A Connectionist Approach for Adaptive Lesson Presentation in a Distance Learning Course

K.A. Papanikolaou, G.D. Magoulas, M. Grigoriadou
Department of Informatics, University of Athens, TYPA Buildings, GR-15784 Athens, Greece
E-mail: {spap, magoulas, gregor}@di.uoa.gr

Abstract

The issue of implementing adaptation in a Web-based course using an adaptive lesson presentation (or content-level adaptation) method is a promising direction of research. The goal is to adapt dynamically the supplied educational material so that it meets the individual educational needs of each particular learner. An important aspect in producing a learner-adapted system is the structuring of the domain knowledge in such a way that it will be possible to do adaptations. In this paper, a connectionist-based structure of the domain knowledge model is adopted. This approach allows generating the content of a hypermedia page from pieces of educational material based on a goal-oriented way of teaching and making use of the background knowledge of the learner.

1. Introduction

A broad mix of learners with diverse backgrounds, concerning their culture, cognitive abilities, interests and knowledge status attend a usual Web-based course. Thus, a serious problem facing the distance educator is adapting the educational material to the knowledge goals and abilities of each learner. Adaptive hypermedia systems [1][2][10] face this problem by building a model of each individual user and using this throughout the interaction with him/her. Introducing adaptive hypermedia systems we aim to avoid information overload by adopting the educational material provided to each individual learner's background knowledge. So two serious problems we face are:

- *Disorientation* experienced by users not knowing where they are within hypertext documents and not knowing how to move to the desired location (commonly know as "lost in hyperspace"); and
- *Cognitive overload* which is imposed on users as they navigate through the hypertext.

One method of implementing adaptation in hypermedia systems is adaptive lesson presentation [8] or content-level adaptation. In adaptive presentation the content of a hypermedia page is generated or assembled from pieces of educational material according to the learner's knowledge state. The adopted model of the domain knowledge, i.e. of the educational domain that acts as the source for the knowledge to be presented, strongly affects the effectiveness of the adaptation method. In fact, the model should be structured in such a way that it will be possible to do adaptations.

In this paper, a connectionist approach structuring the domain model is proposed. The decomposition of the domain knowledge in modules (see figure 1), such as knowledge goals, concepts, educational material is incorporated in a connectionist architecture. The proposed approach allows the adaptation of the educational material to the individual's learner level of understanding.

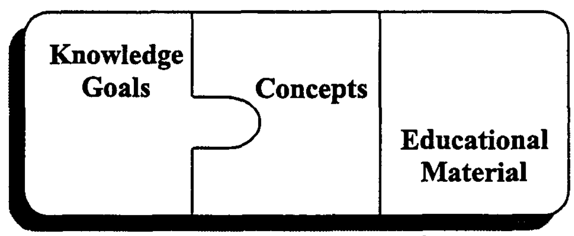

Figure 1. The domain knowledge of a course

2. Goal-Oriented Lesson Generation

In this research, a goal-oriented way of teaching is adopted, which is supposed to be adequate to adults who are motivated to learn a specific knowledge goal. Following this approach, the learner is able to choose from a set of predefined knowledge goals. These *goals* are explicitly defined and are referred to a subset of the domain knowledge. Depending on the knowledge goal, the associated concepts receive different characterisations. Some of them, named *outcome concepts*, are fully explained in the HTML pages constructed for the corresponding goal, with the use of text, images, examples, exercises and so on. Others, named *related concepts,* are simply mentioned in the HTML pages of the goal. These are related to specific outcome concepts but they are not so important for the selected goal. Finally, there are *prerequisite concepts,* which are necessary so that the

0-7803-5529-6/99/$10.00 ©1999 IEEE

learner understands the outcome concepts of a goal. Thus, a generated lesson includes: (1) complete presentation, in terms of text, images, examples, and simulations (if any), of the outcome concepts, (2) links to the main HTML pages of the prerequisite concepts, (3) links to the related concepts in a glossary and (4) tasks and questions.

Order	Outcome concepts	Prerequisite concepts	Related concepts
1.	Switching		Communication link. Link Error control
2.	Switches		Node.
3.	Packet Switching	Packet. Switching node. Line throughput. Propagation delay.	Packet. Topology.
4.	Datagram		
5.	Virtual circuit		
6.	Store & forward packet switching		
7.	Switching circuit	Packet.	Topology.

Table 1. Knowledge goal "Switching" (15 concepts).

In Tables 1-2, two goals of an introductory course on Computer Networks are exhibited. Note that the concepts included in the domain knowledge of each goal have been selected and sequenced by an expert. Each row contains an outcome concept followed by its prerequisite and related concepts. The order of the outcome concepts corresponds to the sequencing adopted by an expert in a traditional lecture.

Order	Outcome concepts	Prerequisite concepts	Related concepts
1.	Multiplexing	Flow of information	Physical link,
2.	Statistical Multiplexing		Packet, buffer
3.	Frequency division multiplexing		Packet, Communication channel, Transmission media
4.	Time division multiplexing		Packet, Communication channel, Transmission media

Table 2. Knowledge goal "Multiplexing" (10 concepts).

3. The structure of the domain knowledge

According to our approach, the knowledge modules of the domain model are represented at three hierarchical levels of knowledge abstraction. In the *first layer* the knowledge goals are defined while the *second layer* consists of the concepts of the domain knowledge. In the *third layer* the educational material related to each concept is represented in different classes, such as text, images, simulations, examples, solved and unsolved-exercises and so on. These levels of the hierarchical scheme, representing knowledge modules of the domain model, correspond to the different stages of a connectionist network (see Figure 2).

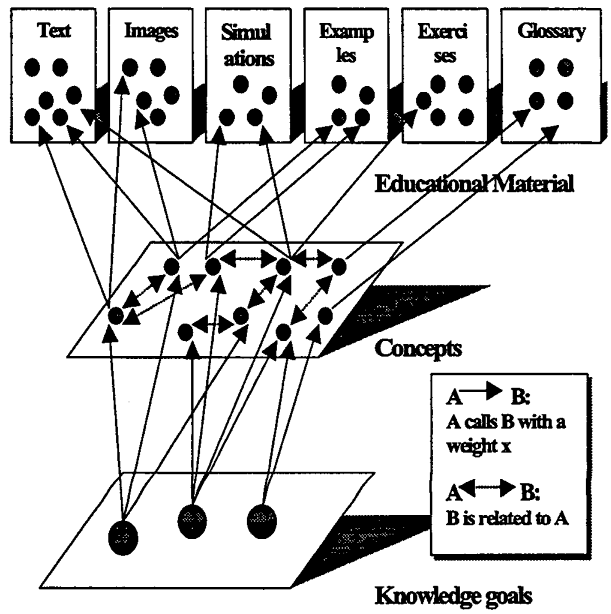

Figure 2. Schematic of the three-stage connectionist network.

3.1. The concepts layer: an associative memory

All the concepts of the domain knowledge of the course are represented in the second layer of the connectionist network. Each concept corresponds to a single Concept Node (CN) of a dynamic associative memory, named Relationships Storage Network-RSN [5]. An enhanced form of associative recall is employed, the so-called autoassociative recall, so as to produce an improved version of the input pattern in case of disturbed input conditions. The RSN is described by:

$$\mathbf{x}(k+1) = sat(\mathbf{T}\mathbf{x}(k) + \mathbf{I}) \quad (1)$$

where **T** is a N×N symmetric weight matrix with real components T(i,j) and **I** is a constant vector with real components I(*i*) representing external inputs. The RSN operates synchronously: (*i*) it updates the states of its nodes simultaneously, and (*ii*) all the nodes have the same input patterns during each iteration cycle.

An educational application such as a distance learning course has to employ a representation of the *instructional knowledge* (teaching strategy) for selecting and sequencing the subject matter [3][9]. In our case, patterns of relationships among concepts implement different teaching strategies. A teaching strategy, in the form of a collection of m patterns defined on $\{-1,1\}^n$, is stored in the RSN using a storage algorithm that utilises the eigenstructure method [4]. Examples of teaching strategies are presented below:

- *Teaching strategy A.* A learner achieves a knowledge goal when s/he studies successfully all the outcome concepts of this goal.
- *Teaching strategy B.* A learner has successfully studied all the prerequisite concepts of a knowledge goal. Then, in order to achieve this goal, s/he has to study only the outcome and the related concepts.
- *Teaching strategy C.* A learner has successfully studied several prerequisite or related concepts of a knowledge goal. Then, in order to achieve this goal, s/he has to study the entire outcome concepts and the rest of the prerequisite and related concepts.
- *Teaching strategy D.* A learner "has failed" in a number of outcome concepts. Then in order to achieve this goal, s/he has to study only these outcome concepts and their prerequisite and related ones.

The patterns of relationships are stored as asymptotically stable equilibrium points of the RSN and the network is capable of organising its internal states in accordance with the underlying structure of the stored patterns. The RSN possesses some striking features: (*i*) it is globally stable, (*ii*) all the desired patterns are guaranteed to be stored as asymptotically stable equilibrium points providing error correcting ability, (*iii*) the total number of patterns which can be stored and recalled reliably greatly exceeds the order of the network and (*iv*) the number of spurious states can be made small while the domain of attraction of the equilibrium points is large.

3.2 Evaluating the priority of the concepts

In generating a lesson, the level of understanding of the learner is an important factor taken into consideration. In our approach, we maintain a record for each learner that contains all the domain concepts of the course associated with a numerical or linguistic rating value. This indicates the learner's level of understanding regarding this concept. Based on this information, the importance of each concept, in a group, in achieving a knowledge goal has been obtained using a procedure based upon paired comparisons [6]. This procedure allows handling uncertainty and imprecision due to vagueness in the learner evaluation and can be summarised as follows.

Let W_1, W_2,..., W_p be the membership values of a fuzzy set with p members, where p is the number of the concepts involved. For example in Table 5 the concept 13 (Layer) is associated with weights {1, 0.88, 0.78, 0.58, 0.28, 0} depending on the level of understanding of the learner (1 indicates "Insufficient" level of understanding while 0 indicates "Sufficient" level of understanding). The following comparison matrix is constructed:

$$A = \begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_{21}} & \cdots & \frac{W_1}{W_p} \\ \frac{W_2}{W_1} & \frac{W_2}{W_2} & \cdots & \frac{W_2}{W_p} \\ \cdot & \cdot & \cdots & \cdot \\ \frac{W_p}{W_1} & \frac{W_p}{W_2} & \cdots & \frac{W_p}{W_{p1}} \end{bmatrix}$$

A second matrix B arise by assigning linguistic terms, which describe the relative importance of the relationship between two concepts of the domain as suggested by [7]. Table 3 presents the basic linguistic terms that can be assigned to a relationship between concepts. Intermediate terms between two adjacent characterisations can also be assigned.

	Characterisation	Explanation
1.	Equally important	Two concepts contribute equally to the knowledge goal
2.	Moderately important	Slightly favouring one concept over another
3.	Essential or strongly important	Strongly favouring one concept over another
4.	Absolutely important	The evidence favouring one concept over another is of highest order of affirmation

Table 3: Characterisations of the concept relationships.

The matrix B is defined as:

$$B = \begin{bmatrix} \beta_{11} & \beta_{12} & \cdots & \beta_{1p} \\ \beta_{21} & \beta_{22} & \cdots & \beta_{2p} \\ \cdot & \cdot & \cdots & \cdot \\ \beta_{p1} & \beta_{p1} & \cdots & \beta_{p1} \end{bmatrix}, \beta ij = \min \left\{ \left| a_{ij} - \frac{x}{y} \right| \right\}$$

where $\hat{a}_{ij}$ is the distance to the closest x/y (minimum value) and $x/y \in$ {1/9, 1/8, ...,1/2,1,2,3,...,8,9}, when a scale of nine grades is applied.

By solving the eigenvalue equation:

$$Bw + \lambda_{\max} w,$$

where ë$_{\max}$ is the maximum eigenvalue of B, the eigenvector w is obtained (see [7]). This vector can be used to determine the priority of the different concepts concerning a knowledge goal and its evaluation depends on the individual learner's level of understanding regarding these concepts. A higher priority setting corresponds to a greater importance.

Therefore, each lesson is constructed according to the individual educational needs (knowledge goals) of each learner and to his/her level of expertise.

3.3. The educational material layer

In the *third layer* the educational material related to each concept is represented in different classes, such as text, diagrams and images, examples, simulations, solved-exercises, unsolved-exercises and so on. Weights connecting the second and the third layer are unique for each concept and each concept may be connected to several classes of educational material. The educational material is then joined under a predefined form of presentation to generate a course.

4. Example

The proposed approach is domain independent and has been tested on an introductory course on Computer Networks at the University of Athens. This course corresponds to 10 hours of lecture. A domain expert undertook the task of the decomposition of the domain knowledge in modules. The proposed connectionist model has been implemented in MATLAB 4.2 and has been tested with various learner profiles. The response of the system has been evaluated by teachers-experts in *Computer Networks* and has been characterised as predictable and reliable. Below we illustrate an example, the knowledge goal *ISO Architecture*.

Order	Outcome concepts	Prerequisite concepts	Related concepts
1.	Multi-layer architecture	Layer, Communication protocol	
2.	Open Systems Interconnection		International Standards Organisation
3.	Physical layer	Transmission means, Synchronisation	Digital transmission
4.	Data Link layer	Packet, Error detection & correction	Transmission means
5.	Network layer	Packet routing	Packet
6.	Transport layer	Flow control, Traffic metering	Packet
7.	Session layer	Synchronisation, Communication half / full duplex	Packet
8.	Presentation layer	Data compression, Encryption	Compatibility
9.	Application layer	File transfer protocol, Virtual terminal	

Table 4. Knowledge goal "ISO Architecture" (26 concepts)

The concepts associated with this goal are exhibited in Table 4 whereas in Table 5 importance factors for the concepts of this goal are defined. The notation used in Table 5, for characterising the learner's level of understanding, is: {I, AI, RI, RS, AS, S} = {Insufficient, Almost Insufficient, Rather Insufficient, Rather Sufficient, Almost Sufficient, Sufficient}

Bellow we present examples of input patterns generated according to different learner profiles. The teaching strategies implemented in each case have been described in Section 3.1. In the reported examples, all learners have selected the goal: *ISO Architecture*.

1. In case of a novice learner following *teaching strategy A*, the system generates a lesson that presents the 26 concepts of Table 4.
2. In case the performance of a learner has been characterised as "sufficient" regarding all the outcome concepts of a goal, then the system, following *teaching strategy A*, generates an "empty" page.
3. In case the performance of a learner has been characterised as "sufficient" regarding all the prerequisite concepts of a goal, then the system, following *teaching strategy B*, generates a lesson that presents all the concepts of the goal apart from the prerequisite ones. An example of this case is presented below. The system generates a lesson that presents the following 13 concepts of Table 4:
   Multi-layer architecture (oc-14), Open Systems Interconnection (oc-16), International Standards Organisation (rel-12), Physical layer (oc-19), Digital transmission (rel-7), Data Link layer (oc-6), Transmission means (rel-24), Network layer (oc-15), Transport layer (oc-25), Session layer (oc-21), Presentation layer (oc-20), Application layer (oc-1), Compatibility (rel-4).
4. In case the performance of a learner has been characterised as "sufficient" regarding several prerequisite or related concepts, then the system, following *teaching strategy C*, generates a lesson that presents all the concepts of the goal, apart from the successfully studied prerequisite or related ones. An example of this case is presented below. The system generates a lesson that presents all the concepts of Table 4 apart from the following ones:
   layer (pre-13), communication half / full duplex (pre-2), packet (pre-17), synchronisation (pre-22), transmission means (pre-24), compatibility (rel-4).
5. In case the performance of a learner has been characterised as "insufficient" regarding several outcome concepts, then the system, following *teaching strategy D*, generates a lesson that presents these outcome concepts, their prerequisite and related ones. An example of this case is presented below. The system generates a lesson that presents the following 12 concepts of Table 4:

Data Link Layer (oc-6), packet (pre-17), Error detection & correction (pre-9), Transmission means (rel-24), Network layer (oc-15), Packet routing (pre-18), Session layer (oc-21), Synchronisation (pre-22), Communication half / full duplex (pre-2), Transport layer (oc-25), Flow control (pre-11), Traffic metering (pre-23).

In the above cases, *oc* indicates an outcome concept, *pre* indicates a prerequisite concept and *rel* indicates a related concept, while the number in the brackets denotes the number of the concept in Table 5.

Concepts		Level of Understanding					
		I	AI	RI	RS	AS	S
1.	Application layer	1	0,92	0,82	0,62	0,32	0
2.	Communication half / full duplex	1	0,86	0,56	0,36	0,16	0
3.	Communication protocol	1	0,88	0,58	0,38	0,28	0
4.	Compatibility	1	0,74	0,44	0,14	0,14	0
5.	Data compression	1	0,75	0,55	0,25	0,15	0
6.	Data Link layer	1	0,96	0,86	0,66	0,36	0
7.	Digital transmission	1	0,78	0,58	0,38	0,28	0
8.	Encryption	1	0,84	0,54	0,24	0,14	0
9.	Error detection & correction	1	0,84	0,54	0,24	0,14	
10.	File transfer protocol	1	0,84	0,54	0,34	0,24	0
11.	Flow control	1	0,75	0,55	0,25	0,15	0
12.	International Standards Organisation	1	0,99	0,79	0,59	0,29	0
13.	Layer	1	0,88	0,78	0,58	0,28	0
14.	Multi-layer architecture	1	0,99	0,69	0,49	0,29	
15.	Network layer	1	0,95	0,85	0,65	0,35	0
16.	Open Systems Interconnection	1	0,98	0,68	0,48	0,28	0
17.	Packet	1	0,88	0,68	0,48	0,28	0
18.	Packet routing	1	0,86	0,56	0,26	0,16	0
19.	Physical layer	1	0,97	0,87	0,67	0,37	0
20.	Presentation layer	1	0,91	0,81	0,61	0,31	0
21.	Session layer	1	0,93	0,83	0,63	0,33	0
22.	Synchronisation	1	0,86	0,56	0,36	0,26	0
23.	Traffic metering	1	0,75	0,55	0,25	0,15	0
24.	Transmission means	1	0,78	0,48	0,28	0,18	0
25.	Transport layer	1	0,95	0,85	0,65	0,35	0
26.	Virtual terminal	1	0,75	0,45	0,15	0,15	0

Table 5: Importance factors for the concepts of the goal "ISO Architecture".

5. Conclusions

The proposed connectionist approach for a learner-adapted hypermedia system provides a mechanism to represent the knowledge domain and facilitates the adaptation of the lesson to the learner's needs. The proposed approach makes use of the knowledge provided by the domain expert: the network represents the available information, letting the training procedure to perform the fine tuning. In this way, software development time can be reduced when compared to the pure symbolic approach. The level of understanding of the learners is also used so that each lesson provided is constructed according to their individual educational needs (knowledge goals) and to their level of expertise on the concepts they have already studied.

The connectionist approach also facilitates the independence of instructional and domain knowledge. Furthermore, learner modelling and instructional methods, can be formulated in a domain-independent fashion. So concerning the Intelligent Tutoring Systems research area, diagnostic and instructional modules can be used and tested across a broad range of domains and vice versa.

References

[1] Brulikovsky, P., Ritter, S., & Scwarz, E. (1997). Distributed intelligent tutoring on the Web. In Proc. of the 8th World Conf. of the AIED Society, Kobe, Japan, pp. 18-22.

[2] Brulikovsky, P., Scwarz, E., & Weber, G. (1996). ELM-ART: An intelligent tutoring system on World Wide Web. In Proc. of the 3rd Inter. Conf. on Intelligent Tutoring Systems, Frason, C., Gauthier, G., & Lesgold, A. (eds.). Berlin: Springer, pp. 261-269.

[3] Burns, H.L., & Capps, C.G. (1988). Foundations of Intelligent Tutoring Systems: An Introduction. In Foundations of Intelligent Tutoring Systems, Polson M.C. & Richardson J.J., (eds.), pp.21-53.

[4] Michel, A., Si, Y., & Yen, G. (1991). Analysis and Synthesis of a Class of Discrete-time Neural Networks Described on Hypercubes, *IEEE Tr. Neural Networks*, 2, pp. 2-46.

[5] Michos, S. E., Magoulas, G. D., & Fakotakis, N. (1995). A hybrid knowledge representation model in a natural language interface to MS-DOS. In Proc. of the 7th IEEE Int. Conf. on Tools with Artificial Intelligence, pp. 480-483.

[6] Saaty, T. L., & Khorya, M. W. (1976). A measure of world influence, *J. Peace Sci.*, 2, 1.

[7] Saaty, T. L. (1978). Exploring the interface between hierarchies, multiple objectives and fuzzy sets, *Fuzzy Sets and Systems*, 1, 57-68.

[8] Vassileva J. (1997). Dynamic course generation on the WWW. In Proc. of Int. Conf. Artificial Intelligence in Education.

[9] Reusser, K. (1996). From Cognitive Modelling to the Design of Pedagogical Tools. In International Perspectives on the Design of Technology-Supported Learning Environments, Vosniadou, S., De Corte, E., Glaser, R., Mandl, (eds.), pp. 81-103.

[10] Weber, G., & Specht, M. (1997). User modelling and adaptive navigation support in WWW-based tutoring systems. In Proc. of the 6th Int. Conf. on User Modeling, Chia Laguna, Sardinia, Italy, also in *User Modeling* Jameson, A., Paris, C., & Tasso C. (eds). Wien: Springer-Verlag, pp.289-300.