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Neural Network Models for Adaptive Multi-scale Relief Shading

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Abstract:

Relief depiction by shading is one of the most effective methods of vividly reproducing the terrain on (topographic) maps. In cartography, the types of representation have therefore been progressively refined over the course of time and finally led to the Swiss style shaded relief, which was further developed in national maps as a grey background image and in school atlases such as the Swiss World Atlas as a colored representation. However, these representations are very difficult and time-consuming to produce manually. The list of approaches to automatic analytical shading is therefore very long, but none could come close to the best manual products. It was only with machine learning methods that it became possible to analyze the cartographic knowledge of existing relief shading and use it to generate new relief shading for any area. This is where the presented doctoral project of Marianna Farmakis-Serebryakova (Farmakis-Serebryakova 2025) comes in, using machine learning methods (neural networks) consistently and comprehensively to deal with the various aspects of creating such relief maps.

Cartographic multi-scale relief shading is essential for accurate and intuitive terrain representation on maps. Relief shading, traditionally performed manually, enables users to interpret topography through three-dimensional effects. However, digital elevation models (DEMs) have made analytical relief shading more prevalent, offering speed and reproducibility. Despite these advantages, digital methods often struggle to represent diverse landscapes effectively. This research project addresses these limitations by evaluating various digital shading techniques, incorporating machine learning for terrain segmentation, and developing guidelines for scale- and resolution-adapted relief shading. Three core research questions guide the study: 1) Which (greyscale) relief shading techniques are best suited for specific landforms? 2) Can terrain segmentation improve relief shading through automation? 3) Can shaded reliefs be generated at arbitrary scales and resolutions based on limited manual data? The methodology includes literature reviews, user studies, and the integration of neural networks, specifically U-Net architectures, for terrain segmentation. An interactive tool allows users to compare manual and automated shading outputs. The findings contribute to both cartographic science and societal applications, enhancing map readability and communication of spatial information across disciplines.

Manual shading, exemplified by the Swiss style, relies on artistic principles such as adjusting light direction, applying aerial perspective, and accentuating terrain features. These methods produce highly intuitive and visually appealing results but are time intensive. Digital relief shading automates this process using DEMs. Techniques like Lambertian models, multidirectional oblique-weighted (MDOW) shading, and aerial perspective adjustments enhance terrain visualization. However, digital methods often lack the nuanced generalization of manual shading, especially at small scales with diverse landforms. Terrain segmentation, crucial for relief shading, involves dividing landscapes into meaningful morphological units. Advances in machine learning, particularly convolutional neural networks (CNNs) like U-Net, have enabled automated segmentation and shading. Early neural approaches, such as style transfer and encoder-decoder networks, inspired more refined applications like *eduard.earth* software, which replicates Swiss-style shaded reliefs. These developments underscore the potential of combining manual techniques with modern computational tools.

First, classical (non-machine-learning) analytical relief shading methods applied to various (mainly Swiss) landforms are analyzed through an online survey. Participants assessed six shading techniques across nine landforms, including mountains, valleys, and plateaus, using visual and aesthetic criteria. It was found that the clear sky model performs best for most mountainous and valley landforms, offering clarity and depth. Cluster shading is effective for hilly regions. Texture shading and MDOW methods often overemphasize detail, reducing readability. Glaciers are best depicted using

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aspect shading, while custom lighting enhances alluvial fans. These results highlight the need for tailored shading techniques to enhance the readability and visual quality of specific landforms. The findings can be used for the development of machine learning models for adaptive shading.

Then, a U-Net-based approach for terrain segmentation to improve relief shading is introduced. The study area focuses on Switzerland, using swisstopo manual shadings and SwissALTI3D DEMs. The U-Net model was trained to recognize and segment 9 landforms (see above paragraph), enabling the application of optimized shading techniques for each terrain type. Key innovations include blending shading methods seamlessly and adapting the model for diverse (even global) terrains. The results demonstrate high accuracy in segmenting landforms and applying appropriate shading, particularly for complex landscapes like the Swiss Alps, but also for mountainous landscapes elsewhere. The chapter underscores the scalability and flexibility of the U-Net model, which adapts to varying resolutions and landforms. This approach bridges the gap between manual artistry and automated processes, advancing the field of cartographic relief shading.

Finally, the relationship between DEM resolution and shading scale using U-Net models is explored. Four scales (1:25,000 to 1:200,000) and corresponding DEM resolutions according to Tobler's rule (Raster resolution (m) = map scale denominator/1000/2) were analyzed to establish optimal scale-resolution ratios for relief shading. It can be stated that DEM resolution significantly influences shading appearance, with higher resolutions capturing finer details. Scale-to-resolution ratios ensure consistency across different map scales, improving readability and visual coherence. Furthermore, an interactive web tool was developed which allows users to compare manual and neural shadings, offering qualitative and quantitative insights into tonal distributions and generalization levels. These guidelines enable cartographers to produce high-quality relief shadings tailored to specific scales and applications. The integration of neural networks ensures efficiency and adaptability for modern mapping needs.

The project provides contributions to cartographic science, including the identification of optimal shading techniques for diverse landforms, the development of U-Net models for terrain segmentation and adaptive shading, and the setting up of guidelines for scale- and resolution-adapted relief generation. The research demonstrates the potential of neural networks to replicate and enhance manual shading principles, bridging traditional cartography and computational methods. Future work may include refining segmentation algorithms, expanding training datasets to additional landscape types, and exploring applications in dynamic and interactive mapping contexts.

References

Farmakis-Serebryakova, M. (2025). Adaptive Cartographic Multi-Scale Relief Shading. Doctoral thesis, ETH Zurich, 143 p.

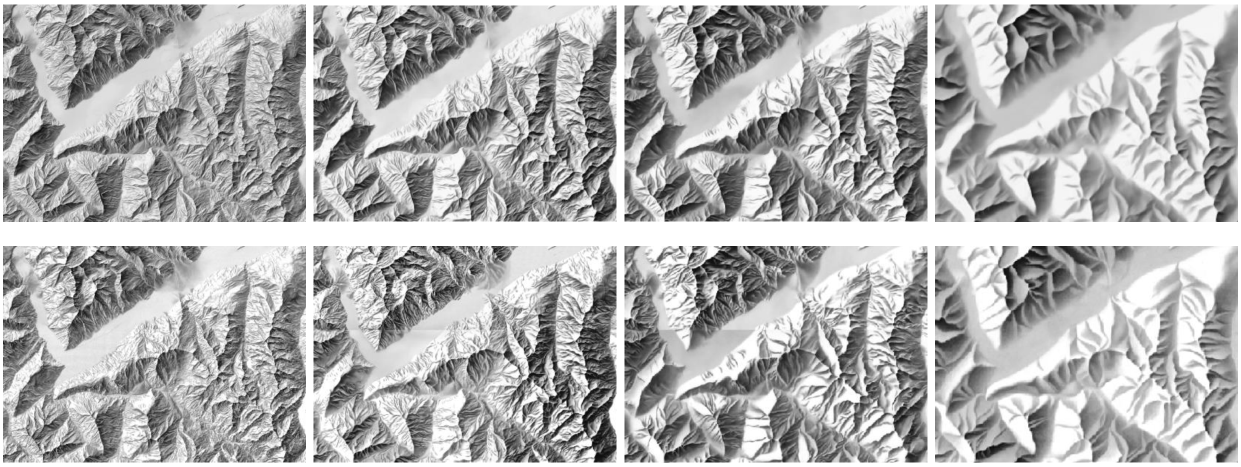

Figure 1: Comparison of the best neural predictions 1:25,000, 1:50,000, 1:100,000, 1:200,000 (upper row) and manually shaded reliefs (lower row)

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