Cross curriculum search through the GeoSkills Ontology

Paul Libbrecht,
http://www.activemath.org/~paul/

Competence Center for E-Learning,
DFKI GmbH, Saarbrücken, Germany

Abstract. Interactive Geometry is gaining momentum; it is becoming a core part of mathematics curriculum in several countries and is recognized as a major experimentation possibility for the discovery and acquisition of mathematical principles (see, e.g., [1]). Interactive geometry constructions' however, are scattered in separate, tool-, nation-, and language-bound, communities. The aim of the project Intergeo, an EU eContentPlus project, is to break the barriers that cause this scatter by providing a shared file format and a multilingual platform to share the existing assets.
In this article, we focus on the search and annotation process of the platform that crosses the boundaries of national curriculum and language communities. This is done with the help of an ontology, the GeoSkills ontology, which catalogues the relevant competencies, topics, and educational-contexts in a multilingual way. We explain how the ontological nature helps both in management and in search-engine fuzziness.

1 Introduction

Interactive geometry resources are in wide use in many educational institutions to teach mathematics. Their adoption, however, is often difficult as is often the case with information technologies at school. More convergence is required, the Intergeo project intends to approach it through three different aspects:

- Define a common file format enabling the interactive geometry constructions to cross the software borders which, currently, often prevent neighbours to reuse each others' resources.
- Create a web-based platform where learning resources with interactive geometry constructions are visible, exchangeable, and searchable: this should cross the borders of national curriculum.
- Allow the users of the platform to annotate the resources with quality statements so that interactive geometry resources are validated, in particular, for their appropriateness in a particular educational context.

The purpose of our article is the web-based platform that Intergeo is currently setting up with its challenge of an annotation and search facility that crosses national curriculum boundaries.

The basis of our approach lies on a list of mathematical competencies and topics which have names in many languages and which can be tagged on each resource as competencies being required or trained. Similarly, a list of educational levels and programmes is set up and can be tagged on resources. Together they provide a fine-grained approach to annotate and retrieve learning resources. These lists are arranged as an ontology so as to provide, on the one hand, a strong knowledge management tool to model lists' elements and their relationships, and, on the other hand, a set of practical tools aiming at standards-based interoperability with guaranteed computational results.

Outline This paper starts with a motivating example and follows with a description of the INTERGEO web platform, starting with a short survey of the existing repository and cross-curriculum approaches. The ontology that lies in the heart of the cross-curriculum aspect is then explained followed by its usage in management and search. We conclude with interoperability perspectives.

Acknowledgements This paper is presenting the work of a group of people in the work-package 2 of the INTERGEO project. Although the author is alone, the work presented is the result of a collaboration between curriculum experts, ontology experts, and web developers. This includes Odile Bénassy, Albert Creus-Mir, Cyrille Desmoulins, Michael Dietrich, Maxim Hendriks, Colette Laborde, and Christian Mercat. This work has been published as a conference paper [2] and as a project deliverable [3], this paper presents a shorter overview which is also more up-to-date. This work is partially funded by the European Union under the eContentPlus programme.

1.1 A Simple Example of Cross-Curriculum Search

Consider the competency of *contructing the division of a segment in n equal parts*. This should be matched by queries using strings such as "divide in equal parts", "diviser en parties de même longueur", etc. Curriculum standards, however, do not all speak about this topic in the same way. The English curriculum only mentions the operation of *enlargement*, whereas the French national program of study mentions "connaître et utiliser dans une situation donnée les deux théorèmes suivants" and provides the formulation of the "Théorème de Thalès" and its converse [4]. All these should match in *some way*.

A simple example of a mismatching across some of the curriculum boundaries is the name "Thales' Theorem". In French (*théorème de Thalès*) and Spanish (*teorema de Tales*) it indicates the intercepting lines theorem. However, Thales' Theorem in English or in German (Satz des Thales) refers to another theorem.

2 The INTERGEO platform

In this section we review the existing approaches to annotation and retrieval for learning purposes with a special focus on cross-curriculum-search.

2.1 Annotations and Retrieval in Learning Object Repositories

In order to approach the realization of the INTERGEO platform for sharing interactive geometric constructions across curriculum boundaries, we survey the state of learning object repositories which are closest to what the INTERGEO platform should be.

As far as we could observe, learning object repositories all classify learning objects of a highly variable nature using a certain amount of bibliographic information augmented by some pedagogical and topical information. Unfortunately, there is rarely enough information to allow fine-grained search. Topical information is, at most, encoded in broad taxonomies such as the Mathematical Science Classification (MSC)[5]. The most fine-grained is the WebALT repository [6] which attempts to refine the MSC to a level close to a curriculum standard.

Other approaches that tend to be fine-grained are the tag-based approaches, where any tag can be attributed freely by any person providing content. While this approach works fine for statistical similarity and in communities that share a language, it does not work so well to provide similarity measures of concepts in a well managed fashion: it could only offer translation capabilities if mostly used by multilingual users and users that bridge several communities; we have not found, yet, such users to be common.

A learning object repository that provides topical information directly within the curriculum is GNU Edu [7]: this platform catalogues learning objects according to the skills described in a curriculum, split into years and chapters. GNU Edu allows the skills to be annotated with keywords which can be used to access the skills directly. The keywords are translated and this is how GNU Edu achieves cross-curriculum search: a query matches a set of keywords, each matching skills from each curriculum. GNU Edu does not, however, rank the results or generalize a query so that related keywords also matched.

The emergent repository TELOS from the LORNET research network, and its associated competency framework [8] have been considered, but rejected because of its main focus on the design and organization of coherent courses or evaluations; on the contrary, INTERGEO resources will be aimed at being used as building blocks by more elaborate Learning Content Management Systems.

Several approaches to link resources to curricula are available. England's Curriculum Online [9], a concerted effort between the Education Board of England and several publishers to present the curriculum standard of England associated with resources that schools may purchase. Microsoft Lesson Connection is a joint of effort of Microsoft [10] and a publisher or the ExploreLearning [11] entreprise do the same for the curricula of the USA. Most of these approaches seem to be based on directly and manually associating resources to lines in curricula, something which is clearly not an avenue for us, since we want the resources to *cross the curriculum barriers*, even being available for a freshly encoded curriculum.

The CALIBRATE project as explained in [12] and further detailed in private communications has appeared to be a first-class provider of annotated curriculum. Unfortunately, their intent did not seem to converge with a cross-curriculum search and their coverage intent appeared to be weak.

The analysis above leads us to the belief that text search engines, still tend to be the most used approach for learning object identification. Information retrieval, the science of search engines, is a very mature field with pioneer works such as [13]. Software tools such as Apache Lucene [14] provide a sturdy basis to apply the theories of this field with good performance expectations. Indeed, we shall exploit partial search queries as often as 100 times a second for the purpose of *designating* the topics. Information retrieval has taught us the fundamental approach to quantify the *relevance* of a document matching a query: this yields search results that are ranked from most to least relevant and expects users to read only the most relevant results.

The diverse relevance is meaningful in the sense that the user expects more than just an exact word match; for this purpose queries are often generalized. One way is to make the query tolerant to typos or to match phonetically. Another way is to generalize the search by including *semantically close* words. An example is the Compass tool [15], which uses an ontology of all concepts to generalize queries using concepts related to the query words. But even the Compass approach needs to be complemented for cross-curriculum search of interactive geometry, since we wish that a search in French for the topic *théorème de Thalès* should match (at least mildly) a construction contributed by an English speaker who has annotated it with the competency of *recognizing an enlargement*. As a result, the INTERGEO project needed an approach that imitates the query-expansion mechanism found in Compass and others but that performs this expansion with the mathematical relationships. Hence we need to tackle the work of encoding the geometric parts of curriculum standards of Europe in a way that identifies the common topics and their relationships.

Having documented the general problematic of applicable technologies, we now turn to a more precise description of the work-flows and shall cover the literature relevant to curriculum encoding after it has been presented.

2.2 Choice of Repository Platform

In order to obtain all the objectives of the INTERGEO platform, we settled on building on the Curriki learning object portal [16], an open-source extension of the XWiki platform, which provides HTML-editing and communication services, and appeared easy enough to be developed further to accomodate needed extensions such as the search tool.

2.3 User Workflow for Searching and Annotating

The INTERGEO platform's main goal is to allow sharing of interactive geometric constructions and related materials. This material can take on the form of interactive geometric constructions, with or without concrete learner tasks attached to them, as well as web-based materials that encompass these. We shall use the term *resource* here, as has been done often on the web, to denote any of these data types. What does the sharing mean? Overall, it is the execution of the following *roles*:

- the *annotator role*: provision of authoring, licensing, topical, and pedagogical information about a resource contributed to the Intergeo platform;
- the *searcher role*: navigation and search through the platform's database to find relevant resources to use in teaching, to edit, or to evaluate.
- the *curriculum encoder*: input and maintenance of the set of topics, competencies, and educational contexts along which the resources shall be tagged
- the *competency translator*: maintenance of the names and descriptions of the topics, competencies, and educational contexts along which the resources shall be tagged.
- the *quality evaluator* role as described in [17]

A crucial condition for the annotator's and searcher's roles to work is that together, they use a similar vocabulary to input the information about the resources and to search for the resources. A fundamental aspect of Intergeo is to solve this in a cross curriculum fashion, so that the annotator and searcher are different persons that can express themselves in vocabularies that may be in different human languages and in different environments but still match together

Thus the role of the annotator is to provide sufficiently detailed topical and educational context information so that all users can find resources using the language of their curriculum as well as using everyday language.

For this to work, we have added the third and fourth roles to this work-flow, that of curriculum encoder and competency translators. They make sure that each competency and topic in the curriculum standard they are responsible for, is properly listed and properly inputtable.

2.4 Linking to Topics, Competencies, and Educational Contexts

A first important aspect in order to allow web-based navigation and to allow the annotation of curriculum texts and textbooks is that the topics, competencies, and context are addressable through URLs which can also be presented in a browser. This is currently done by a generic tool called OWLdoc which resembles javadoc. It describes all the elements of the ontology. A browser version can be seen from `http://i2geo.net/ontologies/dev/`.

2.5 Designating Topics, Competencies, and Educational Contexts.

Search engines are a crucial part of everyday Internet usage, they are the applications that power information retrieval (see [13]). Their simplicity is created, on the one hand, by simple text input and, on the other hand, by the fast results which stimulates numerous search attempts to attain the right set of documents.

But because search engines are generally text-based, they are improper to search for conceptual entities such as described in the previous section, which can be made of several (overlapping) words. Therefore we designed two means to let the users easily designate *tokens* (that is, topics, competencies, or educational contexts): by typing text or by pointing in a book.

Designating by Typing: SkillsTextBox We extend the familiar autocompletion: users can type a few words in the search field, these are matched to the terms of the names of the tokens; the auto-completion pop-up presents, as the user types, a list of matching tokens similar to figure 1. This list presents, for each candidate, the full name, the number of related resources, an icon of the type, and a link to browse about the token and around it. When chosen using either a click, or a few presses of the down key followed by the return key, the sequence of words is replaced by the name of the token, surrounded by square brackets to indicate an exact reference to the given token.

This process is used not only to search but also when annotating a resource: individual competencies, topics, and educational usage are then provided.

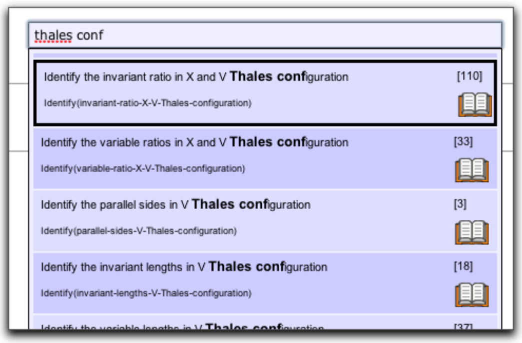

Figure 1: Choosing among competencies about “Thales conf”

SkillsTextBox uses a simple HTML form equipped with a GWT script [18]. This script submits the fragments typed to the index on the server which uses all the retrieval matching capabilities (stemming, fuzziness through edit distance or phonetic matching) to provide an object description of the best matching 20 tokens, which the script renders as an autocompletion list. More information about it is at `http://www.activemath.org/projects/SkillsTextBox/`.

Designating by Pointing in a Book Supplementary to letting users search for resources by explicitly typing the names of competencies and topics, we will offer the possibility to do this implicitly by linking them from sections of curriculum standards or of text books that users know well. Although we shall mostly not be able to offer whole text books to browse through, we expect it to be unproblematic to display their tables of contents.

The idea is that a user can then browse through a table of content, through pages he is graphically familiar with, and click on sections of interest. This click will trigger the selection of the competencies and topics associated with these sections, adding the necessary queries in the search field.

3 The GeoSkills Ontology

Having described the user-interface of our search and annotation tool we now turn to its essential enabler of multilinguality: the multi-lingual list of topics and competencies. This list is organized as an OWL DL ontology for reasons that we shall explain below.

Its essential ingredients are the following. For each of them, a set of names is provided, at least one in each language. This allows elements of the lists to be presented to the user but also SkillsTextBox's auto-completion to work as well as the search engine to match. Because names vary in their frequency of usage, they are of four different degrees (common, uncommon, rare, false-friend) which are taken in account when a word is matched with it. These names are not be mistaken with identifiers which are ASCII names expected to be used in such references as URIs or URLs (e.g. when browsing about a topic).

Topics: are made as a taxonomy, that is, a hierarchy of classes each representing mathematical topics and objects. Multiple inheritance is added as extra facility. Because we shall relate to topics, each class has a single *representative* individual. Examples of topics include Isoceles_Triangle or ApproximationProcess_for_roots.

Competencies: are becoming the major entity of assessment and learning-plans. In GeoSkills, just as in [12] or [19], competencies are made of a verb and a set of topics. The class hierarchy of competencies represents the specialization hierarchy of verbs.
Examples of competencies include Calculate_trigonometric_ratio, Explore_points_with_given_distances_to_two_points, or Identify_square_numbers.

Pathways: are a series of educational contexts such as elementary-school, or Secondaire_de_Qualification_Technique_Artistique.

Levels: are elements of a pathway, for example one of its year. For example Gymnasium_Saarland_7te, or Bachillerato_Ciencias_y_Tecnologia_2.

Programmes: a programme is the concrete plan of a level within a pathway, it is bound to curriculum standards. A programme can contain a list of competencies or the URL of an HTML where they are referenced.

The ingredients of this ontology are among the ingredients of the metadata structure that the Intergeo platform will be manipulating [20]; they contribute to its finest classification, similarly to [9]. Thanks to their *name-abilty*, they can enter an information retrieval process for both the auto-completion paradigm (as explained above) and the search tool paradigm (as explained below).

3.1 Rationale of GeoSkills

On the theoretical level, the approach is to rely on well-defined semantics, decidable knowledge representation and widely interoperable languages. OWL-DL meets such requirements. It is an interoperable format provided by the W3C [21]. Its well-defined logic is the Descriptive Logic, that has been proved to be decidable. Additionally, widely used OWL editors such as Protégé [22] or Hozo [23] and several inference engines [24,25,26] are available that could help searching,

This contrasts with the topic-maps standard that we mentioned above. There exists a standardized language [27] for them and an editing tool [28]: but this editor is less widely used than Protégé and, more importantly, there are no results about the decidability of algorithms on topic-maps.

On the practical level, the idea is to use tools providing enough affordance for non computer scientists like curriculum experts from several countries, and to ask them to collaboratively construct the ontology and benchmark it with instances taken from the localized geometry curriculae they master.

Protégé has been chosen has an editing tool both for the design of the ontology and for its first validation by a small group of experts. It offers OWL-DL editing, which is coherent with the theoretical requirements. It is usable for non-computer-scientists or non OWL-specialists. It is the most widely used ontology editor at this moment.

3.2 Ontology Maintenance Practice

In order to guarantee long-term quality of the list of competencies and topics, the management tasks have to be taken care of seriously. Aside of the many possible hand-crafted error-reporting rules that will be written as needs arise, the OWL DL ontology nature provides us several tools ready to be used:

OWL-DL axioms to constrain properties: several axioms can be encoded as part of the ontology constrain the properties of the individuals. For example, one axiom stipulates that at least a topic should be as an argument of a competency individual.

OWL-DL class membership by Extension: OWL-DL allows axioms to state sufficient conditions for an individual to be part of a class. This allows, for example, the competency individuals that are instances of the Construct competency class and have another as well as the a Compass topic to be instances of the Construct_with_Compass class as well

Abstraction for Similar Individuals: OWL-DL axioms can inject automatically property values implicitly based on class-membership. This is of particular use in countries where many educational regions exist such as Germany (each of the 11 Bundesländer has its own set of educational programmes) or Switzerland (each of the 22 Cantons has its own set of educational programmes). This abstraction allows to speak of a ninth class of a german Gymnasium with the same common-name (9. Gymnasium, neunte, 9.) which then gets specialized per Bundesland. All these abstractions take advantage of the ontology nature of our list of competencies and topics. The fact that the description logics formalism is used provides reasoners with predictable performance. Our current usage is based on the Pellet reasoner [26], an open-source, java-based, OWL-DL reasoner.

3.3 Populating the Ontology

In the first phase, the curriculum experts of our group of the Intergeo have been involved closely followed by touches at the ontology structure, advise on the best ways to encode, and adjustments at the editing interface. The Protégé editor is the main editing tool currently.

We have used the Protégé client-server setting[1] which allowed team members to work synchronously on the ontology from remote places provided they are equipped with a very good network connection; only Universities met this challenge thus far. For other members, in particular companies involved in the INTERGEO project, it was necessary to allow exclusive work on a local copy.

Another limitation was met in the generic ontology-editor nature of Protégé which makes it able to perform all sort so changes which should be reserved to ontology experts.

We are working on a competency editor web-based tool: it will complement the curriki-based platform we have described above to allow:

- platform user browse the competencies, topics, levels, and their relationships (e.g. from a resource annotated with a given topic): this provides the necessary links for a curriculum text or a text-book table-of-contents to be encoded
- platform users to become *translators* and add or edit the various names for the ingredients of the ontology (competencies, topics, programmes)
- platform users to become *curriculum-encoders* which create and edit competencies and topics.

Usage of this tool will start in August and we have expect all INTERGEO partners to encode the competencies of the complete math curriculum of secondary schools of their countries.

4 The INTERGEO Search Tool

We have explained above, the retrieval process that searches through the labels of the ontology and proposes an completion list of tokens. Once, chosen, the tokens can be used for the annotation or represent particular query-terms of the search tool. In this section we explain the search tools' query mechanism, which, again, relies on the knowledge of the ontology.

In making the search tool, we rely on classical information retrieval principles which stipulate an easy query and result process with a result-list ranked by *relevance* as described, e.g in [13] and using the Lucene [14] library.

The query term shall be made of a set of terms, related by operands, each made of a set of words. Some set of words such as `[utiliser les propriétés du triangle isocèle]` represent a single node of the ontology, other set of words represent an arbitrary match. For each set of words, a query expansion is performed:

- each set of words is expanded to a query for the competencies, topics, or levels, whose names match the set of words, along with a query for the resources whose text contains the set of words
- each query to a competency is expanded to a query for resources annotated with this exact competency or resources annotated with topics of that competency, or resources with *parent-competencies*; the second is less *boosted*.

[1] The Protégé client-server setting is based on Java RMI and is documented at `http://protegewiki.stanford.edu/index.php/Protege_Client-Server_Tutorial`

– each query to a topic is expended to match itself or, less well, its parent or children topics

This query expansion mechanism, which is detailed further in [3] is the key to a tolerance of the search tool, a fundamental criterion of search tools' acceptance. This tolerance is enabled by the knowledge stored in the competency ontology. For example, it will allow a scottish teacher to search for *enlargement* in the platform and still find what a French teacher will have annotated as being annotated for the competency or recognizing the V-configuration or applying the intercepting lines theorem.

5 Conclusion

In this paper we have introduced how a list of topics, competencies and educational levels, provide convenient methods for annotation and fuzzy search in a multilingual and international settings and have explained how its ontological nature helps its development. We conclude with a description of the current status and the open perspectives of interoperability.

5.1 Implementation Status

The GeoSkills ontology is now stable in structure, it is being documented and enriched with axioms. The geometry parts of the topics and competencies of the curriculum of several years of the French collège are fully encoded, and in parts for two years of the curriculum of Cataluña and the one of Saarland.

We expect the enrichment status to grow much larger in the fall of 2008 when many simultaneous curriculum experts will be working on it. The curriculum editor to be used in under work at DFKI.

The Intergeo platform's basis, the Curriki platform, is already exploited large scale on `http://curriki.org/`. A graphical and metadata tuning of it is under work while a preliminary version, with the same technological basis, has been exploited on `http://i2geo.net/` since March resulting to *traces* of more than 3000 interactive geometry resources. The search tool is being implemented and should see its first appearances in September.

5.2 Interoperability Perspectives

The standards-based encoding nature of the GeoSkills ontology promises further interoperability because its semantic commitment and its intent of full european coverage by the end of the project.

A first challenge we are trying to face is to make the GeoSkills' ontology available to an external server such as the PHP server of GNU edu: together with its authors, we attempt to bring the reasoner results to a place where apparently no OWL reasoner is available. We shall probably do so with a set of web-service-based queries although the scalability of such a solution is not at all clear yet.

A part of the GeoSkills which seems to have a large potential for re-usability is the part about educational contexts which catalogues educational regions, pathways, levels, and programmes. Based on reference texts, we seem to be able to provide the coverage of the full set of European schools in strongly structured way. GeoSkills can probably enter as standardization candidate to encode the content of any curriculum.

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