Semantic Web of Things (SWoT)

An introduction

Gérald Rocher, Jean-Yves Tigli, 31/01/2017

Internet of Things (IoT)

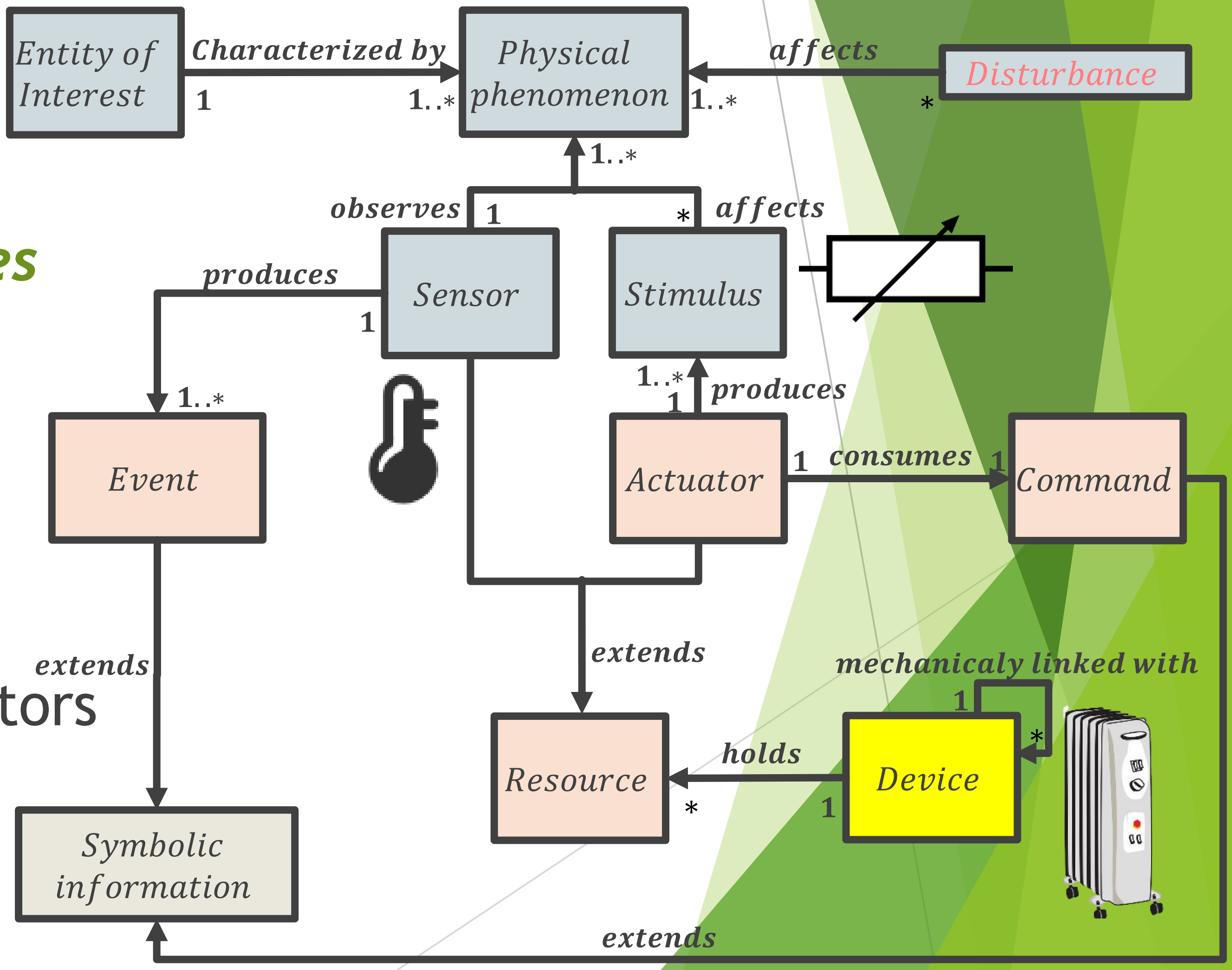
Internet of Things (1/3)

- *Physical* things connected to *Devices*




- A Device provides access to *resources*
  - *Sensors*,
  - *Actuators*.

- Devices can be…
  - *Physically coupled* sensor & actuators
    - Heater (resistor + temp sensor).

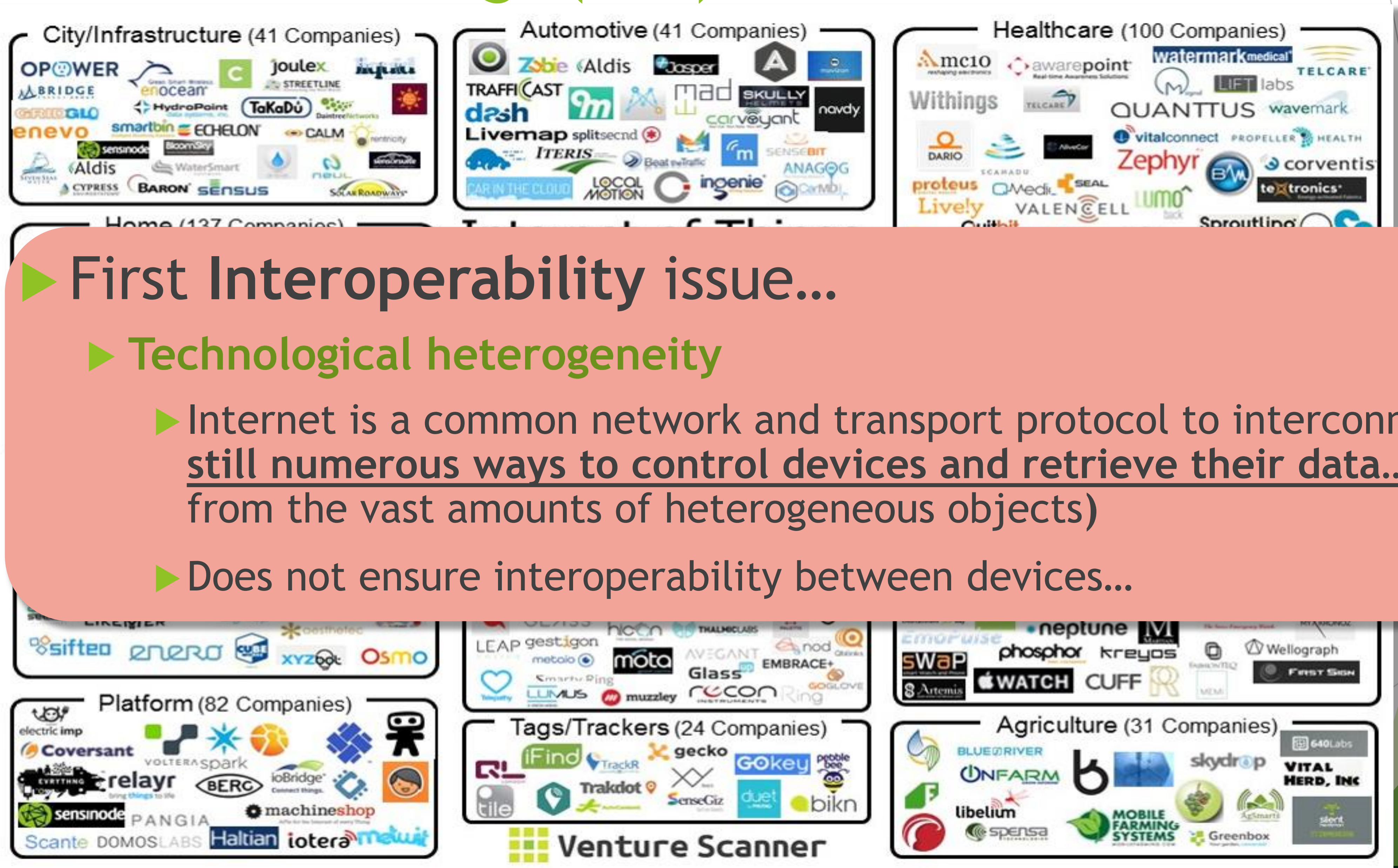


Internet of Things (2/3)

- An hardware layer to connect devices to the internet through ***communication protocols***…
  - Devices ***accessibility***,
  - Devices ***unique identification***.
- As…
  - Network of networks (gateways between heterogeneous protocols),
  - Things over internet (gateways toward a common protocol).
- **Devices can also be…**
  - ***Logically coupled*** sensor & actuators
    - Switch connected to a light.

AITU-T Study Group, “New ITU standards define the Internet of Things and provide the blueprints for its development,” ITU, 2012. [Online]. Available on http://www.itu.int/en/pages/default.aspx

Internet of Things (3/3)

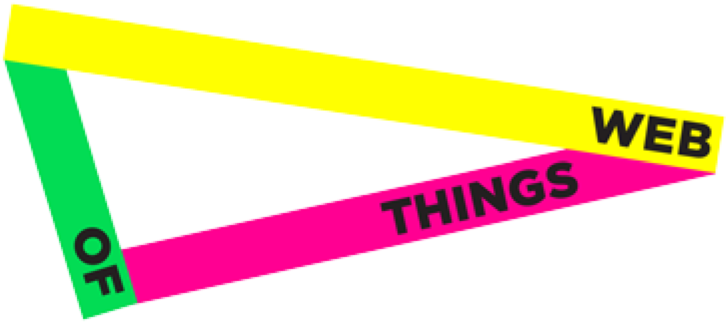


- First **Interoperability** issue…
  - Technological heterogeneity
    - Internet is a common network and transport protocol to interconnect devices **but still numerous ways to control devices and retrieve their data…** that derives from the vast amounts of heterogeneous objects)
    - Does not ensure interoperability between devices…

Web of Things (WoT)

Introduction

- **Approaches, software architectural styles and programming patterns that allow devices to be part of the World Wide Web…**
- **Dominique Guinard --** PhD thesis (2011)
  - Four layers IoT **common application architecture**
    1. **Accessibility,**
    2. **Findability,**
    3. **Sharing,**
    4. **Composition.**

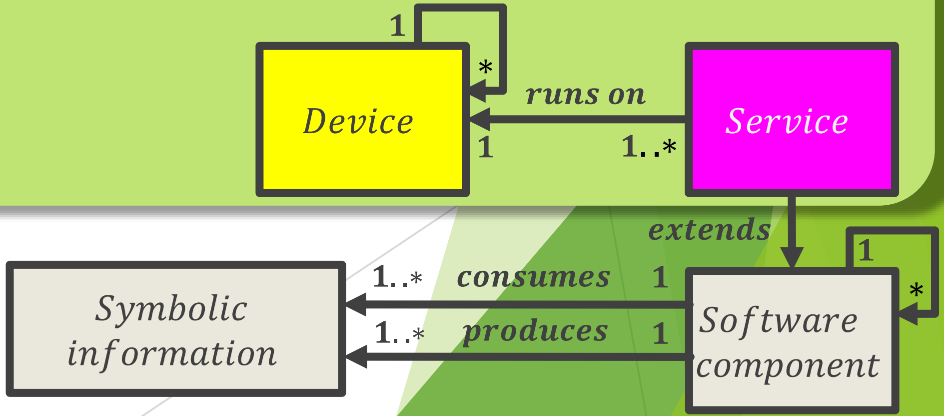


A Web of Things Application Architecture - Integrating the Real-World into the Web.
PhD thesis No. 19891, ETH Zurich, Zurich, Switzerland, August 2011

Accessibility Layer

- Resource Oriented Architecture (ROA)
  - RESTful services & description (RSDL)
  - data centric: over HTTP
    (GET, POST, PUT, DELETE, etc.)
- Service Oriented Architecture (SOA)
  - SOAP services → WS-* (functional control),
  - API descriptions (WSDL).

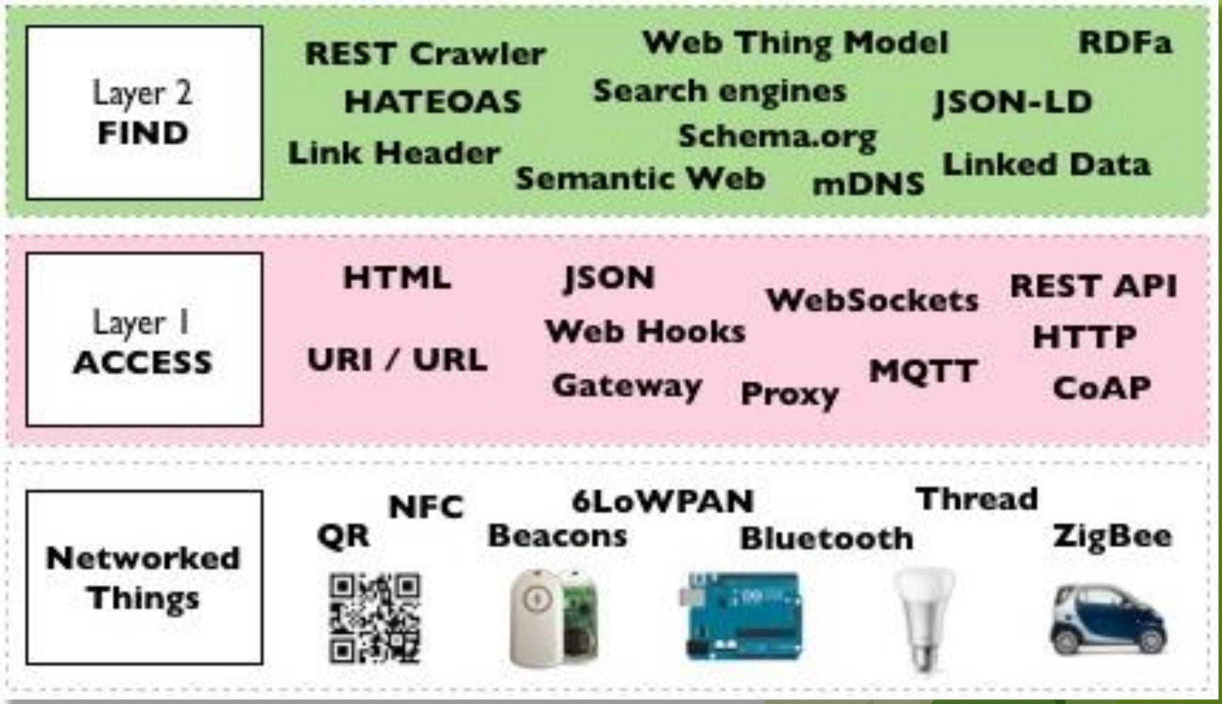
- **A common & generic way to access devices data and API through gateways**
  - Devices technological abstraction,
  - Fixing the IoT Technological Heterogeneity issue.



- Once devices are accessible to the web, web applications and tools can be used…

Findability Layer

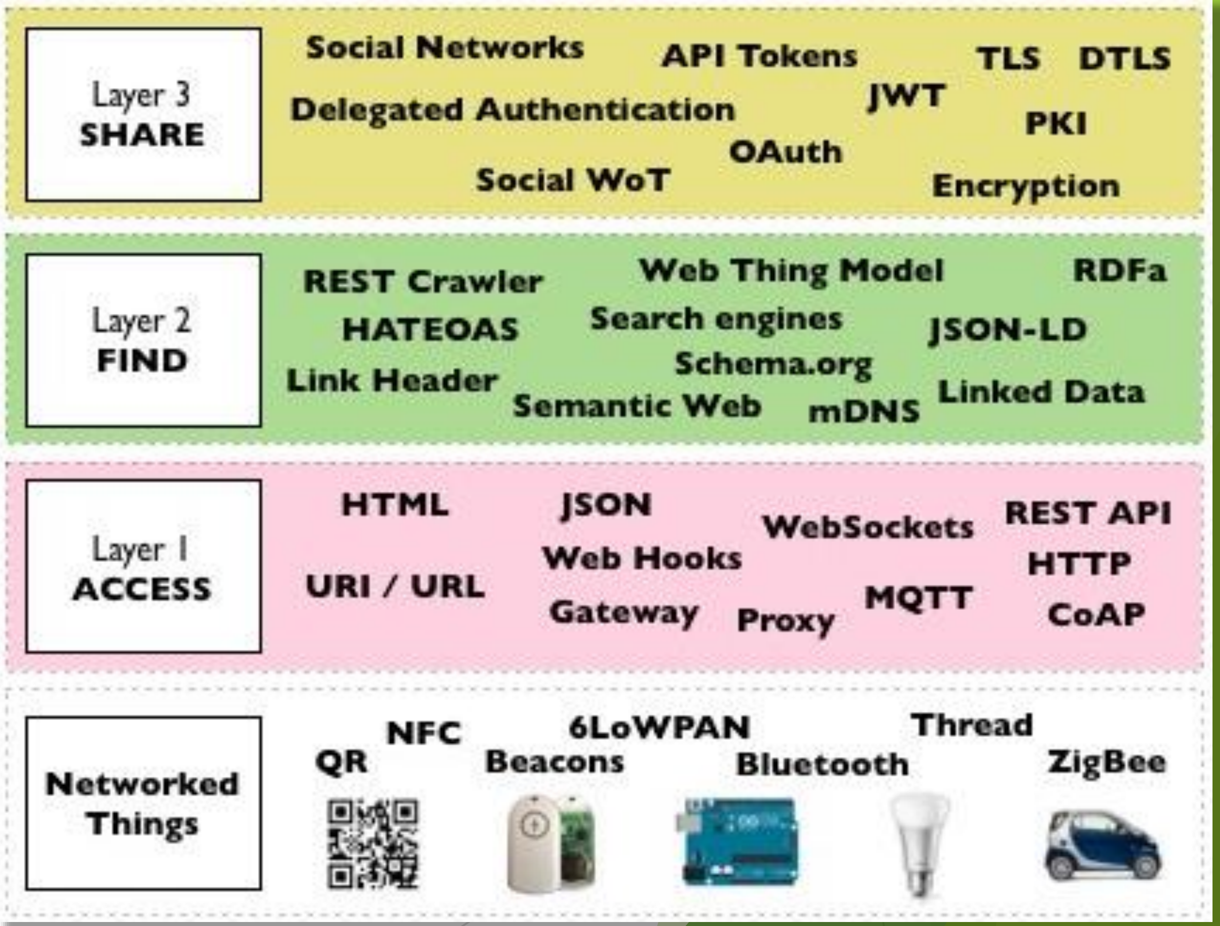
- Provides a way to **find** and **locate** relevant services (devices) on the Web
  - Search engines,
  - Crawlers,
  - Etc…
- **Metadata model** for describing smart things and their services…
  - **Integration/indexation of smart things to existing search engines**,
  - **Semantic annotations** based on microformat/RDFa to describe static properties (product, service) and dynamic properties (Location, Quality of Service).



https://fr.wikipedia.org/wiki/Microformat

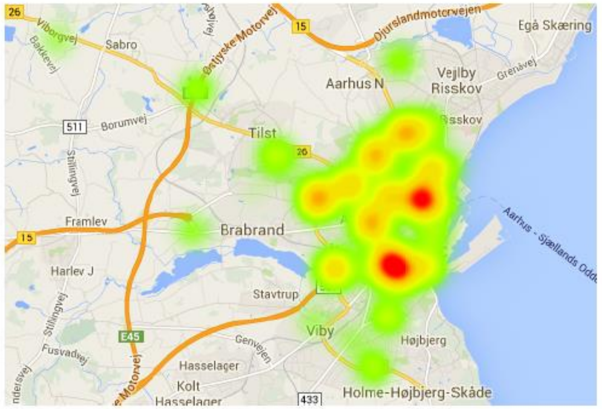
Sharing Layer

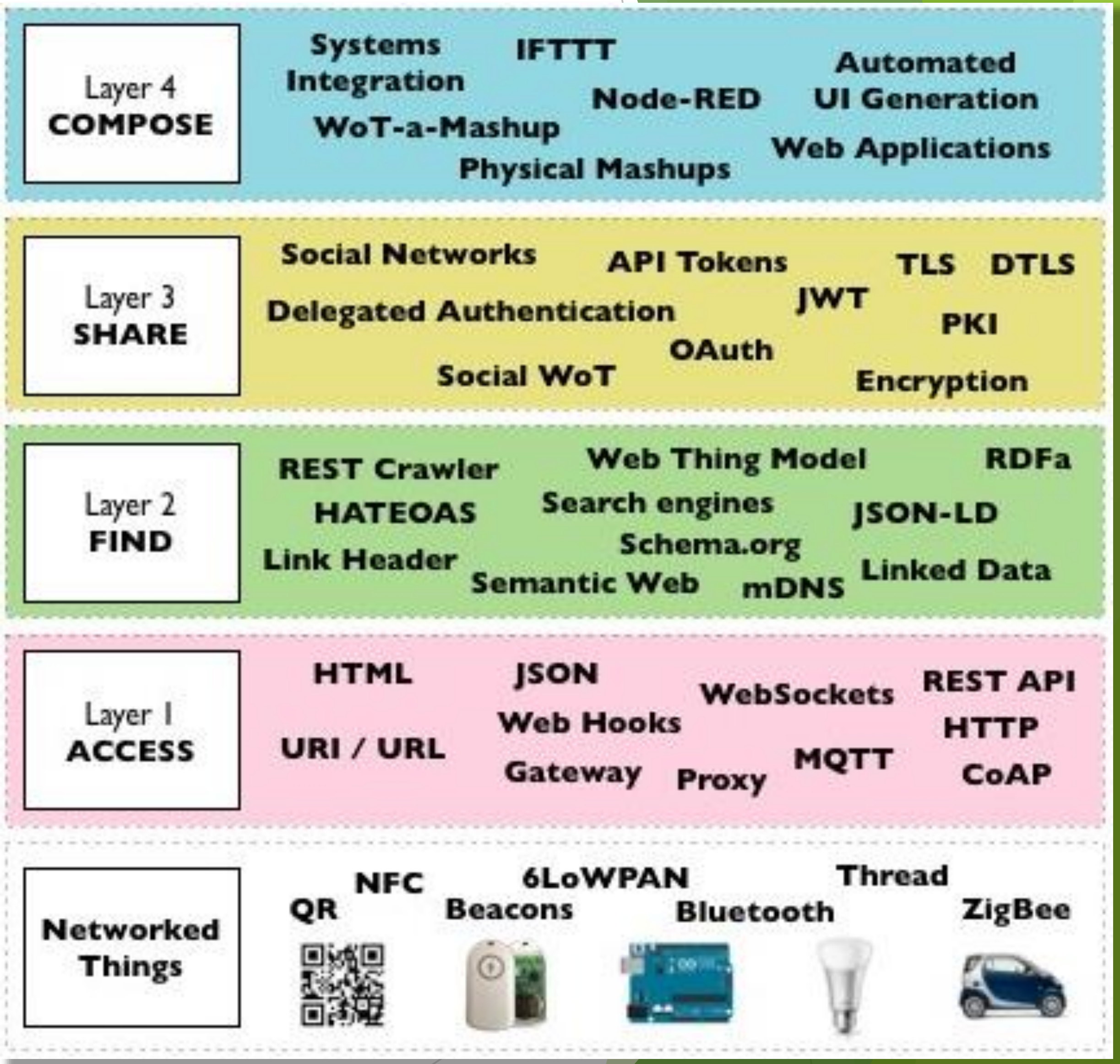
- Ensure data generated by devices are shared in an efficient and secure manner.
  - Security (encryption, authentication)
  - JWT, API tokens
  - Etc...



Composition Layer

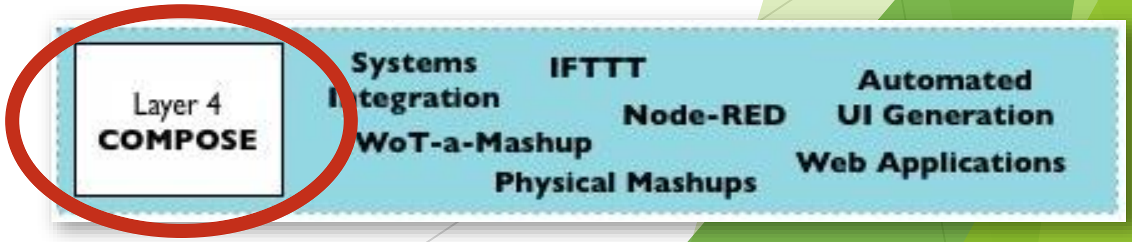
- Integrate the services and data offered by the devices into higher level Web tools:
  - Analytics software,
  - **Physical mashups**, **composite applications**,
  - Etc…



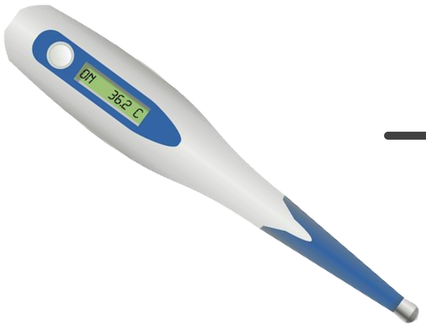


What’s the problem?

- Second **interoperability** issue…
  - **Semantic heterogeneity**
    - Numerous devices, manufacturers, ways to describe Devices, services and data…
    - Numerous data sources and types…
- How to describe data to get it **machine understandable** and establish **collaboration** among devices (full interoperability) far beyond microformat, RDFa, …?



Problem illustration (1/2)



37.8°C → Sensor data

160.0°C → Sensor data

73.0°F → Sensor data

How machine can interpret data semantics?

Problem illustration (2/2)

Looking for a display…

How machine can interpret devices functionality ?

WSDL, RSDL, etc… are syntactic descriptions; microformat/RDFa semantics descriptions are limited…

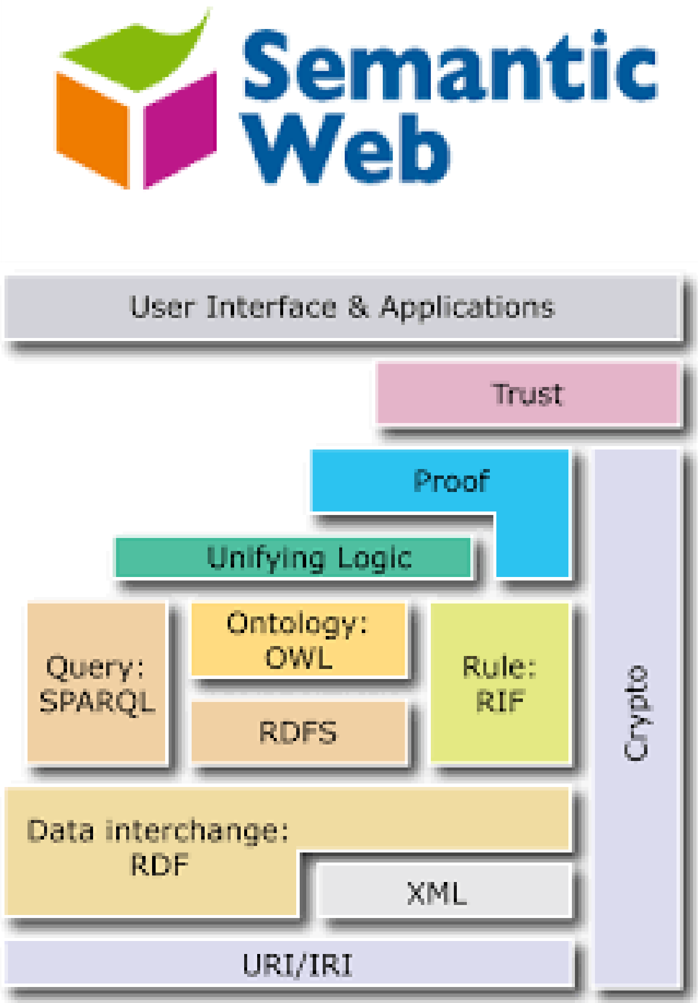
Semantic Web of Things (SWoT)

Jara AJ, Olivieri AC, Bocchi Y, Jung M, Kastner W, Skarmeta AF (2014) **Semantic Web of things: an analysis of the application semantics for the IoT moving towards the IoT convergence.** Int J Web Grid Serv 10(2):244–272

Introduction

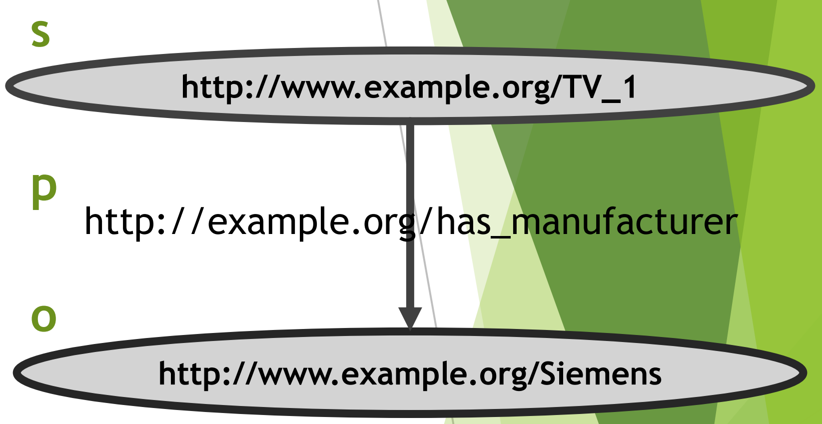
- Reuse **Semantic Web standards** to explicitly (formally) describe things, devices, their services and the data they publish...
  with semantically enriched annotations
- In a nutshell:
  - Knowledge formal description (RDF, RDFS, OWL),
  - Enables Machine to Machine (M2M) communication.
  - Reasoning (Inference Rules),
  - Querying (SPARQL).

https://www.w3.org/standards/semanticweb/



Semantic Web standards basics (1/4)…

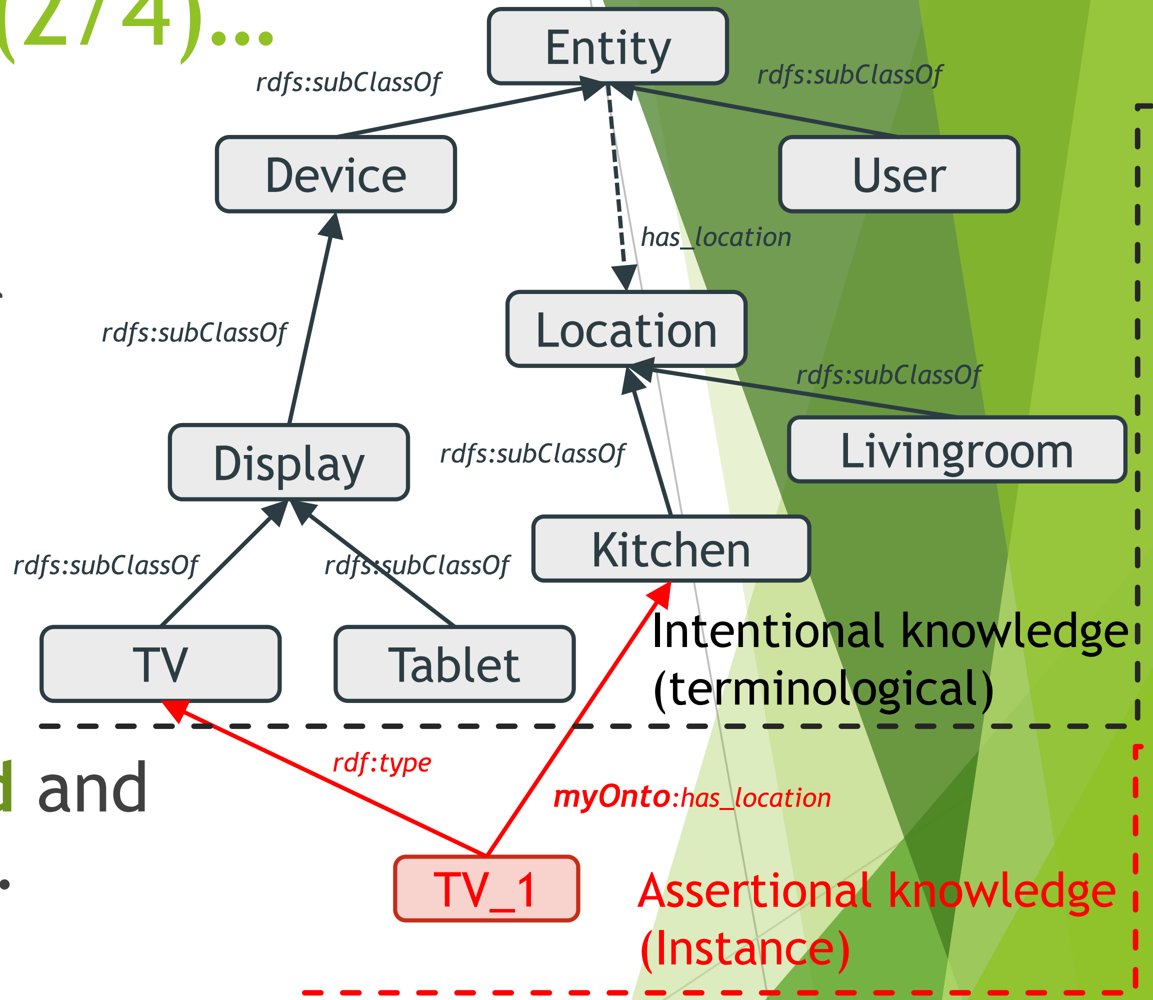
- **Resource Description Framework (RDF)**
  - **RDF triple** (**s**ubject, **p**redicate, **o**bject)
    - Labelled connection between two resources,
    - **s**, **p** are URI (**unambiguous**),
    - **o** is URI or literal,
    - **p** states the relationship between **s** and **o**.
  - RDF triples are **directed labelled graph**.



- **Minimum vocabulary to describe the knowledge (taxonomy)**
- **Without restrictions / conditions…**
- RDFS & OWL family languages allows more expressivity needed to build ontologies…

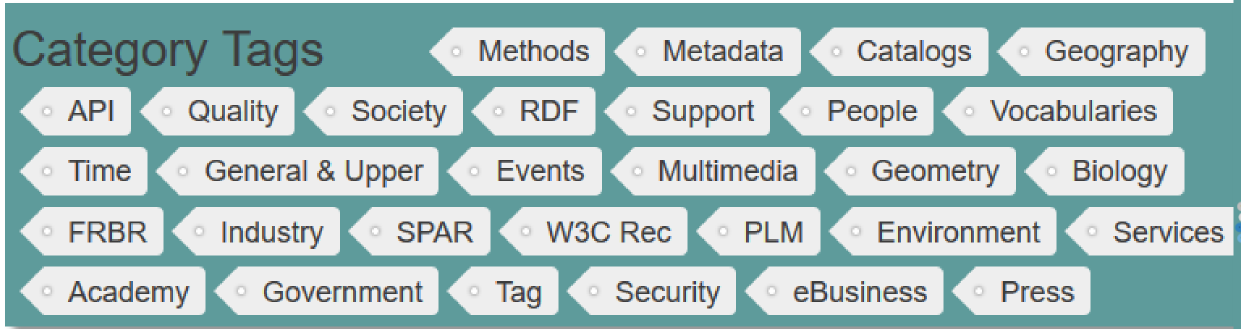
Semantic Web standards basics (2/4)...

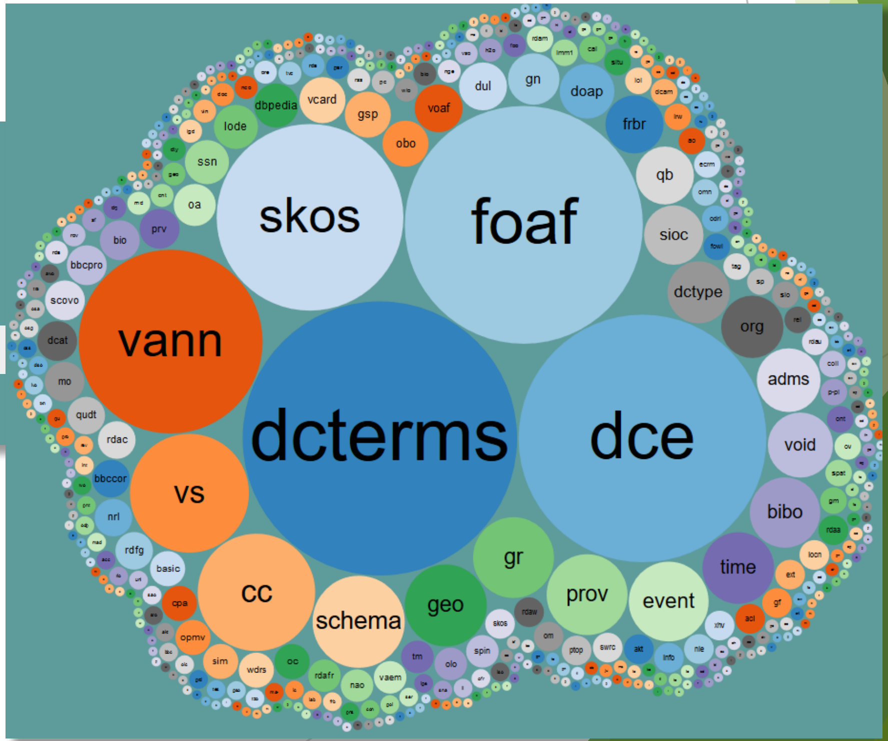
- **Ontology (aka vocabulary)**
  - **Formal knowledge description** of a domain:
    - Class (concept), Class hierarchy,
    - Properties, instances,
    - Restrictions, etc…
  - A **consensual** knowledge to be **reused** and **shared** across applications and people.
- Knowledge expressivity depends on the description language used (RDFS, OWL-LITE, OWL-DL, OWL2, etc…).



Semantic Web standards basics (3/4)…

- **Reuse** existing ontologies as much as possible
  - SSN-XG (Semantic Sensor Network ontology) https://www.w3.org/2005/Incubator/ssn/ssnx/ssn
  - Part of the **Linked Open Vocabularies** (LOV) effort http://lov.okfn.org/dataset/lov/





- Up to 533 vocabularies to date…

Semantic Web standards basics (4/4)…

- **Knowledge base (KB)**
  - **Stores** intentional (**Tbox → ontology**) and assertional knowledge (**Abox → instances**),
  - An **Inference** engine that can reason about the knowledge and use rules and logic to **deduce new knowledge** or **detect inconsistencies**.
  - A **query engine** (SPARQL) to retrieve, add, remove RDF data from the KB.

Ontology modeling layers

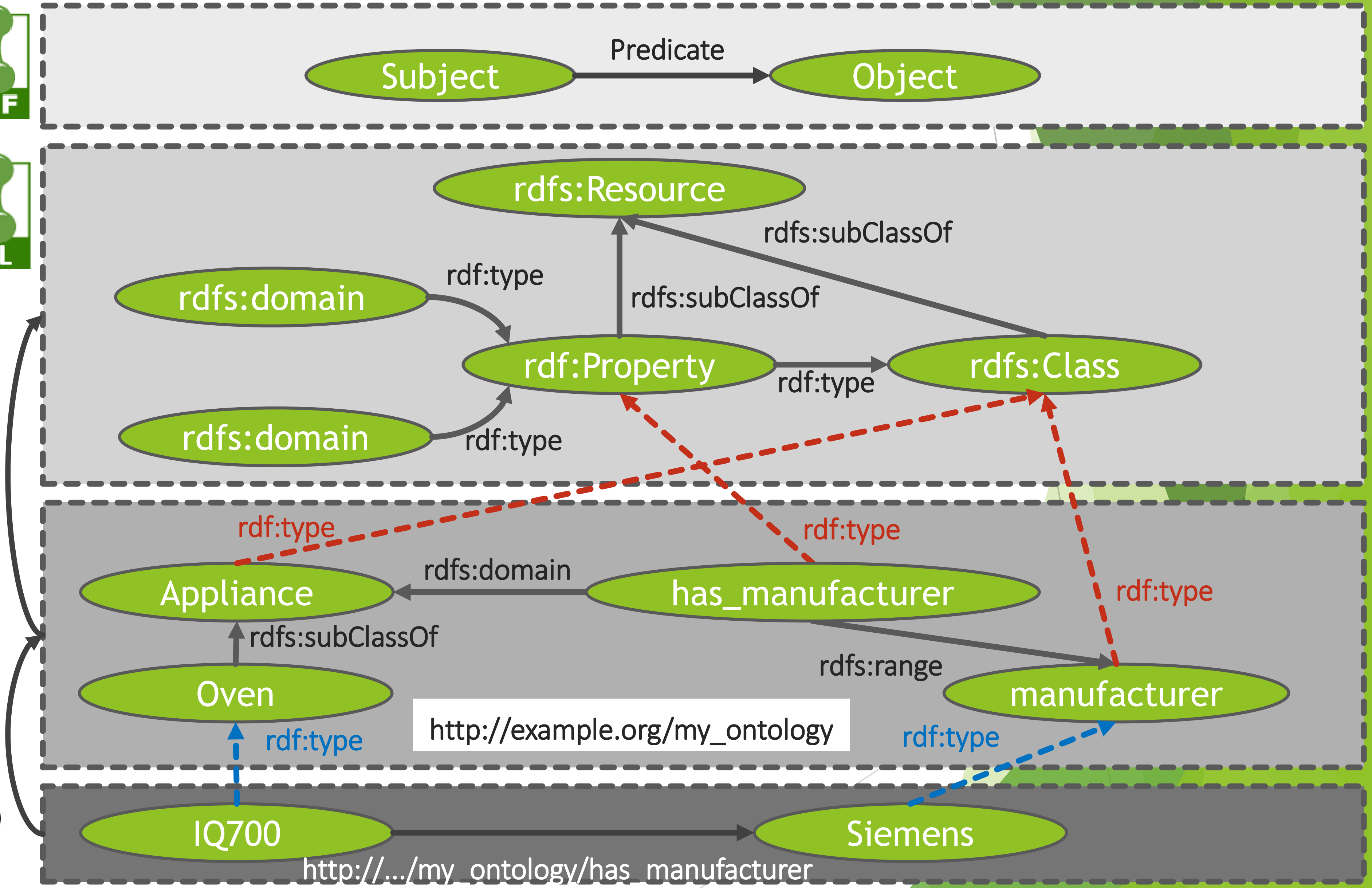
Meta meta model
(Ontology modeling languages)

Relies on

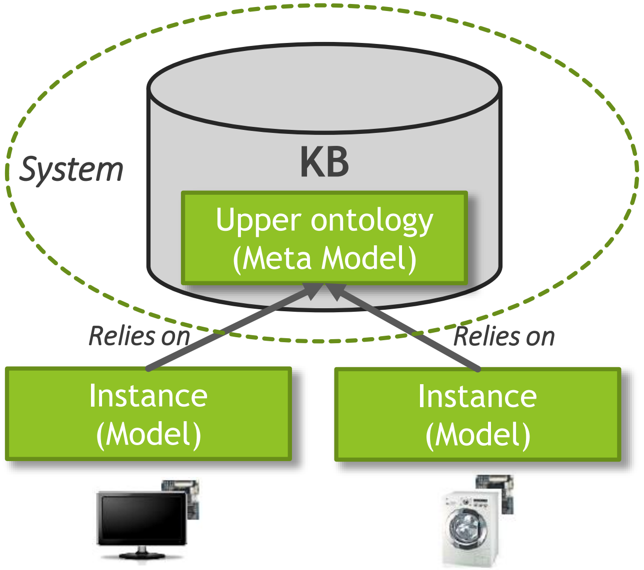
Meta model
(Specific domain ontology, aka upper ontology)

Relies on

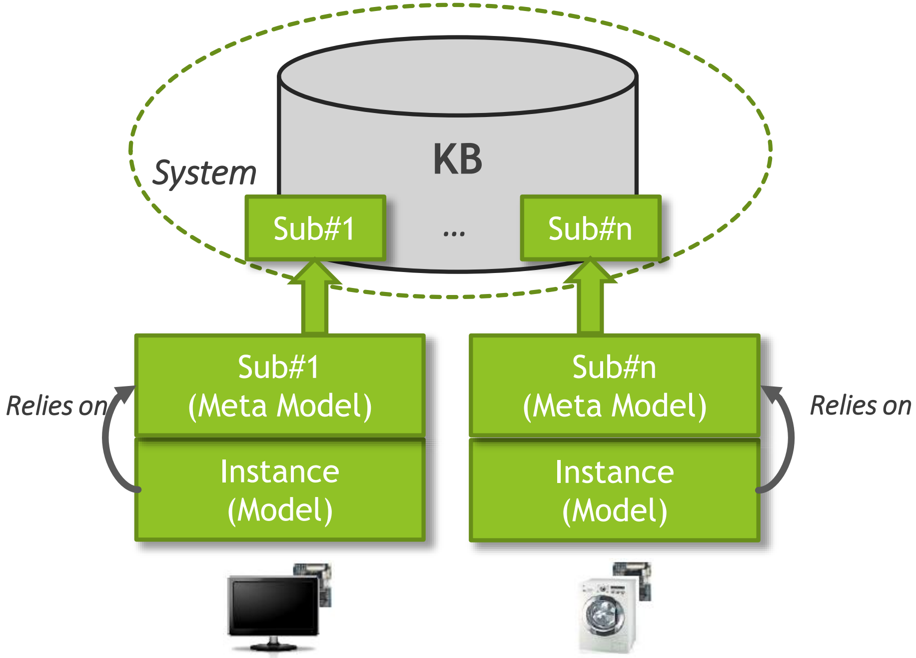
Model (Device annotation)
(Assertions about the world)



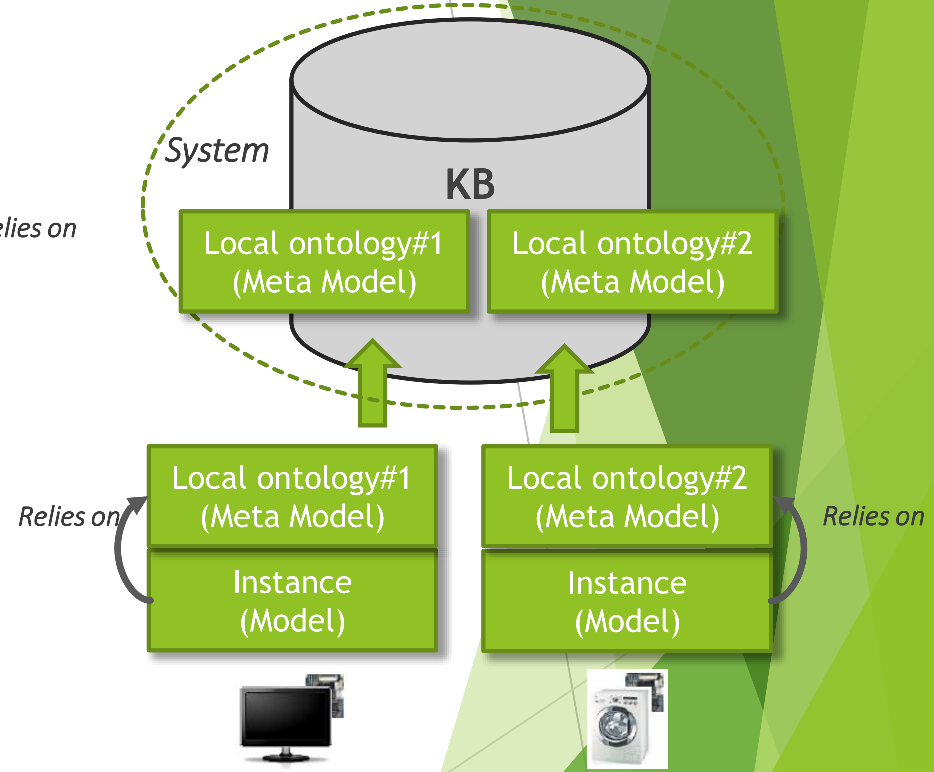
Ontology modeling (main) approaches in SWoT



Global approach : each device relies on a common upper ontology to describe its instance



Fragmented upper ontology approach : each device relies on fragments of a common upper ontology to describe its instance. The KB is enriched over time and contains only the needed knowledge.



Heterogeneous approach : each device relies on its own ontology to describe its instance. The KB is enriched over time with new meta models.

Semantic Web standards basics…

- Online resources
  - https://www.w3.org/standards/semanticweb/
  - http://www.inria.fr/centre/sophia/actualites/mooc-web-semantique-et-web-de-donnees
  - http://www.dcs.bbk.ac.uk/~michael/sw/sw.html
  - Etc…

SWoT Applications

SWoT Application domains…

- Smart Home,
- Smart Office,
- Smart Cities,
- Building automation,
- Assisted living,
- Smart Energy,
- Farming,
- Sensor networks,
- Etc…

The Internet of Things vision: Key features, applications and open issues, Eleonora Borgia Institute of Informatics and Telematics (IIT), Italian National Research Council (CNR), via G. Moruzzi 1, 56124 Pisa, Italy Computer Communications 54 (2014) 1–31, paper

SWoT for **context awareness (1/4)**

- Interconnecting devices and gather data from them allows to create **context aware** (aka situation) applications:
  - Better understanding their surrounding environment,
  - Making intelligent decisions and better **reacting** to the **dynamics** of their environment.

C. Perera, A. Zaslavsky, P. Christen and D. Georgakopoulos , "**Context aware computing for the internet of things: A survey**" , IEEE Commun. Surveys Tuts.

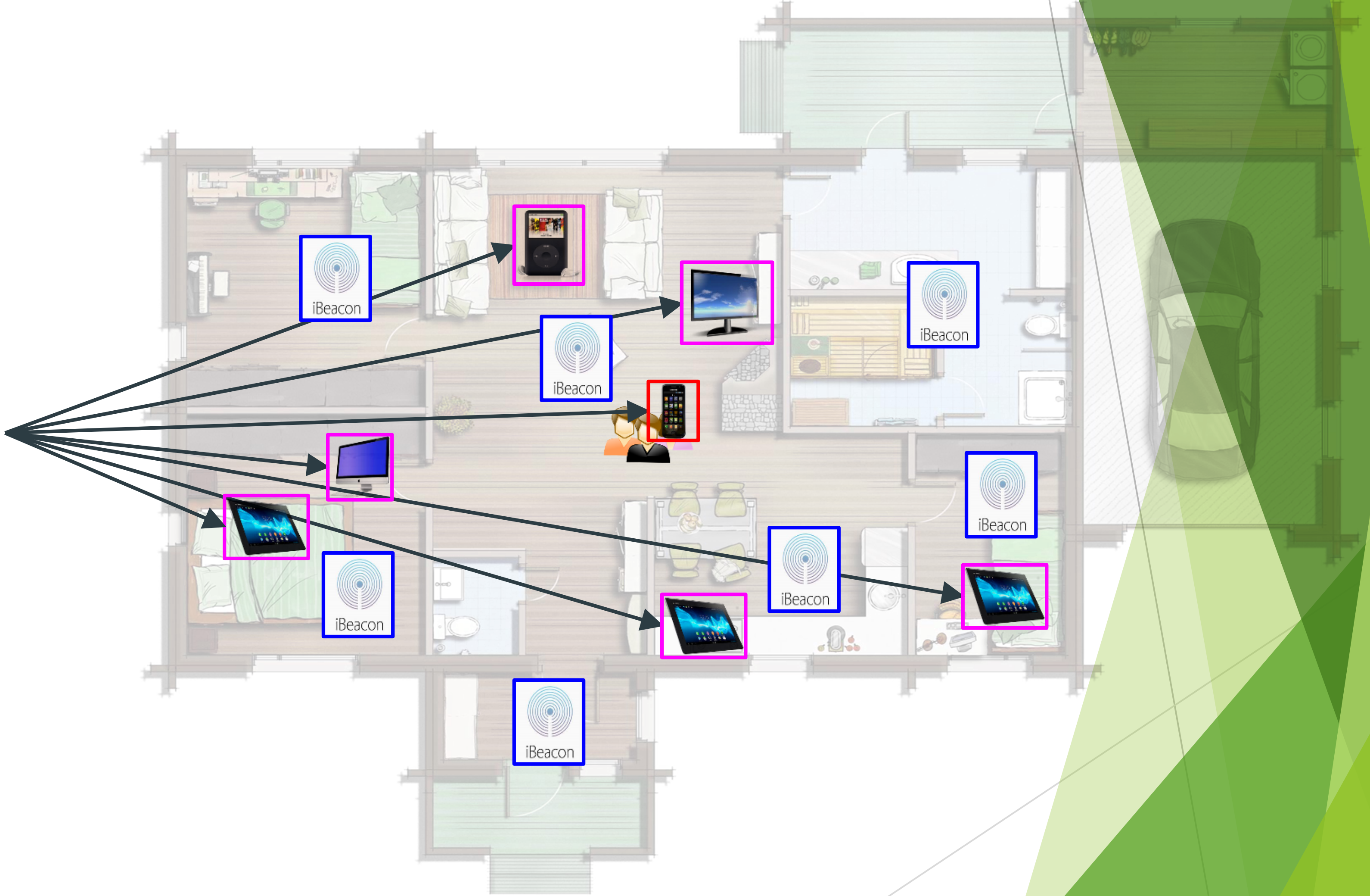
SWoT for context awareness (2/4)

Application objectives

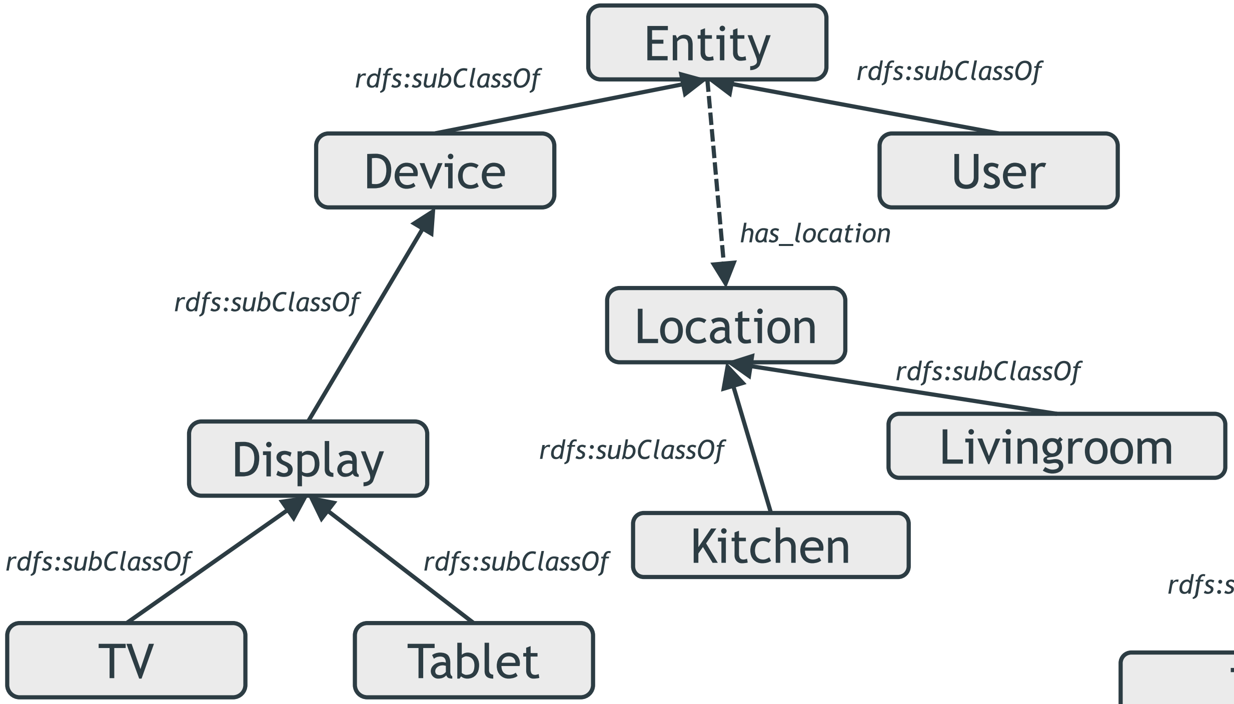
Display movie in the livingroom

Display movie for Bob

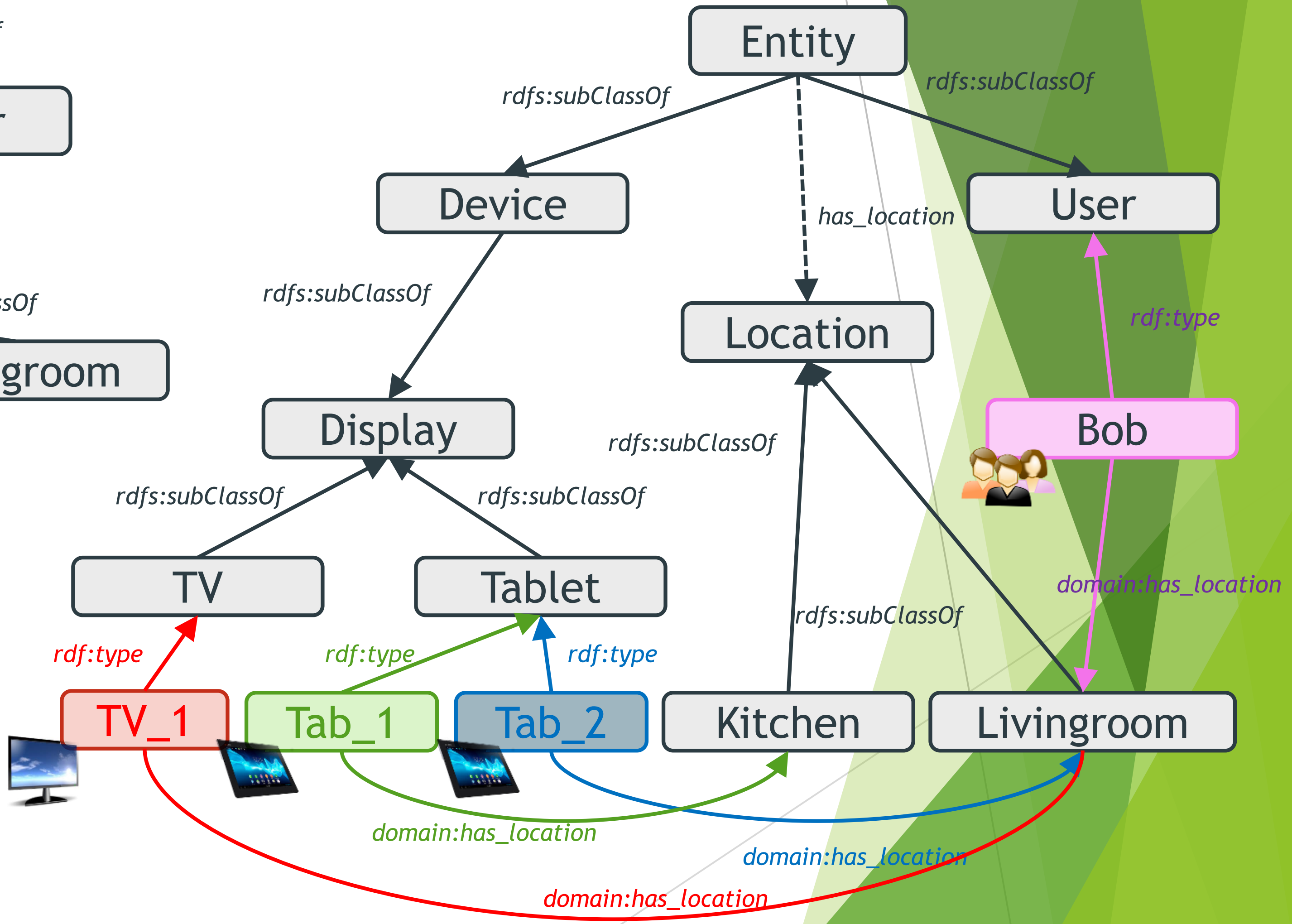
System



SWoT for context awareness (3/4)



Upper ontology

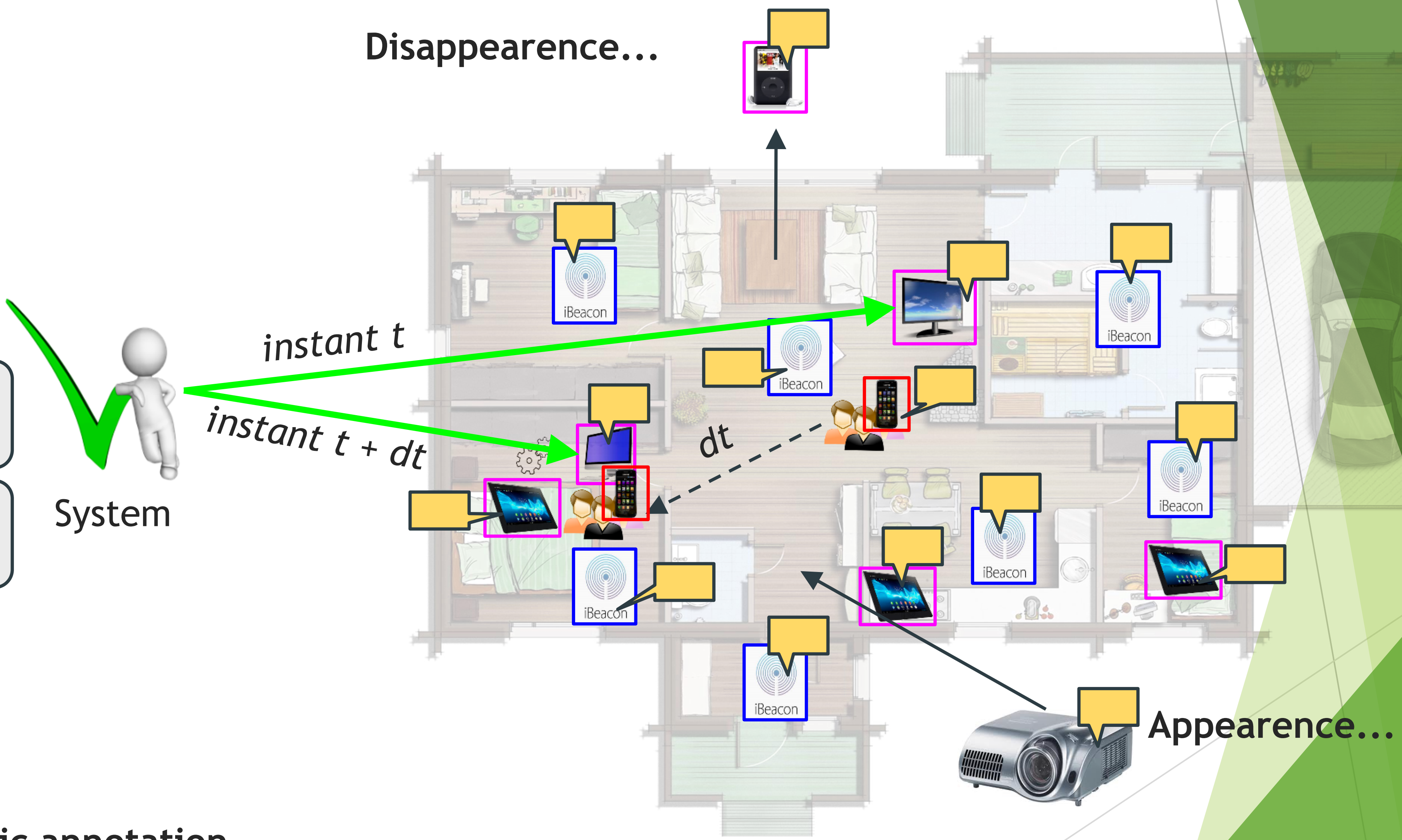


SWoT for context awareness (4/4)

Application objectives

Display movie in the livingroom

Display video for Bob



Semantic annotation

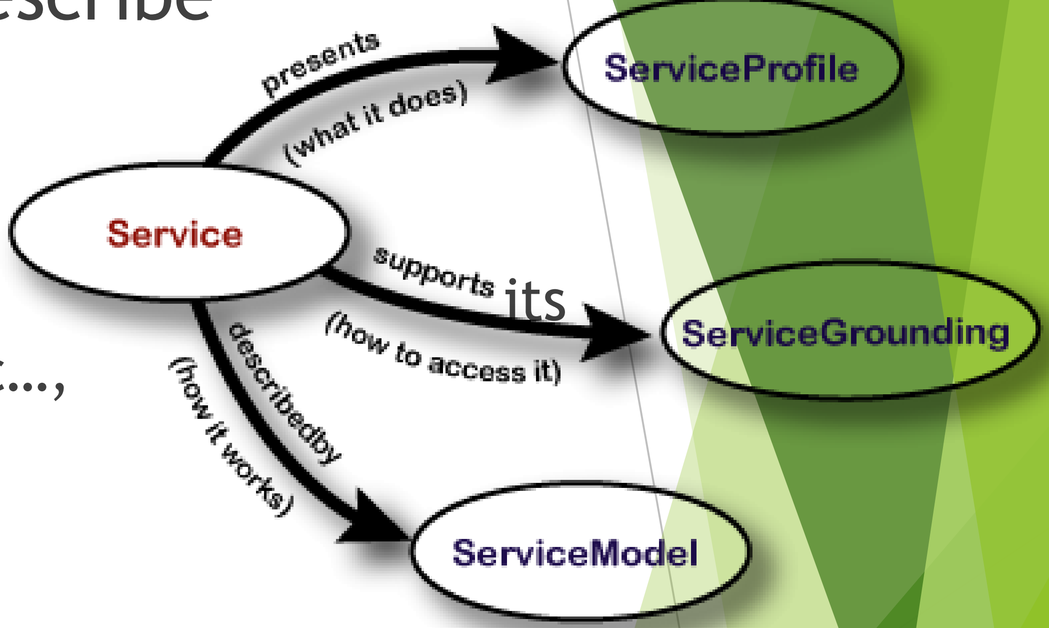
SWoT for **services composition**

- Services functionalities & context understanding enables applications to be composed using **relevant** services.
  - **Self-adaptive systems**,
  - **Continuity of service**.
- Solutions have been developed, allowing to **semantically describe web services** and ease their **discovery**, **composition** and **invocation**:
  - **OWL-S** (Semantic Markup for Web Services) http://www.daml.org/services/owl-s/1.0/owl-s.html
  - **SAWSDL** (Semantic Annotations for WSDL) https://www.w3.org/TR/sawsdl/
  - WSDL-S, WSMO, and more…

Lemos, A. L., Daniel, F., & Benatallah, B. (2015). **Web Service Composition: A Survey of Techniques and Tools**. ACM Computing Surveys (CSUR), 48(3), 33.

OWL-S Upper ontology (Three main parts)

- **Standard vocabulary** to semantically describe services
  - **Service profile**
    - Describes what the service does, its name, description, the quality of service (QoS), etc…,
    - Primary meant for human reading…
  - **Process Model**
    - Describes how a client can interact with the service.
    - Input, Output, Pre-conditions, Effects/Results (IOPE/IOPR).
  - **Service Grounding**
    - Information needed to interact with and instantiate the service,
    - Communication protocol, Message format, Port number, Etc.



SAWSDL

- OWL-S ontology leaves out domain specific objects, and also Groundings for other service technologies like UPnP…

- **SAWSDL…**
  - Semantic annotations for WSDL components (Web Service Description Language),
  - **Allows references to domain specific ontologies.**

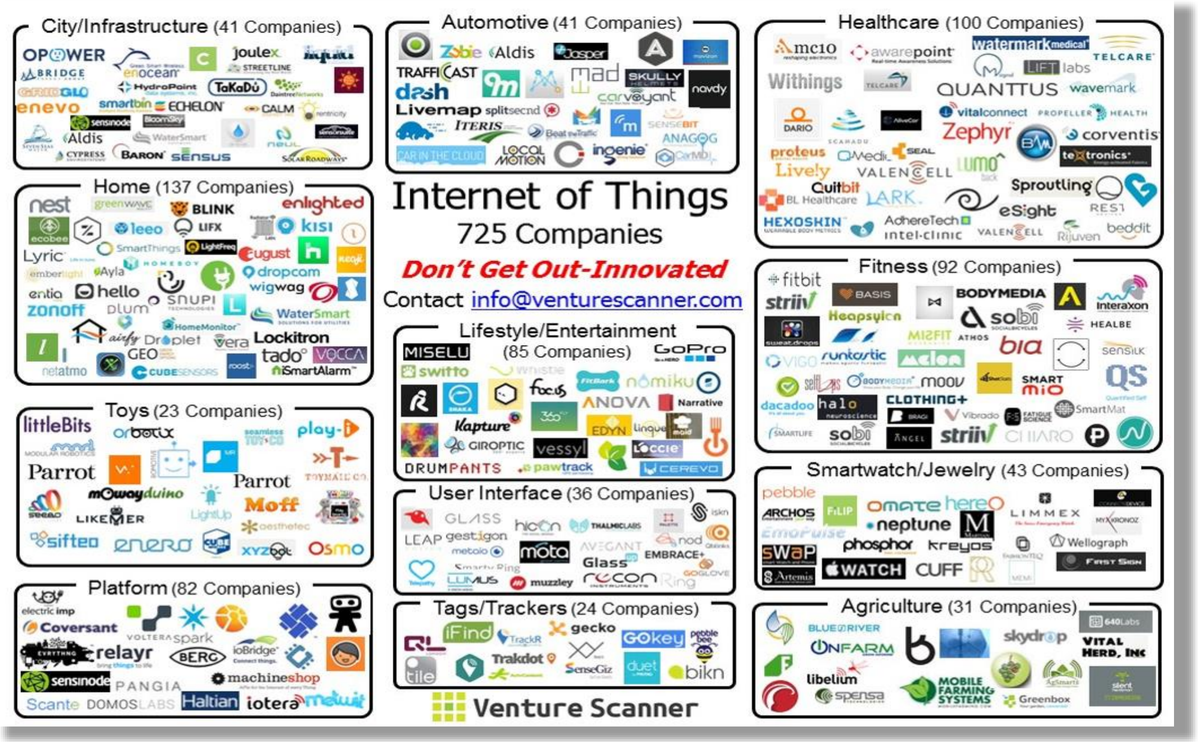
Semantic services composition approaches

- **Planning techniques**
  - Problem of finding and aggregating a series of services with compatible **IOPR/Es** allowing to reach the desired goal.
  - Multi-objective Quality of Service (QoS)
- **Model-driven**
  - Defining a high level abstraction (model of the target application),
  - **Matching/service selection** approach to iteratively check each service, trying to match with the required functionality.

Looks good! What's wrong???

Internet of Things numerous actors…

- That (will) most likely **develop their own ontologies** to describe their devices…



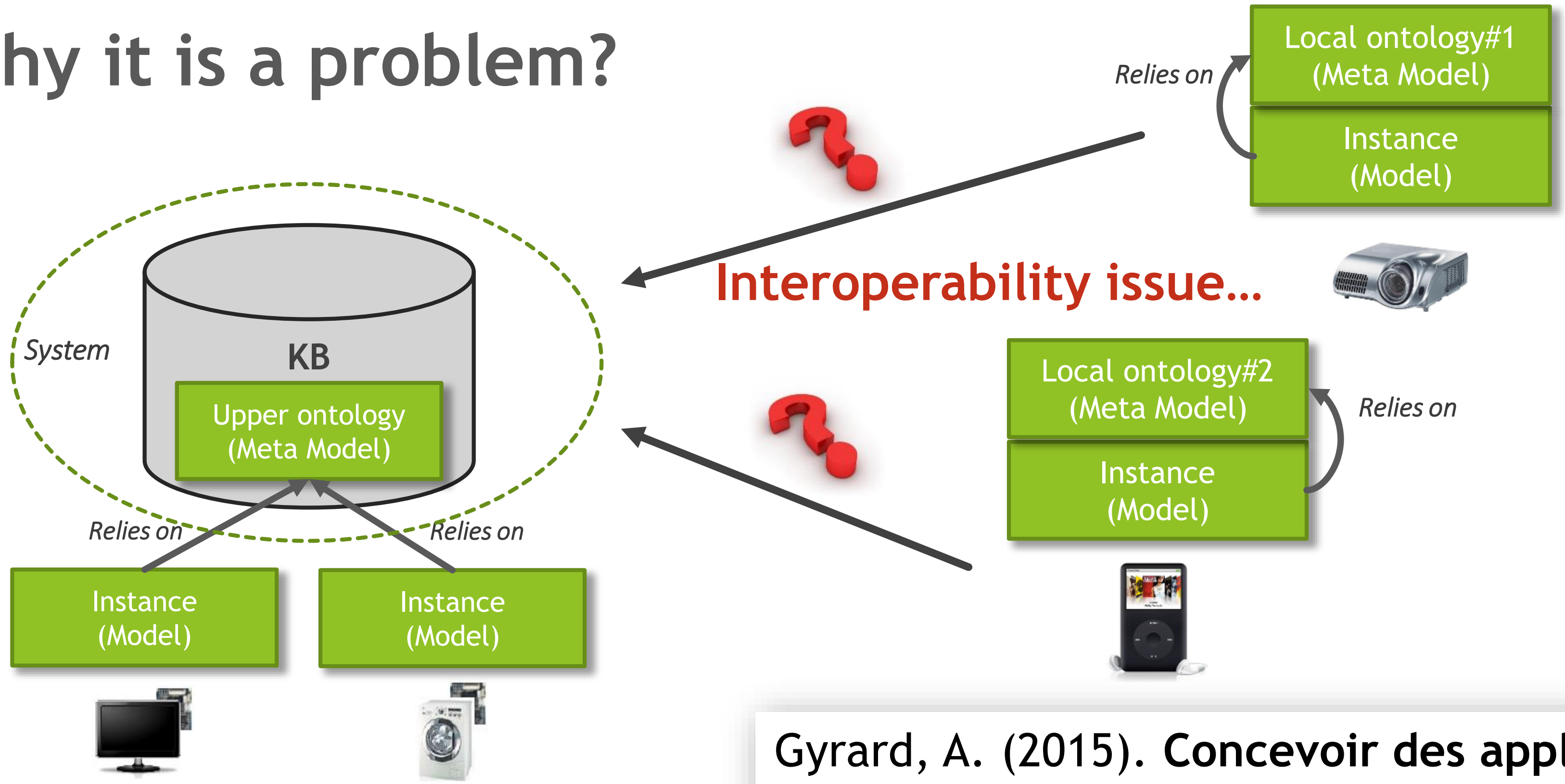
- The development of a comprehensive ontology **describing the world is unlikely to happen…**

Internet of Things ontologies…

- Numerous ontologies available, **targeting different domains…**
- http://www.sensormeasurement.appspot.com/?p=ontologies references up to 296 different ontologies…

Full interoperability not yet a reality…

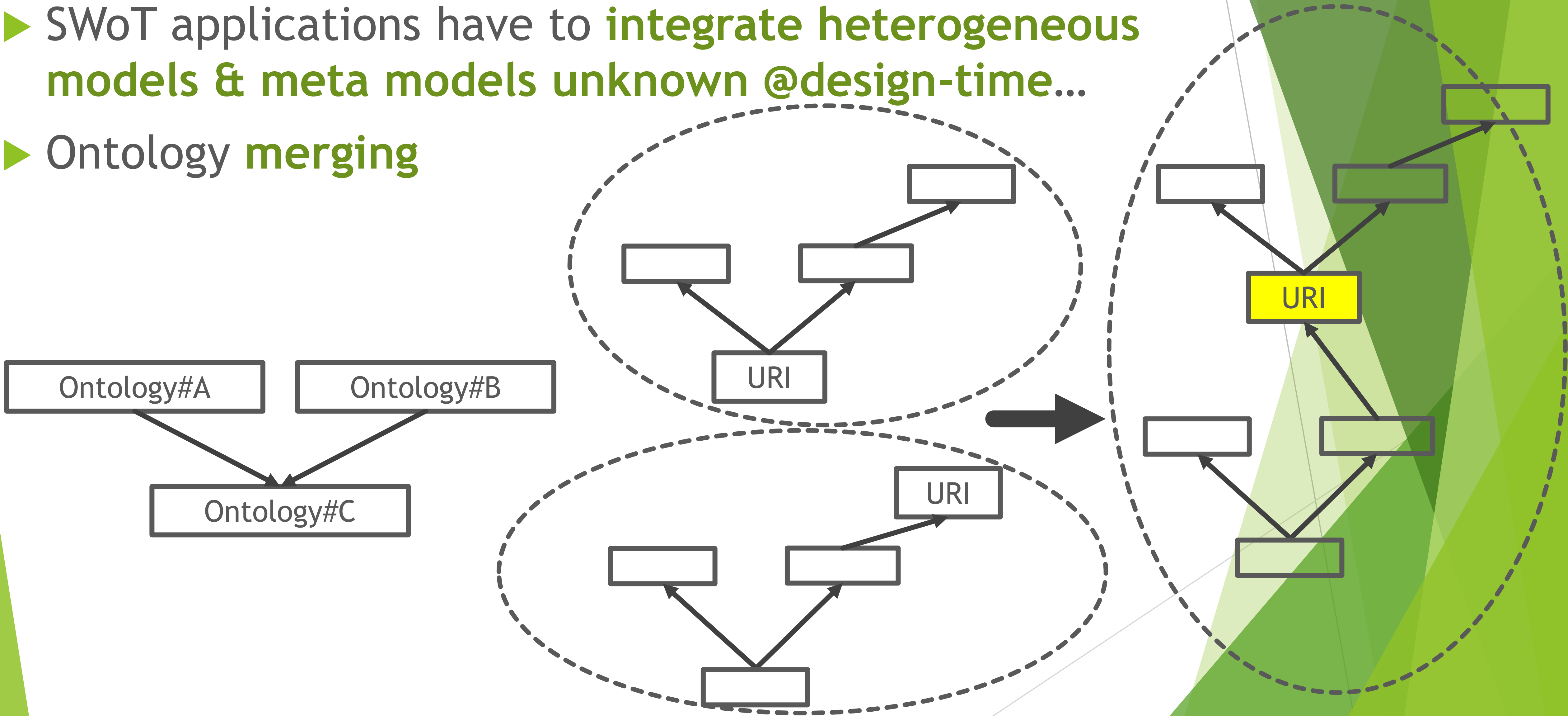
- Actually, most of the current SWoT applications rely on *ad-hoc* ontologies that cannot be reused → It works but is application/domain specific.
- **Why it is a problem?**



Gyrard, A. (2015). **Concevoir des applications internet des objets sémantiques** (Doctoral dissertation, Paris, ENST).

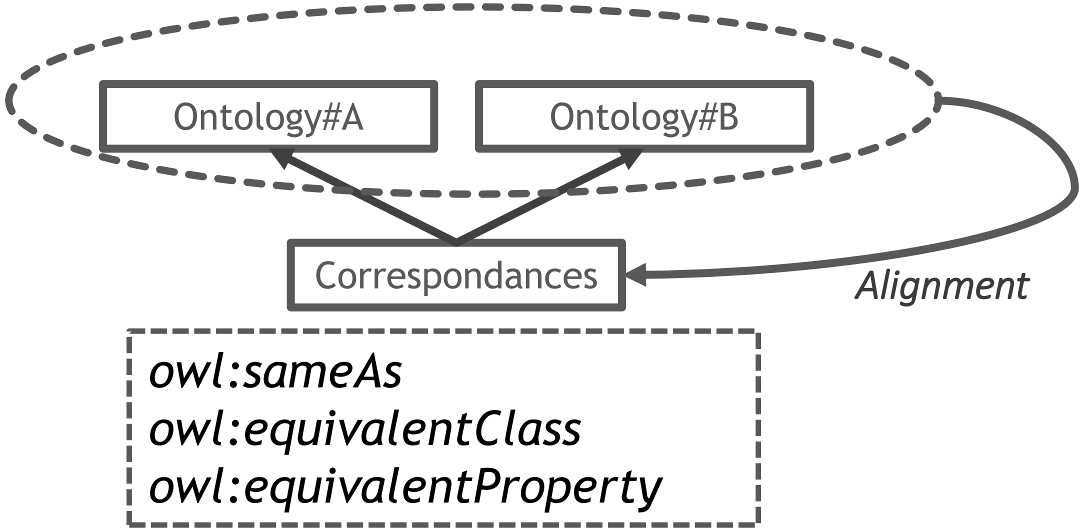
Knowledge base enrichment over time (1/4)

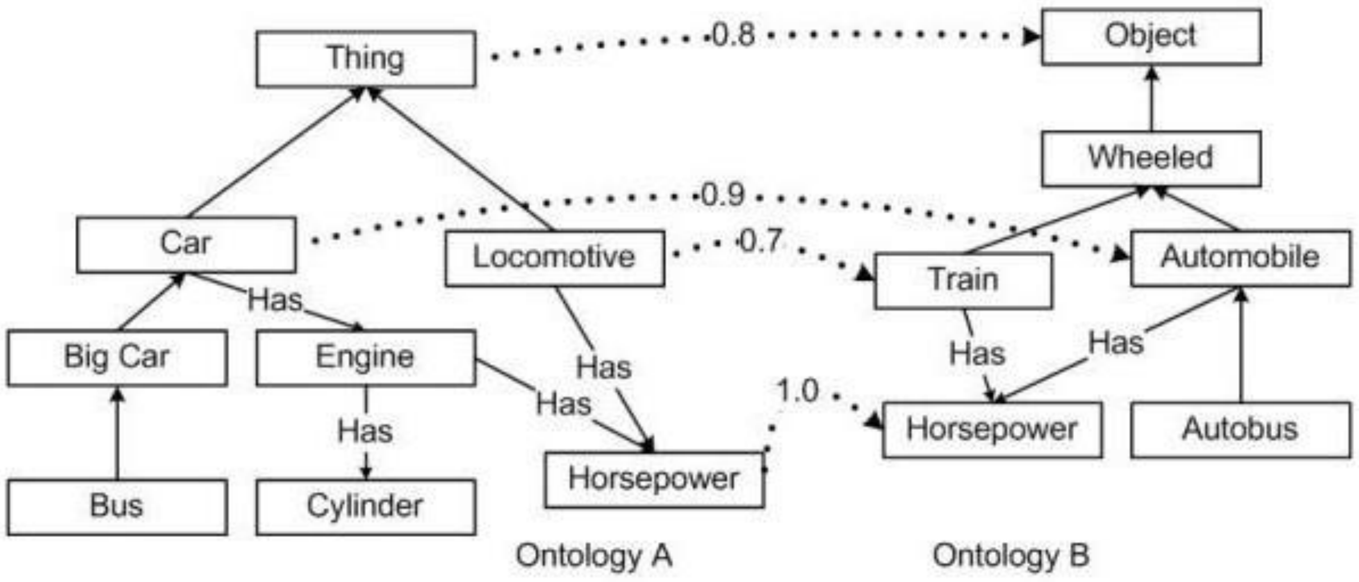
- SWoT applications have to **integrate heterogeneous models & meta models unknown @design-time…**
- Ontology **merging**



Knowledge base enrichment over time (2/4)

- Ontology **alignment** & **Mapping**





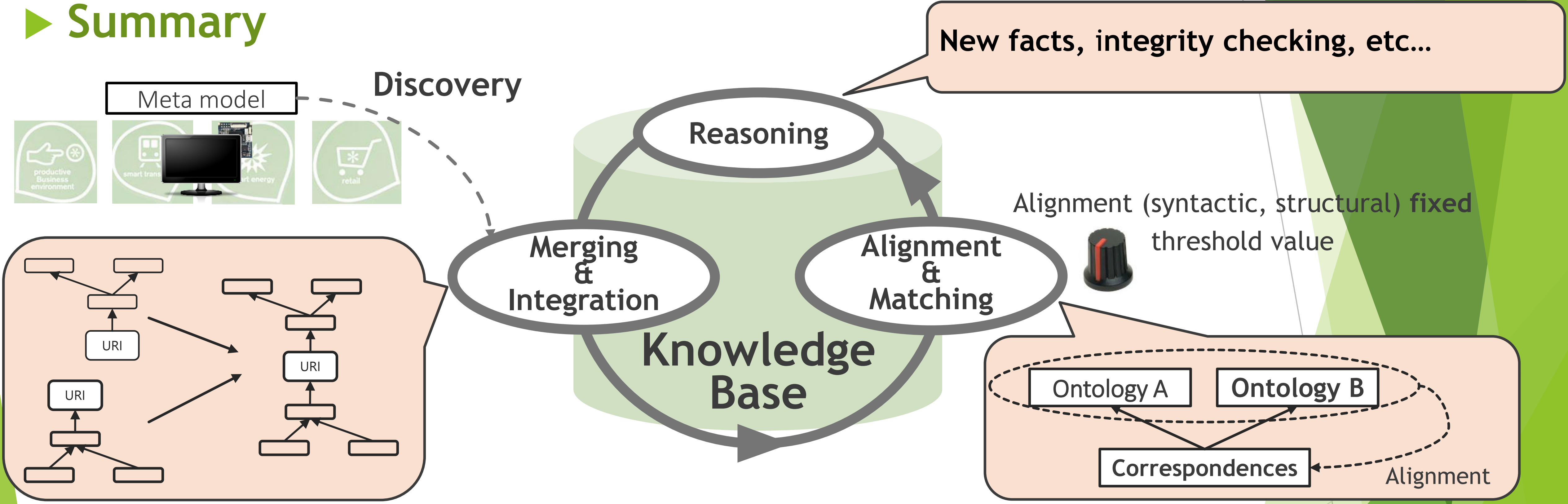
Example from http://www.webology.org/2006/v3n3/a28.html

- **Several algorithms available…**
  - Syntactic alignment,
  - Structural alignment
- **Alignments are not perfect and depend on a pre-defined threshold value…**

http://www.sensormeasurement.appspot.com/?p=ontoMappingTool

Knowledge base enrichment over time (3/4)

- **Summary**



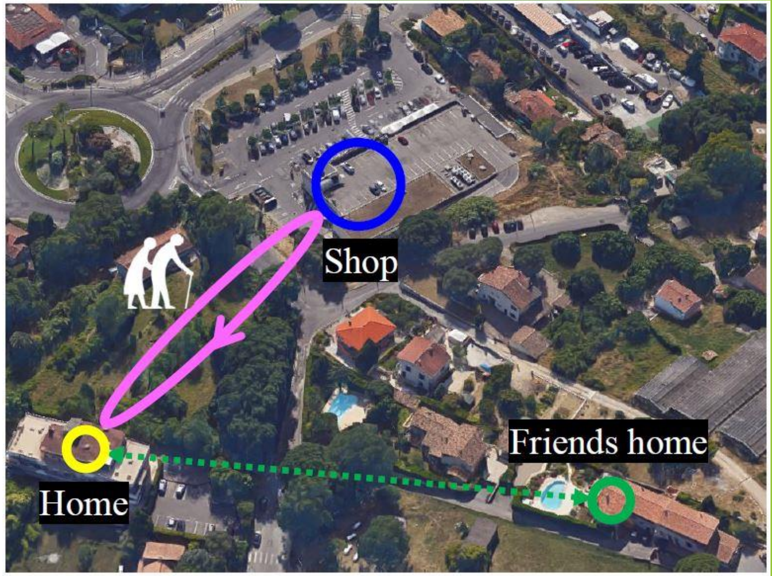
- **!!! KB content management !!!**
  - **Validity over time?**
  - **Inconsistencies management?**

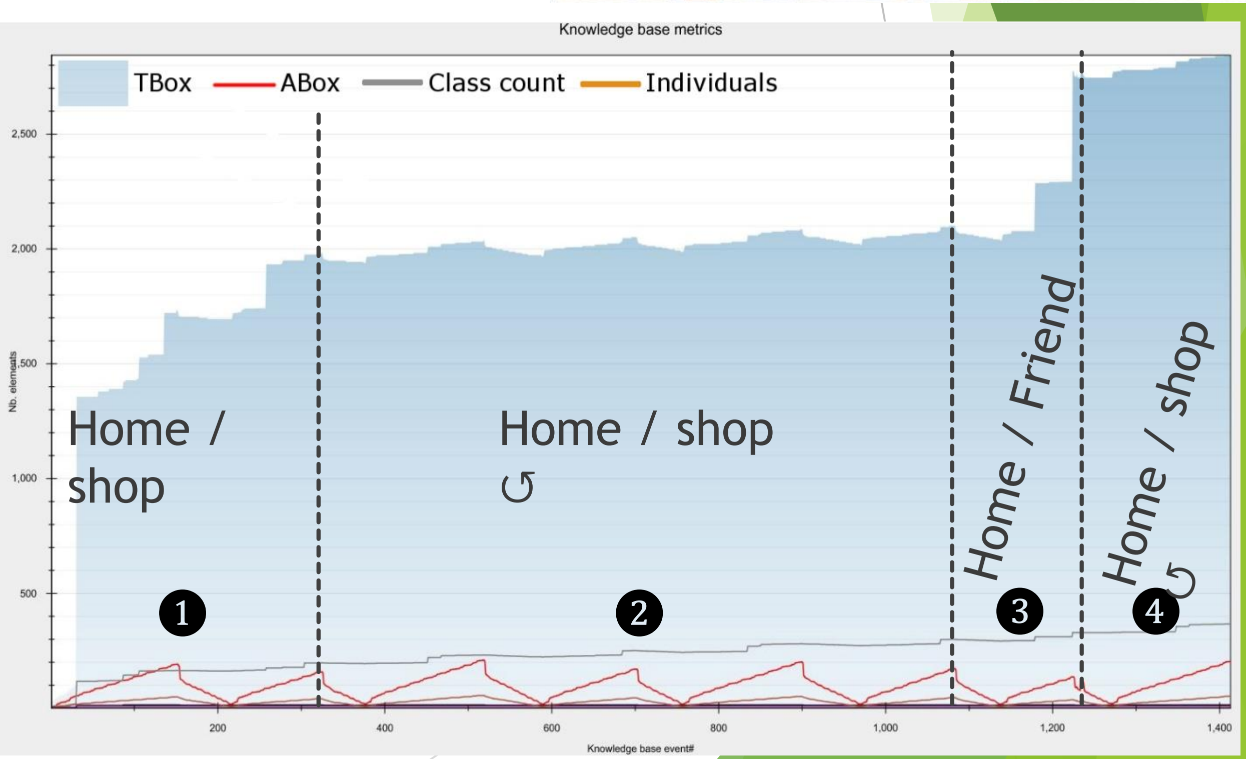
Rocher, G., Tigli, J. Y., Lavirotte, S., & Daikhi, R. (2015, October). **Run-time knowledge model enrichment in SWoT: A step toward ambient services selection relevancy**. In Internet of Things (IOT), 2015 5th International Conference on the (pp. 62-69). IEEE.

Knowledge base enrichment over time (4/4)

▶ Example

Location	Device	Classes	Axioms	Degradation
Home	Boiler	100	453	0%
Home	Clock	13	69	43.44%
Home	Computer	24	124	0%
Home	Cooker	48	109	73.28%
Home	DeepFreezer	48	105	76.87%
Home	DishWasher	38	110	75.22%
Home	Fan	24	124	0%
Home	Oven	109	489	0%
Home	Printer	24	124	0%
Shop	CoffeeMaker	24	124	0%
Shop	Computer	13	58	53.22%
Shop	DeepFreezer	100	454	0%
Shop	Entertainment	11	30	75.80%
Shop	Fan	2	4	96.77%
Shop	Fridge	44	73	85.45%
Shop	Printer	11	49	60.48%
Friend	**Clock**	24	122	0%
Friend	Computer	2	4	96.77%
Friend	**Cooker**	88	408	0%
Friend	**DishWasher**	97	444	0%
Friend	Entertainment	24	124	0%
Friend	Fridge	109	502	0%
Friend	Oven	26	67	86.29
Friend	WashingMachine	110	490	0%





Some tools…

Some tools (1/2)…

- Ontology engineering
  - Protégé (http://protege.stanford.edu/)
- Java framework
  - Knowledge base
    - Apache Jena (https://jena.apache.org/)
    - The OWL API (http://owlapi.sourceforge.net/)
  - Reasoners
    - Pellet (https://github.com/Complexible/pellet)
    - HermiT (http://www.hermit-reasoner.com/)
  - Alignment
    - Alignment API (http://alignapi.gforge.inria.fr/)

Some tools (2/2)…

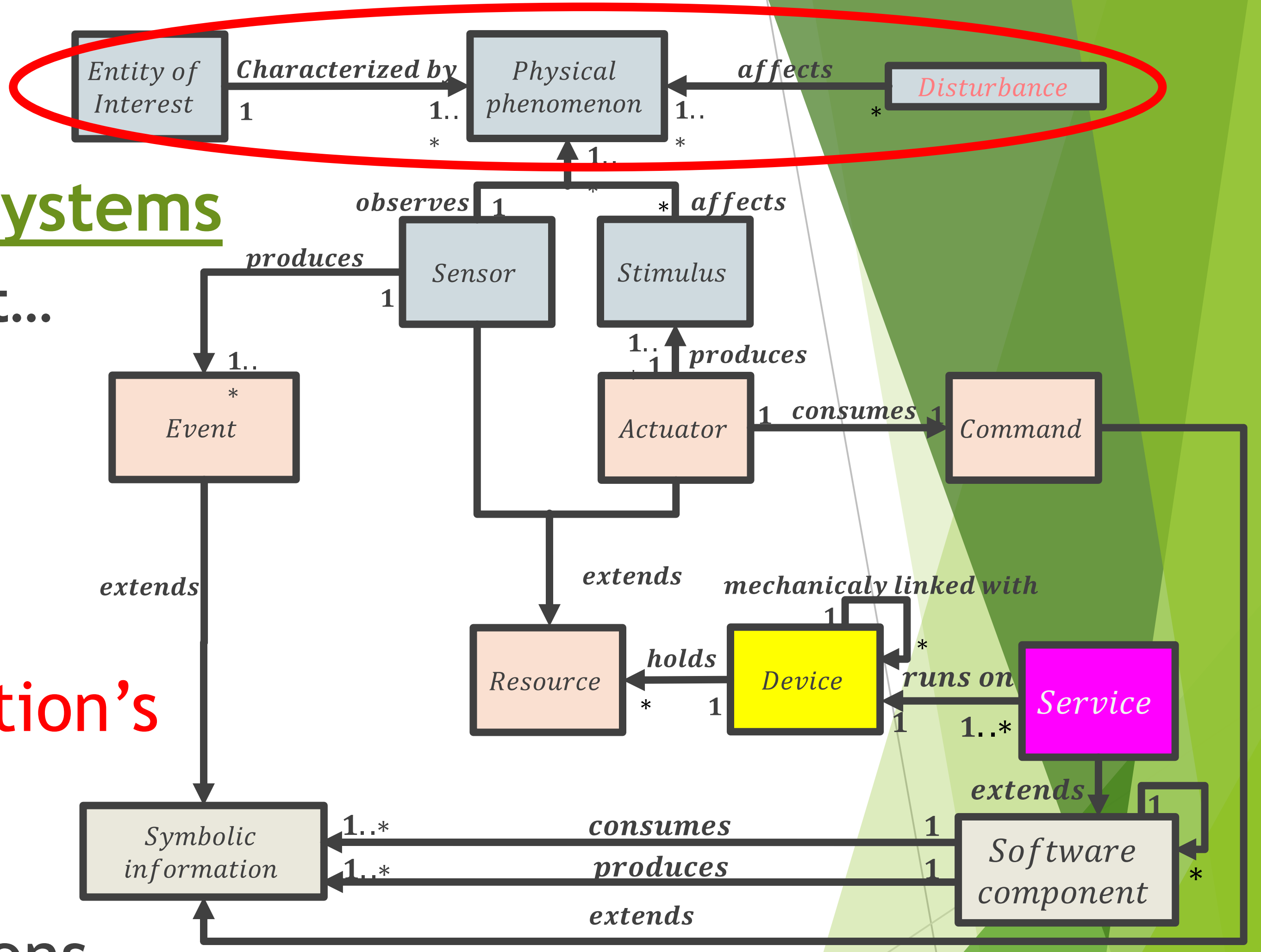
- Ontology search engines
  - Watson (http://watson.kmi.open.ac.uk/WatsonWUI/)
  - Swoogle (http://swoogle.umbc.edu/)
- Ontology online validators
  - W3C (https://www.w3.org/2001/sw/wiki/SWValidators)

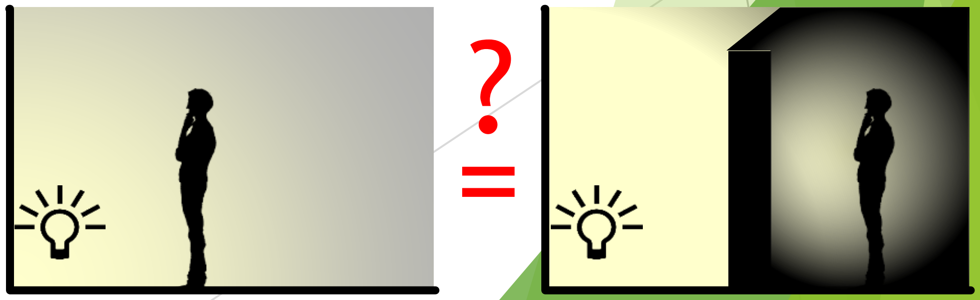
  - More tools are listed here : http://www.sensormeasurement.appspot.com/?p=semanticTool

Is SWoT good enough?

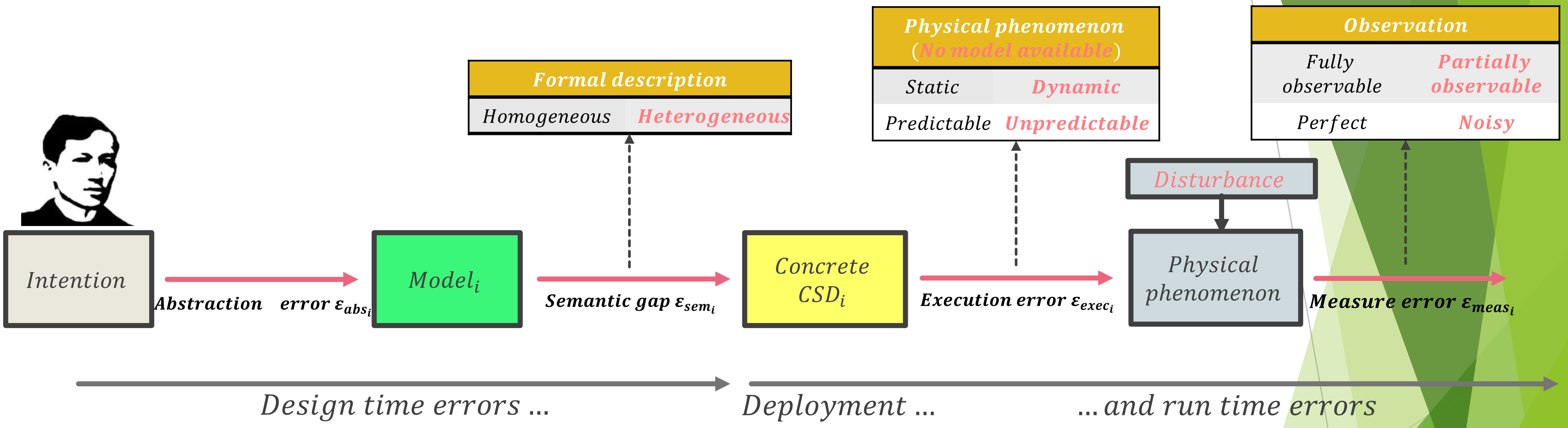
Is SWoT enough?

- SWoT seen as Cyber-Physical systems
  - Actions in physical environment…
    - Non-deterministic,
    - Dynamic,
    - Implicit interactions,
    - Etc…
- **One cannot ensure the application's functionality is satisfied and maintained over time…**
- …Even with semantic descriptions.



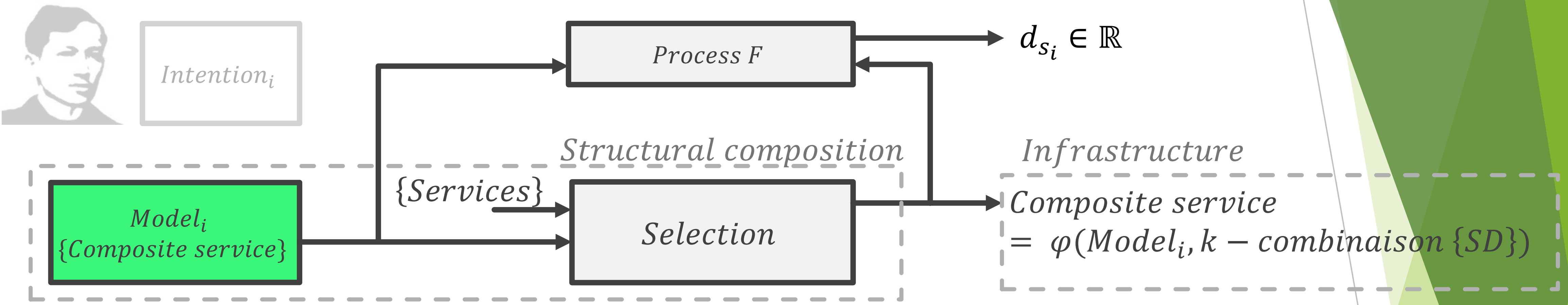


Cyber Physical Systems : problem statement

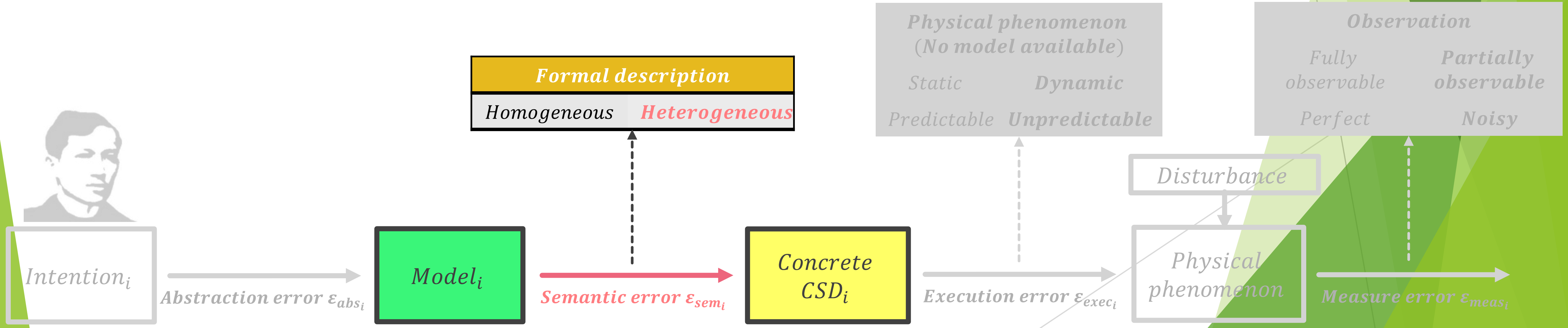


One cannot ensure the intention is satisfied and maintained over time…

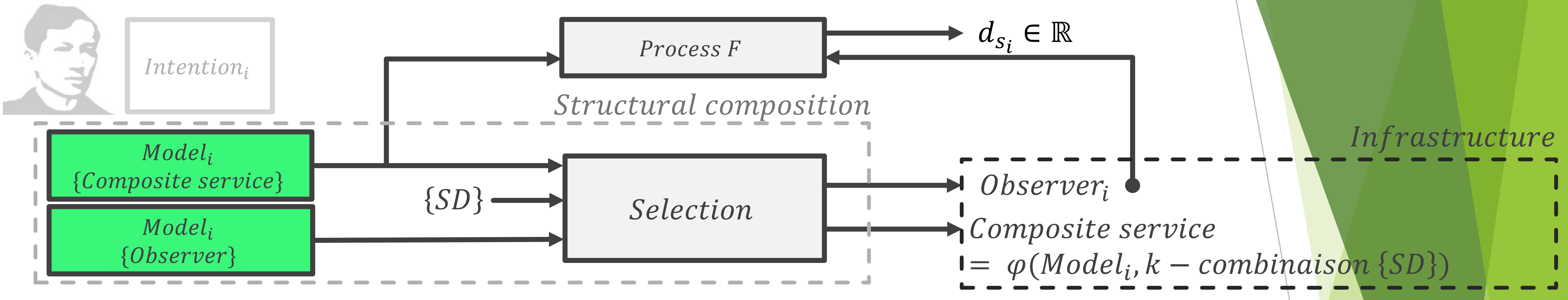
Feedforward approach



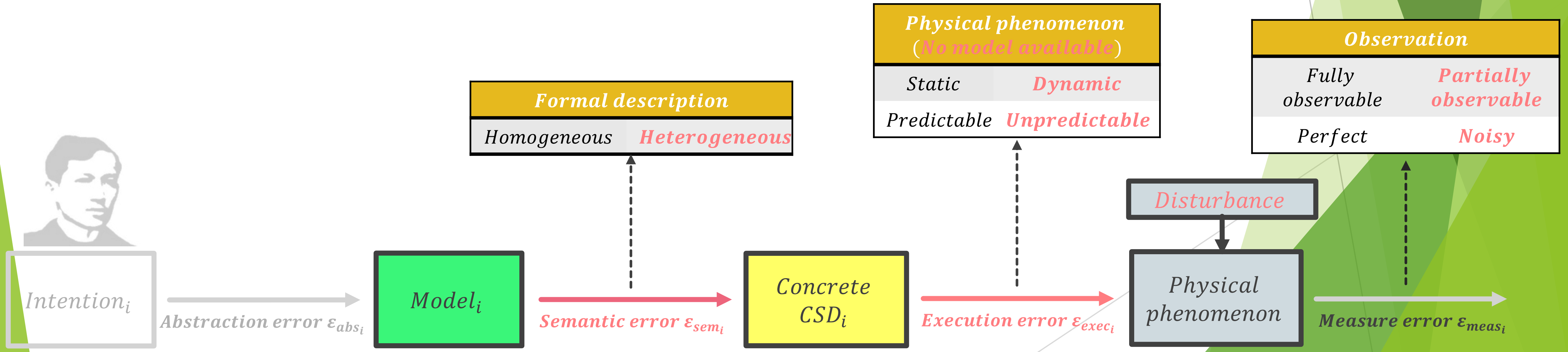
d_{s_i} *depends only on* $Model_i$*, gives* ε_{sem_i} ➔ (Semantic gap measure)



Feedback approach : -- Cybernetics --



d_{s_i} *is* Obs_i *dependent, gives* $\varepsilon_{sem_i} + \varepsilon_{exec_i}$ (Takes into account physical interactions)



Thank you!