Proceedings of

REDISCOVER 2004

Southeastern Europe, USA, Japan and European Community Workshop on Research and Education in Control and Signal Processing

June 14-16, 2004

Hotel Croatia
Cavtat
CROATIA

ISBN: 953-184-077-6

Publisher:

Faculty of Electrical Engineering and Computing
University of Zagreb

Editors:

Stjepan Bogdan
Zoran Vukic

CIP - Katalogizacija u publikaciji
Nacionalna i sveucilišna knjižnica – Zagreb

UDK 681.5(063)
621.39(063)

SOUTHEASTERN Europe, USA, Japan and European Community Workshop on Research and Education in Control and Signal Processing (2004 ; Cavtat)
Proceedings of REDISCOVER 2004 / Southeastern Europe, USA, Japan and European Community Workshop on Research and Education in Control and Signal Processing, Cavtat, Croatia, June 14-16, 2004. ; <editors Stjepan Bogdan, Zoran Vukic>. - Zagreb : Faculty of Electrical Engineering and Computing, University of Zagreb, 2004.

ISBN 953-184-077-6

I. Automatsko upravljanje II. Obrada signala

440531121

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Process Control Knowledge Representation by Fuzzy Cognitive Maps in an Intelligent Tutoring System

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Abstract

Process control is intensively dynamic occurrence. Teaching process control with tutoring system should intrinsically include not only process parameters, equations and constants but also a process control dynamical model. Intelligent hypermedial authoring shell Tutor – Expert System structure enables incorporation of Fuzzy Cognitive Maps (FCM) to represent and to model process control units and causal relations existing among them. Existing knowledge base can be used to extract knowledge necessary for building FCM. Ones the map is built it can model dynamical behavior of represented system.

1. Introduction

Intelligent tutoring systems (ITS) are computer programs for supporting and improving the process of learning and teaching. Depending on students' learning capabilities, ITSs can adjust the contents and the way of domain knowledge perception. ITSs are built on a fairly well established architecture, which relies on four interconnected modules, see Image 1: *expert module* acting as the domain knowledge unit, *student module* comprehending the generated student model based on the learning and teaching process in the domain knowledge, *teacher module* guiding the learning and teaching process and *communication module* realizing the interaction among student, teacher and knowledge [1].

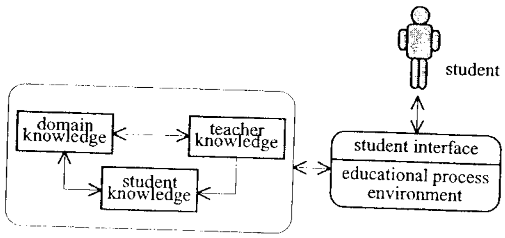

Image 1. General ITS Architecture

As the need to cover a variety of different domains have arisen since, instead of having a number of specialized ITSs for the domains of interest, "ITS generators" were developed, which are usually denoted as authoring shells [2]. These shells can be "programmed" for a particular domain by modifying the domain knowledge thus resulting in a specific ITS. Beside that, authoring shells support a non-programmer user to develop the knowledge base for particular domain knowledge.

Considering modern information and communication technology and their implementation in the instruction system as well as the implementation of the principles of system science, didactics, individualized teaching, together with expert systems and knowledge representation techniques, we have developed the intelligent hypermedia authoring shell TEx-Sys (Tutor-Expert System) [3]. The system has been developed with the aim to be adaptable to the needs of both the teachers and students, thus being an improvement to interdisciplinary learning and teaching.

TEx-Sys is structured into the following modules, (see Image 2):

- Login for legalization of work on the system;
- Developing for building the knowledge base of freely chosen domain;
- Learning and Teaching of freely chosen domain knowledge;
- Testing evaluation of a student's knowledge within a teaching scenario, according to Piaget's theory of "guided free play" [4] and combinations of scenarios of teaching by "articulated experts" and "dialogues of divided initiatives" [5];
- Evaluation access to the achieved results of learning and teaching;
- Quiz is implementation of the test, in which student gets set of questions with attached answers, which can be correct or incorrect. Student solves the test by marking the answers he assumed correct. After student solves the test he gets a mark and maybe a recommendation for learning more about some entities of domain knowledge.

Fuzzy Cognitive Maps (FCMs) are fuzzy weighted, oriented graphs representing some domain causal knowledge.

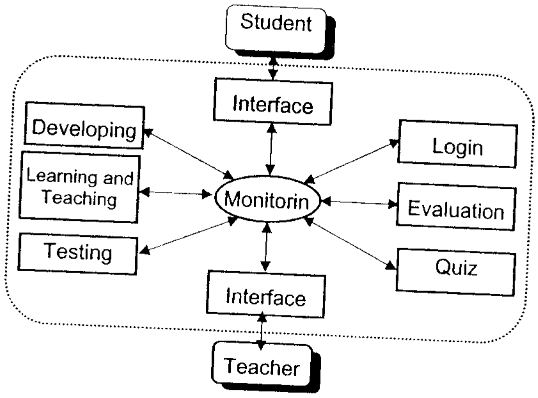

Image 2. The TEx-Sys structure

Based on Axelrod definition of Cognitive Maps FCMs where developed by Kosko in 1986 [7], [8], [14]. FCM can be used and are mainly used as a powerful modeling, simulation and representation technique applicable to different kind of systems (economic, political, technical, etc.) [9]. System represented with a FCM consists of concepts (entities, variables) and fuzzy cause-effect relations between concepts. Each concept is a node or vertex of a FCM graph while each relation is a weighted edge.

Our main idea is to incorporate FCMs into ITS. Structure of TEx-Sys makes this idea possible. Semantic network used in TEx-Sys, with less supplementation, can be used to carry knowledge necessary to build a FCM. This idea is more elaborated later in the paper after short introduction to FCMs.

2. Fuzzy Cognitive Map

FCM are primarily used for causal knowledge representation because of its cyclic nature. FCM has a networked structure that unleashes for each node to be connected to any other node and to create cycles existing in causal knowledge [10], [11]. Constructed graph is nonlinear dynamic discrete system that could be activated by the given initial state of concepts. Concept states are calculated from initial state and adjacency matrix.

Adjacency matrix is n×n matrix containing weighted factors of causal relations where n is overall number of concepts in a FCM (Image 4). Inference engine is simple multiplication of adjacency matrix and vector of current concept states. Edge weights and concept states have to be normalized inside interval [-1, 1]. Because inference engine can lead to concept state values outside interval some kind of transformation function have to be used after multiplication. This is very similar to calculation performed in neural networks so some authors define FCM as combination of fuzzy logic and neural networks [14].

Usually real concept values are not inside interval so appropriate mapping, not strictly defined in FCM, from real values to the interval [-1, 1] has to be applied.

Calculation of node value is done according to the Equation 1. A_i^t is state of the i-th concept (node) at discrete time t, w_{ji} is the i-th column of adjacency matrix

$$A_i^t = f\left(\sum_{\substack{j=1 \\ j\neq i}}^{n} A_j^{t-1} w_{ji}\right) \quad \text{Equation 1.}$$

A_j^{t-1} is state of the j–th concept at discrete time $t-1$, f is transformation function to ensure that concept state is always inside [-1, 1] and n is total number of concepts in FCM.

FCM could be used for qualitative dynamic analysis of technical system behavior. Let us show one example from the field of the process control theory. The system is shown in Image 3. Two different kind of liquid pour into the tank through valve1 and valve2 causing a chemical reaction. Specific gravity measured by sensor has to be maintained in the range between G_{max} and G_{min} and height of the liquid in the tank has to be maintained in the range between H_{max} and H_{min}. Valve3 releases the liquid from the tank.

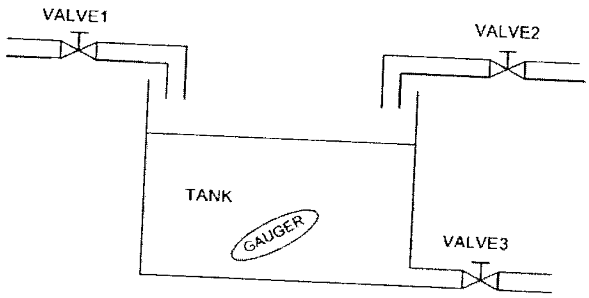

Image 3. Process control system with tank, three valves and gauger

FCM shown in Image 4 consists of five nodes/concepts (valve1, valve2, valve3, tank, gauger) and their mutual interrelations [14]. For example, concept valve1 positively influences concept tank. That implies if the value of valve1 grows (valve is more and more opened) height of the liquid in the tank also grows. On the contrary concept valve3 negatively influences tank concept because opening the valve3 leads to decrease of the height of the liquid in the tank.

The numbers represent roughly the degree of influence. For example, the influence of the valave3 to the liquid height is double grater in comparison with the influence of the valve1.

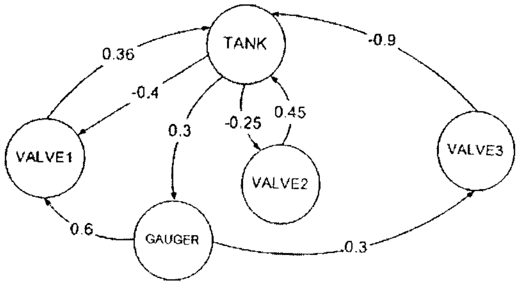

Image 4. FCM for process control system with tank, three valves and gauger

The adjacency matrix is shown on Image 5.

$$W = \begin{bmatrix} 0 & -0.4 & -0.25 & 0 & 0.3 \\ 0.36 & 0 & 0 & 0 & 0 \\ 0.45 & 0 & 0 & 0 & 0 \\ -0.9 & 0 & 0 & 0 & 0 \\ 0 & 0.6 & 0 & 0.3 & 0 \end{bmatrix}$$

Image 5. Matching adjacency matrix

Let us suppose initial state of concepts is [0 1 1 0 0] which means that valve1 and valve2 are set to maximum. FCM starts to simulate the behavior of the process. Initial state leads to rising liquid height in the tank and rising specific gravity measured by the sensor. As direct result valve3 will be opened to its half and valve1 and valve2 will be closed to its half. FCM reaches equilibrium state after 13 steps. Results are shown in Table 1.

TANK	VALVE1	VALVE2	VALVE3	GAUGER
0.0	1.0	1.0	0.0	0.0
0.6921	0.5	0.5	0.5	0.5
0.53369	0.57442	0.45685	0.53742	0.55172
0.46911	0.58201	0.46669	0.54128	0.53994
0.43483	0.58029	0.47071	0.5404	0.53512
0.46845	0.57958	0.47284	0.54004	0.53256
0.4351	0.57921	0.47075	0.53985	0.53507
0.52476	0.57957	0.47283	0.54004	0.53258
0.52471	0.57921	0.46724	0.53985	0.53927
0.52476	0.58019	0.46725	0.54035	0.53927
0.52464	0.58019	0.46724	0.54035	0.53926
0.52464	0.58019	0.46725	0.54035	0.53926
0.52464	0.58019	0.46725	0.54035	0.53926

Table 1. Concept values in FCM with initial state of concepts [0 1 1 0 0] until map has reached equilibrium

Equilibrium state answers the question what happens with this control system if we open valve1 and valve2 to the maximum? To maintain the system in defined range (G_{max} - G_{min}, H_{max} - H_{min}) valve3 has to open to some degree, while valve1 and valve2 have to close to some degree. FCM gives good insight in the dynamic behavior of the system. The values are not precise but the qualitative behavior of the system is maintained.

In the next chapter we will explain in details how FCM could be integrated in TEx-Sys knowledge representation structure.

3. Intelligent Tutoring System & Fuzzy Cognitive Map

3.1. ITS in process control teaching

Process control teaching can be made with laboratory plant like in [15]. Exercises with mathematical and linguistic model of a particular system are used in a teaching process. Dynamic behavior of the process is investigated on the laboratory model with aim to maintain the overall process control goal. In this paper we propose the use of the FCM to model dynamic behavior of the process control system. Lab model or mathematical model of system is not required. This does not mean that teaching process control in way we described so far is cast aside. It is expanded with FCMs. Using knowledge encoded in the TEx-Sys a FCM of a given system can be built. In such way the teaching process control dynamic becomes undistinguishable part of TEx-Sys and not a separate method. FCM can represent dynamic behavior of the system.

The student can have deep insight in process dynamics. For example, we could ask TEx-Sys what will happen if the process input variable_1 increases? How would the system behave? Which variables have to be changed if the output variable_4 must be decreased? This kind of knowledge about dynamic behavior of the system can be very useful in process control teaching.

3.2. Knowledge representation

The knowledge in the TEx-Sys is presented by semantic networks with frames. Basic components in semantic network are nodes and links. Nodes are used for presentation for domain knowledge objects, while links show relations between objects. Nodes can have different meaning and signification like: understanding of an entity, entity attributes event description and entity state. Beside nodes and links, the system supports properties and frames (attributes and respective values), along with property inheritance. The system heavily relies on modern supporting technologies, such as multimedia, with the following structure attributes: picture, animation, slides, hypertextual description and URL address. TEx-Sys uses the following predefined semantic primitives: IS_A, SUBCLASS, A_KIND_OF, INSTANCE and PART_OF. Besides, the TEx-Sys uses semantic primitive labeled PROPERTY for showing properties, as well as Minsky diagram [6] that encodes knowledge in packages, so called FRAMES, that are incorporated in network with searching capability, so all of that is called frame based system (Image 6). Frame is usually assigned to object, and it is called object in semantic network. An object has optional SLOT number, i.e. attribute set (<SLOT>) and their values (<FILLER>).

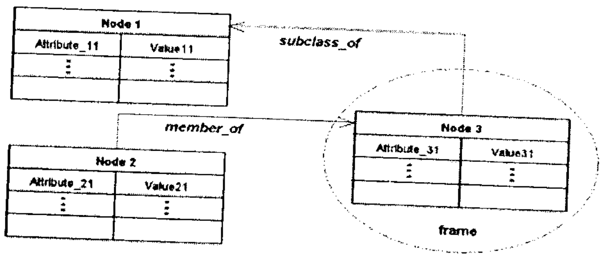

Image 6. Structure of semantic network with frames in the TEx-Sys

Image 7 shows concept Tank from the FCM in Image 3 like node in semantic network of TEx-Sys. Node Tank is related with nodes Valve1, Valve2 and Gauger with weighted factors -0.4, -0.25 and 0.3. Other concepts are also represented with nodes carrying causal-effect relationships with other nodes.

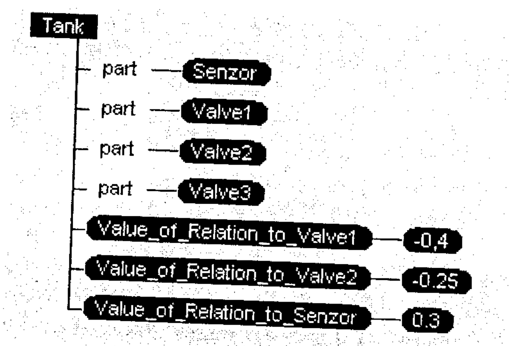

Image 7. Semantic network node Tank with relations to Valve1, Valve2 and Gueger from FCM in Image 3

To build a FCM from semantic network nodes like one in Image 7 requires also developing interpreter that will be able to pass through semantic network and extract information required for building a FCM. This part of the ITS is not done yet and it is part of the future work.

4. Conclusion

FCM can be combined with the knowledge representation in the TEx-Sys. TEx-Sys knowledge representation in form of a semantic network can be broaden with slight adjustments of the semantic network so that frames containing attributes of a node carry information necessary for FCM. Primarily is it a concept and is it in causal relation with some other concept. This will provide to students and teachers an ITS with dynamical knowledge, that is, an ITS with knowledge of system dynamic behavior, particularly useful in process control teaching.

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ACKNOWLEDGMENT

This work has been carried out within projects No. 0177110 "Computational and didactical aspects of intelligent authoring tools in education" and No. 0023008 "Intelligent Agents in Modelling and Control of Complex Systems" funded by the Ministry of Science and Technology of the Republic of Croatia.