Multimapper – Prototype System for Designing Multi-Scale Maps

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Abstract. Various methods and rules are developed for symbolizing objects on multiscale maps. However they presuppose symbolization of multitude of scale levels, which is time-consuming task. This work presents new approach that allows automatic translation of symbology through levels of detail.

Keywords: multiscale maps, symbology, generalization

1. Introduction

Clear and understandable map design is obtained by generalisation that is appropriate for map content, scale and purpose. In multiscale mapping generalisation is performed every time the scale changes. Rules and principles are proposed for symbol selection and definition of scale ranges for topographic maps (Brewer Buttenfield 2010) and hypsometric relief maps (Samsonov 2011). Current research is directed to dynamic vector maps (Gaffuri 2012, Lienert et al. 2012) that allow setting arbitrary scale, on-demand changing of symbols, blending geometries and adaptive projections (Jenny 2012).

Visual and semantic differences between levels of detail are produced by application of various operators to map content. Roth et al. (2011) developed typology of such operators grouping them into content, geometry, symbol and label categories. They also provided cases in which every operator can be applied. Geometric operators and algorithms are the most studied, being a hot topic of research for the last decades (DeLucia Black 1987, McMaster Shea 1992, Slocum et al. 2008). Symbolization of objects is not always considered as generalization operator. At the same time, zooming alongside with geometric and content transformations often produce situations in which changes in symbology are vital to make scale transition consistent and to keep legibility of the map.

A good support in decision-making is ScaleMaster diagram introduced by Brewer et al. (2007) and advanced by Roth et al. (2011). It gives the synoptic picture of events that accompany scale changes with focus on different datasets, their scale ranges and operators applied to them. However the process of decision-making is not automated, and operators are selected by cartographer. After the operators are selected, they can be performed manually or automatically. While all geometric operators are more or less automated, symbolic changes remain alchemy in the hands of cartographer. Contemporary GIS software does not provide direct tools for automation of symbolic transformations. Every level of detail (usually group of layers with defined scale range) should be symbolized manually to reflect changes in scale, content and geometry. If the symbology for one layer changes, then all work should be redone. Choi and Hwang (2009) introduced idea of using knowledge base to render features at three different levels of detail. This helps to simplify map project structure, because there is no need to maintain separate layers for different scales. But this does not replace manual symbol preparation.

As we see, there are two levels of unsolved automation problems that concern symbology on multiscale maps. The first one is decision-making level, where proper operators should be selected. The second level is automation of these operators in terms of manipulation of Bertin's visual variables (Bertin 1983).

In this study we set up and examine hypothesis that symbology can be transformed automatically during the process of map generalisation. Given the predefined symbology for the minutest level of detail (LoD), this approach potentially would allow deriving symbols for all remaining LoDs. We analyze common practices and factors that influence symbol transformations, establish conceptual framework, offer some formal symbol transformation rules and implement them in a prototype application called Multimapper. Advances and shortcomings of proposed methodology alongside with its future perspectives are discussed in concluding part.

2. Factors of symbol transformations

Transitions of visual variables between map scales are usually gradual. It helps map user to track relations between objects of the same type in different levels of detail. Some visual variables are inherited from previous state and others are altered or completely replaced. It can be deduced that all graphic elements of image have tendency to become smaller and thinner while scale decreases. This technique allows to free space for other objects while competition between them is hard. On the other side, it gives the impression of viewing map from the higher altitude. This effect helps making scale transitions similar to observing features in a real world from different distances. The larger the distance is, the more common features are revealed.

From the point of view of transformation of symbology several cases of geometry and content changes are important:

- *Object content and dimensionality remains the same*. In this case geometry may be simplified, but object content is retained. This is a common practice for river network. For example, line width for river symbol is decreased to avoid self-overlapping of bends and to free space for other objects, but its color is not changed. On the next scale transition the width and color remain the same, but line transparency increases to reflect the fact that streams of this order are not important in this level of detail.
- *Object is reclassified or eliminated*. This commonly takes place in road network and land use classifications on topographic maps, choropleth and diagrams on thematic maps. Object classes can be added, eliminated, grouped or replaced. The variety of possible cases is enormous. Transition of symbols in this case should be performed in a manner that guard map user from confusing different classes to be the same.
- *Object is collapsed*. Collapse is commonly applied to river geometry (polygon to line) and complex road junctions (lines to point). In this case some visual variables are often adopted from previous state. For example, the stroke of the polygon is then used as symbol for resulting linear feature.
- *Object is replaced by superordinate entity*. Replacement can be result of aggregation or clustering. For example, city blocks are commonly aggregated into bigger ones. This helps to maintain optimal size of polygons according to scale, and on the other side resulting polygons reveal more global features of city structure. In case of aggregation the symbol is often adopted from previous level of detail.

The tricky side of “change symbol” operators is that there are several parallel threads of symbol transformations that are applied to different layers and different objects inside layers. For example, one river remains polygonal and other collapses to linear, land use is reclassified, minor road classes are eliminated and city blocks are aggregated. All this events happen at the same time and as a result symbols should be altered, but in coherent way. Two or more hierarchical levels of phenomena are often shown simultaneously, but graphic accent is switched to the level that is most relevant to the scale of visualization. This is typical for administrative units.

Summarizing analysis provided above, we could list main factors that influence changes in symbology. These factors are changes in:

- *Size on screen*. The smaller the object is, the more prominent its symbol should be, if it is important to recognize.
- *Class*. If object class changed or eliminated it should be reflected in symbology. Some visual variables from previous classification can be adopted in new symbology to set relations between previous and current state of the map.
- *Density/sinuosity*. The denser is the set of points or lines, the smaller should be their sizes or widths. The same concerns line sinuosity.
- *Dimensionality*. If object is collapsed, then a new symbol is introduced that can inhere some visual variables from previous state.
- *Entity*. If object is replaced by superordinate entity, its symbol can be adopted or new symbol introduced instead depending on the situation

The next chapter describes conceptual framework that can potentially treat these factors.

3. Conceptual framework

As we see from previous chapter, symbol transformation is complex process that is influenced by many factors. The situation becomes more complicated because color changes are very hard to formalize. As problem is not deeply investigated up to date, it is impossible to provide all-in-one solution that would suit every possible case. Thus we formulated main principles that comprise conceptual framework for automatic symbol translation between levels of detail. Then some formal rules and algorithms for particular cases are proposed and tested.

Our conceptual framework for automatic symbol translation consists of the following propositions:

1. The starting point for map preparation is manually designed map at most detailed level.
2. For each smaller map scale, generalized layers are provided by existing database LoD or real-time generalisation.
3. All object entities in current and previous map scale are linked through ID field. I.e. object in previous state points to ID of object that was derived from it by generalization. This field can be populated automatically after generalisation.

4. All object entities in current map scale have attribute field that describes how object is derived from previous map scale, i.e. it contains a list of generalization operators. This field can be populated automatically after generalisation.
5. Additionally an attribute field that stores classification can be added database layer so the system can estimate differences between classifications of two levels of detail.
6. Hierarchical tree of object states is established using the links provided by ID attribute field.
7. Appropriate transformation of symbology is selected with respect to differences in map scale, classifications, spatial and attribute characteristics between two consequent levels of detail in the tree. Translation is propagated through the full tree.

The nodes in the tree are connected by elementary geometry transformations that are classified into 18 possible combinations. Some examples are presented on **Figure 1a**. For every type of transformation several rules are possible: color and transparency correction, width correction, symbol change etc. (**Figure 1b**). Example of full tree is presented on **Figure 1c**. One path in the tree is a chain of symbol transformations controlled by changes in classification, spatial and attribute characteristics. How these changes can be particularly used to manage symbols? We tested several case studies that are described briefly in the next chapter.

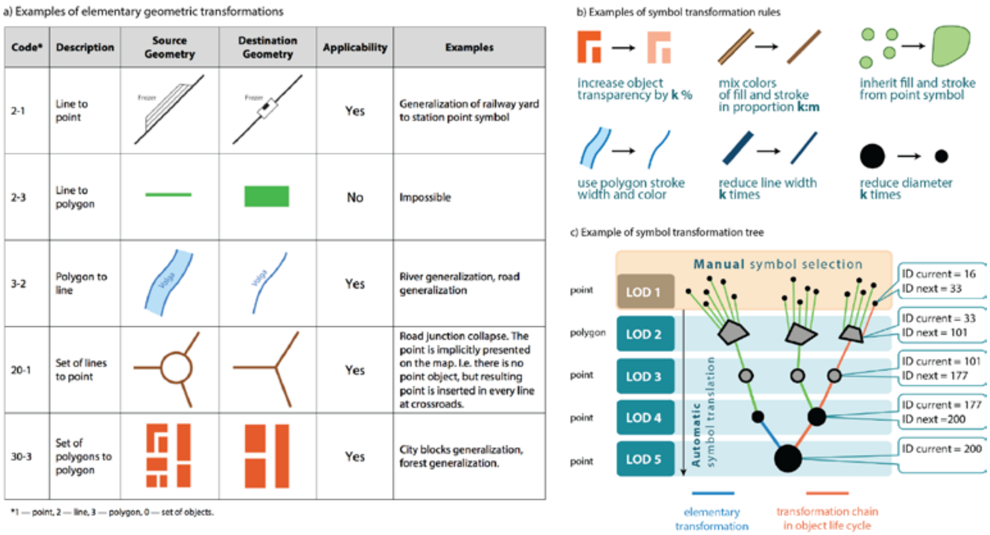

Figure 1. Theoretical basis of automatic symbol translation through multiple scales

4. Case studies

First two case studies, presented in (Podolsky Samsonov 2013) concern topographic elements: city blocks and road network. Another two cases are diagrams and choropleth on thematic map (Yurova Samsonov 2013). Given the initial map design we searched for formal rules that can manage transformation of symbols and visual variables. We investigated such factors as:

- Scale (all cases)
- Area of polygon (city blocks, diagrams)
- Density of lines (road network)
- Number of classes (road network, diagrams, choropleth)
- Statistics on attribute value (diagrams, choropleth).

The work was conducted in the following manner: initially the map was manually designed in several scales that differ two times in value. Then we tried to find and formalize rules that can be applied to symbols of the most detailed level to derive map designs at smaller scales. We decided to obtain results for simple cases and postpone complex symbology for future research. Thus we used simple fill and stroke for polygons and simple symbology for lines. More detailed description of the work is provided in proceedings papers mentioned above, and here we will summarize the results.

For city blocks the linear dependence between lightness of fill color and size of the block was considered to be useful. If mean area of the city block decreases during scale transition, then lightness decreases appropriately. An interesting effect was found when level of detail switches from LoD derived from 1:500 000 topographic map to LoD derived from 1:1 000 000 map. Here the aggregation of blocks is so sizeable that even when scale decreases two times, the mean size of blocks becomes larger on the screen. And lightness is adjusted appropriately — it is slightly increased, but visually it seems that it remains the same.

Road network generalization was made by omission of classes. We calculated the density of lines on the screen at every scale. We found linear dependence between line width and density to be useful. If the road network at particular class becomes denser, then line width is decreased accordingly (Podolsky Samsonov 2013).

Changes in symbology for diagrams were tied together with changes in area of administrative units and changes in the total value of the attribute that is mapped. First of all, optimal scales were calculated for each administrative level using mean width of minimum bounding rectangles (MBR) enclosing polygons of each level. The united classification of attribute for all levels of detail performed and appropriate classes for each level were selected. Then we calculated mean ratio of areas R_a and values R_v between municipalities and districts, and between districts and regions. Finally a formula was derived that can be used to alter diameter of circle in scale transition with respect to changing in scale, area and value. If scale decreases two times and the mapping unit remains the same, then diameter decreases two times. If mapping unit is replaced by superordinate entity, then diameter depends on how the value and area increase on average. The overall effect is gradual decrease of mean diameter that follows natural principle of viewing map from an increasing altitude.

Finally, we tested possibilities to automate selection of color scale, classification for use on choropleth maps. We found that differences in relative indexes (that are usually mapped using choropleths) are not so dramatic as in the case of absolute values. In many cases the same classification and color scale can be used in all levels of detail, however, some classes can be merged if they contain too little entities. But here we derived conceptual principle of automated color scale selection based on asymmetry of data distribution. If the distribution is symmetrical, then simple color scale based on one hue can be applied. If distribution is asymmetric, then two-hue scale is selected and additional color is used to represent anomalous values (Yurova Samsonov 2013).

5. Multimapper application

Multimapper is a prototype Java application that has a functionality based on a conceptual framework introduced in this work and specially intended for multiscale map design. For now it consists of three panels: layer panel, map panel and design panel (**Figure 2**). Layer panel is used for management of layers. It allows adding, removing and dragging layers. All layers should be joined into thematic groups, i.e. rivers, roads, diagrams etc. ID field and generalization history field are selected in the properties of a group (all layers should have a field of the same name). Then user should mark layers that comprise the most detailed level and design them manually (Municipalities level on Figure 2). Symbology is set up using dialog.

After the selection of symbols is completed, user switches to design panel. This panel is intended for selection of reference scales, algorithms of symbol transformation and for presentation of resulting parameters of these transformations (for example, coefficients of diagram reduction). For now it works only with one selected group of layers. User chooses an appropriate reference scale for each layer using slider or typing scale manually. Then an algorithm of symbol transformations should be selected. For now design panel contains a list of hard-coded algorithms based on case studies from chapter 4. User selects a scenario that suits his task and presses Compile button. After calculations are made, remaining layers in selected group (Provinces and Regions in **Figure 2**) are populated with symbols. The functionality of design panel can be greatly improved by inclusion of somewhat similar to ScaleMaster diagram introduced by Brewer et al. (2007). Another important issues for future research are automatic selection of appropriate symbol transformation algorithm and possibility to make some manipulations to all groups when root of layer tree is selected.

Visualization of layers is made in map panel. This panel was programmed in grid layout to allow user quick and comfortable way to see several levels of detail or several regions simultaneously. Layout manager is located in the top part of the window and contains quick buttons for popular layout configurations and button for setting an arbitrary layout. Every map pane inside panel is linked to the same tree of layers, but is controlled independently from others. User can set up scale and extent for each map pane individually. Every tool bar contains standard navigation tools and useful «center» button. If user presses this button, all other map panes are centered on the same point (scale is not altered).

Multimapper lacks legend panel that will be programmed in the future.

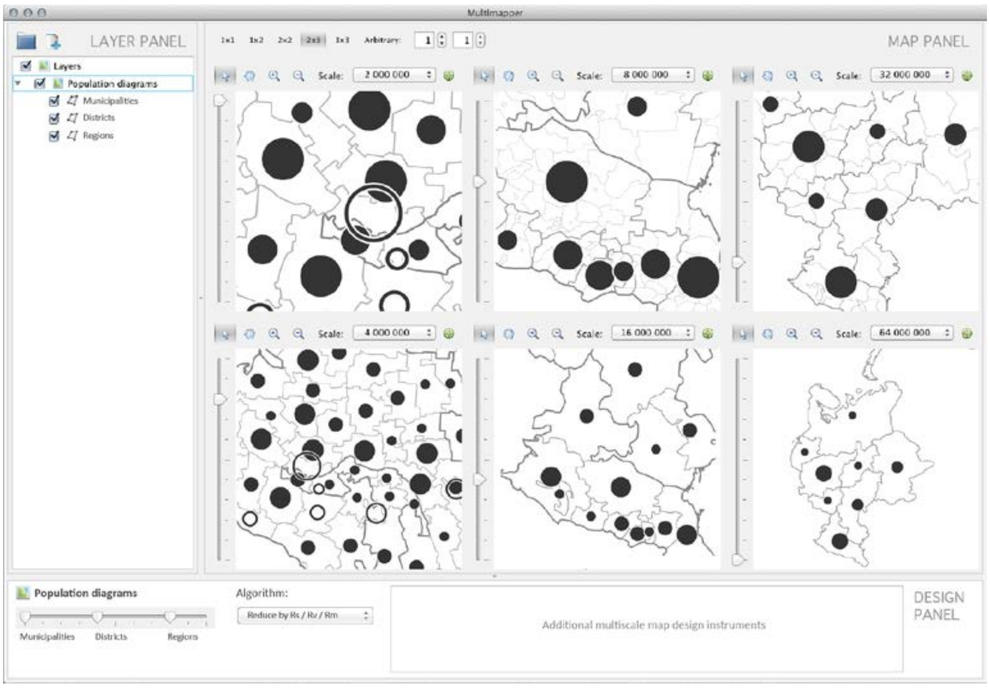

Figure 2. Multimapper application window

6. Conclusion

A new scale-adaptive approach to symbolization of vector data on multiscale maps is introduced for automatic translation of symbols from one detailed level to others.

The proposed conceptual framework depends on well-prepared data that suits the scale of visualization. It can be seen as a bottleneck of the whole method. What if database structure changes or information about object IDs is absent? However, it helps us to solve symbology problems apart from content and geometry changes but with respect to their results. If we have a solution for well-prepared data, then it can be extended for the case, where data needs pre-processing.

Another shortcoming of current approach is that it concerns transformations only of one map layer without any reconcilement with changes in other layers. This can lead to disagreement between layer symbology. The study of this issue will be a subject of future investigations.

Finally, the effectiveness of proposed methodology should be assessed in terms of time and energy. It should be compared to traditional approach that assumes manual design of map symbology at multiple scales.

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