Design of an interactive Web-based e-learning course with simulation lab: a case study of a fuzzy expert system course

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ABSTRACT: A four-week e-learning course on design architecture, combining multi-media learning materials and a simulation lab for fuzzy expert systems, is presented in this article. The learning materials of the course include html pages, images, flash files, Java applets and instructional videos. A simulation lab designed with java programming language is also employed for the students to build their fuzzy expert applications based on the scenarios they create. Six core concepts of the fuzzy expert systems are included in this study: 1) membership function; 2) fuzzification; 3) fuzzy rule; 4) fuzzy inference; 5) defuzzification; and 6) fuzzy expert application. The proposed course design is suitable for the courses related to fuzzy expert systems for university junior students, such as artificial intelligence, fuzzy systems, business intelligence, artificial methods in finance, etc.

INTRODUCTION

Multimedia learning materials have been used in e-learning for decades. Moreno and Mayer discussed the principles of multimedia learning form the viewpoint of the role of modality and contiguity [1]. To improve learning efficiencies, some previous studies discussed how to make the cognitive loadings suitable for learners. An early study on reducing cognitive load by mixing auditory and visual presentation modes has been proposed by Mousavi et al [2]. Gerjets and Scheiter presented the goals and strategies relating to instructional design and cognitive load, which focused on hypertext t-based learning [3]. Brunken et al provided a computer-based direct measurement of cognitive load in multimedia learning [4]. Mayer and Moreno proposed nine ways to reduce cognitive load for multimedia course design [5]. Paas et al discussed recent developments in cognitive theory and instructional design [6]. Moreno and Mayer studied the effect of animation in multimedia learning [7]. Sweller et al concluded that different levels of learners' experiences should be taken into consideration when designing multimedia courses [8]. Leahy et al conducted two experiments to discuss the appropriate timing to add auditory presentation in multimedia instruction [9].

Over past decades, due to the rapid development of computer technologies, including software and broad networking technologies, a large portion of learning activities are conducted via the Internet. Without the limitations of time and distance, e-learning, therefore, can play a very important role in daily learning activities. Many computer-based learning material design tools were also developed to produce learning material. Popular learning material design tools include Flash, Director, Blaze Media Pro, MediaBlender and Dazzler. Further, some computer programming languages provide graphical tools for programmers to design visual displays. Java applets are one of the most popular Web technologies used to build visualisation components. With Java applets, course designers easily can create graphically interactive learning materials. In addition, one of the benefits of using Java applets is that they are portable and can be integrated with Java technologies. This makes it possible to combine computer programming and learning material design. After completing a course design, instructors need to put the learning materials on an e-learning platform. Most of the Web-based learning platforms are built for general purpose use. Examples include Moodle, ATutor, Claroline, Dokeos, eFront, LAMS and Fle3. It is somewhat difficult to customise a well-built e-learning platform according to a user's special needs. For example, to build a simulation lab for learners to simulate the scenario-based learning environment, the course designer may need to use some computer programming techniques. Java technologies provide good tools for designing graphically interactive learning materials and building computer-aided simulation labs.

Artificial intelligence has been applied to different areas, such as business, engineering, science and medicine. Several techniques of artificial intelligence are often used, including neural network, genetic algorithm, fuzzy expert systems (FES) and data mining. This study focuses on FES. A course design architecture combining multi-media learning materials and a simulation lab for a course about FES is proposed. The course design from several aspects, including learning topics and objectives, learning materials, simulation lab, learning sequences and suggested learning schedule,

will be described. This study uses Java technologies to build an e-learning platform for a FES course where Java applets are used to generate interactive visual components. Meanwhile, html pages, images and flash files are also adopted to produce learning material. In addition, a simulation lab designed, using the java programming language, is employed for the students to set up their FES applications based on scenarios they create. The course designed in this study can be used as a 4-week lecture series suitable for courses related to FES, such as artificial intelligence, fuzzy systems, business intelligence and artificial methods in finance.

BACKGROUND ON THE FUZZY EXPERT SYSTEM

Founded by Zadeh, fuzzy logic has been widely used to define variables which have uncertain values. A traditional crisp set employs a binary value (*0 or 1*) to represent whether an element belongs to the crisp set. In a fuzzy set, on the other hand, a value μ ($0 \leq \mu \leq 1$) is used for an element to describe the degree or amount of participation of an element in the fuzzy set. The process of *fuzzification* is used to determine the value of μ for an element. Membership functions describe the mappings of inputs to outputs for a fuzzy set. Similar to the thinking process of human beings, FES uses fuzzy rules to solve problems. Fuzzy rules are constituted as an IF-THEN structure and often are obtained from human domain experts. To obtain the outputs, a *fuzzy inference* process is employed to determine the fuzzy conclusions (fuzzy outputs) by firing the fuzzy rules. However, in the real world, crisp values are required as a solution. A *defuzzification* procedure is used to obtain crisp outputs from the fuzzy conclusions. Below, FES is briefly described to give readers the necessary background.

Membership Functions and Fuzzification

A triangular membership function is the simplest used in fuzzy logic. A triangular membership function is defined by three parameters: *a*, *b*, and *c*, as follows [10]:

$$Triangular \quad (x) = \begin{cases} 0 & x < a \\ (x-a)/(b-a) & a \leq x < b \\ (c-x)/c-b & b \leq x < c \\ 0 & x \geq c \end{cases} \quad (1)$$
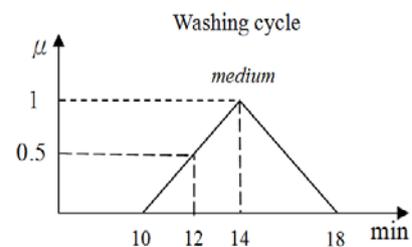

Figure 1: Example of membership function and fuzzification.

Another popular membership function is the trapezoidal function, usually specified by four parameters [10]. Consider a washing machine with a fuzzy variable of *washing cycle*. Figure 1 shows a triangular membership function to describe the fuzzy expression of *washing cycle is medium*, where $a = 10$ (minutes), $b = 14$ (minutes) and $c = 18$ (minutes). From Figure 1, the matching degree (μ) of the input 12 minutes is 0.5. Figure 1 demonstrates the fuzzy expression of *washing cycle is medium*, but in most cases, a washing cycle might have several fuzzy expressions, such as *washing cycle is long*, *washing cycle is short*. It is convenient to define different fuzzy expressions with fuzzy levels, e.g. washing cycle = {long, medium, long} where *washing cycle* is a fuzzy dimension and {long, medium, long} is the set of the fuzzy levels associated with *washing cycle*.

Fuzzy Rules

A fuzzy rule consists of two parts: an *if-part* (antecedent) and a *then-part* (consequent) as follows:

IF <antecedent> *THEN* <consequent>s

Mathematically, a fuzzy rule is defined by:

IF X_1 is X_1^p AND X_2 is X_2^q AND …… X_n is X_n^u *THEN* Y is Y^v

where X_i is the ith fuzzy input dimension and X_i^j is the jth fuzzy level in the fuzzy level set associated with X_i. Y is the fuzzy output dimension and Y^v is the vth fuzzy level in the fuzzy level set associated with Y.

Fuzzy Inference (Min-Min-Max Method)

A fuzzy inference has the following three steps:

Step 1: Determine the minimum of the matching degrees:

Consider a fuzzy rule with *n* input variables $X_1, X_2, …, X_n$. Suppose the input data for these variables are $X_1 = x_1, X_2 = x_2$, …, $X_n = x_n$. The overall matching degree μ_X of the fuzzy rule is obtained by the following formula [10]:

$$\mu_X = \min\{\mu_{X_1}(x_1), \mu_{X_2}(x_2), \quad \ldots, \mu_{X_n}(x_n)\} \tag{2}$$

where $\mu_{X_i}(x_i)$ is the matching degree of x_i associated with X_i.

Step 2: Performing α-cut:

Mainly, two inference methods are used in fuzzy expert systems: the clipping method and the scaling method. The clipping method is used in this study. Figure 2 demonstrates a conceptual diagram of the clipping method.
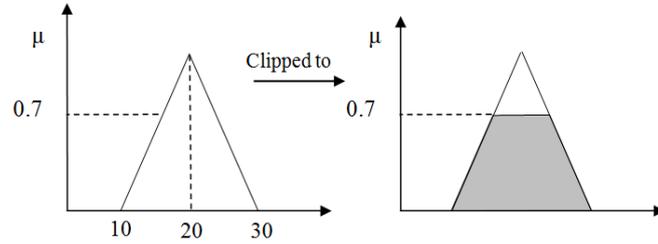

Figure 2: Example of an α-cut (the clipping method).

Step 3: Determine the overall fuzzy conclusion by taking the union of individual fuzzy conclusions:

If a fuzzy rule is fired by the input data, we get a single fuzzy conclusion for this fired fuzzy rule. For convenience, a fuzzy conclusion conducted from a single fuzzy rule is called a *rule-level fuzzy conclusion*. Normally, in a fuzzy expert system, there are multiple fuzzy rules fired by the input data. A *system-level fuzzy conclusion* is obtained by taking the union operations on all of the rule-level fuzzy conclusions conducted from all of the fired fuzzy rules.

As mentioned, in the real world crisp values might be needed to solve a problem. Therefore, the final step for a FES is called *defuzzification*, which generates a crisp value from a system-level fuzzy conclusion.

Defuzzification

The most popular defuzzification method is the Centre of Area (COA) method. It finds the centre of a system-level fuzzy conclusion and uses the centre as the defuzzified value. The COA method computes the weighted average over an entire system-level fuzzy conclusion set. The COA defuzzification method is given by the following formula [10]:

$$def_{COA} = \frac{\sum_i \mu_{Y^v}(y_i) \times y_i}{\sum_i \mu_{Y^v}(y_i)} \tag{3}$$

where def_{COA} is the defuzzified value, and $\mu_{Y^v}(y_i)$ is the matching degree of discrete input y_i associated with Y^v.

Another defuzzificatin method is the Mean of Maximum (MOM) method. The computational details of this method can be found in the publication by Yen and Langari [10]. This study uses the COA method as the defuzzification method. Figure 3 shows the conceptual diagrams of the entire procedure of FES.
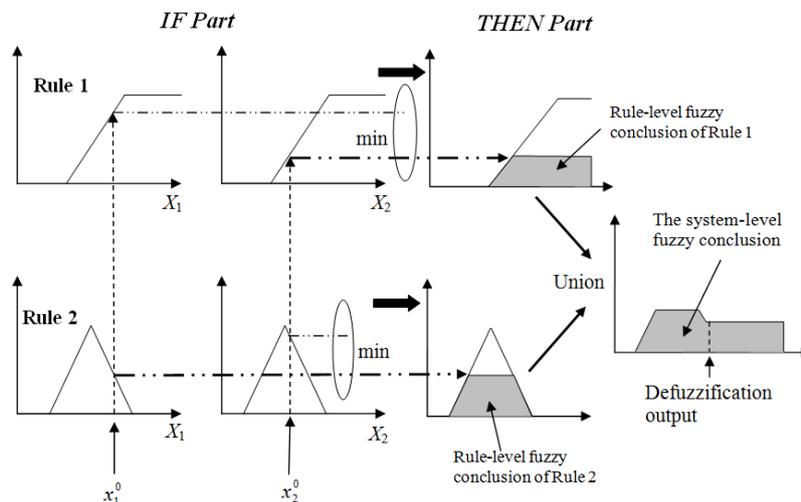

Figure 3: Procedure of an entire fuzzy expert system procedure [10].

COURSE DESIGN

There are two parts in the FES course *versus* learning about FES and developing FES applications using the simulation lab. The course design, from several aspects, is described in this article, including learning topics and objectives, learning materials, simulation lab, learning sequences and suggested learning schedule.

Learning topics and objectives of the FES course include:

1. Membership function: How to use a membership function to describe a problem with uncertainty.
2. Fuzzification: how to get a matching degree (a fuzzified value) from a crisp value using a membership function.
3. Fuzzy rule: Generate fuzzy rules based on well-defined membership functions.
4. Fuzzy inference: Understand the fuzzy inference principle and be familiar with the fuzzy inference processes, including finding the minimum matching degree, α-cut clipping and union of fuzzy conclusions.
5. Defuzzification: Understand the defuzzification principle and be familiar with the defuzzification process.
6. FES application: How to build FES applications with the simulation lab to solve real-world problems.

The learning materials include:

1. HTML pages with images.
2. Animations: using Flash.
3. Interactive learning materials: using Java applets.
4. Video: recorded by instructor.
5. Simulation lab: implemented by the Java programming language.

The simulation lab allows users to:

1. Generate and edit fuzzy variables with appropriate membership functions.
2. Generate and edit fuzzy rules with well-defined fuzzy variables.
3. Enter crisp input values,
4. Derive final defuzzified crisp outputs.

Suggested sequences of learning activities is:

1. Read the html pages and Flash.
2. Watch the Flash-based animations (using video, if necessary).
3. Conduct interactive activities with interactive learning materials implemented by Java applets.
4. Use the simulation lab to create fuzzy expert system application.

Suggested learning schedule is:

Week 1: Introduction (history of fuzzy logic, basic concept of fuzzy logic, examples of FES applications), membership functions and fuzzification.
Week 2: Fuzzy inference method and the defuzzification procedure.
Week 3: Implement fuzzy expert application project.
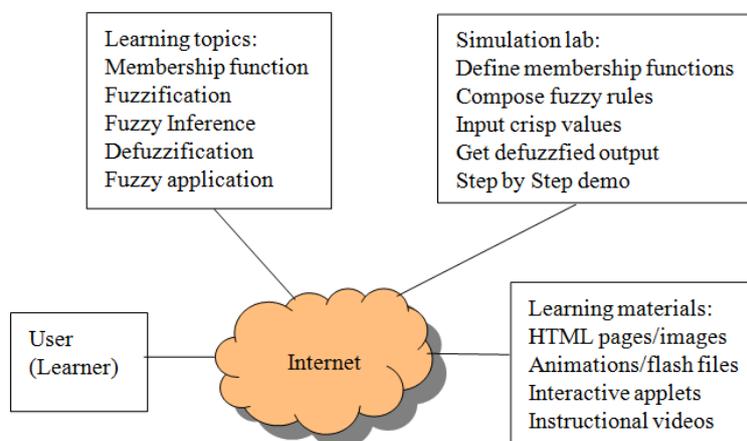Week 4: Project demonstration and concluding review on the project.

Figure 4: An overall diagram of the FES course design.

Figure 4 shows an overall diagram of the FES course design. Figure 5 shows selected examples of interactive learning materials implemented by Java applets. In Figure 5(a), a learner can define a triangle membership function (or a

trapezoid membership case) by entering the three parameters *a*, *b* and *c* (Eq. (1) on input boxes *a*, *b* and *c*. The membership function is then visually generated on the screen. If the learner enters a crisp input value on the input box *x*, the applet calculates the matching degree μ associated with the crisp value and displays it on the screen. In addition, the learner can also use a horizontal scroll bar to locate the crisp input value by pressing-and-shifting the bar. Figure 5 (b) demonstrates a fuzzy inference process with an α-cut clipping.
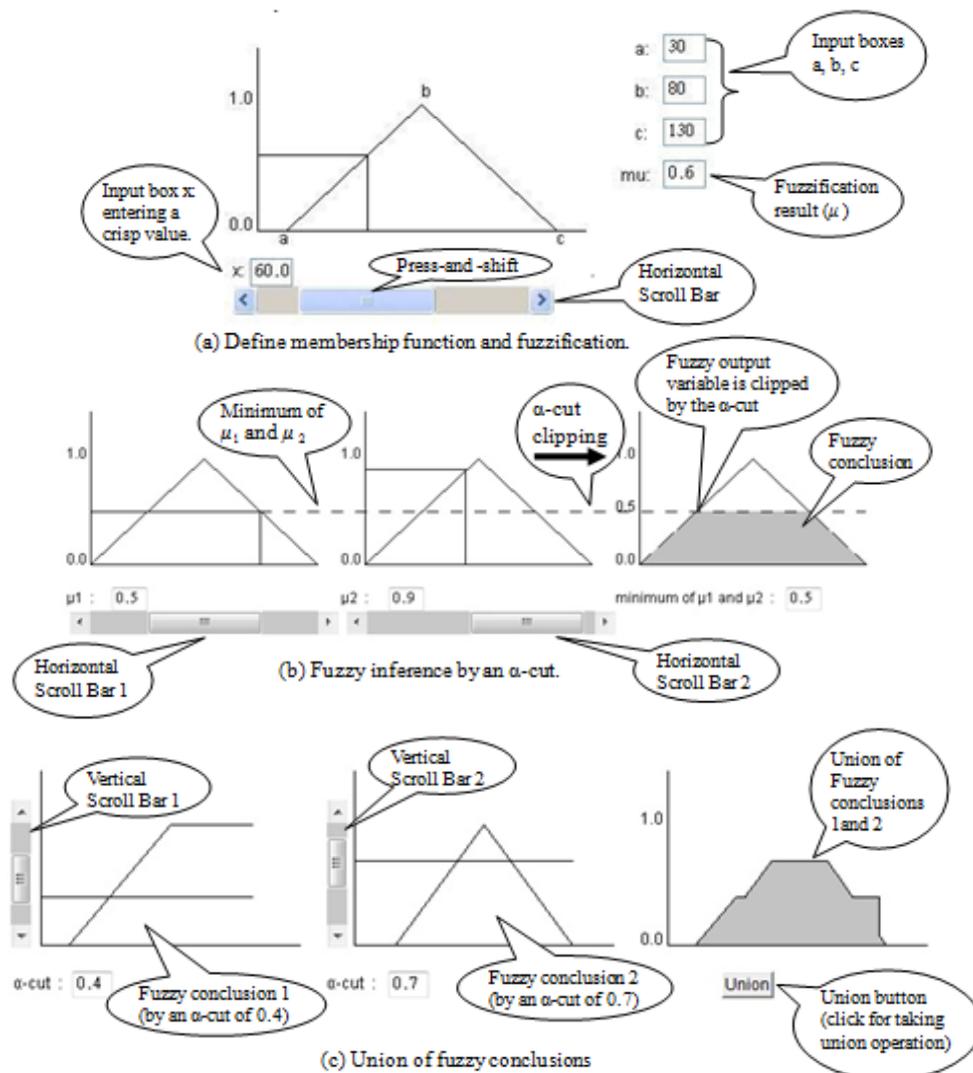

Figure 5: Examples of interactive learning materials implemented by Java applets.

In Figure 5(b), a learner can use two horizontal scroll bars to locate two crisp inputs and the applet will generate two matching degrees (μ_1 and μ_2) associated with the two inputs. The two matching degree will be shown on the screen. The minimum of μ_1 and μ_2 is then calculated by the applet, which is the value of the α-cut to clip the fuzzy output variable. The fuzzy conclusion is produced by the fuzzy inference (the α-cut clipping). Figure 5(c) shows the union of two fuzzy conclusions.

In Figure 5(c), a learner can use two vertical scroll bars to manipulate two α-cuts to simulate two fuzzy rules fired by the α-cuts. The applet will then react to the learner with two fuzzy conclusions associated with the two α-cuts. If the learner clicks on the *Union* button, the applet takes a union operation on the two fuzzy conclusions, and shows the result (the union of the fuzzy conclusions) on the screen. With the interactive learning materials done by Java applets, learners might have more understanding of the individual step-by-step operations of fuzzy expert systems.

CONCLUSIONS

An e-learning course design architecture was proposed in this article, combining multi-media learning materials and a simulation lab for a course on fuzzy expert systems. Introduced first was the background of fuzzy expert systems and then the design of the course was described from different aspects. This included learning topics and objectives, learning materials, simulation lab, learning sequence, and learning schedule.

The course design proposed in this study can be used as part of artificial intelligence courses. The learning materials of the course include html pages, images, Flash files, Java applets and instructional videos. In addition, a simulation lab is

also used for students to set up their fuzzy expert systems based on the scenarios they create. Six core concepts of the fuzzy expert systems are included in this study: 1) membership function; 2) fuzzification; 3) fuzzy rule; 4) fuzzy inference; 5) defuzzification; and 6) fuzzy expert application. The course can be used as a 4-week lecture course for fuzzy expert systems.

The simulation lab can be used in courses related to FES for different majoring students, such as engineering, business administration, finance, and education. Instructors of FES can encourage the students to build their FES applications based on the students' majors. Through qualitative research, various usages of FES applications among different majoring students could be explored. This might be an interesting topic for future studies.

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