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Leveraging machine learning and spectroscopic techniques towards estimating paper map scale levels

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Abstract:

Map visual complexity has been a significant area of focus in cartographic research. Current methodologies provide a variety of techniques and metrics that can be used to objectively assess both the effectiveness and the efficiency of maps (e.g., Schnur et al., 2018; Liao et al., 2019; Tzelepis et al., 2020). Notably, the scale of a map seems to have a substantial impact as it correlates with the precision and volume of information conveyed by a cartographic product (Dumont et al., 2020). However, the scale information may not always be available. For instance, in historical paper maps, the scale information might be corrupted or inadequately represented.

In this study, we introduce a new methodology to estimate the scale level differences of a paper maps' dataset, relying solely on their visual heterogeneity as captured by spectroscopic techniques. Machine learning models are employed to accurately determine the map scale level. This method builds upon the preliminary results presented by Merlemis et al. (2022), where diffuse-reflectance spectroscopy was utilized to record spectra from random segments of paper maps. The technique proved efficient in characterizing the visual heterogeneity and the scale of the maps across a set of paper maps with varying scale levels.

We used a similar dataset comprising twenty regions in Greece, generated using the standard layer of OpenStreetMap (OSM), as it is provided by the terrestris GmbH & Co. KG harnessing the corresponding Web Map Service (WMS). It is worth noting that OSM cartographic backgrounds exhibit a high level of information density and diversity (i.e. content) across different zoom levels compared to other online map services such as Google Maps, Here WeGo, etc. (Skopeliti and Stamou, 2019). Since OSM is a Volunteered Geographic Information (VGI) project, the involved Geographical Shared Data Sources (GSDSs) are the result of a social process also conveying information about the contributions themselves (Mayer et al. 2020). In this sense, OSM potentially provides the necessary level of detail because the information required is supplied at will by the contributors (volunteers) (Mocnik, 2021). As a consequence, the level of information (i.e., the number of elements) appears to grow over time (Mocnik et al. 2017; Mocnik, 2021).

For each one of the twenty regions, we examined five different map scale levels (1:k, 1:2k, 1:4k, 1:10k, 1:40k), resulting in a dataset of 100 different maps. The produced maps were printed using the same paper quality, ink, and printer. We adopted the same experimental setup as demonstrated in Merlemis et al. (2022), using a low-cost optical spectrometer to record the spectra of 40 random segments of the maps, yielding a total of 4000 spectra. The diameter of the randomly selected segments was approximately 3 mm, and 1091 spectral channels were recorded for each sample in the visible region of the spectrum (380 nm - 749 nm).

The recorded spectral channels serve as predictors in various machine learning models to evaluate the effectiveness of estimating the scale level by just one measurement (one spectrum) of a random map segment. Initially, 3600 samples were used for model training, and 10% of the samples were reserved for testing (400 samples). The results show that the test accuracy can reach up to 78.5% using a Trilayered Neural Network. To expedite the training and prediction process, the raw spectra were smoothed by averaging every 3 nm of the 1091 spectral channels, thus reducing the number of

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channels used as predictors to 78. Smoothing facilitates rapid model training and achieves a test accuracy of 79.8% when using a Wide Neural Network. Other machine learning models also yield similar accuracies, as depicted in Table 1.

Machine Learning Model	Accuracy % (Validation)	Training Time (s)	Accuracy % (Test)	Prediction speed (obs/s)
Wide Neural Network	79.1%	194	79.8%	39000
Medium Neural Network	79.1%	99	79.5%	47000
Trilayered Neural Network	78.9%	148	78.8%	35000
Narrow Neural Network	78.4%	92	77.2%	50000
Bilayered Neural Network	77.0%	141	79.0%	46000

Table 1. Accuracy (validation and test) of machine learning models used in this work

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