Evaluation of generalisation quality

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Abstract

This paper proposes a methodology to assess the quality of generalisation. Generalisation consists in representing in a simplified way a geographic space, according to the scale and to the objectives of the map. The automation of this process makes the derivation of data easier, but the data quality of the results is often not evaluated. This paper deals with the definition of generalisation evolution reference and of an assessment model. A generalisation evolution reference is the definition of the expected evolution of a geographical feature property during generalisation. The assessment model is based on (1) a data characterisation in their initial and final state at different level of analysis (micro and meso), (2) a data quality assessment from the comparison of the two previous characterisations and (3) the aggregation of the various assessment results to summarise data quality. The assessment algorithm has been implemented and the method has been tested to assess the generalisation of a small urban area. A visualisation tool of assessment results has been developed to validate the generalisation evaluation. Results are presented and discussed at the end of the paper.

Keywords: quality assessment, cartographic generalisation, evolution reference, feature characterisation, evaluation, aggregation, and visualisation.

1 Introduction

The automatic generalisation process is often divided into three parts (Agent 99): (1) the description and the analysis of the spatial context of geographic features, (2) an algorithmic processing adapted to this context, and (3) an evaluation of the generalisation, i.e. the qualification of the generalised data and the validation of the generalisation results. Research in generalisation has especially focused on the first two points. This work fits in this framework and focuses on the assessment step.

In the literature, the assessment of generalisation has been *"a forgotten consideration in generalization research*" [Müller & Al. 92] and "*has received relatively little attention in research so far*" [Weibel & Dutton 99, p150]. Moreover, João reports what we define as a generalisation paradox: "w*hile scientists have long been aware that generalisation has an important influence on map features and analysis, surprisingly little research has been devoted to quantify it* (…) *the development of methods to quantify and control generalisation effects is still a priority*" [João 98]. Only few studies have assessed the impact of derivation on data quality. In view of the assessment complexity, the problem have been broken down into studies which focus on a single type of geometric primitive: lines [McMaster & Shea 92; João 98, Skopeliti & Tsoulos 01], surfaces [Dettori & Puppo 96; Cheng 01; Peter 01], or on the validation of some specific generalisation process [Brazile 00; Agent 99] or on a more generic approach [Ehrliholzer 95; Harrie 01].

Traditionally, cartographic generalisation is manually performed and visually assessed. The storage of geographic information into databases allows a systematic control of generalisation results with computer processing. Nevertheless, the cartographic analysis and reasoning during the evaluation are difficult to decompose into simple procedures. For instance, the selection of the main roads on a semantic criteria of road types (elimination of the secondary roads) leads to accessibility problem management. The access to a forestry house or the passing through a valley by a secondary road might or might not be removed to preserve the coherence of the road network. It seems to be difficult to determine if the presence of such features is due to an error of generalisation or not.

This example shows the importance of the context in generalisation. Generalisation rules exist but are adapted to the context of generalisation. The transposition of such rules into generalisation specifications is one of the evaluation difficulties. How to assess the quality of generalisation if the rule is modified for each context of generalisation ?

The main objective of this paper is the definition of an assessment model for cartographic generalisation. The first part exposes the problematic of generalisation assessment. This work is based on a fundamental principle: the definition of reference generalisation evolution, defines in the second part. The third one details the proposed method and we finish with the presentation of the application developed and some results.

2 Problematic

The generalisation is a process of simplification of a geographic space representation. By simplification, geographic features are modified with operations of displacement, aggregation, elimination and caricature. The objective is to qualify this result of generalisation according to two aspects: 1) to assess if the preserved data are pertinent or not, i.e. correspond to the user needs, and 2) to assess if the modifications are acceptable or not, i.e. if the data still reflect the reality. The problem to solve is illustrated in figure 1 and is posed like this : from a giving generalisation, how to define its quality ?

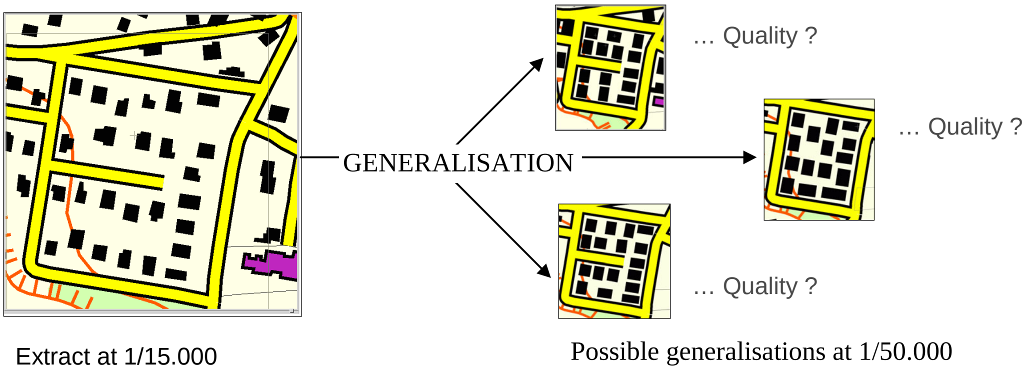

Figure 1. Generalisation of an urban block: non uniqueness of the result.

Two mains difficulties have been identified: on the one hand, the existence of several possible generalisation solutions for the same initial configuration [Spiess 95], see figure 1, and on the other hand the difficulty to acquire knowledge on generalisation specifications.

The non uniqueness of the generalisation result is problematic to define a reference of generalisation, if such a reference exists. From a general point of view, the assessment consists in the comparison of an observed result to an "ideal" result called the reference. So, the assessment is a measure of the distance between the observation and the reference. Yet, in the case of the generalisation, several references are possible and are not all known and not easy to order.

The acquisition of the necessary knowledge for assessment conditions the parameterisation of evaluation. For instance, the legibility threshold is defined to 400 m² for building size at the 1 to 50.000 scale. But, the human eye is unfitted to distinguish a building of 420 m² size, from a building of 380 m² at this scale. As a consequence, we state that each specification of generalisation might be weighted with a tolerance value.

3 The definition of reference evolution

The definition of the generalisation specifications is one of the principal difficulties in the setting of a generalisation assessment. These specifications are of two types: cartographic and users. The cartographic specifications are related to the final scale of generalisation and constrain the size of the cartographic symbols associated to the represented features, e.g. the minimal size of a building. The specifications of the user correspond to the definition of the significant points to evaluate according to a specific user, e.g. to fix the displacement tolerance for roads at 50m, or remove 20% of the roads.

For this, we propose the use evolution of reference. An evolution of reference is the expected evolution of a geographical feature property during generalisation. A property is a geographical characteristic of a feature (e.g. position, size for a building). Several levels of analysis are necessary to apprehend the properties of geographical space. The properties are described using measurements. For example, the property of size of a building is measured by its surface.

For each identified property of a geographical feature, a theoretical value is computed starting from the curve of evolution of reference defined for this property. Then, the difference between the theoretical value and the observed value (i.e. generalised) is computed. This variation is interpreted according to the tolerances fixed for each property in the user specifications.

The figure 2 illustrates this principle of reference evolution for three properties: the position, the concavity ratio and the size. The position is a property which should not be modified too much, this is why the curve of reference is a curve of type: initial position equals generalised position. The concavity ratio (ratio of the surface on the surface of the convex envelope) is a measurement of the property of shape. The weaker this rate is, the more the shape of the object is complex. The evolution as the reference is a weak simplification of the very complex objects (left part of the curve), i.e. that one caricatures the objects of remarkable shape, and a complete simplification of the shape of the features of not very complex shape (right part of the curve), i.e. which these features are rectangular shapes after generalisation. The evolution of the size property of a building, is an enlargement beyond a threshold of legibility for the non legible buildings on a final scale, an enlargement for the buildings close to this threshold (part of the reference curve in staircase) and a light increase in size for the buildings located very beyond this threshold before generalisation (right part of the reference curve where the initial size is identical to the generalised size).

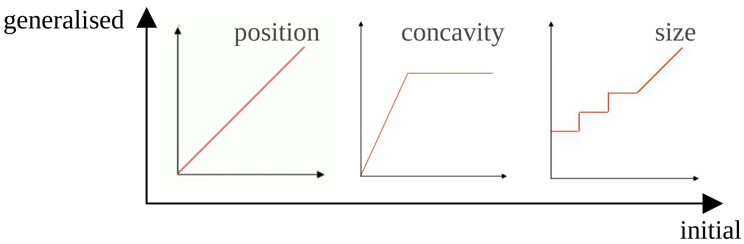

Figure 2. Example of evolution reference function for position, concavity ratio and size properties.

4 The proposed method

This section presents the theoretical background of our work, and begins with the definition of the assessment model, continues with the presentation of the three mains steps of our approach. For more details and a formalisation of this methodology, please report to [Bard 02; Bard 03].

4.1 The assessment model

Our assessment model combines two kinds of information: (1) the information required to provide a generalisation assessment, i.e. a schema of data, and (2) the information required to perform generalisation assessment, i.e. the algorithms for evaluation. In this section, we model the first kind of information in classes and attributes, the second one as methods.

The geographic information is represented through a geographic schema. Such schemas are composed of classes of objects representing features of the reality, e.g. buildings, roads, vegetation. Generalisation can be defined as a process of change of state, i.e. the change from an initial state (before generalisation) to a final state (after generalisation) for a geographic feature. The model proposed in figure 3 is an extension of a classical model, with the addition of an explicit representation of these two classes that represent initial and generalised states: Geographic_Class_ungen and Geographic_Class_gen. Then, two more classes have been added for the assessment: Characterisation and Evaluation. Those classes model the steps of our approach of generalisation quality assessment.

Geographic_Class. The geographic class the generic geographic class of ungeneralised objects: Geographic_Class_ungen, and of generalised objects: Geographic_Class_gen. In the initial state, objects belong to the ungeneralised class. In the final state, i.e. after the generalisation process, objects belong to the generalised class. During the process of generalisation, objects are reduced by elimination or aggregation, so that one generalised object can be linked with one or several ungeneralised object (see figure 1). This modelisation allows a simple data matching between ungeneralised and generalised objects, the identifiers deriving from the latest to the first.

Characterisation. The Characterisation class reports the description information of the ungeneralised and generalised objects. This class is associated to the Geographic_Class. The inheritance relation permits the characterisation of ungeneralised and generalised geographic feature. A method Characterise() is associated to this class to compute the value of the attributes.

Evaluation. The Evaluation class reports assessment information on the quality of the generalisation. Thus, this class is associated to the class of generalised objects. There are two kinds of quality information: a detailed information, i.e. criteria by criteria, or a more general information, i.e. coming from an aggregation of all the quality information on the feature. Two method: Evaluate() and Aggregate() are defined on this class. The first one provides an assessment for each criterion. The second one produces a global assessment of the generalised feature.

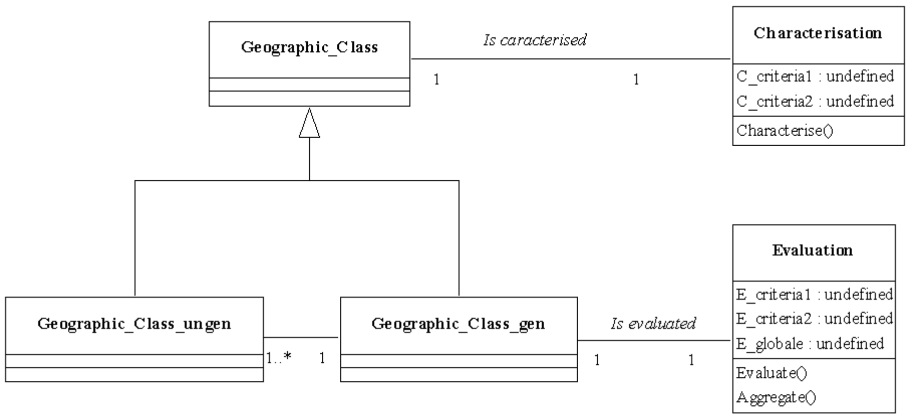

Figure 3. The generalisation assessment model

The advantage of this assessment structure is the possibility of a recursive application to all the geographic objects of a database schema.

4.2 The characterisation

Data must be characterised *a priori* and *a posteriori*, i.e. in its initial (before generalisation) and in its final state (after generalisation). The characterisation functions correspond to the Characterise() method and consists in the description of the feature by particular geographical properties: geometric, semantic and topologic ones. Each property is associated with one or several measures, e.g. area, perimeter, length or width can measure the geometric characteristic 'size'. Characterisation requires the analysis of geographical information at several levels of analysis: micro, meso and macro (Ruas 00). The micro level represents individual geographic features described by their own properties independently of others features, e.g. a building can be described by its shape, position, orientation, size and granularity. The meso level is made of groups of micro or meso features, e.g. a set of buildings (micro feature) or a group of urban blocks (meso features). Meso information is contextual, the feature is described by density, proximity relations, structure or pattern it belongs to. The macro level concerns the population of features, e.g. all the buildings or all the roads. Macro information is global and corresponds to statistics on feature population properties such as distribution for one character, sum, mean.

For example, a building is characterised by its properties of size, position, orientation, shape and granularity. A particular measure is associated with each property, respectively surface, the coordinates of the centre of gravity, the orientation of the walls, the elongation (width over length) and the concavity ratio (surfaces on surface of the convex envelope), and smaller edge size. As an example, for a given building, it corresponds to: size 250 m², position (872000;134000), orientation 12°, elongation 0.91 (form), concavity ratio 0.8 (form) and granularity 4 m.

4.3 The evaluation

The evaluation corresponds to the computation and the interpretation of the difference between the observed result and the theoretical result (of reference). The reference is defined starting from the evolutions of reference specified by the user and the initial characterisation of the object. This reference is compared with the value of the generalised characterisation. The difference between both values is then interpreted according to specifications of generalisation (see figure 4). If the variation is smaller than a value of acceptance defined according to the tolerance specified by the user, then the interpretation is that generalisation is accepted (good quality). If the variation is higher than the threshold of refusal, then the interpretation is that generalisation is refused (bad quality). If not, generalisation is regarded as tolerable (medium quality), i.e. it is accepted but does not constitute one of the best solutions.

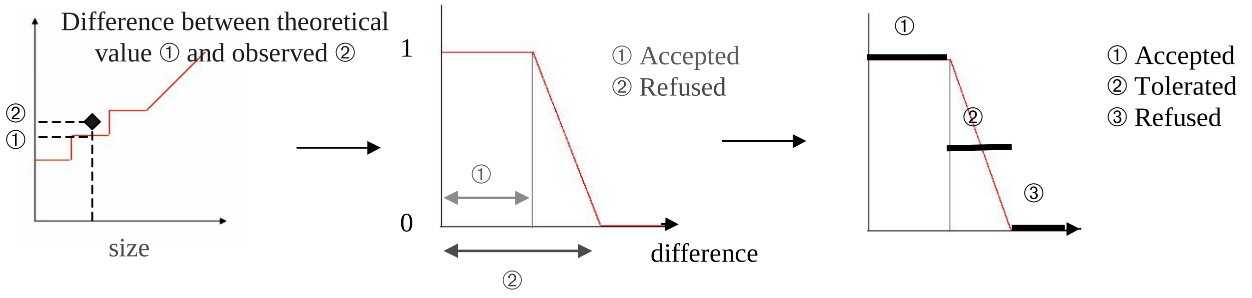

Figure 4. Function of evaluation and interpretation

For example, let us consider the evaluation of the variation of size criterion. The theoretical value is of 425 m², the observed value of 380 m². The variation compared to the theoretical value is thus of 45 m². The tolerance defined by the user in the specifications is 30 m², the value of refusal of 60 m². The variation is in the zone of tolerance. The evaluation interpretation of the property of size is that this generalisation is tolerated.

4.4 The aggregation

Aggregation aims to provide a synthetic result of evaluation. This result is computed at various levels of analysis included one in another. The first interesting level is the level of a geographical feature. We saw indeed, that the evaluation related to characteristic properties of a feature (its shape, its position, its size). Aggregation then consists in incorporating these values of evaluation in a value representative of the quality of the generalisation performed on this feature. The objective is to have a simple result of evaluation for each geographical feature, i.e. to answer the question: what is the quality of generalisation for this object? The second level relates to the aggregation of the results of evaluation with class of features. The objective is to have an idea of the quality of generalisation about each class of geographical features from the preceding results of aggregation about a feature, i.e. to answer to what the quality of generalisation is for this class of objects. For example, to evaluate the quality of generalisation of the road feature class or of the building class. The third level is the most general level of aggregation since it relates to the aggregation of the generalisation quality evaluation of each class of features in order to obtain a global evaluation of the generalised map, i.e. to answer to what the quality of generalisation of this map is.

The principal difficulty consists in determining the weight of each criterion for the evaluation. We have to define a hierarchy between criteria. For this, we use methods of supervised learning [Mitchell 97]. From the expertise of several cartographers on an generalisation evaluation, we learn decision rules on an extract of data. These rules of aggregation are then applied to the whole dataset to evaluate.

4.5 The presentation of the assessment results : visualisation and report

The evaluation should be coupled with a module of visualisation of the results [Beard and Buttenfield 99]. The interest of this module is the visualisation of the zones where generalisation is not satisfactory (particular context, systematic error) to control if the expert agrees with the automatic result. In this way, it allows interactive corrections. An evaluation report is also generated. This report is appeared as a general evaluation, i.e. high level, which can be detailed up to the level of a feature, i.e. low level.

5 Applications and results

The test dataset used is an extract of the topographic database BDTopo of the IGN. The initial scale is the 1/15.000, the scale of generalisation is the 1/50.000. The prototype of generalisation used to generate the generalised dataset is the prototype AGENT [Agent 99]. The module of evaluation of generalisation was implemented in the SIG Lamps2 of the LaserScan company. The programming language used is Lull (Lamps2 User Language).

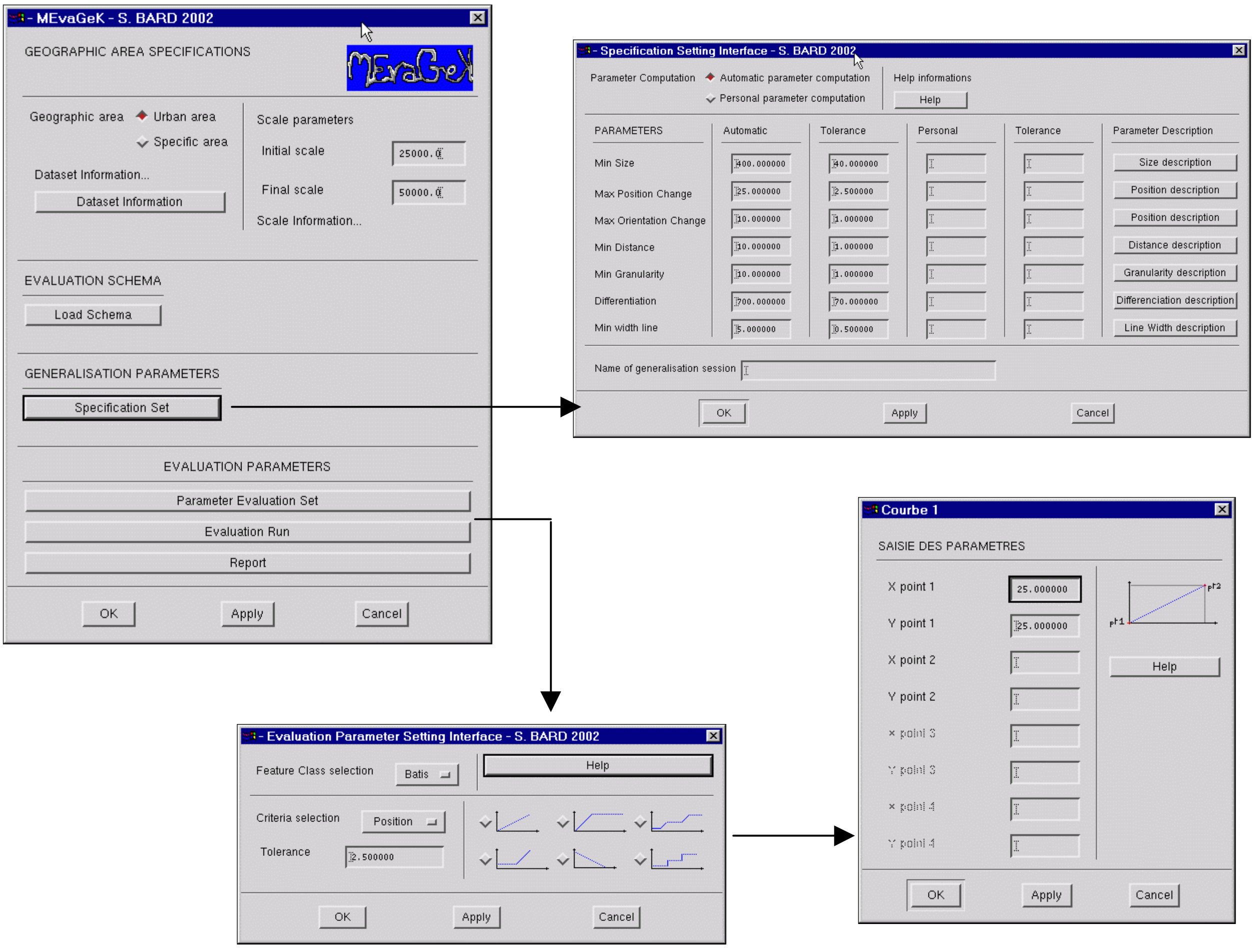

Figure 5. Interface of generalisation specification settings, of assessment schema loading and of evaluation running

The interface of generalisation specifications settings developed is composed of four parts, see figure 5. The first, counts general information on the data file to be evaluated, such as the initial and final scales. The second part is made up of a button to load the evaluation schema. The third relates to the settings of the cartographic specifications and the tolerance levels, such as the minimal size or maximum displacement authorised. The fourth is the definition of evolution reference function for each criterion of evaluation. The last two components are used to start the evaluation and to generate the evaluation report.

In our work, we have restricted the visualisation of data quality to the representation of generalisation assessment results with an adapted semiology. The aim of the visualisation is to enable the validation and the verification of the assessment process, i.e. to check if it provides the same results as those from a cartographic expert estimation. This tool is used as a display tool of the results, and also as an analysis tool to determine for instance which are the most important properties in order to adjust the weight for different properties at the aggregation step, see figure 6.

Figure 6. Example of generalisation and assessment for size criterion.

The advantage of such a tool is to determine thresholds of evaluation by a series of successive tests until the result of evaluation converges towards a coherent result. By this method, the acquisition of knowledge relating to the specifications of generalisation is easier.

6 Conclusion

In this paper, the quality assessment of geographical data has been managed as a complex issue and the proposed methodology of assessment is based on the use of three successive steps: characterisation to describe initial and final data, evaluation to quantify and qualify the differences between data, and aggregation to summarise assessment information.

This work contributes to the data quality assessment in the field of cartographic generalisation, and more generally to the improvement of the data quality description in geographic information, by proposing and formalising an assessment methodology, and by the realisation of a visualisation tool of generalisation assessment results.

Finally, further work is still required into three mains domains: (1) the evaluation of the evolution of distribution values for feature characteristics at meso level, (2) the implementation of the aggregation step, i.e. to define and to test aggregation functions computed by supervised learning, and (3) in the extension of our methodology to a large range of assessed feature class combined with the validation of cartographic experts.

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