LOGISTICS-AS-A-SERVICE: ONTOLOGY-BASED ARCHITECTURE AND APPROACH

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ABSTRACT

Cyber-Physics System (CPS) is a relatively new term assuming tight integration of physical systems and cyber (IT) systems interacting in real time. Such systems aim at providing a flexible and extensible infrastructure supporting a variety of inputs (e.g. sensor-based and customer needs) and outputs (actuators or indicators/displays). CPSs rely on communication, computation and control infrastructures to provide for efficient utilization of logistics infrastructure resources. In this context, Logistics-as-a-Service (LaaS) is a logistics network of organizations, people, information and resources supported by service-oriented cyber-physical systems. Intelligent multimodal logistics network is an important node in the worldwide logistics, involved in moving a product from supplier to customer or providing an accompanying service. The paper presents a generic architecture for LaaS, which is based on representing elements of the logistics networks as services. In this environment, the role of an application ontology and integration of individual and organizational competences is investigated and the use of ontology matching for finding suitable resources in a multi-lingual logistics network is discussed.

KEYWORDS: Cyber-Physics-System, Logistics-as-a-Service, ontology matching, competence modeling

MSC: 90B06

RESUMEN

Sistemas Cíber-Físicos (CPS) es un término relativamente nuevo asumiendo una estrecha integración de sistemas físicos y sistemas cíber (IT) interactuando en tiempo real. Tales sistemas tratan de proveer una flexible y extensible infraestructura que soporte una variedad de entradas (ej. sensores-basados y necesidades de clientes) y salidas (actuantes o indicadores/displays). CPS`s se basan en infraestructuras de comunicación, computación y control para sustentar la utilización eficiente de recursos de infraestructuras logísticas. En este contexto, logística-como-un-Servicio (LaaS) es una red logística de organizaciones, personas, información y recursos suportado por sistemas cíber-físico logística servicio-orientadas. Una red logística multimodal inteligente es un nodo importante en la logística a lo ancho del mundo, envuelta en mover un producto de una suministrador al cliente o proveyendo un servicio acompañante. Este trabajo presenta una estructura genérica para LaaS, la que se basa en representar elementos de las redes logísticas como servicios. En este ambiente, el papel de una aplicación ontológica y la integración de competencias individuales y organizacionales es investigado y el uso del ontológico coincidente para hallar recursos adecuados en una red logística multi-lingue es discutida.

1. INTRODUCTION

Cyber-Physics System (CPS) is a relatively new term assuming tight integration of physical systems and cyber (IT) systems interacting in real time. Such systems aim at providing a flexible and extensible infrastructure supporting a variety of inputs (e.g. sensor-based and customer needs) and outputs (actuators or indicators/displays). CPSs rely on communication, computation and control infrastructures to provide for efficient utilization of logistics infrastructure resources. The increasing interconnection of information systems or production planning systems in enterprises with CPS is of high importance for numerous application domains, e.g. transport and logistics, automation and production, or the *factory of the future*, just to mention a few examples [2, 8]. Important requirements to be met by such interconnected systems are privacy, security and reliability aspects, autonomous evolution and adaptation during the runtime of the systems, adaptivity of the value chain, integration of heterogeneous organization units in

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real-time and the integration of data both in local enterprise software and between enterprises. Suitable concepts, methods and technologies for configuration of CPS, consistency analysis as well as situation and context awareness have to be developed [5, 7].
In this context, the paper aims to contribute to CPS in enterprises and enterprise networks with a focus on the logistics domain. Logistics-as-a-Service (LaaS) is a logistics network of organizations, people, information and resources supported by service-oriented CPS. Intelligent multimodal logistics network is an important node in the worldwide logistics, involved in moving a product from supplier to customer or providing an accompanying service. The paper presents a generic architecture scheme for LaaS, which is based on representing elements of the logistics networks as services. In this environment, the role of an application ontology (AO) and integration of individual and organizational competences is investigated and the use of ontology matching for finding suitable resources in a multi-lingual logistics network is discussed.

2. LOGISTICS-AS-A-SERVICE APPROACH

The main idea of the proposed approach is to develop models and methods that would enable self-configuration of resources for decision support in ad-hoc sustainable logistics. The decision support is planned to be based on dynamic optimization of the route and transportation means (thus providing for the multimodal logistics) as well as to take into account *user preferences* (using competence supply methods) together with unexpected and unexpressed needs (on the basis of the profiling technology).

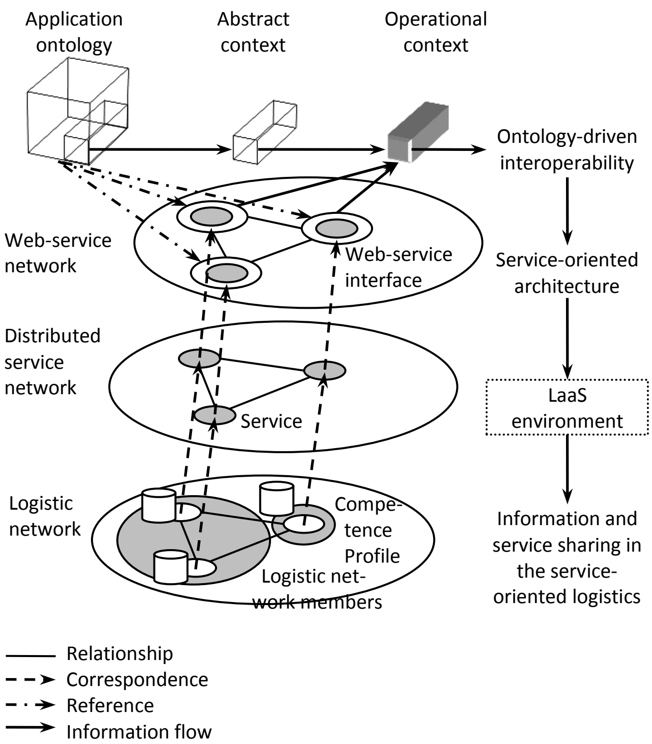

Figure. 1. Generic architecture of the approach

Figure. 1 illustrates the generic architecture of the approach. The main idea of the approach is to represent the logistics system components by sets of services provided by them. This makes it possible to replace the configuration of the logistics system with that of distributed services. For the purpose of semantic interoperability the services are represented by Web-services using the common notation described by AO. Depending of the given problem the relevant part of AO is selected to form the abstract context.
The operational context is a specification of the abstract context for a particular real world situation. It is a result of filling the abstract context with values from the information sources available: when the information of the open information environment becomes available from the services identified in the abstract context, the appropriate values are assigned to the attributes of the classes of the abstract context. Due to the usage of the notation of object-oriented constraint networks [11 - 13], the operational context is also a model of the current situation in the

mentioned notation with values assigned to the variables. This model can be interpreted as a constraint satisfaction task that is solved for the service network configuration.
Since the services represent physical and information resources, the approach operates with three types of self-configuring resources. Information resources provide information from information sources as sensors, databases, etc. Problem-solving resources are computational modules, applications, services, and the like that can be used to solve such problems as routing, transportation network configuration, etc. Acting resources are organizations and persons involved in the current situation according to their roles.
Based on the results provided by problem-solving resources, the acting resources represented by services are organized to efficiently perform the tasks set. For this purpose they modify their characteristics, negotiate and undertake joint actions.
The presented approach relies on the following major assumptions:

1. *Contribution*: the resources have to cooperate with each other to make the best contribution to the overall system's benefit – not to the resources' own benefits.
2. *Task performance*: the main goal is to complete the task– not to get profit out of it.
3. *Non-mediated interaction*: the resources operate in a decentralized community and in most of the negotiation processes there are no units managing the negotiation process and making a final decision.
4. *Common terms*: since the resources work in the same system they use common terms for communication. This is achieved via usage of the common AO.
5. *Trust*: since the resources work in the same system they can completely trust each other (the agents do not have to verify information received from other resources).
6.

The service-oriented architecture has a number of advantages resulting from its principles [3]. Among these the following ones should be mentioned (the specifics related to logistic network configuration are indicated with italic):

1. **Service Autonomy.** Services engineered for autonomy exercise a high degree of control over their underlying run-time execution environment. Autonomy, in this context, represents the level of independence which a service can exert over its functional logic. *With regard to logistic networks the autonomy also reflects independence of the network members, which are independent companies in real life.*
2. **Service Abstraction.** Further supporting service autonomy and service-oriented architecture advocates the scope and content of a service’s interface to be both explicitly described and limited to that level, which is absolutely necessary for the service to be effectively employed. Beyond the service interface, abstraction applies to any information, in any form, describing aspects of the service’s design, implementation, employed technologies, etc. *This principle helps to abstract from real services provided by the logistic network and concentrates on their modelling via Web services.*
3. **Service Standardisation.** As services are typically distributed throughout networks, they must be easily accessible by other entities in terms of discoverability and consequential invocation. Given this requirement, service-oriented architecture recommends that services adhere to standards, including, for example, standards for the language used to describe a service to prospective consumers. *In the proposed approach the standardisation is achieved via usage of the common standards such as WSDL (Web Service Description Language) and SOAP (Simple Object Access Protocol), negotiation protocol, as well as common terminology described by AO. As a result the services constituting the network are fully interoperable and can communicate with each other without any problems.*
4. **Service Reusability.** Reusability is a central property of any successful service. It denotes the capacity of a service to be employed in support of not just one but rather a variety of business models. Service-oriented architecture promotes such functional reuse through stipulations for service autonomy and interface abstraction. With these features, the same service can be invoked by multiple consumers, operating in various business domains, without requiring the service provider to re-code service internals for each application domain. *Service reusability significantly facilitates the modelling process and decreases the amount of the work required for building a model for further configuration. Besides, the existing services of logistic network members can be used.*

In [3] two more service-oriented architecture principles are defined, namely service composability and service discovery. However, the benefits from them are out of the scope of the presented approach unlike those described above in detail
The general three-level scheme of the approach is shown in Figure. 2. The technological base is provided by Web-services. The problem is described via object-oriented constraint networks and the semantics is provided for by using ontologies. The semantic level provides for knowledge sharing and exchange in the logistics system.

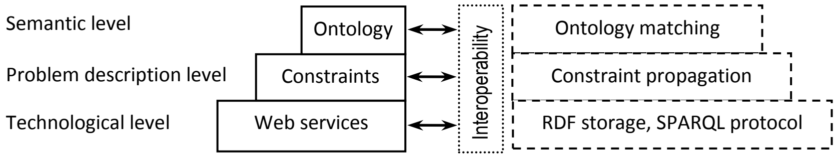

Figure. 2. Three-level scheme of the proposed approach

For the resources to be able to exchange information about their needs and capabilities and to share their knowledge, they are supported by AO. The agreement between the resources and AO is expressed through alignment of the descriptions of the Web-services modeling the resource functionalities and AO. As a result of the alignment operation the Web-services are provided with semantics. The operation of the alignment is supported by the developed tool that identifies semantically similar words in the Web-service descriptions and AO.

3. ONTOLOGY-BASED COMPETENCE PROFILES

While the above approach is focusing on representing traditional (physical) resources in a logistics network, additional concepts are needed for including individual and organizational competences, which can be based on work from competence management. Competence supply and management is a promising research area, which encompasses different scientific fields, like human resource management in economics, lifelong learning in educational sciences or social competence in psychology. The field of competence supply and management offers concepts and approaches which can be applied to identify, describe and search for competences at both organizational and individual levels. For example, for flexible supply networks it is important to describe what the different suppliers can contribute in order to find required production capability or services [10]. Providing information on available competences and making this information accessible to the decision-makers contribute to intelligent information supply solutions in an enterprise. When competences of workers are available as machine-readable profiles, they can be represented as ontologies and included in AO of our approach. If a request for a certain competence is raised in the logistics network, a competence demand description can be translated into a formal query to find matching profiles.

However, it is necessary to utilize exactly the same skill name as the ones used in the profile representation. This makes specification of competence demand very rigid because people would normally use different names of the same skill. Thus, an enrichment of competence profiles with synonyms is recommended, which could be extracted from the Wiktionary thesaurus. The Wiktionary thesaurus was chosen by reasons of its free use, its multilingual support, and keeping, besides lexical relations, definitions of words. Competence profiles are stored in an OWL (Web Ontology Language) ontology, which can be enhanced based on the data of the English Wiktionary accessible via a SPARQL (SPARQL Protocol and RDF Query Language) endpoint and stored in the RDF (Resource Description Framework) storage.

RDF is a data model for representing information about World Wide Web resources. SPARQL [1] is a query language for this data model. It is standardized by the World Wide Web Consortium. Now SPARQL is supported by most RDF triple stores.

For this purpose, the nodes corresponding to the AO concepts are linked to nodes representing their synonyms and associated words as this is given in the machine-readable dictionary. The machine-readable dictionary extracted from the Wiktionary includes 1) a set of words defined in the Wiktionary along with each word 2) definitions given for this word, 3) a set of synonyms, if any, and 4) a set of associated words. Words associated to the word are considered the hyperlinked words occurring in the Wiktionary definition given for this word. The links between the nodes are labeled by the weights of relations specified between the concepts represented by these nodes in the machine-readable dictionary. Weight w of a relation specified between two concepts t_i and t_j is given by:

$$w = \begin{cases} 0{,}5 & \text{if } t_i, t_j \text{ are synonyms} \\ 0{,}3 & \text{if } t_i, t_j \text{ are associated words} \\ \infty & \text{if } t_i, t_j \text{ are the same word} \end{cases}$$

For this purpose such sources as Wiktionary or WordNet can be used, which are dictionaries and thesauri. WordNet is created by experts for the English language in a machine-readable form. It is based on psycholinguistic theories to define word meanings. Wiktionary is a multilingual and multifunctional dictionary freely available and containing a huge number of words with translations to many languages. Wiktionary can be transformed into the machine-readable form [6].

The analysis and automatic processing of the English Wiktionary show that the average polysemy, the number and the distribution of word meanings follow similar patterns in both expert and collaborative resources with relatively minor differences. Also the comparison of the proprietary dictionary PAPEL with the Portuguese Wiktionary shows that the folksonomy generated dictionary is a valuable resource for enriching existing lexical knowledge bases.

4. MULTILINGUAL ONTOLOGY MATCHING

Ontology matching is the process of finding corresponding elements between ontologies to allow them to interoperate. In the LaaS context, ontology matching can be used as a part of the process of configuration and finding resources. A relatively new direction is concerned with an alignment of ontologies presented in different languages, i.e. multilingual ontology matching, which is needed in the context of logistics networks with partners from different countries since such networks are potentially including resource description in different languages. Multilingual ontology matching is based (in our approach) on the machine-readable Wiktionary, which is a project intended for extraction of different types of lexicographic data stored in the Wiktionary: definitions, thesaurus and translations. Only the thesaurus of the English Wiktionary is used in this project. There are several types of semantic relations (paradigmatic relations) extracted from the Wiktionary: synonyms, antonyms, hypernyms, hyponyms, meronyms, holonyms and troponyms. Figure 3 shows the automatic multilingual ontology matching strategy and evaluation in the system.

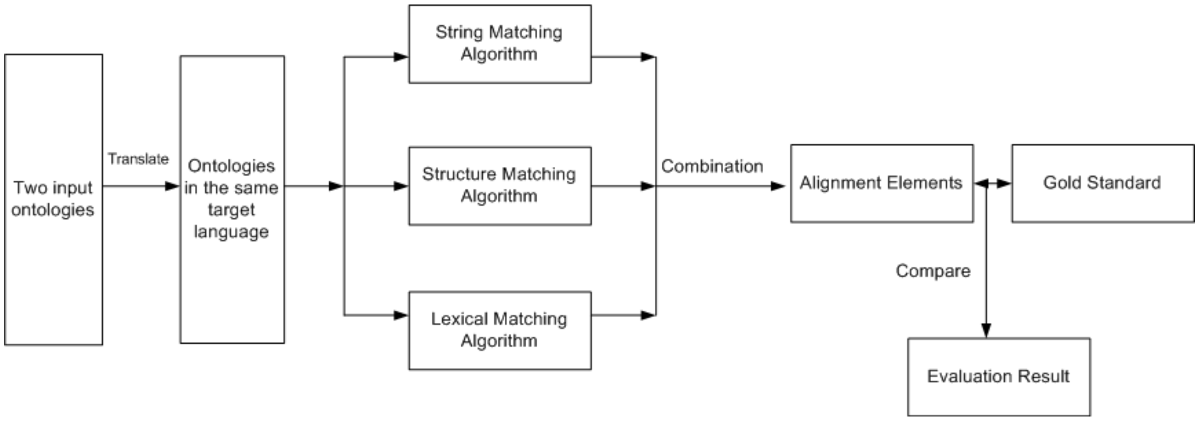

Figure. 3. An automatic ontology matching strategy and evaluation

The technology relies upon knowledge of the application domain. This knowledge is represented in AO. AO is created by subject experts, knowledge and ontology engineers. It either can be created from scratch or through integration of existing ontologies.

AO is made up of two non-instantiated constituents: domain knowledge and problem-solving knowledge. Domain knowledge describes conceptual knowledge about the domain. Problem-solving knowledge formalises problems that may require solutions in different decision-making situations. Types of decision-making situations depend on the application domain. These types are specified in AO.

In the LaaS, individual and organizational competences are considered when finding suitable resources for the application. Our approach consists of several steps. First, we match AO and operation context ontology (OCO) using the automatic ontology matching method. Then we match competence profile ontology (CPO) and AO, CPO and OCO using automatic ontology matching method (Fig. 4). Based on the above overlap (Fig. 5), we divide areas A, B, C, D, E and F into three layers. Area B is layer 1. Area A, C and D is layer 2. Area E, F and G is layer 3. We set different weights for different layers' relationships. Then we do instance level matching and show the final results depending on competence [9].

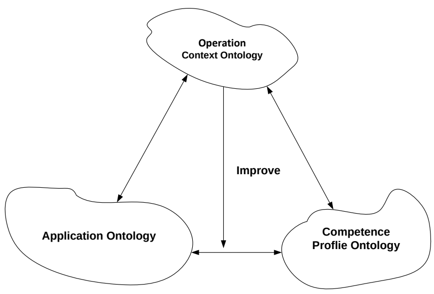

Figure. 4. Competence-based semantic matching approach

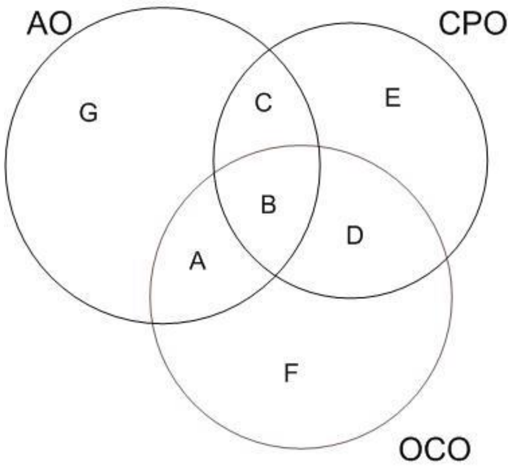

Figure. 5. Ontology matching overlap

With the help of D2R server [4] the data extracted from the Wiktionary are presented in the form of RDF store. So, the lexicographic information extracted from the Wiktionary is accessible by using SPARQL requests (Figure. 6).

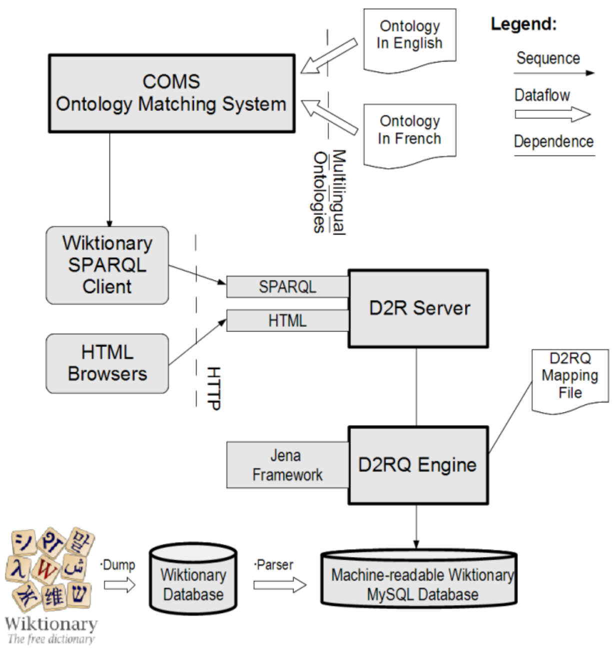

Figure. 6. Architecture of the platform integrating the ontology matching system with the machine-readable Wiktionary accessible via SPARQL queries

5. SUMMARY AND FUTURE WORK

The paper investigated the integration of information systems and production planning systems in enterprises with physical systems, like automation and control systems, into CPSs with focus on the logistics domain and on a service-oriented approach. The core contribution is a generic architecture for Logistics-as-a-Service systems, representing elements of the logistics network as services. The generic architecture is enriched with concepts from competence management and ontology matching. From competence management, we propose to use ontology-based competence profiles for representing individual and organizational competences. Ontology matching contributes to configuring and finding resources in LaaS. Within the ontological representation of services and competences, multi-lingual ontology matching is proposed.

The conclusion of the work is that the generic architecture, ontology-based competence profiles and multi-lingual ontology matching all contribute to LaaS, complement each other and share a common ground in the ontological representation and service-oriented structure, which is a promising basis for future work.
Future work will be of experimental and conceptual nature. From an experimental perspective, the proposed approach has to be implemented and evaluated in controlled environments or real-world cases. This will most likely lead to changes, refinements and improvements of the proposed approach. The conceptual work includes further elaboration of the aspects of the generic architecture, formalization of the integration of competence profiles in this architecture, identification of the most effective and efficient ontology matching implementation, and environments for implementation.

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