A GENERALIZED FRAME FOR CARTOGRAPHIC KNOWLEDGE REPRESENTATION

Bo SU
School of Surveying and Land Information
Curtin University of Technology
GPO Box U 1987
Perth WA 6001 Australia

Abstract

Application of expert systems is currently a fashionable topic in cartography. From the mid 1980s, researchers in cartography have attempted to realize the automation of map design and production using expert systems. To develop map design expert systems, the first step must be the formalisation of the map design procedure, and the basis of knowledge formalisation is the knowledge representation methods. This paper aims to present a new knowledge representation method for map design, i.e. a Generalized Frame (GF) in Artificial Intelligence (AI). This method has been employed by MAPKEY (Zhang, 1990) - a thematic map design expert system, which has been used for the design and production of an atlas (Huang, 1994). This new method improves knowledge representation capacity of the so-called frame method in AI. It also possesses the advantages of all other methods, i.e. frame, rule, relation and procedure.

1. Introduction

Map design process embodies high-level human intelligent behaviors. It "cannot be easily simulated with traditional computing methods" (Muller et al, 1986). Most researchers in the area of automated mapping have focused on the use of Artificial Intelligence (AI) techniques, in particular, Expert Systems (ES) (Forrest, 1993). The key to such an application is the acquisition and formalisation of domain knowledge. In the case of cartographic knowledge, as Forrest (1990) points out, the first step must be the formalisation of the map design procedure so that it can be represented by knowledge representation method in ES.

From literature, it can be seen that, in recent years, a lot of research has been undertaken in this area, especially for map symbolisation. For examples, Muller et al (1986) focus on the development of a formal model of cartographic knowledge and its representation. They proposed a two level hierarchy of declarative knowledge for both mapping requirement and map specifications. The system developed by them was nevertheless an operational cartographic expert system (Forrest, 1993). Wang (1990) uses conceptual graph in AI to construct a schema for cartographic quantitative information. As stated by himself, this schema is just simplified model of reality and it might not be able to handle the complexity in the real world. Jaakkola et al (1990) emphasize on the formalisation of knowledge for selecting a type of thematic presentation. Unfortunately, as Forrest (1990) points out, little has been done in the knowledge formalisation of a whole process.

Indeed, map design process is a mixture of graphics, art, cognition, color science and expertise etc. Thus it is very complex. Besides, not all phases of map design require an expert system approach (Buttenfield et al, 1990). Therefore, no single representation method currently used in AI is capable of representing all the mixture of knowledge in map design process. It means that a new representation method is a matter of some urgency which takes into consideration this mixture of knowledge. This paper is an attempt to provides a solution.

In this paper, a new method, Generalized Frame (GF), is proposed and a description is also given regarding its realisation. The GF improves knowledge representation capacity of the so-called frame method in AI. The GF has many advantages as will be discussed in Section 6.

A brief description of the characteristics of map design process knowledge and of existing frame will first of all be given in Section 2, followed by an introduction of GF in Section 3. After that, the realization of GF will be discussed in Section 4. Then, an example of representing map design process by GF will be given in Section 5.

2 Frame

The frame representation method provides a structure of an object or a class of objects. Frames can represent classes into *taxonomies*. A class can be depicted as a specialisation (subclass) of other more generic classes. For example, one frame might represent general maps, and another thematic maps. Thematic maps possess a set of properties that distinguish themselves from other kinds of maps.

The essence of frame representation method is to organise the semantic knowledge of objects, of events, and of status as a structural entity, and to computerize the information represented by frame structure.

2.1 Structure of frame

A general structure of frame can be described by BNF as follows:

<frame>:=<frame-name><slots>
<slots>:=<slot>|<slot><slots>
<slot>:=<slot-name><facets>|<frame>
<facets>:=<facet>|<facet><facets>
<facet>:=<facet-name><facet-value>
<facet-name>:= value| data-type | range | default | <demon>
| <attached-procedure>
<demon>:=if-needed | if-added | if-removed
<facet-value>:=<context> | <default-value> | <inheritance-value> (1)

According to the description of a frame given above, its data structure can be depicted in Figure 1.

frame-name	ISA	attribute	slot-value	default	demon	attached-procedure

Figure 1. Data structure of a frame

2.2 Inference of Frame

According to the data structure of frame, inference methods in frame systems can be classified into three types as follows:

- Inference based on inheritance
  When the inheritance-based inference is used, frame systems can be viewed as an extension of semantic nets. In fact, this kind of reference is based on the inheritance relationship among frames and default values of frames. It is also the main method by which frame systems retrieve information.

- Inference based on 'demons'
  In a classic frame, 'demon' includes three types of specially attached procedures, i.e. if-added, if-needed and if-removed. They are used to deal with slot values. No special control mechanisms are set for the demons-based inference. As soon as demons are triggered in frames system, this kind of inference begins to work.

- Inference based on attached procedure
  Attached procedures are programs developed in computer language, e.g. Lisp, Prolog, etc. They are important methods by which frame systems connect structural knowledge and procedural knowledge. Indeed, frame represents a structure of knowledge. In order to solve problems using this kind of knowledge, some procedures i.e. this kind of attached procedures, are needed to effectively organise, manage and invoke such knowledge. Normally, the names of the attached procedures are placed in slot values. The execution of attached procedures is triggered by messages from other frames. Figure 2 illustrates a general procedure as described above. Thus a frame-based inference system can be formed using this kind of attached procedures.

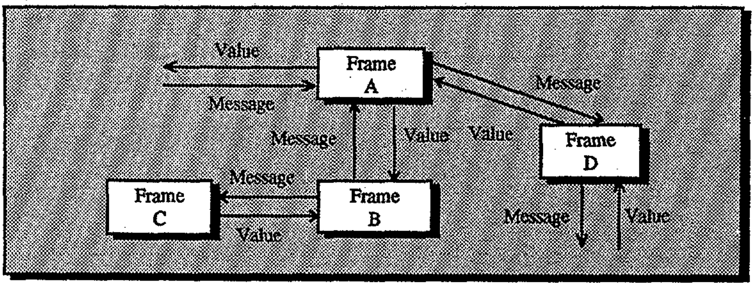

Figure 2. Inference of Frame System Based on Attached Procedure (after Zhang, 1989)

Furthermore, the integration of these three reasoning methods described above might greatly improve the knowledge representation capacity and reasoning ability of frame systems.

3 Generalised Frame

As described previously, frame is an effective method for representing structural knowledge, i.e. *static* knowledge. However, the inference of frame systems in applications is controlled by dynamic knowledge, which is also referred to as control knowledge or procedural knowledge. Traditionally, control knowledge in frame systems is made available by using a rule base. Dynamic knowledge combines frame and rule representation methods and forms a hybrid knowledge representation method. Even this combination of these two representation methods is still not sufficient to copy with the variety of knowledge sources in map design process. Therefore, the integration of intelligent and conventional programming methods is necessary, which is the main characteristic of the Generalized Frame (GF) proposed in this paper.

3.1 Integration of Frame and Relation

A frame is a structural description of knowledge, and it can depict the spatial relationships of objects. Traditionally, frame systems are normally developed using high level languages e.g. Lisp, C etc. This kind of frame systems uses the linkage mechanisms provided by high level language to manage frame knowledge. Therefore, it is difficult for conventional frame systems to maintain large number of frames. Robert and Michael (1987) discuss a method using relation to manage frames in KEE. According to the data structure of frame, the relation method can be integrated with frames in GF. The relation method is responsible for managing frame instances and organising knowledge sources. Figure 3 shows the natural relationship between frame and relation.

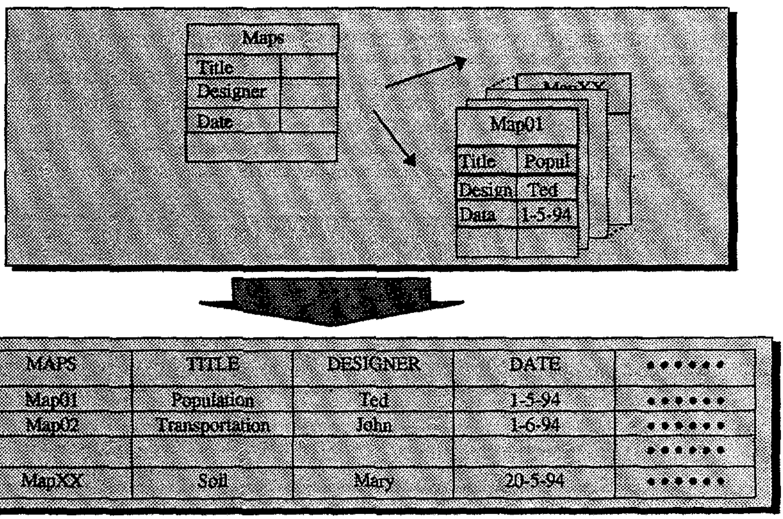

Figure 3. Integration of frame and relation

The integration of frame and relation leads to a new knowledge representation method. It has two advantages: (1) it can effectively represent spatial knowledge which needs a strict structural relationship and includes a large number of instances, i.e. fact and data. (2) it extends the range of relation attribute values, in which frames, rules base and procedures can be regarded as valid values. Thus, knowledge of entities, of application model and of other data processes can be added to relations so that the semantic interpretation of entities in relations can be realised using these processes based on knowledge and procedures.

3.2 Hybrid Knowledge Representation

The objective of knowledge representation is to translate domain knowledge and experience into a computer compatible form. From literature, it can be seen that most researchers (Pfefferkor et al 1985, Jaakkola et al 1990, Muller and Wang 1990, Wang and Brown 1990, Hua and Gao 1993) in cartography and computer science stress the application of pure artificial intelligence, such as pure rule system, pure frame system. In this way, some advantages of conventional programming are disregarded. In GF, frames are not only used to represent structures of domain knowledge, but also to manage knowledge sources which can be represented in rules, frames, procedures and relations. For example, a sample of map design process knowledge can be represented in Figure 4.

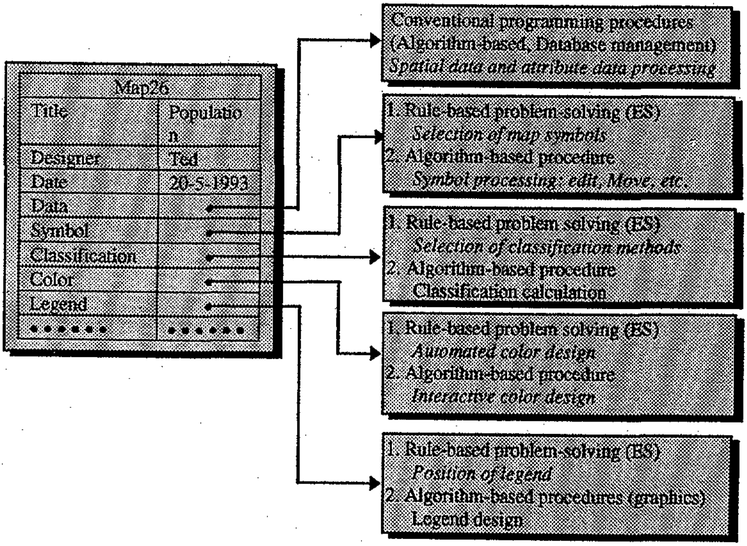

Figure 4 An example of managing hybrid knowledge sources using frames in GF

In Figure 4 map design process is represented using frames. Different knowledge sources are included in different stages of map design process. The central control of system is based on frame-based inference. The demons and attached procedures of frames are used to trigger the different problem-solving methods. Frame-based knowledge is provided in a form of relations and will be invoked by rule-based inference and algorithm-based procedure in run time. The aim of this kind of method is to integrate advantage of conventional programming methods and knowledge-based methods so that hybrid knowledge can be effectively represented.

3.3 Fuzzy Frame

It is difficult to represent some knowledge exactly in practical application areas, such as sensitive level of color (e.g. warm 56%; cold 30%). In order to represent this kind of knowledge, one knowledge representation method based on fuzzy theory and probability theory has been developed, i.e. fuzzy (uncertainty) knowledge representation method, such as uncertainty reasoning in MYCIN in which certainty factor is proposed. This kind of method is mainly for production system. In GF, the concept of fuzzy frame is proposed and its calculation expression and calculation methods are introduced in this section.

Definition of Fuzzy Frame

According to formula (1), frame structure can be further abstracted as follows:

$$Frame = \{slot_1.value, slot_2.value, \cdots\cdots, slot_{n-1}.value, slot_n.value\} \quad (2)$$

Therefore, certainty factor of frame depends on certainty factors of its slot values. According to Expression (1), fuzzy frame is defined as follows:

$$Frame = \{slot_1.value\ CF\ cf_1, slot_2.value\ CF\ cf_2, \cdots\cdots, slot_n.value\ CF\ cf_n\} \quad (3)$$

Calculation method

Slot values are used to describe the concept represented by frame. The calculation expression of fuzzy frame is defined as follows

$$\begin{aligned} Frame\ CF\ cf = \ & slot_1.value\ CF\ cf_1 \\ & AND\ slot_2.value\ CF\ cf_2 \\ & AND\ slot_3.value\ CF\ cf_3 \\ & \\ & AND\ slot_n.value\ CF\ cf_n \end{aligned} \quad (4)$$

The calculation methods for this expression are listed as follows:

(1) When frame includes one slot, the certainty factor of frame equals the certainty factor of slot value.

(2) When frame includes more than one slot, there are four kinds of calculation methods for this expression as follows:

(a) Minimum value method

$$cf = Min(cf_1, cf_2, cf_3, \cdots\cdots, cf_n) \quad (5)$$

(b) Product method

$$cf = (cf_1 * cf_2 * cf_3 * \cdots\cdots * cf_{n-1} * cf_n) / (100)^{n-1} \quad (6)$$

(c) Average method

$$
\begin{aligned}
cf &= (Min\,(cf^{(n-1)}, cf_n) + (cf^{(n-1)} * cf_n)/100)/2 \\
cf^{(n-1)} &= (Min\,(cf^{(n-2)}, cf_{n-1}) + (cf^{(n-2)} * cf_{n-1})/100)/2 \\
&\vdots \\
cf^{(2)} &= (Min\,(cf^{(1)}, cf_2) + (cf^{(1)} * cf2)/100)/2 \qquad (7) \\
cf^{(1)} &= cf_1 \\
n &= 1,2,3,\cdots\cdots
\end{aligned}
$$

(d) Bonczek-Eagin method

$$
\begin{aligned}
cf &= ((cf^{(n-1)} * cf_n)/100) * (2 - MAX\,(cf^{(n-1)}, cf_n)/100) \\
cf^{(n-1)} &= ((cf^{(n-2)} * cf_{n-1})/100) * (2 - MAX\,(cf^{(n-2)}, cf_{n-1})/100) \\
&\vdots \\
cf^{(2)} &= ((cf^{(1)} * cf_2)/100) * (2 - MAX\,(cf^{(1)}, cf_2)/100) \qquad (8) \\
cf^{(1)} &= cf_1 \\
n &= 1,2,3,\cdots\cdots
\end{aligned}
$$

It is noted that different calculation methods have different characteristics (Su, 1989). Therefore, different fuzzy reasoning stage should adopt different calculating method.

4 Realisation of GF

4.1 Definition of relational table for frame structure

As described in the section 3.1, a natural relationship of correspondence between frame and relation can be built. A relation table for a frame structure can be defined in Figure 5.

Frame	ISA	Slot	Value	scf	Default	Dcf	If-added	If-needed	If-removed	Procedure

Figure 5. Relational table for frames

In figure 5, "scf" stands for a certainty factor of a slot value, "dcf" stands for a certainty factor of a default value and "procedure" refers to other attached procedure. However, a number of redundant records will be produced in the above relational table since not all frame has default value and attached procedures, i.e. values of most fields are null in the marked part in Figure 5. Therefore, a more effective structure is defined in Figure 6.

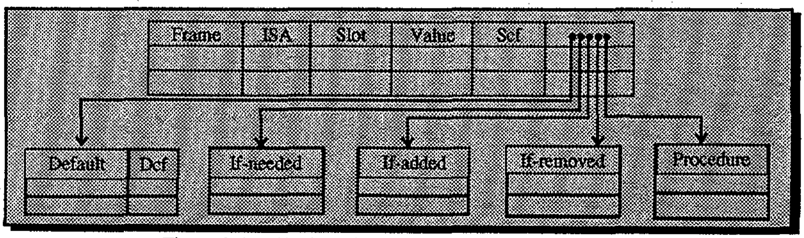

Figure 6. An effective relational table structure for frames

In Figure 6, default facet, demons facets and attached procedures facets are separated from Figure 5, and every facet is respectively represented using a relation table. The key words for index in relation table of facets are frame name and slot name. When there are values in the above facets, corresponding records in relation table are built.

4.2 Inference based on GF

The inference mechanism of knowledge system is dependent on knowledge representation methods. GF contains three methods, i.e. inference based on inheritance, based on demons and based on attached procedures. A reasoning process of frames based on 'demons' according to the table structure for frames in Figure 6 can be illustrated in Figure 7.

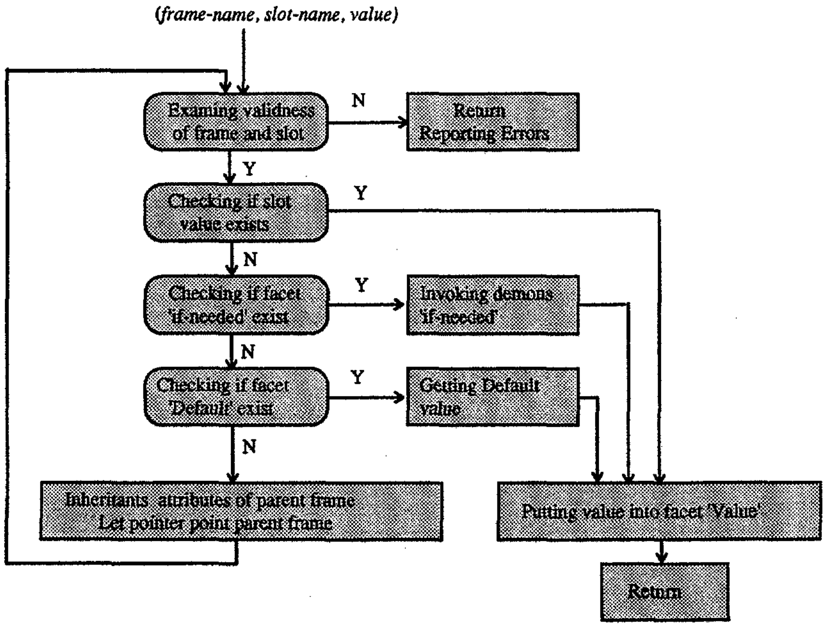

Figure 7. A reasoning procedure of frames based on 'demons'

From Figure 7, it can be found that reasoning process of frame system is a process of filling slot values. After filling all slot values of frames which represent contents, target and process of map design, result of map design will be achieved.

5 An example of symbol design stage based on GF

According to previous discussion, the following example demonstrates a simple process of symbol design stage.

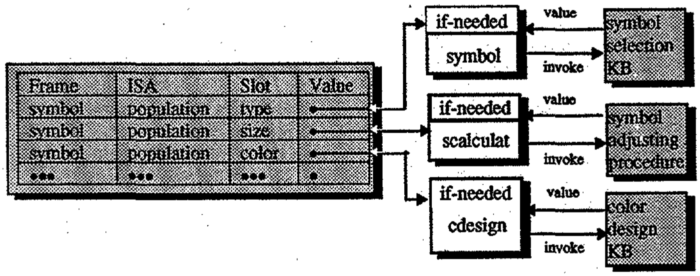

Figure 8. An example of symbol design under GF

This example is to determine the type, size and color of thematic symbol in a map named "Population".

6. Conclusion

GF knowledge representation method is an attempt to systematically manage, organise and represent map design process knowledge. The line of thought used in GF is fully comparable to the idea of "component" proposed by Microsoft. Indeed, the concept of frame is similar to the one of object-oriented (OO) method.

GF also possesses the advantages of all other methods, i.e. frame, rule, relation and procedure. It is applicable to the representation of a hybrid knowledge. Its main characteristics are as follows:

- It integrates frame method and relation method. The former is used to depict the structure of spatial object while the latter is used to manage instances of object.
- Frame, rule, procedure and relation etc. can be referenced one another. Frame is used to organise and control rules, procedures, and relation which depict actions of every map design process and others are capable of referencing the content of frames.
- Relation is used to manage knowledge base, which makes maintenance of knowledge base easier.

The further work is to discuss relationships between frame method and OO method. Then a more effective GF representation system can be developed using object-oriented programming language.

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