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Formal Description and Automatic Generation of Learning Spaces based on Ontologies

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Abstract

A good virtual Learning Space (LS) should convey pertinent learning information to the visitors at the most adequate time and locations to favor their knowledge acquisition.

Considering the consolidation of the internet and the improvement of the interaction, searching, and learning mechanisms, we propose a generic architecture, called CaVa, to create virtual Learning Spaces building up on cultural institution documents. More precisely, our proposal is to automatically create ontology-based virtual learning environments.

Thus, to impart relevant learning materials to the virtual LS, we propose the use of ontologies to represent the key concepts and semantic relations in an user- and machine-understandable format. These concepts together with the data (extracted from the real documents) stored in a digital storage format (XML datasets, relational databases, etc.) are displayed in an ontology-based learning space that enables the visitors to use the available features and tools to learn about a specific domain.

According to the approach here discussed, each desired virtual LS must be specified rigorously through a domain specific language (DSL) that was designed and implemented.

To validate the proposed architecture, three case studies will be used as instances of CaVa architecture.

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1. Introduction

With the popularization of the Internet, its use in information access became common anywhere, to anyone and in many computing devices, such as smartphones, tablets, personal computers, etc. Moreover, many ways to store data in digital format emerged. These storage formats help to improve the accessibility to the information originally kept in physical documents belonging to museums, libraries or similar institutions. This storage is held in repositories of

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digital objects. Therefore, having information associated with digital objects on the Internet, they can be distributed and viewed through sites which possess features for viewing, interacting and navigate over them.

The popularity of Internet, making information accessible to everyone, anywhere, at every moment created the opportunity to evolve traditional exhibition spaces, as reading and show rooms, to virtual spaces on the web in order to enable new learning approaches.

Traditional Learning Spaces (LS) are physical locations, normally within schools and universities, exposing objects with information (whether material or immaterial things), arranging them in order to convey a message to the LS visitor[1,2]. LS host groups of people (usually students) debating about a specific subject and someone (usually a professor) who leads the debate, organizing behaviors through formal methods of education, to impart knowledge to the group.

However, most people's knowledge is not acquired in formal methods of education (as learning in a classroom, for example), but during their leisure time outside the classroom, using their laptop, smartphone or any device to socialize with other people, as well as snack bars at breakfast, travelling on a train, and also visits to museums, libraries and the like[3]. Therefore, any physical space that features knowledge sharing can be considered a learning space.

In short, the previously cited features allow a range of people (not only students) to use these learning spaces to generate and acquire knowledge. Thus, the term e-Learning should not be applied in this context to avoid misunderstandings, because it is usually used to describe LS just for students enrolled in distance education, which is not our purpose in this work. Virtual Learning Spaces, like virtual classrooms, virtual seminars, virtual museums, improve learning experience by supporting learning at leisure time, i.e., at flexible locations and time.

To build these virtual Learning Spaces, data about the desired domain should be stored in a way that later can be processed and displayed to the learner in the best possible way.

The focus of the work here reported is to build virtual Learning Spaces adapted to Cultural Heritage (CH) domain.

According to UNESCO, the legacy of physical artifacts (tangible[1]) and intangible[2] attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations are called Cultural Heritage[4]. Cultural Heritage is not limited to material manifestations, such as monuments and objects that have been preserved over time. This notion also encompasses living expressions and the traditions that countless groups and communities worldwide have inherited from their ancestors and transmit to their descendants, in most cases orally[5]. We understand culture as what we live, encompassing the daily life, traditions, attitudes, and norms of the society. Culture changes according to ones experiences, i.e., what each person learns. The heritage, is a patrimony that does not change, because it is what we inherit, i.e., what come from the past (wealth of the past).

Concerning this project, we are working with intangible CH objects with the goal of creating virtual Learning Spaces to disseminate knowledge.

The project proposal aims at automating the creation of web-based virtual Learning Spaces using an ontology and a Domain Specific Language (DSL). The ontology will serve two purposes: first, give semantics to the digital object repository; and second, describe the information that must be displayed. The DSL should allow a detailed description of the desired space. So the specific goals of this project are to create a formalism (DSL) to describe rigorously Learning Spaces taking into account the domain ontology; and develop a mechanism to generate automatically the virtual LS from its formal specification. It is a challenging idea, different from all similar projects found in the literature.

Aiming at validating the proposed architecture, three real case studies – (1) Emigration Documents belonging to *Fafe's Archive*; (2) Collection of life stories of the *Museum of the Person*; and (3) The prosopographical repository of the *Fasti Eclesiae Portugaliae* project – will be used. These real scenarios are actually relevant as they promote the digital preservation of our Cultural Heritage, contributing to human welfare. As said above, it opens many possibilities of disseminating the knowledge preserved.

Namely, it is not another project in the area of eLearning (actually we are not concerned with the topic involved in distance education targeted to closed sets of students enrolled in some course) also it is not a new approach in the area of creating digital versions of traditional museums.

[1] http://www.unesco.org/new/en/cairo/culture/tangible-cultural-heritage/
[2] http://www.unesco.org/culture/ich/index.php?lg=en&pg=00022#art2

Summing up, this work is motivated by an unpublished idea of creating virtual Learning Spaces to impart knowledge of cultural heritage.

This paper is structured as follows. Sections 2, 3 and 4 detail the three main areas (ontologies, domain specific languages, and learning spaces) involved in this work, providing the basic concepts. Section 5 presents the related work, showing the main approaches found in the literature. Section 6 outlines the proposed approach and gives details about the architecture proposed. Section 7 shows the implementation of the 1st case study, presenting the development made about the Module A and Module B of CaVa. Finally, Section 8 concludes the paper and describes the future work, aiming at the automatic creation of virtual Learning Spaces.

2. Ontologies

According to [6], the computer science area defines ontology as a formal and explicit specification of a shared conceptualization, where conceptualization refers to an abstract model of some phenomenon in the world which identifies relevant concepts of the phenomenon itself; formal refers to the fact of the ontology be understood by the machine; and shared gives the notion that an ontology gets the presented knowledge not only by a single individual but by a group.

Some authors define formally ontologies as a set of tuples [7,8,9]. These formal definitions are more common in the area of Computer Science. Based in aforementioned works, we define formally an ontology $\boldsymbol{O}$ as a 4-tuple $\boldsymbol{O = (C, I, P_{dtO}, A)}$, where **C** is a set of concepts (classes or entities) of the domain; **I** is a set of instances (individuals) of a class; P_{dtO} is a set of properties that individuals and classes may have: P_{dt} is a data type property, i.e., is the relation between classes, or instances of classes and atomic values, such as strings, integers, etc; P_O is an object property, i.e., is a relation between classes, or instances of classes and other classes, or instances; and **A** is a set of axioms. They hold the knowledge that can be inferred and that is not clearly detailed in the taxonomy of the ontology.

Most formal definitions of ontologies usually share characteristics, independently of the approach. Normally the use of *concepts (classes or entities)* is to group individuals (instances) that share properties (relations and literals); the use of *instances (individuals)* is to group them in classes; the use of *properties (object properties or data type properties)* is to define relations and individuals characteristics.

Taking into account the CH domain – which has its history (persons, events, places, periods, etc.), is related in many ways to the society as archival collections, and has cultural collections content with semantic richness – stays clear the importance of using ontologies to describe the Cultural Heritage domain [10].

Besides this, Cultural Heritage is a promising application domain for semantic web technologies due the semantic richness and heterogeneity of cultural content [11]. Some ontologies that can describe the CH domain are ABC [12], DOLCE [13], CIDOC-CRM [14], among others that can be seen in [15].

The ontology to describe the domain area depends on the project that CaVa will be used. This means that if a museum curator has the domain of his application described in another ontology, CaVa will do the job. In other words, which ontology will be used, depends of the project. In this proposed architecture, ontology contents and notation is not restricted. For our three case studies, we are going to use CIDOC-CRM.

3. Domain Specific Languages

Domain Specific Language (DSL) is an old term defined in general as a language targeted to solve a specific problem. Its development is hard because it requires both domain knowledge and language development expertise [16].

With an appropriated DSL, we can develop complete application programs for a domain more quickly and more effectively than with a general-purpose language [17].

The most declared advantage of DSLs is the expressiveness that DSLs have. It enables DSL programs to be expressed in the level of abstraction of the problem domain. Thus, domain experts can understand, validate, and even specify DSL applications.

Because a DSL has a higher level of abstraction, the ease of learn and use it is more accessible than general-purpose languages. Furthermore, with this level of abstraction, the communication between the developers and domain experts can improve [18].

There are some similar DSLs related to the purpose of this work: MobiDSL [19], EngenDSL [20], WebDSL [21], WebML [22], WeSiMoLa [23], among others. The three more interesting are described next.

In the work [19], the author developed the MobiDSL language, which has the goal of specify pages/screens to mobile applications allowing the programmer to specify page structure, presentation (views), data retrieval, etc. In the work [20], the author developed a DSL called EngenDSL which aids in developing applications by abstracting user interaction concepts based on the Interaction Flow Modeling Language (IFML) standard using the Apache Velocity template engine. Another DSL for this purpose is WebDSL described in [21]. WebDSL is a language for developing dynamic web applications with a rich data model translating the specification in Java web applications.

These DSLs are languages to create, in an abstract way, web applications in general. Besides, most of them need expertise in technical tools and programming languages to specify the entire web application. The difference of these works to our proposal is that they require expertise in the computer science area. We created a DSL with an abstract definition level that the user does not need to know about data persistence, programming or markup languages. Furthermore, our DSL is focused on the vocabulary of the museum curators, facilitating the specification of the virtual Learning Space.

4. Learning Spaces

The spread of the internet and technology has changed the way of reading, writing, thinking, and learning [24]. Furthermore, according to [25], the rapid and continuing advances in information and communication technologies are changing the ways people share, use, develop and process information and technology.

As consequence of this, the traditional way of learning is changing. The facilities to find the desired information nowadays grow up every day due to the internet. Thus, the learning environments also have changed.

As previously mentioned in this work, is hard to explain the virtual Learning Spaces without refer to the educational LS, because that is the main domain where they are discussed in the literature. Most of the works are related to the virtual Learning Environments for students and professors where the educational scenario has a professor, tutor, or someone to lead and to impart knowledge to the whole class virtually. This scenario applies to educational institutions, like schools and universities, offering e-Learning and distance education. Some of these works are [26, 27], among others.

On the other hand, there are many works in the area of museums and cultural institutions focused in a 3D virtual tour or digitization of the documents and objects, like [28, 29], among others. In our work, we want to create Learning Spaces to the end-users (the institution "visitors") without a tutor; we do not want to create virtual reality environments like 3D virtual museums or analogous. So, the end-users should learn from provided information through non-formal methods, in their leisure time and in informal occasions and places. So, the definition and practical applications of Learning Spaces can be usefull both to the educational institutions and to the cultural ones.

Thus, we define a virtual Learning Space similar to a digital library. A digital library, according to [30], is a focused collection of digital objects that can include text, visual material, video material (stored in electronic media formats), along with means for organizing, archiving, and retrieving the files and media contained in the library collection. Thinking this way, a book – of a library –, a document – of an archive –, or an object – of a museum – are similar things that can be stored in collections. Each one is an information source; that information should be stored and displayed through the virtual environment so that the end-users can learn effectively.

Thus, in the context of this doctoral work, the specific definition of a virtual Learning Space is an environment similar to the traditional one, but without a person to lead the knowledge transmission; the information to be passed to the learners is arranged in such a way that the users can learn individually using the tools and features provided to them by the environment. These features and tools can be a powerful search mechanism where the information displayed is only that the users want.

5. Related Work

Some projects regarding the creation of virtual learning spaces not just for students as happen with e-Learning, but for a large range of persons have been proposed. Some interesting projects, more related to our approach, in addition to those mentioned in Section 4, concerning the 3D virtual spaces and e-Learning, exist. Here are reported three of them:

- *The Domus Naturae Project* which aims at creating a virtual museum application using tools for managing structured knowledge based on ontologies [31]. This project is similar to CaVa, since it uses ontologies to describe the repository of digital objects allowing a navigation over such objects. However, the ontology of CaVa serves to describe and relate semantic concepts of a specific domain, connects such concepts with the digital objects stored in the database repository, and makes the automatic generation of a virtual LS closer to the knowledge the end-user wants to get;
- The *Personalised Access to Cultural Heritage Spaces* (PATHS[3]) which proposes the creation of a system (virtual thematic paths) that acts as an interactive and personalized tour guide through all objects available in the European Digital Library (Europeana). The aim of this project is to make the exploration of Cultural Heritage collections easy for people, leading them along a pathway that can be created by themselves or experts. Even though this project is similar to CaVa, the creation of paths to connect collections of objects is not what we intend;
- The *MuseumFinland* is a semantic portal for publishing heterogeneous museum collections on the Semantic Web. The system allows to make collections semantically interoperable, and provides the museum visitors with intelligent content-based search and browsing services, thanks to a set of ontologies. This system uses ontologies to navigate through meta-information based on a central repository [32]. This project is similar to CaVa, however, we intend to allow the automatic creation of virtual LS not focused on museums collections.

In short, the projects presented above regard the area of learning spaces as web-based learning environments for knowledge generation and dissemination. Compared to the projects here discussed, the main feature that CaVa will innovate is the automatic generation of virtual learning spaces through a specification (a DSL), based on an ontology that describes and organizes the information stored in a digital repository.

6. Proposed Approach

As explained in Section 1, and based in the problem investigation, we want to create automatically virtual Learning Spaces as web pages. This creation is based on an ontology — that describes an institutional information repository — and on a DSL specification — that defines which concepts should be exhibit and how they should be placed in the final virtual LS.

Previous sections introduced and illustrated (definitions and examples were given) the relevant terms to a better understanding of the scope of this work. These concepts will be applied in our proposal, called CaVa, to achieve the objectives outlined in Section 1. The CaVa architecture was created and designed as can be seen in Figure 1.

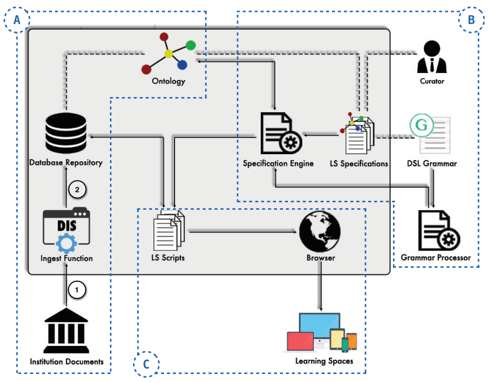

Fig. 1: CaVa architecture

[3] available at: http://explorer.paths-project.eu/

The architecture depicted in Figure 1 is built up on three modules. Module A is the institution repository (*Institution Documents*); it comprises the real documents, the *database repository*, the *ingest function* implemented as a *Document Ingestion System* (DIS), to upload the documents and to aid in data management, and the main *ontology*. Module B is made up of two components that are *specification engine* and *LS Specifications* written in a DSL designed specifically for this project. Notice that the *specification engine* is generated automatically from the DSL grammar. Module C includes the script files (*LS scripts*) and the *browser*, where the final component, Learning Space, is located.

This architecture was not designed for a specific domain. In the other way around, it shall cover any domain as museums, libraries, archival or schools. Next will be detailed the role of each CaVa's module.

6.1. Module A

The first important task to perform in CaVa is access the sources, represented in Figure 1 by number (1), via a DIS, which is an application to aid the upload of the institution documents data into a relational database, represented by the edge (2) (Figure 1). A DIS can be implemented resorting to any kind of technology (e.g. a script, a web application, etc.) that reads data, validates it, and stores it in a database. The database has the goal of storing the information extracted from the sources (archives, museums, libraries, etc.) according to the traditional relational model. Then an ontology offers a more abstract, on concept-oriented, view over that repository.

The implementation of Module A for case study number 1 – Emigration Documents belonging to *Fafe's Archive* – was realized by SGPE, an web-based application. This work was already published in [33], and can be consulted at http://www.di.uminho.pt/~gepl/museu_emigracao.

As mentioned earlier, to generate the virtual Learning Spaces, which have the objective of impart knowledge about a specific domain to the end-users, it is necessary to describe the knowledge implicit in the information contained in the sources. This is the purpose of the ontology in Module A. It describes and relates semantic concepts of a specific domain, in addition to connecting these concepts with the digital objects stored in the database repository. This mapping allows to query the database repository through the ontology. This mapping should specify targets and sources. It means that the target (path on the ontology) needs to be specified to find the instances in that source (path on the database).

Some works have been done in this area, and the most known and used is R2RML [34], a language for expressing customised mappings from relational databases to Resource Description Framework (RDF) datasets. Besides, there is a framework called Ontop – accessible at: http://ontop.inf.unibz.it/ –, which is a platform to query databases as virtual graphs using SPARQL. Ontop uses native and R2RML mappings. Ontop was used to accomplish this task.

After reviewing the literature we decided to adopt the standard ontology that represents the Cultural Heritage domain, used in many projects, called CIDOC-CRM. In the context of our first case study (that realizes CaVa proposal), this standard ontology is used to define the concepts and semantic relations needed to generate the emigration virtual Learning Environments.

6.2. Module B

It is the core of CaVa architecture. Module B contains the main components to achieve the objective outlined in this thesis.

To create a Learning Space (this is to state the concepts that shall be displayed and how to show them), the curator must write a *LS Specification* using the Domain Specific Language (DSL) designed specially for that purpose and defined by an appropriated *grammar*. To be clear, these specifications are built manually by the curator that should have knowledge about (1) the language rules defined by the *DSL Grammar*, and about (2) the main ontology that describes the documents repository.

The *LS Specifications* enable the definition of a part of the main ontology to describe the subset of concepts that are really desired to be shown to the visitor of the LS. After that, it is necessary to describe how Learning Spaces are structured and which objects will fit in each part of the screen.

For the *Specification Engine* to perform its tasks, a *LS Specification* should be provided as an input, written in the DSL defined by CaVa Grammar. That grammar is recognized by a *Grammar Processor* (i.e., is a parser generator and a compiler constructor) that will generate the *Specification Engine*.

The compiler generators *ANother Tool for Language Recognition - ANTLR*; *Construction of Useful Parsers - CUP*; *Java Compiler Compiler - JavaCC*; *Yet Another Compiler-Compiler - YACC*, are among others possible candidates as grammar processors. The *Specification Engine* transforms the formal description of a Learning Space into *LS scripts* – written in PHP, Python, Perl, Ruby, CSS, etc. –, which, in turn, are processed by the web *browser* to render the final virtual LS.

Summing up, this *Specification Engine* needs to be able to performs basically two tasks before creating the LS scripts: (i) recognize the input specification of the LS, written by the museum curator; and (ii) access the mapping rules – associated to a subset of the main ontology – to search for the concepts referred in the specification in order to identify their instances.

6.3. Module C

The *Specification Engine* generates the correct LS scripts to be consumed and interpreted by the browser to automatically generate a final web-based Learning Space. For this, the *LS scripts* should be able to perform two roles: (i) query the database repository to fetch the real information with the goal of reach each instance of the ontology concepts passed to it; and (ii) use this information to render the final virtual Learning Spaces through a web-browser.

The *LS scripts* generated by the *Specification Engine*, describe the intended LS in a less abstract level, more precisely in a programming language style. They state how to get the instances in the database repository with the actual data that shall be displayed in the final virtual Learning Environment. These *LS scripts* should call an external program that executes the mappings, and the SPARQL queries and return the results to them. Thereafter, a browser must interpret the LS scripts to exhibit the web page that constitutes the final Learning Spaces.

7. Results based on the first case study

To check the flexibility and usefulness of our work, we have applied the approach outlined in Section 6 to a 1st case study about the Emigration Documents belonging to Fafe's Archive, more specifically, the passport application forms.

As stated in Section 6.1, the access, collection and storage of the documents (work done in collaboration with the municipal archive of Fafe) was already published in the paper[33]. The creation of an ontology, called OntoME, to describe the Emigration Museum assets was published in the paper[35].

To access that documents' data stored in the relational database following our approach, i.e., to provide the curator access to the repository via OntoME's vocabulary, it was necessary to apply a mapping between the database and the ontology. As said before, the Ontop framework was used to accomplish this task. To create mappings via Ontop, it is necessary to connect the concepts and properties (object and datatype) of the ontology with views (SQL) over the repository's data through a specification. An excerpt of the specification made is shown in Listing 1.

The mappings' specification should have one or more mapping axioms[4] that transform the repository's data into a set of RDF triples. The mapping axioms are composed of three fields: (a) *mappingId* – a string that identifies the mapping axiom; (b) *target* – a triple template which references column names used in the database (source) query through placeholders (terms between curly brackets); and (c) *source* – a SQL query over the database, which should contain the column names used in the target's placeholders.

Through the mapping specification of Listing 1, the database can be queried via SPARQL Protocol and RDF Query Language (SPARQL). Ontop combines these mapping axioms to create complex SQL queries to query the relational repository.

The specification of the mapping contains other sections (prefix and source declaration). For the sake of space, these sections were suppressed and are represented here by the first "......" sign. To complete all the mapping between OntoME and the database, the last "......" sign represents the other mapping axioms.

Having the mapping done, the next step was to define the DSL to formally describe the virtual Learning Spaces. The LS Specification enables the description of a part of the main ontology aiming at describing a subgroup of

[4] More about the mapping axioms can be found at: https://github.com/ontop/ontop/wiki/ ontopOBDAModel#Mapping_axioms

Listing 1: *An excerpt of the mapping between the database and OntoME*

```
......
[MappingDeclaration] @collection [[
mappingId    Emigrante
target       :Emigrante#{idEmigrante} a :E21.1_Emigrante ;
             :P131_is_identified_by :nomeEmigrante/{idEmigrante} ;
             :P152_has_parent :Filiacao#{idFiliacao} ;
             :P98i_was_born :nascimentoEmigrante#{idEmigrante} .
source       SELECT idEmigrante, idFiliacao FROM identificacaoEmigrante
......
]]
```

concepts that are desired by the curator to be exposed to the LS visitors. Subsequently, it is necessary to describe the structure of the virtual Learning Space, providing some properties of the Web pages like static content and elements' position as well as which data will fit in each part of the screen.

So, to create a virtual LS about the emigration phenomena in Portugal, supported by the stored passport application forms, a LS Specification should be created. A fragment of the specification done for this 1st case study is shown in Listing 2.

Listing 2: *Learning Space Specification*

```
mainconfig [
  LSTitle: ''Emigration Phenomena in Portugal'',
]
menu [
  brand: ''Emigration Museum'',
  backgroundColor: orange,
  fontColor: white,
  behaviour: static, //or fixed
  options [
    label: ''Home'', url: ''home'',
    label: ''Exhibitions'', dropdown [
      labelDropDown: ''Permanent Exhibitions'', urlDropDown: ''permanent_exhibitions'',
      labelDropDown: ''Temporary Exhibitions'', urlDropDown: ''temporary_exhibitions'',
    ]
  ]
]
exhibitions [
  exhibition [
    title: ''Reflexos da Emigração no Concelho de Fafe nas décadas de 60 a 80 do século XX'',
    shortDescription: ''Processos de emigração de grande riqueza para a avaliação de projetos migratórios individuais ou familiares.'',
    icon: ''file-archive-o'',
    additionalInfo [
      additionalInfoTitle: ''6459'',
      additionalInfoDescription: ''Total number of documents'',
    ]
    behaviour: expanded, //or collapsed
    type: permanent, //or temporary, closed, future
    E21.1_Emigrante->all(), //concept of the ontology + operator
  ]
  ......

]
......
```

Listing 2 presents the specification of a virtual LS that describes a web page with the "Emigration Phenomena in Portugal" title.

A menu element with the allowed configurations must also be defined. After that, a list of exhibitions can be defined in the *exhibitions* element. For each *exhibition* entry, an exhibition is created. This kind of element can have a title, a short description, an icon, an additional info, a behaviour (related to the manner that the exhibition is shown), a type (permanent, temporary, closed or future). In addition to these settings, each *exhibition* element contains space to query the repository through the concepts of the ontology (in this case, OntoME). In this example, "E21.1_Emigrante" concept was chosen with the operator *all()*, which selects all instances of the desired concept (in this case, all emigrants). Notice that there are other operators to specify the way to query the database through the ontology. This example only presents the operator *all()*.

In addition to the example of Listing 2, other elements as footer, carousel (slideshow for cycling images), among others can be specified.

The specification of a Learning Space in the domain specific language exemplified in Listing 2 – called CaVa^{DSL} – allows the curator to describe virtual learning environments based on a pre-defined web template created with the Smarty[5] template engine.

8. Conclusion

In this paper, a project (CaVa) to automatize the creation of museum's exhibition rooms (LS) was described. Also the basics about the three main areas involved were provided, introducing the main concepts and discussing some important related works. After formulate the research hypothesis, we have proposed an architecture to prove it (Section 6).

We have already implemented the CaVa modules for the 1st case study. Module B is the heart of our approach as it enables the museum curator to specify the final virtual LS in the developed DSL, generating the necessary scripts (php, css, html, etc.) for the browser's interpretation.

At moment we have already specified that DSL. The processor that reads a *LS Specification*, and creates the virtual Learning Spaces was also implemented. With the mapping and the *LS Specification*, the scripts to build the virtual Learning Spaces can be automatically generated.

As future work, we plan to test the proposal with the other two case studies, creating LS based on their holdings.

Note that the mapping between the repository and ontology should be done for each domain, so for the other two case studies, we need to build new mappings. The *LS Specification* language, because it is generic, it is developed once and can be used for any domain; only new specification for each concrete LS should be done.

With this architecture implemented, we expect that our research will bring benefits to both the academic, and museum communities. According to[36], "Domain-specific languages allow solutions to be expressed in the idiom and at the level of abstraction of the problem domain. The idea is domain experts themselves may understand, validate, modify, and often even develop domain-specific language programs". Applied to the CH domain, this means that the curator only needs to be concerned with his duty, describing how exhibitions should be organized and what objects should they contain, discarding the technical details about the retrieving of objects from the warehouse on the mounting of the exhibition. Based on this statement, we can say that our approach built upon an ontology oriented DSL specification (written by the curator) describing the virtual Learning Space using the ontology's vocabulary and at a high level of abstraction is actually a good solution for the stated problem.

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