Preserving Line Sinuosity in Hydrographic Feature Simplification

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Objectives

- Explore methods to simplify linear stream features in a manner that more accurately retains the geometric variability (along with positional accuracy of the data) than traditional methods
  - Identify a rule or rules to estimate an appropriate amount of sinuosity to remove during simplification to smaller scales
  - Test automated methods to implement the rules
  - Methods should provide a good compromise between operational (display speed, legibility, etc.) and analytic usefulness.

Problem Statement

- Problem: Simplification and other generalization operations can impact data and associated investigations regarding stream geomorphic conditions, particularly at smaller scales. Limits usability of generalized data.
- Problem: Cartographic production requires multiple simplification tolerance values that are tailored to landscape conditions.
Stream sinuosity varies in different landscapes

Rough terrain

Flat terrain
Sinuosity is defined as the length of a line (feature) divided by the distance between its endpoints.

Straight line sinuosity = 1;
else
    sinuosity > 1

Residual sinuosity is sinuosity - 1
How and why is stream sinuosity related to geomorphic conditions?

- Within local conditions, channel stability, shape, and sinuosity are influenced by sediment load.
- Over the course of the river channel, critical thresholds in sediment load and slope alter a channel’s pattern, which cause variations in channel sinuosity.

As shown above, Lazarus and Constantine (2013) propose a generic theory for channel sinuosity whereby sinuosity is related to landscape slope relative to flow resistance (topographic roughness and vegetation).

Stream Geomorphology Conditions (zonal mean for each density partition)

- **RUNOFF**
  - Runoff (mm/year)
  - 5 km cells
  - High: 6847
  - Low: 0

- **SLOPE**
  - Slope (percent rise)
  - 5 km cells
  - High: 69.04
  - Low: 0

- **SOIL Permeability**
  - Soil Permeability (mm/hour)
  - 1 km cells
  - High: 482.82
  - Low: 0

- **Rock Depth**
  - Rock Depth (inches)
  - 1 km cells
  - High: 75.41
  - Low: 0

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Results: Synoptic review of sinuosity and geomorphology characteristics for a study area

We see a similar relation as described by Lazarus and Constantine (2013).

Dry 14-purple, 10-green; Humid 010-reddish, 07-orange.

Regions 01, 07, Subregions 1019, 1025, 1027, 1401, and 1405
Sinuosity vs. Runoff

Regions 01, 07, Subregions 1019, 1025, 1027, 1401, and 1405
Sinuosity vs. Slope

Regions 01, 07, Subregions 1019, 1025, 1027, 1401, and 1405
Sinuosity vs. (Slope * Stream Formation Potential)
Methods: Study Sample

38 sections of linear stream features sampled from four scales (152 samples):
- 1:24,000-scale (24K) and 1:100,000-scale (100K) NHD,
- 1:1,000,000-scale (1M) and 1:10,000,000-scale (10M) National Atlas
Methods: Study Sample

Section of Alabama River sample at four benchmark scales.
Residual sinuosity of stream lines from four scales of hydrographic data

<table>
<thead>
<tr>
<th>Scale</th>
<th>Residual Sinuosity</th>
<th>Average</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td>0.71</td>
<td>0.09</td>
<td>1.84</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>100K</td>
<td>0.69</td>
<td>0.08</td>
<td>1.80</td>
<td>1.72</td>
<td>1.72</td>
</tr>
<tr>
<td>1M</td>
<td>0.64</td>
<td>0.05</td>
<td>1.43</td>
<td>1.38</td>
<td>1.38</td>
</tr>
<tr>
<td>10M</td>
<td>0.28</td>
<td>0.04</td>
<td>0.67</td>
<td>0.63</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Variation in sinuosity is inversely related with generalization.
Residual sinuosity of stream lines from 24K and Bend-Simplified using 50, 500, and 5000 meter tolerance

<table>
<thead>
<tr>
<th></th>
<th>Residual Sinuosity from Bend-Simplify</th>
</tr>
</thead>
<tbody>
<tr>
<td>24K</td>
<td>24K</td>
</tr>
<tr>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>500 m</td>
<td>500 m</td>
</tr>
<tr>
<td>5000 m</td>
<td>5000 m</td>
</tr>
<tr>
<td>Average</td>
<td>0.71</td>
</tr>
<tr>
<td>Min</td>
<td>0.09</td>
</tr>
<tr>
<td>Max</td>
<td>1.84</td>
</tr>
<tr>
<td>Range</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Variation in sinuosity is inversely related with level of simplification.
Percent reduction in residual sinuosity from simplification of 24K lines with Bend-Simplify operator with 50, 500, and 5000 meter tolerance

Percent reduction of 24K residual sinuosity from Bend-Simplify operator using tolerance of

<table>
<thead>
<tr>
<th>Meters</th>
<th>50</th>
<th>500</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>-0.821</td>
<td>-14.802</td>
<td>-54.825</td>
</tr>
<tr>
<td>Median</td>
<td>-0.316</td>
<td>-10.982</td>
<td>-55.211</td>
</tr>
<tr>
<td>Min</td>
<td>-13.730</td>
<td>-47.190</td>
<td>-89.162</td>
</tr>
<tr>
<td>Max</td>
<td>-0.002</td>
<td>-0.621</td>
<td>-8.988</td>
</tr>
<tr>
<td>Range</td>
<td>13.729</td>
<td>46.569</td>
<td>80.174</td>
</tr>
</tbody>
</table>
Simplification constrained to preserve sinuosity

- Adjust simplification tolerance for each feature to constrain the reduction in residual sinuosity to the minimum
  - 100K scale: 0.0015 to 0.0020 percent reduction (50 m tol)
  - 1M scale: 0.60 to 0.65 percent reduction (500 m tol)
  - 10M scale: 8.95 to 9.00 percent reduction (5000 m tol)

- Iteratively adjust Bend-Simplify tolerance until residual sinuosity is reduced within limits.
  - **Bend-Simplify**: eliminates bends having a diameter that is less than the tolerance


Simplification constrained to preserve sinuosity: results

100K scale: 0.0015 to 0.0020 percent reduction
1M scale: 0.60 to 0.65 percent reduction
10M scale: 8.95 to 9.00 percent reduction

<table>
<thead>
<tr>
<th>Tolerance (meters)</th>
<th>100K to 24K Residual Sinuosity Difference (percent)</th>
<th>1M to 24K Residual Sinuosity Difference (percent)</th>
<th>10M to 24K Residual Sinuosity Difference (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>15.3</td>
<td>118.1</td>
<td>850.3</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>14.5</td>
<td>108.6</td>
<td>935.2</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.4</td>
<td>18.0</td>
<td>39.7</td>
</tr>
<tr>
<td>Maximum</td>
<td>50.0</td>
<td>445.0</td>
<td>3915.0</td>
</tr>
</tbody>
</table>

Range of residual sinuosity | 1.75 | 1.74 | 1.60 |
Benchmark range (res. sin.) | 1.72 | 1.38 | 0.63 |

- Retained most of variation in sinuosity in the simplified features.
- Reduction of sinuosity is near target constraints. Therefore, it is possible to estimate original sinuosity values from resulting features and constraint values.
Simplification constrained to preserve sinuosity: vertices per kilometer

<table>
<thead>
<tr>
<th>Source 24K</th>
<th>24K Simplified to 100K</th>
<th>24K Simplified to 1M</th>
<th>24K Simplified to 10M</th>
<th>Benchmark Data 100K</th>
<th>Benchmark Data 1M</th>
<th>Benchmark Data 10M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>29.8</td>
<td>29.4</td>
<td>20.7</td>
<td>12.0</td>
<td>8.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>22.9</td>
<td>22.8</td>
<td>15.4</td>
<td>10.6</td>
<td>3.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.1</td>
<td>4.4</td>
<td>3.2</td>
<td>1.8</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>84.8</td>
<td>84.6</td>
<td>56.1</td>
<td>40.3</td>
<td>14.8</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Little reduction of feature vertices is achieved.
Range of conditions and tolerance results

• 1.42 sinuosity
• High frequency small bends
• Arid, rugged slopes
• 90 percent stream type
• Tolerance to achieve target constraints: 3.7 to 40 meters

• 1.37 sinuosity
• No small bends, meandering pattern
• Humid, flat terrain
• Artificial path type in polygonal stream
• Tolerance to achieve target constraints: 10 to 3900 meters
**Summary**

- Sinuosity and other hydrographic line feature characteristics are related to geomorphic conditions and are useful for hydrologic investigations and modeling.
- Traditional generalization and simplification techniques can substantially reduce the magnitude and variation of sinuosity values, and thereby limit usefulness of the data.
- Proposed method adjusts simplification tolerance to achieve a relatively constant reduction of sinuosity and maintain more variation in sinuosity values than traditional simplification methods.
- Further testing is needed to find optimal constraints that are a good compromise between legibility, positional accuracy, and shape integrity.
Future Work

Develop and test automated simplification approach:

- Parameters: scale denominator
- Constraints:
  - Positional accuracy (1/50th inch, NMAS)
  - Legibility (0.414 mm, screen pixel diagonal)
  - Percentile reduction of sinuosity determined from simplification with legibility constraint.
- Possible algorithm
  1. Bend-Simplify data with legibility tolerance
  2. Identify target percentile reduction of sinuosity for a dataset, and build a constraint interval centered on the percentile reduction.
  3. Iteratively simplify each feature, allowing tolerance to expand until target sinuosity reduction is achieved.
     - Do not allow bend to be removed if it violates positional accuracy constraint
- Implement distributed processing techniques for enhanced processing speed.
THANK YOU!

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