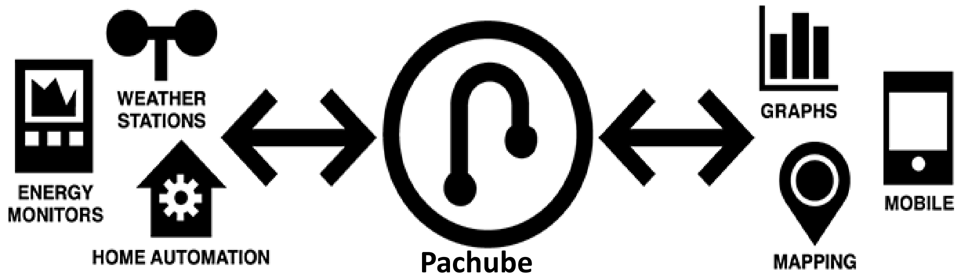
Ph.D. Thesis of D. Guinard

REST responses and payloads

- JSON (easiest to process from JavaScript, i.e. in client Web apps)
- XML
- CSV
- RDF


```
{"resource":
        {"name": "Temperature",
         "content":
                {name":"Current Temperature",
                "description":"Ambient Temperature",
                "value": 24.0,
                "unit": "celsius"}
        }
}
```

COSM/Pachube.com example



- Send your data to Cosm Cloud DB over simple REST API
- Access the data from other components of your application
  Request: GET http://api.pachube.com/v2/feeds/1977/datastreams/1
  Response: { "current_value":"100", "max_value":"10000.0", "at":"2010-07-02T10:16:19.270708Z", "min_value":"-10.0", "tags":["humidity"], "id":"1" }
- Utilize reusable Web widgets,
  - E.g. for visualization of data-streams
  - E.g. for wrapping user input as data-stream(s)

Web and IoT

- Applying Web architecture to Internet of Things (WoT) is a great facilitator of interoperability, BUT:

- WoT is mostly about the protocols and formats

- WoT as such will not enable realization of the following:
  - 2 temperature sensors both delivering measurements over HTTP GET as JSON, but of different structure and with different object/property names (e.g. Dev1:Temp and Dev2:temperature)
  - 2 heater devices accepting commands over HTTP PUT as JSON, but of different structure and with different object/property names
  - 1 motion-detector&light-switch application receiving measurements' data by connected devices (motion detector and switch, via a gateway) and sending commands back to them using heterogeneous vocabularies (e.g. app:Motion and dev:Movement) and syntax (XML vs JSON)

- For true interoperability, we need also Semantic Interoperability, the ability of the devices and applications to unambiguously convey the meaning of data they communicate over Web protocols

Semantic Interoperability

Semantic technology

- Problem: Make computers act in an intelligent way
  - **Approach 1**: To make computers ***so clever*** that they will be able to process the information about the world in its ***full complexity***, e.g. understand human language => traditional Artificial Intelligence (AI)
  - **Approach 2**: To ***simplify*** the description of the world to a level that even ***stupid*** computers will be able to act “intelligently” based on it => Semantic Technology.
- The goals of semantic technology:
  - to make the meaning of data as **explicit** and **unambiguous** as possible
  - to **link** data sources globally: more meaning with same data (small messages, fetch the rest from Web)
- Achieved through “three pillars” of the semantic technology: *Semantic Web data model (RDF)*, *URI*, and *Ontologies*.

Semantic Interoperability of Information Systems

Semantics

- …meaning, the relation between words, phrases, signs, symbols, and what they stand for

Semantic Interoperability

- The ability of information systems to disambiguate information so that receiver and transmiter agents can ”understand” each other and collaborate
- or… ”The mapping of information from one system to another in a meaningful way for their agents”

Ontologies play a key role to this mapping of information (mediated mapping of information via ontologies)

- Not to confuse with Mediated Ontology Mapping
- Recently, Sem. Int. explicated for information that resides in smart devices/objects or things in the Internet (IoT).

This work was carried out during the tenure of an ERCIM "Alain Bensoussan" Fellowship Programme. This Programme is supported by the Marie Curie Co-funding of Regional, National and International Programmes (COFUND) of the European Commission

Semantic Interoperability in Smart Environments/IoT

Problem

- an agent responsible for the management of a smart entity connected to the IoT or in a smart home network, should
  - be able to exploit network information as it was its own
  - have the ability to express its actions' intentions according to a self-owned ontology

Objectives

- agents should be able to semantically associate information from other agents or sources with that agent's own information
- agents and information sources need to share an integrated view of information

Goal (twofold)

- meaningful information exchange or integration between agents that manage entities in smart environments (smart homes, cities, IoT)
- seamless querying and access of distinct and disparate information sources under a common view

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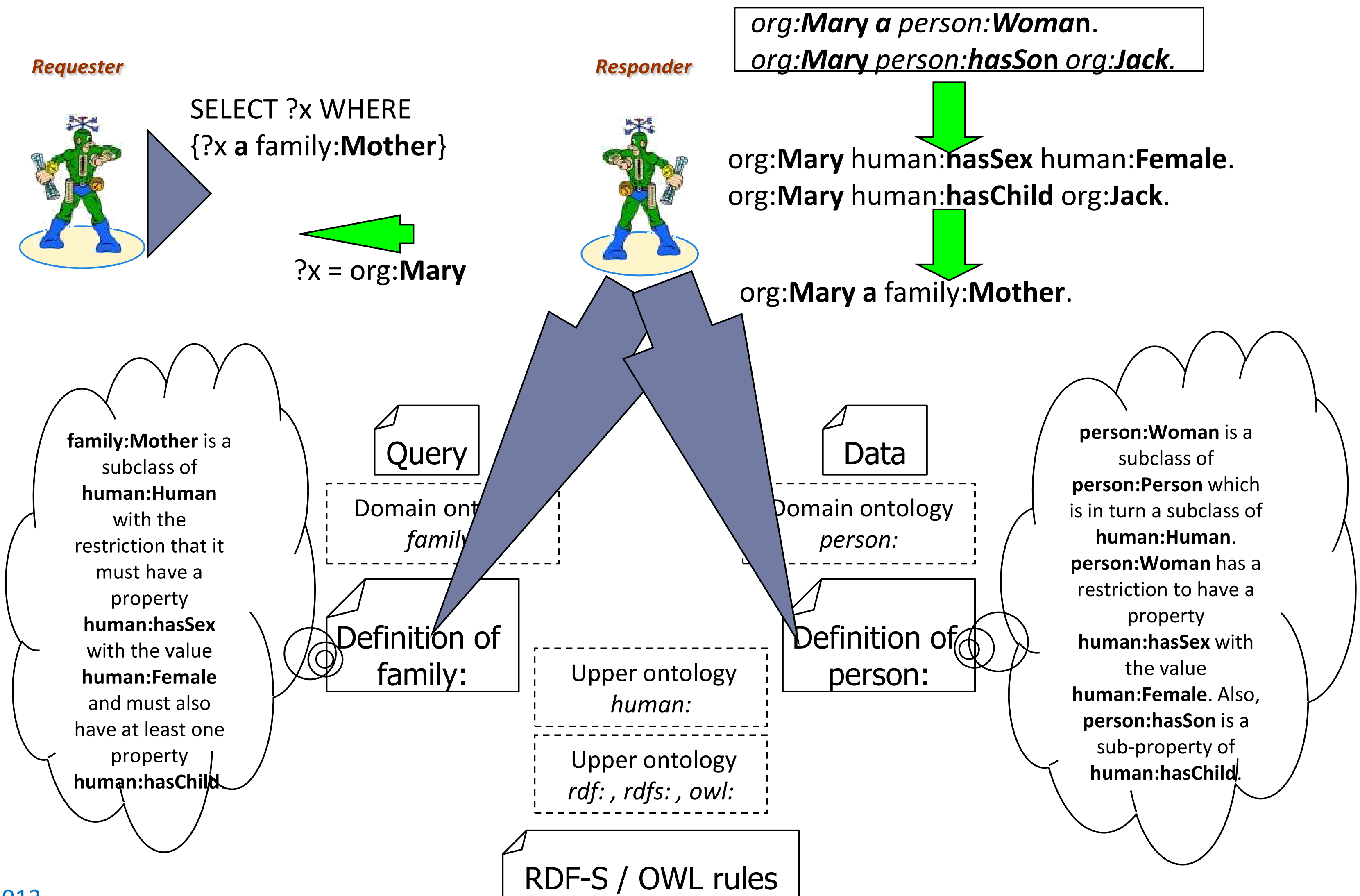
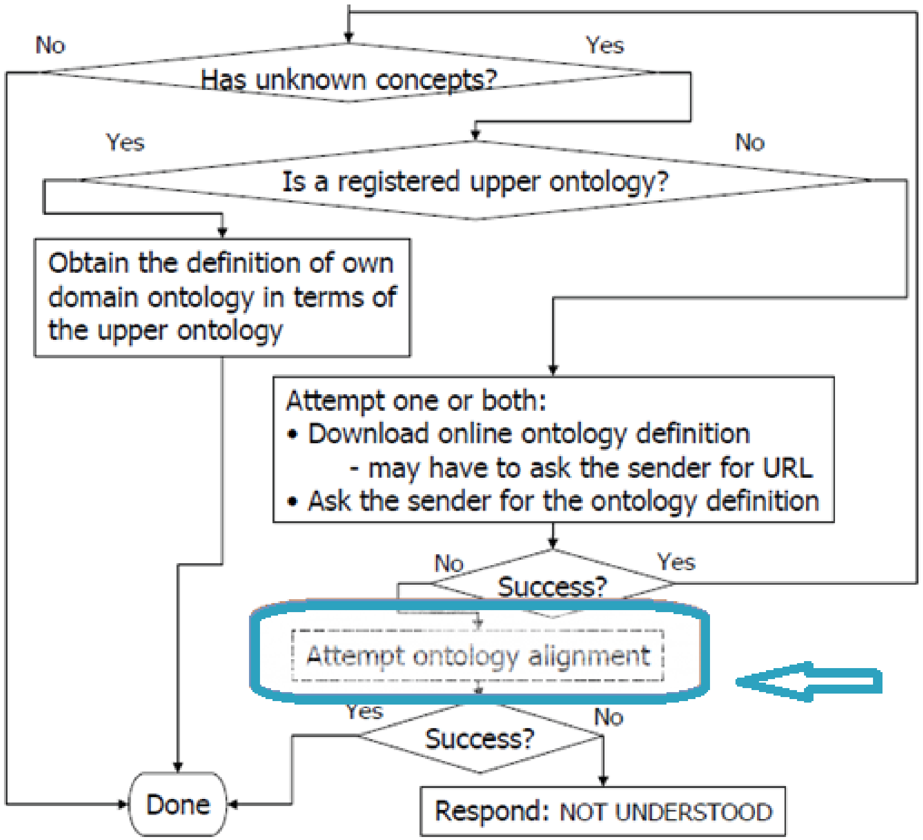
Semantics for interoperability



Ontology linking process



[Katasonov & Terziyan, 2010]

Problem

- devices have their own representation of knowledge in correspondent ontologies but this knowledge is negotiated by their relative agents via an upper ontology that have been agreed at design-time

What if…

- ontology linkage (domain to upper) process is failed due to absense of an upper ontology
- No online definition available
- The sender will not respond to a definition request???

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SSGF and Smart Proxy approach

(at VTT/ERCIM funded work)

Device/Application communication

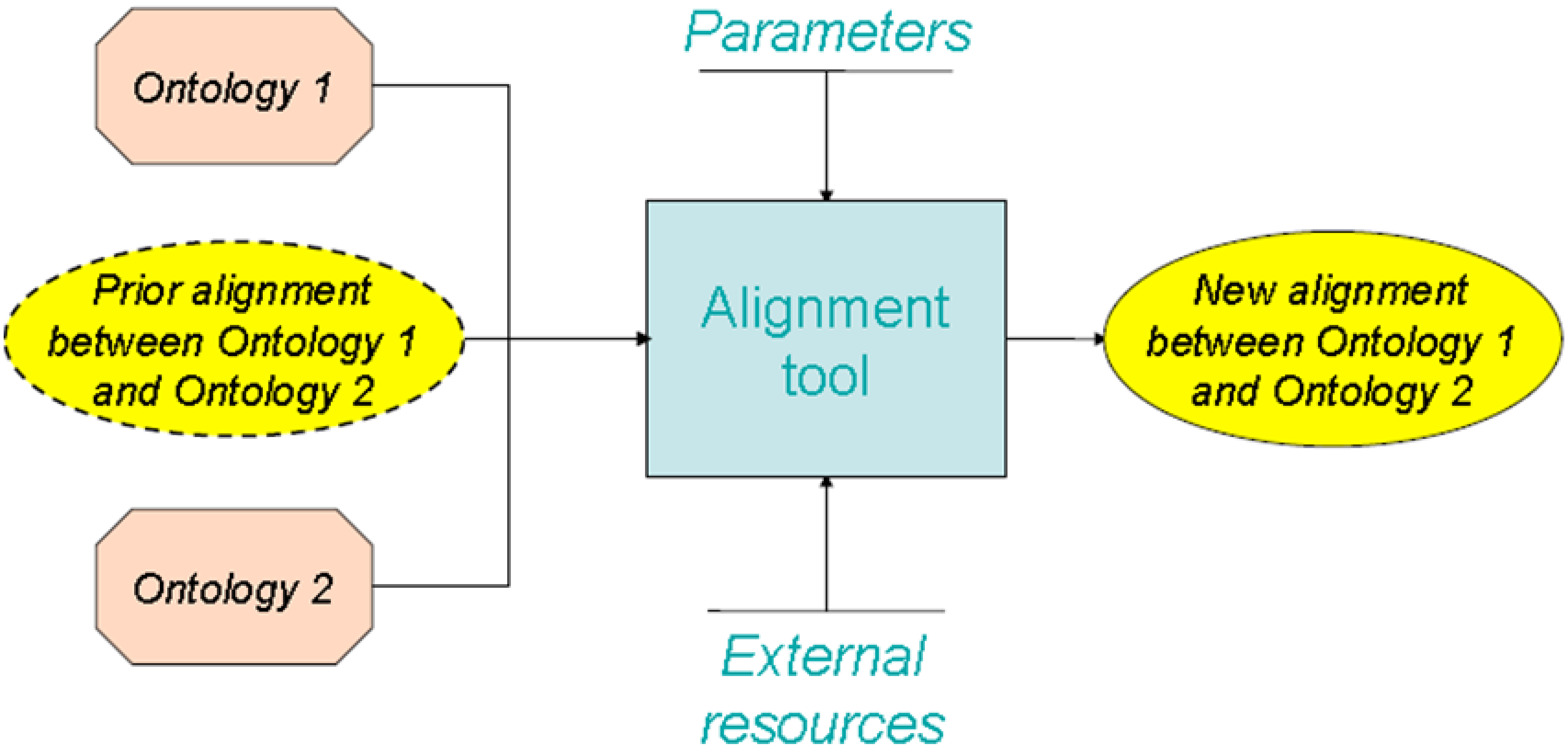
- IoT entities are
  - devices (sensors, actuators associated with physical objects that observe or act on)
  - applications that utilize devices' data in order to run e.g. temperature or movement readings or issue commands to manage them
- In a real smart environments
  - Different kind of devices may exist
  - More than one application may require data from more than one device to run

…AUTOMATED DEPLOYMENT of APPLICATIONS in IoT settings

The Semantic Smart Gateway Framework

- **Task 1:** Register IoT entities (smart devices and smart applications) to a semantic registry (implemented by a shared IoT ontology) (**semantic registration**)
- **Task 2:** Compute alignments between entities' semantics (annotations) and find the similarity of these entities - identify which applications are related to which devices (**ontology alignment**)
- **Task 3:** Compute alignments between the exchanged messages' data of the matched entities (identified in Task 2) (i.e. correspondences of classes/properties used for the semantics of exchanged messages) (**ontology alignment**)

Ontology Alignment task

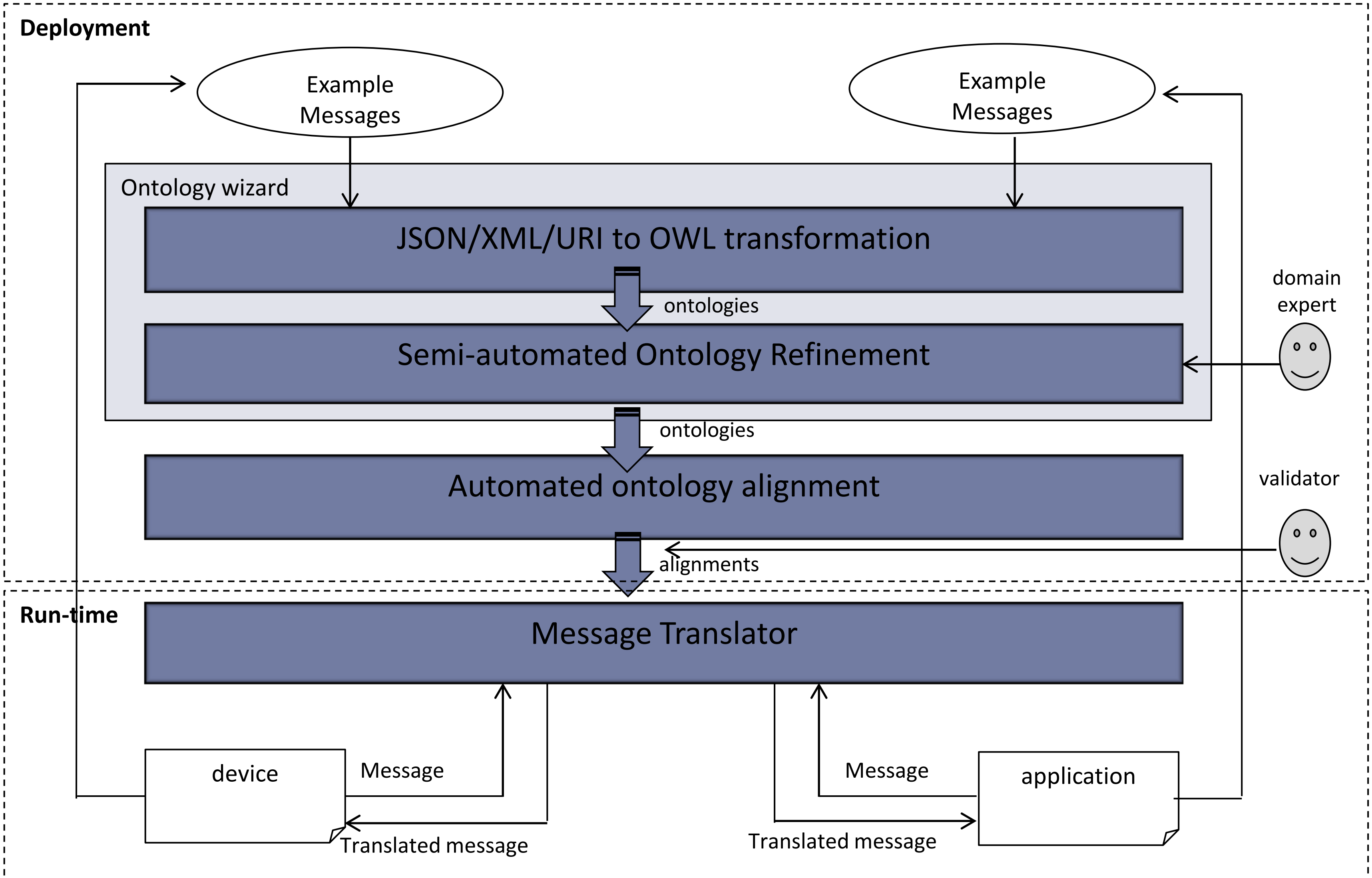


An evaluation setting

- 1 Motion detection sensor observing movements in a room (smart entity)
- 1 Switch actuator and a lamp plugged to it (smart entity)
- 1 Gateway, interconnecting the sensing and actuating devices through wireless technology and providing a ‘device-as-service’ interface via REST data messages exchange.
- A smart application that utilizes the above devices (control entity)
- The **Smart Proxy toolset**

- ❑ **The application is able to ‘understand’ motion detection events and issue commands to the switch actuator e.g. for switching on/off the attached device (lamp)**
- ❑ **The Switch actuator is able to ‘understand’ commands issued by the application**

“Smart Proxy” implementation of SSGF



Example data messages

- Messages
  - ThereGate to App (in JSON):


```
{
 "List": [
  {
   "TimeStamp": 1333450241.736228,
   "Signal": "PropertiesChanged",
   "data": {
    "MotionDetected": true
   },
   "IDeviceId": 25
  }
 ],
 "until": 1333450241.741899,
 "tobj": "signals"
}
```


  - Application to ThereGate (in XML) :


```
<event>
        <type>movement</type>
        <value>false</value>
</event>
```

Alignments discovered encoded in OWL axioms

- Alignments
  - In Alignment API format

```
<map>
  <Cell>
    <entity1 rdf:resource='http://there#motionDetectorSignal_List_Data_MotionDetected'/>
    <entity2 rdf:resource='http://app#movementDetectorResponse_Event_Movement'/>
    <relation>=</relation>
    <measure rdf:datatype='http://www.w3.org/2001/XMLSchema#float'>1.0</measure>
  </Cell>
</map>
```

  - In OWL equivalence axioms

```
<owl:DatatypeProperty rdf:about="http://there#motionDetectorSignal_List_Data_MotionDetected">
  <owl:equivalentProperty rdf:resource="http://app#movementDetectorResponse_Event_Movement"/>
</owl:DatatypeProperty>
```

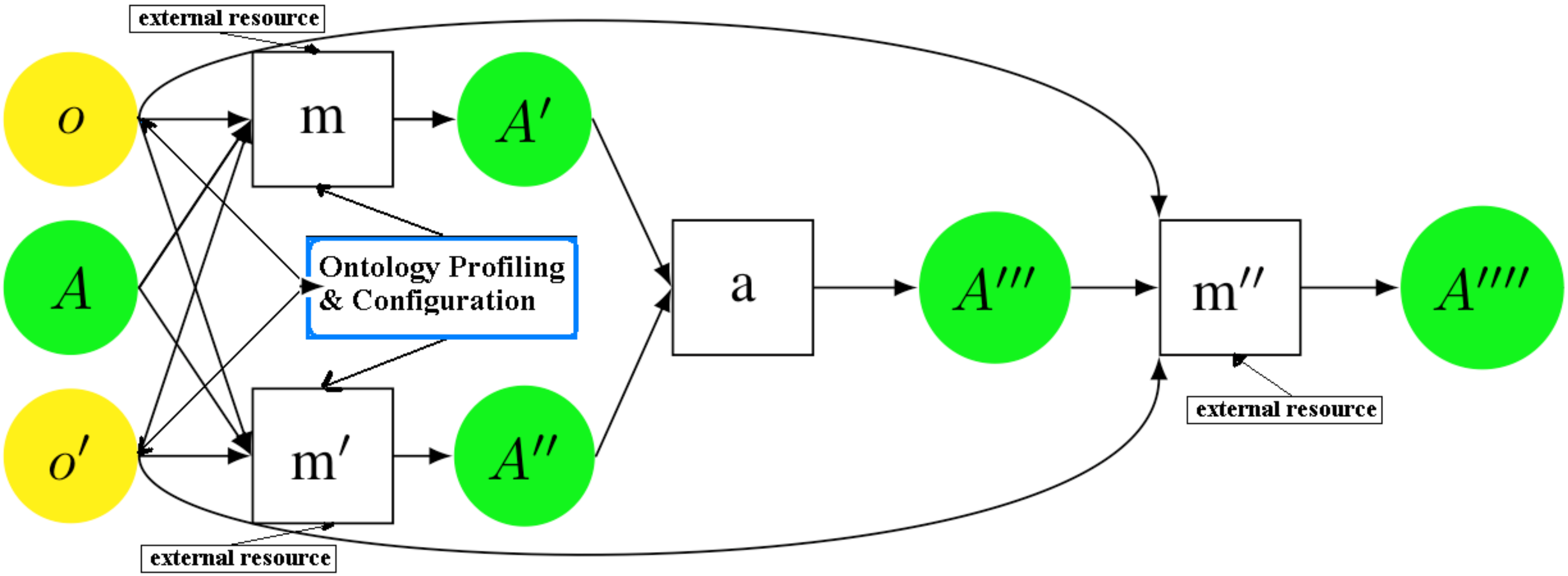
Assumption in Ontology Alignment

- Not a fully automated process
- Human involvement is required for
  - disambiguating ‘hard’ cases of terminology i.e. terms that have not entry in a lexicon e.g. ‘ts’
  - Validation of ontology definition alignments
- BUT…we now place this process at a 3rd (middle) point, i.e. at the SIaaS provider side, so
  - e.g. Mary has nothing to do related to this expert task

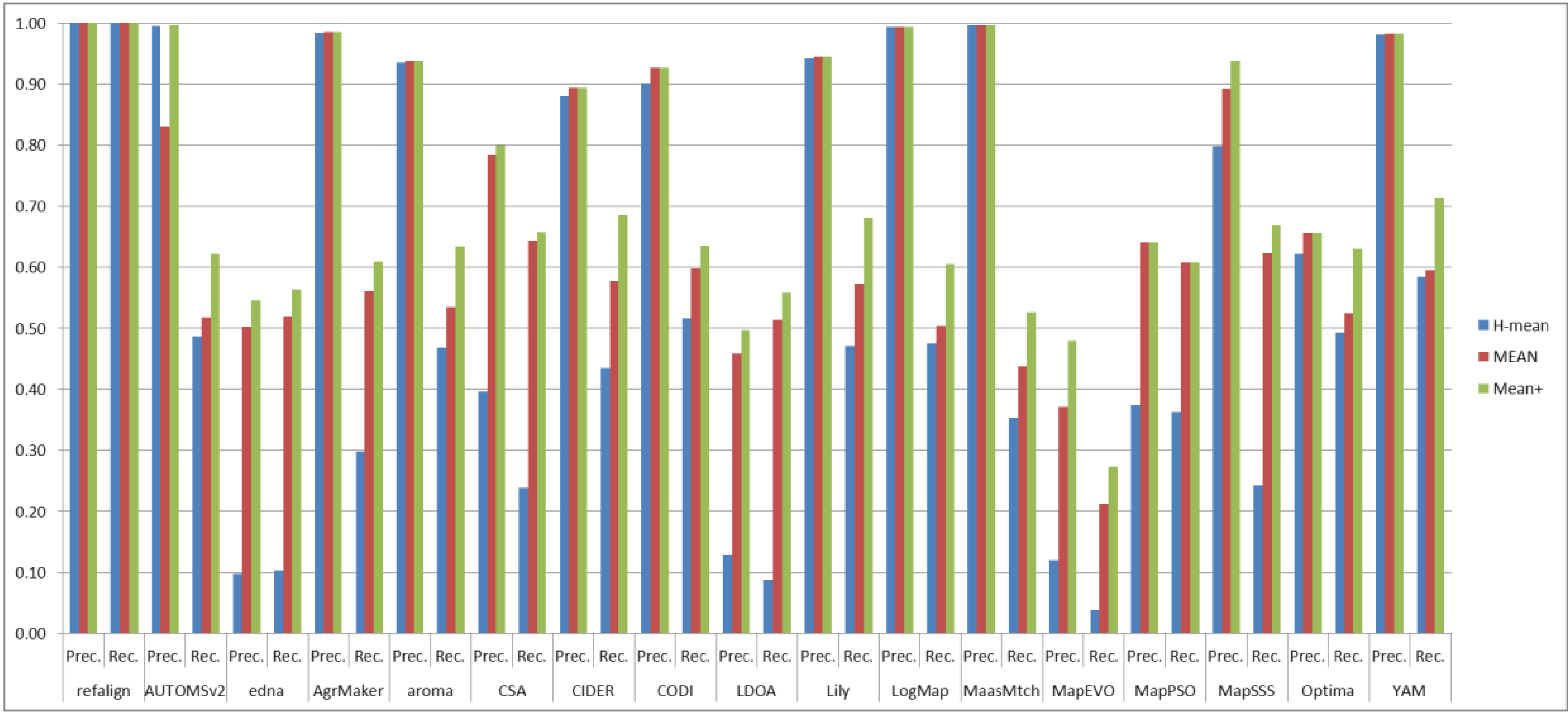
AUTOMSv2 features

- 1:1 alignments, 2 domain ontologies, equivalences between classes and properties
- Uses open source Java Alignment API
- Synthesis of methods (lexical, structural, instance-based, vector-based, lexicon-based), ability for different aggregators e.g. union
- Implements an alignment-methods' configuration strategy based on ontology profiling information (size, features, etc.)
- Integrates state-of-the-art alignment methods with standard Alignment API methods
- Implements a language translation method for non-English ontology elements

AUTOMSv2 architecture



AUTOMSv2 evaluation / OAEI 2011 Benchmark dataset



- better in precision (from 0.83 to 1.00) than recall (from 0.49 to 0.62)
- outperforms 6 others in MEAN precision
- performs close to 100% precision for H-Mean and Mean+
- 6 out of the 16 achieved a better Mean recall than AUTOMSv2
- outperforms almost all others tools in H-mean recall

Prec: correct pairs among the retrieved ones
Rec.: correct pairs among the ones should have been retrieved

H-mean: Harmonic mean
Mean+: Mean of non-zeros

Further Work

Ontology Alignment:

- Improve **AUTOMSv2** tool (alignment methods' design)
- Re-evaluate AUTOMSv2 with OAEI 2012 datasets
- Implement a light version of AUTOMSv2 based, called **ASE** (no profiling, configuration, complex and resource demanding methods)
- Evaluate ASE in OAEI 2012 contest

SSGF:

- PoC system for the automated deployment of applications in IoT settings
  - Use of ontology and **Smart Proxy toolset**
- Use SSGF to support the concept of "**SIaaS providers**"
- Revise I**oT-ontology** as a semantic registry for entities in IoT

Related self-publications

- Kotis, K., and A. Katasonov, "**Semantic Interoperability on the Internet of Things: The Semantic Smart Gateway Framework**", *International Journal of Distributed Systems and Technologies (IJDST)*, In Press.
- Kotis, K., A. Katasonov, and J. Leino, "**ASE results for OAEI 2012**", *Seventh International Workshop on Ontology Matching, ISWC 2012*, Boston, CEUR-WS, 11/2012.
- Kotis, K., A. Katasonov, and J. Leino, "**AUTOMSv2 results for OAEI 2012**", *Seventh International Workshop on Ontology Matching, ISWC 2012*, Boston, CEUR-WS, 11/2012.
- Kotis, K., A. Katasonov, and J. Leino, "**Aligning Smart and Control Entities in IoT**", *The 5th Conference on Internet of Things and Smart Spaces 2012*, issue LNCS 7469, St. Petersburg, RU, Springer, pp. 39-50, 2012.
- Kotis, K., and A. Katasonov, "**Semantic Interoperability on the Web of Things: The Semantic Smart Gateway Framework**",*CISIS 2012*, Palermo, Italy, 2012.

Related Work

FP7 IoT projects

- **IoT-A** (http://www.iot-a.eu/) aims at defining an architecture reference model and key building blocks for IoT.
- **iCore** (http://www.iot-icore.eu/) is focused on the cognitive capabilities of interconnected objects, which are called virtual objects in the project. The virtual objects can be networked and composed to deliver services for various stakeholders.
- **SPRINT** (http://www.sprint-iot.eu/) considers the methodology for engineering complex systems by utilising IoT, thus enabling system engineering process on the internet.
- **Gambas** (http://www.gambas-ict.eu/) and **Butler** (http://www.iot-butler.eu/) investigates middleware platforms for creating pervasive, context-aware personal applications based on IoT.
- **Open-IoT (**http://openiot.eu/**)** joint effort of open source contributors towards enabling open large scale intelligent IoT applications according to a utility cloud computing delivery model.

IoT Platforms

- **Cosm** (https://cosm.com/),
- **Nimbits** (http://nimbits.com/)
- **Paraimpu** (http://paraimpu.crs4.it/)
  - provide similar services of sharing, storing and accessing IoT data
  - Data providers can use the platform APIs to update data streams and store historical data
  - Data users can query and access the data streams in order to develop applications

More Platforms

- **ioBridge** (http://www.iobridge.com/)
  - strong focus on helping domain application providers to connect to various hardware devices via cloud. It actively supports the development of hardware devices and gateways to interface with their cloud service
- **Axeda** (http://www.axeda.com/)
  - domain specific commercial M2M service provider.
  - focused on M2M applications for asset tracking while seamlessly integrating assets management with enterprise systems such as ERP, CRM and analytics.
  - provides cloud services to host the applications and manage large amount of asset data.

Interoperability platforms for SE

- Smart/Open-M3
  - M3 (**M**ulti-vendor, **M**ulti-device and **M**ulti-domain) *semantic information sharing platform*
  - Well-known, widely-used, open-source
  - Identify 3 interop. levels: device, service, smart space
  - Centralized-approach, depend on common Info. Broker (SIB), common ontologies

Future Work

- IoT / Cloud convergence
  - Plug-n-play IoT PaaS
    - Focus on the **virtualisation** of IoT resources towards enabling the access and management of IoT devices and solutions through software interfaces that are directly usable by cloud applications
    - Assist **IoT solution providers** to integrate new or legacy IoT resources **fast** and **easy**, and **application providers** to efficiently develop novel applications by exploiting the newly integrated resources

Objectives

Develop

- a unified framework of semantic models (in the form of combined ontologies) for the specification of IoT resources
- methods for the semi-automatic semantic registration of new devices and for the required evolution of the core models
- methods for the semi-automatic semantic registration of legacy IoT solutions
- semantically enhanced methods for selecting and retrieving registered (virtualized) IoT resources

Exploring Novel Ideas

- Plug-n-Play IoT
  - uses semantic techniques to virtualize device interfaces and control logics of IoT solutions, enabling IoT resources to be efficiently provisioned as computing resources on cloud
- IoT PaaS
  - IoT PaaS extends traditional PaaS cloud capabilities with the models, methods and tools for efficiently utilizing IoT resources in cloud applications: *The consumers of IoT and cloud resources do not manage or control the underlying IoT or cloud infrastructure, but use the capabilities and tools provided by the platform to configure, deploy and manage IoT applications.*

Contribute in novel solutions

- IoT-Toolkit and SmartObject API (http://www.iot-toolkit.com/) by **OPEN SOURCE INTERNET OF THINGS MEETUP GROUP (**http://www.meetup.com/The-Open-Source-Internet-Of-Things-Silicon-Valley/**)**

&

- **THE OPEN HORIZONTAL PLATFORM FOR THE INTERNET OF THINGS**

  … beyond Silicon Valley, grow a global Open Source ecosystem for the IoT

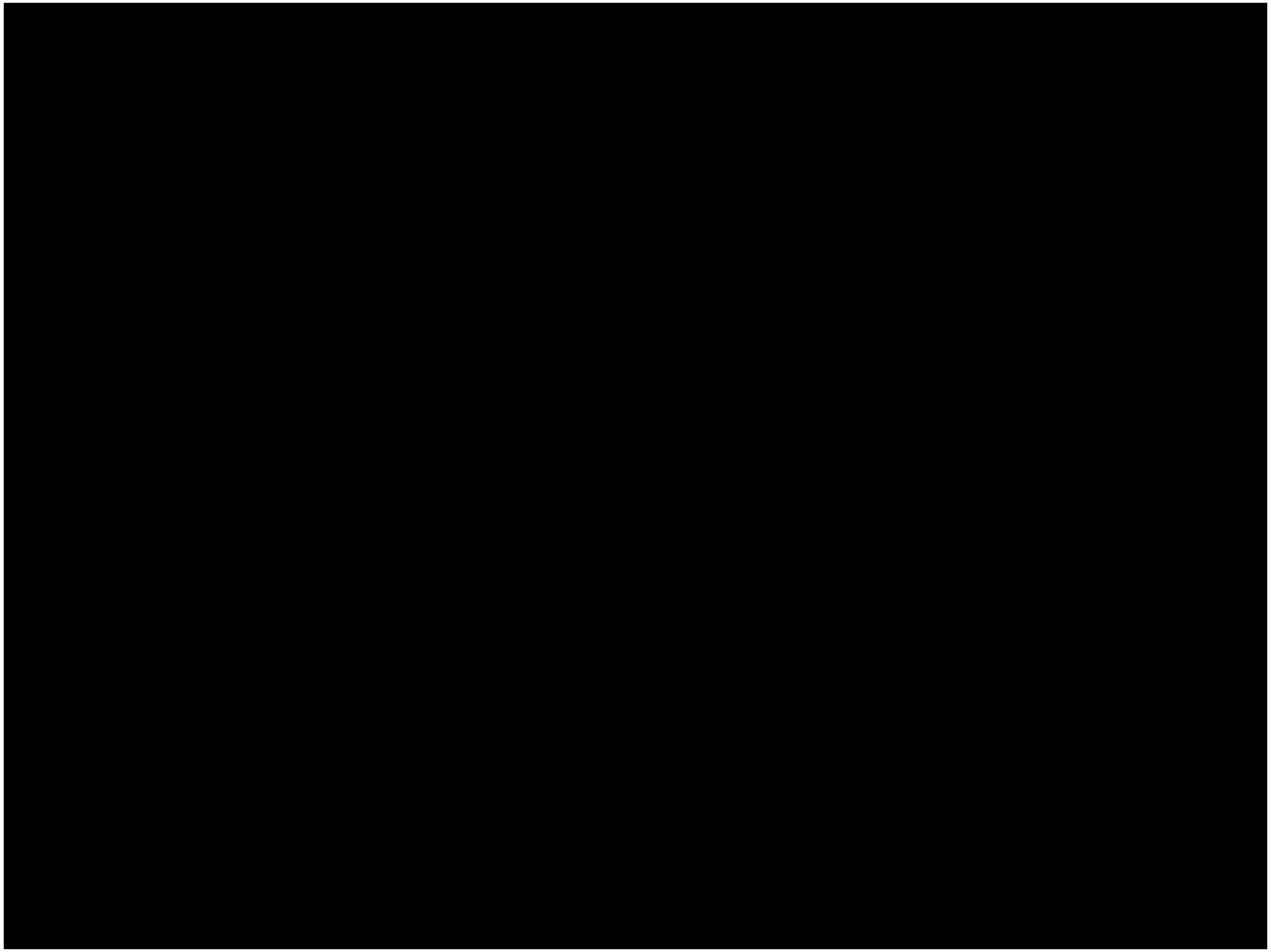
  An effort managed by **Michael Koster (USA)**

Additional research plans

- Sensor Data Integration
  - S3-AI approach
    - Open sensor data from multiple 'data silos' (LOD paradigm)
    - Federated Querying over unified data (ontology mediated SPARQL queries)
    - http://www.samos.gr/apps/s3-ai/egovTicketapp.xhtml
    - Experimental domain: IT helpdesk support ticketing apps
    - Scheduled domains: Environmental, Marine Information

Interoperability solution demo.

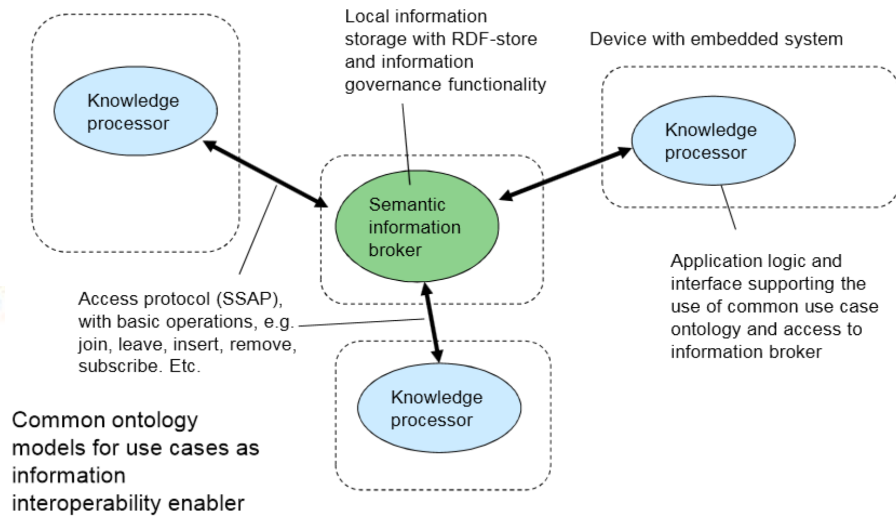
- Open-M3 platform (VTT)
  - VTT GardenCare, a Smart Home Gardening with uID and M3

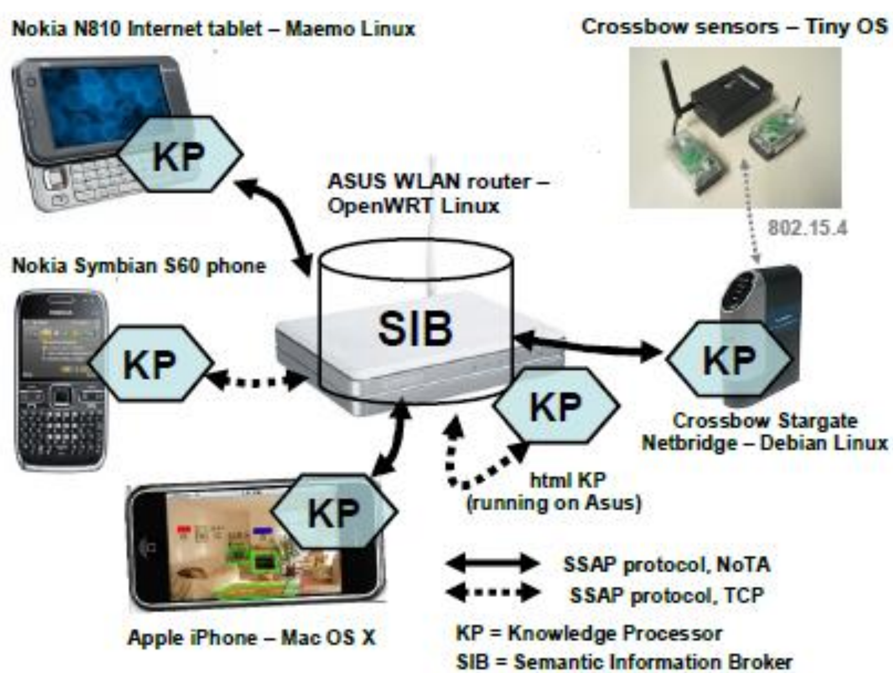


kotis@aegean.gr / kotis@samos.gr

Smart/Open-M3 platform

http://www.open-m3.org/





Smart/Open-M3 platform

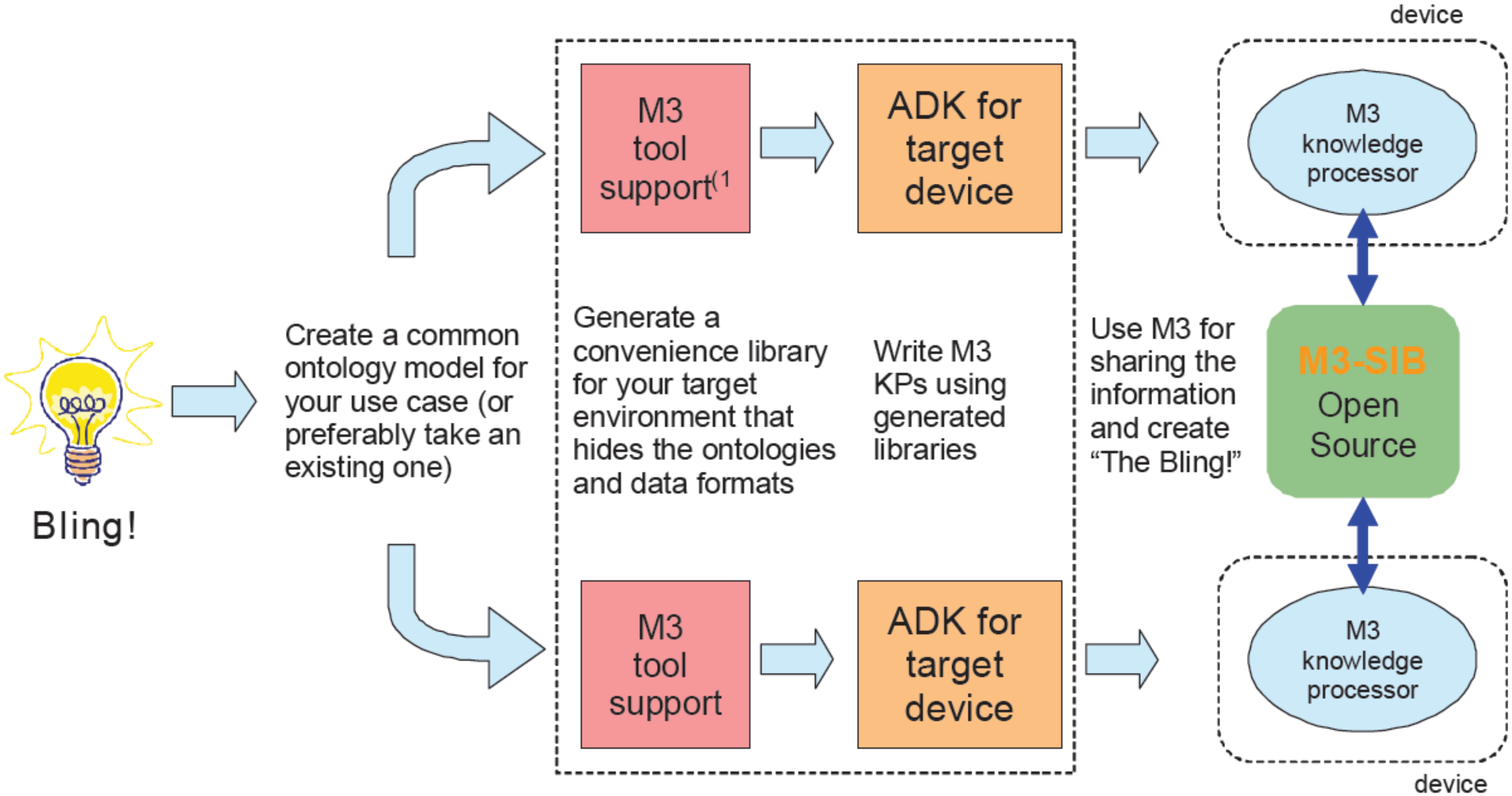
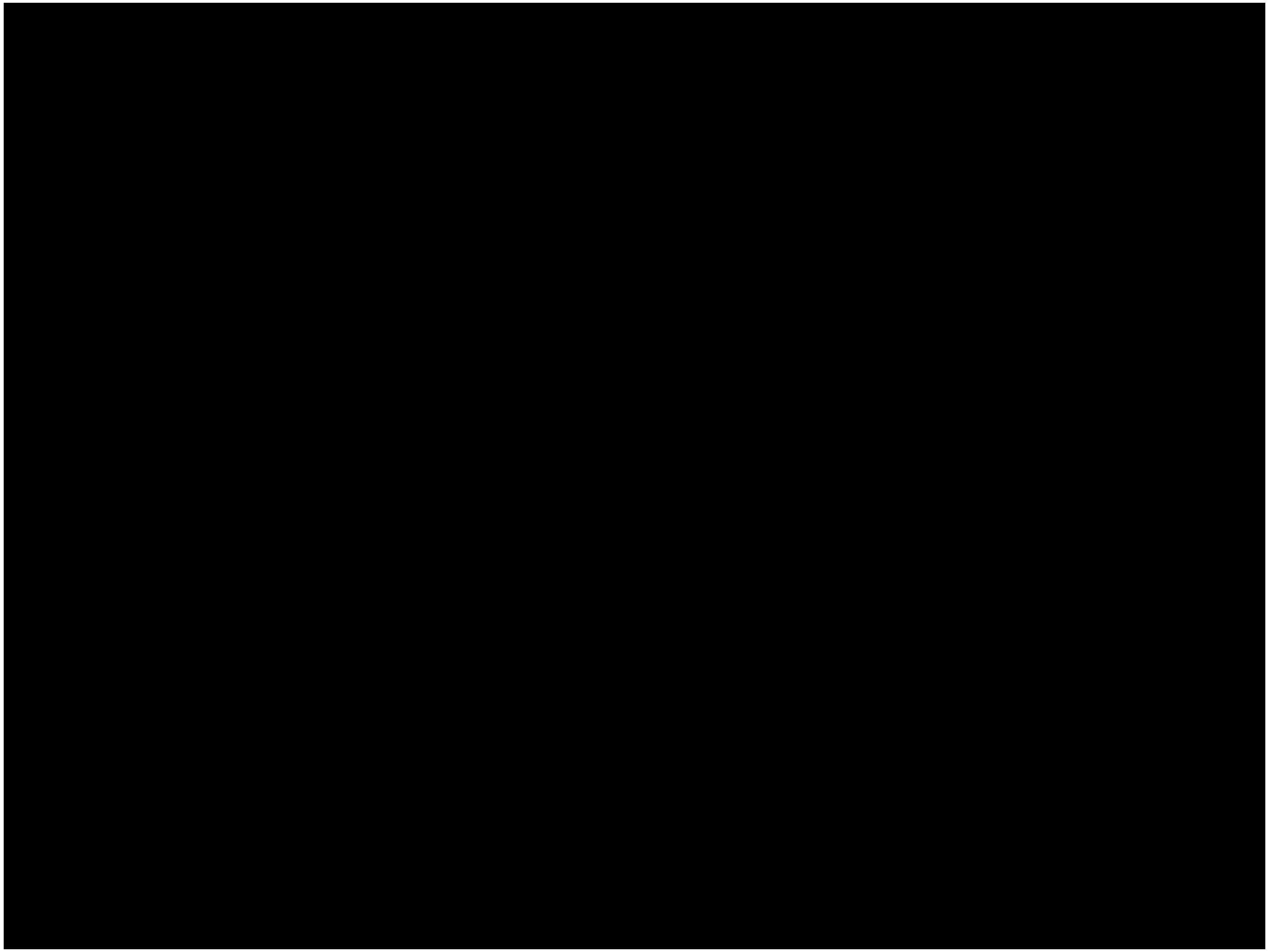


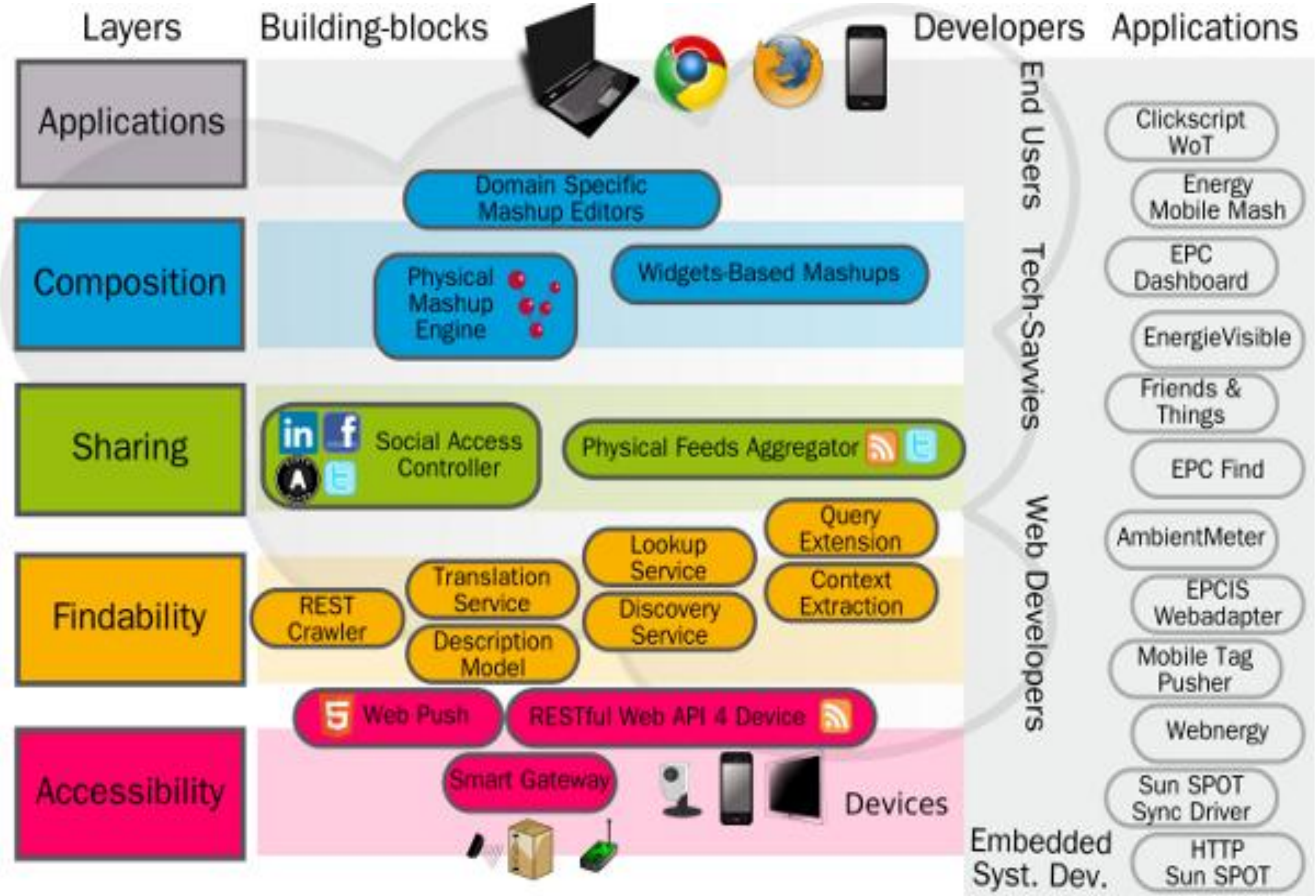
Figure 6. Ontology based application development flow. [1)] M3 ontology compiler developed by Åbo Akademi (available at www.sourceforge.org Smart-M3 project).

Interoperability solution demo.

- Smart Proxy SSGF (VTT)
  - Smart room video at YouTube: http://youtu.be/R15Xnc2-Ovs



Web of Things Architecture



Ph.D. Thesis of D. Guinard

Semantic reasoning for dynamic coordination

Agent 1

“I plan to *x:**Send*** a book y:**HarryPotter** to or **AgPS4e**”

Agent 2

- “I now *z:**Scan*** a document on org:**AgPS4e**”
- “Does Agent1’s intention concern me?”
- “I do not know what x:**Send** means..”

Intention

Domain ontology DO1

Definition of DO1

Data

Domain ontology DO2

Definition of DO2

Upper ontology: *Coordination*

Upper ontology: *BDI*

Upper ontology rules

Coordination rules

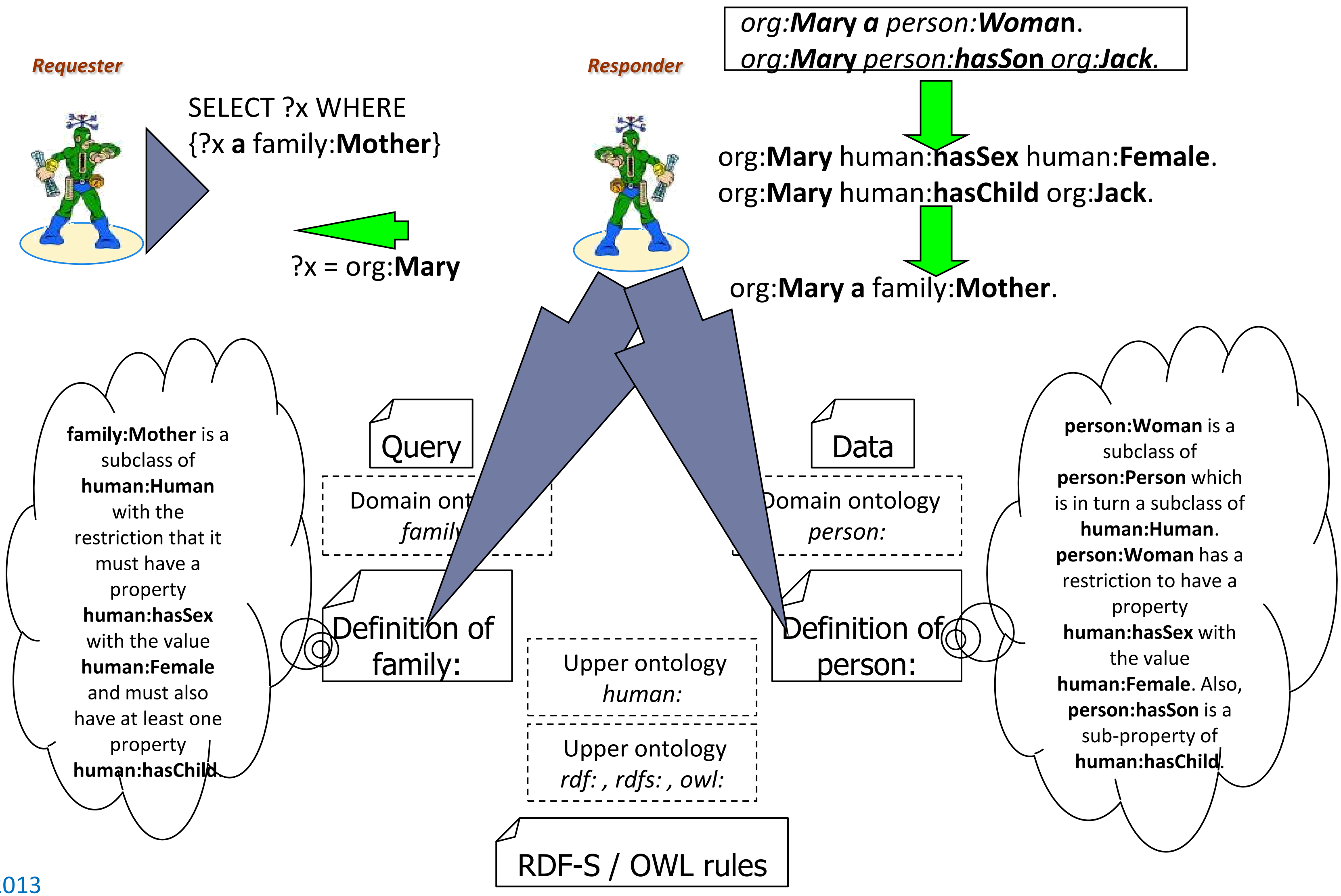
To interpret action intentions

To resolve conflicts

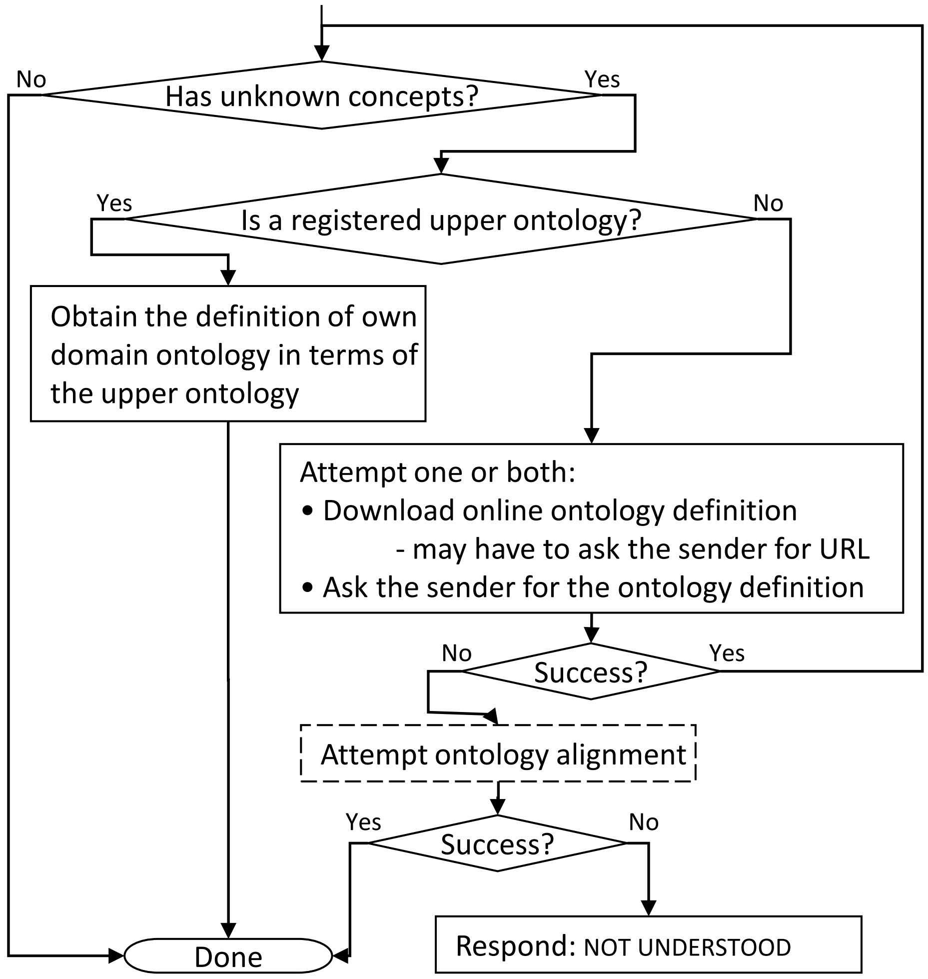
e.g. of Tamma et al. (2005)

Beliefs-Desires-Intentions model

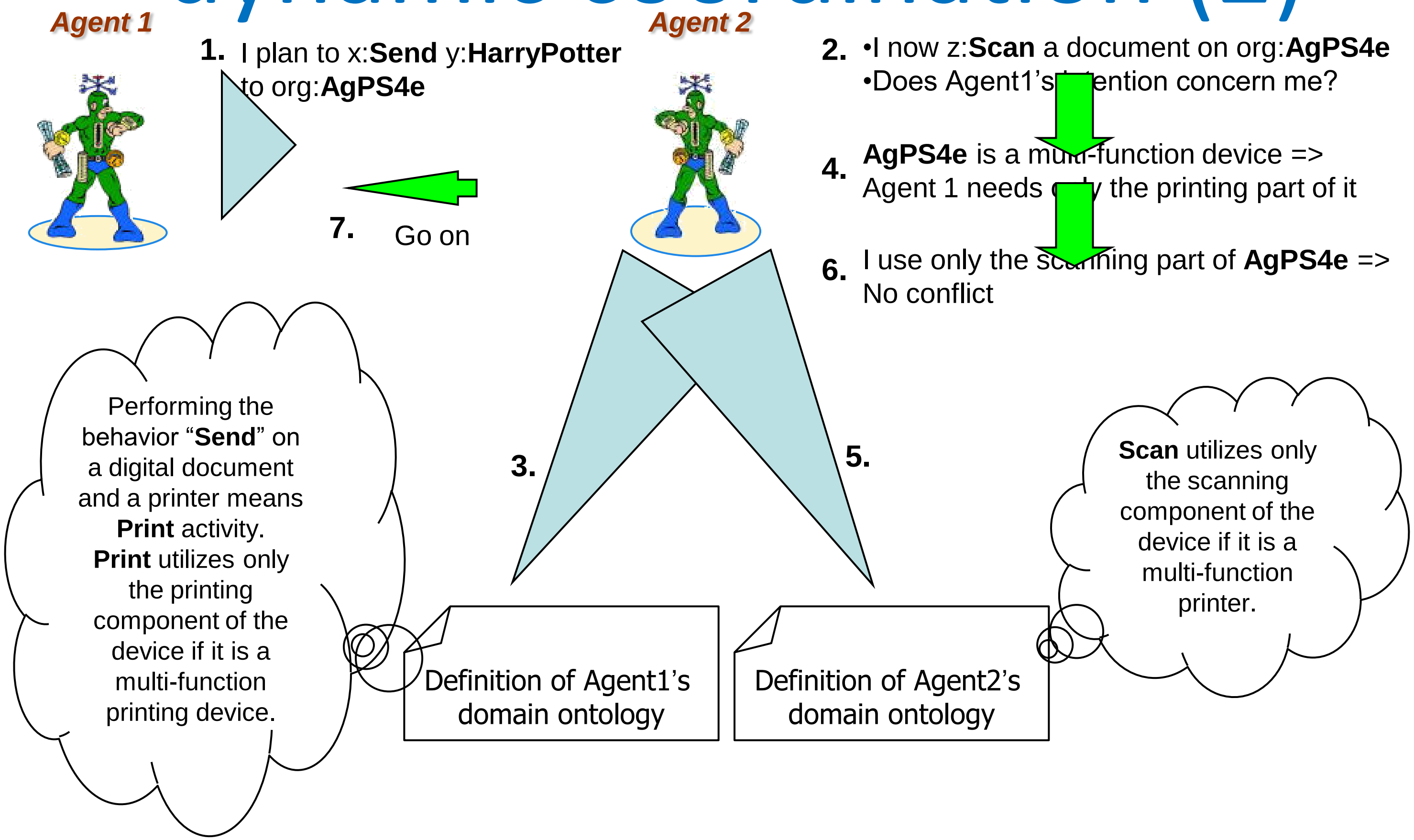
Semantics for interoperability



Ontology linking process

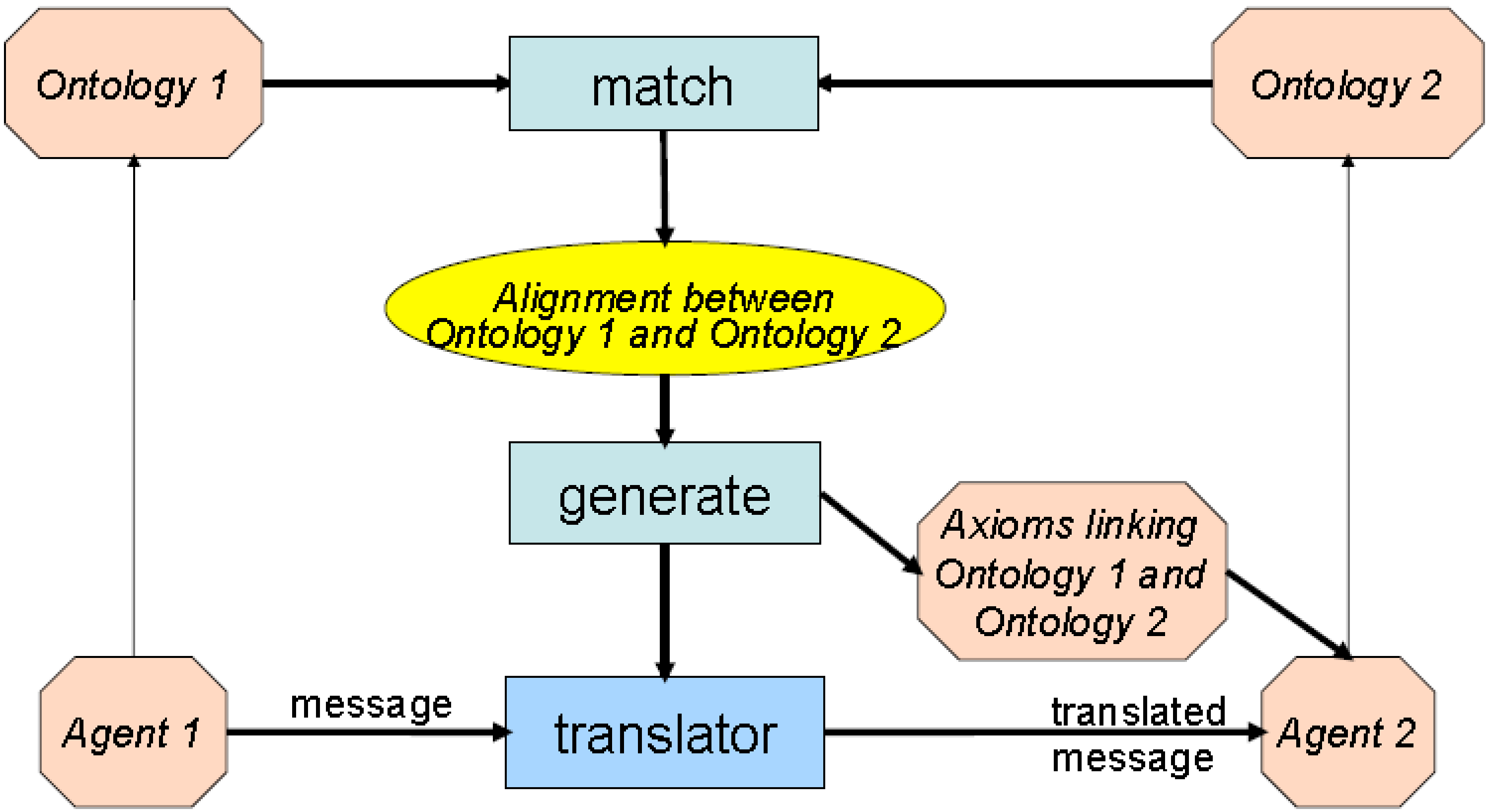


Semantic reasoning for dynamic coordination (2)

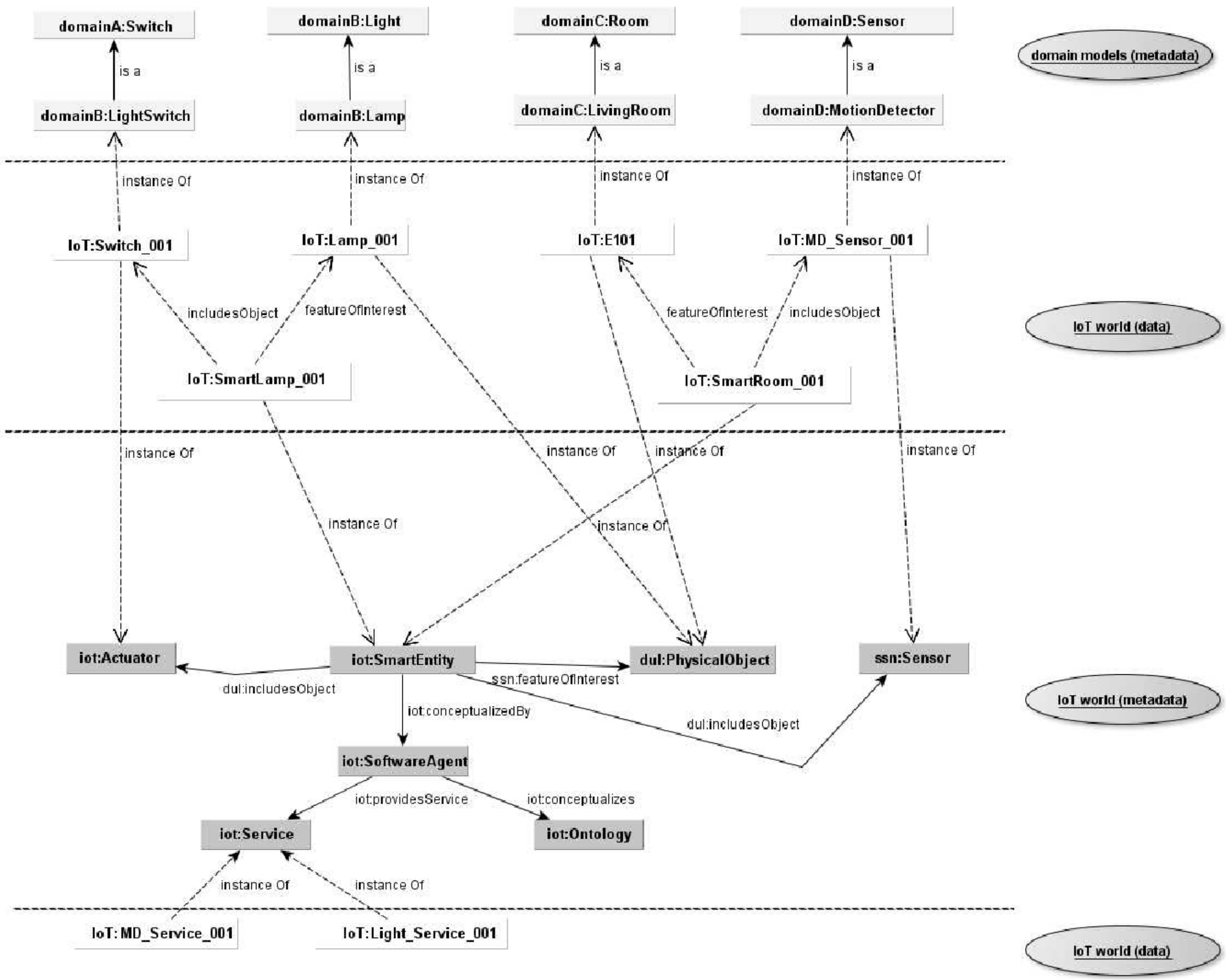


Katasonov A. and Terziyan V. (2010) *Using Semantic Technology to Enable Behavioural Coordination of Heterogeneous Systems,* In: Gang Wu (ed.) Semantic Web, In-Teh, January 2010, pp. 135-156

Ont. Alignment in agent/entity communication

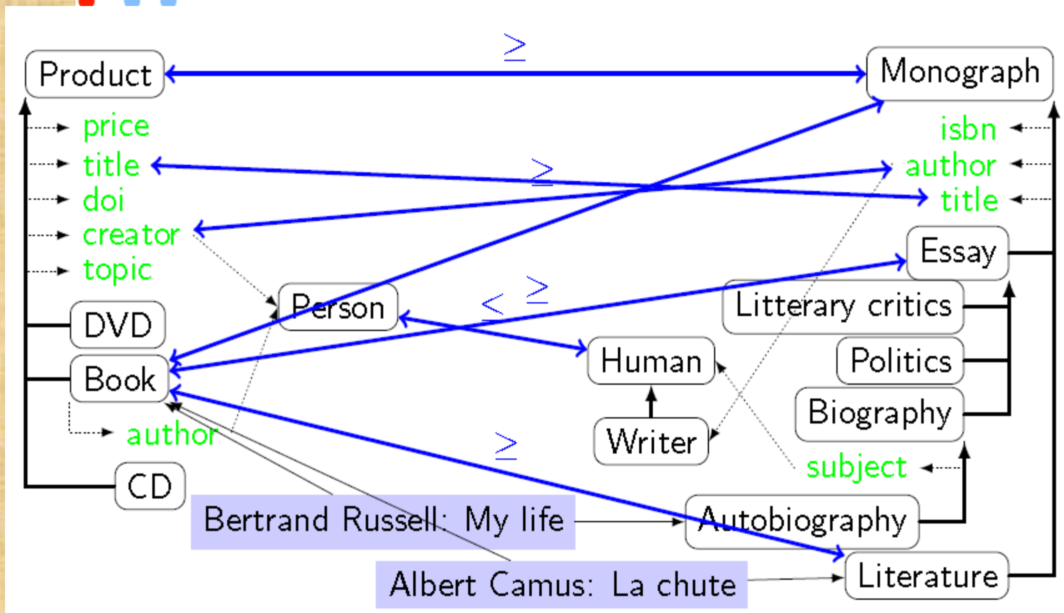


Semantic Registry snapshot

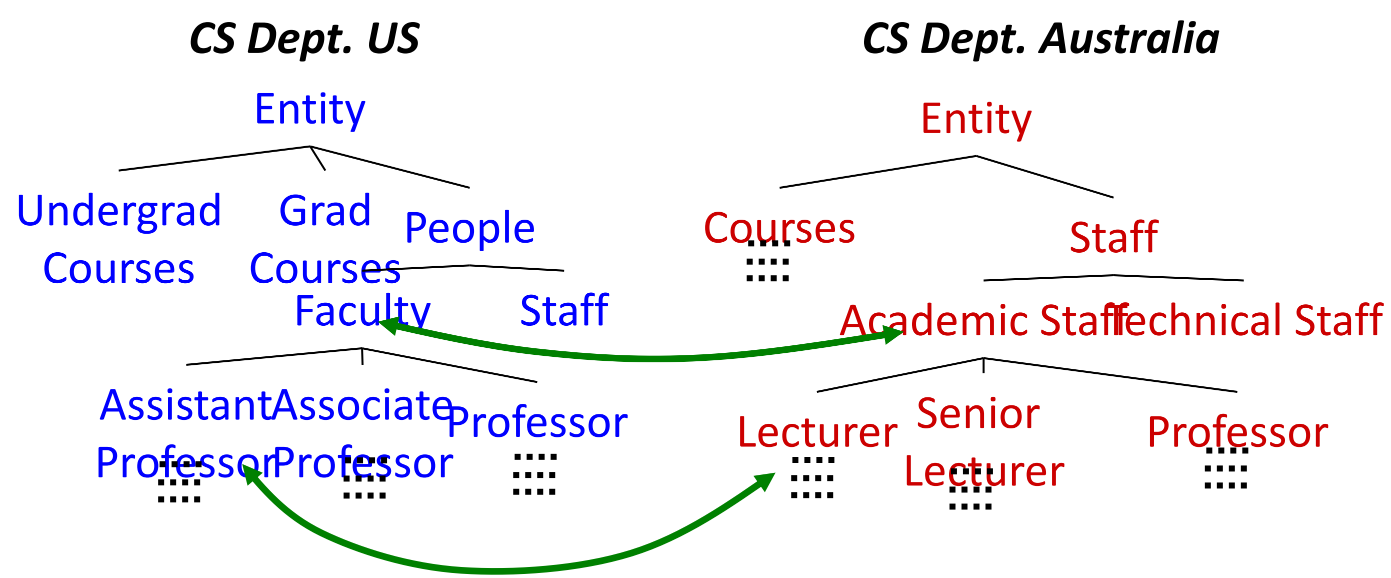


Globally accessible blackboard

- The blackboard approach like in COSM/Pachube is **one approach to interoperability**
- While potentially having some issues with respect to scalability and performance, on the positive side **it separates the data itself from such questions as: data availability (where?) and transmission (when?)**
- Such a blackboard approach has also been recently utilized outside the "Web of Things" work, e.g. in **Tekes DIEM / EU SOFIA projects (Smart-M3 platform):**
  - Proprietary protocol.
  - API libraries for various platforms, which is just slightly better than "a particular software client"



(a)



(b)

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