Automatic Association of Strahler's Order and Attributes with the Drainage System

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***Abstract*— A typical drainage pattern is an arrangement of river segment in a drainage basin and has several contributing identifiable features such as leaf segments, intermediate segments and bifurcations. In studies related to morphological assessment of drainage pattern for estimating channel capacity, length, bifurcation ratio and contribution of segments to the main stream, association of order with the identified segment and creation of attribute repository plays a pivotal role. Strahler's (1952) proposed an ordering technique that categories the identified stream segments into different classes based on their significance and contribution to the drainage pattern. This work aims at implementation of procedures that efficiently associates order with the identified segments and creates a repository that stores the attributes and estimates of different segments automatically. Implementation of such techniques not only reduces both time and effort as compared to that of manual procedures, it also improves the confidence and reliability of the results.**

Keywords- Stream; digitization; Strahler's order.

I. Introduction

A drainage pattern pertaining to a terrain is a mesh of interconnected streams. This mesh may be of different types such as Dendritic, Trellied or Lattice, Radial or Concentric, Parallel, Rectangular, Deranged, Centripetal and Violent. The formation of mesh depends upon the morphological aspect of the terrain the drainage system is subjected to such as slope, varied resistance of rocks and its geological and geomorphological past[1]. In studies related to drainage system and its effects on the terrain demands classification of the system into identifiable classes or identifiable orders.

There are different systems for ordering drainage pattern designed by Horton (1945), Strahler (1952), Scheideggar (1965) and Shreve (1967) for associating order with stream segment in drainage segment.[1]

The order of a stream segment depends upon the order of its tributaries. The point where tributaries meet is called as a junction. In studies related to drainage system streams are also referred to as links.

Links are typically of two types namely internal and external. Links are classified based on whether they do or do not have tributaries. Link that stretches from source to a junction is referred to as external links whereas link that stretches from on junction to another is referred to as internal links. Each of these identified streams have their own order, length, channel capacity and bifurcation ratio.

In order to associate order with the stream segment in a drainage pattern either traditional tedious manual technique can be used or a process can be designed based on certain criteria or knowledge of any ordering techniques.

Traditional techniques for associating order with segment involve manual digitization, manual association of order and attributes etc. This demands greater effort, time and cost investment. Design of automated procedure for the same would greatly reduce investments; in addition it enhances quality and reliability of the results.

This proposed work automatically extracts segments from a drainage pattern, associates order and also estimates various attributes related to the same. This work relies on the concept of Strahler's ordering technique for performing qualitative and quantitative assessment of the drainage system. In order to minimize the time and space complexity of identification and storing attributes, two important procedures are used.

On analyzing the drainage pattern it was observed that the contributing tributaries always converges inwards to form a segment of higher order and these converging streams are always located towards the bound. So, in order to identify these streams traditional row column traversal technique proves ineffective and would consume more time.

To minimize the time required for determining segments an efficient and effective spiral navigation technique is used [2]. In order to store the indentified segments of variable length an efficient 2D data structure (jazzed array) is used to store the detail that optimally utilizes memory space. The proposed schema is shown in figure 1 below.

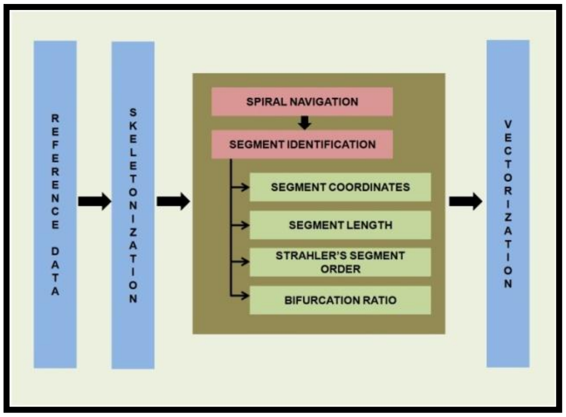

Figure 1. Schema for stream order & attribute association.

II. Stream Ordering

In Strahler's (1952) system [3]

- if a stream has no contributing tributaries, then order of the stream is 1
- else if the stream has more than on tributaries, and their orders are i and j then
  - if i==j then the order of the resulting stream will be i+1 or j+1
  - else if i<j then the order of the resulting stream will be j
  - else if i>j then the order of the resulting stream will be i

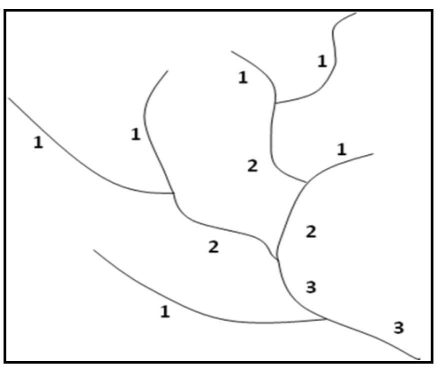

Figure 2. Strahler's Ordering Scheme

Two streams with same order *i* unite to give a stream of order *i+1* and if the streams of different order unite the new stream retains the order of the highest order stream.

III. Related Work

Stream ordering has wide range of application in hydrological studies for e.g. run-off modeling, fisheries etc. Association of stream ordering is tedious and time consuming task, thus method for determining stream order automatically for various drainage network topologies plays a crucial role in various studies related to drainage pattern.

Andy Ward et al [4] in their study related to stream classification has expressed that Stream order plays significant role in determining the expected ecological function of drainage system. Stream order is extensively used in River Continuum Concept RCC which is used for classifying, describing flowing water and classification of sections of waters based on presence of indicator organisms and Flood Pulse Concept (FPC), a concept that describes the interaction between water and land or hydrological conditions takes into basis the orientation of the stream in a drainage pattern for analysis.

Dawson et al [5] have developed an automated computer based extraction procedure on GIS system which helps in classification of rivers in Britain.

Many researchers have used terrain analysis of a DEM for extracting drainage pattern and associating attributes with each stream using Strahler's ordering technique. P. Venkatachalam et al. [5] have suggested a procedure for delineating drainage and watersheds from DEM of a terrain. David et al. [7] have used DEM as source for automatic delineation of flow path, sub-watershed and flow networks for hydrographic modeling. Storey and Wadhwa [8] have also estimated the length of each stream using terrain analysis of DEM based on LiDAR survey to produce stream channel maps. Ejstrud [9] have also constructed digital dataset of streams, lakes and wetlands using DEMS.

Alper Sen et al. [10] in their study related to drainage pattern used k-means clustering method for grouping rivers into different categories for creating reduced scale map for a drainage system taking into consideration various river attributes.

In spite of wide hydrological application, very few works has been carried for automatic digitization and association of order.

IV. Methodology Used

A typical stream segment is represented by (Start, End, Length, Order and Bifurcation Ratio). Start represents starting coordinates of a stream segment. End represents ending coordinates of a stream segment. Length represents Length of the stream. Order represents the order of the segment. Bifurcation ratio is the number of streams of order u divided by number of streams of order (u-1).

A. Data Traversal Procedure

In order to decrease the total amount of time required for determining the peripheral stream this work uses an efficient traversal scheme based on spiral navigation [1] rather than the traditional row column approach for navigation.

The peripheral streams that converge to form a main stream are often oriented around the main stream, so to identify these contributing stream spiral traversal proves efficient. The traversal process in case of spiral traversal may end at any step between 0 to n^2 against n^2 in case of traditional row column approach.

This traversal scheme exhaust the values in the data set in spiral manner either in a clockwise direction or an anti-clock wise direction, in order to ensure that the procedure terminates at a single point or coordinate the dataset has to be odd order so, in case if the dimension is not odd then row or column of non-significant values are added.

B. Procedure for Determination of segment initiation point

The implemented process takes in skeletonized binary image (0 (non-significant) or 1(significant)) of the drainage system for performing the classification process.

While traversing the data set in a spiral manner two possible types of values might be encountered either 0 or 1.

- On encountering 0 (insignificant value) the spiral traversal continues.
- On encountering 1 (significant value) the spiral traversal temporarily stop and either of the two actions are performed.
  - If the encountered 1 is in previously visited coordinate, then spiral traversal continues.
  - If the encountered 1 is an unvisited coordinate, then the spiral navigation is temporarily put to halt and segment navigation procedure is initiated.
- On completing segment navigation procedure the spiral traversal process resumes.

The process is repeated until all external links are exhausted.

C. Segment Navigation Procedure

This procedure aims at determining various segments, their starting coordinate, intermediate coordinates and terminating coordinate. It also determines length of the identified segment and associates order for an identified stream.

- *Identification of leaf segments*

On encountering a significant unvisited value during spiral navigation, the significant value is traversed until a junction is not encountered. On encountering a junction the segment navigation process stops and the navigation status is saved in a data structure.

The traversal status includes information such as starting coordinate, intermediate coordinates and terminating coordinates along with the length of the segment.

In order to prevent misinterpretation of traversed coordinates a status variable is maintained of equal dimensions as the actual data. As and when a coordinate value is visited the status of that coordinate is changed to visited (1 for visited and 0 for not visited).

The dataset is traversed until and unless all the leaf segments are determined. The traversed leaf segments have variable length, so the process demanded an efficient data management scheme that utilizes the memory efficiently, so in this work a jazzed data structure is implemented in order to store the segment information.

The individual rows in the jazzed data structure represent a segment and store the coordinate points for the segment. Additional information such as segment coordinate count is also maintained for determining length. Every leaf stream encountered is assigned a Strahler's order 1.

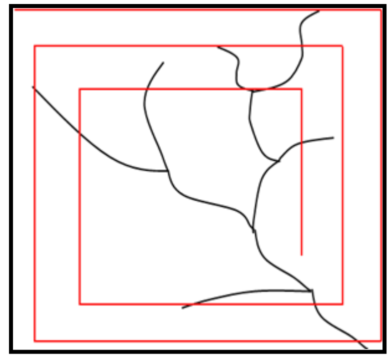

Figure 3. Spiral Navigation Scheme

- *Identification of non leaf segments*

Upon completing identification of leaf segments, the process for identifying non leaf segment is initiated. For determining the non leaf segment, spiral traversal is not used rather in order to reduce the complexity, the initially created jazzed structure is taken as input. The entries in the jazzed structure are scanned for determining junction. Junction is determined by determining entries that terminate at same coordinate. All such junctions are identified. For each identified junction segment navigation is done in order to identify second order streams and their status is saved in the data structure.

In order to determine i^{th} order streams, all entries related to $(i-1)^{th}$ order streams in the jazzed structure are taken into consideration.

This process terminates when there are no junctions left to be extended.

- *Procedure for Strahler's ordering*

If in case

i. the terminating coordinates in the jazzed structure are same and their orders are same (say *i*) then the order of the segment extending from their intersection will be (*i+1*)

ii. the terminating coordinates in the jazzed structure are same and their orders are different then the order of the segment will be the highest of the orders

This process is repeated for all orders until and unless all the streams are not exhausted.

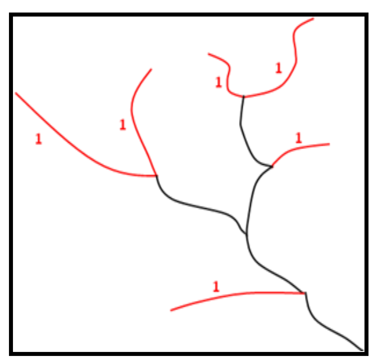

Figure 4. Identification of 1st Order Streams using spiral traversal

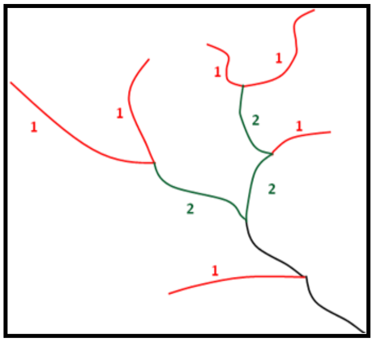

Figure 5. Identification of 2nd Order Stream using junction extension

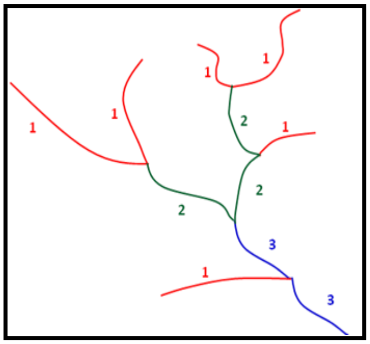

Figure 6. Identification of 3nd Order Stream using junction extension

V. Results and Discussion

The skeletonized images of the drainage pattern were taken into consideration for evaluation the performance of the techniques.

The skeletonized image was processed in order to determine the number of segments, coordinate points, length, and order and bifurcation ratio. The input and the output image along with the various attributes are represented below in table 1.

VI. Conclusion

This works aim at developing an automatic procedure for digitizing and vectoring drainage pattern. Implementation of such process tremendously reduces the amount of effort and time required in order to digitize and classify segments in a drainage pattern. In addition to classification it also associates attributes with the identified segments of drainage pattern.

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Authors Profile

Mohan P Pradhan, He received B. Tech, M. Tech degrees in 2006 and 2009 respectively from Sikkim Manipal University, Sikkim, India. He is currently persuing his Ph. D for Sikkim Manipal University in the field of automatic digitization for GIS applications. He is currently working as Assistant Professor in department of Computer Science and Engineering, Sikkim Manipal Institute of Technology, Sikkim Manipal University since August 2006. His research interest includes RS and GIS, Algorithms, Image Processing and Software Engineering.

Professor (Dr.) M. K. Ghose is the Dean (R & D), SMIT and Professor & Head of the Department of Computer Science & Engineering at Sikkim Manipal Institute of Technology, Mazitar, Sikkim, India since June, 2006. Prior to this, Dr. Ghose worked in the internationally reputed R & D organization ISRO – during 1981 to 1994 at Vikram Sarabhai Space Centre, ISRO, Trivandrum in the areas of Mission Simulation and Quality & Reliability Analysis of ISRO Launch vehicles and Satellite systems and during 1995 to 2006 at Regional Remote Sensing Service Centre, ISRO, IIT Campus, Kharagpur in the areas of RS & GIS techniques for the natural resources management. He was also associated with Regional Engg. College (NIT), Silchar (1979 – 1981) as Teaching Asst. and Assam Central University, Silchar as COE and HOD of Computer Science Department (1997-2000).

His areas of research interest are Data Mining, Simulation & Modelling, Network, Sensor Network, Information Security, Optimization & Genetic Algorithm, Digital Image processing, Remote Sensing & GIS and Software Engineering.

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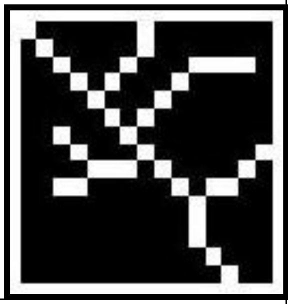
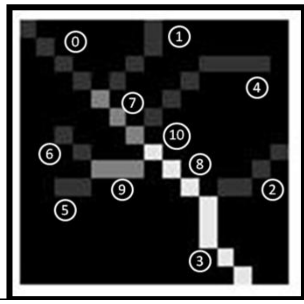
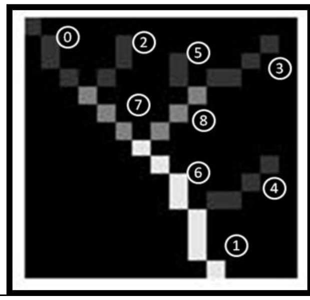
TABLE I. DIGITIZATION OF DRAINAGE PATTERN USING STRAHLERS ORDERING TECHNIQUE AND ATTRIBUTE ASSOCIATION

Input	Output	Segment	Points	Count	Order	Bi. R
		0	(0,0)(1,1)(2,2)(3,3)(4,4)	5	1	2.000
		1	(0,7) (1,7) (2,6)(3,5) (4,4)	5	1	2.000
		2	(7,14)(8,13)(9,12)(9,11) (10,10)	5	1	2.000
		3	(14,12)(13,11)(12,10) (11,10)(10,10)	5	3	-
		4	(2,13)(2,12)(2,11)(2,10) (3,9) (4,8)(5,7)(6,6)	8	1	2.000
		5	(9,2) (9,3) (8,4)	3	1	2.000
		6	(6,2) (7,3) (8,4)	3	1	2.000
		7	(4,4) (5,5) (6,6)	3	2	1.500
		8	(10,10) (9,9) (8,8) (7,7)	4	3	-
		9	(8,4) (8,5) (8,6) (7,7)	4	2	1.500
		10	(6,6) (7,7)	2	2	1.500
		0	(0,0)(1,1)(2,1)(3,2)(4,3)	5	1	2.500
		1	(14,10)(13,9)(12,9)(11,9)	4	3	-
		2	(1,5)(2,5)(3,4)(4,3)	4	1	2.500
		3	(1,13)(2,12)(3,11)(3,10)(4,9)	5	1	2.500
		4	(8,13)(9,12)(10,11)(10,10)(11,9)	5	1	2.500
		5	(2,8)(3,8)(4,9)	3	1	2.500
		6	(11,9)(10,8)(9,8)(8,7)(7,6)	5	3	-
		7	(4,3)(5,4)(6,5)(7,6)	4	2	1.000
		8	(4,9)(5,8)(6,7)(7,6)	4	2	1.000