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Towards constraint formulation for chorematic schematisation tasks - work in progress

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For our research on chorematic diagrams and their automatised construction, we strive for a formal definition of chorematic diagrams. One approach for such a formal definition is to define generalisation constraints on their graphical, topological and geometric attributes. During our previous work, it became clear that the generalisation needs of chorematic diagrams are only partially covered by current cartographic constraint models. In this work in progress, we delineate the main schematisation tasks and show which can and which cannot be modelled with current constraint measures. We go on to make suggestions on how to extend existing constraint models correspondingly.

1 Introduction

Chorematic diagrams have been characterised as being a "[...]kind of powerful diagram (*chorème*) that Brunet has perfected and which manage to convey the essential message of a complex argument with a few carefully chosen pen strokes, symbols and shading." (Clout, 1992). If one follows this evaluation, it is plausible to assume that the increasing demand for new visualization methods can partially be satisfied with automatically generated chorematic diagrams conveying "the essential message of a complex argument". Such praise can be found in several places, and it is safe to say that they have proven their ability to communicate what they wanted to with minimal means of graphic expression (). If generated automatically, chorematic diagrams could be used for such diverse scenarios as presenting visual syntheses of geodatabase content, gaining overview knowledge over multiple spatial simulation runs or in time-critical situations as well as on mobile devices. The "chorematic style" could also represent a new generalisation goal for specific kinds of map-users, that do not need full information for a given task, widening the options for graphic representation in general. The fundamental question raised then is: how to carefully chose those few "pen strokes, symbols and shading"? Our approach (Reimer and Dransch, 2009) treats some of the problems as generalisation problems. Our main method is knowledge aquisition (Weibel, 1995; Kilpelainen, 2000; Sarjakoski, 2007; Li, 2007b) from analysing existing chorematic diagrams. Analysing existing maps is sometimes referred to as Reverse-Engineering (Weibel, 1995; Sarjakoski, 2007). The aquired knowledge is to be formalized with cartographic generalization constraints, first proposed by Beard (1991), as straightforward rules-based and knowledge-based approaches are understood to be too limiting (Sarjakoski, 2007; Harrie and Weibel, 2007).

1.1 Chorematic Diagrams

From a background of spatial analysis, French geographer and cartographer Roger Brunet developed classes for spatial structures and processes along with a specific way of rendering them graphically (Brunet, 1980, 1987). He called them *chorèmes*, a neologism composed of the Greek word χώρα, meaning space, territory, place and the suffix -ème from theoretical linguistics (Brunet, 1987). The term is to be understood as an analogue to words such as morpheme, phoneme or grapheme, which refer to the smallest linguistic (audible and written repectively) units that carry (semantic) meaning. For a more extensive discussion of choremes as theoretical conepts in geography, see Tainz (2001) (translation in Reimer and Dransch (2009)) and Reimer (2010). They were popularized by the work done within the Groupe d´Interêt Public (GIP) RECLUS, which was founded in 1984 under Brunet´s leadership (Ormeling, 1992; Lacoste, 1995). Their output included many thematic maps, partly or entirely made from choremes. Because these chorematic diagrams garnered particular attention, the term choreme became synonymous with a certain style of graphic depiction of geographic space. We use the term *chorematic diagram* as overarching term for all those concrete maps and diagrams that contain one or more choremes. Reserving the term *choreme* for Brunet's basic geographic building blocks allows for better differentiation of graphic artefact and theroetical concept.

One of the main advantages of chorematic diagrams is that they are in a closer relation to a mental model of the depicted geographic space than a regular thematic map would be. This closer relation goes both ways: a spatial analyst can express his mental model easier with chorematic maps, which in turn is understood easier by a reader. This lead to great success for Brunet and GIP-RECLUS (Brunet and Dollfus, 1990; Ormeling, 1992; Dühr, 2007), but also highlights the problem of how much trust is actually placed in the analysis that lead to the mental spatial model. Although chorematic diagrams and their proponents lost some of their popularity and nearly all of their institutional backing in the nineties, they did serve as inspiration for several working groups and individuals, mostly European, in more recent times (van Elzakker, 2004; Klippel, 2004; Brunet, 2005; Laurini et al., 2006; Ligozat et al., 2007; Lardon and Capitane, 2008; Fatto, 2009).

1.2 Examples for Chorematic Diagrams

To illustrate our considerations regarding chorematic diagrams, three are presented as example for some of the more prominent characteristics. Figure 1 shows a conventional choropleth map with graduated circles and its matching chorematic diagram. The changes from choropleth to chorematic diagram include a reduction of quantitative data from the circle diagrams into area-class (Mark and Csillag, 1989) information, a highly generalized (smoothed) depiction of the territorial outline using a combination of polyline segments and Bezier-curves and the addition of some regionalization information in the form of additional curves and line-strokes.

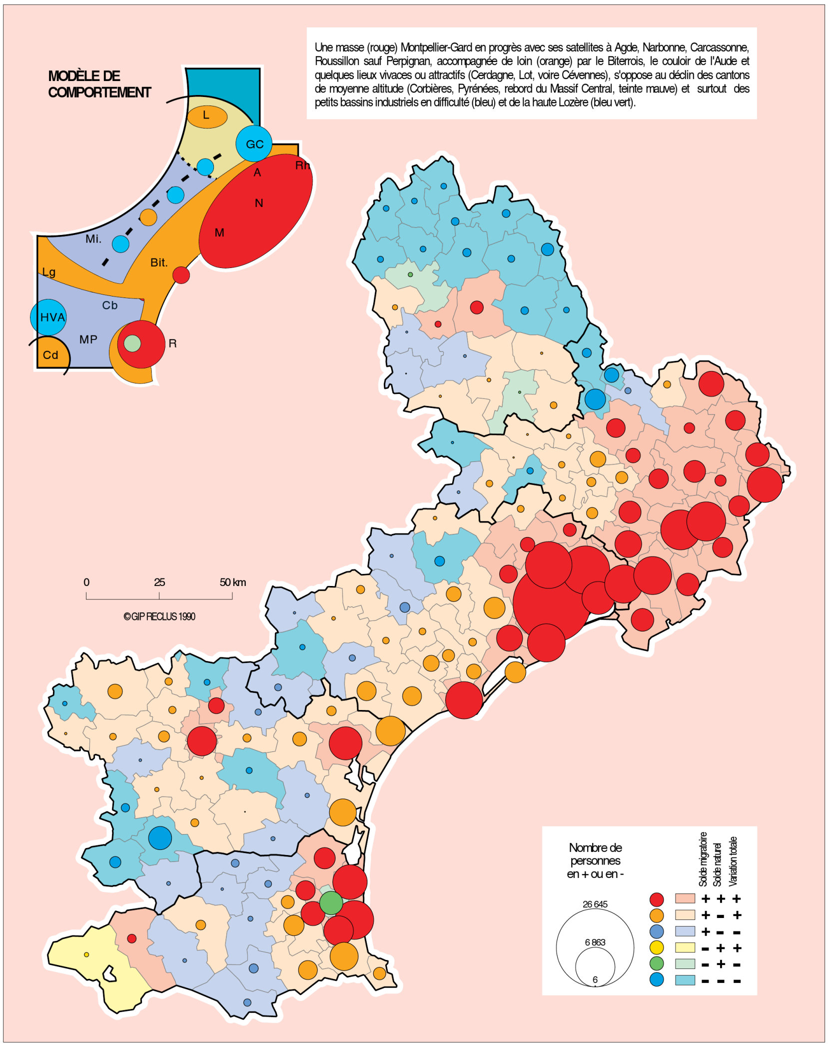


Figure 1: A choropleth map and a chorematic diagram (upper left). (Brunet, 1991)

Part of a series of chorematic diagrams about Vietnam on a national level is presented

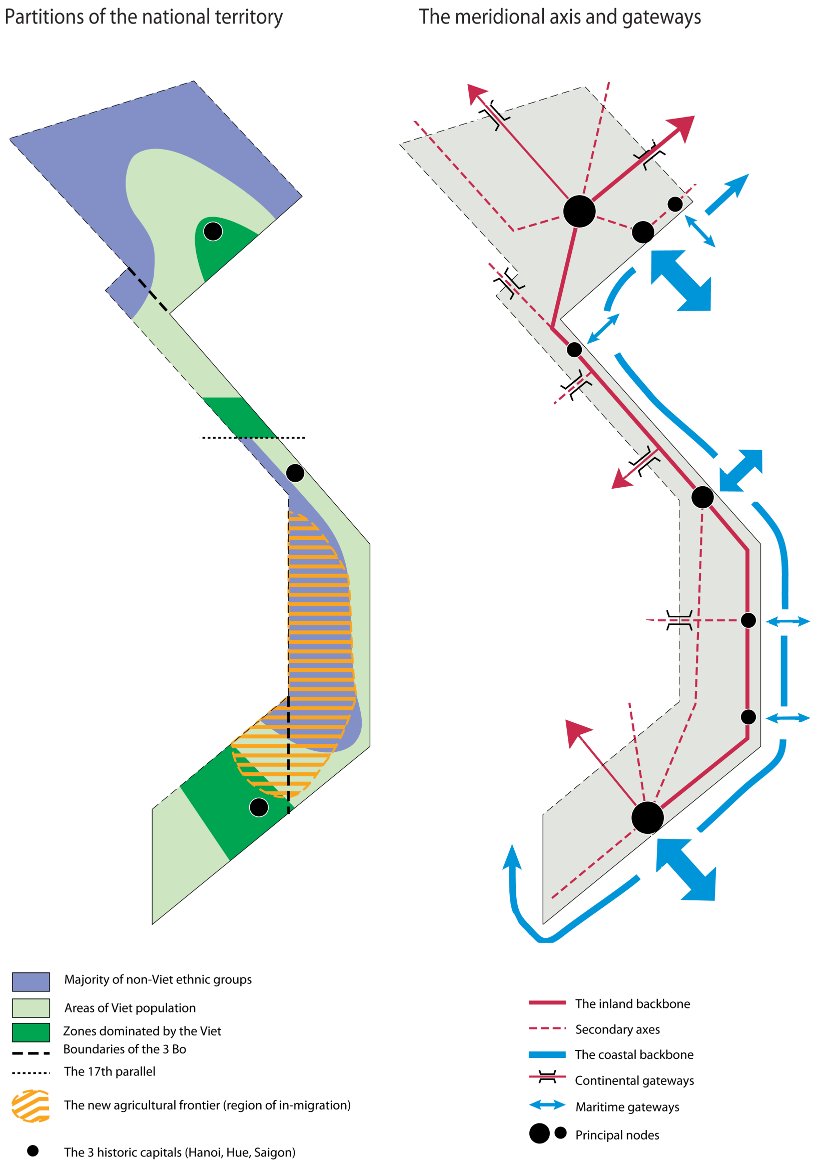


Figure 2: Two chorematic diagrams of Vietnam. (Taillard and tu Lâp, 1994)

in Figure 2. While the territorial outline here appears simplified and lacks any Bezier-curves, it is in fact also smoothed. The few remaining vertices have been moved by the cartographer in such a way that increases the amount of virtually parallel line segments in the territorial outline of Vietnam. While this specific territorial outline approaches octolinearity, many other chorematic diagrams use arbitrary angles, but tend to use parallel lines where possible. The left hand diagram depicts thematic information on ethnicity as area-class information, with low-order (quadratic and cubic) Bezier-curves as area boundaries. Three population centers are presented as circles, and some more regionalization information is provided in form of line-strokes and a hachure.

The right hand diagram is an example for the use of lines and arrows in chorematic diagrams, using both straight line-segments, as well as curves. Octolinearity is not observed, and visual clutter (Ellis and Dix, 2007) is reduced by exemption ("fat-positives"; cp. *Freistellung* in German cartographic literature).

2 Towards Constraint Formulation

Analogous to the Grünreich-style models of generalisation that differentiate between model generalisation and cartographic generalisation (Foerster, 2010; Li, 2007b; Sarjakoski, 2007), we differentiate between chorematic schematisation and chorematic modelling. Chorematic modelling encompasses the regional geographical analysis process in the spirit of the chorematique, whereas chorematic schematisation refer to the (carto-)graphic generalisation processes. In this work, we are concerned with the latter.

A general strategy for automated construction of chorematic diagrams is to first create the territorial outline of the region, and then map all features to this new "container"-outline. This of course assumes that the geographical analysis, i. e. chorematic modelling has already taken place. Smoothing, simplification and exaggeration for polylines are the main generalisation tasks in the first step. The second step encompasses selection, typification, amalgamation, exaggeration and displacement for point, line and area features (fundamental generalisation operators as per Regnauld and McMaster, 2007). Hence, the three most important chorematic schematisation tasks are the generalization of the territorial outline, the aggregation and exaggeration of area features (from polygons to Bezier-curve boundaries; choropleth to area-class) and the reduction of clutter arising due to overlapping elements, including layer hierarchy questions.

In order to automatise these schematisation task, we first need to define generalisation goals specific to chorematic diagrams in the form of soft and hard constraint measures (Steiniger and Weibel, 2007). These constraint measures are supposed to be used for a more formal description of existing chorematic diagrams and their characteristics. In turn, they shall guide our efforts of automatic construction by enabling the evaluation of experimental results numerically in addition to visual evaluation (Sarjakoski, 2007).

2.1 Related Work in the Generalization Domain

While automated cartographic schematisation is a burgeoning field, most efforts have looked at the most famous schematic map, the London Tube map for inspiration, e.g.

Avelar (2002); Stott et al. (2009). There are other types of schematised maps that are notably different from the schematic line drawings of underground maps. Most of these have not been subject of generalisation research, albeit some have been investigated cartographically e. g. (Scharfe, 1997; Dühr, 2007). We understand chorematic diagrams to be part of that larger group of schematised maps (Table 1) and reserve the term *schematic map* for those line network topograms that are inspired by the London Tube Map. This is congruent with the definitions of schematic maps used by (Avelar, 2002; Swan et al., 2007; Anand et al., 2007; Dong et al., 2008; Stott et al., 2009), e. g.: *"Schematic maps are linear abstractions of functional networks."* (Avelar, 2002) and *"a schematic map is a diagrammatic representation based on linear abstractions of networks"*(Swan et al., 2007). This emphasis on line network topograms naturally resulted in very specific array of generalisation methods, with topology and turning point information as hard constraints and vertex angle, orientation, clearance, length and node displacement as soft constraints (Table 1). Likewise, the concrete constraint measures are peculiar to the line network topogram domain.

Some works attempt to identify corresponences between basic visual structures and wayfinding tasks, that can help in presenting highly generalized route information (Klippel, 2004; Sester and Elias, 2007). These schematisation efforts are more related to marching sketches used in the military, sketches and maps prepared for the sport "orienteering" and the cognitive processes behind them rather than geographic schematisation in thematic maps. Their cartographic generalization approaches are also mainly concerned with line topogram construction and thus also correspond to schematic map research. Cartograms, by their very nature, decline to use existing mental images of a territory as a guideline for generalisation. Rather, they gain their communicative power from depicting geometries in an unexpected way, highlighting the relational differences between geometric areas and a chosen quantitative attribute of those areas. As chorematic schematisation is concerned with using, communicating and reinforcing existing mental images of territorial shapes, instead of deconstructing them, we currently see research into cartogram construction (e. g. (Kreveld and Speckmann, 2007)) as being related to our work on territorial outlines in an orthogonal way. Cartograms are also semantically comparable to choropleth maps, which map quantities to colors, whereas chorematic diagrams abolish quantities and choropleths for qualitative area-classes. As such, we currently view them as orthogonally related to the choropleth-to-area-class schematisation tasks. For a more extensive contextualisation of chorematic diagrams and schematised maps, see Reimer (2010).

2.2 Chorematic Schematisation

In our ongoing research on chorematic diagrams, we have identified several salient characteristics of their idiosyncratic cartographic style. A complete presentation of our taxonomy developed on the basis of our quantitative and qualitative analysis is given in (Reimer, 2010). Some of the most prominent characteristics are presented in the following. Chorematic diagrams:

Table 1: Constraints in schematic map generation as used by various authors

authors	approach	constraint	constraint measure handling
Avelar	Iterative-rules-based; gradient descent; user evaluation	angle	enforced octolinearity
		length	>threshold
		distance	>threshold
		topology	topology check
Anand et al	simulated annealing	topological	topology check
		orientation	relaxed octolinearity
		length	> threshold
		clearance	> threshold
		angle	> threshold
		rotation	minimize orientation change
		displacement	minimize distance
Dong et al	progressive generalization	topology	topology check
		orientation	minimize orientation change
		length	>threshold; maintain rel.ordering
		angle	>threshold
		rotation	relaxed octolinearity
		clearance	>threshold
		semantics	semantics check
Stott	hill climbing multicriteria optimisation	angular resolution	maximised
		edge length	equalized over map
		balanced edge length	incident edges
		edge crossings	reduce unneccesary ones
		line straightness	edge cluster
		octolinearity	attempt
		bounding area restriction	edge move restriction
		geographic relationships	enforced
		occlusions	avoid by restrictions
		edge ordering	preserved
		labeling	multiple criteria

Table 2: Types of Schematised Maps

	basemap	thematic layers	symbols	content
schematic maps	absent/ analytical distortion	topologically correct	lines	networks
geopolitical and propaganda maps	naturalistic	stark emphasis	mostly arrows and emphasised areas	politics/ ideology
mass media maps	naturalistic	single layers	high iconicity or bars and circles	varies
mental map sketches	cognitive distortion	striving for topological correctness	full range	varies
geodesign maps	simplified	multiple	systemized hachures and point symbols	spatial planning guidelines
croquis	naturalistic	few	defined set	applieg geography
Faustskizzen and Merkbilder	schematised	topology	reduced set	topography
cartograms	warped	single	Size-modified areas	Attribute-area discrepancies
chorematic diagrams	schematised	single or multiple	defined set (no quantities or ordinal)	regional analysis

- use one or more choremes
- display geometries highly more generalised than is usual at comparable scale
- do not display quantitative data
- abolish choropleth depictions in favour of very few, highly generalised area-classes; the area-class boundaries are depicted with Bezier curves (Mark and Csillag, 1989)

These observations encompass what Armstrong (1991) called structural knowledge, answering the questions *when* and *where* map generalisation is needed. Our work in progress tries to tackle the realm of *procedural knwoledge* i. e. the question of *how?* (Armstrong, 1991). As the identified schematisation tasks are mostly concerned with polyline and especially polygon generalisation, we looked into existing constraint models for these. Galanda (2003) proposed a model of polygon constraints and discussed possible measures and evaluation techniques (Fig. 3). Steiniger and Weibel (2005) developed a more comprehensive model of relations for thematic (and especially area-class) maps, incorporating Galanda's constraint model and measures and suggested constraint types for every type of structural relation.

2.3 Constraint measures for territorial outline schematisation

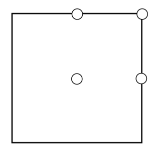
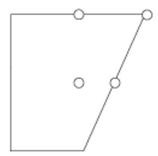
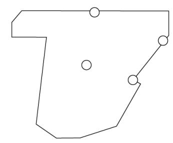
There are some propaedeutic presumptions published by other authors regarding shape characteristics of chorematic diagrams. A mapping of all angles to 45° as with schematic maps of metro-lines has been perceived (Klippel, 2004; Dühr, 2007). As mentioned above, we have not encountered a widespread octolinearity in existing chorematic maps (Reimer, 2010).

Instead, regarding the chorematic schematisation of territorial outlines, chorematic diagrams (Table 3):

- have at least three numerically and conceptually identifiable ways of presenting a territorial outline as basemap:
  - as symmetric, regular polygon (circle, hexagon, square etc.)
  - as asymmetric simple form or polygon with very few vertices (4-7)
  - as asymmetric highly smoothed polygon

The most radical chorematic schematisation exchanges a topographically recognizable and specific shape with a regular, symmetric polygon. As this violates any vertical relation (for vertical vs. horizontal relations see Steiniger and Weibel (2005)) that might remain between source shape and generalization aim, this is interpreted as a symbolization problem, best solved with heuristic rules regarding the use case. If an area is to be depicted as regular polygon, the decision to do so or the choice of polygon cannot be derived from geodata. Choosing simple forms analytically has been shown to be computationally hard (Haunert and Wolff, 2006; Haunert, 2008), with heuristics being one way to avoid such problems.

Table 3: Different types of chorematic territorial outline schematisation

territorial outline	description	generalisation operators	proposed generalisation strategy	Example (Spain)
symmetric model	regular polygons and forms with at least one axis of symmetry (ellipse, rectangle etc.)	symbolisation	heuristics/ user choice	
asymmetric model	polygons without axis of reflection symmetry and 4-7 vertices	exaggeration	characteristic point detection	
schematised map	polygons and forms with recognizable outline	simplification and smoothing	CP-detection; smoothing	

The other two presentation types can most likely be reached via geometric generalisation. In order to describe the shapes of these kinds of chorematic outlines, Metric Variables and Relations (Steiniger and Weibel, 2005) can be considered. The only horizontal relations that are of interest for the schematisation of single territorial outline, are those dealing with properties of the shape itself. From those we can ignore the metric variables that are invalidated by the vertical relation to a regions or countries idiosyncratic shape. As a geographic region can take any shape from shapes like Chile's to that of Spain or Greece, there can be no absolute MBR, compactness, MBR orientation, elongation, moments or centroids, for example. This is markably different from generalising a specific kind of object class like buildings, isolines or roads that have recurring and objective matching qualities in those areas, that can be met (e. g. (Heinzle et al., 2006)). Instead, we suggest to consider the vertical relation between source outline shape and the schematised outline. Some objective measures exist though, due to the confinement of existing chorematic diagrams size to a sheet of paper, such as minimal distnance and simple size considerations. Ensuring an appropriate outline granularity is a well known problem and complicated by inclusion of Bezier-curves in territorial outlines (Figure 1).

The consecutive vertex distance (M1 in Figure 3) is a basic and very important constraint and measure for characterising polygons, as long as they do not include Bezier curves. Bezier curves pose a problem insofar as they will be broken down into a varying number of short polyline segments when represented in nearly all GI-Systems and databases. Calculating the minimum consecutive vertex distance for existing chorematic diagrams makes no sense if Bezier curves are involved, as the resulting measure would be arbitrary and misleading (Figure 4).

We therefore suggest to add *Length of polyline in map units per cubic Bezier-curve* as a measure, when Bezier-curves are encountered. Just as a low number of vertex points is an indicator of graphic simplicity, a low number of curves is one, too. Although computationally consisting of an infinite number of vertices, curves are perceptually easily grouped and perceived as single, simple form, especially the less directional changes they have. Consequently, an outline with a large distance covered per cubic Bezier-curves has fewer directional changes and is thereby simpler.

2.4 Constraint measures for choropleth to area-class schematisation

This schematisation task must consider horizontal relations more strongly than the territorial outline schematisation. As exemplarily shown in Figures 1 and 2 , the area-boundaries are usually depicted with Bezier-curves. Assuming the chorematic modelling i.e. model generalisation has already happened, and the number of classes has been reduced and every choropleth element has been assigned to a new class and aggregated with its matching neighbours, the cartographic challenge of drawing the new area-boundaries in the chorematic style remains. Even with the mentioned assumption, generalizing the boundaries to curves has semantic repercussions even for the aggregated areas. In turn, the curve-fitting to the identified polylines needs metric parameters, especially for the maximum allowed distance between polyline and fitted curve(Li, 2007a). These can take the forms like width (maximum of distance betweeen curve and polyline), the integral

Constraint	Goal value
M1 Consecutive vertex distance	> 0.1 mm
M2 Outline granularity	
minimal shape width	> 0.6 mm
minimal shape height	> 0.4 mm
M3 Distance btw. boundary points	> 0.6 mm
M4 Minimal area	> 4 mm^2
M5 Respect spatial context	TRUE
M6 Object separation	> 0.6 mm
M7 Number of categories	varying

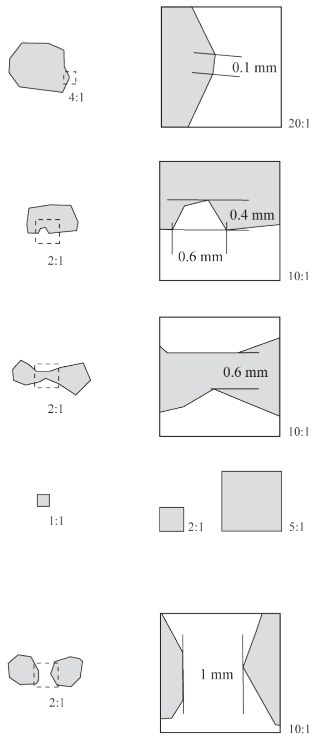


Figure 3: Goal values of metric constraints (in map units) for polygon generalization with respect to paper maps after Galanda 2003

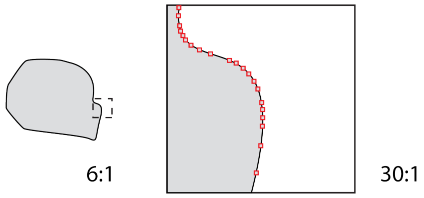


Figure 4: A cubic Bezier curve of a polygon, broken down into polyline segements

i.e. the absolute area betwen them or the Fréchet metric. Solutions must then be checked for the amount of semantic reclassification that will occur, possibly weighted by semantic importance, and checked for topology violations.

2.5 Map wide constraint measures

While the above two chorematic schematisation tasks consider single steps in the process that need measurement, the whole diagram itself needs to be considered, too. One of the most obvious differences between chorematic diagrams and thematic maps of other kinds is the low visual complexity of chorematic diagrams. While many more complex information density and diversity indices and messures are known, some more straightforward ones encountered in the related work appear to suit our purpose. Following Fairbairn (2006), one can use loss-free compression rates, for example from bmp to png-8 at a constant resolution of 300 dpi as an indicator for visual complexity with just as much explanative power as more complex ones. This map-level constraint measure can be augmented with simple measures for complexity such as total object number (ON), the absolute object line length (OLL), following Harrie and Stigmar (2007). The number of objects (NO) and the summed length of all object lines (OLL) have been found to correspond best with human-perceived complexity and amount of information (Harrie and Stigmar, 2007). We suggest to introduce a normalisation over the drawing area in map units (OLLpA), i. e. $\frac{mm}{mm^2} = \frac{1}{mm}$. This allows comparison of information density between different types of maps, on contrast to OLL which is a measure of absolute information content. Using drawing space millimetres as the dimension for OLLpA is convenient as it produces numbers interpretable for cartographic practice due to its relation to staples of generalisation like minimum size and minimum distance.

$$OLLpA = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}}{ab}$$

where l_{ij} is the line length of object o_{ij} of object type i, and a,b are the long and short side of the bounding box around all map objects. The variable i stands for the number of different object types and j for the number of objects of that type i

Structurally this is the cartographic line frequency, related to Bertin's density concept of sign per minimum visible distance, which is why we suggest the name Bertin [Bt] for this unit of measurement. Existing chorematic diagrams have OLLpA values in the

0,2-0,4 [Bt] range, depending on type, whereas conventional thematic maps we measured consistently reached 1 Bt and above.

These measures can serve as last evaluation step, but do not directly tie into the problem of how to reduce clutter (Ellis and Dix, 2007) or solve visual and semantic hierarchy questions. These problems are related to semantic (priority) and structural relations (background-foreground/ figure-ground seperation) as per Steiniger and Weibel (2005), and are known to be hard to model. Automatisation of cartographic clutter reduction via automated exemption (*Freistellung*) appears not to be a heavily researched subject, with early proposals such as Irmer and Woijdziak (1989) seemingly stillborn. Further research into these areas is definitely needed, but is not within our current focus.

3 Work in Progress

We have collected and vectorized chorematic diagrams from 161 sources from which we developed our current understanding of chorematic diagrams. Some of the more straightforward and easily obtainable measures have been collected, such as number of vertices, OLLpA and average vertex distance for territorial outlines. Some of the more interesting vertical relations currently cannot be measured for the whole dataset, because not all are georeferenced, as the vectorization was done in a vector graphic program to allow full color control and correct reproduction of Bezier-curves. Due to that circumstance, we search for good candidates for constraint measures and apply them to a smaller subset. Our current candidates are summed up in Table 4

Table 4: Constraint Measures for chorematic outline schematisation under consideration

Constraint measure	Constraint type	Relation type
number of vertices	shape	|vertical
area difference in mm^2	size	
distribution of correspondance classes	position	
vertex displacement in mm		|horizontal
average/min/max distance between vertices in mm	size	
line length per cubic curve in mm		
summed length of parallel line segments in mm	orientation	
practical parallelity threshold in °		
conceptual parallelity threshold in °		

We have reimplemented and modified two algorithms for characteristic point detection and correspondence evaluation from the realm of polyline morphing (Nöllenburg et al., 2008). The correspondence relationship classes are explored as another way of gaining information about the vertical relations between schematised outline and the source outline. The correspondence class profiles still need to be compared to correspondence classes of other map pairs, to see whether this measure has in fact additional explanative power. The orientation constraint measures are all aimed at increasing the number and length of parallel line segments in a single outline by moving vertex points, similiar to a method used by (Stott et al., 2009). The measure "practical parallelity" must be included to decide which line segments shall count as being parallel in the existing chorematic diagrams. As they have been drawn by hand originally and vectorized manually, very few lines are mathematically parallel. The conceptual parallelity threshold on the other hand is supposed to take into account the angle at which two line segments should be changed to be parallel, which is needed for the actual schematisation.

4 Conclusion

We have presented the main chorematic schematisation tasks that we have identified, along with a short discussion of constraint measures from the related literature. Our next goal is to better describe existing chorematic diagrams with constraints, with partial reproduction as validation of the description.

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