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Aligning the FEDeRATED Upper Ontology with Battery and Electronics Ontologies to Aid Circular Economy Monitoring in Practice

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Abstract. Facilitating Circular Economy (CE)'s monitoring requires access to data from different systems and data spaces. Motivated by this, a number of organizations have established data sharing agreements in line with the European Interoperability Framework to facilitate technical, semantic, organisational, and legal interoperability. Each data space, however, may follow its own domain-specific semantics. While this supports data's interoperability within the data space, it also poses a challenge in cases such as CE's monitoring, which requires data from several data spaces to be accessed, combined and analyzed. Supporting findable, accessible, interoperable and reusable (FAIR) data sharing not only within but also between data spaces is key. Ontology alignment can help facilitate semantic interoperability across data spaces and support CE's monitoring. Following this, we present an upper-ontology-based alignment approach to aid CE's monitoring in practice. We showcase the implementation of the approach for aligning the FEDeRATED upper-level ontology for data sharing with the RePlanIT (electronics), BattINFO (batteries) ontologies and the Catena-X (cars) data model. As a result, the alignments can be used by parties interested in data sharing between the battery, electronics and car data spaces to generate data sharing agreements, define data access controls and ultimately monitor CE's implementation. We also share lessons learned from the implementation of the approach and provide a discussion on future directions for semantic-enabled CE monitoring.

Keywords: Ontology alignment, Upper ontology, Data spaces, Circular economy, Electronics, Batteries, FAIR data, Semantic interoperability

1 Introduction

Governments are introducing new policies and regulations to motivate the transition towards a circular economy (CE) and boost sustainability (e.g. the Paris Agreement [14], European Green Deal [13], the CE Action Plan [11]) as well as numerous specific regulations such as the Battery Regulation [9], the Proposal for Sustainable Eco-design Regulation [12] and Carbon Border Adjustment Mechanisms [10]. However, to steer the transition towards CE governments need to have access and ability to monitor CE-relevant data and information as discussed in studies [36] [34] [37] [30] [44]. Such data resides in different systems and platforms of parties operating in a variety of supply chains [25] [45]. These systems and platforms follow their own data models (e.g. ontologies) that may be quite diverse and domain specific. Digital product passports (DPPs) will make sharing of some of this data with government obligatory (see e.g. the Battery Regulation [9]). However, beyond the mandatory data there is a plethora of data residing in business systems which may be shared with government on voluntary basis, given the right incentives are in place (e.g. trade facilitation) [35] [42]. The main challenge, however, is that to facilitate CE monitoring, one needs to access, combine and analyse large volumes of heterogeneous data from multiple platforms and systems, which raises the question of data's interoperability [25] [45]. With the emergence of data spaces, companies have started to organise themselves and make shared commitments regarding preferred data models to be used in a battery data space, and automotive data space as an example. Despite that, data heterogeneity is still a challenge limiting the implementation of findable, accessible, interoperable, reusable (FAIR) [46] data. As discussed in study [21], for governments to have a uniform way of accessing data available in different platforms and data spaces, data space interoperability needs to be achieved on both technical and semantic levels. Regarding the semantic level, the use of a semantic data sharing architecture, as well as the use of upper ontology and ontology alignment with (lower) ontologies have been proposed as ways forward to create basis for government to tap into the wealth of business data for CE monitoring [21].

Ontology alignment itself has been a topic of interest for the Semantic Web community for many years. Our investigation of related work in Section 2 shows that most of the existing work focus on the theoretical side of ontology alignment and that there is a lack of practical applicability of the engineered alignment approaches, especially for CE's monitoring. To adopt semantics for CE monitoring at scale, especially in industry, practical aspects such as ease of approach implementation, application and execution should be equally considered.

Motivated by the need for better cross-data space data sharing and semantic interoperability and upcomming CE regulations (especially for batteries and electronics), we propose an upper-ontology based approach for manual alignment of the electronics and batteries data spaces on semantic level to support CE's monitoring. The approach focuses on the utilisation of the FEDeRATED upper level ontology for alignments with and of the RePlanIT[1] electronics ontology and the BattINFO [3] battery ontology. The FEDeRATED ontology was selected as it has been specifically built to support data sharing in practical industry settings (e.g., sharing data about goods and services between companies), while BattINFO and RePlanIT represent batteries from different lenses (discussed later on in Section 2.2). The approach also illustrates how the Catena-X[2] data model for batteries can be transformed into a battery ontology to facilitate its upper-ontology alignment. In light of the upcoming CE regulations and requirements such as providing DPPs for electric vehicle batteries, our approach enables the access, use and sharing of CE relevant information across data spaces, which ultimately supports CE's monitoring. For example, the resulting alignments can be used by parties interested in data sharing between the battery, electronics and car data spaces to gener-

[1] https://kind.io.tudelft.nl/replanit/docs/ [27]
[2] https://catena-x.net/en/standard-library

ate machine-readable data sharing agreements and define data access controls. Last but not least, we share lessons learned from the implementation of the approach and provide a discussion on future directions for semantic-enabled CE monitoring. In summary, we define our main contributions as follows:

- A practical approach for ontology alignment based on the FEDeRATED upper-level ontology for cross-industry data sharing.
- Enabling semantic interoperability across data spaces for CE's monitoring with upper-level ontology alignments.
- Lessons learned by applying the approach and guidelines for future work.
- Raised awareness of the value of semantics in the CE domain, especially in supporting data interoperability across data spaces.

The rest of the paper is structured as follows. Section 2 presents an overview of existing relevant to our work ontology alignment approaches. Section 3 outlines our approach, while Section 4 presents its practical application(s). Discussion and conclusions are presented in Sections 5 and 6 respectively.

2 Related Work

Similarity-based ontology alignment (manual and semi-automated) has been a common approach for ontology alignment through the years. Several prominent studies such as [15] [8] [7] [43] [23] propose various alignment approaches based on the combination of similarity measurements. A survey of such approaches is presented in study [31]. In contrast, our work utilises upper-level ontologies for alignment - an approach that several other studies have focused on as well.

Silva et al. [40] recognize the need for better data interoperability to advance discoveries in the bioinformatics domains and propose the Open Biological and Biomedical Ontologies (OBO) [41] alignment for Enriched Annotation (OBOAEA) approach. As a start, domain specific ontologies are selected for the alignment that the upper-level ontology will support. This is followed by a semi-automatic annotation of data from the Gene Ontology Database [16] with the selected ontologies. A set of source ontology terms (based on the user's preference) is derived and used for extracting specific ontology fragments to reduce the processing time for large ontologies such as OBO. Cleaning unnecessary metadata is also used as a strategy to reduce the size and complexity of the ontologies. At the core of the alignment is the Naïve Ontology Mapping (NOM) technique used by the FOAM tool. Previous alignments are recorded and used as references to improve and evaluate the approach. Experimental application showed that the approach can significantly improve the accuracy of the alignments.

By building upon their ontology alignment approach in [23], Jain et al. present its newer version BLOOMS+ [24], which utilises schema-level mappings from linked open data (LOD) clouds to the we analyse the classes, looking for the most suitable class to align to the conceptProton [5] upper-level ontology. BLOOMS+ has improved concept-pairs alignment discovery between ontologies and utilises context-specific information to further confirm or reject proposed alignments. The approach utilises three types of similarity measurements, namely class, contextual and overall similarity between ontologies. Experimental evaluation of BLOOMS+ for the manual alignment of several LOD ontologies to Proton showed that it outperforms existing systems such as its predecessor BLOOM [23] in terms of precision and recall.

An upper-level ontology alignment approach has also been carried out by Scheider [38]. The author's main goal is facilitating the alignment of several building and construction ontologies (e.g. SAREF [6], DogOnt [1]) with the help of the Building Topology Ontology (BOT) [33] upper-level ontology. For each ontology, possible class and sub-class alignments to BOT have been manually derived. The resulting alignments have been implemented as separate ontologies importing BOT. and have been evaluated with the HermiT [17] reasoner. The results validate the feasibility of the approach. However, they also highlight limitations such as having alignments mostly on class level between ontologies, which can alter the semantics of concepts. Overall, as discussed in study we analyse the classes, looking for the most suitable class to align to the concept [38], the approach needs further improvements and testing and as proposed by the author and an agreed upon by domain experts mapping.

Dalal et al. [4] further investigate how ontology alignment can be carried out when having ontologies built by following an upper-level ontology versus using modular ontology design approach. Driven by the complexity of the process, especially for non-specialists, the authors propose an extension to the Comprehensive Modular Ontology IDE (CoModIDE) [39] tool for upper-level ontology alignment that can be used as plugin in Protégé. The tool's interface enables one to visually model a domain of interest by using concepts from existing pre-loaded lower and upper-level ontologies. Further, it supports the use of ontology design patterns and directly outputs the visual model encoded as an OWL ontology. As discussed by the authors, possible future work can be carried out to semi-automate and even fully-automate upper alignments and to further validate the tool's usefulness.

Recent work in ontology alignment explores the automation of the process itself. For example, Geng et al. [16] present an application focused ontology construction and alignment approach, which integrates both semantic- and structure-based algorithms (i.e. Word2vec [2] and Node2vec [18] respectively) to measure the similarity between concepts from different ontologies. Another example is the BERTMap [20] ontology alignment system based on the Bidirectional Encoder Representations from Transformer (BERT) language transformation model. BERTMap utilises BERT's capabilities to improve its comprehension of concepts' semantics and contexts to make better and time-wise more efficient mapping suggestions. Following the same trend of automating alignments, Hao et al. [19] propose the Siamese-GCN ontology alignment approach, which combines Neural Network Language Model (NNML) for embedding semantics and Graph Convolutional Network (GCN) for structural purposes. All of these approaches have undergone evaluations with benchmarks, which have showcased their feasibility. However, due to being quite novel approaches, limitations are still present.

To conclude, most of the existing work has focused on advancing the scientific side of the ontology alignment process. Similarity between ontologies (e.g. at a class-level) has been a key guiding principle when performing alignments. While this can be sufficient for some cases, in the case of CE's monitoring for batteries, we aim to align ontologies that are not similar but rather complementing and extending each other's knowledge of the domain(s). Existing work has so far examined to a limited extent the potential of using upper-level ontologies and demonstrating a practical approach to ontology alignment based on it. Real-world application and validation of the approaches have often been set as future work. Motivated by this and the need for FAIR data sharing across domains that can help facilitate CE's wider adoption, we propose a practical upper ontology-based alignment approach for CE's monitoring in the case of batteries. In the next section we introduce the FEDeRATED semantic model for the the logistics domain and propose to use parts of it as an upper ontology to align three lower-level ontologies, namely RePlanIT, BattINFO and Catena-X.

2.1 The FEDeRATED Upper-Level Ontology for Data Sharing

Our ontology alignment approach utilises the FEDeRATED[3] upper-level ontology, which has been piloted on a larger scale for logistics data sharing. In XXX project (anonymized for the review), the potential of FEDeRATED is further explored to examine its feasibility to be applied in the context of CE monitoring.

At FEDeRATED's core is the concept of an event (see Fig. 1). Events can associate real-world things such as legal/natural person, and digital twins (e.g. a battery is has a digital twin) in place (infrastructure, location) and at time (past, present, future). Event associations are shared to synchronise business activities where synchronization is represented by states, state transitions, interactions combined into interaction patterns. Business documents are seen as a specific state.

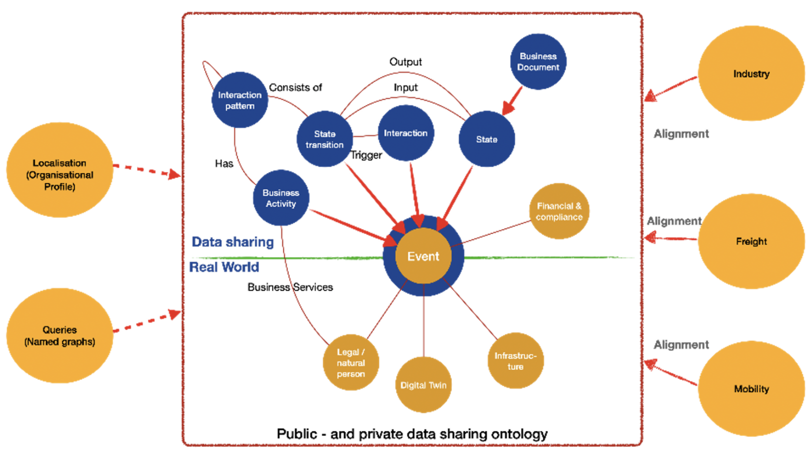

Fig. 1. FEDeRATED upper level ontology for data sharing

[3] https://www.federatedplatforms.eu/index.php/products/developer-portal

The ontology focuses on representing data sharing interactions between enterprises or between enterprises and authorities and can be aligned with lower-level sector ontologies such as industry, freight and modality ontologies. These ontologies can be further specialized for electronics data sharing. Applying FEDeRATED either by specialization or alignment with existing ontologies specifies 'services' for business collaboration (e.g. a multimodal supply chain visibility service). Booking, quotation, ordering, and payment are other examples of a 'service', which is an interaction pattern and can be implemented by many IT services through open Application Programming Interfaces (openAPIs).

For data sharing, organizations customize these services by specifying what type of business activities and interaction they support and the subtypes of Digital Twin (e.g production of batteries). Customized services are represented by a 'profile'. Subsequently, queries on the data can be done by using the agreed access rights based on the profiles customizing 'services'. Further information about the FEDeRATED approach and the ontology can be found online[4] and in [22] [21].

2.2 The RePlanIT, BattINFO and Catena-X Lower-Level Ontologies

We utilise FEDeRATED to align three domain specific ontologies, namely RePlanIT[1] [27], BattINFO [3] and Catena-X[2]. Each one of these ontologies considers batteries from different perspectives. The RePlanIT ontology for representing DPPs of ICT (e.g. laptop and data servers) was built in response to the lack of unified semantic model that can represent the lifetime of an ICT device and its hardware components through the CE. Following an extensive literature survey [26] and interviews [29] with government and industry representatives in The Netherlands, RePlanIT represents knowledge about a device on several levels - ICT device, hardware components (e.g. batteries), materials and CE processes applied to them. In addition, the ontology represents a set of indicators (i.e. economical, sustainability, functional), which can be used to evaluate the suitability of a device during processes such as ICT procurement.

In comparison to RePlanIT, which represents batteries as a hardware component of an ICT device (see Fig. 2), the BattINFO ontology focuses on the batteries themselves. By utilising the European Materials and Modelling Ontology (EMMO) [28] as a top-level ontology and following principles of electrochemistry [32], BattINFO represents batteries down to the chemical and electrochemical processes and reactions taking place when electric current passes through batteries. Further, the ontology represents interfaces that aim to support battery data interoperability.

Finally, we utilize the Catena-X data model, which has been built to support manufacturing in the automotive industry. We focus on Cattena-X's battery pass[5] module, which represents batteries, their properties (e.g. power, material composition, voltage) and relevant information such as battery component suppliers and entities involved in their manufacturing. Since the battery pass module is not an ontology, we have transformed it into one for the purpose of our work. Details on each ontology's alignment are presented in Section 4.

[4] https://www.federatedplatforms.eu/index.php/library

[5] https://github.com/eclipse-tractusx/sldt-semantic-models/tree/main/io.catenax.battery.battery_pass

3 Methodology

We used the FEDeRATED semantic data sharing architecture and upper ontology as a starting point. Subsequently, we specialised this upper ontology for the domains of electronics and batteries. For the electronics, the RePlanIT ontology was used for the alignment. For the batteries, alignment was performed using both BattINFO ontology and Catena-X. Table 1 summarizes the alignment steps followed aligning FEDeRATED with RePlanIT, BattINFO and Catena-X. Additional steps were performed for the alignment with Catena-X (e.g. transforming the data model to an ontology prior to the alignment). The semantic interoperability of a multidisciplinary ontology assumes different industries are aware of each other's alignment to the upper ontology and possible updates. A solution for such a vocabulary hub could constitute a cloud hosted ontology version management platform such as the Semantic Treehouse[6], which we used in this research. The platform provides storage, limited access control, and supports version management of the aligned ontologies. A demo[7] of the approach, its methodology and other resources needed for its implementation are available online[8].

4 Case Study Applications

In this section we present the findings from the alignment process of the electronics RePlanIT ontology (Case 1), the BattINFO battery ontology (Case 2), and the Catena-X data model for batteries (Case 3) with the FEDeRATED upper ontology.

4.1 Case 1: FEDeRATED-RePlanIT

When aligning ReplanIT (Fig. 2) to the upper-level ontology, the main factor we consider is the conceptual similarity of all the classes involved in both ontologies. Starting with the upper-level ontology, we analyse the classes and which would relate to an electronics product and we identify the Digital Twin of Product as the most suitable class to be aligned to. Next, we consider ReplanIT and we analyse the classes, looking for the most suitable class to align to the concept of a 'product'. We identify the ICTDevice class as the most suitable. Our reasoning for this design choice is that all the attributes in ReplanIT are either directly linked to the ICTDevice class or one of its' subclasses. Therefore, any attributes that might be relevant in a message model based on ReplanIT are integrated with the upper-level ontology concepts. As a result, one is able to construct named graphs where upper ontology events involve electronics from ReplanIT. To summarise, the alignment introduces a new named graph that of the alignment between the upper level ontology and the ReplanIT electronics ontology. The new named graph denotes the new relation, that ICTDevice is a subclass of the Product upper level ontology class. The alignment is reflected in the following one triple statement:

[6] https://www.semantic-treehouse.nl
[7] https://collegerama.tudelft.nl/Mediasite/Channel/datapipe-project/watch/f3a9265c04e0449db155393c68dd80fc1d
[8] https://github.com/Datapipe-demonstrator/semantic-interoperability

Table 1. Step by step analysis and alignment

Cases	**Steps for analysis and alignment**
Case 1: Upper-ontology alignment with RePlanIT ontology	1. Open the RePlanIT ontology with ontology visualization tool (Protégé) 2. Perform an exploratory analysis of the entities (classes, object properties and data properties). 3. Evaluate conceptual similarity involved in both the upper and RePlanIT ontology 4. Analyze the upper ontology to identify class that relates to the electronics product 5. Analyze the RePlanIT ontology to identify most suitable class to align to product 6. Perform alignment
Case 2: Upper ontology alignment with BattINFO ontology	1.Open BattINFO with ontology visualization tool (Protégé) 2. Perform an exploratory analysis of the entities (classes, object properties and data properties). 3. Explore the upper ontology and the BattINFO ontologies for similarity 4. Analyze BattINFO to identify the most suitable class to align to product. 5. Perform alignment
Case 3: Catena-X ontology	1. Translate the Catena-X data model to RDF-based translation to an ontology 1.1 Catena-X: BAMM TO RDF (1) – Classes 1.1.1Used Battery Pass ttl file from sldt-semantic-models/io.Catena-X.battery.battery_pass/3.0.0/BatteryPass.ttl at main · eclipse-tractusx/sldt-semantic-models (github.com) 1.1.2 Manual conversion based on rules: bamm:Entity = owl:Class 1.2 BAMM TO RDF (2) – Datatype Properties 1.2.1 For every bamm:Property, look at their bamm:characteristic, 1.2.2 If the corresponding bamm:characteristic has bamm:dataType . . . entity then ObjectProperty 1.2.3 Otherwise, look for the name of the characteristic and find the bamm-c:Measurement, get bamm:dataType, and specify bamm-c:unit = owl:DatatypeProperty/owl:ObjectProperty (depending on bamm:exampleValue or if there exists an entity for that property) 1.3 BAMM TO RDF (3) - Object Properties 2. Upload the ontology in the visualization tool 3. Explore the upper and Catena-X ontologies for similarities 4. Identify the most suitable class for product from the Catena-X derived ontology 5. Perform alignment

```
Statement:
    replanit:ICTDevice rdfs:subClassOf DigitalTwin:Product
Triple analysis:
    Subject = replanit:ICTDevice
    Predicate = rdfs:subClassOf
    Object: DigitalTwin:Product
Named graph (name we give to the new alignment ontology link):
    RePlanIT-alignment-Upper-Level-Ontology
```

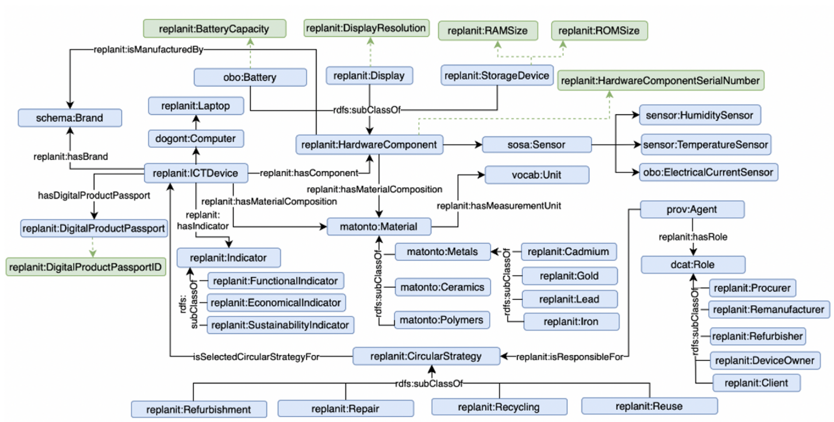

Fig. 2. RePlanIT ontology v3.3 overview (Main classes in blue, data properties in green)

The alignment did not encounter any conceptual roadblocks as both ontologies are based on the RDF standard of W3C and they are also structured in a hierarchical manner, making use of the *rdfs:subClassOf* property. Consequently, this allows a single triple statement between two concepts to link up many more at the same time, reducing the syntax complexity. The alignment of RDF-based ontologies to the upper ontology enables a unified syntax of information gathering in a querying process. Together with the version management system of aligned ontologies, these two concepts allow users to define well-formed SPARQL (querying language for triple statements) queries that queries that may request industry specific information by accessing upper-level ontology events. For example, when defining a car window we consider the plastic casing, the glass piece and the electronic control system that defines the movement of the glass piece. Out of the three elements the car window contains, only the control system may be expressed using the ReplanIT ontology. Therefore, the other two elements can be expressed using the upper-level ontology class Product. This can be used to construct a SPARQL query that would return the lifetime of the up/down switch of the control system. Example of competency questions and SPARQL queries is available online[9] (e.g.

[9] https://github.com/Datapipe-demonstrator/semantic-interoperability

Table 1 in the Appendix[10]). Based on our analysis , we denote that understanding the structuring of the triples of an ontology is a hard prerequisite and is addressed by using vocabulary hubs such as Semantic Treehouse. As results of the SPARQL queries and the denoted capabilities of alignments, we compare the DPP alike multiple SPARQL queries, one for each one of its attributes.

4.2 Case 2: FEDeRATED-BattINFO

In the batteries domain, we have considered both the BattINFO and Catena-X and have analysed their strengths and weaknesses. Our criteria for analysis has been the practicality (i.e. how easy would it be for a person with no semantic experience to understand it), usability (i.e. how easy is it, conceptually as well as syntactically to align it to the upper level ontology) and the compliance of the ontology to the required information in a battery passport by the European Union.

First, when opening the BattINFO ontology in Protégé[11] we perform an exploratory analysis of the entities (classes, object properties and data properties). We observe that the syntax is hard to decode, as there is no top class to start exploring from. The Battery class is found at the 9th level in a nested structure. This requires time and exploration or being familiar with the tool's querying capabilities. In comparison with the ReplanIT ontology, which we loaded in a similar tool, we denote BattINFO to be more complex in terms of its comprehension. Second, the BattINFO ontology addresses the information needed for a battery DPP at the level of the Battery class. This entails the possibility of an easy one triple statement alignment (similar to ReplanIT). Third, the BattINFO ontology addresses all technical, electric engineering aspects, but it does not address all the mandatory points from the BatteryPass[12]. which identifies elements that may be required by legislation. The BattINFO ontology does not model classes or properties about the warranty, legal compliance and manufacturer indicatory usage (for example recommended charging temperature and voltage).

4.3 Case 3: FEDeRATED-Catena-X

To overcome the limitations of BattINFO we investigated other battery ontologies that can capture information needed for CE monitoring in more detail. The Catena-X data model (not yet an ontology) was identified as a suitable fit and we carried out its in depth analysis. First, when analysing the Catena-X we denote that all the properties of a battery are coupled to the top class BatteryPass. However, since the data model is not an ontology it is challenging to visualise and explore it without proper tooling, unavailable as open source. Due to this we encoded Catena-X as an OWL ontology.

The resulting ontology and it presents a similar structure with the ReplanIT ontology, a top class oriented coupling of attributes. Second, the Catena-X translated ontology couples all the information needed for a battery DPP at the level of the BatteryPass

[10] https://github.com/Datapipe-demonstrator/semantic-interoperability/blob/main/ESWC%202024%20resources/_ESWC_2024__Ontology_Alignment-3.pdf

[11] https://protege.stanford.edu

[12] https://thebatterypass.eu/

top class. Consequently, a 1 triple statement alignment may be used to align the Catena-X ontology to the upper-level ontology, similar to the ReplanIT ontology.

Third, the Catena-X data model itself did not tackle all the required data presented in the Battery Pass European project and thus we have provided an RDF-based addition, to tackle all the non-addressed fields. Therefore, the Catena-X translated ontology, alongside its' addition, models all the required information from the Battery Pass European project.

By comparing the two ontologies (BattINFO and the derived Catena-X ontology) we have observed that Catena-X is more suitable for our use case, as it presents no weaknesses based on the criteria we have chosen. Moreover, the chosen ontology also presents a similar structure to the ReplanIT ontology, offering cohesiveness and clarity of structuring for users of the initiatives. Similarly to the alignment of the ReplanIT ontology, a single triple statement is required to align the Catena-X translated ontology to the upper-level ontology:

```
Statement:
    Catena-X:BatteryPass rdfs:subClassOf DigitalTwin:Product
Triple analysis:
    Subject = Catena-X:BatteryPass
    Predicate = rdfs:subClassOf
    Object: DigitalTwin:Product
Named graph (name we give to the new alignment ontology link):
    Catena-X-alignment-Upper-Level-Ontology
```

4.4 Graph Walk Based on the Aligned Ontologies

The alignment of the application data sharing ontologies related to batteries (Catena-X derived ontology) and electronics (RePlanIT ontology) and the upper ontology allows to create links between these application ontologies via the upper ontology, enabling parties (e.g. authorities) to access data that may be stored in DPPs related to batteries and electronics. We create a visual example of how DPPs' work on a semantic level.

We adapt the conceptual figure on alignment discussed earlier [22] based on the practical alignments with Catena-X and RePlanIT, resulting in Fig. 3. Starting from the bottom, we look at an instantiation of a primitive event and a request of information from the event, expressed as SPARQL query. In order for the SPARQL query to return the correct result, the query must be correctly formulated according to the ontology used in the event. When formulating the query, the expressiveness of alignments alongside a knowledge engine is highlighted, as knowing the structure of the ontology, the creator of the query knows how to 'walk back' the alignment graph. The path to be walked to obtain a correct SPARQL query is denoted in light blue, starting from the instantiated event.

5 Discussion

The following subsections present a discussion on our alignment approach and its practical applicability to address interoperability needed for accessing data from different systems and data spaces.

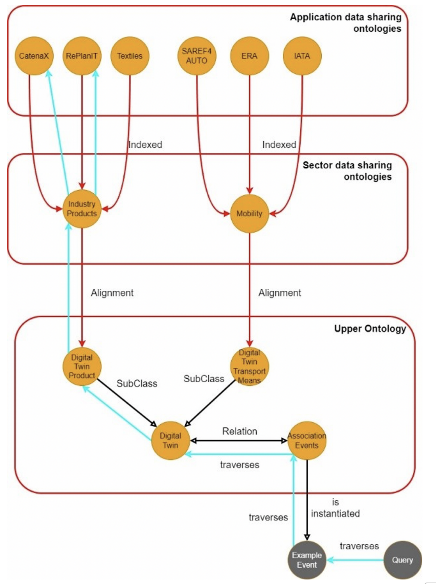

Fig. 3. Graph walk (Adapted from [22] [21])

5.1 Discussion on the Proposed Alignment Approach and Future Directions

Our work demonstrates that the upper-level ontology developed in the FEDeRATED project can be used as an upper ontology and can be aligned and specialized with other domain ontologies to enable CE data related to products and their material composition to be shared between and within authorities. The following lessons learned can be derived:

1. If the domain ontologies are well structured and a top node can be easily identified, the alignment with the upper ontology is straightforward and can be achieved with limited sentences.
2. We can also work with cases where we do not start with an ontology but with a meta model (i.e. not encoded as an ontology). We have demonstrated that in this case alignment with the upper ontology is also possible, however, an additional step is needed (i.e. converting the meta model to an ontology). This shows that the approach can work also in cases when there are no pre-defined ontologies but only meta models as a start.
3. Currently, the alignment is performed by keeping the associations (that were hard-coded) in the original ontology. This has as an advantage that by taking the ontology as a whole and keeping the associations, the logic of the relationships in the ontology is clearer. At the same time this also has disadvantages, as a specific ontology hard-codes specific associations, while in other cases other associations between concepts of the ontology may be needed. Further research can focus on decoupling some of the associations to create more modular and reusable components and using constraints, which would allow for more flexibility.
4. In the current research the alignment of the ontologies using the Semantic Treehouse was done via a manual ontology matching and alignment process. Further research can explore whether the alignment process using vocabulary hubs such as the Semantic Treehouse can be automated.
5. Current literature on ontology alignment focussed largely on exploring similarities between ontologies. In our ontology alignment approach, however, we are not focusing so much on

the similarities in terms of overlaps between the ontologies (i.e. to what extent two battery ontologies are similar), but rather on their complementarities (i.e. how via the upper ontology we can merge different ontologies like batteries and electronics).

6. Based on the application of the ontology alignment processes, we identified that having ontologies that have a specific topology characteristics (e.g. top node) are easier to align with the upper ontology. Further research can also examine whether certain topology characteristics of the lower ontology has an influence on the alignment processes and its efficiency.
7. Reflecting on the ontologies used, the RePlanIT ontology has so far received limited validation, as it has been validated with end users that would like to procure a laptop in a more sustainable manner. Further research can focus on validating the ontology with a larger stakeholder group, including manufacturers.
8. Last but not least, we note the following advantages to our approach. By being a manual alignment approach, it facilitates collaboration and knowledge exchange between different experts (e.g. ontology engineers, sustainability, electronics and regulatory experts), which is key for enabling CE's monitoring and encouraging innovation. The alignment is transparent, and the process of implementing it is traceable (not the case if fully automated with AI). The manual investigation and selection of each suitable ontology was performed by domain experts, which we believe leads to better results in terms of quality as well. Our approach also helps implement a flexible, adaptable and extensible solution that enables authorities to access data from a variety of platforms, data spaces and legacy systems and to adapt easily to new legislative changes. For example, it allows to easily align with new ontologies in the future (e.g. tires) if new legislation for monitoring new product groups is introduced.

While our research shows that FEDeRATED can enable alignment with lower level ontologies and this can be used for enabling data sharing with government, for the actual data sharing to take place a number of additional steps are needed. For the authorities and other actors to be able to execute the actions referred to in the previous section, additional steps are needed both on the technical, as well as the governmental side. On the technical side, all stakeholders require:

1. A software tool (e.g. ontology viewer, visualiser), where parties can either build or visually explore an ontology to understand it in an easy manner. For example, free to use tools such as Protégé or a commercial subscription based solution such as TopBraid[13].
2. A query formulation tool (a triple database like GraphDB[14]) where they can run SPARQL query requests, coming from the authorities, on their already shared data.
3. A data sharing environment (e.g. a solution like the BDI[15] node8 where one only needs to configure a POST HTTP action to the correct endpoint for the BDI node, for both querying and data transmission).
4. A vocabulary hub (e.g. Semantic Treehouse) to host, update and notify collaborators about the structure of the data and its' possible maintenance.
5. Finally, the technical flow of an information inquiry of the authorities would represent formulating the SPARQL query based on a competency question(s), posting the SPARQL query to the original (car) equipment manufacturer (OEM) via the data sharing environment. The (car) OEM runs the SPARQL query on their local triple store where the sensitive data is stored, and then posts the result of the SPARQL query to the authorities. Authorities can check the result of the SPARQL query on their local triple store and decide if the information conforms to their requirements.

[13] https://www.topquadrant.com
[14] https://graphdb.ontotext.com
[15] https://github.com/TNO/FEDeRATED-BDI

5.2 Discussion on Practical Applicability

As discussed, the context of CE monitoring is particularly interesting for ontology alignment using upper ontology, as authorities need access to multiple systems/data spaces. To show the potential for the practical applicability, and to highlight the strength of our interoperability solution, we draw a fictitious simplified scenario with three different companies, one specialized in electronics, one in batteries (battery producer) and a (car) OEM. Each enterprise is a member of their industry specific data space. Each data space adopts their own standardized ontology for semantic interoperability, where each participant commits to using the chosen ontology for all external communication. Assume the battery data space uses the Catena-X data model (in our case concerted to the Catena-X ontology), the electronics data space adopts the ReplanIT ontology and the (car) OEM data space employs a (car) OEM ontology (in this research for simplicity we did not include also a Car ontology in the alignment process but the alignment steps would be similar as for the other ontologies). Furthermore, assume also that all three data spaces are members of a vocabulary hub, such as Semantic Treehouse, where they host their standardized ontology and alignments to the upper-level ontology. The next step towards interoperable data spaces represents the collaboration of members from these different data spaces.

Towards this goal, the involved parties must have an agreement on sharing the underlying ontologies and alignments to the upper level ontology with one another via a vocabulary hub, alike Semantic Treehouse. For example, when a (car) OEM assembles a car, they include parts insourced from companies of other data spaces (electronics and batteries here), digitally represented using the RePlanIT and Catena-X ontologies. When insourcing the parts, the (car) OEM requests access to the ontologies used by the electronics and batteries collaborators, via the vocabulary hub. Moreover, when considering to move to an open neutral data sharing infrastructure, this can be achieved by cooperation through a vocabulary hub and making agreements on business data sharing ontology, interaction patterns and linked event protocol. To illustrate this step, assume authorities of a country, where the (car) OEM wants to sell a car, want to check if the car and its' parts comply with the regulations. To verify this information, the authorities can query information about the cars' parts, knowing the underlying shared ontologies, from the vocabulary hub. Assuming the authorities already have access to the standardized ontologies on the vocabulary hub, they can check based on the element mappings of the ontologies which attributes correspond to the regulation articles to be verified. Once the authorities form a SPARQL query using the syntax of the attributes they found at the previous step, they can send the query as a request to the OEM.

In the current setting we investigated about data spaces, as data spaces evolve as communities to organize multiple companies to share data around domains such as healthcare, mobility, etc. However, this discussion is all about system boundaries: what is a data space. What if we forget about these boundaries and focus on an individual participant? Individual participants have particular business activities, digitally supported by standardized 'services'. Thus, what we require is standardization of 'services' for business activities. This can be done by what can be called 'Design Authorities'. Registration of individual stakeholders for digital data sharing also has to be managed to create trust. This requires issuing policies, preferably based on (public) regulations. Following this line of thought further research may explore the possibility to move beyond the data space discussions towards more holistic apporach.

6 Conclusions

The main contribution of this paper is a practical upper ontology based alignment approach for CE monitoring. We demonstrate how FEDeRATED as upper level ontology, that has been specialized for the logistics domain, can be aligned with an electronics (RePlanIT) and batteries

(BattINFO) ontologies, as well as a battery ontology derived from the Catena-X data model. We also demonstrate how a vocabulary hub such as Semantic Treehouse can be used for version management and storage of the aligned ontologies which can be subsequently deployed via a semantic data sharing architecture. The study shows that the upper ontology that was initially specialized to enable data sharing for logistics events can be also specialized for the electronics and batteries domains to enable data sharing of CE-relevant data.

Our work is limited to the conceptual analysis and prototype level implementation of the proposed upper-ontology alignment approach for CE monitoring. While we present a demo of it, further investigation of its application to more domains, adoption by real-life use cases by collaborating with companies, exploring wider stakeholder validation and up-scaling scenarios towards operational environment is needed. We have already outlined several research directions on how the approach can be further developed in the paper. Further, we have provided examples of and have discussed how governments can utilise the resulting aligned ontology and the steps of how the aligned ontologies can be further piloted in a demonstration setting.

While in this study we took data spaces as an example starting point, further research can explore what is needed to move towards a more holistic approach, which moves beyond the boundaries of individual data spaces. In this paper, we also used the functionality of the Semantic Treehouse where the aligned ontologies are stored. Further research can examine the possibility of vocabulary hubs in the future that do not store the aligned ontologies, but only the alignments with URIs of the two ontologies, as well as feasibility of completely decentralized implementation of a vocabulary hub.

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