# Economics of Information Networks

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**Abstract**

*We continue discussion of the "modern" economics of networks, which considers the effect of structure of networks on economic (including social) behavior.*

# Structure and behavior

- Network structure induces constraints on behavior.
  - At a granular scale, in a city you can go from anywhere to anywhere by automobile.
  - By contrast you can only go from station to station on a train; you can't even get off between stations as you pass by.
- In this sense, economics (which studies how people deal with constraints) can be considered to "include" social behavior.

# Symmetry and asymmetry of nodes

This page refers to Figure 3.11.

- Before going on to the obvious feature of the network, I'd like to point out the symmetry of $E$ and $F$, and the two unnamed nodes in that group.
  - $E$ and $F$ are connected to all other group nodes except each other.
  - The unnamed nodes are connected to all other group nodes except $B$.
  - $E$ and an unnamed node are different in a minor way ($E$ is not connected to its twin $F$, while the unnamed nodes have a common unconnected group member), and in a more important way:
  - $E$-$C$ is *length 2*, while from an unnamed node to $C$ is *length 3*.
- One obvious feature of the network is the gatekeeper position of $B$ is stronger than $C$ and $D$, though they are also gatekeepers.
- Another is the centrality of $A$ in its group.

# Centrality and neighborhood overlap

- An important aspect of social (including economic) networks is *centrality*. This applies to both nodes and edges. Simple binary notions are those of nodes that are *pivots* and *gatekeepers*, and edges that are (local) *bridges*.
- Neighborhood overlap is a quantitative generalization of bridge. Let $|A|$ be the size of the set $A$, $N(A)$ be the set of *neighhbors of* $A$, and $O(A, B)$ be the *neighborhood overlap* of an *edge* connecting $A$ to $B$. Define

$$O(A, B) = \frac{|N(A) \cap N(B)|}{|N(A) \cup N(B)|}.$$

# Centrality and neighborhood overlap, example

- Fig. 3.7 shows the relationship between edge weight and neighborhood overlap in the who-talks-to-whom network of cell-phone users, establishing an edge if each end made at least one call to the other over an 18-month period (Onnela *et al.*[334]).
- This network has a giant component of 84% of the users, and cell-phone numbers are not listed in a public directory.
- *Tie strength* is measured by the number of minutes spent in conversation during the period.
- When $O(A, B) = 0$, the edge connecting $A$ and $B$ is a (local ) bridge. Strong closure theory says that local bridges are generally weak ties, so we predict an increasing relationship (the larger $O$ is, the farther an edge is from being a bridge).
- This relationship is reflected in the graph.

# Discussion/Homework

- Why didn't the previous slide need to specify the way neighborhood overlap is measured?
- Why is it significant that cell-phone numbers are not publicly listed?
- What can you say about a pair where one end made "very many" calls to the other with *zero* replies (or "very few" replies)?
- How might that change if you removed the instances of the word "very"?

# Tie strength and global structure

- Onnela *et al.* looked at global structure and the relationship to tie strength.
- First they eliminated ties one-by-one, starting with the *strongest* and going in decreasing order of strength. They found that the giant component shrank steadily, that is, shedding individual nodes and small components, until it became quite small, then broke into smaller, similar-sized components.
- Then they went in reverse order, and the giant component shrank more rapidly and fragmented much sooner.
- Kleinberg and Easley write:

> This is consistent with a picture in which the weak ties provide the more crucial connective structure for holding together disparate communities, and for keeping the global structure of the giant component intact.

# Centrality and embeddedness

This page refers to Figure 3.11.

- We define an absolute version of *neighborhood overlap*, called *embeddedness*:
  - The *embeddedness of an edge* is the number of common neighbors of the edge's endpoints.
  - This is just the numerator of the fraction defining neighborhood overlap, $|N(A) \cap N(B)|$.
  - Note that an edge with embeddedness zero is a local bridge.
- Kleinberg and Easley write:

  > [W]hat stands out about A is the way in which all of his edges have significant embeddedness. A long line of research in sociology has argued that if two individuals are connected by an embedded edge, then this makes it easier for them to trust one another, and to have confidence in the integrity of the transactions (social, economic, or otherwise) that take place between them [117, 118, 193, 194, 395].

# Graph partitioning

See Figure 3.13.

- Links are defined by friendship (each end declares the other to be a friend).
- The two nodes with heavy borders have special roles. Node 1 is the instructor (who is authorized to test candidates and bestow rank), and Node 34 is the club president.
- The club split into two clubs while under study, with the node colors indicating who joined which club.
- Could this split have been predicted from the friendship structure?

# Betweenness, flow, and partitioning

- Betweenness can be defined in terms of an abstract flow. Imagine that one unit of fluid flows between each pair of nodes, say $A$ and $B$. This flow is equally divided among all shortest paths between $A$ and $B$.
- The *betweenness* of an edge $E$ is computed as follows:
  1. Find all shortest paths between all pairs of nodes.
  2. For each pair of nodes, determine the amount of flow through $E$. (A pair with no shortest path through $E$ will contribute 0.)
  3. Sum flows through $E$ over all node pairs to get *betweenness of* $E$.

# Girvan-Newman partitioning

1. Calculate beteweenness for all edges.
2. Remove all edges with highest betweenness.
3. If the graph becomes disconnected, this is the $n$-th step partition.
4. If there are any edges left, go to 1.
5. Stop.