Towards quantitative measures of interoperability

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Abstract: Nowadays, due to the increase of IoT devices in the world, the need to homogenise heterogeneous data has become a challenge. There are many standards that promote methodologies to achieve this interoperability, however, the same methodology can be performed in different technical ways, making it difficult to quantitatively measure the interoperability between different devices. This paper proposes a methodology to evaluate and certify interoperability based on a chosen standard with the same technical implementations defined by consensus, guaranteeing communication between different heterogeneous systems. A use case in the AURORAL project is presented to illustrate the application of the proposed methodology.
Keywords: Interoperability Certification, Interoperability Conformance, Semantic interoperability

1. Introduction

Currently, there are over 20 billion Internet of Things (IoT) devices and services that are deployed in numerous domains of diverse nature such as home automation, industrial, medical, military, among others [1]. These IoT devices and services are commercial products that provide access to their data relying on a wide range of protocols (e.g.,CoAP, MQTT, or HTTP.). In addition, their data are expressed relying on diverse formats (e.g., JSON, CSV, XML, etc.), and even the few data that may be expressed with the same format tend to rely on different data models. In fact, the heterogeneity of IoT data is a well-known problem in research and industry [2].

This heterogeneity presents a challenge for data exchange and consumption that is addressed by semantic interoperability approaches [3, 4]; which allow heterogeneous systems to seamlessly interact with each other. Currently, in both industry and research, numerous semantic interoperability technological solutions have been presented [5,6], along with standards that promote methodologies to achieve interoperability; e.g., Minimal interoperability mechanisms (MIMs)[1], ISO/IEC 21823-1:2019[2], or the European Interoperability Framework (EIF)[3]. Most of these approaches are based on setting a common set of technologies, formats or protocols, and all this together leads to the semantic interoperability framework, that is agreed by all actors by consensus for data exchange that oblies systems to adopt certain formats, models, etc.

Dataspaces create an ecosystem in which users voluntarily contribute data from their devices, where part of the data can be generated by IoT devices [7]. This environment is based on sovereignty, trust, and security, supported by a framework of governance, organisational protocols, regulations, and technical systems. But as dataspaces have to deal with multiple heterogeneous data sources, they also have to establish a semantic interoperability framework. However, the interoperability between the devices shared in the dataspace is not measurable, so a system is needed to provide a certification that interoperability requirements are met within these dataspaces, otherwise devices cannot communicate with each other.

In the context of measure the semantic interoperability in dataspaces, an interoperability consensus must be defined within the dataspace based on interoperability standards, but there is currently no quantitative way to measure interoperability and therefore no reliable method to provide such certifications, then, we propose a method to measure quantitatively the interoperability in order to provide interoperability certifications. To address this gap, this position paper proposes how this semantic interoperability could be quantitatively measured in order to grant interoperability certificates to participating members of a dataspace, and presents a use case in the AURORAL project, that have technical specifications similar to the dataspaces, and how a solution was developed and tested to quantitatively measure semantic interoperability as a prerequisite to ensure communication between two or more systems.

[1] `https://oascities.org/minimal-interoperability-mechanisms`
[2] `https://www.iso.org/standard/71885.html`
[3] `https://ec.europa.eu/isa2/eif_en/`

2. Interoperability framework

As mentioned above, there are a multitude of standards methodologies to reach the interoperability, separated in different levels. For example, the EIF have 4 interoperability levels or the ISO/IEC 21823-1:2019 have 5 interoperability levels. Although the levels of interoperability are common to the interoperability framework in use, this is not the case with the implementation, as the same standard may be implemented with different technologies, making it difficult to measure interoperability.

In the AURORAL dataspace, the ISO/IEC 21823-1:2019 have been choosen to be the standard methodology to achieve the semantic interoperability. The AURORAL project is a digital service platform tailored to the needs of rural communities. It features an ecosystem of fully interoperable applications and services that help these areas achieve innovation and smart transformation. By providing the essential infrastructure, AURORAL enables long-term social, environmental, and economic advances. This platform emphasises openness, interoperability, and decentralisation, ensuring that it meets the diverse demands of rural environments [8].

AURORAL consists of a network of nodes interconnected through a cloud that leverages semantic interoperability, enabling the integration of heterogeneous infrastructures from different stakeholders to meet the diverse needs of rural areas in five key areas: agriculture, mobility, energy, tourism, and health.

However, the problem of the semantic interoperability in AURORAL lies in the need to measure the exchange and understand data transparently and integrate different heterogeneous data sources proposed by consensus. This situation means that the exchanged data cannot be consumed transparently. To address this challenge, a common data format and ontology are established by consensus according to the standard methodology. Furthermore, data harmonisation techniques, such as RDF materialisation, are suggested for the effective integration of diverse information sources.

Then, it becomes essential to distinguish between different levels of semantic interoperability of data exchange. These following levels of semantic interoperability can be defined: technical, syntactic, semantic, behavioural and privacy interoperability, as depicted in Figure 1. Each of these levels focusses on different aspects of the information exchange and processing process, as described below:

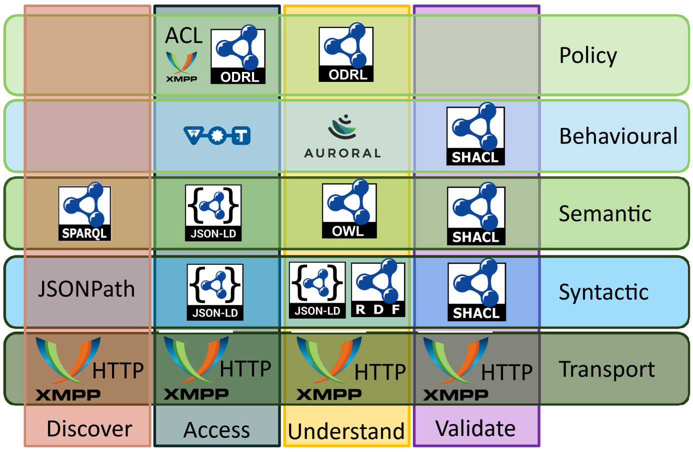

Fig. 1. AURORAL Interoperability profile

- **Technical interoperability**. The ability of systems to connect and communicate at hardware and software level. This level ensures that devices and systems can establish a network connection and share data over these connections without technical problems. At this level, data are interchangeable, but this does not mean that they are semantically interoperable.

- **Syntactic interoperability**. In this layer, the structure of the exchanged data is analysed, ensuring that the data format is understood by all the systems involved. Syntactic interoperability implies that data are interchangeable in the same format, but does not imply the same semantic interpretation by different systems.

- **Semantic interoperability**. Semantic interoperability refers to the ability of systems to interpret and process information in accordance with an existing ontology and their level to be achieved for semantic interoperability. Semantic interoperability is achieved at this layer, however, devices may not interpret data uniformly if multiple ontologies are used.

- **Behavioural interoperability**. Different systems can interpret the same data set differently if they use different ontologies. Although systems can share data in the same structured formats (syntactic interoperability), variation in semantic interpretation if different ontologies are followed can compromise semantic interoperability. Therefore, in this layer it is determined whether the ontologies used by the different systems can communicate effectively.

- **Policy-based interoperability**. Once the previous layers have been achieved, it is posible to use the Open Digital Rights Language (ODRL) standard to manage and enforce privacy policies regarding data access between different systems.

However, our position is that these interoperability layers should be measurable quantitatively based on the requirements defined by consensus in order to receive a certificate of interoperability and, measured by constraints that can be verified to confirm whether or not they comply with the defined interoperability framework. Therefore, in AURORAL H2020 a service has been created that automatically measures the interoperability framework defined in AURORAL by consensus, indicating to nodes whether they are partially or fully interoperable, and providing certificates if they are semantically interoperable.

3. Conformance

In the context of semantic interoperability, conformance is the way to check that the whole system meets with the standards specified by consensus, by checking that both the layers defined in the methodology used and the chosen technological implementation at each interoperability layer are met.

To meet interoperability requirements, AURORAL conforms to an interoperability profile in which open standards are used. The AURORAL platform requires the data used to be fully aligned with the AURORAL ontology, but, however, nodes may contain different errors (nodes not accessible by the AURORAL network, errors in the format of the shared data, or data not aligned with the AURORAL ontology). Therefore, a service that provides a report on the conformance of data within AURORAL provided by the nodes is needed.

At this moment, to measure the level of semantic interoperability in AURORAL, the conformance service has been developed that measures the minimum interoperability requirements needed in AURORAL in the horizontal layers of transport, syntactic, semantic, and behavioural, and for the tasks of accessing and understanding data, as depicted in Figure 2. Such requirements imply the use of existing and well-known standards. This service evaluates the conformance level of the nodes and catalogues them as follows:

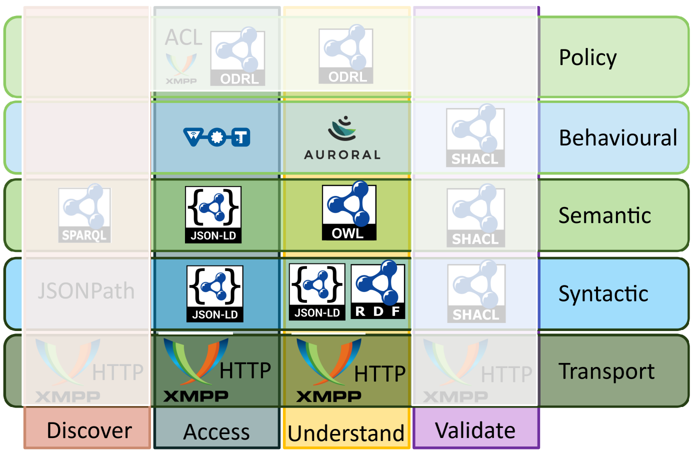

Fig. 2. Ensuring conformance in AURORAL

1. **Not checked**. Indicates that an evaluation has not been performed to determine whether the node complies with the interoperability requirements.

2. **No access**. The node could not be accessed, which may be due to security restrictions, privacy or network configurations. This prevents any form of interoperability.

3. **Access level conformant (Technical interoperability)**. The node meets the minimum requirements for interoperability in terms of data access. It ensures that there is adequate technical infrastructure to support basic connections and communications.

4. **JSON conformant (Syntactic interoperability)**. It reflects that the node can handle and exchange data in JSON format. This level ensures that structured data can be correctly interpreted and used by different nodes.
5. **JSON-LD 1.1 conformant (Syntactic interoperability)**. The node supports JSON-LD 1.1, a format that extends JSON to include links to data defined in specific contexts, which enhances the ability of the node to handle RDF data.
6. **Ontology conformant (Semantic interoperability)**. This point shows that the node data uses specific ontologies to ensure semantic interoperability, allowing consistent interpretation and processing of the meaning of the data. This level ensures that different nodes understand the information in the same way.
7. **AURORAL conformant (Behavioural interoperability)**. Refers to conformance within the AURORAL framework, assessing that nodes follow the ontologies designed in AURORAL, so that nodes deployed in AURORAL are interoperable with each other.

3.1. Conformance in AURORAL

With this tool, compliance verification has been automated in accordance with the interoperability framework established in AURORAL. As depicted in Figure 3, now it is ensured that from 116 nodes, 91 nodes are fully interoperable with each other in the AURORAL network and can communicate effectively with each other without losing information or suffering from errors in the process.

Node status:

Status	Number of Nodes
Total	116
Conformant	91
Not Conformant	25

Node details:

Status	Number of Nodes
Not Checked	0
No access	11
Access level conformant (Technical interoperability)	0
JSON conformant (Syntactic interoperability)	4
JSON-LD 1.1 conformant (Syntactic interoperability)	10
Ontology conformant (Semantic interoperability)	0
AURORAL conformant (Semantic interoperability)	91

Fig. 3. Conformance status of AURORAL

For each node, a detailed overview of the current state in terms of compliance with the interoperability framework is provided. Figure 4 indicates the case of a node failing at the ontological level, using values that are not defined in the ontologies used in the context provided in the JSON-LD 1.1. In this case, in the payloads only the context of the AURORAL ontology was provided, so since no specific keys provided are present in the ontology, it would no longer be either semantically conformant or AURORAL conformant.

4. Conclusions and future work

In this position paper, different levels for measuring the conformance of the semantic interoperability have been identified and described technical, syntactic, semantic, behavioural, and policy; each addressing different aspects

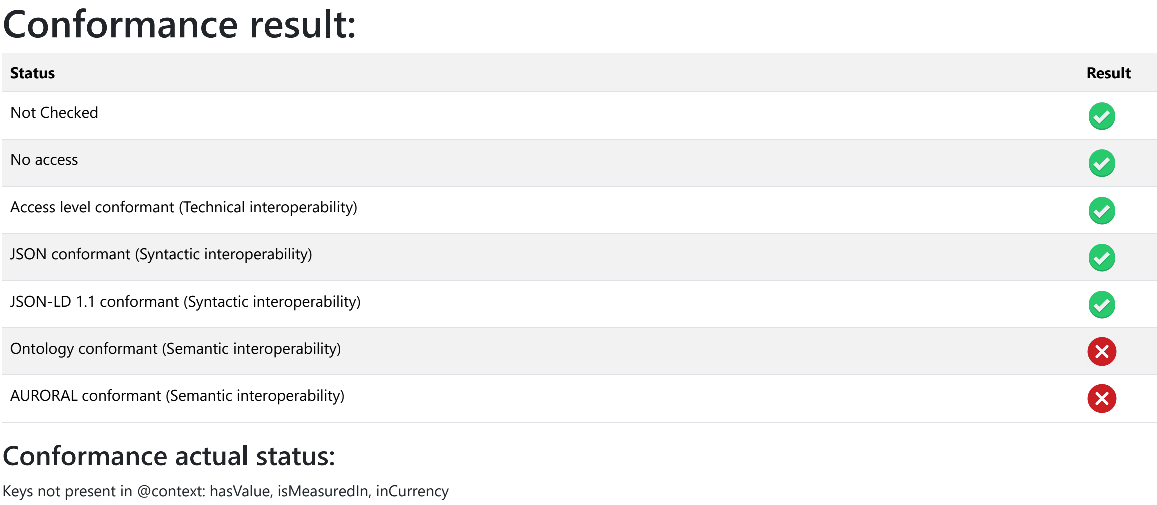

Fig. 4. Example of a not semantic interoperable node

of the semantic interoperability. However, defining interoperability levels in a system must be measured manually or automatically to confirm or indicate whether it is compliant or not with an interoperability framework defined through constraints.

Through the use case of the AURORAL platform, it is demonstrated how it is possible to verify whether the deployed nodes are compliant or not with the inteoperability framework defined, and at what level of semantic interoperability these nodes are, thus guaranteeing effective interoperability in the AURORAL network, providing positive results with clear descriptions of where nodes that are not fully interoperable fail.

For future work, non-project-specific automated tools will be developed that facilitate the evaluation of the conformance between different systems given an interoperability framework, being a modular tool that can be adjusted and configured to any project without the need to programme new functionalities by users, and issuing interoperability certificates based on other technologies that ensure the transparency and security of said certificates (blockchain , DLT, etc).

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