Drainage tree construction based on patterns in a river network

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Abstract. In this paper, the river network is divided into sub-networks forming a hierarchy of drainage systems following the Horton order. Then, drainage systems are rearranged based on their pattern to obtain more homogeneous drainage systems which do not necessarily follow the Horton order. Such reorganization facilitates the description of the network system. Such organization can be useful for terrain analysis as it can help provide a qualitative description of the terrain or for generalization as river selection can be adapted to the type of network.

Keywords: River network, Drainage tree, Drainage pattern

1. Introduction

A drainage basin is seen as an indivisible part of the land in terrain analysis. The network of valley lines provides a supporting structure for the drainage system while ridges define the drainage divides. The drainage system is the structure formed by streams, rivers and lakes in a drainage basin. In GIS, river networks forming a drainage system are stored as sets of rivers described by their geographical coordinates and their topological relationships. In a drainage basin, the pattern of river network is classified on the basis of their form and texture according to slope and structure. The shape or pattern develops in response to the local topography and subsurface geology. In structural geology, drainage patterns not only offer clues to geological structure, but also help to decode regional geological chronology (Hills, 1972). Moreover, drainage patterns are useful to search minerals (e.g. Binks & Hooper, 1984; De Wit, 1999).

At present, much research has been done on the description of drainage patterns in geography and hydrology (e.g. Howard, 1967; Lambert, 2007; Pidwirny, 2006; Twidale, 2004). Although semantic information can be added at the river level, no semantic information such as patterns is computed and stored at the network level. Automatic pattern identification was addressed by Zhang and Guilbert (2013) who classified river networks into five types of drainage (Figure 1). The method can be applied to classify each individual sub-network at different orders but the result obtained on larger networks does not reflect the variation of patterns a river can go through. Such organization can be useful for terrain analysis as it can help provide a qualitative description of the terrain or for generalization as river selection can be adapted to the type of network.

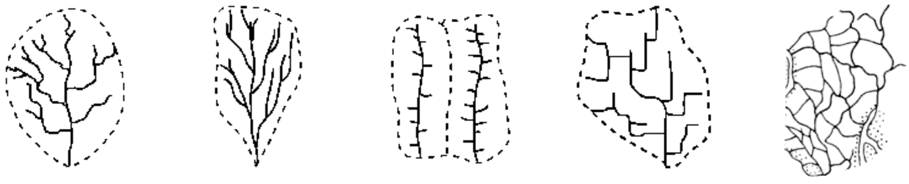


Figure 1 Drainage pattern examples (diagrams modified from Ritter, 2006).

In this paper, drainage patterns are identified for each drainage system at different levels of representation. The river network is divided into sub-networks forming a hierarchy, and rearranged based on their pattern to obtain more homogeneous drainage systems. Such reorganization facilitates the description of the network system. The method is applied to the description of several river networks and the relationship between the level of representation and the type of drainage pattern is discussed in relation to the scale and the topographical characteristics of the networks.

2. Related works on river network organization

2.1. Ordering scheme for river tributaries

Ordering schemes are built by assigning an order number to each tributary. Ordering starts by assigning order 1 to branchless tributaries. The order of a stream is always higher than the order of its tributaries so that the highest order is assigned to the segment connected to the outlet. In this procedure, the Horton-Strahler scheme based on (Horton, 1945) and modified by Strahler (1957), and the Shreve scheme (Shreve, 1966) have been considered the most relevant schemes for the multi-scale representation of river networks (Rusak Mazur & Castner, 1990). In the Horton-Strahler scheme, each branchless segment is assigned an order 1. A segment is assigned an order equal to the highest order of its tributaries or to the highest order plus one if there are several tributaries of this order. An example is illustrated in Figure 2(a) This order can be computed recursively (Gleyzer, Denisyuk, Rimmer, & Salingar, 2004).

2.2. Coding system for drainage basins

In order to support GIS-based hydrological analyses, much research on coding drainage networks has been done. The coding applies not only to a river network but also to its associated drainage basin. The Pfafstetter coding system, proposed by Otto Pfafstetter (1989), is a subdivision and codification method for describing river basins based on the natural topology of the land surface (Verdin & Verdin, 1999). The system is built into a hierarchal structure from a whole basin to its sub-basins step by step recursively. A basin can be divided into a maximum of 10 sub-basins, which are assigned a number from 0 to 9 based on their location and area (Furnans & Olivera, 2001). Much research has been done to modify and apply Pfafstetter codification method (Fürst & Hörhan, 2009; Jia et al., 2006; Shrestha, Kazama, & Newham, 2008; Verdin & Verdin, 1999).

At present, much research has been done on ordering tributaries and coding basins. Although the drainage pattern is recognized as an important element in GIS, no river network has been organized based on drainage patterns. Therefore, this paper proposes a method establishing a drainage hierarchy according to drainage patterns.

3. Drainage tree construction

The drainage pattern of a given river network computed from the shape of its main stream and tributaries has been discussed by Zhang & Guilbert (2013). Drainage patterns form a hierarchical structure following the river network structure; however one river stream may not follow only one pattern but can go through different patterns along its course. Therefore, after recognition, adjacent drainages of the same type are merged in the drainage tree to identify the different portions of the river. The whole process includes 4 steps in sequence:

(1) Identify reticulate patterns in the river network;

(2) Identify all sub-networks forming the drainage tree;

(3) Characterize drainage patterns in the sub-tree;

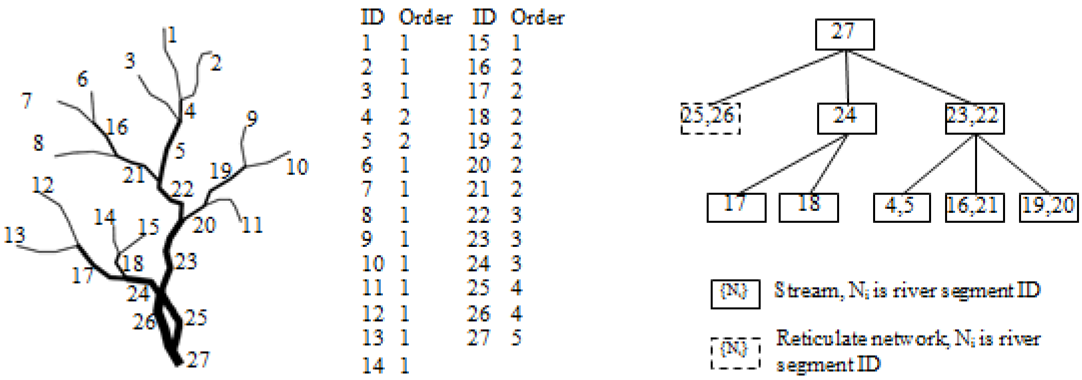
(4) Merge adjacent patterns of the same type.

Steps 1 and 3 are addressed in Zhang & Eric (2013)'s paper. Following Section 3.1 describes the process building the drainage tree (step 2). Section 3.2 presents the merging process (step 4).

3.1. Drainage tree construction based on patterns

Construction of the drainage tree is done in two steps. First, all reticulate networks are identified as cycles. They are removed from the river and replaced by a virtual note to maintain the connectivity of network. Second, the main stream of each sub-network is identified. Levels of representation are defined by the segment order following the Horton-Strahler scheme.

The drainage tree is built by starting from the outlet and, for each node of the tree, by adding the river streams or reticulate networks below. An example of drainage tree obtained from the river network of Figure 2(a) is shown in Figure 2(b). Each sub-network is identified by the segments forming the main stream or by the list of segments forming a cycle. The stream defined by segment 27 contains the outlet and represents the whole network noted (27). Segments 25 and 26 form a reticulate network (25, 26) and, with sub-networks (23, 22) and (24), are located under the root. That means that they form three sub-networks at the level below the main river network. A drainage pattern can be defined for each sub-network.



ID	Order	ID	Order
1	1	15	1
2	1	16	2
3	1	17	2
4	2	18	2
5	2	19	2
6	1	20	2
7	1	21	2
8	1	22	3
9	1	23	3
10	1	24	3
11	1	25	4
12	1	26	4
13	1	27	5
14	1		

a. Initial river data. The marking beside the river is river segment ID. The table is river segment ID and its Horton-Strahler order.

b. Result of sub-networks hierarchy.

Figure 2. The drainage tree.

3.2. Merging drainages along a river stream

The process yields a drainage tree where all existing sub-networks are characterized. However, a river stream can go through different types of terrain where its tributaries follow different patterns. Therefore, a river stream can be split in sections forming different drainage patterns. The algorithm starts from the root of the drainage pattern tree and moves down to the leaves. For each river stream, if two adjacent sub-networks are of the same pattern, they can be merged into a larger drainage, meaning that this portion of the river goes through an homogeneous topography. Two drainages are adjacent if they connect to the same segment and lie on the same side of it, or connect to the same node.

Taking the river network in Figure 2 as an example, sub-networks (24), (17) and (18) are supposed dendritic, sub-networks (4,5) and (16,21) are parallel, and sub-network (19,20) is a trellis (Figure 3a). Networks (17) and (18) have the same pattern as their parent (24) therefore they hold redundant information and can be removed. Networks (4, 5) and (16, 21) share the same pattern and are both connected to segment 22 while trellis (19, 20) is connected to segment 23. Therefore, the stream (22, 23) goes through two drainage systems: first a trellis and second a parallel drainage. Therefore, network (22, 23) can be split into one parallel network (22) and one trellis (23). The resulting drainage tree is shown in Figure 3b.

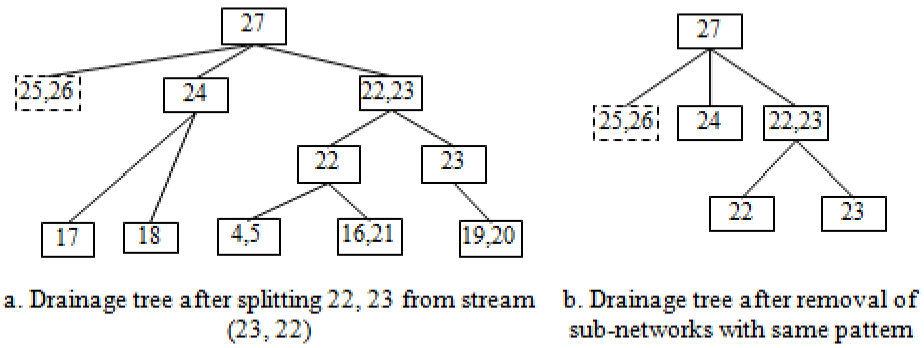


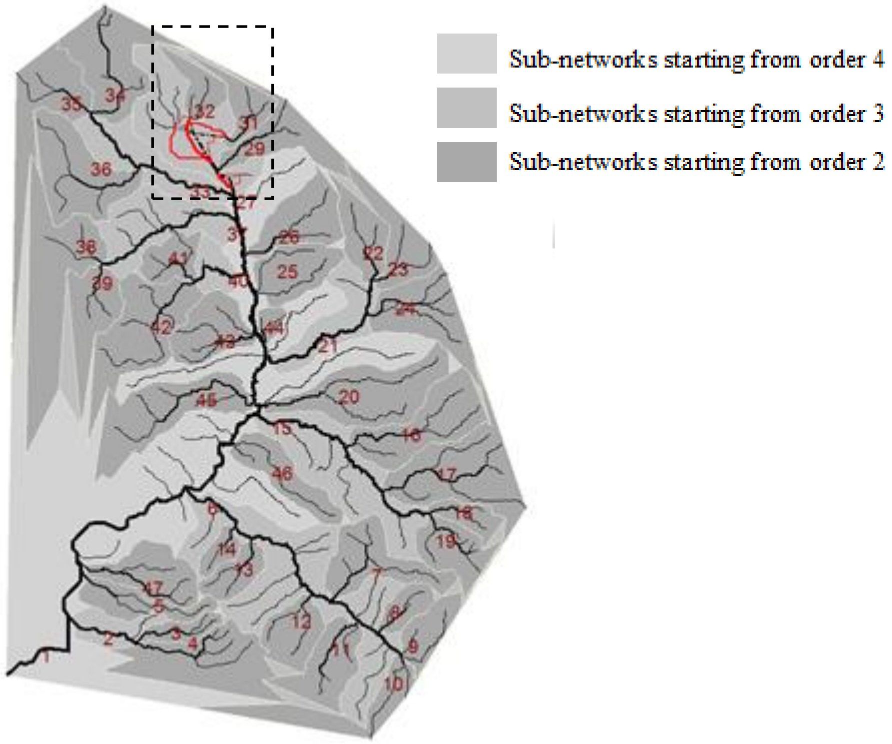
Figure 3. Merged hierarchy of sub-network from Figure 2.

4. Experiment and result

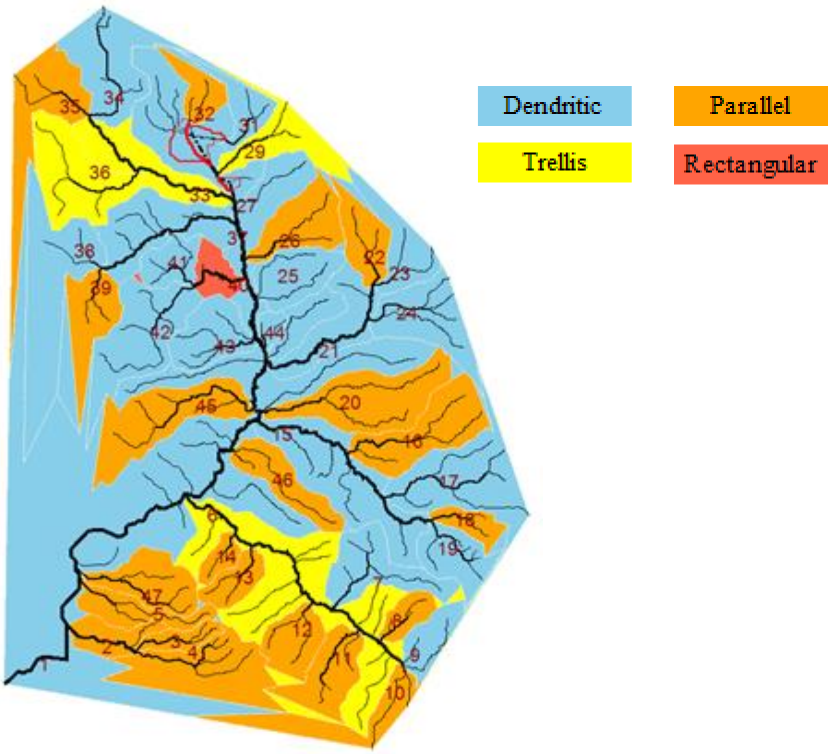
A sub-network is selected from the Russian river[1] (California, United States) at 1:24,000 scale for the case study. Here, a sub-network of the Russian river is selected to illustrate the results in the process of the drainage tree construction. The selected river network is illustrated in Figure 4(a). There are two reticulate parts in the river network, shown as red pieces. Inside the river network, each sub-network is located in a drainage basin which is extracted by the method of the hierarchical watershed partitioning (Ai, Liu, & Chen, 2006). Each sub-network is assigned a number.

Figure 4(b) shows the drainage pattern classifications divided by watershed and rendered with color. The selected river network is recognized as dendritic. Inside the network, 18 sub-networks are classified as dendritic and 21 sub-networks are parallel. Besides, there are 4 trellis networks and 1 rectangular network.

[1] http://www.rrwatershed.org/



a. Selected river network from the Russian river



b. Sub-catchments with drainage patterns

Figure 4. Experimental data.

In Figure 5, the root node is arranged at the top, and leaves are at the bottom. A node, which indicates a sub-network, is represented as a number that corresponds to the numbers of the sub-networks.

All sub-networks are identified and formed as a drainage tree for the selected experimental data, which is shown in Figure 5(a). The sub-networks classified as reticulate are located in the nodes with red dashed box. These features of the hierarchy are followed not only in this sub-network hierarchy but also in the drainage tree in the following sections. In the sub-network hierarchy of the selected river network, there are 46 sub-networks. The whole river network is noted as (1), and two reticulate networks are (28) and (30) respectively.

Figure 5(b) shows the resulting drainage tree for all classified sub-networks before merging. In the result, red dashed boxes also indicate reticulate networks. In addition, boxes filled with sky blue, orange, yellow and tomato colors represent dendritic, parallel, trellis and rectangular networks respectively. The selected river network is recognized as dendritic. Inside the network, 18 sub-networks are classified as dendritic and 21 sub-networks are parallel. Besides, there are 4 trellis networks and 1 rectangular network.

From Figure 4 (b), we can see that some networks are adjacent. For example, sub-networks (2), (5) and (47) should be merged due to their locations on the right side of the main stream. So, some nodes of the drainage tree should be split and merged. After this process, the drainage tree is illustrated in Figure 5(c). In the figure, nodes with an asterisk (*) are new networks split from the main stream, and the new node ID is based on the last used number. The sub-networks (2), (5) and (47) have been merged, because all of them are parallel and adjacent. In network (6), along its main stream from outlet to source, (10), (11), (12), (13) and (14) are all on the right, so the main stream should be split for their merging. Although (7) and (9) are also on the same side, they cannot be merged because of the interruption of network (8). Networks (20) and (45) are placed on opposite sides of the main stream, but they also are merged because they both connect to the same river segment.

The last process is to remove the redundant information in the drainage tree. Inside the network (49*), two sub-networks (23) and (24) are removed because both of them are identified as dendritic as their parent (49*). Networks (10), (11), (12), (13) and (14) are merged and noted as network (48*), under which all sub-networks can be removed. Similarly, the sub-networks under networks (50*) and (51*) also should be removed. Although network (52*) and its direct sub-networks are identified as dendritic, it cannot be simplified. Because there is a sub-network, (22), under (21) which is parallel. The final result of the drainage tree is provided in Figure 5(d).

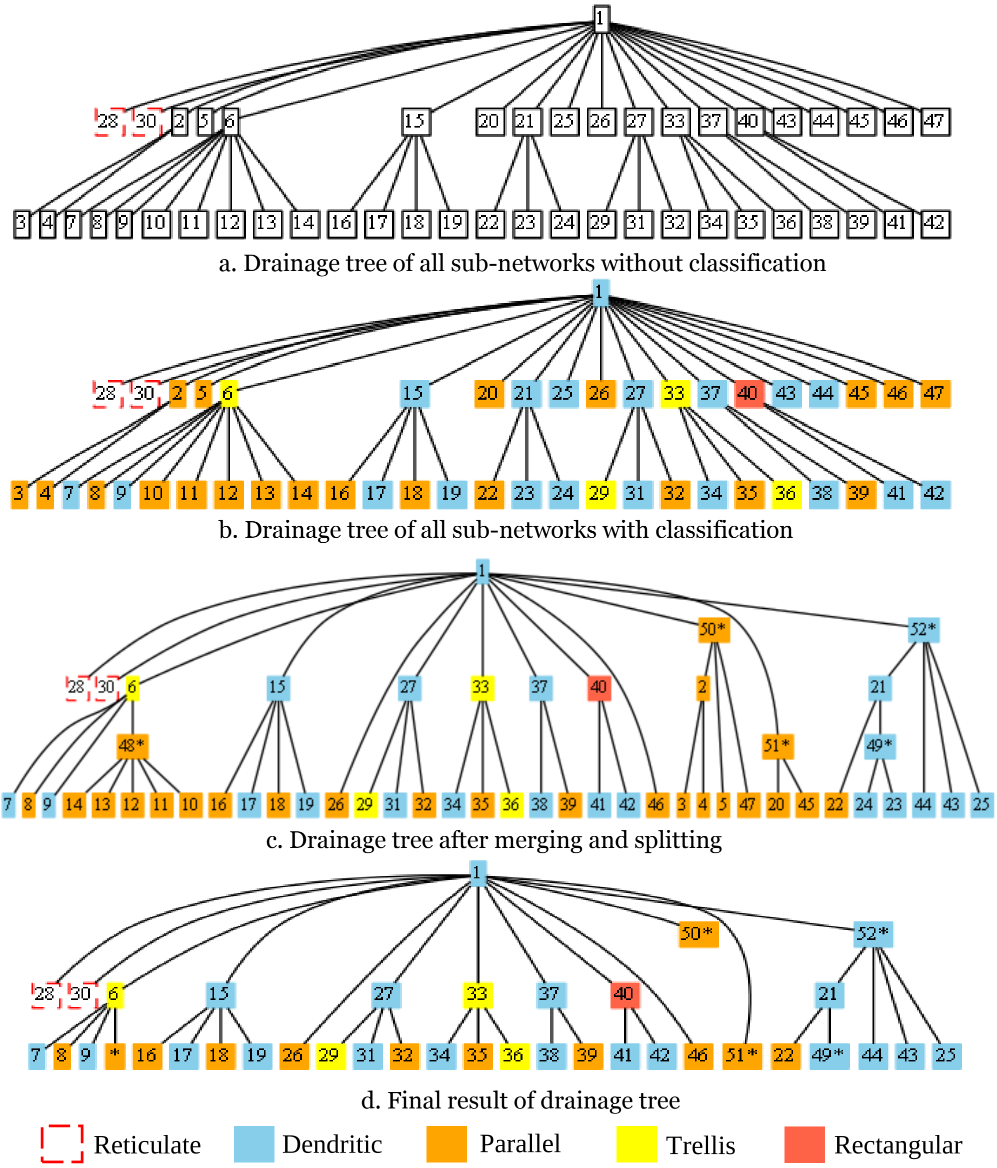


Figure 5. Drainage tree construction stages.

The selected river network is a typical dendritic drainage, where most of the tributaries flow into a larger one with an angle less than 90 degrees and the catchment is broad. The river network is in the upper course of the Russian river, which is a headwater region that collects and funnels water to the main stream. It coresponds to that the dendritic river network has many contributing streams that are used for collecting water. Parallel networks are formed where there is a pronounced slope, and they can be found in the upper course. As the upper course is steep, V-shaped valleys are formed by the prevailing downward erosion, and it is one of the landform with pronounced slopes.

However, there are still some other patterns such as reticulate, trellis and rectangular patterns. In general, in the upper course, these patterns do not appear except for human intervention. The area in Figure 6 is located in the dashed box of Figure 4(a), the Potter Valley, a place in Mendocino County, California. Man-made irrigation canals or ditches destroy the nature of the river network at the reticulate region to a certain extent.

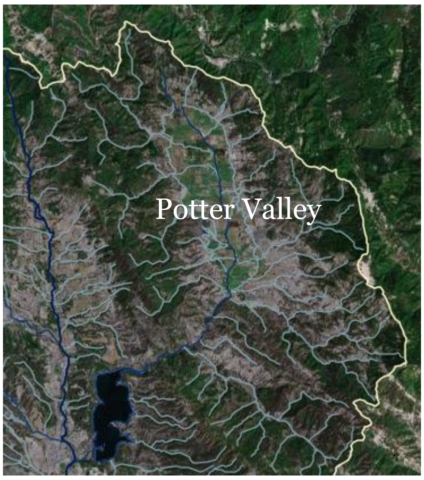


Figure 6. Image of the selected experimental area (from Google Map)

5. Summary

The drainage pattern is an important geographic factor for a river basin. Different patterns in a river network were identified separately and correspond to more or less complex networks with different Horton-Strahler orders, and were organized into a hierarchical structure representing levels of description of the drainage pattern. The method was finally applied on a case study, the Russian river network, and the resulting classification was discussed.

Due to the tree-like characteristic of a river network, the hierarchical structure for drainage patterns is built based on a recursive method which can be stated shortly and clearly and implemented as shown in experiments. Such classification and organization can be useful for terrain analysis as it can help provide a qualitative description of the terrain or for generalization as river selection can be adapted to the type of network.

For the future work, (1) The influence of scale shall also be studied. Results were discussed at 1:24000 scale river data only. However, the scale may affect the number of tributaries represented in the network. As the drainage system is often extracted from the terrain model, the accuracy of drainage pattern classification at different orders may be related to the resolution of the terrain model. (2) The drainage tree can be considered for applications in terrain analysis and cartography. In cartography, drainage patterns provide information about the network structure and can be used in river tributary selection for map generalization (Stanislawski, 2009; Touya, 2007). As the drainage pattern is related to the morphology of a terrain, it can be used to enrich the terrain model and characterize morphologic features.

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