USING TOPIC MAPS FOR WEB-BASED EDUCATION

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Abstract

In this paper we discuss the educational and research benefits of applying an innovative technology - Topic Maps - for organizing and retrieving online information in the context of Web-based courseware. Topic maps offer a standards-based approach to encoding expert’s domain and instructional knowledge, i.e. to building educational ontologies and courseware components. This allows further reuse, sharing, and interoperability of knowledge structures and teaching units between courseware authors and developers. We also present our current work on developing, evaluating, and utilizing Topic maps-based courseware modules.

Key Words

WBE, concept-based courseware, semantic Web, ontology, Topic maps

1. Introduction

Web-based learning gains an increasing popularity in college education and business training. However, its effectiveness and efficiency for both learners and instructors depend crucially on the organization of the online learning resources, which determines the easiness of their creation and retrieval. Currently available online educational materials, such as electronic textbooks and Web-based courses, are mostly hypertext containing hierarchical links that represent the book or course structure, and possibly simple “horizontal” (contextual) links from a page to associated pages that are similar [1]. The main problems related to using educational hypertext for learners are cognitive overload, disorientation and
distraction, poor narrative flow, and poor conceptual flow [2]. To overcome these problems e-learners need support in retrieving and evaluating online information. This requires efficient organization of Web learning resources.

In this paper we present an innovative approach to creating ontology-oriented courseware in Computer Science based on Topic maps. Topic maps (TM) offer a standards-based approach to building educational ontologies and courseware components that allows reuse, sharing, and exchange of teaching materials. We start with a discussion on the benefits of applying Topic maps in the context of Web-based learning and then we present our current work on developing, evaluating, and utilizing ontology-based courseware modules.

2. Towards Re-usable and Shareable Courseware

Modern research approaches related to courseware content organization, are based on knowledge classification and indexing of learning material. In adaptive educational hypertext systems, the conceptual structure of the content is hidden, i.e. embedded in the educational text (Web pages) by linking concepts in one page to other pages relevant to those concepts, as for example, in InterBook, ELM-ART, MetaLinks, and AHA! [1,3,4,5]. It is used for adaptation of the presentation (content adaptation) and of the navigation support (link adaptation).

In concept-based courseware support systems, the conceptual structure is explicitly represented in the system, i.e. there is a clear separation between the teaching and learning materials (a set of Web pages or a library of educational documents) and the conceptualization of the subject domain, which is represented by a set of concepts connected to each other. There is a great diversity in the depth of the conceptual domain representation on the ‘conceptual layer’ and in the ways of its usage [5,6,7,8,9,10]. The latter include identifying gaps or misunderstandings in a learner’s knowledge, predicting and controlling a learner’s problem solving performance, or using a learner’s represented knowledge as a guide for instructional design purposes, e.g., course sequencing, task-based information handling support, etc.

One of the main problems for authors of hypertext and concept-based courseware is the difficulty to reuse and share existing instructional units. This is a very serious problem in the light of the exponential growth of Web-based courses. Obviously, there is a pressing need of course content ‘interaction’. To achieve this we need courseware that is reusable (modular), discoverable (tagged for search and retrievable), and interoperable (cross-platform). One feasible approach to this problem is standardization. This should be achieved at two levels: knowledge level and technological level. At the knowledge level the courseware standardization efforts require creating of specialized ontologies - well-
founded and agreed upon systems of concepts and the relationships that exist between those concepts - to be used as a backbone in courseware development. By providing common vocabulary for domain knowledge representation they can support sharing, reuse, and exchange of knowledge bases and courseware functional components among different courses and authors (instructors). More and more general and specialized task and topic ontologies are becoming available and will need to be shared, reused, and easily maintained [11,12,13,14,15]. That is why new methods for knowledge organization and processing are required to facilitate knowledge sharing among authors, including support for merging and reusing knowledge structures. The latter is closely linked to metadata (XML) and reusable components.

A negative effect of the proliferation of different Web-based systems with variety of developers and learning content formats is that the learning content developed for a particular system may not be reusable in others. At technological level standardization requires defining standard courseware structures - learning objects - and providing technological support for describing, formatting, retrieving, relating, and presenting their content. By learning object we mean any entity that can be used, re-used, or referenced during Web-supported learning. A learning object can be a unit, lecture, exercise, problem, Web page, image, etc., with a specified instructional purpose. Standardization at these two levels will set the basis for the creation of ‘educational’ semantic Web.

The semantic Web research and standardization efforts [16] resulted in two standards for interchanging semantic information – RDF (Resource Description Framework) and Topic Maps (TM). Topic mapping has its roots in traditional publishing and library science concepts such as back-of-book indexes, glossaries and thesauri. RDF has its roots in formal logic and mathematical graph theory. Topic Maps are often compared to RDF. Although they have similarities with respects to their application, these two standards have also big differences. While Topic mapping is a knowledge representation applied to information management from the perspective of humans, RDF is knowledge representation applied to information management from the perspective of machines [17]. Topic maps were designed to facilitate navigating, searching, filtering, customizing, and merging Web information.

3. Topic Maps

Topic maps are a new ISO standard [18] that can be viewed as an interchangeable hypertext navigation meta-layer above diverse electronic information sources supporting topical finding of various kinds of resources, such as documents, graphics, images, database records, audio/video clips, etc. Thus a special characteristic of the Topic maps model is the
clear separation between the description of the information structure and the physical information resources (like Web pages, multimedia content, images, and books). The navigation meta-layer is independent of the format of the actual resources and enables the creation of an external index that makes the information findable.

The main Topic maps components are topics, associations, and occurrences [18]. Using those elements, one can create maps in document repositories. The topics represent the subjects, i.e. the things, which are in the application domain, and make them machine processable. They can have zero or more topic types and also have names (a base name and variants for use in specific processing contexts). A topic association represents a relationship between topics. Associations have types (e.g. illustrated_by, example_of, written_in, etc.) and define roles of the participating topics (e.g. example - concept description; prerequisite - result; document - language). Occurrences instantiate topics to one or more relevant information resources. An occurrence can be anything; most often it is a URI or a document (article, picture, video, etc.). Scope defines the extent of validity of a topic characteristic assignment: the context in which a name or an occurrence is assigned to a given topic, and the context in which topics are related through associations. One useful and potentially very powerful application of scope is to permit capturing of different viewpoints of the subject. An important concept in TM is this of identity. Two topics are the same if both have the same name in the same scope or both refer to the same subject indicator. The topics and all their characteristics could be merged if this condition holds.

Topic maps provide a language to represent the conceptual knowledge with which a student can distinguish learning resources semantically. Apart from their major purpose to index information resources, Topic maps embody knowledge. A semantically reach Topic map would enhance the value of a teaching unit. Moreover, Topic maps are very suitable for representing the course unit ontological structure. For example, an ontology of car repair may include concepts such as ‘engine’, ‘transmission’, ‘emission ignition’, and ‘brakes’ and assertions such as ‘mechanic repairs car’. In a corresponding Topic map all these concepts would translate into topics where ‘repairs’ would introduce an association between the topics ‘car’ and ‘mechanic’.

Our current research aims at experimenting with this innovative technology for organizing and retrieving online information. We believe that it is very promising for Web-based education and can be an answer to many of its challenges.
4. Advantages of Using Topic Maps

In this section we discuss the advantages of using Topic maps in Web-based learning from three perspectives, those of learners, courseware authors, and software developers. We distinguish between courseware authors and courseware developers. The latter are the developers of TM-based authoring applications, while the former are only users of the developed authoring environments.

4.1. Learners’ perspective

TM-based WBE applications can support learners in:

- **Efficient context-based retrieval** of online information relevant to their current learning tasks. This is based on the possibility for learners to search and navigate in both the information (resource) layer and the semantic (topic) layer. The learners can first search the topic layer guided by the type-subtype topic associations and the roles that topics play in these associations. When they find a topic of interest, they can dive into the information layer straight to the resources connected to that topic. By allowing students to specify topic domains of different level of generality TM enable search with high precision of the search results.

- **Acquiring new topical knowledge.** Learners can gradually build their knowledge through natural and intuitive topic-aware content browsing. By topic-to-topic navigation and following topic occurrence links they can access the actual learning objects (resources) associated with domain topics.

- **Deeper understanding of the domain conceptual relations.** This is a synthesized result of navigating and exploring the topic layer, which is a coherent presentation of the subject domain as a network of topics (domain terms) and their relationships. The view on the ontological structure of the subject domain supports learner’s reflection on their knowledge, and knowledge capture and refinement, thus leading to better understanding of the domain.

- **Better information comprehension.** TM-based applications include browsers that visualize Topic maps. Both the visualization and domain navigation facilities help learners to get quickly and easily orientated within the subject domain and build up their own understanding and conceptual associations. It supports their visual thinking and imagination and helps them create their own problem-solving paths.
Better browsing awareness. A ‘bird-eyes’ view over the learning material (information resources) as a whole give learners better understanding of its conceptual structure and supports better assessment and control of learners’ own browsing experience.

Customized views, adaptive guidance, and context-based feedback. Topic maps-based applications can reason over learner’s performance thus allowing for customized views on the same set of resources, adaptive guidance and context-based feedback depending on the current learner’s task and goals. This adaptivity helps learners stay focused within the context, establish efficient learning strategy and be aware of the learning process.

4.2 Authors’ perspective

Modern concept-based educational courseware includes domain knowledge at two levels: an information (learning) resource repository and an ontological (semantic) layer that conceptually models the subject domain. It also includes indexing that connects domain concepts to repository objects or external Web documents. This makes the process of authoring rather complex. Topic maps support naturally both knowledge representation and information organization and management, thus providing the author with a structured approach to coordinate all the activities during the courseware creation. Topic maps offer the following advantages to the courseware authors:

Knowledge externalization support. The TM approach allows the authors to efficiently externalize their implicit knowledge on both the conceptual and information levels by building an explicit conceptual domain structure and linking relevant online resources to it.

Effective management and maintenance of knowledge and information. Authors are facilitated in the efficient manipulation and maintenance of knowledge structures and information resources and the links between them. TM-based applications offer possibilities for searching, navigating and visualizing both the conceptual and resource layers. Reasoning rules based on the rich semantics of TM allow guiding the author in the organization of resources into a new, ontology-aware information space, where they are linked in a semantically meaningful way.

Augmenting learning space beyond teaching space. Authors can ‘open’ their courseware/course libraries by including ‘external’ online documents linked to the domain concepts. In this way they are able to augment the learning space with information beyond the course teaching material.

Rapid and efficient courseware development. Topic maps use standards-based representation that allows authors to share and exchange developed courseware modules (learning objects). Moreover, they are
specifically designed to support easy and effective merge of existing information resources maintaining their meaningful structure, which allows for flexibility and expediency in re-using and extending existing courseware.

- **Collaborative authoring.** Topic maps support of ontologies and standardization allows collaborative authoring of educational resources and merging information with other groups (individuals) or institutions.

- **Personalized courseware presentations.** Courseware topics can have many descriptive dimensions, for example, they can be described at different levels of granularity or can be viewed from different perspectives. Topic maps allow explicit representation of context or viewpoints through the use of *scopes*. This feature can be used by authors to create different personalized views of the same set of resources adapted to specific learner stereotypes (e.g. beginners, intermediate, advanced) or purposes (e.g., current instructional tasks, goals, etc).

### 4.3 Courseware developers’ perspective

Here are some advantages of Topic maps for course developers:

- **Building ontology-aware applications.** Topic maps are particularly suitable for representing ontologies, which would facilitate the development of well-structured and intuitive authoring environments for ontology-based courseware.

- **Building open-ended learning environments.** The ability of Topic maps to link resources anywhere in the semantic Web, and organize these resources according to a consistent ontology, allow the construction of *open-ended* course libraries.

- **Building adaptive educational applications.** The possibility for providing customized views on selected TM fragments allows for development of *adaptive TM-based applications* that filter information depending on learners’ profiles.

- **Building courseware templates and development patterns.** Topic maps’ modularized structure allows developers to create templates and various development patterns, which can increase the efficiency of courseware authoring.

- **Enhanced navigational and retrieval tools.** Using the TM properties, application developers can create navigational tools such as indexes, cross-references, glossaries, etc., and use them for virtual document assembly, and for creating thesaurus-like interfaces to corporate knowledge bases. Moreover, TM structure enables intelligent retrieval of information through the use of inference-based queries.
• **Reuse, sharing and interoperability.** The open standard technology XML Topic maps (XTM) [15] and ISO 13250 Topics Maps [18] permit the representation of knowledge in an interchangeable form and provide a unifying framework for knowledge and information management. Thus TM application developers have a better chance that learning resources created by their applications are reusable, sharable, and exchangeable.

• **TM tools and API.** There are already several tools and APIs available for Topic maps manipulation, e.g. Ontopia [20], Mondeca [21], Empolis [22], Topic Map Loom [23], etc. By using such tools, courseware developers will be able to shorten the life cycle of their application development and increase the quality of their product.

### 5. Project Goals and Phases

We have two major goals in this research. The first one is to test the appropriateness of using the Topic map technology to improve learning in Web-based courses. The second goal is derived from our belief that Web-based education needs ontological support. It can be viewed as an initial step aimed at fostering broadly agreed-upon ontologies (vocabularies) for exchanging courseware content in some (restricted) fields of Computer Science. Both aim at encouraging the development and use of interchangeable and searchable courseware units on the Web (based on XML formatting). For this purpose we are currently developing ontology-based courseware modules and are designing pilot experiments to assess the impact of the new TM technology on the efficiency and effectiveness of both student learning and courseware authoring. Consequently, the project includes three phases.

The first phase is focused on creating specialized ontologies. In our pilot project we have selected 5 modules from Computer Science courses and have started developing topic ontologies for them. Our preference was for modules that are common for two or more courses so that we can experiment with sharing and reusing them in different Web-based courses at local level. We are planning to create a website for publishing the ontologies and will invite colleagues worldwide to comment on them so that an agreeable version is reached. Such an effort will have its own significant value – the created agreed specialized ontologies can be used in other concept-based courseware systems. We assume that as a result of projects like this one, more and more specialized ontologies for more and more domains would be created and interrelated. They would reside on different servers around the Web and eventually would be linked into a shareable library of terms. This is one way to realize the vision of the semantic Web.
Phase II is aimed at developing Topic map-based courseware. We have reviewed currently available TM software and have selected Ontopia’s Knowledge Suite [20]. We are currently experimenting with Topic maps in the XTM language [15] and are exploiting Ontopia’s Omnigator to view the developed Topic maps. In the second stage of the project we plan to develop a custom-designed TM editor for authoring Computer Science courseware.

Phase III is focused on evaluation of the developed modules. Ontology development is necessarily an iterative process, thus rigorous evaluation (both formative and summative) is necessary at several dimensions and levels: evaluation of the developed ontologies, of the developed Topic maps-based courseware modules including assessments of all aspects (scholarly, technological, and pedagogical) of learning objects; and evaluation of the impact of using TM-based courseware on student learning.

6. Courseware Development: An Example

Our goal is to develop ontology-based courseware that

- supports learners in their reflection on knowledge, knowledge refinement, and communication, and
- can be used as a Web-based task-support environment that assists students in locating information necessary to perform course tasks (e.g. home assignments, projects, etc.). Thus, it should allow students to navigate and search course related material by broadly understood categories.

As it was mentioned, in our pilot project we chose modules that are common for at least two Computer Science courses in order to be able to experiment with reusing them. Among them are the units “Number Systems”, which is relevant to “Introduction to Programming”, “Assembly Language Programming”, and “Computer Architecture”; “Introduction to Entity-Relationship Model”, which is included in two Database courses and in the “Systems Design and Development” course; and “Prolog”, which is included in the “Artificial Intelligence” and “Programming Languages” courses.

In order to illustrate Topic maps-based courseware design, we give an example from the course module “Prolog”. In this exploratory phase we use the Ontopia Omnigator - a generic application built on top of the Ontopia Navigator Framework that allows users to load and browse Topic maps. A screen shot of the interface is illustrated in fig. 1. The page shown is the *Topic Page* where “Prolog” is the current topic – instance of the topic “Reasoning Systems”. The
Topic Page presents the information held in the Topic map about the current topic. The kind of information displayed depends on the nature of the topic. Under “Related subjects” we see a list of topics associated with “Prolog”.

The topic “Prolog” (which defines a class of topics) doesn’t participate in any associations apart from the class-subclass associations. All the occurrences of the topic “Prolog” are shown on the right organized by type. Note that occurrences are displayed in different ways, depending on whether the occurrence is internal or external to the Topic map. With internal resources (History, Seminal Contribution, Brief Description, Tutorial, Notes) the contents of the resource are shown inline. With external resources (Tutorial, Notes), only the address of the resource is shown. Clicking on the address makes the browser go to the resource. The “Name Origin” – ‘Programming in Logic’ shown under the heading “Metadata” is another example of internal resources. Because “Prolog” is a topic type, the Omnigator displays a list of topics of this type: ‘Facts and Rules’, ‘Lists’ and ‘Recursive Rules’, in other words, an index of Prolog subjects. These topics are listed under the heading “Topics of this type” and can be seen when scrolling down. By clicking on any of the subtopics, it becomes the current topic.

Figure 1. The ‘Prolog’ Topic.
Assume that we click on the topic “Lists”. The result is a new Topic Page, “Lists”, shown in fig. 2. All topics that are related to the current topic through some associations are listed under “Related subjects” grouped according to the association type. This is the equivalent of “see also” in a back-of-book index. For “Lists” we have defined associations labeled “are illustrated by”, “extended to”, ”processed by” and “subclass of”. We see that “Lists” are illustrated by “List Processing Examples” and that “Lists” are processed by “Recursive Rules”.

When displaying names of associated topics, the Omnigator assumes a current context defined by the current topic. If we move the cursor over the associated topics, e.g., “List Processing Examples”, we will see the text “Role type: example” appearing as a pop-up. This tells us that “List Processing Examples” plays the role of example in that association. If the association is scoped, the names of the topics comprising the scope will also be displayed. Notice that associations provide a mechanism for establishing a network of links layered over a collection of information, which can be used to navigate the information in different ways (not only hierarchically). The links connecting the topic “Lists” with “List Processing Examples”, “Difference Lists”, “Recursive Rules” and “Prolog” express the associations between the topics (e.g. “are illustrated by”, “extended to”, “processed by” and “subclass of”). Associations extend the power of traditional hyperlinks to model networks of knowledge and information recourses.

Obviously, the Omnigator's user interface is not very suitable for direct use by learners. Learners should not know that the application they are using is driven by a Topic map. They should not be exposed to concepts such as “topic”, “topic type”, and “associations”. The learners should simply interact with an interface that makes it possible for them to find the information they are looking for, quickly, easily, and intuitively. However, at this stage our immediate goal was to explore the advantages and the expressive power of Topic maps with respect to ontology-driven WBE applications and the Omnigator was sufficient for that goal.
7. Conclusion

In this paper we report initial stages of research aimed at experimenting with a new advanced technology for organizing and retrieving online information, Topic maps, which seems very promising for developing Web-based courses. Topic maps resemble semantic networks and conceptual graphs, but offer much more - a standards-based way of encoding the knowledge. Thus an advantage of using the TM technology is that the developed teaching material is in a standard XML format, which makes it shareable and interchangeable. This is in line with the current trends in Web developments indicating that building ontologies and shareable components should be based on the representational layer of the semantic Web.

Our initial experience in developing TM-based courseware units indicates that while Topic maps offer a powerful and promising technology for intelligent organization and access of information in general, creating Topic maps for specific course modules is not an easy authoring task. In addition to the recognized difficulties that authors face when creating conceptual structures [24], there are some specific issues, for example, ones related to using general TM supporting tools for courseware authoring, where the author has to be familiar with the Topic maps concepts. These difficulties require the development of specialized education-oriented TM tools that facilitate the creation, maintenance,
search, and visualization of Topic maps-based learning resources. There is an obvious need of specialized environments designed to enable educators to build Web-centered applications based on user-specific requirements, without knowing the Topic map model and being aware that they work with Topic maps. These specialized environments should provide instructors and learners with intuitive and easy to use tools for creating and navigating Topic maps.

A number of research questions have to be explored in this relation, such as: how to transform the standard TM knowledge representation-oriented terminology into a domain-specific user (instructor/learner)-oriented terminology; how to provide course developers with a set of reusable TM-based components from which specific learning units can be rapidly built; how to personalize views on the same learning material; what are the ‘standard’ views (if any) that might be of interest in different educational contexts, etc. These questions combined with the results of our planned evaluation of the developed computer science modules will form the agenda of our future research efforts.

References


[22] Empolis, http://k42.empolis.co.uk. [Last viewed April 5, 2003].
