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Context-aware Process Support through automatic Discovery and Invocation of Semantic Web Services

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Abstract

Current technologies aimed at supporting processes – whether it is a business process or a learning process – are usually based on using a dedicated set of metadata to describe a process which refers to some specific data, used in the process. Process metadata is usually specific to a standard specification – like the Business Process Modeling Notation (BPMN) or the IMS Learning Design Standard – while used process data is specific to a specific process context. These facts limit the re-usability of a process model across different standards and contexts. To overcome these issues, this paper describes an innovative semantic web service-oriented architecture aimed at changing this data- and metadata-based paradigm to a highly dynamic service-oriented approach following the idea of a semantic abstraction from process metadata as well as process data. This approach enables a dynamic adaptation to specific actor needs and objectives and supports the development of abstract semantic process models which are re-usable across different contexts and standards. To illustrate the application of our approach, we describe a prototypical application to the domain of E-Learning.

1. Introduction

Organizational processes are currently supported by a variety of dedicated information systems. These are primarily based on using a dedicated set of metadata to describe a – business or learning – process that makes use of specific process resources. The process metadata is usually based on proprietary or standard-specific specifications, such as the Business Process Modelling Notation (BPMN) [14] or the IMS Learning Design standard [9]. Furthermore, the resources are sets of data or services useful in a specific process context.

For instance, in the domain of E-Learning the current state of the art to support learning processes is based on composite learning content packages – i.e. learning objects (LO). Each package contains the physical learning resources as well as a learning process model based on

specific metadata. The latter specifies the sequence to be followed by the learner for accessing the physical data or services. Due to this approach, a new learning package has to be developed for every different learning context. For example, a learning package suiting the needs of a learner with specific preferences – e. g. his native language, maximum costs or technological platform - cannot be reused across different learning contexts.

Several general limitations and issues are observable across different process domains:

- L1. Limited reusability of process applications (models) across different process contexts and metadata standards.
- L2. Limited appropriateness and dynamic adaptability to actual process contexts.
- L3. High development costs

To overcome these limitations, we propose a highly dynamic service-oriented approach based on semantic Web services (SWS) technology. Our approach enables the automatic allocation of resources – services as well as data – at runtime of a process. In our vision, processes are described in terms of user objectives (goals) and abstract from any specific data and metadata standard. Goals are accomplished by automatically selected functionalities fitting the actual user needs and process contexts. To actualize this vision, we adopt a layered approach: Web services provide the base layer of executable functionalities; a SWS broker and ontologies support the selection, composition, and invocation of services appropriate to a given process goal as well as context. Finally, semantic mappings link our process descriptions to existing metadata standards.

As a result, we enable a paradigm-shift from the current manual allocation of resources at design-time to an automatic allocation of functionalities at run-time, which indeed provides the dynamic adaptation to different contexts. Furthermore, the introduction of standard-independent semantic process models addresses the reusability across multiple metadata standards. Finally, both the dynamic adaptation and standard

independence lead to a reduction of the development costs.

The following section of the paper provides brief background information about SWS, whereas section three explains our vision and approach of using a SWS oriented architecture to support processes. Sections four and five explain an application of our approach to the domain of E-Learning as well as an initial prototype application based on the described principles. In the last section we discuss our contributions and finally, provide an outlook to future work related to our approach.

2. Semantic Web Services: IRS-III and WSMO

Semantic Web services (SWS) technology aims to automate the development of Web services (WS) based applications through the Semantic Web technology. By providing formal descriptions with well defined semantics, it facilitates the machine interpretation of WS descriptions. The key areas of concern are automatic discovery, mediation, and composition of Web services.

IRS-III [3], the Internet Reasoning Service, IRS-III is a broker based platform that provides a powerful execution environment. It enables semantic descriptions to be associated to a deployed Web service and used during discovery, mediation, composition and invocation activities. By definition, a broker is an entity which mediates between two parties and IRS-III mediates between a service requester and one or more service providers

At the heart of IRS-III there is a SWS Library, where semantic descriptions of WS, and the reference Domain Ontologies and Knowledge bases (instances) are stored using OCML representation language [5]. IRS-III adopts the Web Service Modelling Ontology (WSMO) [18] as reference ontology model for WS descriptions. WSMO is a formal ontology for describing the various aspects of services in order to enable the automation of WS discovery, composition, mediation and invocation. The meta-model of WSMO defines four top level elements:

- Ontologies provide the foundation for describing domains semantically. They are used by the three other WSMO elements.
- Goals define the tasks that a service requester expects a Web service to fulfil. In this sense they express the requester's intent.
- Web Service descriptions represent the functional behavior of an existing deployed web service. The description also outlines how web services communicate (choreography) and how they are composed (orchestration).

- Mediators handle data and process interoperability issues that arise when handling heterogeneous systems.

One of the main characterizing features of WSMO is the linking of ontologies, goals and web services by mediators which map between different ontological concepts within specific WSMO entity descriptions. In order to facilitate appropriate mapping mechanisms, four classes of mediators are considered within WSMO. For example, an OO-mediator may specify an ontology mapping between two ontologies whereas a GG-mediator may specify a process or data transformation between two goals.

3. Analysis of Current Issues

Current technologies and approaches aimed at supporting organizational processes are mainly based on the following practices:

- Widely use of data and metadata standards for delivering appropriate resources - either data or services - to support a specific process objective.
- Resources are manually associated with specific process objectives based on the limited knowledge and subjective decisions of a specific individual.
- Resources are allocated at design-time of a process - i.e. when the specific process metadata is described.

Due to these facts, the following limitations have been identified (cf. [2], [11], [4], [12]):

- L1. *Limited reusability across different process contexts and metadata standards.* A package suiting the context and the preferences of specific user – e. g. his/her objectives, native language, technological platform – cannot be used by other users having distinct situations and preferences. Moreover, a package developed using a specific standard might not be used in information systems adopting different specifications. As a result, distinct packages have to be developed to meet multiple scenarios or user needs.
- L2. *Limited appropriateness and dynamic adaptability to actual process contexts.* Since the actual context can be considered at runtime only, the appropriateness of the data to the actual process context is limited. Moreover, the use of data excludes the dynamic adaptability a priori. In parallel to data-centric approaches, analogous issues can also be observed with service-oriented approaches. However, in that case, these issues are related to the allocation of services only.

L3. *High development costs.* Since process data is allocated manually at designtime (L1 and L2) high development costs have to be taken into account to create applications appropriate for different contexts and processes.

4. A Semantic Web Service oriented Architecture: Vision and Approach

This section describes our vision as well as the approach to support E-Learning based on semantic web services.

4.1. Vision: Context-Adaptation through automatic Service Discovery

To overcome the limitations described above, we consider the automatic allocation and invocation of functionalities at run-time. Processes are described in terms of composition of user objectives (goals) and abstracts from any specific data and metadata standard. In principle, several available functionalities can fulfill a generic goal. The most adequate functionality is selected and invoked dynamically regarding the demands and requirements of the actual (specific) context. This enables a highly dynamic adaptation to different contexts and actor needs. This vision is radically distinctive to the current state of the art in this area (Section 3). Moreover, using adequate mappings, our process models can be translated into existing process metadata standards and languages. Therefore, it can be reused within multiple run-time environments.

Addressing the limitations L1 and L2 identified in Section 1, we consequently reduce the efforts of creating process models (L3): one unique process model can adapt dynamically to different process contexts and can be translated into different process metadata standards.

4.2. Approach: Semantic Abstraction from Process Metadata, Functionalities and Data

Our approach is fundamentally based on utilizing Semantic Web technologies to realize the following principles:

1. **Abstraction from data and functionalities:** based on SWS technology
2. **Abstraction from process metadata standards:** based on semantic process model descriptions

To support these principles, we adopt a layered approach as well as mapping in order to achieve a gradual

abstraction; Figure 1 depicts an example for business and learning processes.

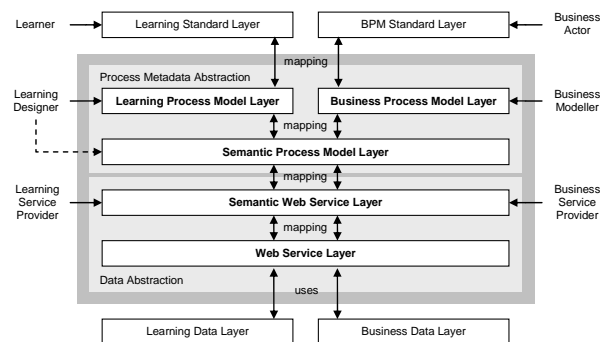


Fig. 1. Semantic Layers and Mappings applied to learning and business processes

Abstraction from Data and Functionalities. To abstract from existing process data and content we consider a Web Service Layer. It operates on top of the data layer and exposes the functionalities appropriate to fulfill specific objectives. This first step enables a dynamic supply of appropriate data and contents, on the basis of a given context. Note that each service exposed at this level may make use of the semantic descriptions of available process data.

In order to abstract from Web service functionalities, we introduce an additional layer: Semantic Web Service Layer. The latter enables the dynamic selection, composition and invocation of appropriate Web services. This is achieved on the basis of formal semantic descriptions, which enable the dynamic matching of service capabilities to specific user goals.

Abstraction from Process Metadata. A first layer is concerned with the abstraction from the current process metadata standards: Semantic Process Domain Model Layer. It allows the description of processes within a specific process domain – business and learning processes in Figure 1 - in terms of domain-specific concepts. This layer is mapped to existing semantic representations of process metadata standards. For instance, Semantic Learning Process Model Layer is aimed at semantically representing the higher-level concepts of a learning process such as learning goal, learner, and learning context.

To achieve a further abstraction from domain-specific process models, we consider an upper level process model: *Semantic Process Model Layer*. For instance, the concepts introduced in the Learning Process Model Layer can be mapped to business processes as described within the semantic Business Process Model Layer.

Based on mappings between the described layers, upper level layers can utilize information at lower level

layers. This particularly includes the dynamic selection and invocation of a Web service (Web Service Layer) from, for instance, a standard-compliant learning application (Learning Application Standard Layer). This can be supported by using a mapping between a specific learning objective within a specific learning situation and a WSMO goal (Section 2). This enables the dynamic selection and invocation of services appropriate to achieve a specific learning objective. As a result, a dynamic adaptation to the individual demands of the learner within a specific learning context is achieved by using existing standard-compliant learning applications.

5. A context-aware Prototype Application for the E-Learning Domain

In order to validate the technical feasibility of our approach, a prototype application has been implemented realizing the introduced principles in the domain of E-Learning. The application implements an initial use case by utilizing the semantic layers and fundamental concepts introduced in the previous section.

5.1. Use Case Scenario

We consider a scenario, where learning resources are allocated at runtime of a process based on a mapping between learning contexts, SWS (WSMO) as well as two different metadata standards - IMS Learning Design [9] and ADL SCORM [1]. In the use case scenario, several learners request to learn three different languages: English, German and Italian. This introduces three possible learning *objectives*. Moreover, it is assumed that each *learner* has one unique preference associated with his/her native language. Objective and native language represents the two parameters that define the actual learning *context*. For instance, if a learner is authenticated as a person with the native language “English” and wants to learn the language “German”, the learner expects to be provided with an English-based online learning unit aimed at teaching the German language.

Following the current approaches, for every individual learner, learning objective as well as metadata standard, a specific learning content package would have to be created (Section 1). Conversely, our approach will enable all learners to use the same learning content process description – compliant with the metadata standards IMS LD and ADL SCORM. The standard-compliant package dynamically meets the multiple learner-specific requirements. Furthermore, used resources – services as well as data - will not be allocated at design-time, but retrieved at run-time selecting among several distributed repositories.

We are aware that the considered scenario is very simple. However, since the general principle and approach - stated in Section 3 - is implemented, the scenario could be easily extended in the future to achieve a dynamic adaptation to more complex learning contexts.

5.2. Staged Ontological Mapping

To actualize our vision (Section 3) and approach, we implemented different ontologies aimed at providing abstract semantic descriptions of learning data, processes and contexts. Figure 2 gives an overview of the main ontological representations considered in our approach as well as the mappings between them.

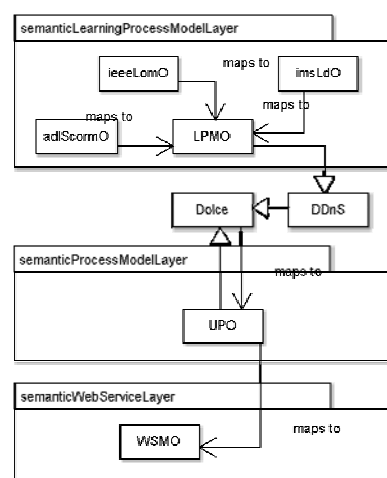


Fig. 2. Conceptual overview of proposed ontological framework

The *Learning Process Modelling Ontology (LPMO)* implements the Semantic Learning Process Model Layer and is mapped to ontological representations of standard learning process models. Currently, representations of the following metadata standards are partially implemented: ADL SCORM 2004 [1] (adlScormO), IMS Learning Design [9] (imsLdO) and IEEE Learning Object Metadata [6] (ieeLomO).

The general process ontology that implements the Semantic Process Model Layer is named *Upper Process Ontology (UPO)* and is currently being developed as part of the SUPER project [17]. SUPER is concerned with applying the described approach to support business processes. UPO will enable the description of a process independent from its specific purpose and could be mapped to domain specific process ontologies such as the LPMO. In order to enable a high level of interoperability of our ontologies, both LPMO and UPO are aligned to the DOLCE foundational ontology [8]. In particular, context descriptions are based on the Descriptions and Situations

module (DDns) [7] of DOLCE. Finally, the UPO is mapped to the WSMO standard (Section 2). As a result, the ontologies introduced above allow us to realise a gradual mapping between a standard E-Learning process representation and WSMO descriptions.

It is important to note that our ontological architecture enables the mapping not only between multiple semantic layers but also within a specific semantic layer. For instance the LPMO concepts can be mapped to existing semantic descriptions of learning related concepts.

5.3. SWS-oriented Architecture

Our current implementation makes use of standard runtime environments: IRS III [3] is used as SWS broker as well as development environment for WSMO descriptions; the Reload software suite [16] is used for editing and runtime processing of IMS LD and ADL SCORM content. Several distributed Web service and data repositories provide the functionalities to achieve learning goals. Figure 3 outlines the Semantic Web Service Oriented Architecture (SWSOA) used in the current prototype. The defined architecture realizes all of the principles described in Section 4.

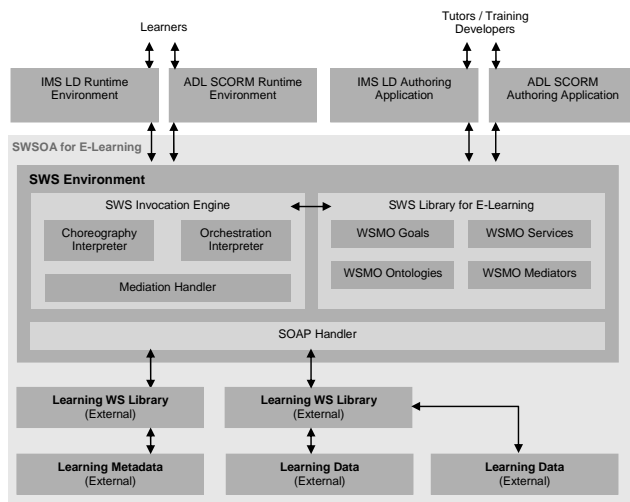


Fig. 3. SWS-based software architecture as utilized in the prototype application

To support the scenario described in Section 5.1, the following elements had to be provided within the general architecture presented above:

1. *Learning Web services libraries.* Web services were provided to support the authentication of the learner, the retrieval of semantic learner profiles, learning metadata and learning contents. Web services utilized

in this demonstrator were partly developed within the LUISA project [13].

2. *WSMO Ontologies.* To implement the Semantic Learning Process Model Layer, initial semantic representations of ADL SCORM, IMS LD, the LPMO and content objects provided by the Open Learn Project [15] have been created. To support individual learner preferences, we particularly consider semantic learner profiles, describing the native language of every learner. All ontologies have been developed by using OCML [5] as ontology language.
3. *Mappings between semantic layers as well as metadata standards.* We created mappings between the initial implementations of semantic representations of metadata standards (IMS LD, ADL SCORM) and the LPMO as well as WSMO. For instance, we defined a mapping between the *lpmo:Objective* and the objective description used within the IMS LD metadata (*imsl:Objective*). Moreover, semantic learning object descriptions based on the LPMO were mapped to OpenLearn content units (*ol:Content Unit*), whereas the language of a content unit (*ol:Language*) was mapped to the native language of a learner (*lpmo:Language*). Since the UPO is not currently supported by any run-time environment, the LPMO objective is directly mapped to a WSMO goal. Figure 4 depicts the main ontological mappings as defined in our prototype. The defined mappings are performed at runtime as specific functionalities. These functionalities are exposed as Web services, which are part of an external learning Web services Library.
4. *WSMO Goal, Web Service, and Mediator descriptions* of the available Web services, based on the concepts defined in the WSMO ontologies.

5. *Standard-compliant content packages describing the learning activities.* IMS LD and ADL SCORM compliant learning processes were provided and included into IMS content packages. Instead of grounding the learning activities to static learning data, no static resources were associated with these learning processes. In contrast, only references to the described WSMO goals were associated with every learning activity. This mapping is achieved by associating a learning activity within the learning metadata with HTTP references to a web applet enabling to request the achievement of a specific WSMO goal from the SWS broker.

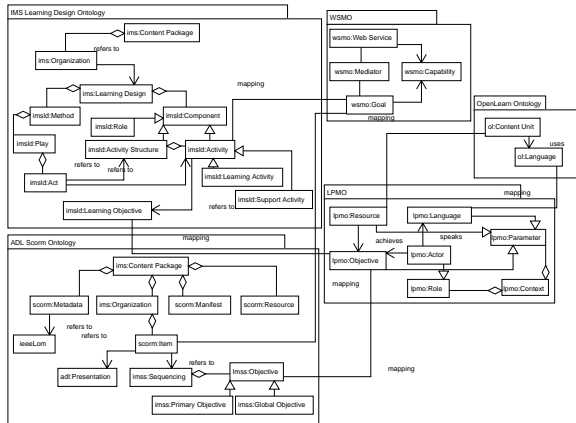


Fig. 4. Ontological mappings implemented and utilized in the prototype application

6. Dynamic Context-Adaptation at Runtime

At runtime, an end-user (learner) accesses a standard-compliant player and loads the content packages compliant with IMS LD and ADL SCORM as defined in bullet 5 of the previous section. The learning application then sequentially presents all of the learning activities that would have to be performed. An initial activity first authenticates the learner and retrieves the semantic learner profile description. The WSMO goal associated with such an activity is invoked, and the SWS broker dynamically selects and invokes the WSMO Web service showing the appropriate capabilities to achieve the specified goal. At this point, the learner preferences are set within the player environment.

In the same way, when the learner selects an individual objective within the standard content package, our infrastructure dynamically selects and invokes semantic Web services according to his/her preferences and stated objectives. For instance, if a learner is authenticated as an English-speaking person (`lpmo:Language=English`) and uses an ADL SCORM-based package to learn the language German, a `scorm:Item` with the `imss:Objective=Learn German` is mapped to a WSMO Learn-German-Goal.

The accomplishment of such a goal involves the selection, orchestration and invocation of different Web services, which perform the described mappings and retrieve appropriate learning content. Therefore, a mapping between a WSMO goal and WSMO Web services was implemented based on the WSMO framework. Usually, different services are able to achieve a given goal. This means, several Web services are linked to a specific WSMO goal by using a dedicated WSMO mediator (WSMO WG Mediator).

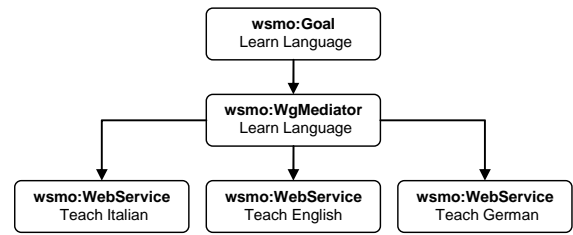


Fig. 5. Linking of WSMO goals, mediators and Web services

Based on semantic capability descriptions of available services, the most appropriate service can be selected to suit a given goal. Listing 1 shows a portion of OCML code of a WSMO capability description of a Web service able to provide learning content to teach the language German.

```
(DEF-CLASS ACHIEVE-OBJECTIVE-GERMAN-WS-CAPABILITY
(CAPABILITY)
?CAPABILITY
((USED-MEDIATOR :VALUE ACHIEVE OBJECTIVE-GERMAN-MED)

(HAS-ASSUMPTION
:VALUE
(KAPPA
(?WEB-SERVICE) (= (WSMO-ROLE-VALUE ?WEB-
SERVICE 'HAS-IMSS-OBJECTIVE) "Learn German"))))
```

Listing 1. Portion of source code of a Web service capability description

In Listing 1, a WSMO description defines the assumption of a Web service that the objective provided by the ADL SCORM content package is valued by “Learn German”. The WSMO service used in our prototype application to achieve this objective requires an orchestration of several services to support this learning objective. Therefore, the goal achievement triggers a sequence of services needed to get information about the actual learner, to retrieve content appropriate to his specific objective as well as to select content appropriate for his specific requirements.

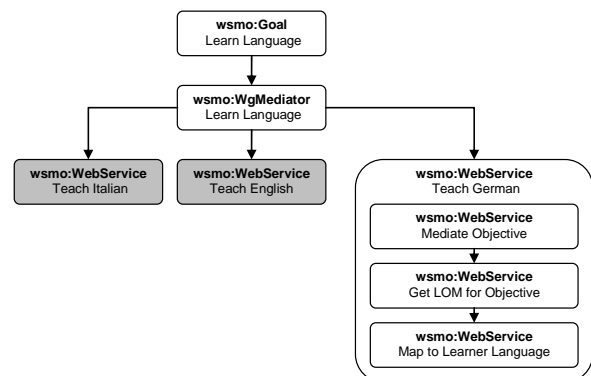


Fig. 6. Orchestration of Web services to achieve a specific goal aimed at language learning

For instance, if a learner is authenticated as an English-speaking person (*lpmo:Language=English*) and uses an ADL SCORM-based package to learn the language German, an *imsslitem* with the *imss:Objective=Learn German* is mapped to a specific WSMO-Goal. The accomplishment of such a goal involves the selection, orchestration and invocation of different Web services, which perform the described mappings and retrieve appropriate learning content: (i) the *imss:Objective* is mapped to the *lpmo:Objective* concept; (ii) the *lpmo:Objective* is used to retrieve the semantic learning object metadata (LOM) of an appropriate learning object; (iii) the retrieved LOM is used to obtain an Open Learn learning unit appropriate to the individual language of the learner and its current objective. Each of these goals is accomplished by a distinct Web service dynamically selected at runtime.

The retrieved learning object is finally presented in the ADL SCORM runtime environment.



Fig. 7. Reload ADL SCORM Design Player while dynamically invoking SWS for E-Learning

Figure 7 depicts a screenshot of the Reload ADL SCORM 2004 Package Viewer while presenting a standard-compliant ADL SCORM 2004 content package and dynamically invoking SWS appropriate to fulfill the given learning objective “Learn German”. Besides several limitations, our current prototype implements the basic approach of a standard-compliant SWSOA for E-Learning as described here.

7. Conclusion and Future Work

In this paper, we introduced an innovative approach to support process models based on a dynamic run-time invocation of Web services. This approach is radically distinctive to the current state of the art in this area, which is based on the manual allocation of process resources (data or services) at design-time. Adopting Semantic Web

technologies – in particular Semantic Web Services - we overcome current limitations (Section 1) and support a high level of standard-compliance and re-usability. To summarize, the following contributions should be taken into account:

- Dynamic adaptation to specific process contexts at runtime;
- Automatic allocation of distributed resources based on comprehensive semantics;
- High reusability across process contexts;
- Metadata standard-independence as well as compliance;
- Reuse and integration of distributed process resources;
- Decrease of development costs.

Furthermore, our approach can lead to contributions for developing domain-specific SWS applications in general, since we consider mappings between the WSMO standard and higher-level process modeling as well as domain specific process modeling standards. This enables the development of complex SWS-based applications and therefore several benefits are envisaged:

- Re-usability of SWS-based applications based on semantic mappings with existing process metadata standards;
- Utilization of established standard-compliant process metadata runtime environments to implement complex SWS- based architectures.

To prove the benefits of the proposed approach, we described an initial prototype application. The current prototype implements the basic approach of a standard-compliant SWSOA for E-Learning and will be extended in the future in order to address existing limitations and cover more comprehensive use cases.

Since this work is ongoing research, next steps have to be concerned with the implementation of complete ontological representations of the introduced semantic process layers as well as of current process metadata standards and their mappings. Besides that, future work will be concerned with the mapping of semantic process models across different process dimensions – e. g. business processes or learning processes to enable a complete integration of a SWSOA in an organizational process environment.

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