Lecture Notes in Artificial Intelligence, Vol. 2358, 2002, pp. 670-679

An Intelligent Knowledge Processing System on Hydrodynamics and Water Quality Modeling

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Abstract. In order to aid novice users in the proper selection and application of myriad ever-complicated algorithmic models on coastal processes, needs arise on the incorporation of the recent artificial intelligence technology into them. This paper delineates an intelligent knowledge processing system on hydrodynamics and water quality modeling to emulate expert heuristic reasoning during the problem-solving process by integration of the pertinent descriptive, procedural, and reasoning knowledge. This prototype system is implemented using a hybrid expert system shell, Visual Rule Studio, which acts as an ActiveX Designer under the Microsoft Visual Basic programming environment. The architecture, solution strategies and development techniques of the system are also presented. The domain knowledge is represented in object-oriented programming and production rules, depending on its nature. Solution can be generated automatically through its robust inference mechanism. By custom-built interactive graphical user interfaces, it is capable to assist model users by furnishing with much needed expertise.

1 Introduction

Numerical modeling of hydrodynamics and water quality is a highly specialized task that entails expert knowledge. Nowadays, the technology is quite mature with a diversity of mathematical schemes being available [1-4]. The basis of the numerical technique can be finite difference method, finite element method, boundary element method or Eulerian-Lagrangian method. The time-stepping algorithm can be implicit, explicit or characteristic-based. The shape function in the numerical analysis can be of first order, second order or higher order. The covered spatial dimensions can be one-dimensional, two-dimensional depth-averaged, two-dimensional layered, three-dimensional, etc.

Heuristics, empirical knowledge and previous experience are often entailed for any justifiable simplifications as well as the selection of the appropriate modeling technique during the formulation of numerical models on coastal hydraulics and water quality problems by the specialists. Yet, the precision and accuracy of the numerical computation depend largely on the accurate representation of the actual open boundary conditions, the adopted numerical scheme as well as model parameters [5].

The emphasis has always been focussed on the algorithmic procedures in solving some specific coastal problems. These conventional numerical models, being not user-friendly enough, lack knowledge transfers in model interpretation and effective developers/users communication. It results in significant constraints in model uses and a large gap between model developers and application practitioners.

As such, previous attempts have been made to integrate artificial intelligence technology (AI) with some one-dimensional mathematical models in order to aid users to select and apply them at ease [6-7]. These prototype expert systems employed the commercial expert system shell VP-Expert, which run on microcomputer and DOS operating environment. They are useful for practitioners to select a suitable numerical model and facilitate easy representation of heuristic reasoning. Nowadays, with the popular use of the interactive Windows platform, they are no longer adequate.

During the last decade, there has been a widespread interest in intelligent knowledge management and processing systems, which can simulate human expertise in narrowly defined domain during the problem-solving process [8]. They are able to couple together descriptive knowledge, procedural knowledge as well as reasoning knowledge. The recent advent in AI techniques renders it possible to develop these intelligent systems by employing shells of hybrid knowledge representation with established development programming environments such as Visual Basic, C++, etc. In this paper, the architecture, development and implementation of a prototype intelligent knowledge processing system on flow and water quality modeling, employing the shell Visual Rule Studio, are delineated. The primary aim of the work is to couple descriptive knowledge, procedural knowledge and reasoning knowledge for this domain problem together into an integrated system. In particular, highlight is made on the establishment of knowledge base and the interactive visual aids during the problem-solving process.

2 Acquisition and Elicitation of Domain Knowledge

The domain knowledge in hydrodynamics and water quality modeling primarily encompasses matching applicable conditions and model selection. The major task for a knowledge engineer becomes thus to represent them into an intelligent knowledge processing system. Prior to set up the prototype system, it is imperative to abstract the characteristics and applicable conditions of these diverse hydrodynamics and water quality models. The domain knowledge entailed in the development of this intelligent knowledge processing system has been encoded mainly on the basis of interviews with experienced numerical modelers and literature review. Table 1 lists the choice of some principal model parameters of diverse numerical models in common use. There are in total fifteen principal model parameters and each numerical model can be identified by a combination of some of these choices. As such, depending upon the nature and requisite tasks of the project, the most appropriate model can be selected with respect to the criteria of accuracy and computational efficiency. The knowledge base of this intelligent knowledge processing system on hydrodynamics and water quality is developed in compliance with Table 1.

Table 1. Choices of some principal model parameters in hydrodynamics and water quality modeling

Parameter	Selection 1	Selection 2	Selection 3	Selection 4	Selection 5
Numerical method	finite element	finite difference	boundary element	Eulerian-Lagrangian method	
Dimensions	1-d	2-d vertical	2-d horizontal	3-d layered	3-d fully
Co-ordinate system	rectangular	curvilinear	polar		
Scheme	explicit	implicit			
Time-stepping algorithm	single step	alternating velocity and elevation split step	alternating direction split step		
Grid	uniform	not uniform			
Stability	unconditional stable	conditional stable			
Turbulence model	mixing length	k-ε model	dispersion coefficient		
Error of scheme	first-order	second-order	higher-order		
Equation	momentum	continuity	state	density	pressure
Forcing	tide	river discharge	wind	density difference	
Initial condition	zero	non zero			
Boundary condition	zero value	first order zero	second order zero	in-out-bc	
Vertical co-ordinate	normal	sigma	refined near surface	refined near bottom	refined near specified area
Equation term	advection	Coriolis force	horizontal diffusion	decay	sediment interaction

3 The Intelligent Knowledge Processing System

The most difficult task for the novice users is to select an appropriate model and the associated model parameters. With the recent advancement of information technology, it is feasible to furnish more assistance on the selection and manipulation of the ever-complicated models on hydrodynamics and water quality that emerge constantly. When compared with the traditional algorithmic tools, the major distinct feature of an intelligent knowledge processing system is the provision of the decision support with visual window interfaces during the problem solving process.

3.1 System Architecture

Figure 1 shows the architecture of the knowledge processing system. The representation of knowledge in production rules and object-oriented programming is at the core of the process. The knowledge rules comprise two groups, namely, Rule Sets I and Rule Sets II. Based on the responses made by the user on the problem specifications, Rule Sets I generates the conditions of model selection. Rule Sets II then recommends the most appropriate model for a project with a specific task.

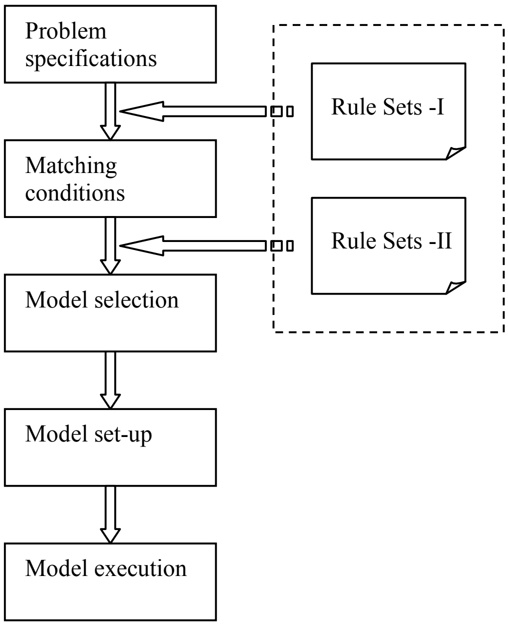

Fig. 1. Architecture of the intelligent knowledge processing system

3.2 Visual Rule Studio

Visual Rule Studio acts as an ActiveX Designer under the Microsoft Visual Basic programming environment [9]. The Production Rule Language, used by Visual Rule Studio, is a high level grammar for problem representation and abstraction designed specifically for the specification and processing of rules. Its grammar employs an object-oriented notation that is common with other programming environments, such as, C++, Java, Visual Basic, etc. It not only facilitates ease of learning, but also furnishes for the easy mapping of client objects to the objects of Visual Rule Studio. By isolating rules as component objects, separate from objects and application logic, this shell allows developers to leverage the proven productivity. Thus rule development becomes a natural part of the component architecture development process. As such, it is no longer acceptable to require that an entire application be developed wholly within a proprietary development tool in order to realize the benefits of rules programming and knowledge processing applications. They are no longer the limitations of traditional expert system development environments.

The structure of a Visual Rule Studio object basically comprises name, properties, and attributes. The attributes are composed of name, type, facets, method, rules and demons. Visual Rule Studio possesses a robust inference engine and supports three types of inference strategies, namely, backward-chaining, forward-chaining and hybrid-chaining. These inference strategies model the reasoning processes an expert employs when solving a problem.

3.3 User Interface

Practicing hydraulic and environmental engineers are often familiar with the projects but not quite with the ever-complicated numerical models. It is a difficult task for users to select an appropriate model. Instead, well-planned interactive questionnaires, comprising the requisite problem specifications, can be easily understood and responded by users. Depending upon the replies made by the users, a well-defined user interface can duly abstract the requisite information to infer the intrinsic conditions of selection of numerical model. The major task at this stage is to glean and lay out all the pertinent determining variables that have significant effect on simulating computation.

If the nature of the project is known, the scopes of applicable mathematical models can be narrowed since every project type certainly rules out the use of some models. For instances, if reservoir routing is considered, the water level in such a storage facility may be considered horizontal. This simplifies the analysis significantly since dynamic effects are neglected and only the continuity equation needs to be considered. A finite difference approximation can be utilized to simulate the change of storage in the de Saint-Venant continuity equation. Besides, data availability as well as tasks on the hydrodynamics and water quality modeling have also significant effects on the selection of numerical model. In cases data are not sufficient, selection can merely limited to some simplified numerical schemes. Some complicated models are entailed for some special tasks to be performed, for examples, on unsteady simulation of phytoplankton growth in a coastal water system and simulation of flooding and drying of tidal waves.

A window type tabular interface is designed based on the knowledge and previous experience about numerical models. Each tab control is designed to assist the user to locate different groups of questionnaires. The purpose tab is mainly furnished for selection of either real-time or planning condition. The project tab is employed to define the nature of a project from 11 optional buttons, namely, river flood forecast, flood plain, tidal dynamics, estuarine hydrodynamics, salt water intrusion, wave propagation, eutrophication, temperature/density distribution, water pollution, wind storm propagation and outfall.

3.4 Model Selection

Once the users have entered their responses to the questionnaires, the conditions for selecting models can be generated automatically. Figure 2 shows the hierarchy of matching conditions for model selection. Problem specifications are at the first hierarchical level, which covers the key parameters that have significant effect on model selection. The answer sets, which consist of the answers for each problem specifications, constitute the second hierarchical level. The hidden condition sets of intrinsic constraints on model that are acquired through Rule Sets I compose the third hierarchical level. The fourth hierarchical level is condition sets after some repeated conditions are filtered, through which the Rule Sets II can be fired.

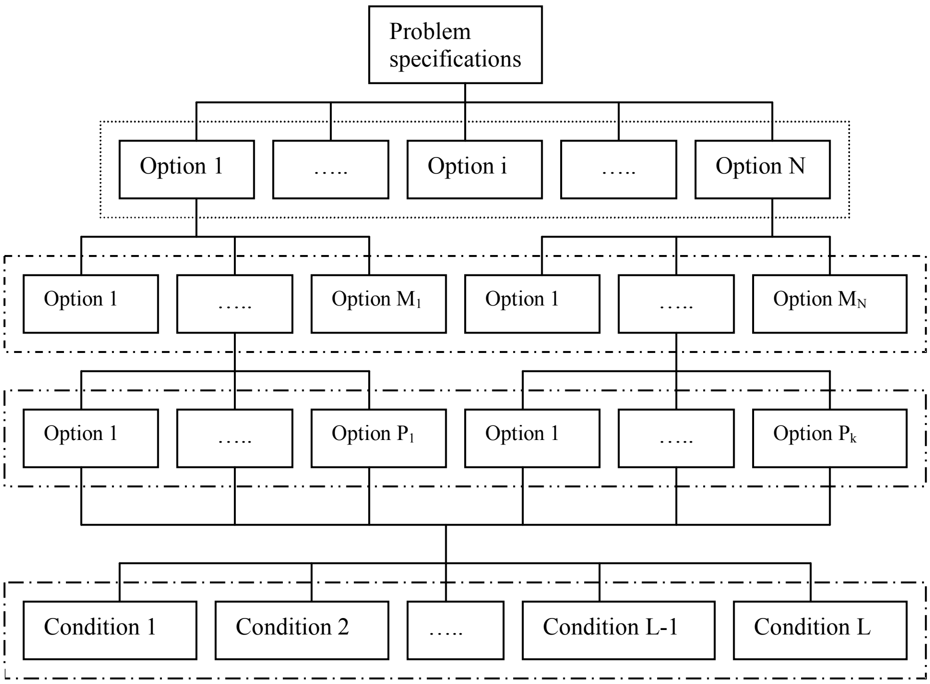

Fig. 2. Hierarchy of matching conditions for model selection

3.5 Knowledge Base

In this prototype system, the knowledge is represented in both object-oriented programming and production rules, depending on the nature of the knowledge.

Object-Oriented Programming. Under the system, three classes are employed, namely, *Section*, *Problem* and *Question*. For instances, the structure of the class *Problem* is shown as follows:

```
CLASS Problem
WITH ComputationTime COMPOUND Limited, Not strict,
Unlimited
WITH Accuracy COMPOUND Significant, Less Significant
WITH Current COMPOUND Large vertical current, Vertical
variation of current, Depth_averaged form, Omitted
WITH StratificationOfWater COMPOUND Significant, Less
Significant, Omitted
WITH DifferenceOfSalinity COMPOUND Significant, Less
Significant, Omitted
WITH DifferenceOfTemperature COMPOUND Significant ,Less
Significant, Omitted
WITH Geometry COMPOUND Very complex, Less complex, Not
complex
WITH GridSize COMPOUND Large, Smaller, Uniform,
Irregular
WITH BoundaryCondition COMPOUND Open, Closed, Closed
reflection, Zero diffusion
WITH WaterDepth COMPOUND Larger variation, Very deep,
Omitted
WITH DataAvailable COMPOUND Detail, Part
```

The class S*ection* and its attributes related to the features of models are based on the model characteristics as shown in Table 1. The class *Problem* comprises attributes pertinent to the condition sets of numerical models. The class *Question* consists of attributes related to the questionnaires, which are consistent with visual options in the tab screens under the problem specifications.

Production Rules. Once all the questionnaires in the tab screens have been completed, the conditions on selection of models can be generated on the basis of the production rules. The following shows some sample rules under this category.

```
!==================================
! Rules for Purpose
!==================================
```

```
RULE 1 Conditions from Planning
IF Question.Purpose IS Planning
THEN Problem.ComputationTime IS Unlimited

RULE 2 Conditions from Planning
IF Question.Purpose IS Planning
THEN Problem.ComputationTime IS Not strict

RULE Conditions from Real_time
IF Question.Purpose IS Real_time
THEN Problem.ComputationTime IS Limited
```

Under this system, the conclusions from Rule Sets I will become the premises of Rule Sets II. The model selection depends mainly upon the model characteristics. Once these questionnaires have been responded and completed, the model characteristics can be inferred through the production rules. The following shows some sample rules under this category.

```
!=================================
! Rules for Scheme
!=================================
RULE Explicit method
IF Problem.Accuracy IS Significant
   AND Problem.ComputationTime IS  Unlimited
THEN Section.Scheme IS Explicit

RULE Implicit method
IF Problem.Accuracy IS Less Significant
   AND Problem.ComputationTime IS Limited
THEN Section.Scheme IS Implicit

RULE Semi_implicit method
IF Problem.Accuracy IS Less Significant
   AND Problem.ComputationTime IS Not strict
THEN Section.Scheme IS Semi_implicit
```

3.6 Inference Mechanism

The inference mechanism controls the strategies that determine how, from where, and in what order a knowledge base draws its conclusions. The class *Question* comprises attributes with answer sets acquired from the questionnaires through the interactive user interfaces in the tab screens. Attributes under *Problem* are used in the conclusions drawn from the premise using attributes under *Question*, but are also used in the premise about intermediate conclusions related to attributes under *Section*. The logical relationship is thus *Question* → *Problem* → *Section*. Once the problem description in the tab screens have been entered, the process of model selection can be generated automatically, according to the Rule Sets I and Rule Sets II. This system starts the backward inference process with the attribute *Scheme*, which is one of the goals under the class *Section*. The search returns to a rule with the conclusion related to attribute *Scheme* under the class *Section*. If the premise is related to the attribute *ComputationTime* under the class *Problem* in the rule and its value remains unknown, through rule chaining, it then returns to another rule with conclusion related to the attribute *ComputationTime*. If the premise of the rule is met, the corresponding production rules will be fired. Otherwise, the search finds other rules with conclusions related to the attribute *ComputationTime*. The above processes will be continued until all the goals have been exhausted. The rules for the attribute *Purpose, Project* and *Tasks* will be searched in sequence.

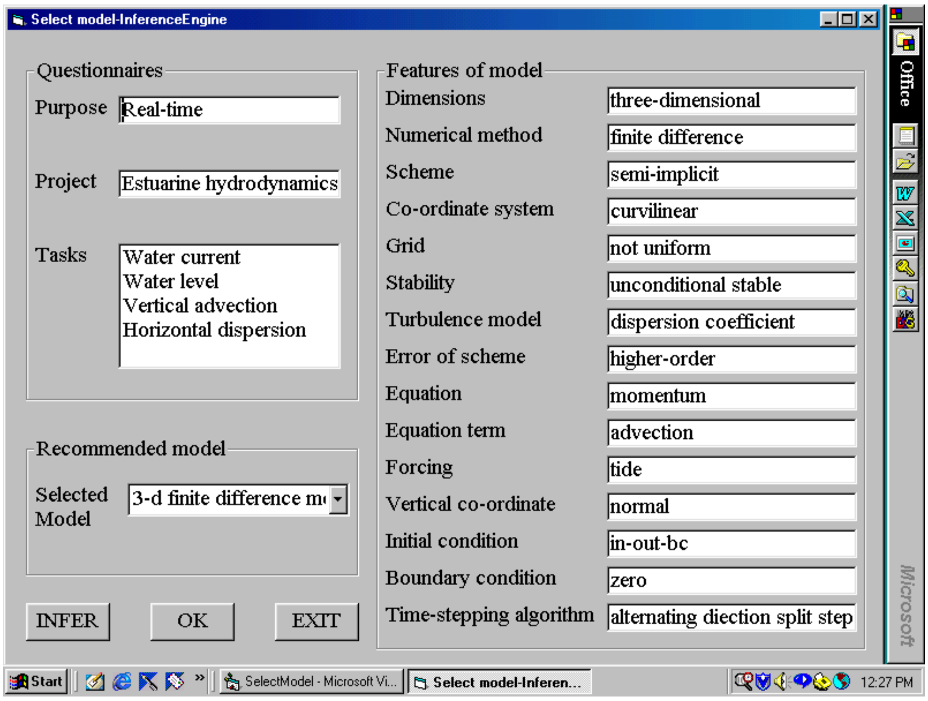

Fig. 3. Screen displaying inference results for Pearl Estuary

4 Results from Prototype System

In order to demonstrate the use of this prototype system, it is applied to Pearl Estuary in the vicinity of Hong Kong. Details of the numerical modeling of the estuary can be found in [2]. On the basis of the available information and the local characteristics for Pearl Estuary, the questionnaires are duly completed through the friendly user-interface. After the input data have been entered and a command button is clicked, a summary of the input requirements and the inference results are shown in the left and right frames of the screen in Figure 3, respectively, which are found to be consistent with the expert opinions.

5 Conclusions

A prototype intelligent knowledge processing system on hydrodynamics and water quality modeling is successfully developed and implemented. It is demonstrated that the hybrid knowledge representation approach combining object-oriented programming technique and production rule system is appropriate for this domain problem. The focus has been concentrated on the establishment of knowledge base and the interactive visual aids during the problem solving process. A user-friendly interface is capable to bridge significantly the gap between the numerical modelers and the users. By using custom-built interactive graphical user interfaces, it is able to assist designers by furnishing with much needed expertise and cognitive support in the numerical modeling of hydrodynamics and water quality.

6 Acknowledgement

This research study was supported by the University Research Grants of Hong Kong Polytechnic University (G-YC39) and the Natural Science Foundation of China (No. 60073037).

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