"CONFLICT DETECTION AND RESOLUTION FOR THE COMPOSITION OF NAUTICAL CHARTS IN AN EXPERT SYSTEM ENVIRONMENT"

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ABSTRACT

Current commercially available cartographic systems do not incorporate tools to support an "automated" map/chart composition process. This is due to the fact that cartographic composition is a complex and rather subjective process, mainly based on the cartographic knowledge and expertise, which cannot be represented and processed by the low level of systems' intelligence. On the other hand, traditional cartographic knowledge is being substituted gradually by map/chart specifications. The specifications do not always cover the wide variety of problems appearing in map/chart design and composition. Although digital cartographic systems constitute valuable tools for the production of maps/charts, do not lead to efficient and economic solutions The utilization of the expert systems technology to substitute - to a certain degree - the human factor and to "absorb" the knowledge required for the design and composition of maps and charts is a very promising solution. This paper elaborates a methodology for conflict resolution among point symbols in the framework of a hybrid (GIS - Expert System) environment. Indispensable component of this methodology is the knowledge base of the system, which is based on the existing specifications and the cartographic expertise.

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1. INTRODUCTION

During the last two decades, a considerable number of cartographic systems has been developed to support map/chart design and production. The evolution of digital technology combined with the reduction of cost, the availability of digital information and the standardization of cartographic databases, generated a potential for the automation of map design and production process. Cartographic design and production constitute complex and time-consuming processes. The cartographic experience and expertise are indispensable for the design and production of maps and charts with aesthetic quality and communicative ability. Digital systems provide powerful tools and - to some degree - procedures, which support the cartographic production process. However, the cartographer is still the "core" in decision-making and managing the rather complicated cartographic process. This paper elaborates an approach for the automation of conflict resolution, with the utilization of expert systems. The conflict resolution of map/chart features - as seen from the generalization point of view - is achieved through graphical conflict detection. Cartographic systems do not support the detection and management of graphical conflicts. The development of a hybrid system utilizing the expert systems technology along with GIS provides significant advantages for map/chart composition. Emphasis is given here, to the composition of nautical charts, as being one of the most standardized cartographic products.
The production of a map/chart is implemented through the following phases: Area Definition, Selection of Information (Selection), Transformation of Projection, Identification of Portrayal Method (Symbolization), Graphical Conflict Resolution (Generalization - Composition), Portrayal of Symbols and Text, Generation of Supplementary 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" *(Tsoulos and Stefanakis 1999)*. Selection, Symbolization and Composition are included in the first category.

2. SYSTEM DEVELOPMENT ENVIRONMENT

In the framework of this project, an Expert System (Elements Environment) interfaced with a Geographic Information System (Arc/Info) is being used. Elements Environment incorporates through its knowledge base, the design and composition methodology and handles the wide variety of entities appearing in maps/charts.

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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.
Elements Environment provides with a number of representational structures *(Neuron Data 1996)*. There are *objects* and *classes* to describe the cartographic entities. 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, 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. 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, which is a decision between different possible inference paths. 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 database, which has been organized according to the I.H.O. Standard for Digital Hydrographic Data *(I.H.O. 1996).*

2.1 Knowledge base architecture

The expert system applies two main representational paradigms: objects and rules. The system designer describes the map/chart with its features, in terms of entities (objects), generalizations of entities (classes), parts of entities (sub-objects), and their attributes (properties). The knowledge in the domain is encoded in the form of rules, which constitute the "building" components 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 contains the following categories of rules:

- *Selection rules* serve the selection -from the database- of those features required for the production of themap/chart. These rules generate the representations of features, to the object-orientated 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. The selection, design, composition and procedural rules, are organized into separate knowledge bases, which are loaded and unloaded accordingly.

3. SYMBOLIZATION

Symbolisation involves the process of transformation of entities to graphical features. The methods of symbolisation used are recorded and classified. These methods apply to point, line and area entities and generate point, linear, area symbols and texts *(simple methods)*, or combination of them *(complex methods).* At this phase also, the entities with small dimensions are transformed to point or linear features according to their characteristics.
The symbolisation process is implemented within the expert system environment where the rules *(symbolisation rules)* and methods *(symbolisation methods)* are applied *(Tsoulos and Stefanakis 2000)*. This methodology utilises the characteristics of the object-oriented model inherent to the system. Graphical features are generated and managed as objects. Graphical features / objects having similar characteristics are organised into common classes. In order to simplify the process of composition, features are represented temporarily by 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.

4. 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, area symbols and text, may generate graphical conflicts. In general, cartographic features require more space than their actual dimensions dictate. Maps and charts also include "abstract" phenomena, like names (e.g. textual descriptions to symbols, toponyms), isolines (e.g. contours, depth contours), heights and soundings, which are not tangible and do not have real dimensions. These features constitute additional sources of graphical conflicts.
The methods applied during map/chart composition and resolution of graphical conflicts, are: *simplification, selective omission, combination, exaggeration, displacement and elimination (Keates 1989, p.37-48).* In addition, the method of *"selection of alternative form"* is applied for the resolution of graphical conflicts. This method is applied to a small number of point features, which can be portrayed with alternative symbols and to textual descriptions, where the use of abbreviations is possible. *Table 1 shows* the generalization methods applied to nautical charts.

	Simplification	*Selective omission*	*Combination*	*Exaggeration*	*Displacement*		*Change of form*	*Eliminat ion*
					Change of position	*Change of geometry*		
Point features		Soundings			Harbor facilities, tidal streams and currents, types of seabed		Marine farms	*
Linear features	Coastline	Depth contours	Submarine cables and submarine pipelines			All features except coastline		*
Area features		Groups of islets	All features except land are	Islets	Wrecks	All features except coastline		*
Text features					Textual descriptions	Toponyms	Textual description s	*

Table 1. The generalization methods and the features involved

The composition and graphical conflict resolution methodology, is based on the following principles:

- The composition process is based on the "addition" of thematic layers. Thematic layers are composed separately, although their features are represented into unified structures (e.g. classes of point symbols, classes of textual descriptions, CTIN structure for the representation of linear and area symbols). When the composition of one layer depends on the composition of another, the second layer is processed first. For instance, soundings depend on the portrayal of depth contours. The composition of the layer of depth contours layer will precede the composition of the layer of soundings.
- Topology among the chart features must be preserved.
- The methodology applied must follow a specific sequence. This facilitates the development of the system and reduces the processing time.

The map/chart composition can be divided into the following phases: definition, detection and resolution of graphical conflicts. In general, a graphical conflict arises when features are so close as to be indistinguishable. (W. Mackaness, 1994). Graphical conflicts can be further distinguished to *intra* and *inter* conflicts. *Intra* conflicts occur to linear features or outlines of area features, while *inter* conflicts occur among different cartographic features. Graphical conflicts are classified according to the cartographic features involved:

- Among point symbols / texts
- Among point symbols / texts and linear symbols
- Among point symbols / texts and area symbols
- Among linear symbols
- Among linear symbols and area symbols
- Among area symbols

Some of the above-mentioned conflicts are properly described by geometric conditions concerning the dimensions of the features involved (e.g. point symbols / texts), while in others geometric conditions must be

accompanied by additional information concerning the thematic characteristics of the features involved (e.g. point symbols / texts and linear symbols).
In this paper, the methodology is elaborated and implemented for the detection and resolution of conflicts among point symbols of a nautical chart.

4.1 Knowledge organization for graphical conflict detection and resolution

The knowledge concerning the detection and resolution of graphical conflicts is stored, in the following forms:

- <u>Expert system's rules (production rules)</u>

These rules constitute the building components of composition procedures (e.g. rules which implement the resolution of graphical conflicts among point symbols), or criteria (e.g. which feature is less important for the application of the elimination process), which are usually called explicitly. Rules are triggered through the mechanisms provided by the expert system's inference engine.

- <u>Methods of the applied object-oriented model</u>

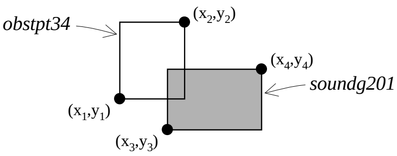
A method is structured similarly to a rule and functions as programming language routine. Methods are attached to objects and define their behavior during system operation. Objects/point features are supported by methods during the conflict resolution process. The design of rules does not need to focus on special cases, because this type of knowledge can be encoded in the form of methods and attached directly to the objects concerned. This feature provides considerable flexibility to the system development and maintenance.

- <u>Parameter tables</u>

Parameter tables are developed as lists or tables of information and generally store simple relationships for access by some relational referencing methodology during rule-based processing *(Shea 1991,)*. Information expressed through parameter tables, constitutes declarative knowledge. Parameter tables may be simple or complex in nature and are managed as ASCII files. The editing process of these files is carried out, without modification of the system's code.

4.2 Detection of graphical conflicts among point symbols

In the expert system environment, point symbols are represented by their minimum boundary rectangles. The detection of conflicts among point symbols can be perceived as detection of overlaps among the corresponding rectangles (figure 1). Such a condition constitutes graphical conflict, which deserves resolution, independently of the involved features. The mathematical condition, which expresses the existence of an overlap between two rectangles, has the form included in figure 1.



IF ($x_4 \leq x_1$ OR $x_3 \geq x_2$ OR $y_4 \leq y_1$ OR $y_3 \geq y_2$) THEN disjoint ELSE overlap

Figure 1. Point symbol conflict

4.3 Methodology for graphical conflict resolution among point symbols

The graphical conflict resolution among point symbols is achieved through the application of the generalization methods of: displacement, selection of alternative form (selection of alternative symbol) and elimination. The diagram of figure 2 presents the logical order of execution of these methods.
The method of displacement of the two symbols involved into a graphical conflict is first applied. In case that this method fails to resolve the conflict, the methods of selection of alternative symbol and elimination are applied. If an alternative symbol is provided - in the chart specifications - for the features involved in a graphical conflict, then this symbol or symbols are applied and the method of displacement is re-executed. In the case that no alternative symbol is provided the method of elimination is executed, which leads undoubtedly to the graphical conflict resolution. This process is repeated until all the detected graphical conflicts have been resolved.
The system must examine and resolve at first place the most significant graphical conflicts and then the less significant ones. The process implemented must conform to the principle of cartographic composition by thematic layer. Graphical conflicts are classified according to the "weight" of the cartographic features involved. A light for instance, is more significant to navigation than a landmark; thus conflicts among lights

are more significant than conflicts among landmarks or conflicts among lights and landmarks. Thus, the resolution of conflicts among lights will proceed. The "weight" or "significance" of the cartographic features is expressed by the *feature priority factor.* A feature with higher priority is characterized as more significant than a feature with a lower priority. Feature priority factors, besides their use for the evaluation of graphical conflicts, are also applied to the methods of displacement and elimination.
The cartographic features are also accompanied by a *tolerance factor.* The tolerance factor expresses the maximum distance from the original location where a point symbol can be portrayed. This factor is used during the execution of the displacement method. It varies from zero (0) millimeters for the features, which cannot be displaced (e.g. light symbols), to several millimeters for those which can be displaced (e.g. symbols of currents).

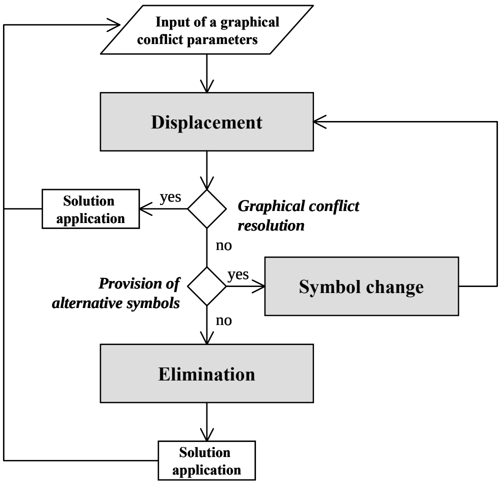


Figure 2. Order of execution of conflict resolution methods

The displacement method may lead to the generation of new conflicts, if it is executed without taking into account the interaction of the examined point symbols with their neighbors. The displacement of point symbols for graphical conflict resolution is applied only under the following conditions:

- The displaced symbols remain within the chart border.
- The displaced symbols are located in distances from their original positions shorter than their corresponding tolerance factors.
- The displacement does not generate new graphical conflicts of higher "significance". If the displacement of two point symbols produces new graphical conflicts of lower "significance", then the method is applied and the new conflicts are stored and subsequently examined.
- The displacement of a point symbol should trigger the appropriate displacement of the point, line or area feature, which is associated with it. The displacement of a buoy for instance, should cause the displacement of the vertex of the anchorage area where it is linked.

If alternative symbol or symbols are provided for the features involved in the conflict, the selection of alternative symbol is applied. Alternative symbols have smaller dimensions than their corresponding original ones and they are used when the chart information is very dense. The substitution of a point symbol with a smaller one does not always resolve a graphical conflict. However, it improves the conflict conditions and the search of an acceptable solution is favorable. The elimination method is applied when displacement fails to resolve the conflict and no alternative symbol is provided for the features, which take part in the conflict. Thus the less significant feature is eliminated from the chart. When a graphical involves features from the same layer - with equal priority factors - the less significant feature is identified after the examination of the thematic attributes of the two features. In the case of conflicts among lights, the less significant light is the light with the shorter range. When wrecks are involved, the less significant wreck is this one with the deeper depth (less dangerous). Similar criteria - and ones that are even more complex - can be formed for all map/chart features.

4.4 Implementation of point symbols conflict resolution methodology

Point features are represented as objects into the expert system environment. The graphical features (point symbols and texts) used for the portrayal of point features, constitute sub-objects of the object/point features. The slots of object/point features are utilized to store the thematic attributes and the geographic position of these features (figure 3). Objects/point symbols are attached to slots where the used symbol code and the shape of the corresponding minimum boundary rectangle are also stored. The graphical conflict resolution methods are applied to the objects/point symbols. During the resolution process, the thematic attributes of the corresponding point features can be easily accessed. Objects/point features and objects/point symbols inherit from their parent classes slot values and methods, which are used during the graphical conflict resolution process.

The feature classes are provided with slots such as *"alternative_symbol"*, *"displacement_distance"* and *"feature_priority"*, where the code of the possible alternative symbol, the tolerance factor and the feature priority, are stored respectively. The values of these slots for each feature class have been stored into a parameter table and are retrieved by the system when they are to be used.

The detection of a graphical conflict among point symbols is executed by triggering the method, which locates an overlap between two rectangles. This method examines the objects of the *"pointsymbol"* class. When a graphical conflict is detected, a new object *(conflict object)* is created and the process of detection is completed, the graphical conflicts are evaluated and ranked. The process of resolution begins through the examination of the most significant conflicts and proceeds with the less significant ones. The evaluation of conflicts is being executed in such way that the process of resolution takes place by thematic layer.

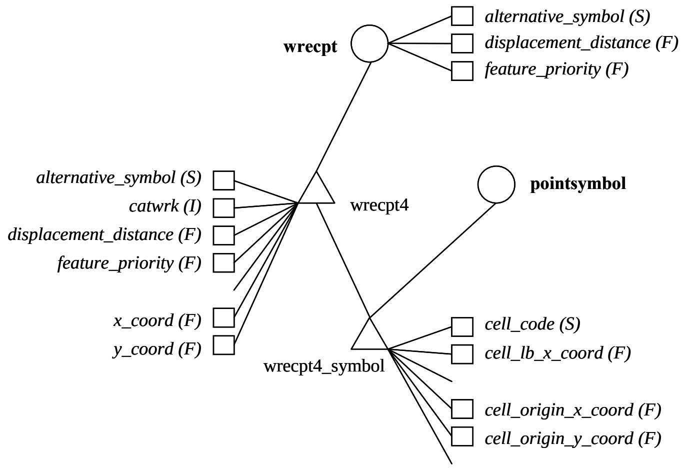


Figure 3. Storage of point feature characteristics

The structure of the rules, which are used in order to resolve a graphical conflict among point symbols, is portrayed in figure 4. The rule *"resolve_pntvspnt"* constitutes the "core engine", which controls the graphical conflict resolution process. This rule selects - from the class of conflict objects - the object with the highest priority. The rules, which implement the methods of graphical conflict resolution, are then triggered. The rule *"resolve_pntvspnt"* is provided with a *context link*, which enables its execution until all the detected conflicts have been resolved.

The rule *"resolve_pntvspnt"* inserts the *"action.h"* hypothesis into the system's agenda for evaluation. The rules *"test_pntvspnt"*, *"displace_pntvspnt"*, *"changeform_pntvspnt"* and *"eliminate_pntvspnt"*, which are provided with *"action.h"* hypothesis, are then scheduled for evaluation and an "or graph" is created. The order of evaluation of these rules is controlled by the set rule priorities. The operator *"exhaustive evaluation"* has been set in the "OFF" mode, so that the evaluation of *"action.h"* hypothesis stops when the first rule in the "or graph" has been evaluated as "TRUE".

The operation of the rules participating in the "or graph" process is briefly described in the following paragraphs:

- Rule *"test_pntvspnt"* (priority: 15)

This rule is first evaluated. The application of displacement and selection of alternative symbol methods may lead to the resolution of other graphical conflicts in the area. The evaluation of this rule ensures whether the examined conflict still exists.

- Rule *"displace_pntvspnt"* (priority: 10)

The displacement method is implemented by the rule *"displace_pntvspnt"*. The displacement vectors are first computed in order to resolve the graphical conflict between two symbols and a temporary solution is identified. This rule inserts into the system's agenda the rules *"test_pnt_border"*, *"test_pnt_original_position"* and *"test_pnt_influence"* (figure 6), which test the temporary solution's integrity according to the criteria described in the methodology. If one of these rules is evaluated as "FALSE", the displacement of point symbols is cancelled. If all these rules are evaluated as "TRUE", displacement of the point symbols is applied followed by the displacement of the associated features (message passing to the method *"displace_mastft).*

- Rule *"changeform_pntvspnt"* (priority: 5)

The selection of alternative symbol is implemented by the rule *"changeform_pntvspnt"*. If an alternative symbol is provided for either feature in a graphical conflict, then the symbol or symbols substitution is executed and the rule is evaluated as "TRUE". Otherwise, this rule is evaluated as "FALSE" and the system proceeds with the examination of the rule *"eliminate_pntvspnt"*.

- Rule *"eliminate_pntvspnt"* (priority: 1)

This rule has the lower priority in the "or graph" process. The evaluation of the less significant feature participating in a graphical conflict and its subsequent elimination is implemented by this rule. When the features belong to the same layer, backward chaining activates specific rules/criteria, which specify the less significant one with regard to the features' thematic attributes.

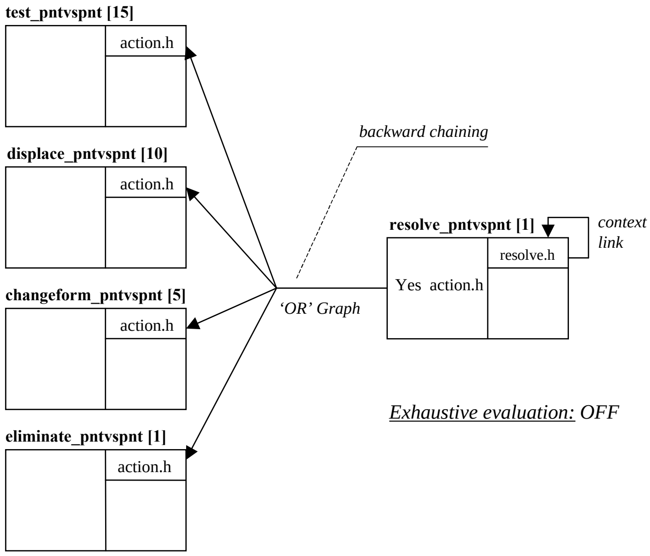


Figure 4. Rules structure for the resolution of graphical conflicts among point symbols

During the execution of the graphical conflict resolution process among point symbols, a report file is generated, where the decisions and actions of the system are recorded. The efficiency of the described methodology is certified through the system's output, which is portrayed in the figure 7.

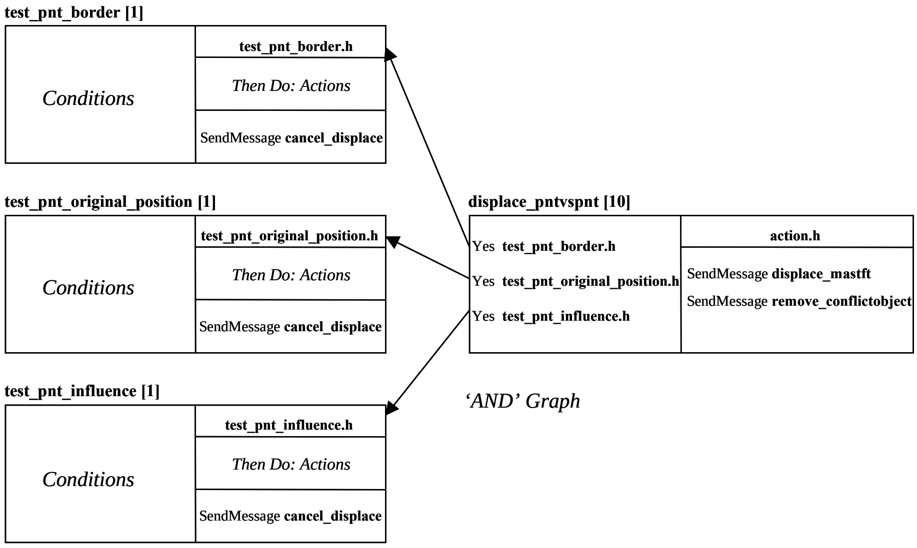


Figure 5. "And graph" created for the execution of displacement

5. CONCLUDING REMARKS

This paper has demonstrated how spatial conflicts are defined, identified and resolved in the framework of a hybrid system environment, consisted of an Expert System and a Geographic Information System. The methodology elaborated, shows that this approach is realistic, efficient and gives promising solutions to fundamental cartographic problems, as automation of generalization and map/chart composition. The system assesses automatically the solution and/or alternative solutions for each case of conflict. It is evident that the successful utilization of the system depends not only to its architecture and the processes involved, but to the integrity and completeness of the knowledge base, which supports the identification of the conflict, its nature and the appropriate solution.

Figure 6. Conflict resolution for point symbols

We are convinced that the issue of spatial conflicts resulting from map generalization must be dealt with hybrid systems, which have the level of intelligence to store and utilize human expertise in Cartography. Further research towards the conflict resolution of features represented by other geometric primitives (lines, areas) is indispensable.

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