Visualizing Fuzzy Boundaries of City Neighbourhoods

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This paper presents the outcome of the study attempting to improve the cartographic visualization of crisp and fuzzy boundaries and internal structure of neighbourhoods as placial features. In the study preceding this paper, a number of visualization techniques depicting neighbourhood structure were generated. The evaluation survey results indicated that vague segments are easier to identify in comparison to crisp ones; most successful are the techniques which clearly show internal subdivision of a neighbourhood and allow to see the basemap under the symbology layer.

Keywords: fuzzy boundaries; neighbourhoods; visualization; sense of place

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1 Introduction

In everyday life, people use a wide variety of geographical terms. However, most of them are not a part of a formal geographical vocabulary. City dwellers, for instance, often use identifiers such as 'downtown' and, significantly less often, the names of official administrative districts. These unofficial names often identify the locations important for residents, carrying special meanings and associations, but most of the time they are left unattended since geography of perception is hard to capture and use.

Researchers working in this field refer to informal regions as vernacular regions or neighbourhoods. They both represent cognitive spatial objects of different scale. Vernacular regions tend to be large portions of countries united by cultural and geographical connotations (Zelinsky, 1980), while the term 'neighbourhood' is usually applied to areas within a city sharing some common stereotype and having a certain 'popular' name. This also applies to communication between residents (Galster, 2001). In the study preceding this article, the issue of neighbourhood boundary visualization was investigated at the example of three university neighbourhoods in Moscow: Lomonosov Moscow State University, Higher School of Economics, and Bauman Moscow State Technical University. These university neighbourhoods are an interesting spatial phenomenon since they all have their own spatial relationships with their surrounding area – from isolation to interweaving – due to geographical, historical, and institutional reasons. It is a challenging cartographical task to convey these complex relations in a clear way. This paper does not go into details of the study of university neighbourhoods per se, but concentrates on the outcome of the visualization of neighbourhood boundaries in general.

The current neighbourhood research is mostly lying on the cross section of human geography and social sciences. Published works demonstrate solid theoretical background and interesting semantic findings, but they lack proper visualizations. Applying cartographic methods to the visualization of neighbourhoods can be beneficial for human geographers and social scientists who work in the field and want to better represent the places they study cartographically.

How do then neighourhoods relate to place theory? It is widely known that Tim Cresswell describes place as 'a space with a meaning' (Cresswell, 2004). Yi-Fu Tuan pointed out that place does not have

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a certain scale or size by providing the extreme examples of the favourite armchair by the fireplace and the whole Earth, two examples both of which can be treated as places (Tuan, 1977). Bearing this in mind, a neighbourhood can be considered a platial feature – it completely relies on feelings, associations, and the identity that connects people to certain places. It is a spatial feature in terms of geographic extent, and it is a place in terms of emotions that define it.

The general objective of this study is to develop suitable visualization techniques to convey how university neighbourhoods embed in the urban environment. This paper[1] focusses on the evaluation of how well these techniques convey information about the geography and and the sense of place of neighbourhoods.

2 How to Draw a Neighbourhood: Methodology

The first step prior to the visualization of boundaries is to identify the location of the neighbourhood boundaries in terms of the residents' perception. To do so, a pre-study online survey was conducted. The respondents were asked to outline the area they consider belonging to their alma mater.

A pile of overlaying polygons drawn by the participants was gathered during the survey. One of the ways to locate the boundaries of informal regions on the basis of this data is to divide the study area into cells and calculate for each cell a percentage of the respondents who claimed it their neighbourhood. To do so, an auxiliary polygonal layer of tiny square cells was created and each cell was assigned with the calculated number of intersecting polygons – identically to the raster calculator operations. The visualization techniques discussed below were applied to the resulting smooth surface created on this step. Adapting the terminology from Meinig (1965), three hierarchical levels of the neighbourhood were defined based on the results: the core (an area marked as a core – in a separate question – by more than 50% of the respondents), the domain (an area marked as a neighbourhood by more than 50% of the respondents), and the sphere (marked by 25–49% of the respondents).

When selecting proper cartographic means for vague regions, it is common to start with Bertin's visual variables (Bertin, 1983; Thomson et al., 2005). MacEachren et al. (2012) argue that the variables crispness and location are most suited for uncertainty depiction, followed by value, arrangement, size, and transparency. We can adapt their findings to fuzziness depiction, which is a concept closely related to uncertainly. The overview of the variables considered suitable for vague objects depiction is presented in Figure 1.

By applying various cartographical means, we can emphasize on either the inner of the neighbourhood or its boundaries. Figure 1 accordingly distinguishes between these different focuses. Also, assumptions regarding uncertainty are included in the set of visualizations. Not all of the theoretically possible techniques shown in the table can be applied to the considered cases. The techniques suitable for the depiction of the neighbourhoods are outlined with blue frames. We will compare the various combinations of these in the next section.

In the experiment, a set of twelve visualizations was created to test how well different visual variables are able to convey fuzziness and sense of place of the considered neighbourhoods. The tested visualizations are characterized by varying affordances. The variables most widely used are transparency, size, and texture, as well as location as 'indispensable' variable (Roth and MacEachren, 2016). Almost all the techniques visualize the place boundaries in a discrete way, because the explicit consideration of the three parts of the neighbourhoods (core, domain, sphere) was part of the assumed methodology. In rare cases of continuous visualizations, the boundaries between these parts are, however, blurred. Only a few techniques allow to still read the basemap by not hiding it, or only partially hiding it. Also, the visualizations are tested on individual isolated neighbourhoods, so not all of them can be used to visualize overlapping districts.

Figure 2 allows to anticipate which of the techniques are able to successfully convey neighbourhood boundaries. The sections of the table clarify on which visual variables the techniques are based. According to the combination of the outlined formal criteria, the *contour lines* (#1) and *circles of varying size* (#9) techniques appear to be the most promizing, followed by the *layer tinting* (#2) and *varying contour weight* (#5) techniques. However, there is no way to theoretically estimate the intuitiveness of these techniques. The evaluation survey quantified this missing information and allowed to compare the 'predictions' collected in the pre-study with the final survey results.

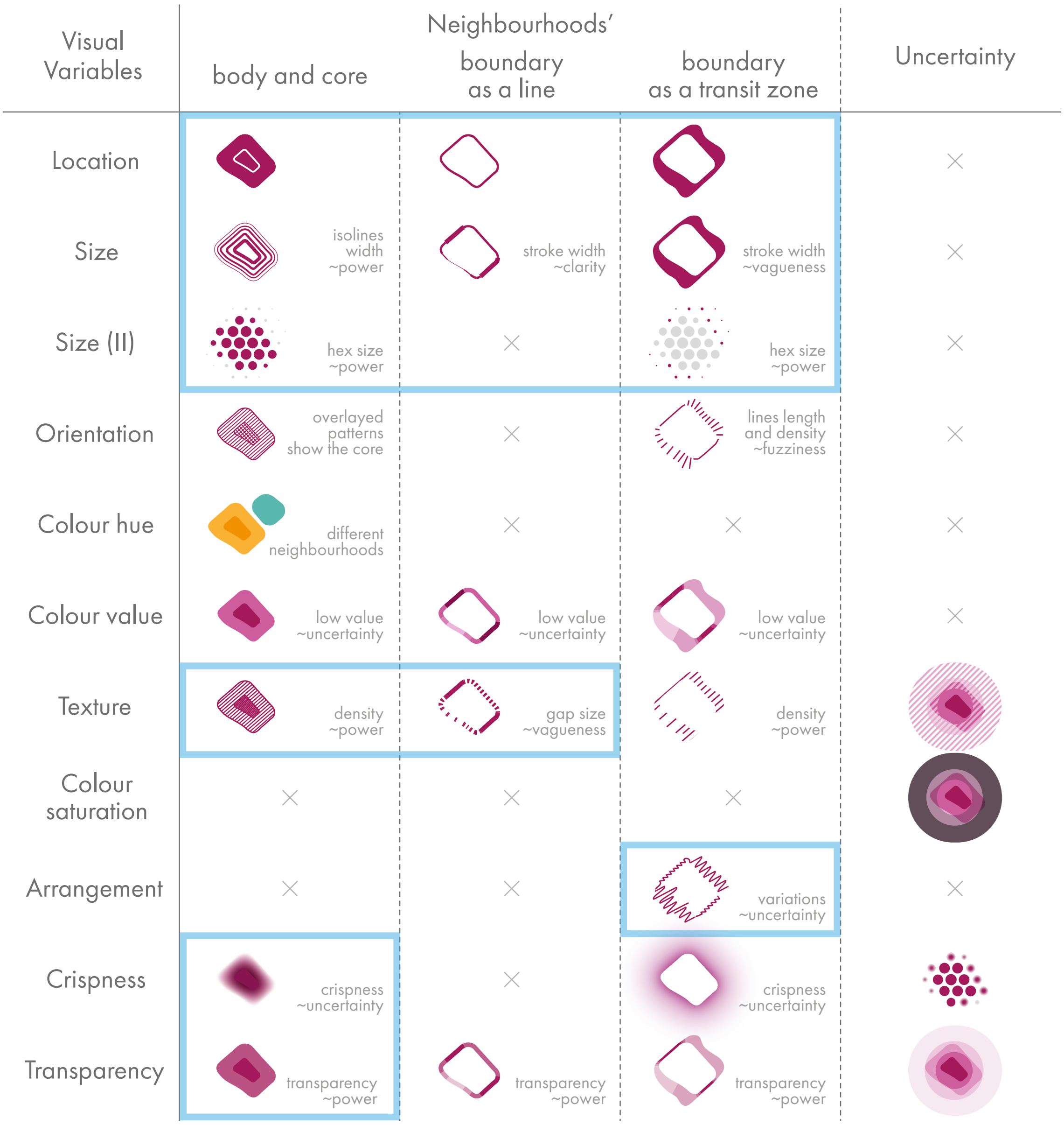
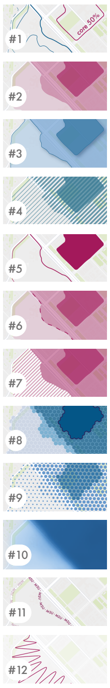


Figure 1: The visual variables considered in the maps design



Visualisation technique	Visual variable employed	Continious or discrete	Clearly differentiates between C, D, S	Allows to see the background	Allows overlap with neighbouring districts	Allows to increase the number of 'steps'	Allows to implement uncertainty information
#1	location, size	D	✔	✔	✔	✔	✔ (e.g., transparency)
#2	transparency	D	✔	✓	×	✔	✔ (e.g., hatching)
#3	crispness, transparency	D	✔	×	×	✔	✔ (e.g., hatching)
#4	texture, size	D	✔	×	✔	✔	✔ (e.g., transparency)
#5	location, size	D	✔	✓	✔	✔	✔ (e.g., transparency)
#6	transparency, size, texture	D	✔	×	×	×	× (will look cluttered)
#7	transparency, size, texture	D	✔	×	×	×	× (will look cluttered)
#8	transparency, texture	D	✔	×	×	✔	✔ (e.g., transparency)
#9	size	C	✔	×	✔	✔	✔ (e.g., layer of white dots of smaller size, etc.)
#10	crispness	C	×	×	×	×	✔ (e.g., hatching)
#11	texture, size, transparency	D	×	✔	✔	×	✔ (e.g., transparency)
#12	size, arrangement	D	×	✔	✔	×	✔ (e.g., transparency)

Figure 2: Formal affordances of the visualization techniques

In the survey, one map randomly drawn from the set of twelve visualization styles was presented to the respondent, who was then asked to identify clear and fuzzy boundaries by placing markers from two corresponding sets along them. The maps were intentionally presented without a legend in order to test how intuitive the visualizations are. It was decided to show only one example (although it will obviously lead to a fewer evaluated techniques) since otherwise, by comparing different techniques showing the same phenomenon, the person would potentially and subconsciously perceive more information than he or she would do in both cases individually. In that way all visualizations have been tested.

3 Results and Discussion

By analysing the results of this task, we could estimate how successfully different visualization techniques provide information about boundary characteristics. Unfortunately, not all of the maps resultet in a sufficient amount of user data to allow for an analysis. Two maps from the set were either never drawn or ignored by the respondents. Most of the evaluated techniques allowed to identify fuzzy and crisp boundaries at least partly. The *contour lines technique* (#1) succeeded best in terms of providing the correct visual impression of crisp boundaries. This also applied to the fuzzy boundaries as conveyed by the *hexagons* (#8) and *circles* (#9) techniques, and a combination of *layer tinting with hatching* (#7).

To measure subjective opinions, the participants were asked to rank the visualization techniques. They were asked to choose three maps they like the most and one map which they find, on the contrary, the most unattractive. The respondents find the *layer tinting technique* (#2) the most appealing, and a low standard deviation also points out that this result somehow reflects common perception. The second most popular map is a variation of the first. It employs the same visualization technique supplemented with *solid and dashed lines* (#6). The third most popular choice, the *3D layers technique* (#3), demonstrates that among the most popular maps are also the most simple ones. Basically, they only represent three areas of the same colour yet varying transparency. The absolute outsider is the *jagged line technique* (#12). Despite the fact that the users understand the zigzag line representing fuzziness, they also noted that the technique evokes stress and is not suited for the purpose. The technique so often used to represent fuzziness, *a heatmap* (#10), turned out to be the second least popular choice. Figure 3 is summarizing the results of the evaluation survey.

Related to the topic of geographical data uncertainty, a distinction is often made between vagueness caused by the lack of trustworthy data and vagueness reflecting unclarity of how to define or describe the objects. A similar terminological problem reveals itself with identifying crisp and fuzzy boundaries. It is easily understood by users when there is a long smooth transition from the core to the sphere (a typical case of a fuzzy boundary), or the contour lines of a domain and a sphere run along close to each other forming a clear boundary with no transition zone. But once we have a boundary of a sphere that has a distinctive geometrical shape, this can cause confusion. It is not absolutely fuzzy since we can determine, more or less, its location; but the 'expressiveness' of the neighbourhood is quite low in this part so it is not crisp either. It is not fully clear how to handle such situations, but it might be a good decision to emphasize the fuzziness in such cases more prominently.

In summary, fuzzy boundaries can more successfully be identified than crisp ones. Among the possible reasons might be a confusion created by the three-parts structure – the boundaries of the domain are often taken for the boundaries of the neighbourhood. The crispest boundaries can easily be recognized by respondents when they run along old and well-established borders of neighbourhoods where they duplicate physical or natural barriers, like roads or rivers. At the same time, streets can be both limiting borders and inner axes which the neighbourhood is strong on. Oddly enough, depicting the crisp segments with a separate symbol does not necessarily improve the situation. On the contrary, such techniques appear to be overwhelming and overloaded with unnecessary details. Ideally, when the difference is visible through varying transparencies and densities, it appears to be perceived subconsciously. The users can see and comprehend in this case the difference by themselves, instead of being presented with the information processed and highlighted for them. Also and beyond pure symbology, the geometry of a boundary contributes to its identification. People notice the shape of the boundary prior to its symbology – a rounded wandering line is more likely to be identified as a fuzzy boundary than a straight line.

According to the preferences of the respondents and their comments, the most important characteristics for the users are clarity, simplicity (a minimum number of colour/texture steps) and, last but certainly not least, the ability to see the basemap. The latter was particularly often mentioned as a positive feature of the preferred visualization and a common complaint about some of the unpopular techniques. It is possible to overcome this obstacle by changing the order of layers on the map and bringing, e.g., the streets network on top. Also, the maps most appealing for the respondents are not necessarily the easiest to work with. The techniques which demonstrated the best result in crisp and fuzzy boundary recognition had only average levels of appealingness in comparison to the other techniques tested.

Is it possible to predict how successfully the technique will convey fuzziness? According to Figure 1, which summarizes the formal characteristics of the various tested techniques, the potential favourite is a *contour lines method* (#1) as it differentiates clearly the core, domain, and sphere parts; allows to see the background; and is flexible with changing the number of internal steps and the overlapping with other neighbourhoods. This agrees with the findings of the evaluation survey, where the crisp and fuzzy segments were identified quite correctly on this map. Despite this, the technique is not amongst the most popular maps and not the easiest to work with, according to the Figure 3. The *varying contour weight technique* (#5) also looked quite promising in the visualization techniques table. Unfortunately, there is not enough data to confirm or deny that assumption. The next candidates – *varying circles* (#9) and *hatching* (#4) techniques – showed different results. The former performed rather well and was also evaluated as the easiest technique to work with, while the latter appeared to be quite confusing. With a limited amount of data, it could also be concluded with a certain degree of confidence that the contour lines and the circles of varying size techniques perform decently and can be employed for the representation of the fuzzy areas. *Heatmap* (#10) and *jagged line* (#12) techniques have both performed poorly.

Despite strong differences the performance of the various visualizations, it is hardly possible to name one clear one-fits-all technique. The answers demonstrated that the most important characteristics of a successful visualization technique are the ability to see a basemap, simplicity, and clarity. The techniques possessing these characteristics can be employed to the visualization of a neighbourhood

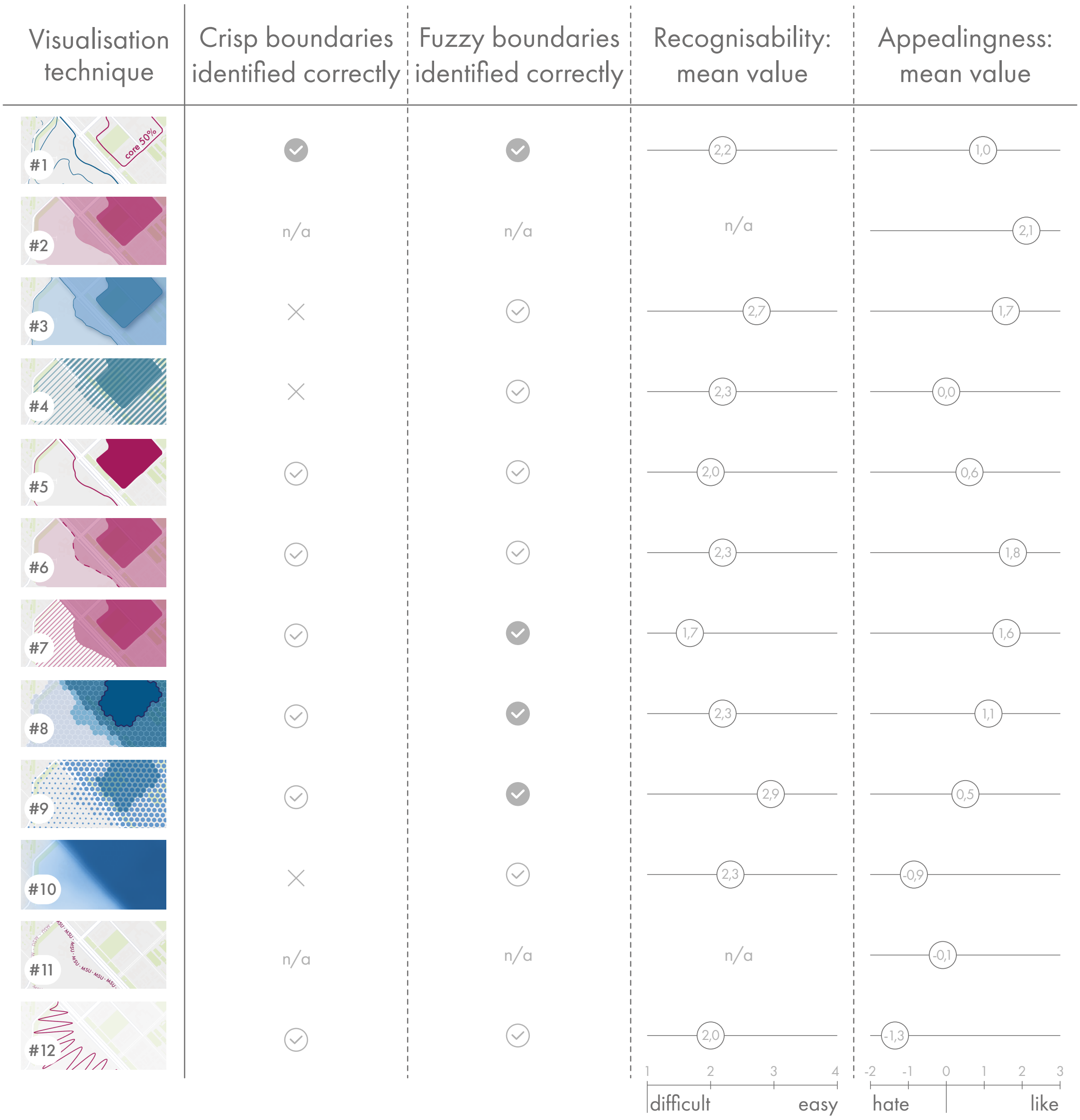


Figure 3: Performance of the tested visualization techniques

and are able to successfully convey both crisp and fuzzy boundaries. Apart from that, it is beneficial to know how the city dwellers perceive the urban area to then employ a corresponding technique for its visualization. This can help researchers working in the field to better convey their findings to a broader audience.

Notes

1. This paper is a summary of an MSc thesis (Glebova, 2021).

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