AN AXIOMATIC APPROACH TO KNOWLEDGE-BASED MAP GENERALISATION

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Abstract

The process of map generalisation may be represented as a transitional model in which generalisations are expressed as state transformations. In the transitional model, the process of map generalisation is expressed as a series of state transformations ***g*** from the original map ***E(S,A)*** (where ***E*** is a set of map entities, ***S*** is a set of cartographic symbols and ***A*** is a set of attributes) into the target map ***E'(S',A')***, under the constraint specifications ***C***, by applying the generalisation operators ***O***.

To formalise the process of map generalisation, an Axiomatic System for Map Generalisation (ASMG) was developed. Five axioms named '**map generalisation axioms**', represented in predicate formulas, were established. The **objective criteria** for acceptable generalisations and the transitional model were represented by the ASMG.

This study implemented a prototype knowledge-based system, MapGen, based on the axiomatic system (ASMG). The research explored new technologies for integrating GIS and knowledge based systems by embedding inference engine into GIS, via Dynamic Data Exchange (DDE) and Dynamic Link Libraries (DLLs), under Windows environment.

1 Introduction

Generalisation is one of the important elements of cartography and has been the topic of considerable research. However, in spite of these efforts, sound, and truly automated generalisation systems that are supposed to be able to transform both the spatial and the attribute information of a map from one scale to another, do not yet exist [3]. Many researchers have argued that automated map generalisation should incorporate more "intelligence" [1,3,4], and should be more comprehensive. Knowledge-based or expert system for map generalisation is one of the attempts. However, one of the basic problem in digital map generalisation is still unsolved: what are the criteria for acceptable generalisation in digital context.

In this paper, first a new conceptual framework of the process of map generalisation, named transitional model, is introduced. Then, an axiomatic system for map generalisation (ASMG) is defined. The criteria of acceptable generalisation and the transitional model then are represented by the ASMG. Finally, a prototype system is implemented and sample results are shown.

2. Transitional Model of Map Generalisation

2.1 Components Of A Map Generalisation Task

Four components of a map generalisation task in digital context must be considered:

1) the specification of map constraints (eg, scales, purpose etc);
2) the original map represented in map entities, cartographical symbols and attributes **E(S, A)** (where **E** denotes a map entity, **S** denotes cartographical symbol of the map entity and **A** denotes the attributes of the map entity) ;
3) a set of generalisation operators **T** (eg, smooth, simplify, aggregate, etc); and
4) the generalised map with new map entities, represented by new cartographical symbols and new attributes **E'(S', A')**. (see Fig 1)

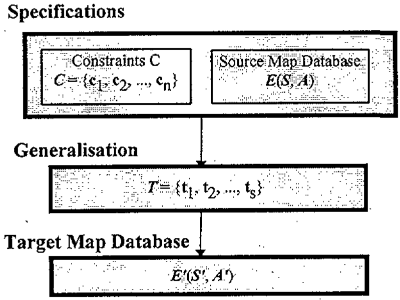

Figure 1 **Basic components of a map generalisation task (a)**

2.2 The Transitional Model

The process of generalisation can be represented as a series of state transformations. At each step of the transformation, the generalisation proceeds with one map entity, and the selection of generalisation operators depends on the constraints specification, the map entity in the original map database and also depends on the partial generalisation history. This is the transitional model.

In the transitional model, the process of map generalisation was represented as a series of transitions: from the original map to the target map, under the constraints and the acceptance criteria, until the 'terminate' condition was met. Differing with existing models, the transitional model was arranged as a **loop** in which every generalisation step was tested against the acceptance criteria and the specification of constraints, and a feedback was set up where the test conditions were not satisfied.

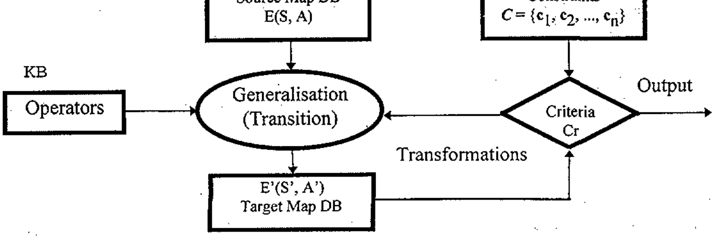

Figure 2 **The transitional model for map generalisation**

3 Map Generalisation Axioms

Axiomatic method is a kind of systems representing concepts and theories by using formal theory. The familiarity of domains especially the domains like cartography which are relying much on commonsense, makes it particularly easy to abuse notation in knowledge-based programs and to use a single symbol in different ways that are not mutually consistent. A formal definition of the meaning of the symbols is very helpful in avoiding this kind of bug. The knowledge structures used in the program may be based on the formal theory. For this purpose, the key part of the formal theory is the definition of the symbol and the semantics of the symbols.

To represent the process of map generalisation, five axioms are developed. These axioms are represented by first order logic. [5].

3.1 Map Generalisation Axioms

Axiom 1: *Transformation Axiom*

Any transformation in map generalisation must maintain the nature of entities. In other words, **natural_trans(X,Y) must be true.**

For all map generalisations, there are only six kinds of transformation can make natural_trans(X,Y) true: ***point-to-point***, ***line-to-line***, ***region-to-region***, ***region-to-line***, and ***region-to-point***. All these transformations consist of related generalisation operators [5]. The point-to-point transformation can be formally defined as follows.

natural_trans(X, Y) <=> symbol(X, source_map_scale)= 'point' ∧ ks_point_point(X,Y) ∧ symbol(Y, target_map_scale)= 'point'.

Other transformations can be defined in the same way.

Axiom 2: ***Selection Axiom***

All entities to be generalised, must be well-selected. In other words, the predicate well_selected_ent(X,Y) must be true, and only the entities that passed the ks_omit_filter(X,Y),are well-elected.

well_selected_ent(X,Y)<=>ks_omit_filter(X) = Y.

Axiom 3 ***Validity Axiom***

A valid generalisation maintains the nature of an entity.

valid_gen(X, Y)<=>well-selected_ent(X,Z) ∧natural_trans(Z, Y)

Axiom 4 ***Non-conflict Axiom***

The conflicts among the map entities must be resolved.

non_conflict(X,Y) <=> ks_conflict_resolve(X,Y).

Axiom 5 ***Constraint Axiom***

Any map entity must satisfy the specification of the constraints defined for the given problem area (eg. map symbols in certain scales). The predicate **constraints_sat(X),** defined previously, must be true.

constraints_sat(X).

3.2 Acceptable Generalisation and The Transitional Model

The criterion for an acceptable generalisation is represented by the predicate acceptable_gen(X,Y) where acceptable_gen(X, Y)<=>valid_gen(X, Z)$\wedge$non-conflict(Z,Y)$\wedge$constraints_sat(Y)

The generalisation of Y from X is acceptable if and only if Z is transformed by a valid generalisation from X; Y is come from Z and is conflict-free with other generalised entities, and Y satisfies the constraint specifications. In Short, **an acceptable generalisation must satisfy the acceptability axioms.**

The transitional model for map generalisation in ASMG is a recursive loop which finds an acceptable generalisation for each entity to be generalised. Assuming that ASMG has a backward-chaining inference engine, then the transitional model may be formally defined as

transition([], []).   /*stop condition */

acceptable_gen(X, Y) $\wedge$transition(X1, Y1)=>transition([X|X1], [Y|Y1]).

write('Can't satisfy the axioms, Stop.')=>transition(X, Y).   /*stop condition */

4. Implementation

A prototype of the axiomatic system named MapGen is shown in figure 3. MapGen is a multiple inference engine and multiple knowledge base consisting of a meta level reasoning. a set of knowledge sources and a map data database. The meta level reasoning has an inference engine (M.4) which uses ASMG, the axiomatic system, as knowledge base. The map database employed MAPINFO for storing map elements. The knowledge sources are the procedures written in MapBasic, C++ and M.4 Rules. MapGen runs under Windows 3.1. The inference engines and map database are integrated together and communicate with each other via Windows message passing, Dynamic Data Exchanging (DDE), and Dynamic Link Libraries (DLL). The main interface of MapGen is Mapinfo and M.4 (with Visual Basic Interface).

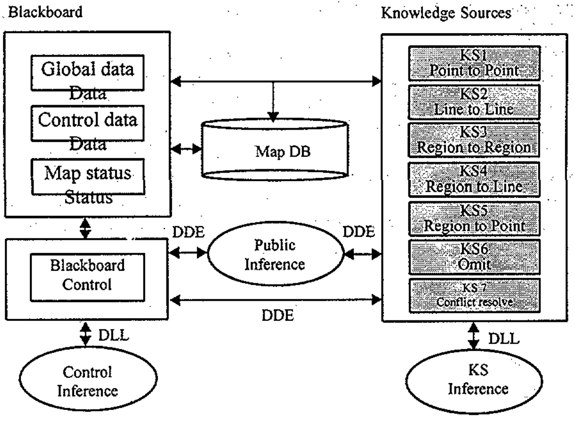

Figure 3 The structure and components of MapGen

5 Examples

Several sample maps have been generalised by MapGen. Figure 4 shows an example where ASMG as meta level reasoning and operators as operational knowledge sources. The work interface is shown in Figure 5.

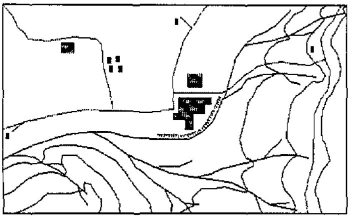

Figure 4 sample map

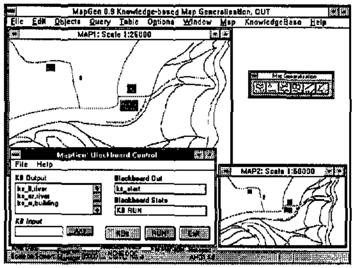

Figure 5 Generalised map (and interface)

6 Conclusion

Axiomatic system approach is an effective way to formalise the process of map generalisation and to implement knowledge based system.

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