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A Semantic Web Services-based Infrastructure for Context-Adaptive Process Support

Stefan Dietze, Alessio Gugliotta and John Domingue
Knowledge Media Institute
Open University
Milton Keynes, MK7 6AA, UK
E-Mail: {s.dietze, a.gugliotta, j.b.domingue}@open.ac.uk

Abstract

Current technologies aimed at supporting processes – whether it is a business or learning process – primarily follow a metadata- and data-centric paradigm. Whereas process metadata is usually based on a specific standard specification – such as the Business Process Modeling Notation (BPMN) or the IMS Learning Design Standard – the allocation of resources is done manually at design-time, and the used data is often specific to one process context only. These facts limit the reusability of process models across different standards and contexts. To overcome these issues, we introduce an innovative Semantic Web Service-based framework aimed at changing the current paradigm to a context-adaptive service-oriented approach. Following the idea of layered semantic abstractions, our approach supports the development of abstract semantic process model - re-usable across different contexts and standards - that enables a dynamic adaptation to specific actor needs and objectives. To illustrate the application of our framework and establish its feasibility, we describe a prototypical application in the E-Learning domain.

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 process – e. g. a learning or business process - that makes use of predefined resources. The process metadata is usually based on proprietary or standard-specific specifications, such as the Business Process Modelling Notation (BPMN) [18] or the IMS Learning Design standard [11]. Furthermore, the resources are sets of data useful in a specific process context.

For instance, in the E-Learning domain 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 data as well as the metadata that describes the learning process. The latter specifies the sequence to be followed by the learner for accessing the physical data.

Due to such metadata- and data-based approaches, several general limitations and issues are observable across different process domains. They can be summarized as follows:

L1. Limited reusability 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. 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. Functionalities support the process accomplishment by delivering to the user the adequate resources. 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 gradual abstraction from the functionality selection, composition, and invocation to the process context adaptation; in particular, we use IRS-III [5] as SWS broker and WSMO [22] as reference ontology for describing services; 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 rest of the paper is organized as follows: Section 2 provides background information about SWS, IRS-III and WSMO. Section 3 outlines the limitations of existing approaches for supporting organizational processes. On

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the basis of such an analysis, we introduce our vision and approach in Sections 4. In Section 5 and Section 6, we detail our approach by using E-Learning as application domain. Finally, we provide a conclusion and an outlook to future work in Section 7.

2. Semantic Web Services: the IRS-III approach

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 [5], 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 [7]. IRS-III adopts the Web Service Modelling Ontology (WSMO) [22] 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 fulfill. 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.

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], [13], [6]):

L1. *Limited reusability across different process contexts and metadata standards*. A package suiting the context and the preferences of a 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.* Due to L1 and L2, high development costs have to be taken into account to provide appropriate process support.

4. Vision and Approach: Automatic Resource Allocation based on SWS

This section introduces our vision and approach to overcome the limitations described above.

4.1. Vision

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 abstract 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,

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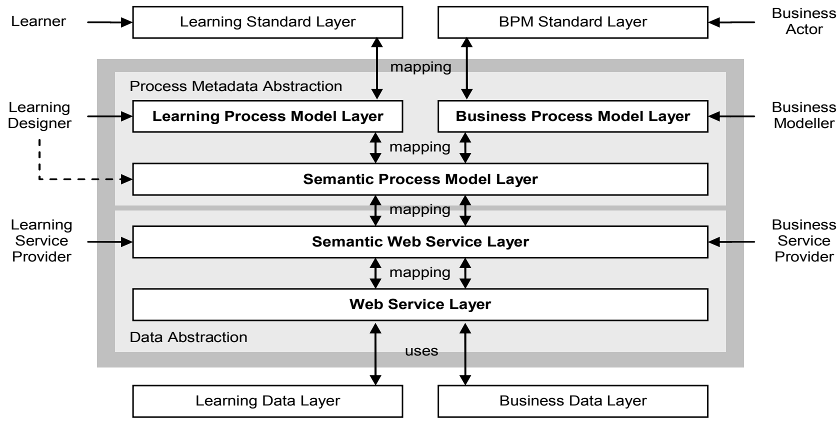

Figure 1. Semantic Layers and Mappings applied to learning and business processes

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 3, 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 Abstractions

To support our vision, we adopt a layered approach in order to achieve a gradual abstraction. Figure 1 depicts an example applied to business and learning processes.

Abstraction from Data and Functionalities based on SWS technology.

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 over the 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 based on semantic process model descriptions

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, the (*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*. This layer enables the mapping between different process domains – e. g. to map between a Learning Process Model and a Business Process Model.

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 business process model application (BPM Standard Layer).

5. An Ontological Stack for the E-Learning Domain

To actualize our vision and approach (Section 4), we consider the E-Learning domain. We implemented different ontologies aimed at providing abstract semantic descriptions of learning data, processes and contexts. Figure 2 gives an overview of the ontologies considered in our approach as well as the mappings between them.

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 [11] (imsLdO) and IEEE Learning Object Metadata [8] (ieeeLomO).

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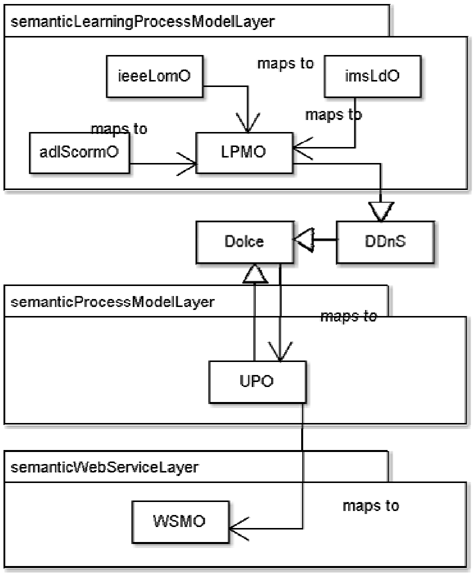

Figure 2. Conceptual overview of proposed ontological framework

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 [22]. UPO will enable the description of a process independent from its specific purpose and could be mapped to domain specific process ontologies such as our LPMO. In order to enable a high level of interoperability of our ontologies, both LPMO and UPO are aligned to the DOLCE foundational ontology [10]. In particular, context descriptions are based on the Descriptions and Situations module (DDns) [9] 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. LPMO has to be perceived as the central ontology within our architecture. It describes the semantics of a learning process from a general point of view, independently from any learning technology standard. To afford this, we represented into the ontology the archetyped concepts only. Figure 3 depicts the main concepts of the proposed LPMO as well as some mappings to key concepts of different semantic layers. It is important to note that a LPMO learning objective is mapped to the upo:Goal (Semantic Process Model Layer). The latter is furthermore mapped to the wsmo:Goal (Semantic Web Service Layer) to enable a capability-based matching of appropriate Web services.

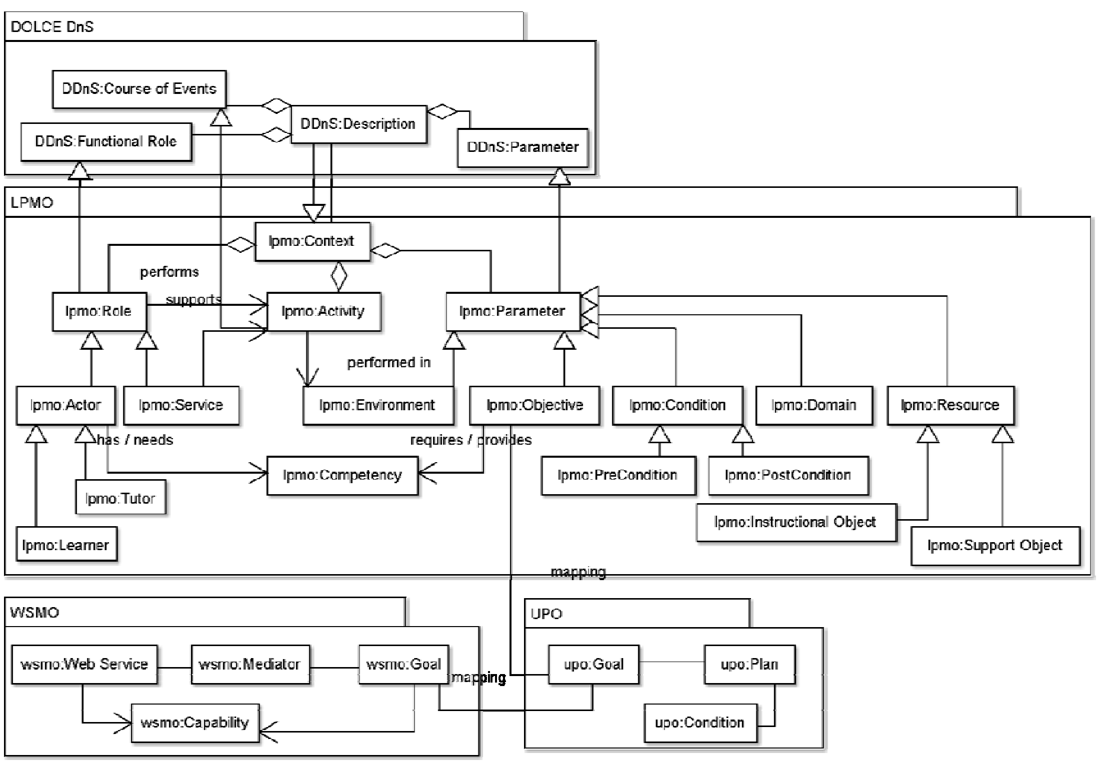

Figure 3. Conceptual model of parts of the LPMO and key mappings to the UPO and the WSMO framework.

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6. A Prototype Application: An adaptive IMS LD learning package to support Language Learning

In order to validate the technical feasibility of our approach, a prototype application has been implemented mapping to IMS Learning Design [11]. The application implements an initial use case by utilizing the semantic layers and fundamental concepts introduced in Section 4 and Section 5, respectively.

6.1. Scenario

We consider a scenario where 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 and learning objective a specific learning content package would have to be created (Section 3).

Conversely, our approach will enable all learners to use the same learning content package - an IMS LD compliant content package -, which dynamically meets the multiple learner-specific requirements (Section 4). Furthermore, the content will not be pre-defined at design-time, but retrieved at run-time selecting among several available repositories.

We are aware that the considered scenario is very simple. However, our approach already introduces an improvement compared to other approaches. Since the general principle and approach stated in Section 4, the scenario could be easily extended in the future to achieve a dynamic adaptation to more complex learning contexts.

6.2. SWS-oriented Architecture

Our current implementation makes use of standard run-time environments: IRS III [5] is used as runtime processing unit - SWS broker - as well as development environment for WSMO descriptions; the Reload Learning Design Editor and Player [21] are used as editing and runtime processing environment of IMS LD. Figure 4 outlines the Semantic Web Service Oriented Architecture (SWSOA) used in the current prototype. The defined architecture actualizes all of the principles described in Section 4.

To support the scenario described in Section 6.1, 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 [17].
2. *WSMO Ontologies*. To implement the Semantic Learning Process Model Layer, initial semantic

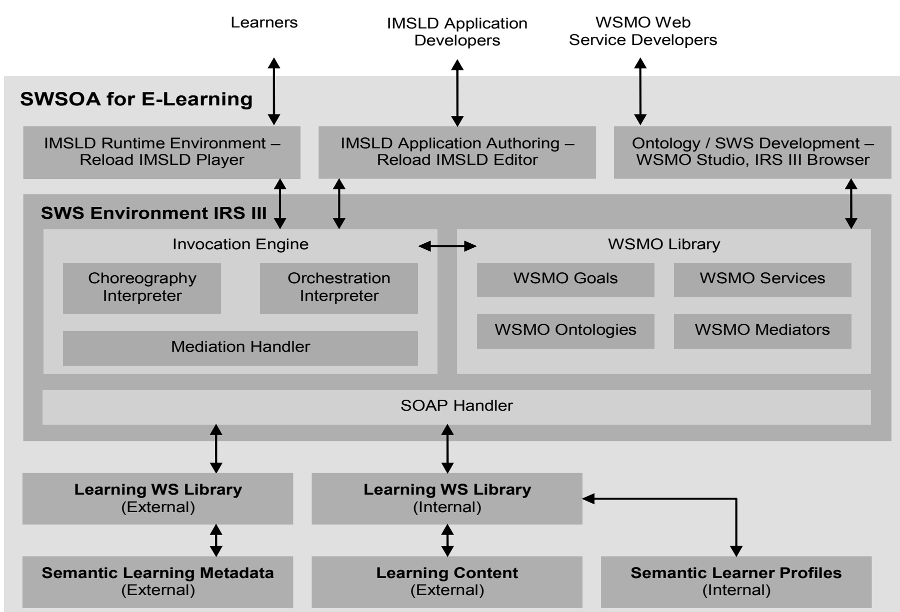

Figure 4. SWS-based software architecture as utilized in the prototype application.

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representations of the LPMO, IMS LD and content objects provided by the Open Learn Project [19] have been created. To support individual learner preferences, we particularly considered semantic learner profiles, which describe the native language of every learner. All of the ontologies have been developed by using OCML [7] as ontology language.

3. *Mappings between the semantic layers as well as the IMS LD standard*. We created mappings between the initial implementations of semantic representations of the IMS LD standard, the LPMO and WSMO. For instance, we defined a mapping between the *lpmo:Objective* and the objective description used within the IMS LD metadata (*imsld: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, we do not define the mappings to the UPO. Instead of that, the LPMO objective is directly mapped to a WSMO goal. Figure 6 depicts the main ontological mappings as defined in our prototype. The defined mappings are performed at run-time as specific functionalities. These functionalities are exposed as Web services, which are part of the internal Learning WS Library.
4. *WSMO Goal, Web Service, and Mediator descriptions* of the available Web services, based on the concepts defined in the WSMO ontologies.
5. *IMS LD-compliant content package describing the learning activities.* The learning process is defined in terms of learning activities (*imsld:Activities*) as well as corresponding sequencing information. Instead of grounding the learning process activities to static learning resources, we only associated the respective IMS LD metadata definitions with the appropriate WSMO-Goal descriptions. Such an association is achieved by linking IMS LD learning activities to a Web applet via HTTP-references. The HTTP-reference contains the appropriate WSMO goal achievement request for the SWS broker. The Web applet will simply trigger such a request.

6.3. Dynamic Adaptation at Runtime

At run-time, an end-user (learner) accesses the Reload IMS LD player and loads the IMS-LD-compliant package defined in bullet 5 of the previous section. The Reload IMS LD player 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 IMS LD player environment.

In the same way, when the learner selects an individual objective within the IMS LD 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 IMS LD package to learn the language German, an *imsld:Activity* with the *imsld: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.

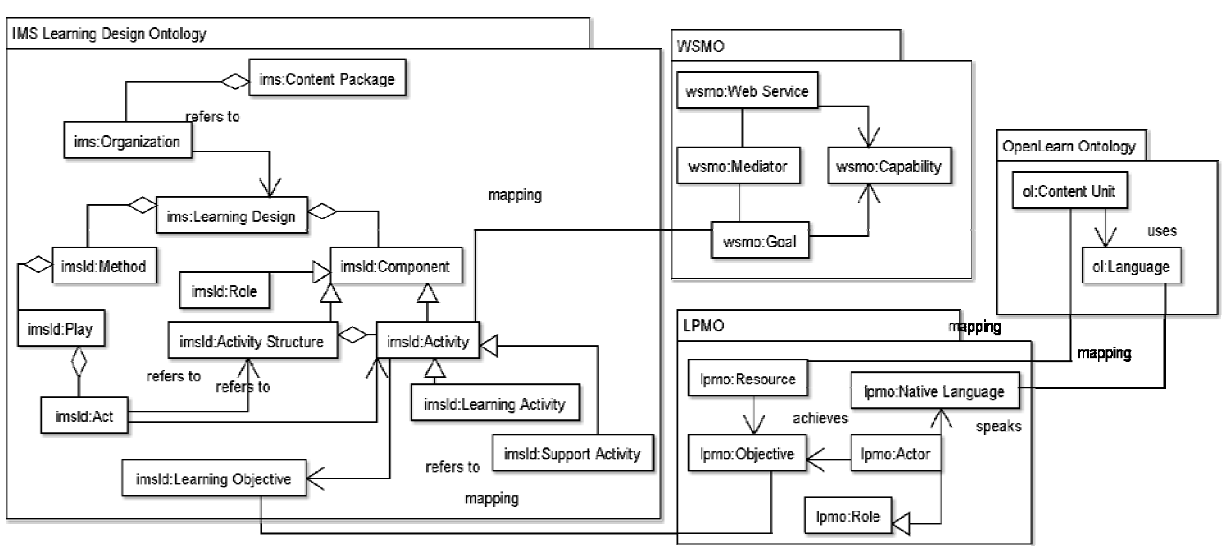

Figure 5. Ontological mappings implemented and utilized in the prototype application.

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The following listing shows a portion of the capability description of a Web service, which is able to provide learning content to teach German. Specifically, the capability assumes that the objective provided by the IMS LD package has to be “Learn German”.

```
(DEF-CLASS ACHIEVE-IMSLD-OBJECTIVE-GERMAN-WS-
CAPABILITY (CAPABILITY)
   ?CAPABILITY
     ((USED-MEDIATOR :VALUE
       ACHIEVE IMSLD OBJECTIVE-GERMAN-MED)
      (HAS-ASSUMPTION :VALUE
      (KAPPA(?WEB-SERVICE) (= (WSMO-ROLE-VALUE
               ?WEB-SERVICE
               'HAS-IMSLD-OBJECTIVE)
            "Learn German")))
```

Such a Web service orchestrates the following WSMO goals: (i) the *imsld-Objective* is mapped to the *lpmo:Objective* concept; (ii) the *lpmo:Objective* is used to retrieve the semantic metadata of an appropriate learning object; (iii) the retrieved learning object identifier 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 run-time. The retrieved learning object is finally presented in the IMS LD runtime environment.

Figure 6 depicts a screenshot of the Reload IMS LD Player while presenting the developed standard-compliant IMS Content Package and dynamically invoking SWS appropriate to fulfill the given learning objective “Learn German”.

7. Conclusion and Future Work

In this paper, we introduced an innovative approach to support process model 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 the limitations described above and support a high level of standard-compliancy and re-usability. To summarize, the following contributions should be taken into account:

- Dynamic adaptation to specific process contexts at runtime;
- Automatic allocation of resources based on comprehensive semantics;
- High reusability across process contexts;
- Platform- and standard-independence;
- Reuse and integration of existing 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

Figure 6. Reload IMS Learning Design Player while dynamically invoking SWS for E-Learning

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- Utilization of established standard-compliant software 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. However, the described approach is already applied to another E-Learning standard: ADL SCORM 2004.

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. To provide a valid quantification of the benefits we are expecting from our approach, we are going to provide concrete values based on case studies to illustrate the formalization introduced in Section 3. 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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