Strategic Network Formation with Structural Holes

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In this paper we briefly summarize the sociological theory of structural holes, which asserts that people benefit from acting as bridges between groups of people who do not otherwise interact. We then summarize recent work on modeling this phenomenon using network formation games. We conclude by providing open questions in the study and modeling of structural holes.

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A fundamental principle in sociological research is that there is greater homogeneity of behavior, opinion, information, and ideas within groups of people than between groups of people [Burt 2004]. Thus an individual who acts as an intermediary or a bridge between distinct groups of people would have access to a more diverse set of ideas and information to draw upon. Such an intermediary could benefit from this position in a number of ways. First, he or she could apply ideas, techniques, and practices taken from one group to problems faced by another. Second, he or she could innovate by synthesizing and combining different ideas taken from more than one group. The notions of homogeneity inside groups and brokerage between groups form the basis for the theory of *structural holes* pioneered by Ron Burt [Burt 1992; 2004; 2007]. This theory not only analyzes the links in a social network, but also the places where there is a sparsity or a lack of links between

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groups of people. Burt's studies of managers in a large electronics company show that people who occupy bridging positions between groups in a network are "higher risk of having good ideas" [Burt 2004]. Furthermore, occupying these positions is correlated with a higher compensation, more positive performance reviews, and promotions [Burt 2004].

Since people who act as bridges and intermediaries gain an advantage over those who do not, there is a natural strategic and dynamic aspect to this theory. The data used to support this theory, however, has typically been based on snapshots of social networks that make it hard to analyze the detailed dynamics taking place. We build on and extend Burt's work by modeling how social networks change over time if everyone is vying for these bridging positions [Kleinberg et al. 2008]. We model the benefits people receive both from attaching to other nodes directly and from bridging pairs of nodes that would otherwise be disconnected or sparsely connected. We consider individual utilities in which these benefits are balanced against the costs of maintaining the corresponding relationships. Given these utility functions we analyze the types of networks that arise at equilibrium.

Our results are derived via theoretical analyses and computational simulations. The equilibria found illustrate a number of qualitative observations that appear in the literature on structural holes. They show that the underlying dynamics result in a type of symmetry-breaking where nodes occupy different social strata at equilibria. Nodes settle into different levels of a social hierarchy where there are few or no edges between nodes at the same level, and where individuals at high levels form links to large numbers of nodes at lower levels. These topologies show that complex bridging behavior can arise — with nodes differentiating their behavior in equilibrium — even when all nodes have equal incentives to engage in such bridging behavior. Figure 1 shows pictorial examples of the types of equilibria found.

So far there are only two other papers that we are aware of that explicitly model the notion of structural holes using a network formation game. The first, [Goyal and Vega-Redondo 2007], considers a model in which a node u can benefit from serving as an intermediary between v and w even when u lies on an arbitrarily long path between v and w. In their setting the authors show that a star is the only robust equilibrium. A second paper, [Buskens and van de Rijt 2008], shares with our model the property that u can only benefit from being an intermediary when u is on a length-two path between v and w. This modeling decision is motivated by sociological studies suggesting that in practice most of the bridging benefits arise from being directly connected to the two people one is bridging, rather than serving as an intermediary on a path of length three or more [Burt 2007]. The work of Buskens and van de Rijt casts the network formation problem somewhat differently from the set-up of our model. Instead of a utility function based on the benefits of bridging, they model the cost of wasting effort on redundant length-two paths. They also use a more complex notion of equilibrium called "unilateral stability". They restrict their attention to the setting where all edges cost the same; interestingly, in this case we find equilibrium graphs with similar topology to theirs.

As the above review has shown, the study of structural holes spans the fields of sociology, economics, and computer science. As a result, a variety of techniques have been used in this area. These techniques include sociological studies, computational simulations, and theoretical analyses. Each one of these techniques has yielded different and valuable insights into the formation of structural holes. For example, the sociological investigation has shown the correlation between bridging and success with an organization (as indicated by salary, reviews, promotion, and other measures). The theoretical analyses and computational simulations have helped elucidate the dynamics of structural holes. We believe that there is further potential in this interdisciplinary approach, and we illustrate this with three possible directions for future work. First, it would be interesting to perform further empirical studies of organizations to look for evidence of some of the more fine-grained predictions of the theoretical models. Second, one could generalize the theoretical models to explicitly represent the different forms of expertise that people have, and by extension, the different forms of collective expertise that groups have. With this more detailed representation, one may be able to formulate the benefits of bridging in terms of the expertise in the groups being bridged. Finally, it would be interesting to study network formation and structural holes in a theoretical model of organizational structure via an objective function that measured the global success of the organization. In this way, one could investigate the potential ways in which individual incentives to bridge structural holes may be in some ways aligned with — and in other ways at odds with — the overall goal of organizational performance.

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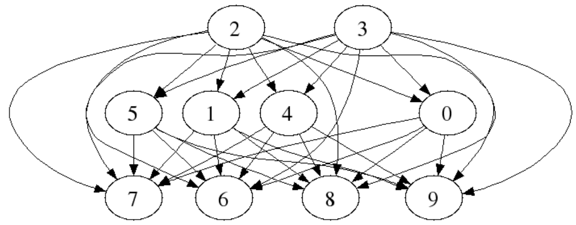
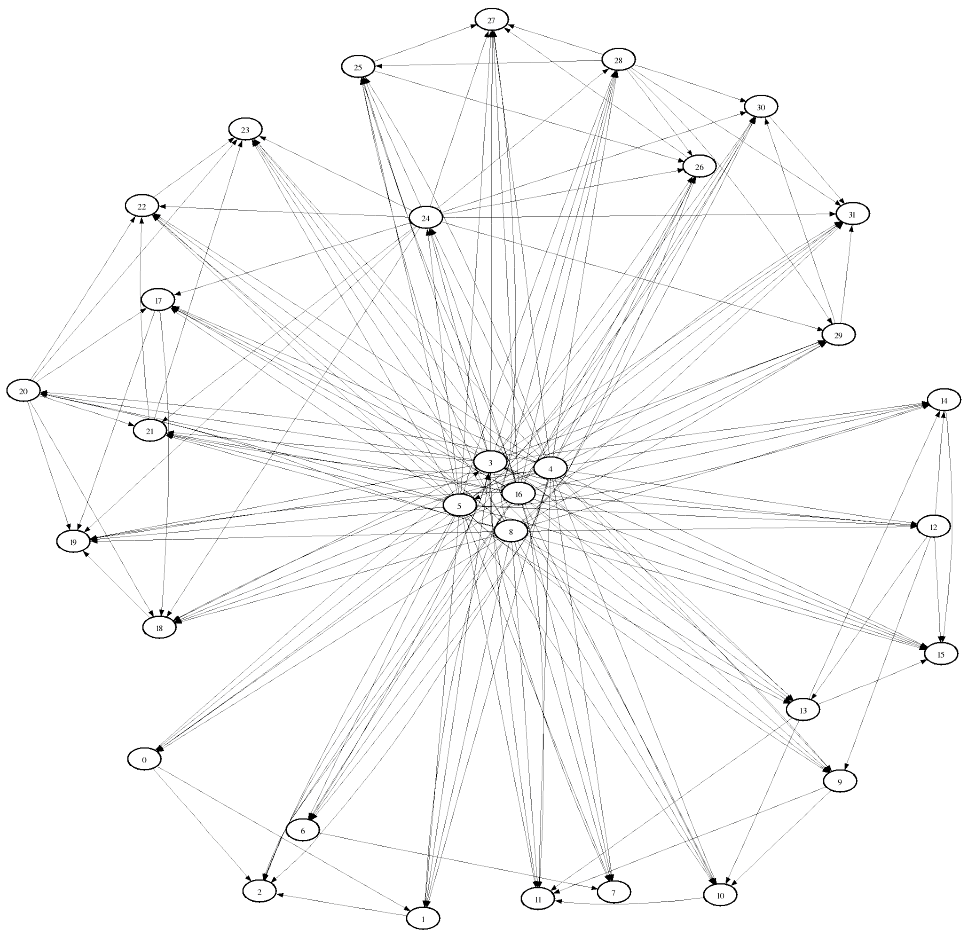


(a) Uniform Metric



(b) Hierarchical Metric

Fig. 1. (a) An example of an equilibrium with 10 nodes where the cost of an edge is a constant. Nodes at higher levels form bridges between all pairs of nodes at lower levels. (b) An example of an equilibrium with 32 nodes where the cost of each edge is defined by a hierarchical metric. There are a small number of nodes with connections to every other node, there are a few nodes with connections to moderate sized subtrees, and some nodes with only local connections.