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A fifth generation numerical modelling system in coastal zone

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Abstract:

Nowadays, artificial intelligence (AI) technology is gradually integrated into the numerical modelling system to make the system more intelligent and more user-friendly. The characteristics of the fifth generation numerical modelling are connected with AI applications. The expert system technology as a widely applied AI technology, is integrated into our modelling system for coastal water processes with traditional numerical computational tools and the data and graphical pre-processing and post-processing techniques. Five kinds of knowledge bases are built in the system to describe the existing expertise knowledge about model parameters, relations between parameters and physical conditions, various possible selections for parameters and rules of inference. The inference engine is designed to be driven by the confidence of correctness, and the rule base is built with the factor of confidence to link the various relations. The decision tree is designed to drive the inference engine to explore the route of selection procedure of modelling. The decision tree depends on the real problem specifications and can be modified during the dialogue between the system and the user. The forward chaining and backward chaining inference techniques are mixed together in the system to help matching the parameters in the model and the possible selections with sufficiently high confidence. The expert system technology is successfully integrated into the system to provide help for model parameter selection or model selection, and to make the numerical model system more accessible for non-expert users.

Introduction

In the analysis of the coastal water process, numerical models are frequently used to simulate the flow and water quality problems. The rapid development of numerical models provides a large number of models to be used in engineering problems or environmental problems. Usually, selecting a suitable numerical model to solve a practical problem is a highly specialised task, requiring detailed knowledge on the application and limitation of models. Ragas et al. (1997) have compared eleven UK and USA water quality models used in discharge permitting and found that model selection is a complicated process of matching model features with the particular situation. Therefore as the design aid or training tool for engineers or students, it is necessary to include some features to provide help for selections of models.

As the development of numerical modelling system advances, the trend to incorporate more and more features based on the advanced computer technology has become obvious. The notion of "generations" of modelling to describe this trend of development was introduced by Abbott (1989) and Cunge (1989). The so-called third generation modelling is a kind of modelling system to solve some special problems only. It can be used and understood only by the modeller himself and also special users well trained over periods of many months. It has incorporated very few features to facilitate other users and for other problems. Typical examples are some sophisticated 2-dimensional or 3-dimensional numerical models on tidal flow and on a particular water quality phenomenon (Chau and Jin, 1995; Chau and Jin, 1998). The fourth generation modelling has become much more useful to a much wider range of end-users. It provides menu of parameter specification, automatic grid formation, pre-processing and post-processing features, and features of management of real collected data for modelling, etc. It acts as an intelligent front-end to support the handling of the simulation model on a particular hydrological or water quality problem (Recknagel et al., 1994). In the modern era with boom of knowledge, the fourth generation modelling starts the technological research to transform the knowledge of computational hydrodynamics into the products (Abbott, 1991). The fourth generation modelling equips the system with powerful tools, appears as very user-friendly and powerful software package for the non-specialist, and makes it possible to solve relatively wide problems. Nowadays, as the development of computer technology goes further, it can be seen that "usage wizard" providing help and guidance for use and direction often accompany more and more software systems. The "wizard" integration in the system is usually related to artificial intelligence technology (AI), such as expert system technology. Ragas et al. (1997) also suggested, though they did not actually implement, the development of an expert system for model selection in order to deal with uncertainty in model predictions, after compared a number of UK and USA models. The fifth generation modelling system (Abbott, 1989,1991) is acknowledged to have the features of integrating AI technology and computational hydrodynamics in one system. AI technology becomes a unique feature of the fifth generation numerical modelling.

Recently, some literatures about study into the feasibility of integrating expert system with the numerical modelling can be found (Blanpain and Chocat, 1994; Ghosh Bobba et al., 2000; Knight and Petridis, 1992; Uzel et al., 1988). Most of this kind of the fifth generation numerical modelling system in coastal area only refers to a one-dimensional modelling system for river network or river planning (Chau and Yang, 1993; Jamieson and Fedra, 1996). Some reasons are for its simplicity of knowledge and selection procedure. For two or three-dimensional modelling, the integration of expert system and problem solution in a single system will become much more complex. To introduce the expert system technology into the system is a method to make the system capable of providing advice to parameter selection or model selection, and to make the system to have the intelligent features of "usage wizard" if the program is written in some embedded forms of code. Expert system technology, building knowledge base covering the related domain expertise and being controlled by inference engine, has been shown as a feasible solution for providing help in the numerical modelling system. It can also provide help for the model manipulation if a knowledge base can be built on the dynamic data relationship of modelling results. The literatures on the introduction of expert system technology into the manipulation of numerical modelling are scarce up to date.

This project aims at the integration of the expert system technology, numerical computation tools and some pre- and post-processing graphic features in one modelling system. It is within the scope of the fifth generation modelling system. The main demands for the modelling systems are:

1. The system, including hydrodynamics and water quality simulation tools in coastal area, will serve both as design aid and training tool.
2. The system integrates the expert system technology to give advice on the selection of simulation methods and various model parameters. Domain knowledge base and inference engines are included in the system. Some interactive forms are designed to let users to have access to modify the knowledge base according to their own opinions.
3. The system provides interpretation of model results with the post-processing features. Under the help of the knowledge base, the system can provide comparison and assessment for different models to understand their advantages, applicability and limitations. The system also includes some features for help on the model manipulation.
4. The system can solve some real prototype problems in Hong Kong coastal area.

In this paper, the application of the expert system technology in the part of the selection of numerical model is discussed. In consideration of the development of the fifth generation modelling system and its trend to integrate many features in a large system, the part of selection of models and the part of manipulation of modelling are designed separately. Some of the tools integrated in the system are even designed in the forms of add-in tools. Due to the reason trying to integrate many features in a single system, we do not choose the traditional expert system shells as the system design language, but choose the more fundamental windows based computer language Visual Basic 5.0 (VB) as the program development environment. VB is an object-oriented language and has included most of the control objects of the common interface in Windows 95/98. It fits the demand of interface friendliness in the fifth generation numerical modelling. In addition, VB is capable to integrate some tools made in other language, such as Fortran 90, into the system. It has been developed to include more Internet techniques in the language, which will be convenient for the future trends and versions of the system designed for the Internet.

The Procedure of Selecting Numerical Model

The numerical model is a tool to simulate the physical problem with the method of solving differential equations. The selection of a numerical model can be divided into several steps: choosing problem-related equations, discretization of equations, formulation of proper boundary conditions, selection of suitable coefficients of turbulence, and then running the results using the problem solving algorithm on the discretized equations. These steps refer to about 40 parameters to be selected. These steps are composed of full decision tree of model selection procedure.

Interviews with some numerical modellers have been undertaken. In the interviews, the order of importance of the parameters, the sequence of making decision on parameter selections, personal experience in selecting parameters, personal opinion on difficulties of model selections, etc., were discussed. It was found that more differences exist, than it is supposed, in the selection manner between well-experienced modellers and non-experienced modellers. This finding also supports the necessity of an expert system for model selection. Well-experienced modellers can combine the knowledge from books or literatures and knowledge from practice well to obtain a more reasonable result, with relatively reasonable balance of accuracy and effectiveness of model simulation. On the contrary, non-experienced modellers tend to follow fully to what the book says, and tend to be lack of a good balance between the accuracy and effectiveness, even in the status of low accuracy and low effectiveness. The fact reminds us that it is important to include as much knowledge as possible from the expert's experience in the system. However for the lack of a wide variety of sources in obtaining different experts' experience, the knowledge base in our system is encoded mainly from books and literatures. The improvement of the system in the aspect of encoding expertise will depend on frequent use of the system and frequent feedback from the users to update more experts' experience in making decision. It will also depend on the formal report and its validation of personal conclusion and experience in the literatures.

All the parameters to be selected for a numerical model in the steps mentioned above can be classified into 6 types of parameters: dimensions and method, grid, scheme, turbulence, boundary condition and driving force, and "some others" (such as initial conditions and geometry background). The details of the classification are shown in Table 1. This kind of classification not only makes the formulation and search of knowledge base and rule base easier and quicker, but also reflects some important branches in the research of the numerical modelling.

Clearly, the driving force of the selection of numerical model is the need of its user. The selection of a model, or the selection of a set of parameters, is the function of four aspects: the user's purpose in using the model, the physical conditions in the user's specific problem, the user's experience in using models, and user's understanding about possible model results. Most of expert systems in the numerical model refer to the first two aspects above, i.e. the user's purpose of using model or the so-called problem specification, and physical conditions in the problem. In our system, in consideration of intelligent help for different kinds of user, we try to include the third aspect, the user's experience of using model, by querying his opinion and deducing some advice from his answer. The fourth aspect mentioned above, the user's understanding about possible model results, is obviously related to the user's experience in using model, which will play a very important part in the model manipulation procedure. The fourth aspect is not discussed here. The details of first three aspects of the facts about user's specifications are listed in Table 2.

A numerical model will be suitable for an user, if the model parameters match with the users' specific conditions. The selection of a numerical model becomes a task to query the conditions in Table 2, and then to obtain the suitable selection in Table 1. The expert system technology provides the method to link Table 2 and Table 1, by building the knowledge base, rule base and suitable inference engine to search and match between them. Because a numerical model includes a set of parameters, these parameters should be specified in the procedure of model selection. A decision tree, describing the steps in selecting a numerical model, represents the whole procedure of model selection. The procedure of selecting a numerical model then becomes filling the decision tree. The concept of the decision tree will be discussed in the inference engine section.

Most discussions on the selection of models are usually related to the balance of accuracy and effectiveness. The common knowledge on the selection of numerical method is that finite element method always results to the low effectiveness in comparison with finite difference method. The common knowledge on the selection of scheme and grid is that large step of grid spacing and large time step always result in high effectiveness and low accuracy. This kind of common knowledge is included in the knowledge base and the system can search the rule base to suggest the selections by querying the users' demand of the emphasis on the accuracy or effectiveness. In other words, the system cannot automatically balance the accuracy and effectiveness. It needs to ask the users and then help to select. Because the selection decision is designed to be driven by the factor of confidence, the knowledge must be encoded into the knowledge base so that the system can suggest a good balance. As the development of computer speed and memory becomes more and more rapid nowadays, the accuracy consideration is surely enhanced in the future in comparison with consideration on effectiveness. Therefore the balance in the accuracy and effectiveness may be easier to realise in the future by modifying the knowledge base with new conclusions on treatment and balance.

The Knowledge Base of the System

The knowledge base about the selection of parameters of modelling consists of several sub-bases: relation base, selection base, question base, rule base and model base.

Figure 1 shows the screen displaying part of the relation tree of model parameters, which describes how many factors one parameter is related to. Figure 2 shows the screen displaying part of the selection tree of the model parameters, which describes how many forms or values of selections can be suggested for one parameter. The relation base describes the structure of relation tree. The tree nodes are always in the form of one layer and sometimes are in the forms of two layers if the related factor is as well related to other factors. Figure 3 shows part of the relation tree of model parameters. The structure of the selection tree is quite simple. The selection base describes this; one node of selection tree represents one parameter and its many branches represent many possible selections of the parameter. Figure 4 shows part of the selection tree of model parameters. The relation tree and the selection tree are two trees in the system, designed to help describing the parameter relations and selections vividly. In the query period, the relation tree is useful to help in searching the related factors. In the period of decision making, the selection tree provides the image of several possible routes of selections. It can be concluded that any expertise knowledge, such as the relation and selection knowledge, can be described in the form of a knowledge tree. A knowledge tree is a static tree, the structure of which is known before the model selection. Though the decision tree is also described by a tree form, it is not static and the structure of its branches changes as the user changes his specifications.

The question base stores questions in asking the user for his specifications of the factors, which is related to the parameter described by the relation base. Figure 5 shows part of the question tree of user's specifications. Figure 6 shows an example of the inference direction of a parameter related to the user's specifications. This direction deduces an item of query and a set of answers to be selected. When the user selects an item of his specifications, the feedback to the system is given, and the inference engine will drive the selection decision forward. Figure 7 shows an example of the inference direction of the user's specification through the system inference.

The rule base is different from those knowledge bases describing the relations or suggesting selection of parameters. It describes the inference rules from the user's specification to the parameter selections. The following statement is a standard rule item including the fuzzy description:

If the water depth is very deep and the density difference in vertical direction (stratification) is very significant, the 3-d dimensional model would be selected with confidence of 90% of correctness. The left-hand side of this kind of rule statement describes what conditions of depth and stratification are satisfied (deep, density difference), and the extent of the description (very deep, significant density difference). The right hand side of rule statement describes what the selection item would be suggested (3-d for dimensions selection), and the confidence of this suggestion (90 % confidence of correctness).

In the rule base, about three hundreds of this kind of rule statements in the form of fuzzy relation are included. In the system, we make the confidence of parameter selection as an important factor to control the inference and the destination of selections, which will be detailed in the next section. Since confidence is an important control factor in the system, the rule base is built to link the user's conditions and the suggested selection by using confidence of match.

For some continuously varying conditions, such as the water depth or the vertical density difference, the user can specify them with fuzzy description or with definite numerical values. The system can automatically transfer the numerical values into fuzzy description with the fuzzy member curve to calculate its relevant confidence of membership before searching the rule base. Figure 8a shows the fuzzy description of water depth. Curve A represents the fuzzy definition of "very deep", curve B represents " deep" and curve C represents "shallow ". Figure 8b shows the relation between six possible selections of dimensions parameter and water depth condition. The relation is measured by the confidence.

Another knowledge base in the system is model base, which stores many famous and useful models in coastal simulation. The model base can be visited to show some examples of selection cases of modelling in the world. It provides the references for modelling. When the user of a system finishes all the parameter selections necessary for modelling, the system may check whether or not there are existing models in the model base with similar consideration of parameter selections. It then asks whether the user would like to make the model selection based on that existing model.

The knowledge bases discussed above are built item by item through concluding and encoding from literatures of numerical modelling research and application. In consideration that most of the difficulties in selection and application of numerical modelling are related to the numerical scheme, turbulent coefficient formulation and open and close boundary condition representation, the knowledge bases about these three classes of parameter selections are built particularly delicately.

Inference Engine

The inference engine is designed to drive the selection of parameters by the factor of confidence. For a parameter, before any selection is made, a default value is given corresponding to a confidence assumed to be 50, which means whether or not the default value is suitable for real condition is not yet known. As the real physical conditions are specified by the user through the query, the new inference is processed by the system so that the default value of parameter is changed, and the new confidence for match of parameter and selection is greater than 50. Usually, there are several suggestions for a parameter selection, the system will ask the user to select an item of suggestion with the highest confidence.

It is known that selection of a suitable parameter involves matching the parameter and its possible selection with relatively higher confidence. Any questions can be asked by the system, and user can make any specifications. However, if the system cannot find any rules that match with the specifications of the condition, or cannot determine any change of confidence under the new specifications, nothing will happen in the selection procedure. Therefore, the inference engine is a set of code in the system to search the route of raising confidence of parameter selection. Here are some mechanisms of inference engine linking to the confidence of selection:

1. It is designed that some models with many specific values of parameters can be run without specifying anything. The user is allowed to run the existing model for any of his purpose. The problem is whether or not the model is suitable to his special conditions. In other words, if the location and bathymetry of existing model are different from the real data supplied by the user, the confidence of the model selection will be very low.
2. If the user can specify as much information as possible to tell the system his specified conditions, the chance for the inference engine to search out the selection with relatively higher confidence would be greater, and the confidence of the selection would be raised.
3. The purpose of asking questions to the user in the dialogue box is to understand the user's purpose or physical conditions so as to raise the confidence of the model selection. If the question or answer has only a little contribution to the confidence of selection, it may not be very necessary to appear.
4. There are several related factors for one parameter, which are described in the relation base. For any related factor there are several possible real conditions to be specified. The system will simulate every possible condition before asking the user to specify, and find the possible greatest change in the confidence of selection by searching any match from the rule base. It will then select the most important factor, which relates to the greatest change in the confidence of selection to be the first query question to ask the user.

A useful concept in the system is the decision tree, which has been referred to in the previous section. The decision tree is a pre-set route to drive the work of the inference engine. The set of parameters, which should be specified to run a numerical model, was described in the form of a decision tree. The system automatically searches the decision tree and queries the user to specify various conditions until all the branches are filled with the suitable item of selections. This is the whole procedure of parameter selections. Some kinds of decision trees are prepared for selection of different specific problems. There are simple trees for simple problems, and typical trees for the typical problems, and the full tree including all the possible decisions for complicated problems. The system can help to produce and cut the nodes of decision tree as the query to the user is carried out. After any conditions are specified by the user, the inference engine runs to search the rule base, and calculates the new distribution of confidence for every branches in the decision tree, and then cut the impossible branches of selection (with the confidence below 20) away from decision tree. Therefore the decision tree is a route in the form of tree skeleton. It guides the inference engine to query the user and ask the user to follow it to make decision. Luckily in the computer language of Visual Basic 5.0, the control object of TreeView has many useful features for programming facilities. It is convenient to realise the functions of tree adding, tree cutting, tree searching and tree shape changing, and it is easy to display the trees on the interface.

There are two strategies in the inference engine, the forward chaining and backward chaining, to control the match of the facts and rules. Both strategies are used in the system: forward chaining searches the evidence from the query and modifies the decision tree, backward chaining searches the parameter needed to specify and finds the question to begin the query.

Figure 9 shows the relationship between five knowledge bases and inference engine. The mechanisms of inference engine to explore in the knowledge bases can be described as follows:
1). Search the decision tree to find which parameters should be specified which have great effects to the confidence of model selection.
2). Search the relation base to find which physical conditions or problem specifications are related to the parameter found in step 1).
3). Search the question base to find questions and the possible answers, and then begin to dialogue with the user to catch the fact of condition specifications.
4). Search the rule base to find any rule fired under the user’s new specifications, cut the impossible branches in the decision tree, calculate the confidence distribution for the possible selections and select the item with higher confidence and ask the user to confirm this suitable selection.
5). Report the new selection of model parameter and its confidence, report the new form of decision tree.
6). Ready to repeat from step1) to step 5) again.

Conclusion

From the beginning of the production of the fourth generation modelling system, some of the research interests has been transferred to the technology research on integration of computer technology development into the system. Here it is shown that the expert system, as a kind of AI technology, can be integrated into the model system, to provide help on the selection of model parameters. Though the knowledge base in the system is not too powerful now to include all the expertise of numerical modelling, it still can demonstrate the usefulness of expert system. The static knowledge, such as the knowledge in relation base and selection base describing the dimensions, grid, scheme, and turbulence is relatively easy to be encoded into knowledge base. The “dynamic knowledge” related to boundary condition and data input and output is relatively difficult to be encoded.

Another difficulty is the lack in the source of expertise to be encoded into the system. Most of the knowledge comes from formally published literatures. It seems that some experts’ experience cannot be written down in their papers but is very useful to be encoded into the knowledge base if personal interviews and discussions are held purposely. This kind of work is supposed to be able to do some day under the help of wide range investigation by Internet.

Verification and validation are always needed for any simulations or models. AI application in the numerical modelling is particularly difficult to be verified. It is because there are few methods and resources to test whether or not the effectiveness of modelling is raised under the help of the system and to what extent the parameter selection is optimised under the advice of the system. Because the factor of confidence is the main control of the inference engine, testing the result of confidence transmitted under various conditions and modifying the rules of different descriptions on confidence values are the main tasks after the knowledge base has been set up. However, modification and verification still depends on the experience of the designer and the user. Some of the validation has been done in the procedure of system design. The method is usually to compare the advice with the common conclusions in literatures and famous models by inputting some similar physical conditions and testing what the system gives. For any products of artificial intelligence, the standards and methods to test their effectiveness are still difficult now.

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Table 1. The classification of parameters

Class	1	2	3	4	5	6
Name of type	Dimensions and Method	Grid	Scheme	Turbulence	Boundary Condition and Driving Force	Some Others
Parameters	Dimensions Numerical method Co-ordinate system Numerical method in vertical direction Vertical co-ordinate	Grid shape x-grid spacing y-grid spacing Vertical grid spacing Grid uniform or not Type of point setting	Advection term Explicit or implicit Stability Error of scheme Alternating direction or not Algorithm	Turbulence model Vertical eddy viscosity Horizontal eddy viscosity Vertical eddy diffusion Horizontal eddy diffusion Bottom drag coefficient	Wind at surface Tide at open boundary River discharge at open boundary Value and variation at open boundary Value in close boundary Variation in close boundary High order variation in boundary	Coliolis force Geometry Bathymetry Initial conditions of elevation Initial conditions of current Initial conditions of water quality

Table 2. Possible specifications of the user

Problem specification	**Physical conditions**	**User's experience of using model**
Storm surge	Water depth	Stability of scheme
Tidal propagation	Vertical density variation	Accuracy of scheme
Salt water intrusion	Vertical current variation	Effectiveness of scheme
Waste water discharge	Geometry complexity	Grid formulation
Hot water discharge	Vertical mixing	Turbulence model and vertical variation
Tidal dynamics for sediment transport	Longitude and latitude of location	Initial condition
Source and sink of water and properties	Existence of river	Accurate representation of the driving forces
Water exchange between water bodies	Tidal elevation comparing to depth	Open boundary at surface
Turbulence effect research	Horizontal space scale	Open boundary at river end and ocean end
Coastal seasonal current structure	Time scale	Interaction of boundary conditions if adjacent to each other

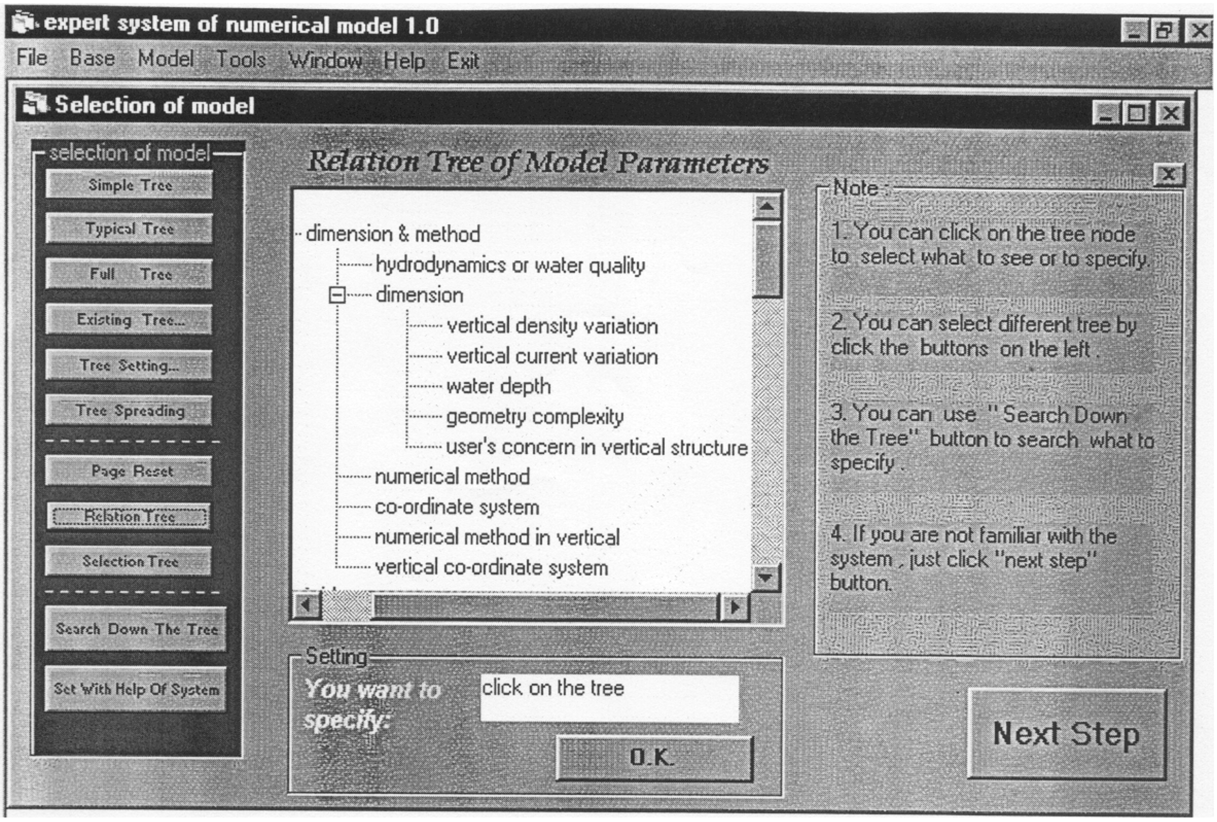

Figure 1. Screen showing part of the relation tree of model parameters

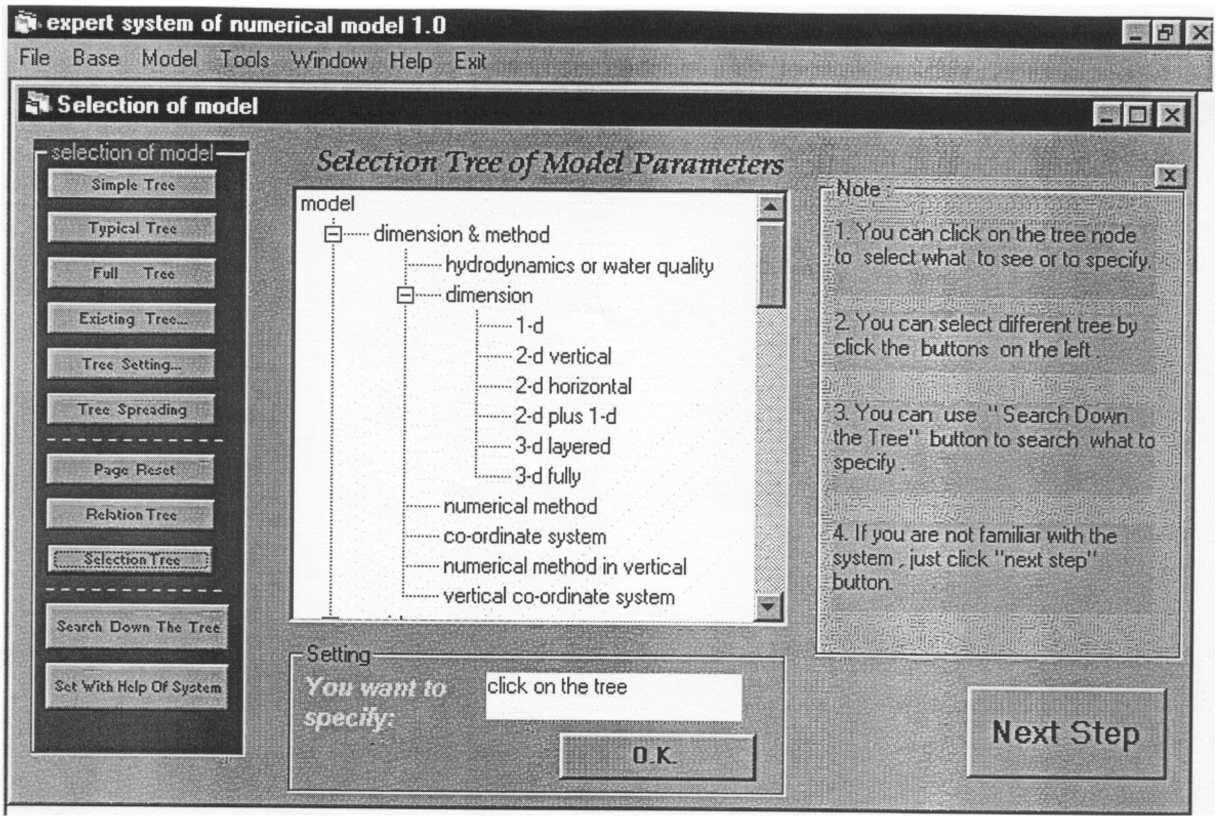

Figure 2. Screen showing part of the selection tree of model parameters

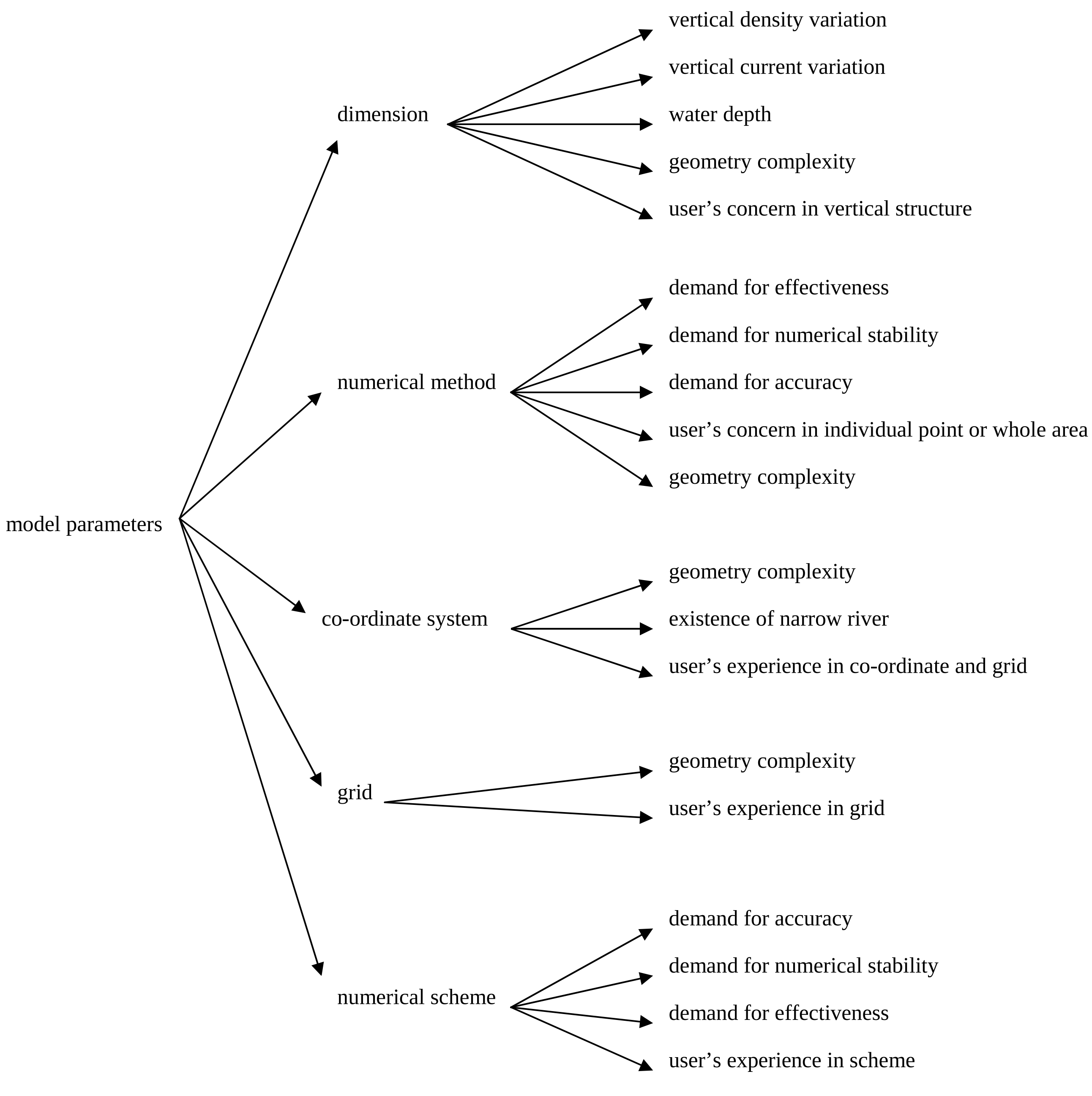

Figure 3. Part of the relation tree of model parameters

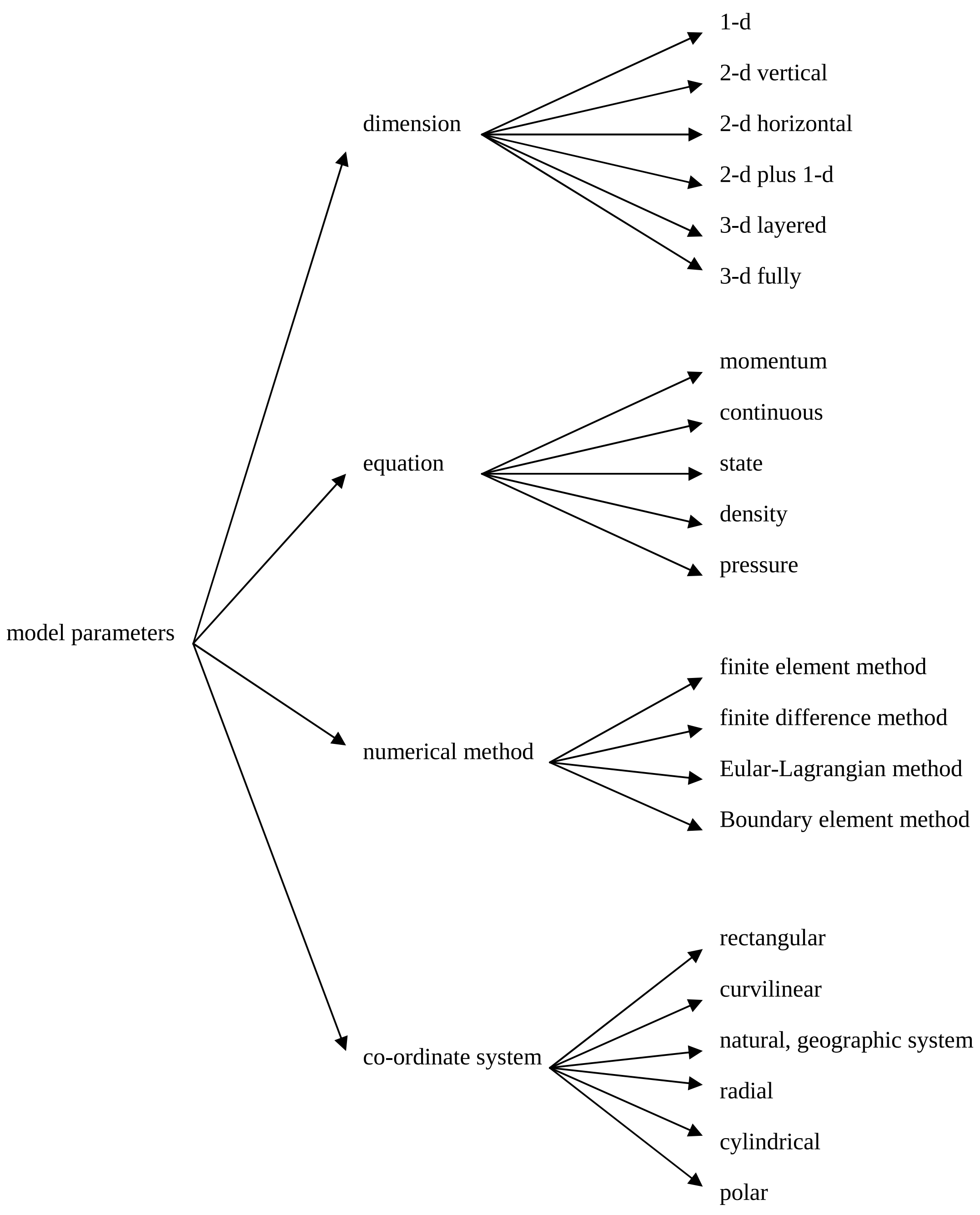

Figure 4. Part of the selection tree of model parameters

Figure 5. Part of the question tree of model parameters

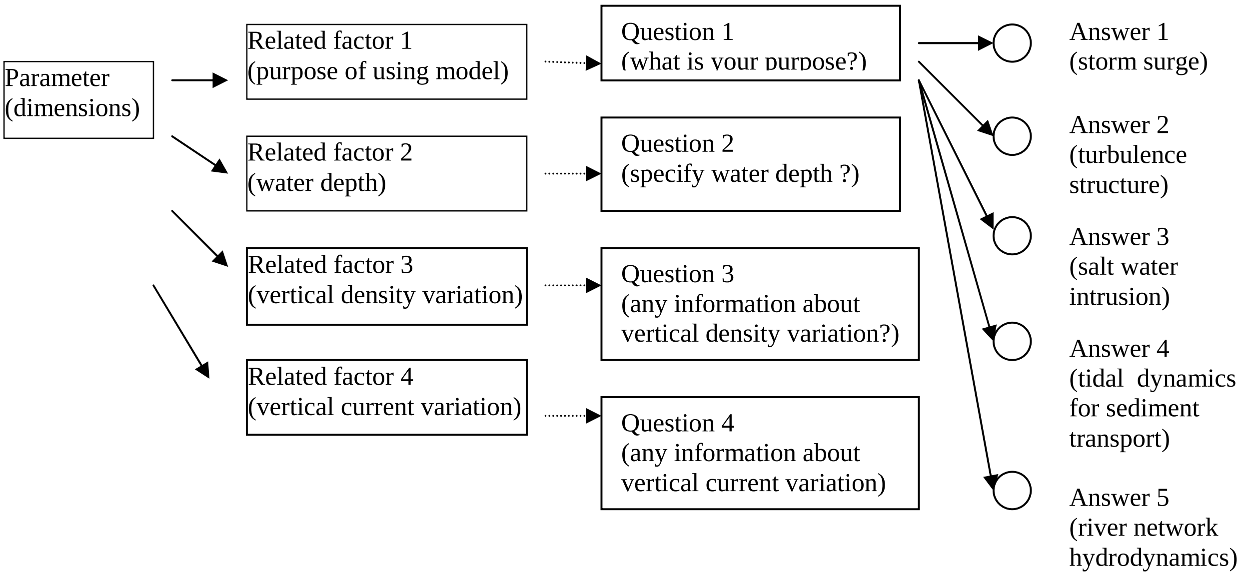

Figure 6. An example of the inference direction from a parameter to questions and answers

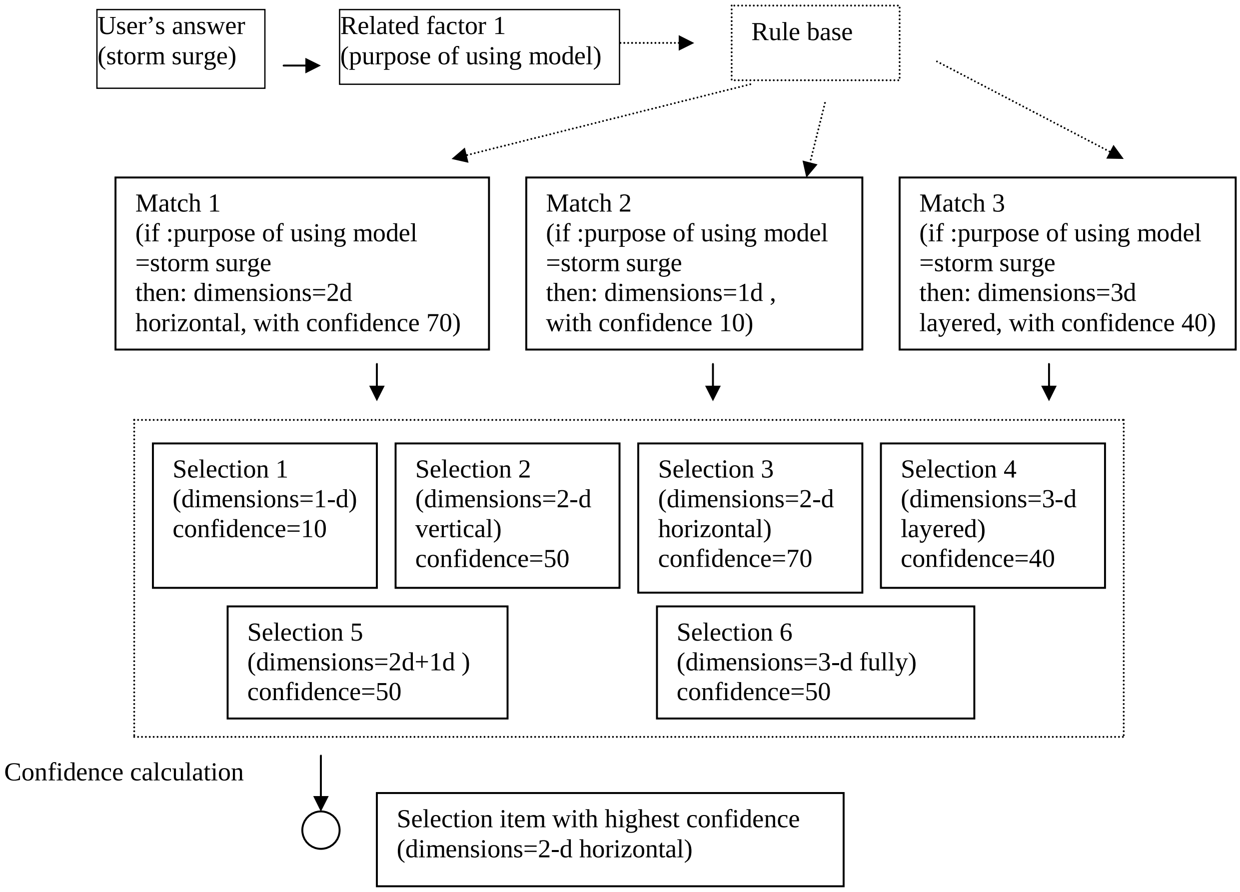

Figure 7. An example of the inference direction from the user's specifications through the inference engine

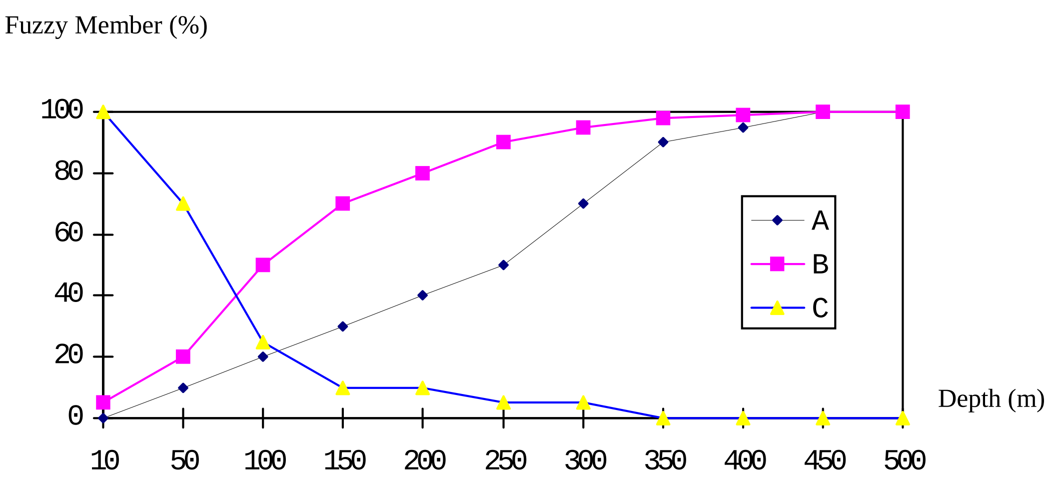

Figure 8a. Fuzzy description of the water depth (A---very deep)
(B---deep)
(C---shallow)

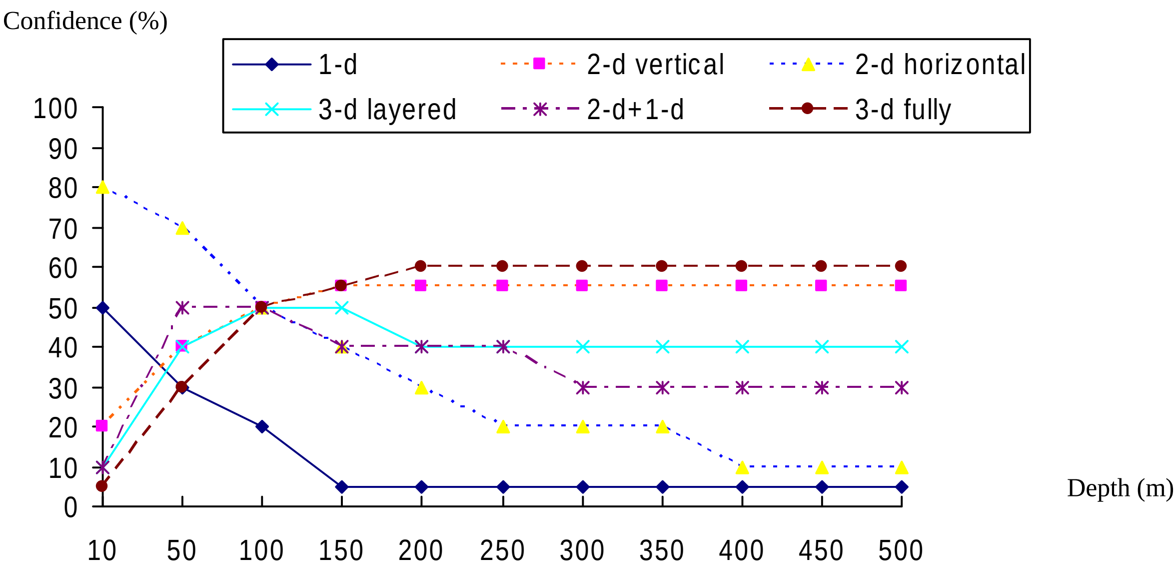

Figure 8b. The confidence of six possible selections of dimensions under the condition of depth

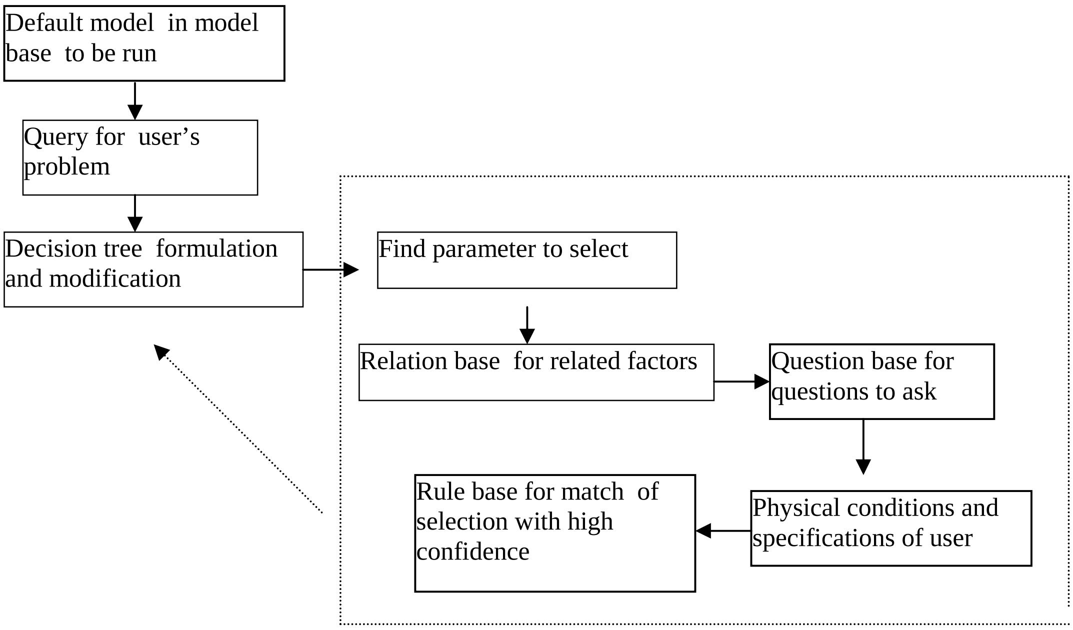

Figure 9. The relationship between knowledge and inference engine