A cooperative problem solving approach dedicated to spatial decision support in forest fire prevention

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INTRODUCTION

Each year, forest fires destroy several thousands of hectares of forest, being sources of multiple detriments (ecological, economical, moral...). Prediction methods are progressively introduced and several computer tools, sometimes unjustly qualify of Decision Support Systems, are proposed to managers. Our work is directed by two complementary goals. First, reduce a gap between the points of view of researchers, developers and users of Decision Support Systems. This is especially true in domains gathering very different aspects, as forest fire prevention and fighting. Second, there are technical issues, of which the foremost is to build a generic architecture focussed on knowledge representation (data, models and tools).

Thus, we propose a cooperative problem solving approach, based on an Artificial Intelligence paradigm (knowledge-based system concept), in order to allow the user to intervene and steer the solution process. Control over the level of intervention should also be permitted. For instance, it should be possible for the user to fully steer the solution, or for the system to proceed with minimal or no user intervention. In order so enable such flexible system-user cooperation the reasonning process must be exploitable by the system and must be easily understadable by the user. This has carried us to the design and the development of MERIS, a cooperative problem solving environment prototype. Its aim is to provide information, knowledge, models and software tools which can be used by those engaged in the management of forest fires.

keywords: cooperative problem solving, knowledge-based system, forest fire prevention.

1. RESEARCH BACKGROUND: THE BALANCE BETWEEN DECISION, SUPPORT AND SYSTEM

A Decision Support System dedicated to forest fire prevention and fighting is concerned with intellectual as well as computer-related technologies. It is the combination of computer technologies and knowledge about decision which makes decision support effective. We need to have a more ambitious view of decision making dedicated to forest fire prevention and fighting if we pay the same attention to support and to technology. Nowadays, there is not any decision support system dedicated to forest fire prevention and fighting which is equally focused on *Decision*, *Support*, and *System*. If we analyse the existing systems, we note that they are only focussed on technical aspects.

In the forest fire field several Decision Support Systems that integrate several types of software try to adress many aspects of fire management. Most of them are available as prototypes or near-operational tools. These systems generally combine commercial products with dedicated modules specially designed to make up for the insufficiencies of the main tool used : i.e. the Geographical Information System (GIS).

A review of the current developments and functions is given by Vasconcelos (1995):

- monitoring and forecasting of weather data (Carrega, 1990),
- risk assessment by danger indices (Chuvieco, 1989),
- early detection of fire (De Vries, 1993),
- simulation of fire propagation (Chou, 1992),
- advising for pre-suppression planning (Eftichidis, 1994),
- fire suppression decision support (Cohen, 1989),
- training (Lovborg, 1992).

The cooperative problem solving approach, based on the Artificial Intelligence paradigm, is focussed on knowledge acquisition and representation and problem solving methods. This approach tries to consider at the same time the three aspects of DSS, i.e. Decision, Support and System (Keen, 1987):

- "Decision" relates to non-technical, functional and analytical aspects and to criteria for actions.
- "Support" focuses on understanding how operational people work and what kind of help they need.

- "System" emphasizes on technology design and development and on integration of tools.

MERIS, a knowledge-based system, tries to consider the concepts "interactive" and "problem solving" in a single paradigm as proposed by Kant (1988). Focussing on problem solving that occurs in data interpretation, simulation or scenario design as identified tasks which will organized in order to become more complex and thus to solve a problem.

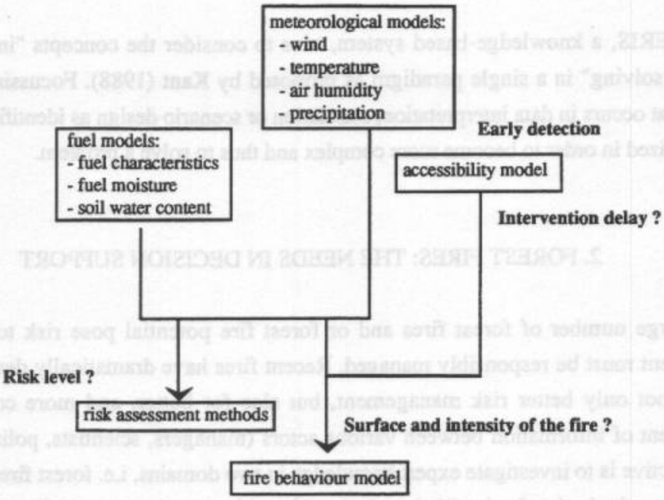
2. FOREST FIRES: THE NEEDS IN DECISION SUPPORT

Large number of forest fires and or forest fire potential pose risk to man and the environment must be responsibly managed. Recent fires have dramatically demonstrated the need for not only better risk management, but also for better, and more comprehensive, management of information between various actors (managers, scientists, politicians...). Our main objective is to investigate expert knowledge in two domains, i.e. forest fire managers and scientists, on the basis of a detailled analysis of interviews and protocols. The main questions that are adressed in our approach are what and how information, knowledge, models and tools can assist the managers. We should point out that our understanding of the nature of the decision making process in forest fire management and its interpretation is slowly emerging and much more research should be done in this area. So the current work has a tentative status, and the ideas developed here should be thoroughly tested in practice.

In the domain of forest fire management we have point out four main indissociable needs:

- early detection of fires,
- risk assessment (in relation with meteorological conditions in order to enable hourly monitoring),
- accessibility of an aera govern the control of the phenomenon (knowing, on the basis of european empirical rules, that there is no danger when the burnt area at the moment of intervention is less than 1 ha.),
- simulation of fire propagation (closely related with the accessibility concept).

In the scientific domain, we have identified and designed a set of models (a system of models) which consists of a set of related models which describe individual processes (weather conditions, risk assessment, fire spread...). This first model (see figure 1) is essentially conceptual. Our major interest is to organize the knowledge in a global forest fire context (Guarnieri, 1995a). Henceforth, it must be formalized according to our cooperative problem solving approach.



(figure 1: A system of models for forest fires)

3. A COOPERATIVE PROBLEM SOLVING APPROACH

A task is defined as the problem solving description according to a recursive decomposition in sub-problems more and more basics which can be directly solved by the execution of elementary actions (Uvietta, 1993). A set of organized sub-tasks composes a complex task. Thus, the execution of the task is executed through the execution of any of the sub-tasks.

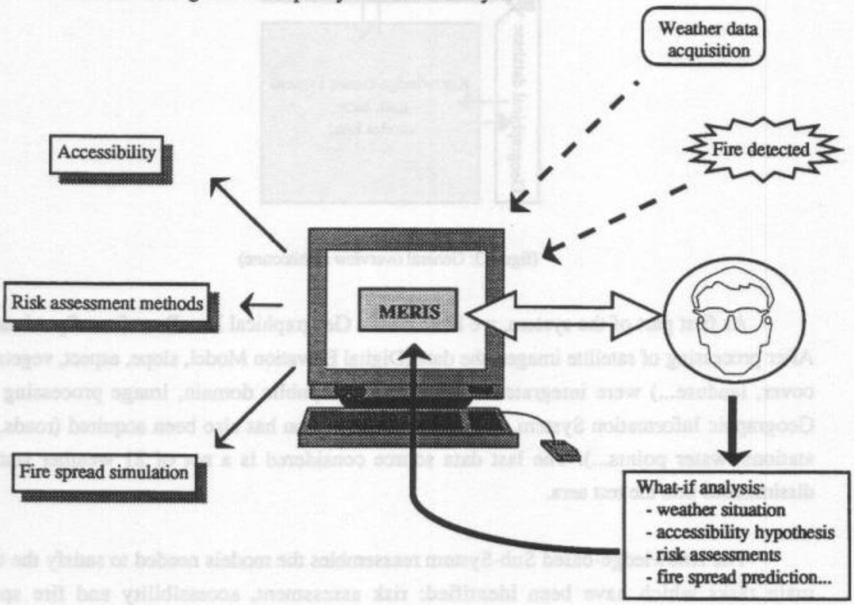
Example of complex task: compute the danger index "I'85" (Carrega, 1990), consists of:

- first, execute sub-task 1 (weather data acquisition),
- then, execute sub-task 2 (fuel moisture estimation),
- and finally execute sub-task 3 (risk assessment computation).

MERIS is partly written in IlogRules (1994), a knowledge-based system generator which inference engine operates in a forward-chaining mode. This software implements an algorithm called RETE (Forgy, 1982). This algorithm operates in the domain of pattern matching and in a totally object-oriented environment. Thus, this software provides two ways for representing the knowledge: an object-oriented language in order to describe information, knowledge, models and tasks and a rule production language in order to formalize specific knowledge or in order to manage the process execution (models and tasks).

MERIS supports an interactive problem solving methodology with a task representation and a control system. This knowledge-based system provides (see figure 2):

- a structure integrating code modules (i.e. the models used for the simulations) written in various computational languages,
- a single mechanism that can manage and control the configuration and execution of tasks proposed by users or by an other task dedicated to a particular problem,
- a knowledge based approach allowing the interaction with users in order to have real time monitoring and the capacity of what-if analysis.



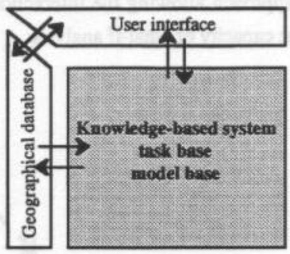
(figure 2: MERIS overview)

Two major components contribute to the task module and the configuration reusability:

- the definition component describes, according to a declarative mode, a task herself (name, function, associated models...),
- the execution component connects a task to other tasks by describing physically the different methods (models). This mechanism is supported by a rule base which links tasks and models using an event oriented mechanism.

4. ARCHITECTURE OVERVIEW

The MERIS knowledge-based system integrates three specialized sub-systems: the Geographical DataBase, the Knowledge-base and the User Interface (see figure 3).

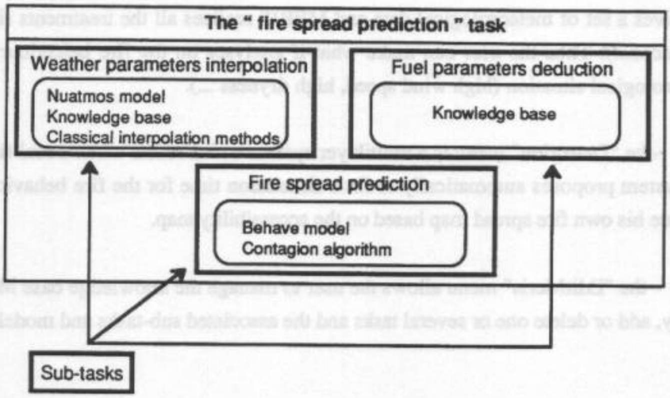


(figure 3: General overview architecture)

As first part of the system, we have built a Geographical DataBase from Spot images. After processing of satellite images, the data (Digital Elevation Model, slope, aspect, vegetation cover, landuse...) were integrated in GRASS4.1, a public domain, image processing and Geographic Information System. Digitalizing information has also been acquired (roads, fire stations, water points...). The last data source considered is a net of 21 weather stations disseminated into the test aera.

The Knowledge-based Sub-System reassembles the models needed to satisfy the three main tasks which have been identified: risk assessment, accessibility and fire spread computation. For each task we have identified organized sub tasks characterized by a model. As example, we only consider the complex task "compute the fire spread". This task is divided in three main sub-tasks (see figure 4):

- the first sub-task consists of the weather parameters interpolation. Concerning the wind behaviour, we use the Nuatmos model (Ross, 1988). This numerical model (finite elements) produces a three dimensional mass-consistent wind field over complex terrain based on observations from weather stations. In order to improve the results obtained by this model we decided to link it with an expert system (Guarnieri, 1995b). A model based on the knowledge of an expert determines a "wind type". A set of virtual sensors is associated for each "wind type" and the model gives a value for each of these virtual weather stations (wind direction and speed). These virtual sensors are used in addition to the real set of sensors as input data of the Nuatmos model. In the same time the other meteorological parameters (temperature, humidity and precipitation) are computed using a two-dimensional interpolation technique which uses inverses distance squared weighting.



(figure 4: A Complex task)

- the second sub-task consists of the fuel parameters deduction. Several parameters, also inputs needed for the fire behaviour model and the risk assessment methods, are estimated on the basis of an empirical set of rules (Botehlo, 1993).

- the last sub-task is the fire behaviour prediction. We use the Behave system (Rothermel, 1972). This model consists in several modules concerning fuel description and fire behaviour. It uses physical parameters (moisture, fuel particule size ...) which are combined using physical arguments in order to give the components of a formula for the rate of spread.

In order to help the user in his decision-making job, the User Interface Sub-System gathers the actions initiated by the user with the goal to act on the data (visualize a map, consult the weather data...) and on the models (ask for a fire behaviour simulation, weather data interpolation, accessibility computation...). The MERIS user interface provides several functions:

-the "Geographical Information" menu allows the user to visualize maps managed by the Geographic Information System.

-the "DataBase" menu allows the user to manage the descriptive database of the system. The user is able to update and to visualize all the data (weather data, fire location...) by the use of simple menus and buttons.

-the "Simulation" menu lets the user select models in order to make a simulation. The user gives a set of meteorological data and MERIS realizes all the treatments (interpolations, inferences...). Thus the user can make what-if analyses on the fire behaviour for a critical meteorological situation (high wind speed, high dryness ...).

-the "Detection" menu is a multilayer system which reacts when a real fire is detected. The system proposes automatically to fix a simulation time for the fire behaviour model and compute his own fire spread map based on the accessibility map.

- the "EditMeris" menu allows the user to manage the knowledge base MERIS. He can modify, add or delete one or several tasks and the associated sub-tasks and models.

5. MERIS AND LEVEL OF SUPPORT

It seems easy to provide "support" to forest fire managers. Nevertheless, the fundamental question is "what level of support". This is a main issue for definition for action, both in research and practice. In order to have a look at the possibilities of MERIS in terms of decision support, we consider a potential real world situation:

09h00 (AM):
MERIS interrogates the weather sensor net. All the parameters (wind speed, wind direction, air humidity, air temperature, rain) are collected and stored in the

Geographical Database. Then, it executes the sub-task (see §4) related to the weather parameters deduction. Several map are thus computed.

09h05 (AM):

At the end of this sub-task, the sub-task "fuel parameters deduction" is triggered. At each step, the forest fire manager is informed by messages describing the state of the system.

09h07 (AM):

The sub-tasks "risk assessment" and "fire spread" are triggered.

The forest fire manager visualizes all the maps computed and with the risk assessment map is enable to organize the intervention means on the field. Nevertheless, analysing the real world situation, he makes the hypothesis that the weather conditions may change. So, he declares his own weather situation scenario. MERIS computes the hypothetical world situation.

10h15 (AM):

A fire is detected and located on a map, immediately the forest fire manager interrogates the Geographical Database:

- fuel maps:

fuel characteristics: small scrub.

dryness: very high.

- meteorology: strong west wind (between 50-70 km/h).

- topography:

complex terrain, slope between 10 and 15%.

- initial intervention evaluation:

dense road network,

semi-urban area,

2 water points,

firefighter intervention is estimated at 15 minutes (deducted with the accessibility model).

The forest fire manager asks for a fire spread simulation. MERIS computes the spread map, considering the deducted accessibility time, and displays the potential threatened zone. The forest fire manager informed of a delay appoints his own simulation time, 40 minutes. MERIS computes another fire spread map.

On the basis of this short example, we can consider that MERIS provides a "traditional support". It is in a way a "computerized staff assistant". The forest fire manager's judment selects alternative (i.e. meteorological scenario, fire spread time...) and assesses results. This is characterized on "what if" analysis which is based on the assumption the the ability (given by the DSS) to generate and analyse more alternatives improves the effectiveness of the decision making process.

Although there is some conceptual and commonsense evidence to consider that this level of support contributes to the decision making job, this approach downplays the problem of quality of judgment. Looking at more allternatives is not a causal force for improving decision making. This highlights the fact that such level of support has a weak and informal concept of how to improve the decision process. So, we need to turn toward an "extended" support, which involves an explicit effort to influence and guide decision making, while respecting the primacy of judgement and focussing very carefully indeed on how forest fire managers think, what aspects of their decision process they are likely to be willing to delegate, their expectation and attitudes about the user of decision models and tools.

6. CONCLUSION

The design of the MERIS system was done in order to propose an efficient spatial decision support tool but also to enable future improvements. The system backbone, built around the cooperative problem solving approach, is enable to extend easily the task concept. Thus, the general use of declarativity allows the user to maintain the reliability, as the complexity of the system, in terms of tasks and models management. The MERIS system is in the validation phase for a test region in the French Riviera. From the results of this stage, we will define the next development stages. One of them, and the most important one at this time, will be to perform our perception of the decision making job in forest fire prevention and fighting extending the acquisition and the formalisation of the user needs.

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