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Towards a Multidimensional Ontology Model for DIH-Based Organisations

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ABSTRACT

Digital innovation hubs are of utmost importance when they sustain cooperation in innovative technological domains like the cyber-physical system. In this paper, the authors introduce, in the first part, a DIH ontology that they extend (1) with network and (2) with CPS entities. For this, they remind the questions that the ontology must answer, deploy the methodology proposed by Noy and McGuinness to identify the classes and the associations between classes, and integrate the new CPS ontological extensions. In the second part, they implement the full innovative DIH4CPS ontology within Protégé, and they instantiate it to a real company.

KEYWORDS

CPS, Cyber-Physical System, Digital Innovation Hub, Network, Ontology, Protégé

INTRODUCTION

A Digital Innovation Hub (DIH) is defined by Crupi et al. (2020) as a one-stop shopS that can help companies use digital technologies to become more competitive in their business/production processes, products and product development (Chaochotechuang et al., 2015), or services. The purpose of a DIH is to guarantee that all companies, whatever their size, can benefit from the advantages of new digital technologies (Pan-European Network of Digital Innovation Hubs, 2016) and, thereby, find the appropriate competence regarding digital technologies and IT, which, for Rüßmann (2015), is paramount for the manufacturing industry. DIH are by essence strongly associated to network of partners (and, *de facto*, partner selection) (Pongsathornwiwat et al., 2017), and it is essential for DIH to set up the most efficient tools as possible to support the market in discovering digital information (technological, business, or even scientific) in an accurate and prompt manner since both are essential for the existence of the company (e.g., in the consumer-centric open innovation framework for food and packaging manufacturing (Tsimiklis et al., 2015). Moreover, as already observed, DIH are especially of utmost importance when they are encouraging and sustaining cooperation (Sassanelli et

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al., 2022) in cutting-edge technological domains like the cyber-physical system (Gunes et al., 2014; Jamaludin & Rohani, 2018).

In this context, an ontological representation of a DIH4CPS may be perceived as a contribution with high impact since it offers an "explicit specifications of (DIH4CPS) conceptualizations" and, as a result contribute to sustaining the networking environment in which DIH behaves (Guarino et al., 2009). Unfortunately, to our knowledge such ontology for specifying the digital innovation hub surrounding the promotion, strengthening, cooperation, and co-development of CPS[1] networks has never been developed. The problem with this absence is that it hinders effective communication, collaboration, and coordination among stakeholders within the hub. Without a standardized framework for capturing and representing the relevant concepts, relationships, and properties, there is a risk of ambiguity, inconsistency, and inefficiency in the interactions and activities within the digital innovation hub. This poses challenges in achieving seamless integration, interoperability, and progress in the development and advancement of CPS networks. Therefore, the real problem lies in the need to address this gap by developing a comprehensive ontology that can serve as a common language and structured framework for the digital innovation hub, facilitating effective communication, collaboration, and coordination among all stakeholders involved (Garetti et al., 2015).

Accordingly, the research problem that this paper addresses concerns the development of an ontology (Guarino et al., 2009) for specifying the digital innovation hub surrounding the promotion, strengthening, cooperation, and co-development of Cyber-Physical Systems (CPS) networks. This problem may be structured in three sub-problems. The first involves defining the scope of the digital innovation hub. This entails clearly establishing the boundaries and components of the hub that supports CPS networks. By doing so, a solid foundation for ontology development can be established. Defining this scope will help determine the specific areas, activities, and stakeholders that the ontology should encompass, ensuring that it effectively captures the essence of the digital innovation hub. Once the scope is defined, the next step is to identify the relevant concepts and relationships within the hub. This requires conducting a comprehensive analysis of the various elements, processes, actors, and relationships involved in the promotion, strengthening, cooperation, and co-development of CPS networks. Through this analysis, a deeper understanding of the intricate dynamics within the digital innovation hub can be obtained. It will enable the identification of key concepts and their interrelationships, providing insights into how different entities collaborate and contribute to the advancement of CPS networks. With a clear understanding of the scope and the relevant concepts and relationships, the final critical step is ontology design and development. This involves designing and creating a formal representation, or ontology, that captures the identified concepts, relationships, and their properties. The ontology serves as a structured framework that allows for precise specification and interoperability among different systems and stakeholders within the digital innovation hub. It provides a shared language and standardized framework for communication, facilitating seamless collaboration and coordination.

Acknowledging this, the paper aims to describe and instantiate the ontology by formalizing the existing knowledge on DIHs competences, organization, experience, technologies, network, and the interoperability requirements of their networks and with their partners. Accordingly, the development of the DIH4CPS ontology includes a dimension related to inner consortiums development and cooperation, as well as inner networking activities among the partner from a DIH. As a matter of fact, the target audience of this paper extends far beyond the traditional academic audience and targets project consortiums and the project partners responsible for the development of the DIH4CPS models. Those partners will use the ontological model described in this paper to achieve several development processes later. The paper also allows audiences to understand how the ontology was built and its potential links with existing ontologies. Therefore, in the paper we define an ontology for the CPS. This ontology has the particularity to be oriented to the surrounding network of the CPS organizational management that is addressed by the lens of Digital Innovation Hub.

This paper is structured as follows: After having reviewed related work and demonstrating the lack of existing DIH for CPS ontology, we will present an innovative ontology for explicitly respecifying competences and organization. This initial ontology is the result of the project DIH4CPS and consists in a dedicated deliverable called D3.3 in the following of the paper. Then, this initial ontology will be extended with a network ontological extension and with a CPS ontological extension. Finally, the complete ontology will be validated by means of inferences in the context of a real case study and we will conclude the paper and propose future work.

RELATED WORKS

While Cyber-Physical Systems have existed for a few decades, scientific contributions directly addressing the inter-relation between physical and cybernetic knowledge entities dates from twenty years with an acceleration in the volume of publications since 2018. This includes but is not limited to CPS for a plethora of areas to generate a common language and structured framework for the digital innovation hub such as for the traffic light and mobility (Shih et al., 2016), facilities management tools like door opening and conditioning systems (Terreno et al., 2020), robotics and healthcare cyber-robots (Yang et al., 2020; Zhang et al., 2015), mobility and self-driving cars (Kim et al., 2013), telecommunication (Kim et al., 2017), and SME (Crupi et al., 2020). Accordingly, and as it is usual to do in the academic field, many authors have produced state-of-the-art advancements in this field. Some of these are strong and well documented, including: Kim et al. (2017), which analysed CPS through two criteria: CPS's characteristics and architectures; Kumar et al. (2020), which stresses how attacks on cyber-physical systems (CPS) continue to grow in frequency and, accordingly, identifies a set of relevant research opportunities; and Sun et al. (2018), which specifically focuses on CPS security and service portfolio (Asplund et al., 2021) and describes future research directions to secure critical CPS (Blangenois et al., 2013, and Feltus et al., 2022).

Although there is an impressive number of existing publications dealing with CPS, little research so far has focused on the modelling of the CPS system, which is paramount to understanding the underlying structure and communication mechanisms between the cyber-physical systems sub-components. In that regards, Weyer et al. (2016) propose a framework for modelling and simulation of CPS-based factories and applied it to the automotive industry that the authors consider as the most competitive, advanced, and complex industrial sector; Jeon et al. (2012) developed a CPS dedicated Meta Modeler (CMM) allowing to design complex and large scale systems; and Yu et al. (2011) proposed (1) a method to model and analyse CPS using a hierarchical and compositional modelling approach contributing to solve the tight coupling between physical and cyber world and (2) basic transformation rules to translate the CPS model into the networks of timed automata. Apart from these few contributions (Yu et al., 2011; Jeon et al., 2012; Weyer et al., 2016,) and some other less significant studies, modelling CPS remains a rather marginal area of research (Zamiri et al., 2021).

Modelling is a powerful tool that provides a picture of the CPS and its environment. The project DIH4CPS goes one step further and proposes the elaboration of an ontologically structured knowledge base allowing reasoning based on CPS entities to represent effective communication, collaboration, and coordination among stakeholders. Although CPS ontologies (Petnga & Austin, 2016; Xu & Kosaka, 2017; Hildebrandt et al., 2018) have already been proposed in the literature as well, the ontology proposed in this paper proposes to enrol a CPS ontology in the context of Digital Innovation Hubs competences and networking environment. To our knowledge, only some initial work on this integration has been achieved so far in Nicolas et al. (2023).

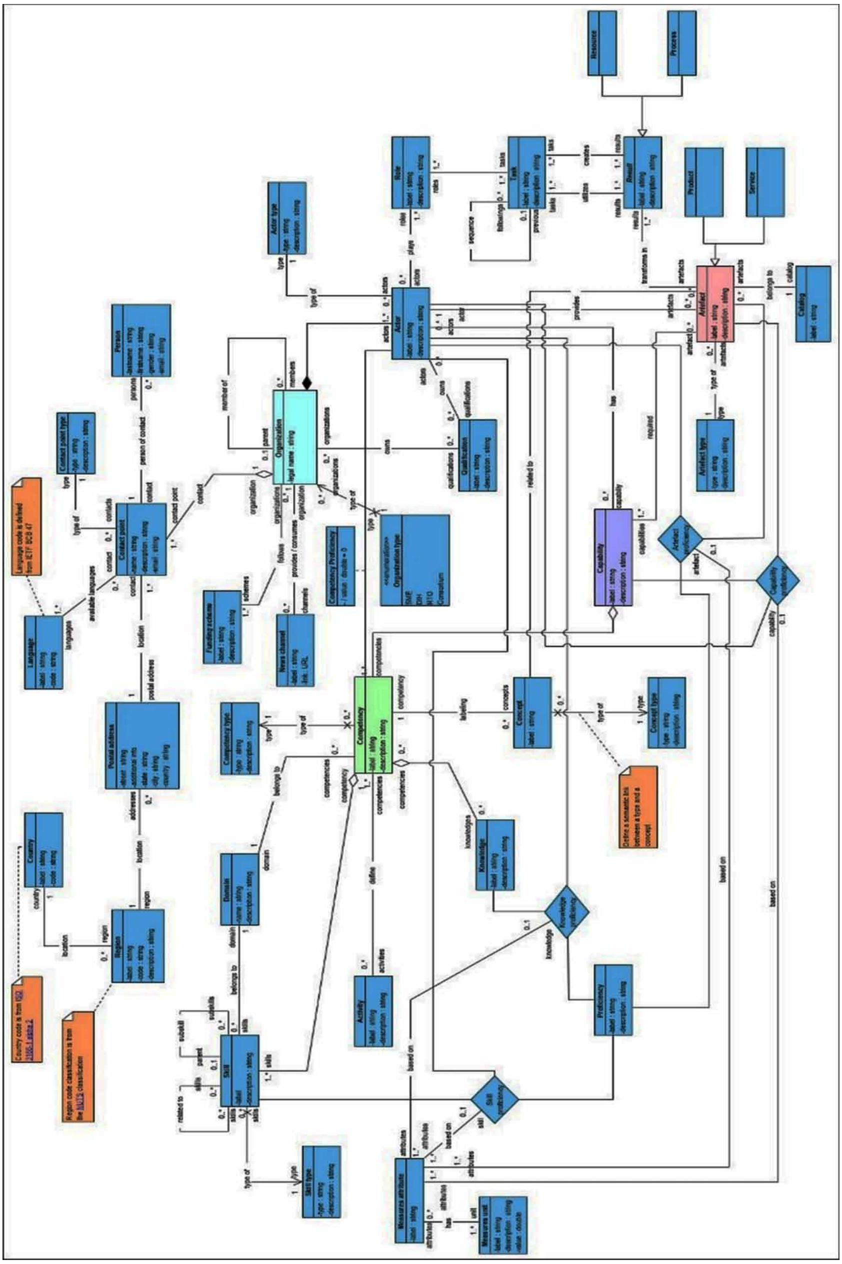
GENERIC ONTOLOGY

The ontology first reviews the Digital Innovation Hub, then it extends it to the network dimension and to the CPS dimension.

Digital Innovation Hub Ontology

The DIH ontology that we extend to the CPS has been proposed in deliverable 3.3b of the DIH4CPS project. The global UML model of this DIH4CPS ontology is represented on Figure 1 and further details are available in D3.3a and b[2].

Figure 1. Integrated network ontology extension



Extension to the Network Dimension

To define the generic network ontology extension, we first had to determine and select the most appropriate method for ontology development. The review of the literature proposes therefore various approaches among which: Ushold and King (1995), Grüninger and Fox (1995), Ushold and King (1996), but also Methontology (Fernández-López et al., 1997), KACTUS (Schreiber et al., 1995), SENSUS (Swartout et al., 1996), the Cyc Method (Fernández-López et al., 2002), On-To-Knowledge (Pan-European network of Digital Innovation Hubs (DIHs), 2016), ISO15504-based approach (Feltus & Rifaut (2007), Rifaut and Feltus (2006) and NeOn methodology (Terreno et al., 2020; Rüßmann, 2015). For the CPS ontology, we have decided to work with the methodology proposed by Noy and McGuinness (2001). According to Noy and McGuinness method, the development of an ontology requires the following steps:

1. Determine the domain and scope of the ontology.
2. Consider reusing existing ontologies.
3. Enumerate important terms.
4. Define the classes & class hierarchy.
5. Define the properties of classes.
6. Define the facets of the slots.
7. Create instances.

Determine the Domain and Scope of the Network Ontology Extension

This section aims to determine what the ontology is going to cover, for which purpose, and especially who will maintain and use this ontology. According to Noy and McGuinness (2001), one method to determine this domain and scope is to enumerate a list of question that the ontology must be able to answer afterwards. This list of question has been iteratively determined through working groups meeting. Examples of these questions are: Which recent sectorial newsfeeds, surveys, or trend reports are available in the network? Who is the contact point for a certain Network Service (Gâteau et al., 2009) or Social Service System (Meng et al., 2016)? Are there large industry partners looking for collaborations? Who is willing to join an existing consortium for project collaboration on a certain domain/call? What are the network's objectives (e.g., privacy [Feltus et al., 2017]) or security-driven (Mayer et al., 2019) knowledge inferences)? Which types of services does the network provides? Is the network public or private?

Consider Reusing Existing Ontologies

Reusing existing ontologies is a step that has been achieved in preamble to the methodology. See the section "Digital Innovation Hub Ontology," which presented the DIH ontology used as an initial ontology to be extended with a network and CPS ontologies.

Enumerate Important Terms

The enumeration of the important terms, and their definition is summarised in Table 1.

Based on these definitions and explanations, the above concepts have been gathered in an integrated ontology as represented in Figure 2.

Define the Classes and Class Hierarchy

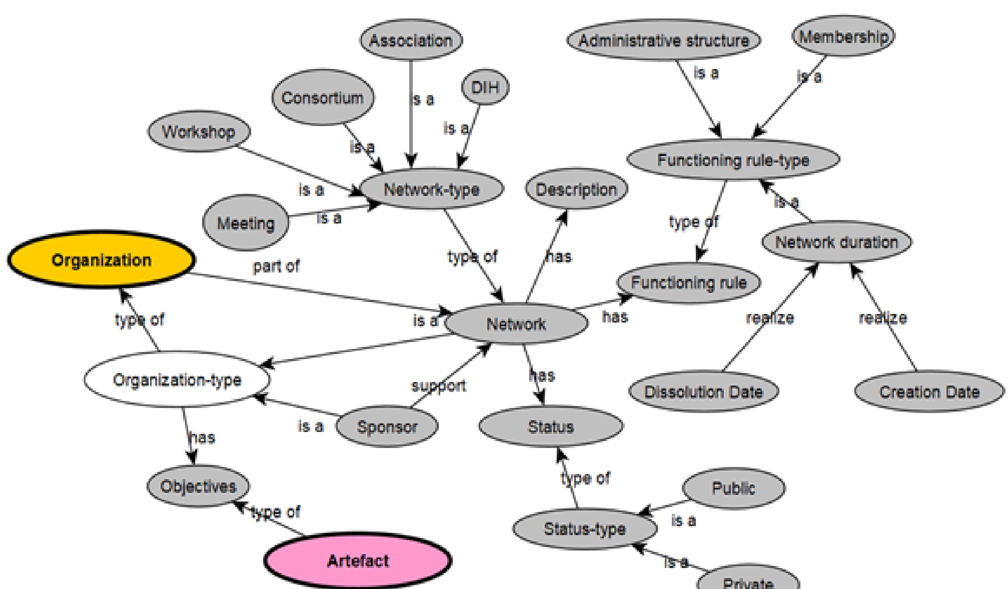
Based on the important concepts enumerated in Table 1, the list of class and class hierarchy is as follows:

- Organization and Network are type of Class and Organization is part of Network.
- DIH, Association, Consortium, Meeting, Workshop is a Network-type.
- Network has Functioning rule.

Table 1. Network terms

Concepts	Definition - Explanation
Network	The network is a type of organisation with specific objectives, functioning rules, status, and type.
Network type	A network type corresponds to the characteristic of the network. It may be, e.g., an association, a consortium, a meeting, a workshop or a DIH.
Objective	A network exists to fulfil an objective. This objective may be for instance, to offer a new type of service and value (Xu & Kosaka, 2017), to make decision on emergency situations (Blangenois et al., 2013), to exchange parties on a business sector, to submit a proposal for a call for tender, etc.
Functioning rule	The network behaves following official or informal rules that defines the duration of the network (when it starts, when it stops), the membership rules, the administrative structure, etc.
Administrative structure	The administrative structure of a network represents the way it is organised, the way decisions are made (e.g., multiple attribute decision making (Guo et al., 2015), the agenda, the hierarchy, the organisation.
Membership	The membership of a network defines the conditions under which an organisation is part of a network. This may be after the payment of a contribution, signing an agreement, or simply by joining voluntary a team.
Network duration	The network is supposed not to be definitive and to be a temporal structure with a duration fix or depending on an objective. For instance, a project consortium exists until the end of the project.
Status	The status of a network represents a regulation that could intrinsically apply to the network. E.g., public, or private network.
Sponsor	A person or organization that supports a thing through a pledge, promise, or financial contribution. E.g., a sponsor of a Medical Study or a corporate sponsor of an event.
Description	A description of the item.
Creation date	The date that this organization was created.
Dissolution Date	The date that this organization was dissolved.

Figure 2. Integrated network ontology extension



- Administrative structure, Membership, Network duration is a Functioning rule-type.
- Network has a Status.
- Public and Private is a Status type.
- Network is an Organization type.
- Network has Objectives.
- Network is member of network.
- Network has Description.
- Sponsor supports Network.
- Creation date realizes Duration.
- Dissolution date realizes Duration.
- Artifact is an Objective.
- Sponsor is an Organization type.

The class Organization and Organization-type already existed in D3.3b. In this paper we have linked these classes with the Network class as explained in point 1. Moreover, given that an Organization is member of Organization, no new association has been added to realize point 9. Finally, rather than associating the network with objectives, we have completed D3.3b with the Objective class and we have associated this class to the Organization with an association of a type "Organization has Objectives." This allows for associating the network with objectives afterward, as requested in point 8.

Define the Properties of Classes

According to Noy and McGuinness (2001), the classes defined above do not contain enough information to fully and correctly answer all the questions listed above. Therefore, in this section, the methodology aims to describe the internal structure of each concept. This step is important and has already partially been achieved in previous section. For instance, the structure of the Network concept has been explained based on the Network-type, the functioning rule and Status, and the relation with the Organization. It will not be further extended here.

Define the Facets of the Slots

Following Noy and McGuinness (2001), the cardinality defines, among others, the cardinalities and values a class may have. Accordingly, in this section, we will focus on defining the classes and associations cardinalities, as explained in Table 2.

Create Instances

This last step in the methodology will be addressed in the "Operational Ontology" section below.

Extension to the CPS Dimension

Methodological Approach

This section will extend the ontology with entities aiming at representing the cyber-physical systems (CPS). Therefore, we used the same method (from Noy and McGuinness) as proposed above. However, to keep the deliverable efficient, we only focus on the presentation of the results.

To extend the ontology to CPS, we have reviewed the state of the art in CPS ontologies, we have extracted the most important concepts, and we have proposed our own integrated model. Nine additional entities have been added to the DIH4CPS ontology to express that a CPS is a type of product, itself being a type of artefact. This CPS extension claims that CPS are composed of a Cyber Process entity, which is a type of Process and of a Physical Resource entity, which is a type of Resource (Imeri et al., 2018). According to Bertoli et al. (2021), the key characteristics of a CPS are the Sensors, the Actuators, and the HMI for the Physical part, and the Computing, The Software

Table 2. Network cardinalities

Cardinality	Concepts	Association	Cardinality	Concepts
1	DIH, Association, Consortium, Meeting, Workshop	**Is a**	1	Network
1	Networks	**Has**	1 to n	Functioning rules
1	Administrative structure, Membership, Network duration	**Is a**	1	Functioning rules
1	Networks	**Has**	1 to n	Status
1	Networks	**Is a**	1	Organization-type
1	Networks	**Has**	1 to n	Objectives
1	Networks	**Is member of**	0 to n	Network
1	Functioning rule-type	**Type of**	0 to n	Functioning rule
1	Network-type	**Type of**	0 to n	Network
1	Status-type	**Type of**	0 to n	Status
1	Network	**Has**	0 to n	Description
1	Creation date	**Realizes**	1	Duration
1	Dissolution date	**Realizes**	1	Duration
1	Sponsor	**Support**	1 to n	Network
1	Sponsor	**Is a**	1	Organization-type
1	Artefact	**Type of**	0 to n	Objective

Communication and the Data storing and analytics for the Cyber part (Feltus, 2022), as represented in Figure 3 (extracted from Bertoli et al., 2021).

Determine the Domain and Scope of the CPS Ontology Extension

Accordingly, the objective of extending D3.3b's Abstract entity with a CPS is to provide a theoretical framework for answering the more technical and component-related questions, including but not limited to: Who can give me advice on CPS technology applications? Who can give advice for a specific technology? Which university can offer IT support? Which technologies use organization A for data storage? Who has experience on sensor sensitivity and calibration? Who has expertise in working with Augmented Reality?

The concepts listed in Table 3 constitute our CPS extension of the Artefact entity.

Based on these definitions and explanations, the above concepts have been gathered in an integrated ontology as represented in Figure 4.

Define the Classes and Class Hierarchy

Based on the important concepts enumerated in Table 3, the list of classes and class hierarchies is as follows:

- CPS are types of Product.
- Physical Resource and Cyber Process compose the CPS.
- Sensor, Actuator and HMI are types of Physical Resource.
- Data Storage and Analytic, Communication and Computing are types of Cyber Process.
- Physical Resource are types of Resource.
- Cyber Process are types of Process.

Figure 3. Key CPS characteristics according to Bertoli et al. (2021)

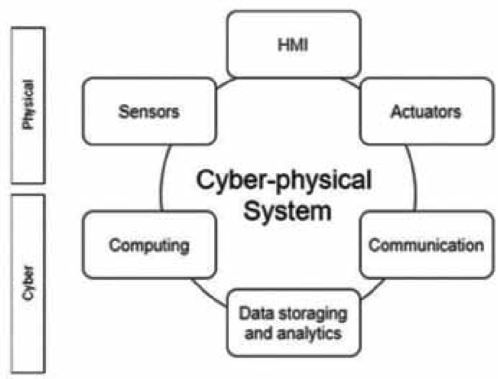


Table 3. CPS terms

Concepts	Definition - Explanation
CPS	Cyber-physical systems are the key technology enabling Industry 4.0 and can be applied on different levels in the modern value chain (Bertoli et al., 2021). According to the University of Yichita,[3] CPS are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components.
Cyber Process	According to Guo (2017), a cyber process system is a huge system with mass components and complex communication protocol
Physical Resources	The Physical Resource system corresponds to the integration of the physical components or mechanical parts of the CPS
Software Communication	The exchange of messages between end-devices and a central network
Computing	The realisation of a set of algorithms having an impact on the state and behaviour of the physical system
Data storing and analytics	The activity of analysing, holding, deleting, backing up organizing, and securing information to be compute to the purpose of the CPS
Sensors	A physical device that detects information form inputs from the physical environment and generates the expected responses
Actuators	A physical device that achieves physical behaviour in response to a cyber or physical order or command
HMI	The hardware or software through which an operator interacts with a controller[4]

Define the Facets of the Slots

Finally, according to Noy and McGuinness (2001), the cardinality defines, among others, the cardinalities and values a class may have. Accordingly, in this section, we will focus on defining the classes and associations cardinalities, as explained in Table 4.

The complete ontology, extended with the network and CPS extension is presented on Figure 5. This figure is depicted using a code of colours summarized as follow:

- **Blue:** Capacity class.
- **Green:** Competence related classes.
- **Pink:** Artefact related classes.
- **Orange:** Organization related classes.
- **White:** Classes relevant for more than one domain.

Figure 4. Integrated CPS ontology extension

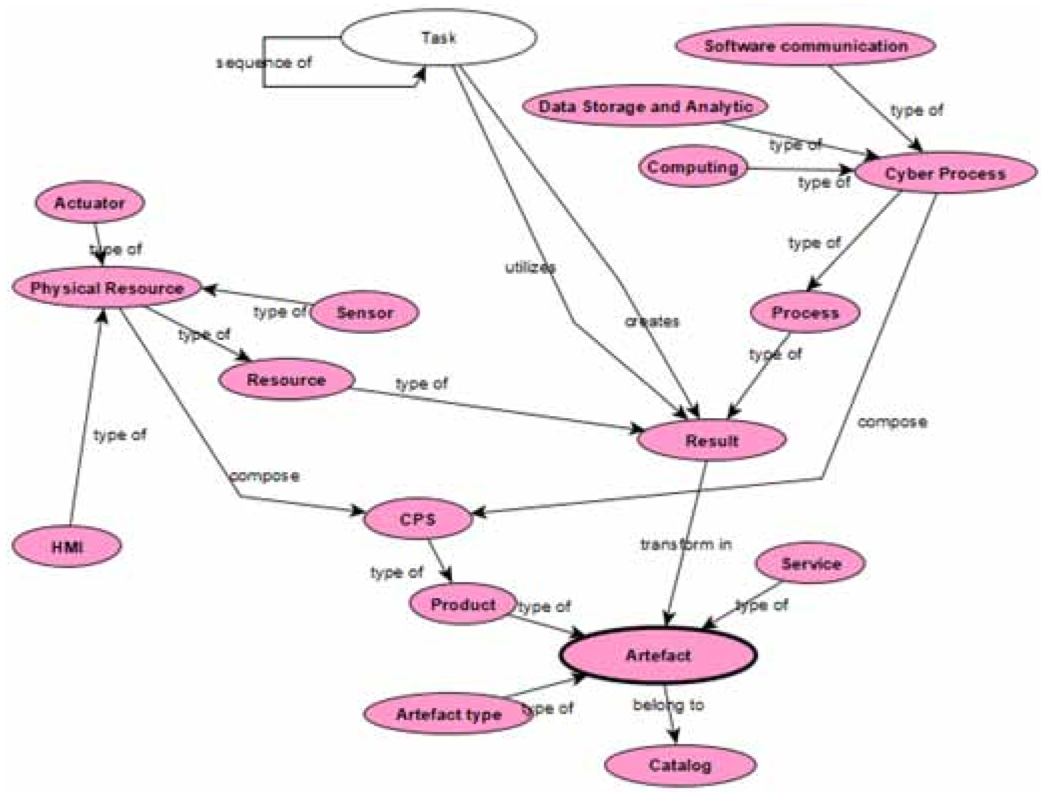


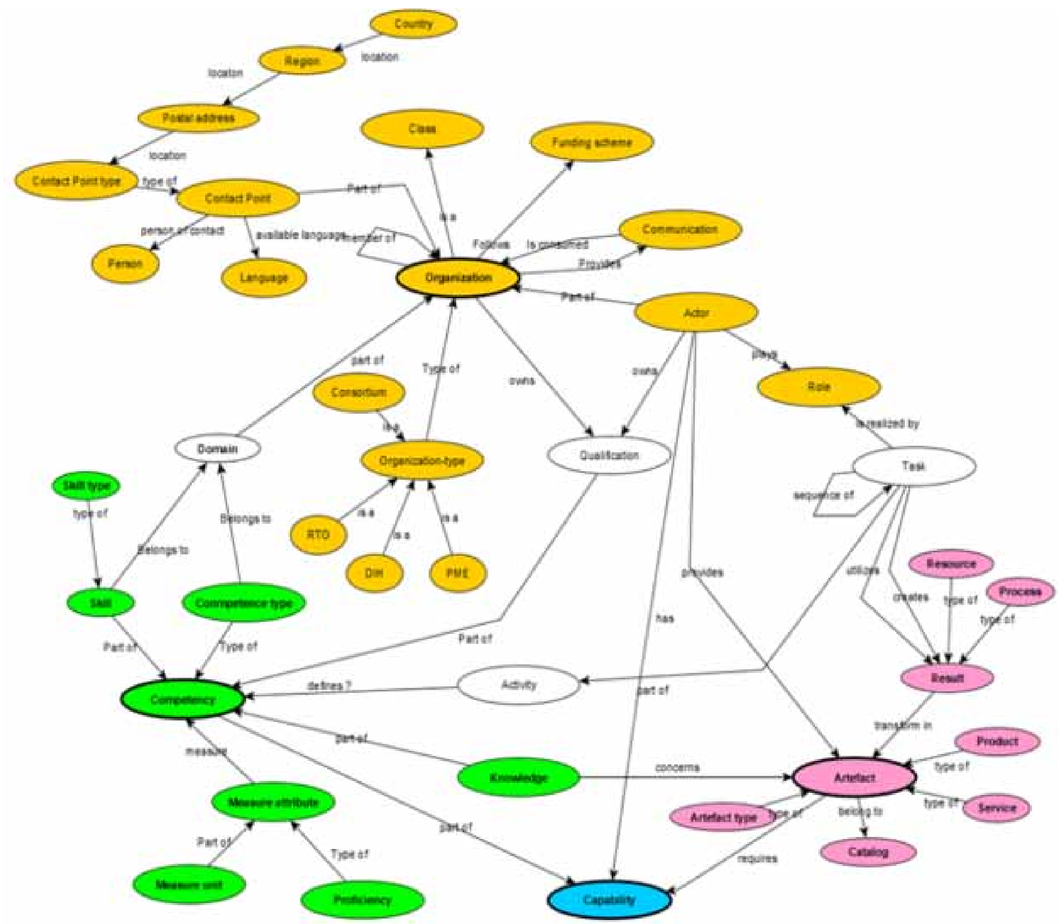
Table 4. CPS cardinalities

Cardinality	Concepts	Association	Cardinality	Concepts
1	CPS	**Type of**	1	Product
1	Actuator, Sensor, HMI	**Type of**	1	Physical Resource
1	Data Storage and Analytic, Communication, Computing	**Type of**	1	Cyber Process
1	Physical Resource	**Type of**	1	Resource
1	Cyber Process	**Type of**	1	Process
1	Physical Resource	**Compose**	0 to n	CPS
1	Cyber Process	**Compose**	0 to n	CPS

OPERATIONAL ONTOLOGY

The instantiation of the ontology for the one concrete company is realized with the tool Protégé, and the Luxembourg Institute for Science and Technology was chosen to test the instantiation of the DIH4CPS ontology because it covers a large set of services, competencies, domains, and skills.

Figure 5. Integrated CPS ontology extension



Implementation in Protégé

According to Stanford University,[5] Protégé is a "free, open-source ontology editor and framework for building intelligent systems"; moreover, "Protégé is supported by a strong community of academic, government, and corporate users, who use Protégé to build knowledge-based solutions in areas as diverse as biomedicine, e-commerce, and organizational modelling." Using Protégé to support the exploitation of the DIH4CPS ontology, first, the 67 classes have been encoded in Protégé (Figure 6).

Then, 49 object properties have been encoded (Figure 7).

Protégé, the relations between classes must be defined as object properties. For instance, as illustrated on Figure 7, the association name "is located" that associates the class "Region" and the class "Country" is the property named "isLocatedInCountry" and this property has for Domains: "Country", and for Ranges: "Region". Given that all associations with a same name (e.g., "is located") have different Domains and Ranges, we must create as many associations as there exist cases. Therefore, for the "is located," we have three different properties: "isLocatedInCountry," "isLocatedIn- PostalAddress," and "isLocatedInRegion" (see Figure 8).

Figure 6. Example of DIH4CPS classes implemented in Protégé

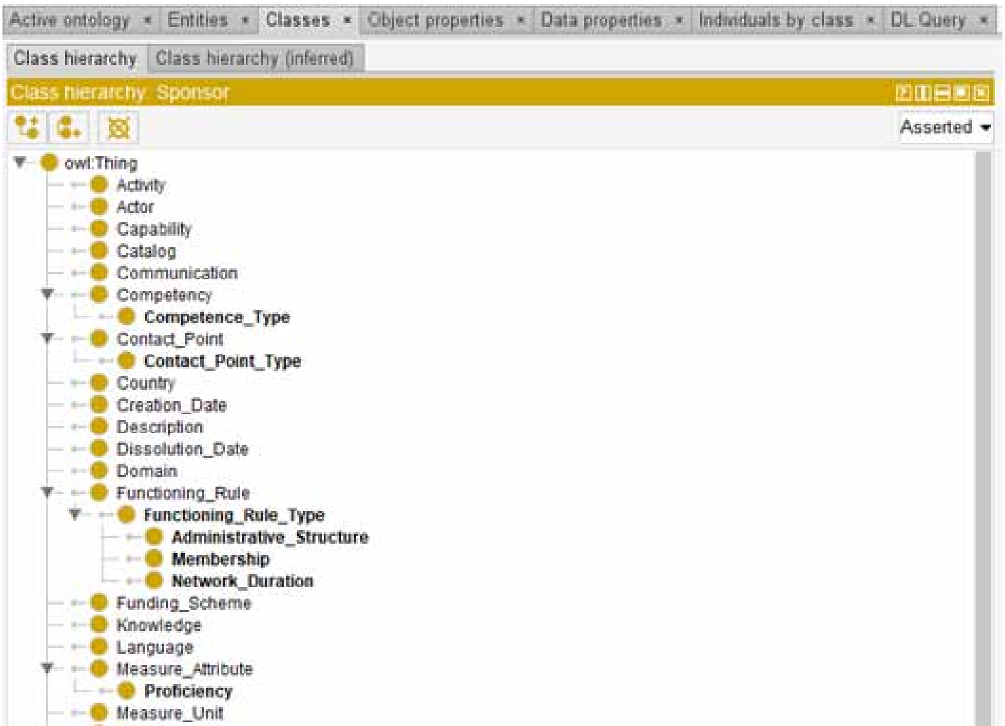
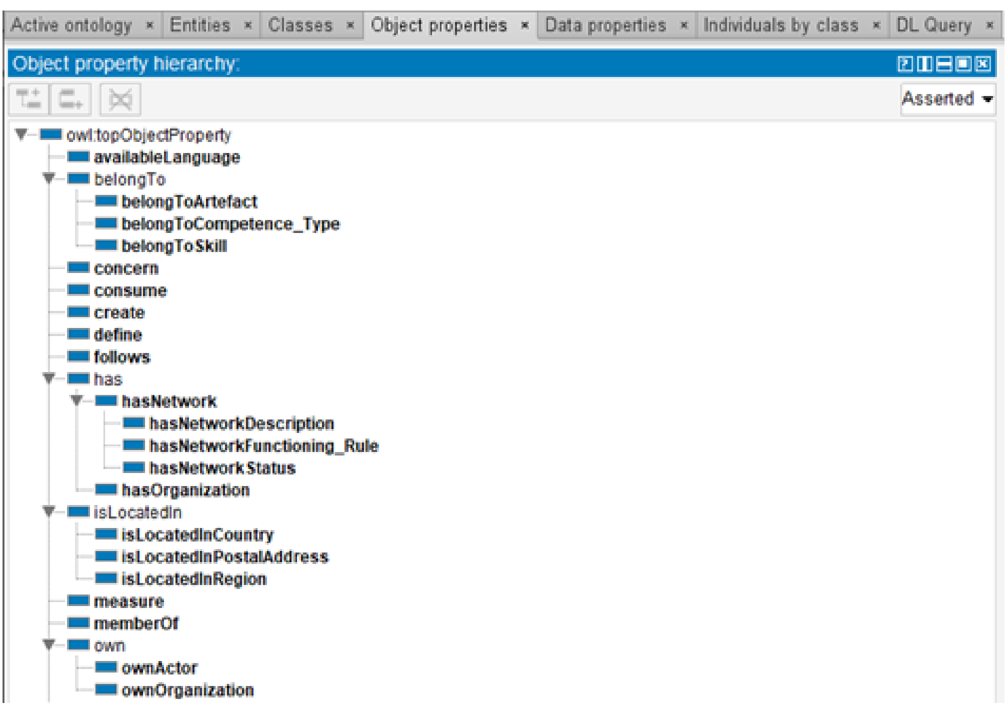


Figure 7. Example of class properties (relations) encoded in Protégé



Business Case Validation Using Inferences

Business Case Validation using Inferences is a way to validate and evaluate the integration of two ontologies by leveraging the power of logical reasoning and inference. When integrating two ontologies, it is essential to ensure that the merged ontology produces accurate and meaningful results. In this context, Business Case Validation refers to assessing the integration's value and suitability in addressing specific business objectives or requirements. Using inferences enables the detection of any inconsistencies, contradictions, or gaps that might arise during the integration process. By applying reasoning mechanisms, such as rule-based reasoning, the integrated ontology can be examined for any logical errors or conflicts. Furthermore, inferences help in validating the integrity of the integrated ontology by inferring new knowledge or conclusions based on the combined concepts and relationships. This allows for the evaluation of the ontology's ability to generate accurate and meaningful insights.

Concretely, to validate the ontology and to illustrate how it is possible to use it to infer new knowledge, we illustrate how an instance of the PME concept may also be an instance of an RTO using the inference mechanism. To do so, first we have created the individuals (instance of concepts) and data properties of these individuals, then created rules, launched the reasoning, and finally analysed the new created knowledge base.

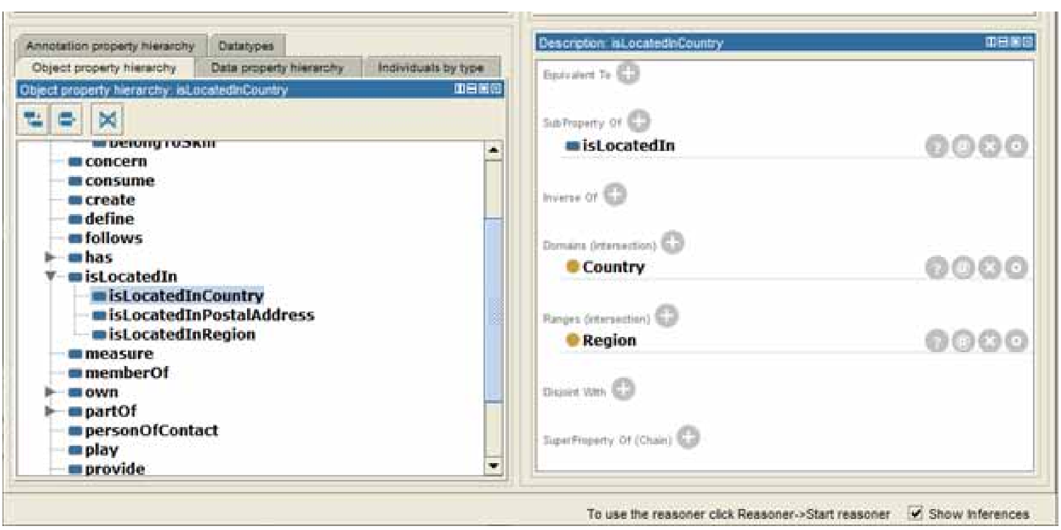
Creation of Individuals

The creation of a new individual consists of defining a new direct instance of a class. For instance, we created an instance of the class PME by selecting the targeted class concept on the top left frame and pushing the mauve lozenge in the bottom left frame.

After the individual is created, it is possible to assign it with Data properties. Data properties need to be defined before being assigned. Therefore, in Protégé's Data property frame, we have defined 3 instances:

- **makesResearch:** Which is a property that may be assigned to a PME or an RTO, and which is a type of Boolean (True or False).
- **isPublic:** Which is a property that may also be assigned to a PME or an RTO, and which is a type of Boolean (True or False).
- **hasEmplosees:** Which is a property that may also be assigned to a PME or an RTO, and which is a type of integer.

Figure 8. Example of property



Finally, these data properties may be asserted to created individuals. For example, we have asserted that LIST makes research, is public, and has 750 employees.

Creation of Rules

The second step to create inference consists of generating inferring rules. There exist various options. In this paper, we have decided to express an "Equivale To" rule in the description of the RTO class. This rule, illustrated on Figure 8, shows that an RTO is equivalent to a class with the following characteristics: it is an individual of a class "PME" and its data properties include having more than 500 employees, being public, and making research. As illustrated on Figure 8, this is expressed by:

PME and (hasEmploees some xsd:integer[>=500]
and (isPublic value true) and (makesResearch value true)

Reasoning

Reasoning can be employed with the DIH4CPS ontology for many reasons, such as ensuring the consistency of the ontology by identifying and resolving any contradictions or conflicts within the defined concepts, relationships, and properties. This helps maintain the integrity and reliability of the ontology, avoiding potential issues in communication and collaboration. Reasoning mechanisms can also be utilized to answer complex queries based on the defined concepts and relationships. This enables stakeholders to retrieve relevant information and insights from the ontology, facilitating decision-making and problem-solving within the digital innovation hub. Concerning this decision making, reasoning allows providing decision support by evaluating different options or scenarios based on the ontology's defined concepts and relationships. By applying logical rules and constraints, reasoning can assist stakeholders in making informed decisions regarding the promotion, strengthening, cooperation, and co-development of CPS networks within the hub. In this work, reasoning is used to infer and deduce knowledge based on the logical relationships and rules defined in the ontology. This allows for deriving new knowledge or making logical conclusions from the existing information. It can help discover implicit connections, patterns, and dependencies within the hub, aiding in the identification of innovative opportunities and potential collaborations.

Accordingly, the last step in inferring new knowledge from the ontology consists of launching the reasoner. Before doing so, we observe that the RTO has not LIST individual as direct instance although LIST is an individual of PME. To launch the reasoning, it is necessary to run a reasoner from the top menu of Protégé. In our case, we have worked with Pellet inference engine (reasoner).

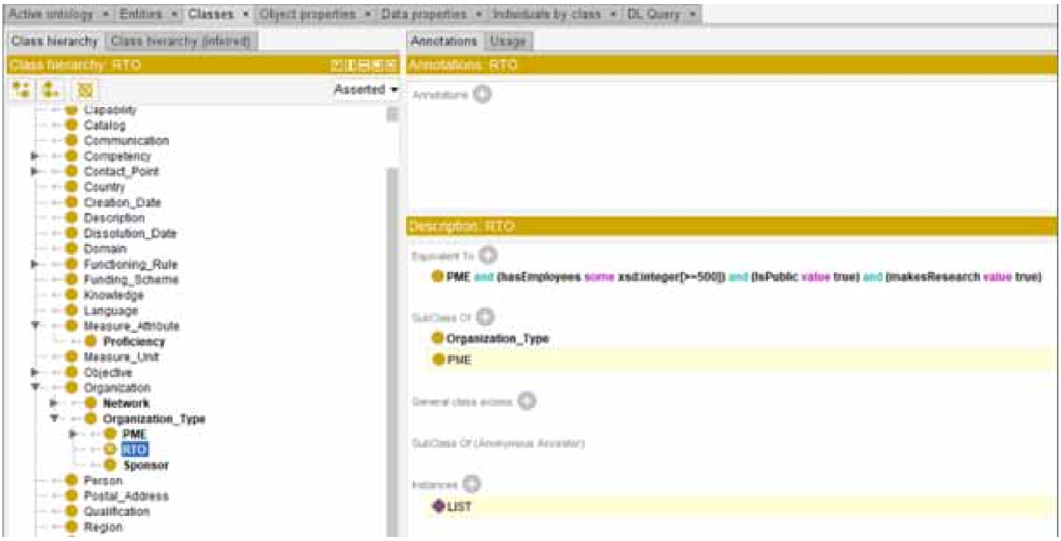
New Knowledge Base

After this reasoning, new inferences are automatically detected and add to the existing knowledge base. For instance, in the case of LIST, Pellet has detected and a PME may also be considered as a subclass of RTO and that LIST fulfils the 3 conditions to be an RTO to know: to be public, to make research and to employ more than 500 employees. As illustrated on Figure 9, the newly inferred knowledge is highlighted in light yellow.

CONCLUSION AND FUTURE WORKS

This paper describes, as main result, the first part of the DIH4CPS ontology presented in D3.3, including its two dimensions, to know: competence and organization. In the second part we have developed the third area of the DIH4CPS ontology dedicated to networking. Therefore, we have reviewed the questions the ontology is required to answer, we have developed the methodology proposed by Noy and McGuinness (2001) to identify the class and their associations, and we have integrated this networking area with the competence and organizational areas. Then, we have extended

Figure 9. Example with inference



the Artefact Ontology with a CPS description using the same methodology than for defining the network one. Finally, we have encoded the full DIH4CPS ontology within Protégé, we have instantiated it to a real company case (to know: the Luxembourg Institute of Science and Technology), and we have validated its usability by means of inferences. Business Case Validation using inferences provides a rigorous approach to assess the integration of two ontologies. By leveraging logical reasoning and inference, it enables us to validate the integrated ontology's consistency, coherence, and relevance to specific business needs. This validation process ensured that the integration is reliable, accurate, and aligns with the desired objectives.

Concerning the maintenance of the ontology, reasoning mechanisms can assist in the evolution and adaptation of the ontology over time. By analysing changes in the digital innovation hub or new requirements, reasoning can help identify necessary modifications to the ontology, ensuring its relevance and effectiveness in capturing the evolving dynamics of CPS networks and the hub itself.

Based on the outcomes of this instantiation, updates on the DIH4CPS model could be foreseen if needed following by the instantiation of all the DIH4CPS network. This paper could also be used as a baseline for the development team of the DIH4CPS platform and for further use cases with other companies and considering other technologies like the blockchain (Imeri et al., 2018).

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ENDNOTES

1. A Cyber-Physical System (CPS) is, according to Wikipedia, a computer system in which a mechanism is controlled or monitored by computer-based algorithms.
2. All DIH4CPS deliverables are available at https://dih4cps.eu/
3. https://www.wichita.edu/research/netcpsreu/CPS.php
4. https://csrc.nist.gov/glossary/term/human_machine_interface
5. https://protege.stanford.edu/

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