

Building a Rule-Based Generalisation Service for Geovisualisation of Business Data

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Abstract. Effective geovisualisation is characterised by the fact that the application context, the output medium and the visual-cognitive abilities of the targeted audience are carefully considered when it comes to an informed (carto)graphic representation of a spatial data set. In this way, an optimal visual communication and analysis of the spatial facts is made possible. An essential key to this is the absence of graphic conflicts that tend to impede proper visual perception. At the level of (carto)graphic modelling, this is achieved by application-specific generalisation measures that are bundled in a toolbox. In the automated generation of effective map graphics, these generalisation measures are used in a rule-based manner. To avoid specific graphical conflicts, interactive components are integrated into the processing chain that support expert generalisation solutions. To date, such tools, some of which work automatically, exist for specific visualisation systems and GIS only. A professional generalisation solution that is automated and can be implemented across systems and platforms is currently missing. Against this background this paper discusses a modular, web-based concept for the rule-based generalisation service of quantitative business data.

Keywords: Geovisualisation · Cartographic modelling of spatial data · Graphical conflicts · Cartographic generalisation · Automated generalisation

1 Introduction

The aim of visualisation is the transformation of (spatial) alphanumeric data into a graphical form of representation. Every alphanumeric representation is scale-free. Every graphic representation of spatial data is subject to scaling and it causes abstraction or generalisation. Geovisualisation enables "visualisation" of semantic relationships in their spatial reference [1]. The lack of generalisation, e.g., when zooming in and out, destroys or hinders the transmission of information. That is why it is not an expert requirement, but a shere communication necessity. Experts make generalisation possible. The spatial reference of alphanumeric data is established by assigning characters to data objects (theme) in connection with their mapping onto a data-related base map. A

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characteristic of the thematic map is the variety of cartographic design modalities. These are directly dependent on the data basis, and indirectly on the scale. This results in the problem of ineffective information transfer. The basic spatial method basis of object-sign referencing finds its application in applied cartography in the form of cartographic representation methods.

A generalisation of spatial visualisation without expertise leads to ineffective map graphics. Effectiveness requires intuitive interpretability from a visual representation [2]. Generalisation is thus considered a decisive influencing factor in the practical application of representation methods. Here the problem arises that generalisation is scale-dependent, but semantically based. This results in the imperative need for expertise. With regard to a largely automated generalisation service, the system should be able to mirror this expertise. Richardson and Müller [3] comment that "automated solutions to generalization should emulate the cartographer's decision making." "However, it is not clear that algorithms and procedures can suffice by themselves" Buttenfield [4] points out.

The solution must be a professional web service that constructs the necessary production steps of a high-quality graphical representation into a process as automatically as possible. One of these essential construction steps is generalisation. While the cartographic generalisation of topographic representations is confronted with graphical conflicts that arise due to the derivation of a subsequent map, i.e., the transfer of map contents of a smaller scale map, the generalisation in thematic cartography is independent of scale. Digital generalisation is defined by McMaster and Shea [5] "as the process of deriving, from a data source, a sybolically or digitally-encoded cartographic data set through the application of spatial and attribute transformations." Regnauld and McMaster [6] see in McMaster and Shea's remarks "the maintenance of graphical clarity at the target scale" as one of the goals of digital generalisation. For the technical implementation of a professional web service for semi-automated generalisation, theoretical cartographic knowledge has to be formalised. This comprises solutions for map construction including the generalisation of thematic maps as well as modalities of further conflict types. Standardised map construcxtion including the required generalisation procedures. Starting from a map image as an intermediate result after running through a map construction pipeline [7], the generalisation is run through in the further processing to create the final visualisation model (Fig. 1).

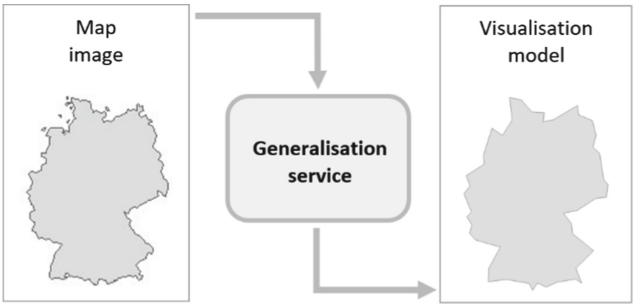

Fig. 1. Simplification of shape throught generalisation service

2 Solution Approach

The mapping of spatial business data is often done by means of choropleth or area diagram maps (Fig. 2). These represent the results of the cartographic representation methods used. The latter are characterised, among other things, by certain requirements for the data to be depicted (e.g., scaling level). The unique signatures for different map types and cartograms to convey the information content (e.g., area signatures or diagrams) also require special properties of the data to be displayed [8]. For the visualisation of statistical business data in area diagram maps and choropleth maps, mostly diagrams (circles, columns, bars) or area colours are used. Kishimoto [9] describes choropleth maps, which are also used under other names, as "undoubtedly one of the largest groups of maps for the representation of statistical data". Unfortunately, they are often used improperly. Therefore, the focus of this paper is on area diagram maps, which are an adequate professional alternative.

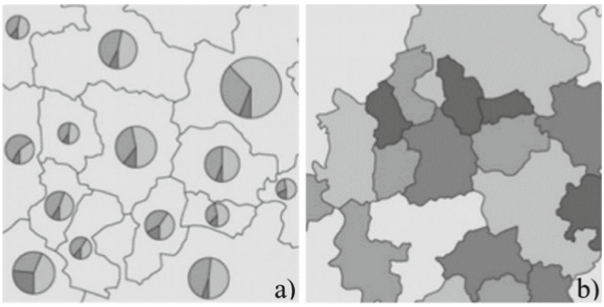

Fig. 2. Mapping principle of (a) area diagram maps and (b) choropleth maps

The above-mentioned diagrams and area fillings are embedded in the respective administrative unit, regardless of their form and colour, and represent an information layer. The administrative reference units themselves form a separate information layer. The filling of these administrative units occurs in the cartographic representation method of area cartograms and could be combined with the layer of area diagram maps if certain conditions are met. Thus, a statistical map representation entails several information layers that require generalisation measures coordinated with the layers.

A base map serves to locate the topic in order to ensure regional comparability. The content of a base map depends on the topic to be depicted. In addition to the core element for embedding the topic, representation of water bodies, depiction of administrative or other territorial units support orientation. There is disagreement on the question of relief representation and forest areas. Various sources show different opinions on the necessity of base map content.

The thematic information to be conveyed by the map will generate different generalisation needs depending on the cartographic means of expression used. In some cases, data generalisation has been done in advance for map image production. A recursion to this already completed data generalisation module may be useful in the course of the

generalisation. When these circumstances occur is to be investigated in the course of processing identified conflicts within the generalisation process.

One aim of the generalisation is to harmonise the base map elements in order to achieve the map objective of an optimal graphical representation of the thematic spatial content. The need for generalisation of the base map used as the map basis for establishing the spatial reference and of the thematic representation layer can be determined at the level of model generalisation and map generalisation [11]. Furthermore, an emerging need for generalisation after the merging of both layers has to be identified. Generalisation measures to be introduced must be found to solve the problem graphically.

Automation requires a form of standardisation. This can be implemented through rules. Therefore, in addition to special map type-dependent generalisation modalities, the complexity of a map representation should be described in a rule-based manner by defining the degree of generalisation. Since the contents of the base map depend on the topic, as mentioned above, the strict scale independence of generalisation measures recedes in favour of thematic reference. When generalising map images, it is important not to proceed completely independently, but to keep the scale in mind. For example, national borders must be depicted jaggedly because these borders are artificial (not visible in the real world). A natural border, formed by a river whose oscillating centre line is real and has to be generalised according to the roundness of the water body. Objects and their regional distribution play a greater role in the special theme because they represent the theme. AI (artificial intelligence) can take a look at regional context of the topic after appropriate learning effect.

Certain generalisation operators, which are usually used in the generalisation of topographic maps to resolve rule conflicts, cannot generically be applied in the generalisation of tematic maps because they are strictly scale-bound. An example of this is the mathematically based Töpfer's root law [12], which can positively influence a reduction of quantities and thus the graphic map load. However, scale-boundness must also be kept in mind when generalising thematic map representations in connection with the desired output parameters. A screen presentation, for example, has different requirements for the presentation than a print edition.

Both forms of presentation (see Fig. 2) require a two-dimensional irregular surface representation of the reference unit. Other contents of the base map are used as needed for each application. This requires a regulation in the form of a catalogue, which can be expanded in each application depending on the map topic. Other contents besides the representation of delimited, irregular area units to which the data to be mapped directly or indirectly refer depend on further factors. The density of the map content (also map load) describes the map complexity. When assessing map load, thematic elements must be prioritised.

The need for generalisation results from the conflicts that a first map image brings with it after object-character referencing has taken place. In order to identify conflicts a catalogue of rules is necessary. For this purpose, generally valid visualisation rules are taken into account as far as possible in the application of cartographic representation methods. The aim of these rules is to ensure the readability of the representation. Occasionally they reach their limits due to subject matter and scale, and leave behind

graphic conflicts. At the latest, however, when several information views interact or when localities are referred to purely semantically.

Generalisation operations must be specified in a standardised way for grouping use cases. Even if regional diversity requires individual case solutions, a rule set must first be set up to start generalisation, on which potential machine learning systems can base the use case group extension. When it comes to thematic generalisation, the user enjoys greater freedom. This implies more responsibility and consequently requires subject matter expertise. Solutions for the generalisation of visualisation models, consisting of map theme as well as base map, are first converted into process diagrams. The representation of the conceptual processes is module-based using SysML activity diagrams. The resulting process diagrams are algorithmised in a modular way and related in a rule-based way by connectors.

This generalisation service is not necessarily to be called up in its entirety. Rather, a specific process is requested for each use case, which determines the necessity of individual generalisation operators based on rules, connects to them and initiates their execution. This approach ensures maximum effectiveness in the computational effort and minimisation of the time required to perform the service. An implementation takes place within the development of the "expertly" web-based map construction service, which provides high-quality, semi-automatic map construction. A qualitative advancement through AI focuses on the regional context, which cannot be considered in the full automation due to the diversity for a generic solution. In any case the final decision on the success of a generalisation solution is left to the expert user.

The following work packages result from the explanations:

1. compilation of a generalisation rule catalogue,
2. identification of the resulting conflicts and further conflicts to justify the need for generalisation,
3. highlighting and describing solution options,
4. description of the way from map image to generalised visualisation model via process modelling for the development of the modularised generalisation service.

3 Implementation Strategy

Generalisation "is a selection of the most important, essential and its purposeful generalisation, in which it is important to depict reality on the map in its most important, typical features and characteristic peculiarities according to the purpose, the subject and the scale of the map" [13].

While going through a visualisation process [7] or after applying a system to create a map image, the user receives at one break point a map image that is aligned with the desired spatial section for the output parameters selected by the user (e.g., size for printing, or screenwidth). Such a graphic is mapped on the interface within the framework of the user-system interaction as a graphical draft of a map representation (presented as an example in Sect. 4). This map image requires generalisation.

WHY generalisation is necessary can have various reasons. Not all conflicts can be avoided by pre-selected parameter and signature decisions. If conflicts can be completely excluded, this also means a restriction of freedom in design. The process step of

generalisation should not be dissolved even in such a case, because this would exclude a subsequent change of output parameters, such as the size of the map display on the screen.

In principle, generalisation should be carried out when ineffective map images are presented. In order to be able to assess the intended effectiveness, a comparison of the actual state with a defined target state is necessary. Such a comparison can be carried out semi-automatically on the basis of a rule catalogue. Generalisation is used in the case of control deviation. The need for generalisation can also arise when the user makes subsequent changes to decisions made in the map production process, for example:

- Changes to the data to be mapped,
- Extension/reduction of the room section,
- Modification of the output parameters (reproduction via beamer instead of laptop)
- Change of the design medium for the reproduction of the map theme (e.g. bar sectors instead of circle sectors for diagrams)

A representation of map objects is scale-bound, but there is also a need for generalisation that is detached from this. On the one hand, graphic conflicts are taken into account during generalisation, which are of pictorial origin on the raster level. They are considered to be the result of object sign referencing (OSR). On the other hand, within the framework of the generalisation of content-related or thematic object features, model generalisation (e.g., classification of objects) can bring about a changed graphic representation.

Generalisation measures answer the question HOW generalisation takes place. Slocum et al. [14] list ten "Fundamental Operations of Generalization":

- "Simplification: Selectively reducing the number of points required to represent an object;
- Smoothing: Reducing angularity of angles between lines,
- Aggregation: Grouping point locations and representing them as areal objects,
- Amalgamation: Grouping of individual areal features into a larger element,
- Collapse: Replacing an objekt's physical details with a symbol representing the object,
- Merging: Grouping of line features,
- Refinement: Selection specific portions of an object to represent the entire object,
- Exaggeration: To amplify a specific portion of an object,
- Enhancement: To elevate the message imparted by the object,
- Displacement: Separating objects."

These generalisation measures are used in topographic cartography. Simplification and displacement, for example, can also be used in thematic cartography. Effects on other map objects are far less significant than those produced during generalisation within topographic maps. In this work, the generalisation of thematic map representations for mapping statistical data is considered. Partial automation is aimed at and embedded in a generalisation service. "The aim, like that of all generalising, is to simplify a complex process to manageable proportions" [15]. These sub-processes must be broken down to the operator level so that they can be implemented in an algorithmised way.

3.1 Rule Base

The automation of generalisation processes first requires the definition of generic generalisation rules and editorial guidelines. The automation of individual generalisation processes requires a definition of the generalisation sequence, because the results of the individual measures have an impact on the other measures, or are the first to trigger them. This means that conflict identification must be carried out iteratively after each generalisation process. "There is no natural order for the execution of each generalisation operation." [16]. When setting up a rule catalogue, such an order must be determined.

The following rule catalogue (excerpt) (Table 1) applies to an intermediate map image that aims to be an area diagram map after completion of all process steps required for map creation:

Table 1. Excerpt of a rule catalogue for generalisation of an area diagram map (see Sect. 4)

Object	Rule
Administrative unit	Data basis: Polygons 1:3,000,000 from Eurostat simplificated by Mapshaper.org (Visvalignam Weighted Area, degree of generalisation 90%)
Administrative unit	Contour: line width 0.0706 mm, colour RGB 99, 99, 99
Administrative unit	Filling thematic polygons: RGB 230, 230, 230
Labelling	Country names: placement under diagram
Labelling	Diagram labeling: at the upper right corner of the diagram or diagram section
Diagram	Typ: rectangle, vertical, subdivided
Diagram	Filling: greater value RGB 240, 240, 240 and hatching pattern (ancle 45°, line width 0.0706 mm, hatch width 1 mm, structured: prarallel, coloured in grey tone of smaller value), smaller value RGB 99, 99, 99
Diagram	Area proportionality: none
Diagram	Width: maximum until smaller value subdivision of diagram reaches line width of 1.7 mm
Diagram	Height: minimum 3.4 mm

3.2 Conflict Identification

According to McMaster and Shea [17], the specific case in which generalisation is necessary is determined by a cartometric evaluation of Geometric Conditions, Spatial and Holistic Measures. The authors differentiate the generalisation measures according to spatial transformations (simplification, smoothing, aggregation and so on) and attribute transformations (classification and symbolisation). In this work, however, the symbolisation of attributes is considered as OSR, which must precede the generalisation service within process design of map production, since only then do graphical conflicts arise.

Generally, classification is prior to graphic generalisation. In case of graphic conflict, it may be useful to reclassify the data.

In order to identify existing conflicts and to specify solution models, a comparison with a rule base is necessary. Töpfer [12] is convinced that "the use of numerical criteria [.] ensures the correct evaluation of the details and thus the correct generalisation". Ruas and Duchene [18] take these specifications into account by terming it a "required value" of the object when establishing the principles of their "Generalisation Model". To ensure a future full automation of the generalisation procedures, we apply this approach.

3.3 Solution Options

Solutions exist for various conflicts. Some are implemented as tools, others as a mathematical approach, others again on a conceptual level. Some conflicts do not yet have generic solutions, which are solved individually by hand by experts. For example, freeing map characters (e.g., bridges or lettering) solves a graphical conflict that does not classically belong to generalisation measures. Also, not every solution is suitable for every application. Slocum et al. [14] show the problem that a line generalisation solution is not generally applicable due to semantics. Not even within an information category like borderline generalisation of administrative reference units.

For individual generalisation measures, tools exist, which were mostly designed and developed to meet the requirements of topographic maps. For thematic map display, for example, MapShaper and ColorBrewer can be used. MapShaper is a web-based solution software running in the browser to simplify the geometry of lines (e.g., administrative boundary lines and other contours). The user determines which of three available algorithms is to be used for the simplification (Douglas-Peucker, Visvalingam, modified Visvalingam-Whyatt [14], and the degree of generalisation can also be set individually. ColorBrewer is used for the selection of colour scales. Conditions such as colour blindness, printability or even colour selection using relief shading can be set.

3.4 Process Modelling

For the processing of a generalisation service, the rules relevant for the applied representation method and the map elements required with it must be specified in the rule catalogue, as exemplified in Sect. 3.1. Furthermore, generalisation measures on the algorithmic level of operators must be assigned to the conflict cases. For this purpose, a generalisation catalogue is used according to the scheme developed by Ruas and Duchene

Table 2. Generalisation catalogue principle [18]

Agent	Constraint	Conflict	Operator
A geographical object	Required value of characteristic of an object/two objects/a set of objects	Fact that one object does not satisfy a specific constraint	A generalisation action

[18] (Table 2). The values to be determined per conflict type and object element or group per use case are also entered in this. The order of the cases listed in the generalisation catalogue determines the prioritisation during processing, starting at the top.

The conflict column is variable for each process iteration, as values are currently recalculated. The generalisation service is to be regarded as a box in which, according to the SysML model concept, there are various roles that manage subordinate roles on their part (Fig. 3). Each role can contain an activity that can be executed independently as a process section. This hierarchical modularised concept should make it easier for the developer to set up and later maintain the components. Since each generalisation operator can be controlled individually as a role, they can be edited or deleted individually. Apart from the GenToolConnector, which must be adapted for each change, all other modules of the service remain untouched and unaffected. It is also possible to add further operators, which are integrated via the GenToolConnector. A new creation of solution operators is possible both comando-based and via a GUI (graphical user interface), or as an implementation in an outsourced web application. An application-specific adaptation of the generalisation tool to be used is also guaranteed. The changes are saved separately after execution for the purpose of reusability and the GenOperator resets itself to its original state if it is an on-board operator. GenOperator roles can also integrate APIs (interfaces) of external services such as Mapshaper, Colorbrewer or similar. In order to determine whether one of the mentioned roles is used at all, the generalisation service begins with the generalisation identification (GenIdentifier).

When this comes into action (act GenIdentifier), the underlying geometry data is first checked by the TopologyChecker. This looks for line intersections, non-closed polygons, voids in adjacent surfaces and other conflicts in the database. In order not to influence the determination of generalisation conflicts of quality deficiencies of the data set, this role must be upstream of all other process sections. Once any corrections have been made within the TopologyChecker action using TopoRepair, the search for generalisation conflicts in the map image (act GenCartoEvaluator) begins.

This connects each agent with the current feature class and reads out the associated constraints. An agent stands for an object or an object class in the map display and behaves in a 1:n relationship to the instance constraint. All target values of different object features are loaded. Then, for each potential conflict area, current values for occurring map elements are determined iteratively (act GenCalculator). The target-actual comparison is carried out by the action act GenController, which outputs boolean values (conflict present: yes, no) and saves the sizes of the deviations in a file. This can be queried by the user. In this way, e.g. minimal deviations can be judged as tolerable by the business user and thus removed from the generalisation catalogue. If no deviation from the target value is determined for the loaded agent, the loop is executed iteratively for the subsequent agent listed in the generalisation catalogue. However, if a need for generalisation has been determined, whether as a default decision after calculation by the service or corresponding assessment by the business user, the operators assigned to the individual conflicts in the generalisation catalogue are called one after the other. A generalisation operator stands for exactly one stored solution algorithm. For each line in the stored conflict value file, the respective generalisation operator is integrated successively via act GenToolConnector. After all generalisation cases have been processed, the

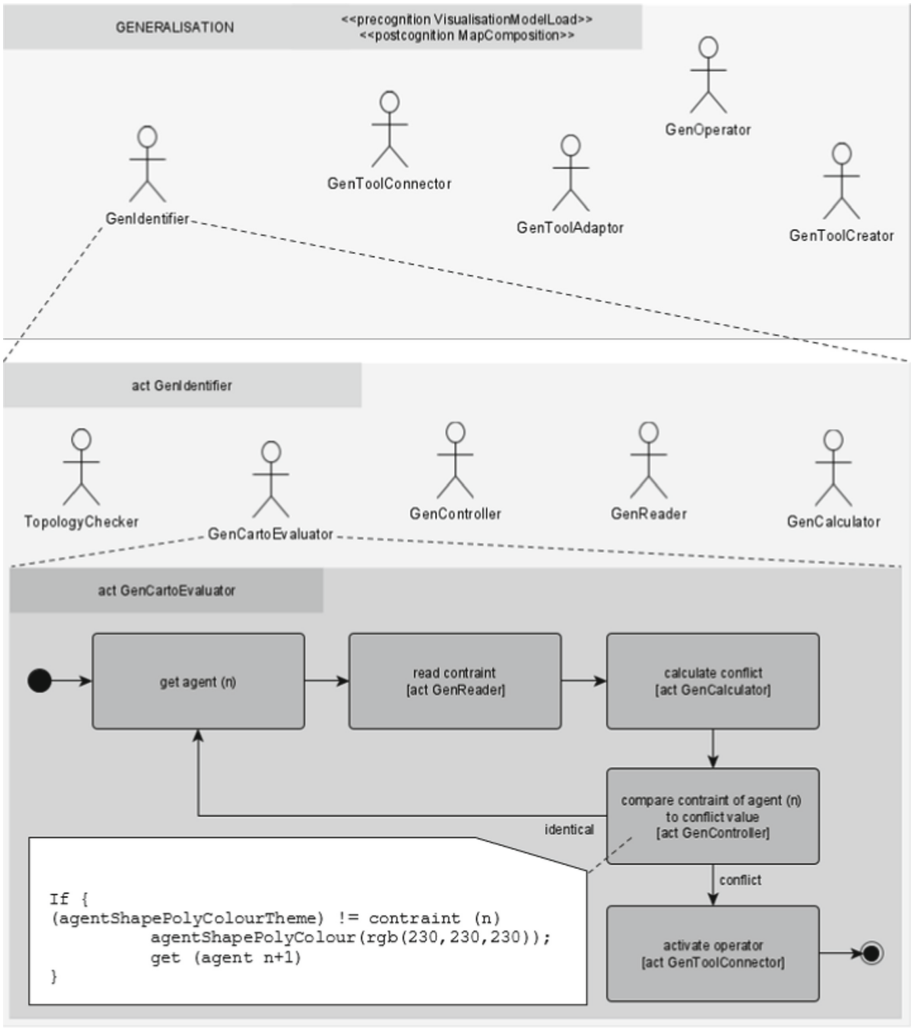

Fig. 3. Conceptual model of the generalisation service based on SysML

generalised visualisation model is mapped for evaluation and is available for any further editors that may be required or directly for further processing within the framework of map composition.

After the shape generalisation as the first measure, the action of TopologyChecker must be repeated before further processing in the generalisation catalogue. In this way, conflicts such as intersections or undercutting of minimum distances resulting from changes in the shape of the base map or its base point reduction can be eliminated.

4 Use Case

For the map image in this use case, following map purpose was defined:

Representation of a company's own exports of a product type (in tons) to Scandinavia (defined here: Denmark, Sweden, Norway, Finland). In comparison, import quantities from the entire EU are to be indicated for the same product category and year. This pursues the map objective of market analysis. The informative gain should consist of 1) highlighting one's own market position in the target region for this particular product category and furthermore making it easy to read how much market potential can be exploited in the short term, possibly without major operational investments. The interim result of the visualisation process (Fig. 4) was based on the following data:

Fictitious export quantities of a product category of a producing and exporting company were used, which has a near monopoly position in production in a certain country and knows the European competitors. Furthermore, import quantities for the product category in question were taken from Destatis for Scandinavia. Base map data (administrative units) available at Eurostat was downloaded for the selected spatial section.

Output parameters are now set for this example:

- given is a maximum image area of 12 * 19 cm, portrait format,
- black and white output, on screen, printable,
- insular map presentation,
- spatial section Scandinavian countries as described above,
- coordinate system used ETRS1989_LAEA (Lamberts Azimuthal Equal Area),
- spatial section and available mapping area define an output scale of 1:20,000,000.

This map image shows various visualisation problems. The boundary lines, especially the outer boundary lines, are displayed in a too differentiated manner. In doing so, the minimum dimensions for the representation of the islands are undershot and the minimum distances are not observed. Recesses are not always clearly recognisable as such. The map theme is implemented with a vertically positioned rectangle. However, these do not dominate, so that the map background seems to have a higher visual weight. Perceptionwise, it needs the other way around. To achieve this, colouring has to be changed, the optimal location of the diagrams needs to be checked, too. When placed within the reference area, the limiting factor is the smallest available space. The diagram for Denmark fits in exactly, but it influences the size of the other diagrams and thus limits the visual weighting. A solution to this could be: Balance out Norway and Finland as far as possible, taking up space, and place the Denmark diagram, which has now become too large for embedding in, outside the reference area and connect it with a line to the reference area. This measure is also possible if the underlying statistical data entail an enlarged diagram representation for Denmark and smaller ones for the other countries. Placing the represented values next to the diagrams increase the effectiveness of the visualisation model.

The generalisation service has traversed the presented rule catalogue for the described map target with the desired spatial section, specified data basis, taking into account the required output parameters (e.g., mapping area size, black/white representation) (Fig. 5).



Fig. 4. Map image prior to generalisation: business export volumes in comparison to EU-import volumes to Scandinavian countries for a certain year and product category

The base map areas are no longer dominant, but rather appropriate for the purpose: the theme. The portion of imports which is not served by companie's exports are now expressed as potential volumes. Former map image ignores the potential due to whitening related diagram section. Applicated colouring based on the classification of colorbrewer2.org. Three grey tones have been used for the visualisation model with one minimally intensification in favour of an optimised figure-ground distiction.

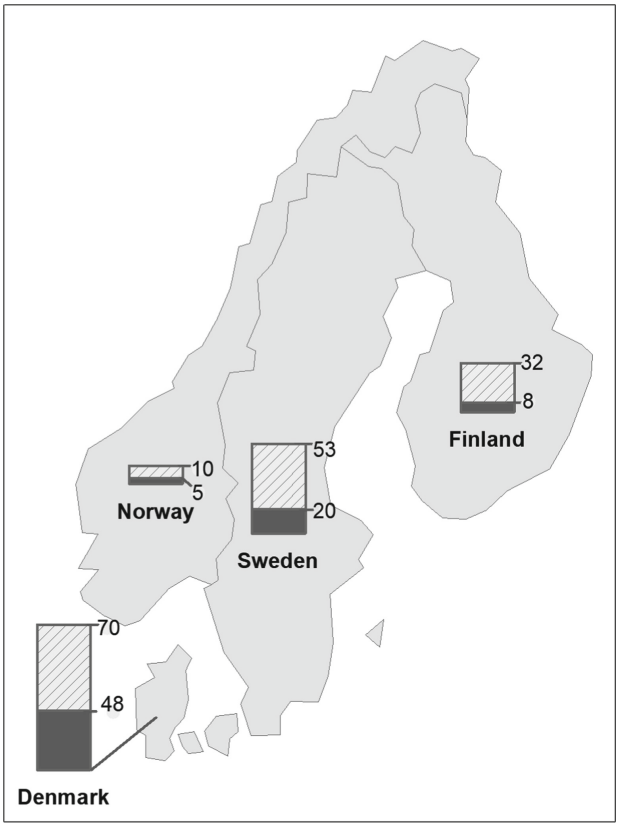

Fig. 5. Generalised visualisation model at map scale 1:20,000,000

5 Conclusion and Outlook

Graphical transformation of spatial data forces generalisation. This results in the resolution of graphical conflicts: effective information transfer via the visual channel is ensured. A rule catalogue for generalisation has been created, a comparison with the actual state of a map image carried out and solution options used. A process section has been presented and the work steps have been run through using an example. The result presentation of the generalised visualisation model is included in the previous chapter.

A use of the generalisation service with mass data enables a grouping of the use cases. These serve to develop a form of standardisation of the generalisation process. Generalisation service has interfaces for various web-based generalisation services, as well as an embedded editor, for subsequent editing by the user.

To support this, self-learning systems can be used at break points where a expert user still have to make decisions. This can, after a suitable number of training sessions, enable automatic case-specific generalisation. AI (artificial intelligence) can analyse and cluster use cases by means of machine learning, so that adapted standard solutions with a view to regional context can be developed through an increasing number of cases of

resolved conflicts by the specialist user. This requires the definition of scale areas in order to be able to standardise the respective generalisation requirements.

For businesses the generalisation service helps to increase or even enable information value for represented data. It optimises the effectiveness of visualisation models produced by map functions of data discovery systems (DDS) or business intelligence software (BIS).

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