Modelling Cartographic Relations for Categorical Maps

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Abstract: Map generalisation seeks to maintain important map objects, patterns, and relationships, while suppressing unimportant ones. Hence, the spatial and semantic characteristics of map objects as well as the relations existing between them have to be detected, preserved and exploited for generalisation. Two main groups of relations can be differentiated: Horizontal relations exist on the same level of detail (LOD), or scale, and represent common structural properties. Vertical relations appear between homologous objects and object groups in a collection of the same map type but across different map scales. Focusing on thematic categorical maps, the paper emphasises the importance of horizontal and vertical relations in automated generalisation. Hence, a typology of horizontal and vertical relations for categorical maps is presented and links to existing generalisation operators are identified. A selection of relations is discussed and illustrated in more detail.

1. INTRODUCTION

The research on automation of map generalisation has mainly been pushed forward for topographic maps. This is obvious because they are the main interest of national mapping agencies. However, most maps produced today are special-purpose thematic maps, ranging from short and medium-term maps, such as weather forecasts and hazard maps, to long-term maps, such as administrative, statistical or geological maps. Common to thematic maps is the (geo-)spatial reference of their content. But since the subjects covered are very diverse the main geometric data types can be polygonal subdivisions (e.g. climate or geologic maps), points of interest (e.g. in location based services, LBS) or linear objects (e.g. navigation routes and facility maps). The focus of this paper is on categorical maps – maps representing categorical data by polygonal subdivisions (i.e. by a mosaic of polygons) – and the relations that can be found between the polygonal map objects. As mentioned above, only relatively little work has been carried out on automated cartographic generalisation of this map type so far. Peter (2001) lists measures for the characterisation of polygonal subdivisions mainly derived from metrics of FRAGSTATS (McGarigal and Marks, 1995), a program widely used in landscape ecology for patch analysis. Galanda (2003) presents polygonal constraints for a constraint-based generalisation model. Further literature can be found on semi-automatic and interactive generalisation of soil maps (Fuchs, 2002), geologic maps (Downs and Mackaness, 2002), and different map types for the Atlas of Canada (Brooks, 2002).

1.1 Data Enrichment

Map generalisation seeks to maintain important map objects, patterns, and relationships, while suppressing unimportant ones. Hence, the spatial and semantic characteristics of map objects as well as the relations existing between them have to be detected in order to obtain priority rankings among map objects, meaningful groups of objects (e.g., clusters of objects or objects aligned in a particular arrangement), as well as spatial and semantic relations (e.g., topological, directional and proximity relations, hierarchical relations) and thus help to make informed decisions about generalisation. It is important to note, however, that such rich information is typically not available in the spatial databases that are used for categorical mapping. Ruas and Plazanet (1996) state that [..] *data enrichment is necessary to perform generalization.*[..]. More precisely Neun et al. (2004) describe data enrichment as "[..] *necessary process to equip the raw spatial data with additional information about the objects and their relationships.*[..]". Hence, it requires the previous extraction of map object relations. Data enrichment itself should support different processes during the automated generalisation of maps. It concerns data characterisation, conflict detection, indirectly also the algorithm selection, and finally the evaluation of the map. Therefore, a need for extracting relations is given. Beyond the scope of this paper building a typology of relations for polygonal subdivisions is essential not only for thematic (categorical) maps but also for topographic maps since a certain number of relations is common to both map types.

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1.2 Horizontal and vertical relations

In our classification of relations we differentiate between horizontal and vertical relations. This differentiation does not derive from a spatial property. Instead, it is implicitly given by the map purpose and map scale. Horizontal relations of map objects exist within one specific scale, or level of detail (LOD), and represent common structural properties – e.g. neighbourhood relations and patterns (Neun et al. 2004). On the left of Fig. 1 an example of a horizontal relation is presented by a curved polygon alignment. The use of horizontal relations is currently limited since generalisation of topographic maps requires only a subset of the horizontal relations for thematic maps presented here and in more detail in Steiniger and Weibel (2005a). Vertical relations are links between single objects or groups of objects on different map scales or levels of detail (LOD), respectively (Fig. 1, right). They can be represented and stored in Multi-Resolution Databases (MRDB) and can be exploited for paper map generalisation as well as for web and mobile mapping applications. In the case of web mapping services the response time to user actions such as zooming is mission-critical. Thus, time consuming generalisation processes have to be replaced – e.g. by use of Adaptive Zooming which makes use of previously extracted vertical relations (Cecconi and Galanda, 2002). In our present work we use two methodologies to formalise the above-mentioned types of relations. In a top-down approach we analysed conceptually and visually our datasets for noticeable patterns. In the second approach, not presented here, we use statistical analysis methods (e.g. Principal Component Analysis and clustering) to identify hidden and extraordinary patterns and relations.

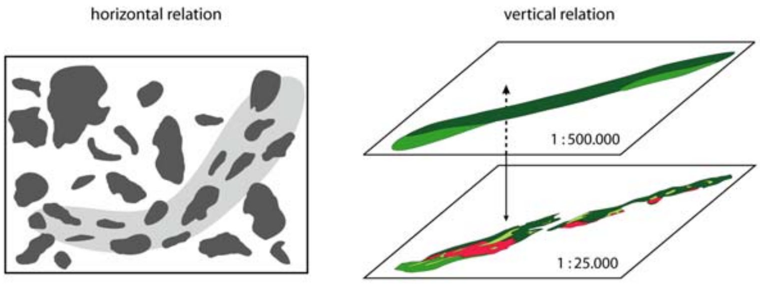

Figure 1: Horizontal and vertical relations in categorical maps

1.3 Research on map generalisation and map relations

Today, detection and use of map relations is in most cases restricted to identifying proximity relations and proximity conflicts. Examples include the detection of overlaps and the consideration of minimum distances between buildings and road objects in topographic maps. Furthermore, proximity relations can be extracted to obtain free space for feature displacement and to aggregate area objects of the same class (e.g. buildings). The detection of more complex structures – so called higher order features – in topographic maps is mainly focusing on the preservation of settlement character (Gaffuri and Trevisan, 2004; Sester, 2005) or building groups and alignments (Regnauld, 1996; Christophe and Ruas, 2002).

Another view on the consideration of relations, especially the ones between objects of different type, is offered by Fuchs (2002) in his derivation of a small scale soil map. Here, the focus is rather on semantic proximity of the different soil types than on spatial proximity between the soil patches. These relations are extracted and used for the aggregation of polygons in a phase of structure analysis (Steiniger and Weibel, 2005b), which is somewhat similar to model generalisation (Weibel 1995) during the generalisation of topographic maps. Conversely, the other examples above are more or less part of cartographic generalisation. It is important to note that in Fuchs' work the evaluation of the outcome of structure analysis is interactive since only proposals of how to merge different soil types are generated. The decision on acceptance ultimately has to be made by the soil expert.

The domain of vertical relations is mainly associated with Multi-Resolution and Multi-Representation Databases (MRDB). Research on MRDB for map generalisation is relatively sparse and has so far exclusively concentrated on databases for topographic mapping. Examples include the work by Abraham (1989) and Jones et al. (1996). An issue that has received particular attention is the task of building a MRDB by matching homologous map objects of separate databases representing different LODs and linking them across scales. Flewelling (1999) introduced a method for measuring similarities between spatial datasets. Sester et al. (1998) present techniques to match and link objects of different spatial data sets by integration and aggregation. Sheeren et al. (2004) introduce an approach to deal with representation differences in the matching and data integration process for preserving object consistency. A very promising use of the matched and linked objects is the incremental generalisation approach originally proposed by Kilpeläinen and Sarjakoski (1995). Also Harrie and Hellström (1999) present a prototype system for propagating updates between cartographic data sets. Hampe et al. (2003) illustrate the use of MRDB applications for data revision and real-time generalisation in the context of the projects WIPKA (Germany) and GiMoDig (EU).

For representing cartographic objects in a multi-scale data structure Timpf and Frank (1997) proposed the use of acyclic graphs. In Timpf (1998) hierarchical structures for aggregation, generalisation and filtering are introduced. As traditional entity-relationship modelling of spatial data has limitations, the MADS model uses object oriented modelling and offers therefore more flexibility, according to Parent et al. (1998). The concepts of Multi-Scale (Multi-Resolution) and Multi-Representation and solutions to achieve flexible support of Multi-Representation in GIS databases are investigated by Spaccapietra et al. (2000). Using a MRDB to represent map object relations, as the work by Cecconi (2003) suggests, offers a considerable potential, particularly in time-critical mapping applications such as web mapping or LBS.

The management of the extracted relations during the generalisation process is carried out in different ways. Restricting the generalisation process modelling approaches to the constraint-based one (Beard, 1991) we can distinguish between the agent-based approach, combinatorial optimisation, and continuous optimisation (Harrie and Weibel, 2005). The agent-based approach currently appears to be the most promising modelling techniques for generalisation. Here, two types of treatment of relations exist. The model by Ruas (1999) deals with micro, meso and macro agents, whereby especially the meso agents – sometimes called group agents (Galanda 2003) – represent relations explicitly. Inter-object conflicts are resolved by orders which are passed by the responsible meso agent to the associated micro agents. In the agent model of Duchêne (2004) the relations are represented either by meso agents – as in the previous model – or by a relation object. Here, solutions for inter-object conflicts can additionally be obtained by negotiation between the micro agents. Some examples preserving higher order features in settlement structures by use of an agent system are given by Gaffuri and Trevisan (2004).

2. HORIZONTAL RELATIONS

2.1 Why consider horizontal relations?

Data enrichment with horizontal relations fills the link between structural knowledge on one hand and procedural knowledge on the other hand. Here, structural knowledge (Armstrong, 1991) denotes the information obtained by data characterisation and cartographic pattern and structure recognition. Hence, it answers the question *when* (and *where*) map generalisation is needed (McMaster and Shea, 1992). Procedural knowledge holds information about suitable generalisation operators and available algorithms, as well on how to control them. It is therefore related to the question of *how* to solve a given generalisation problem.

A simple example of four polygons (e.g. four lakes) presented in Fig. 2 should emphasise the need for horizontal relations. A well legible map meets several visual requirements, including that an object should have a minimum size on the map so that it can be perceived by the map reader. In our example three of the lakes would not meet the constraint. And we – or the computer – have to decide how we want to solve the problem. Fig. 2 shows two simple solutions on the upper right. Here, the link between structural and procedural knowledge is made by way of simple object characterisation without considering the relations to other, neighbouring objects. Thus, the possible solutions presented on upper right of Figure 2 are either to delete the three objects found to be too small or to enlarge them, respectively. These solutions do meet the basic requirement of visualisation (minimum size) but do not necessarily present a good cartographic solution from the structural point of view. A good cartographic solution of generalisation problems should also maintain the typical structures and emphasise the specificities of a map. Such a satisfactory solution can only be obtained by consideration of inter-object relations (see Fig. 2, lower right). The presented solutions both preserve the typical properties of the spatial arrangement of the polygonal patches.

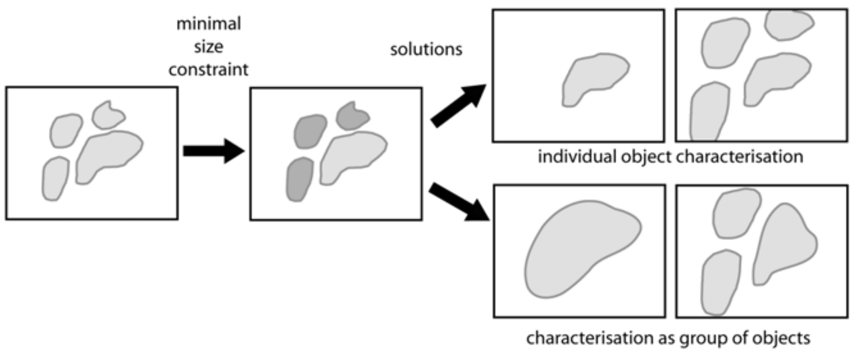

Figure 2: Different generalisation solutions if horizontal relations are not observed (top) or observed (bottom)

2.2 A typology of horizontal relations in categorical maps

Since the extracted relations should be used in automated generalisation an obvious starting point is to organise them with respect to existing classifications of map constraints or measures used in generalisation. Starting with classifications of constraints two kinds of taxonomies can be distinguished. The first classification is organised by the function of the constraints whereas the second orders the constraints by the scope of usage. An example for functionally oriented ordering is the typology into graphics, structural, application and procedural constraints originally suggested by Beard (1991). This grouping has been revised by different authors with respect to specific geometry types, functional purpose or generalisation process modelling (cf. Harrie and Weibel, 2005). A specific classification for constraints of polygon generalisation and categorical maps is proposed by Galanda (2003). He distinguishes four groups, namely: metric, topological, structural and procedural constraints. In contrast to this functional approach Ruas (1999) classifies constraints according to the scope (or levels) of usage. Here, the classification is made into macro level (entire dataset or category), meso level (group of objects) and micro level (constraint of a single object).

Another scope oriented typology, but applied to measures, is presented for landscape metrics by McGarigal (2002). Here the levels are called patch, class and landscape. Patch metrics are applied to a discrete area of relatively homogenous environmental conditions. Class metrics describe measures for all patches of one type and landscape metrics are integrated over all patch types of the entire dataset or selected frame. In landscape ecology the metrics are also classified into spatial and non-spatial categories, where the first group is called composition metrics and the second spatial configuration metrics (Gustafson, 1998; McGarigal, 2002). The classification of measures for automated map generalisation by Peter (2001) is closely related to the functional constraint typologies. He distinguishes between: size, distance and proximity, shape, topology, density and distribution, pattern and alignment, and semantics.

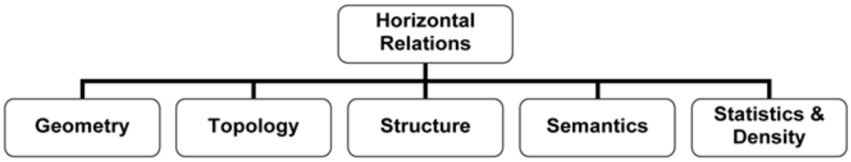

Figure 3: Typology of horizontal relations

The typology for horizontal relations proposed in this paper is based on Peter's classification of measures but merges the first three groups into one called geometric relations. The other four classes remain as separate groups. The resulting typology is organised by functional purpose and shown in Fig. 3.

2.3 A more detailed view and characterisation of horizontal relations

Relations between map objects can be established by simple and complex methods. An example for a simple extraction method would be the comparison of attribute values of two objects. This can simply be done during the generalisation process as it does not require major computation power. Conversely, relations may require more complex methods, such as the use of auxiliary data structures – e.g. a minimum spanning tree (Regnauld, 1996). Usually such data structures need more computing resources and should be established in a pre-processing phase. Since object relations can change during the generalisation process, however, dynamic data structures like the Simplicial Data Structure (Jones et al., 1995) should be preferred.

The following subsections present a short version of an inventory of horizontal relations given in Steiniger and Weibel (2005a). The typology is organised into the five classes shown in Figure 3. Starting point for the definition of horizontal relations was a number of geological, soil and thematic atlas maps covering a range of scales between 1:10'000 and 1:25'000'000. Most of the relations can be found in geological maps and soil maps. Such maps typically contain topographic information in addition to thematic information.

2.3.1 Geometric relations: Most of the metric variables are well known in GIS and generalisation since they describe object-specific properties such as area, perimeter, etc. Four groups of variables have been identified which are size variables, position variables, shape and orientation variables. Here, the term variable is used since most of the geometric relations are inferred only at runtime by simple comparison of the values of such variables to each other or against a threshold. Therefore, a further distinction is made into relative and absolute variables. For the latter, the relations themselves are obtained by comparison. Relative variables such as distance measures already represent relations (between two or more objects), but are metric values as well. Measures on geometric variables and relations exist for all indices apart from orientation patterns (cf. Steiniger and Weibel, 2005a), which are a special kind of geometric relation.

2.3.2 Topological relations: The extraction of these relations requires an implementation of a topological data structure in the generalisation system. This can be done by use of an intersection model (see Egenhofer and Herring, 1993; Clementini et al., 1993) and additionally either by the use of a planar graph (Bobzien and Morgenstern, 2002) or of auxiliary data structures such as the Delaunay triangulation (de Berg et al, 1997). After establishing the topological model four types of topological relations should be distinguished: **topological structure**, the order of **topological neighbourhood**, **intersection type** (e.g. overlap, touch, cross, etc.) and **ring model**. The topological structure relation separates three types of structure models. These are: island polygon, island cluster, and landscape mosaic. Ring model describes a containment relationship of polygons as can often be seen in isarithm maps visualising continua (temperature map, snow height map).

2.3.3 Statistical and density relations: A number of measures for this sort of relations is used in landscape ecology. Originally these measures/relations were developed to describe the heterogeneity of a landscape. Whereas in landscape ecology a general grouping into spatial configurations and non-spatial composition indices is made (Gustafson, 1998) we will distinguish here between five groups of indices. These are: **statistical base parameters** (mean, variance, etc.), **area relations**, **type relations**, **diversity metrics** and **configuration metrics**. Area and type relations describe ratios of areas or types, e.g. area of one soil type to map area or number of polygons of different soil types to each other. Diversity metrics characterise a map or map section either by measuring the amount of information, the so-called entropy, or by use of probability measures (Simpson indices). Configuration metrics are indices of landscape or map interspersion (McGarigal and Marks, 1995) and common appearance, e.g. measuring the length of common border between two soil types (Fuchs, 2002). The use of these relations has two main goals. First, the preservation of map heterogeneity and second the detection of dominant or rare objects.

2.3.4 Semantic relations: Consideration of semantic relations is important for categorical map types. If a choropleth map is directly derived from GIS data or if a small scale map should be derived from a medium scale map, then the first stage of generalisation is structure analysis (Steiniger and Weibel, 2005b). In contrast to the generalisation of topographic maps no fixed reclassification scheme is given which defines the number of categories in the final map. Instead, the number of categories has to be defined during the stage of structure analysis. Therefore it is necessary to define or to derive – by the use of data analysis methods – semantic relations between classes. Four types of these relations could be elaborated: **similarity** – for aggregation of categories, **priority** – for generalisation process modelling, **resistance / attraction** – for aggregation of single polygons and **causal relation and logic**. Priority relations are used in the generalisation process to give some special object type more importance than others, e.g. a small polygon of a rare soil type should be exaggerated instead of being eliminated. Thus, the neighbouring soil polygons with lower priority are downscaled. Causal and logic relations describe type dependencies of object types within a single theme. For instance, the definition of the topographic object type island is bound to a surrounding area of type water.

2.3.5 Structural relations: These relations are intimately connected to Gestalt theory and visual perception (Wertheimer, 1923). As the word "structure" suggests the relations of this group should classify types of patterns which are perceived in maps. A distinction is made into five relations: **background-foreground** relation, **nature of origin**, existing **inter-thematic relations**, **macro structures** and **meso structures**. The background-foreground relation describes the visual order (e.g. visual weight by colour; cf. Dent, 1990) of adjacent objects. Nature of origin describes the nature of the object by assigning it to classes such as: without structure, artificial structure and natural structure. These values could be saved as attributes of the specific map, the feature class or the polygon that the nature of origin relation is associated with. Inter-thematic relations could exist, for example, for a gravel soil type which is bound to a river bed. Thus, movements of the river during generalisation induce also changes on the soil entity. Macro structure relations are visible patterns if the map reader has information about them. These patterns are often not directly manifested and visible on a map of a given scale as they relate to a different (macro scale) level and resolution than the given map. Examples are topographic landscape structures formed during ice age. They can hardly be perceived in soil maps of scale 1:25'000 but are obvious in soil landscape maps of scale 1:500'000. In contrast to macro structures, meso structures are defined as visible and detectable. Meso structures could be visual patterns that are obvious for every map reader (e.g. four lakes forming a line) and visual thematic patterns, only obvious to the experts.

3. VERTICAL RELATIONS

3.1 Why consider vertical relations?

Vertical relations are links between single map objects or groups of map objects between different map scales (Levels of Detail, LOD). Linking map objects and their generalised counterparts on a lower scale contains implicitly information about the preceding generalisation. Data enrichment with vertical relations fills the missing link between generalisation and procedural knowledge but does so in an abstract way. Procedural knowledge can be contained in information about (generalisation) algorithms and parameters used. The detection of vertical relations is important on one hand for the updating geodatabases (Kilpeläinen and Sarjakoski, 1995; Harrie and Hellström, 1999) and on the other hand for supporting web-mapping features such as seamless zooming between the original map scales by interpolating intermediate map scales (Cecconi, 2003). The enrichment of the raw data with vertical relations helps choosing the appropriate algorithms and their parameters and it also allows a better evaluation of the results. The vertical relations contain rich – but implicit – knowledge about the whole generalisation process from the larger to the smaller scale. Thus, such relations could also be used for learning algorithms (Weibel et al., 1995). Inductive learning algorithms would benefit from the extracted procedural knowledge or neural learning algorithms could be trained with the relations. Examples include work using inductive machine learning in the context of road generalisation algorithms (Plazanet et al., 1998; Mustière and Zucker, 2002) as well as the use of interactive systems and machine learning (Reichenbacher, 1995).

The typology in Figure 4 shows the two main types of vertical relations. The **LOD relations** contain changes between properties of the whole LOD, such as a class aggregation hierarchy, general priorities associated with object classes or a topological adjacency matrix for the whole map. The **map object relations** can link homologous objects and are thus expressing a partonomic relationship or also other interdependencies between the map objects (identity relation) or object groups (group relation). Such vertical map object relations may be enriched with additional information about their characteristics. These **relation properties** extend the vertical relations with information about the type and the value of the changes.

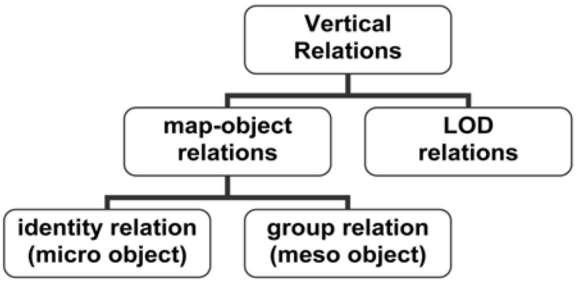

Figure 4: Typology of vertical relations

Vertical relations can be seen as abstract procedural knowledge. The most straightforward way of gaining procedural knowledge would be to record the whole process of the generalisation from a larger to a smaller scale, and then store and use this knowledge about the used algorithms and parameters. However, most maps today are not created completely from scratch but are based on previous, manually produced versions. Therefore it is necessary to compare existing maps and to try to extract the implicitly contained procedural knowledge. Comparing the outcome of a previous generalisation, not the exact algorithms but only the probably used generalisation operations can be formalised. These spatial and attribute transformations, e.g. simplification, smoothing, aggregation, collapse or displacement (McMaster and Shea, 1992) can be taken as the basic type of a vertical relation and then be further enriched with additional relation properties.

Figure 5 shows an example of an aggregation relation between *n* objects on the larger scale (LOD1) and 1 object on the smaller scale (LOD2). These objects, representing drumlins in a postglacial zone, have similar characteristics. In the smaller scale only these characteristics are important for the overall impression of the map. Thus, mainly the two characteristics orientation of the single drumlins and density of drumlins in the surrounding area are important. A vertical relation having these characteristics as additional properties can thus be used e.g. for deriving an intermediate map scale by creating larger drumlins, meeting the minimum size constraint, and maintaining the orientation and the density of the original drumlin field.

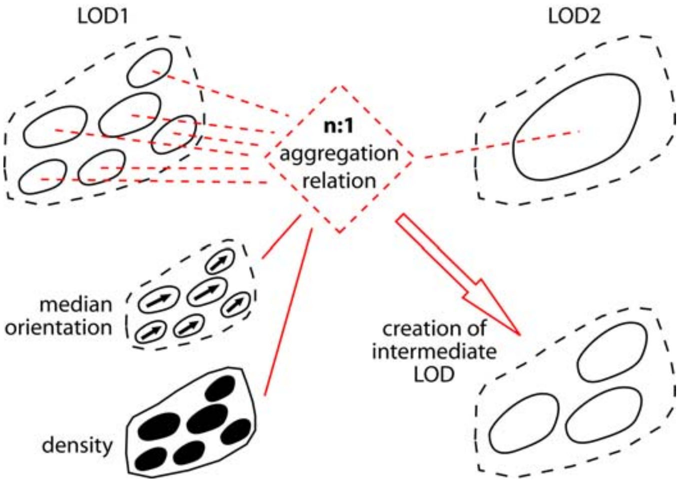

Figure 5: Aggregation relation for creating intermediate LODs

3.2 Characterising vertical map object relations in categorical maps

Vertical map object relations link map objects or object groups across scales. We distinguish simple and complex map objects (groupings). **Identity relations** (1:1) can be established between simple map objects on two LODs (cf. Fig.6). **Group relations** (*n*:*m*) link 1 *to n* objects on one LOD with 1 *to n* objects on another LOD (cf. Fig.7). Each map object consists of its semantics (name, attributes ...), its geometry, and its topology. These identity and group relations are primarily used for linking objects on one LOD with their corresponding counterparts, representing the same real-world object, on the other LOD. Further they might also be used for linking horizontal relations on two LODs or for linking horizontal relations with objects on the other LOD. Thus they may express constraints to amplify structures that have been maintained in both LODs. Examples are causal or inter-thematic relations such as that a certain soil type results out of prepared surfaces for roads (cf. Section 2.3.5). Establishing vertical relations is usually accomplished during the matching process of two LODs in the pre-processing phase. The relations should then be saved persistently in a database and only be updated if objects change or constraints are violated.

The starting point for the definition of vertical relations was a number of thematic maps over a broad scale range, plus the typology of basic spatial transformations by McMaster and Shea (1992), which was adapted to the needs of thematic maps (see examples in Section 3.3). Thus, vertical relations represent only quasi-procedural knowledge as they try to formalise only the abstract spatial transformations instead of the used algorithms and their parameters. The vertical relations express the geometrical, topological and semantic outcome of a preceding generalisation process. The process of matching of existing LODs and establishing the vertical relations between objects on the different LODs can be seen as a kind of reverse engineering (Weibel, 1995; Leitner and Buttenfield, 1995). Every relation can be characterised by at least one **relation property**. The relation properties may include either additional information found and/or used during the matching process or they may also represent changes between corresponding horizontal relations or measures (Steiniger and Weibel, 2005a) on the two LODs.

The most obvious relation property types are the **geometric properties**. Examples include the change of the polygon **size** as a simple factor, the translation of the old to the new map object **position** as a path or vector, the changes of the object's **shape** (e.g. vertices that are removed), the object **orientation** or a mean orientation of object groups and also the change of the geometric **type** e.g. as a result of a collapse operation of a polygon to a point or line. Some of those properties are continuous from one LOD to another. Others, however, express discontinuous changes and need therefore a kind of **threshold** level. An example for such a threshold is the scale level at which a geometric type change takes place. Up to this threshold the polygon properties are of importance, beyond it the collapsed point or line has to be characterised. Geometric relation properties can mainly be used for the characterisation of the geometrical outcome of identity relationships and then be used for the implementation of fast scale interpolation algorithms, such as morphing operations for web mapping applications (Cecconi 2003).

Topological relation properties have to express the topological structure and neighbourhood, for example, to preserve accessibility. Examples for **topological properties** are the general **neighbourhood structure** of a map object, the **intersection type** with other map objects, the **change originator** linking to the object e.g. responsible for a displacement, the neighbourhood **configuration** e.g. whether a map object is an island or part of a landscape (complete tessellation) and last but not least the **object containment** (ring model) expressing that an object lies strictly within another one.

Every map object has its a semantic context. The **semantic properties** characterise the **resistance** or **attraction** between different map objects, they may express **similarity** (e.g. an aggregation hierarchy for the reclassification), they may define a **threshold** level at which a **reclassification** has to take place or they may also express **statistical information** such as the density of a object type in a certain area for the typification.

3.3 A selection of vertical relations

The following sections show what vertical map object relations and their characterising properties look like. The typology follows the distinction of identity and group relations of Figure 4. For the purposes of this short paper this is just a selection of example relations and does not claim to be complete.

3.3.1 Identity Relations are links between corresponding map objects among two LODs. Usually in map generalisation the following operations are used on single objects: simplification, smoothing, collapse, symbolisation, exaggeration, enhancement, displacement (McMaster and Shea, 1992) and the special case selection (or elimination). The following examples (see also Fig. 6) show selected relations and what they might characterise. The **simplification** of a map object only affects some points of an object. The object itself also continues to exist on the smaller scale. Possible relation properties for such a simplification relation are shape and orientation but also the neighbourhood structure and containment. Such properties have to be preserved or taken into account during generalisation. **Exaggeration** moves only some points of a polygon. The properties express information about the shape and position of certain points of the object. However, both simplification and exaggeration can also be again part of another transformation or be combined with other transformations. **Symbolisation** is often related to a collapse. Polygons will be collapsed and then displayed by a symbol. As a result, different geometry types, such as a polygon and a point, will be linked by a vertical relation. An additional geometry for a point symbol, expressing the extent needed by the symbol, may be important for the displacement. The **displacement** of an object always has a reason. So, the displacement can first of all be characterised by the reason for this change, such as a link to the object causing the displacement, and by a path or vector describing the displacement. In general the identity relations are straightforward abstract representations of previously conducted generalisation operations on single objects. The biggest challenge is not the representation itself, it is first of all the matching process. This process of extracting the vertical relations and inferring the previously used generalisation operators is difficult, time consuming and usually subject to uncertainty. Another major challenge with vertical relations is the implementation of algorithms which can directly benefit from those vertical relations and thus improve the generalisation speed or the quality and map consistency.

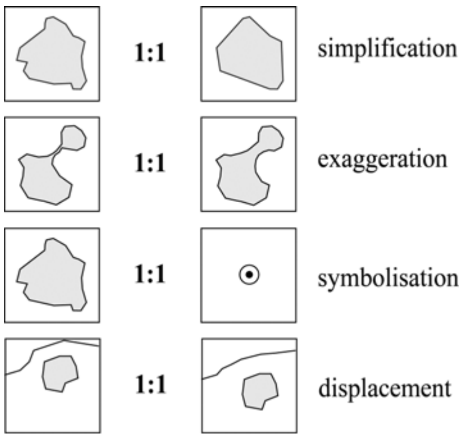

Figure 6: Examples for simple (identity) relations

3.3.2 Group Relations traditionally express a hierarchical relation of map objects at different LODs affected by aggregation or amalgamation operations (Fig. 7). Unfortunately not all group relations can be expressed by a *n*:1 hierarchy. For instance, a polygon may belong to two alignments or a single polygon may even be split up because two other objects are aggregated in the lower scale LOD. Thus, the flexibility of *n*:*m* relations is needed, the *n:1* relation being only a special case. In the domain of buildings, hierarchical structures have been expressed by Timpf (1998). Research on clustering (Regnauld, 1996) and on building alignments (Christophe and Ruas, 2002) has also been accomplished. Research on procedural knowledge about such set-to-set relations is very sparse. The following examples (cf. Fig.7) show a few group relations and what they might characterise. With a *n:*1 **aggregation** typically a group or cluster of non-touching (i.e disjoint) objects on the larger scale LOD are aggregated to one object (polygon). In some cases a group of objects is aggregated to another (mostly smaller) group of objects. This *n*:*m* relation can not any-more be expressed by a strictly hierarchical aggregation tree. A group relation object is needed. The **typification** can be seen as a special case of a *n*:*m* aggregation where a certain density and general structure has to be preserved. Also **alignments** generally are special cases of aggregations and typification. The defining property of an alignment is the orientation or a path along which the group is aligned. In the case of buildings or other regular objects, alignments may additionally be typified. In contrast to the three mentioned aggregations the **amalgamation** operation unifies touching objects. This process sometimes is also stated as being implicit to **reclassification** of object types (Galanda, 2003). Both aggregation and amalgamation need certain attraction or resistance values assigned to each object resulting from type similarities or an aggregation hierarchy. These attraction/resistance values may be used to control the cost with which polygons are combined. Relation properties which may be assigned to a vertical group relation are in the majority of semantic or topological nature, including neighbourhood structure, object configuration, object containment, object resistance or attraction, statistical information about a group of polygons and the threshold at which certain changes take place. Geometric properties are only in some special cases (e.g. in alignments) of major importance. Due to their complexity group relations crucially depend on a good and powerful representation in the data model.

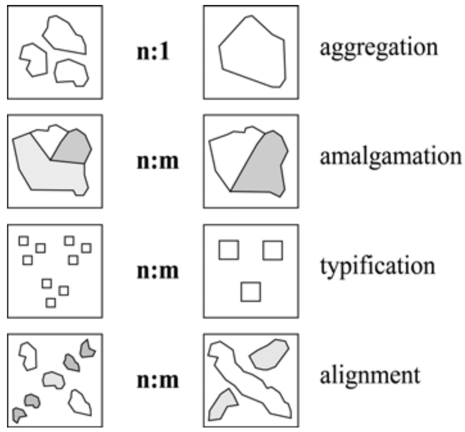

Figure 7: Examples for complex (group) relations

4. STORING RELATIONS

Finally, while this is not the main focus of this paper, we would like to briefly address the modelling and storage of the horizontal and vertical relations in a Multi-Resolution Database (MRDB). The integrated database model is necessary for a high quality and efficient map generalisation environment. The MRDB has to be both a Multi-Representation database (Spaccapietra, 2000) for horizontal relations and a Multi-Resolution database for vertical relations. It should also be possible to implement directly certain generalisation operations associated with saved relations (e.g. via stored procedures) in the database in order to speed up the generalisation process. For horizontal relations three different representation types are possible. It is recommendable to store the measure results as attribute values if the data type offers the possibility and if computation of relations can be deferred until run-time. Furthermore, storage of extracted or pre-defined relations can be implemented by **relation matrices** (RM). Here, a distinction is made between symmetric (RMs) and non-symmetric (RMns) matrices. The matrix storage type provides fast access to relations and is particularly useful if all map objects or types/classes have more or less a relation to each other (i.e. in the case of densely populated matrices). The third storage type, the **relation object** (RO), is used if only few map objects have something in common. This type has already been used in the agent model of Duchêne (2004) as a relational object and as so-called meso structure in the agent model of Ruas (1999). Besides this kind of modelling as a “real” object, a relation object can also be implemented by a graph structure (e.g. a neighbourhood tree).

5. CONCLUSION

In presenting a comprehensive typology of map object relations for categorical maps, a first step towards developing more comprehensive automated generalisation strategies of such map types has been made. It has been shown that horizontal relations can be used to characterise map data and that they describe structural knowledge, while vertical relations, enriched with relation properties, can be a solution for representing implicit procedural knowledge. The immediate objectives for future work are the definition and the identification of further group structures, the assessment of measures for the relations, the modelling of the relations and the implementation of matching procedures that try to extract the implicit knowledge between two map scales. The objectives and the cartographic relations will be investigated further in the context of the project DEGEN at the University of Zurich.

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