Forest Fires Prediction by an Organization Based System

Aitor Mata, Belén Pérez, and Juan M. Corchado

Abstract. In this study, a new organization based system for forest fires prediction is presented. It is an Organization Based System for Forest Fires Forecasting (OBSFFF). The core of the system is based on the Case-Based Reasoning methodology, and it is able to generate a prediction about the evolution of the forest fires in certain areas. CBR uses historical data to create new solutions to current problems. The system employs a distributed multi-agent architecture so that the main components of the system can be remotely accessed. All the elements building the final system, communicate in a distributed way, from different type of interfaces and devices. OBSFFF has been applied to generate predictions in real forest fire situations, using historical data both to train the system and to check the results. Results have demonstrated that the system accurately predicts the evolution of the fires. It has been demonstrated that using a distributed architecture enhances the overall performance of the system.

Keywords: Forest fires, Organization Based Systems, Services Oriented Architectures.

1 Introduction

Prediction and simulation of forest fires propagation is an important problem from the computational point of view due to the complexity of the involved models, the necessity of numerical methods and the required resources for calculation.

The phenomenon of forest fires has not only given as a result an important loss of forests and damage in the economy, but it has also seriously affected human health and environment. The fire fighting should have at its disposal the most

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advanced resources and tools to help the use of available resources in the most efficient way do diminish fire effects as much as possible.

This paper presents OBSFFF, a Organization Based System for Forest Fires Forecasting. This system deploys a prediction model which makes use of intelligent agents and Case-Based Reasoning systems to determine the possibility of finding forest fires in a certain area once a fire has nearby started. It also applies a distributed multi-agent architecture based on Service Oriented Architectures (SOA), modeling most of the system's functionalities as independent applications and services. These functionalities are invoked by deliberative agents acting as coordinators.

The system presented in this paper generates as a solution the future situation of an area, considering the present one. Predictions are created using a Case-Based Reasoning system. The cases used by the CBR system contain atmospheric data (wind, temperature and pressure) and may also contain information about an specific situation to be solved (forest fires) OBSFFF combines artificial intelligence techniques in order to improve the efficiency of the CBR system, thus generating better results. OBSFFF has been trained using historical data. The development of agents is an essential piece in the analysis of data from distributed sensors and gives those sensors the ability to work together and analyze complex situations.

In the following section, a brief description of the forest fires problem is shown. Section 3 explains the main concepts of the organizations of agents. The fourth section describes the OBSFFF system and the final two sections show the results and the conclusions.

2 Forest Fires

Forest fires are a very serious hazard that, every year, causes significant damage around the world from the ecological, social, economical and human point of view [1]. These hazards are particularly dangerous when meteorological conditions are extreme with dry and hot seasons or strong wind. For example, fire is a recurrent factor in Mediterranean areas.

Fires represent a complex environment, where multiple parameters are involved. In this sub-section, a series of applications and possible solutions are explained. They are different approaches to the forest fire problems, including all the main phases existing in the evolution of this kind of problem.

The OBSFFF system presented here was applied to generate predictions in a forest fire scenario. Forest fires represent a great environmental risk. The main approaches that have been used to solve this problem begin with the detection of the fires [2]where different techniques have been applied. Once the fire is detected, it is important to generate predictions that should assist in making a decision in those contingency response situations [3]. Finally, there are complex models that tackle the forest fire problem by trying to forecast its evolution and to minimize its associated risks [4].

The data used to check the OBSFFF system were a subset of the available data that had not been previously used in the training phase. The predicted situation was contrasted with the actual future situation as it was known (historical data was used to train the system and also to test its correction). The proposed solution, in most of the variables, had a near 90\% accuracy rate.

Table 1 Variables that define a case, applying OBSFFF to the forest fires problem

Variable	Definition	Unit
Longitude	Geographical longitude	Degree
Latitude	Geographical latitude	Degree
Date	Day, month and year of the analysis	dd/mm/yyyy
Bottom pressure	Atmospheric pressure in the open sea	Newton/m2
Temperature	Celsius temperature in the area	ºC
Area of the fires	Surface covered by the fires present in the analyzed area	Km2
Meridional Wind	Meridional direction of the wind	m/s
Zonal Wind	Zonal direction of the wind	m/s
Wind Strenght	Wind strength	m/s

To create the cases, the geographical area being analyzed was divided into small squares, each of which was considered a case, with its associated parameters shown in *Table 1.* The squares determine the area to be considered in every case. The problem is represented by the current situation of the area (all its parameters and the presence, or lack thereof, of fire). The solution is represented by the situation in that area in a future moment (same location but parameters changed to those for the next day -or the next step, if less than a day is considered in every step-). The data used are part of the SPREAD project, in particular the Gestosa field experiments that took place in 2002 and 2004 [5]. The experiments of the Gestosa field began in 1998 and finished in December 2004. They were aimed at collecting experimental data to support the development of new concepts and models, and to validate existing methods or models in various fields of fire management.

3 Organizations of Agents

In the multiagent field, the term organization has been mainly used to describe a set of agents that, using some kind of roles, interact with each other coordinating themselves to achieve the global objectives of the system.

L. Gasser assumes that organizations are structured systems with activity, knowledge, culture, history, and ability pattern, different of any particular agent [6]. Organizations exist in a completely different level than individual agents that make up the organizations themselves. Individual agents are replaceable. Organizations are established in a space; it either be geographical, temporal, symbolic, etc. So, an organization of agents proportionates a kind of workspace for the activity and interaction of the agents by defining roles, behavioral expectatives and relations.

Ferber indicates that organizations proportionate a way to divide the system, crating groups or units that form the interaction context of the agents [7]. The organization is then based in two main aspects: structural and dynamic. The structure of the organization represents the remaining components when the individual elements enter or leave the organization. The organization is composed by the set of relationships that allow seeing a number of different elements as unique. The structure defines the way the agents are grouped in organizational units and how those units are related with each other. The roles needed to develop the activities of the organization are also defined in the structure, as long as the relationships and restrictions.

The organizational dynamics is centered in the interaction patterns defined for the roles, describing the way to get into or to leave the organization, the parameters of the roles and the way the roles are assigned to the agents.

Finally, V. Dignum, affirms that the organizations of agents assume that there are global objectives, different from the individual agents' objectives [8]. Roles represent organizational positions that help to achieve those global objectives. Agents may have their own objectives and decide if they take any specific system role or not, determining which among the available protocols are more suitable to achieve their chosen objectives.

4 System Description

In this paper, a new Organization Based System for Forest Fire Forecasting (OBSFFF) is presented. It is formed by an organization of agents that connects some different interface agents, dedicated to interact with the users in different platforms, to an inner CBR system, made by different services, implemented by a series of agents that answer to the different requests of the users.

In OBSFFF, the data collected from different satellites is processed and structured as cases. *Table 1* shows the main variables that defines a case. Cases are the key to obtain solutions to future problems through a CBR system. The functionalities of OBSFFF are accessed using different interfaces executed on PCs or PDAs (Personal Digital Assistant). Users interact with the system by introducing data, requesting a prediction or revising a solution generated (i.e. prediction). The interface agents communicate with the services through the agents' platform and vice versa.

The interface agents perform all the different functionalities which users make use for interacting with OBSFFF. The different phases of the CBR system have been modeled as services, so each phase can be independently requested. For example, one user may only introduce information in the system (e.g. a new case), while another user could request a new prediction.

All information is stored in the case base and OBSFFF is ready to predict future situations. A problem situation must be introduced in the system for generating a prediction. Then, the most similar cases to the current situation are retrieved from the case base. Once a collection of cases are chosen from the case base, they must be used for generating a new solution to the current problem. Growing Radial Basis Functions Networks [9] are used in OBSFFF for combining the chosen cases in order to obtain the new solution.

OBSFFF determines future probabilities in a certain area. OBSFFF divides the area to be analyzed in squares of approximately half a degree side for generating a new prediction. Then, the system calculates the demanded parameters in each square. The squares are colored with different gradation depending on the values of the requested parameters.

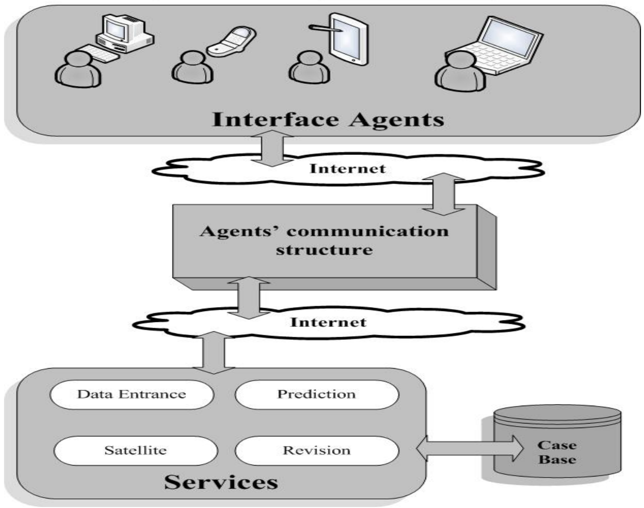

Fig. 1 OBSFFF structure

Figure 1 shows the structure of OBSFFF. There are three basic blocks in OBSFFF: Interface Agents, Services and Agents' Communication Structure. The system covers from the users interfaces, solved by the interface agents, to the data management, solved by the services that can access the case base. These blocks provide all the system functionalities and are described next:

Interfaces Organization represent all the programs that users can use to exploit the system functionalities. Applications are dynamic, reacting differently according to the particular situations and the services invoked. They can be executed locally or remotely, even on mobile devices with limited processing capabilities, because computing tasks are largely delegated to the agents and services.

The *CBR Services Organization* represent the activities that the architecture offers. They are the bulk of the functionalities of the system at the processing, delivery and information acquisition levels. Services are designed to be invoked locally or remotely. Services can be organized as local services, web services, GRID services, or even as individual stand alone services. OBSFFF has a flexible and scalable directory of services, so they can be invoked, modified, added, or eliminated dynamically and on demand. It is absolutely necessary that all services follow a communication protocol to interact with the rest of the components. CBR systems have proved to be quite efficient in prediction tasks in environmental situations[10].

The *Communication Organization* integrates a set of agents, each one with special characteristics and behavior. An important feature in this architecture is that the agents act as controllers and administrators for all applications and services, managing the adequate functioning of the system, from services, applications, communication and performance to reasoning and decision-making. In OBSFFF, services are managed and coordinated by deliberative BDI agents. The agents modify their behavior according to the users' preferences, the knowledge acquired from previous interactions, as well as the choices available to respond to a given situation. The communication protocol allows applications and services to communicate directly with the Agents Platform. This protocol is based on SOAP specification to capture all messages between the platform and the services and applications [11]. Services and applications communicate with the Agents Platform via SOAP messages. A response is sent back to the specific service or application that made the request. All external communications follow the same protocol, while the communication among agents in the platform follows the FIPA Agent Communication Language (ACL) specification.

Agents, applications and services in OBSFFF can communicate in a distributed way, even from mobile devices. This makes it possible to use resources no matter its location. It also allows the starting or stopping of agents, applications, services or devices separately, without affecting the rest of resources, so the system has an elevated adaptability and capacity for error recovery. Users can access to OBSFFF functionalities through distributed applications which run on different types of devices and interfaces (e.g. computers, PDA). Next, the disaggregation of the CBR methodology into services is explained. The four main phases of the CBR cycle are divided into different services covering the entrance of data, the recovery of information from the case base and the solution generation and validation.

The data used to check the OBSFFF system were a subset of the available data that had not been previously used in the training phase. The predicted situation was contrasted with the actual future situation as it was known (historical data was used to train the system and also to test its correction). The proposed solution, in most of the variables, had a near 90% accuracy rate.

4.1 Data Introduction and Case Base Creation

When data about a forest fire is introduced, OBSFFF must complete the information about the area including atmospheric and weather information. OBSFFF uses Fast Iterative Kernel PCA (FIKPCA) which is an evolution of PCA [12]. This technique reduces the number of variables in a set by eliminating those that are linearly dependent, and it is quite faster than the traditional PCA. To improve the convergence of the Kernel Hebbian Algorithm used by Kernel PCA, FIK-PCA set ηt proportional to the reciprocal of the estimated values. Let $\lambda t \in \Re r+$ denote the vector of values associated with the current estimate of the first r eigenvectors. The new KHA algorithm sets de i^{th} component of η_t to the files.

$$[\eta_t]_i = \frac{1}{[\lambda_t]_i} \frac{\tau}{t+\tau} \eta_0 \ , \quad (1)$$

When introducing the data into the case base, Growing Cell Structures (GCS) [13] are used. GCS can create a model from a situation organizing the different cases by their similarity. If a 2D representation is chosen to explain this technique, the most similar cells (i.e. cases) are near one of the other. If there is a relationship between the cells, they are grouped together, and this grouping characteristic helps the CBR system to recover the similar cases in the next phase. When a new cell is introduced in the structure, the closest cells move towards the new one, changing the overall structure of the system. The weights of the winning cell ω_c, and its neighbours ω_n, are changed. The terms ε_c and ε_n represent the learning rates for the winner and its neighbors, respectively. x represents the value of the input vector.

$$\omega_c(t+1) = \omega_c(t) + \varepsilon_c(x - \omega_c) \tag{2}$$

$$\omega_n(t+1) = \omega_n(t) + \varepsilon_n(x - \omega_n) \tag{3}$$

Once the case base has stored the historical data, and the GCS has learned from the original distribution of the variables, the system is ready to receive a new problem. When a new problem comes to the system, GCS are used once again. The stored GCS behaves as if the new problem would be stored in the structure and finds the most similar cells (cases in the CBR system) to the problem introduced in the system. In this case, the GCS does not change its structure because it has being used to obtain the most similar cases to the introduced problem. Only in the retain phase the GCS changes again, introducing the proposed solution if it is correct.

4.2 Prediction Generation after a Request

When a prediction is requested by a user, the system starts recovering from the case base the most similar cases to the problem proposed. Then, it creates a prediction using artificial neural networks. Once the most similar cases are recovered from the case base, they are used to generate the solution. Growing RBF networks [14] are used to obtain the predicted future values corresponding to the proposed problem. This adaptation of the RBF networks allows the system to grow during training gradually increasing the number of elements (prototypes) which play the role of the centers of the radial basis functions. The creation of the Growing RBF must be made automatically which implies an adaptation of the original GRBF system. The error for every pattern is defined by (4).

$$e_i = {}^{1}/_{p^*} \sum_{k=1}^{p} ||t_{ik} - y_{ik}|| \,, \tag{4}$$

Where t_{ik} is the desired value of the k^{th} output unit of the i^{th} training pattern, y_{ik} the actual values of the k^{th} output unit of the i^{th} training pattern.

Once the GRBF network is created, it is used to generate the solution to the proposed problem. The solution proposed is the output of the GRBF network created with the retrieved cases. The input to the GRBF network, in order to generate the solution, is the data related with the problem to be solved, the values of the variables stored in the case base.

5 Evaluation of the Results

OBSFFF uses different artificial intelligence techniques to cover and solve all the phases of the CBR cycle. Fast Iterative Kernel Principal Component Analysis is used to reduce the number of variables stored in the system, getting about a 60% of reduction in the size of the case base. This adaptation of the PCA also implies a faster recovery of cases from the case base (more than 7% faster than storing the original variables).

Table 2 Percentage of good predictions obtained with different techniques

Number of cases	RBF	CBR	RBF + CBR	OBSFFF
100	43 %	38 %	43 %	45 %
500	48 %	43 %	46 %	54 %
1000	50 %	48 %	58 %	68 %
2000	55 %	53 %	63 %	77 %
3000	59 %	56 %	68 %	84 %
4000	60 %	63 %	73 %	88 %
5000	62 %	68 %	79 %	93 %

The predicted situation was contrasted with the actual future situation. The future situation was known, as long as historical data was used to develop the system and also to test the correction of it. The proposed solution was, in most of the variables, more than a 90% accurate. For every problem defined by an area and its variables, the system offers 9 solutions (i.e. the same area with its proposed variables and the eight closest neighbors). This way of prediction is used in order to clearly observe the direction of the fires which is useful in order to determine the areas that will be affected by the fires.

Table 2 shows a summary of the results obtained after comparing different techniques with the results obtained using OBSFFF. The table shows the evolution of the results along with the increase of the number of cases stored in the case base. All the techniques analyzed improve its results while increasing the number of cases stored. Having more cases in the case base, makes easier to find similar cases to the proposed problem and then, the solution is more accurate. The "RBF" column represents a simple Radial Basis Function Network that is trained with all the data available. The network gives an output that is considered a solution to the problem. The "CBR" column represents a pure CBR system, with no other techniques included; the cases are stored in the case base and recovered considering the Euclidean distance. The most similar cases are selected and after applying a weighted mean depending on the similarity of the selected cases with the inserted problem, a solution s proposed. The "RBF + CBR" column corresponds to the possibility of using a RBF system combined with CBR. The recovery from the CBR is done by the Manhattan distance and the RBF network works in the reuse phase, adapting the selected cases to obtain the new solution. The results of the "RBF+CBR" column are, normally, better than those of the "CBR", mainly because of the elimination of useless data to generate the solution.

Finally, the “OBSFFF” column shows the results obtained by OBSFFF, obtaining better results that the three previous analyzed solutions.

Several tests have been done to compare the overall performance of OBSFFF. The tests consisted of a set of requests delivered to the Prediction Generation Service (PGS) which in turn had to generate solutions for each problem. There were 50 different data sets, each one with 10 different parameters. The data sets were introduced into the PGS through a remote PC running multiple instances of the Prediction Agent. The data sets were divided in five test groups with 1, 5, 10, 20 and 50 data sets respectively. There was one Prediction Agent for each test group. 30 runs for each test group were performed. First, all tests were performed with only one Prediction Service running in the same workstation on which the system was running. Then, five Prediction Services were replicated also in the same workstation. For every new test, the case base of the PGS was deleted in order to avoid a learning capability, thus requiring the service to accomplish the entire prediction process.

6 Conclusions and Future Work

OBSFFF is a new solution for predicting the future situation of the forest fires, analyzing different parameters.. This system presents a distributed multi-agent architecture which allows the interaction of multiple users at the same time. Distributing resources also allows users to interact with the system in different ways depending on their specific needs for each situation (e.g. introducing data or requesting a prediction). This architecture becomes an improvement with previous tools where the information must be centralized and where local interfaces where used. With the vision introduced by OBSFFF, all the different people that may interact with a contingency response system collaborate in a distributed way, being physically located in different places but interchanging information in a collaborative mode.

OBSFFF makes use of the CBR methodology to create new solutions and predictions using past solutions given to past problems. The CBT structure been divided into services in order to optimize the overall performance of OBSFFF.

Generalization must be done in order to improve the system. Applying the methodology explained before to diverse geographical areas will make the results even better, being able to generate good solutions in more different situations. The current system has been mainly developed using data from the Gestosa experiments in central Portugal. With that information, OBSFFF has been able to generate solutions to new situations, based on the available cases. If the amount and variety of cases stored in the case base is increased, the quality of the results will also be boosted.

Although the performed tests have provided us very useful data, it is necessary to continue developing and enhancing OBSFFF. The number of possible interfaces can be augmented, including independent sensors that may send information to the system in real-time. The data received by the system must be analyzed in order to detect new useful information and to generate fast and accurate solutions to existing problems without the direct intervention of the users.

Then, the system will not only be a contingency response but also a kind of supervising system especially in dangerous geographical areas.

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