A Linked Data-driven & Service-oriented Architecture for Sharing Educational Resources

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Abstract. The two fundamental aims of managing educational resources are to enable resources to be reusable and interoperable and to enable Web-scale sharing of resources across learning communities. Currently, a variety of approaches have been proposed to expose and manage educational resources and their metadata on the Web. These are usually based on heterogeneous metadata standards and schemas, such as IEEE LOM or ADL SCORM, and diverse repository interfaces such as OAI-PMH or SQI. Also, there is still a lack of usage of controlled vocabularies and available data sets that could replace the widespread use of unstructured text for describing resources. On the other hand, the Linked Data approach has proven that it offers a set of successful principles that have the potential to alleviate the aforementioned issues. In this paper, we introduce an architecture and prototype which is fundamentally based on (a) Linked Data principles and (b) Service-orientation to resolve the integration issues for sharing educational resources.

Keywords: Linked Services, Semantic Web, Linked Data, SOA, eLearning, Technology-enhanced Learning.

1 Introduction

Recently, learning resource repositories have been widely used in higher education to enhance the learning process for both students and course creators or teachers. One important feature of Web-based learning repositories is to make educational resources reusable and shared. Although most of the learning repositories provide open access to their educational resource repositories, the integration process is still costly as different learning repositories are isolated from each other and based on different implementation standards [18]. Therefore, an intuition approach is to federate different learning repositories from different institutes, which can foster the aims of reusing and sharing educational resources without costly duplicating them into local learning repositories. Following such an approach, four major research challenges need to be taken into consideration to ensure Web-scale interoperability:

1. *Retrieving distributed data from heterogeneous Learning repositories*: distributed heterogeneous data and services are neither widely reused nor integrated into learning application environments sufficiently. Standardized methodologies to solve heterogeneities between terminologies used by distinct data or service providers are not available. Therefore, interoperability and scalability of current E-Learning applications is limited [17].

2. *Dynamic metadata mediation*: since learning contents and their metadata are stored in heterogeneous repositories, the metadata and the services consuming the content are usually described by using distinct schemas such as Dublin Core[1] and IEEE Learning Object Metadata (LOM) [11], and a variety of vocabularies accordingly. Therefore, to achieve interoperability, distinct schemas need to be mapped and aligned.

3. *Extensible learning environment*: in highly distributed Web-based environments, frequent changes occur to available interfaces. That is, services as well as repositories are usually added, modified or removed regularly based on the new requests and new considerations.

4. *Enriching existing educational resource metadata*: many educational resource metadata stored in different Web repositories are non-aligned, incomplete, and poorly structured, i.e. free text is still widely used for describing educational resources. Therefore, to allow machine-processing and Web-scale processing, distributed educational metadata needs to be enriched, that is transformed into structured and formal descriptions. This may lead to wider interoperability by linking to existing vocabularies, schemas and taxonomies.

The most recent development of the Semantic Web [1] is Linked Data (LD) [2] which has successfully established a set of principles to expose data and metadata on the Web and has led to the widespread availability and use of schemas, vocabularies and data sets spanning across all application domains. In that, the Linked Data approach offers opportunities to substantially alleviate the challenges addressed above.

In this paper we introduce a Linked Data-driven & Service-oriented architecture to address the discussed issues above. The four major contributions are:

1. Linked Data-principles are applied to model and expose metadata of both educational resources and educational services and APIs. In this way, not only resources are connected but also services' description and resources are exposed in a standardized and accessible way.

2. Existing heterogeneous and distributed learning repositories, i.e. their Web interfaces (services) are integrated on the fly by reasoning and processing of Linked Data-based service semantics (see step 1).

3. Metadata retrieved from heterogeneous Web repositories, for instance IEEE LOM resource metadata, is automatically lifted into RDF and exposed as Linked Data, exposed and accessible based on Linked Data principles.

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[1] http://dublincore.org/documents/dces/

A set of RESTful APIs is developed on top of the integration framework to allow third party applications to consume and interact with the data exposed by our approach.

The remaining sections of the paper cover: Section 2 discusses the background and motivation of our work. Section 3 illustrates the overview of our proposed architecture. Section 4 describes the different parts of the architecture while Section 5 introduces an educational application from the biomedical field. Section 6 discusses the related work and Section 7 finally concludes the paper.

2 Background and Motivation

One use case motivating a general architecture to address above research problems is a federated search across educational data crossing distributed Web repositories. More specifically, the user would search educational resources based on, for instance, a set of keywords, content types, educational subjects or preferred language. That however requires to: (1) integrate suitable resource stores via their APIs and Web services that can deliver correct educational resources; (2) dynamically invoke the suitable services and mediate the results into a single standard and meaningful response; (3) transform and automatically expose it as structured well-interlinked Linked Data.

One way to enable educational resources inside individual learning repositories to be accessed and integrated through distributed environments is to develop Web services and open APIs on top of educational repositories. However, this naturally introduces a heterogeneous API landscape, as it is characteristic for the current Web. For example, one Web service interface from the PubMed[2] repository provides an OAI-PMH-based REST-ful service where response messages are based on XML. Other Web services offering educational Linked Data from The Open University[3] provide a SPARQL [25] end point where response messages are RDF-based. Furthermore, different services may also operate on a certain language based on the target user groups. Meanwhile, there are multiple types of educational resource metadata schema such as IEEE LOM and Dublin Core. Therefore, dynamic mediation between different metadata schemas and API interfaces is required. However, the current metadata standards are mainly stored and exposed based on XML and relational databases and consist largely of poorly structured text keywords, lacking formal semantics and interlinking with established vocabularies to allow more advanced discovery and inference mechanisms. That leads also to highly ambiguous descriptions, which, considering the medical domain, for instance, can prove as crucial factors for the value and quality of resource descriptions.

Although some efforts have been made on providing an IEEE LOM-RDF binding[4], this early work was (a) discontinued a few years ago and (b) only focused on the binding aspect rather than further working towards a Linked Data-principles compliant approach, e.g. by reusing elements of established Linked Data schemas or linking metadata to established Linked Data vocabularies.

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[2] http://www.ncbi.nlm.nih.gov/pubmed/
[3] http://data.open.ac.uk/
[4] http://dublincore.org/educationwiki/DCMIIEEELTSCTaskforce/RDFPAR

While our work considers the integration of arbitrary data on the Web, we use the mEducator educational resource RDF description schema (see mEducator project[5]) as a schema according to which we lift existing (non-RDF) metadata for further processing and exposure as fully interlinked Linked Data. The mEducator RDF schema[6] is fully compliant with Linked Data principles.

The other important factor of the challenge is the distributed and Service-oriented environment. The services operating on educational repositories are very dynamic, in that they might change behaviors and interfaces according to new requirements. Also, new services (and stores) regularly join the environment while others might disappear. Therefore, the extendable environment feature is a very important requirement mainly considering supporting the modification, adding or removal of services without any impact to upper layers (e.g. existing educational applications and user interfaces). Therefore, facilitating easy-to-use service representation based on standard service vocabularies (e.g. SAWSDL [15] and WSMO-Lite [13]) is an important requirement to allow third party service providers to independently provide meaningful service descriptions and interlink their services with the environment.

In this paper, we are building on top of two fundamental technologies which facilitate data interoperability (a) Semantic Web technologies to facilitate data interoperability and (b) Services-orientation to allow interoperability at the repository level.

The four principles of LD are [2].

1. Use URIs to identify things.
2. Use HTTP URIs so that these things can be referred to and looked up ("dereference") by people and user agents.
3. Provide useful information about the "thing" when its URI is dereferenced, using standard formats such as RDF-XML.
4. Include links to other, related URIs in the exposed data to improve discovery of other related information on the Web.

The above principles have proved largely successful throughout the past years, leading to an ever increasing amount of LD-compliant schemas and data-sets[7] as well as general-purpose tools and APIs allowing to generate and interact with LD.

Linked services adopt the LD principles to support publishing of service annotations as LD, expressed in terms of a simple generic service conceptual model that can be consumed by both humans and machines. While there is a growing set of tools supporting the development and processing of Linked Services, the iServe platform[8] is one of the implementations to publish Linked Services [16]. In order to cater for interoperability, iServe uses what can essentially be considered the maximum common denominator between existing Semantic Web Services (SWS)

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[5] http://www.meducator.net/

[6] http://purl.org/meducator/ns/

[7] http://richard.cyganiak.de/2007/10/lod/

[8] http://iserve.kmi.open.ac.uk/

formalisms that we refer to as the Minimal Service Model (MSM). Services are defined as having a number of operations. Each operation has an Input and Output *MessageContent* and Faults. *MessageContent* is defined to may have *MessageParts*. Additionally, iServe adopts the SAWSDL, WSMO-Lite and hRESTS [14] vocabularies. The SAWSDL vocabulary is used to capture modelReference, liftingSchemaMapping and loweringSchemaMapping that are important for lifting and integrating services' outputs. WSMO-Lite extends SAWSDL with a model to specify the semantics of the particular service annotations. The hRESTS vocabulary allows modeling of additional information necessary for Web APIs.

3 Overall Architecture

In this section, we provide an overview of a general-purpose framework which aims at (i) integrating heterogeneous educational resources and (ii) exposing its metadata as well-structured and interlinked Linked Data. Our overall proposed architecture includes three layers: *(Web) data and service layer*, *Data and service integration layer* and *Application and presentation layer* that are shown in Figure 1.

- *The (Web) data and service layer* consists of available educational resource metadata, Web services and data sources such as the ones part of the Linked Data cloud.
- *The data and service integration layer* is based on the Linked Services approach, exploiting Linked Data based service annotation, the APIs to broker services and an RDF repository for exposing enriched educational resource data. The iServe [16] & SmartLink [6] repositories store two different kinds of service annotations separately, namely functional and non-functional service annotations.
- *The application and presentation layer* uses the APIs provided by the data & services integration layer to interact with underlying data & services and provides an interface to end-users.
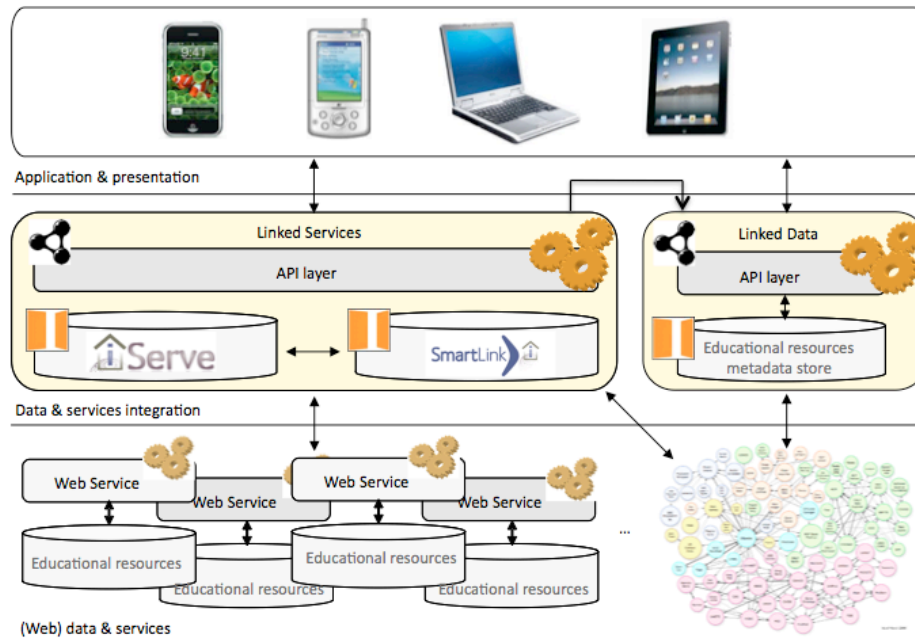
Fig. 1. Architecture overview.

The proposed architecture supports a particular methodology as below:

1. *Query across distributed educational repositories*: The Linked Services environment allows distributed queries across distributed and heterogeneous educational repositories (via their services/APIs) on the fly while query results will be lifted into RDF automatically. The Linked Services component facilitates dynamic discovery of suitable stores/services (for instance services matching a particular user language or subject) and execution by adhering to particular execution constraints. New repository services can be added by simply adding semantic annotations of the services via our Linked Services annotation environments. The service discovery engine searches the semantically suitable services by matching service annotations with service request parameters that are passed through the application layer. Suitable services for a given query are invoked sequentially. Finally, different service outputs are lifted into the RDF mEducator RDF schema. That way, heterogeneous service responses are consolidated into a single schema that simplifies further processing by the application layer.

2. *Storage of selected metadata in RDF store:* Exposing of retrieved results as Linked Data/RDF in an RDF store. The RDF repository supports two main purposes: (1) allows content providers who do not have a metadata publishing platform to publish their educational resource metadata through the application layer; (2) allows metadata sets from the distributed learning

repositories (Step 1) to be enriched and exposed in a Linked Data-compliant way. The RDF store is implemented based on a Sesame RDF store with a BigOWLim and mEducator RDF schema compliant repository and a dedicated REST API. Each resource entity owns a unique URI identifier that can be dereferenced.

3. *Data enrichment and interlinking:* Metadata can be enriched based on LD datasets, e.g. particular ones from the biomedical field. That is of particular importance for metadata properties such as keywords, discipline or subject where established vocabularies exist on the Web, and in particular the LD cloud. Enrichment takes advantage of available APIs such as the ones provided by *Bioportal*[9], which allow access to a vast number of established taxonomies and vocabularies, such as *SNOMED*[10], *MESH*[11] or *Galen*[12]. That way, unstructured free text, for instance the keyword "Thrombolysis", is enriched with unique URIs of structured LD entities - such as *http://purl.bioontology.org/ontology/SNOMEDCT/89551006* which refers to a related concept within the *SNOMED Clinical Terms* ontology – which allow not only further reasoning on related concepts but also enables users to query for resources by using well-defined concepts and terms as opposed to ambiguous free text.

4   Data and Services integration: the Linked Services Approach

Our current implementation of the data and service integration layer builds on existing Semantic Web Services research, namely the Linked Services approach. As discussed in Section 2, the Linked Services approach uses a rather lightweight service annotation schema and applies Linked Data principles to the services domain. Based on RDF models describing core elements of the service (e.g., operations, input, output) services are discovered and executed based on a given set of service consumer constraints.

To this end, we use the iServe open platform for publishing semantic annotations of services based on a direct application of LD principles [16]. As introduced previously, the MSM – iServe's underlying RDF schema - focuses on functional properties while the SmartLink service annotation model focuses on non-functional properties (NfP) as extension to the MSM. SmartLink NfP data are stored in a dedicated RDF store that is synchronized with the iServe repository at runtime.

The whole lifecycle of the Linked Services approach includes 3 major steps:

1. Editing and publishing service annotations through the SmartLink service annotation online interface. SmartLink allows service providers to use a Web form to easily annotate service properties step-by-step following the extended MSM schema. Meanwhile, service requesters can also look up services

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[9] http://www.bioontology.org/wiki/index.php/BioPortal_REST_services

[10] http://www.ihtsdo.org/snomed-ct/

[11] http://www.nlm.nih.gov/mesh/

[12] http://www.co-ode.org/galen/

manually apart from using our automatic API-based service discovery and invocation approach.

2. Services discovery based on service request: a set of RESTful APIs has been developed to let third-party applications send service requests distinguished by different parameter values to discover semantically suitable educational resource services.

3. Services invocation and lifting: finally, the identified services are invoked and heterogeneous service responses are lifted to comply with the mEducator Learning Content RDF description schema.

The rest of this section will introduce above steps in details.

4.1. SmartLink: Linked Services editor and search environment

In order to provide a Linked Services editor that allows the annotation of Web services and Web APIs without any pre-existing documentation, a services annotation and search tool is developed, *SmartLink[13]* (SeMantic Annotation enviRonmenT for Linked services). SmartLink allows annotation of Web services and Web APIs based on the MSM from scratch, that is, without any pre-existing services documentation such as WSDL or HTML files, as assumed by existing annotation tools (Section 1). SmartLink operates on top of LD stores such as iServe and is an open environment accessible to users simply via OpenID[14] authentication.

SmartLink exploits an extension of the MSM schema including a number of additional non-functional properties. These non-functional properties cover, for instance, contact person, developer name, Quality of Service (QoS), development status and service license. MSM-schema properties are directly stored in iServe, while additional properties are captured in a complementary RDF store based on OpenRDF Sesame[15]. The following Figure 2 depicts the overall architecture of the SmartLink environment.

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[13] http://smartlink.open.ac.uk & http://kmi.open.ac.uk/technologies/name/smartlink
[14] http://openid.net/
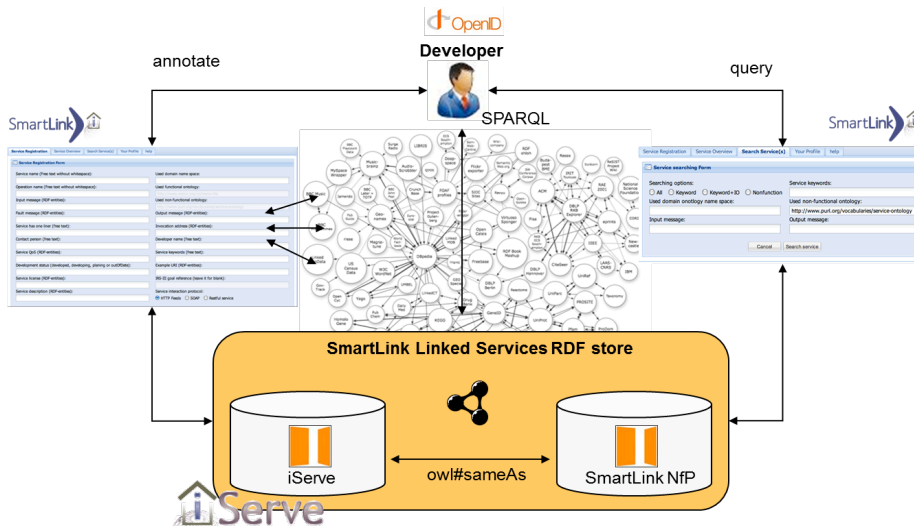[15] http://www.openrdf.org/

Fig. 2. SmartLink process and architecture.

Being a Linked Data-compliant environment, one of the core features of MSM is the capability to associate service descriptions with so-called *model references* that refer to RDF descriptions in external vocabularies defining the semantics of the service or its parts. That way, for instance, a particular *service response message* can be associated with an external RDF description which details and further describes the nature of the response. However, while this feature is useful and even necessary in order to provide meaningful service models, finding appropriate model references across the entire Web of data is a challenging task. Therefore, SmartLink uses established Linked Data APIs – currently the WATSON[16] API - to identify and recommend suitable model references to the user.

4.2. A RESTful API for Linked Services discovery and execution

A RESTful API was developed and designed to allow third party applications to interact with our RDF annotations of educational services and APIs, for instance, to discover and execute services.

The service discovery function of our developed REST-ful API takes three service requirement parameters of category, subject and language, which can each be referenced by RDF entities defined in Link Data cloud, such as http://www.daml.org/2003/09/factbook/languages#English. One example vocabulary for service categories is the *Service-finder ontology*[17]. The subject finally specifies the educational domain that the service operation deals with. Different vocabularies can be used to define subjects, for instance the Open Learn classification vocabulary[18]

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describes *OpenLearn*[19] learning subject categories. The language specifies the language requirement for service operation output, and in that, allows the discovery of services which offer access to educational data in a specific user language. All the requirement properties are optional (but at least one property should be specified). By taking these service request parameters into account, the discovery API circulates a SPARQL query to the iServe and Smartlink service annotation repositories for gaining information about suitable services. The discover response message is a RDF based output that contains service name, service description, subject, endpoint and output language. The Listing 1 is one example of the service discovery RDF for a service request.

```
<rdf:Description rdf:about="http://www.meducator.net/services#UH-Helsinki-OAI-DC-metadata">
    <hasAddress rdf:resource="http://helda.helsinki.fi/dspace-oai/request?verb=ListRecords&metadataPrefix=oai_dc"/>
    <liftingSchemaMapping rdf:resource="http://meducator.open.ac.uk/xsparql/uhlifting"/>
    <hasDeveloper>University of Helsinki</hasDeveloper>
  − <hasOneLiner>
        Learning resources metadata from University of Helsinki, Metadata in OAI-Dublin Core XML. Feed compliant with OAI-PMH.
    </hasOneLiner>
    <subject rdf:resource="http://meducator.open.ac.uk/ontologies/open-learn-classification#education"/>
    <metadataLanguage rdf:resource="http://www.daml.org/2003/09/factbook/languages#English"/>
</rdf:Description>
```

Listing 1 Service description excerpt.

A particular invocation method is provided by the API that supports the lifting of service responses – whatever response message format (e.g., XML or JSON) – into RDF compliant with the mEducator RDF schema. The service invocation API method takes service invocation parameters provided by the application layer and returns a mEducator RDF schema compliant RDF output.
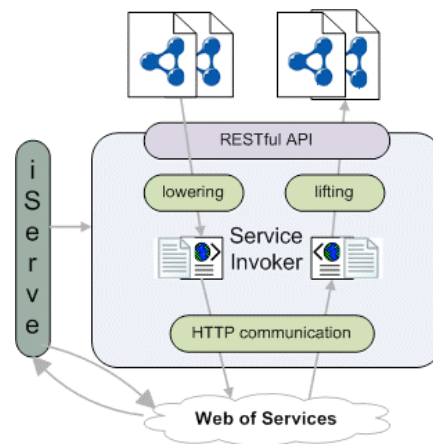

Fig. 3 Service invocation and lifting process.

Service invocation and lifting: based on service input and output annotations and corresponding lifting/lowering schema description, an RDF service invocation message is generated by dynamically matching parameters (specified by client users)

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[19] http://www.open.ac.uk/openlearn

to service semantic annotations. As shown in Figure 3, the RDF input message will go through the "lowering" process of the invocation API to the actual input format of the service. A service is then invoked with the lowered input. Meanwhile, each individual service may give different output result such as XML, RDF or JSON. In order to provide service response messages compliant with the mEducator RDF schema, native output from service invocations will be transformed via the "lifting" step to RDF compliant with the mEducator RDF schema. Not only does the RDF output enable data mashup at semantic level, it also could be used, directly or in combination with other RDF data, for the invocation of further services through the invocation API.

5 Metamorphosis+: An Application Layer Combining Social Computing with Semantic Data and Services Integration

The data and services integration architecture presented in previous sections is fully exploited in Metamorphosis+, which merges the paradigms of semantic and social web to produce an environment for sharing educational resources in health sciences. MetaMorphosis+ (or MM+) realizes the integration of a novel social environment as the application layer and user interface with the semantic data and services linking architecture presented here.

At the application layer, MetaMorphosis+ can be viewed as two distinctive and interacting networks. The first one is a network of persons, including authors, potential authors and final users of learning objects (students, teachers or others, e.g. educational managers, etc). The second is a network of educational resources. The network of persons is functioning in a way similar to other social networks. Persons can interact with each other via their personal blogs, declare friends and create their own interest groups. At a different level, educational resources themselves create an equivalent social network. Educational resources in MetaMorphosis+ can be resources residing in a Learning Management System (LMS), in another educational repository, or merely available on the Web. Resources (like humans) are represented in MetaMorphosis+ by their profile. Educational resources as social objects can exhibit different aspects of 'object sociality' [12]: (a) the obvious connections via common tags; (b) connections based on collective usage and other related interaction of human users; (c) social connections based on the inheritance as realized via educational content repurposing; (d) semantic connections realized via semantic annotations and linking of educational resources. This later social dimension is fully realized via semantic data and service linking as described in the previous sections.

The application layer, via the Resource Profile View allows viewing and management and annotation (Figure 4) of the educational resource metadata as they are lifted from the RDF triple store. Additionally, a new resource and its metadata can be declared via the application layer, with the respective updating of the triple store.

Fig. 4. Resource annotation in Metamorphosis+

The application layer fully exploits the search and retrieval APIs searching for relevant resources two distinct mechanisms: (a) either search in the RDF store; or (b) on the distributed learning repositories semantically linked via the data and services integration layer. The search can be focused on general keywords or keywords found inside specific profile fields of each resource (Figure 5)

Fig. 5. Search interface of MetaMorphosis+. The user can do the simple search by putting keywords or do advanced search by specifying the interested metadata fields.

6 Related Work

A peer-to-peer architecture (LOP2P) for sharing educational resources among different learning Institutions is proposed in [18]. LOP2P aims at helping different educational institutions to create course material by using shared educational resource repositories. The major advantage of the peer-to-peer approach is that the learning repositories can be easily integrated after adding the LOP2P plugin and mediation layer to each different repository. A similar peer-to peer architecture has also been proposed in the EduLearn project [17] and [8]. Meanwhile, Simple Query Interface (SQI) is introduced in [23] designed to query different learning repositories using a comment query language. However, query format and result format have to be agreed among different repository providers before using the query functionalities, which means that a wrapper service is required to ensure compliancy of all involved repositories with the agreed format. These approaches are sharing three disadvantages: (1) instead of accepting the heterogeneous landscape of the Web, all approaches impose either a common schema or interface approach on the underlying stores. Therefore, the heterogeneity issue hasn't been solved. (2) The sharing functionalities are limited by using a defined mediation layer and the mediation is based on syntactic matching, which is not an efficient mechanism to deal with an open and distributed environment.

The work described in [20] and [21] utilizes Semantic Web as well as Web service technologies to enable adaptation to different learning contexts by introducing a matching mechanism to map between a specific context and available learning data. However, this work neither considers approaches for automatic service discovery nor it is based on common standards. Hence, the reuse and automatic allocation of a variety of services or the mediation between different metadata standards is not supported. These issues apply to the idea of "Smart Spaces" [22] for learning as well. The work in [3] follows the idea of using a dedicated personalization Web service that makes use of semantic learning object descriptions to identify and provide appropriate learning content. Neither is the integration of several distributed learning services within the scope of this research, nor is the allocation of services at runtime. Further related research on [9] and [10] allows a mediation between different services based on a so-called "connector service".

7 Conclusion and Future Work

Integrating educational resources becomes more and more important since plenty of educational resources are published to be available online while a range of interfaces and description approaches are being used. In this paper, we introduced a Linked Data-driven & Service-oriented architecture to resolve the integration issues by addressing interoperability issues in a distributed and heterogeneous environment via dynamic metadata mediation towards an extensible and fully Linked Data-compliant resource description layer. The Metamorphosis+ application, an open environment for (biomedical) education has been developed based on our proposed architecture.

While the presented work is ongoing research and tackles a number of distinct challenges such as metadata interoperability, services discovery or data mediation, there are plenty of opportunities for future works. In the short term and most importantly, these cover: (1) investigating ways to enable efficient, accurate and dynamic enrichment of educational data, what involves research fields such as text mining, entity recognition and ontology mapping; (2) extending the framework with additional open repositories and data stores to further showcase and evaluate our services integration approach; (3) integrating the APIs of the "data & services integration layer" with additional third party applications to further evaluate the performance and scalability of the architecture. In particular, (1) also needs to cover the consideration of security and authentication aspects while context-awareness is an important aspect to be taken into account with respect to (2). Additionally, many aspects of our proposed framework are domain-independent and it is intended to deploy similar approaches in different areas, such as eScience.

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