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# Structural holes and bridging in two-mode networks

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ABSTRACT

Social networks are often structured in such a way that there are gaps, or "structural holes," between regions. Some actors are in the position to bridge or span these gaps, giving rise to individual advantages relating to brokerage, gatekeeping, access to non-redundant contacts, and control over network flows. The most widely used measures of a given actor's bridging potential gauge the extent to which that actor is directly connected to others who are otherwise not well connected to each other. Unfortunately, the measures that have been developed to identify structural holes cannot be adapted directly to two-mode networks, like individual-to-organization networks. In two-mode networks, direct contacts cannot be directly connected to each other by definition, making the calculation of redundancy, effective size, and constraint impossible with conventional one-mode methods. We therefore describe a new framework for the measurement of bridging in two-mode networks that hinges on the mathematical concept of the intersection of sets. An actor in a given node class ("ego") has bridging potential to the extent that s/he is connected to actors in the opposite node class that have unique profiles of connections to actors in ego's own node class. We review the relevant literature pertaining to structural holes in two-mode networks, and we compare our primary bridging measure (effective size) to measures of bridging that result when using one-mode projections of two-mode data. We demonstrate the results of applying our approach to empirical data on the organizational affiliations of elites in a large U.S. city.



## 1. Introduction

That social networks are often characterized by the presence of structural holes, or gaps, between different network regions is a crucial point in understanding social structure (Burt, 1992). In contrast to clusters and cohesive subgroups, structural holes can impede the diffusion of information and other resources in a network, reduce contact between different social groups, and otherwise increase distance between actors in a given social setting. Much research has also addressed the consequences of structural holes for the actors who compose social networks. The foundational work on this concept (Burt, 1992) highlights the ancillary benefits of structural holes for actors (i.e., boundary spanners) who help to establish "bridges" that link otherwise poorly connected contacts or regions. Sitting on a bridge that spans a structural hole yields brokerage potential, gatekeeping power, access to alternative and independent contacts, and other third-party benefits (Burt, 1992; Burt et al., 2013; Gould, 1989; Gould and Fernandez, 1989; Granovetter, 1973; Simmel, 1950).

Unfortunately, the concept of structural holes has not been fully developed for application to two-mode networks. Despite the fact that there is widespread interest in the structure of two-mode networks (Borgatti and Everett, 1997; Breiger, 1972; Field et al., 2006; Latapy, Magnien, and Del Vecchio, Latapy et al., 2008), few scholars have attempted to identify bridges in such networks or to describe how actor-level bridging capacity can be measured. To be sure, the concept of structural holes as it was developed by Burt (1992) is not easily adapted, in a strict graph-theoretic sense, to the case of two-mode networks. Actors who span structural holes are those whose first-order contacts are not connected to each other. But there is no possibility of such connections in two-mode networks. The immediate first-order contacts of the individuals in individual-to-organization networks, for example, are organizations, which by definition cannot be connected to each other directly because they are only *indirectly* linked to each other, via individuals. Thus, the direct application of Burt's (1992) measures to bipartite two-mode data is impossible when attempting to identify structural holes between two actors of the same set.

This poses a challenge to researchers who study two-mode networks: How can we identify structural holes between actors of a given type when there must always be intermediary actors of another type between them? To return to the example of individuals' organizational affiliation networks, one might be interested in identifying those individuals who span structural holes that exist

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among those individuals by virtue of the particular organizations with which they are affiliated. Surely, some individuals occupy positions in the larger organizational network that allow them to fill gaps or holes that few other actors in that structure occupy. For example, research shows that there is variation in actors' tendencies to occupy positions between different types of organizations (e.g., McPherson, 1983; Popielarz and McPherson, 1995). This type of behavior should create variation in actors' capacities to serve as bridges between structural holes. How can we quantify this variation?

A common but naïve approach is to project the complete two-mode matrix down to a one-mode affiliation matrix, which in the case of individuals would reflect the number of organizational affiliations those individuals share. One problem with this approach – as we will show – is that it masks the particular sources of individuals' connections to each other, in turn making it difficult to discern the presence of bridging opportunities. This paper provides a solution to this problem. We describe a set of measures that can be used to identify the members of one node class (e.g., individuals) who span structural holes between members of that same class who are otherwise poorly linked by virtue of the secondary nodes (e.g., organizations) to which they are connected. We base our approach on the mathematical notion of *intersection*. We begin by describing the logic behind and the calculation of these measures, and we then demonstrate their calculation using real data on the organizational affiliations of 312 community elites in a large U.S. metropolis.

## 2. Structural holes

Structural holes are gaps that exist between different regions of a network – that is, regions that have few connections between them. At the local level, a structural hole manifests as a "separation between nonredundant contacts" within a given actor's network (Burt, 1992:18). There are numerous reasons one may be interested in this structural possibility within a social network. For one, structural holes represent opportunities for the focal actor, ego, in his or her local network. For example, non-redundant contacts cannot constrain ego's capacity to gatekeep and to benefit from controlling the flow of resources between the non-redundant regions of the network (Burt, 1992).

How does one go about identifying structural holes in a social network? Regardless of whether one is examining a one- or a multi-mode network, one begins at the local level, focusing on egocentric network structures. Fixing a particular node *i* (ego) in a network, a redundant contact of that node is one that is connected to other contacts of. Where *i* is connected to non-redundant contacts, *i* sits on a "bridge" between those separate areas of his or her local network. Otherwise,' s local network is composed of some degree of redundancy, or closure. Thus, the task of identifying structural holes in local networks is a matter of identifying actors whose contacts are not connected to each other.

### 2.1. One-mode networks

Network analysts have developed several methods for measuring the presence of structural holes in one-mode networks. In this paper, we focus primarily on the original redundancy and effective size measures, though we also address the issue of constraint. Given an ego, *i*, in some one-mode network, the notion of redundancy captures the extent to which another node, *j*, is structurally equivalent to some other node, *k*. In Burt's (1992) words, these contacts are "redundant to the extent that they lead to the same people, and so provide the same information benefits" (p. 17). Gaining a handle on which contacts are redundant in an ego network helps us understand the extent to which the ego in question is well connected

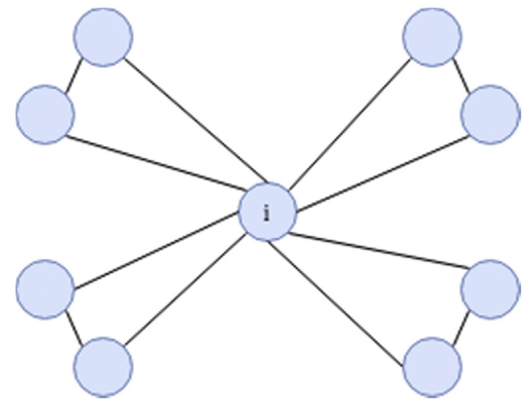


**Fig. 1.** Effective size in an example network.

to disparate or unconnected (i.e., *nonredundant*) contacts, and thus illuminates their bridging potential in the network. This bridging potential is captured by the ego's effective size, or the "true" size of their network absent of redundant contacts.

Burt (1992) defines redundancy mathematically as follows. The extent to which *j* is a redundant contact of, with *i* being the ego under evaluation, is:

$$\sum_q p_{iq}m_{jq},\ q \neq i, j. \tag{1}$$

$p_{iq}$ is the proportion of time and energy that *i* invests in some shared contact, *q*, between *i* and *j*, and $m_{jq}$ is the marginal strength of contact between *j* and *q* with regard to *j*' s contact with every other node. $p_{iq}$ and $m_{jq}$ are defined below.

$$p_{iq} = \frac{z_{iq} + z_{qi}}{\sum_j z_{ij} + z_{ji}},\ i \neq j \tag{2}$$

Here, $z_{ij}$ is the tie strength between *i* and *j*, – that is, the tie weight. A larger $z_{ij}$ represents a stronger tie, and a smaller $z_{ji}$ represents a weaker tie. Both directions (i.e. $z_{iq}$ and $z_{qi}$) are included in the event that the direction of the tie matters. For the marginal tie strength,

$$m_{jq} = \frac{z_{iq} + z_{qi}}{max(z_{jk} + z_{kj})},\ j \neq k \tag{3}$$

where $max(z_{jk})$ is the largest of *j*' s tie weights with any other node. Burt then states that "one minus this expression is the nonredundant portion of the relationship" (p. 52), and therefore the effective size of' s ego network is the sum of this nonredundant portion of *i*' s relationship over all contacts:

$$Effective\ size\ of\ i^{'}snetwork = \sum_j [1 - \sum_q p_{iq}m_{jq}],\ q \neq i, j \tag{4}$$

The first summation covers all primary contacts *j* in' s network, and the second covers all intermediary contacts *q* between *i* and *j*. Consider the example ego network in Fig. 1.

Assume that all ties have an equal weight of 1. Then, using the definitions above,' s redundancy with any of its primary contacts *j* is $\sum_q p_{iq}m_{jq} = \frac{1}{8} * 1 = \frac{1}{8}$, and therefore its effective size is $\sum_j [1 - \sum_q p_{iq}m_{jq}] = 8[1 - \frac{1}{8}] = 7$. As Borgatti (1997) points out, Burt wrongly assigns this same network an effective size of 4, even though it is actually 7 when the mathematical definitions are followed (despite the wrong answer's intuitive appeal).

Equipped with this necessary background, we are prepared to reason about possible definitions in two-mode networks.