NetworkGT Toolbox

Version 0.1

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Contents

1.0 Background

1.1 Citation and Acknowledgments

The NetworkGT (Network Geometry and Typology) Toolbox is a set of tools designed for the geometric and topological analysis of fracture networks in ArcGIS 10.4 >. The toolbox provides a range of tools that allow the user to utilize a number of traditional sampling methods in order to automatically conduct a robust characterization of the networks geometric and topological properties as well as assessing its spatial variability. The toolbox has been designed and made publically available by the authors of this workflow, all of whom are academic geoscientists. The different types of analyses are described and discussed in detail within the corresponding article by Nyberg et al., 2018 published in *Geosphere*. If you use this toolbox for your own analyses or research we require that any corresponding results, reports, publications or presentations to CITE AND ACKNOWLEDGE both:

a) The NetworkGT Toolbox

b) Nyberg, B., Nixon, C.W., Sanderson, D.J., 2018, NetworkGT: A GIS tool for geometric and topological analyses of two-dimensional fracture networks. *Geosphere, v. 14, no. 4, p.1-17, doi:10.1130/GES01595.1.*

1.2 License

The scripts used in this program are written in the Python programming language under a GNU General Public License V3 which states:

1.3 Requirements

The NetworkGT toolbox is available from **ArcMap version 10.4** and **requires the Advanced ArcGIS License** (http://pro.arcgis.com/en/pro-app/get-started/license-levels.htm).

2 Installation

2.1 NetworkGT Download

1. Download the latest release of the NetworkGT toolbox from https://github.com/BjornNyberg/NetworkGT/releases
2. Unzip the NetworkGT-version.zip file into a **permanent working directory** that has **read/write** capabilities.

2.2 Python Installation

The toolset utilizes a set of scientific third-party packages that are typically not available in a standard ArcGIS installation. If you have **admin rights** on your computer **follow procedure 2.2.1,** otherwise use instructions to **install Anaconda in step 2.2.2**, which **does not require admin rights.**

2.2.1 ArcGIS Python module installation

1. Navigate to the Install folder of your working directory (step 1) and find the file **Install.py** → right click → Edit with IDLE.
2. Press F5 to run the file and wait until a message 'Finished' is returned

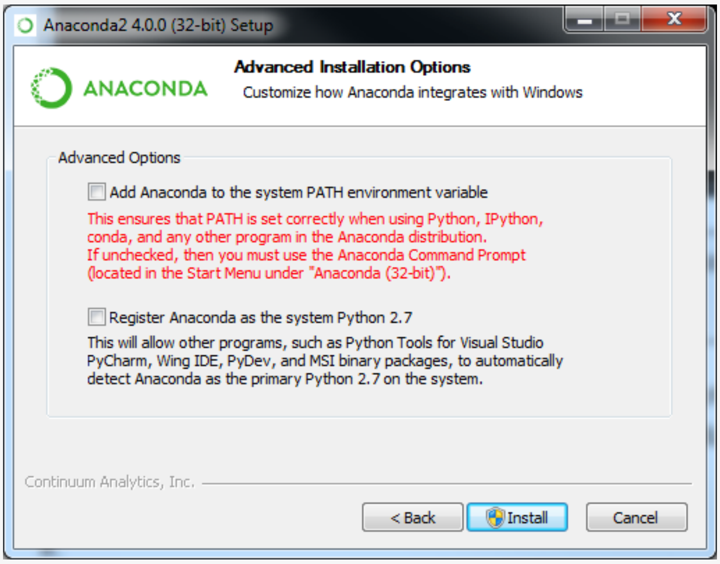
2.2.2 Anaconda Python module installation

1. Download and install the 32bit or 64bit Anaconda Python 2.7 from https://www.continuum.io/downloads into a **permanent working directory** that has **read/write** capabilities.

IMPORTANT – During the installation process of Anaconda make sure to uncheck the following options to ensure that it does not conflict with ArcGIS Python 2.7

"Add Anaconda to the system PATH environment variable"

"Register Anaconda as the system Python 2.7"



2. Navigate to the Install folder of your working directory (step 1) and find the file Pathway2Anaconda.py → right click → Edit with IDLE.

3. Navigate to the end of the file and locate a line that reads

python_exe = r'D:\Anaconda2\python.exe'

Change the line of code to the directory pathway of the Anaconda python executable (python.exe). Remember to keep the new line within the r and quotation brackets. For example

python_exe = r'D:\New_Pathway\Anaconda2\python.exe'

4. Press Ctrl+S to save the file

5. Press F5 to run the file and wait until a message 'Finished' is returned

2.3 NetworkGT Toolbox Installation

1. Open ArcMap
2. Find the ArcToolbox by navigating to the tabs Geoprocessing → ArcToolbox
3. Right click the ArcToolbox icon →Add Toolbox and navigate to the NetworkGT.tbx file in your working directory (Step 1 in section 2.1).
4. Right click the ArcToolbox icon → Save Settings → To Default. The toolbox is now saved under the current ArcToolbox settings.

The toolset is now ready for use!

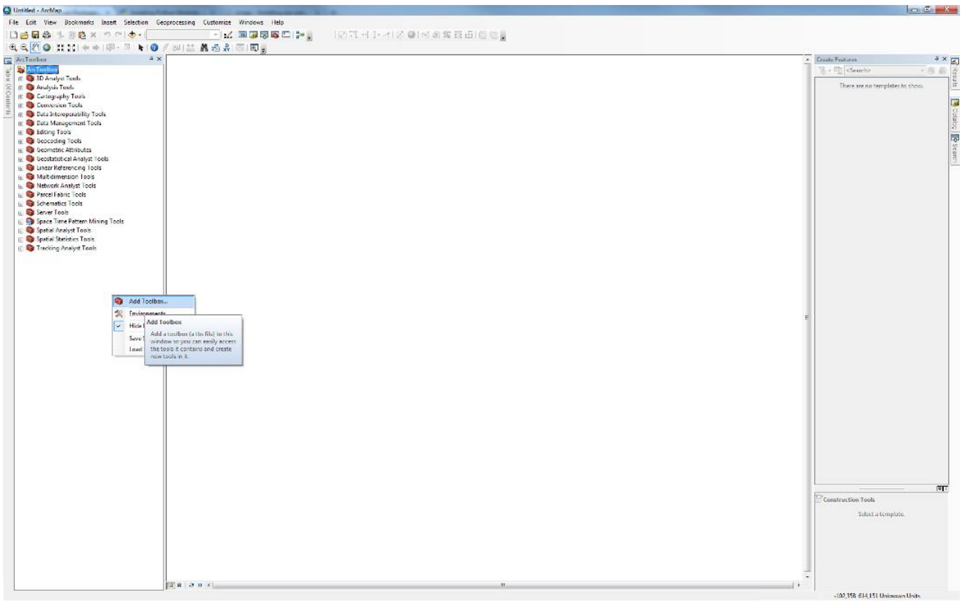


Figure 1

3 Workflow

3.1 Digitizing Fracture Network

3.1.1 *Interpretation of Fracture Network*

- The fracture network needs to be digitized correctly as polylines at the interpretation stage.
- It is important to always use the ‘snap’ function when creating fracture polylines.
- This should be used to snap to another fracture polyline if the two fractures are intersecting or to the interpretation boundary polygon if the fracture leaves the interpreted region.
- The snapping toolbar can be accessed via the editor toolbar when interpreting/creating new features. This becomes important for later steps in the workflow.

3.1.2 *Repair Fracture Network*

- If a network has been incorrectly digitized, NetworkGT provides a tool to ‘Repair Network’ geometries and topologies.
- First input the digitsed network polylines and then select from a range of repair options.
- These include deleting short isolated fractures, trimming fractures, extending fractures, merging fracture segments, and deleting interpretation artifacts such as loops.
- The specified length of shortening and extending can be user defined.

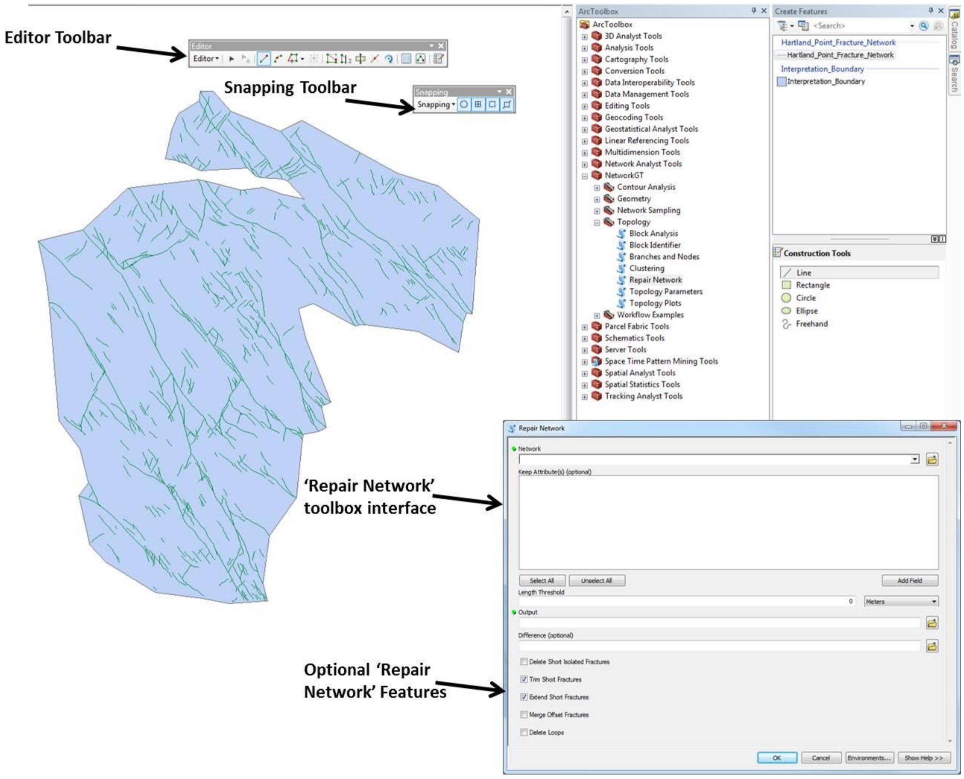


Figure 2

3.2 Geometrical Analysis

3.2.1 Rose Diagrams

- 'Rose Diagram plots' allow the user to create Rose Diagrams from the fracture network polyline feature class using user defined degree bin sizes.
- These also have the option to be weighted by a fracture attribute such as length or displacement (Fig 3A and B).
- The tool can optionally be run on groups of fractures defined by attributes such as sets and types.

3.2.2 Fracture Sets

- Using the rose diagrams, any number of fracture sets can be defined by orientation ranges using the 'Sets' tool (Fig 3C) and then visualized (Fig 3D).
- This uses the fracture network polyline feature class as the input.
- Note that set orientations ranges must be between 0-180 degrees and defined within brackets, with each set separated by a comma (see Fig 3C for example).
- The orientations and set numbers will be added automatically to the fracture network attribute table, allowing the user to then visualize the network based on these.
- The tool can optionally be run on groups of fractures defined by attributes such as sets and types.

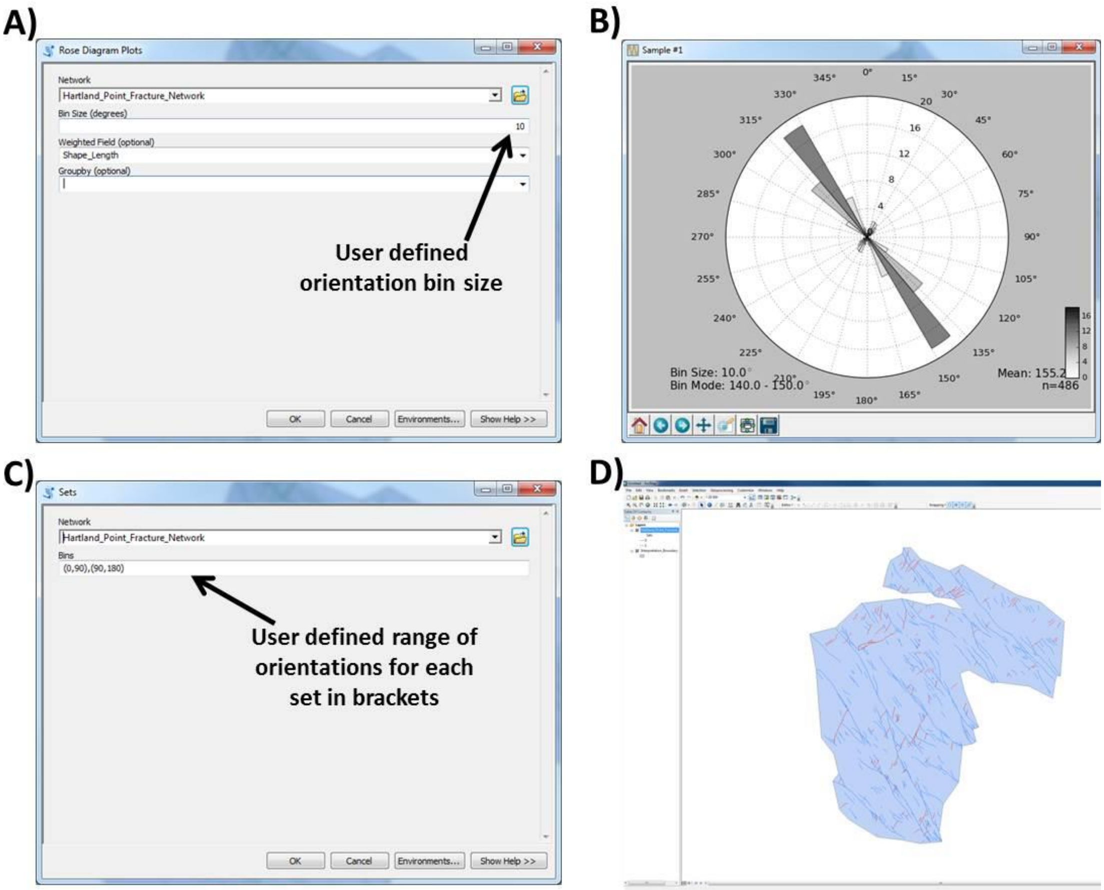


Figure 3

3.2.3 Fracture-Size Distributions

- Using the fracture network polyline feature class as an input, distributions of fracture lengths, displacements or apertures etc can be analysed using either the 'Distribution Analysis Plots' (Fig 4A and B) or the 'Histogram Plots' (Fig 4C and D) tools.
- These generate a number of graphs and plots that help the user to identify the frequency distributions of different fracture sizes.
- For histograms the bin size is user defined (Fig 4C).
- The tools can optionally be run on groups of fractures defined by attributes such as sets and types.

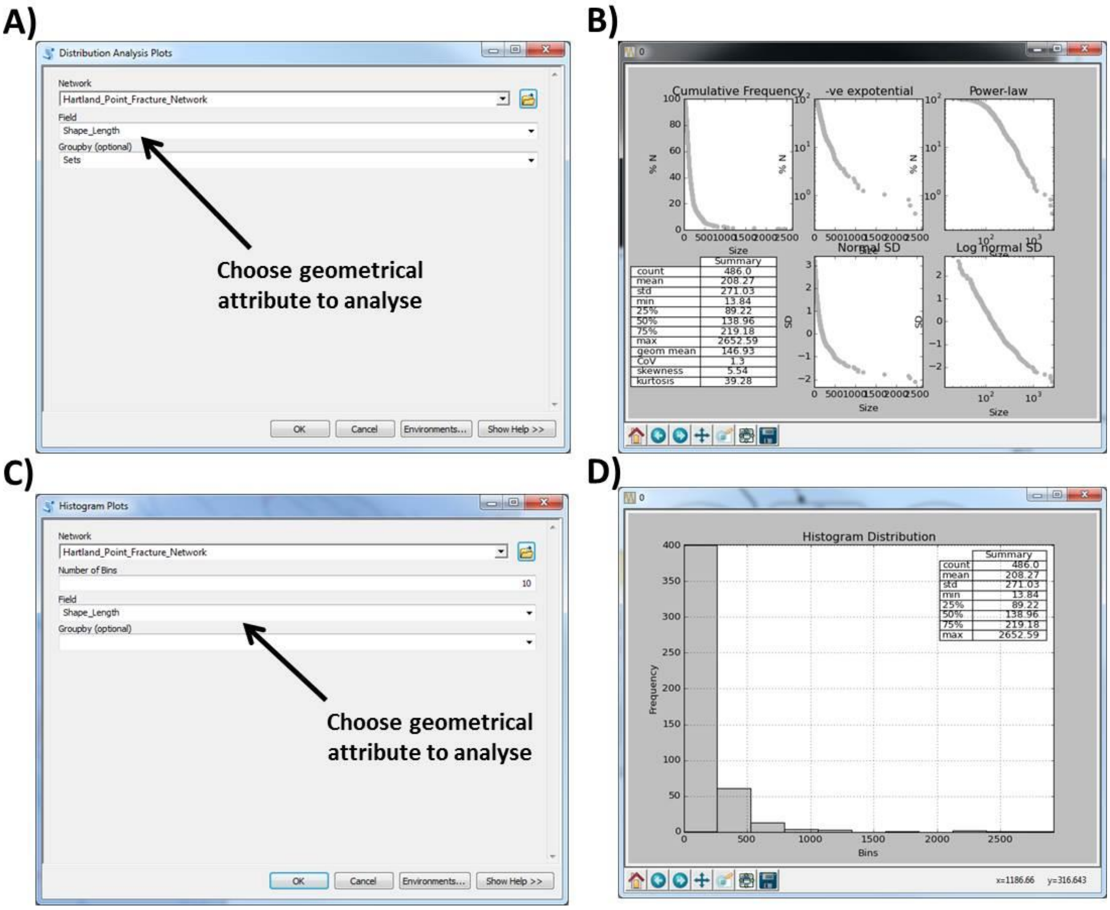
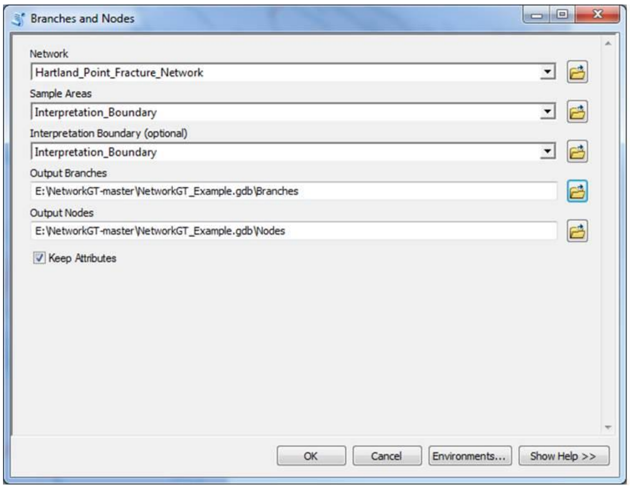


Figure 4

3.3 Topological Analysis

3.3.1 Branches and Nodes

- Branch and node types can be automatically extracted using the ‘Branches and Nodes’ tool.
- The inputs for this tool are the fracture network polylines, the sample area(s) polygon (in the example below this is the interpretation boundary), and optionally an interpretation boundary polygon can be used.
- The interpretation boundary is important as it defines the limit to which the fracture network can be interpreted. Any fracture that intersects the interpretation boundary polygon creates an edge node.
- The outputs of this tool are two new feature classes: Point Feature Class for Nodes; Polyline Feature Class for Branches.
- The feature classes will have corresponding attribute tables detailing the different node and branch type, each node and branch is drawn automatically with an assigned symbology depending on their type.
- Nodes identified as errors mean that the network has some inconsistent digitized fracture polylines. This can be useful for identifying if the network needs repairing using workflow 3.1.



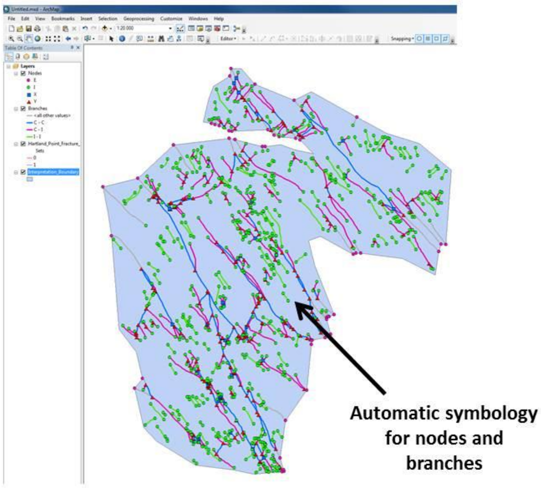


Figure 5

3.3.2 Topological Analysis and Plots

- Once the branch and node feature classes have been extracted in workflow 3.3.1, specific topological parameters can be calculated using the 'Topology Parameters' tool (Fig 6A).
- The inputs into this tool are the extracted branch and node feature classes as well as the sample area(s) polygon.
- A duplicate polygon feature class of the sample area(s) is output with a number of calculated parameters added to the attribute table for each saaple area, such as node and branch counts, 1D and 2D fracture intensity, connecting node frequency, connections per branch, connections per line etc.
- Optionally an Excel file can also be produced and saved with all the information (Fig 6A).
- The 'Topology Parameters' output feature class can be used to create triangular plots of the different node and branch proportions using the 'Topology Plots' tool (Fig 6B).
- Each sample area will be plotted as a coloured dot and the triangular plots also have the connections per branch contoured onto them (Fig 6c and D).

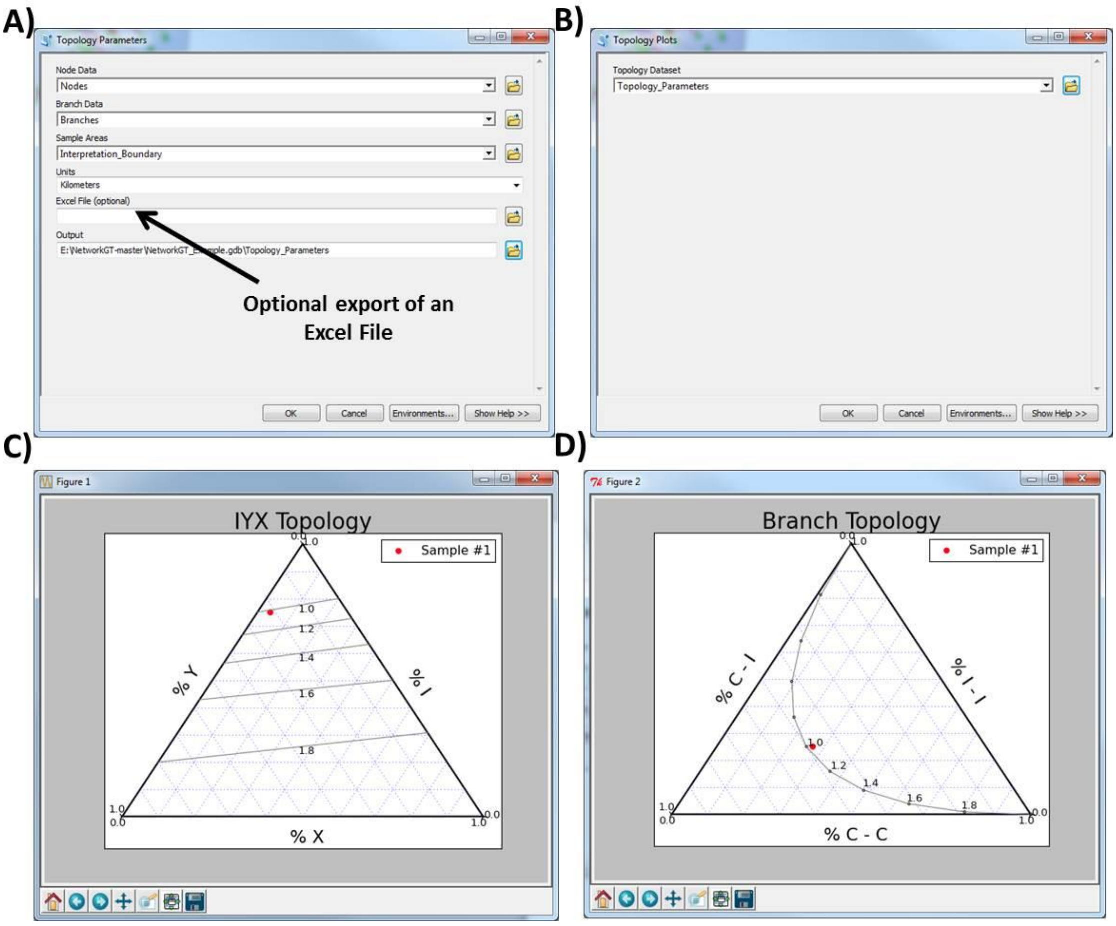


Figure 6

3.3.3 Clustering

- Clusters can be identified and extracted from a fracture network using the ‘Clustering’ tool.
- This uses the extracted branch feature class from workflow 3.3.1 as an input.
- A polyline feature class of branches grouped into clusters is output whereby each branch has an associated cluster number.
- Optionally the branches within each cluster can be dissolved by ticking the *Dissolved Branches* box. This option outputs clusters as single features in a polyline feature class with statistical information on each cluster recorded in the attribute table, such as the number and type of branches within each cluster and the total length of the cluster and its backbone or dangling ends.
- When extracting the clusters a number of options are available: *dissolving branches* – which extracts clusters as single features instead of groups of individual branches; *only connected clusters* – which extracts only clusters with connect branches (i.e. I-C or C-C branches); *split clusters* – which splits clusters if they leave the sample area polygon.

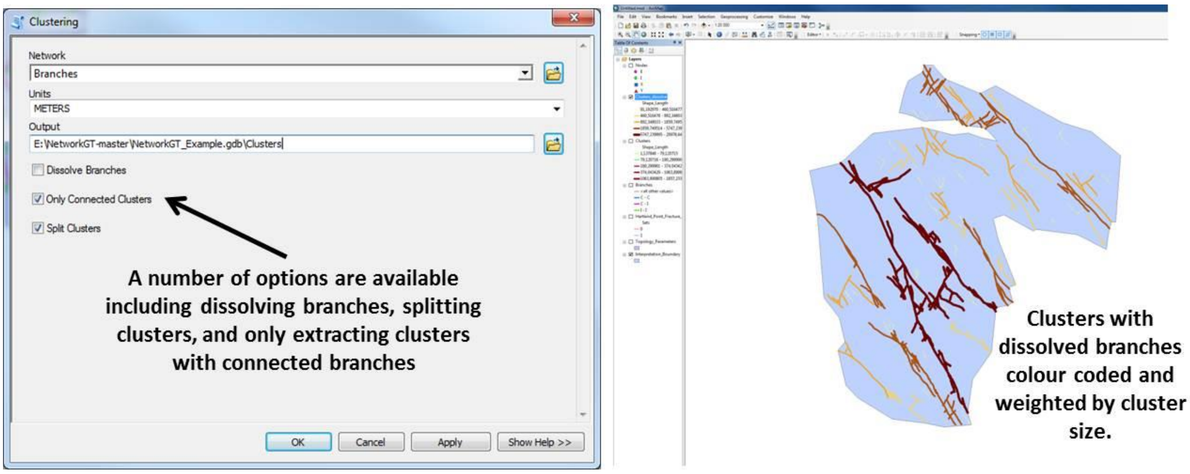


Figure 7

3.3.4 *Block Analysis*

- Statistical information about the number of blocks or compartments within a fracture network can be extracted using the 'Block Analysis' (Fig 8A) and 'Block Identifier' (Fig 8B) tools.
- The 'Block Analysis' tool uses the node point feature class extracted in workflow 3.3.1, the topology parameters dataset extracted in workflow 3.3.2, and the clusters feature class extracted in workflow 3.3.3.
- It is important to note that the clusters must NOT have dissolved branches (i.e. when creating the feature class in workflow 3.3.3, do not tick the *dissolved branches* option).
- The 'Block Analysis' tool calculates and adds a number of fields to the topology parameters attribute table describing the block statistics of each sample area, such as the number of theoretical blocks, number of whole blocks, average block size etc. (Fig 8C).
- The 'Block Identifier' tool will extract all the whole blocks as polygons from a network of polylines within a sample area polygon (in the example below the topology parameters polygon feature class is used).
- Whole block information will be added to the attribute table of the sample areas describing the number of whole bocks, max block size, min block size, and average block size.

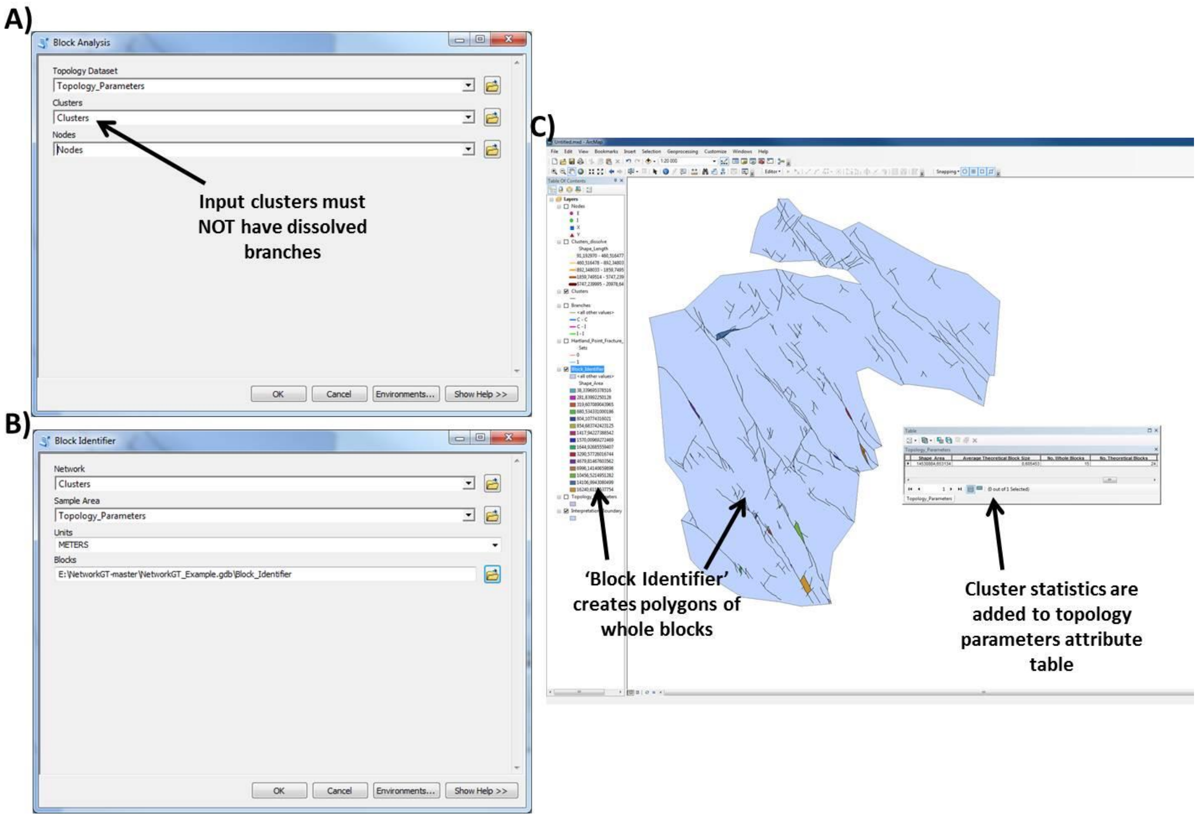


Figure 8

3.4 Spatial Analyses

3.4.1 Grid Sampling and Contour Plots

- A network of polylines can be sampled by a grid within the interpretation boundary polygon using the 'Network Grid Sampling' tool (Fig 9A).
- The tool outputs a polygon feature class of grid cells within the interpretation boundary (Fig 9C) that systematically sub-samples the network and can be used later to create a contour plot illustrating spatial variations in network properties.
- The tool allows the user to specify the size of the grid cells as well as applying a search radius (Fig 9A) for sampling branches and nodes associated with each grid cell.
- Branches and nodes should be extracted using the' Branches and Nodes' tool, following workflow 3.3.1, by using the grid cell polygon feature class as the input for the sample areas (Fig 9B).
- This extracts branches and nodes for every grid cell using the search radius to define a circular sample region.

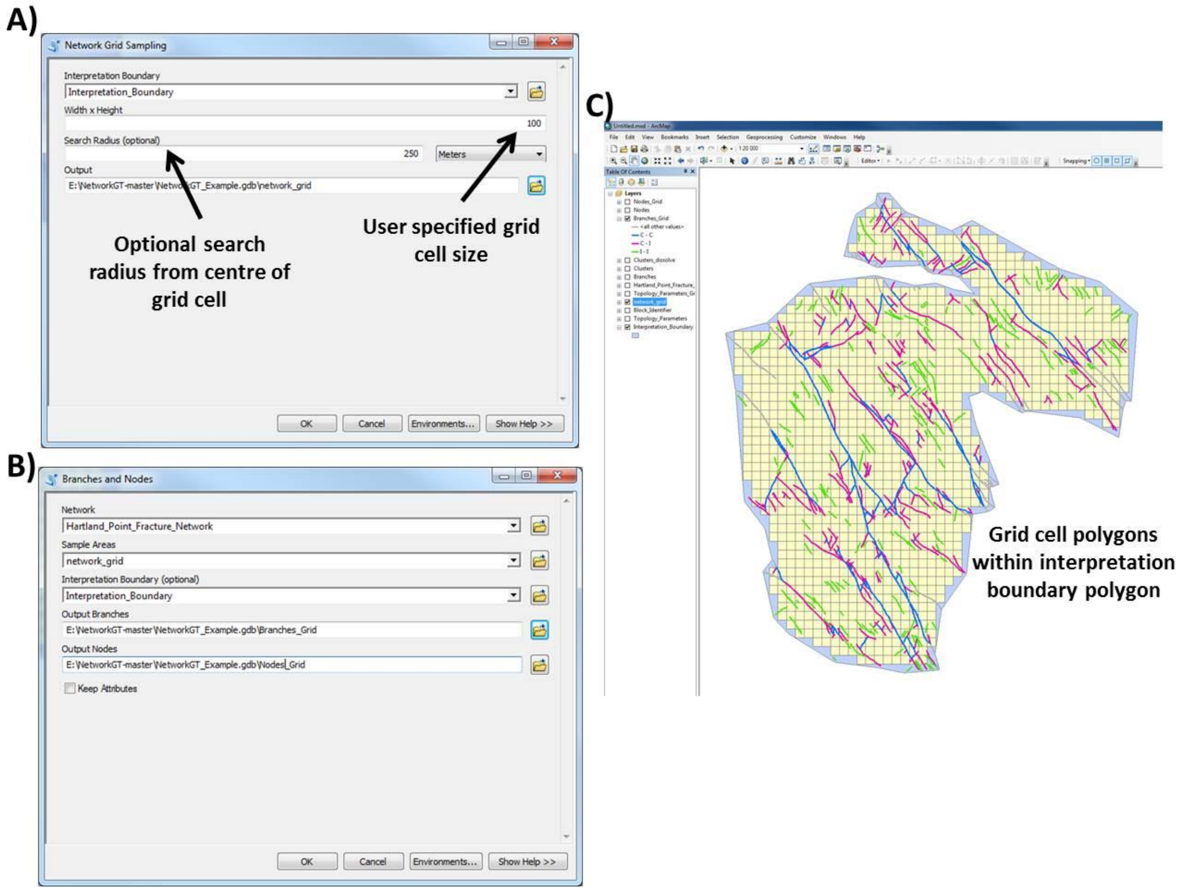


Figure 9

- Topological parameters can be calculated following workflow 3.3.2, by using the extracted branches and nodes for each grid cell as inputs and the grid cell polygon feature class (Fig 10A).
- This creates a duplicate polygon feature class of the grid cells with an attribute table of numerous topological parameters including fracture intensity, connections per branch, connections per line etc. Further parameters can optionally be calculated and added following workflows 3.3.3. and 3.3.4.
- The duplicated grid cell polygons can be colour coded by various topological parameters allowing the user to create contour plots of different network properties such as fracture abundances or degree of connectivity (Fig 10B), providing a means to visualize spatial variations.

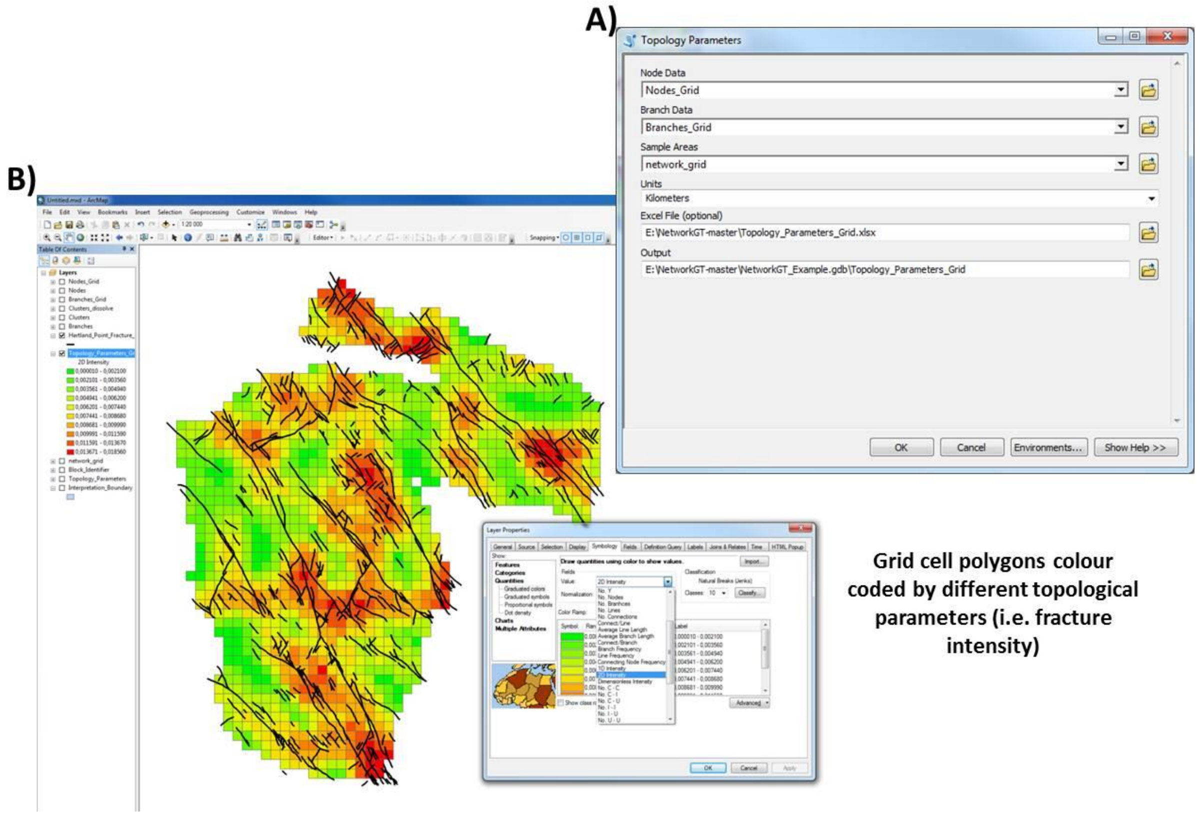


Figure 10

3.4.2 *Line Sampling and Spatial Heterogeneity Analyses*

- The 'Line Grid' tool defines an equally spaced set of polylines at a user defined spacing and orientation (Fig 11A).
- The spacing parameter is user defined in the dimensions of the map units and the angle parameter is user defined between 0 and 180 degrees.
- The 'Line Sampling' tool (Fig. 11B) samples a set of user defined polylines (e.g. Fig 11A) against a fracture network to determine the spacing and the attributes of the intersected fractures (Fig 11C). It is recommended to define the sample lines perpendicular to a fracture network set (i.e. using the defined angle parameter in the 'Line Grid' tool, Fig. 11A).
- An optional interpretation boundary may be used to define the length of the sample lines or an optional trim parameter will trim each sampled line to its first and last intersection with a fracture polyline.

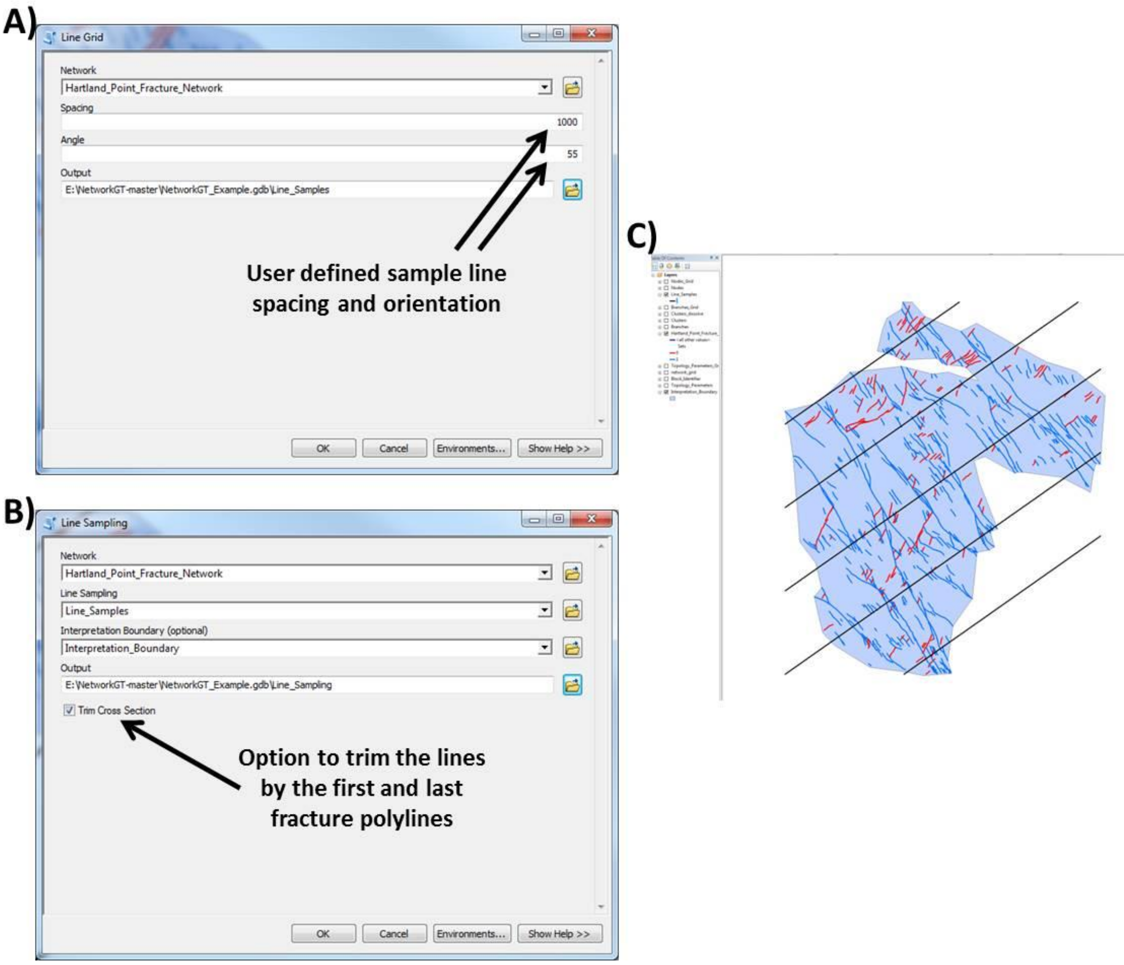
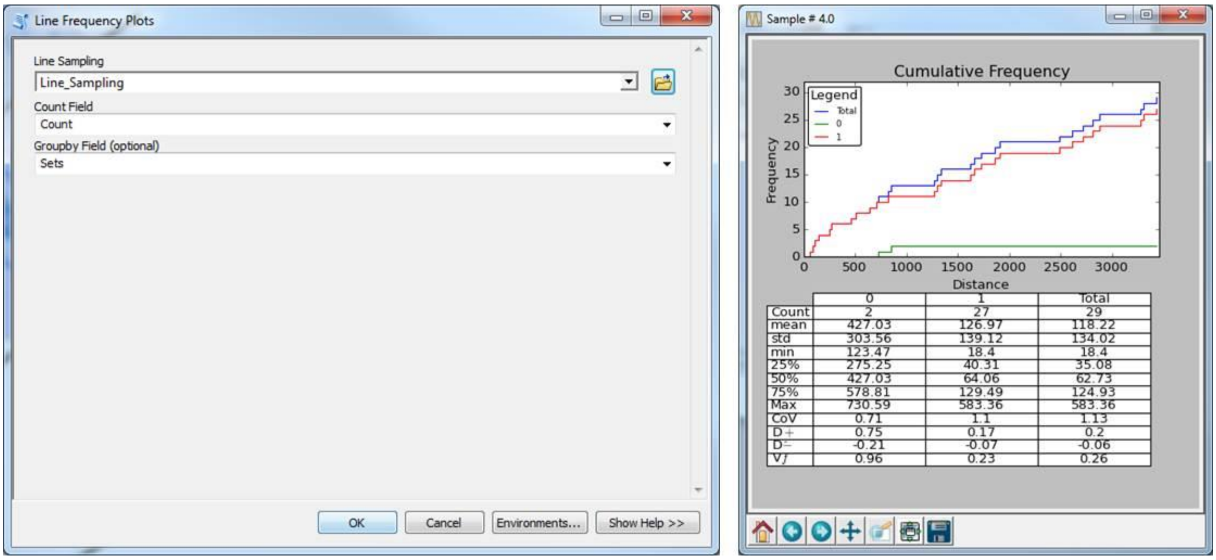


Figure 11

- The ‘Line Frequency Plots’ tool (Fig. 12) uses the extracted set of polyline(s) that have been sampled against a fracture network using the ‘Line Sampling’ tool (e.g. Fig. 11B).
- This plots the frequency of fracture occurrences versus distance of each sampled line(s) (Fig. 12).
- The Count Field is used to assess the spatial heterogeneity along a sampled line of user defined attribute such as fracture count or fracture displacement.
- A table will show the statistics of the fracture spacing for each sample line(s). D^+, D^- and V^f are useful parameters to quantify the spatial heterogeneity of the fracture network spacing.
- An optional Groupby Field will subdivide the line frequency plot and its statistical summaries by a user defined fracture network attribute such as sets.



	0	1	Total
Count	2	27	29
mean	427.03	126.97	118.22
std	303.56	139.12	134.02
min	123.47	18.4	18.4
25%	275.25	40.31	35.08
50%	427.03	64.06	62.73
75%	578.81	129.49	124.93
Max	730.59	583.36	583.36
CoV	0.71	1.1	1.13
D+	0.75	0.17	0.2
D−	-0.21	-0.07	-0.06
Vf	0.96	0.23	0.26

Figure 12

4 Contact Information & Feedback

Please report any bugs or errors on the GitHub NetworkGT repository issues tab https://github.com/BjornNyberg/NetworkGT/issues