Improving Industrial Collaboration with Linked Data and OWL

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Abstract. We present a product-centric collaboration platform comprising partner companies and their customers. By employing the Linked Data principles it enables them to easily publish and retrieve information about products and to include user-generated content as well as publicly available information from the Linked Open Data web. Information about products is modelled as OWL ontologies, which makes it more useful and easier to understand for application developers. Self-explanatory data structures also lower the threshold for new partners interested in joining the network and contributing their products. The versatility of this approach is illustrated by two application scenarios.

1 Introduction

Companies often form data silos: their information is stored in proprietary formats that are difficult to understand without expert knowledge that can only be obtained from the system developers and operators. The meaning of data structures is contained implicitly in the procedures operating on these structures, and the vocabulary that is employed is not usually understandable for an outsider. Inclusion of information from outside the company or sharing of information with partner companies therefore happens rarely and involves a significant effort. For a customer without IT expertise, it is utterly impossible to connect his personal web information with the corresponding company.

However, especially for small and medium-size companies, collaboration with partner companies often is a requirement in order to offer a satisfactory product range to the market, since a small company does not have the same large area of expertise as a large competitor. Interlinking with other (small) companies can lead to more attractive products. In order to achieve visibility in the web, it is also important to include customer recommendations and to meet potential customers in places where they spend their time online, e.g. social networks.

This paper presents first results from the project ComVantage[6] (Collaborative Manufacturing Network for Competitive Advantage), which is funded by the EU FP7 programme and comprises thirteen collaborating companies and universities. It aims at developing a collaboration platform integrating information from partner companies, end-customers, and public sources, and at offering this information in such a way that it can be easily consumed by lightweight applications running on various devices, including mobile phones and tablet computers. In order to achieve this aim, the platform uses OWL and RDFS ontologies and the Linked Data (LD) principles [4]. The motivation for using semantic technologies is that capturing a company's knowledge in an ontology makes its meaning explicit and thus easier to understand for people and machines. Moreover, a large amount of publicly available data is represented in the Linked Data format.

ComVantage ensures the usefulness of its results for practical applications by employing a sophisticated business modelling approach [6], by using an integrated security concept, and by including application scenarios from very different business areas, namely automotive plant engineering and commissioning, machine maintenance, and tailor-made clothing. In this paper, we present results based on the first prototype finished after the first year of the project, and we focus on the aspects relevant for semantic technologies within the two latter application scenarios.

2 The ComVantage architecture

The aim of our platform is to facilitate collaboration among various organisations involved in industrial supply chains, enabling an efficient flow of information in value generating processes, without introducing a high level of complexity. In order to achieve this, our goals are:

- Making relevant information from business software accessible as LD
- Making factory-level information from device middleware accessible as LD
- Maintaining access control for LD between partners of virtual factories
- Supporting business end user interaction with LD on mobile devices

Due to the dynamic nature of the envisioned virtual factories, the technology for sharing the data needs to be highly de-centralised, i.e. it must not rely on a central managing partner with a centralised platform. Furthermore, the ability to quickly integrate new partners needs to be supported by light-weight, easy to implement approaches for the necessary data exchange formats and interfaces. As such dynamic collaborations evolve over time, the formats and interfaces also need to be designed for extensibility.

Since we want to avoid disrupting existing workflows, we do not require a complete move of all existing data to the OWL/RDF format and into a triple store, but we include the existing systems by transforming their contents into RDF syntax on the fly [11]. Figure 1 shows this approach: next to the company's

[6] http://www.comvantage.eu

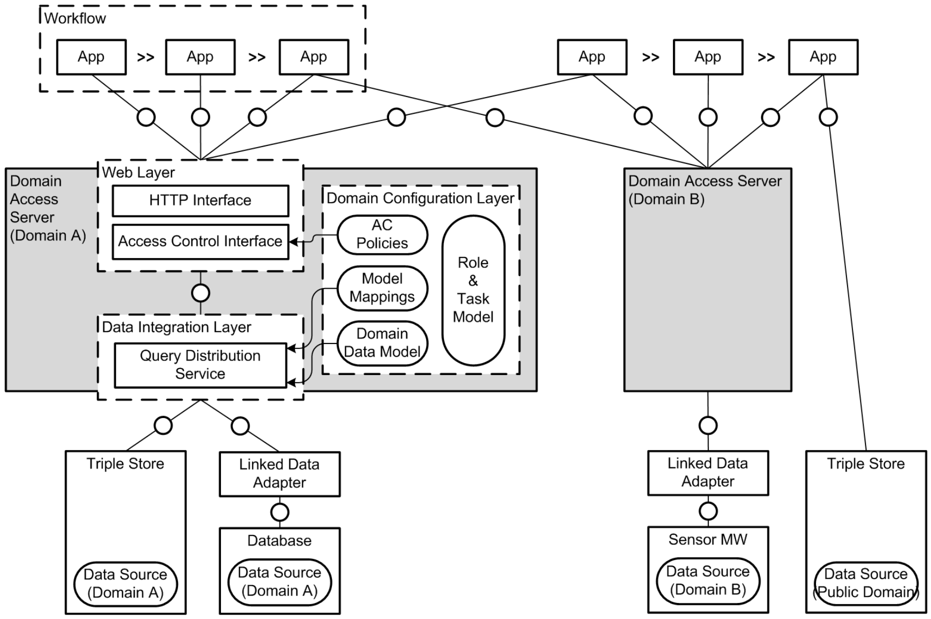

Fig. 1. ComVantage architecture

triple store at the bottom left, which contains the new OWL data models and additional information, there is the legacy database, whose content is transformed into RDF by the Linked Data adapter sitting on top of it. This procedure, which is also called *semantic lifting*, is comparably easy for static data sources such as databases, and software performing this task is readily available [3]. When dealing with live sensor data from a machine middleware, as on the bottom right, a more complex approach is required to deal with the stream nature of the data.

One advantage especially for small companies is that existing public ontologies, both for terminologies and for instance data, can be included easily in the data model because of the common data format, as can be seen on the far right. Another advantage is having a common data format that is valid for the entire network and thus makes including a new partner easier. Even if this partner's data sources require an extension of the existing ontology, this is feasible by introducing new classes and properties. A tool for extending an existing ontology is currently under development [5]. If the built-in annotation features like `rdfs:comment` and `rdfs:description` are used extensively, applications can be developed without contacting the owner of the underlying data sources.

Access to the information repositories is controlled by the Domain Access Server (DAS), which extends the access policies for the legacy systems to the semantically extended versions. The DAS is also responsible for mapping entities from different sources and for distributing complex queries to the respective data sources. The data is presented to the users by a set of task-centric, small and easy to use applications, which fulfil their requirements as an ensemble (this approach is described in detail in Section 3).

2.1 Employing existing software

A smooth management of multiple datasets is necessary for spanning a virtual factory with the described architecture. This includes the creation and modification of common vocabularies, the seamless integration of existing software and data and the interlinking between prior isolated information spaces. However, most of these tasks are already well supported by appropriate tools. The LOD2 project, for example, provides a software stack of "aligned tools which support the whole life cycle of Linked Data from extraction, authoring/creation via enrichment, interlinking, fusing to maintenance" [2]. ComVantage adapted this list of tools for the purposes of virtual factories. An excerpt of the chosen tools will be presented in this section.

Relational databases are frequently used in today's companies for storing data in a structured and well supported format. The stakeholders of virtual companies have to expose some of this information as Linked Data for their partners to allow value-added services across multiple stakeholders. Within ComVantage it was decided to use the D2RQ platform [3] as a Linked Data adapter for this task (e.g. in the use case of customer-oriented production as described in Section 4.2). The D2RQ platform reads data from a relational database, converts it into RDF and provides this data both as HTTP-representations in RDF or HTML and through a SPARQL endpoint (which Triplify[7] as major alternative does not provide). Since D2RQ uses JDBC drivers it can be connected to a wide range of relational databases. The conversion is applied according to a set of rules which logically contains the semantics of the database.

The management of ontologies is another important task because every consistent model should have well-defined vocabularies. This is becoming even more important when considering multiple stakeholders which have to understand, use, and maintain the vocabularies of their partners. For ComVantage the expressiveness of OWL-Lite is sufficient for providing the possibilities of declaring hierarchies, identity and some major restrictions. However, we opted to use OWL rather than RDFS since the stricter OWL syntax provides better guidance and because its reasoning capabilities can provide a sanity check for newly developed ontologies. Since the LOD2 stack lacks an ontology engineering tool, ComVantage uses Protégé, because it exactly focuses on the creation and modification of OWL ontologies and has a broad user community [10].

The vocabularies as well as other information that cannot be dynamically generated have to be stored in a persistent triple store. ComVantage decided to follow the suggestion of LOD2 and use Virtuoso [7]. It supports a fine-grained access control and access interfaces via configurable SPARQL endpoints. Virtuoso additionally provides possibilities for content negotiation allowing the delivery of resource information in different formats. Besides several serialisations of RDF,

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[7] `http://triplify.org`

this includes different HTML representations of the stored RDF data, which enables easy debugging.

Every stakeholder usually has different information sources. These datasets can be interlinked during the conversion process utilising known attributes of the entities. However, the full power of Linked Data comes into play when connecting information from different stakeholders as the scenario descriptions will show in Sections 4.1 and 4.2. There, datasets usually have neither common vocabularies nor common keys that can be used for effortless linking. Thus, a tool is necessary that can find appropriate links between two entities. Their attributes are only described by ontologies and can need transformation before comparison with each other. Silk [16] supports this task very well and works directly on the provided data via access through SPARQL endpoints.

2.2 Developing ontologies

For the creation of the ontologies for our application scenarios, we considered three ontology engineering methodologies: the TOVE methodology [12], the Enterprise methodology [15], and Methontology [9]. The Enterprise methodology turned out to be best suited for ComVantage because it provides enough guidance to steer the ontology development process (TOVE does not differentiate clearly between the different phases; see also [8]) without introducing unnecessary overhead regarding the production of documents or running several tasks in parallel (Methontology involves a complex set of activities and extensive documentation). The Enterprise methodology specifies the following phases:

1. Identifying the purpose: determining why the ontology is being built, who will use it, and for which aim.
2. Building the ontology:
   (a) Capturing: identifying the key concepts, producing definitions for these concepts, and agreeing on names for these concepts.
   (b) Coding: representing the conceptualisation produced in the previous stage formally in an ontology language.
   (c) Integrating existing ontologies: finding usable terms from other ontologies and connecting them with the terms from the newly developed ontology.
3. Evaluation: making a technical judgement of the ontology with respect to the requirements specification or the real world.
4. Documentation: recording all important assumptions and decisions.

Several features of the Enterprise methodology turned out to be helpful for our purposes, since they helped in keeping the discussion focused, and since they improved the communication between ontology engineers and domain experts. For example, in the *capturing* phase, the authors recommend agreeing on the definition before deciding on the term to be used for the concept because people working in different areas tend to have different association with terms, which makes it difficult to reach an agreement if the term is chosen first. Moreover, unlike most other methodologies for software or ontology engineering, the Enterprise methodology suggests neither a top-down approach (going from the most general to more specific terms) nor a bottom-up one (in the opposite direction), but rather goes *middle-out*, i.e. it starts from the most frequently used concepts, which normally are located at the middle height in the ontology hierarchy.

3 User interface

In a collaboration environment, different information spaces from various stakeholders need to be interconnected to be able to support complex workflows. While the individual information spaces have a high level of internal connectivity and may be semantically well enriched, external connections (i.e. to information spaces of other stakeholders) are sparse. Apps[8] perfectly match these circumstances because they support a certain enclosed task (such as browsing a list, analysing a diagram or sending a report) and usually rely on only a single information space. Linked information in other information spaces usually model different aspects and thus should be handled by other appropriate apps. That allows application developers to concentrate on a specific information space exploiting the full power of underlying OWL ontologies.

However, for supporting industrial workflows the tasks supported by single apps have to be connected. This is possible because within ComVantage apps can rely on a common business model and associated business processes. It is clear that whole sets of apps may be necessary in order to accomplish complex tasks. They have to be used in the right order, must have access to associated information and must be adapted to the context of use.

For these reasons, we argue that in the industrial context a semi-automatic orchestration of apps is more feasible than individual app selection and management by each user [17]. Therefore we have developed an innovative concept called *Mobile App Orchestration* that allows for building mobile applications which support complex workflows and leverage inter-organizational collaboration spaces. It consists of three major steps. *Select* and *Adapt* are executed at the design time of the applications, while the *Manage* step reaches into run time.

During the *Select* step, apps are selected from a repository according to the workflow that shall be supported. The selection of appropriate apps is achieved through reconciliation of the app description with the workflow model, according to semantic similarity. The level of automation is dependent on the availability and extent of task, data, context and workflow models that the collaboration stakeholders provide. Ideally, all required apps can be found in the App Pool. If this is not the case the respective task is omitted and an appropriate app can later be added to the ensemble.

In order to satisfy all needs for industrial usage the selected apps need to be *adapted* to the context of use. Basic adaptation can be achieved by parametrising the data acquisition, setting a style sheet and choosing app parameters. The

[8] Applications that run on mobile devices and are task-centric, context-aware and well adapted to a specific platform and context of use

adaptation of the information retrieval takes the data model, the used ontologies and access rights into account and thus heavily relies on self-explanation of information and a good ontology engineering process as described in Section 2.2. Furthermore, the visual appearance may be adapted to comply with corporate design or presentations rules or the interaction may be configured for specific modalities, such as voice or gesture interaction.

During the *Manage* step, a run time component is created which is responsible for the management of the adapted apps. Therefore the navigation design is derived from the workflow model. The run time component and the adapted apps form an ensemble which can be deployed to the mobile device. At run time this component loads the navigation design and manages inter-app-communication, app switching and data access. Users can begin the workflow by logging into the collaboration network and are then guided from app to app until they have completed the entire workflow.

4 Application scenarios

4.1 The Mobile Maintenance scenario

The Mobile Maintenance scenario is concerned with accessing data about production lines and their machines. This data has to be integrated from various sources, like the producer of the machine, its owner, and the service company. The use of modern mobile devices is key to simplifying the training on the job and to improving tools for the maintenance staff, since a consistent user interface for all machines reduces the training efforts. The data presented to the service personnel can be either static, e.g. describing the structure of a machine, or *transient*, i.e. changing quickly (within the magnitude of milliseconds), e.g. from sensors for environmental data like temperature or pressure. For the diagnosis, access to the current data is vitally important. Integrating transient data within our environment requires additional effort since entering each value into a triple store is not feasible due to the high updating rate and the large number of available sensors in a factory. We therefore developed an LD adapter for the machine middleware, which provides the sensor data.

There exist approaches for handling large networks of sensors, like the Linked Sensor Middleware[9] with over 100000 sensors worldwide or the Semantic Sensor Network[10]. However, these networks have significantly longer update intervals (in the order of magnitude of minutes), and thus their results are not applicable within this scenario.

The Data Harmonisation Middleware Adapter. The *Data Harmonization Middleware Adapter* or DHM-Adapter performs the following tasks in order to identify and access live data: firstly, it identifies the sensor using the sensor's

[9] `http://lsm.deri.ie/` and `http://code.google.com/p/deri-lsm/`
[10] `http://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/`

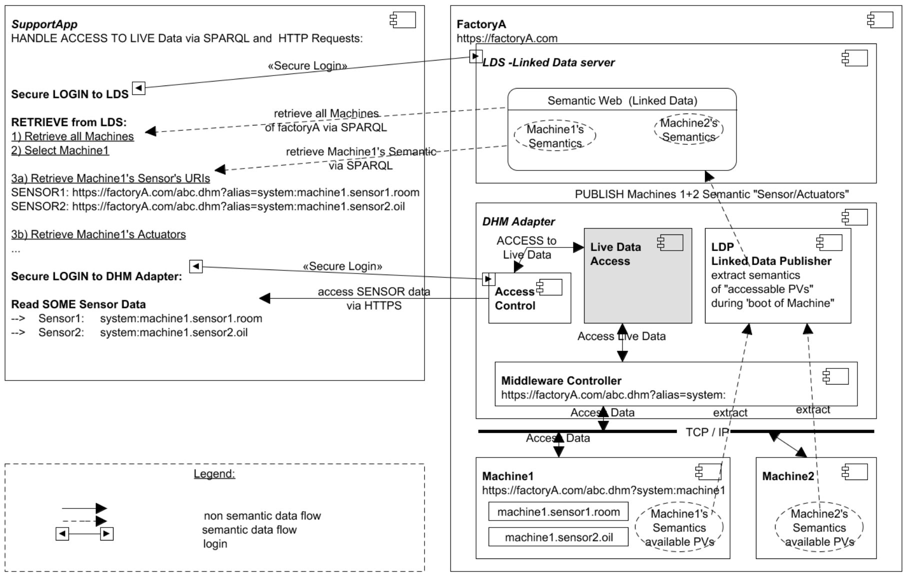

Fig. 2. Architecture of the DHM

URI and the ontology containing the machine semantics. Then it accesses the sensor's current data by performing an HTTPS request for this URI. In Figure 2 the functionality of the DHM-Adapter is shown in detail:

The Middleware (like OPC[11] or GAMMA V[12]) controls one or more machines, which contain the sensors that should be accessed.

The Machine Semantics is an OWL ontology representing hierarchical description of the factory using terms like enterprise, site, area, or module, down to single sensors. It conforms with the physical model of *ISA-88/IEC 61512* standard[13] and thus is suitable in many environments.

Linked Data Publisher (LDP) collects the content of the Machine Semantics about all available sensors from the machine's configuration.

The Linked Data Server (LDS) accesses the Machine Semantics from the LDP component and provides a SPARQL endpoint for the SupportApp.

The SupportApp provides the user interface for the maintenance staff. It retrieves all relevant semantic information about the machine from the LDS. It allows browsing through the machine hierarchy and reading sensors.

The Access Control component restricts the access to the DHM-Adapter.

The Live Data Access component (shaded in grey in Figure 2) receives a sensor's URI, issues a call to the machine middleware, transforms the return value into RDF and returns this current value to the caller.

[11] `http://www.opcfoundation.org`
[12] `http://www.rst-automation.de`
[13] `http://www.isa-88.com`

4.2 The Customer-Oriented Production scenario

The customer-oriented production scenario is focused on a small network-based company offering tailor-made business shirts over the internet. In the fashion industry, end-customers' requirements are rarely integrated with the design and production processes, while on the other hand there is an increase of requests for individualization of products. The unique selling proposition (USP) of the customer-oriented production scenario aims at being different both from the producer's and the customer's point of view. Thus, the ordering and production process is managed completely virtually while the customers have high degrees of personalization.

Challenges for the customer-oriented production scenario. As a result of the project we envision a prototype for mobile devices whose interface allows better collaboration between suppliers and customers. Currently the virtual supply chain works via e-mail coordination or already existing communication between partners and a low involvement of the customer. The ComVantage customer and producer application shall involve the web shop in a virtual collaboration space with different stakeholders and customers all over the world. Thus, the challenges for our Linked Data and OWL based ComVantage platform range from allowing real-time decisions within the network, to providing in-time supplier substitutes, up to integrating end-customers in production processes following open innovation concepts.

For this purpose, we will develop two main applications: The aim of the *mobile customer application* is to improve customer involvement following an open innovation/open design approach; e.g. enabling the customers to access style recommendation services, shirts designed by the crowd and product information via social media platforms as well as in-time change of shipping modalities or in-time integration of user feedback into the production etc. As soon as the shop confirms an order, the *producer application* can dispatch the order information to the appropriate stakeholders within the collaboration space (according to the stakeholder's resources, price, and location). Furthermore, the open nature and easily understandable meaning of the Linked Data and OWL based infrastructure allows all interested stakeholders (e.g. persons or organizations providing design, sewing, delivery, etc.) within the collaboration network to join the value chain by simply downloading the mobile producer application and relevant guidelines. Linking different data and systems allows high personalization and flexible and individually composed production processes. Thus, a small company can become a part of a virtual factory and join a flexible cooperative network.

Addressing key requirements with mobile and semantic technology. Based on stakeholder and customer interviews we identified two key requirements to be addressed by taking advantage of mobile and semantic technology. The idea is that everyone who wants to join the network can do so simply by downloading a mobile app. The Linked Data and OWL approach allows high flexibility e.g. to re-use and share already existing ontologies of the textile domain. By focusing on a clear user interface complex technology in the background should be easy to use. Thus, also micro companies without any background in semantic technologies can provide, consume and exchange relevant information in the virtual collaboration network. The identified key requirements can be summarized as follows:

- Lightweight and affordable infrastructure for application in technological unaware environments. Especially small and micro companies working for the textile industry, e.g. sewer companies in Slovenia, lack a sophisticated IT environment. However, to realize the envisioned application scenario as well as to enhance the competitiveness of such companies, end-to-end transparency about processes is required. Additionally, joining the virtual factory network should not require high costs.
- Flexible and usable solutions supporting an open virtual factory spirit. For allowing a designer or a self-employed sewer to easily join the virtual network regardless of place and time, the technical solution has to be very flexible and easy to use.

A Visionary Scenario for customer-oriented production. Manuel is a customer ordering a business shirt with the web shop's app on his tablet PC. He selects the style from a designer who won the shop's latest design competition and enters his body measurements. As sustainability, fair trade, and corporate social responsibility (CSR) are very important values for Manuel, he chooses this additional option for his shirt. In the next ordering step, a sketch of the whole value chain opens. For each step in the chain, different suppliers are recommended and partner descriptions, ratings and their social activities are provided. Manuel can select suppliers for each step individually throughout the whole chain and receives the required information regarding shirt prices and shipping in runtime. After completing his order, the shop system checks the data and sends the request to all involved suppliers. As availability of capacities has been checked before, the order can be processed successfully. All involved suppliers use the production application on their smartphones or tablet computers in the production environment to track and indicate the individual production steps. Thus, Manuel can follow the process with his smartphone and still perform any modifications if desired. When the shirt arrives, he takes a photo and posts it on his facebook account, which is linked from his customer account. Afterwards, he receives a facebook comment from the designer: "Thanks for buying my shirt design." Another comment comes from the sewer: "Enjoy it, I sewed it."

First Results: From a vision to a ComVantage prototype. The development of ontologies is motivated by scenarios that arise in the applications. In particular, such scenarios may be presented by industrial partners as problems which they encounter in their enterprises. The motivating scenarios are story problems or examples which are not adequately addressed by existing ontologies. A motivating scenario also provides a set of intuitively possible solutions to the scenario problems. These solutions provide an informal intended semantics for the objects and relations that will later be included in the ontology.

The main results achieved so far from the beginning of the project cover the refinement of the use cases with respect to their business model by elaborating in detail the personas, the scenarios and use cases as well as a set of initial requirements for the target system. Based on these results, an ontology representing the data structures of the scenario has been created by domain experts and knowledge engineers according to the methodology described in Section 2.2. In a second step, the content of the existing shop database was integrated with this data model by using the D2R adapter described in Section 2.1, which uses the vocabulary from the FOAF[14] and vCard[15] ontologies and also includes links with DBpedia [1] entries for the fabric used. This allows the the shop owner to provide the customer with a large amount of additional information about the product without having to maintain this data himself. In the future, our plan is to also integrate the eClass [13] and GoodRelations [14] ontologies with the shop ontology in order to make the shop offers more accessible for semantic search engines.

5 Conclusion and Outlook

In this paper, we have demonstrated how we use OWL ontologies and the Linked Data principles to facilitate collaboration, integration and end-customer interaction within business contexts. For the different application scenarios, we have shown how we created ontologies and integrated the existing infrastructure into the Linked Data web. Based upon this, the ComVantage integration platform can support different kinds of interaction between companies, partners and customers. The ideas underlying our ontology development concept and the user interfaces have been explained.

This paper describes the status of the project after one year of its planned three-year runtime. Consequently, some parts of the platform are still in an experimental stage, e.g. the integration of Linked Open Data, and we cannot yet provide extensive experimental results. Some other aspects have been omitted due to space restrictions; e.g. the *Plant Engineering and Commissioning* scenario. In addition to these topics, the development of the app suites for the different scenarios is among our goals for the next phase of the project. We also plan to use the OWL reasoning capabilities to find modelling errors in ontologies and to make knowlege that is contained implicitly in the ontology explicit and thus usable.

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[14] `http://www.foaf-project.org`

[15] `http://www.w3.org/TR/vcard-rdf/`

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