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Extraction of Valley Networks in Mars Elevation Maps

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1. Introduction

The identification of valley networks and channels is an essential tool for geomorphological interpretations of the fluvial, glacial and volcanic history of Mars. While the creation of valley networks by erosion is an accepted hypothesis, the flow of water as the sole cause has recently been put into question [1]. To investigate the origin of the networks, their detailed properties have to be mapped at a global scale. In previous attempts of computer-generated global mapping, manual verification of the results was necessary [2]. Herein, we present a novel algorithm to automatically extract valley networks in terms of extremal lines and compare the extraction results with manually mapped ones that were published in [3,4].

Extremal lines are a subset of the topological skeleton of the elevation map. The skeleton encodes the essential information and can be iteratively simplified to obtain different levels of detail in the elevation map. The hierarchization process is thereby fully automatic and does not involve any algorithmic parameters. Using the measure *separatrix persistence*, we are able to assess the topological importance of each element of the skeleton. This enables a reduction to the most dominant extremal lines. This topological analysis allows for an unbiased extraction of all extremal lines in an elevation map. The data analyst is provided with a slider to choose an appropriate level of detail for further analysis.

2. Background

The topological skeleton of a given $2D$ height field consists of the critical points (minima, saddles, maxima) and the separatrices, which are integral lines in the gradient field connecting the critical points. The skeleton divides the height field in distinct regions and in each region the height field behaves monotonically. The boundary of a region consists always of the quadruple minimum, saddle, maximum, saddle and their connecting separatrices. A monotony break only occurs at separatrices. Extremal lines are therefore covered by them. Since valley networks appear as extremal lines, it is reasonable to compute the separatrices of the field.

Extremal lines differ in their importance. Some lines are dominant whereas others are only spurious. Hence, we are interested in a weighting of the corresponding separatrices. The weighting should be thereby robust against small perturbations of the field in order to guarantee a robust extraction. This is achieved using the importance measure 'separatrix persistence' [5]. Separatrix persistence measures the strength of the monotony breaks at each separatrix with respect to a nested sequence of topological skeletons. Such a sequence can be obtained using the concept of persistence [6]. The measurement is thereby of global nature and defines a hierarchy of extremal lines. This allows for a reduction of separatrices to their most dominant extremal parts.

3. Method

Elevation maps of the Martian surface have a preponderance of craters scattered on them. This complicates a direct application of the topological analysis in [5]. In terms of persistence the craters correspond in general to dominant minima. The incident separatrices therefore also dominate. However, we can use the topological analysis to circumvent this problem by masking out the craters.

Given an elevation map, we first compute the hierarchy of topological skeletons as illustrated in [5]. In this first step, we are only interested in the minima. Among other features, the minima represent craters. The data analyst chooses a level of detail in the sequence of skeletons such that all craters contain at least one minimum. The set of minima are used as seed points for a simple flooding algorithm. For each seed point, the flooding is done until the corresponding crater is covered. Given this binary mask, we can now start to extract all extremal lines. As described in [5], we compute the hierarchy of skeletons for the masked elevation map. In this step, we are interested in the minimal lines and their importance.

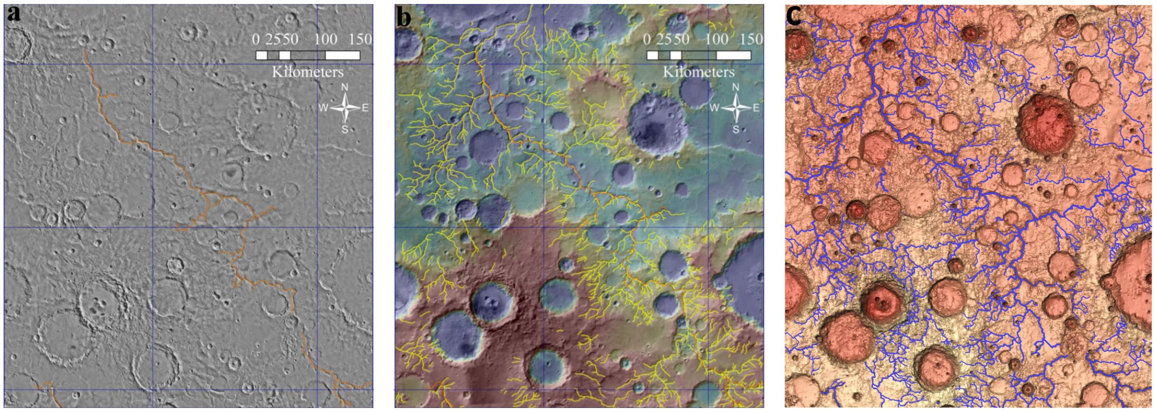

Figure 1: Comparison of valley networks: a) and b) show the valley networks manually mapped by Carr [3] and Hynek et al. [4] as orange and yellow lines. c) shows our automatic extraction result as blue lines (scaled by separatrix persistence).

4. Results

We applied our new method to Mars Orbiter Laser Alimeter (MOLA) data with a resolution of 128 pixels per degree. Specifically, we concentrated on the region that was already investigated by Carr [3] and Hynek et al. [4]. This allows for a comparison of their manual mapping with our automatically computed hierarchy. As can be seen in Figure 1, the extremal lines extracted by our method cover most of the lines manually mapped by Hynek et al. This indicates that separatrix persistence assigns highly important-values to erosional structures. However, there are also additional lines that were not mapped by them. Figure 2 depicts four levels of the hierarchical representation of the masked elevation map. While in the initial level all extremal lines were present, only the most dominant lines remain in the last levels. The central channel is clearly the most dominant structure.

5. Future Work

The presented algorithm is able to automatically extract all extremal lines. Although no model knowledge was incorporated in the *separatrix persistence* measure, the experiment shows clearly that it is able to extract valley networks. We will investigate the measure in more detail to determine the degree of over-interpretation. How many lines are actual valleys (false positives)? How many valleys are missing (false negatives)? Model knowledge has to be applied in a post-processing step to achieve robust mapping results. As a next step, we want to test the algorithm on higher resolution Martian topography (e. g. HRSC, HiRise) to see the difference in terms of the results, and apply it to terrestrial elevation data where the valley networks are already mapped.

References

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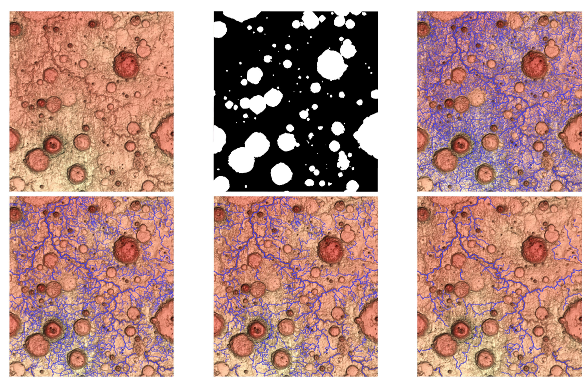

Figure 2: Different levels of detail of extremal lines: For a given elevation map, a binary mask was computed to mask the craters. Four levels of the hierarchy are depicted – the initial skeleton (where all extremal lines are present) and three less detailed skeletons are shown. The width of the extremal lines is scaled by separatrix persistence.