EU-IOT AND ONTOCOMMONS WORKSHOP ONTOLOGICAL INTEROPERABILITY, STANDARDIZATION RECOMMENDATIONS DISCUSSION

REPORT
JULY 2022

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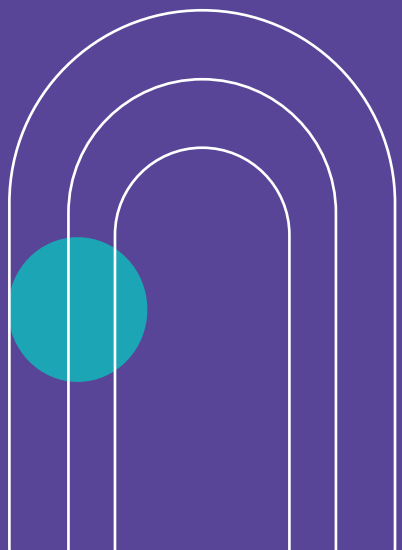
ONTO COMMONS
ONTOLOGY-DRIVEN DATA DOCUMENTATION FOR INDUSTRY COMMONS

EU IOT

CONTENTS

LIST OF ACRONYMS

Acronym	Definition
AIOTI	Alliance for the Internet of Things Innovation
BDVA	Big Data Value Forum
COB	Core Ontology for Biology and Biomedicine
CSA	Coordination and Support Action
DAIRO	Data, AI, and Robotics
FAIR	Findable, Accessible, Interoperable, Reusable
IAOTA	International Association of Trade Associations
IOF	Industry Ontology Foundry
IoT	Internet of Things
M2M	Machine to Machine
NIST	National Institute of Standards and Technology
OBO	Open Biological and Biomedical Ontology
OEO	Open Energy Ontology
RIA	Research and Innovation Action
SAREF	Smart Applications REFerence
SDO	Standards Development Organization
WG	Working Group



1. MEETING PURPOSE, AGENDA, MATERIAL, PARTICIPANTS

Meeting purpose: This online meeting was jointly organized by the Coordination and Support Actions **EU-IoT** and OntoCommons. EU-IoT is working together with different standards development organizations and supporting different Research and Innovation Actions (RIAs) to derive research recommendations and a fine-grained mapping of knowledge areas to standardization with focus on IoT and Edge computing across different vertical domains. **OntoCommons** is collaborating with existing European and international initiatives which focus on the standardization of documentation based on ontologies. The project aims to establish synergies with all relevant bodies and initiatives to ensure that it represents the interests of their stakeholder groups, and that it carries over their key recommendations, roadmaps, and requirements as part of the OntoCommons activities.

The **meeting theme** concerned semantic interoperability and specifically, the role of ontologies in providing interoperability. Semantic interoperability is one of the key pillars of open and flexible IoT systems. Ontologies are a key component of semantic interoperability, as they provide the foundation and capability for machines to interpret and infer knowledge from different data sets. Ontologies are, however, often vendor or protocol based, and therefore, building universal ontologies or addressing mechanisms that can support an adequate interconnection across different ontologies is time-consuming and error-prone.

To assist in overcoming the above-mentioned challenges, this online workshop was dedicated to the discussion of the status of ontological interoperability provided by different key stakeholders, and to a panel discussion for recommendations that can facilitate a better deployment of ontological interoperability across different vertical domains.

The expected outcome of this meeting was:

- An overview on key priorities and challenges being addressed by different SDOs, e.g., AIOTI, BDVA/DAIRO, IAOA, NIST, etc.
- Feedback on recommendations that should be addressed in projects.
- Additional suggestions for the coordination of standardization efforts.

1.1 Material

- **Agenda and Meeting Material folder:**
  https://drive.ngiot.eu/index.php/s/PwCMcTmoKPRPjzi?path=%2FEU-IoT-OntoCommons-Workshop-SemanticInteroperability
- **Recording:**
  https://www.youtube.com/watch?v=S1B5FJPpuzk&t=1314s

1.2 Agenda
07.07.2022, 15CEST-18CEST

Time (CET)	Session
3:00 - 3:10	Welcome, Rute C. Sofia (fortiss/CSA EU-IoT WP3 leader) and Hedi Karray (ENIT/ Technical Coordinator CSA OntoCommons)
3:10 - 3:20	EU-IoT overview, Lamprini Kolovou (Martel/Project Manager CSA EU-IoT), 10m OntoCommons overview, Hedi Karray (ENIT/CSA OntoCommons) 10m
3:20 - 3:30	Interaction session 1: Poll on Ontological interoperability (aspects) - what is important, on which domain do you apply them, set of challenges, etc
3:30 - 4:35	Session I: perspectives on Ontological Interoperability, challenges, and key priorities Chair: Rute C. Sofia Speakers: • 3.30:3.45 - StandICT/OntoCommons Technical Working, Arkopaul Sarkar (ENIT) and Ray Walshe (DCU) • 3.45-3.55 EU-IoT, Standardization and Open-Source activities, Rute Sofia (fortiss/ EU-IoT) • 3.55-4.05 AIOTI Working Group Standardization priorities, Laura Daniele, (TNO/ AIOTI WG Standardization) • 4.05-4.15 SmartM2M (ETSI SAREF), Mauro Dragoni (Fondazione Bruno Kessler) • 4.15-4.25 OpenDEI focus on standardization for interoperability, Antonio Kung, Trialog 4.25-4.35 Questions and answers
4:35 - 4:45	Interaction session 2: Challenges and key priorities - Audience perspective
4:45 - 6:00	Panel: Recommendations for ontological interoperability across vertical domains Chair: Rita Giuffrida Panellists: • IAOA - Stefano Borgo (CNR) • NIST - Boonserm Kulvatunyou (NIST) • ETSI - Mauro Dragoni (FBK) • AIOTI WG Standardization, Laura Daniele (TNO/AIOTI WG Standardization)
6:00 - 6:10	Summary and Closure, Hedi Karray (OntoCommons coordinator), Rute Sofia (EU-IoT)

1.3 List of participants

The workshop had 90 registered participants in Eventbrite and an average of 40 active participants. The participants represented experts in ontology-related fields who mainly work in universities, research institutions, industries, and SMEs. They were primarily joining from Europe, but the workshop proved to be interesting also for people living outside Europe, like USA or Australia as shown in Figure 1 and Figure 2.

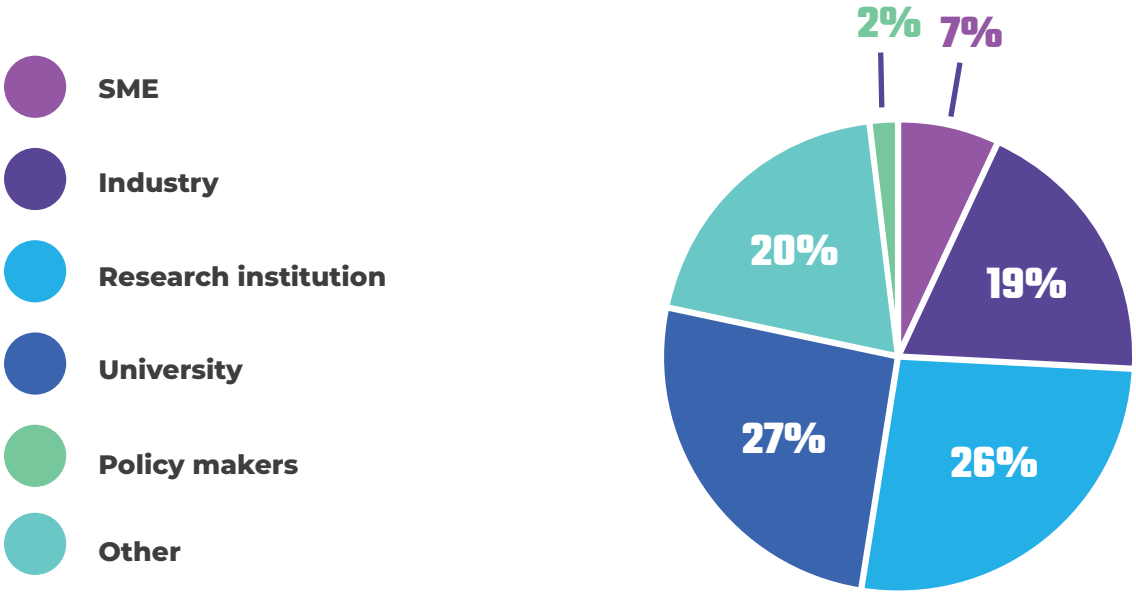


Figure 1 – Type of stakeholders that joined the workshop.

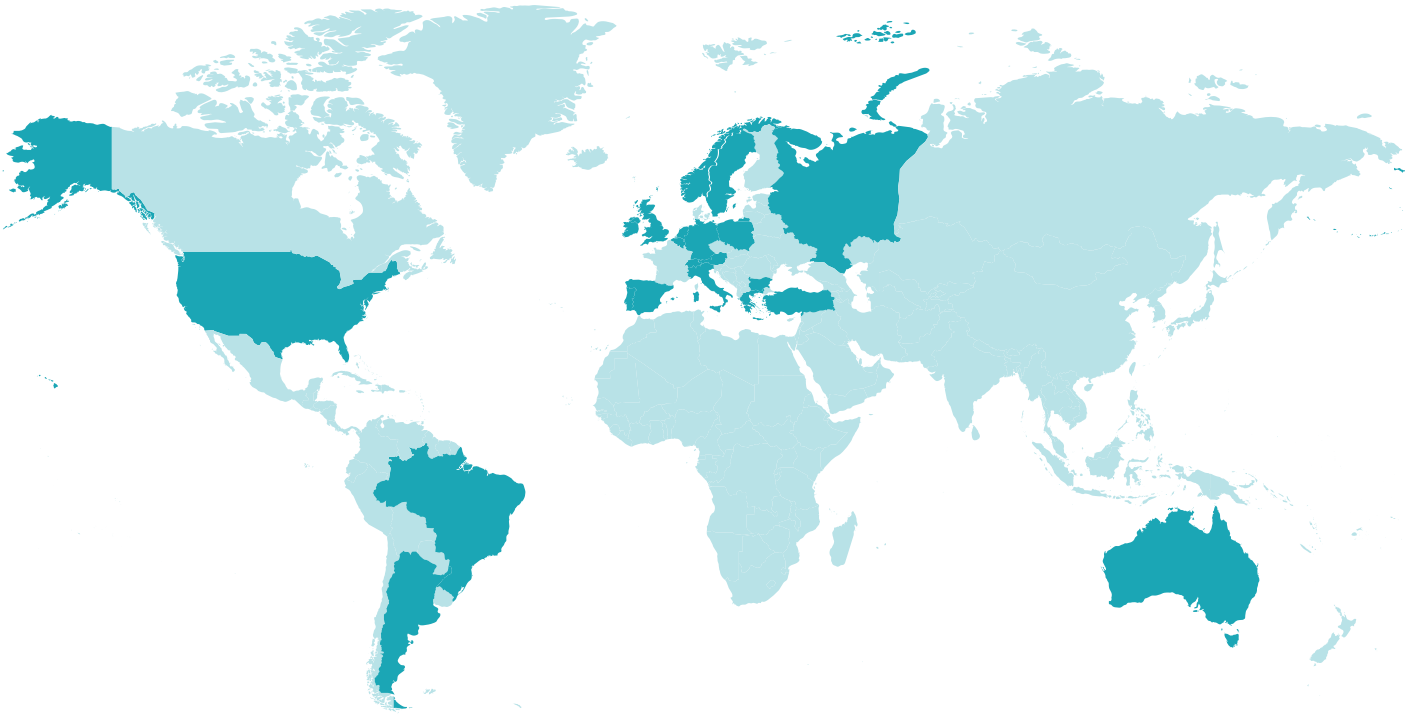


Figure 2 – Attendees' countries.

2. SESSION OVERVIEW

2.1 Introduction to EU-IOT and ONTOCOMMONS

Moderated by Rute C. Sofia (EU-IoT), the session started with a presentation on the Coordination and Support Action (CSA) EU-IoT, where Lamprini Kolovou introduced EU-IoT and the work under development by EU-IoT in the context of Next Generation IoT, explaining how EU-IoT is contributing with research and policy recommendations towards next generation IoT/Edge-based applications.

Hedi Karray then introduced the role of the CSA OntoCommons, and how ontologies are seen as a key enabler for different technologies. Hedi explained that while there are multiple initiatives focusing on semantic interoperability, most fail to truly drive interoperability. OntoCommons is building an Ontology Commons Ecosystem (OES) integrating networked ontologies, tooling, and specifications, among others.

2.2 Interaction session 1: Poll on ontological interoperability aspects

Rita Giuffrida (Trust-IT) moderated the first interaction session with the audience, where polls had been set up so that the attendees could express key interoperability challenges.

In particular, the participants were asked to reply to the following five questions:

1. What is your domain of expertise?
2. Which ontologies and standards do you currently use? In which domains do you apply them?
3. Which challenges do you face in applying ontologies and standards in your domain of expertise?
4. Do you see a need of creating new standards in the domain of your expertise?
5. How do you perceive the role of open-source initiatives in increasing ontological interoperability?

2.2.1 Domain of expertise

The interactive session showed that most attendees are experts in the fields of knowledge engineering, ontologies, digital agriculture, manufacturing, supply chain, standardisation, federated learning, and IT, as shown in Table 1 and Figure 3.

Table 1: Field of expertise of the attendees.

Field of expertise	Percentage
Ontology	14%
Knowledge Engineering	12%
Manufacturing	7%
Digital Agriculture	4%
IoT	4%
Healthcare	4%
Intermediate	2%
Automation	2%
Sensor	2%
AIoT hardware	2%
Localization	2%
Software Engineering	2%
Digital Transformation	2%
Research ICT	2%
Research Data Management	2%
Acceleration	2%
Data mesh	2%
Supply Chain	2%
AAS	2%
Federated Learning	2%
Academic	2%
Systems Integration	2%
Heterogenous hardware	2%
Standardisation	2%
Knowledge Graph	2%
Organizational knowledge	2%
UFO	2%
Technology Research	2%
Classification	2%
Librarianship	2%

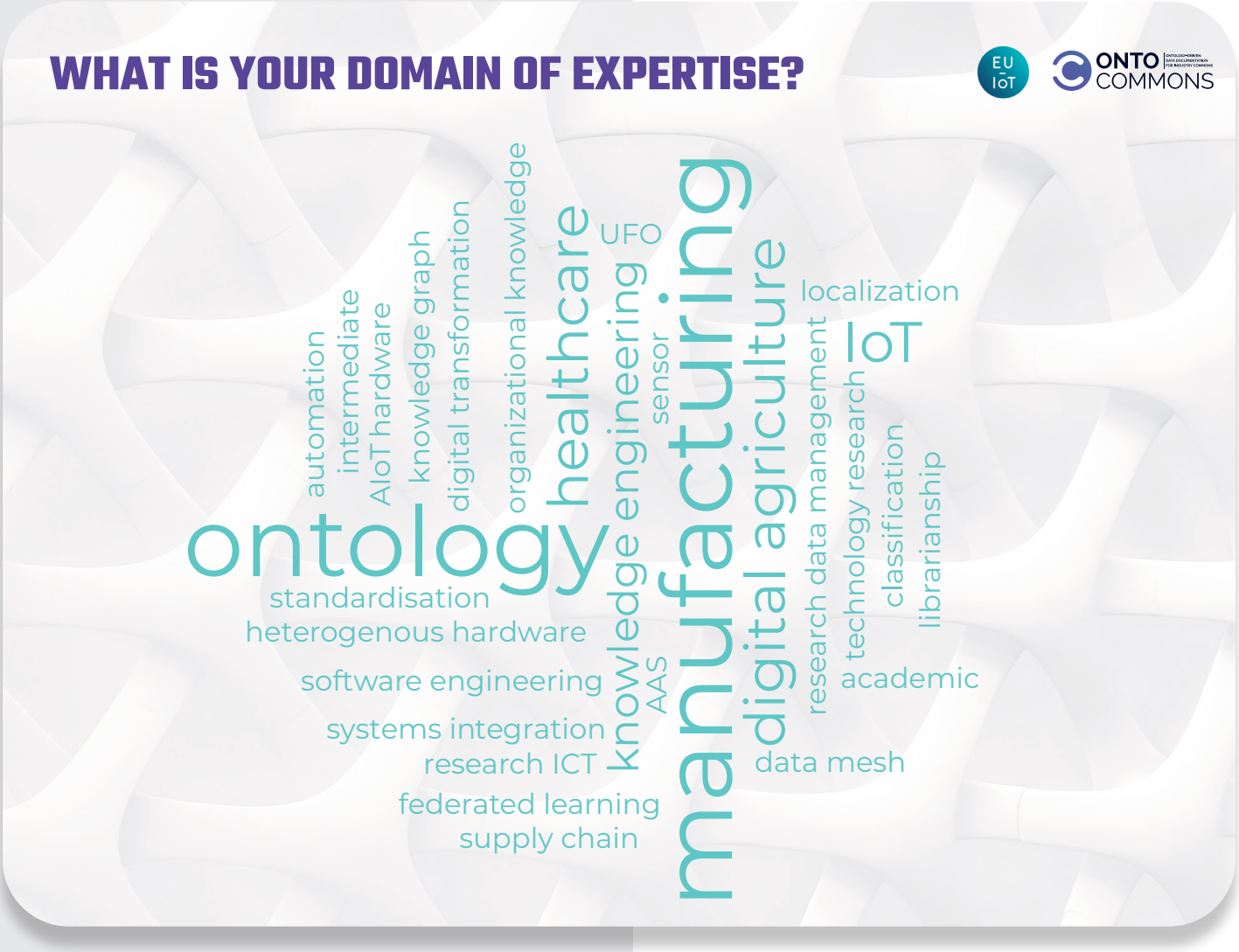


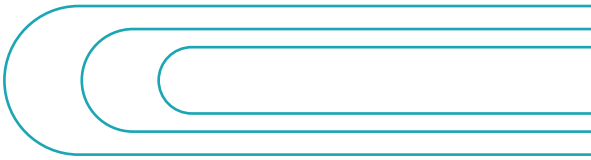
Figure 3 – Attendees' inputs for the first question during the interactive session.

2.2.2 Current use of ontologies and standards

Most participants currently use standards and ontologies in manufacturing, ICT, energy, healthcare, and IT, but they face several challenges in applying standards and ontologies to their field of expertise, as shown in Table 2 and Table 3. Moreover, while some attendees believe that it is crucial to use existing standards and extend them to other domains whenever possible (32%), the majority (68%) feels the need to create new standards in specific sectors, like AI, Digital Twins, Circular Economy, Secure Trusted Chips, Life Cycle Management, and Digital Product Passport.

Table 2 – Ontologies and standards used by the attendees and domains of application.

Ontologies / Standards	Domain
SAREF	Manufacturing
EPCIS	Supply Chain
ROMAIN	Maintenance
Standard Business Reporting	Energy
Platoon	Smart Lifts
SOSA / SSN	Healthcare
IOF	Wearable domain
FIBO	Financial industry
SIMPM	IoT
OBO	Hardware
PICMG	Biomedicine
Schema.org	Process Planning
OPCUA	Biopharma
DOLCE	Digital artifacts
ISA	IT management
BFO	Ontology Merging



2.2.3 Challenges

Participants mentioned several challenges, as described in Table 3. These included fragmentation of information models (related to vendor lock-in). Expressivity and incompatibility of upper ontologies, or incompatibility of versions were also mentioned.

Table 3 - Challenges faced by the participants in applying ontologies and standards in their domain of expertise

Challenges in applying ontologies and standards
Fragmentation of information
Knowledge Alignment
Expressivity
Incompatibility of upper ontologies
Vendor-lock - Ontologies linked to proprietary solutions
Different abstraction levels
Traditional developers are not familiar with ontologies and semantic technology
Hard to adapt data models to real applications
Lack of tools
Data integration
Lack of standards
Semantic schema used
Ontology Versioning
Duality of planning and execution
Emerging Technologies
Issues in Collaboration and coordination
Lack of training
Interoperability
Domain experts do not understand ontologies. They do data models

2.2.4 Need for new standards

Participants have also expressed a need to consider the development of new standards in specific areas of knowledge, as described in Table 4.

Table 4 - Domains where the participants feel the need for new standards.

Areas for new standards development
AI
Data Governance
Digital Product Passport
Digital twin
Quantum Computing
Continuity of care
Circular Economy
Production Planning and Scheduling
Digital Humanities
FAIR digital objects
Secure Trusted Chips
Life Cycle Representation

2.2.5 Role of open-source in ontological interoperability

Most participants perceive open-source initiatives as being crucial to increase ontological interoperability, as observable in Figure 4.

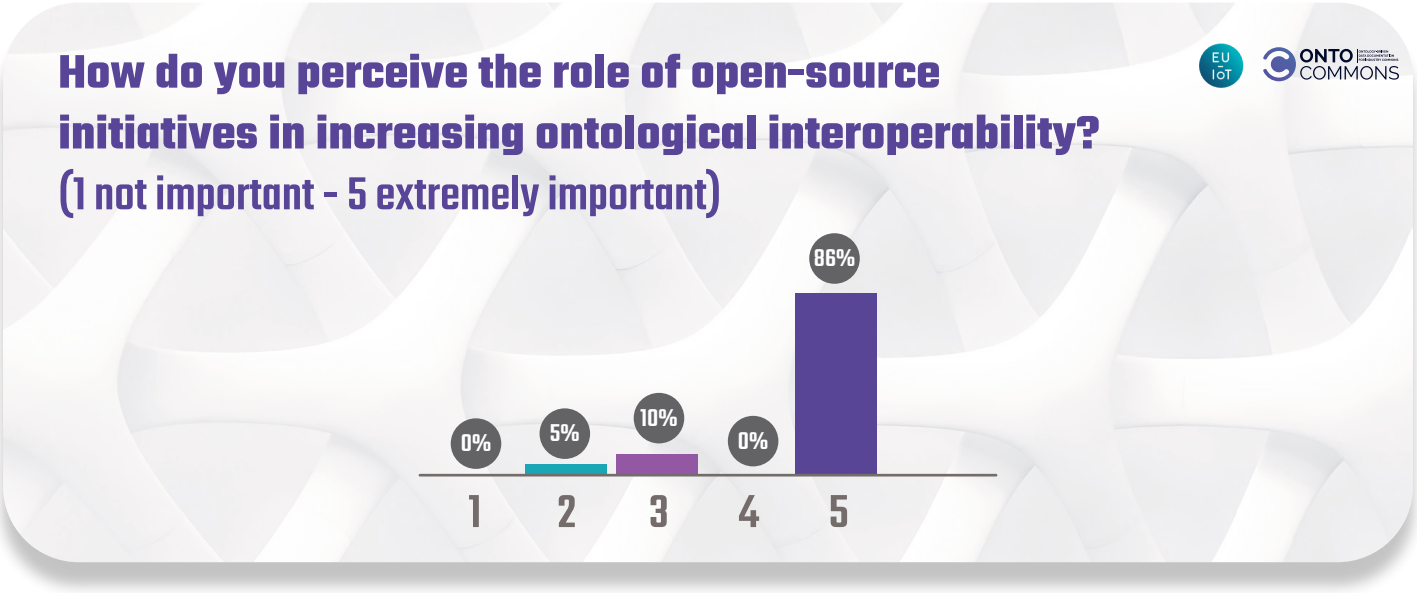


Figure 4 – role of open-source initiatives in increasing ontological interoperability

2.3 Session I: Perspectives on ontological interoperability, challenges and key priorities

Moderated by Rute C. Sofia (EU-IoT), the session consisted of talks by experts on key aspects under development as well as challenges regarding ontological application and interoperability. The round of talks started with Ray Walshe, who provided the perspective of StandICT, explaining the topics under development, open calls, and promoting relevant upcoming landscape reports for Ontologies, Edge and IoT. Ray also called attention to the StandICT academy https://www.standict.eu/euos-academy.

Arkopaul Sarkar followed, presenting the repository http://industryportal.enit.fr, which is accessible for entities to upload ontologies in manufacturing. See the Landscape reports developed by the StandICT TWG (the one on ontologies based on the work presented by Arkopaul will be released in the next couple of months): https://www.standict.eu/landscape-analysis-reports.

Rute Sofia then presented the CSA EU-IoT work focusing on research recommendations towards standardisation, highlighting the EU-IoT SDO catalogue resource (https://www.ngiot.eu/archive-standardisation-bodies).

Laura Daniele explained the work the AIOTI WG on standardisation is developing, e.g., white papers, semantic interoperability tutorials, and the ongoing effort to classify existing IoT ontologies. See AIOTI WG standardisation deliverables and whitepapers here: https://aioti.eu/resources/standardisation-resources. The AIOTI WG on standardisation has also developed a landscape report that describes key challenges, such as: completeness, sustainability, adoption, usability, lack of tooling, skills training, and material for fast adoption.

Mauro Dragoni presented the work of SmartM2M and indicated SAREF as a potential universal enabler for interoperability. SAREF as a conceptual model provides a high degree of flexibility. ETSI has already several extensions that make it possible to use SAREF within different domains. See https://saref.etsi.org/extensions.html for multiple domains and SAREF for developers: https://forge.etsi.org/rep/SAREF.

2.3.1 Session I discussion, questions and answers

- SDOs are developing standards in an efficient way. It is not realistic to expect that they extend to other areas. SDOs are working more and more project based with heavy pressure to deliver results as fast as possible.
- **The grand vision of data interoperability is akin to developing the *Esperanto* of Data Science**. One major move could be to iterate on a smaller set of relations (OWL object properties), akin to using a reduced set of verbs, in existing ontological models.
- **What is the relationship between OntoCommons Industry Space and AIOTI Landscape database?** To get ontology into OntoCommons Industry Space, what is the vetting process? How does it allow the publishing organization (SDO) to update, e.g., is there an API? For example, IOF is creating an automated ontology publication process. Maybe as part of the process we can distribute the releases to these portals.
  - The vetting process in the future will have to follow a process and criteria. Then we can measure the maturity and the accuracy of an ontology
  - Currently there is no relation, but there is alignment in terms of meta-data so a cooperation could be relevant to the overall community. Right now, only SAREF-manufacturing ontologies are considered.

- **Vertical domains such as manufacturing and energy have concrete directions in terms of ontology application. What is happening in the health domain? How do you see it?**
  - Areas like Smart Cities are a melting pot of standardisation that crosses many domains!
  - TC15 as a key example of a potential silo.
  - SAREF as conducting line for cross-domain interoperability. For instance, there are extensions for health.
  - Health, automotive domains are still seen as complex silos where the use of ontologies is still complex.

2.4 Interaction session 2: Challenges and key priorities

The second interactive session was moderated by Rita Giuffrida (Trust-IT) and aimed at understanding challenges and key priorities for applying ontologies and standards in the ICT, Materials and Manufacturing, Energy, Health, and Agriculture European competitiveness domains. The inputs shared by the participants are summarised in Table 5. Challenges common to all domains are: i) interoperability and data sharing; ii) lack of documentation (use-cases, best practices); iii) fragmentation; iv) security, privacy, accountability.

Moreover, in some domains such as health, participants also expressed the problem of close communities and lack of communication, creating further fragmentation.

Figure 4 – role of open-source initiatives in increasing ontological interoperability

ICT	ICT already has a lot of existing standards, and ontologies have a hard time providing the same functionality without introducing extra complexity
	Initiatives work in silos
	Goals of European and global initiatives are not always aligned
	Domain experts can provide taxonomies, but need experts' support in adopting ontologies
	There is a very fragmented landscape of standards
	Lifecycle, Governance, Ecosystem management and trustworthiness of ontologies issues
	Achieving cross-domain interoperability is challenging
	Need to improve modularity and composition

Materials & Manufacturing	SDOs follow a process to define standards, but many ontologies do not respect any existing standards regarding terminology selection, materials characterisation, or manufacturing methods
	There is also no relevant documentation of ontologies, making them impossible to use in practice or train people to use them
	It is needed to include experts in these domains to build ontologies
	Issues with Interoperability, data sharing and traceability
	Lifecycle issues: it is not always clear in which phase it is crucial to apply ontologies
	There are a lot of standards and ontologies, but no documentations about practical integration
	Problems with brownfield integration
	Need in improving modularity and composition
Energy	Energy Security
	Issue with communicating with different stakeholders that have diverse backgrounds and use different standards
	Issue with interoperability and data sharing
	Lifecycle issues: it not always clear in which phase to apply ontologies
	Issue with cross-domain interoperability, e.g., interconnection between Energy and Mobility
Health	The healthcare domain already has a lot of mandated ontologies. They are, however, quite primitive, unclear in scope and do not follow best practices in ontology engineering
	Issue with data interoperability and data sharing
	Lack of single ontologies that connect various virtual models
	Issue with security, privacy, and accountability
	Closed communities not willing to share best practices
	Lifecycle, Governance, Ecosystem management and trustworthiness of ontologies issues

Agriculture	Agriculture is a vast area and ontologies are related to very diverse topics (animals, diseases, plants, fertilisers, pesticides etc)
	Issue with interoperability, data sharing and traceability
	Lifecycle and ecosystem management of ontologies issues
	Ontologies can help to make cohesive Agri systems
	Critical to find genomic typing and nomenclature for subspecies for standardising cultivar names

2.5 Panel: Recommendations for ontological interoperability across vertical domains

The panel was moderated by Rita Giuffrida (OntoCommons) and counted with the following speakers and perspectives:

- Stefano Borgo (IAOA, CNR)
- Boonserm Kulvatunyou (NIST)
- Mauro Dragoni (ETSI, FBK)
- Laura Daniele (AIOTI WG Standardization, TNO)

The panel took the form of continuous interaction with the audience, where different speakers addressed a number of questions as described in the following subsections.

2.5.1 Dependency of information models on communication protocols – impact in manufacturing

A first question was related to the existing fragmentation in manufacturing due to the use of information models that are dependent on the existing communication protocol, e.g., OPC UA. Panellists highlighted the need to change the perspective of standards and to ensure that information models are not dependent on specific protocols. However, encoding of data may always be protocol dependent. With an adequate design, people can create specific semantic models and encode them with any existing protocol. There are aspects to consider, e.g., identifier for the entity.

ETSI M2M is checking the level of interoperability between the SAREF and OneM2M information models. Alignment across different protocols is an interesting direction to pursue.

The AIOTI WG Standardisation perspective notes also that there are different levels of semantic interoperability, so ontologies should not have any protocol dependency.

2.5.2 Use of ontologies in different domains: Level of complexity

A second challenge debated concerns whether there are domains where ontologies may be harder to use and to apply.

The key aspect in this context is not a specific domain but in fact the cross-domain interoperability. Cross-domain interoperability needs an adequate interfacing approach.

It has been mentioned by the audience that in the Open Biological and Biomedical Ontology (OBO) focused on life sciences, it has been interesting in that though upper level Basic Formal Ontology (BFO), and now experimentally the Core Ontology for Biology and Biomedicine (COB), are the top level ontologies at play, the relations being used are actually sequestered over in the OBO Relation Ontology, which in itself is an ontology. That allows a bit more flexibility in introducing somewhat more domain specific relations that are still shared for use across the community. COB is seen as a reference approach for the biomedical domains; the Industrial Ontology Foundry-core (IOF-core) plays the same role for industry. Unification between COB and IOF-core at least to synchronise has been encouraged, so this may be a starting point to address the key problem of cross-domain interoperability.

Another approach discussed by the audience would be to address an "Esperanto of data science", where instead of focusing on the interfacing, the focus would be on the definition of a flexible, common language to be applied to all ontologies. A suggestion was to sort out basic modelling approaches such as object property focused vs data property focused. Ontologies need a universal language, and cross-domain interoperability is highly dependent on this aspect.

2.5.3 The role of open-source in boosting ontological interoperability

Open Ontologies efforts are currently being pursued in some domains, e.g., the Open Energy Ontology (OEO) for the Energy domain, based on BFO, COB for the Biomedical domain. The debate in this point addresses the role of open-source in boosting a faster deployment of ontologies and as a consequence, boosting interoperability.

While all panellists expressed a common view on the role of open-source, there was also a note on the fact that there are several open ontologies available that are usually not even reused. Hence, the problem is not the use of open-source but the promotion of open initiatives in a way that reaches a broad base of stakeholders.

The use of open ontologies would enhance overall interoperability. It should, however, be left to the end-user to evaluate the use of parallel ontologies due to the complexity of use – for example, cross-application between energy and building management, or the demands stemming from the circular economy. However, open initiatives also require the support of open communities.

Furthermore, while the ontologies should be open, it was also noted that it is necessary to address the mapping across different ontologies. For instance, the IOF-core and COB already have some overlap; SAREF-industry and IOF-core as well. These could be starting points to provide a global approach for the mapping that could also boost interoperability.

A final aspect debated was the need to clearly define what open and open-source would mean in this context. There is a need to make open-source initiatives uniform or to adopt uniform rules also across specific domains.

2.5.4 The role of best practice development

In terms of interoperability, this question concerned the development of best practices to assist in deploying ontologies addressing overall interoperability.

Here, there is the risk of creating best practices based on specific use-cases. Therefore, examples, more than best practices, are seen as extremely relevant to boost interoperability.

For instance, common search engines or aggregators could assist the end-user in understanding which ontology to apply, and which model and parameters to consider. Recommendation systems for ontology reuse could also be relevant in this context.

Examples should consider that ontologies and standards must be FAIR. Reuse in this case is also important. Moreover, examples that can assist the harmonization of ontologies both intra- and inter-domain is extremely important.

2.5.5 Facilitating ontologies to the community: The role of CSAs

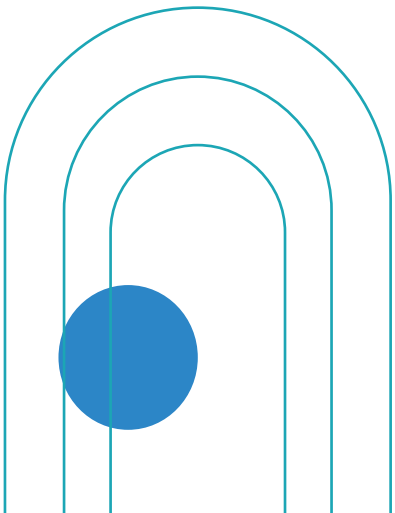
A third category of challenges concerns facilitating the use of sets of ontologies to the research community worldwide in different vertical domains. In this context, Coordination and Support Actions (CSAs) such as EU-IoT and OntoCommons can play a supporting role. Identification of concrete tools to achieve this purpose would be a useful first step.

CSAs can help across the different projects, proposing for instance plans to address identified challenges, e.g., sustainability.

Moreover, SDOs have specific resources, so CSAs may assist in evaluating the ongoing work of the SDOs and providing recommendations towards interoperability.

On the other hand, Research, and Innovation Actions (RIAs) usually define a standardisation plan but in this context, there is not a clear check on the efficacy of contributions to SDOs. CSAs can assist in this aspect.

Moreover, important to have **sustainability and exploitation plans**.



3. SUMMARY AND NEXT STEPS

The EU-IoT and OntoCommons workshop held on 7th July 2022 brought together multiple experts and different relevant European and international entities that are developing efforts towards an increased efficiency of ontologies. The topic of semantic interoperability, and the role of ontologies in increasing interoperability are key pillars in the context of open and flexible IoT systems.

In this context, the two CSAs EU-IoT and OntoCommons workshop provided a forum for open discussion in steps to take towards overcoming interoperability challenges, a key problem in IoT.

The workshop provided participants with an overview on challenges concerning the use and application of ontologies by different relevant entities across Europe and from the USA (NIST). It also provided relevant input in terms of open initiatives, such as the Industry space by OntoCommons, or the AIOTI Ontological landscape, and open standards, such as ETSI SAREF, i.e., tools that should be considered in the development of further steps towards semantic interoperability.

The information provided by participants on the interactive sessions and via the questions and answers during the informative session I and panel session corroborate that there are three main challenges to be addressed: i) **fragmentation and vendor lock-in**; ii) **cross-domain interoperability**; iii) **lack of open tooling and application examples**.

Via the panel, experts provided several recommendations regarding the challenges described:

- To prevent **fragmentation**, experts highlighted the need to ensure that information models are not dependent on specific protocols or vendor-based information, but the encoding of data may always exhibit some dependency which needs to be considered in open standards.
- To promote **cross-domain interoperability**, experts consider the use of open-source and open ontologies to be essential. However, it is also relevant to consider a universal language and a universal approach to mapping across different ontologies. The examples of IOF-core for industry and COBE for the biomedical domains have been suggested as good examples to derive further modelling; SAREF and its extensions to different domains is also a relevant starting point to achieve a global approach for cross-domain mapping.
- **Open-source, open ontologies and tooling** that can provide examples of application have been considered essential to achieve interoperability. Examples can promote both intra- and inter-domain harmonization of ontologies.

As next steps, the current cooperation between EU-IoT and OntoCommons is going to be further developed in cooperation with interested participants of the workshop in the form of a white paper jointly developed by EU-IoT and OntoCommons, expected to be released in October 2022.

4.
ACKNOWLEDGEMENTS

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- Hedi Karray, ENIT, Technical Coordinator of the CSA OntoCommons
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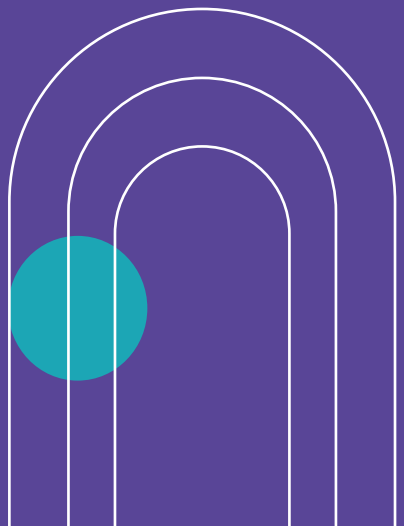
- Arkopaul Sankar, ENIT, StandICT/OntoCommons Technical Working Group
- Ray Walshe, DCU, StandICT
- Rute C. Sofia, fortiss, EU-IOT Standardisation and Open-source WP leader
- Laura Daniele, TNO, AIOTI Working Group on Standardisation
- Mauro Dragoni, FBK, ETSI SAREF
- Antonio Kung, Trialog, OpenDEI
- Stefano Borgo, CNR, IAOA
- Boonserm Kulvatunyou, NIST
- Rita Giuffrida, Trust-IT



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