An Experiment to Assess the Perceptual Organization of Polygonal Objects

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Abstract. The process of cartographic generalization requires that extraordinary and typical geographical structures be maintained. We have set-up a pencil and paper experiment to analyze what extra-ordinary structures, i.e., groups of polygons, are perceived by humans, and to explore the principles that lead to the visual grouping of polygonal objects. In this paper, we outline the associated research objectives and describe the test material and procedure. We then sketch how the survey results are stored and present a method for assessing the similarity among polygonal objects groupings. Finally, we present some preliminary statistics derived from the survey data and lay out our future work.

Keywords: perceptual grouping, pencil and paper experiment, polygonal objects, cartography.

1 Introduction

Automated map generalization describes the process of controlled (map) data reduction and transformation in consideration of the map purpose and cartographic design principles to ensure the map legibility. It is one stage of the overall process of map compilation besides data acquisition, data preparation, map maintenance, cartographic finishing, and printing. In automated map generalization research, various authors [1,2] have stressed the role of structure recognition or cartometric analysis as a key initial step in the automated generalization process. The aim of the structural recognition stage is to classify and describe the data that should be mapped to enable informed decisions on the appropriate cartographic treatment for a particular situation during the map generalization process. For instance when a single building is too small to be clearly visible in the final map, then one can eliminate the building or enlarge the building. The decision if the building must be enlarged or eliminated will depend on (a) its semantics, i.e., is it a hospital (possible treatment: enlarge + symbolize), or (b) its geographic context, i.e., is the building a garage in the city (eliminate), is the building a cabin in the forest that may be a good point of orientation for hikers (enlarge), or is the building part of a row of terraced houses (merge or typify together with the neighboring buildings).

In our work we concentrate on the context classification of polygonal objects such as lakes, islands and buildings to enable informed decision making with automated methods. We are interest in particular in the perceptual grouping of such objects, as processing decisions should be based on the properties of a perceptual group (i.e., the context) and not only on the properties of the single object. For instance, Bertin [3] recommends that islands or lakes, that are part of the core of a lake district, or an island archipelago respectively (i.e., that form a perceptual group), should not be eliminated since they build the skeleton of such structures [4]. Similarly, isolated islands (i.e., objects not part of any perceptual group) should also be preserved, since they may be an important point of orientation for map users. If such rules are not observed during data reduction, then the general pattern of the spatial arrangement of islands or lakes will be destroyed, and situations in the final map may be wrongly interpreted by the map reader, or the correspondence between the map and the realty can be lost.

The development of computer-based algorithms that are able to extract perceptual groups of objects (i.e., that classify grouping situations in the map data) for their later use in map generalization involves three components. These components are (1) the identification of the visual patterns of interest, (2) the formalization of patterns (i.e., in terms of their construction principles), and (3) the development of pattern recognition algorithms based on the discovered principles [5]. To identify perceptual patterns of interest (i.e., the first stage), we have designed a pencil & paper experiment. The remainder of this article will (a) outline the questions that our experiment is intended to answer, (b) describe the test material and applied procedures, and (c) the methods that have been developed to assess our test results. Since this paper presents work in progress, we will only report preliminary results; however, we will present and discuss more detailed experimental results at the workshop.

2 Objectives for the Pencil and Paper Test

The first and foremost objective, with respect to our later application area in cartography, is the identification of groups of polygonal objects that need to be preserved during the cartographic generalization processes. As we aim to develop automated detection algorithms, we need to know what factors are responsible for the grouping of objects. Gestalt theory has extensively dealt with the exploration of principles that let humans perceive groups rather than single objects. Of particular note, is a list of *laws on organization in perceptual form* introduced by Wertheimer in 1923 [6]. Some of these laws/principles have been previously applied in map generalization to group objects. For instance, Regnauld [7] applied the *principle of proximity* for the grouping of buildings, and Thomson and Richardson [8] applied the *principle of good continuation* to extract salient road network structures (for a review see [5]). However, while some of these concepts, such as the principles of similarity and proximity, are narrowly defined, the formalization of other principles, such as the *principles of Prägnanz* (conciseness) and *Good Gestalt* (good continuity), are less well defined.

In addition to the problem of formalizing these ‘Gestalt’ principles for general visual grouping, we are not aware of any experimental results that satisfy the following conditions:

- show the validity of the Gestalt principles for polygonal objects,
- show that the set of principles is exhaustive, covering all possible perceptual organization cases of polygonal objects, and
- show how the principles can be ranked against each other.

Several questions appear with respect to the formalization of Gestalt principles and their transfer into pattern recognition algorithms. For instance, (a) can we classify the groups with respect to the number of group objects and/or shape of the group? (b) How do people delineate these groups? (c) Are there noticeable grouping differences between people with a cartographic and geographic background than those without?

Finally, we also conducted this test to obtain validation data for testing the algorithms that will be developed at a later stage of analysis.

3 Test Material and Procedure

A pencil and paper test was carried out by giving each test participant several sheets that displayed polygonal objects. Our test consists of seven sheets that show lakes, buildings, islands and triangles[1] as the sole feature class, and an additional questionnaire. Test participants were instructed to delineate groups of objects they thought best belonged together. Additional information given to subjects included (a) the purpose of the test, (b) the type of objects displayed, (c) the geographical location of the test areas, (d) the map scale, and (e) the notion that structures might exist at different scales. More precisely, there could be large groups of dozens of objects and small groups of only a few objects. Should a person want to delineate differently sized groups, different colour pens were provided. There was no set time restriction; however, most took between 15 and 30 minutes to complete the test. To date, 30 persons (one sheet by 40 subjects) have performed the test. About 3/4th of the participants either have a background in geography or cartography, and about 90% of the subjects are of German or Swiss nationality. The age of the participants ranged between 20-55 years (with only few students) and the ratio of male to female has been 29:11. In total, approximately 3200 groups were delineated by the 40 participants. Figure 1 shows a sample of the groups that have been marked in the Åland island dataset.

4 Representation and Analysis Methods

All groups that have been marked on the sheets were digitized, stored and queried with the open source Geographic Information System OpenJUMP[2]. For the digitization and data analysis, a custom set of tools has been programmed and the survey data were stored within a specifically developed object-oriented data structure.

[1] The triangles size, orientation and position are derived from one island/building dataset.
[2] www.openjump.org

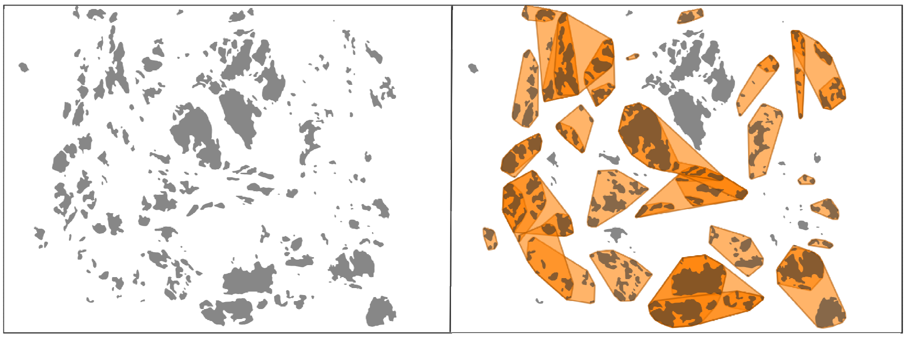

Fig. 1. An example of one sheet (scale 1: 590,000) illustrating islands near Finland (Åland). The plot on the right side shows groups marked by their convex hull, which have been selected by at least five participants and have not more than 12 member objects

In this data structure every dataset object contains a set of group objects and their geographic features i.e., the islands, buildings, etc. One group object holds (a) the identifiers (IDs) that link to the geographic features, (b) the ID of the user that marked the group, and (c) a link-list that is used to store links to similar groups. This ID-based storage schema allows for an efficient comparison of groups from different users by keeping the memory and processing needs comparably small.

For our evaluation, we are interested in those groups that have been marked by several people. Therefore, we needed to assess the similarity among all groups within a single dataset. The similarity analysis between two groups should account for three criteria: (1) the number of group objects, (2) the spatial location, and (3) the area of the group convex hull (i.e., footprint). A similarity query that can account for the first two criteria has been developed, and is based on a binary representation of the groups. Therefore, all groups are stored in a binary n x m matrix with n rows, the number of groups, and m columns, the number of objects. Two groups can then be compared by calculating the so-called Hamming distance h [9], i.e., the binary difference, between two rows. If the distance between two groups is 0, then they are identical. If h=1, one of the two groups has one more object than the other.

If similar groups with parameter $h > 0$ are queried, then it is useful to add a second test that compares the ratio of the footprint between the single groups and the aggregation of the two groups to test. In other words, it is important to be able to distinguish, for example, between two small groups (e.g., of 3 and 5 objects respectively) with similar group core, but vastly different spatial extents.

A second analysis method has been developed to identify groups that are not formed in accordance with the Gestalt principle of proximity. A group is not considered proximity-based if the real-world distance of one of the group objects to the next non-group object is smaller than the distance to the next group object.

Finally, we also implemented methods to assess the distribution parameters of (minimum) connection distances between the group members. These will help to identify if proximity-based perceptual grouping can be related to the size (i.e., area) of one polygon, and if there exists a maximum connection distance among the members of a group. These distance evaluations utilize an implementation of the *Minimum Spanning Tree* by Regnauld [10].

5 First Results and Future Work

An example of preliminary statistics generated from the survey data can be found in Table 1. The table data show that we are able to evaluate approximately 330 groups, which have been delineated by at least 3 participants, on their forming principles. If one compares the results for the datasets Åland and Maine we can see that 26 percent (86/325) vs. 10 percent (13/129) of the groups marked are non-proximity groups. Furthermore it is to see that the maximal connection distance[3] is 6.98 vs. 13.1 units. This shows that humans may bridge large distances in comparison to the object size when they group objects. A further result, not shown, indicates that the distribution of the distances for the dataset and the groups are strongly skewed. This fact needs to be considered when one studies and compares the distance mean and standard deviation values in Table 1.

Table 1. Statistics for the different datasets.

	dataset						
	Åland	Maine	Nyon	Joensuu	Lyon	Triangle	
						Åland	Nyon
# participants	40	30	30	30	29	26	28
# geograph. features	214	157	162	99	147	214	162
# marked groups	792	513	541	341	382	360	370
# groups for h=0	325	129	188	138	168	219	141
# non-proximity groups for h=0	86	13	70	59	59	95	40
# groups for h=0 and selected at least 3x	85	53	59	35	36	29	34
mean-connection distance[3] [stdv]	1.18 [0.91]	2.06 [2.33]	1.44 [0.81]	1.11 [0.83]	1.22 [0.76]	1.55 [1.12]	1.50 [0.76]
Maximum-connection distance[3] [proximity groups]	6.98 [3.68]	13.1 [13.1]	5.88 [4.45]	4.14 [3.69]	5.29 [3.88]	7.51 [5.65]	4.77 [4.77]

The next steps of the survey evaluation will cover an analysis of the within-group distances to explore if there exists a statistically significant difference between the datasets and between *proximity* and *non-proximity* based groups, and if the connection distance is data driven, or a feature of human vision. We will then analyze the object groups with respect to the principles outlined by Wertheimer [7].

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[3] The connection distance is a ratio calculated between real-world distance (m) and the largest adjacent polygon diameter (m). Hence, a ratio value of 1.2 indicates that the connection distance between the two objects is equal to 1.2 times the diameter of the larger polygon.

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