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Application note

Structural design for management and visualization of information for simulation models applied to a regional scale

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Abstract

A Modeling Applications System Integrative Framework (MASIF) was developed to facilitate regional-scale long-term simulations. MASIF links an array of existing visualization, analytical, and data management software to manage large volumes of model inputs and outputs as well as model execution to facilitate model development and analysis. Information from MASIF is shown in visual form, an approach that we believe is preferable for comprehending information contained in large datasets associated with models that simulate processes and patterns at regional scales. As an example, MASIF was used to manage and visualize daily simulations of maize growth, development, and yield from 1055 Midwestern locations in the United States. © 2001 Published by Elsevier Science B.V.

Keywords: Modelling environment; Regional modeling; Crop growth; Crop yield; Visualization; Commercial software

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1. Introduction

Regional analysis via modeling is becoming more common in the scientific literature (Burke et al., 1997; Thompson and Randerson, 1999; Pijanowski et al., 2000). Current developments in monitoring technologies are increasing the spatial and temporal resolution of the environmental data available as input for regional models. The potential increase in the volume of information used and produced by models will require a framework for the modeling environment that incorporates appropriate tools for the exploration, analysis, and presentation of data (Brown et al., 1995). We developed a Modeling Applications System Integrative Framework (MASIF) whose components are shown in Fig. 1 and is characterized by: (1) a scalable data management module for rapid and ready access to input and output data; (2) a visualization module for the exploration, description, and analysis of

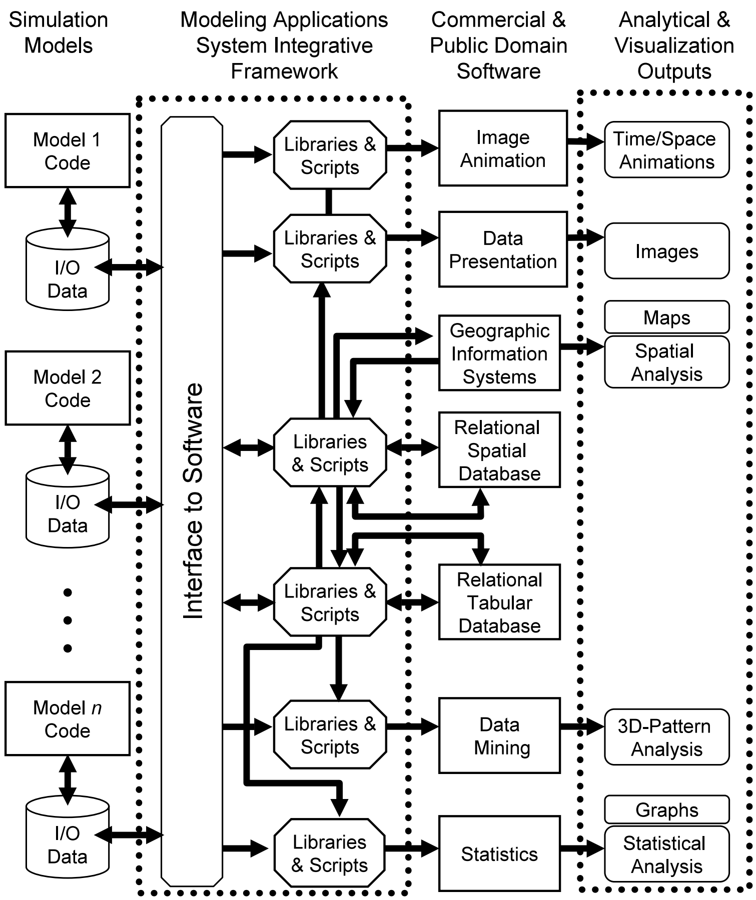

Fig. 1. Integration of commercial and public domain software for the analysis and visualization of simulation models via MASIF.

spatial and temporal patterns; (3) a statistical analysis module to conduct and compare model scenarios; (4) an output animation module to produce spatio–temporal time series of model output; and (5) the potential to use web-based interfaces to interact with the model.

2. Implementation of the MASIF concept

To implement MASIF we selected six software products: Visual Basic 6.0™, Oracle 8.05™, MS Access 2000™, ArcView 3.2™, MineSet 3.0™, and S-Plus 2000 2.0™. These products represent a class of existing upgradeable applications that are inherently useful for the analysis of large data sets, are widely used worldwide, and include libraries that facilitate interconnections. The major steps in the implementation of MASIF included: (a) the design of database tables for data storage and management; (b) the development of the interface to the geographic information systems (GIS) module; (c) the establishment of connections between the Visual Basic™ interface and the analytical software; and (d) the development of a user interface to integrate a specific model to the various software options (Fig. 2).

2.1. Database tables

Three tables contain the data infrastructure for MASIF: an input variables table, an output variables table, and a parameters table. The process of using a parameters table allows modelers to store parameters during different model runs rather than storing millions of records of model output data associated with parameter modifications. Modelers can recall the parameters used for a specific simulation run and re-run the model.

2.2. Geographic information system (GIS) module

To perform in-line mapping of simulation results, we integrated a geographic information system into MASIF by developing a set of scripts to access model output, conduct spatial interpolation of selected output variables at any place in time, and present the resulting map(s) on the computer display. The scripts were developed using ArcView™ Avenue™. In addition, modelers have access to the ArcView™ interface which allows them to optimize other GIS analytical tools provided by the software.

2.3. Connectivity between the user interface and the analytical software

The connection between ArcView™ and Visual Basic™ was established using DDE, an MS Windows™ supported client/server mechanism that enables two applications to communicate. When the user selects the GIS option, the interface (Visual Basic™) initiates communication with ArcView™ and sets it up as the server. Visual Basic™ thus becomes the client and requests ArcView™ to imple-

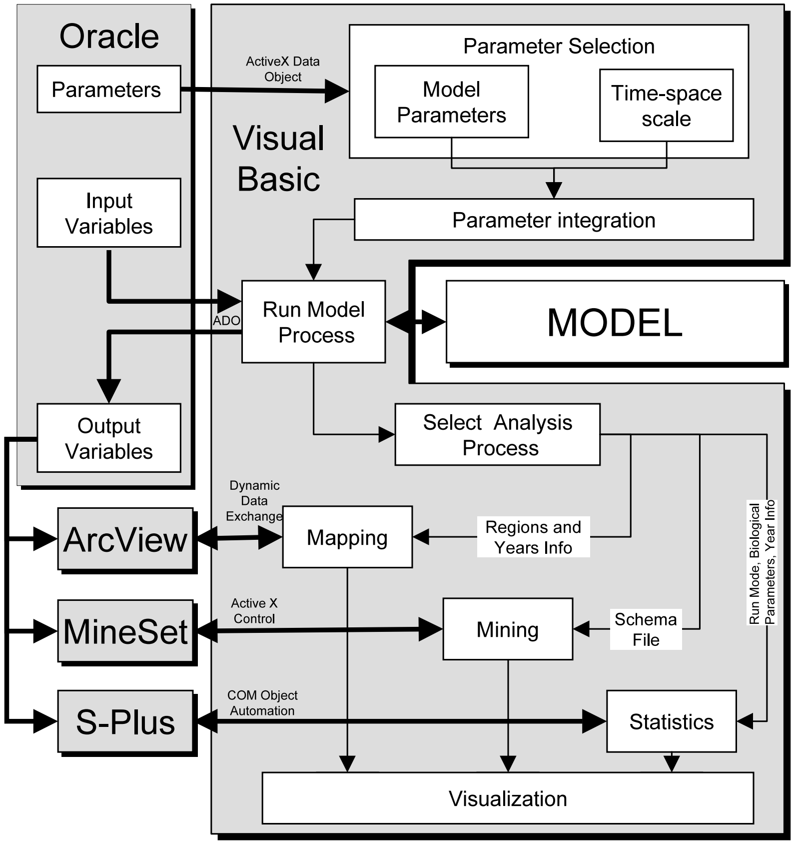

Fig. 2. Diagram representing the implementation of MASIF using five different types of software for model data management and analysis.

ment specific tasks by issuing Avenue commands through the Dynamic Data Exchange (DDE) channel. Through Data Dynamic Exchange (DDE), Visual Basic™ launches ArcView™, closes the default ArcView™ project, opens the project containing the scripts and calls the master script with the user specified model parameters as input. Thereafter, the master script calls the necessary scripts within the project to produce the analysis specified by the user.

The connection between MineSet™ and Visual Basic™ was developed using ActiveX technology. MineSet™ provides an ActiveX control, named VizComposite, that is able to display any type of MineSet™ visualization within a Visual Basic™ application. When the user selects the Multidimensional Visualization option, a MineSet™ schema file is created based on the user input and passed to the VizComposite control. The control then interprets the schema file appropriately and displays the visualization within Visual Basic™.

The connection between S-PLUS™ and Visual Basic™ was made using an Object Linking and Embedding (OLE) Automation, which enables one application (client) to access the resources and functionalities of another application (server). In MASIF, S-PLUS™ is the application server that provides resources in the form of Type Libraries, a collection of objects, functions, properties and methods. The interface (Visual Basic™) is the application client that calls the appropriate Type-Library entities to execute the analysis requested by the user. Upon the execution of a given S-PLUS™ command, the resulting graph-sheet or report is returned to Visual Basic™ as an OLE object and is thus embedded into MASIF.

2.4. Interface to the model

A Visual Basic™ interface was developed to allow modelers access to the model and the analytical tools. The interface has two major menus: model settings and model analysis (Fig. 3). In the model settings menu modelers select the temporal and spatial scales for the simulation, and can also modify the model's parameters. A 'set paths' menu option allows the user to modify and manage the paths where software components are installed. Modelers can run the model once the settings are complete. The model 'analysis' menu allows modelers to access the analytical tools of the geographic information system (GIS), multidimensional data mining, or statistics where modelers select variables of interest, perform statistical analysis, and visualize outputs and reports.

3. Testing of MASIF using a crop physiological model

As part of an ongoing effort to analyze regional crop productivity, we integrated into Modeling Applications System Intgerative Framework (MASIF) a physiological simulation model of maize (*Zea mays*), referred to in this paper as maize, developed by Muchow and Sinclair, (1991)Muchow and Sinclair, (1995), and

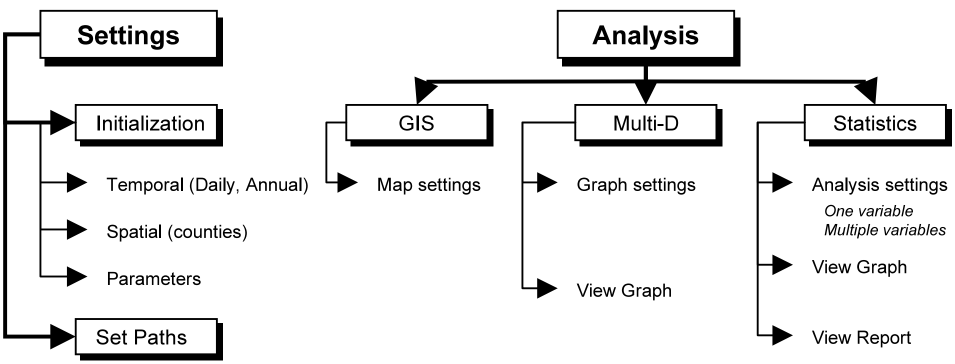

Fig. 3. Menu of the MASIF interface.

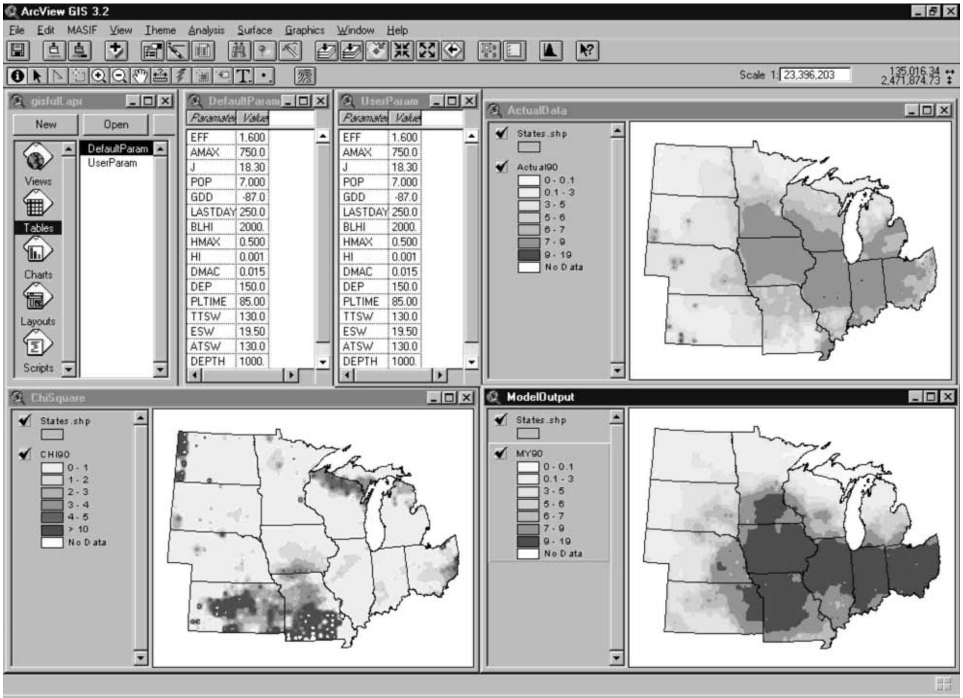

Fig. 4. Geographic information systems (GIS) interface in a MASIF prototype after running the maize model for the year 1990 using the default model parameters (see DEPTH = 1000). This interface shows: default and user selected panels of model parameters (upper left), map of annual actual yields based on USDA-NASS estimates (upper right), map of annual predicted yields (lower right), and map of model accuracy based on a χ^2 statistic compared for each raster cell (lower left).

Muchow et al. (1990). Although the model is site specific, model developers demonstrated regional application potential (Muchow et al., 1990) and provided potential modifications for its use in cold climates (Wilson et al., 1995). This model simulates daily maize growth and productivity based on daily weather input. The input variables table, consisting of five variables for 1055 locations amounting to 7.7 million records, was structured in a relational database management system using Oracle™ and MS Access™.

The developmental computational platform for MASIF–MAIZE was a 700 MHz PC. Databases for model input and output were hosted on an SGI Origin 200 server. Communications between the PC based MASIF and the server was via Ethernet at an average speed of 70 Mbps. An example of model output of corn yield in the GIS interface for a 1 year simulation is shown in Fig. 4. A daily simulation for a maximum of 250 days, for 1055 counties over a 20 year period required 1 h and 56.3 min when the output from the model was streamed to an ASCII file. This was approximately 3.5 times faster than loading the output into an Oracle™ table and 10 times faster than loading it into an ACCESS™ table. Rapid access to large scale model outputs will significantly enhance MASIF usability. We are currently exploring new technologies to address this issue.

We have successfully linked MAIZE to the MASIF environment and we plan to couple the MASIF modules to other simulation models. We believe that building modules based on the integration of multiple existing software applications permits modelers and analysts to concentrate on developing and using models that simulate real world processes without being encumbered with developing analytical tools and integrating them with model output. Different degrees of commercial software integration with simulation models have been achieved in other systems. Examples include the Landscape Management System (McCarter et al., 1998), the Ecosystem management Decision Support (Reynolds, 2001), and the Spatial Modeling Environment (Voinov et al., 1999). The MASIF environment provides a reasonably powerful and flexible environment that allows one to conduct creative regional experiments with either complex or simple regional models. We recognize the value of stand-alone and network-based analytical environments for model assessment and application and, thus, envision the potential to run, analyze, and visualize web-based simulation models.

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