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COLLABORATION IN SUPPLY CHAINS FOR DEVELOPMENT OF CPS ENABLED BY SEMANTIC WEB TECHNOLOGIES

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ABSTRACT

The development of Industrial Cyber-Physical Systems (ICPS) requires new ways of collaboration between ICPS vendors and companies which provide them with parts and components. As ICPS extend existing systems, e.g. machines or healthcare equipment, by electronic components, new supply chains will evolve between companies which were not connected before. Hence, traditional methods for collaboration will not fit for them anymore. We propose a new approach for collaborations in ICPS development. It relies on technologies from the Semantic Web and consists of a web platform where ICPS vendors and vendors of electrical, electronical, information and communication technology components can virtually meet. Component vendors can describe their products, ICPS element vendors their product ideas and requirements. To match requirements and offers, semantic descriptions of both are necessary. Then, matching of requirements and offers will be realized by semantic reasoners. They have to find RDF graph chains which link requirement and offer descriptions.

1 INTRODUCTION

The digital transformation of EU business and society presents enormous growth potential for Europe. European industry can build on its strengths in advanced digital technologies and its strong presence in traditional sectors to seize the range of opportunities offered by technologies such as the Internet of Things, Big Data, advanced manufacturing, blockchain technologies and artificial intelligence.

Digital transformation is characterized by a fusion of advanced technologies and the integration of physical and digital systems, the predominance of innovative business models and new processes, and the creation of smart products and services (European Commission 2017).

This will lead to the massive use of Industrial Cyber-Physical Systems (ICPS) in industrial production, logistics and services. This requires that ICPS elements are designed, produced and offered. These ICPS elements may either be completely new systems or extensions of existing elements of production, logistics and service systems by electrical and electronical sensing, acting and communicating components.

Although many of the components needed for such extensions may already exist as they are used in today's ICT systems, they may be new to vendors of traditional production, logistics and services system elements like machine tools or healthcare equipment. Their developers know neither the components nor their vendors. Hence they do not know about the opportunities already existing components would provide them with to realize new product ideas for ICPS.

Traditional methods for supplier acquisition like RFQs or catalogue search cannot solve this problem since they require knowledge on existing suppliers and their products on a syntactic level (i.e. one needs to know names of potential suppliers, names of product categories or specific products to find matches).

Semantic descriptions can help close this gap. We propose the concept of an open online collaboration platform (OOCP) on which ICPS product vendors and component suppliers can meet virtually. There, product vendors can describe their product ideas and concepts with their requirements to components, and component suppliers their components with their features, respectively. The platform system is then intended to find matches between requirements and offers. To enable this, a first requirement is that all descriptions have to be given in a unique description language and on a semantic level. This could be achieved by using the semantic web technology stack (W3C 2012; 2017b). The challenge is then to automatically find links between the graphs with requirements and the graphs with component offers . For this, semantic web reasoners will be used. Such reasoners are already successfully used in b2c environments to match private customer demands and product offers. The approach will be adapted to the creation of ICPS product development.

We will outline a concept for an open online collaboration platform which contains all of these elements and will thus help to accelerate the development of ICPS systems.

The remainder of this paper is structured as follows: In chapter 2 we present the context of this work in terms of research projects and initiatives and related work in the fields of Semantic Web technologies, collaboration platforms and blockchain technology. In chapter 3 we introduce our collaboration platform concept with its building blocks. In chapter 4 we give two sample use cases for the platform, and with chapter 5 we conclude and give an outlook on future research.

2 CONTEXT AND RELATED WORK

2.1 European Projects and Initiatives

Digitalization of production, services, business and society is a main topic all over the world. Europe can build on its strength in production and manufacturing in traditional and modern industries like automotive, machine making, electrics and electronics. However, compared to other regions digitalization is adopted slowly by the European companies, despite large initiatives and associations like Industrial Data Space and Platform Industry 4.0.

The European co-founded innovation and lighthouse program Productive 4.0 (Figure 1) aims to create a user platform across value chains and industries, thus promoting the digital networking of manufacturing companies, production machines and products. The participating partners will examine methods, concepts, and technologies for a service-oriented architecture as well as for components and infrastructure in the Internet of Things. The main objective of Productive 4.0 is to achieve an improvement of digitizing the European industry by electronics and ICT. Structured into nine work packages, more than 100 partner institutions work together towards this goal (http://productive40.eu). This paper provides a part of WP7, an exploitation platform concept.

2.2 Semantic Web Technologies

The concept of the Semantic Web was introduced by Tim Berners-Lee in 2001 (Berners-Lee et al. 2001; Shadbolt et al. 2006). The aim is to provide Web contents not only in human-readable form as in the traditional WWW, but also in machine-readable form. That is, IT systems should be enabled to process information from web sites and other data resources in order to recognize relationships and dependencies between pieces of data, make implicit knowledge explicit and link data from different data resources effectively. This requires a semantic annotation of the content of the Web.

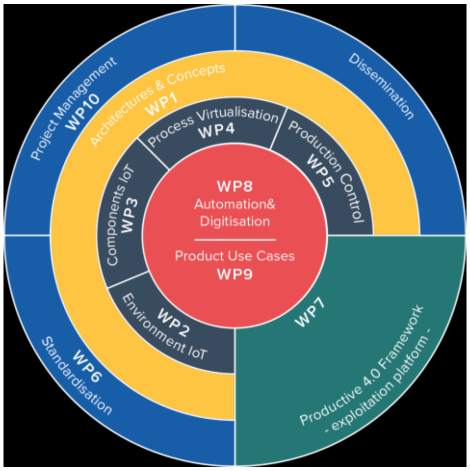

Figure 1: Work Packages of Productive 4.0.

Initially, these annotations were realized by extensions of traditional HTML and XHTML languages in which semantic statements could be embedded, e.g. by means of RDFa. Google used RDFa statements in web sites, stored and analyzed them to improve the search results. Later, algorithms emerged which were able to analyze traditional web sites and automatically annotate them with semantic information. Specific servers in the web stored this semantic information separately from the original pages. DBpedia, for example, is the server that stores the semantic counterparts of all Wikipedia sites. As DBpedia allows open access to its data base, it is one of the most prominent servers in the so called Linked Open Data (LOD) cloud.

One of the first widely recognized applications of this development was IBM Watson, a software program that has won the popular Australian quiz show Jeopardy in 2011 (Markoff 2011). Watson implements natural language processing and information retrieval based on methods and algorithms from the areas of machine learning, semantic knowledge representation, and automatic inference. It makes use of some important technologies of the Semantic Web.

The base model for knowledge representation is the Resource Description Framework (RDF). All knowledge is expressed as triples in the form “Subject Predicate Object”. Subjects are representatives of artefacts of the physical or digital world; predicates express properties of these artefacts. Objects are either again artefacts, or literal data. The corresponding predicates are called object properties (if the property is a relation to an artefact object) and data properties, respectively.

All elements of an RDF triple, except literals, must be represented by Unified Resource Identifiers (URI), which can link them to a unique web resource. These resources may provide more information on the artefact, and at least a worldwide unique identifier is given which can be used to detect occurrences of the same artefact in different data resources.

As RDF triples can be interpreted as nodes and edges between them, a collection of RDF triples is called a RDF graph. Hence, data storage systems containing collections of RDF triples are called RDF triple stores or graph stores. Today, there exist a range of commercial and open source implementations of graph stores, e.g. OpenLink Virtuoso, Complexible StarDoc, Oracle and Apache Jena Fuseki.

From a conceptual point of view, a collection of RDF triples which describes a certain domain of knowledge is called a knowledge base. They store knowledge for the purpose of having automated deductive reasoning applied to them. To enable such reasoning, the knowledge base needs to comprise two different kinds of knowledge: ontologies proper and data about individuals (RDF instance data).

If a knowledge base would only contain unstructured data on individuals, no reasoning would be possible on it. The instance data needs to be structured. This structure will be given by controlled knowledge organization systems such as taxonomies and ontologies. A taxonomy describes a class or concept hierarchy of the domain under consideration. An ontology imposes more structure such as property hierarchies, property characteristics (e.g., transitivity and symmetry), property domain and range, as well as logical rules and constraints. Both for taxonomies and ontologies standardized languages have been established: RDFS for taxonomies and the Web Ontology Language (OWL) for ontologies. Together with the RDF model, the query and update language and protocol SPARQL, and the language for reasoning rules Rule Interchange Format (RIF), they belong to the so called Semantic Web Technology (SWT) stack which is maintained by the World Wide Web Consortium (W3C 2012). Figure 2 shows the layered structure of the technology stack graphically. A comprehensive overview of the technologies is given by Hitzler et al. (2009). A compact summary of the advantages of the use of these technologies is provided by Oracle (2016).

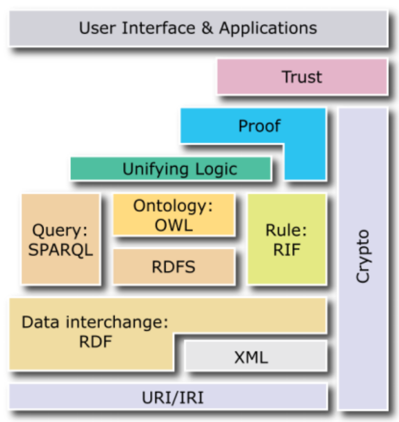

Figure 2: The Semantic Web Technology Stack (W3C 2012).

Meanwhile, approximately 10.000 data sources exist which are freely accessible and form the Linked Open Data (LOD) cloud (Abele and McCrae 2017), which is often seen as synonymous to the Semantic Web. They contain about 150 billion RDF triples.

The main domains of the LOD cloud are publications, government, geography, linguistics, media, social networking, and life sciences. IBM Watson used many of these data sets and combined them to win Jeopardy, as quiz shows typically ask for a combination of knowledge from different domains, e.g. famous people, geography, and publications.

Beyond a pure scientific use, e.g. for literature classification, structuring and research, commercial usages of these data sets are fairly common today. The currently most rapidly growing area in LOD, the life sciences, is driven by medical science but also by pharmaceutical companies trying to optimize the development of new drugs and medicines.

Social networking data is used by large search engine providers, e-commerce companies and advertising agencies. They collect data about the users, derive user classifications and their current demands, link them to product offers and provide it on the user's web browser or smartphone app. Insights into the technologies used in this b2c domain are provided by Beldjoudi et al. (2011) and Cano et al. (2011). Google, Microsoft, Yahoo and Yandex founded Schema.org, a "collaborative, community activity with a mission to create, maintain, and promote schemas for structured data on the Internet, on web pages, in email messages, and beyond" (http://schema.org). They rely on large central graph stores which they fill using web crawlers and extend them by triples they infer by reasoners similar to Watson.

This is possible since all LOD triples existing so far will not fill the capacity limit of large triples stores which is one trillion triples, as reported in (Oracle 2016).

2.3 Industrial Applications of Semantic Web Technologies

While public and b2c applications of Semantic Web and its technologies are widespread today, industrial applications are rare. Taylor reports an application by Mitchell 1, an information service provider for small, universal brand garages in the US. They used SWT to integrate data from different sources at the car manufacturers and provided a unified view on those data sets to the mechanics (Taylor 2015).

Petersen et.al. built a company-wide information model for a large German manufacturing company which uses this for example for the tracking machine tools and for energy consumption monitoring of single production orders (Petersen et al. 2017).

Further single company-internal applications, e.g. for data integration between ERP, PLM, MES and CRM systems may exist but are not published so far.

Meanwhile, many large initiatives on production digitalization, Industrial Internet of Things (IIoT) architectures and frameworks rely on SWT, for example the Industrial Data Space (IDS) which has SWT deeply integrated into his IDS Reference Architecture Model (Otto et al. 2017). SWT are used to model the components, roles etc. of the architecture model itself. More importantly, the architecture model expects data exchange between partners in supply networks to be based on controlled vocabularies. Data providers are expected to describe data sources using generic and domain specific vocabularies offered by a Vocabulary Provider (Otto et al. 2017). As vocabularies are expressed by RDF graphs themselves they can be transferred together with the user data they structure. With this, dynamic data interpretation is possible for the data receiver. While this architecture is innovative and sound, no applications are reported publicly so far.

A further building block for the realization of IIoT based on SWT is provided by the World Wide Web Consortium (W3C) with the ontologies for Semantic Sensor Networks (SSN). Besides the large and highly axiomatic SSN ontology, a smaller, self-contained kernel ontology called Sensor, Observation, Sample, and Actuator (SOSA) ontology, is provided. Both ontologies are intended to support a wide range of applications and use cases, including satellite imagery, large-scale scientific monitoring, industrial and household infrastructures, social sensing, citizen science, observation-driven ontology engineering, and the Web of Things (W3C 2017). As the IIoT will consist of and rely on the data from many sensors, these ontologies are a basis to structure the domain of sensing and sensors. Without a useful und unique semantic structure of this domain, the realization of the IIoT vision is hardly imaginable.

2.4 Collaboration in Product Development

Nowadays, a myriad of collaboration software is offered in the net. They address mainly functions such as file sharing, common editing, chats and message exchange, online project management (e.g. status reporting and monitoring), in some cases translations between CAD formats. I.e., these platforms are intended to support human interaction in development collaborations.

Product and component offers may further be found on supply chain collaboration platforms. The offers are organized as product catalogues, which typically are structured according to a product classification scheme. A search in such a catalogue requires knowledge about the domain and concrete names of products or product categories. Typically, collaboration is offered in separate application areas of these platforms.

In scientific literature, several approaches for development collaboration based on semantics can be found. They address mainly the aspect of knowledge management in product development. However, these concepts are intended to be used within one company (Sriti et al. 2006), or do not consider relationships between product concepts and parts or components that could be used for their production (Assouroko 2014), or start with the process support only when customer and supplier have gotten to know each other (Felic et al. 2014). Approaches which match supplier component offers and vendor product ideas and requirements in the phase before the companies are even in contact, i.e., the awareness phase of the buying process, could not be identified so far. We address this target by our collaboration platform concept.

The success of such a platform requires acceptance and trust. The Productive 4.0 environment provides this by the definition and acceptance of common goals. After the project, the adherence of Intellectual Properties (IP) for product ideas and concepts could be assured by blockchain technology. This means that ideas can always be tracked back to their innovators and that innovations cannot get lost.

3 COLLABORATION PLATFORM CONCEPT

As described above, the process which has to be covered for collaborative product development of ICPS has to start with sales and marketing activities of the component vendors and in parallel with the awareness of ICPS product vendors of the need for electrical, electronical, and IT components. Figure 3 shows this situation for two parallel processes, but also a common main problem: a misalignment of the processes.

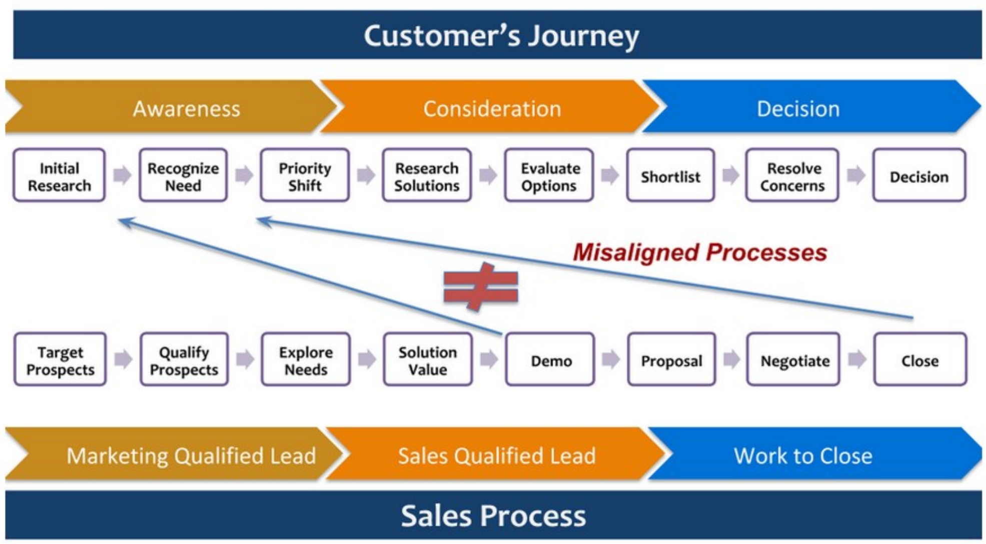

Figure 3: Misaligned sales and buying process (Williams 2017).

Two main reasons for this misalignment are seen in the typical sequential way of work in traditional sales and in keyword based search and response in online search and sales platforms. As leading company in the b2c area for working with customer needs, queries and their processing, Google has published five emerging trends for their work in query processing (Anthony 2015):

1. Implicit Signals
2. Compound Queries
3. Keywords vs. Intends
4. Web Search to Data Search
5. Personal Assistants

These trends obviously need to be transferred to the b2b world of supply chains for development (and later production) of ICPS, but they can be seen as a roadmap for the necessary functionalities of a collaboration platform in their early stages, the sales and marketing stage.

Furthermore, technical concepts are proposed which are intended to overcome the typical sequential work of sales people. Cloud-based platforms should be permanently available and should continuously support the buying and the sales process, as shown in Figure 4.

One important aspect of the user analysis and query processing in b2c is that private internet and smartphone users act in a few typical contexts only, e.g. in a search for food or accommodation, travel planning (short term – search for public transport opportunities or long term – holiday planning), consumer products, or a certain service, e.g. repairs in their apartment. The success of Google and similar companies in recognizing implicit signals and intents of the users is based on a classification of these contexts and the match of typical needs of people in such a context.

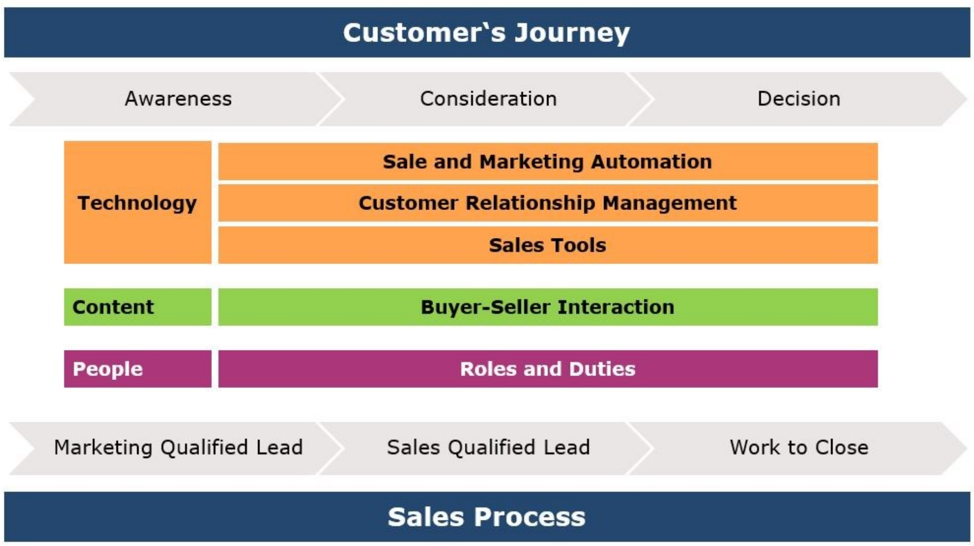

Figure 4: Continuously supported sales and buying processes (Williams 2017).

Compared to the everyday activities and contexts in b2c, development of technical systems like ICPS is a rather rare situation and is conducted by much less people. It cannot be expected that the classification and recognition approaches from b2c will work in this context. Hence, we propose a different approach for the recognition of context and intent: their explicit modeling on a semantic level.

This requires on the one hand the provision of adequate ontologies which guide ICPS developers in the description of their product ideas and concepts by expressing intended product features, functions, and behavior. On the other hand, ICPS developers need to be informed about and trained in semantic technologies.

One ontology that can serve as a blueprint for that purpose is the Semantic Sensor Network (SSN) ontology by the World Wide Web Consortium (W3C 2017), see above. With concepts like System and Platform, ICPS can be described. Their features and functions may be modelled as Sampling, Observation, and Actuation, the context of the systems by FeatureOfInterest and Stimulus.

As shown in the ontology graph of SSN in Figure 5, the system is directly connected to a sensor. Also, a system may consist of several subcomponents which in turn are systems themselves. Also, the relation between a property on the systems level and an ObservableProperty on the Observation level should be noted.

These relations in the ontology can be utilized to map feature and function descriptions of the ICPS developers product idea to components which may help to realize these functions.

This leads to two even more important parts of the platform: the semantic description of the components for ICPS and a reasoning system which is able to match component descriptions with function or feature descriptions of the ICPS product concepts.

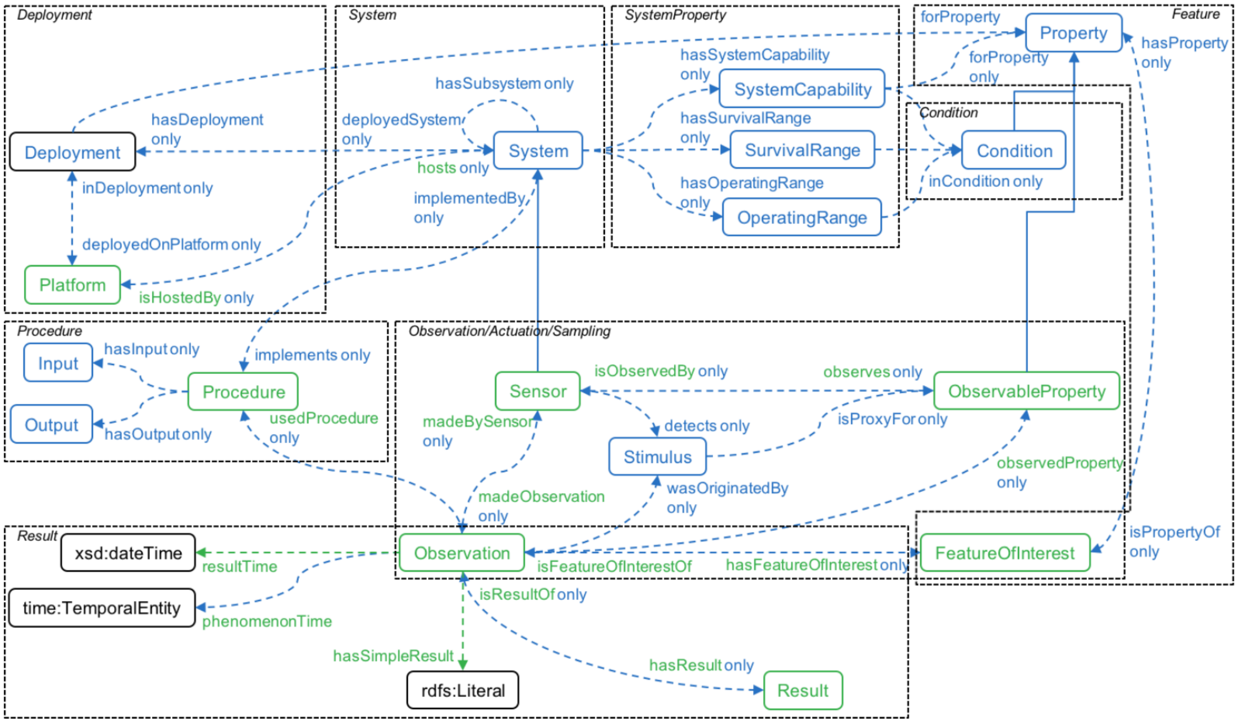

Figure 5: Overview of the SSN classes and properties (W3C 2017a).

The component descriptions will adopt the concept of lists of characteristics for products, as used in master data of ERP systems (DIN 2012). This is necessary to enable the linking between property descriptions. Typical product catalogue approaches which are based on product classifications like eCl@ss (eCl@ss 2017) would not fulfill this requirement since the ICPS ontologies typically do not know which concrete components will be included. The component descriptions are expected to be more detailed and concrete than descriptions in freely accessible catalogues or on web sites, since the collaboration platform is a secured environment. Like today's supply chain collaboration platforms (e.g. SupplyOn, GT Nexus) or open innovation platforms (e.g. Chaordix, Spigit, Nosco, and Qmarkets) they require a registration and logon of users which will later form communities or specific supply chain networks.

The main task of reasoners on knowledge bases is to extract implicit knowledge from the data. The better the knowledge base is structured, the more inferences can be drawn from it. If there is only RDF instance data available, the only type of inference possible is the unification of artefacts with identical URIs. That is, if an artefact occurs in several RDF triples as subject or as object, these triples may be grouped around the artefact and all information which is related to it can be displayed together. Further, RDF chains may be created which link different artefacts in a sequence of occurrences as object in one triple and as subject in another one. With this, artefacts can be related to each other indirectly.

With an RDFS structure in place, stronger inferencing is possible based on class and property hierarchy relations (class – subclass; property – subproperty) and the corresponding inheritance principles. That is, elements of a sub-class inherit all properties of the super class. Further, specifications of property domains and ranges can be used to deduce memberships of artefacts to certain classes. For instance, if a property "senses" has the class "sensor" as domain and the class "observable" as range, and if there is a RDF triple in the knowledge base that states "X4711 senses smoke" then a reasoner can conclude that the artefact "X4711" must belong (be a member of) class sensor and "smoke" must be an observable.

The highest level of inference is possible based on full-fledged ontologies, e.g. expressed in the Web Ontology Language OWL. OWL allows to specify characteristics and relations of properties, like inverse, symmetric, transitive, functional and inverse functional properties, as well as cardinality restrictions. Moreover, OWL contains Boolean combinations of class expressions like union, intersection and complement which can be used to define classes by statements and assign memberships to these defined classes to the right individuals.

Our platform will leverage inference mechanisms based on RDF, RDFS and OWL as much as possible to detect relations between technical components (like semiconductors) and ICPS product concepts in the knowledge base, e.g. by unifying observable properties and system parameters or sub-systems with components. The definition of corresponding rules and defined classes will lead to the identification of adequate components for an intended product feature of the ICPS – provided that they are described semantically in sufficient detail.

While the current concept requires the ability of ICPS product developers to describe their concepts, ideas and requirements directly according to an ontology, in the future tools should be developed which guide or automate this process. Suitable approaches for this may range from structured modelling templates which ask the developers for adequate terms that can then be condensed into classes to adapted ontology learning algorithms which extract the individual information from documents, graphics, or other documents.

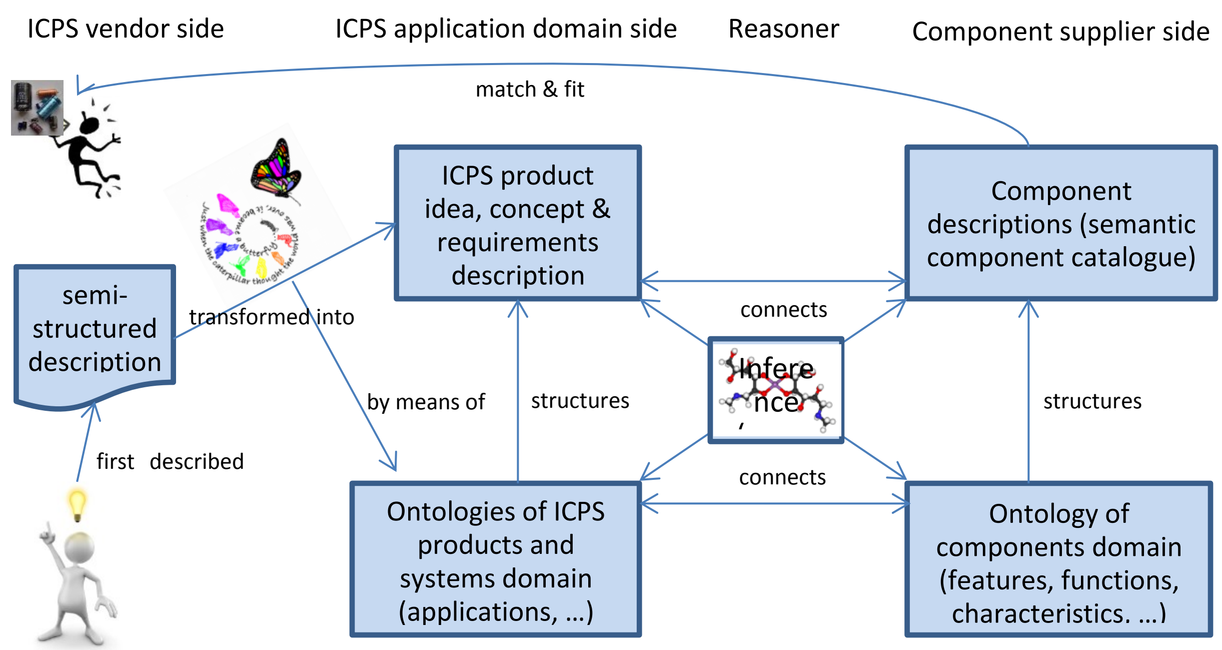

Figure 6: Architecture of the collaboration platform (awareness phase).

Figure 6 summarizes the concept and components of the platform. Currently, the concept covers the awareness phase at the ICPS vendor side but can be extended by other collaboration functionalities for later phases of the collaborative product development process.

4 CASE STUDIES

The platform concept is currently elaborated by means of two use cases at Infineon, a smart textile use case and a healthcare use case.

While the collaboration platform is intended to be scalable from small, simple to large, complex business networks, the idea for the first case study within a semiconductor company is a small one, and will be called Smart. Smart could cover a small and simple network of industry partners and research institutes that are concerned with the development of consumer products. Smart could be funded by the German Federal Ministry for Economic Affairs and Energy and the semiconductor company could be part of this project as one of market leaders in electronics. The aim of this project would be to develop a complete value chain for smart consumer products via an innovative platform, a smart service platform for smart consumer products. In order to meet the desired objectives we mentioned, the current communication and marketing set-ups are not able to effectively support the flow of information between the different stakeholders of the project. Thus, the described collaboration platform could be recommended to be used as a collaboration tool to match products and application ideas from consumers (like smart textiles) manufacturers with electronics suppliers that enable smart textiles. This web platform could support the generation of a new b2b business model based on an information-driven, interactive innovation platform between producers, smart textile developers and users.

A second use case is currently elaborated within the project Productive 4.0. In this use case, a company which has a product idea for an innovative CPS in healthcare meets with people from the semiconductor company by accident, who could recommend a specific component which can help to realize the CPS. This case increased the awareness of the semiconductor company for the fact that there may be huge market potential in areas they do not cover so far by their marketing and sales processes. A retrospective to this case will be used to elaborate and evaluate the platform concept.

As a first step, a product ontology and a description of the component, a specific sensor, as individual according to the ontology are developed. This product ontology consists of classes that characterize the functions as well as the form and possibly interfaces. For instance, in order to describe certain features, like a particular accuracy of a sensor, it is important to state that the sensor has specific features and that one of these features is the measurement with a certain accuracy. Thereby the inventor shall be supported to find sensors, actuators and other equipment that fit best within their use case.

5 OUTLOOK AND FUTURE RESEARCH

This paper represents our idea of a collaborative ICPS platform, incorporated as a near-to-use prototype through the efforts of work package 7 of Productive 4.0. Furthermore, the authors hope that this paper will stimulate a scientific discussion to help us answering our open questions, which are stated in the following. How can the ideas and requirements of the product developers be modelled as exactly as possible? Is there an ontology for CPS in general? Are there ontologies for specific CPS in certain areas which can contribute? Which performance will the reasoning have, or for that matter, need? Are standard reasoning mechanisms sufficient, what level of expressiveness to we need for our specific use case?

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REFERENCES

Abele, A. and J. McCrae. 2017. *The Linked Open Data Cloud*. http://lod-cloud.net, accessed April 5th, 2018.

Anthony, T. 2015. *5 Emerging Trends in Online Search*. https://www.slideshare.net/TomAnthony/5-fundamental-changes-in-search-searchlove-san-diego, accessed April 5th, 2018.

Assouroko, I., G. Ducellier, B. Eynard, P. Boutinaud. 2014. "Semantic Relationship Based Knowledge Management and Reuse in Collaborative Product Development", *International Journal of Product Lifecycle Management* 7(1):54–74.

Beldjoudi, S., H. Seridi, C. Faron-Zucker. 2011. „Ambiguity in Tagging and the Community Effect in Researching Relevant Resources in Folksonomies". In *Proceedings of the International Workshop on User Profile Data on the Social Semantic Web (UWeb)*. May 30th, 2011, Heraklion, Greece. http://www.wis.ewi.tudelft.nl/uweb2011/, accessed April 5th, 2018.

Berners-Lee, T., J. Hendler and O. Lassila. 2001. "The Semantic Web." *Scientific American*, May 2001, 29–37. https://www-sop.inria.fr/acacia/cours/essi2006/Scientific%20American_%20Feature%20Article_%20The%20Semantic%20Web_%20May%202001.pdf , accessed April 5th, 2018.

Cano, A.E., A.-S. Dadzie, V.S. Uren, F. Ciravegna. 2011. "Sensing Presence (PreSense) Ontology – User Modelling in the Semantic SensorWeb". In *Proceedings of the International Workshop on User Profile Data on the Social Semantic Web (UWeb),* May 30th, Heraklion, Greece. http://www.wis.ewi.tudelft.nl/uweb2011/, accessed April 5th, 2018.

Deutsches Institut für Normung (DIN). 2012. *Sachmerkmal-Listen - Teil 1: Begriffe und Grundsätze*. DIN 4000-1. Berlin: Beuth-Verlag.

eCl@ss e.V. 2017. *eCl@ss classification and product description*. https://www.eclass.eu/en.html, accessed April 5th, 2018.

European Commission. 2017. GROWTH Internal Market, Industry, Entrepreneurship and SMEs: Digital transformation. https://ec.europa.eu/growth/industry/policy/digital-transformation_en, accessed April 5th, 2018.

Felic, A., B. König-Ries, M. Klein. 2014. „Process-Oriented Semantic Knowledge Management in Product Lifecycle Management". In *Proceedings of the 8th International Conference on Digital Enterprise Technology – DET 2014 – "Disruptive Innovation in Manufacturing Engineering towards the 4th Industrial Revolution"*, ScienceDirect, CIRP 25:361–368.

Hitzler, P., M. Krötzsch, and S. Rudolph. 2009. *Foundations of Semantic Web Technologies*. Boca Raton: Chapman & Hall/CRC.

Markoff, J. 2011. "Computer Wins on 'Jeopardy!': Trivial, It's Not". In *New York Times,* February 16th, 2011. http://archive.nytimes.com/www.nytimes.com/2011/02/17/science/17jeopardy-watson.html, accessed April 5th, 2018.

Oracle, Inc. 2016. *Oracle Spatial and Graph: Benchmarking a Trillion Edges RDF Graph*. http://download.oracle.com/otndocs/tech/semantic_web/pdf/OracleSpatialGraph_RDFgraph_1_trillion_Benchmark.pdf, accessed April 5th, 2018. Oracle White Paper.

Otto, B., S. Lohmann, S. Auer et al. 2017. *Reference Architecture Model for the Industrial Data Space*. München: Fraunhofer-Gesellschaft. https://www.internationaldataspaces.org/publications/industrial-data-space-reference-architecture-model-2017/, accessed April 5th, 2018.

Petersen, N., L. Halilaj, I. Grangel-Gonzalez, S. Lohmann, C. Lange, S. Auer. 2017. „Realizing an RDF-Based Information Model for a Manufacturing Company – A Case Study". In *Proceedings of the 16th International Semantic Web Conference (ISWC17)*, October 21st –25th, Vienna, Austria.

Shadbolt, N., W. Hall, and T. Berners-Lee. 2006. "The Semantic Web Revisited". *IEEE Intelligent Systems Journal* 21(3):96–101.

Sriti, M.F., B. Eynard, P. Boutinaud, N. Matta, M. Zacklad. 2006. "Towards a semantic-based platform to improve knowledge management in collaborative product development." In *Proceedings of the 13th International Product Development Management Conference*. Milano.

Taylor, A. 2015. *Semantics for Dummies*, MarkLogic Special Edition. Hoboken: J. Wiley & Sons.

Williams, C. 2017. *Converting Keywords & User Intent Into Marketable Content.* https://www.marketwithagility.com/salesenablement.html, accessed April 5th, 2018.

World Wide Web Consortium (W3C). 2012. *The Semantic Web Technology Stack.* https://commons.wikimedia.org/wiki/File:Semantic_Web_Stack.png, accessed April 5th, 2018.

World Wide Web Consortium (W3C). 2017a. *Semantic Sensor Networks.* http://www.w3.org/TR/vocab-ssn/, accessed April 5th, 2018.

World Wide Web Consortium (W3C). 2017b. *Semantic Web*. http://www.w3.org/standards/semanticweb, accessed April 5th, 2018.

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