Functional Solution of the Knowledge Level Control Problem: The Principles of Fuzzy Logic Rules and Linguistic Variables

Ali M. Abbasov and Shahnaz N. Shahbazova

Abstract This paper addresses the problem of imitating a teacher evaluating the students' levels of knowledge. It proposes application of fuzzy logic to construct and manage a knowledge control system used for generating evaluating questions. The system contains a knowledge base with relevant information and a set of rules. Students build the rules based on the analysis of answers and relevant reactions to questions. The algorithms governing the system allow for an automatic selection of sequences of appropriate and customized questions. The presented system for knowledge control and generating questions is comparable in quality and efficiency with the real teacher's questioning process.

Keywords Decision making · Uncertainty · Fuzzy logic · Neuro-fuzzy expert systems · Complex systems · Expert knowledge

1 Introduction

A system for evaluating learnt knowledge and managing it is one of the main elements of successful educational or research activities. An efficient and effective process of appraising gained knowledge – called hereafter a knowledge control process – influences all aspects of education and research as they rely on the outcome of learning activities.

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From a practical point of view, procedures of knowledge control should allow for questioning students with the aim of verifying their knowledge and skills in the field of study. The effective control of knowledge should be able to mimic a teacher of the relevant subject. Therefore, a system that is able to simulate the teacher's behavior is the most reasonable to develop. The analysis of the teacher's behavior in performing an evaluation process leads to construction of a system for an automated knowledge control. This system is able to conduct evaluation of students' knowledge, and determine correctness and incorrectness of provided answers.

2 Implementation of Intelligent System in Educational Process

The quality of a teaching system depends on the precise definition of the characteristics of several key factors defining the student's knowledge level and abilities: results of absorbing material recently presented to her, mastering the material presented in the past, and current moral and psychological state of the student.

The problem of selecting further actions is solved by the system based on these key factors. The possible actions may be: continuation of the teaching process, asking questions related to the previous material, repetition of already asked and answered questions, or completion of the training process.

The system's electronic catalog stores all data related to the student's abilities, her test schedule, etc. In addition, it contains personal data of the student.

In the process of working with the program, the student is able not only to test her knowledge, but also to learn. This is achieved by the way questions are asked, and by the presence of all of the questions, comments, and explanations given by the teacher. Access to the Internet provides the student with the ability to explore information anywhere in the world, including the best libraries, archives, etc.

Once the sustainable results are achieved for a certain part of the material, the student can proceed to the next level of difficulty of questions. This transition will allow the student to continue her learning process further.

This step-wise training process gives the student the necessary time to fully master and strengthen the knowledge of a given material, and then to move to a new, more difficult material. Each transition is accompanied by a small test on the previous material, and an analysis of its mastery.

To this date, the work has been done on learning and testing of a group of students at the same time. A teacher creates shared folders on a particular subject or subjects. Using these shared folders, the teacher can give tasks and exercises to a group of students, as well as check their solutions and results. The shared folders are structured in a way that simplifies the work with groups of students. The teacher has access to the working directories of students, and is allowed to deal individually with each student. The same thing happens when a re-take of a course is recommended, or a more detailed analysis of errors in the shared directories is required. The sophistication of the Intelligent Information System of Learning and Control of

Knowledge (IISLCK) allows the teacher to add and edit her material, and to make corrections according to the latest achievements of science and culture [1].

One of possible ways to improve the functionality of the systems of technical control of knowledge is the application of intelligent technologies in particular methods based on the diverse hybrid Expert Systems (ESs). Hybrid ESs represent different kinds of knowledge and are equipped with conceptual, expert, and factual methods of its processing.

The main task of the development of hybrid systems is to combine different forms of representing knowledge and methods of its processing, and merge them with decision-making approaches of ES. This means, that the actual problem is to investigate the possibilities of optimal connection of different mechanisms of knowledge processing to improve the quality, mobility and efficiency of ES in solving problems of a knowledge control process in conditions of uncertainty.

The mobility of ES is due to the mobility of the knowledge base (KB) and its ability to replenish material/facts/data from different information components (database, bases of expert knowledge (BEK), the base of conceptual knowledge (BCK), dynamic files, etc.), as well as various procedures of drawing conclusions. The concretization of knowledge processing in solving problems decomposes them into accurate and inaccurate, complete and incomplete, static and dynamic, single-valued and multi-valued, etc. In addition, the expert knowledge is inaccurate due to their subjective character. The approximation and multiple meanings of knowledge processing means that the ES has to deal with several alternative areas. Therefore, the processing of incomplete knowledge can use several sources of knowledge.

The application of a fuzzy logic hybrid ES for knowledge control may have at least three implementations:

(1) Processing of fuzzy uncertainty of expert expressions, i.e. when the pre-condition is fuzzy variables, but an inference machine is a data extraction mechanism from these preconditions.
(2) Using a matrix of fuzzy connections, determining a number of factors and preconditions. The matrix contains the fuzzy relations between variables, represented as real numbers [0, 1], and determines the cause of a condition. The matrix and factors form equations of fuzzy relations. The resulting system is solved using minimum-maximum fuzzy inference mechanism.
(3) Using fuzzy conclusions. This approach is most often used in the construction of fuzzy knowledge bases [2].

The application of fuzzy hybrid ES to solve problems and control parameters of knowledge processing extends the capabilities of this class of intelligent systems, as well as increases their flexibility and mobility. This allows conducting expert evaluation of a large number of variants, increasing the credibility and accuracy of the evaluation of the results.

In this paper, the main principles of construction of a neuro-fuzzy hybrid ES with diverse knowledge and its analysis in conditions of uncertainty of its parameters are considered. Additionally, the application of a dynamic knowledge base combined with neural networks (NN) is being investigated [3].

In the neuro-fuzzy hybrid ES, standard model (SM) is stored in the knowledge base containing processed knowledge, and is refined in the process of acquiring new knowledge. The real model is formed in a database environment, and communication with the EM is achieved via the user's requests. Solving the problem of designing an intelligent system for quality knowledge control built based on a hybrid ES is done with taking into account the characteristics of the environment of ES.

The hybrid ES consists of the following parts: a database that stores standard and factual evidence about the process; the results of their comparison, conceptual, physical and info logical models; knowledge base (KB) – its static part (knowledge is stored in the form of expert knowledge (of products) as well as formulas, facts, dependencies, tables, concepts specific subject area), and its dynamic part (the knowledge is stored in combined models of NN in the form of standard of dynamic processes taking into account the partial or complete uncertainly parameter of control); a mechanism of logic inference that is based on an algorithm for generating cause and effect network of events functional-structural model; adaptation mechanism to coordinate the work of the database (DB) and KB in the process of logical inference depending on the situation, explaining the mechanism, which is an interpretation of the process of logical inference; planner coordinating the process of solving the problem; solver for finding effective solutions to positive, negative and mixed statements of problems.

The content, form and algorithms for representing information inside the hybrid ES are flexible and depend on the complexity of a situation being modeled, and the specific and individual characteristics of the user.

The expert presents her knowledge in the form of sets of examples. A derivation tree is used as the internal form of presentation of the knowledge. A set of examples is described by attributes. All examples of the same structure, as defined by its attributes, are linked by logical transitions. In this case, the relevant trees of inference are combined in such a way that at the terminal vertex of one tree another tree is added.

The Computational Model of the ES and the DB in solving problems under uncertainty is given in the form:

$$W = <A, D, B, F, H>, \tag{2.1}$$

where A – is a set of attributes of DB and KB; D – denotes domains (attribute values of DB and KB); B – is a set of functional dependencies defined over the attributes; F – denotes descriptions of all types used in the functional dependencies B; and H – is a set of fuzzy relations over a set of attributes A [4].

One of the most difficult aspects to achieve in the hybrid ES is the requirement of dealing with different forms of knowledge representation, such as frames, semantic networks, databases, the concepts presented in KB, neural networks, fuzzy logic, genetic algorithms. All of these components have to share a single information space in the hybrid ES. For example, in the hybrid ES, diverse knowledge is stored in static components of ES, while dynamic knowledge about the current state of information is stored in neural networks. The modern information and database technology (for example, Object Linking and Embedding paradigm) can easily share diverse knowledge within a single information space [5].

It should be noted that the approach considered here, i.e., the application of hybrid ES as the basis for the intelligent system for knowledge control in the presence of uncertainty allows for:

(1) Actively applying the diverse knowledge (conceptual, structural, procedural, factual, base rule with membership function, rules and fuzzy rules of DB, KB, BEK procedures) together with inference mechanisms for finding effective solutions to the problem of determining the level of student's knowledge;
(2) Summarizing and improving the conceptual model of representation of diverse knowledge among relational DB and the managed DBMS; and interacting with the core of hybrid ES;
(3) Effectively solving the problem of optimizing and distributing information streams among individual subsystems of the hybrid ES under the conditions of uncertainty.

The methodology of constructing diverse knowledge storage for hybrid neuro-fuzzy ES includes the following stages [6]:

(1) The formalization of the domain (the development of a conceptual model);
(2) The description of knowledge model as individual concepts (knowledge) in the KB;
(3) The formation of KB with the base rule as a managing components of intelligent core;
(4) The description of diverse information to control the student's knowledge in the individual sub-systems of the hybrid ES (DB, KB, EKB, a graphical DB, the computed files);
(5) Selecting a neural-network model and learning rules;
(6) Development of fuzzy logic procedures;
(7) Distribution of information streams between the ES and its individual subsystems;
(8) Testing individual subsystems of the ES;
(9) Testing the neuro-fuzzy hybrid ES.

3 The Methodology for Knowledge Control

An important element of the learning system is its ability to make decisions regarding the level of difficulty of questions which should be posed to students. This should be preformed based on the results of answering previous questions. The solution to this problem depends on numerous parameters, most of which are unknown to the system. A fairly accurate answer can be found with the help of the mathematical apparatus of fuzzy logic [7].

The analysis of the current situation depends on following:

(1) Questions answered correctly by a student;
(2) Questions answered incorrectly by a student;
(3) Question answered incorrectly to previous questions by a student;
(4) Preliminary analysis of a student's ability;
(5) The number of correct answers coupled with their difficulty and in respect to erroneous answers.

This list reflects the real computational tasks. A decision-making process is carried out in order to select questions, which according to the program, corresponds to student's ability. An incorrect answer triggers a re-valuation process of the data about the student and leads to less difficult questions to be asked in the next time. In the case of a correct answer, the program asks questions with progressive difficulty. This decision-making method allows an individual to make a progress during the learning process [8]. Furthermore, it gives the most accurate evaluation of the student abilities.

At the end of the evaluation process, when both student and teacher want to sum up the result of the educational session, the program analyses the number of correct answers and their complexity. It starts with updating the relevant database record of the student, and then begins the process of analysis that aims at providing updated and correct information about the student.

This information can include: the current level of mastery of the subject of the student; comparison with previous results of analysis of the student's incorrect responses, the visualization of the correct answers with commentary, as well as comments provided by the teacher while entering questions into the database [9].

The importance of evaluation of the executed test could be adjusted by the program and/or by the teacher. This approach allows for performing individual pretests and tests at different levels of difficulty.

As stated, due to the large number of external parameters a decision-making process is done with the help of the mathematical apparatus of fuzzy logic. The responsible subsystem also includes conducting tests that satisfy the following requirements [10, 11]:

(1) Protecting answers from unauthorized access;
(2) Preventing a student from modification of the number of correct answers to questions;
(3) Providing equal conditions for the tests.

During the process of testing, the next question is read from the database based on the inference result obtained from a knowledge base located in the network. The question is displayed in a form convenient for the student (Fig. 1).

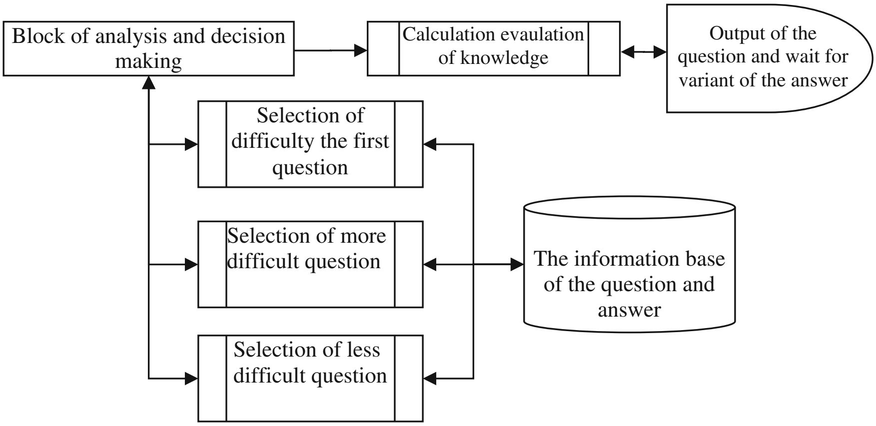

Fig. 1 Simplified block-schema of the control system of knowledge

These expressions can be represented in the form of conditional statements of complicated structure. As a very simple example is the expression of the form:

$$\textbf{\textit{If the Previous Answer}} = \textbf{\textit{Right}},$$
$$\textbf{\textit{THEN Correct Answers}} = \textbf{\textit{Correct Answers}} + \mathbf{1}$$

The next level of complication of the statements is to generate weighted questions (complexity):

$$\textbf{\textit{If the Previous Answer}} = \textbf{\textit{right}},$$
$$\textbf{\textit{Then Weight Correct Answer}} = \textbf{\textit{Weight Correct Answer}} +$$
$$\textbf{\textit{Table Weight}}\ (\textbf{\textit{Index Current Answer}})$$

The level of intelligence of the subsystems can be increased by adding records of the elapsed time and other parameters, and providing complicated logic expressions. In such a case the level of testing provided by subsystems can be compared with surveys conducted by the real teacher [12]. Additional parameters in mathematical expressions provide the descriptions of the following characteristics: the ability to remember, attentiveness, reaction speed, decision-making speed, reading speed, etc.

In the process of working with the program, the student cannot only test her knowledge, but also learn. This is accomplished when the question is asked, and also with the access to all of the comments and explanations given by the teacher.

Once stable results are obtained for a certain group of questions, the student can move on to the questions on the next level of complexity [13]. This transition enables the student's further development without being stack at the achieved results.

A gradual learning process gives the student the necessary time to complete mastering and strengthening the material, and then transit to a new, more complex material. Each transition is accompanied by a small test containing questions related to the previous material, and an analysis of its mastering.

4 Decision Making and the Knowledge Control in the Managing System

The algorithm of choosing the first and subsequent questions uses the results of carrying out the following tasks.

- preliminary analysis – used to evaluate the level of student's knowledge for making a decision regarding the first question (students lagging in knowledge assimilation are asked questions from a group of simple questions, while prepared students are given more difficult questions) [1] (Fig. 2).

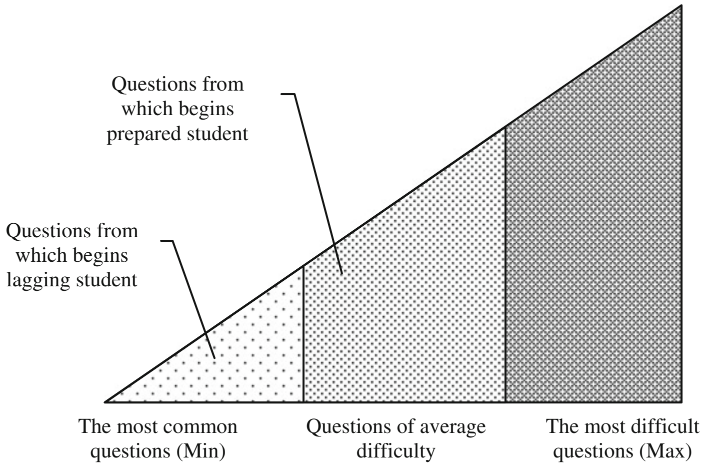

Fig. 2 Strategy for selection of the first question

- The formula below represents one of functions of the decision making block. Its essence comes down to choosing the next question, which corresponds to the student's level of knowledge. If an incorrect answer is chosen during the evaluation, the student will be given a less difficult question (2). If the correct answer is selected, the program will choose the more difficult question (1). The decision process can be described in the following way.

- A student answers the previous question correctly: in such a case the student is asked a question of increased difficulty (Fig. 3). The formula for selecting the next question is [6]:

$$Q = \frac{(Max(A^+) + Max(A^-))}{2} \pm 2\,\% \qquad (4.1)$$

where, Q is the next question, (A+) is the level of difficulty of a correctly answered question, Max(A+) is the maximum level of difficulty of the questions to which the student gave the correct answers, (A-) is the level of difficulty of an incorrectly answered question, and Max(A-) is the maximum level of difficulty of the question to which the student gave the incorrect answer. In case the student has not given an incorrect answer yet, the assigned value is the maximum level of difficulty of the questions for this course. ± 2 % is the maximum deviation in the level of the next asked question, and it represents randomness in a selection process.

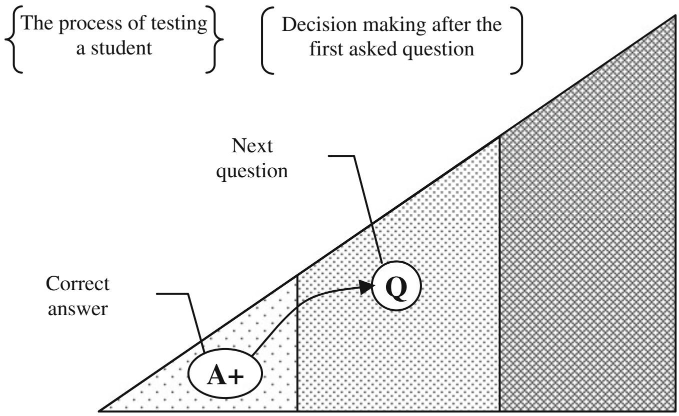

Fig. 3 The strategy of selection question after the correct answer

- A student answers the previous question incorrectly: in this case the student is asked a less difficult question (Fig. 4). The selection formula of the next question is [7]:

$$Q = \frac{(Max(A^-) + Min(A^+))}{2} \pm 2\,\% \qquad (4.2)$$

where, Min(A+) is the minimum level of difficulty of the correctly answered question, while Max(A-) is the maximum level of difficulty of the question to which the student gave the incorrect answer. If the correct answer was not given by the student, the assigned value is the minimum level of difficulty of the questions for this course.

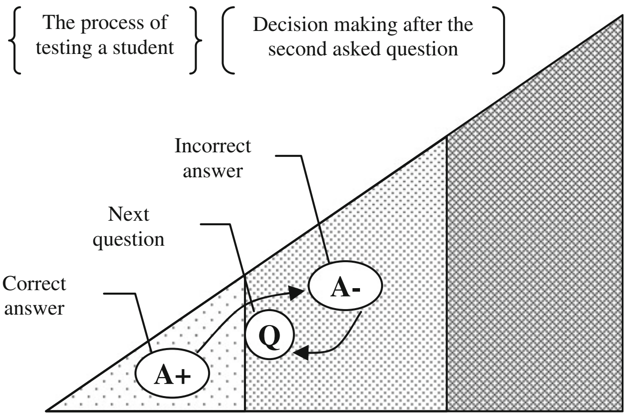

Fig. 4 A strategy for selecting the next question after an incorrect answer

The deviation included in the formulas ensures that for every student group there are no be two students that are given the same questions, even if the order of correct and incorrect answers are the same [2].

- processing the results and making a decision related to the final evaluation or continuation of testing – the number of correctly answered questions multiplied by their difficulty in relation to the number of mistakes and sets of correctly and incorrectly answered questions are the input to the decision-making subprogram; this results in a final evaluation or, if there remains a high probability of uncertainty, in continuation of testing (according to formula 4).

$$Z + jP = f\left(\frac{\sum_{i=1}^{N}\left(A_i^+\right)}{N}, \frac{\sum_{j=1}^{M}\left(A_j^-\right)}{M}, \left[A_1^+, A_2^+, \ldots, A_N^+\right], \left[A_1^-, A_2^-, \ldots, A_M^-\right]\right) \tag{4.3}$$

where, Z – evaluation of knowledge, P – uncertainty of evaluation, f – the decision making subprogram which works based on the following characteristics of conducted testing, (A_i+) – the set of difficulty levels of correctly answered questions, (A_j–) – the set of difficulty levels of incorrectly answered questions, N – number of questions with the correct answers, M – number of questions with the incorrect answers [5].

The result of the formula 4 is a complex number. This number represents the response of the decision making subprogram and indicates a degree of uncertainty in the students' knowledge [3]. This uncertainty provides a level of confidence in the evaluation process. Its value relates to the coverage of questions in the learning process. Higher the coverage less the uncertainty, which depends on the number of asked questions (Fig. 5). For example, the student can answer only a few questions and obtain an excellent score, but the uncertainty in this case would be very high, due to the fact that only several questions covering a significant amount of extremely difficult course material have been asked.

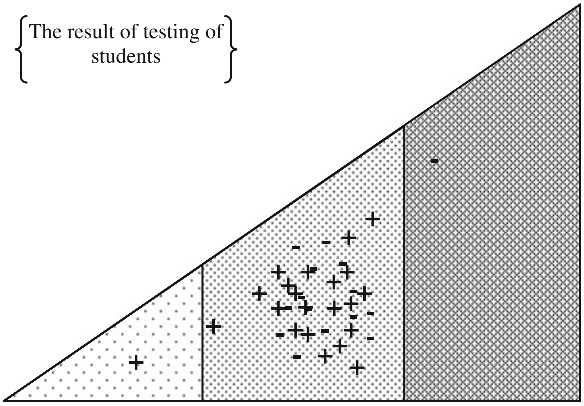

Fig. 5 Example distribution of answers after testing

Thus, the system containing the flexible algorithm of questioning, allows the teacher to decide about the volume of material covered in the course and the number of questions that should be asked to students in order to make an accurate determination of students' knowledge [4]. The preformed test may be an intermediate exam related to a small amount of learning material (10–20 questions in 20–30 min), or a full-scale exam based on the entire volume of the studied material (100–150 questions in 3–4 h).

5 Conclusion

The developed decision-making algorithm can determine the level of knowledge of a tested person on the basis of questioning with the minimum possible number of questions. This allows providing an evaluation of the students' knowledge level, over a short period of time, with a high degree of reliability when compared to the traditional method of questioning conducted by a teacher. Hence, an ingenious system of knowledge control has been developed via the application of fuzzy logic. It is very close to imitating the teacher's behavior in the process of student's questioning. It includes ability and precision that have not been seen before in any automated system. The proposed system integrates elements of expert systems, processes of development and populating a database, as well as construction of powerful and flexible rules. All system's aspects described above indicate effectiveness and flexibility of algorithms and functions used to build the knowledge control system. and confirm usefulness of applied newest technologies.

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Professor Dr. Ali M. Abbasov - Minister of Communications and High Technologies of the Republic of Azerbaijan. He has a long and remarkable career in academia, education and the public sector. His recent experience includes the following positions: Director of Institute of Information Technologies of the National Academy of Sciences of the Republic of Azerbaijan (1991–2000), Rector of Azerbaijan State Economic University (2000–2004), Minister of Communications and High Technologies of the Republic of Azerbaijan (2004– present).

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Professor Dr. Ali M. Abbasov has lectures and researches in the fields of digital economy, network design and application, artificial intelligence, Big data and some others. He did his PhD in microelectronics at the Academy of Sciences of Ukraine. In 1994, he defended his thesis, entitled "Information processing and systems management", and was awarded with degree of doctor of technical sciences. Dr. A.M. Abbasov is a full-time professor since 1996, and is a full member of the National Academy of Sciences of Azerbaijan since 2001. Furthermore, he is full member The World Academy of Sciences, International Informatization Academy, International Telecommunication Academy, International Academy of Engineering and as a fellow of the IEEE.

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