Dynamic Linked Data and Internet of Things

SEPA training

24th Conference of the Open Innovations Association FRUCT

Moscow, Russia

April 9th-10th, 2019

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https://site.unibo.it/wot/en

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA ARCES

IEEE

IEEE ComSoc IEEE Communications Society

IEEE Italy Section

Back to past (1991)

Computer Science Laboratory @ Xerox Palo Alto Research Center

Source: M. Weiser The Computer for the 21st Century. *Sci. Am.* September **1991**, 265, 3, 94-104.

Ubiquitous computing

Cheap

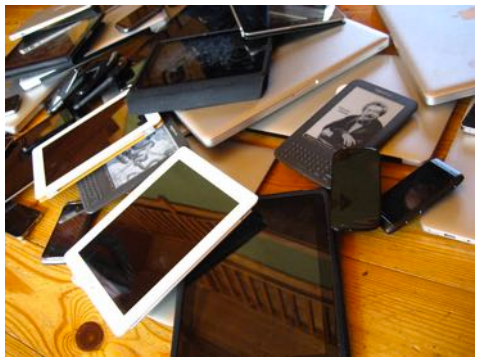
Connected

Small

Low power

Context-aware computing

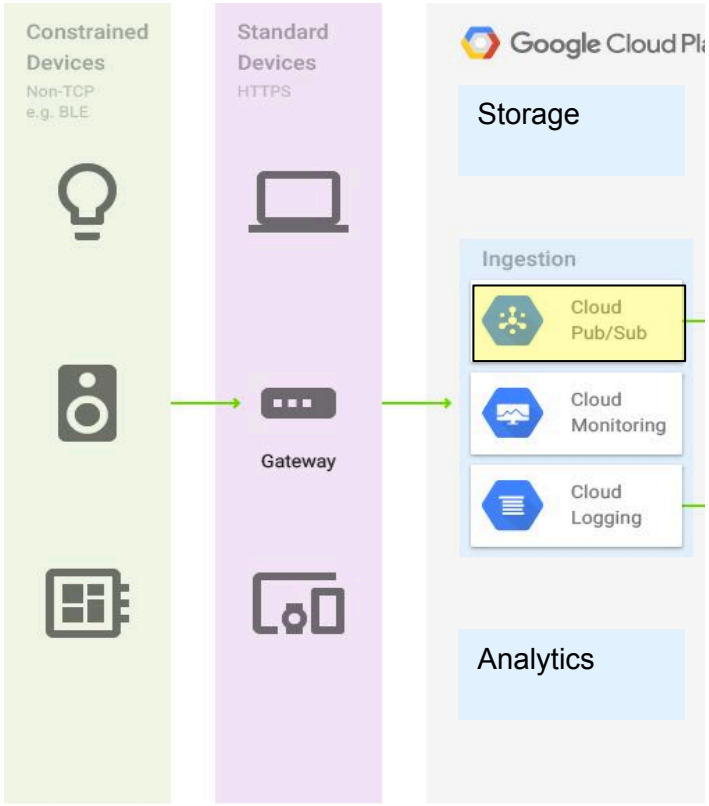
Mobile (**Sensors** Augmented) Devices



Radio **F**requency **IDENTIFICATION**

Welcome to the jungle!

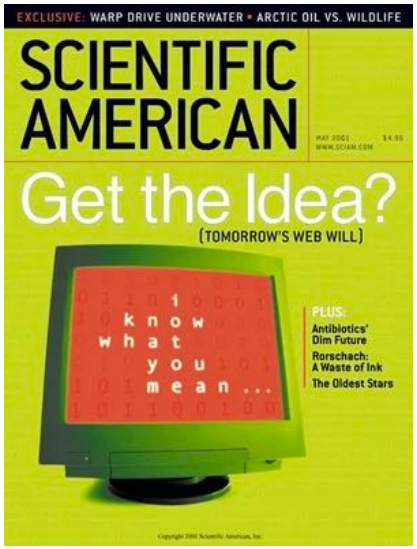
https://cloud.google.com/solutions/iot-overview



https://software.intel.com/en-us/**iot**/hardware/**gateways**

http://www.eurotech.com/en/products/devices/**iot+gateways**

Back to the past (2001-2009)



Semantic Web

*"Most of the Web's content today is designed for **humans** to read, not for **computer programs** to manipulate meaningfully"*

Berners-Lee, T.; Hendler, J.; Lassila, O. The Semantic Web. *Sci. Am.* **2001**, 284, 28-37.

Resource Description Framework (RDF): Concepts and Abstract Syntax (**2004**)
https://www.w3.org/TR/rdf-concepts/

N. Shadbolt, T. Berners-Lee and W. Hall, "The Semantic Web Revisited," in *IEEE Intelligent Systems*, vol. 21, no. 3, pp. 96-101, Jan.-Feb. **2006**.

Linked Data

Tim Berners-Lee
Date: **2006**-07-27, last change: $Date: **2009**/06/18 18:24:33 $
Status: personal view only. Editing status: imperfect but published.
https://www.w3.org/DesignIssues/LinkedData.html

Bizer, C.; Heath, T.; Berners-Lee, T. Linked Data-The Story So Far. *Int. J. Semant. Web Inf. Syst.* **2009**, 5, 1-22.

Web data versus Web documents

About: Università di Bologna

An Entity of Type : organisation, from Nam

Linked Data ← LINK → Linked HTML pages

L'Alma Mater Studiorum - Uni
antica università d'Europa. No
esisteva già dall'XI secolo: secondo alcuni storici l'anno della fondazione è il 1088, data fissata, in occasione dell'ottavo centenario,
da una commissione presieduta da Giosuè Carducci; il fondatore è considerato Irnerio, morto presumibilmente dopo il 1125.

dbo:city	dbr:Bologna
dbo:country	dbr:Italy
dbo:facultySize	2850 (xsd:integer)
dbo:motto	St. Peter is the father of all places and Bologna the mother of the Law Petrus ubique pater legum Bononia mater (Latin)
dbo:numberOfPostgraduateStudents	29576 (xsd:integer)
dbo:numberOfStudents	82363 (xsd:integer)
dbo:numberOfUndergraduateStudents	52787 (xsd:integer)

Coordinates: 44°29′38″N 11°20′34″E

ntinuous operation,[2] as well as
ommonly ranking in the first

to define the institution located in
about 85,500 students in its 11
t also has a school of excellence
ess S.p.A. (BUP).

ave been 1088.[6] The university
entury, a committee of historians led
hich would make it the oldest

‹ The template *Infobox university* is being considered for merging. ›

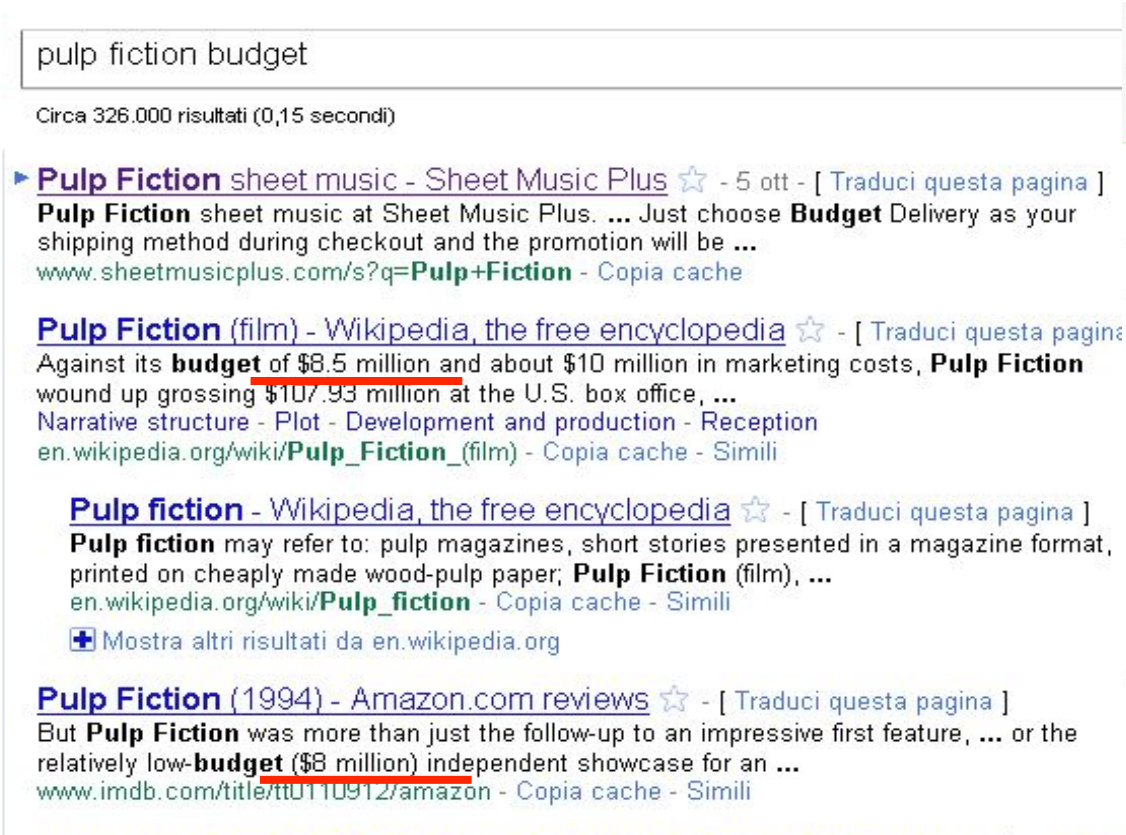
University of Bologna

Università di Bologna

Latin: *Universitas Bononiensis*

Motto	*Petrus ubique pater legum Bononia mater*[1] (Latin)
Motto in English	St. Peter is everywhere the father of the law, Bologna is its mother
Type	Public
Established	c. 1088; 930 years ago
Rector	Francesco Ubertini
Academic staff	2,850
Students	82,363
Undergraduates	52,787
Postgraduates	29,576
Location	Bologna, Italy
Campus	Urban (University Town)

The budget of Pulp Fiction by Google



2012

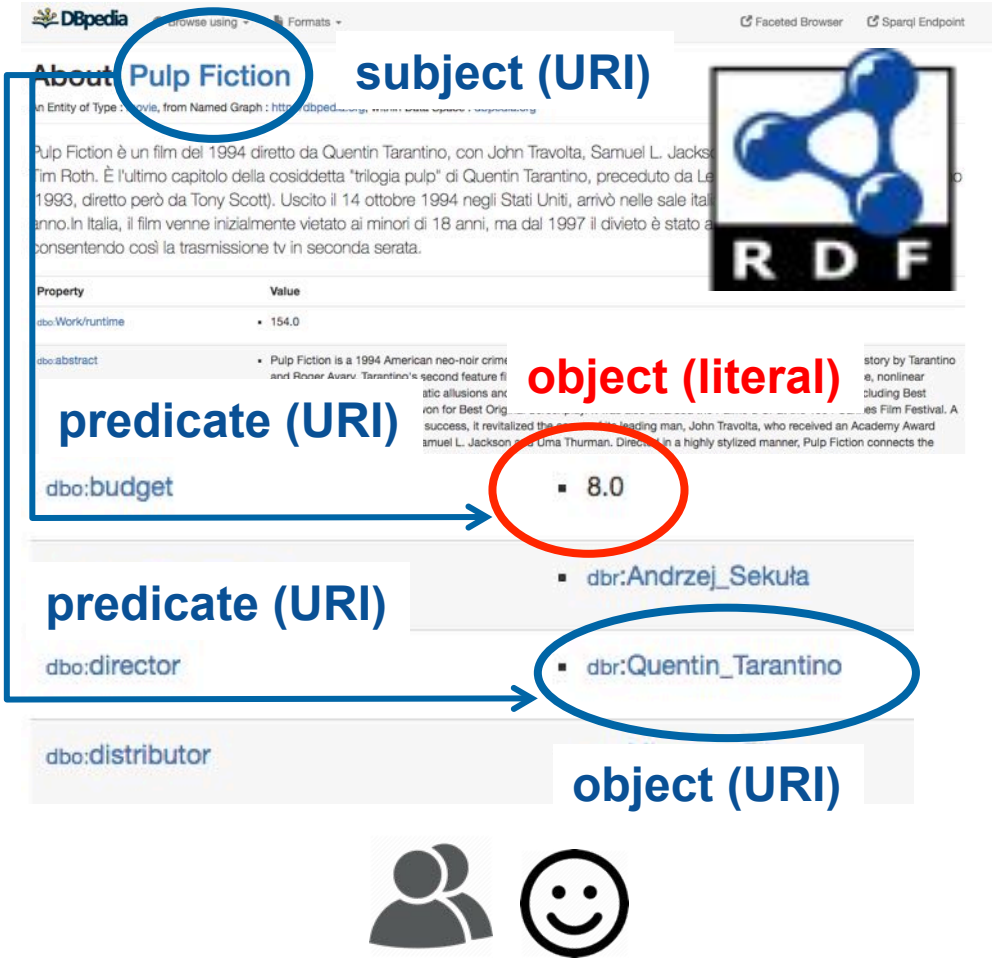
☹ **326 K results** ☺ **150 ms**

2018

☹ **5.7 M results** 😐 **560 ms**

The budget of Pulp Fiction by DBpedia

http://dbpedia.org/resource/Pulp_Fiction



SPARQL:

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX foaf: <http://xmlns.com/foaf/0.1/>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
PREFIX : <http://dbpedia.org/resource/>
PREFIX dbpedia2: <http://dbpedia.org/property/>
PREFIX dbpedia: <http://dbpedia.org/>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
SELECT ?budget {<http://dbpedia.org/resource/Pulp_Fiction> dbo:budget ?budget}
```

Results: Browse Go! Reset

SPARQL results:

budget
"8.0"^^dbpedia:datatype/usDollar

1 result

500 ms

DBpedia in numbers

Dbpedia knowledge base (English version):

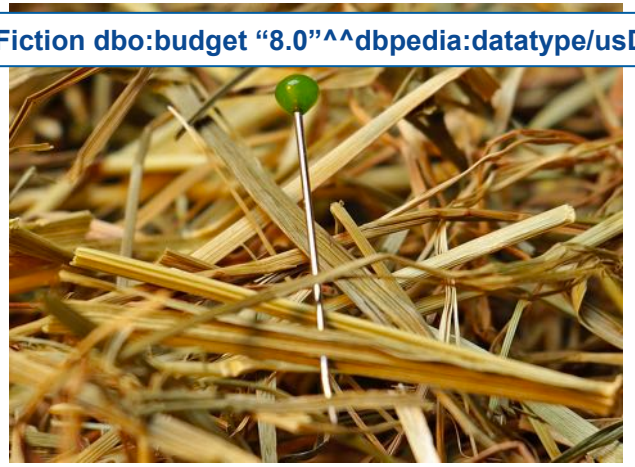
- 4.58 million things
  - 1,445,000 persons
  - 735,000 places
  - 411,000 creative works
    - 123,000 music albums
    - 87,000 films
    - 19,000 video games
  - 241,000 organizations
  - 251,000 species
  - 6,000 diseases

Localized in 125 languages ➔ **38.3 million things**

DBpedia is connected with other Linked Datasets by around **50 million RDF links**.

Altogether the DBpedia **2014** release consists of **3 billion RDF triples**

:Pulp_Fiction dbo:budget “8.0”^^dbpedia:datatype/usDollar



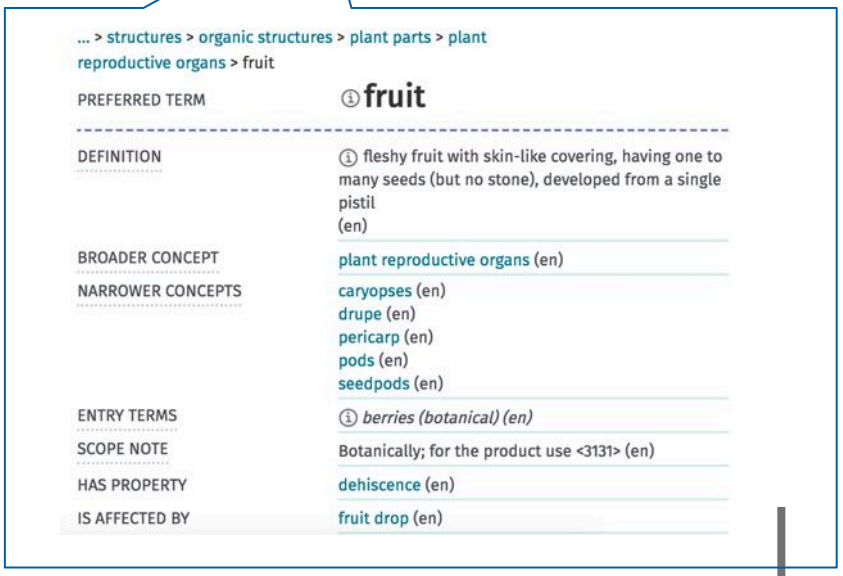
The full DBpedia data set features:

- 38 million labels and abstracts
- 25.2 million links to images
- 29.8 million links to external web pages
- 80.9 million links to Wikipedia categories

Ontologies

- Enable a **common understanding** of the structured information among **people** and/or **software** agents
- Make domain knowledge **reusable**
- Enable the **interoperability** among models or specific domain vocabularies
- Allow to model the **context** from diverse and heterogeneous source
- Enable **reasoning** and inference mechanisms by means of explicit representation of semantics

The **AGROVOC** thesaurus was first published at the beginning of the 1980s by the **Food and Agriculture Organization (FAO)** of the United Nations. Today, AGROVOC is available as a **Linked Data** (LD) set composed of **35,000+ concepts** available in up to **29 languages**.



Linked Data & IoT

Decentralization

Linked Data➔ Data

IoT ➔ Computational power

Interoperability

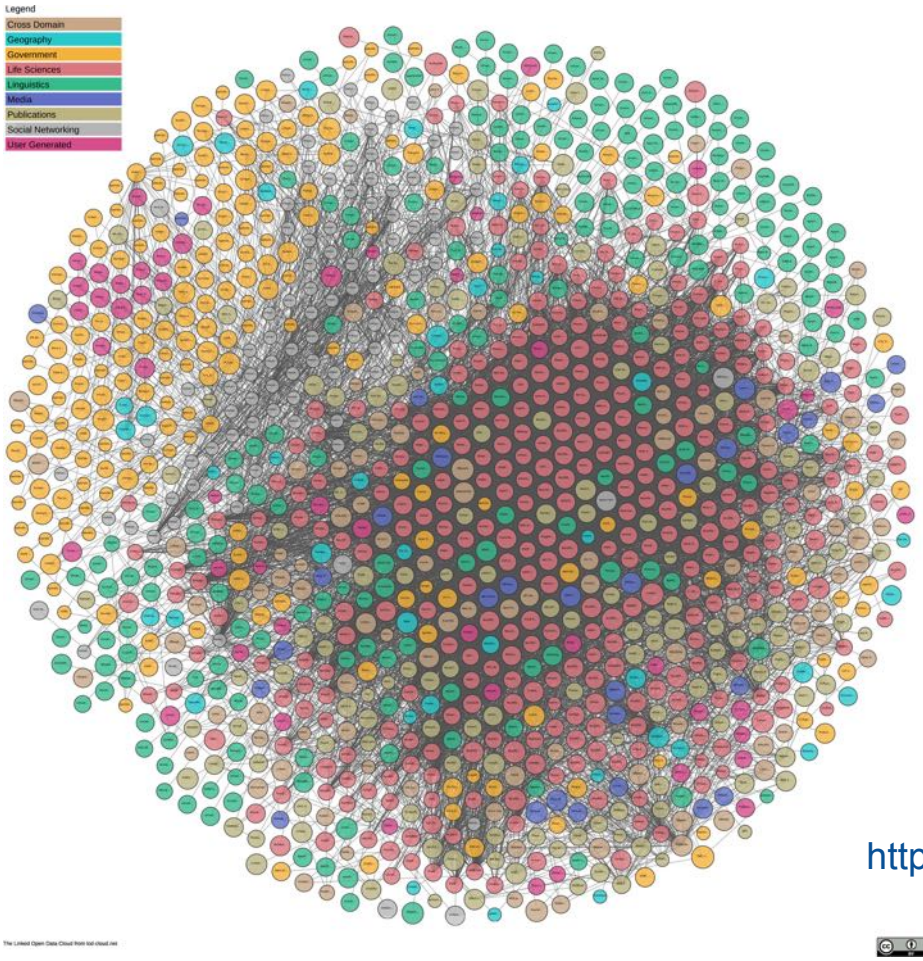
Linked Data➔ by definition

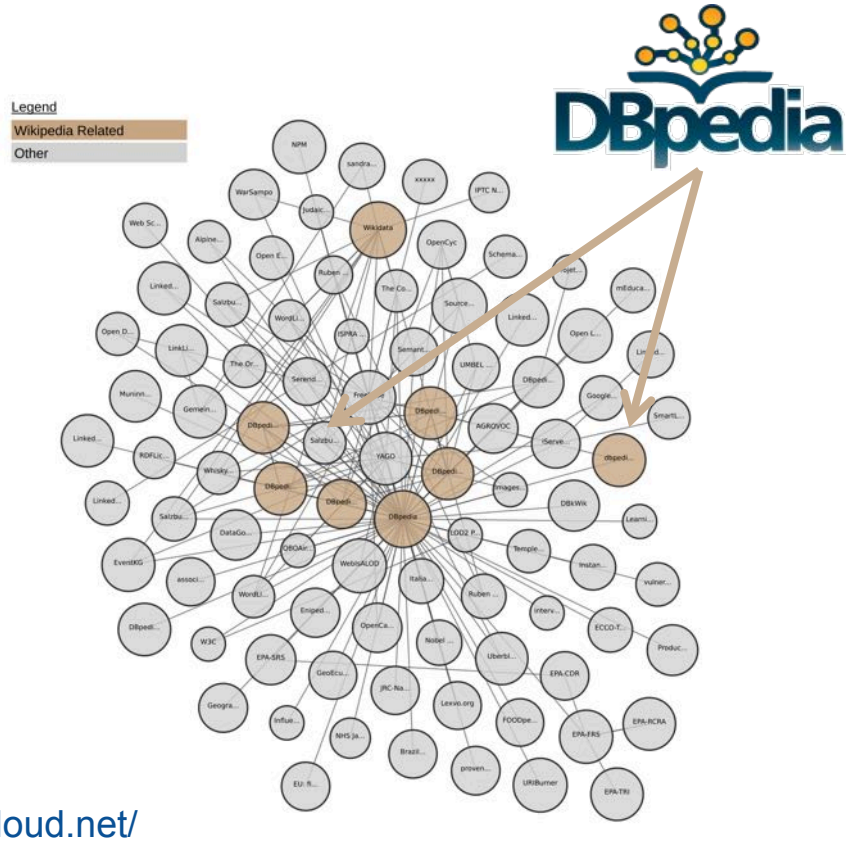
IoT ➔ a must

Are there any **evidences** that after so many years the interest on Linked Data is still high?

Can Linked Data be considered as **enabling technologies** for the IoT?

Linked Open Data cloud





https://lod-cloud.net/

The Cross-Domain Linked Open Data Cloud from lod-cloud.net

The dataset currently contains **1,224 datasets with 16,113 links** (as of June **2018**)

Ontologies and vocabularies

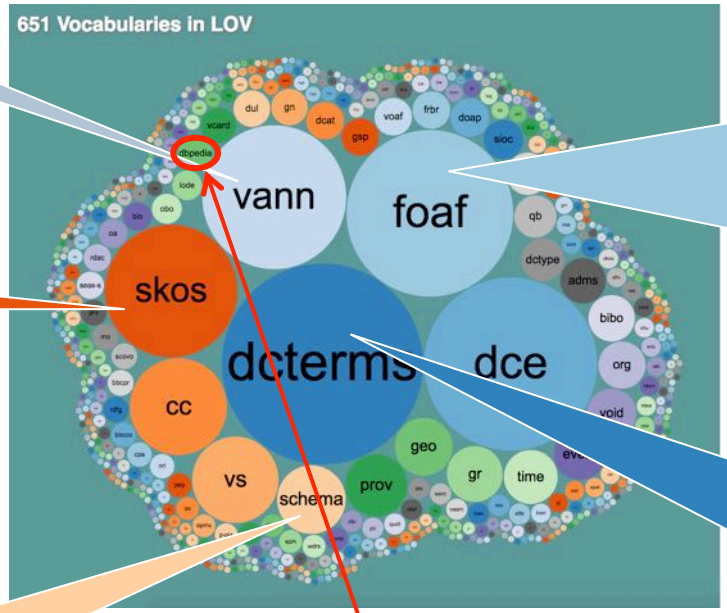
A vocabulary for **annotating vocabulary descriptions**

Simple **K**nowledge **O**rganization **S**ystem

W3C

Linked **O**pen **V**ocabularies

https://lov.linkeddata.es/dataset/lov



Friend **O**f **A** **F**riend integrates three kinds of network: **social networks** of human collaboration, friendship and association; **representational networks** that describe a simplified view of a cartoon universe in factual terms, and **information networks** that use Web-based linking to share independently published descriptions of this inter-connected world.

Dublin Core Metadata Initiative

The **Dublin Core Metadata Element Set** is a vocabulary of fifteen properties for use in resource description (**contributor**, **coverage**, **creator**, **date**, **description**, **format**, **identifier**, **language**, **publisher**, **relation**, **rights**, **source**, **subject**, **title**, **type**).

Schema.org

Google Microsoft YAHOO! Yandex

DBpedia

W3C recommendations overview on Linked Data (2013-**2017**)

SPARQL 1.1 **Query** Language
https://www.w3.org/TR/sparql11-query/

SPARQL 1.1 **Update** Language
https://www.w3.org/TR/sparql11-update/

(**2013**)

SPARQL 1.1 Federated Query
https://www.w3.org/TR/sparql11-federated-query/

SPARQL 1.1 Graph Store HTTP Protocol
https://www.w3.org/TR/sparql11-http-rdf-update/

SPARQL 1.1 Protocol
https://www.w3.org/TR/sparql11-protocol/

SPARQL processing service (or endpoint)

Linked Data Platform 1.0 (2015)
https://www.w3.org/TR/ldp/

JSON-LD 1.0 (2014)
https://www.w3.org/TR/json-ld/

Linked Data Notifications (2017)
https://www.w3.org/TR/ldn/

RDF store

RDF 1.1 (2014)
https://www.w3.org/TR/2014/REC-rdf11-concepts-20140225/

RDFS 1.1 (2014)
https://www.w3.org/TR/2014/REC-rdf-schema-20140225/

SPARQL endpoints (NO-SQL/Graph databases)

OpenLink Virtuoso (powering DBpedia)
https://virtuoso.openlinksw.com/

Blazegraph
https://www.blazegraph.com/

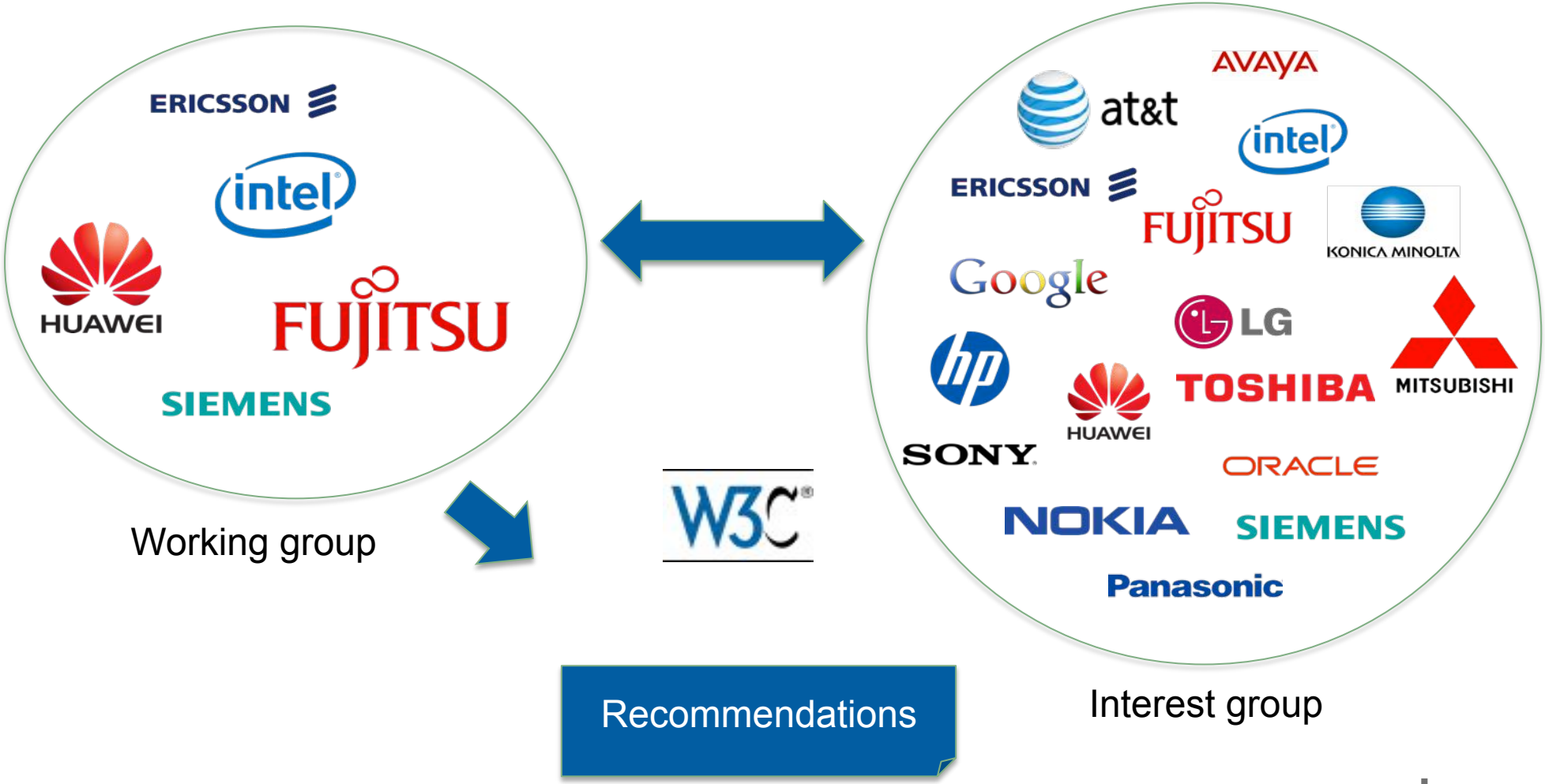
Apache Fuseki (based on Apache Jena)
https://jena.apache.org/documentation/serving_data/

StarDog
https://www.stardog.com/

Neptune by Amazon (released in 2017)
https://aws.amazon.com/neptune/

"... fast, reliable, fully-managed **graph database** ...
... highly **connected datasets**...
... optimized for storing **billions of relationships** and querying the graph with **milliseconds latency** ...
... supports popular graph models ... **W3C's RDF**... **SPARQL** ...
... use cases such as recommendation engines, fraud detection, knowledge graphs, drug discovery, and network security."

W3C Begins Standards Work to Reduce IoT Fragmentation (24 February 2017 - **ongoing**)



Web of Things

“The Internet of Things (IoT) suffers from a lack of **interoperability** across platforms…before the Internet when there were **competing non-interoperable networking technologies**…

…**interaction models** exposed to applications…

…**communications and security requirements** for platforms to communicate effectively…

…enable platforms to **share the same meaning** when they exchange data…building upon W3C's extensive work on **RDF** and **Linked Data**…

…using scripting **languages** like **JavaScript**, data **encodings** such as **JSON**…**protocols** such as **HTTP** and **WebSockets**…

…direct access to IoT **sensors and actuators from the browser**…

…**gateways** that use IoT protocols to access embedded/constrained devices, and web protocols to expose them to service platforms…

…"Things" in the Web of Things are not limited to connected devices…**people** and **places**, and **abstract ideas**, such as **events** (e.g. a concert), **organizations**, and **time periods** (e.g. the 70s)…”*

*W3C Web of Things main page, https://www.w3.org/WoT/

Ontologies for IoT & time

OWL-Time provides a vocabulary for expressing facts about **topological** (ordering) **relations** among **instants** and **intervals**, together with information about **durations**, and about **temporal position** including **date-time** information (**2017**)

The **Semantic Sensor Network (SSN)** ontology is an ontology for describing **sensors** and their **observations**, the involved **procedures**, the studied **features of interest**, the samples used to do so, and the **observed properties**, as well as **actuators**. SSN follows a horizontal and vertical modularization architecture by including a lightweight but self-contained core ontology called **SOSA** (Sensor, **Observation**, Sample, and Actuator) for its elementary classes and properties (**2017**)

Cool! Enough evidences? But what about performance?

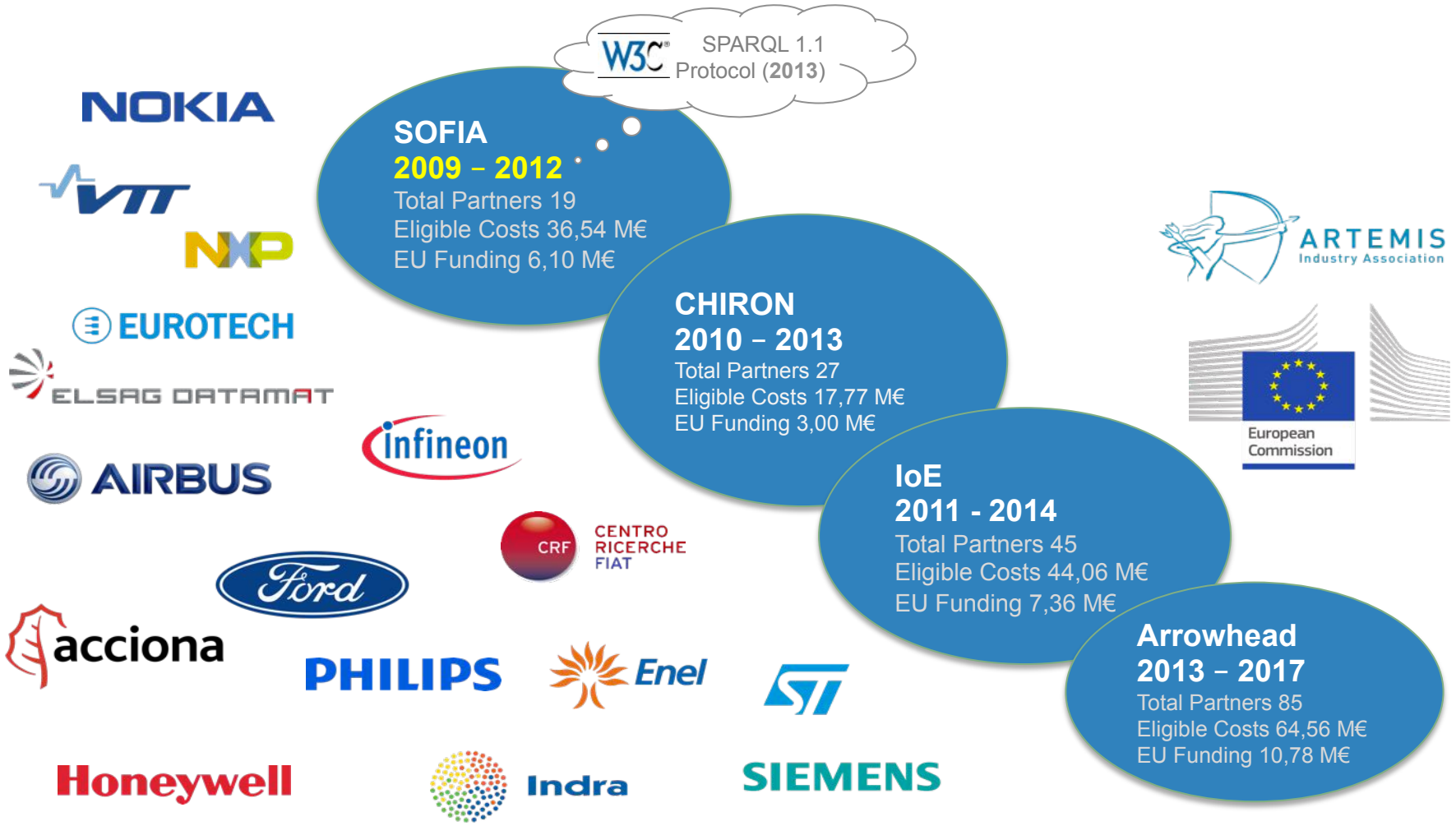
"The main drawback of Linked Data technologies concerns the low level of performance that makes it difficult to achieve **responsiveness** and **scalability** required in many *IoT* applications…Linked Data technologies have been designed to process data sets consisting of **big amounts** of Resource Description Framework (RDF) triples **that evolve constantly but at a much slower rate** compared to the rate of elementary events occurring in the physical environment."*

Linked Data should become **D**ynamic **L**inked **D**ata (DLD).

DLD is the set of mechanisms, algorithms and protocols designed to enable the **fast and scalable detection and notification of changes** (i.e., events) on top of Linked Data.

* Roffia, L.; Morandi, F.; Kijander, J. ; D'Elia, A.; Vergari, F.; Viola, F.; Bononi, L. ; Salmon Cinotti, T., "A Semantic Publish-Subscribe Architecture for the Internet of Things," in *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 1274-1296, Dec. **2016**.

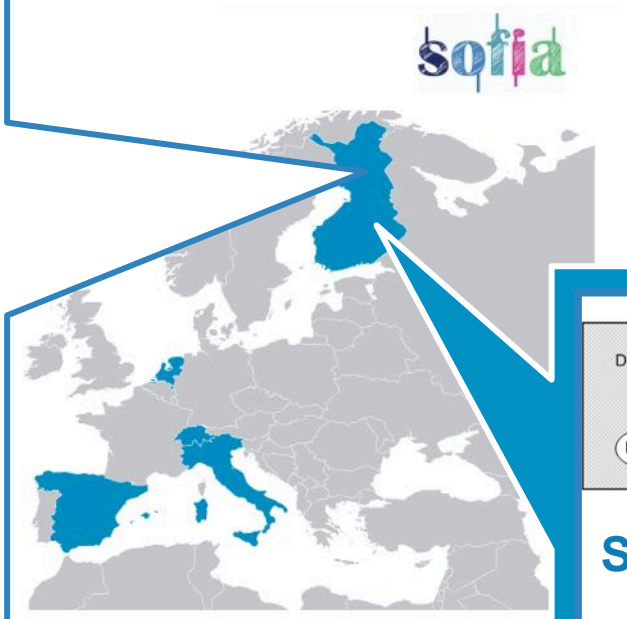
Artemis IA EU Research on Smart Spaces



Dynamic Linked Data: the origins

Source: https://en.wikipedia.org/wiki/Smart-M3

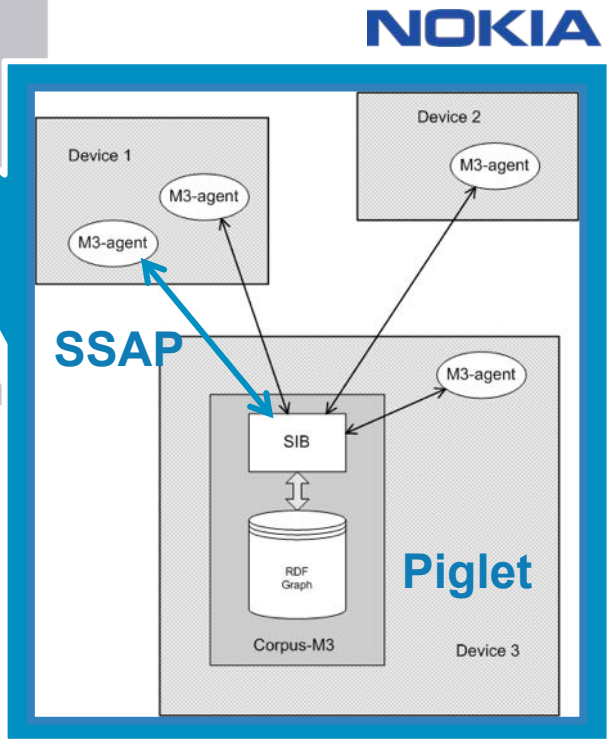
L. Roffia, A. D'Elia, F. Vergari, D. Manzaroli, S. Bartolini, G. Zamagni, T. S. Cinotti, and J. Honkola, "A Smart-M3 lab course: approach and design style to support student projects", in *8th FRUCT Conference of Open Innovations Framework Program FRUCT*, S. Balandin and A. Ovchinnikov, Eds. Lappeenranta, Finland: Saint-Petersburg State University of Aerospace Instrumentation (SUAI), **2010**, pp. 142 – 153.



Smart **S**pace **A**ccess **P**rotocol

- Publish/Subscribe
- TCP/IP sockets
- XML message format
- Query/subscription languages:
  - Wilbur
  - RDF-M3
- Triples (no quads)

Ora Lassila, Programming Semantic Web Applications: A Synthesis of Knowledge Representation and Semi-Structured Data, *Doctoral Dissertation*, Helsinki University of Technology, Department of Computer Science and Engineering, Laboratory of Software Technology, **2007**



Source: https://en.wikipedia.org/wiki/Smart-M3

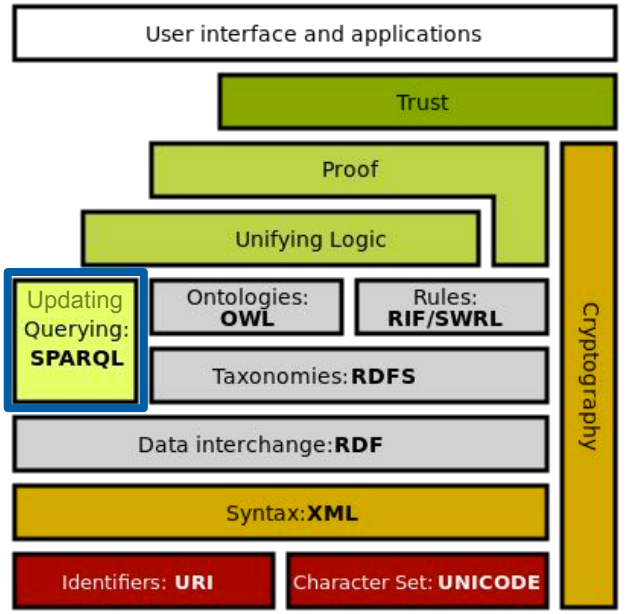
SPARQL Event Processing Architecture

Enabling the **detection** and **notification** of *changes over Linked Data* by means of a **content-based publish-subscribe** mechanism, where publishers and subscribes use respectively SPARQL 1.1 updates and queries

Roffia, L.; Azzoni, P.; Aguzzi, C.; Viola, F.; Antoniazzi, F.; Salmon Cinotti, T., Dynamic Linked Data: A SPARQL Event Processing Architecture. *Future Internet* **2018**, 10, 36.

https://github.com/arces-wot/SEPA GitHub

Subscribe +



W3C F2F meeting and plugfest in Dusseldorf, July 9th and 13th, **2017**

21st Conference of Open Innovations Association (**FRUCT**), Helsinki, **2017**

HABITAT (2016 - **2018**)

Regional project (POR-FESR 2014 - 2020)

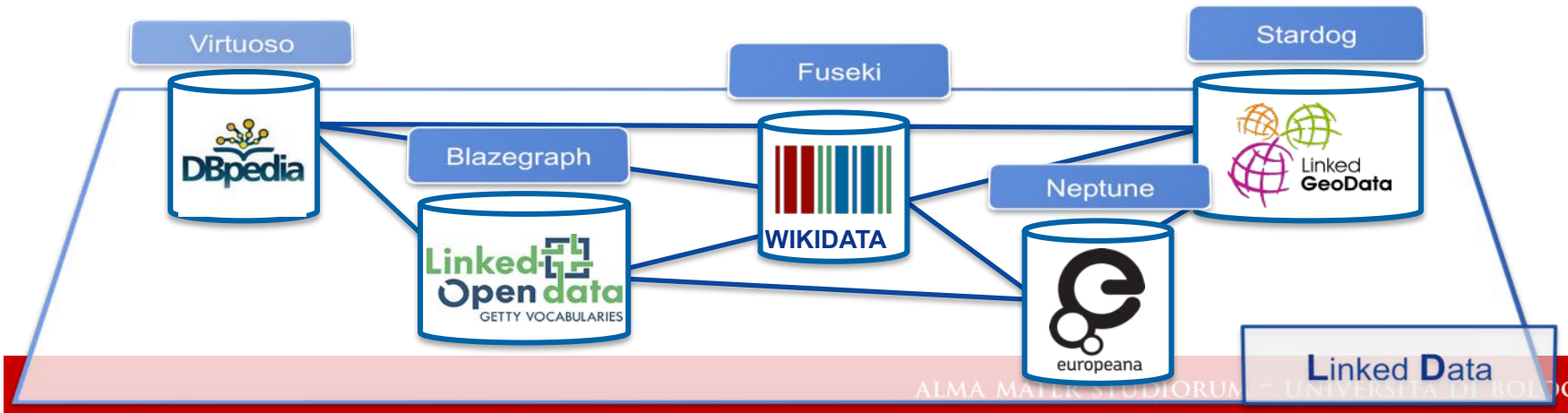
http://www.eng.habitatproject.info/

SWAMP (2017- **2020**)

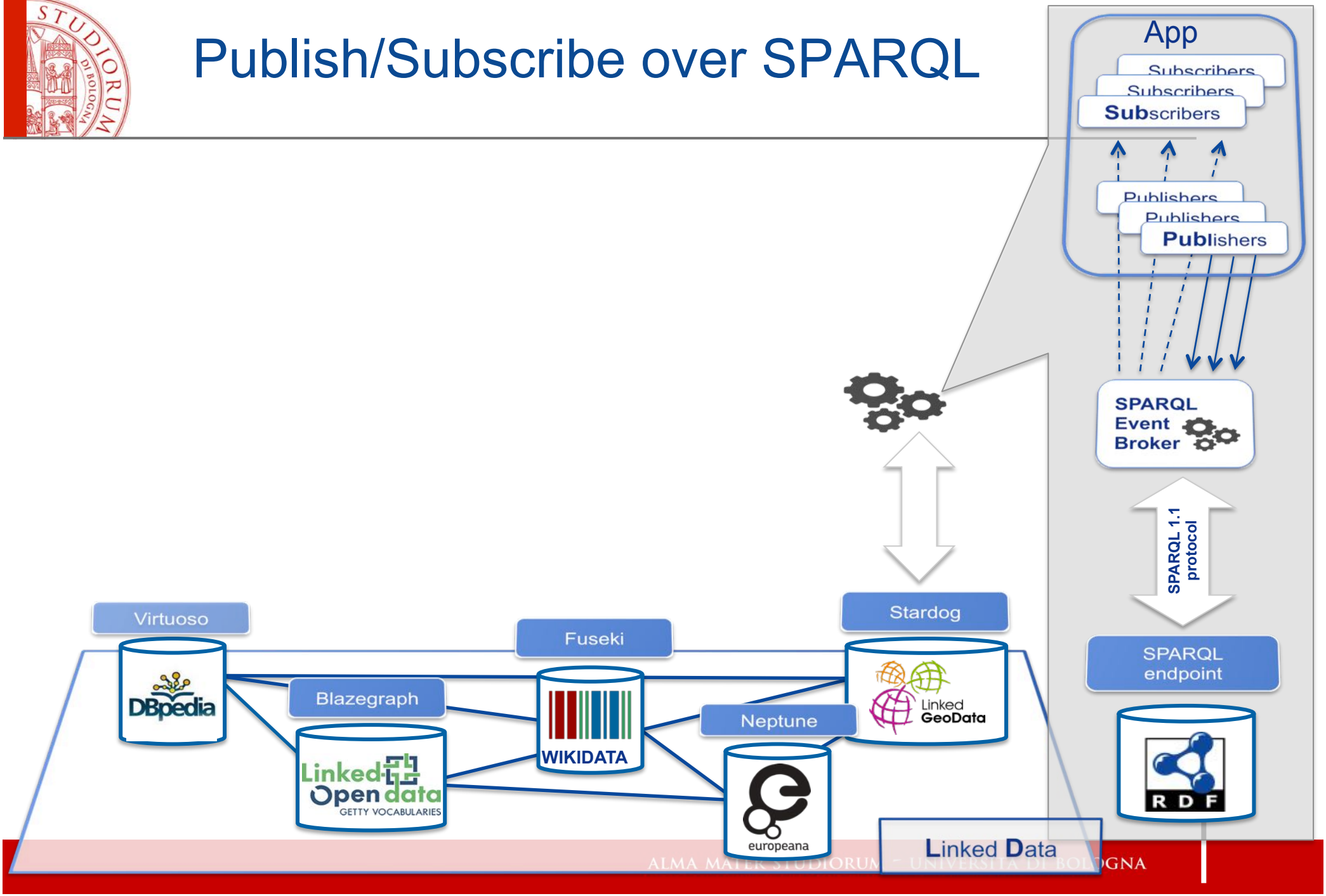
EU H2020 project

http://swamp-project.org/

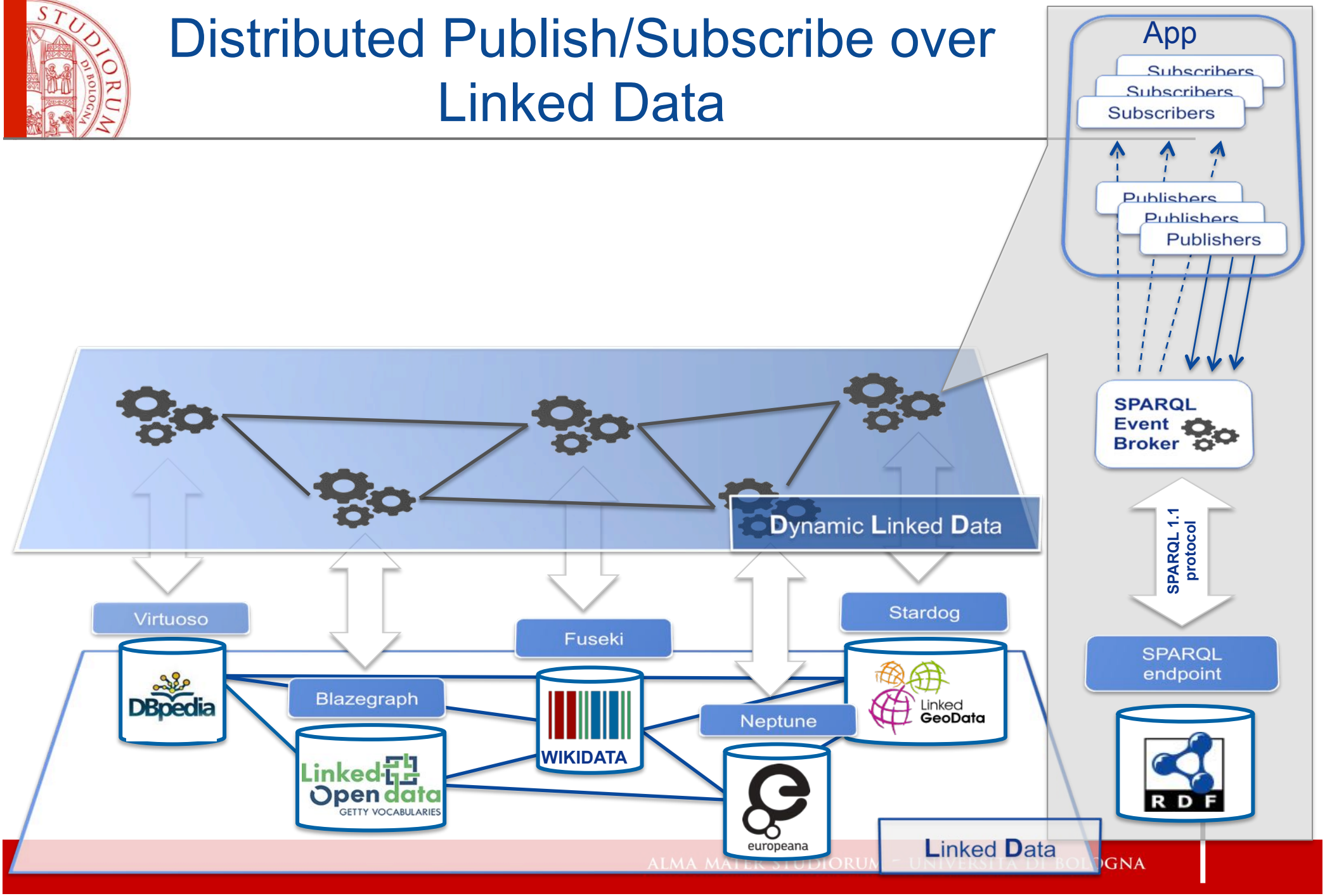
Linked Data

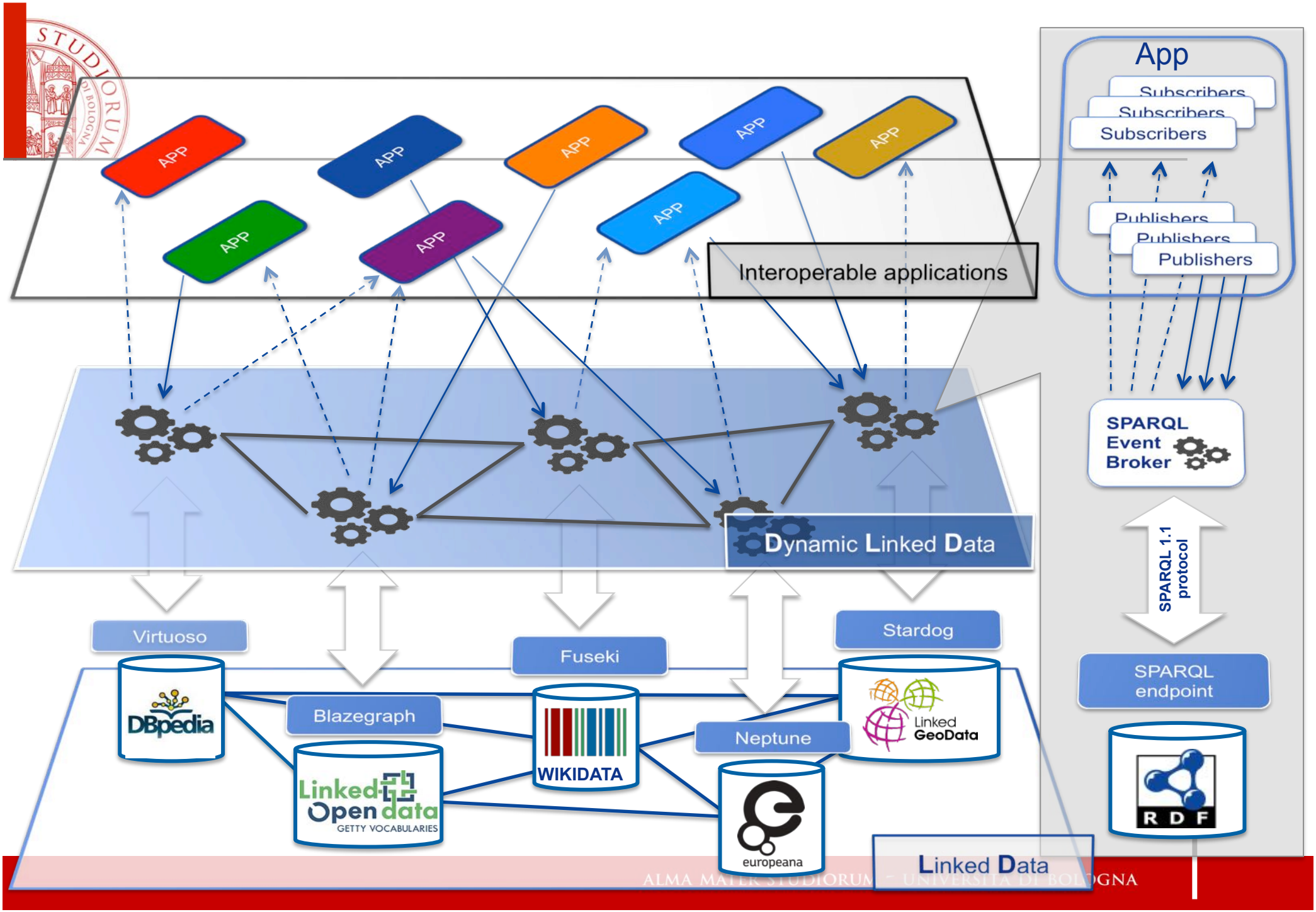

Virtuoso
DBpedia
Blazegraph
Linked Open data
GETTY VOCABULARIES
Fuseki
WIKIDATA
Neptune
europeana
Stardog
Linked GeoData
Linked Data

Publish/Subscribe over SPARQL



Distributed Publish/Subscribe over Linked Data




APP
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APP
Interoperable applications
App
Subscribers
Subscribers
Subscribers
Publishers
Publishers
Publishers
SPARQL
Event
Broker
SPARQL 1.1
protocol
SPARQL
endpoint
Dynamic Linked Data
Virtuoso
Fuseki
Stardog
DBpedia
Blazegraph
WIKIDATA
Neptune
Linked
GeoData
Linked
Open data
GETTY VOCABULARIES
europeana
R D F
Linked Data

How far we are to see real-life DLD applications?

DLD technologies provide an unique opportunity for business and research:

- The **Web of Things** is one of the most valuable context where DLD technologies can be experimented and developed
- Thanks to DLD, it would be possible to develop **distributed**, **context-aware** and **interoperable web** applications
- By having the Linked Data cloud as potential source of **context** information, the number of possible applications powered by DLD technologies would be "unlimited"

Not so far…the future of DLD is now!

"***Solid*** *(derived from "social linked data") is a proposed set of conventions and tools for building* ***decentralized social applications*** *based on* ***Linked Data*** *principles. Solid is modular and extensible and it relies as much as possible on existing* ***W3C standards and protocols***."

From: https://solid.mit.edu/

"***Inrupt*** *is building a* ***commercial*** *ecosystem to fuel Solid's success and protect the* ***integrity*** *of the next phase of the web. Its mission is to restore* ***rightful ownership*** *of data back to every web user and unleash a new wave of innovation - for developers, for business, for everyone.*"

From: https://www.inrupt.com/

SEPTEMBER 28, 2018 - Tim Berners-Lee