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A REGIONAL FORECASTING MODEL

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The objective of this three year project is to develop an expert system which can be used to make a short-range weather forecast from limited data. The expert system will not be tied to any particular station. This will be done by determining and utilizing the physical relationships between the synoptic weather and variables that affect the local weather such as terrain, geography and surface type.

This report describes the system architecture which structures the knowledge bases within a larger framework of C-Code that supports the user interface and other computationally intensive requirements. During this second year, the project has moved from a 386 PC environment to a full workstation implementation of the system.

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I. Introduction

The past several years have seen a rapid growth of experimentation with expert systems in meteorology. Early systems to forecast severe weather such as WILLARD (Zubrick and Riese, 1985) and METEOR (Elio, 1985, and Elio et al., 1987) were intriguing enough to stimulate further development in this and other areas of meteorology. Examples include upslope snow forecasting in Colorado (Swetnam and Dombroski, 1985), fog forecasting (Stunder, 1987), interpretation of radar signatures (Campbell & Olson, 1987) and the formation of ice on roads and bridges (Takle, 1990). As a sign of the increasing maturity of this technology, several systems developed for forecasting severe weather were tested in a common field experiment during the summer of 1989, and their results are currently being evaluated (Roberts et al., 1990).

As meteorologists' experience with expert systems continues to grow, what is commonly thought of as human expertise or problem solving ability will be included in an increasing number of applications. Because these applications will be addressing increasingly complex problems, expert knowledge alone will be only one part of the full solution. An application will succeed to the extent that it is able to incorporate the needed expert knowledge and integrate it with other algorithmic tools needed to solve the selected problem.

The objective of this project is to develop an expert system which can be used to make a short-range weather forecast from limited input data. The expert system will not be tied to any particular station. This will be done by determining and utilizing the physical relationships between the synoptic weather and variables that affect the local weather such as terrain, geography and surface type. This problem is particularly interesting because, in addition to its practical aspects, the ingredients necessary to solve the problem include the integration of many software components such as structured processing, numerical computation, inferencing, and heuristics.

This interim report describes the progress at the end of the second year of this three year contract. The discussion in this report is centered around a detailed description of the system architecture. A major change that occurred near the end of the second year was the decision to migrate the expert system to a true workstation environment. This decision was made because of limitations that were beginning to manifest themselves on the 386-PC environment and the coincident availability of a Silicon Graphics Personal Iris workstation. The NEXPERT-Object software will continue to be used as the expert system development tool, and knowledge bases will continue to be developed in the PC environment before incorporation on the workstation. At the time of this report, about half of the C code had been converted to run on the workstation.

II. System Description

The task of forecasting short-range weather from limited data requires a variety of skills. Some of these skills, such as heuristics concerning physical behavior, can be efficiently described in terms of collections of rules, commonly referred to as knowledge bases (KBs). Other skills may be more effectively emulated through the use of neural networks. For example, drawing information from an upper air sounding involves pattern recognition skills. Other types of knowledge, such as information about the temporal behavior of weather elements such as fronts, can be described in terms of networks of time relationships.

The diverse set of tools required to embody these skills and make them accessible to the user suggests that a successful forecasting system be able to incorporate them all. Many previous systems have not had this ability because they were built using a single software tool (e.g., an expert system shell) or programming language (such as LISP, Prolog or a proprietary language). Oftentimes these systems were very good at dealing with one aspect of their targeted problem but performed other functions poorly. The current trend is away from such "monochromatic" systems and towards flexible, more opportunistic systems.

The system currently under development (and given the working name Itasca) is designed to have the potential to use any knowledge bases that can communicate with C-language routines and databases. Because C is the dominant language for systems running on microcomputers and workstations, many knowledge expression methodologies have been developed to work with C routines. The following system description highlights the major components of Itasca, starting with the C-coded command structure that ties all the knowledge tools together.

A. Control Structure

Systems that are exclusively rule-based generally have domain knowledge expressed in only a fraction of their rules. While for simple systems this fraction may be large, as system size and complexity grow, the portion of rules containing procedural or "control" information increases rapidly. This control overhead arises because rules are not efficient managers of user interfaces or databases. The same can be said, to a lesser extent, of LISP- and Prolog-based systems. In addition, rules and LISP functions are particularly poor means of describing numerical algorithms.

On the other hand, routines coded in C are well suited to expressing computational algorithms, driving user interfaces and accessing databases. A large volume of C-based libraries exist for graphics and interfaces on microcomputers and workstations, and C is highly portable. Most of the middle- and upper-priced expert system and neural network development tools provide the ability for their products to call (and be called by) C routines.

Itasca therefore works on the principal of using each tool (inferential KB, neural network, C graphics routine, etc.) to do what it does best. C is used as the language by which all tools communicate, and provides the backbone of the system (Figure 1). This imbedded architecture permits almost total interconnection: C routines can call KBs (and vice versa), KBs can call neural networks, neural networks can call C routines for initial data (and vice versa), temporal networks and databases can be accessed or modified by any tool, and so on.

The C routines are divided into control blocks that are roughly analogous to the major tasks of the forecaster. The initialization block establishes the local environment in terms of geography and climate. The observation block is used to input, modify, and preprocess surface and upper air observations. The analysis block produces a representation of the current meteorological state, and the forecast block is concerned with the carrying of this state into the future. Routines that span two or more of the blocks are placed in a global block, allowing them to be accessed by all routines. Examples of these are computational routines, routines that access the databases, and graphics and system utilities.

B. Knowledge Bases

KBs in the system serve to contain the expert knowledge obtained from a meteorologist with single-station forecasting skills. KB domains will generally be broken along lines of the control blocks noted above, with the exception of global KBs that will exist for the life of the forecasting session. Non-global KBs will be loaded and unloaded as they are needed, permitting a dynamic allocation of resources and more sharply defined task domains. Loading and unloading of KBs can be accomplished through C routines and other KBs.

The dynamic use of KBs and their ability to be called from other KBs contributes to the goal of keeping KBs simple, concise and understandable. This is especially important during the development stage, where KBs are frequently modified. Division of the tasks into small KBs allows the system to be built incrementally, as each KB can be added to the C backbone as it is completed and immediately tested. This serves to make each KB easier to verify and validate in its intended operating environment.

An essential feature of KBs is their ability to contain class and object definitions. Classes and objects are used to create self-descriptive representations of both geographical and meteorological entities. These objects are intimately tied to rule-based knowledge structures, enabling them to activate processes that determine values for their attributes, or slots. For example, if a KB determines that a cold front exists (based on cloud observations), the KB creates a cold front object from the class *cold-front*. This object inherits a variety of slots from its defining class and other classes higher in the class hierarchy. One of the slots is *time-to-arrival* of the cold front, to which is attached a "metaslot" which contains procedures to be invoked when *time-to-arrival*'s value is needed. At some later time, when the value is needed, the metaslot invokes a rule sequence to supply the value.

KBs are being developed in the microcomputer and workstation environments using NEXPERT Object by Neuron Data. NEXPERT Object supports a wide range of capabilities, its KBs are transportable across a variety of platforms, and the runtime library permits the inference kernel and KBs to run as an embedded system. The microcomputer version of the NEXPERT kernel supports only Microsoft C at this time.

C. User Interfaces

The task of weather forecasting (and, specifically, single-station forecasting) has many highly graphical components. Forecasters generally use graphic representations of data in forming a model of current conditions. These representations may be realistic, such as surface maps of pressure and front locations, or abstract, such as upper air profiles or wind hodographs. In a fully automated system none of the graphical forecasting tools would be required; the user would need only a graphic representation of the forecast fields. However, because it is desirable to keep the human forecaster "in the loop" and allow him or her to modify analyses and forecasts, all the graphical tools needed by a single-station forecaster should be built into the system. Itasca uses a variety of mouse-driven graphical user interfaces (GUIs) to implement these forecasting tools.

Itasca GUIs may be broadly classified as *Viewers* and *Editors*. *Viewers* are used to aid the forecaster in understanding either the data (geographic, climate or observation) or system products (analyses and forecasts). *Editors* provide the user with the capability of entering or changing both qualitative and quantitative information. An example is the *Upper Air*

Observation Editor, a text-based dialog box that allows the user to enter upper air observation data. The companion *Upper Air Observation Viewer*, on the other hand, is a fully interactive skew-T diagram with time series and wind hodograph plotting capabilities. Another example is the *Analysis Editor*, which will use a mixed graphics and text display to give the user freedom to change elements of the analysis (such as the parameters that describe a front).

Pull-down menus and dialog boxes are employed by the user to navigate the system. Menu items are activated (made selectable) and deactivated as system status changes, providing a degree of built-in guidance for the user. For example, the menu item that causes the system to produce an analysis is not activated until the system has been initialized and the observation time has been specified.

D. Computational Routines and Neural Networks

Many weather forecasting tasks involve pure numerical computation. Examples of these tasks include determining shear, calculating stability and temporally smoothing highly variable surface data. Itasca uses C routines to perform these tasks, removing them from KBs where they may be cumbersome and would obscure the meaning of KB operation. As noted previously, these routines may be called from KBs if and when needed.

Neural networks are being used in AI applications to solve problems that are not directly suited to either pure numerical computation or pure rule-based expert systems. Neural nets are patterned after neuron connections in the brain, and therefore provide an alternative that may be more appropriate for cases in which intuition and past experience play a large role in solving problems. Some neural nets are simply constructed once and never change or adapt to new situations. These are often applied to problems involving pattern recognition, where incomplete or corrupted patterns are input and the "correct" pattern is returned. Most neural nets, however, can be trained to "learn" functional relationships. These are adaptable to changing environments, and have the ability to generalize to situations that have not been previously encountered.

An example that is being explored in the development of this system is the detection of airmass boundaries in sounding profiles. This can be treated as a pattern recognition problem, and so is amenable to neural net solution. Itasca may use neural nets to solve this and similar problems, with the nets called from KBs or C routines in much the same way as computational routines. All neural networks employed by Itasca are expected to be trained during the development phase and not during actual system use. So far, the use of neural networks has been explored in the microcomputer environment using the OWL software package by Olmstead and Watkins.

E. Temporal Networks

Forecasters analyzing data or maps often form patterns of expected future weather behavior in their mind. For example, if a forecaster perceives that a cold front is approaching, he or she will anticipate possible convective precipitation and wind shift associated with the frontal passage and, in the new airmass, gusty winds with colder temperatures.

Such temporal reasoning is possible because meteorological events at any given time are highly dependent on preceding events. This extensive time-dependence, if properly captured, can be used to provide guidance during analysis of current weather and forecasting of future events. This is particularly true when working with limited data.

Time dependence networks provide a representation of events that may be used as templates for analyzing data and constructing forecasts. Developed by Allen (1983) and Koomen (1989), time networks relate temporal intervals during which physical events occur through the use of simple, straightforward constraints such as "after" or "during". Relational networks are then built from the intervals and their constraints in a way that minimizes computer memory requirements without sacrificing information content. The network provides the capability of obtaining the constraint between two intervals even though that constraint is not explicitly present. Rules from a KB may be used to modify, add or delete intervals contained within a time dependence network, or merge entire networks.

As a part of this project, time networks are being explored as a possible means of using knowledge about time-dependent events. They may be used in the identification of the current synoptic state, knowledge of which is of fundamental importance, and in predicting future events. The synoptic state can be determined through the observations of cloud types, pressure changes, wind shifts, etc., that occur in physically and temporally consistent order. In operation, time networks of observations may be compared to predefined networks of events describing typical synoptic configurations. Information relating to the absolute timing and duration of events, not contained in the time network, is obtained through the use of KBs and the other tools employed by the system.

F. Databases and Objectbases

Limited-data, short-range forecasting uses information about local geography and climate to establish surface-induced weather modifications and to set baseline values and ranges of meteorological parameters. This requires the availability of a geographic database (containing information about topography, surface roughness, etc.) and a climatological database (with statistics for mean temperatures, diurnal variations, etc.). As these databases are necessarily large, Itasca will make use of databases stored on disk. These databases will be accessed using the C routines mentioned above.

Observations (both surface and upper air) are frequently accessed by the system and occasionally updated or modified. These observations are stored in random access memory (RAM) with a duplicate maintained for security on a hard disk.

A large number of objects are created by C routines and KBs during system execution and are collectively referred to as the objectbase. These objects describe, among other things, geographic and meteorological entities and their attributes and are maintained in RAM. These are created chiefly for use by KBs.

III. Summary and Plans for Year 3

A. System Design

The overall design of the system has been completed during the first two years. The meteorological entity and meteorological data class/object networks were defined and a NEXPERT Object knowledge base was constructed with these classes/objects. The organization of many of the classes is based on the geometry: points, lines and regions. Geographic features such as stations (points), rivers (lines) and mountains (regions) can be represented as subclasses of these geometric definitions. For meteorological entities, geometry and time are linked in the network description of the meteorological entities by combining the geometric concepts of points, lines and regions with time to form moving points (e.g. pressure systems), moving lines (e.g. fronts) and moving regions (e.g. airmasses). Meteorological observations are represented by classes such as surface observations, rawinsonde observations and pibal observations. Other pertinent information such as local station climate data and local terrain influences are represented by classes connected to the station class through the network hierarchy.

While the design of the class/object network is considered complete, there will undoubtedly be some modifications and additions as the project continues. Any changes which may be made to incorporate new or unanticipated needs will have little effect on the existing structure.

B. Knowledge Bases

The largest effort during the third year of the contract will be on the continued knowledge base development. As described above, the class/object knowledge base is fully functional. We will continue the development of the diagnostic portions of the knowledge base. Approximately half of the time will be spent on the diagnostic portion of the knowledge base and half on the prognostic portion. We plan on having our consultant, Mr. W. K. Henry, on site approximately three weeks during the year.

Considerable experience was acquired in understanding and using neural networks during the past year. In particular, the general backward propagation technique was investigated for a couple of applications. The original application of identifying the distribution of airmasses in the vertical was determined to not be a good first example. In addition to the fact that the problem had to be designed to fit the computational requirements of the neural network algorithm, the identification is sufficiently complicated, employing both other knowledge and time changes of sounding features, that it was determined that the suitability of the problem and the development of an effective training set was beyond the scope of this contract. However, effort will be spent on identifying smaller portions of the diagnostic or prognostic problem that might be appropriate for treatment with neural networks, and then on applying them to the solution.

C. Integration

The conversion of the C code shell and its associated routines to the Silicon Graphics workstation will assume the highest short term priority. Effort will continue on integrating the various components of the system. KBs and computational routines required by the knowledge bases will be integrated into the system shell as they become available. Further integration of routines for the entering and editing of surface and upper air data, for the viewing of data in either graphical or text form, and for displaying analyses, forecasts and other information will be adapted or developed as required.

D. Evaluation

Informal evaluation is a continuing process during expert system development as rules are developed, evaluated and modified. This is particularly true during the development of the diagnostic portion of the development. More formal measures can be made on the prognostic portion of the system, and we plan on performing a limited objective evaluation on independent data near the end of the year.

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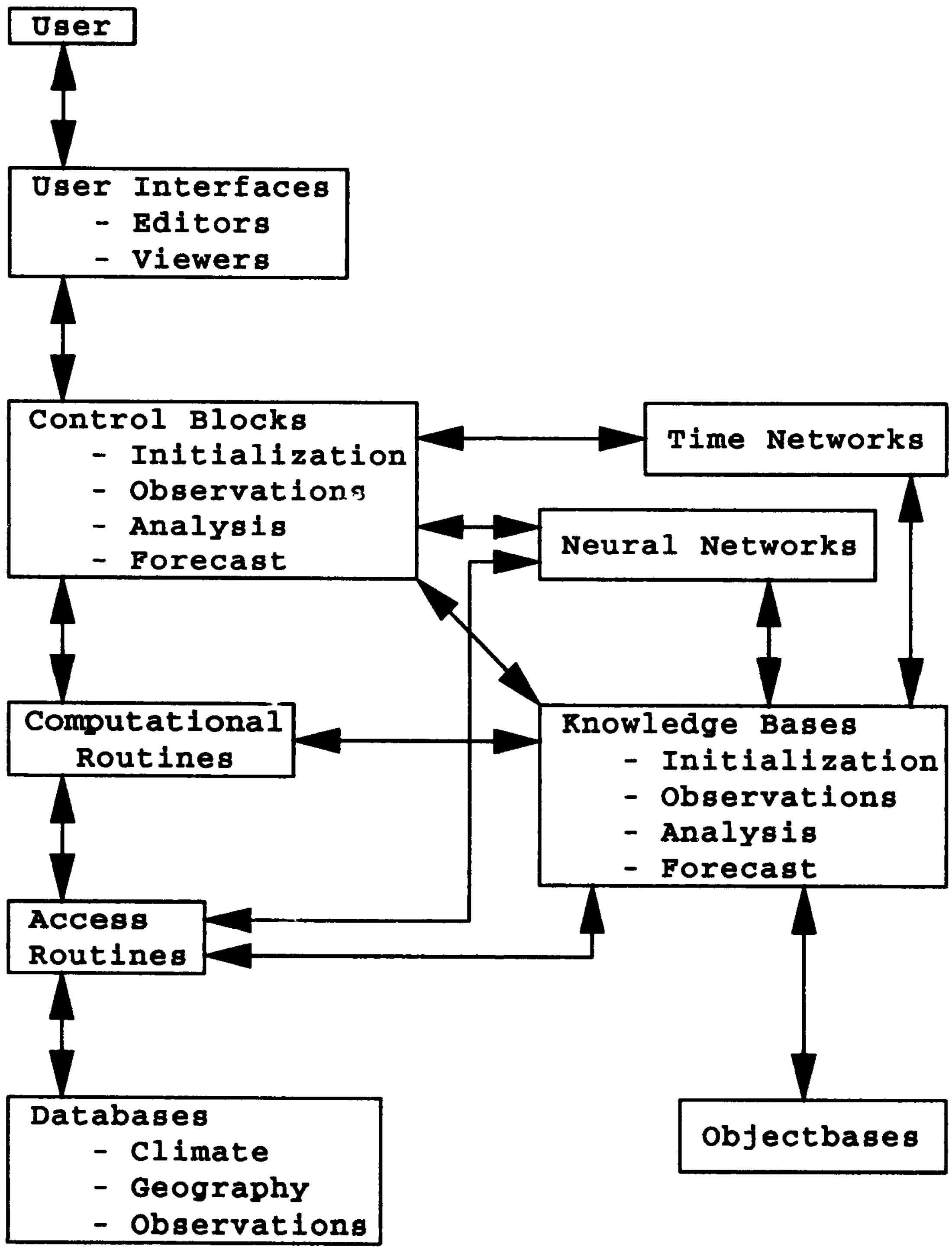

Figure 1. ITASCA SYSTEM OVERVIEW