A Formal Context-aware Visualization tool for Adaptive Hypermedia Learning

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Abstract: - This paper presents the OntoVisID, a context-aware visualization tool. Three context-aware aspects of the OntoVisID for adaptive hypermedia learning will be discussed: ontological structuring of course content, retrieval of learning materials and visualization of the concept space. These aspects capitalize on the clustering of concepts in Formal Concept Analysis (FCA) to create context and a natural ontological structure for navigation and visualization. Attributes that describe each concept in FCA’s formal context enables indexing and easy retrieval of concepts and learning materials.

Key-Words: - Contextual Learning, Course structuring and retrieval of learning materials, Ontology, Formal Concept Analysis

1 Introduction

e-Learning serves as a means to implement educational models within various teaching and learning modes (such as face-to-face, on-line, Web-based or mobile) based on eclectic applications of educational theories such as behaviorism, cognitivism and constructivism. Among these learning theories, constructivism is the most learner-centered, encouraging learner-initiated and learner-controlled exploration of a concept or learning goal in relation to the curriculum.

However, two pertinent problems need to be addressed before educational systems can truly be constructivist. Learners (especially novice and weaker students) can only initiate, explore and control their own learning if the educational system has been designed to reduce disorientation and cognitive overload [1]. In addition, learning materials should be easily accessed.

Addressing disorientation, cognitive overload and access to learning materials thus require reconsideration of hypermedia interaction design in terms of the course structure, its visualization and means for indexing learning materials.

2 Problem formulation

Hypermedia interaction design in general can be approached from three perspectives: first, educational-oriented systems, second technological tools that enable personalization and third, standardization in terms of indexing of learning objects and content management in order to enable interoperability and reusability of learning materials [2].

An ontological architecture that encompasses all three aspects has been proposed by [3]. This architecture can serve as a guide to the development of future web-based educational systems. The ontological architecture consists of the educational content represented in the form of the domain knowledge and pedagogical strategies, personalized view of learning materials through the presentation planner which customizes learning materials to different student models, assessment, references and collaborative systems. Authoring and learning tools provide the interactive interface between the instructor, system and learner. An example is the GET-BITS framework for constructing intelligent Web-based systems.

Of primary importance to both [2] and [3] is the role of ontology in representing educational domains and instructional strategies and in laying the foundation for building personalized intelligent educational systems and in enabling standardization in systems design and development and interoperability.

Internal ontological representations however, need to be made explicit and visualized externally. Visualization using squarified cushion tree maps, hyperbolic trees and Venn diagrams for accessing learning object repositories such as ARIADNE has been discussed in [4] and its advantages and disadvantages identified.
Questions raised in [4] are firstly visualization of learning objects which may be too many at one level requiring a means to filter irrelevant information, secondly optimal use of space and dynamic reallocation of elements in space, and thirdly the need to still retain an overview of the learning object repository after having zoomed in into a particular element.

3 Problem solution

This paper aims to improve on hypermedia interaction design through a formal approach, i.e. Formal Concept Analysis (FCA). FCA is used for course structuring, visualization and subsequently, retrieval of learning materials through RDF-compliant XML representations. These three aspects are integral to the OntoVisID tool explained in Section 4.

3.1 Significance of the study

The OntoVisID, a component of the CogMoLab architecture, uses ontology to structure and cluster concepts to reduce disorientation. Contrasted with [4], composition is used to represent concepts and subsequently to retrieve learning objects or materials. Compositing of concepts to different levels of abstraction creates smaller windows of focus, thus reducing cognitive overload. Furthermore, composition answers the question of having too many learning objects at one level and the question of optimal space usage. In addition, in order to retain a bird’s eye view of other concepts in the concept space, the learner can zoom out and pan through the concept space.

In the next section, the framework for a context-aware educational system will be discussed, followed by a brief review of main tenets of concept lattices/formal context analysis, the application of concept lattices for ontological course structuring, navigation, query and retrieval of concepts and learning resources and finally, visualization of the concept lattices in the OntoVis visualization tool.

3.2 Framework for a context-aware educational system

The CogMoLab architecture [5] works along the guidelines suggested by [3], working towards developing a context-aware adaptive hypermedia learning system. CogMoLab’s educational orientation focuses on the modeling of cognitive structures in line with a constructivist approach, cognitive flexibility theory. Cognitive flexibility theory [6] aims to enhance the association of related concepts to form more accurate mental models by presenting the same concepts from different perspectives. A laboratory analogy is used because construction and revision of mental models is similar to the making, testing, analysis and revision of hypotheses in a laboratory.

Technological and personalization concerns are addressed through the self-organizing map-principal component analysis student model. The student model creates an overlay stereotyped profile of the students in terms of knowledge states for adaptive generation of links and retrieval of learning materials in the OntoID authoring tool and granulated hints in the Merlin agent-assisted collaborative concept map. Formal concept analysis creates the ontological structure for designing domain knowledge and instructional strategies. An ontology mapping and merging tool addresses the standardization aspect raised by [2] and [3].

3.3 Formal concept analysis for creating context-awareness

3.3.1 Main tenets of concept lattices

The concept lattice is formed based on the identification of the formal context and Galois connection. Formal or relational context in the concept lattice is provided by the formalization of contexts, which begins with the formal context as a relational structure \( K = (E, P, R) \). \( E \) is defined as a set of formal objects, \( P \) a set of formal attributes and \( R \) a binary relation between \( E \) and \( P \), which identifies which formal objects contain which formal attributes. If the entity \( e \in E \) is in relation \( R \) to the property \( p \in P \), it means that the entity \( e \) has the property \( p \). This is represented as \( eRp \).

Nodes in the concept lattice are associated via the Galois connection [7]. Galois connection is defined by two functions:

Firstly, if \( e \in E \) and \( p \in P \), \( f(E) \), the set of all properties common to all entities in \( E \) is defined as

\[
f(E) = \{ p \in P \mid \forall e \in E \cdot eR \cdot p \} \tag{1}
\]

Secondly, \( g(P) \), the set of all entities which contain all the properties in \( P \) is defined as

\[
g(P) = \{ e \in E \mid \forall p \in P \cdot eRp \} \tag{2}
\]

The duple \((f,g)\) forms a Galois connection between \(2^E\) and \(2^P\).

The formal context \( K \) is also defined in terms of an ordered pair \( c = (A, B) \) whereby the formal extension \( A \) (the extent of \( c \) represented as \( Ext(c) \)) comprises all the formal objects of the formal context which contains the formal attributes in the set \( B \). The formal
intension $B$ (the intent of $c$ represented by $\text{Int}(c)$) comprises of all the formal attributes of $c$ for all the formal objects in the set $A$.

Referring to equations (1) and (2), the formal concept $(\text{Extent}, \text{Intent})$ is a pair whereby $\text{Extent} \subseteq E$, $\text{Intent} \subseteq P$ and $f(\text{Extent}) = \text{Intent}$ and $g(\text{Intent}) = \text{Extent}$.

### 3.3.2 Ontological structuring and navigation of concepts

The concept lattice fulfils two main definitions:

**Definition 1:** A partial order is imposed on the concepts whereby for concepts $c_1, c_2 \in L$, $c_1 \leq c_2$ iff $\text{Extent}(c_1) \subseteq \text{Extent}(c_2)$ and $\text{Intent}(c_1)$ is the superset of $\text{Intent}(c_2)$.

This ordered relation is represented as

\[
(\text{Extent}(c_1) \leq \text{Extent}(c_2)) \quad (\text{3})
\]

\[
(\text{Intent}(c_2) \leq \text{Intent}(c_1))
\]

In Figure 1, $\{\text{Topic2}\} \leq \{\text{Topic2, Topic3}\}$

![Hasse diagram](image)

**Figure 1. Example of partial order relations**

**Definition 2:** If $(E, P, R)$ is the formal context, and $L$ is a concept lattice of formal concepts obtained from $(E, P, R)$ and $S$, the concept space, is a subset of $L$ ($S \subseteq L$), then the meet and join elements are defined as below:

\[
\text{Meet}(S) = (\text{Extent}(c), f(g(\text{Intent}(c)))) \quad (4)
\]

\[
\text{Join}(S) = (g(f(\text{Extent}(c)), \ \text{Intent}(c)) \quad (5)
\]

An example of a relational matrix for the concept lattice is shown in Table 1. Partial order relations, meet and join operations for the relational matrix in Table 1 are presented in a Hasse diagram in Figure 2.

Referring to equation 4, $\{\text{Topic2}\}$ and $\{\text{Topic3}\}$ meet at $\{\text{Topic1}\}$. $\{\text{Topic1}\}$ is the most specific concept or the greatest lower bound with partial order relations with $\{\text{Topic2}\}$ and $\{\text{Topic3}\}$. Conversely, for equation 5, $\{\text{Topic2}\}$ and $\{\text{Topic3}\}$ join at $\{\text{Topic2, Topic3}\}$. It forms the most general concept or the least upper bound for the concept lattice.

If there is no union or join or no specialization for a particular concept, 2 elements $T$ and $\perp$ can be used [8]. These 2 symbols can be defined as the concepts of “anything” and “nothing” in the formal context. So, $T$ can be the common parent and $\perp$ can be the common child to each pairs of concepts.

### Table 1. Relational matrix for the concept compression

<table>
<thead>
<tr>
<th>Topics</th>
<th>Attributes</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topic1</td>
<td>(IP)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td>Topic2</td>
<td>(IC)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td></td>
</tr>
<tr>
<td>Topic3</td>
<td>(IC)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
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<td>(IC)</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td></td>
</tr>
<tr>
<td>Topic5</td>
<td>(IC)</td>
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<tr>
<td>Topic6</td>
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</tr>
</tbody>
</table>

* A = sampling, B = quantisation, C = frame rate, D = frame size, E = colour depth, F = spectral redundancy, G = psychovisual redundancy, H = spatial redundancy, I = text representation, J = FFT, K = DCT, L = RLE, M = Arithmetic encoding, N = Huffman encoding, O = interframe, P = high rate of compression
3.3.3 Ontological query and retrieval of learning materials

The concept lattice \( L \) of the formal context \( (E,P,R) \), is a complete lattice of formal concepts obtained from the formal context. In terms of query and retrieval, the concept lattice’s complete characteristic is applied. According to [8], the extent-intent pairs are considered complete pairs if:

- a) the extent is the set of objects described by minimally the properties in the intents
- b) the intent is the set of properties shared by all the objects in the extent

The intents are represented as query terms. Hence, the object(s) retrieved must fulfill all the terms (properties) specified by the query relevant to the object. This means that a query which requires fulfillment of all terms or properties will retrieve the most general concept in the concept lattice and vice versa. Search generality is increased or decreased as the learner traverses up or down the concept lattice.

In short, the concept lattice can be regarded as an “extensional class hierarchy” which contains the set of instances and common properties shared by these instances [9]. Furthermore, the concept lattice enables a network of nodes to be classified in such a way that each class (concept lattice node) corresponds to a query described by the terms of related documents. In addition, concept extents and intents can be viewed incrementally at different levels of granularity, i.e., in terms of different degrees of generality or specificity by traversing along the edges connecting respective vertices.

Visualization of the concept lattice through the OntoVisID visualization tool is presented in the next section.

4. Visualization of the concept lattice

The OntoVisID tool capitalizes on the topic map standard. Topic maps [10] represent knowledge using topics, associations and occurrences. Topics denote concepts in the curriculum. Associations indicate the type of relations between and among concepts. Occurrences on the other hand, refer to the internal or external information resources relevant to a topic. URIs are used to link to resources (in the educational context, resources refer to learning materials).

For the OntoVisID, the concept lattice is used to form and structure the ontology for the topic map visualization. Nodes in the concept lattice represent concepts. Partial order relationships between nodes in the concept lattice associate more similar concepts together and structure nodes in a superconcept-subconcept hierarchy. Attributes in the concept lattice create semantics that facilitate information retrieval. The concept lattice nodes and attributes are stored as metadata in XML.

Figure 3 below shows the student view of the OntoVisID interface at the highest level of abstraction. The student can search for a particular concept by typing in the keyword in the search dialogue box. After the concept is found, the student can right click on a concept node and OntoVisID will zoom in to subconcepts at the next level or subsequent levels. Visualization of partial order relations provides an explicit indication of the concepts’ ontological hierarchy and degree of association. Students can navigate around, up or down the cluster of concepts. Navigation around related clusters of concepts reduces disorientation. In addition, learning materials relevant only to that concept can be easily retrieved by right clicking on that particular concept. Displaying learning materials which are relevant to a concept reduces cognitive overload.
4.1 Pilot testing

Pilot testing on fifteen students in the Faculty of Information Technology was conducted (Lee & Lim, 2005). Pre- and post-test questionnaires were distributed in order to determine whether the students like navigating and retrieving learning materials in a hypermedia learning environment structured in a composited concept lattice.

4.1.1 Pre-test

In the pre-test, 14 of the respondents prefer to have a 3-dimensional navigational interface in a learning environment compared to a 2-dimensional interface. They think that a 3-dimensional interface enables them to focus on particular concepts in the knowledge domain. This is because a 3-dimensional interface can provide a zooming functionality to allow the learner to concentrate on the specified concept node while keeping the other nodes in the background. Learners also prefer to have a big picture of the whole knowledge domain. They think that a 3-dimensional interface can provide them with a better bird’s-eye conceptual view than a 2-dimensional interface. One of the respondents prefers a 2-dimensional interface because it is simple and provides straightforward interaction.

In addition, 14 of the students think that it is easier to navigate through a 3-dimensional interface. However, only 6 respondents feel that a 3-dimensional interface may provide them with better information retrieval functionalities compared to a 2-dimensional interface.

4.1.2 Post-test

After testing the system, all of them prefer the 3-dimensional interface because it is easy to navigate through the concept space. 6 of the respondents say that the ease in navigation is due to the compositing of concepts whereas the other 4 say that it is because of the association of concepts. 5 of the students agreed that both composition and association contributes to better navigation. Overall, all of them find that it is easy to navigate as the related object classes are encapsulated into a composite object. Thus, information overflow is avoided as may sometimes happen in a 2-dimensional interface.

Moreover, 13 of the respondents agree that it is easy to retrieve learning objects from the 3-dimensional interface after testing the system. Out of the 13, 7 of the respondents say that ease in retrieval is due to both the association and compositing of concepts whereas 6 respondents attribute it semantic associations among concepts. Furthermore, more than half of the students agree that it is easy to remember the associations among the concept nodes. 7 of the respondents feel that it is easy to remember which concept is subsumed or encapsulated in which composite concept. In terms of the ability to know the path they have gone through before reaching a specified concept node, 6 of the respondents find that in the 3-dimensional interface, they can roughly know the path to reach a concept node. Throughout the whole user testing process, the results show that students are positive about the 3-dimensional composited means of navigation and information retrieval.

5. Conclusion

This paper has investigated a formal graphical approach to course modeling, i.e., the concept lattice. The complete concept lattice ensures more efficient course structuring, navigation, and subsequently, query based on extent-intent pairs and retrieval of concepts and learning materials. Pilot tests on the OntoVisID, a visualization tool which capitalizes on the concept lattice’s characteristics are promising. Further development on the OntoVisID involves integration with the OntoID authoring tool.
References


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