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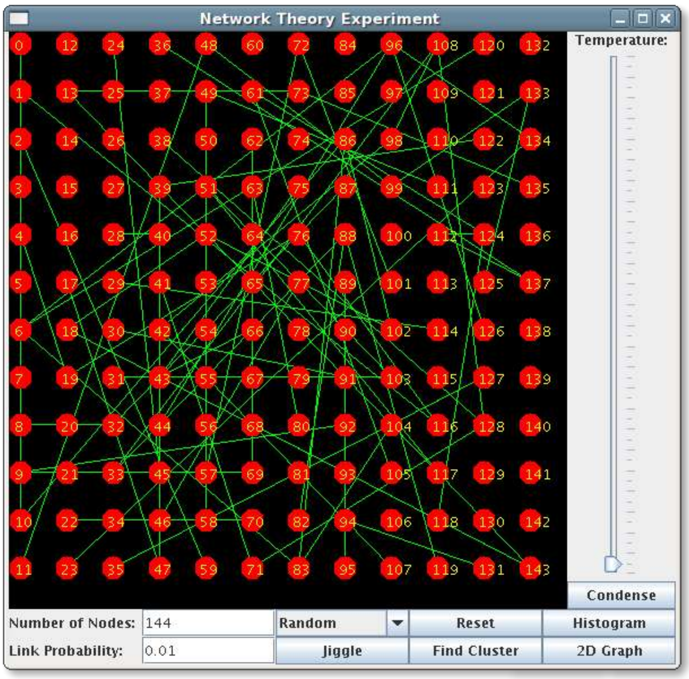
Modelling & Visualisation in Physics
Checkpoint 5: Growing Networks

Program Usage:

The program is contained in five files:

Node.java	Node links, variables and methods
Network.java	An array of nodes and network methods
NetworkGUI.java	The Graphical User Interface and display algorithms
TwoDGraph.java	Code for creating and displaying a 2d graph
Histogram.java	Code for creating and displaying a histogram of the current network

It is run by compiling all files (only tested using Sun Java SDK 1.5.0) and running NetworkGUI. The user is presented with a screen similar to this:



The GUI is split into 3 components, in the centre - the network display, on the right - the temperature controls and at the bottom - the control panel.

Network Display: This area shows the current network, its nodes and the links between each node. The nodes are numbered based on the order in which they were created.

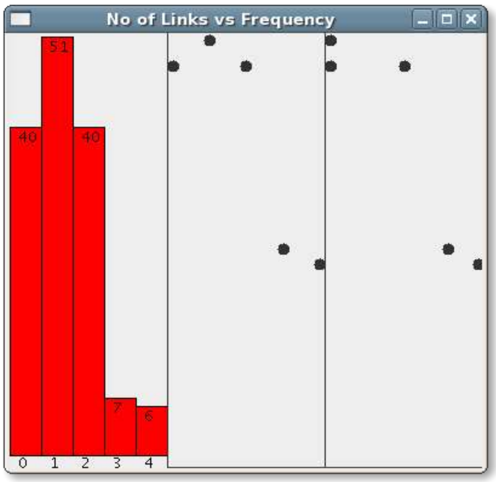
Temperature Controls: The slider bar controls the 'temperature' of the network, from 0 – 50. When the slider is changed the label at the top changes to show the selected temperature. The 'Condense' button applies a set number of condensation iterations to the network at the selected temperature and redraws the result.

Control Panel:

Number of Nodes field	The number of nodes in the current Network. Change value and press enter to read new value into the simulation and reset.
Links Probability field	For the Random Graph type, this is p, for the Evolution and Popularity types, this is K. Change the value and press enter to read the new value into the simulation and reset.
Network type menu box	Random, Evolution and Popularity. Resets to the new type upon selection.
Jiggle button	Tries to minimise the total link length using the Kawasaki method.
Reset button	Resets and randomises the network.
Find Cluster button	Finds and displays the largest connected cluster.
Histogram button	Brings up the Histogram window (see below).
2D Graph button	Brings up the 2d Graph window (see below).

Analysis Tools:

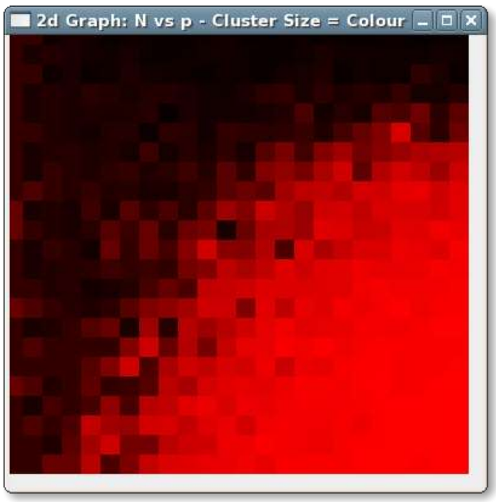
Histogram Window:



The histogram window is split into three areas, the histogram on the left, the semi-log plot in the middle and the log-log plot on the right.

In the histogram the x-axis is the number of links and the y-axis is the number of nodes with that many links. The semi-log plot plots the x-axis as usual against the logarithm of y and the log-log plot plots log x against log y. This is necessary to determine the difference between an exponential relationship and a power law relationship.

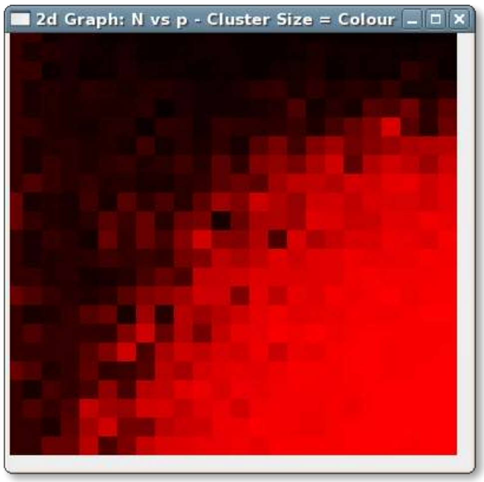
2d Graph Window:



The x-axis represents N, the number of nodes in the network. The y-axis represents p (for the random network) or K (for the evolution and popularity networks. The colour represents the size of the largest cluster in the network. Black means a cluster size of 0 and bright red means a cluster size of N. The range of N is the same for each network type, going from 5 nodes to 125 nodes in 5 node steps. The range of p/K for each network is given below:

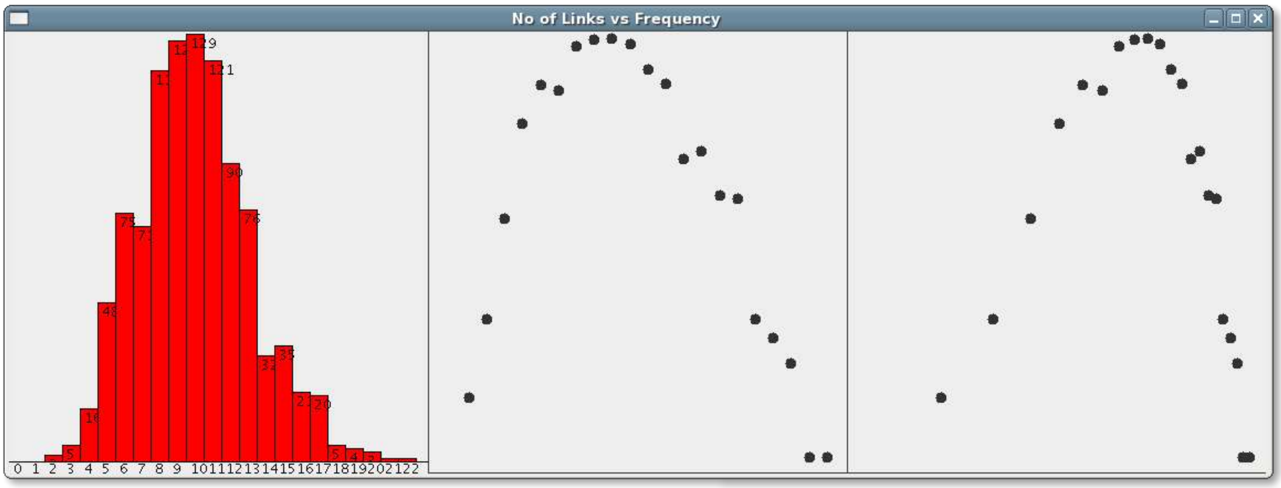
Network Type	***Parameter***	***Range***	***Step Size***
Random	p	0.001 to 0.05	0.002
Evolution	K	0.0 to 2.4	0.1
Popularity	K	0.0 to 5.0	0.2

Results:
Random Graph:
2d Graph:



This graph shows that the size of the largest cluster is dependant on p, the link probability and N, the number of nodes. This means that a random graph network with a very low link probability but a very large number of nodes can still have almost complete connectivity between the nodes.

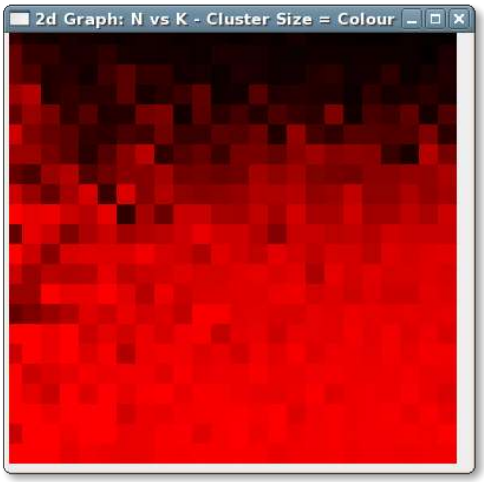
Histogram:



The number of nodes was increased to 1000 for this experiment. These graphs show the expected results for a random graph. The histogram resembles a Gaussian centred around 10 links per node, the log plots show inverse parabolas.

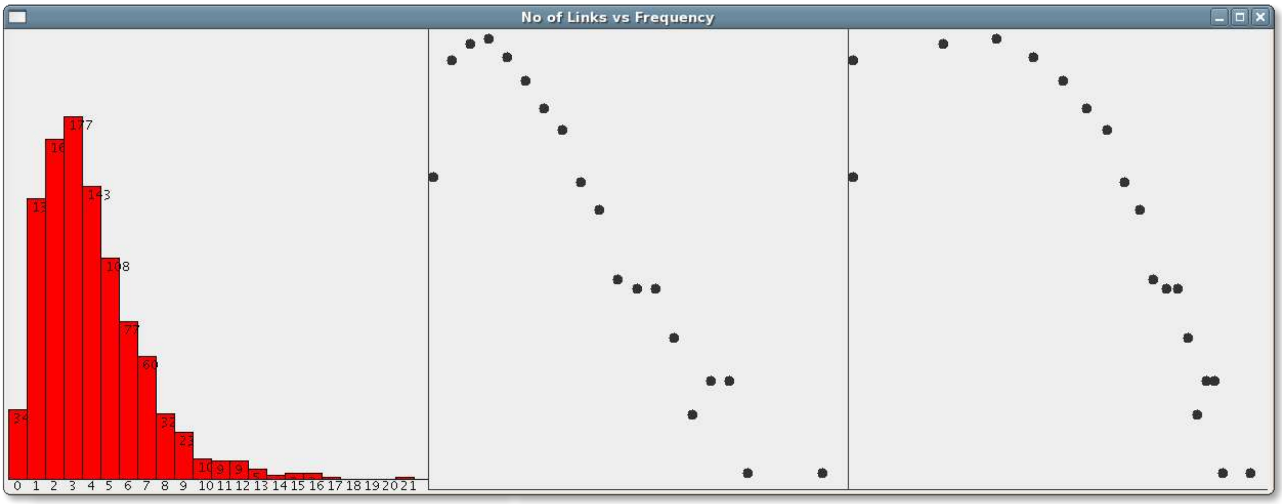
Evolution Network:

2d Graph:



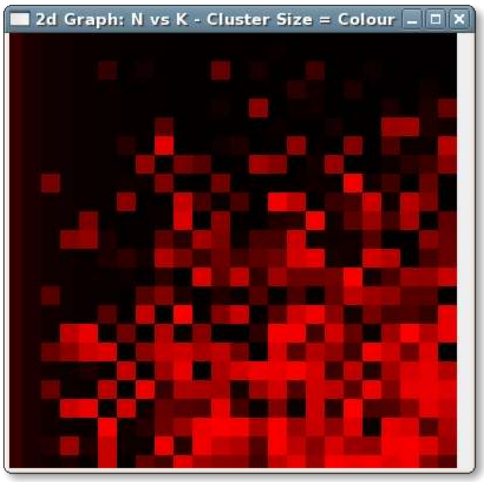
This graph shows that the network grown by evolution has no dependence on N, the number of nodes. This is almost obvious from the definition of the evolutionary network, the probability of forming a link goes down as the number of nodes goes up. It also shows that the largest cluster increases with K, which is also fairly obvious as the link probability = K/n. It does show some odd results at very small network sizes, this is most likely due to finite size effects.

Histogram:



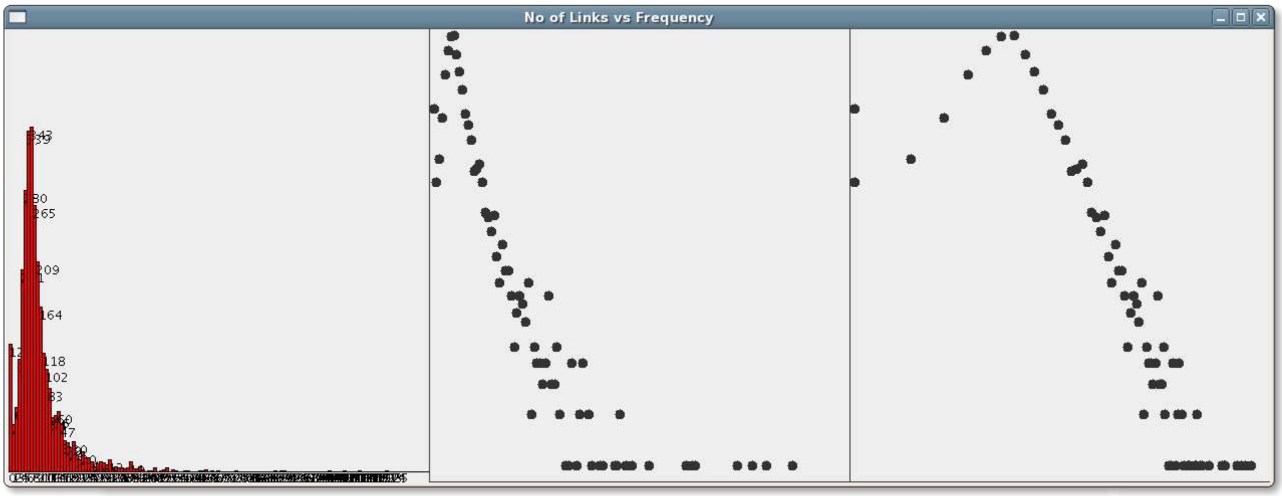
These charts show that the evolutionary network drops off linearly in the semi-log plot but not in the log-log plot, suggesting an exponential relationship between number of links and number of nodes with that many links.

Popularity Attractive Network:
2d Graph:



It is difficult to tell what this chart shows. It was noticed when experimenting with popularity networks that the same initial conditions can produce a wide variety of results. This is shown in the graph, small clusters appearing at big N & K and large clusters appearing at small N & K. There is a general trend, clusters get larger with K. The cluster size does not seem to have a strong dependence on N.

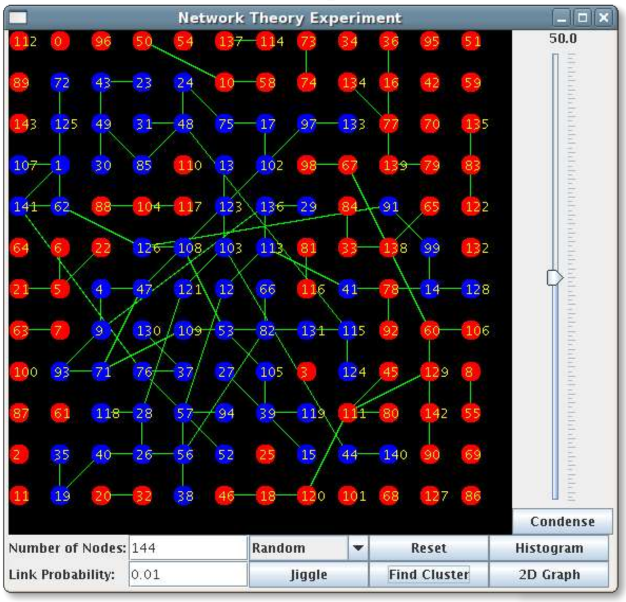
Histogram:

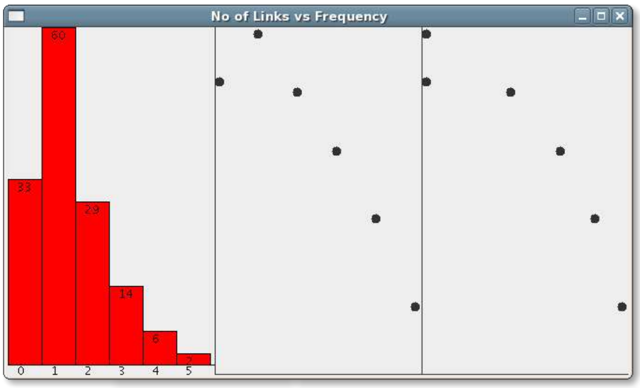


The number of nodes was increased to 3000 for this experiment. These charts suggest that the Popularity attractive network follows a power law as both of the log plots drop off approximately linearly.

Condensation of a Network:

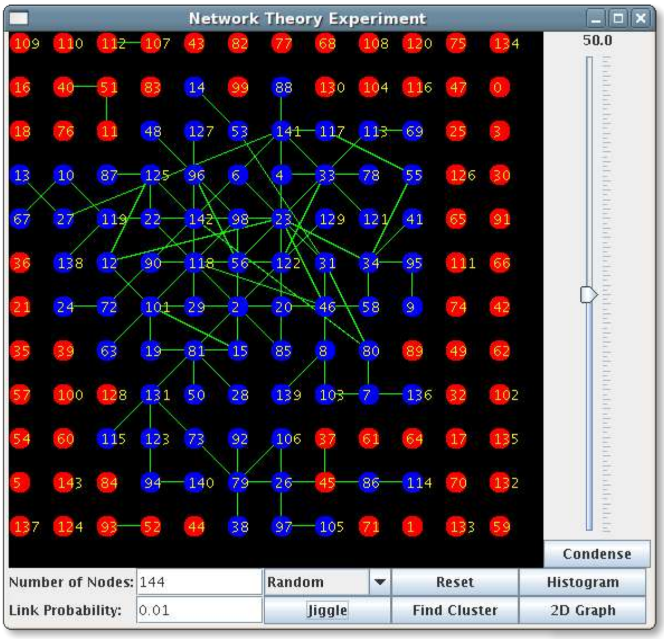
Start Point – Random Graph:





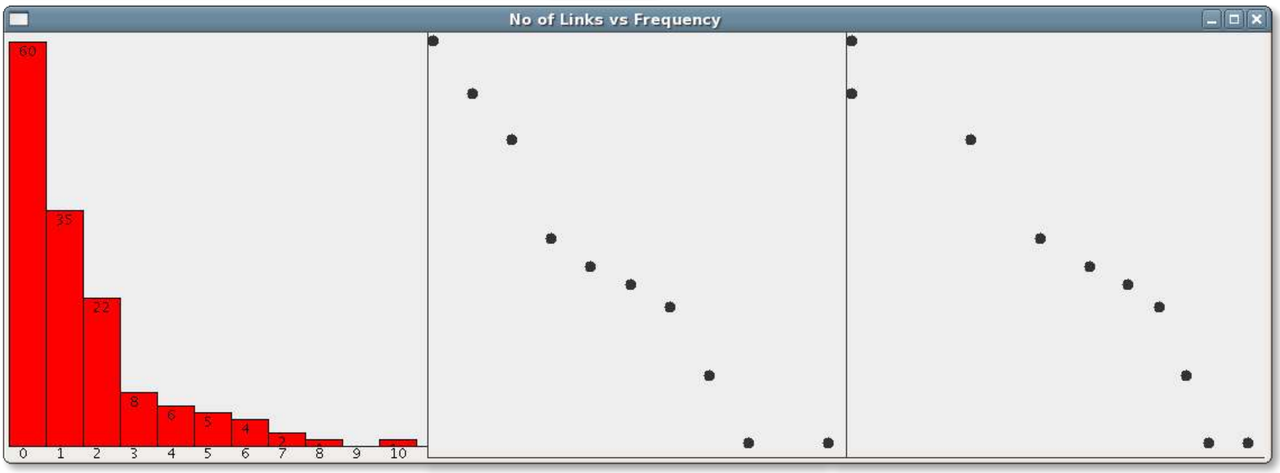
These screen shots show a random graph after it has been 'jiggled' with the largest cluster highlighted, and the corresponding histogram.

Condense – High Temperature:

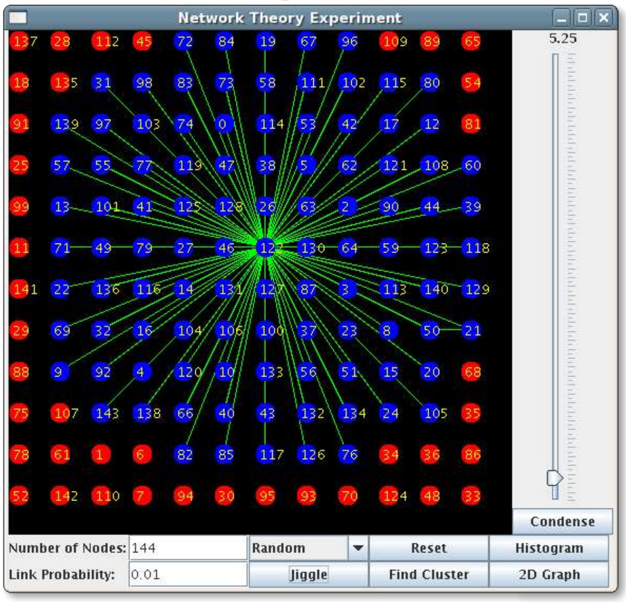


These figures show the results after condensing the random graph above at a temperature of 50 (abstract idea, no units).

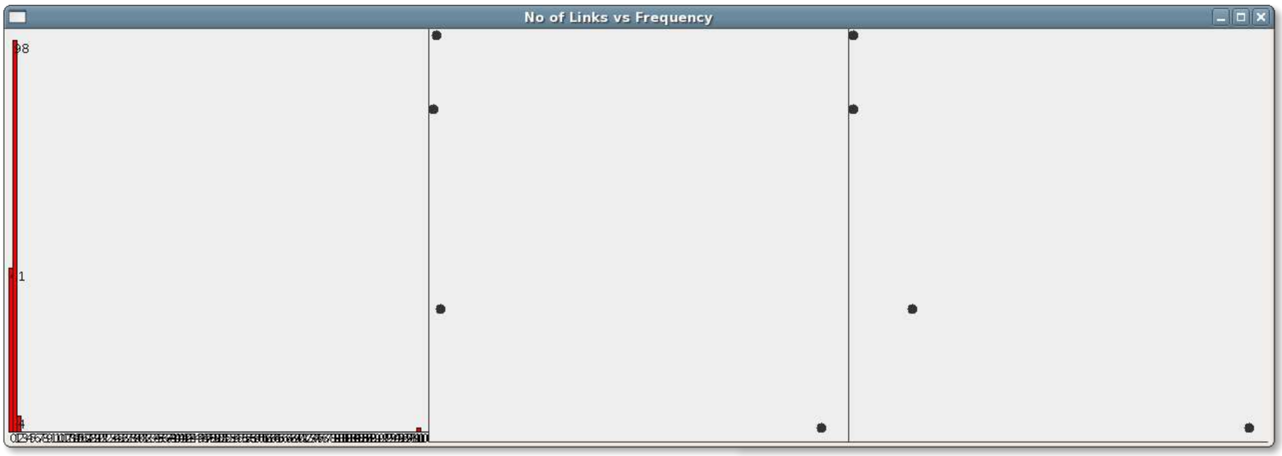
The Graphical display shows the the network has become slightly more centralised. The histogram shows that the distribution of links has moved away from the Gaussian and towards an exponential or power law distribution, difficult to determine which.



Condense – Low Temperature:



The network was then condensed at a low temperature (5.25) and 'Jiggled' to show the results. The graphical display gives a very good representation, almost all the nodes are connected to a single node, very few other nodes have more than 1 link. The histogram confirms this, almost all nodes with 0, 1 or 2 links and 1 node with a lot of links. This is an example of a "Winner takes all" network, where the fittest node as it begins to cool takes all the connections. At higher temperatures, it becomes more of a "Fit get Rich" network, were several nodes can have many links and the network remains stable. It was found by experimentation that in this simulation, with 144 nodes, the critical temperature at which one node wins is 25. In order to spread the links again, the temperature must be increased to approximately 30.



Conclusion:

This simulation has many physical interpretations. The internet, the global plane network, the growth of certain organisms and terrorism groups (http://www.dougsimpson.com/blog/archives/000075.html) to name but a few. It has also been shown that the properties of these scale-free networks are very similar to that of Bose-Einstein condensates, specifically in the "Winner takes all" example above.