SSKM: A TOOL TO IMPROVE SPATIAL DECISION SUPPORT ABILITY OF GIS

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ABSTRACT:

Spatial decision support is an important research area of spatial information science and should be an integrated function offered by GIS (Geographical Information System) software. It has been proved that many spatial problems are semi- or ill-structured and cannot be solved by traditional GIS that has no domain knowledge support. It is highly desired to include the theory of knowledge management with the intention of improving GIS spatial decision support ability. Integrating spatial information management and human or domain knowledge is an essential way. This paper proposes the concept, principle and method of Structured Spatial Knowledge Management, or SSKM, an effective domain knowledge management method Compared with non-spatial knowledge, spatial knowledge, as its name indicates, is defined here as a kind of geo-referenced knowledge that is location-specifically applicable. Centered on structured knowledge representation (or SKR), SSKM offers a comprehensive platform capable of expressing a clear and uniform spatial knowledge views so both knowledge access, knowledge utilization and knowledge-based spatial reasoning become easier than represented in other ways. In this way semi- or ill-structured spatial problems solving based on existing spatial/non-spatial knowledge and general spatial analysis functions usually identical to GIS can be collaborated seamlessly to generate understandable spatial decision results. As the center of SSKM, SKR is a hybrid knowledge representation strategy that combines object-oriented and rule-base knowledge representation, while domain analysis is the first step to extract conceptual and logical knowledge framework so SKR representation can then be implemented. An integrated unit of knowledge-based spatial reasoning and GIS named GIS distributed intelligent agent, or GIS-DIA, is proposed as an embodiment of this research. GIS-DIA aggregates both data, knowledge and general GIS functions, and thus offers both knowledge support and GIS function to complete certain geo-referenced problems. Related GIS-DIAs usually collaborate together to solve semi- or ill-enhance problem. In the end a case study in agriculture decision-making is given. After domain analysis of possible decision classification and required knowledge, GIS-DIAs are designed and developed that are able to identify proposed problems and give a corresponding decision result to each problem.

1. INTRODUCTION

Spatial analysis for both spatial and attribute data to support the decision-making activities of the organization (Grimshaw, 1994). Since the Canada Geographic Information System or CGIS, generally acknowledged as the first GIS system, was developed to help solve environmental problems (Peuquet, 1977), the use of GIS for analysis, modeling, and decision support in a wide range of application areas has been growing very rapidly and applications as mapping, monitoring, decision making, and research benefit greatly from the GIS technology. The past several decades have seem an explosion in the technological base for those systems, particularly in the areas of spatial data processing, but one recent trend in the evolution of the GIS technology is the inclusion of artificial intelligence into the GIS design and operation (Smith, 1984). The value of knowledge integrated in GIS can be summarized as following three points.

- Intelligent spatial reasoning
- Introduce how to use the system through graph-based user interface
- Model selection in particular field

Goodenough etc. (1994) researched on queries and their application to reasoning with remote sensing and GIS, which actually generates a series of processes that are arranged through expert knowledge organized in logic formalized rule or case-based reasoning. Spatial decision support system (SDSS) is just a direction that integrates knowledge in making GIS-based decision to solve Ill-structured or semi-structured problem and has attracts hot focus (Tarantilis & Kiranoudis, 2002; Vacik & Lexer, 2001). In a knowledge-based spatial decision system, a decision-making process is regarded as a series of steps that interpret a given problem and form a problem-solving sequence.

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In this process, the former step prepares input information for the next step and so on until the ultimate result is got. One important factor that stimulates this process is domain knowledge, or knowledge that is particular to a certain field usually grasped by expert. When the knowledge is stored and managed in a GIS system, it can be accessed and utilized by system to give expert alike decision support so the result will be more valid. In this point, knowledge management in GIS, or spatial knowledge management, is very important. This paper will research on spatial knowledge management and propose a mechanism to integrate domain knowledge with the aim of improving the spatial decision support ability of GIS. The base for spatial knowledge management is Structured Spatial Knowledge Management (or SSKM), and the implementation of this base is GIS Distributed Intelligent Agent (or GIS-DIA).

2. OVERVIEW OF GIS

2.1 GIS and Spatial Decision Support

For a long time maps have been major sources of information. In the simplest analysis, GIS are specialized database management systems, displaying maps on the computer screen, performing queries and joins between records based on spatial location, and general computing skills (West & Hess, 2002). While in a wide sense, GIS use digital data, elevation models, satellite images, expert systems and related open source information for planning, detection, evaluation and decision-making (Benedikt, etc., 2002). In many ways, the history of GIS use for managerial decision-making has mirrored the history of MIS and DSS, although with a lag of one to two decades (West & Hess, 2002). So spatial models are integrated in GIS and make it possible for GIS to complete some complex tasks as spatial decision support rather than merely spatial data management (Zerger, 2002). Dragan etc. developed GIS-based spatial decision support system to study soil erosion (Dragan, etc., 2003). GIS are increasingly being used for decision-making, yet it is still not enough to solve semi- or ill- structured decision problems that own the character of fuzziness and uncertainty. This makes the study on knowledge-based GIS interesting to researchers (Cohena & Shoshany, 2002; Yamadaa, etc., 2003). In general, a merger of GIS and expert system technology is called an intelligent GIS (IGIS) (Coulson, etc., 1991). The advantage of IGIS is that the system resulting from the merger of expert system and GIS technologies can make use of the particular strengths of each type of software. Vayssieres, etc. developed state-transition paradigm software of IGIS for rangeland impact assessment (Vayssieres, etc., 1993). In this case, the strong point of GIS software is in the aptitude for efficiently implementing and displaying databases of state variables associated with spatial arrangements of landscape units. The strength of expert system software is its ability to generate transitions from one state to another, using "if-then" rules as a natural representation of expert knowledge about these transitions.

2.2 Limitations and Shortages

It is usually believed that the volume of data used in GIS, the number of diverse data sources, and the spatial relationships among the data add to the complexity of the GIS environment (West & Hess, 2002). Spatial analysis models once proved to be difficult to integrate seamlessly in GIS, but with the effort of continuing research on GIS, it now seems not a matter. The booming of GIS development in recent years, however, imposes other difficulties. The obvious factor that discounts GIS in actual application is its capability in solving the ill-structured problems. Those ill-structured problems are like the following:

- Which way is fastest (not shortest) if we go to Shanghai from Bejing?
- Where should an urban facility be best located?
- What effect it will have if this place is over-populated?

The first question considers the character of road that lead from Shanghai to Bejing, so it is necessary to take character of road like the smooth, the width, not just the length of the road. The second question seems easy to be solved by traditional GIS spatial analysis function of layer overlay. However if we want further to evaluate the analysis result, it is impossible without spatial aid of domain expert and so is question 3. Conclusion can be drawn that GIS, even facilitated with effective models, cannot tackle all spatial problems. This leads to the need of integrating domain knowledge with GIS. (Strore & Kangas, 2001).

3. SSKM

3.1 Knowledge Representation

Knowledge Representation (KR) is a central problem in Artificial Intelligence. Three requirements must be met for computer in order to solve problem: the problem can be formalized, algorithm for calculation must exit and the algorithm should be valid. For semi- or ill-structured problems, KR is the middle device for formalizing all various problems. In order to meet the three requirements, it is necessary to symbolize actual implication with digital symbols and restore the digital symbols into actual implication after calculation. Those digital symbols are the basic elements of KR. Just like human language and body action or all kinds of medias to transmit thoughts or exchange feelings, KR is the unique way to realize the knowledge transition from human to machine and guarantee knowledge utilization in different parts of a machine. As for SDSS, knowledge acquisition, knowledge utilization are based on KR.

3.2 Structured Knowledge Representation

3.2.1 Spatio-temporal Character of Knowledge

Knowledge traditionally is regarded as an abstract concept that itself has no spatial or non-spatial character. In geosciences, however, spatial knowledge usually refers concept, description or feature of spatial relation, spatial distribution or feature of spatial entities. That knowledge is spatially connected and is able to help understand spatial regulation and spatial information, and change spatial state, thus is different from the general concept of knowledge and referred as spatial knowledge here. Spatial knowledge itself is not spatial entities, yet it is composed of spatial characters in its attribute. Thos characters are derived or abstracted from spatial entities and this explains the intersection of information representation between spatial knowledge and spatial entities. This means spatial knowledge and spatial entities are closely bound together, which places the base for the possibility of GIS Distributed Intelligent Agent or GIS-DIA. In addition, knowledge managed in SDSS is time connected and is valid only confined in certain time. The closely combination with spatial entities and time reference, which is called spatio-temporal character, stands for the key features of knowledge in SDSS. Although traditionally overall validity in all processes and no time limitation are the general consideration of knowledge-based system, it is necessary to take the spatial-temporal character of knowledge in SDSS in the process of knowledge acquisition, representation and utilization.

- Time reference of knowledge in SDSS

This indicates knowledge can be modified by time. For example, the knowledge "it does not snow in spring in Wuhan" is time confined by "in spring". If this omitted this knowledge will be invalid.

- Spatial character of knowledge in SDSS

Spatial character of knowledge is also indicated that knowledge should be spatially modified. In the above the knowledge "it does not snow in spring in Wuhan" is also confined by "in Wuhan", not other place. If this place is omitted, this knowledge will become "it does not snow" and obviously is not complete. This character can also be said to "it is very hot in southern China in summer".

The knowledge aiding spatial decision in intelligent SDSS includes the spatial knowledge and the traditional domain knowledge which is overall valid in all processes in a decision making task. As for the former one, it should specially gives the spatial and time modification in knowledge representation and knowledge retrieval. Without those modification (this is also the default) the knowledge will be regarded as overall validity.

3.2.2 Model of SKR

A unique knowledge representation usually cannot meet the need to effectively and efficiently represent varied knowledge.

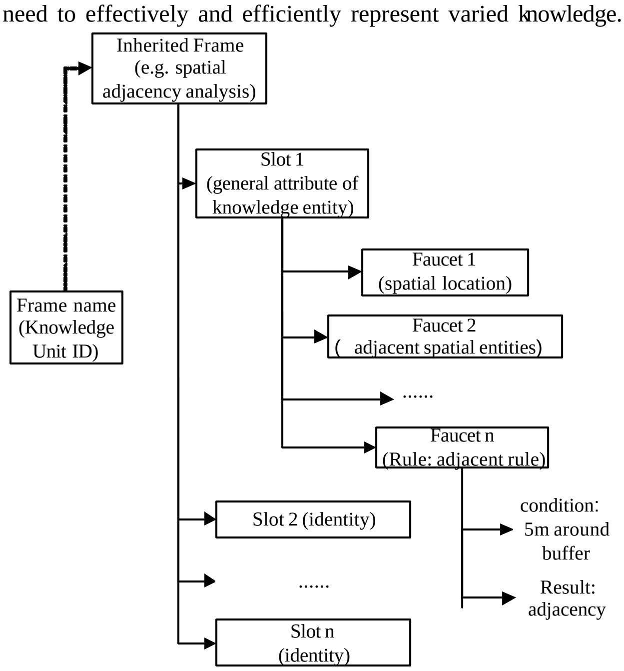
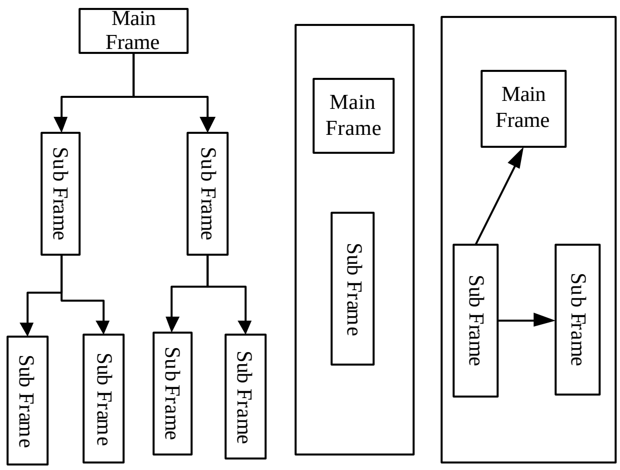


Fig.1 Structural Model for Spatial Knowledge Representation Based on SKR Representation

Structured Knowledge Representation or SKR is a hybrid knowledge representation method that integrates frame-based and rule-based knowledge to represent spatial knowledge, with the frame-based method as a skeleton. A rule-based knowledge base also known as production rule and is used to represent domain declarative knowledge, modeling procedures (methods of formulating, executing and interpreting models) and model calling sequences connected with model base and solver base. A knowledge frame thus can be considered as a generalized framework describing all properties of a model and interactions among models. It is composed of a number of slots and each slot has some faucets to further describe the detailed features of the frame. A frame-based knowledge representation is able to describe spatial knowledge or spatial entities and their relations, and constructs a complex knowledge network system with unit object as its node and the relation between those nodes as its arcs. Here unit object is an abstract concept and can be spatial knowledge or entities. In SKR, frame constructs the skeleton of the structured knowledge system in SDSS, while rule-based representation constructs slots of the frame. A frame slot can hold several knowledge rules. The rules in a knowledge frame are also able to relate with other frames and by this way, the knowledge network system is organized. Figure 1 is conceptual model of SKR. In this model, frame can inherit feature from its father frame. Faucet in slot of a knowledge frame can be outside method (getting location of a spatial entity), or other knowledge frame. Faucet can also be domain rule. In all SKR offers knowledge information and relation information with outer entities and the corresponding method for getting the information.

It has been shown that frame-based method has great power to represent complex knowledge; it has no power to relate different frames. Due to the complex spatial relations between different spatial entities, it is a necessity to extend connection mechanism of frame-based knowledge entities. Here three connections can be established between different frames. These connections are: implication connection, explicit connection and implicit connection. Implication connection is an inherit relation between two frames and is implemented when a frame is designed to inherit the structure of another frame (father frame) (Fig. 2(a)). Explicit connection is also named as conclusion connection. This connection is established when a knowledge frame is designed to have the ability to include another knowledge frame as its



(a) implication connection (b) explicit connection (c) implicit connection element (Fig. 2(b)). Both implication connection and explicit connection between knowledge frames are forceful. The last connection, known as implicit connection, is established by productive rule defined in frames (Fig. 2(c)).

In order to represent spatio-temporal character of knowledge in SDSS, it is necessary to define spatio-temporal (Spatial and Time, or ST) suitability of knowledge to make knowledge valid. As for time, SKR using a time period with starting and end points can be expressed in Abstract Data Type (or ADT):

```
ADT ST_T {
    Methods:
……
    Property:
Time t1;
Time t2;
} ST_T st_t
```

st_t is the entity that defines the time condition for knowledge. As for spatial suitability of knowledge, SKR defines a spatial suitability function S with spatial point as its parameter:

S(x, y, z) ¦ V

Where x, y, z are the location of a spatial point, ¦ is a defined relation, and V is a constant. Spatial points that meet the above equation is called spatially suitable point set and this defines spatial condition for knowledge. The structure of a suitable spatial point is defined in ADT as:

```
ADT Point {
Methods:
……
Property:
float x;
float y;
float z;
}
```

Based on suitable spatial point, the structure of the spatially suitable point set is defined in ADT as:

```
ADT ST_S {
Methods:
……
Property:
Point[] &pt;
} ST_S st_s
```

Where st_s is the abstract spatial condition of knowledge. It is not difficult to include spatio-temporal character of spatial knowledge in SKR since ST_T and ST_S are object-oriented formed that makes it easy to be included in knowledge frame.

In the slot of frame-based knowledge in SKR, some methods, which encapsulate strategies of reasoning, are concluded and thus it is not necessary to construct independent reasoning machine to control reasoning progress. The activation of those methods is the center of the realization of spatial reasoning. The sequence of reasoning is outlined by the activation sequence of those methods and how to control the activation sequence should be properly designed. Controlling frame, which realizes the control of reasoning process, is separated from interface frame and problem solver frame in SKR. The principle of the reasoning process is value filling and comparison. The general process is: interface frame initialized and accept request of user to fill the slot value, certain method in interface frame initialize controlling frame according to the filled value; controlling frame fills the value of its slots and initialize a problem solver frame, which describes the condition of the problem, according to the state of the controlling frame. The problem solver frame fills the slot and compares its slot value to determine the next step and so on (Fig. 3).

3.3 GIS Distributed Intelligent Agent

There exists two traditional ways of integration GIS with knowledge-based system. One commonly adopted approach is planting knowledge-based system originally developed for operation research and management science inside GIS. Another approach is the adoption of GIS knowledge-based system. The above two ways cannot offer seamless integration and thus is not efficient in realizing spatial reasoning. In SSKM, GIS Distributed Intelligent Agent or GIS-DIA is proposed and makes it easy to integrate GIS functions with knowledge-based reasoning.

3.3.1 Basic Character of GIS-DIA

☐ Integrating data, knowledge and methods

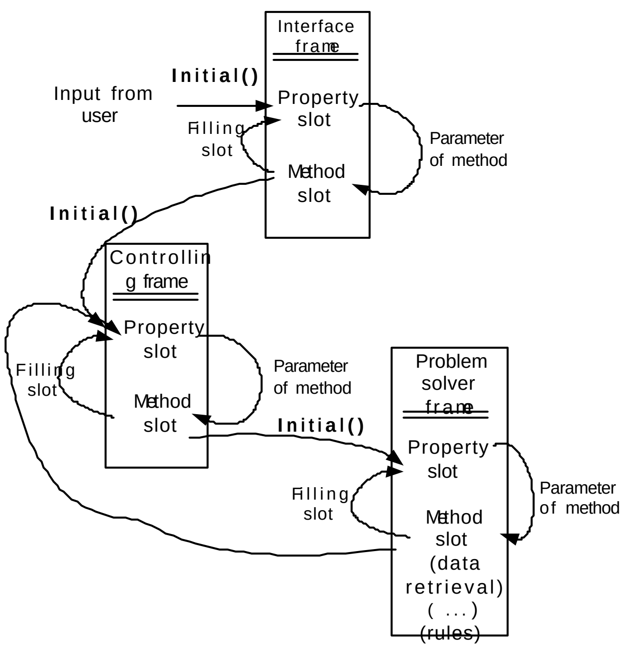
GIS-DIA is an internal independent entity with full functions, usually comprised of spatial data, decision knowledge and calculating algorithms.

☐ Functions realization invisible to external entities

Functions of GIS-DIA are outer embodiment of its methods, which may include private and public methods. Private methods are used by the entity itself while external methods can be accessed by external entities.

☐ Message transmission mechanism

The interaction between GIS-DIAs has two ways: direct access and indirect call through message transmission. Direct access is derived from the principle of object-oriented software design and is introduce here to solve most point-point communication, and indirect communication not only has the ability to obtain point-point communication but also excels at broadcasting, informing a series of related GIS-DIAs to act or cooperate. Thus broadcasting is especially suitable for complex spatial analysis and tasks that has no requirement of synchronous action. We will discuss the latter in more detail in the following section.



□ Hierarchical structure and multi-classification

GIS-DIAs is organized hierarchically and can be classified into several groups. In general, GIS-DIAs is grouped into controlling type and functional type. Controlling GIS-DIA is the core frame that uses domain knowledge to determine the functional GIS-DIAs working sequence while functional GIS-DIAs encapsulates spatial data, spatial analysis (models) and reasoning functions that is able to deal with concrete GIS-base analysis and knowledge-based reasoning. The division, however, is relative since some GIS-DIAs not only has controlling use but also functional use.

□ Collaboration

A spatial decision task is usually very complicated and cannot be solved by a single step or a single GIS-DIA. Collaboration is essential in accomplishing the desired task. As described in the hierarchical structure and multi-classification, functional GIS-DIAs are controlled by controlling GIS-DIA and complete their functions when specific work comes.

3.3.2 Component of GIS-DIA

GIS-DIAs is comprised of 3 basic objects: spatial entity object, knowledge disposal object, and universal object. Spatial entity object is a class model that has the feature of spatial entity (location, geometry features, etc.) and spatial operation as intersection methods with other entities, spatial relation detection methods. Knowledge disposal object is specified with the function to deal with knowledge reasoning, object selection and model selection, which will make a spatial decision task solving process fluent. Universal object, as its name denotes, is designed for common problem as data management, knowledge maintenance and some middle result serialization. A GIS-DIA can be built on any of those objects or conjunction of those objects.

□ Spatial Entity Object

Object-oriented data model has been developed and can be used to organize GIS data distinguished by its geo-location character. This model is similar to our view upon the world organization, esp. in the geographical domain. A river is a spatial entity and so is a parcel of land. Those entities then will be abstracted into polygon object, line object, point object, and composite object based on the former ones. In a GIS application, data organization is very import to fulfill its functions. Those data is represented as spatial entity objects, complex topology and geometry relation constructed by those objects. Because the object-oriented data model encapsulates data (object attributes) and the operation upon those data, spatial objects abstracted from spatial entities facilitate inter-operation, inter-calculation and function reference with other entities. Safety and integrity for a entity can also be guaranteed. Spatial entity object usually servers as base object for GIS-DIAs. Besides spatial entity object, spatial data has special information called meta-data, which offers basic information for spatial data retrieval through the logical information existing among in spatial entities and thus makes spatial data access easier. Meta-data is again organized in object-oriented model and those meta-data constructed objects about spatial entity objects are also included as spatial entity object. Spatial entity object is an import base class for GIS-DIAs.

□ Knowledge Disposal Object

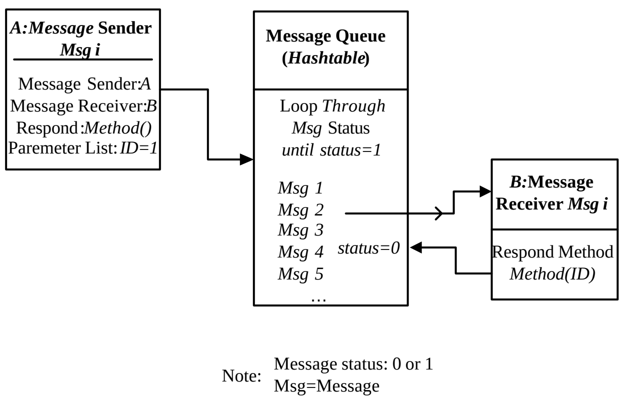
Knowledge disposal object is a knowledge unit that includes knowledge access methods and knowledge-based reasoning methods for semi- or ill- structured problems solving. In spatial decision analysis, domain knowledge of a certain area is a key factor in solving those problems although spatial data is an important system input in decision-making. This can be noticed in an individual decision-making. A group of individuals may make different decision for a given problem even they have the same data input while own different background domain knowledge. In a SDSS, domain knowledge relating to decision areas should be well organized. In a GIS-DIAs based SDSS, domain knowledge is organized and represented in SKR, and knowledge reasoning is processed by a series connecting knowledge disposal objects.

□ Universal Object

Universal object library is a group of object collection independent of the above two types of GIS-DIAs, providing assistant functions as problem recognition, result output. Universal object is a kind of object integrating data model and methods, with a dynamic library offering common functions complex spatial calculation and knowledge reasoning.

3.3.3 Interaction of GIS-DIA

Message mechanism is important in interaction of GIS-DIAs. Spatial reasoning is based on collaboration of related GIS-DIAs objects and message mechanism founds the driven engine for their cooperation. In the process of communication among GIS-DIAs objects, each object has both message sending and receiving ability. If a GIS-DIA sends message it is called message sender, and so a GIS-DIA receives message it is called message receiver. A message-controlling queue is established between message sender and message receiver to control their action so the two ends can act asynchronously. When a message sender plans to send a message to inform its collaborator, it first register the message in the message-controlling queue, a special data structure which holds all waiting messages to be responded. Message structure is composed of 4 parts: message sender, message receiver, responding method, and parameter list. After a message is created, it is verified by message controlling object before it is passed to the message receiver. Besides determining the priority of the waiting messages, the message controlling object have the following possible choices: ? pass it directly to the receiver; ? message or message receiver is amended before it is passed to the receiver; ? message is blocked before it is passed the receiver due to a non-existing receiver, non-existing method, or the sender has no power; ? message is broadcast to a



certain kind of objects. Figure 4 is the designed framework showing the interaction of GIS-DIAs. Message queue loops through messages' status to find those messages that the message status is in the waiting state (status=1) according to their priority. After the message is passed to the destination receiver, the status state is changed into history (status=0). Message queue is the control center for message distribution for GIS-DIAs.

3.4 Knowledge Retrieval

Knowledge retrieval, which has been researched many times, is prerequisite in knowledge access and utilization. It is possible to construct structured knowledge query language by extending the traditional skeleton of structured query language (SQL) to facilitate knowledge query for system user or system modules (Fensel et al., 1998). Currently some successful cases about retrieval language have been studied by extending the traditional structure query language for relational database. TQUEL, TOSQL, HSQL and G/SQL for example is the extension of QUEL and SQL to tackle time tamped, dynamic and spatial object and knowledge retrieval language is actually a protocol established between user (system) and storage device and relates the conceptual level and executable level (Fensel et al., 1998).
KQL (Knowledge Query Language), which is based on SKR, is proposed here. KQL not only realizes the need for knowledge location and access but also makes knowledge updating possible. KQL bridges the connection between user and knowledge base system and packs the user query which is built by graphic user interface and again translates the knowledge object which is returned by knowledge base system into understandable form. KQL has the following characters: (1) compact syntax; (2) well defined semantics; (3) sufficient expressive power; (4) effective reasoning power; (5) suitable for constructing large knowledge database. KQL system is composed of 3 parts: grammar analyzer, language translator and wrapper of knowledge object (Fig. 5). Grammar analyzer is responsible for user or system tasks' query and verifies its grammar format. If it is verified it will be passed to language translator otherwise it will be refused to the next step. In this step, grammar analyzer checks the validity of key operations, the validity of condition element and the validity of condition connector. The key operator in knowledge management includes insert, delete, update, and select. Condition element is the attribute field of knowledge object and condition connector is the connector that connects multi-condition elements. Grammar analyzer verifies every condition element and its name, which is much like the logical expression contained in SQL as like, >, <, etc.. The condition connector is the reserved word in KQL that is used when a knowledge query condition contains more than one condition element. Both condition element and condition connector are called query primitive (QP) in KQL system. Language translator servers as the translator between verified user query or system tasks and SQL and those SQL can then be sent to knowledge database that may be organized in relational database to complete knowledge access or update operations. Knowledge object wrapper take charge knowledge object wrapper returned from the result of knowledge query and those wrapped knowledge objects should be validated by grammar analyzer before it is passed and understood by user or used in solving system tasks. From the above analysis, knowledge retrieval is trigged by two ways. One is the user query through graphic user interface, the other is system application lever that need knowledge support for reasoning.

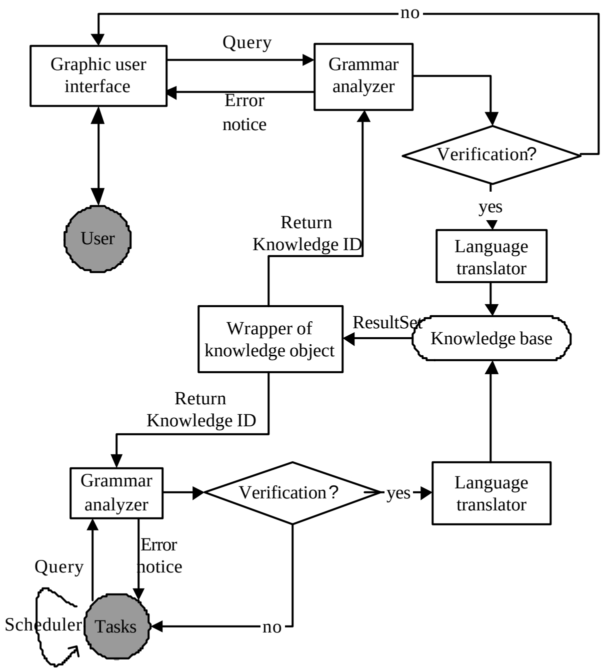


Fig. 5 General Structure of Spatial Knowledge Retrieval System

4. DOMAIN ANALYSIS

Domain analysis is aimed to classify the GIS-DIAs into domain need and generally those GIS-DIAs can be reorganized into interface objects, controller objects, storage objects and logical objects.

- Interface objects

This kind of objects realizes user interface model for integration system. Interface object is a set of GIS-DIAs and can send function message selectively to controller objects and receive result from other objects for understandable graphic expression.

- Controller objects

Controller objects realize the overall controlling for storage objects (including spatial entity and knowledge objects) and logical objects. It determines the executing sequence of storage objects and controller objects. A user task can be processed by a set of grouped storage objects and logical objects according to the message type and message content

- Storage objects

Storage objects are responsible for storage operation for spatial entities and knowledge entities and receive message from controller objects and logical objects.

- Logical objects

Logical object is the key component in a SSKM and GIS integrating system. It receives message from controller objects to complete various kinds of knowledge-based spatial reasoning on

one hand, and returns the reasoning result to interface objects for visualization or storage objects for serialization. Spatial reasoning based on domain knowledge should be designed in logical objects and calling of calculation models in SDSS is also the primary functions offered by logical objects.
The relation of GIS-DIAs through domain analysis is shown in figure 6.

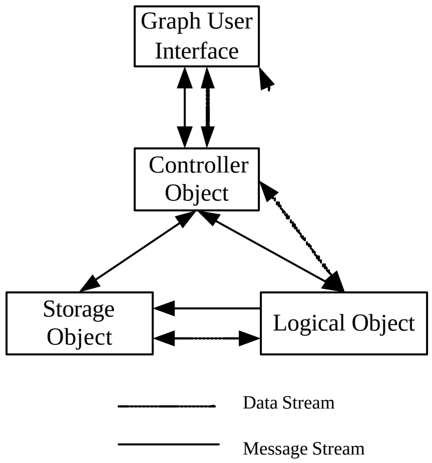


Fig.6 Relations Between GIS Intelligent Objects

5. CASE STUDY

In this case study, a prototype application named Field Fertilizer Diagnosis System or FFDS developed by Java language is built which has intelligent response to user's problems transmitted through the Graphic User Interface (GUI). FFDS delivers spatial decision support information or decision support tools to an agriculture field manager using a ''thin-client'' Web browser like Netscape NavigatorTM or Internet ExplorerTM. The GIS-DIAs are classified and designed as javabeans, collaborating together to solve ill-structured problems. The key component in FFDS is that it keeps well the management of domain knowledge and is easy to integrate with GIS functions. Data and models can also be accessed by users at different capacities for retrieval, maintenance and analysis. Esri ArcIMS is used to publish the decision result map.
A whole process of a decision task can be divided into the three procedures: a problem input, a calculating process, and a result output. Correspondingly intelligent SDSS based on SSKM has three layers: task description layer, decision processing layer, and result layer (figure 7). The user firstly input basic parameters information of the task as a decision goal through interface objects. Universal objects in public object library then translate the task into understandable language for GIS-DIAs and send the task in form of message to controller object. The corresponding controller object accepts the message and decides what logical object should acquire relative knowledge and data to further the problem solving process. After the logical object complete its task, it returns the result in form of analysis table or diagram to public object and, if necessary, storage object will store the result into outer storage media.

Figure 7 shows the general process of decision-making conducted in a compound fertilizer application for a set of agriculture field. The system user uses the interface elements as interface menu, interface button or interface box etc. to input information as field location, fertilizer type, planted crop type. Universal object in public object library get those input information and send message to GIS-DIAs (GIS-DIA 1), and other intelligent GIS object (GIS-DIA 2, GIS-DIA 3, …) then accepts message from GIS-DIA 1. Each GIS-DIAs has its state and acts according to its status information. After several cycling process, a result table or diagram will be formed in the end.

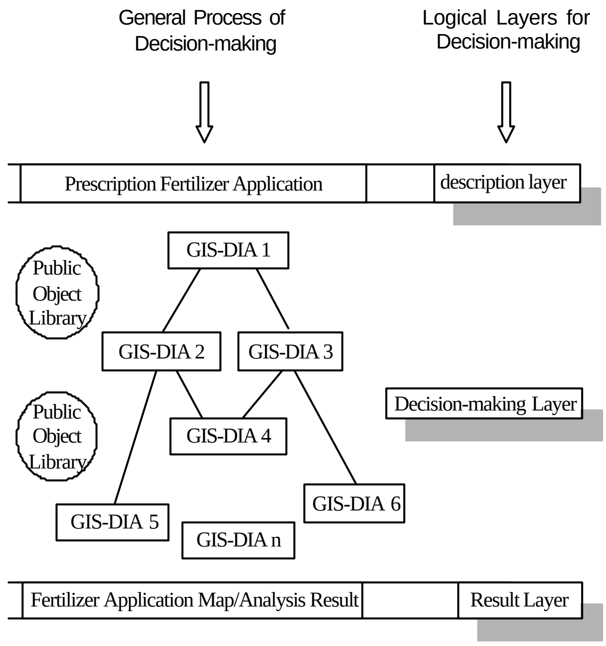


Fig. 7 Spatial Decision Based on GIS Intelligent Objects

6. CONCLUSIONS

Spatial decision support and intelligent decision-making are advanced functions that should be integrated in GIS. Knowledge, as the source of intelligent, must be used if intelligent spatial decision is to be made. This paper proposed SSKM, a tool that is able to enhance the spatial decision support ability of GIS by well managing the domain knowledge integrated in GIS. Spatial knowledge representation named SKR was studied which is an important technical base for SSKM. In addition, GIS-DIA model was also studied, which is another key technique that realizes the SSKM.
SKR was researched to make a better organization and effective retrieval of spatial knowledge in intelligent SDSS. In order to utilize knowledge it is essential to build a knowledge retrieval language to make knowledge accessible. KQL, a knowledge query language based on SKR, was proposed in this study to access domain knowledge. KQL is a formal language interface that translates knowledge semantic implication between user and

system. The structure and basic retrieval process of KQL were given.

Besides spatial knowledge retrieval and knowledge access, this paper detailed an implementation model of SSKM to realize knowledge utilization. This model, named GIS distributed intelligent object, was designed to get a seamless integration of GIS functions and knowledge-based reasoning. It aggregates spatial entities and knowledge object to construct an integrated object with the information of spatial entities, knowledge object and general methods, which makes it possible to realize the extensibility of SDSS.

In the end, a prototype for agriculture fertilizer application was analyzed to make intelligent fertilizer application with expert knowledge support under the frame of SSKM. The result shows that domain knowledge and GIS functions can be well integrated under this frame.

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