

Network Analysis with Cytoscape Tutorial

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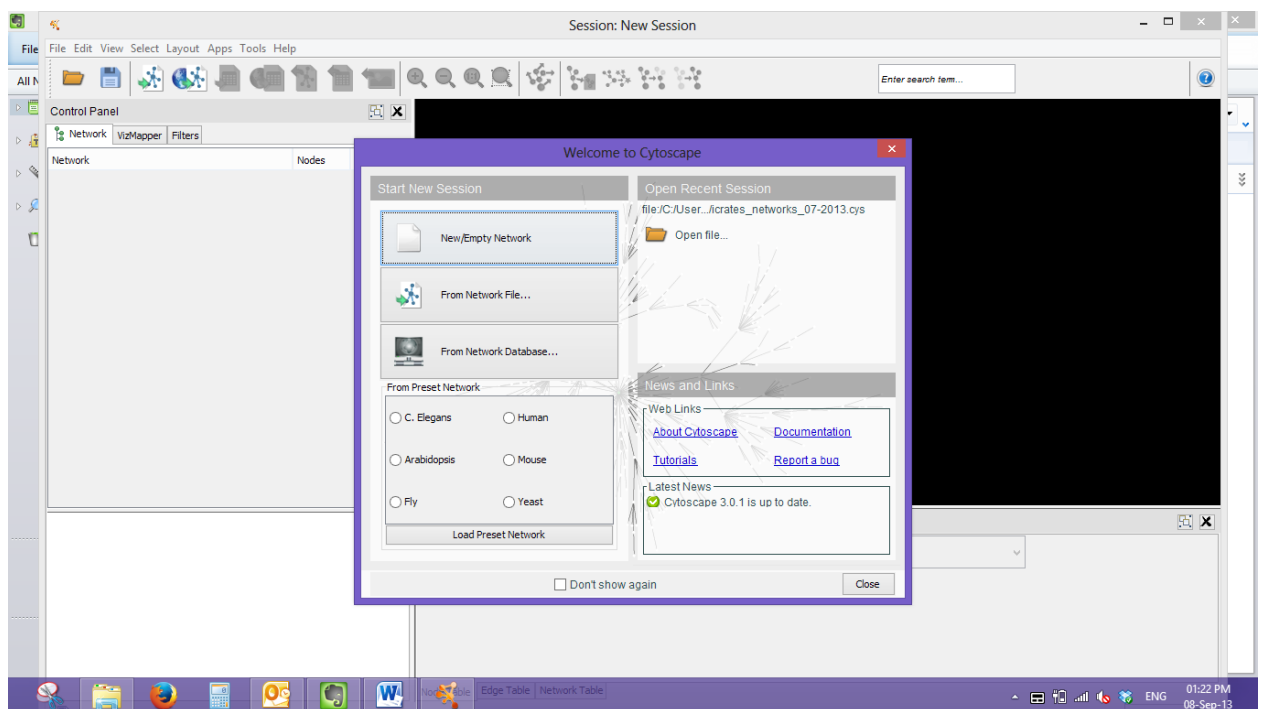
In this practical you will learn how to create, visualise and analyse networks using Cytoscape (<http://cytoscape.org/>), and how to export the results of these analyses. This practical is conceived as an introduction to exploratory network analysis for the Humanities, using an archaeological/geographical example.

Download the files needed for this practical. These should include: 'network.xls' and 'network_attributes.xls'.

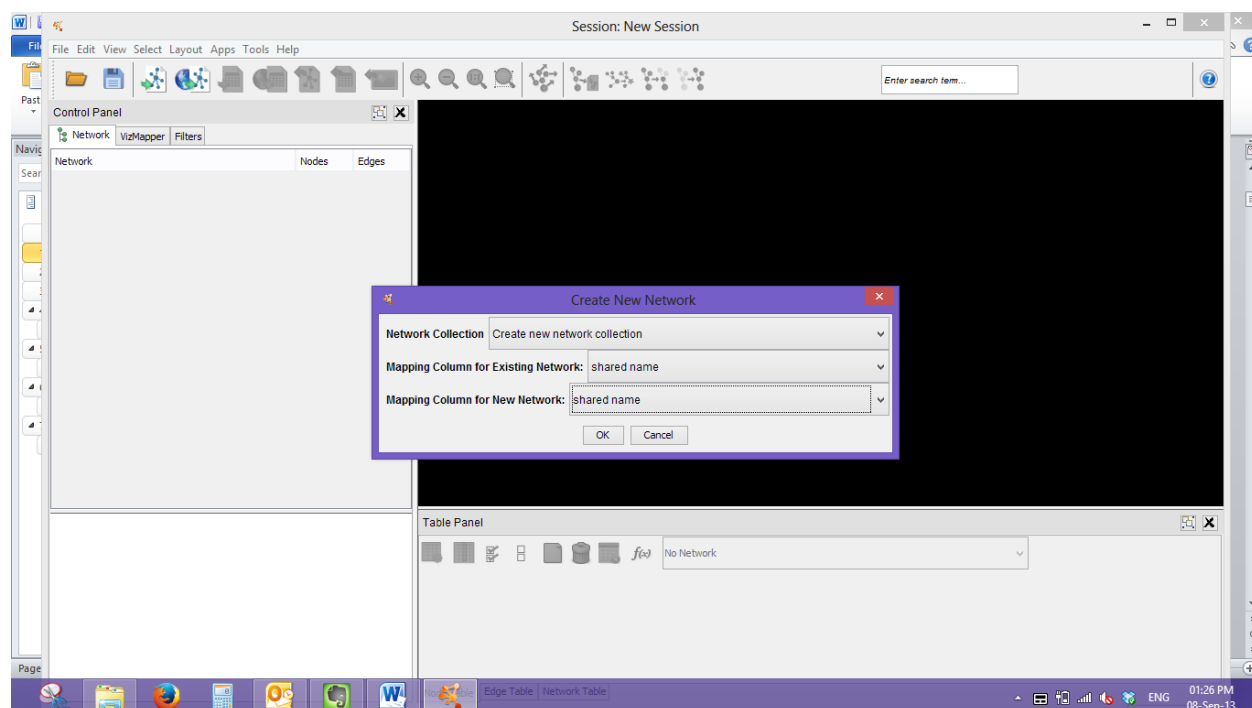
1. Cytoscape interface

Open Cytoscape from the Windows programs menu.

After loading the software Cytoscape will show you a welcome screen. Select 'New/Empty Network':



Accept the default options in the 'create new network' window:



Always start by saving a new session. Select **File > Save As** from the top menu. A dialogue box appears, select the location where you want to save the new session file and click the **Save** button. The name of your session will now appear at the top of your Cytoscape window. Cytoscape saves sessions in its own format, the session files always end in '.cys'.

There are three main parts to the Cytoscape interface: the *control panel*, *table panel* and *workspace*.

Firstly, on the left hand side is the *Control Panel*, which has three different tabs called *Network*, *VizMapper* and *Filters*. The *Network* tab will list all the networks that you have imported or opened, which is why it is now empty. The *VizMapper* tab allows you to apply visual styles to your network and modify every aspect of how they are represented (see section 7 below). The *Filters* tab allows you to create and modify filters to make custom selections from the network (see section 4 below).

Secondly, at the bottom of the screen you will find the *Table Panel*. This is where you can browse through selected nodes, edges, networks and their attributes. The table panel should be empty now. The five buttons at the top left of the *Table Panel* are of interest. The first one allows you to change the table mode, the second one to click attributes on and off, the third one to click ALL attributes on and the fourth one off, the fifth one allows you to create new attributes. The final one allows you to delete attributes.

Thirdly, the black space in between the Control Panel and the Table Panel is your workspace. This is where network windows will show up once you created them. Within network windows you can make selections and modify the position of nodes, as you will see in section 5.

2. Network input files

To create a network you can either make it manually (which will not be covered in this practical) or you can import it from other files. In order to create networks you will need only one thing: a list of all edges or arcs between all nodes (an edge is a line without a direction that connects two points, an arc on the other hand does have a direction, e.g. from node A to node B). These kinds of lists can be very simple as we will see below. In addition to this list we might want to import information about these edges or arcs. This information takes the form of ‘attributes’ of the arcs or edges. At this point we still do not have any information about the nodes, however. To import information on nodes we will need a list of all individual nodes and their attributes. In this section we will have a first look at this data needed to create networks.

Cytoscape can import many different file types. In this practical we will use Microsoft Excel spreadsheets.

The two files you downloaded are Excel spreadsheets: ‘network.xls’ and ‘network_attributes.xls’.

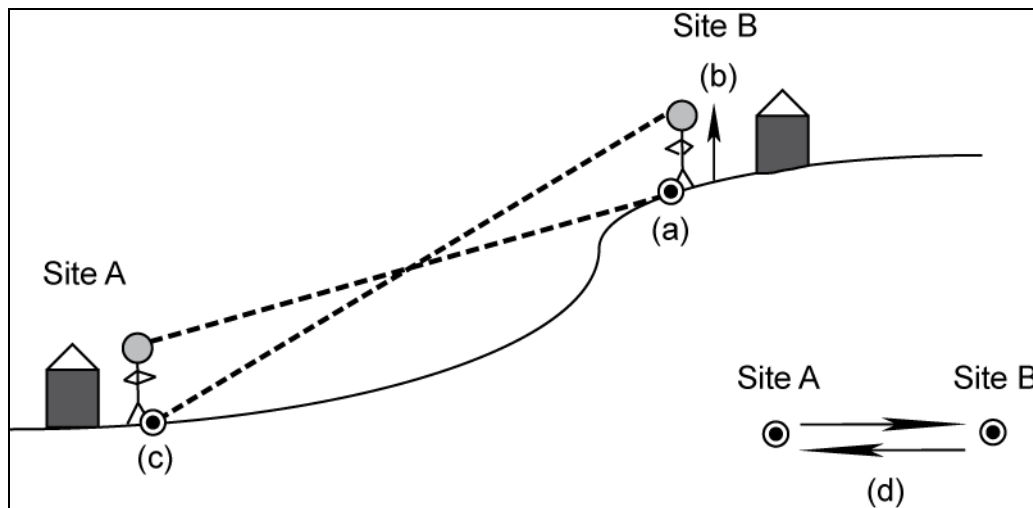
Now we will open these two files in Microsoft Excel (or an alternative spreadsheet programme) to see what kind of data is needed to make networks. First, open ‘network.xls’ in Microsoft Excel. Scroll all the way up to the top of this long document if necessary.

You will see that this spreadsheet consists of nine columns with information. At the top of the spreadsheet the first row describes what kind of information is stored in each column:

line ID	from node	to node	probability	length	from x	from y	to x	to y
---------	-----------	---------	-------------	--------	--------	--------	------	------

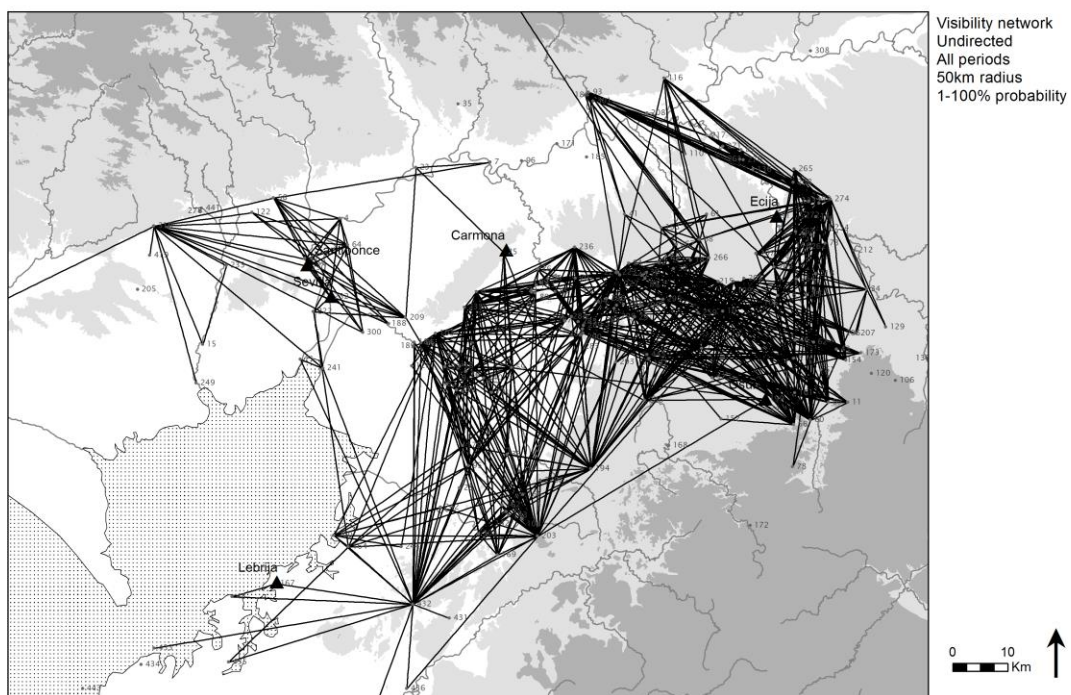
It might not look like a network now, but this spreadsheet actually contains all the information we need to create a really large and complex web of relationships. Every row describes an arc (or directed relationship): the arc starts with the ‘from node’ described as a numerical identifier in the first column (e.g. 2) and ends in the ‘to node’ also described as a number in the third column. All the other columns hold information on these edges, like the probability of an arc, its length, its number, and X and Y geographical coordinates of its endpoints.

You might wonder at this point what all these arcs represent. This specific list of information describes 190 archaeological sites (the ‘from’ and ‘to’ nodes) and each site was given a unique number (in column ‘from node’ and ‘to node’, e.g. 2). This list describes a visibility network: the directed lines that go from one node to the other represent lines of sight. For example, we could read the first row in the list like this: “arc number 1 indicates that an observer at site 2 can see site 445 about 9% of the time, and this line of sight has a length of 10km”. The creation of these lines of sight and this network is described in the figure below:



In this picture we see an observer located on point (a) at site B. This observer can see point (c) at site A with a certain probability. On the latter site another observer can see point (a) at site B with a given probability. We can describe this type of information as a network (d) by representing each site (or at least the observer location selected for a site) as a node and connecting them with directed lines (arcs) if from one site the other can be seen.

This is a geographical visualisation of the visibility network, limited to lines of sight with a length up to 50km:



What is the advantage of looking at this information as a purely topological network rather than a geographically projected network? Why don't we just stare at maps in a GIS? It is important to stress that these different techniques

are by no means mutually exclusive. They complement each other by focusing on different aspects of the same dataset. The advantage of the network approach is that:

- It allows us to visualise this large number of interactions in an explicit way
- It forces us to think through interactions between sites. Links of visibility between sites could indicate that direct communication between these sites through signalling might have occurred. Sites can also exercise visual control over a surrounding landscape and the sites within this landscape. A visibility network will also tell us which sites can be seen from many other sites and from which sites many other sites can be seen. Archaeologists might be interested in exploring if such visual prominence was intentional and what role it played in structuring the interactions between past communities.
- We can explore the structure of all these interactions combined
- We can analyse both the role of individual nodes, as well as the structure of the network as a whole

We will do most of these things in the second part of the practical!

First we will have a look at the second file we downloaded. Open 'network_attributes.xls' in Microsoft Excel. Scroll to the top of the spreadsheet if necessary.

The spreadsheet has seven different columns, each holding a different type of information about the nodes. These are the node attributes. The top row of the spreadsheet describes what kind of information is stored in each column:

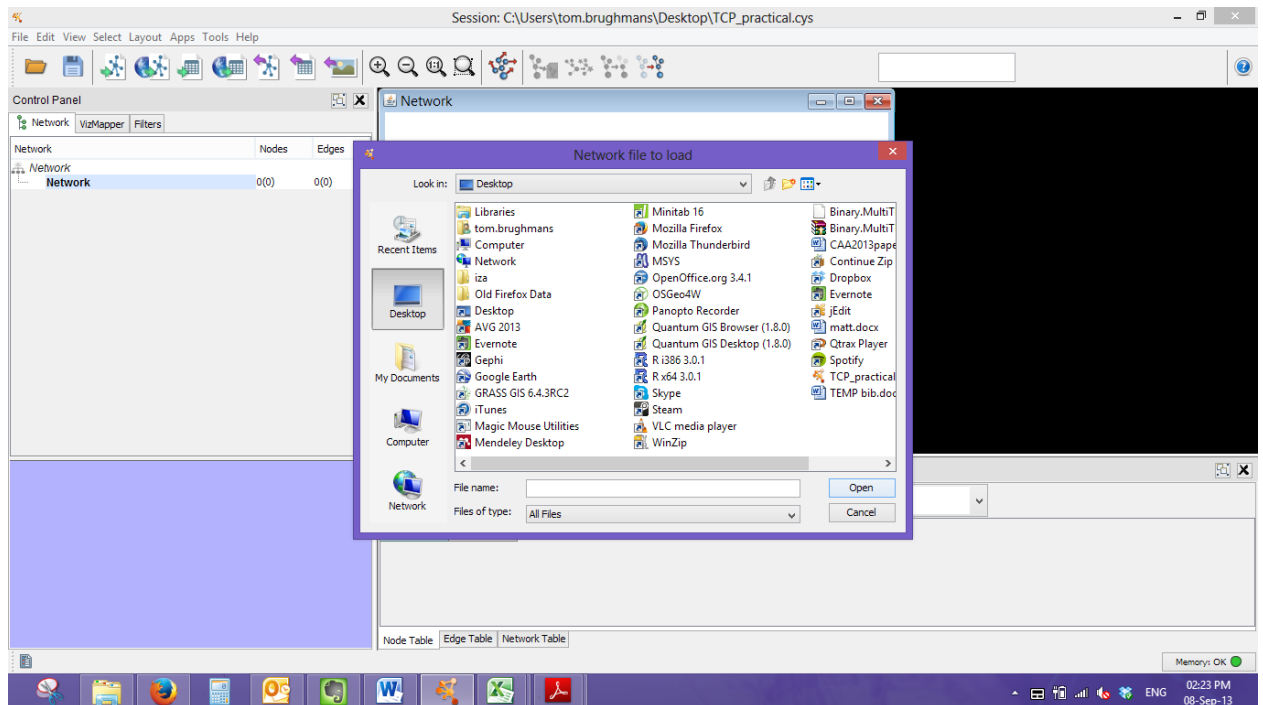
SiteID	Site name	Iberian	Republican	Early Imperial	Middle Imperial	Late Imperial
--------	-----------	---------	------------	----------------	-----------------	---------------

The first column ('SiteID') is the unique code for each site that we have also encountered in the first file we opened (as from node and to node). This column will allow us to link this list of attributes with the list of arcs. All the other columns are attributes of the nodes. The column titled 'Site name' holds the name by which the site is known, and we will use this as a label for the nodes. The next five columns are date ranges of periods: Iberian (Iron Age), Roman Republican, Early Imperial, Middle Imperial, and Late Imperial. A value of 1 indicates that a site was occupied during this period, and 0 means it was not. These columns will allow us to explore how this network of visibility changes through time.

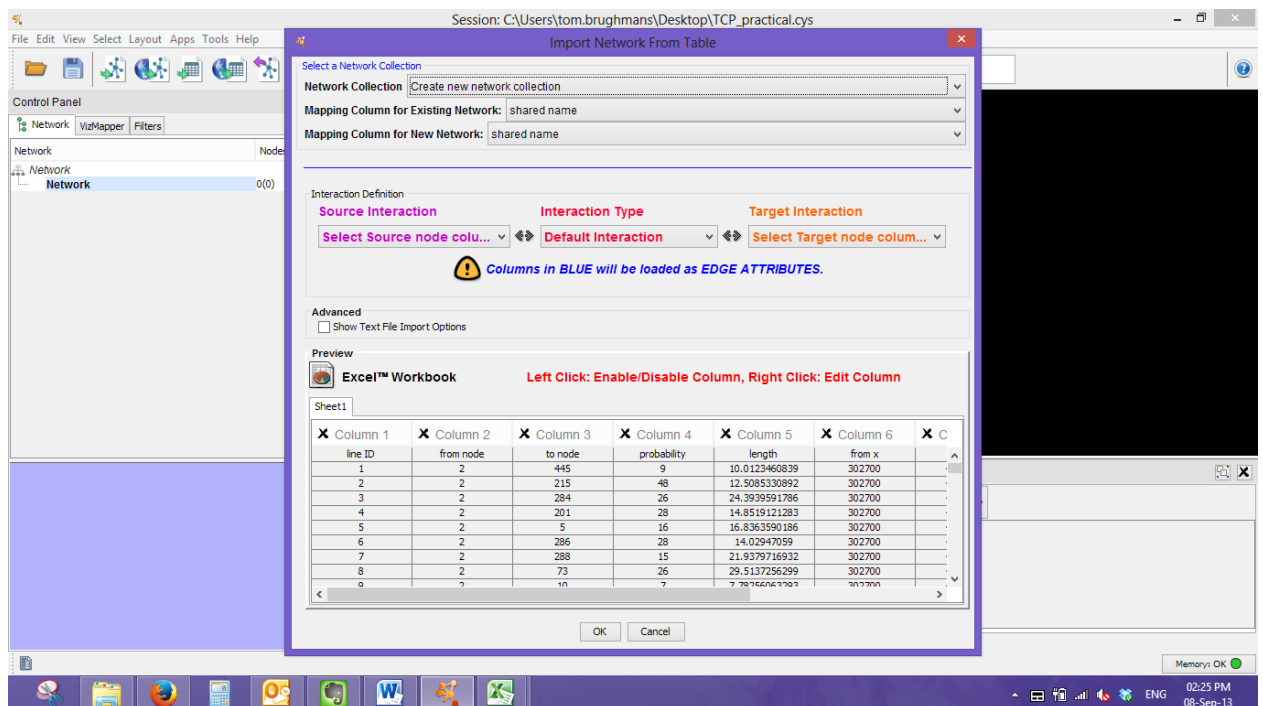
3. Import network

We will now use the two spreadsheets that we looked at in the previous section to create networks.

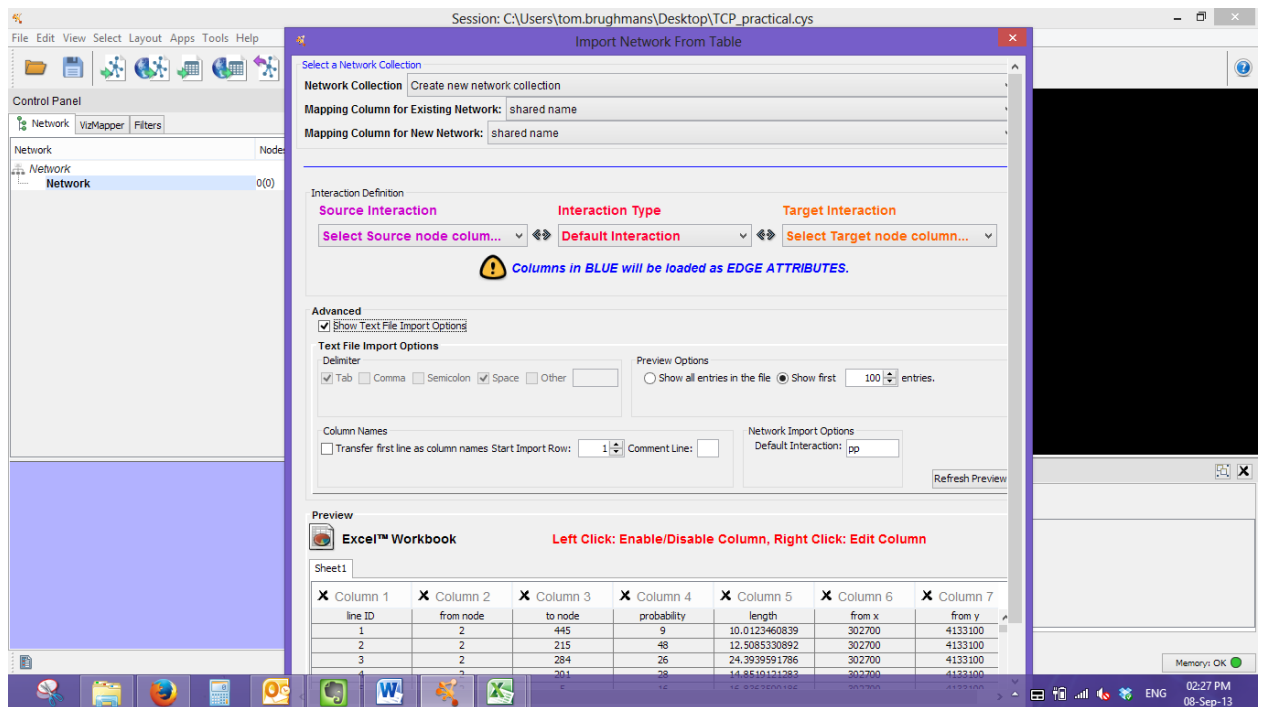
In Cytoscape click **File > Import > Network > File....** A dialogue box appears that looks like this:



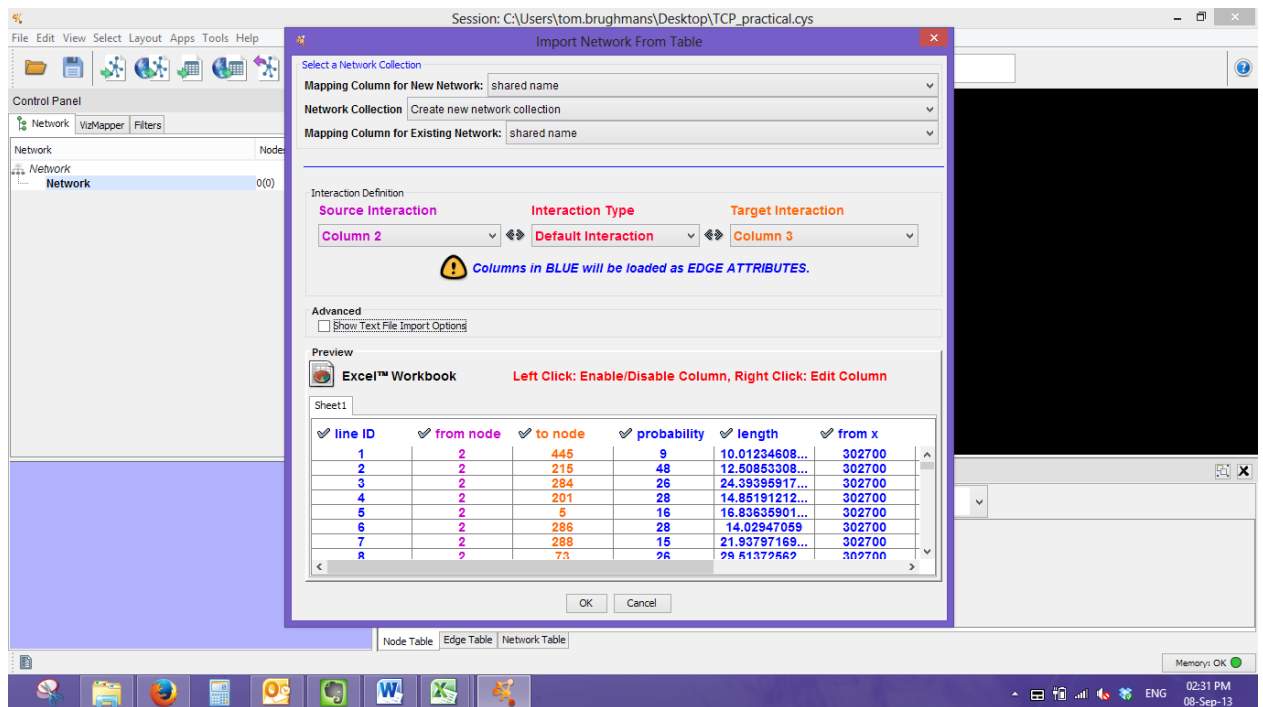
Browse to 'network.xls', select it and click **open**. A new dialogue box appears. You will see that the preview box at the bottom shows part of the spreadsheet:



The first thing we need to do now is make sure that Cytoscape knows the first row holds the labels. To do this, click the box in front of **Show Text File Import Options**. The dialogue box is now extended like this:

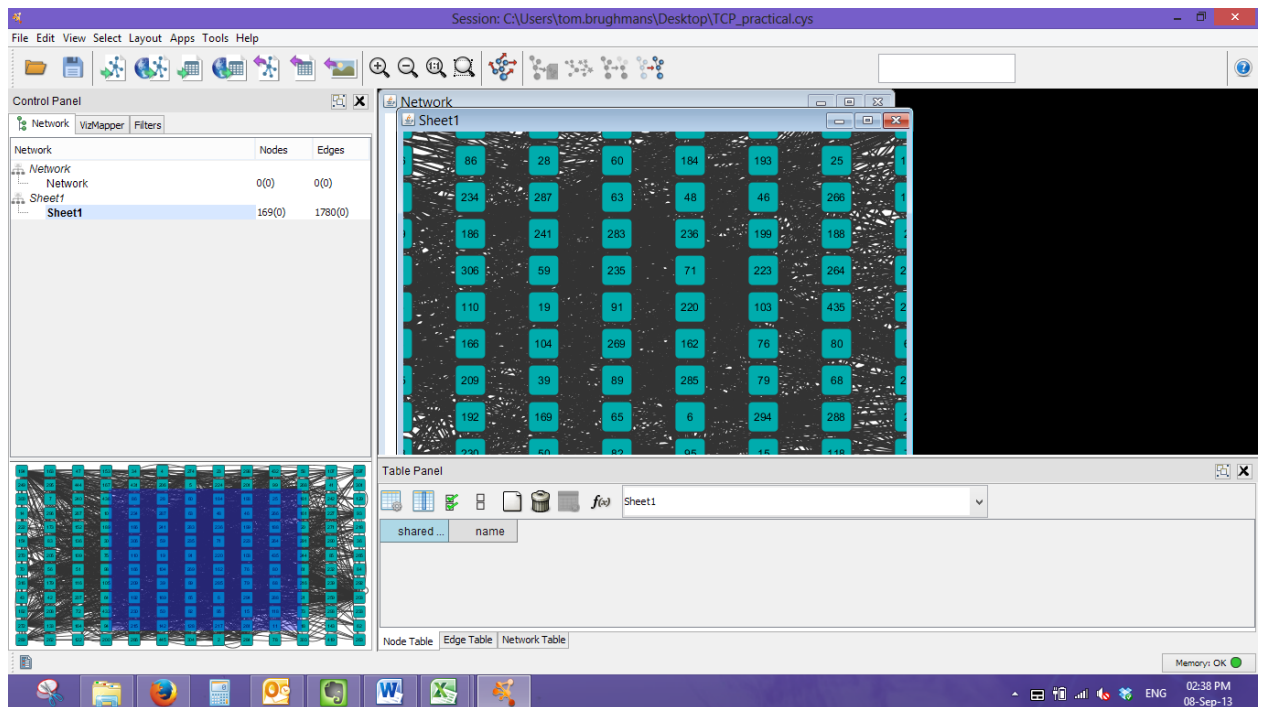


Click on the box in front of **Transfer first line as attribute names**. This will do exactly as it says: the first row of the spreadsheet will be used to label the data in the columns. Next we will have to specify which column holds the starting points for the arcs and which column holds the end points. Note that since our lines of sight have a direction it is extremely important to get the order right: the source is the 'from node' and the target is the 'to node'. To do this, click on the drop down box for **Source Interaction** and select the relevant column. Notice how this column now shows a **V** sign next to the label and is coloured purple. Next click on the drop down box of **Target Interaction** and select the relevant column. This column is now coloured orange. Now we will have to select all the other columns as arc attributes: this is extra information on the arcs that we can use to explore the network. Click once on each of the remaining column labels in turn, notice how they turn blue when selected. Your screen should now look like this:



Now we are ready to import. Click the **OK** button at the bottom of this dialogue box. The network will be loaded into your Cytoscape session, this may take some time. When it is successfully loaded a dialog box will appear that tells you the network has been successfully loaded.

Your Cytoscape window will now look completely different. On the Control Panel you will have a new line highlighted and titled 'Sheet1'. This is the first network you imported. At the bottom of the Control Panel an overview of your entire network is given. If you place your cursor in this panel, click and drag you will be able to move the view. In the workspace you will have a new window that shows your network:

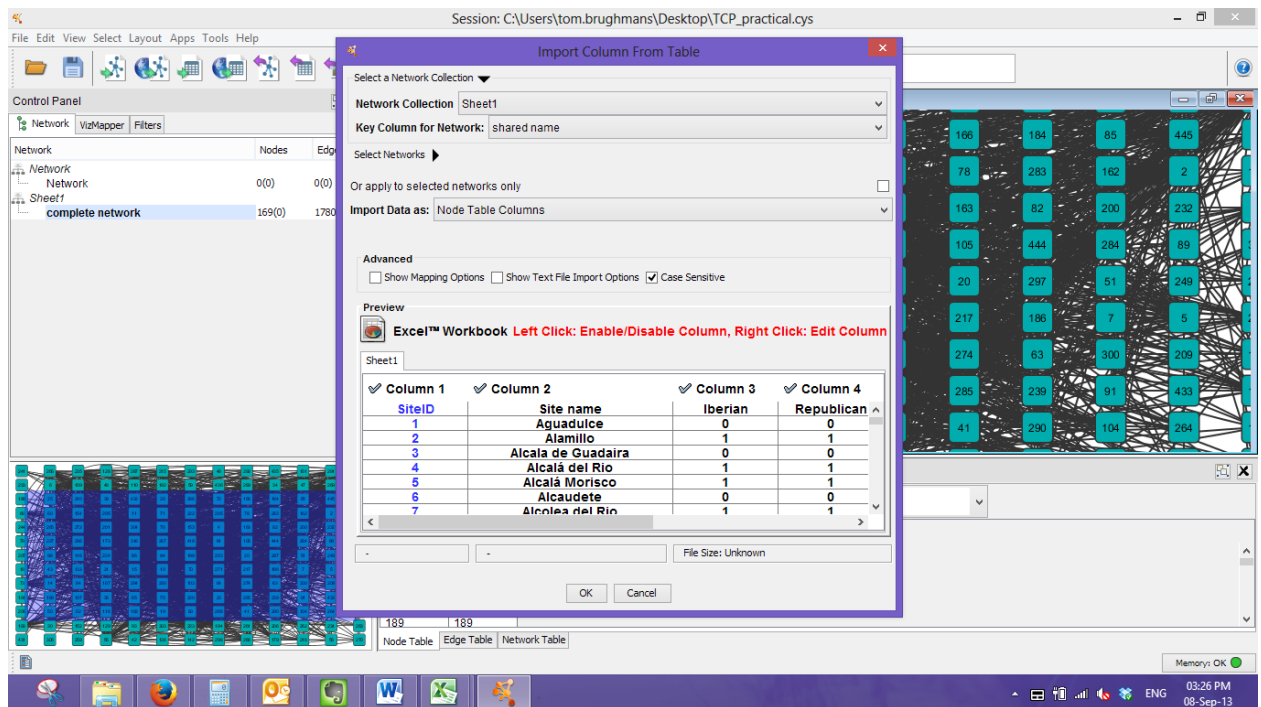


You might want to save your session again at this point!

First of all, let's rename the network so that we remember what data it holds once we have more networks. Right click the 'sheet1' in the Control Panel and select **Rename Network**. A new dialogue box will appear. Give the network the name 'complete network' and click **ok**.

You can maximise your network window to see it more clearly and explore it a bit. You can zoom in and out with your mouse wheel, you can select and move nodes with your left mouse button. By clicking and dragging inside the network overview box below the Control Panel you can change the view in your network window to different sections of the network. You can also do this by clicking and dragging the mouse wheel inside the network view. The network now shows a regular Rectangular layout, we will change this to something more interesting in section 5 of the practical.

This network now only consists of nodes, arcs and arc attributes. What we have to do now is import the node attributes. To do this select **File > Import > Table > File**. Browse to the location of 'network_attributes.xls', select it and click **OK**. A new dialogue box appears. A preview of the information in this spreadsheet is now shown at the bottom of this dialogue box:



First we need to make sure we map these attributes to the correct network. Click on the arrow to the right of 'Select a Network Collection' and select 'Sheet 1'. Again, we will have to tell Cytoscape that the first row holds the column labels. To do this, tick the box next to **Show Text File Import Options** and then tick the box next to **Transfer first line as column names**.

We will not look into more detail at the other options in this box. All you need to know for now is that it reads the spreadsheet and attaches all the information for a specific code ('SiteID') to all nodes in the network with that code.

Click the **OK** button.

Your Cytoscape window does not show the changes immediately. To see the node attributes, in the Data Panel click on the **show all columns** button (third from left). Now if you select a node by clicking on it you will see all the information we have about that node.

It might be useful at this point to give each node a label, so that we can immediately see what it stands for. Click on the *VizMapper* tab in the Control Panel. Here you can modify every aspect of how a network is visualised. In the list of the *Visual Mapping Browser* there should be the property *Node Label*. Double-click it and change the value in the box next to it to 'Site name' (NOT shared name). Make sure the *Mapping Type* is set to *Passthrough Mapping*. This will give each node a unique label based on the node attributes spreadsheet. Now when you zoom into your network you will see that each node has a label (if this is not the case just change the *Mapping Type* to *Continuous Mapping* and then back to *Passthrough Mapping*).

Save your session!

4. Filter network

At this point we have all the lines of sight between 190 sites represented as one single network. The network looks like a very complicated cluster of connections, however. It is not easy to say anything meaningful about it without using some analytical techniques (see section 6), layout algorithms (section 5) or simplifying it. In this section we will see how we can use filters to make a selection from the network and simplify it.

Try to select a number of different nodes and look at their attributes. As we saw when looking at the spreadsheets, each site was occupied during different periods. We will now create a filter that will allow us to look at just one single period.

In the Control Panel, click the *Filters* tab. To create a new filter click **Option > Create new filter**. A dialogue box appears, use it to name your filter 'periods'. Next you will have to select those attributes that you want to use in your filter. Click on the drop down box next to **Attribute/Filter**, scroll down and select 'node.Iberian' (this is the node attribute named 'Iberian'). Then click the **Add** button next to it. Now a new slider will be added in the field below where you can select either just 0, 0 and 1, or just 1. When you select 1 (slide the slider to the right to make the selection 1:1) you will notice that all sites dated to the Iberian period are coloured yellow. Always click the **Apply Filter** button at the bottom left of the screen to make sure your current filter is active.

This filter allows us to explore exactly those nodes we are interested in and how they relate. For example, you can now look at all the attributes of these nodes in the Data Panel.

We can also use filters to create a new network. We will do this now.

Make sure you have all sites dated to the Iberian period selected (click **Apply Filter** again if necessary). Then click **File > New > Network > From Selected Nodes, All Edges**. This will create a completely new network containing only the selected nodes, all the edges between them and holding all the information on those nodes and edges. Go to the *Network* tab in the Control Panel again. You will see that our 'complete network' now has a *child* network derived from it named 'complete network (1)'. Rename this child network to 'Iberian'. You can switch between the views of the different networks by clicking on them.

We can also select multiple attributes. This could be useful if we are interested in exploring the network of two periods combined. To give a specific example, we may want to select nodes that are either dated to **Iberian OR Republican** times. To do this we will have to add another box to our filter (but first make sure that the 'complete network' is selected in the Network tab, since we will be making the selection from this network). Just click the **Add** button one more time but this time with the 'node.Republican' attribute selected in the dropdown box. Now a second box will be added in the field below. Change this box to only select nodes with a value of 1 in this attribute field.

Notice how between these two boxes it says **AND**. This means our filter will only select nodes that are dated to the Iberian AND the Republican periods, which is not what we want. We will have to change this to **OR**. To do this click the + sign next to *Advanced* and next to *Relation* tick **OR** instead of AND. Notice how the AND between the two boxes changes to OR.

Now we can finally make our selection. Click the **Apply Filter** button at the bottom of the Control Panel. You will notice that the number of nodes highlighted in yellow will change. You have now selected all sites dated to both the Iberian and the Republican period.

In the last three sections we will continue to work with the 'Iberian' network we just created.

Save your session!

Exercise

Make four new networks with only sites dated to the remaining four periods: Republican, Early Imperial, Middle Imperial, Late Imperial. Do this by creating a filter to select from the 'complete network' only sites dated to the relevant period and then create a new network. You will need these four networks for the exercises below.

Secondly, it is quite interesting to see exactly which sites are occupied throughout all periods in this study and how they are connected in the network. This reflects a persistent pattern throughout time and will affect our interpretation of the different periods' networks. Create a filter and networks including all sites occupied throughout all periods.

5. Network layout

Our Iberian network is still visualised as a rectangle, which is not very interesting. Cytoscape offers many alternative layouts that each stress different aspects of the network. Most of these are based on the idea that nodes are drawn closer together if they are related to each other. This simple rule will produce a network visualisation in which you can very often pick out clusters of nodes that have a similar structure. In our case it will put sites that are inter-visible with a similar group of other sites close together. This type of visualisation can help you to explore your dataset and identify data-related issues. For example, one of the patterns that often emerge is a dense ball of connections at the centre of the network and many nodes at the periphery with a small number of connections. This would tell you that the sites at the centre are different in some way to the sites at the periphery. More specifically, the sites at the centre are more visually prominent than the sites at the periphery. But what does this mean? We should stress that identifying a pattern is not the same as explaining the pattern. For example, a cluster of sites with a similar assemblage does not necessarily indicate cultural, social, economic or political links between these places. Patterns identified through visualisations will need to be looked at in detail, and

this exploratory network analysis actually allows us to look at the individual sites and particular lines of sight that make up the big patterns. The patterns identified will also need to be re-contextualised within their archaeological, historical and academic frameworks. The value of an exploratory network analysis therefore lies in allowing us to identify large-scale patterns in large and complex datasets, whilst being critical towards their explanation by being able to look at the individual data entities (e.g. a single site, a single line of sight) that create these patterns.

Playing around with different layouts can help us to identify different patterns.

Save your session before you try any layouts, since some of them are very computationally demanding and might cause your PC to crash!

In Cytoscape you will find all layouts under **Layout**. Try out the **Circular, Organic and Random** layouts in **yFiles**. Try to see what the differences are and how they allow you to explore different aspects of this network (DO NOT use Orthogonal, this might take too long or crash your PC).

The organic layout works as described above: nodes that are connected are drawn closer together, creating a centre and periphery structure. What do you think is the logic behind the circular and random layouts?

Play with different layouts for a while and then select the organic one, which we will use in the exercises and sections below.

Save your session!

Exercise

Apply the organic layout to the four other networks. How does the overall structure of your network change through time? What can you say about the centre of each network? What can you say about the periphery of each network? Are there individual sites that are particularly prominent in these networks? How does the position of this site on the networks change through time?

6. Analyse network

So far we have seen what kind of data networks can be created from, how you can import them and how you can explore them using filters and layouts. All of this counts as network exploration, we have not yet done any real analysis on the networks. There are a range of network measures that can tell you something about the role of individual nodes in the network or about the network as a whole. Cytoscape has a very easy built-in function that calculates all of the most popular measures in one go. In this section we will have a look at this function. Please note that the second network analysis practical will deal with these measures in more detail. You can also never take the implementation of these measures in a particular piece of software for granted. Sometimes very different algorithms are used for these measures or different names are given to the same

measure, which might lead to different results. Always refer to the software's documentation before performing an analysis.

By default, Cytoscape uses a plugin called NetworkAnalyzer. To use it click **Tools > NetworkAnalyzer > Network Analysis > Analyze Network**. A dialogue box will appear that asks you whether the network is directed or undirected. Select directed for this specific network. Click the **ok** button. This will start the analysis and this might take a while.

A new window appears that holds a wealth of information. On the first tab called *Simple Parameters* you will find some results that tell you something about the entire network. The network Diameter, for example, tells you the maximum number of steps you can take between two nodes in this network. You can read about what these simple parameters mean here: <http://med.bioinf.mpi-inf.mpg.de/netanalyzer/help/2.6.1/index.html#simple>

The other tabs are charts that summarise a wealth of information. Have a look at the Node Degree Distribution and try to interpret this chart using the description found here http://en.wikipedia.org/wiki/Degree_distribution and here http://en.wikipedia.org/wiki/Scale-free_network. Similarly, have a look at the betweenness centrality and closeness centrality charts and interpret them in light of the information you find here <http://med.bioinf.mpi-inf.mpg.de/netanalyzer/help/2.6.1/index.html#nodeBetween> and here <http://med.bioinf.mpi-inf.mpg.de/netanalyzer/help/2.6.1/index.html#closenessCent>.

Let's be clear, however, that these results are completely meaningless unless we understand exactly how they were calculated and how the definition of your nodes and links (in our case sites and lines of sight) tells you how you should interpret these results. This obviously takes quite a bit of time and will be different for each archaeological network. This practical merely aims at illustrating how to easily analyse a network.

You can save all these results in a single file by clicking the **Save Statistics** button. Do this now. Try to open the file you just saved with Microsoft Excel. You can also easily import these statistics into statistics software like SPSS.

Close the Network Analysis window and click **Yes** when asked if you really want to close it. Once you have performed an analysis of a network all the results are immediately attached to your nodes and edges as attributes. Use the Table Panel to explore the results per node. We will use these results in the next section to explore the networks from a more analytical point of view.

Save your session!

Exercise

Derive these network analytical measures for the other four networks. Read the networkAnalyzer documentation (see links above) and discuss what indegree,

outdegree, and number of connected components represent and mean for these networks. Compare the average degree and connected components score of all five networks. Can you see change in these measures through time? What does this trend mean?

The analyses you perform for all networks will automatically add the results to the nodes as attributes. We will use these results below.

7. Visualise parameters

You can easily visualise network analysis results you produced earlier by clicking **Tools > NetworkAnalyzer > Network Analysis > Generate visual style from statistics**. This will open a new dialogue box where you can select the type of measure you want to visualise and how you want to visualise it. For example, you could map the node size to its indegree (number of incoming connections) and its colour to its outdegree (number of outgoing connections):

The screenshot shows the Cytoscape interface with a network visualization of the Iberian Peninsula. The network is displayed in the main window, with nodes colored and sized based on network analysis results. The Control Panel on the left shows the 'Visual Mapping Browser' with 'Node Fill Color' mapped to 'Outdegree' and 'Node Size' mapped to 'Indegree'. The Table Panel at the bottom shows a data table with columns for various network metrics.

shared ...	Iberian	Early Im...	Site na...	name	Middle I...	Late Im...	Republi...	Average...	Clusteri...	Closen...	IsSingl...	Partner...	Si
95	1	1	El Casar	95	1	1	1	2.177777...	0.353754...	0.459183...	false	18	0
291	1	1	Los Medi...	291	0	0	1	2.251851...	0.455555...	0.444078...	false	9	0
167	1	1	Lebrija	167	1	1	1	3.585185...	0.0	0.278925...	false	1	0
63	1	0	Cerro Gor...	63	0	0	0	2.451851...	0.253676...	0.407854...	false	15	0
241	1	1	Torre de l	241	1	1	1	3.533333...	0.0	0.283018...	false	1	0

Exercise

Try out a number of different visualisations and use the websites mentioned in the previous section to interpret the results.

Try to find a combination of layout and node-edge visualisation that you believe is a particularly interesting way to present your results.

You can always modify particular properties of your network by using the *VizMapper* tab in the Control Panel.

Interpret the changing indegree and outdegree scores of sites through time. Which sites have the highest scores for each period? Can you identify sites which have a high score in one of these (or both) throughout most periods? Can you find an example of a site that has a high indegree but a low outdegree, and vice versa? What does this mean?

Use a filter on the arc attribute field called 'length' to create a new network with only arcs with a length between 0 and 20km. Derive network analytical measures for this new short distance network. How do the indegree, outdegree and connected components measures compare with the longer distance networks you have analysed earlier?

Save your session!

8. Software resources

Pajek: <http://pajek.imfm.si/doku.php>

Up to date set of analysis techniques, can handle large networks, good manual and supporting documentation, less easy to use than UCINET, includes some specific features not included in UCINET (Triad counts; nice matrix graphs; graphs automatically separating components).

UCINET: <http://www.analytictech.com/ucinet/>

up to date set of analysis techniques, good supporting documentation, great for converting to different network data formats. See handout network analysis practical 2.

Cytoscape: <http://www.cytoscape.org/>

Poor documentation, user-friendly interface, easy analysis. See handout network analysis practical 1.

Gephi: <http://www.gephi.org/>

Verry pretty visualisation, poor documentation, user-friendly interface, manual modification of layout algorithm settings.

GIS: Grass and ArcGIS (networkAnalyzer) have some network features. Can be used to produce visibility networks, least-cost paths, etc.

Processing: <http://www.processing.org/>

visualization and animation, programming skills needed.

Mathematica: <http://www.wolfram.com/mathematica/new-in-8/graph-and-network-analysis/index.html>

Matlab:

<http://www.levmuchnik.net/Content/Networks/ComplexNetworksPackage.html>

R: <http://igraph.sourceforge.net/doc/R/00Index.html>

You can do basically anything you want if you can be bothered to code it, some great network analysis libraries (network, sna, Rnetworks, igraph, ergm, networkDynamic, Rsiena, statnet, tnet).

Sci2: <https://sci2.cns.iu.edu/>

Network workbench: <http://nwb.cns.iu.edu/>

Excel and NodeXL: <http://nodexl.codeplex.com/>

Everyone knows how Excel works, now you can use it to make networks.

Python: <http://networkx.lanl.gov/> or <http://igraph.sourceforge.net/>

TRACER: A text re-use tracing software <http://mbuechler.e-humanities.net/tracer/>

VISONE: <http://visone.info/>

Many functions and also runs RSiena

Blocks: free separate program for blockmodeling - very good at it, does nothing else.
Result pages somewhat cumbersome, but very good documentation

9. Bibliographic resources

Introductory publications

- Albert, R. & Barabási, A., 2002. Statistical mechanics of complex networks. *Reviews of modern physics*, 74(January), pp.47-97.
- Barabási, A.-L., 2002. *Linked: The New Science of Networks*, Cambridge, Massachusetts: Perseus.
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