Towards a Computationally Intelligent Lesson Adaptation for a Distance Learning Course

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Abstract

In this paper a neuro-fuzzy approach is introduced to implement lesson adaptation in a Web-based course. Several key points that affect the effectiveness of an adaptive learning environment are investigated: the development of the educational material, the structure of the domain knowledge, the instructional design and the evaluation of the learner knowledge under uncertainty. The proposed 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

Distance Learning through the Web offers an instructional delivery system that connects learners with educational resources. Its main features are the separation of instructor and learner in space and/or time, the use of educational media/technology to unite instructor and learner and transmit course content and the change of the teaching-learning environment from teacher-centred to learner-centred.

The feature of separation between instructor and learner is considered as generating a feeling of isolation, coupled with a lack of motivation due to the physical absence of a tutor and other students. To alleviate this problem, the Web offers asynchronous (Email, Newsgroups) and synchronous (IRC, Web-conferencing, chat rooms) communication mechanisms, which are capable of enabling a supporting environment within the students form a virtual community [17]. Additionally, the user interface and the educational material are important factors that affect the quality of a Web-based course and provide motivation to learners. Their design and development should be based on understanding the learning and instructional process as well as the learner characteristics and educational needs [11].

Thus, one of the challenges facing a Web-based distance learning system is adapting the educational material to the knowledge goals and abilities of each learner. Two methods are generally proposed in the literature for implementing adaptation: adaptive presentation (or content level adaptation) [23] and adaptive navigation (or link-level adaptation) [3]. In the first case the content of a hypermedia page is generated or assembled from pieces of educational material according to the learner's knowledge state [16]; while in the second case altering visible links to support hyperspace navigation is suggested [21] [26].

The paper is focused on the adaptive lesson presentation approach, which is usually realized using symbolic artificial intelligence techniques. For example, in the DCG system [23] the structure of the domain knowledge is represented as an AND/OR graph consisting of the domain concepts connected with relations with various semantics, depending on the type of the domain. Given a goal that the learner wants to acquire and the concepts already known by the learner, the system generates a linear sequence of concepts using certain rules. Learners' knowledge on a concept is evaluated using a simple formula from the number and the difficulty of successfully solved tests-items related to this concept, and represents a probabilistic estimation of the extent to which the learner knows the concept. An alternative symbolic approach has been proposed by Anjaneyulu [1]. The domain knowledge structure is based on a concept level hierarchy where all the concepts are identical and they are connected with prerequisite relations. The evaluation of the learner's knowledge is based on an overlay model that contains a list of all the domain concepts. Each concept is associated with a confidence factor, which takes values from –1.0 (learner does not know the concept) to 1.0 (learner knows the concept). The confidence factor of a concept is increased by a fixed amount every time the learner answers correctly a question on that concept; otherwise it is reduced.

In this paper we focus on the development and structure of the educational material for a Web-based course. That includes informed decisions about what comprises the educational content and how it is to be sequenced and synthesised, taught and learned. In the proposed approach, the selection, sequencing, and synthesis of the educational content takes into account the nature of the content or task that is to be taught and the knowledge level of the learner. To this end, a subsymbolic goal-oriented way for adapting the educational material to the learner is applied. The lesson adaptation is supported by a connectionist network for representing the knowledge of the domain and makes use of neuro-fuzzy synergism to evaluate the knowledge of the learner on already studied concepts of the lesson.

2. Development of the Educational Material

The learning process requires motivation, planning, and the ability to analyse and apply the educational material being taught. In a traditional lecture, the teacher relies on a number of visual cues from the students to enhance and adapt the instructional process. A quick glance, for example, can reveal who is attentively taking notes, pondering a difficult concept, or preparing to make a comment or a question. This type of feedback is missing from a distance learning course and the educational material has to accommodate in a way this entire interaction, for example by embedding all the possible questions and common learners' misunderstandings.

The following procedure for the development of the educational material has been proposed in [8] and has been applied for the development of an adult training course named *"Introduction to Computer Science and Telecommunications"* [22].

- *Create the content outline* based on analysing the audience, defining instructional goals and objectives.
- *Review the educational material* that has been proven effective in the traditional lectures.
- The educational material of the course *is developed and organised* under a predefined structure. It is divided into manageable segments: chapters, units, sub-units, and pages. A chapter is a collection of units, while a unit is a collection of pages, tests and (optionally) sub-units. The educational material includes definitions of domain concepts, texts written in a user-friendly way incorporating various levels of explanation, diagrams-images, examples, exercises and simulations and adopts a hypermedia way of presentation.

The presentation of the domain knowledge follows principles that lead to the «deep approach» of learning, that is to relate new ideas to previous knowledge and new concepts to every day experience. Furthermore, this approach aims at organising and structuring the content, supplementing the theory with a variety of practical tasks and activities and finally, provides learners with self-assessments and assessments to test their knowledge [25]. However, the greatest challenge in the presentation of the educational material is to build an environment in which the learners are motivated to assess their personal knowledge goals and objectives and to become active participants in the overall learning process. Adaptive lesson presentation is a promising research area towards this direction.

3. A Goal-oriented Structure of the Domain Knowledge

An important aspect in producing a learner-adapted system, i.e. a system that meets the individual educational needs and objectives of each particular learner, is the structuring of the domain knowledge in such a way that it will be possible to do adaptations. Below, a connectionist-based structure of the domain knowledge is presented that allows the adaptation of the educational material to the individual's learner level of understanding. The main characteristic of the proposed approach is that the decomposition of the domain knowledge in modules (see Figure 1), such as knowledge goals, concepts, educational material is incorporated in a connectionist architecture.

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 for the learner to understand 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.

Table 1. Knowledge goal "ISO Architecture" (26 concepts). Each row contains an outcome concept followed by its prerequisite and related concepts.

Order	Outcome concepts	Prerequisite concepts	Related concepts
1	Multi-layer architecture	Layer, Communication protocol	
2	Open Systems Interconnection (OSI)		International Standards Organisation (ISO)
3	Physical layer	Transmission means, Synchronisation	Digital transmission
4	Data Link layer	Packet, Error detection and 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	

In Table 1, a knowledge goal with its associated concepts, referred on the chapter *Computer Networks* of the distance learning course mentioned in the previous section, is shown. Note that the order of the outcome concepts in the table corresponds to their sequencing in the course. Examples of other knowledge goals of this chapter are: Data Communication basics, Transmission means, Network Topology, Local Area Networks, Wide Area Networks, Internet administration, etc.

3.1 Modelling the domain knowledge

The domain knowledge is represented in three hierarchical levels of knowledge abstraction (see Figure 1). In the first level the knowledge goals are defined while the second level consists of the concepts of the domain knowledge. In the third level 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 layers of a connectionist network.

Each knowledge goal in the first layer is associated with its corresponding concepts in the second layer. Each concept corresponds to a single Concept Node (CN) of a specially designed dynamic associative memory for this goal, named Relationships Storage Network-RSN [13]. An enhanced form of associative recall is employed, the so-called auto-associative recall, so as to produce an improved version of the input pattern in case of disturbed input conditions. The RSN is described by:

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

where $\mathbf{T}$ is a $N \times N$ 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: (a) it updates the states of its nodes simultaneously, and (b) all the nodes have the same input patterns during each iteration cycle.

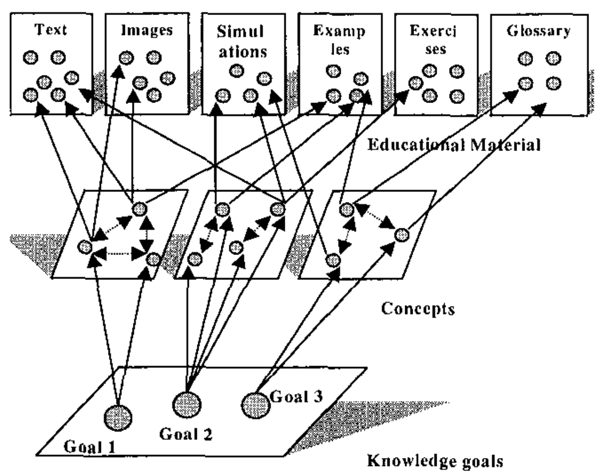

Figure 1. The connectionist-based structure of the domain knowledge of the course.

Patterns of relationships among concepts implement different strategies for generating the content of the selected knowledge goal (more details on planning the content for a knowledge goal will be presented in the next section). At the current stage, a strategy is considered as a collection of m patterns defined on $\{-1,1\}^n$. Various strategies are stored in the RSN using a storage algorithm that utilizes the eigenstructure method [12]. These patterns of relationships are stored as asymptotically stable equilibrium points of the RSN.

In the third layer the educational material related to each concept is organised in classes, such as text, diagrams and images, examples, simulations, solved-exercises, unsolved-exercises and so on, as discussed in Section 2. 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. The Instructional Designer

Pedagogical decision making is concerned with both the content and the delivery of instruction. The issue of instructional design is of major importance in the development of an educational environment [4] [18]. *Instructional planning* is the process of mapping out a global sequence of instructional goals and actions that provides consistency, coherence and continuity in the instructional process [5] [24]. In our case this can be applied in two levels:

- By *planning the content*, that is, presenting concepts related to the knowledge goal selected by the learner by making use of his/her background knowledge. In this way, the content of a hypermedia page is generated from pieces of educational material based on a goal-oriented way of teaching which is supposed to be adequate to adults who are motivated to learn a specific knowledge goal.
- By *planning the delivery* of the educational material. The planning of delivery is responsible for the optimal selection of: the educational material, tutorial activity and presentation style, i.e. the appropriate teaching method. The use of multiple approaches in teaching methods increases the possibilities to meet the needs of a wide range of learners who have different learning styles, time constraints and abilities.

In the proposed approach different strategies for planning the content are implemented by patterns of relationships among concepts stored in the RSN: a *strategy*, in the form of a collection of m patterns defined on $\{-1,1\}^n$, is stored in the RSN. For example:

- *Strategy A.* A learner achieves a knowledge goal when s/he studies successfully all the outcome concepts of this goal.
- *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.
- *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.
- *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 that are stored in the RSN lead the network to organise its internal states in accordance with the underlying structure of the stored patterns. During tutoring, the evaluation of the learner's knowledge on the concepts of a goal (this will be described in the next section) formulates the input pattern of the RSN. The input pattern, during the recall operation of the dynamic network, converges to an equilibrium point, i.e. to one of the m stored patterns that implement a planning strategy. The output response of the RSN is then used for planning the content of the lesson, i.e. present the concepts of the knowledge goal that the learner has to learn next.

The planning delivery based on the results of the recall operation establishes instructional objectives (tutorial activities), which are specific steps leading to the knowledge goal attainment. The optimal selection of the educational material takes into account the relevant importance of each concept on the knowledge goal as well as the preferences of the learner concluding from the learner evaluation stage. Currently, the selection of the educational material is based on the weight values connecting the second and the third layer of the connectionist network.

5. Evaluating the Learner's Knowledge

In adaptive lesson presentation, the level of understanding of the learner is an important factor that needs to be taken into consideration. In our approach, a record for each learner is maintained, which contains all the domain concepts of the course associated with linguistic rating values characterising the learner's level of understanding, i.e. {EI, I, RI, RS, AS, S} = {Extremely Insufficient, Insufficient, Rather Insufficient, Rather Sufficient, Almost Sufficient, Sufficient}. This scale has been experimentally found to provide evaluation results closer to human teachers evaluation performance, when compared with previous work in the area [14] [15] [20].

Learner's knowledge evaluation on the concepts that s/he has studied is based on two types of information:

answers to questions and measurements [6]. In both cases, several factors contribute to uncertainty in the evaluation procedure, such as careless errors and lucky guesses in the learner's responses, changes in the learner knowledge due to learning and forgetting, and patterns of learner responses unanticipated by the designer of the learner model. Thus, the development of an accurate model for evaluating the learner's knowledge is based on uncertain information.

Various types of questions are related to the evaluation of the learner's level of understanding with regard to the concepts of the domain knowledge, i.e. multiple choice, fill-in-the-blanks, boolean, multiple correct answers, each one having a different weight representing its importance in the evaluation procedure [2]. The questions are organized in categories as proposed in [10]:

- *Fact oriented questions*: Questions regarding memorizing which are used to test the knowledge of concept definitions and topic aspects directly related to the content of the lesson.
- *Higher order comprehension questions*: They are used to test the understanding of the concepts. Their aim is to test the conceptual model constructed by the learner and evaluate his misconceptions.
- *Generalization questions*: Questions examining the ability of comparison, differentiation, abstraction and generalization.
- *Questions related to the recognition of functional interrelations*: They test the ability of linking newly acquired with already existing knowledge on the concepts.

In addition, several measurements are recorded from the learner-educational program interaction and used for evaluating the learner: the number of questions and exercises that the student tried to answer or solve, the points scored, the number of learner attempts before giving the correct answer, the frequency of the encountered misconceptions, the number of repetitions of a topic by the learner, the time s/he spends for self-assessment, the type of information the learner prefers (text, pictures, sound, video, simulations, URLs) and how often s/he navigates through the HTML pages of the educational material supplied for a knowledge goal.

Thus, by analyzing the learner's answers and by processing the various measurements conducted by the system, it is possible to trace: gaps in the knowledge of the learner, mistakes and misconceptions. To this end, the hybrid approach proposed in [7] is applied. It consists of three stages realized by a set of connectionist networks. The first stage of each network fuzzifies inputs that contribute to the evaluation of the level of understanding, based on the estimations of experts to the degree of association between an observed input value (in our case we apply a discretization of the universe of discourse) and the learner's knowledge on this concept. Depending on the input, a fuzzy subset is generated for each measurement or answer contributing to the evaluation. The next stage realizes a fixed weight aggregation network, utilizing the union operator, that processes these fuzzy subsets. The network weights are evaluated using the Saaty's method [19] and determine the importance of each preliminary decision in evaluating the learner's knowledge. A preliminary decision is expressed by a fuzzy subset relating a measurement or answer to the possible qualitative characterizations of the learner's knowledge. The last stage of each connectionist network consists of a backpropagation network trained using the BPVS algorithm [9] to evaluate the level of understanding of the learner with regard to a concept by classifying him to one of the categories {EI, I, RI, RS, AS, S}.

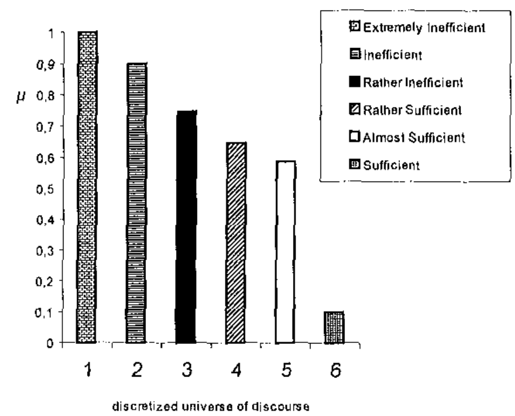

Figure 2. Fuzzy sets (singletons) for the *outcome* concept *"Multi-layer Architecture"*.

Depending on the concept, the qualitative characterizations of the learner's understanding are converted to numeric values (fuzzy singletons), in order to feed the RSNs. Note that, when the learner's level of understanding with regard to a concept is characterized as Extremely Inefficient, a membership degree of approximately 1 is assigned to this concept. This means that the learner certainly has to study this concept. On the other hand, a small membership degree of approximately 0.1 is assigned when the learner's level of understanding on a concept is evaluated as Sufficient.

For example, Figure 2 illustrates the fuzzy set:

$$\mu(x)=\{1|1+0.9|2+0.75|3+0.65|4+0.59|5+0.1|6\}$$

of the outcome concept *Multi-layer Architecture* that belongs to the knowledge goal "ISO architecture", where the symbols "|" and "+" are used only as syntactical constructors. Some other examples are the fuzzy sets:

$$\mu(x)=\{0,98|1+0.88|2+0.58|3+0.38|4+0.28|5+0.1|6\}$$

for the prerequisite concept *Communication protocol*, and

$\mu(x)=\{0{,}95|1+0.74|2+0.54|3+0.24|4+0.14|5+0.1|6\}$
for the relative concept *Compatibility*.

6. Experiments

Experiments have been conducted to evaluate the behaviour of the proposed model in adapting the lesson of a course. The results reported in this section have been obtained using educational material developed for the chapter *"Computer Networks"* of the Web-based course *"Introduction to Computer Science and Telecommunications"* [22]. In this chapter adult learners have to study 25 knowledge goals (some of them have been mentioned in Section 3), each one containing 10-30 concepts. Next, the behaviour of the proposed model is illustrated in two cases.

In the first case, the learner has selected the goal "ISO Architecture" and his performance has been evaluated as "Sufficient" with regard to several prerequisite and related concepts. In response to this input the RSN runs for several cycles and finally settles into a stable state, as defined by its 26-dimensional pattern of activity. Since, a localist concept coding is used, i.e. each node stands for one domain concept that is related to the selected goal, it is easy to follow the activity changes of the RSN in response to an input pattern. In Figure 3, 7 out of the 26 node activity levels are exhibited.

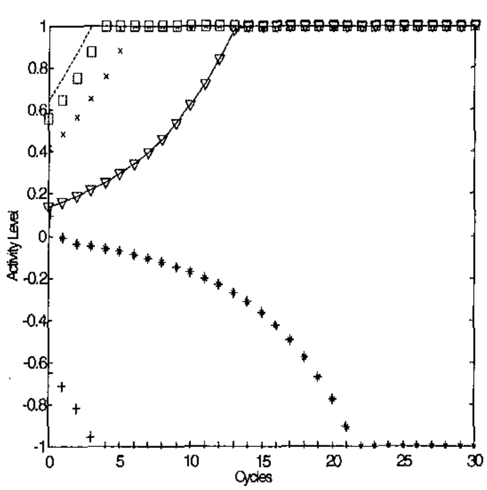

Figure 3. Example of planning strategy C: *Communication half/full duplex*: line, *Compatibility*: square, *Layer*: star, *Network layer*: x-mark, *Packet*: triangle, *Synchronization*: dashed(--), *Virtual terminal*: +-mark.

Following planning strategy C the generated lesson includes all the concepts of Table 1 apart from the successfully studied prerequisite and related ones:

> *Layer, Data compression, Encryption, Virtual terminal, ISO, Traffic metering.*

From Figure 3 it is shown that the activity of the concept node that represents the concept *Virtual terminal* goes to −1, which means that the node is deactivated and the educational material associated with this concept will not be presented. On the other hand, the activity level of the related concept *Compatibility*, in which the learner has been evaluated as "Inefficient", goes to +1 and the material will be presented. Note that, after transformation to the interval (0,1), the activity level at cycle=0 indicates the result of the learner's evaluation, which in the case of the *Compatibility* node is "0.74|Inefficient". Similarly, the concept node *Network layer* is activated since the learner has been evaluated as "Rather Sufficient" in this outcome concept.

In the second case, trying to acquire the same knowledge goal, a learner exhibits performance which is characterised as "Extremely Insufficient" with respect to several outcome concepts. Following planning strategy D, a lesson is generated that presents these outcome concepts, their prerequisite and related ones. The following concepts of Table 1 are included in the lesson:

> *Multi-layer Architecture, Layer, Communication protocol, Physical layer, Transmission means, Synchronisation.*

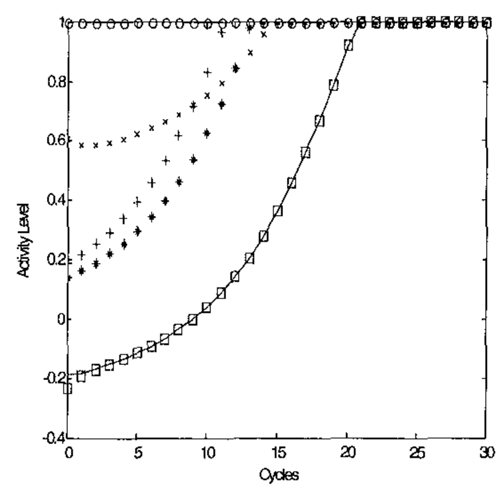

Figure 4. Example of planning strategy D: *Communication protocol*: square, *Layer*: line, *Multi-layer Architecture*: x-mark, *Physical layer*: o-mark, *Synchronisation*: star, *Transmission means*: +-mark.

A sample of the RSN's response is shown in Figure 4, in terms of neurons' activity level. The evaluation of the learner with respect to his/her level of understanding on the outcome concept *Physical layer* indicates that s/he has been "Extremely Inefficient" thus, the corresponding node is rapidly activated. The node of the outcome concept *Multi-layer architecture* is also activated, as well as the nodes corresponding to its prerequisite concepts *Layer* and *Communication protocol*, in which the learner has been evaluated as "0.38|Rather Sufficient".

7. Conclusions

Adaptive lesson presentation is a promising method of introducing flexibility into a Learning Environment. Adaptive hypermedia systems aim at minimising the information overload by adapting the educational material provided to each individual learner's background knowledge.

The design of the educational material supporting such a distance learning process is an important issue contributing to the effectiveness of the adaptation of the overall educational environment, as well as the learner evaluation and the instructional design.

The proposed connectionist approach for representing domain knowledge facilitates the adaptation of the lesson to the learner's needs and allows the independence of instructional and domain knowledge. The level of understanding of the learner is also used so that each lesson provided is constructed according to his/her individual educational needs (knowledge goals) and to his/her level of expertise on the concepts s/he has already studied. The learner's evaluation depends on the designer's ability to analyze the knowledge domain suitably, define appropriate membership functions for the fuzzy sets, and relate learner's response with appropriate knowledge characterizations.

In general, the performance of the proposed approach has been evaluated by lecturers-experts in Computer Networks and has been characterised as predictable and reliable. Its applicability can be further extended by exploiting the training and generalization capabilities of the neural networks to extract information from learner profiles. These profiles implicitly contain a true picture of the possible knowledge levels of the learners and of the possible learning paths.

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