STRUCTURE AND DEVELOPMENT OF A KNOWLEDGE BASE FOR CARTOGRAPHIC COMPOSITION

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Abstract

It is commonly adopted that labour-intensive tasks should be consigned to computer systems in order to be accomplished more uniformly, more rapidly and at a much reduced cost. Although this approach has been successful to a number of application areas; it has been inefficient to others like map/chart composition and production. This is due to the inherent characteristics of map/chart composition and the rather complicated, individually driven cartographic processes leading to the production of a map that serves as a medium of communication, conveying spatial relationships and a multitude of thematic information of the geographic area covered. Despite the lack of success in the design and implementation of integrated digital cartographic systems, the research community still attempts to establish the framework for “automated” map composition and examines alternative routes for accomplishing the goal of an “integrated” or “global” cartographic system. These routes involve mainly state-of-the-art technologies such as expert systems and software agents. This paper deals with the expert systems approach and more specifically with the design and development of the knowledge base that will support map/chart composition. Expert systems receive a good deal of attention because they can utilize knowledge of a human expert - the cartographer - in order to arrive to a set of rules for dealing with the problem of cartographic composition. There is no doubt that this is a rather ambitious task and despite its inherent difficulties, the authors believe that it is worth of the effort.

1. PROBLEM STATEMENT

Cartographic design and production consist of complex procedures, which cannot be “automated” easily. Map/chart design and production is a time consuming and rather costly task, even if it is implemented in a state-of-the-art digital environment. Digital cartographic systems provide powerful tools and - to some extent - procedures, which support the map/chart composition process. However, the cartographer still decides about the selection of information, the symbolization of cartographic features, the resolution of graphical conflicts generated due to scale reduction and the procedures required for the improvement of map graphic quality and legibility. Thus the cartographer constitutes the most critical “factor” in the cartographic process. His/her experience and expert knowledge are indispensable since maps/charts have the following characteristics:

- They are composed of numerous layers
- The portrayal of cartographic features is implemented through rather complex symbolization methods
- Topological relations among the cartographic features must be retained

The automation of cartographic design and production procedures through “traditional” algorithmic approaches, supported by digital cartographic systems is problematic. Most of the problems are caused due to the following reasons inherent to the cartographic process:

- The establishment of a “linear” process for map composition is not feasible. The interaction and interrelations among cartographic features do not allow for the independent composition of the map layers. When composing a layer, besides the examination of the relations among its features (inter-layer relations), the relations between these features and the features of the other map layers (intra-layer relations) must be checked and the problems that arise must be resolved.
The spatial relations among cartographic features are complex and their analytical computation is time consuming. On the other hand the cartographic composition procedures must be implemented in a way that topological relations are retained.

The resolution of graphical conflicts for the improvement of the graphic quality and legibility of a map/chart involves - to a certain extent - the element of “subjectivity” along with an abundance of specific cases/solutions for the various kinds of problems. The rules involved in the detection of conflicts and the triggering of the appropriate actions for their resolution are not easily manageable. Besides the above, it must be taken into account that an integrated cartographic methodology supported by a complete set of rules does not exist. Therefore, the cartographic “knowledge base” must be in a dynamic state and be continuously revised and extended.

2. PRESENT STATUS

The nature and characteristics of the problems concerning the automation of cartographic design and production process have been identified and sufficiently analyzed. Current research focuses on the solution of these problems through the utilization of technologies like Agents and Expert Systems both of which utilize and manage rules. In the following section the basic characteristics of these two technologies are described. Emphasis is given to the technology of Expert Systems that is utilized in this project. It must be mentioned that these two technologies are not mutually exclusive; on the contrary they have much in common both conceptually and logically.

“Multi-agent systems are ones in which several computational entities, called agents, interact with one another. The concept of ‘agent’ implies a problem solving entity that both perceives and acts upon the environment in which it is situated, applying its individual knowledge, skills, and other resources to accomplish high-level goals. Agents thus integrate many of the algorithms and processes that have been independently studied by researchers in artificial intelligence and more widely in computer science. Much of the conceptual power of this exciting new paradigm arises from the flexibility and sophistication of the interactions and organisations in which agents participate. Because an agent is relatively self-contained, it has a considerable degree of freedom in how it interacts with other computational and human agents. Agents can communicate, cooperate, coordinate, and negotiate with one another, to advance both their individual goals and the good of the overall system in which they are situated” (AGENT, 2001).

Expert systems are especially appropriate where there is no efficient algorithmic solution. Such cases are called “ill-structured problems” this typically being true of design problems and specifically of the cartographic design ones. Expert systems act as supplements to humans. If one examines the way in which humans solve problems he/she will realize that very often an algorithm is not used, but a collection of “rules of thumb” which may not guarantee a solution but they make it more likely that he/she will get close to one. Such rules are called heuristics which are criteria, methods, or principles for deciding which among several alternative courses of action promises to be the most effective in order to achieve some goal. This constitutes the basis for the expert systems operation. One of the main arguments against the use of expert systems technology for map/chart composition is that it is nearly impossible to develop a complete set of rules, which foresee all the potential situations that may occur and which can provide efficient solutions. On the contrary, we believe that this argument favours the expert systems route due to the fact that any solution will not be a “one shot” approach but a gradual one based on stages, which will be refined continuously as new cases/solutions occur. The prototype Cartographic Expert Systems (CES) identified in the literature refer mainly to the following specific applications (Forrest, 1993):

- Design of map content and symbolization
- Cartographic generalization
- Portrayal of toponyms

3. SYSTEM DEVELOPMENT ENVIRONMENT

In the framework of this project, an Expert System Shell (Elements Environment) interfaced with a Geographic Information System (Arc/Info) are used. Elements Environment incorporates through its knowledge base, the design and composition methodology and handles the wide variety of entities appearing on maps/charts. Rules (production rules) capture the knowledge necessary to solve particular domain problems (e.g. resolution of graphical conflicts) and they represent - among others - relations, heuristics and procedural knowledge. Rules are symmetric so they can be processed in either a forward or a backward direction and they have three basic parts:

- Left-hand side conditions
- Hypothesis which is a Boolean slot
- Right-hand side actions (Then Do: Actions, Else Do: Actions)
Conditions, rules, and hypotheses are all Boolean data structures and they may have one of four basic values: UNKNOWN, TRUE, FALSE, or NOTKNOWN. An abstract rule structure is shown in figure 1.

![Abstract Rule Structure](image)

**Figure 1: Abstract Rule Structure (Neuron Data, 1996)**

Elements Environment provides with a number of representational structures (Neuron Data, 1996). There are objects and classes to describe the cartographic entities and the generalization of entities respectively. There are properties, which are characteristics of objects, classes, and slots, which store information about specific objects and classes. Meta-slots describe how the slots behave. Properties and values can be inherited from a class or object to another class or object. Certain meta-slots can be inherited from a class or object to another object. In conjunction with rules (production rules), the expert system supports methods and message passing. Methods can be triggered explicitly after receiving a message from a rule or other method, or they can be triggered automatically following a determination made by the system (“if change” and “order of sources” method types). Methods can also be inherited down the object hierarchy. Elements Environment is an agenda-based system. The agenda is a dynamic mechanism. It is the engine of the system that provides the central transformation between the perception of events and the actions the system will take. It is modelled after the notion of attention. At any time, the complexity of the real world can be reduced to a limited set of parameters and possible decisions. In turn they will affect the world and perhaps the next events or actions that were planned. Agenda-based programming incorporates the notions of conflict-resolution (that is inherent to cartographic composition), which is a decision between different possible inference paths and non-monotonic reasoning. The agenda incorporates forward and backward mechanisms.

The Geographic Information System (GIS) manages the geographic entities and provides for the required graphic tools and the interface with the user of the system. The system utilizes the features stored in the cartographic database, which has been organized according to the I.H.O. Standard for Digital Hydrographic Data (I.H.O., 1996).

### 4. CARTOGRAPHIC PROCESS

The production of a map/chart is implemented through the following phases: Area Definition, Selection of Information (Selection), Projection Transformations, Identification of Portrayal Methods (Symbolization), Composition (Graphical Conflict Resolution/Generalization), Portrayal of Symbols and Text, Generation of Supplementary Map/Chart Information (e.g. title, tables, cautionary notes) and Production. The degree of involvement of the Expert System and of the Geographic Information System varies due to the nature of the processes inherent to each phase. We can generally distinguish the phases and the relevant actions to those based on “knowledge” and those based on “algorithms”. The first category includes the phases of Selection, Symbolization and Composition, which are elaborated as follows:

- **Selection**
  Selection is considered as a pre-processing stage where the content of the map/chart is determined. The features and their corresponding attributes needed for the composition of the map are selected and retrieved from the cartographic database. Scale and map particularities are taken into account during the selection. Selection is executed into two phases: a. original selection, where the map layers are selected; b. thematic selection (selective omission), where the cartographic features are selected according to their attributes (Keates, 1989).

- **Symbolization**
  The symbolization of the selected features is compliant to map/chart category, scale and the individual characteristics of the features. Features are then transformed to graphical elements, e.g. point, linear, area symbols and text (Tsoulos and Stefanakis, 2000).
• **Composition**

The improvement of map/chart graphical quality and subsequently its legibility is achieved at this stage through the resolution of conflicts among graphical elements (symbols and texts). The resolution of graphical conflicts is executed through the proper cartographic generalization operations (simplification, combination, exaggeration, displacement and elimination) (Keates, 1989).

5. CARTOGRAPHIC CONSTRAINTS

In the conceptual framework proposed by Beard (1991), a constraint is understood as a condition similar to the predicate of a rule. In contrast to a production rule, however, Beard's definition does not bind a constraint to a particular action. A constraint implies a limitation that reduces the number of acceptable solutions to a problem. This notion is similar to the one used in constraint programming in computer science (van Hentenryck et al., 1996). Constraints are not used directly as a foundation of a programming technique that focuses on operations such as constraint propagation, satisfaction, normalization, and optimization, but rather as a framework for designing the map composition application as a whole. Constraints can be thought of as a design specification to which solutions should adhere, helping to specify the nature of cartographic or database products and the techniques (algorithms, strategies, etc.) that are necessary to derive them (Weibel and Dutton, 1998). Some «design specifications» for maps are thematic (content); others are graphic (appearance); some describe a final product, others describe methods for achieving it. Extending the approach summarised above does not imply that software design considerations will be ignored. On the contrary, we feel it is extremely important to relate analysis of constraints to the means by which they will be implemented (i.e., object-oriented databases and expert systems).

A thorough analysis of the nature, the role and the implementation means of constraints can be found in AGENT project (2001). To our best knowledge this is the most comprehensive analysis of constraints and we are indebted to this source for a considerable part of the material concerning constraints. The effect of constraints is to reduce the number of possible results of a process, while at the same time increasing the proportion of acceptable ones. The two basic categories of constraints are (AGENT, 2001):

- Geographic and cartographic constraints (arising from characteristics of data and map specifications)
- Process constraints (arising from resource limitations and workflows)

The approach suggested in this paper has been implemented in the framework of a pilot project for the design and composition of a topographic map at 1:100,000 scale. The authors compiled a number of constraints pertaining to this project for subsequent formulation and building of the prototype expert system’s knowledge base. These constraints are classified into three categories:

- Internal constraints: They refer to the way a general methodology is applied to a special category or categories of features (e.g. simplification of coastline, simplification of railways)
- Constraints which are applied to other features: They refer to cases where modification of a feature influences other features (e.g. the elimination of an islet causes the elimination of the topographical features which are within it)
- Constraints which are imposed by other features: They concern cases where a modification must take into account the existence of other features (e.g. the simplification of a line feature must not alter the topology of point symbols)

Table 1 shows a part of the constraints identified for the aforementioned pilot project.

6. BUILDING A KNOWLEDGE BASE

In developing an expert system there are two related sets of problems. The first is to transform existing cartographic practice into rule-based knowledge and the second is to guide the system through the map-making task. The knowledge in the domain is encoded in the form of rules, which constitute the “building blocks” of the knowledge base. The application logic and the procedural information of the system are described by rules and operate on objects, classes and slots. The knowledge base of the expert system for the design and composition of maps/ charts contains the following categories of rules:

- Selection rules serve the selection -from the database- of those features required for the production of the map/chart. The selection rules generate the representations of features in the object-oriented structure of the system
- Design rules give cartographic ‘substance’ to the features to be portrayed
- Composition rules make the appropriate changes to position and portrayal of the map/chart features in order to resolve any graphical conflict, according to the adopted specifications
- Procedural rules control of the overall process and guide the system through the various phases

The expert system enables the modularization of the knowledge base, by breaking it up into several knowledge bases. This characteristic of the expert system is utilized to increase efficiency and assist the control. The selection, design, composition and procedural rules are organized into separate knowledge bases, which are loaded and unloaded accordingly. The central mechanism, which is responsible for the control of these procedures, is composed of...
procedural rules. The individual knowledge bases are also provided by centralized mechanisms. These mechanisms control the processes executed within their environment. These mechanisms can also control the behavior of agenda (strategy). Rules within the same knowledge base can be grouped. The central mechanism can call sets of rules - instead of individual rules - in a specific sequence.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Constraint type</th>
<th>Internal constraints</th>
<th>Constraints which are applied to other features</th>
<th>Constraints which are imposed by other features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point features (except buildings)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>1. Overlap among the features is not permitted</td>
<td>1. A feature elimination imposes the omission of the associated text</td>
<td>1. Features displacement must not modify their topology relations with line and area features (coastline, road network, hydrological network, lakes, political and administrative boundaries)</td>
<td></td>
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<tr>
<td></td>
<td>2. Control points (e.g. trigonometric points, lighthouses) are not displaced</td>
<td>2. Overlap of the features with texts is not permitted</td>
<td>2. Overlap of the features' symbols with the coastline symbol is not permitted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Vertices which belong to an artificial coastline are not displaced and eliminated</td>
<td></td>
<td>3. Overlap of the features' symbols with the road network is not desirable</td>
<td></td>
</tr>
<tr>
<td><strong>Coastline</strong></td>
<td>1. The geometric “character” of the feature must be preserved</td>
<td>1. Land polygon is conformed to the coastline</td>
<td>1. Land polygon exaggeration (case of islets exaggeration) imposes the proper modification of the corresponding feature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. The feature must not intersect itself</td>
<td>2. Land cover polygons are conformed to the coastline</td>
<td>2. Land polygon elimination imposes the omission of the corresponding feature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Vertices which belong to an artificial coastline are not displaced and eliminated</td>
<td></td>
<td>3. Vertices displacement and elimination must not modify the topology relations among the feature and point symbols</td>
<td></td>
</tr>
<tr>
<td><strong>Political and administrative boundaries</strong></td>
<td>1. The geometric “character” of the feature must be preserved</td>
<td>1. Vertices displacement and elimination must not modify the topology relations among the features and point symbols</td>
<td>4. Overlap of the feature with point symbols is not permitted</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. The feature must not intersect itself</td>
<td>2. Political and administrative boundaries must pass through the features which marked them (case of point features, case of line features)</td>
<td>5. Intersection of the feature with road network, contours is not permitted</td>
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</tr>
<tr>
<td></td>
<td>3. The features must comprise closed polygons</td>
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<td></td>
<td>4. When a political or administrative unit is eliminated, all junctions where its boundary met others must be collapsed to one point and new edges must be formed that radiate from it</td>
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</tbody>
</table>

Table 1. A subset of constraints used for the composition of 1:100,000 topographic maps

6.1 Selection

In the expert system environment the cartographer introduces the category, the scale and the boundaries of the new map/chart and the system identifies the layers that can be used (original selection). The selection of the features to be portrayed on the map is realized in the GIS environment (Arc/Info). The selected features are transferred to and organized in the expert system environment and those to be considered for portrayal are chosen in accordance with their thematic characteristics (thematic selection). Figure 2 shows the selection process of cartographic features:
In the expert system environment the layers correspond to classes. Each class (represented by a circle in the following figures) has the Boolean type property selection_factor where the value TRUE or FALSE is stored when the corresponding layer is used in map composition (figure 3). The rules for the selection of layers (original selection) examine the parameters of the map/chart and assign a TRUE value in the selection_factor slot of the classes where from the corresponding layers are selected. These classes become object/cartographic features.

The selection of cartographic features (thematic selection) is realized in a similar way. The thematic selection rules set the value FALSE in the selection_factor slots of the objects/cartographic features (represented by triangles) when it is decided that these features must not be used through the examination of their thematic characteristics.

6.2 Symbolization

The process of symbolization of the cartographic features implemented in the expert system environment involves (Tsoulos and Stefanakis, 2000):

- The classification of symbolization methods
- The design and implementation methodology of symbolization
- The representation and organization of the graphical features (symbols and texts) of the map/chart within the object-oriented model of the expert system

The symbolization procedure is shown in the figure 5. The cartographic features are represented as objects accompanied by the necessary characteristics (properties) needed for their symbolization. The symbolization methods determine the graphic representation of the cartographic features in the map/chart and are formed into classes called symbolization classes. Figure 5 shows some symbolization methods for the qualitative differentiation of wrecks portrayed on nautical charts.

The objects/cartographic features are linked to the symbolization classes after the triggering of the symbolization rules. They inherit the appropriate methods from these classes. The activation of the methods linked to the objects results to the creation of new object/graphical features (point, linear, area symbols and texts). These objects/graphical features are sub-objects of the objects/cartographic features and have all the properties required for their exact definition.
6.3 Composition

The phases of cartographic composition are executed within the expert system environment, aiming at the enhancement of map/chart graphical quality and legibility. The interaction among point, linear and area symbols may generate graphical conflicts. In general, cartographic symbols require more space than their corresponding features reserve. Maps/charts also include “abstract” phenomena, like names (e.g. toponyms, textual descriptions of symbols), isolines (e.g. contours), heights, which are not tangible and do not have real dimensions. These features constitute additional sources of graphical conflicts. Graphical conflicts are classified according to the cartographic features involved in the following types (Stefanakis & Tsoulos, 2001):

- Among point symbols/texts
- Among point symbols/texts and line symbols
- Among point symbols/texts and area symbols
- Among line symbols
- Among line symbols and area symbols
- Among area symbols
In order to simplify the process of composition, features are represented temporarily by generalised figures (Tsoulos and Stefanakis, 2000), as follows:

- Point symbols are represented by their Minimum Boundary Rectangles (MBRs)
- Line symbols are represented by the buffer zones applied along the corresponding edges of the computed Constrained Triangular Irregular Network (CTIN) and cover their width.
- Area symbols are represented by the corresponding triangles of the computed CTIN.
- Texts are represented either by their MBRs, if they are aligned along straight lines, or by buffer zones which cover their extension, if they are curved.

The expert system detects graphical conflicts, evaluates them and consequently proceeds to their resolution following the proper cartographic practice. The established resolution methodologies vary in relation to the conflict type and they consist of the basic generalization operators: simplification, combination, exaggeration, displacement and elimination (Keates, 1989). This process must fulfil the following restrictions:

- The topology must be preserved (topological constraints)
- The resolution of a graphical conflict must not generate a new graphical conflict or conflicts

The resolution of graphical conflicts is not executed randomly. A proper linear procedure should be designed in order that the map/chart composition is the result of a controlled process and the system’s processing time is reduced. The established procedure imitates the cartographic practice, where the map/chart image is the result of overlaid layers. Layers are added in a sequence and the cartographic image is gradually created. The sequence of layers in the composition is defined by their priority factor. The graphical conflict resolution follows the procedure of overlaid layers. When a new layer is added to the existing “pile” of processed layers, which forms the “temporary” cartographic image, the system resolves the newly generated graphical conflicts applying generalization operators. A new layer is overlaid and the process of conflict resolution is activated when the temporary map/chart image contains a graphical conflict (Stefanakis and Tsoulos, 2001).

The conflict resolution process is implemented in three stages:

- Detection: The system detects and records a graphical conflict
- Evaluation: The detected conflicts are evaluated and stored in a list (conflict list) according to their significance in descending order
- Resolution: The actual resolution of graphical conflict is executed in this stage. The resolution process follows the sequence of the recorded graphical conflicts as they appear in the conflict list. The most significant conflicts are processed first.

Graphic conflict resolution is implemented within the expert system environment applying three rules, which are linked explicitly with forward chaining mechanisms (context links) and which are triggered in sequence (figure 6). Each spatial change (e.g. change of location, geometry), which may occur to cartographic features (symbols and texts) due to the execution of generalization operators must first be checked for topological consistency. These limitations constitute constraints on the graphical conflict resolution processes and they are expressed as rules within the expert system. The internal constraints and the constraints imposed by other features are usually “linked” to the resolution process with backward chaining mechanisms. However, the constraints which are applied to other features are “linked” with forward chaining mechanisms (figure 6).
This method of organization of the rules concerning graphical conflict resolution has been applied for the development of the knowledge base for the resolution of graphical conflicts among point symbols and text portrayal (Stefanakis and Tsoulos, 2001).

7. CONCLUSION

The automation of map/chart composition process has been a rather ambitious goal for the cartographic community. This goal has not been achieved yet mostly due to the fact that the existing commercial cartographic systems do not incorporate the cartographic knowledge pertaining to the various categories of maps/charts. The work elaborated here suggests an approach for the development of a hybrid system comprised of two tiers: an expert system and a geographic information system. The various stages of cartographic composition are undertaken by the appropriate tier and - when processed – the results are transferred and utilized accordingly. The cartographic knowledge is expressed in the form of rules, which constitute the building blocks of the knowledge base. The rules are derived from constraints pertaining to design specifications such as content, appearance or to the methods adopted for the composition of maps/charts. The structure and organization of the knowledge base is critical for the efficiency and the overall performance of the system. The results achieved so far are promising and show that this approach is a viable way towards the automation of map/chart production.

REFERENCES


