FRAME REPRESENTATION OF ECOLOGICAL MODELS IN FORESTRY PLANNING

Tao Chen Jian Kang Wu Mikio Takagi

Takagi Lab, Dept. of Electronics Engineering
Institute of Industrial Science, University of Tokyo
7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan

Abstract

How to build an image interpretation expert system and other relevant expert systems within a knowledge-based pictorial information system is an ad hoc theme in geographical information system(GIS) field. It plays an important role in building a synthetic information system and in enhancing the GIS system performance. In this article, we present a forestry regional resource planning sub-system, which uses frames to represent the ecological models and other relevant expert knowledge. With the computer aided planning module, we can give in real time the geographic data satisfactory interpretations, perform in parallel certain kind of fuzzy reasoning to obtain the satisfied decision. The results can be used to update the data stored in the information system.

KEY WORDS: GIS, Query Language, Knowledge Representation, Expert System

1 INTRODUCTION

An important part of geographical information system is computer-aided regional resource and environment management, such as city planning, agricultural planning, forestry management, and etc.. These often require system performance such as efficient storage, flexible manipulation, and intellectual usage of large amount of and variety of spatial data. However, most existing practical systems are designed from view point of geo-science. These systems emphasize cartographics rather than system flexibility and intelligence. Therefore these systems often demand well-trained operators. The exploration of the system performance depends heavily on the intelligence of the operators. Because of the system architecture, these systems are not able to support computer aided planning based om some application models. Researchers from the field of computer science have proposed some very promising ideas and designs[1,2]. Here, we present a computer aided forest planning subsystem which employes frame representation of ecological knowledge and other expert knowledges. Its reasoning process consists of a forward reasoning of Bayes classifying of Landsat imagery, a backward reasoning schema using frame representation of knowledges and a reasoning module using spatial consistency model. The system models forestry ecological information, including effects of environment, human management activities (cutting and planting), plan of forest authorities. The model is then represented as frames. The forestry inventory is then carried out by reasoning using Landsat data, geographical data from database and knowledge stored in frames. In the following sections, we first give a brief introduction to the background environment (knowledge based geographical information system KGIS), and then describe frame representation of ecological models in details.

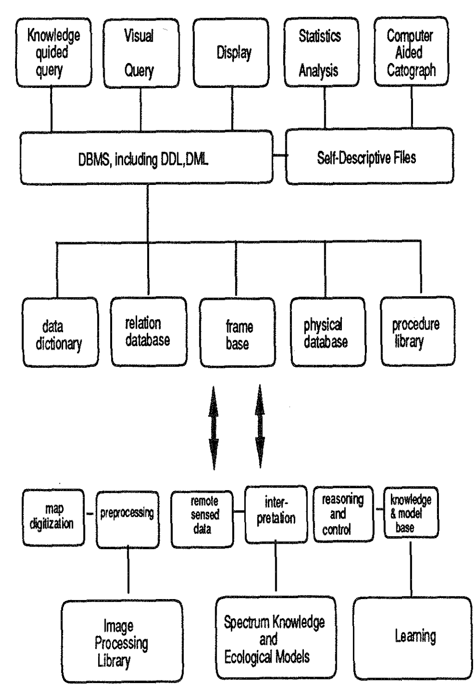

Figure 1: Block-diagram of KGIS

2 SYSTEM BACKGROUND

The system block diagram of KGIS is depicted in Fig.1. The central part is a spatial database management system. It manages relational base, frame base and physical database. The database description is stored in database dictionary. Procedures used to manipulate either logical data or physical data are stored in procedure library. It consists of relational algebra operations and image algebra operations (binary image logic operations, geometric operations, operations for spatial relationship verifications). The input module of KGIS is manual map digitization and preprocessing. All the data entries will be converted into object-oriented runlength code[8] and then inserted into the database. The query output is temporarily stored in a self-descriptive file. The statistical module and computer-aided cartography (CAC) module then produces tabular report and designs maps by using the data stored in the self-descriptive file. CAC module provides abilities for interactive map overlay design, coloring, annotation. The model-based remote-sensed imagery interpretation module and the computer-aided planning module retrieve information from spatial database by using query language primitives, process the retrieved infromation according to domain specific knowledge rules, and perform reasoning to obtain the final output results.

In the database and GIS area, research into semantic data model has led to object-oriented concepts similar to those embedded in programming language and knowledge representation language[9]. The class concept captures the instance-of relationship between an object and the class to which it belongs; the concept of a subclass specializing its superclass captures the generalization (IS-A) relationship, and the composition of an object in terms of attributes captures the aggregation relationship. The KGIS system is an intelligent GIS system which directly supports an object-oriented data model. Any real world entity in KGIS system is uniformly modeled as an object. Furthermore, an object is associated with a unique identifier. Every object has a state and a behavior. The state of an object is the set of values for the attributes of the object, and the behavior of an object is the set of methods (program code) which operate on the state of the object. The value of an attribute of an object can also be an object in its own right. Furthermore, an attribute of an object may take on a single value or a set of values.

In KGIS, a class is specified as a means of grouping all the objects which share the same set of attributes and methods. An object must belong to only one class as an instance of that class. A class is similar to an abstract data type. KGIS allows the user to derive a new class (subclass) from an existing class (superclass), the subclass inherits all the attributes and methods of the superclass. The user may also specify additional attributes and methods for the subclass. A class in KGIS may have any number of subclasses.

The combined notions of a class, attributes, and a class hierarchy mean that the semantic data modeling concepts such as instance-of, aggregation, and generalization are inherent in the object-oriented paradigm. This means that the gap between applications implemented in an object-oriented programming language and an object-oriented database is much narrower than that between object-oriented applications and non-object-oriented database. In particular, one of the problems with implementing object-oriented applications on top of a relational database system is that a relational system does not directly support a class hierarchy and the nested definition of a class, and as such the application programmers must map these constructs to relations. The gap is also much narrower than that which exists between conventional programming languages and conventional database systems. Therefore, it is much easier for KGIS to perform some particular queries such as decision-making, reasoning and model based planning.

2 Modeling process of geographical data

Comparing with ordinary ones, the term "data" here has extended meaning. The data stored in KGIS include:

Data–I Geographical data, originally represented as maps. They can be visually displayed on screen on request.

Data–II attributes of data entries. They are either alphabetic or numerical.

Data–III relational description. It may be descriptions of spatial relations, social relations among data entries, represented by some knowledge representation schemes.

Data–IV domain specific knowledge. It is used for intellectual task reasoning.

Knowledge aquisition can be accomplished through manually inputing, deriving from other data, or learning from human experts. All these types of data should be organized and stored within one database to guarantee data integrity, such that the data appear to the user as well-categorized data set rather that many individual data files. To summarize above discussion, data model of KGIS should provide a data description framework to facilitate efficient storage, easy acquisition, flexible retrieval and intellectual utilization. Landsat imagery interpretation is widely used for earth resource inventory. There has been a lot of effort made to develop techniques to investigate earth resources using Landsat imagery, either by manually reading the images or by computer processing of Landsat images. Computer methods are based on statistical classification algorithms. Classification decisions are made mainly based upon Landsat data only, occasionally with DTM (Digital Elevation Models) added as ancillary data. Although Landsat images represent the reflectance property of objects on land, due to various reasons the signature on images and the objects on land have no unique correspondency. Different objects may have similar signatures, while the same type of objects may have different signatures. This makes computer interpretation difficult and suggests that using Landsat images only may not guarantee satisfactory results. More information is needed for improving results. Consider the mechanism of reading Landsat images by forest expert. The expert makes his decision not only according to image data, but also according to his own knowledge about forest and the specific area. Geographical data include remote sensed images, geographical elemental maps (such as river map, road map, residential map, elevation map, district map, etc.), thematic maps TMs(such as land cover map, forest map, etc.), attributes and knowledges (attributes of objects, spatial relationships between objects, influences of one object over another, etc.). We obtain forest ecological models by processing geographical data in the following three aspects:

Model–I the effect of environment, such as elevation, illumination, water condition, soil condition;

Model–II effect of management activities, such as cutting, planting. This can be derived from road map and residential map.

Model–III effect of forest authority's plan. This can be represented using district map.

Illumination is a very important factor. It has effects not only on the forest distribution, but also on the gray level of MSS (Multispectral Scanner) data. Illumination is derived from elevation map. Take sun angle at the time of MSS image acquisition as reference, the illumination of a point can then be defined as the angle difference between sun incident angle and the normal angle of a small surface centralized at the point.

The effect of management activities is derived from road map and residential map. This is due to the obvious relationship between management activity and transportaion convenience. There are two ways to model management effect. One is to process point by point. For a point in consideration, the management activity is defined as the density of road and residential area within a circle area with the center at the point - the ratio of weighted sum of road segments, residential area inside of the circle area and the area of this circle. The other is to start process from roads and residential area. Consider each road and residential area as a management activity source, model its effect by a spatial function, for example, a normal distribution density function. The effects of all management activity sources are summed up to produce an overall map. The former method seems too time-taking and not as reasonable as the later. The water condition map can be derived using the same method as management activity effect map. Bayes classifier is used as forward reasoning to derive initial certainty factors from MSS images. Geographical maps can not be directly used for reasoning. A forest ecological model should be developed. By the use of this model we could derive from geographical data various ecological factors which have effects on forest distribution.

3 ECOLOGICAL MODELS

Knowledge consists of the symbolic descriptions, which characterize the definitional and empirical relationships in a domain, and the procedure for manipulating these descriptions. Many important concepts have been proposed from modern cognition science, among which perhaps the most important is the concept of the schema, or related concepts such as scripts, frames, and so on. Semantic knowledge can be logically represented in a number of ways, including production rules, semantic nets, frame and mathematic logic[4,5,7]. There has been several famous expert systems developed since M.Minsky first proposed frame knowledge representaion scheme in 1975 [6]. Frame is a large scale data structure which has been posited as playing critical roles in the interpretation of input data, the guiding of action, and the storage of knowledge in memory. Besides, frame is suitable to represent prior knowledge, or in other words, the expectation of a certain kind of objects. Frame allows procedures embeded: procedures are called automaticly to fill an empty slot, procedures can be triggered to do " expectation-driven" reasoning. Here we use frame scheme to represent forest ecological model. An example of common chinafir ecological knowledge represented by frame is depicted in Figure 2. Where, c10 is a character string of 10 bytes, i4 represents an integer number of 4 byte, IF-NEEDED is a procedure which performs the filling of certain slot, and IF-ADDED slots contain attached procedures to match values in the slots against their expectations and produce certainty factors of

```
IS-A: coniferous forest
ELEVATION:
   RANGE: 130-640M
   IF-NEEDED(find the elevation from
                  elevation map)
   IF-ADDED(matching, match slot value
               against range, update with
               degree of macth)
ILLUMMINATION:
   RANGE: 60-92(100Xcosa)
   IF-NEEDED(calculate from elevation map)
   IF-ADDED(matching)
WATER CONDITION:
   RANGE: 0-92
   IF-NEEDED(calculate from river map
   IF-ADDED(matching)
EFFECT OF CUTTING AND PLANTING:
   RANGE: 6-96
   IF-NEEDED(calculate from road map or
               value from modeling result)
   IF-ADDED(matching)
EFFECT OF PLANNING:
   RANGE: 0.0-1.0
   IF-NEEDED(look up planning table)
```

Figure 2: Frame Representation of Common Chinafir

the matching. The IS-A slot indicates the hierarchical relationship of entities, the entity can inherit the properties of its parent. In common chinafir frame listed above, there are six kinds of knowledges represented in the frame. The range slots list the expectation value of each knowledge. After filling and matching for all slots have been completed, a procedure to compute overall certainty factor is triggered. This overall certainty factor will be used to modulate the certainty factor obtained by Bayes classifier. The computer-aided planning sub-system can get data and knowledge either by direct access or through management system. It can perform the query, for example, find the best route for building a road inside the forest area based upon some domain specific knowledge or model. The computer-aided reasoning using spatial consistency model works in parallel. The spatial consistency model should be designed for each specific situation. The general form of reasoning rule is as follow: for each pixel, check its four direct neighbors (above, below, left, right). For each class i, if the classes the four direct neighbors belong to are consistent with class i, update the center pixel's certainty factor of class i by multiplying it with a value great than 1. Otherwise, update the certainty factor by multiplying it with a value less than 1.

The system provides two ways of queries: tabular query from logical description to physical data, visual query from physical data to logical description. Tabular query language(include the forest planning module) definition has the form as

$$(R_1 \dagger r_{11}=\text{a},\ r_{12}=\text{b},...).\text{OP}.(R_2 \dagger r_{21}=\text{u},\ r_{22}=\text{v},...).\text{OP}....$$

where R_i is relation name, r_{ij} denotes jth attribute of relation R_i. OP denotes an operator. It is best to use an example to demostrate the idea of forest planning embeded in tabular

query language.
Query 1: find all pieces of land suitable to plant pines cited on elevation 200M and 450M above sea level. This query can be formally represented as

Xiaoban †forest-type = pine AND.
Elevation †height ≤ 450 AND.
Elevation †height > 200

The system interprets this query as a sequence of operations: relational selection from relation Elevation(≤ 450) and (¿200), image algebrac unification of all regions after first operation, relational selection from Xiaoban, image algebra intersection between intermediate results of Elevation and Xiaoban, and frame matching using the condition "suitable to plant pines". Query optimization is used to order the operation sequence in order to reduce query processing time.
Query 2: find the best way to build a road between area A and area B.

Road † *
District †name = A AND.
District †name = B

The system also interprets this query as a sequence of operations: relational selection from relation District (A and B), relational selection from Road, in this case, the planning subsystem will finds that there is no road already existing between area A and area B. Then, the planning sussystem invoke a calculating procedure to get the height of the two area from DTM map. There exists a cost function for building raod. the cost is determined by the length of the raod, the slope, the trees cutted for building road, and the utility of existing road. When the planning sussystem finds the best road with minimum cost, the sussystem will display the road onto the DMT map containing area A and area B, and print the compenents of cost on screen.

4 INEXACT FRAME MATCHING

In general, the image data in GIS are very large and complex, we can not consider that the knowledge base of GIS give precise and complete description of the applicational domain. This fact is important to the reasoning strategy, frame matching and other operators, we should use approximate reasoning[5] to obtain satisfying results.
The knowledge base consists of a hierachical frame subsystem F. Suppose there are N frames in F, F = [F_1 , F_2, ..., F_N]. Our goal is to find the frame appropriate to the current situation and query. The criterion of frame selection is the matching degree CF derived from slots maching degree. We associate certainty factors with the conclusions of inference rules and procedures attached to each facet of the slots, the number associated with conclusion could be in [0, 1], that represents certainty in the system. If the head parts are themselves uncertain, the number associated with conclusion is modified to account for the uncertainty of its premises. We refer them to degrees of belief. Two functions are used for the frame matching: a slot matching function SMD and a facet matching function FMD. All facet values obtained from procedures calling are matched against the RANGE values for the same slot. The nearer the facet value to RANGE, the larger the number FMD. The facet matching degree FMD is defined mathematically as follow:

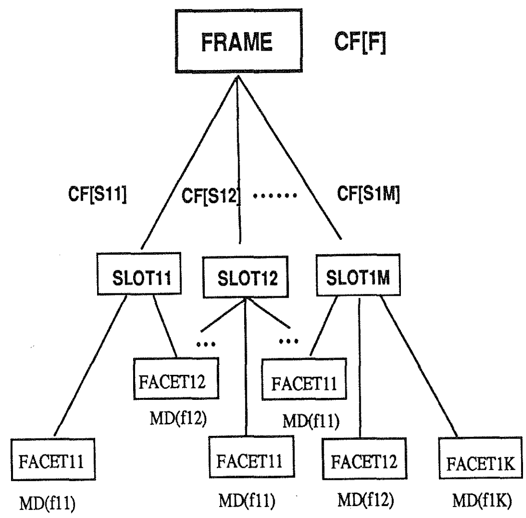

Figure 3: Control procedure of frame selecting

$$FMD(facet) = \frac{|VALUE - RANGE|}{MAX(VALUE, RANGE)} \quad (1)$$

Where, RANGE is the expected value of facet, and VALUE is the computing result of attached procedure.
We can see that:

$$0 \leq FMD(facet) \leq 1 \qquad (2)$$

Suppose there are K_j facets in the slot S_j ($S_j \subseteq F_i$, j=1,...,M_i), the matching degree of slot S_j is defined below:

$$SMD[S_j] = \sum_{k=1}^{K_j} WF(f_k) * MD(f_k) \quad (3)$$

Where WF(f_k)(k=1,2,..., K_j) is the discrete weight for facet f_k,

$$and \qquad \sum_{k=1}^{K_j} WF(f_k) = 1$$

When SMD[S_j] is greater than a threshold value, said T_s, the slot S_j provides evidence for the triggering of frame F_i, frame selecting is based on function CF[F_i] of frame F_i , the weighted average of SMD[S_j]($S_j \subseteq F_i$, j=1,2,..., M_i):

$$CF[F_i] = \sum_{j=1}^{M_i} WS(S_j) * T(SMD[S_j]) \qquad (4)$$

where,

$$T(\alpha) = \begin{cases} \alpha & \text{if } \alpha \geq T_s \\ 0 & \text{otherwise} \end{cases}$$

and

$$\sum_{j=1}^{M_i} WS(S_j) = 1$$

After obtaining CF[F_i] by equation (4), the system can decide frame F_i is suitable or not. If suitable, the frame F_i is triggered, and the result and interpretation is outputed. If not, the system continues the selecting processing, until a suitable frame is found or a new frame is created to describe the current situation.

5 CONCLUSION

Computer-aided planning with the application to forest cutting and planting planning has been described. It seems reasonable to draw the conclusion that building an image interpretation expert system and other expert systems inside a knowledge-based pictorial information system is very efficient. A knowledge based pictorial information system can provide the image interpretation expert system with extensive data, relevant knowledge and procedures. Since the information used in the expert system is modelized and complete, the improvement of interpretation results can be anticipated. The interpretation results can also be used to update the information stored in the information system.

REFERENCES

1. Proceedings of Second International Symposium on Spatial Data Handling, July 5-10, 1986, Seattle, Washington, USA

2. N.S. Chang and K.S.Fu, A Relational Database System for Image, Pictorial Information Systems, Springer Verlag, 1980

3. J.K.Wu and D.S.Chen, Model-based Remote-sensed Imagery Interpretation, Int. J. Remote Sensing, 1987

4. P.H.Winston, Artificial Intelligence, Second Edition, Addison-Wesley Publishing Compang, Inc. 1984

5. Frederick Hayes-Roth, Donald A. Waterman, and Douglas B. Lenat, Building Expert Systems, Addison-Wesley Publishing Company, Inc. 1983

6.M.Minsky, A Framework for Representing Knowledge, in P.Winston(ed.), The Psychology of Computer Vision, McGraw-Hill, 1975, p211-277

7. T.Chen, The Frame-based Spatial Knowledge Representation, 1988 IEEE Workshop on Language for Automation, August 1988, Maryland

8. J.K.Wu, T.Chen, L.Yang, QPF: A Versatile Query Language for a Knowledge-based Geographical Information System, Int. J. Geographical Information System, Vol.3, No.1, 1989

9. W.Kim, Object-Oriented Database: Definition and Research Directions, IEEE Trans. Knowledge and Data Engineering, Vol.2, No.3, Sept. 1990