Proceedings of the 6th AGILE
April 24th-26th, 2003 – Lyon, France

A DECISION SUPPORT SYSTEM FOR FLASH FLOOD EARLY WARNING FOR THE ARNO RIVER BASIN

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1. INTRODUCTION

An effective flash flood warning service requires a set of geospatial data providing information about the values of relevant hydrological parameter from the past to the near future. In particular local and remote sensing measurements series (from raingauges, hydrometers, weather radar, etc.) and quantitative local area meteorological forecasts within 24-48 hours can provide useful data for hydrological scenarios modeling. Anyway the availability and reliability of the information sources and the effectiveness of the adopted hydrological model is not sufficient for implementing an useful warning tool. Indeed decision-makers are often not technical persons and although they can be supported by technical personnel they are not scientists, or computer engineers, but they are instead mainly politicians. This is the reason because they could not correctly utilize the heterogeneous information sources if they are not processed to provide an high-level view that is far from the raw technical information.

The present paper describes the MIMI system developed as part of a project funded by the Italian National Authorithy for the Arno river basin. This solution has been developed to implement a system for flash flood early warning for the Arno river basin (the third biggest river basin in Italy). It utilizes several available geospatial data to feed an hydrological model developed by the Polytechnic of Milan. Such work introduces a new domain ontology, as far as Decision Support Systems for Flash Flood Early Warning are concerned. The Human-System interaction model responses are expressed according to such ontology, and presented using a tool that provides a user-interface designed according to the decision-makers requirements.

2. SCENARIOS FOR DECISION SUPPORT SYSTEM FOR THE ARNO RIVER BASIN

In the current scenario many data and information sources are available for the monitoring of meteorological and hydrological situation of the Arno River Basin. In particular satellites, weather radars, and ground-based sensor networks provide a great amount of valuable data for Flash Flood Early Warning. These data sources are managed by several different public bodies, universities and research centers that typically provide them without any high-level processing or integration, through different communication systems and in heterogeneous formats. Due to these characteristics many data sources are hardly usable by decision-makers who are generally not technicians. Data could be difficult to access or their content could be obscure for the final users. Indeed, in the current scenario, only two information sources are mainly used, since they are rather clear and easily related to possible warnings:

- Tuscany region ground-based sensor network (named MARTE) managed by National Hydrographic Service. MARTE is able to provide data readings of all network sensors (raingauges, hydrometers, etc.) and to collect them in a legacy format file. Update time is 30 minutes, but it can decrease to 15 minutes if a critical event is in progress. In particular measured precipitation data derived by raingauges cumulated rainfall value are mostly used.

- RAMS Local Area Model managed by LAMMA (Regional Laboratory for Applied Meteorology). In particular RAMS provides forecasted precipitation data for the Tuscany Region with a spatial resolution of 4x4 km and working out one map per hour within 48 hours starting from the current time. Maps are encoded in a proprietary binary format file provided along with a text file containing metadata.

Decision-makers access them connecting to the proper data servers and legacy presentation tools. Anyway the information are not integrated or otherwise processed to make them more suitable by the decision-makers, so the knowledge extraction is almost entirely left to them. Moreover the requirement of near real-time operation makes the use of data even more difficult. Thus it is often difficult to extract useful information about possible hazards from that amount of data, and their usefulness is questionable. In synthesis, we can define the current approach as a data-oriented approach.

To improve the described situation drawbacks, the MIMI' project proposed a user-oriented approach. Since decision-makers are not technical persons, no strictly technical information should be presented to them. On the contrary only high-level concepts like (Rainfall) Event, Alarm Threshold, Alarm Status and so on should be handled and visualized by a provided tool that supports decision-makers. To allow that high-level description of the situation, a "smart" integration and processing of several data is required. Thus the MIMI system core is a Hydrological Model developed by the Polytechnic of Milan, that processes input data to extract hydrological parameters that allow to infer other parameters to describe the situation according to the decision-makers point of view.

As shown in (fig. 1), MIMI' carries out two different tasks. First of all, resorting to the Hydrological Model, input data are processed to evaluate some hydrological parameters that have a meaning according to a hydrology ontology. Then a further processing (i.e. an inferring process) extracts the information expressed according to the decision-makers ontology that will be presented to the final users through a Graphic User Interface.

The system is designed to be easily scalable, so while in the present scenario only measured and forecasted rainfall data are used, in a near future the model will be improved to handle other information sources like hydrometers, soil humidity data and radar observations. This will make the result much more rich and reliable for decision-making process.

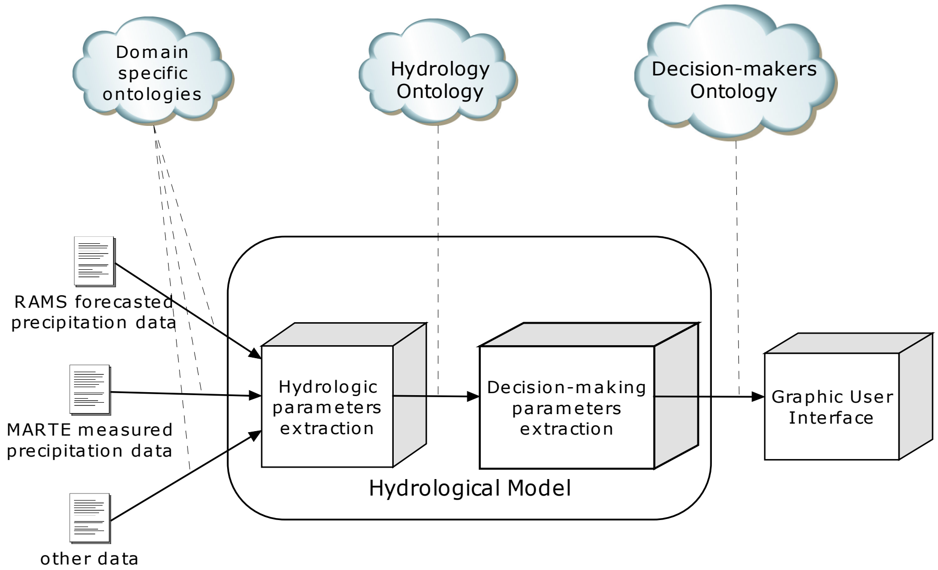

Fig. 1 MIMI' System approach

3. DOMAIN ONTOLOGY

The first step to provide users with a suitable and useful tool, is the definition of a domain ontology. This consists of a listing of concepts and relationships among them [2]. In short we needed to use the users' vocabulary to make them easier to understand the provided information. For example, in our case, decision-makers generally cannot understand technical terms like "Antecedent Moisture Content" (AMC) for soil humidity estimate. Even if it is a very important hydrological parameter it is generally obscure for a non-technical person. Instead decision-makers could easily handle concepts like "Alarm Thresholds" and similar.

Thus a preliminary activity was aimed to introduce a decision-makers ontology. This required:

- the definition of a taxonomy that is the vocabulary of basic terms defining the decision-makers view about the flash flood early warning problem;
- the collection of the information about the relationships between these basic terms in the specific domain;

This activity was performed resorting to hydrologist expertise and through the interaction with the National Basin Authority of the Arno River personnel. As such ontology is concerned, it is possible to distinguish the following main realms:

- the Basin realm;
- the Rainfall Event realm;
- the Rainfall Map event;
- the Raingauge Network realm.

The following figures depict a diagram –according to the RDF graphical notation- for each realm.

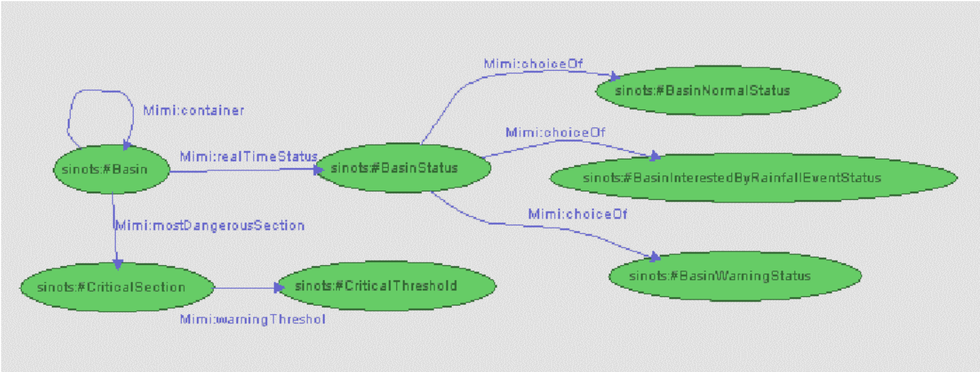

Fig. 2 Ontology diagram – Basin realm

Fig. 3 Ontology diagram – RainfallEvent realm

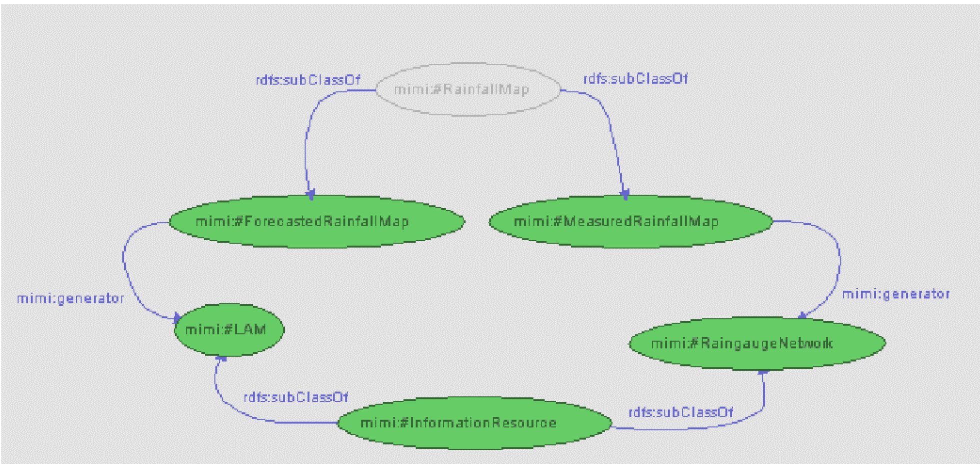

Fig. 4 Ontology diagram – RainfallMap realm

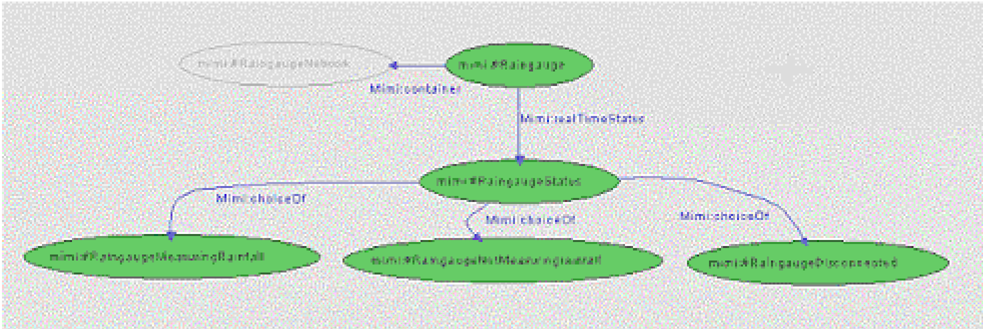

Fig. 5 Ontology diagram – RaingaugeNetwork realm

According to such diagrams, the concept basin (mimi#Basin) is the area interested (mimi#interstedArea) by a rainfall event concept (mimi#RainfallEvent). In the same way a rainfall map concept (mimi#RainfallMap) is the data format (mimi#data) of rainfall concept (mimi#rainfall), and a raingauge network (mimi#RaingaugeNetwork) is the container (mimi#container) of raingauge concepts (mimi#Raingauge). From the diagrams it is possible to work out all the other axioms that constitute the knowledge model of the described solution.

Therefore, a basin is made up of other basin (i.e. sub-basin) and is characterised by a real time status property which is a choice of the following values:

- Normal status;
- Interested by a rainfall event status;
- Warning status.

A raingauge is characterized by a real time status property which is a choice of the following values:

- Measuring rainfall;
- Not measuring rainfall;
- Disconnected.

4. HYDROLOGICAL MODEL

The hydrological model defines the procedure to extract the information contained in the input data and to present it according to decision makers point of view. This is made computing some hydrological parameters that are useful for that high-level description. In the current implementation the system updates the situation (i.e. the statuses of critical sections in the basin) each time a measured (from MARTE) or forecasted (from RAMS LAM model) map is available. According to a model of the area the rainfall is aggregated on each sub-basin. If it is greater than a given value – and the event is not already active – then the event starts; on the contrary, if the event is active and the aggregated rainfall is lower than the threshold for a certain time interval, then the active event is considered finished. For sections with active events the cumulated rainfall is calculated starting from the event begin time. If the cumulated rainfall is greater than a warning threshold a warning status is set. The correct threshold is chosen basing on the Antecedent Moisture Content (AMC) at the event begin time and the event shape obtained from the aggregated rainfall series. So a section in every moment could be in one of three possible statuses (event not started, event started without warning, event started with warning) that corresponds to the decision-makers ontology concepts. The model output is a summary of the situation (sections status, rainfall series, etc.) expressed according to the domain ontology.

Referring to (fig. 1), the Hydrological Model processing can be logically split into two steps. The former is the computation of hydrological parameters such as AMC, aggregated rainfall, and thresholds, while the latter is the evaluation of decision-making parameters, such as the warning status or the event occurrence.

5. SYSTEM ARCHITECTURE

The MIMI system architecture is based on the mediator/facilitator approach [2, 3]. The mediators have the task of integrating applications and heterogeneous information sources and the facilitators give access to the information providers.

The actual implementation of the system is based on a four-tier architecture as shown in (fig. 6). The choice of this four-tier architecture is based on the logical existence of well-defined tiers separated by administrative, technological or logical boundaries. This means that there are four distinguished sections hosting computational entities with different objectives. In particular it is possible to separate the following tiers:

- a data-tier that hosts the systems providing input data and information; it currently hosts the MARTE and LAM forecasts data servers;
- a mediator tier that uniforms data views making them accessible to the hydrological model implementation; it currently hosts a Rainfall Mediator that collects forecast precipitation maps and raingauge readings that are processed to obtain measured precipitation map resorting to the Thiessen algorithm;
- a business logic tier where the data processing to generate results is performed; it currently hosts the Hydro Server where the Hydro Model application runs on;
- a client-tier where results are presented; it hosts the devices where the applications devoted to the visualization and presentation of the results run.

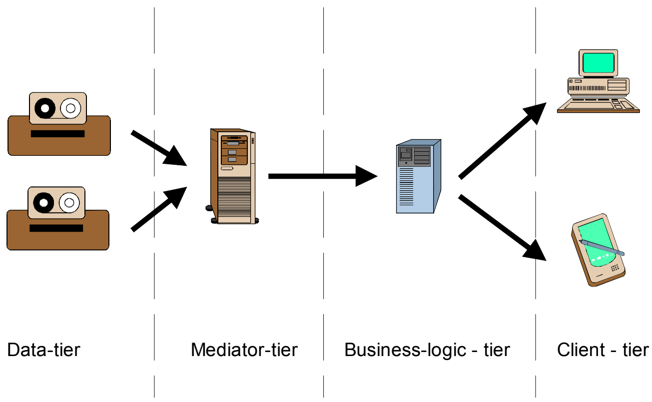

Fig. 6 MIMI' four-tier architecture

6. IMPLEMENTATION

The MIMI system has been implemented resorting to typical e-business solutions where Java, XML and SOAP over HTTP/HTTPS are the core technologies. Indeed they allow to build loosely coupled interacting modules characterized by interoperability, scalability and easy integration with the existing network infrastracture of the National Basin Authority for the Arno River. All computational modules are implemented in JAVA to allow for multi-platform solutions both on server and client sides. In particular the implementation required to develop the Rainfall Mediator module, the Hydro Model module, and a thick and a thin client modules. They communicate using HTTP or SOAP wire protocol over HTTP/HTTPS.

The information exchanged between clients and server is encoded in XML. The existing Data Servers use legacy formats, but the Hydro Model Server encodes its results in XML format according to schemas based on the defined users' ontology. In particular a XML Schema was designed to represent the previously described domain ontology. The use of XML also allows to separate the content structure from the presentation. Clients can access the XML-encoded information after a translation in a proper presentation language. The translation can be performed by the client or by the server. Anyway a wide range of devices and client applications can be supported simply providing a proper translation module.

XML is also used to transfer other structured information like city locations to help clients to dynamically build some layers for its GIS-like interface.

7. HUMAN-SYSTEM INTERACTION MODEL

The Java-based thick client is specifically designed for the decision-makers representing the domain ontology information in a user friendly manner. It offers a Graphic User Interface (GUI) based on the typical use-cases defined in collaboration with the final users. In particular the GUI is designed to allow the users to visualize the time variations of spatial warning situation, and also the information about the features in the observed area. The great amount of available data could easily confuse the user so a careful selection of the information that really need to be showed is performed. In fact only the sections statuses at a given time are visualized, since it is the most important information. In the main window different icons representing the status are located over a digital elevation map in the respective section location. The user can choose the reference time by choosing the measured rainfall map or one of the available forecasted maps. Moreover he can navigate the map, panning and zooming, to show in more details a particular area.

The other information are shown on specific request. Once the global situation is shown, the user can inspect a specific section by double-clicking its icon to obtain charts of aggregated and cumulated rainfall on it. Measured and forecasted data are shown in different colors.

Labels of all the other features shown on the map are visualized in a specific area of the GUI.

In particular it shows the following main characteristics:

- main thematic layers included (e.g. DEM, rivers, main locations, raingauge locations, critical sections);
- basic map navigation functions (four directions pan, zoom in and zoom out);
- basic thematic layers management functions (show/hide, order change, add/delete);
- situation layer selection;
- section boundaries visualization and locking;
- features labeling (i.e. tips over maps);
- visual and sound alert for early warning situations;
- rainfall chart visualization;

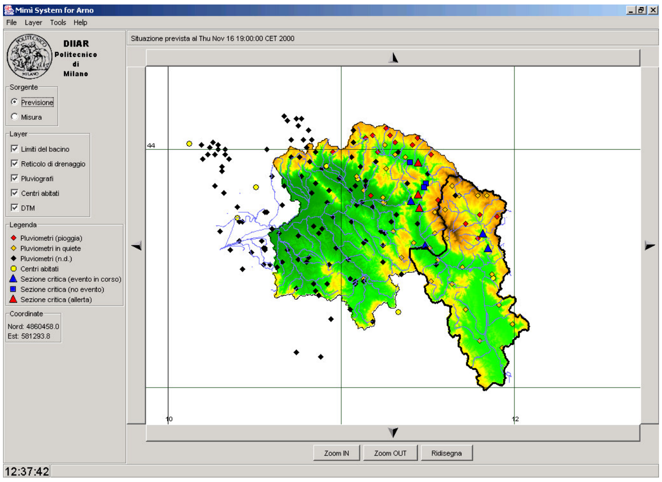

Fig. 7 MIMI' Thick client GUI

8. APPLICATION USER SCENARIO

In the typical user scenario an user equipped with the thick client connects to the web portal and asks to launch the MIMI application. Authorized users that are not equipped with the client can utilize a common web browser to download it from the main system web site along with WebStart standard plug-in. Once the client has started, the system requires an authentication step to verify user identity, then it automatically connects to the web server to collect all needed data and then starts the polling procedure to retrieve the updated situation. No other operation is needed, allowing the user to pay attention to the observation of the warning situation. During the observation the user can visualize the current evaluated warning situation and the forecasted ones. She/he can also analyze single section situation in much detail. Resorting to this information and integrating it with other sources, decision-makers can decide to start alerts and activate emergency procedures. Basic warning functions can be easily implemented to automatically signal possible hazardous situation to users.

9. RESULTS

The system described above has been deployed in the operational setting. An initial test phase, comprising the observation of some critical rainfall event, is under development to help the tuning of the several parameters the hydrological model depends on. As far as the technological aspects are concerned the system has proven to be reliable and scalable. The user-oriented approach allowed to deploy a visual tool, the thick client, that is friendly and highly usable for the final users (decision-makers). In particular since only high-level information are provided to them and according to their ontology, decision-makers can focus on warning management instead on the interpretation of the provided information.

The system improvement to support the integration of additional available data such as soil humidity estimates is expected in the near future. Moreover the choice about the adoption of a particular emergency management policy, could require the extension of the system to support basic warning management functionalities such as messaging and signalling according to standard procedures.

10. REFERENCES

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