AGENT BASED FUZZY COGNITIVE MAPS IN FIRE FIGHTING DECISION SUPPORT

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Abstract

Fire fighting process in Croatia is mainly based on the firefighter knowledge. People on the field decide when to include air forces in the extinction, when to call new forces, etc. Modelling such a complex decision process is difficult and only possible with qualitative modeling techniques. This paper presents the developed agent based fuzzy cognitive map containing fire fighter knowledge. The map can be used as a decision support tool to facilitate the decision process in such a stress situations. Agent based fuzzy cognitive map is qualitative modeling and simulation technique built combining fuzzy cognitive maps and multi-agent systems. Fuzzy Cognitive Maps are qualitative modelling and simulation technique that models system like the group of concepts and the cause-effect relations among concepts. A FCM is represented as a weighted, directed graph with the map concepts as graph nodes and the cause-effect relations as a graph directed edges. FCM is a method for representing the knowledge and an inference process that generates conclusion of the dynamic system behaviour. A multi-agent system can be defined as a network of entities working together on solving the problem that is beyond the agent individual solving capabilities and knowledge with properties like no global system control, decentralized data, etc. The Agent Based Fuzzy Cognitive Map is a Fuzzy Cognitive Map based on a multi-agent system with each concept mapped in to the agent. ABFCM enables each concept in the map to use the different inference process and enables the further extension with the introduction of new agents with specific functionality, like assisting the user with the map results interpretation.

Introduction

The main idea of this work is to facilitate a fire fighter manager work. The term fire fighter manager is used for a person or persons that guide a fire fighting process.

One way to do that is to develop decision support system for a fire fighter manager decision-aid in such a stress situation as a fire fighting (Li at al. 1991). The concept of a decision

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support system (DSS) is very broad since decision support system can take many different forms. We can say that a DSS is a information system that supports decision making (Power, 1997).

Decisions concerning such emergency situations like a fire fighting are numerous. Majority of DSS systems in the fire fighting area are built on a fire risk prediction models and fire propagation models (Sung-Do et al., 2003). Those models are mainly GIS (geographical information system) based. We are developing DSS system trying to incorporate fire fighter manager knowledge about fire fighting forces management. The fire fighter manager knowledge is responsible for the decisions like:

- when to call air support,
- when to relocate forces from one fire scene to another,
- if the fire fighting forces are limited in a case of multiple fires which fire has a priority i.e. if there is just one Canadair to which fire scene will it be sent? Etc.

These decisions are, of course, based on the GIS data but we would try to capture general knowledge that would be applicable to different fire locations with diverse geography.

Since this kind of knowledge and inference process made by a human fire fighting manager is very complex it could not be defined quantitatively. One of the solutions is to use a qualitative model. Qualitative model should capture fire fighter manager knowledge and decision making process. It is important to stress out that this kind of fire domain DSS is in no way replacement for the human, just an aid-tool.

There are many qualitative modelling techniques like qualitative reasoning (Travé-Massuyès et al., 2003), system dynamics (Craig, 2001), semantic networks (Fisher et al., 2002) etc. Here we would use technique called Agent Based Fuzzy Cognitive Map. In short it is a technique developed combining Fuzzy Cognitive Maps and Multi-agent systems. Those techniques are explained in detail in next chapters.

FCM

Fuzzy **C**ognitive **M**ap - FCM is qualitative modelling and system dynamic behaviour technique. FCM models system like a group of concepts and cause-effect relations among those concepts and then represents system as a weighted, directed graph (Kosko, 1986). Bart Kosko has defined FCM in 1986. expanding **C**ognitive **M**aps or **C**ausal **M**aps – CM in a manner that concepts and cause-effects values from {-1, 0, 1} assembly are augmented to the [-1, 1] interval (Kosko, 1992).

It can be said that a Fuzzy Cognitive Map is combination of a conceptual map and fuzzy logic providing more realistic and more accurate real word portrait then the conceptual maps binary logic. FCM modelled system is represented as a weighted, directed graph with concepts represented as a graph nodes and cause-effect relationships represented as a graph directed edges.

FCM develop process is similar to the expert system knowledge base development. One or more expert identifies concepts and cause-effect relations among those concepts. Expert job is also to define cause-effect relations intensity. In a FCM each cause-effect relation is described with the linguistic variable which is then described with the membership function (Cox, 1999).

It is implied that a large cause-effect relation weighted factor means a strong cause-effect relation among concepts. Experts describe relations as a strong, week, etc. like in fuzzy logic. But the defuzzification process is done directly by the expert or by the map creator. For example, strong positive effect in the defuzzification process becomes weighted factor 0.8. Medium strong negative effect in the defuzzification process becomes weighted factor -0.48. The positive weighted factor sign indicates that if the concept from which cause-effect relation originates increases than the concept in which cause-effect relation terminates also increases. The negative weighted factor sign indicates that if the concept from which cause-effect relation originates increases than the concept in which cause-effect relation terminates decreases.

In a simplest form of a FCM, weighted factors are limited to the set {-1, 0, 1}, that is, cause-effect relations strength is maximized. This facilitates transfer of an expert knowledge to a FCM. Sometimes experts don't know how to defuzzificate their knowledge, that is, how to quantify impact among concepts. In that case knowledge engineer can use Questionnaire method or Documentary Coding method to extract expert knowledge linguistically and then proceed with the knowledge defuzzification (Kim et al., 1998).

Questionnaire method is implemented via interviews which provide the knowledge to the knowledge engineer who then fills questionnaires capturing expert knowledge. Documentary Coding method is systematic encoding of available documentation that is at the knowledge engineer disposal and contains system information.

Fuzzy cognitive map represents knowledge about a system but also provides inference mechanism based on the expert knowledge expressed in the FCM form. Because of that FCM can be considered artificial intelligence system (Miao et al., 2000). Inference mechanism in the simplest form is manipulation of two matrices - concept vector and adjacency matrix (Taber, 1991). The concept vector contains fuzzy cognitive map concepts values. The adjacency matrix mathematically represents cause-effect relations among map concepts. If the *i*-th node state at the time moment *t* is denoted with A_i^t and if the *i*-th adjacency matrix column is denoted with w_{ji} simple inference process is introduced with the next equation:

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

The A_j^{t-1} is *j*-th node state at the time moment *t-1*, *f* is a transformation function and *n* is overall map concepts number. The transformation function normalizes node state to the interval [-1, 1]. Transformation function also incorporates expert knowledge. Transformation function is not limited to any predefined function and depends on the system modelled with the map. Commonly used functions include *tanh* function, *signum* function, etc.

Generating conclusion on the system, represented with the map, behaviour is called fuzzy cognitive map dynamic analysis. Map nodes are set to initial state (based on the state of real concepts represented with the map nodes) and then the map is started. Results obtained with the map are map conclusion about system behaviour. The conclusion can be made only if the map enters fixed-point attractor or limit cycle state. With the map fixed-point attractor the map concepts don't change value any more. With the map limit cycle state the map concepts repeat previously reached value.

Multi-agent system

Multi-agent system is a system composed of several autonomous components or agents (Jennings et al., 1998). Agent is a computer system, situated in an environment, it can receive stimulus from the environment and can flexibly and autonomously act in pursuing its goals (Franklin et al., 1996). In our application it is appropriate to observed multi-agent system as a loosely connected network of entities together solving problems beyond agents' individual capabilities. Multi-agent system characteristics include:

- agents have limited information or problem solving capability,
- there is no central system control,
- data are decentralized,
- multi-agent system is asynchronous.

Agent interaction is the key issue in a multi-agent system (Ferber, 1999). Interaction occurs as a chain of agents actions while agents are in a dynamic connection. Interaction consequences influence the future agent behaviour. Agents can realize interaction either directly, either through environment or through some kind of a mediator agent.

Ontology

An agent application covers a limited domain. It is practically impossible to create general multi-agent system. Agent application domain is defined through one or more ontology. Common ontology is something that is mandatory for a multi-agent system. Without common ontology it is not possible to accomplish sensible and useful communication among agents regardless of the used technology, application area or information infrastructure. It is *conditio sine qua non* for a multi-agent system.

Ontology is explicit specification of the knowledge conceptualization (Gruber, 1993). Formal knowledge representation is based on a knowledge conceptualization. The knowledge conceptualization is definition of concepts, objects, entities that exist in the observed domain and their relations. The conceptualization is abstract, simplified domain representation. Each knowledge based system or agent possessing knowledge is bounded to some kind of a conceptualization. When the domain knowledge is formally described, domain objects are called universe of discourse. The universe of discourse is a set of objects and their relations in the developed dictionary describing the knowledge. Knowledge base and ontology are not the same. Common ontology describes the dictionary that can be used in the "conversation" about a domain while knowledge base includes knowledge necessary for solving a problem or answering a domain question.

ABFCM

Multi-agent system and fuzzy cognitive map technologies synergy has provided theoretical basics to define new method for qualitative modelling called *Agent Based Fuzzy Cognitive Map - ABFCM*. Agent based fuzzy cognitive map is a fuzzy cognitive map in which each concept is mapped into the agent in the multi-agent system. Cause-effect relations among map concepts in the multi-agent system are carried out through agent message communication exchanging information about cause-effect relations. In a classic fuzzy cognitive map all concepts use the same inference process to calculate the node new state. Agent Based Fuzzy Cognitive Map enables each concept modelled with an agent to use different algorithm to calculate new state.

Theoretical ABFCM basics are tested with the specially developed ABFCM prototype which is also used in this paper to provide the fire fighter manager with the decision support system. The prototype has a graphical user interface enabling user to simply draw map and to define map concepts inference process and other characteristics like initial state. More detailed ABFCM explanation is provided in a paper currently submitted to be considered for publication in the Journal of Intelligent and Fuzzy Systems.

ABFCM FIRE FIGHTING DECISION SUPPORT SYSTEM

We are developing a fire fighter manager decision support system based on the ABFCM method. The fire fighter manager decision support is not the only disaster management area for the ABFCM decision support.

A fire fighter manager guiding a fire fighting process needs to make many different decisions. ABFCM decision support system can be made and used quickly. The ABFCM is based on the fire fighter knowledge whiteout quantitative values. It can be obtained at the fire site and then used in a decision support for the observed fire. Example of a decision support encompasses situation when a fire fighter manager has to decide how to distribute land and air fire fighting forces among simultaneous fires. That situation is not uncommon on the Adriatic coast especially in the fire fighting season during the summer. Information (the Split-Dalmatia

County from 20.7.2006. till the 29.7.2006.) from the Croatian National Protection and Rescue Directorate (DZUS, 2007) are shown in the table 1. It is not uncommon to have two fires in the same time. The fire fighter manager has to distribute the fire fighter forces according to the fire priorities.

Table 1. Fire locations from the 20.7.2006. till the 29.7.2006. for the Split-Dalmatia County according to the Croatian National Protection and Rescue Directorate

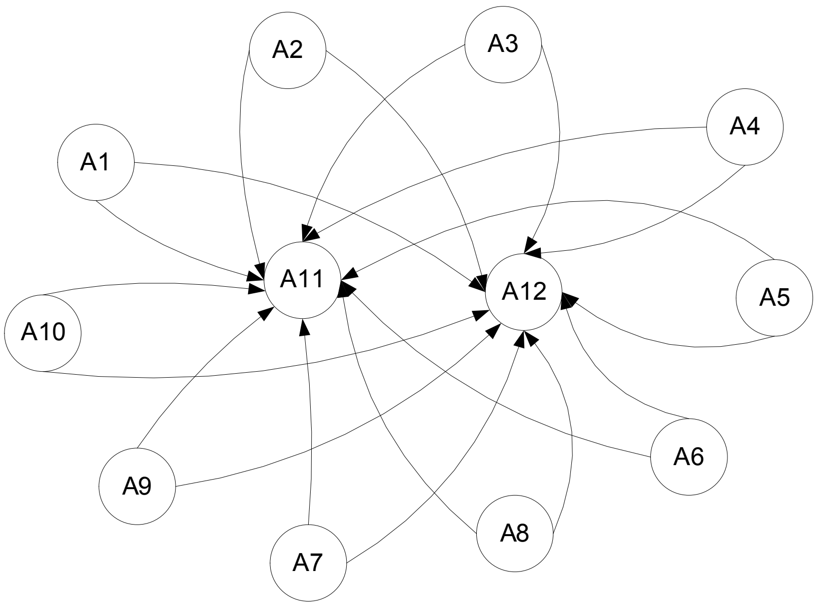
Date	Fires in the Split-Dalmatia County
20.7.2006.	1. Vrgorac
21.7.2006.	1. between Lovreć and Šestanovac (Prpuša) 2. Vrgorac
22.7.2006.	1. between Lovreć and Šestanovac (Prpuša) 2. Sitno Gornje
23.7.2006.	
24.7.2006.	
25.7.2006.	1. Mosor, Debelo Brdo 2. Muć-Ogarje-Karanove Kuće 3. Žrnovnica-Lolići 4. Kaštela
26.7.2006.	1. Vrgorac – Matokit – Sveti Rok 2. Mosor, Debelo Brdo 3. Sadine-Rudine
27.7.2006.	
28.7.2006.	
29.7.2006.	1. Vrgorac – Matokit – Sveti Rok 2. Hvar

Development of the ABFCM map demands extracting the expert knowledge about system concepts and their relations in the modelled system. Knowledge extraction for the obtained map is done by the knowledge engineer using both methods, Documentary Coding and Questionnaire, described in the FCM chapter. Based on the available documentation about fire fighting process, fire fighting management, fire fighting forces (UPVH, 2007) etc. and based on the information provided by the expert the knowledge engineer has identified main concepts. Main identified concepts affecting fire fighter manager decisions on calling and allocating available forces in a fire are:

- possibility of a human loss
- strategic buildings endanger (infrastructure, military objects, …)
- other buildings endanger (houses, business buildings, …)
- proximity of nature monument

- national park or nature park proximity
- fire extension area (an emerging fire is easier to extinguish then the developed one)
- endanger of important traffic routes (like the highway Zagreb-Split) surrounded with mine fields
- the vegetation type caught in a fire
- meteorological factors that influence fire spreading (like the wind)
- the time of day (air forces are neutralized during the night time)

Figure 1. The ABFCM map for the fire fighter decision support



- A1 - possibility of a human loss
- A2 - strategic buildings endanger (infrastructure, military objects, …)
- A3 - other buildings endanger (houses, business buildings, …)
- A4 - proximity of nature monument
- A5 - national park or nature park proximity
- A6 - fire extension area (an emerging fire is easier to extinguish then the developed one)
- A7 -endanger of important traffic routes (like the highway Zagreb-Split) surrounded with mine fields
- A8 – the vegetation type caught in a fire
- A9 - meteorological factors that influence fire spreading (like the wind)
- A10 – the time of day (air forces are neutralized during the night time)
- A11 - land forces
- A12 - air forces

Special provisions at the Adriatic coast refer to the islands and peninsula Pelješac. In a fire case the islands and peninsula Pelješac have precedence over the other regions. This knowledge is not included in the map on figure 1. because the map is limited to a fire fighter manager knowledge fragment for the developed map. Influence of the special provisions can be introduced in the map with the new concept (or concepts) and cause-effect relations. We have restricted the map because this is initial research. The map can incorporate such complex and comprehensive fire fighter knowledge and will be expanded in the future.

Concepts are listed according to the importance. For example, possibility of a human loss has greater impact on a decision to call fire forces than a traffic shutdown. The concept significance is encoded in the map thru cause-effect relation weighted factor. Large cause-effect relation weighted factor implies strong cause-effect relation among concepts. The fire fighter manager main decisions are to call land and/or air fire fighter forces. They are introduced in the map thru two concepts:

- land forces
- air forces

It should be stated that decisions concepts are also simplified. Real life situation is much more complex. The fire fighter manager has to decide will he call just local fire fighter forces or extend the call to outer fire fighter forces. Will he call Canadair or helicopter or other air forces?

The complexity of decision making in a fire fighting situation is just partially presented in this paper. This kind of knowledge and decision making process is hard to specify in the paper, let alone to capture and model. But if the ABFCM can provide just a part of the expert knowledge and generate correct conclusions (even limited ones) it could be very useful.

The map with the identified concepts and cause-effect relations is shown in the figure 1. The concept values and cause-effect relations weighted factors depend on the real fire situation. They can easily be adjusted on the scene to display particular situation. If the observed fire is near national park than this cause-effect relation will have a large weighted factor. If the observed fire is not near national park than this cause-effect relation will have a small weighted factor. Example adjacency matrix could in an assumed case look like:

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6 & 0.7 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & 0.7 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.2 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 0.45 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6 & -0.4 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.7 & -0.5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Adjacency matrix contains cause-effect relations weighted factors depending on a real fire situation. In an assumed case, fire is not near nature monument, national park or nature park so fourth and fifth row of the matrix are zero because these concepts do not affect fire fighter manager decision on bringing land or air forces. The assumed fire occurs during the late afternoon approaching night so there is negative effect (-0.5) on concepts of bringing air forces to the fire scene. Similarly assumed other fire conditions resulted in the cause-effect relations weighted factors in the example adjacency matrix.

The map can also quickly be expanded with totally new concepts besides the concepts already identify. That means that the map can be quickly adjusted if the real fire situation introduces new concepts. For example, the fire is approaching chemical factory that could contaminate drinking water source. Is that covered with the concept buildings endanger or with the concept possibility of a human loss? Or this situation requires the new concept? How the expert (fire fighter manager) makes decision in this case?

These ideas should be tested in the real fire fighter situations.

Conclusion

Agent Based Fuzzy Cognitive Map method facilitates knowledge capture. It enables quick and simple coding of an expert knowledge also providing inference process that generates conclusion about the system behaviour.

This method can be used to provide system decision support in different domains. In this paper ABFCM is presented as a decision support system for the fire fighting domain but the ABFCM can also be adopted in others disaster management domains. The map presented in the paper is generated by the knowledge engineer using Document Coding method and Questionnaire method for the ABFCM map development. The expert itself can also deploy the ABFCM method and build the map according to the real life situation.

As already stated this is in no way replacement for the human expert just a support tool. Decision support system can be quickly built and adjusted to a particular situation customizing map concept values and cause-effect relations weighted factors and it can be extremely useful in a disaster management stress situations.

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