Development of a Cartographic Expert System

Research Team

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1. Introduction

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.

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.
- 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 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 (Agent **[1]**) and Expert Systems both of which utilize and manage rules.

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 thump" 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.

2. 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: a. Left-hand side conditions, b. Hypothesis which is a Boolean slot and c. Right-hand side actions (Then Do: Actions, Else Do: Actions).

Elements Environment provides with a number of representational structures. 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. 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.

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.

3. 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) 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 following phases:

- 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.

- <u>Symbolization</u>
  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).
- <u>Composition</u>
  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.

3.1 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 1 shows the selection process of cartographic features:

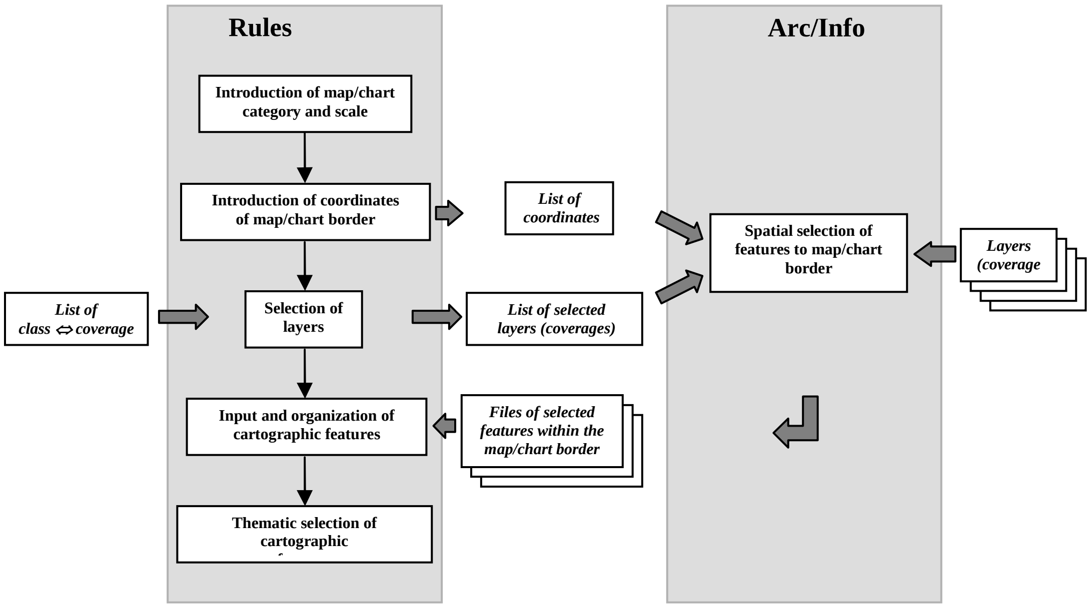

Figure 1. The selection process (Stefanakis **[2]**)

In the expert system environment the layers correspond to classes. Each class has the Boolean type property *selection_factor* where the value TRUE or FALSE is stored when the corresponding layer is used in map composition. 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 when it is decided that these features must not be used through the examination of their thematic characteristics.

3.2 Symbolization

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 2 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.

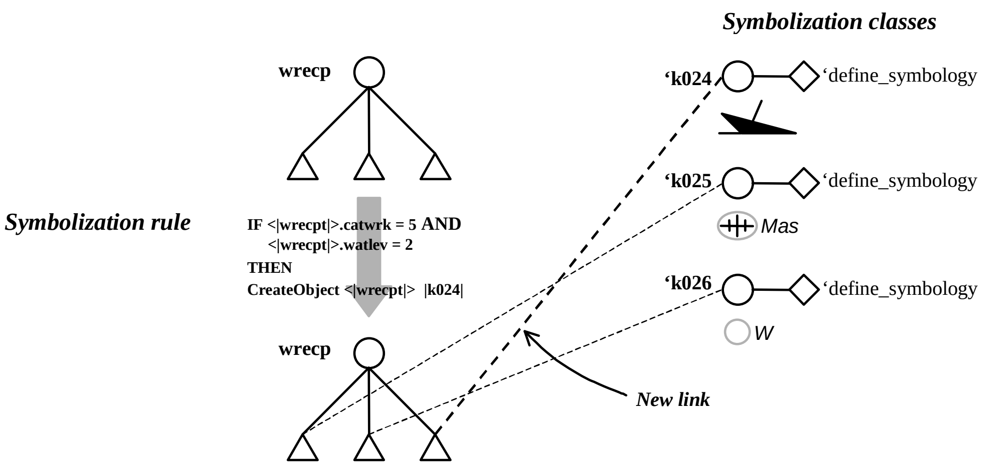

Figure 2. The symbolization process (Stefanakis **[2]**)

3.3 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 **[3]**):

- 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 generalized figures (Tsoulos & Stefanakis **[4]**), 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 **[5]**). This process must fulfil the following restrictions: a. the topology must be preserved (topological constraints) and b. 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 is 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. 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. 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 3).

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 & Tsoulos **[3]**).

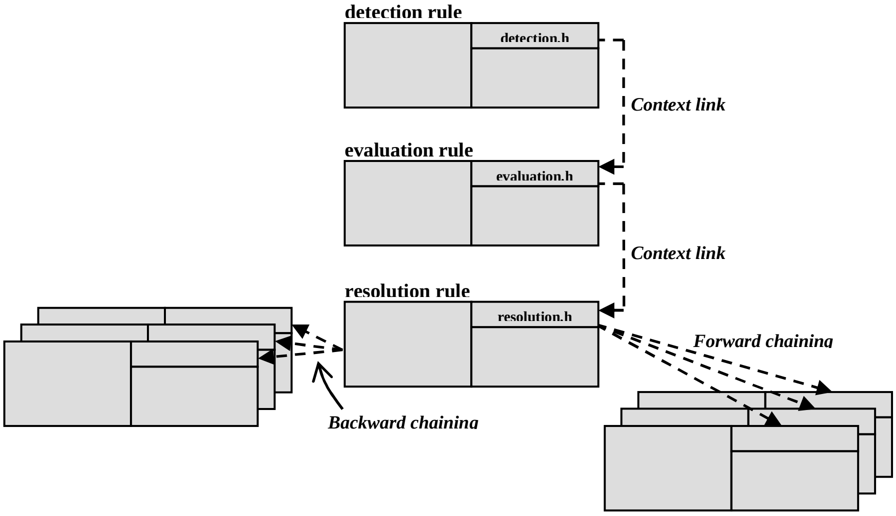

Figure 3. Rules realize graphical conflict resolution (Stefanakis & Tsoulos **[6]**)

4. 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

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