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A Concept for model generalization of digital landscape models from finer to coarser resolution

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Abstract

By model generalization we mean derivation of a coarser resolution digital landscape model (DLM) from a finer resolution DLM. A concept is submitted for the automatic derivation of model generalization. It focuses on the two processes of semantic and geometric generalization and proves the implementability of the concept using the example of transition from ATKIS DLM 25 to ATKIS DLM 250.

Introduction

Geo information systems (GIS) have established themselves to solve a wide variety of tasks in business and administration. Use of these systems requires a rethinking from the analog working procedures used hitherto to newer digital techniques and procedures. The basis for working with these new digital systems is formed by digital data which, depending on the requirement, can be of various semantic and/or geometric resolutions. For the area of Germany, the national mapping agencies are building the ATKIS system with its three different levels of detail - DLM 25, DLM 250 and DLM 1,000. Because the generation, updating and maintenance of these DLM requires enormous personnel and financial inputs, simple and fast methods of producing DLM are to be sought. One means to this end is offered by automatic derivation of a DLM from a DLM of finer resolution, generally referred to as model generalization.

Various techniques for generating a DLM

In many areas the use of newer digital technologies requires the introduction of new terminology and procedures. Hence the cartographic model theory also uses digital models alongside the conventional analog models (maps) to depict or abstract the real world. The digital models are subdivided into digital landscape models (DLM) which present an alphanumerical depiction of the landscape, and digital cartographic models (DCM) which present a pictorial, scale related depiction of the landscape (McMaster, 1992).

On the basis of this model theory, the term model generalization is to mean only the derivation of a coarser resolution DLM from a finer resolution one, which makes possible a clear delineation of model generalization from cartographic generalization.

The generation of a DLM requires from a semantic and geometric point of view a non-contradictory depiction of the individual features of the real world in the model objects of the corresponding DLM. Thus a DLM can only be carried out by the method of direct acquisition of the landscape or by model generalization from a finer resolution DLM (figure 1). Currently DLMs are made almost exclusively through direct acquisition. The landscape is converted into a DLM by taking into account acquisition generalization, with extent and accuracy of this acquisition oriented to the theme-related real world modeling. Special preparatory works are needed to generate a DLM. The relevant landscape features have to be described by feature classes and the kind of geometric modeling as well as the attributional characteristics have to be defined. Criteria and rules for object delineation, the acquisition of the landscape features and their classification in feature classes have to be laid down. These rules and criteria lead to a feature class catalog(FC), and the generation of a DLM by this methodology is called object generalization according to feature class catalog (OF). Depending on the theme-related definitions, this leads to detail rich and precise DLM.

The alternative way, model generalization, is not only a simplification of the data model based on topological landscape description, but also a further simplification of the semantic and geometric landscape description. The derivation of a coarser resolution DLM from a finer resolution one thus combines both processes of semantic and geometric generalization (figure 1). Semantic generalization is defined as the contentual reduction of detail rich landscape description of the finer resolution DLM to the demands of coarser resolution DLM. Geometric generalization is defined as adaptation of the spatial relation of the features to the geometric precision of the model (geometry type change and adjustment of model resolution).

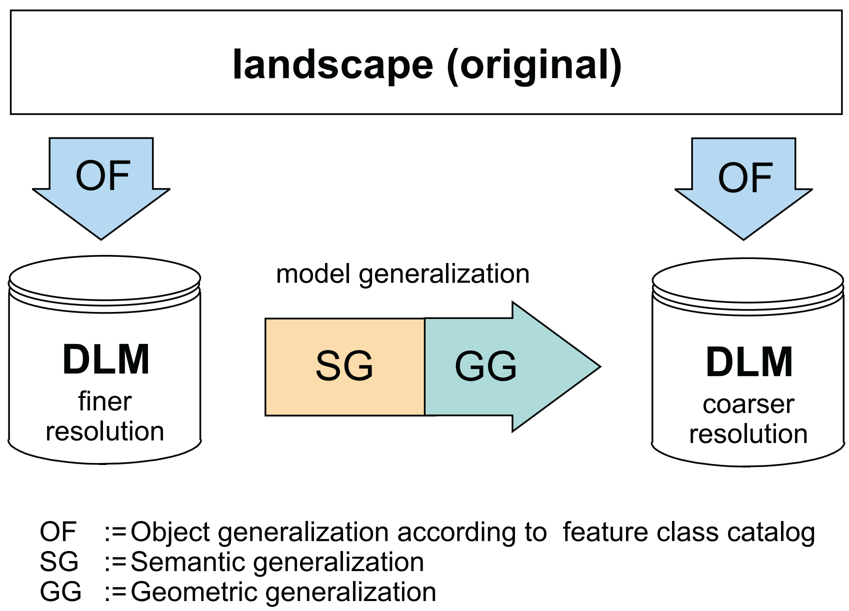

Figure 1. Acquisition or derivation of a DLM

Structure of model generalization

Model generalization is to be explained using the example of the transition from ATKIS DLM 25 to ATKIS DLM 250. The various generalization steps are depicted in Figure 2.

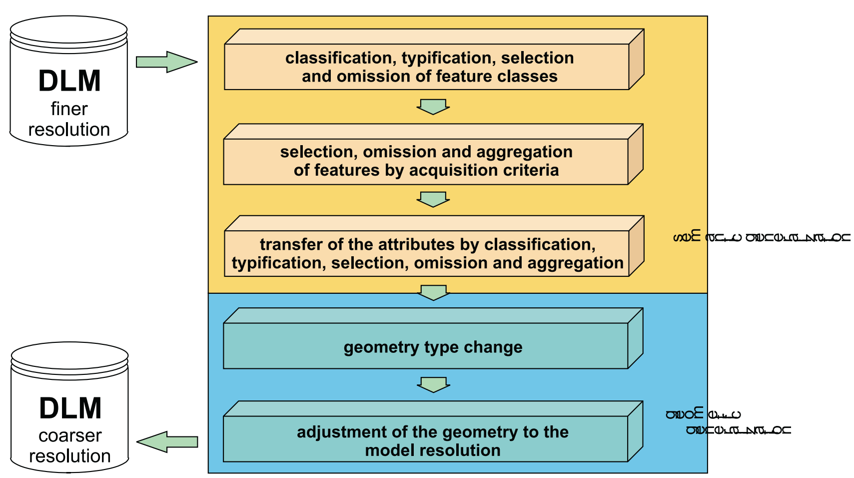

Figure 2. Processes of model generalization

Semantic generalization

The semantic generalization encompasses the steps of classification, typification, selection and omission of entire feature classes, the selection, omission and aggregation of individual features according to their acquisition criteria and the transmission of the attributes by classification, typification, selection, omission and aggregation. The degree of generalization is determined by the predetermined landscape modeling of the feature class catalogs (FC).

1st step: classification, typification, selection and omission of feature classes

In the first partial step of semantic generalization the feature classes of the DLM 25 and the DLM 250 are to be compared and possibly linked in connection with their attributional description so that a clear categorization of the features of various DLM is possible.

This step is shaped and influenced by setting up the modeling regulations of the DLM 250. Thus the processes of "classification resp. typification" as well as "selection resp. omission" are already defined in the generation of the FC 250 with all feature classes and information to be included. Within the framework of the model generalization linkage relations between the various feature classes are to beset upon the basis of the predetermined modeling regulations of the FC 25 and FC 250 (table 1).

Table 1. Relations of combination between the feature classes

	DLM 25				DLM 250	
a)	**Relation of combination 1:1**					
	3101	road	⇨	⇨	3101	road
b)	**Relation of combination n:1**					
	3201	railway	⇨			
	3203	railway (complex)	⇨	⇨	3201	railway
	3204	railway embankment	⇨			
	3205	railway track	⇨			
c)	**Relation of combination 1:0**					
	No example found !					

2nd step: selection, omission and aggregation of features by acquisition criteria

The reduction of the semantic information of the finer resolution DLM is not, however, restricted to the omission of entire feature classes, but can also extend to features that do not meet certain feature characteristics (acquisition criteria). In the omission of features these feature characteristics take into account a specific feature class in DLM 250, its significance and size, and they can be either semantic criteria (e.g. qualitative attributes) or geometric criteria (e.g. feature length, feature breadth, feature area). Whereas the checking of the semantic criteria can be determined relatively simply by calling up the stored feature characteristics, to check the geometric criteria calculations may become necessary because of the current feature geometry because these properties are generally not explicitly stored. A decision on the inclusion or omission of a feature cannot, however, depend only on the feature itself, but must also take into account the characteristics of neighboring features (e.g. "3531 cable" is included if its pylons (feature class "3541 pylon") are higher than 15 meters).

If there are no direct relations between these features, the objects must be retrieved via the search for common geometric primitives from a data base.

For the transition from DLM 25 to DLM 250 the predominant feature reduction is carried out with the generalization step *"Selection, Omission and Aggregation of Features by Acquisition Criteria."* Therefore the acquisition criteria must be carefully defined and laid down. The geometric criteria effect a certain arbitrariness in the selection of features, since these criteria (e.g. length of feature < 300 m) depend greatly on the feature formation and the local topographic situation. Especially with linear features these criteria can destroy the structure of line networks.

3rd step: transfer of the attributes by classification, typification, selection, omission and aggregation

In the third partial step of the semantic generalization the qualitative and quantitative feature information stored in the attributes for detailed description of a feature are adjusted to the information content of the DLM 250. The attribute types for linked feature classes of the DLM 25 are compared with those in the DLM 250 and, insofar as both type and value are predetermined, are taken over. If such classification is not possible, the feature information is either omitted completely or to be typified in a general attributes by aggregating attribute values. In addition to this general case of attribute generalization in the model transfer, the attributes must also be tested in the aggregation of features in the same model (DLM). In this the generalization of the attributes is much more complex due to the outstanding importance to landscape modeling.

Take as an example the amalgamation of two area features to be united within the framework of model generalization. In addition to the feature class for the new feature, the attributes of this feature must also be derived from the features to be omitted. The data modeling in ATKIS provides for separation of the attributes into “feature forming”, “dominant” and “normal” attributes. The feature forming attributes assume special significance because they encode different landscape feature in one feature class (e.g. 3101 road: WDM=1303 federal road, 1304 state road). The omission of such an attribute causes the omission of the entire feature. For this reason the attributes should already be tested in step 2 *Selection, Omission and Aggregation of Features by the Acquisition Criteria* and also be included in the FC 250 as selection criteria for the relevant feature classes. The dominant attributes represent a special local characteristic which must be maintained on feature aggregation. In the case of dominant attributes the greatest attribute value must be taken over (e.g. greatest height of the feature). When in the case of normal attributes features are aggregated from the various values of an attribute type either a value is selected, e.g. from the biggest proportion of a total area an attribute value possesses, or a new value is determined, e.g. by average computation. Table 3 gives an example of the transformation of attributes.

Table 2. Transformation of attributes on the example of the feature class “trail (Code : 3102)”

Transformation of attributes for the example of the feature class “2221 stadium” with the attribute “SPO = sport”	
Attribute values of DLM 25	**Attribute values of DLM 250**
1100 soccer	1100 soccer
1400 riding	1400 riding
1900 racing	1900 racing
1200 athletics 1300 tennis 1500 swimming 1600 skiing 9999 others	9999 others

Processing hierarchy

The main demands to make on the outcome of an automatic generalization are clarity, replicability and comprehensibility of the generalization results. These demands require a complete generalization approach taking into account and integrating generalization technique, modeling technique and data structural components. Computerized processing resp generalization of a DLM further requires a feature-related approach in which the landscape features are no longer addressed, but the individual DLM objects. Implementation of the model generalization concept developed therefore requires a control tool enabling the generalization of features down to the smallest data-structural unit. The most important component of this control tool is the processing hierarchy which lays down both the generalization sequence between the various feature classes and the feature classes with the special processing steps.

In building a processing hierarchy for features of different feature classes both the DLM 25 as source DLM and the DLM 250 as target DLM predetermine the parameters for the model transition with their data structures, varying modeling rules (feature formation rules, acquisition criteria, accuracies and topological references) and data reduction demanded.

Generally, line features are processed before area features, before point features. Depending on landscape modeling, these groups have to be subdivided further so that related feature classes (e.g. the feature classes of the road network) are processed together and the subsequent generalization steps can be built on these interim results.

Sequence of the semantic generalization

Figure 3. ATKIS DLM 25

The semantic generalization is made clear with an ATKIS DLM 25 test area. It shows a small built-up area surrounded by agricultural land. The DLM 25 is characterized by a very detailed feature structure in relation to the line network and the area features.

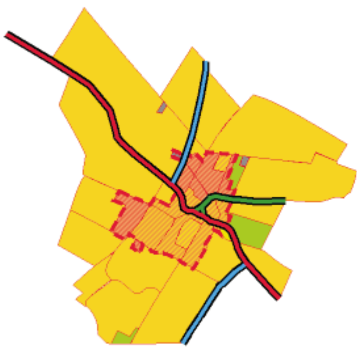

Figure 4. Generalized line features

The generalization of the line features supplies a first digital intermediate model (DIM). The road network depicted now contains only the major roads according to the predetermination of the feature class catalog (FC). By generalization of the related feature classes from one mould, the preservation of the net structure can be steered to the model generalization by means of a special processing hierarchy and adjustment of the feature class catalog.

Figure 5. Creation of generalization blocks

Because most area features of the DLM 25 do not meet the acquisition criterion demanded, several DLM 25 features have to be amalgamated into one DLM 250 feature (amalgamation relationship 6:1). To avoid arbitrary results the amalgamation of the features is carried out in generalization blocks. The blocks are formed automatically by the generalized line network and by the boundaries of significant landscape features (e.g. location of the urban area, forest; 9 blocks in the test area). The amalgamation of the features is effected in the blocks according to the similarity. If a block is too small to form a DLM feature, this feature is subsequently amalgamated with a neighboring feature across block boundaries.

Figure 6. Result of semantic generalization

The result of the semantic generalization is a DIM corresponding to the required level of detail.

Geometric generalization

The geometric generalization comprises the two partial steps of geometry type change and adjustment of the geometry of model resolution (figure 2).

Geometry type change

In their landscape modeling the various feature class catalogs (FC) provide for a special geometry type for every feature (area, line and point related). The geometry types for linked feature classes must be compared in model generalization. If geometric modeling for linked features matches in both DLM, the geometry of the DLM 250 feature can be produced by copying from the DLM 25. If the geometric models do not match, the geometry for the features in the DLM 250 must be newly defined and neighboring features must be adjusted to this new geometric situation. These procedures are referred to as geometry type change, in which only the transitions “Area → Line”, “Area → Point” and “Line → Point should occur in the model generalization. The various geometry type changes and known algorithms to obtain the solution are given in figure 7.

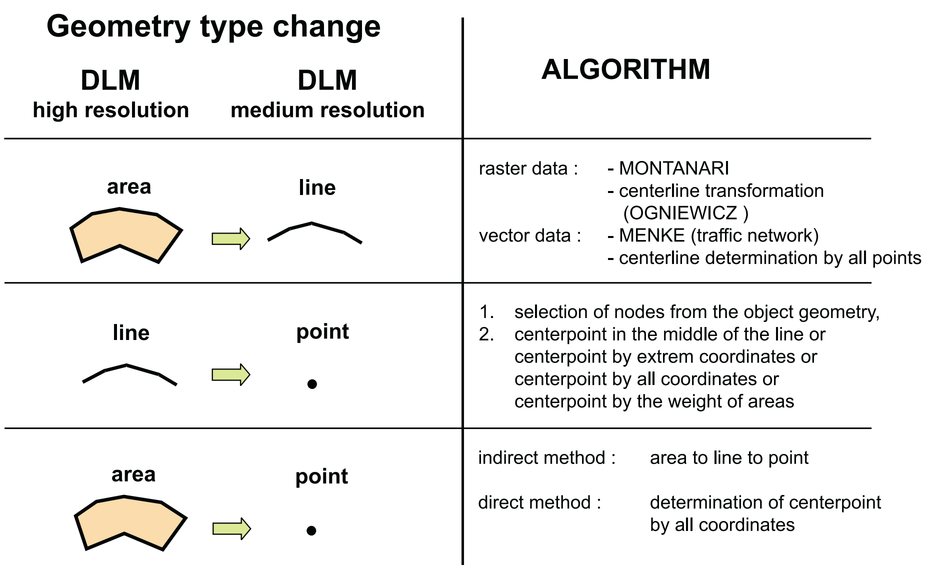

Figure 7. Geometry type change

Adjustment of the geometry to the model resolution

In addition to simplification of the semantics, the transition to a coarser resolution DLM also needs adjustment of the geometry to the required resolution. This partial generalization step is defined as adjustment of the geometry to the model resolution. In line with the object separability distance, model resolution in this context is understood to be the distance between two geometric points so that both points can still be separately acquired and stored. For the transition from DLM 25 to DLM 250 a model resolution of ± 60m was used, taking into account accuracy, presentation scale and manual acquisition data.

The adjustment to the model resolution requires a simplification of the feature geometry encompassing reduction of points and simplification of line in the context of accuracy. For the enormous geometry simplification needed to adjust model resolution in transition from DLM 25 to DLM 250 only those algorithms should be selected from the great number of simplification algorithms which combine point reduction and line simplification. Examples are the DOUGLAS/PEUCKER algorithm and the algorithm with sliding mask (called WEBER algorithm). However, the use of these algorithms requires a differentiation of the feature geometry which can comprise polygonal or curved line (SPLINE).

In the case of lines with polygonal point connections the suggested algorithms (DOUGLAS/PEUCKER and WEBER) produce good results if optimal parameters are selected. Due to their special way of working of these algorithms, the choice of parameters for this line type can simply be derived from the accuracy of the related feature class. The algorithms choose the characteristic geometric points in such a way that with the polygonal link the new line always lies within the predetermined accuracy bench so that the DLM's accuracy is met.

Problems can arise with curved lines (SPLINE) if the simplification algorithms reduce too many geometric points (figure 8). Because of too little point density, simplification of the original line (figure 8, left) by the DOUGLAS/PEUCKER algorithm produces deviations from the original line (figure 8, center) which no longer correctly represent the geometric form and lie clearly outside the accuracy bench. In the case of lines with curved point connections the preservation of distances between selected characteristic points has to be checked after points reduction by a simplification algorithm. If distances between points are too great, deviations can be avoided and accuracy preserved by computing in support points on the basis of the original points (figure 8, right). The securing of an adequate number of geometric points is also of great importance to the subsequent work steps which are based on the generalized data base, because inadequate support point density cannot be remedied.

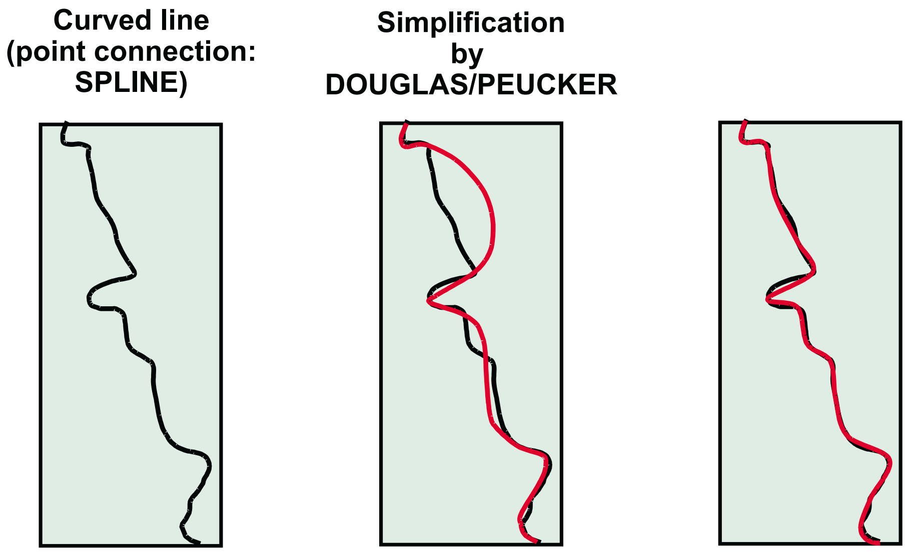

Figure 8. Line simplification and determination of supported points

Conclusions

The trials conducted have shown that the approach to model generalization for transition from DLM 25 to DLM 250 outlined here can be effected automatically to a large degree. In the process of semantic generalization special strategies are necessary for the generalization of line networks and for the amalgamation of area features. The problems which arise can be solved by adjusting the feature class catalog (FC) to the model generalization, establishing a fixed processing hierarchy and generalizing the areas in blocks.

In the process of geometric generalization the known algorithms for points reduction and line simplification must be adjusted to the special problems and continue to be tested in respect of paramaterization.

A comparison of the generalization results with the corresponding topographical maps (e.g.1:250.000) shows that a comparable degree of generalization was achieved. However, the generalized DLM 250 possesses a greater semantic and geometric information density, which is useful for further processing steps with this data base.

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