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Rivers' classification: integrating Deep Learning and statistical techniques for terrestrial and extraterrestrial drainage networks analysis

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Various approaches have been proposed to describe the geomorphology of drainage networks and the intricate relationships between abiotic/biotic factors and their surrounding environment. There is an intrinsic complexity of the explicit qualification of the morphological variations in response to various types of control factors and the difficulty of expressing the cause-effect links. Traditional methods of drainage network classification are based on the manual extraction of key characteristics, subsequently applied to pattern recognition frameworks. These attitudes, however, have low predictive and uniform ability. For this reason, we present a different approach, based on the data-driven supervised learning by images, extended also to extraterrestrial cases. Using deep learning models, the extraction and classification phases are integrated within a more objective, analytical, and automatic toolkit (Donadio et al., 2021).

Pre - processing of satellite and topographical images through image segmentation methods

Extraterrestrial and terrestrial drainage pattern analysis is a topic of central interest since it allows scientists to understand the hydrogeological and geomorphological past of planets and satellites. Earth, Mars, Venus, and Titan's patterns have been taken into consideration in this work. The extraction process, necessary to obtain an outline of the river, can be done through image segmentation, considering different mathematical methods whose efficiency varies according to the conditions and properties of the images. The segmentation methods used can reliably identify objects' contours if in the foreground, separating them from the background. In the context of image processing, this is addressed as Edge Detection.

Two types of images were addressed, respectively, topographic and satellite. In both, an extensive pre-processing phase has been carried out, to reduce background noise with computationally efficient and optimized algorithms. This makes the profiles of the drainage networks stand out from the rest of the image, minimizing the loss of important information and the need for human intervention.

This aims to make the preparatory phase of the images (pre-processing) as self-consistent as possible, to be effectively applied to large volumes of images, allowing the generation of a valid training set for the classification of drainage patterns using self-adaptive methods, based on machine and deep learning paradigms.

In the final work, a good trade-off has been achieved between efficiency and effectiveness of the edge-detection methods. As will be discussed later, the need for an expert's intervention is extremely limited, in most cases not needed at all.

River Zoo survey and classification based on Deep Learning models

This work introduces an innovative approach to river hydrographic basins classification within the River Zoo Survey project. The main goal is to perform a statistical evaluation of the classification of terrestrial and extraterrestrial drainage networks by human experts to be subsequently used as base of knowledge to train supervised Artificial Intelligence (AI) methods.

The idea is to analyze the degree of reliability of class assignment to drainage samples, driven domain expert decisions, based on visual inspection of images and the identification of the right pattern type. Through the analysis of Earth, Mars and Titan's rivers, experts were asked to classify rivers into one of ten distinct patterns, further categorized into two macro-classes: dendritic and non-dendritic.

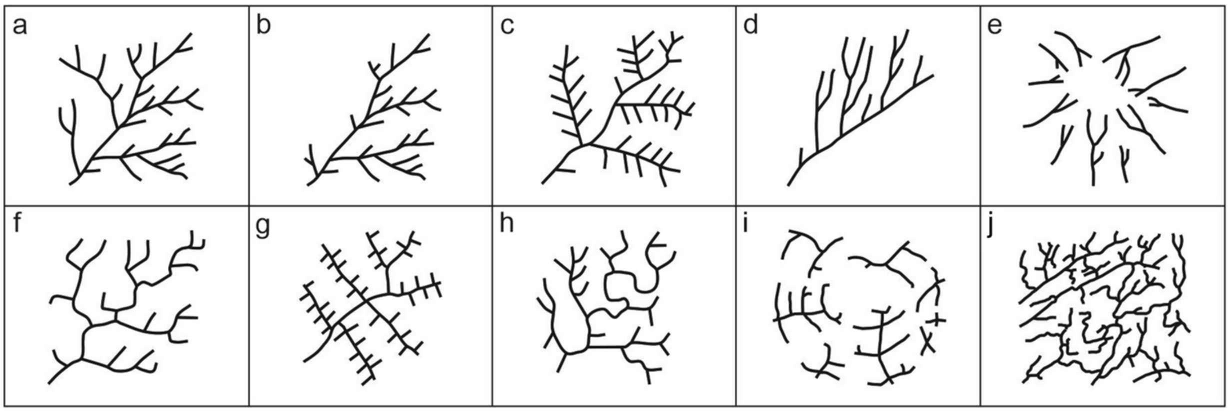

Figure 1 – Different classes of drainage patterns: a) dendritic; b) sub-dendritic; c) pinnate; d) parallel; e) radial; f) rectangular; g) trellis; h) angular; i) annular; j) contorted. (**a**)–(**c**) patterns are related to dendritic forms (D), (**d**)–(**j**) to non-dendritic ones (ND).

The purpose of this study is to establish an objective classification system for rivers, improving the understanding of terrestrial and extra-terrestrial rivers drainage networks. Using statistical techniques, the study explores methods to reduce noise in human based classification, thus providing a robust classification system for the automatic processing of river data with a detail much better (10 classes) than the current two class classification systems (dendritic and non-dendritic).

This work focuses on the methodology and objectives of the research, highlighting its interdisciplinary nature and potential contributions to a better comprehension of river morphologies across different planetary bodies.

Classification of drainage patterns using properties of fractals

Machine Learning (ML) models often require a differentiated and big enough training sequence so that they can output a good prediction rule, a **predictor**, to then use in labeling unseen elements belonging to the testing set. While experts can give their opinions on a given river in relation to the ten classes here considered, it is more of a *subjective truth* than a *ground truth*. To minimize the model's **bias**, the training sequence should contain data as accurately labeled as possible, thus having a great probability of minimizing the true error.

Introducing **fractal geometry**, involving self-similar objects with a fixed degree of complexity, often referred to as Hausdorff Dimension (HD). By computing the HD for a given set of rivers, they can be grouped into classes by defining step thresholds determining the belonging to any of the ten categories. The classification can be further refined by considering the Horton-Strahler number, which is a way of establishing a hierarchy between tributaries in a drainage network. This makes it possible to keep track of the branching of rivers, along with their intrinsic fractal complexity.

To compute the HDs, different methods will be used, leveraging the flexibility and the capabilities of the Python programming language. The best algorithm to compute the HD on rivers, Box Counting (BC), will be analyzed, and compared to the experts' classification, to further comprehend the thought process of a human mind when presented with a classification task involving complex and branched structures.

Results show that fractal analysis is reliable in the context of geomorphology and river patterns, allowing for the creation of a ground truth for the RiverZoo images, and laying the basis for the development of advanced ML algorithms used for classification purposes.