PSYCHOPHYSICS IN MAP PERCEPTION

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Abstract

The choice of display parameters for digital maps (e.g., the scale used) depends on the impression the map will generate in the eyes of the viewer. One relevant property of the map is the information load it generates, expressed as the map's perceived density. The number of displayed objects does not solely determine the map density. In an experiment 54 participants evaluated the apparent density of maps showing different terrains at different scales. A model with four properties predicted the apparent density of a map well (R^2=0.856). When applying log transforms on two of the variables (number of roads and number of junctions), predictions with these two variables alone were even better (R^2=0.903). The study demonstrates the value of applying psychophysical modeling to evaluation of geographic displays and its use in the design of digital map systems.

Introduction

Geographic information systems (GIS) and digital maps are widely used for navigation, orientation and visual object recognition, and their use will probably continue to grow (Wu, 2009). In these systems, as in many other systems (e.g. medical imaging systems, military applications that control remote systems like unmanned aerial vehicles, microscopes in laboratories or industry, etc.) one can easily change the display scale of the displayed object. Relatively little is known about the effects of the digital maps format, including the scale used, on various aspects of user perception, cognition and performance during map use (Montello, 2002; Oliva, 2004).

In this study we focus on the apparent density and complexity of a map. More complex images are usually associated with longer reaction times, greater cognitive load and lower task performance (Wu, 2009, Evans, 1997). These effects are particular critical when digital maps are used while performing another task, such as driving. Visual search time is correlated with feature congestion, entropy level and edge density (Rozenholts, 2007). However, different visual displays with the same number of objects and type of objects may have different apparent densities. Perceived density is a subjective issue, and its judgment is an unconscious process that affects the understanding of the environment and consequently the visual search and the decision-making process (Patel, 2000; Lohrenz, 2009). Most studies on map complexity used only abstract and simple objects. Harrie (2009) suggested dimensions to measure map complexity from two aspects, the quantity of information and its spatial distribution. Patel (2000) developed a model to compute the perceived complexity of geometric shapes, based on their properties. High complexity might lead to clutter, which depends on the amount of displayed information and its variability. Beck (2010) demonstrated that reaction times on global search increased as global clutter increased. Many studies examined the cognitive mechanisms related to map reading and analysis and spatial information processing (MacEchern, 1995; Taylor, 1992). However, no quantitative model exists, yet, to predict the perceived density of a map. Such a model may allow us to adjust the map scale to a predefined level of density according to the usage situation, terrain properties and user preferences.

This study is part of a larger research program which deals with the optimal scale to present digital maps as a function of map- and task properties. As part of the study we conducted experiments on the perceived density of maps (Schwartz-Chassidim & Meyer, 2011). They were conducted to develop a quantitative model to predict the apparent density of a map based on the properties of the map (e.g. number of roads, number of junctions, junction size, distance between junctions, etc.). We focus here on the application of psychophysical log transforms on some of the variables and their contribution to the modeling process.

Method

Participants were 55 students from Ben-Gurion University of the Negev (29 female, 25 male, ranging in age from 23 to 28 with an average of 25.61 ± 1.19 years). They evaluated the apparent density of 60 maps showing various terrains on a scale between 1 and 10. Participants were not instructed what "density" meant.

Participants sat in front of PCs with 19" screens and 1280*1024 pixel resolutions, so that each pixel length on the screen is ($3 * 10^{-4}$) meter. We developed a dedicated Map Related Tasks Experimental Tool (Martex). It is based on the ESRI MapObjects Version 2.4 development environment, which supports various data manipulations, such as map display, panning and zooming, drawing graphic features and text, identifying and selecting features, calculating statistics and rendering features. Maps were selected from the ESRI data & maps and U.S.A. StreetMaps, which includes imagery, base maps, census data, street datasets, and a host of geographic information of Tele Atlas or NAVTEQ. Maps were selected and displayed using the ArcGIS V9.2 ESRI software. Each map contains several data layers and properties (streets, lakes, rivers, background, state/city boundaries, parks, forests, landmarks, etc.). The user interface was developed in Visual Basic.Net and C and supports administrator and user modes, as well as English and Hebrew language interfaces. The experimental data were stored and managed in a SQL 2008 server express data base.

Each experimental session consisted of a questionnaire and the density rating task. A session lasted approximately 45 minutes. The application appeared in an 800x700 pixel window (i.e. 24 x 21 cm), and maps were presented in a 450 x 630 pixel (i.e. 13.5 x 18.9 cm) frame. Users were instructed to indicate the map density, using a scale bar (1-10) located on the right side of the screen. The default density of the map was set to 5 (the middle of the scale bar). The presented maps showed rural, urban and suburban areas, with one third of the maps from each type of area. The order of the maps was individually randomized for each participant. We expected that the scale at which a map is presented might affect the user's assessment of the map density, so each map was shown at three different scales (referred to as initial scale): the largest scale was 1.92 m/pixel [1:6,500] the medium scale was 3.84 m/pixel [1:13,000] and the smallest scale was 5.76 m/pixel [1:19,500].

Based on the information generated by Martex, a set of measures was computed for each map at each scale. The set consists of quantitative measures, which are related to the amount of particular objects (e.g. the number of roads, the number of junctions, length of the roads etc.) and to the spatial distribution of the depicted objects (e.g., the distances between junctions, junction size etc.). Martex also provided information on additional characteristics of the objects and the map (e.g., map scale, road types, maximum speed limit, size of the jpeg file encoding the map).

Results

Martex provides data on 116 variables, but most had little variability in our experiment. From the remaining 20 variables, 12 are the lengths of particular types of roads (road, highway, drive, circle, etc.). Since the definition of these variables did not exactly reflect properties of the road, we chose to exclude them also from the model. We also removed three variables that reflected properties of the depicted area that were not directly displayed in the map (jpeg size, scale and mean speed). The remaining variables were number of junctions, average distance between junctions, average junction size, length of roads, and number of roads.

We conducted a stepwise linear regression with α=0.05 for entry and α=0.10 for removal on these 5 variables. The dependent variables were the mean ratings of the apparent density of the maps. The regression resulted in an adjusted $R^2 = 0.856$, with four significant predictors (total number of junctions was removed).

Since the predicted variable in this study is the perceived density of the map and its relation to the physical properties of the stimuli (i.e. the number and lengths of objects in the map), it is reasonable to expect that some of the variables may not have linear relations to the perceived density, but rather, that psychophysical, non-linear laws may apply. When inspecting the predictor variables in our study, we found that two of the independent variables (i.e. number of roads, number of junctions) had non-linear relations to the predicted variable (see figure 1A).

Applying the logarithmic transform to them (based on the Weber-Fechner law) resulted in linear relationships (see Figure 1B). We performed an additional stepwise linear regression with α=0.05 for entry and α=0.10 for removal on the five independent variables (with the log transformations). The results improved on those of the previous model. After entering three variables (ln(Number of Roads), Total Length of Roads, and ln(Number of Junctions), the model had an $R^2 = 0.925$. Adding the variable Average Distance between Junctions was still significant (p=.03), but the proportion of predicted variance increased only very little to $R^2 = 0.927$. Thus, the logarithmic transformation provided better predictions with fewer predictors, and actually, predicting only from the two log transformed variables led to $R^2 = 0.903$.

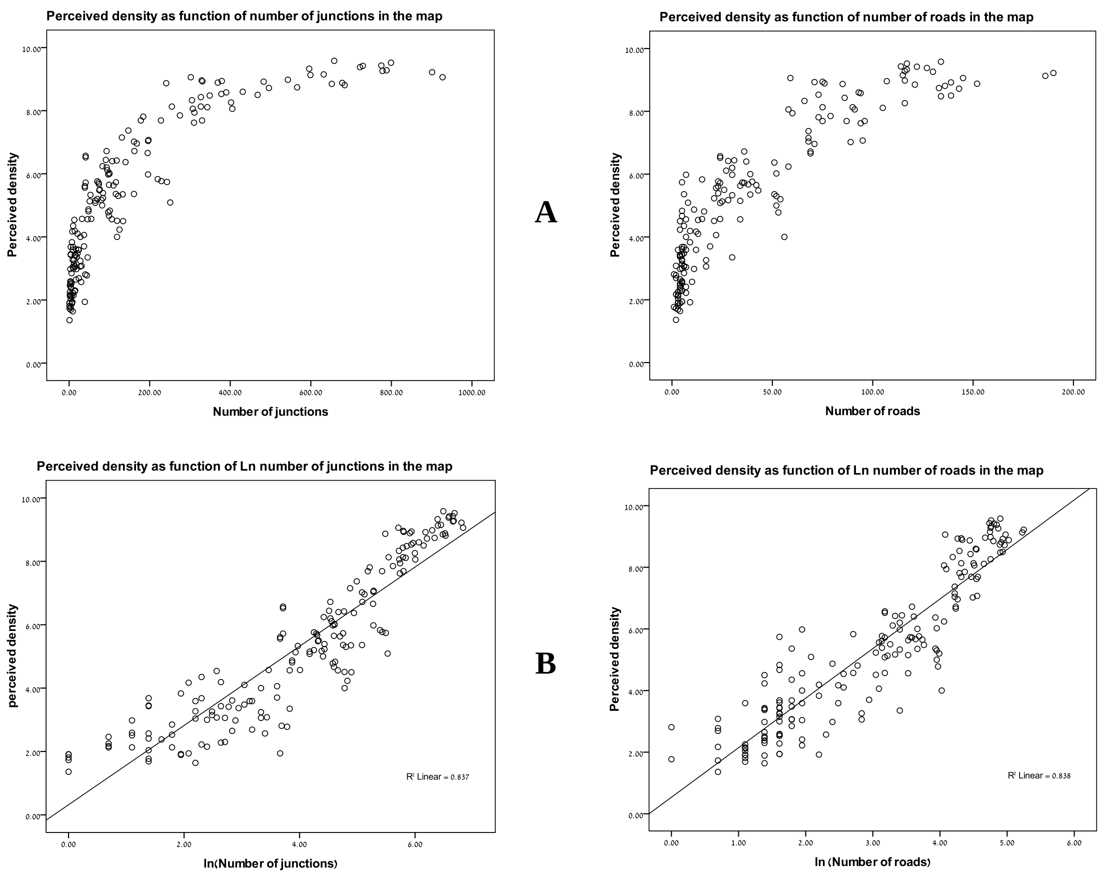

Figure 1 [A] number of junctions (in the left) and number of roads (in the right). [B] The logarithm of the variables from A.

Conclusion and summary

We show here that using psychophysical functions on map properties to predict the perceived density of maps improved the model predictions, while using fewer predictors.

This model can be part of predictive model of judgments. It can be used as one in a set of algorithms in computer systems, such as GIS to adjust the map display to the desirable level of perceived density so that the displayed information will suite the usage situation.

At a more general level, our study is another demonstration of the great applied value the use of psychophysical functions may have. Incorporating these functions into user models of computerized systems may allow us to adjust system properties to the users' subjective perceptions and impressions.

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