NetworkGT Workshop, 13th January 2019

NetworkGT Practical

In this workshop we will focus on working with an interpreted and digitised fault network in ArcMap and how to extract geometrical and topological properties of the fault network as a whole. This will allow you to get a feel for the possibilities and potential of supplementing your field data of a fault population with digital mapping of networks. The exercises are based around ArcGIS, a Geographical Information System developed by ESRI and the NetworkGT toolkit. The software allows handling of geographic information (imagery and mapped features) in a geographic window as a series of map layers. Each map layer represents a particular dataset overlaid in the map. Map data can include:

- Feature classes such as points, polylines and polygons
- Aerial photography or satellite imagery
- Surfaces such as digital elevation models, LiDAR/Bathymetric data which can be represented in numerous ways.

Within ArcMap regions and outcrops with large spatial extents with associated map data can be handled allowing visualisation, interpretation and measurement, and integration of additional field data.

Objectives

- Become familiar with setting up an ArcGIS project and importing a digitised fracture network.
- Explore the layout of the ArcGIS user interface.
- Explore NetworkGT toolkit.
- Analyse and extract geometrical and topological information about the fracture network.
- Be able to visualise the properties of a fault or fracture network as a map in ArcGIS.
- Be able to assess spatial variations in network properties.
- Understand the potential and limitations these datasets can give.

Before you start

All the data you will use throughout this workshop will be on **D:\ NetworkGT-Master**. All of your ArcGIS projects and data should be saved to this folder over the course of the workshop.

No food or drinks allowed in the computer lab!

At the end of the exercise

➢ Please **delete** the all the data from the the D:\ hard drives.

Casey Nixon & Bjorn Nyberg, v1, January 2019

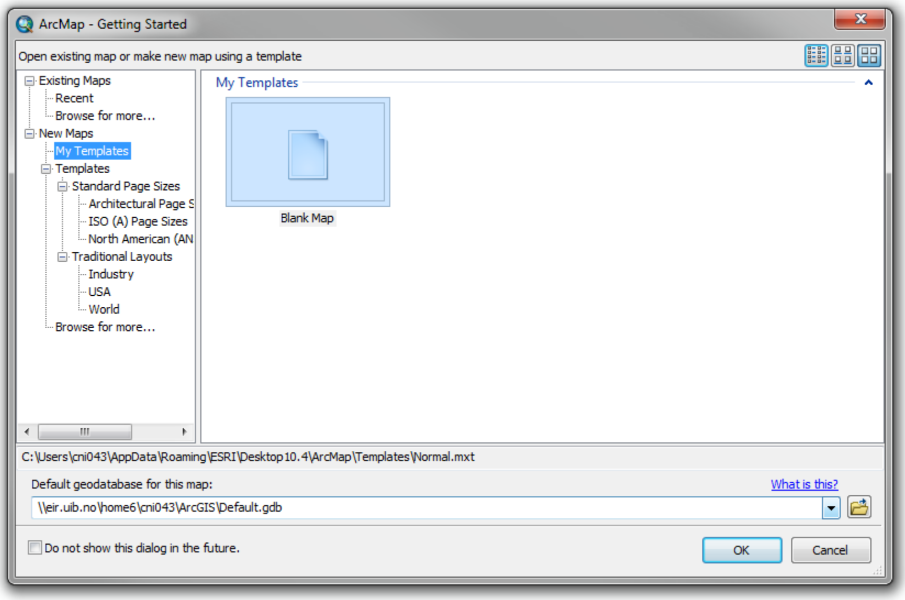
Exercise 1: Importing Networks and Extracting Geometrical and Topological Properties

CREATING A MAP PROJECT IN ARCMAP AND INSTALLING THE TOOLKIT

1) Open ***ArcMap 10.5*** and select blank map from the options.

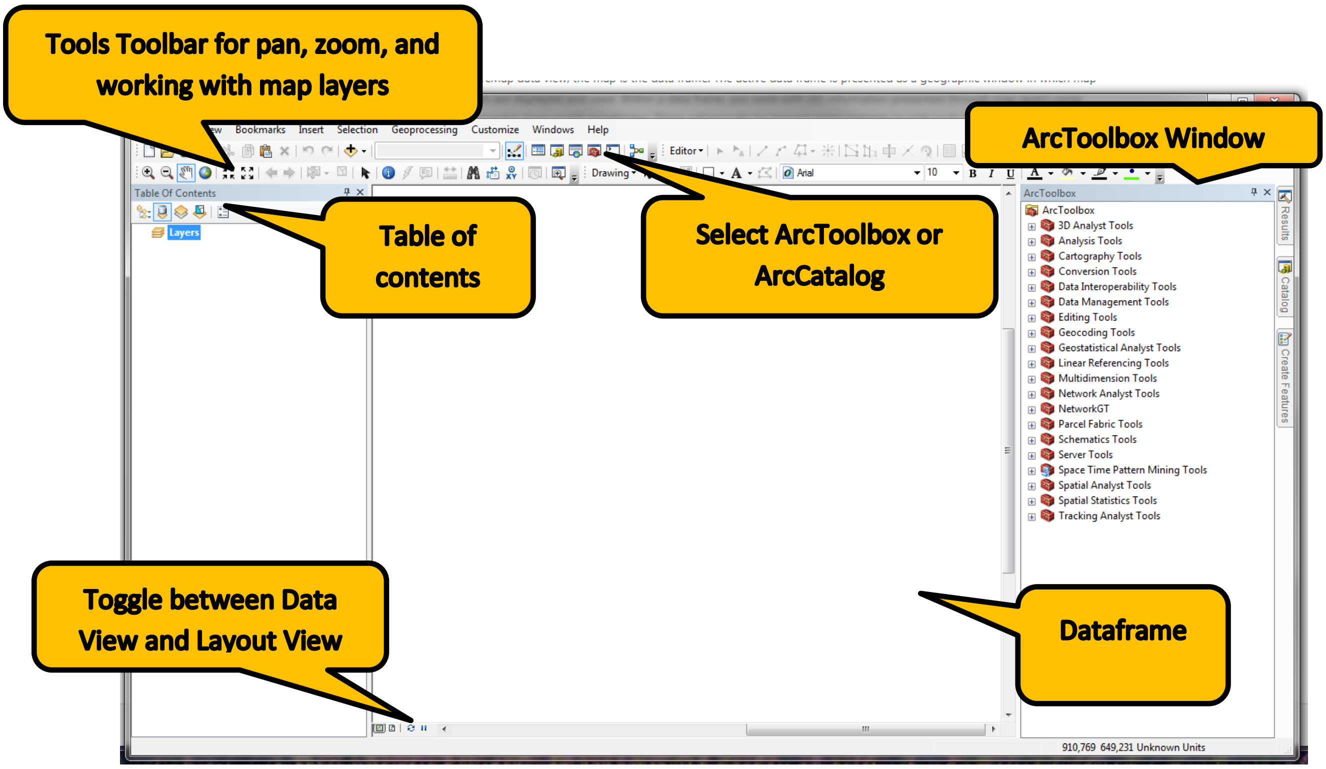
2) At the bottom of the window change the geodatabase to ***NetworkGT_Example.gdb*** which has already been created for you on the D:\. This assigns a single geodatabase to your map project where all features classes and surfaces will be saved to. This is important for keeping the data in your project neat and organised.

3) Click OK

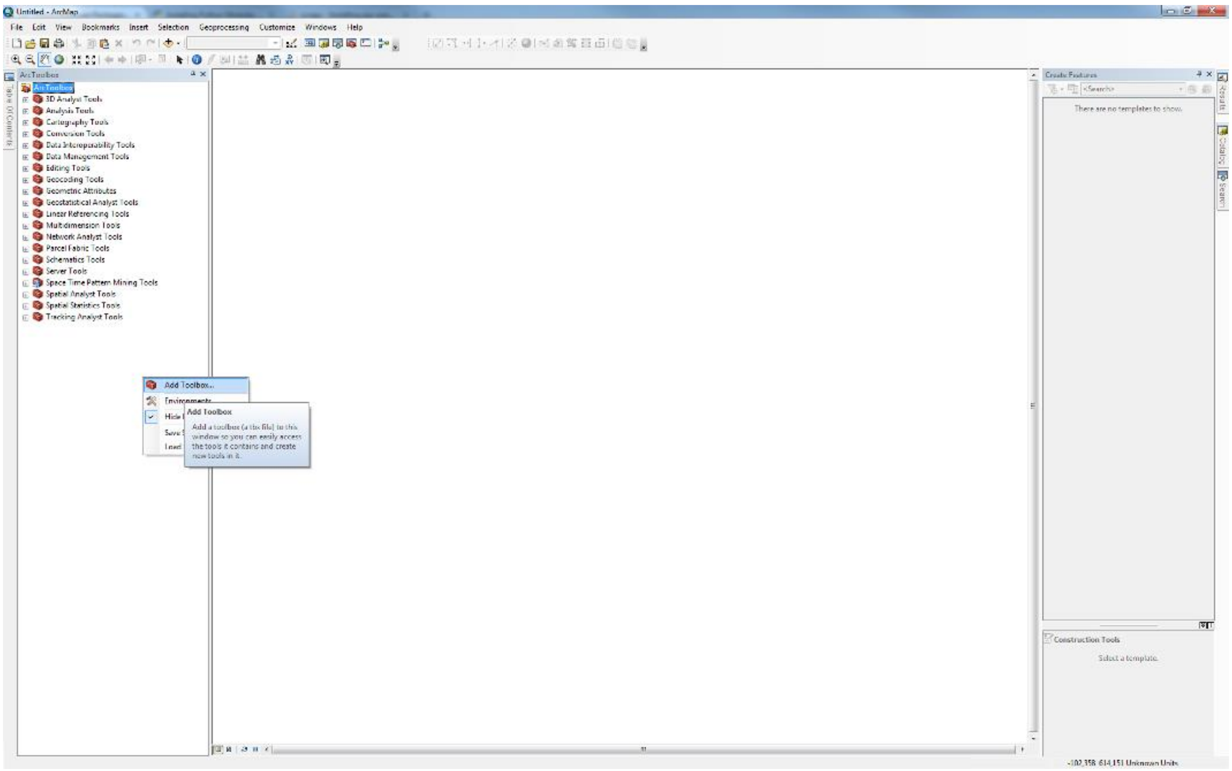


The user interface of ArcGIS consists of several panels as well as the toolbar at the top:

- The toolbar provides access to open several aspects of ArcGIS including: **ArcCatalog** where you can view and organise the data files of your map project; **ArcToolbox** where there are a number of tools to create, analyse and manipulate map data; **Tools toolbar** for primary functions such as pan, zoom and working with map layers.
- To the left is the **Table of Contents** window where any map layers that you import will be shown. The order they are shown here is the order they are layered.
- In the centre is the **Data frame** window where the map layers are visualised. At the bottom you can toggle between a **Data View** and a **Layout View**. The Layout View is where you can make PDF's or printable maps of the layers.
- To the right you have a window that shows features of different aspects of ArcGIS when turned on e.g. ArcToolBox, ArcCatalog etc.



4) Find the **ArcToolbox** by navigating to the tabs **ArcToolbox tab**
5) Once opened right click the **ArcToolbox icon** and click **Add Toolbox**. Navigate to the **NetworkGT.tbx** file in **D:\ NetworkGT-Master folder**.
6) Right click the **ArcToolbox** icon and **Save Setting To Default**. The toolbox is now saved under the current ArcToolbox settings. The toolset is now ready for use!

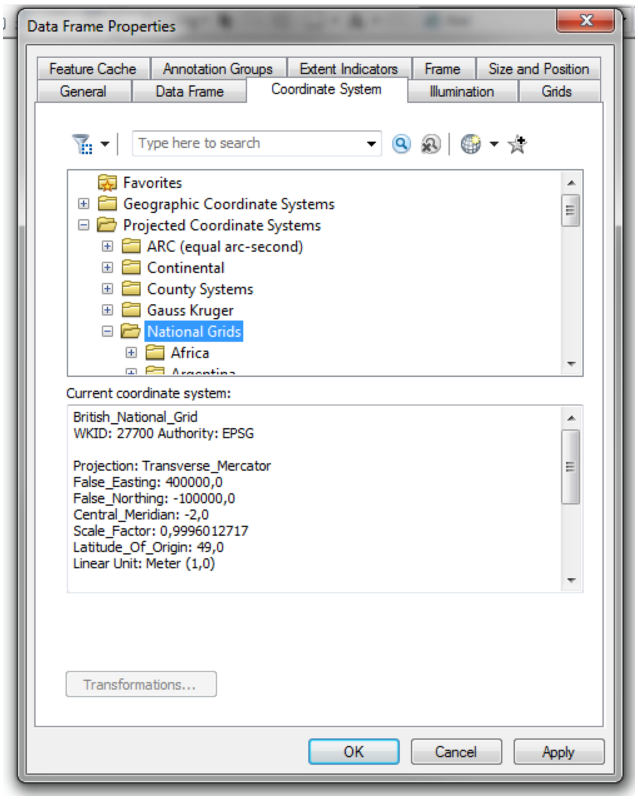


IMPORTING DATA INTO ARCMAP

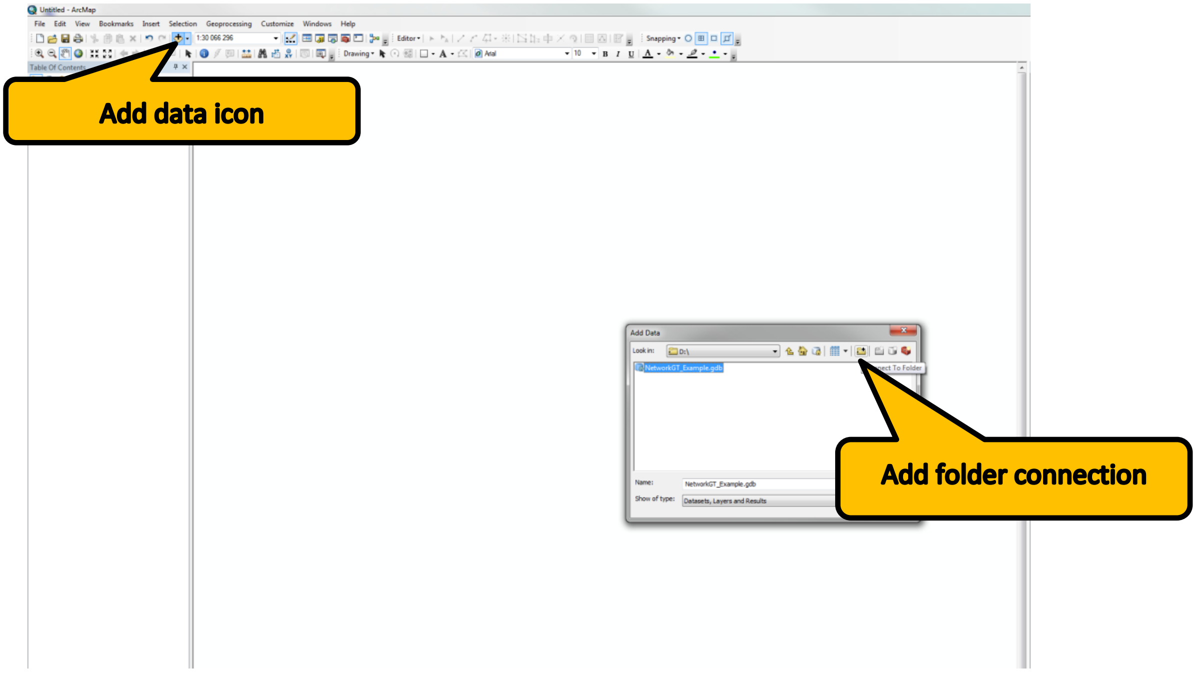
Now that the map project is set up and the toolkit is added you can start importing data. First you will import the polylines of the fault network and a polygon of the interpretation boundary.

Before importing data the data frame need to be given a spatial reference to know where geographically map layers should be drawn. Right-click on the Data Frame and then click on **Data Frame Properties**.

7) Under the **Coordinate System Tab** select **British National Grid** and click apply followed by ok.



8) Importing data can be done selecting the data from the **Add Data** icon. Locate and select the ***Interpretation_Boundary*** and ***Hartland_Point_Fracture_Network*** feature classes within the ***NetworkGT_Example.gdb***. Note that you may need to add a ***Folder Connection*** to navigate to the correct folder.



The different feature classes should now have been added to the map project appearing in the Table Of Contents as map layers and also drawn within the Data Frame. All of these faults were interpreted and created from multibeam bathymetry from *Nixon et al., 2012, Analysis of a strike-slip fault network using high resolution bathymetry, offshore NW Devon U.K., Tectonophysics*. The interpretation boundary represents the extent of the interpreted fracture network and is important for later topological analyses.

At this stage it is important to save the map project. Navigate to: **> File > Save As** and save the map project in the **NetworkGT-Master** folder on the local hard drive. This will create a **.mxd ArcMap file**.

EXPLORING THE DATA AND ANALYSING NETWORK GEOMETRY

One of the most useful aspects of interpreting features in ArcGIS is that each point, polyline and polygon are geospatially referenced and can have a number of attributes associated with them. These can be geometrical attributes which ArcGIS will calculate automatically (e.g. Shape Length, Shape Area etc.) or additional geological information about features such as fault type, lithology etc.

9) To explore attributes of different features right-click on the feature layer in the Table Of Contents and click ***Open Attribute Table***. A table will open for the feature class where each row represents a single point, line or polygon and the column are different attributes of the features. Each attribute table can be sorted and filtered based on any given attribute and features can be selected in order to highlight them in the Data Frame. **Explore the feature class attribute tables to familiarise yourself with the data.**

Q1) What is the type and length of the largest fault?

Q2) What is the area of the interpreted fault network?

Now we will start analysing the geometry of the network using the NetworkGT toolkit.

FRACTURE ORIENTATIONS:

10) Within the ***ArcToolbox*** Navigate to: **> NetworkGT > Geometry** and double click on the ***Rose Diagram Plots.*** 'Rose Diagram plots' allow the user to create Rose Diagrams from the fracture network polyline feature class using user defined degree bin sizes.

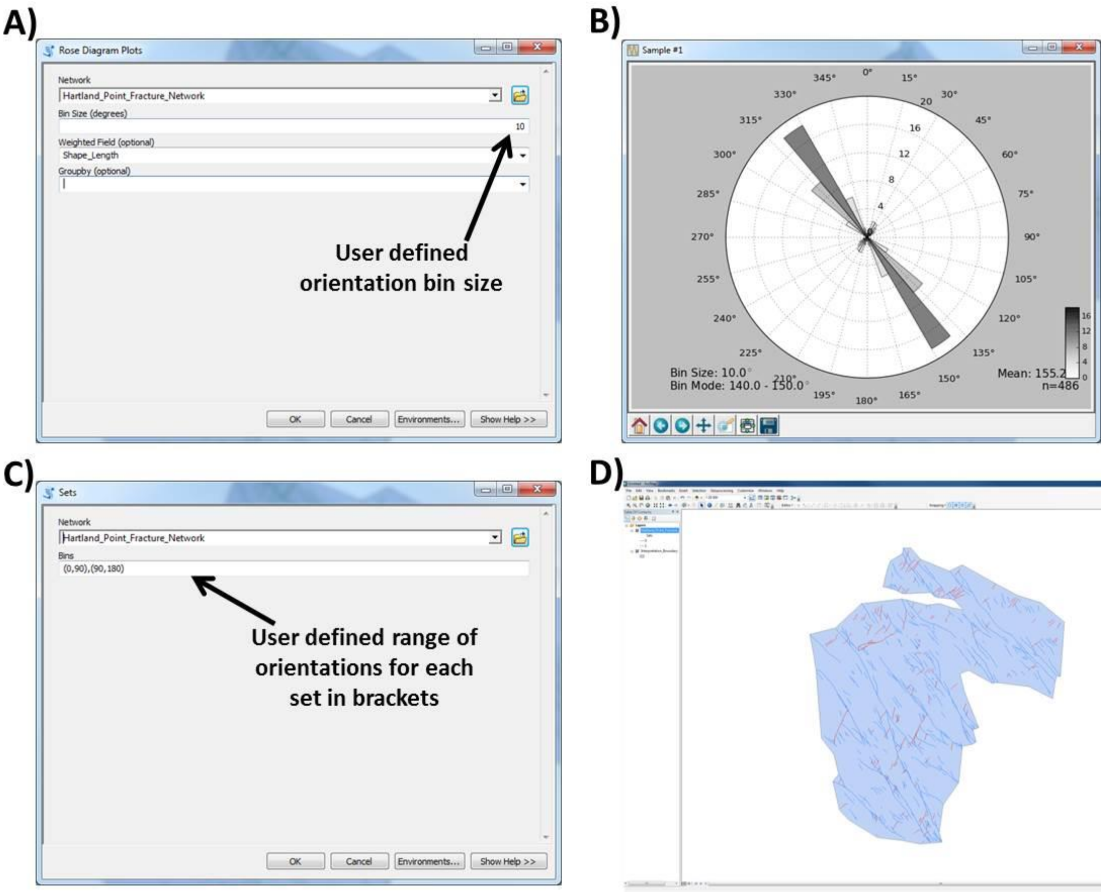
11) Select **Hartland_Point_Fracture_Network** as the input feature class. The bin size is set at 10 degrees by default.

12) The rose diagrams can also be weighted by an attribute such as fracture length, aperture or displacement. Select ***Shape_Length*** for the ***Weighted Field*** option. Click OK. A rose diagram should appear in a separate window. Have a try again using a different bin size.

Q3) The rose diagrams should allow you to identify fault sets, what are the main trends?

13) Using the rose diagrams, any number of fracture sets can be defined by orientation ranges using the 'Sets' tool and then visualized. It is good to classify the fault polylines into sets and add this information to the fault polyline attribute table. In the ***ArcToolbox*** navigate to **>NetworkGT > Geometry** and select ***Sets***.

14) Select **Hartland_Point_Fracture_Network** as the input feature class. Then add the orientation ranges of the sets that you have identified. Note that set orientations ranges must be between 0-180 degrees and defined within brackets, with each set separated by a comma. Click OK.



15) Open the attribute table of the **Hartland_Point_Fracture_Network**. You will now see that two new columns have been added grouping the faults polylines into set numbers and defining their orientation bearing.

16) You can now visualize the network based on these geometrical properties. Right-Click on the **Hartland_Point_Fracture_Network** feature in the **Table Of Contents** and click on **Properties**. Within properties are many tabs that allow you to choose how the feature will be displayed. These include:

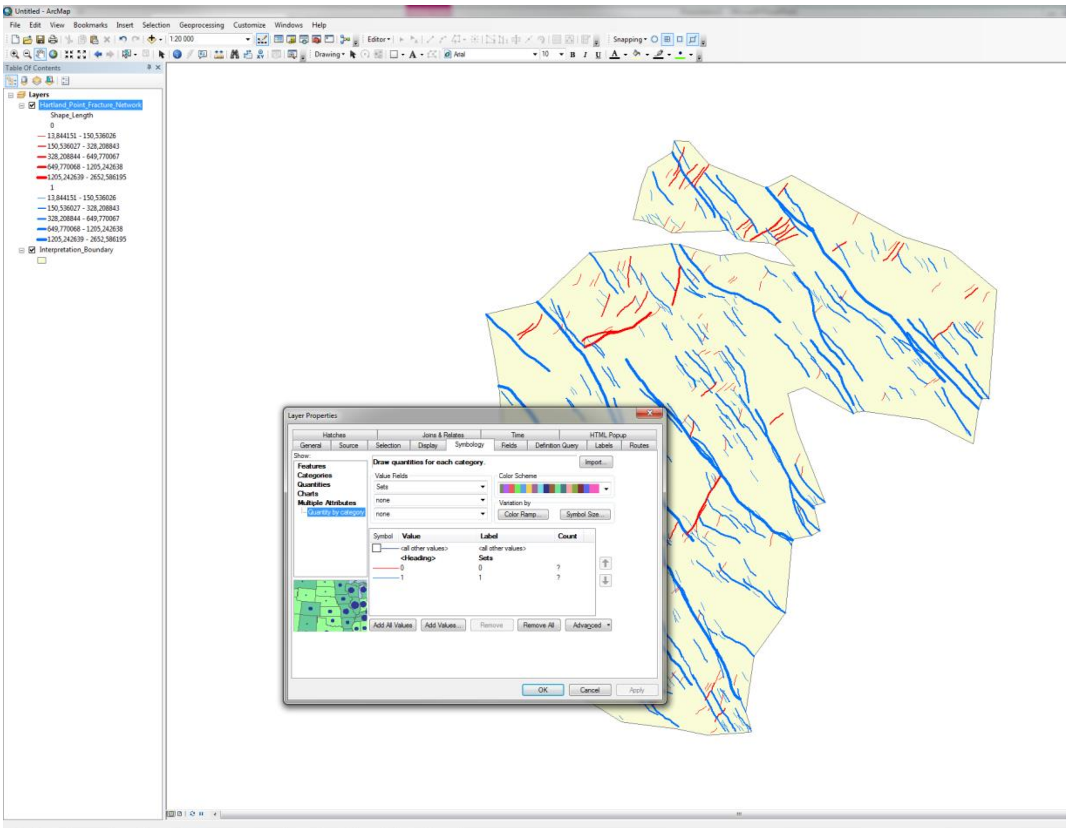
- Display – Allows control of the features transparency,
- Symbology – Allows colour coding and symbol sizes by certain attributes
- Labels – Allows labelling of features based on an attribute

17) Under the ***Symbology*** tab select ***Categories*** and the ***Unique values*** option. Under the ***value field*** select **Set**. Then click Add All Values.

18) Change the colour of 0 (=set 0) to red and 1 (=set 1) to blue. Click apply. You should now see all faults colour coded by fault type.

19) Under the ***Symbology*** tab now select ***Quantities*** and the ***Graduated symbols*** option. Under the ***value field*** select **Shape_Length**. Click Apply. You should now see all fault polylines with line thickness weighted by their length.

Continue exploring the Symbology and visualisation options for Faults including the ***multiple attribute*** option. Notice how the layers change in the Table Of Contents when you change the Symbology.



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' or the 'Histogram Plots' tools.

20) In the ***ArcToolbox*** navigate to **>NetworkGT > Geometry** and select ***Distribution Analysis Plots***.

21) Select **Hartland_Point_Fracture_Network** as the input feature class. Select **Shape_Length** for the ***Field*** option. Click OK. In an external window a series of cumulative frequency plots will be generated along with a table of numerous statistics on the fault lengths.

22) The tools can optionally be run on groups of fractures defined by attributes such as sets and types using the ***Groupby*** field. Rerun the tool, this time grouping the data by the **Set** field.

Q4) What distribution best describes the fault length of the population?

Q5) Does this distribution also fit the different fault sets?

Q6) What limitations are there when digitally analysing fracture length data?

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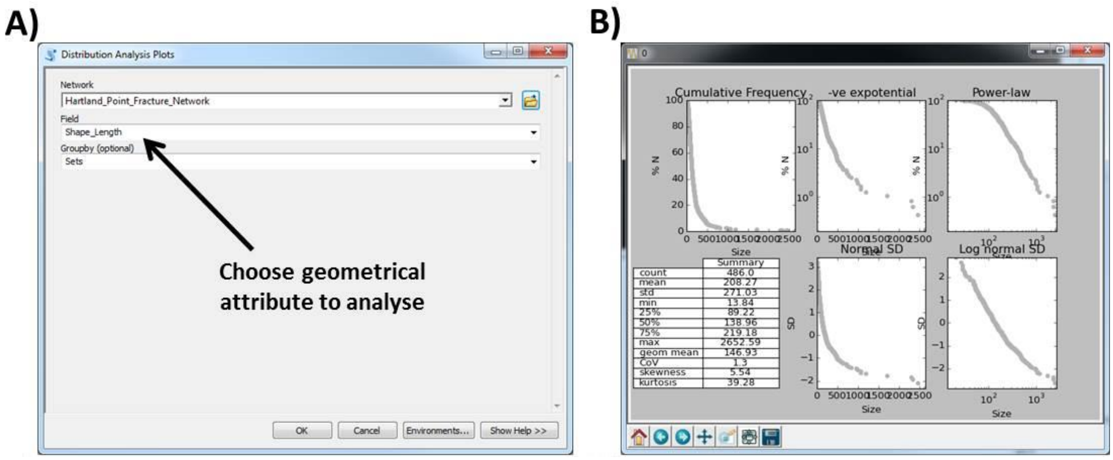

EXTRACTING TOPOLOGICAL INFORMATION FROM A NETWORK

NODES AND BRANCHES

One of the main aims of the NetworkGT toolkit was to provide an efficient and automated workflow for extracting topological information from digitised fracture networks, as it is rather time consuming to manually identify and extract nodes and branches for a large network. The most important topological information to extract are the different node and branch types as these can then be used to characterise the network as well as calculating other topological parameters, such as connections per branch. Branch and node types can be automatically extracted using the ‘Branches and Nodes’ tool.

23) Within the ***ArcToolbox*** Navigate to: **> NetworkGT > Topology** and double click on the ***Branches and Nodes.*** The inputs for the tool are the fracture network polylines, sample area polygon and the interpretation boundary polygon.

24) Select **Hartland_Point_Fracture_Network** as the input ***Network***. For the ***Sample Areas*** select **Interpretation_Boundary** as there are no sub sample areas at this stage and we want to extract the topology of the entire network at this stage.

25) Select the **Interpretation_Boundary** for the ***Interpretation Boundary***. The tool will recognise faults that intersect the boundary and classify the nodes as edge nodes instead of tips. It will also classify the branches as unknown branches.

26) Save the location of the output files to *the* ***NetworkGT_Example.gdb*** geodatabase. Call the ***Output Branches*** feature class **Branches** and the ***Output Nodes*** feature class **Nodes**. Click OK.

27) The tool has an additional option to ***Keep Attributes*** which if ticked will transfer information from the fault over to the branches, such as set number and fault number and type etc.

The tool will now run and output two new features 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. If this happens with one of your own datasets then you can use the repair tool to correct these.

Q7) Why is the interpretation boundary important?

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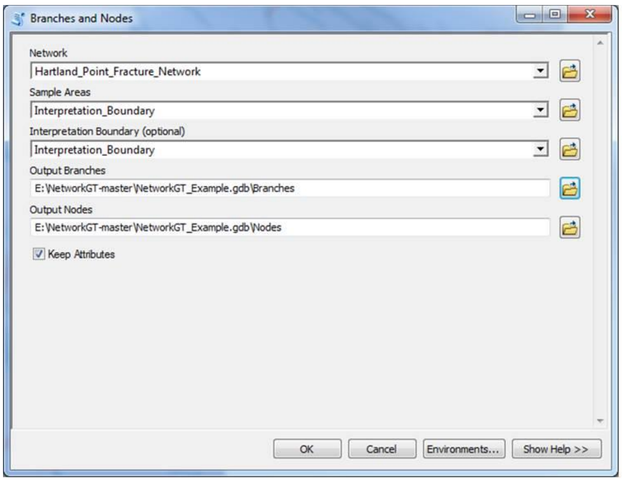
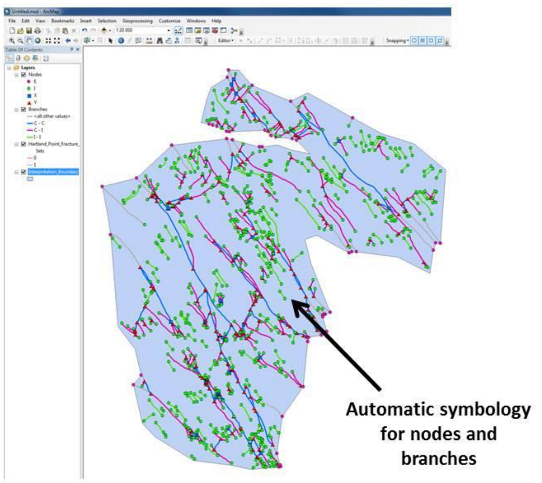




CALCULATING TOPOLOGICAL PARAMETERS AND TERNARY PLOTS

Once the branch and node feature classes have been extracted, specific topological parameters can be calculated using the 'Topology Parameters' tool.

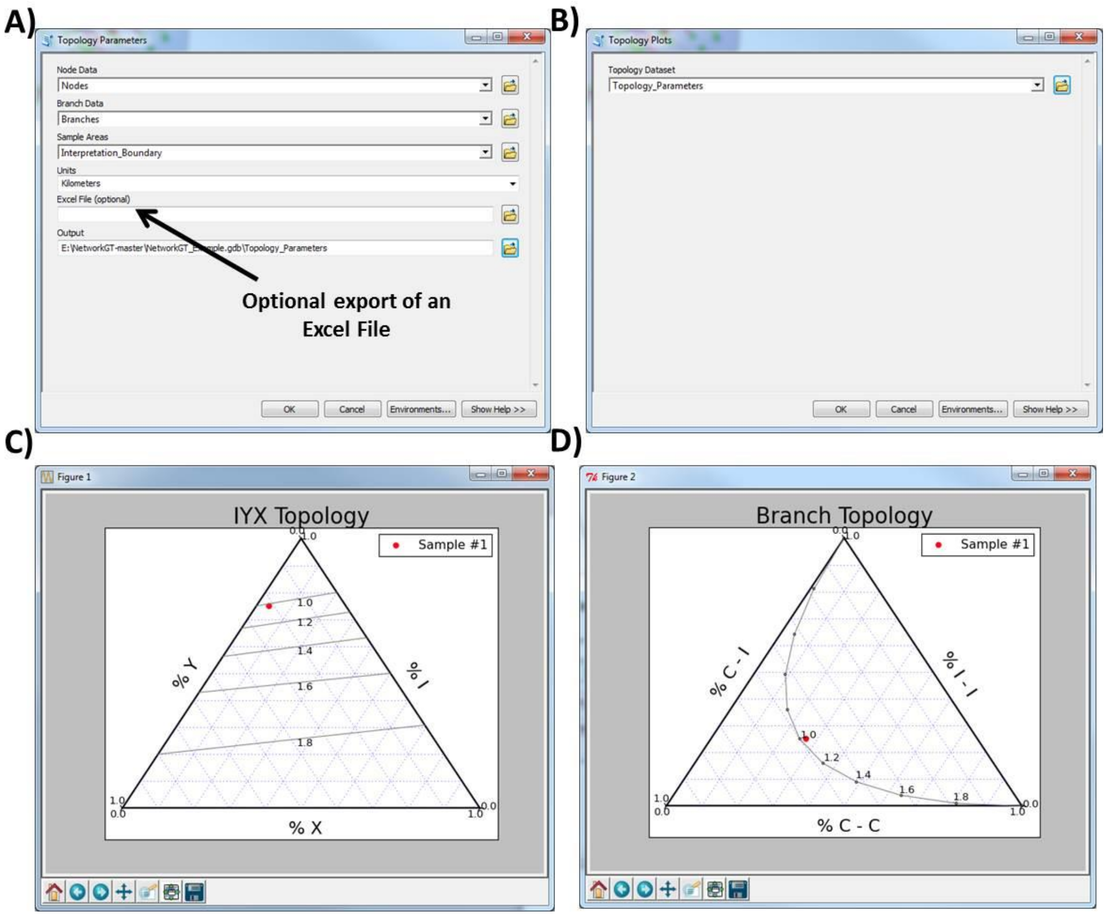
28) Within the ***ArcToolbox*** Navigate to: **> NetworkGT > Topology** and double click on the ***Topology Parameters.***

29) Select the **Nodes** feature class as input for the ***Node Data*** and **Branches** feature class as input for the ***Branch data***.

30) Under ***Sample Areas*** insert the **Interpretation_Boundary**.

31) Save the ***Output*** to the **NetworkGT_Example.gdb** geodatabase and name the feature class **TopologyParameters**. Click OK.

This will create a duplicate polygon feature class of the Sample Area(s) (In this case the Interpretation_Boundary polygon) with an attribute table that has several columns that calculate the proportions of the different node and branch types along with other network parameters such as 2D intensity, connecting node frequency, average connections per line, average connections per branch, average branch length, average line length, dimensionless branch intensity (a percolation parameter). Optionally an Excel file can also be produced and saved with all the information using the Topology Parameters Tool. This can be useful for any further analysis and calculations.



32) 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. Within the ***ArcToolbox*** Navigate to: **> NetworkGT > Topology** and double click on the ***Topology Plots.***

Q8) What is the degree of connectivity of the network?

Q9) What is the 2D intensity of the network?

Q10) Would you describe the network as connected or unconnected? Why?

Q12) What are the main fault trends and what are their fault types?

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Exercise 2: Spatial Mapping of Network Properties Using Contour Grid

GRID SAMPLING A FRACTURE NETWORK

For this exercise we will use a modified version of the fault network used in exercise 1. The network has the same number of fractures but their lengths have been increased by 125 metres to produce a more interconnected network. In this exercise we will use a grid sampling technique to map spatial variations in network properties.

33) Click the **Add Data** icon. Locate and select the ***Hartland_Point_Fracture_Network_Modified*** feature class within the ***NetworkGT_Example.gdb***.

34) A network of polylines can be sampled by a grid within the **Interpretation_Boundary** polygon using the '***Network Grid Sampling'*** tool. In the **ArcToolbox** navigate to **> NetworkGT > Network Sampling** and select ***Network Grid Sampling***.

35) Select the **Interpretation_Boundary** for the input. The tool outputs a polygon feature class of grid cells within the interpretation boundary that systematically sub-samples the network. The tool allows the user to specify the size of the grid cells as well as applying a search radius for sampling branches and nodes associated with each grid cell. Specify **100m** for the ***Width x Height*** and **250m** for the ***Search Radius***.

36) Specify the location of the Output **as NetworkGT_Example.gdb** geodatabase and name it **Network_Grid**. Click Ok.

37) The polygon feature class will be added to the geodatabase but you will then need to **add the data to the ArcMap project**. Once added the grid will appear in the Dataframe and Table Of Contents. Each grid cell represents a represents subsample area of the network.

38) Now extract the topology and topological parameters of the network following **steps 23-31** from **Exercise 1**. It is important that you use the **Network_Grid** polygon feature class as the ***Sample Areas*** input instead of the **Interpretation_Boundary** which is still used as the ***Interpretation Boundary*** input. Add the prefix '**Grid**' to each name (e.g. Branches_Grid, Nodes_Grid, Topology_Parameters_Grid etc.) when saving the output to the **NetworkGT_Example.gdb** in order to distinguish the outputs from those extracted in Exercise 1. When calculating the topological parameters using the extracted branches and nodes for each grid cell as inputs.

The 'Branches and Nodes' tool will extract branches and nodes for every grid cell using the search radius to define a circular sample region. These will be added to the Table OF Contents and again will have an automatic symbology applied. The Topology Parameters tool will output a duplicate polygon feature class of the Network_Grid with a row for each grid cell and a set of calculated parameters.

Q13) Do you notice anything different about the node symbology in the Table of Contents? What could be causing this?

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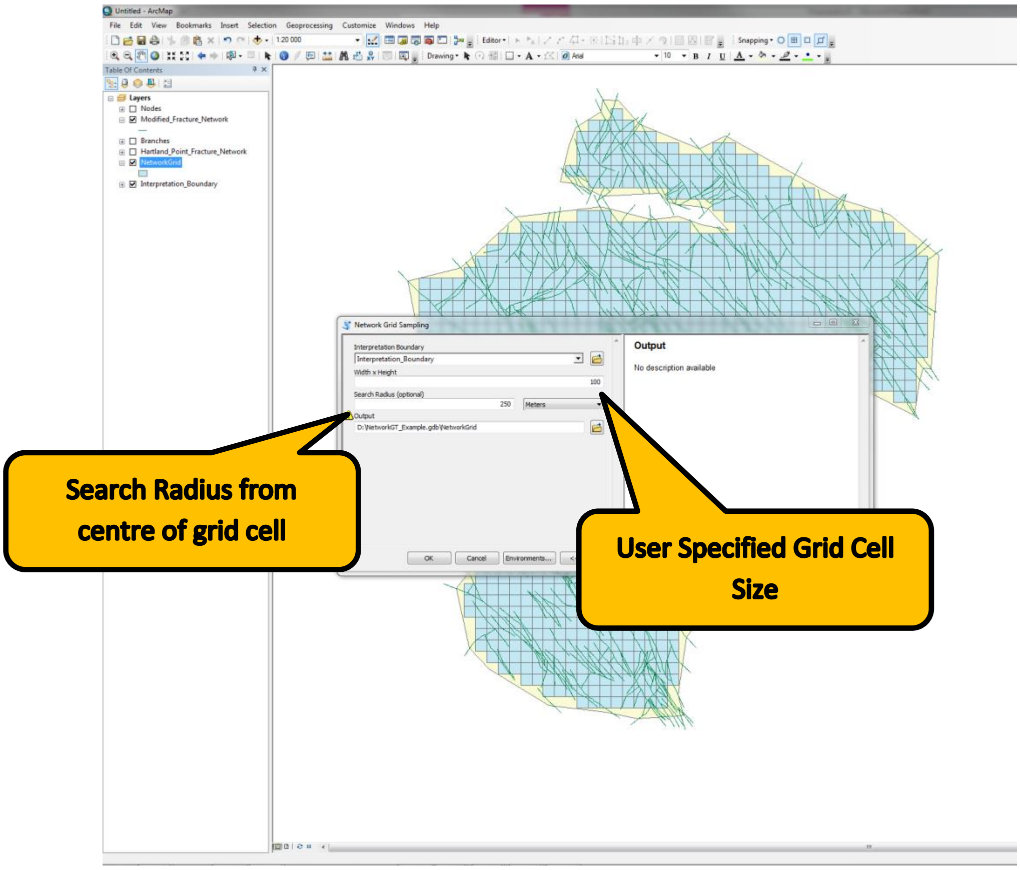

SPATIAL VISUALISATION OF NETWORK PROPERTIES

We now have a grid of polygons that represent circular subsamples of the network. Each grid cell has associated topological parameters and network properties calculated for it meaning we can now assess the spatial variability throughout the network. The best way of doing this is to visualise these spatial variations in the form of a map.

39) Right-Click on the **Topology_Parameters_Grid** feature in the **Table Of Contents** and click on **Properties**.

40) Under the ***Symbology*** tab select ***Quantities*** and the ***Graduated Colours*** option. Under the ***value field*** you will see a number of parameters you can choose from. Select **2D Intensity** and change the ***Colour Ramp*** to Green, Yellow, Red. Click Apply. You should now see all a grid contouring variations in 2D intensity.

Now you can visualise spatial variations in network properties. Have an explore of the different properties including connections per branch and connecting node frequency. Explore the different options for displaying the different quantities.

Q14) Can you see any correlations in the spatial variations of the different network properties? If so what are these and why might you see a correlation?

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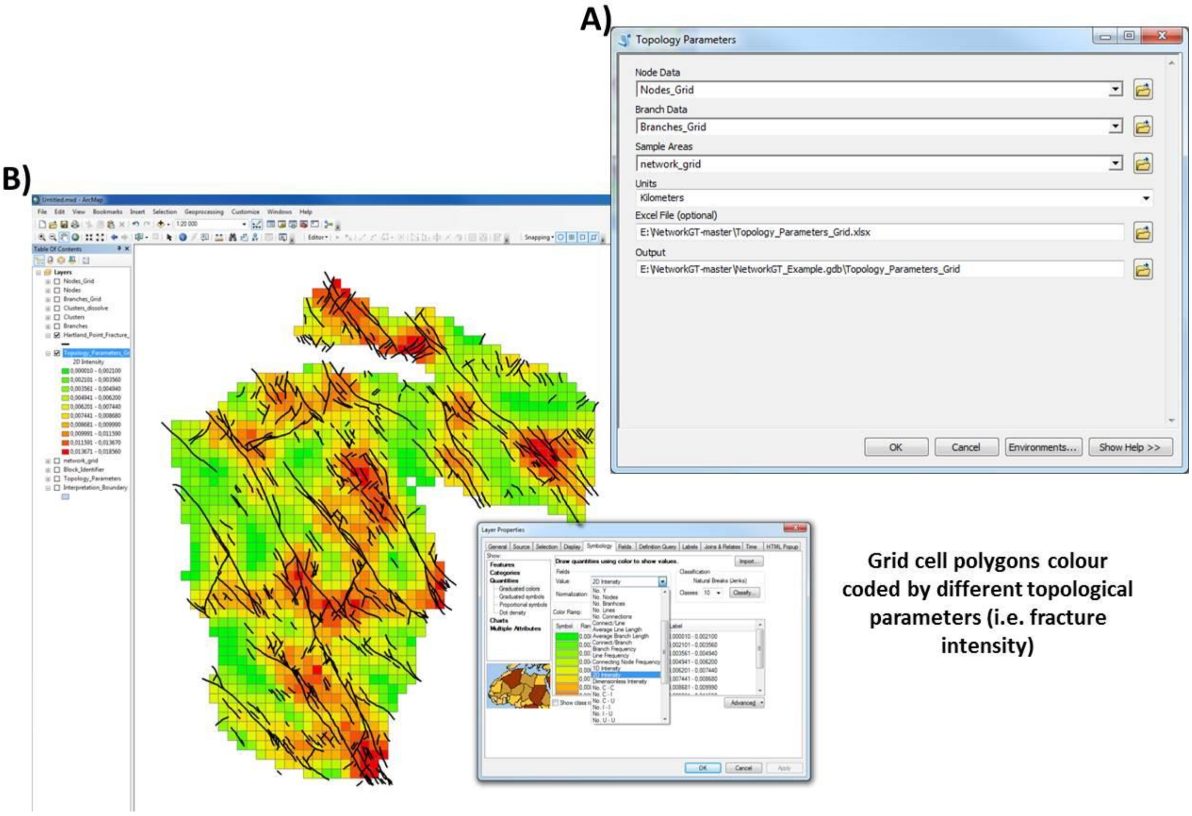
A)
Topology Parameters
Node Data
Nodes_Grid
Branch Data
Branches_Grid
Sample Areas
network_grid
Units
Kilometers
Excel File (optional)
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Output
E:\NetworkGT-master\NetworkGT_Example.gdb\Topology_Parameters_Grid
OK
Cancel
Environments...
Show Help >>
B)
Grid cell polygons colour coded by different topological parameters (i.e. fracture intensity)

Exercise 3: Clustering and Block Analysis

EXTRACTING CLUSTERS

The NetworkGT toolkit provides an automated means of identifying and extracting numbers, sizes, and spatial distributions of clusters within a fracture network. Such analyses provide insight into the fluid flow behaviour of a network helping identify large spanning clusters and potential pathways and/or barriers for fluid flow. Spatial distributions and sizes of internal blocks within a fracture network are important when quantifying the amount of fluid-rock interaction or potential compartmentalization.

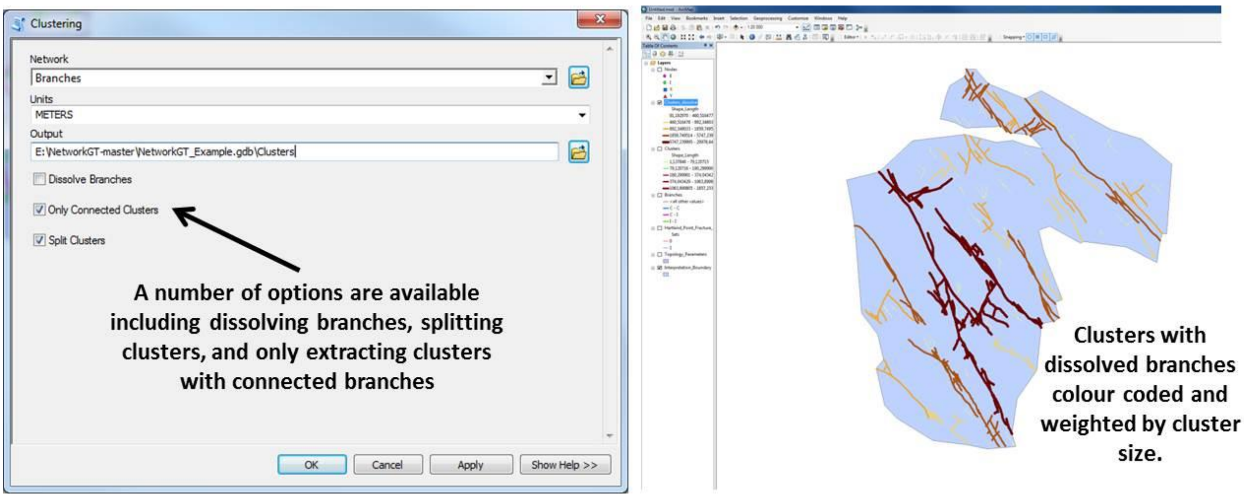
41) Clusters in a fracture network can be analysed by several methods using the NetworkGT toolbox. We will first explore the data from the original fault network used in Exercise 1. In the **ArcToolbox** navigate to **> NetworkGT > Topology** and select ***Clustering***.

42) Select the **Branches (derived in Steps 23-27)** for the ***Network*** input and tick the **Dissolve Branches** option, tick the **Only Connected Clusters** option, untick the **Split Clusters** option. Save the output as **Clusters**. Click OK.

43) The dissolved 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.

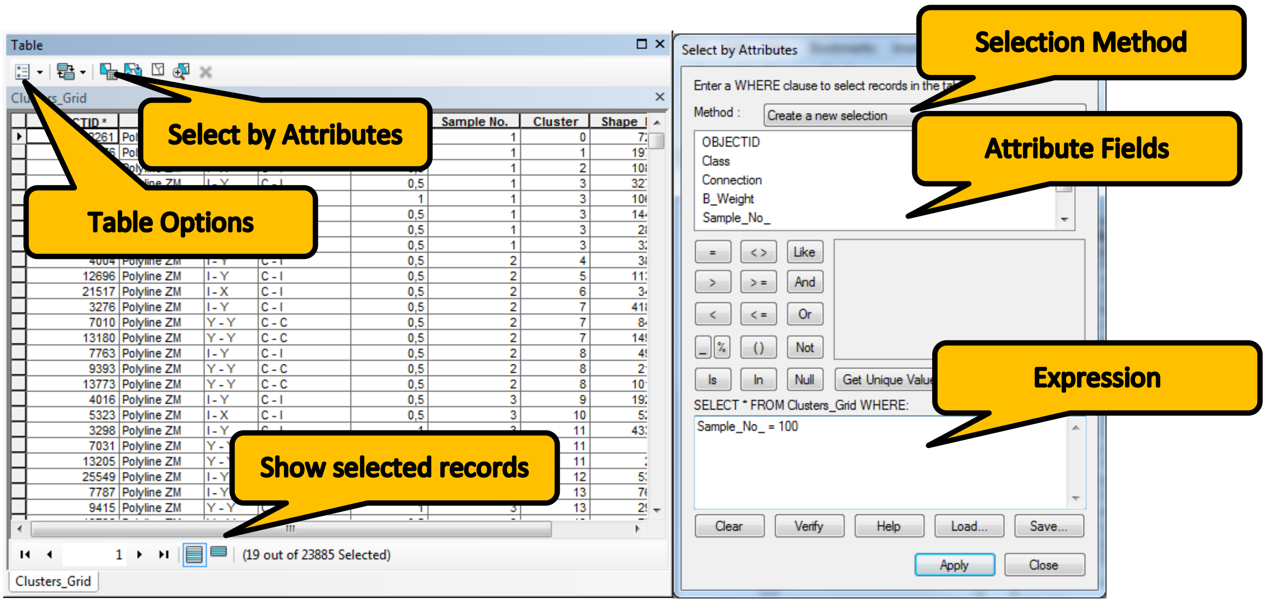
44) Open the Attributes Table and take note on the new attribute fields.

45) Visualize the size of the clusters in the symbology ribbon by right-click on the **Clusters** feature in the **Table Of Contents** and click on **Properties**. Navigate to **Symbology > Quantities > Graduated Symbols.** Under the ***value field*** select **Shape_Length**. Click Apply.



46) Next we will use the output from the Contour Grid in Exercise 2. Select the **Branches_Grid (derived during step 38)** for the **Network** input and keep the default values of the boxes (***Dissolve Branches – unticked***, ***Only Connected Clusters – ticked*** and ***Split Cluster – ticked***). This process will only consider clusters that occur within each sample area radius as defined in the Contour Grid of step 35. Save the output as **Clusters_Grid.** Click OK.

47) Open the Attributes Table of the **Clusters_Grid** and explore the method of clustering achieved. To examine a specific sampling area, click the **Select By Attributes** function found in the upper right hand corner and the third button from the left. Type in the empty expressions box - **Sample_No_ = 100** and click **Apply**. Then click the **Show selected records** button found at the bottom of the Attributes table. Now explore only the clusters found within that sample area by continuing to select records (hold the ctrl key for multiple selections) to highlight records with the same cluster.



Q15) How do the two different clustering methods differ? When is it appropriate to apply one method over the other?

Q16) In the original fracture network, what proportion of the clusters are connected by I-C versus C-C branches?

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BLOCK ANALYSIS

Spatial distributions and sizes of internal blocks within a fracture network are important when quantifying the amount of fluid-rock interaction or potential compartmentalization.

48) First let's identify the blocks that exist in the ***Hartland_Point_Fracture_Network_Modified*** dataset within the boundaries of sampling area. In the **ArcToolbox** navigate to **NetworkGT > Topology** and select ***Block Identifier***. Use the ***Hartland_Point_Fracture_Network_Modified*** as the **Network** input and the **Topology_Parameters_Grid** as the **Sample Area**. Save the output as **Blocks**, click OK and add the resulting data from your database if it did not do so automatically.

49) Open the Attribute Table of the **Topology_Parameters_Grid** and scroll to the right to review the statistics of known block sizes in the fracture network within each sample area. Now

open the Attribute Table of the ***Blocks*** feature class and right-click the header of the attribute field **Area** and select **statistics.** The graph and statistics show you the distribution of blocks of the entire fracture network.

50) Visualize the ***Blocks*** by navigating to **> Properties** > **Symbology > Quantities > Graduated Colours.** Under the ***value field*** select **Block_Size** and choose an appropriate colour ramp. Click Apply.

51) We will now use the clusters to analyse the theoretical number of blocks in the fracture network within each contour grid sampling area. In the toolbox **NetworkGT > Topology** open the tool **Block Analysis**. Use the **Topology_Parameters_Grid** as the **Topology Dataset** input, **Clusters_Grid** for the **Clusters** input and the **Nodes_Grid** for the nodes. Click OK.

52) Visualize the number of theoretical blocks within the **Topology_Parameters_Grid** by navigating to **Symbology > Quantities > Graduated Symbols.** Under the ***value field*** select **No. Theoretical Blocks**. Click Apply. Test other visualization techniques under the symbology section.

Q17) How big is the biggest compartments in the network?

Q18) Do you notice any spatial trends in the compartmentalisation of the fracture network?

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