Data Science in F# conference – Berlin

Using Network Science to improve supply chain resilience

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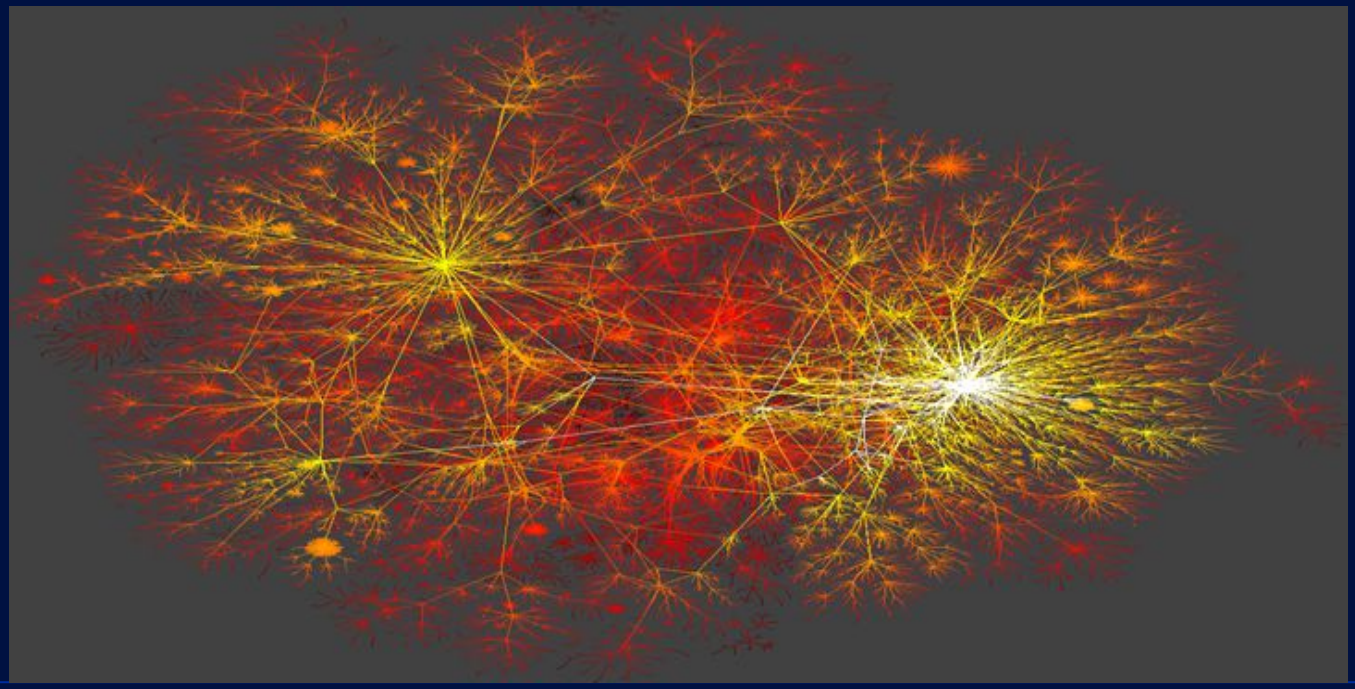
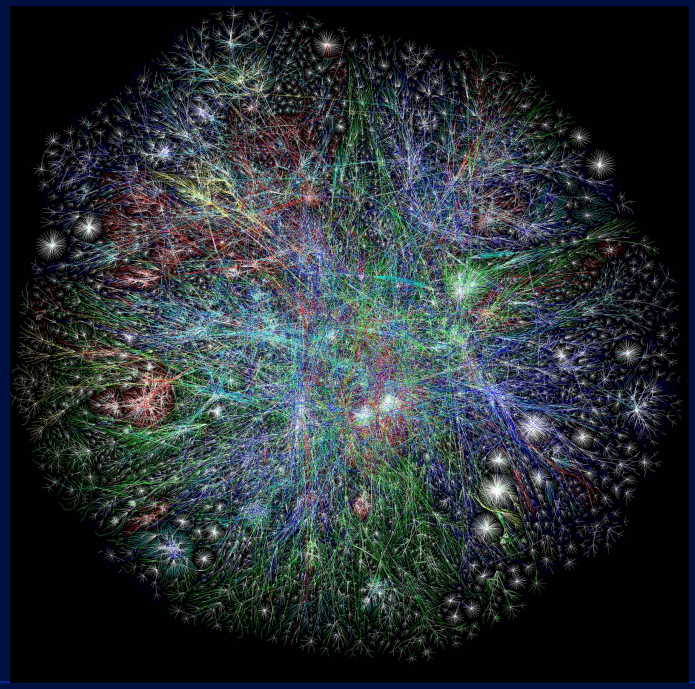
Complex systems are networks

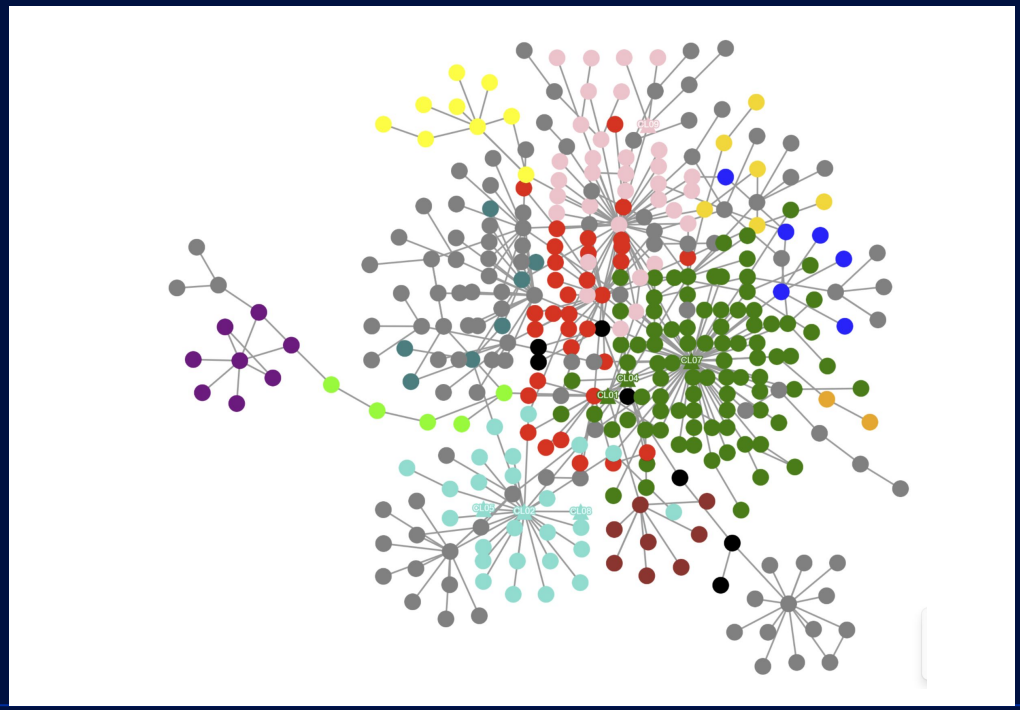
"A key discovery of network science is that *the architecture of networks emerging in various domains of science, nature, and technology are similar to each other, a consequence of being governed by the same organizing principles. Consequently we can use a common set of mathematical tools to explore these systems.*"
Network Science – Barabasi 2016





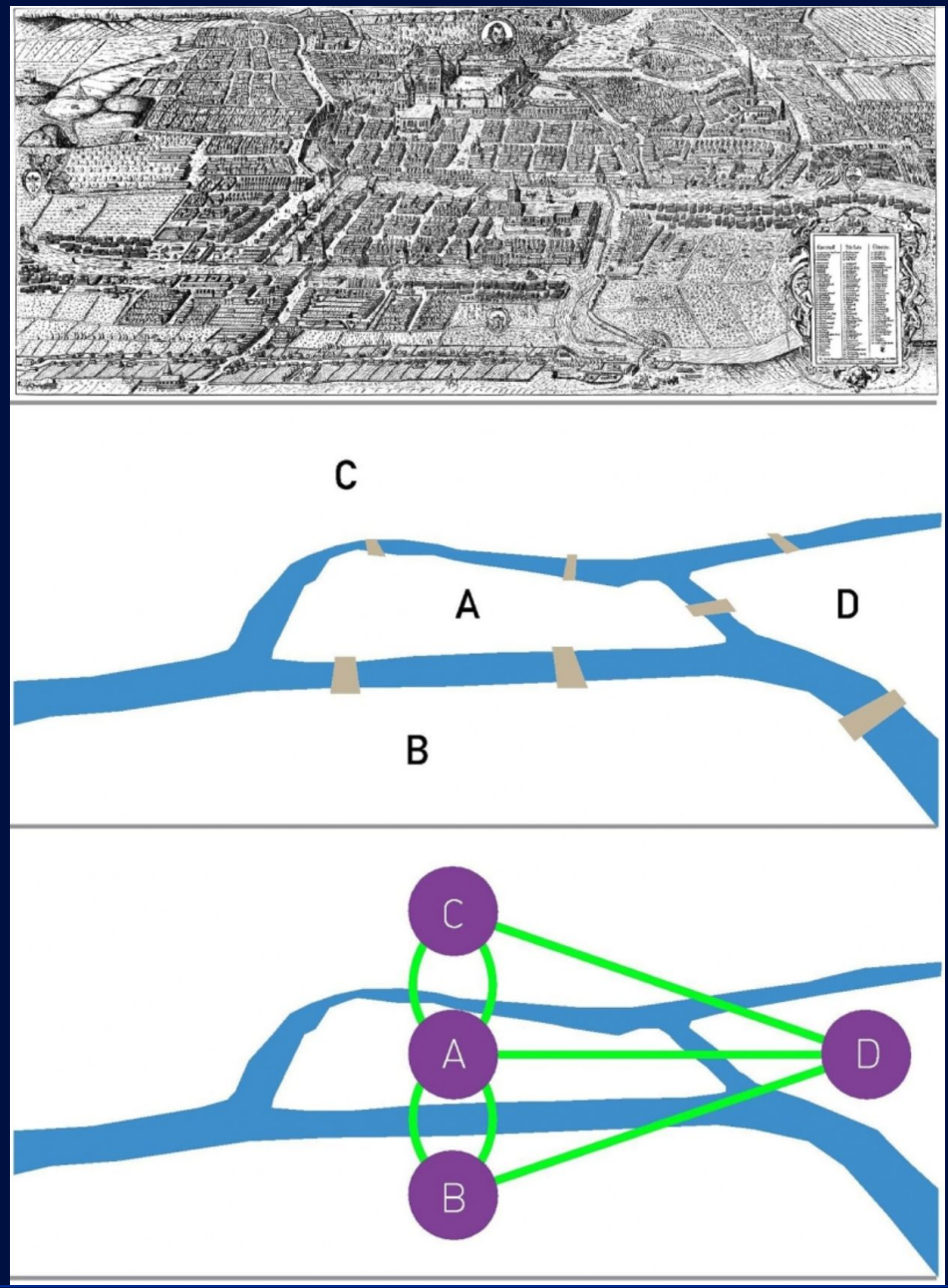
The importance of supply chains

- The world relies on resilient supply chains.
- A supply chain is a complex system.
- Network science provides powerful tools for improving their resilience and sustainability.
- H&C simulated and optimised the US and UK pallet networks.
- This includes 400 million pallets which carry 80% of consumer goods, including food and medicine.



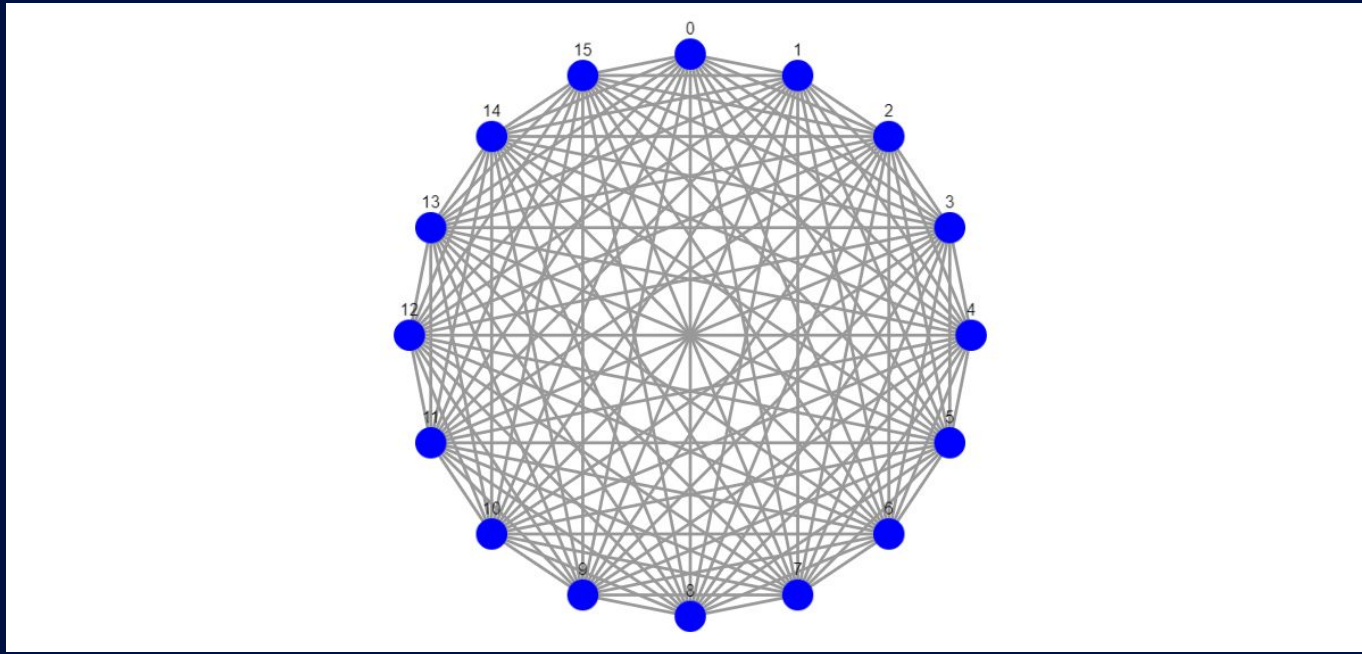
Origins of Network Science

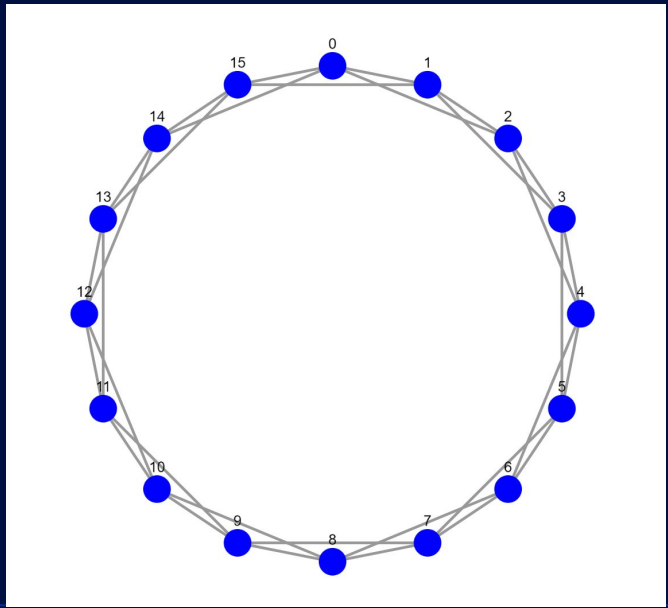
- Network Science developed from Graph Theory
- In 1736 Euler represented the bridges of Konigsberg problem as a graph
- Only the start and end nodes can have an odd number of edges.
- In this graph all the nodes have an odd number of edges

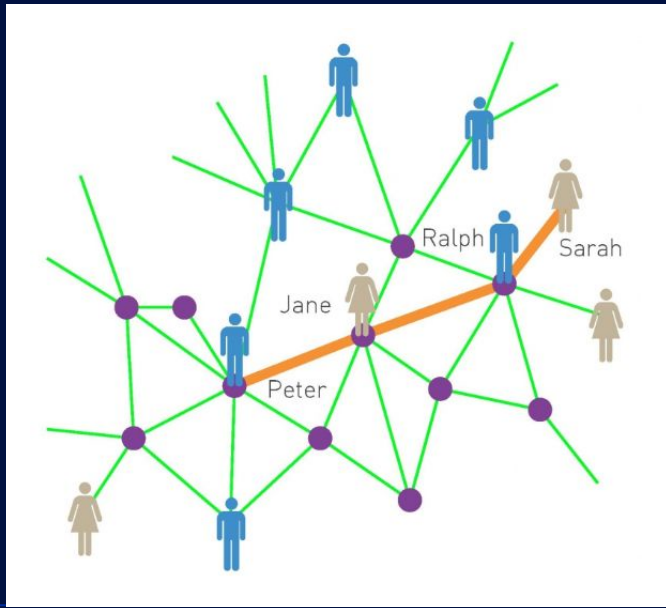


Regular networks and Small Worlds

- Degree is the number of edges of a node.
- Shortest path is the distance in edge count between two nodes.
- The average shortest path of a regular network increases linearly with network size.
- Milgram's letter experiment showed that large real networks have a small world property.







Avg Shortest path

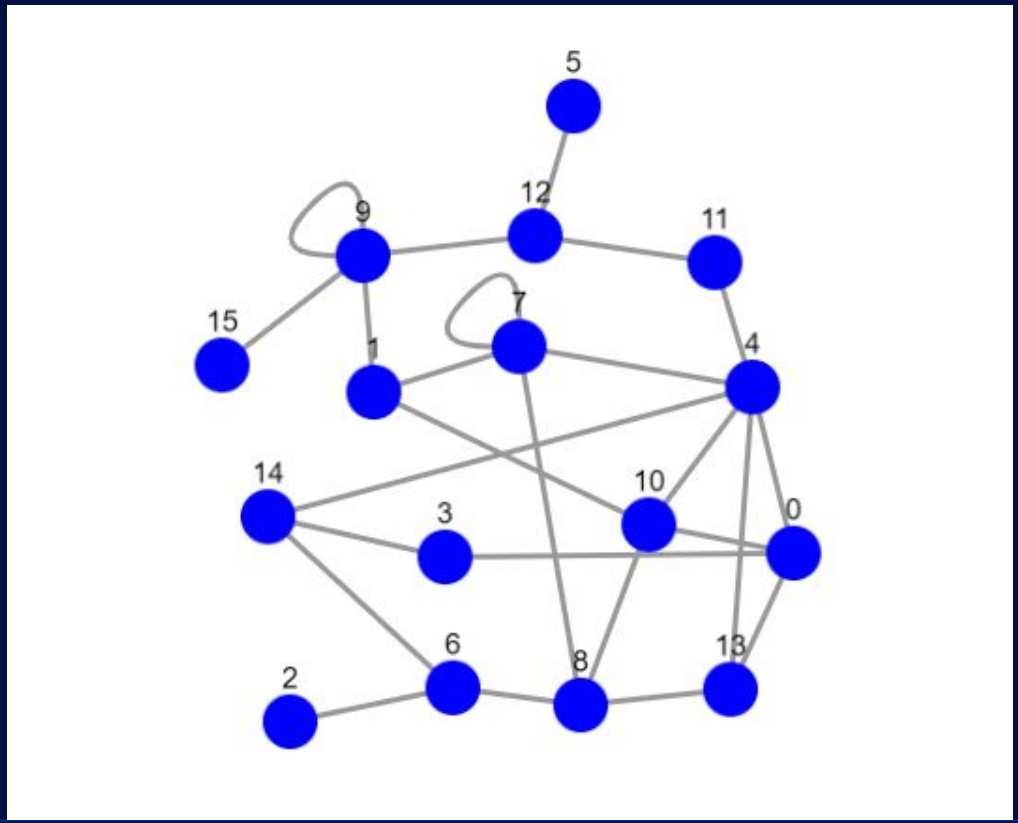
Milgram’s letters: 5.2

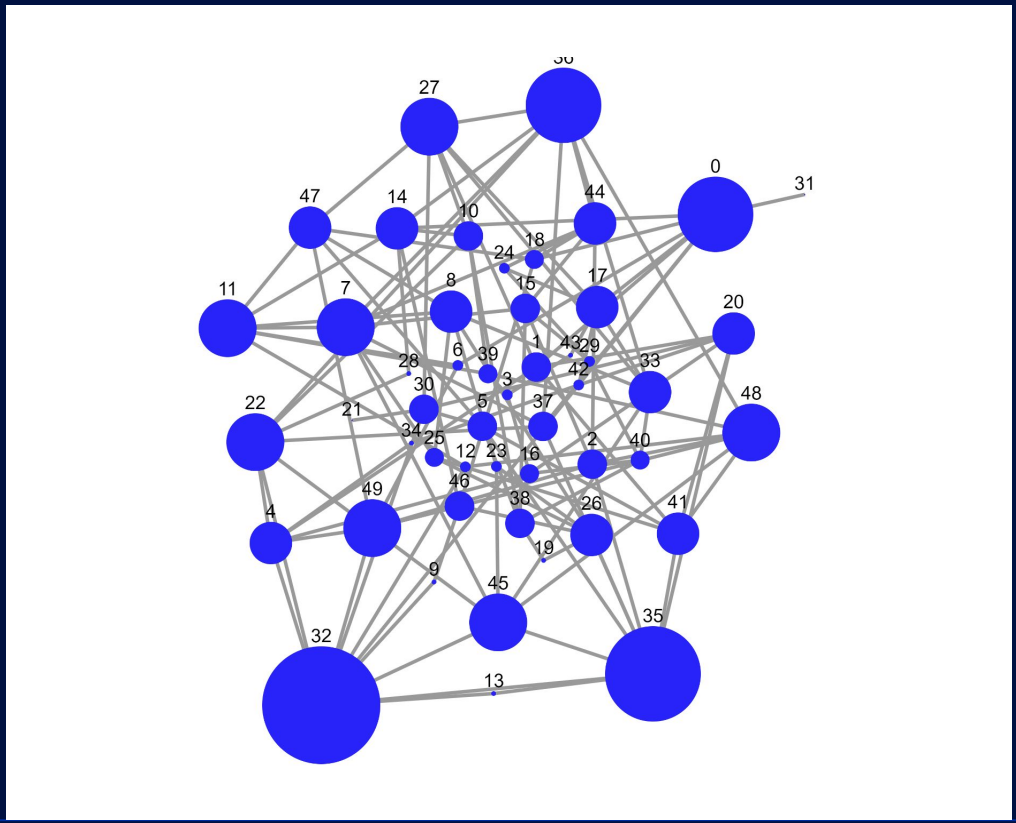
Facebook: 4.7

Candidate models of small world Networks

Erdos Renyi: Generates a graph with a fixed number of nodes and edges. The edges are placed randomly.

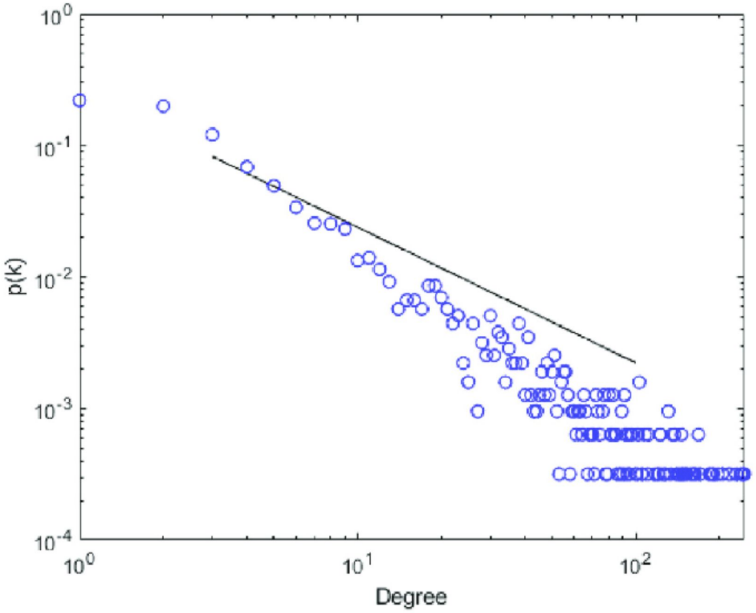
Gilbert Graph : This generates a graph using a fixed probability of an edge between every pair of nodes.





Real networks are scale free and have Hubs

- Real networks very often have Hubs.
- A Hub is a node with a very high number of connections.
- Heathrow Airport or Mr Beast are hubs.
- Networks with Hubs have a power law degree distribution.



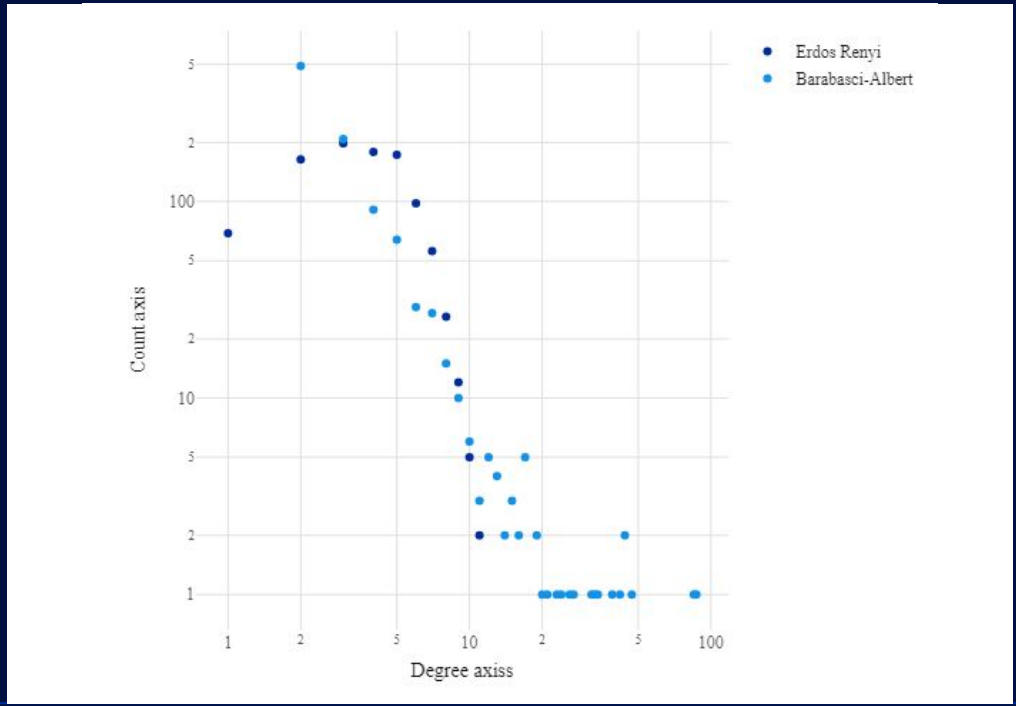
Log - Log plot of Airport degree distribution.

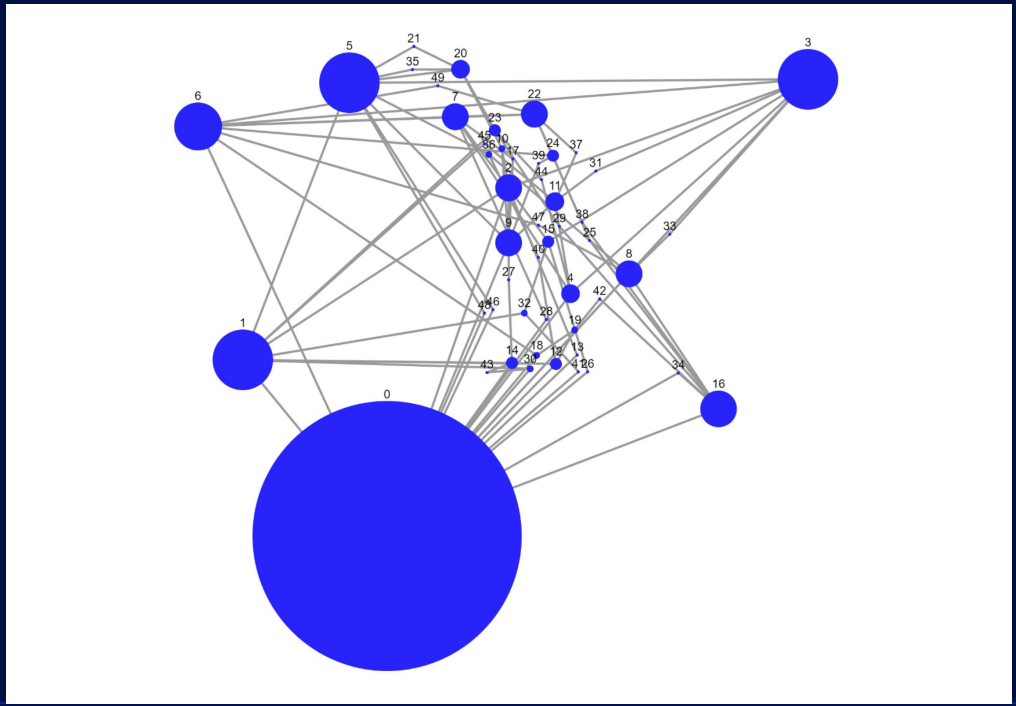
Networks with Power Law degree distribution

- The World Wide Web.
- Social networks (e.g., Twitter, Facebook, LinkedIn).
- Citation networks (e.g., scientific papers, patents).
- Biological networks (e.g., protein-protein interaction networks, metabolic networks).
- Transportation networks (e.g., airports, roads).
- Financial networks (e.g., stock exchanges, currency markets).
- Power grids.
- Communication networks (e.g., phone networks, email networks).

Preferential Attachment and the Barabasi - Albert Model

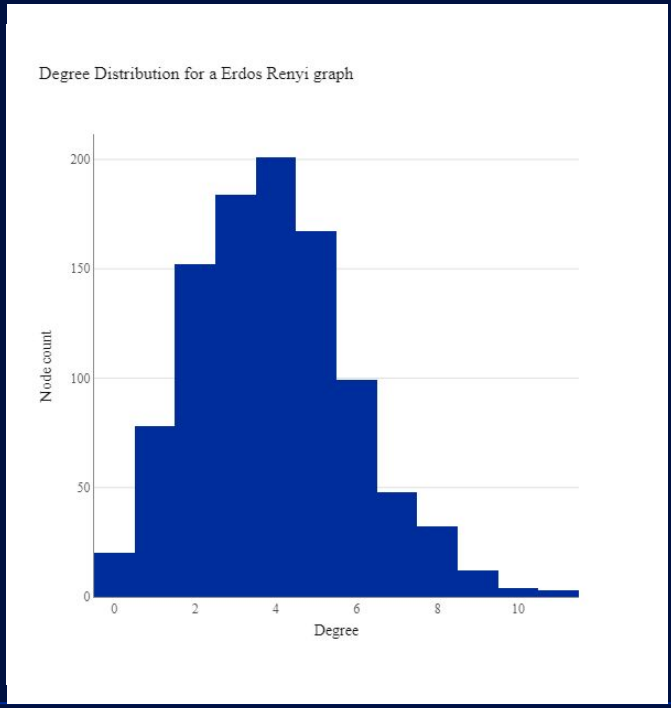
- Generates networks with power law degree distributions using a principal called Preferential Attachment.
- New nodes have a higher probability of attaching to nodes with higher existing degree.
- So as the network grows and new nodes are added the oldest node tends to grow very large.
- This rich get richer model fits the degree distribution of many real world networks.
- Supply chains often resemble the Barabasi - Albert model.

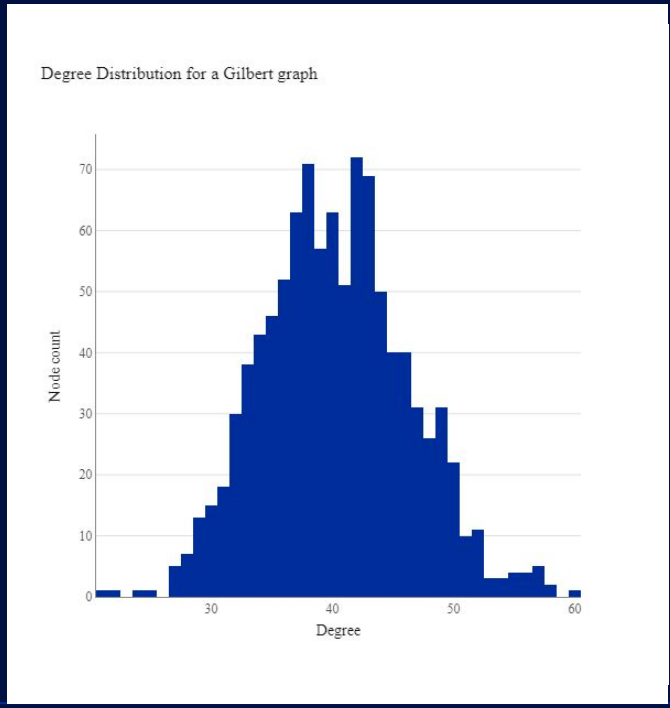


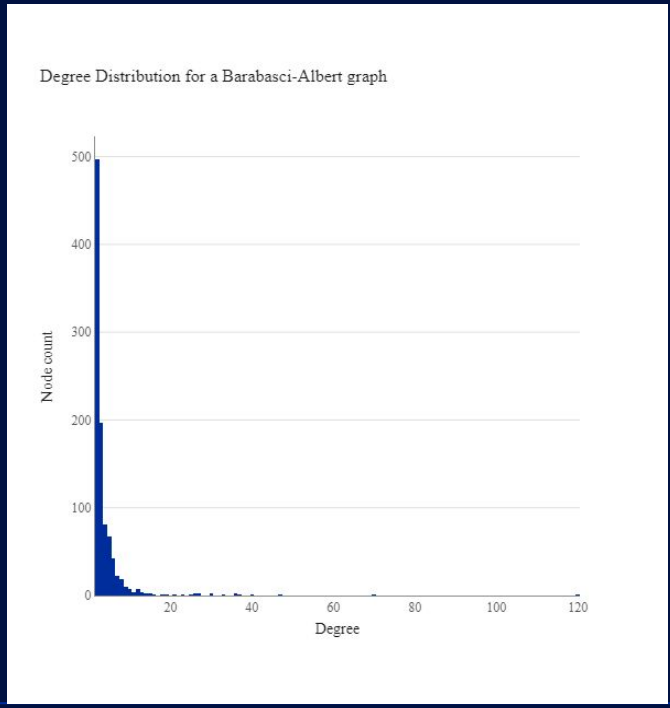


Comparing the models - Degree Distribution

For cost and legacy reasons, supply chains tend to have Hubs and fit a power law distribution.

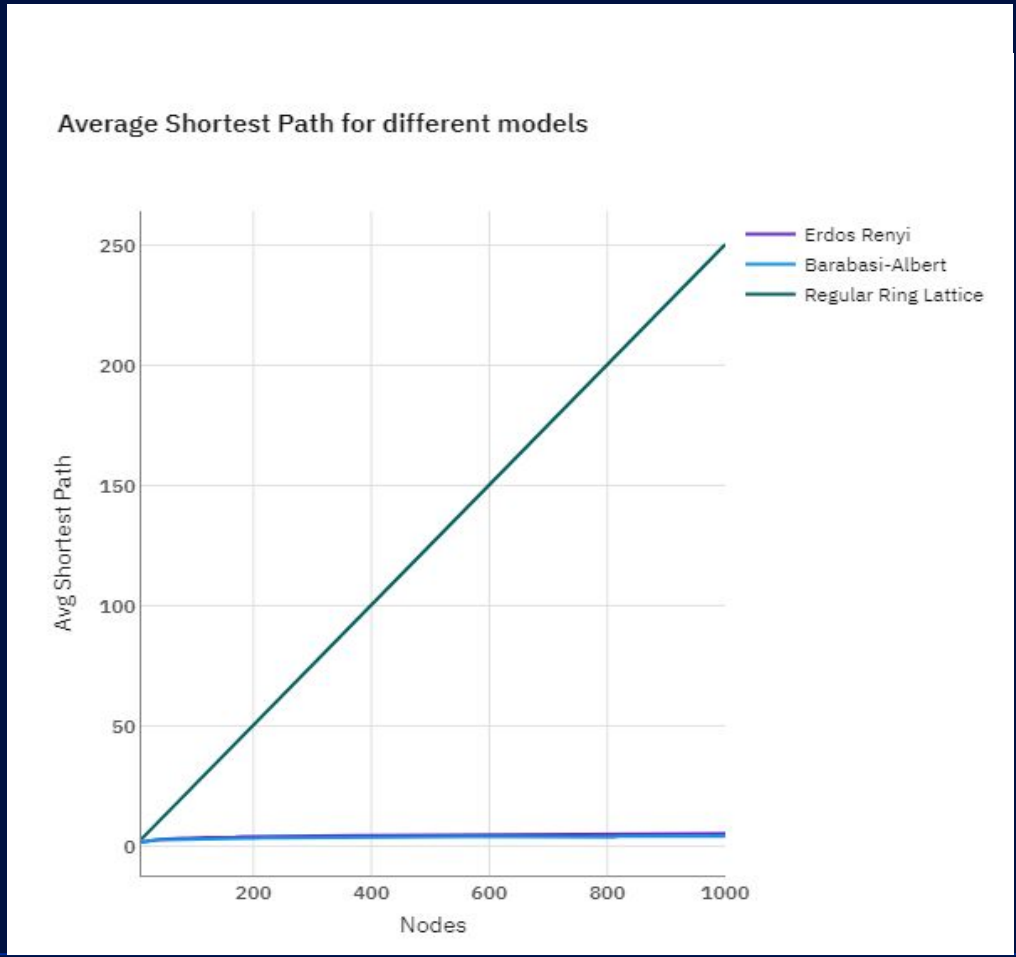


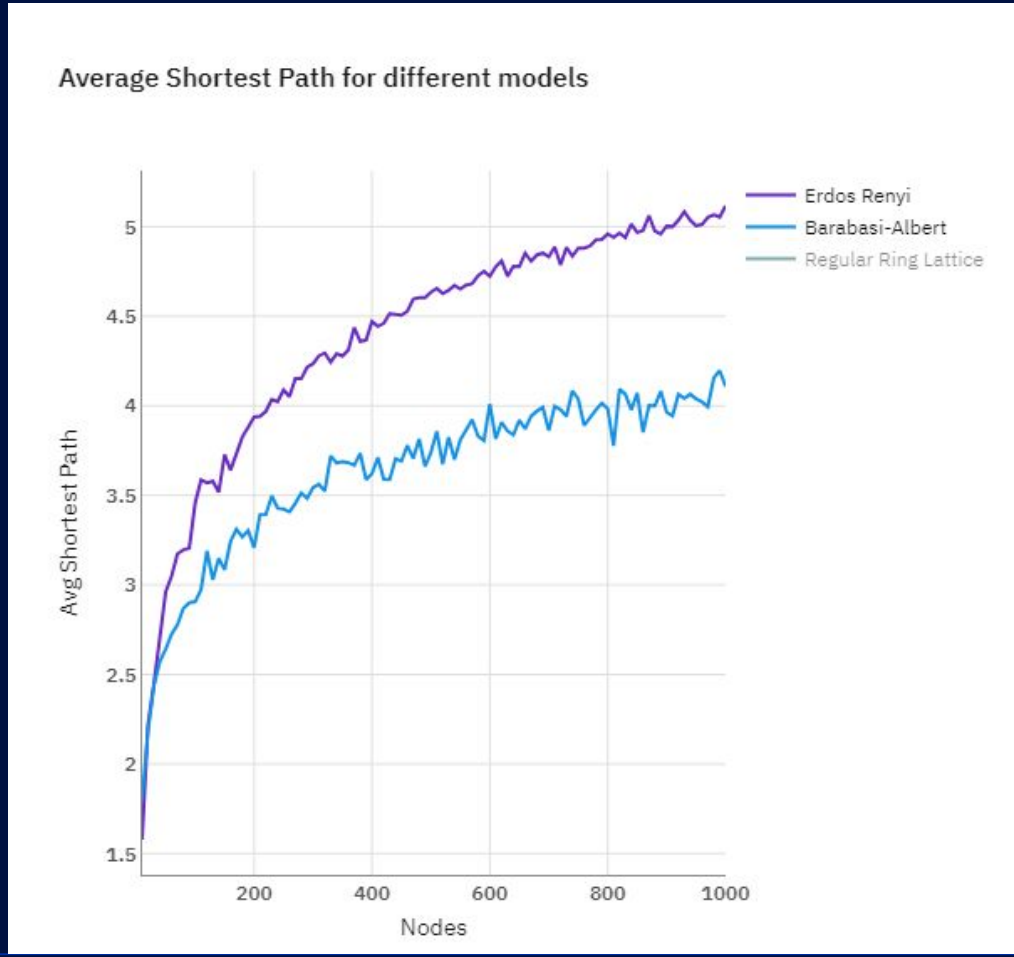




Comparing the models - Shortest Paths

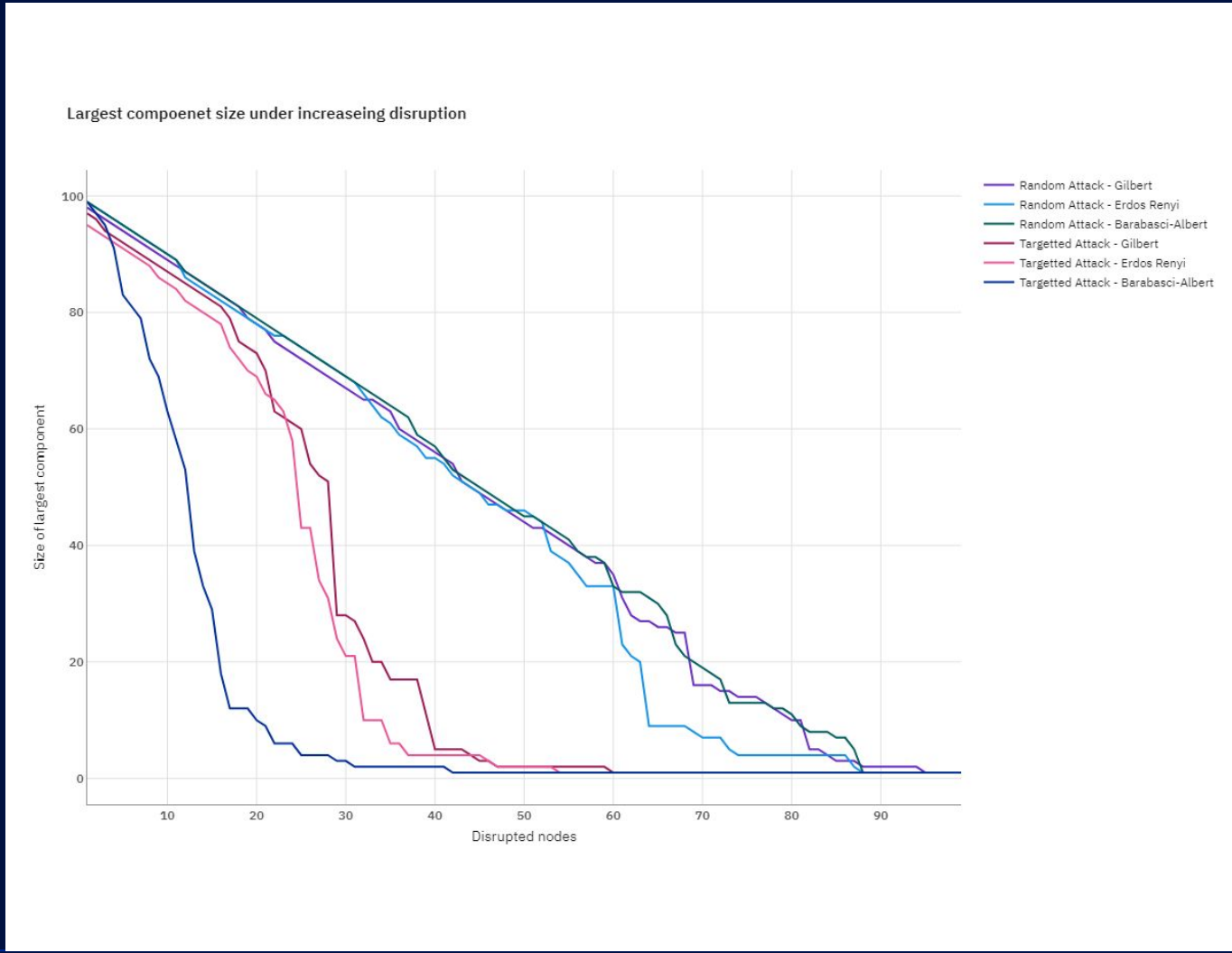
Supply chains optimise shortest paths. This lowers emissions and lead time.





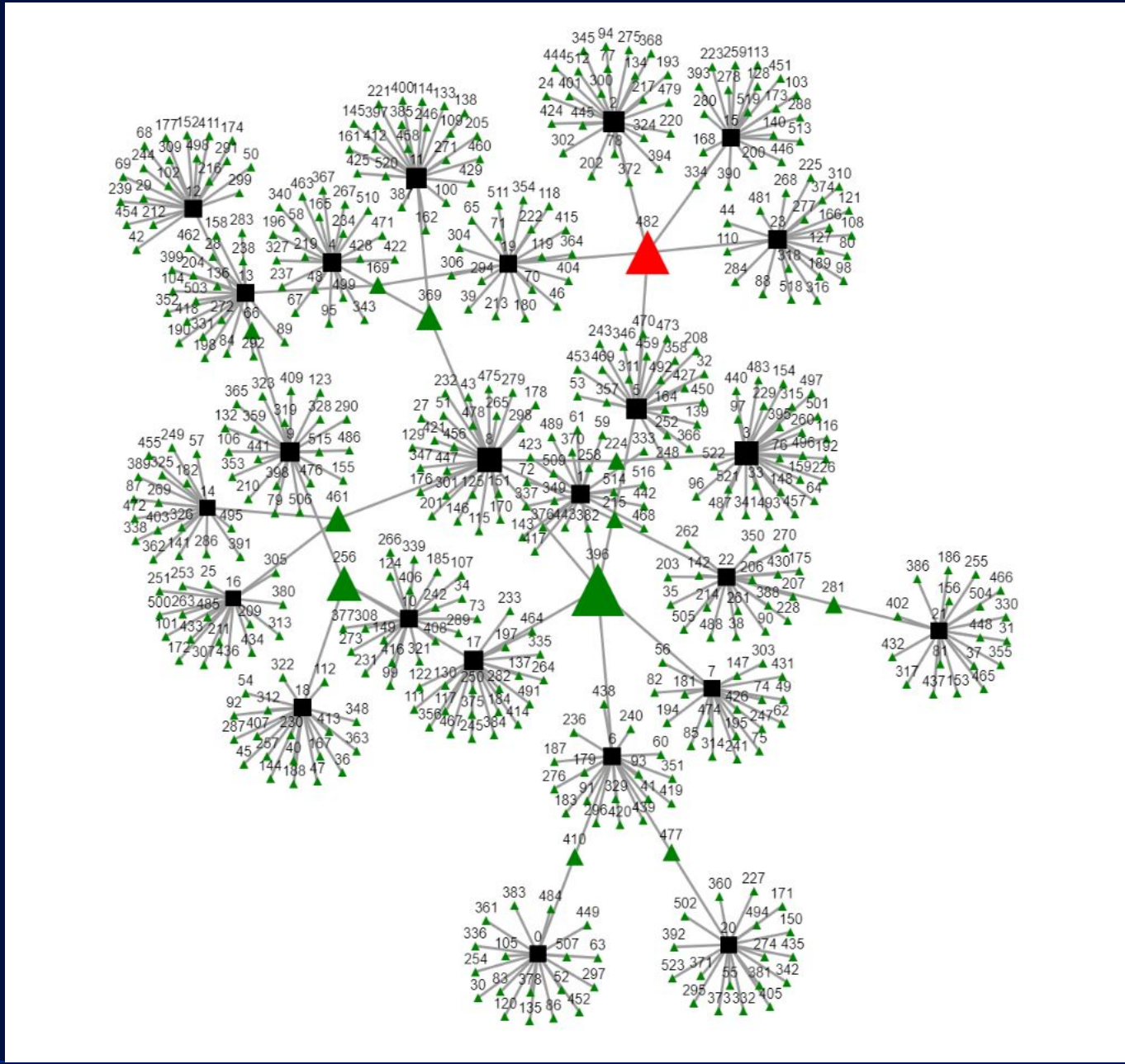
Scale free networks are vulnerable.

- Supply Chain Disruptions have two types.
- Random Attacks: A node is disrupted at random.
- Targeted Attacks: Nodes are selected for disruption in decreasing order of degree.
- The Barabasi-Albert Model is susceptible to Targeted Attacks.



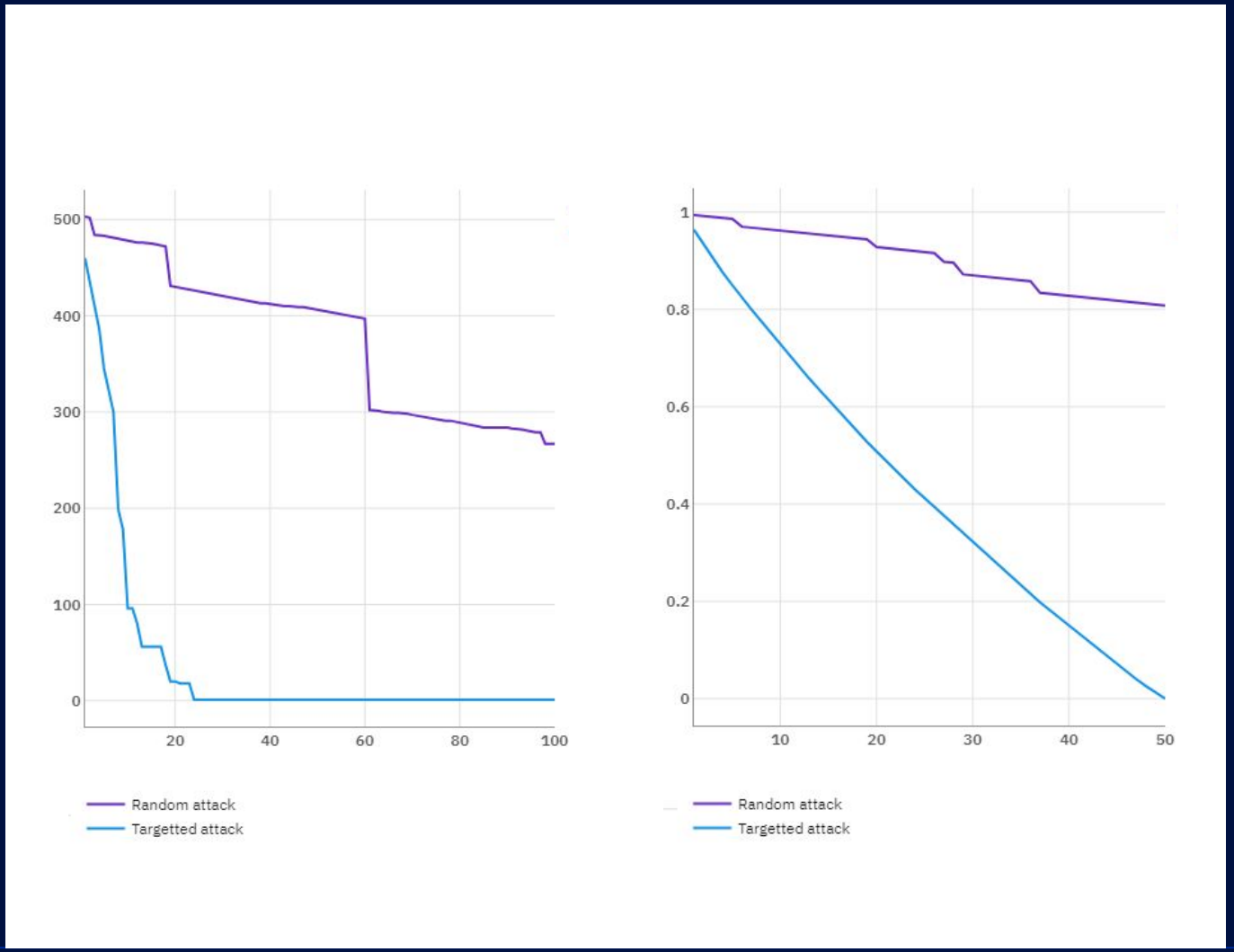
Modelling heterogeneous directed networks

- Graphoscope supports Directed heterogeneous networks.
- Demand nodes are represented by Triangles and Supply nodes are represented by Square.
- Edges between them are directed from the supply node to the demand node.
- Red means not all of the node needs are met by the connected supply nodes



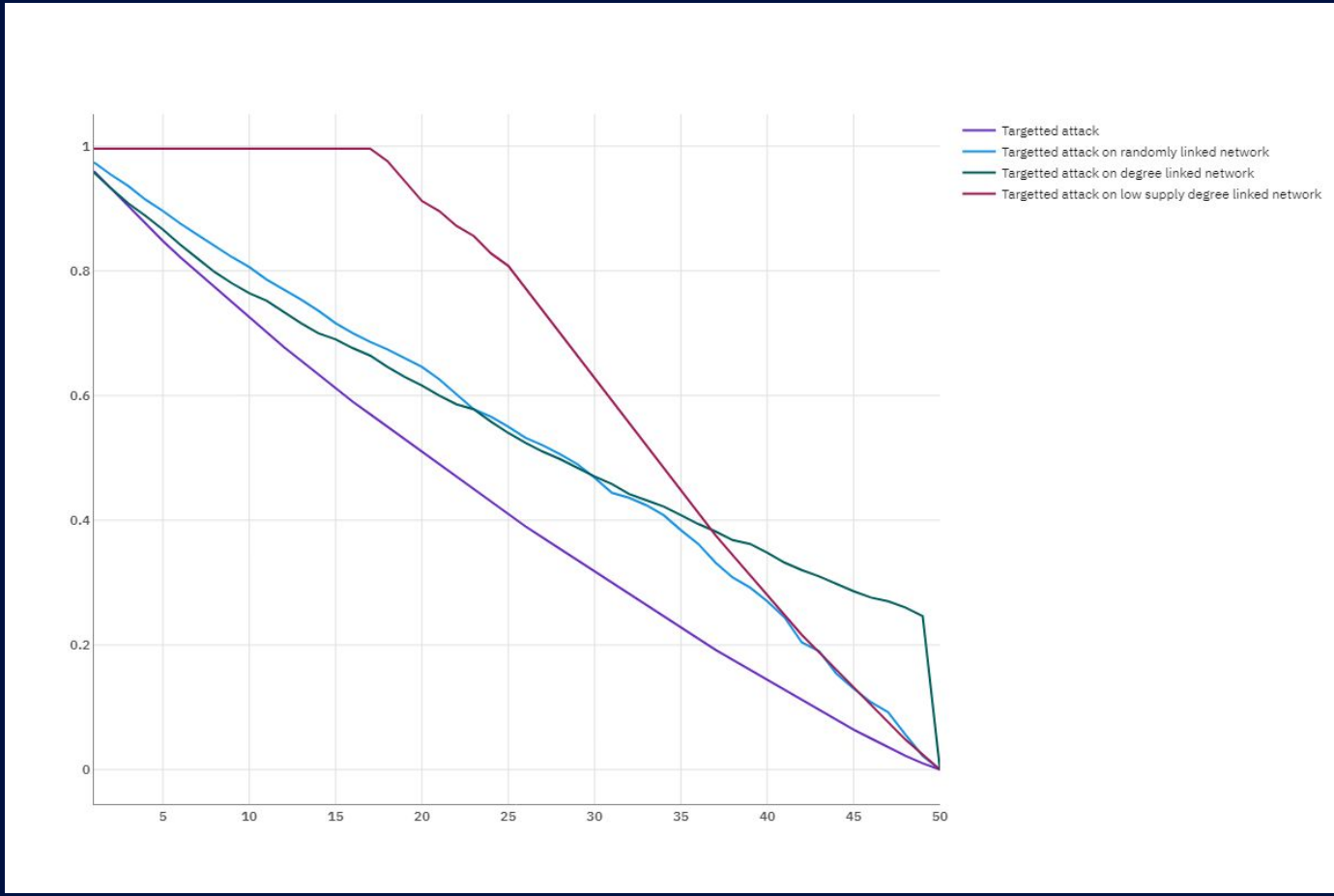
Testing resilience of Supply Chains

- Test the resilience by disrupting nodes randomly or by targeting the ones with highest degree.
- Supply chains often need to remain one connected network.
- Measure impact by size of largest connected component.
- Alternative measure is Supply Availability, which is the ratio of demand nodes which retain access to a supply node.
- Both measures show the network is very vulnerable to targeted attacks.



Improving Resilience

- Resilience of the network can be greatly improved by minimal adding of new links.
- Best performing network is the low supply degree linked network.
- It contains links from demand nodes to other demand node whose supply nodes have low degree.
- Resilience can be improved by connecting demand nodes which are served by smaller supply nodes.
- Distributed networks with smaller localised supply nodes are more resilient.
- Network Science and Simulation can reveal optimal tradeoffs between cost, lead times, resilience and sustainability.



Impactful community driven data science

Graphscope is an open source early stage network science library.

It is open for new contributors!

https://github.com/fslaborg/Graphoscope

All the code from this talk can be found on my GitHub page

https://github.com/HarryMcCarney/SupplyChainResilienceTalk

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