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CHAPTER

Theory and Possibilities in Social Network Analysis

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Abstract

As social network analysis has grown in use over the past quarter century, it has become a staple in the disciplinary toolkit of political science. While political scientists have been at the forefront of innovating network methodologies, these developments have outstripped advances in political network theory. This chapter makes the case for greater attention to political network theory. It points to four promising areas for investigation. First, it advocates greater theorization of the strength of political ties that moves beyond the weak ties/strong ties dichotomy. Second, it identifies opportunities for theorizing types of ties to expand understandings of multiplex networks, such as by modeling their isomorphic structures. Third, it endorses the extension of multimodal models to incorporate the number of types of actors beyond the traditional bipartite structure. Fourth, it proposes blending theories of temporal network dynamics (e.g., preferential attachment, triadic closure, balance, homophily, reciprocity, decay) with extant theories of political time related to path dependence and sequences. Finally, it considers possibilities for traversing these areas of advance using an illustration from the study of political brokerage.

Keywords: social network analysis, network theory, weak ties, strong ties, multiplexity, multimodal, bipartite, temporal network dynamics, path dependence, brokerage

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Introduction

Social network analysis has been an area for social-scientific research for over a century, with the first empirical analyses in this genre appearing in the late nineteenth century (Freeman 2004). The past quarter century in particular has witnessed an explosion of interest in networks across the social and natural sciences, as well as in professional fields such as public health, business, and law. Recent developments have been aided by statistical innovation and growth in computing capacity, as well as by expanded public consciousness of social networks linked to the proliferation of social media. Within political science, network analysis has moved from the periphery of scholarship to a staple of the disciplinary toolkit.

Political scientists have been at the forefront of methodological advances in social network analysis. These advances have included the extension of modern statistical techniques to the analysis of social network data (Cranmer, Desmarais, and Morgan 2021; Cranmer et al. 2017), as well as the integration of experimental approaches (Ichino and Schündeln 2012; Larson and Lewis 2017; Ravanilla, Haim, and Hicken 2022; Sinclair 2012) and "big data" studies (Larson et al. 2019) with network designs.

However, this methodological progress has tended to outstrip potential theoretical developments in the field. In this chapter, *theory* refers to explanations of the *logics* by which actors operate in, exist in, or affect a network. In contrast, *methods* refer to procedures for *measuring* or *estimating* networks or their effects. My claim here is *not* that work on political networks has somehow been atheoretical. Rather, I maintain that studies of political networks have not advanced network *theory* with the same vigor as they have advanced network *methods*. Part of the reason for this tendency may be that political scientists have an inclination to fetishize methods. This lacuna presents opportunities for scholars to forge greater connectedness between the study of networks and other fields of empirical inquiry.

This chapter highlights four areas where political network theories could be fruitfully extended in ways that are concomitant with recent developments in network methods. First, greater theorization of the *strength or intensity of network ties* would permit better understanding of networks ties that are not readily characterized dichotomously as 0 or 1. Second, further conceptualization of the *types of network ties* could enhance the value of examining multiplex over uniplex models of networks. Third, extending the analysis of *types of network actors* has the potential to amplify the benefits of using multimodal network models. Fourth, *temporality* deserves more attention as a theoretical construct, especially given recent innovations in the analysis of time-varying networks.

The chapter begins by presenting the basic network model, which is typically specified with dichotomous ties of a single type (i.e., uniplexity), a single type of actor (i.e., one mode), and one time period (i.e., static analysis). It discusses the power of this model and how it has provided a framework for theoretical progress. Next, four extensions of this basic model and their theoretical potential are discussed. Finally, possibilities for intersection among the four extensions are considered.

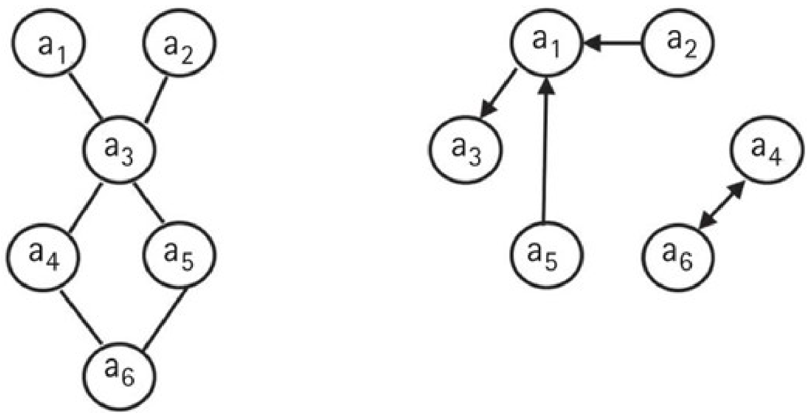
The Basic Network Model

The standard presentation of the network model is given by Ginestra Bianconi (2018, 11), as well as by many other scholars. In this presentation, a network graph (*G*) is formed from a set of vertices (*V*) and a set of edges (*E*) such that $G = (V,E)$. *V* contains the key objects in the network that may be equivalently referred to as nodes, individuals, actors, or points. The number of vertices is given as $N = |V|$. They could be comprised of any of a number of phenomena, such as voters, legislators, nation states, organizations, words in an article, or social media accounts. *E* contains the connective material for *V*, which may be equivalently referred to as links, ties, or lines. Connections could be specified as consisting of communication, friendship, animosity, sexual relations, co-membership in an organization, alliance, war, or any of a wide range of other relations. Theories can be built around graphs (*G*), vertices (*V*), edges (*E*), or some combination of these. That is, it is possible to theorize about the whole network, the actors in the networks, the connections among those actors, or how these factors impinge upon one another.

Study of the basic network model generally focuses on a dichotomous *N* x *N* adjacency matrix, *a*, which is usually defined as $a_{ij} = 1$ if node *i* is linked to node *j*, 0 otherwise. The most basic model assumes a single mode of analysis such that it is possible for any a_i to link to any a_j in *a* where $i \neq j$. That is, there are no classes of nodes within which links are not possible, which also implies that there is no separation among time periods. There is variation among even the most basic models as to whether ties are undirected ($a_{ij} \equiv a_{ji}$) or directed ($a_{ij} = 1 \nRightarrow a_{ji} = 1$ and $a_{ij} = 0 \nRightarrow a_{ji} = 0 \; \forall \; a_{ij} \in a$).

Figure 1 provides examples of two different networks, each of which has six nodes. The network on the left is undirected and the network on the right is directed, where directionality is indicated by arrowheads.

Figure 1



Undirected and directed networks

Source: Author's conceptualization.

Relaxing the assumptions of the basic model is straightforward and many scholars have done so. Before considering these extensions, however, it is worth exploring some of the work that has been done within this simple framework. Indeed, much—if not most—theoretical and empirical social network analysis can be situated within the parameters of the basic model.

For illustration, consider three theories that have been developed with the framework of the basic network model: *centralization theory*, *brokerage theory*, and *small world theory*. For each of these, scholars theorize that the *position* of actors within a network affects how they participate in a network and how that shapes what outcomes they achieve. These perspectives have been applied in a variety of political science studies.

Centralization theory examines the possibility that proximity to (or distance from) the center of a network affects the ability of an actor to obtain information, maintain prominence, or exert influence over a system. The *center* of a network may be conceptualized in different ways, such as occupying a position on the shortest path between other nodes (Freeman 1978 [1979]) or through connection to other influential nodes (Bonacich 1987).

Within the context of political behavior, Betsy Sinclair (2012) showed that citizens with higher network centrality made greater contributions to political campaigns. In his research on international relations, Zeev Maoz (2011) demonstrated that nations with higher network centrality were more likely to influence outcomes in the United Nations General Assembly than were nations with lower network centrality. Along the same lines, Lance Bennett and Alexandra Segerberg (2013) revealed that organizations active in digital networks are able to extract benefits from central positions, enabling them to exert power in social movements. Collectively, these findings support the view that a central position can be of value to political actors in a variety of contexts.

Brokerage theory posits that actors in a network may be able to secure gains when their positions in networks facilitate interaction, exchange, or trust among other actors in a network. Scholars differ in their conceptualizations of brokerage. Roger Gould and Roberto Fernandez (1989) imagined brokerage principally as the ability to navigate among competing groups in a network. Alternatively, Ronald Burt (1992) emphasized that brokerage is valuable to the degree that it connects actors who are otherwise disconnected in a network; these nodes span structural holes.

Political scientists have made fruitful use of these ideas. For example, Michael Heaney (2006) and Dimitris Christopoulos and Karin Ingold (2015) presented evidence that interest groups and other policy-interested actors have greater leverage over policymaking processes when they are poised to exert brokerage. Susan Stokes and her colleagues (2013) leaned heavily on network brokerage to explain the use of clientelism in distributive politics across countries. Henning Hillmann's (2008) historical account of state building in revolutionary Vermont documented how network brokerage was critical to the state centralization by serving to undermine local autonomy. Sarah Brierley and Noah Nathan (2021) established that political parties in Ghana place the greatest value on identifying brokers with the most upward connections to local elites. These findings underscore that the value of networks comes not only from the positions that actors occupy, but also from how they actively use those positions to intervene in the networks of other strategic actors.

Small world theory speaks to how the ties of individual actors in a network affect the global connectivity of its landscape. Scholars investigating small worlds want to know if and how it is possible for actors in a network to span the entire network. How many links would it take for any random person to connect with any other person in the world? This question has long fascinated network scholars, with a primitive formulation of an answer provided in the work of Frigyes Karinthy (1929 [2006]), who postulated that the human population could be connected in not more than five steps. An especially impactful study into this question was made by Duncan Watts (1999), who illuminated the pivotal role of clustering and randomness in influencing the connectivity of large networks.

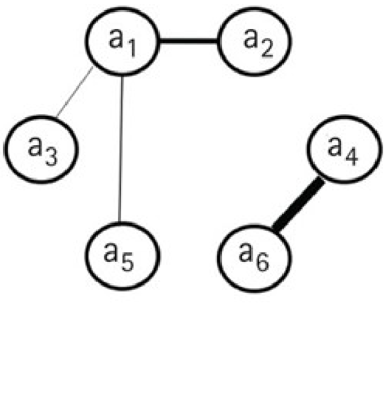
Pursuant to the analysis of Watts and others, political scientists have been keen to know if the small-world properties of a network affect the success of actors in competitive networks. Wendy Tam Cho and James Fowler (2010) reported that these properties matter for the volume of legislation passed in the United States Congress, where smaller worlds correspond with higher legislative output. Navid Hassanpour's (2016) dissection of protest networks during the 2011 Egyptian revolution indicated that the small-world nature of these networks amplified the value of occupying the *periphery* of the networks. This finding stands counter to the evidence (discussed above) on the premium attached to being located at the *center* of an activist network.

Thus, the extant literature demonstrates that even the most basic network model has provided space for scholars to pursue diverse theories and empirical projects. Despite its relative simplicity, it captures the complex structure of relations among actors in potentially large social systems. It has nurtured ideas about variations in the positions the actors occupy, the ways they interact with others, the clustering and roles of groups, the relevance of broad landscapes, and more. Political scientists have published applied studies using this framework in nearly every area of the discipline. At the same time, there are advantages to relaxing the strictures of the basic model, which are discussed in the following sections.

The Strength or Intensity of Network Ties

Rather than assuming that network ties are dichotomous, it may be useful to assume that they may take a wider range of values. For example, to differentiate between "strong" and "weak," a model could be written with a_{ij} = 1 if the relationship between *i* and *j* is strong, a_{ij} = 0.5 if it is weak, and a_{ij} = 0 if there is no relationship. Alternatively, the strength of the tie might vary continuously such that $a_{ij} \in [0,1]$, where proximity to 1 indicates strength and proximity to 0 indicates weakness. Figure 2 provides examples of two different networks, with the network on the left indicating strong (solid) or weak (dashed) ties and the network on the right allowing ties to vary continuously from weak (thin) to strong (thick).

Figure 2



Network ties varying by strength

Source: Author's conceptualization.

The most widely known study employing variation in tie strength is Mark Granovetter's (1973) article on "The Strength of Weak Ties." In it, he offered counterintuitive evidence that job seekers are more likely to obtain information about job openings from their weak ties than from their strong ties. He built the argument that weak ties are better for providing new information because more weakly connected people know different things, while more strongly connected people tend to share redundant information. On the other hand, strong ties are especially good for solidarity and trust in ways that weak ties are not.

Political science research has played on the strong/weak distinction. Daniel Carpenter, Kevin Esterling, and David Lazer (1998) showed that this preference for weak-tie contacts applies within elite networks of American lobbyists. Related findings have been published for internet activism (Valenzuela, Correa, and Zúñiga 2018), legislative outcomes (Kirkland 2011), and public management (Hansen and Villadsen 2017).

Despite their empirical utility, notions of strong and weak ties have been rather vague. To address this shortcoming, some efforts have been made to elaborate on the theory of tie strength. David Krackhardt

(1992) argued that strong ties are grounded in *philos*, a special type of intimate relationship. Krackhardt conceptualized these ties as having three critical dimensions: interaction, affection, and history. Mario Small (2009, 97) was also skeptical of a unidimensional view of strength and instead categorized contacts as "standard intimates," "compartmental intimates," or "non-intimates." Small's perspective enables differentiation between ties not only in their level of intimacy but also in their operant scope in a person's life. Louise Sundararajan (2020) proposed that notions of strong and weak ties are universally important but vary across cultures in how they are understood (see also Gondal 2022). This view recognizes that what makes for strong ties in Japan is not likely to be the same as what pertains in Uganda.

Political scientists have done comparatively little to articulate how the strength or intensity of ties might be theorized in politics. This neglect represents an opening for future scholarship. One approach could be to theorize *dimensionality*; how strength/weakness varies across key dimensions of the ties, such as formality, secrecy, or risk. That is, do the patterns of tie strength depend on whether relationships are formal (such as treaties between nations) or informal (such as conversations among legislators or citizens)? Are the patterns dependent on whether relationships are observed publicly or whether they are exclusive to the confidence of the actors involved? Could the stakes or risks involved in the relations affect how strength is determined? Existing theories of custom (Biggart and Beamish 2003), uncertainty (Kahneman, Slovic, and Tversky 1982), or emotion (Marcus 2000) might be combined with network theory to develop such a perspective.

A second approach could be to think about what degrees of strength must be reached in order to affect the outcomes of political processes. In some cases, the relevance of tie strength could be sensitive to passing key *thresholds* (Granovetter 1978). For example, the stability of international relations depends on trade networks (Hafner-Burton, Kahler, and Montgomery 2009). But what are the thresholds beyond which these trade relationships have an effect? Do thresholds vary from sector to sector? Theories of psychological thresholds—at what point humans notice small changes in states—are built from a long tradition of research that could be informative here (Rouder and Morey 2009). A macro perspective is offered by complex systems theories that have insights on how the behavior of a large number of actors can be governed by critical thresholds (Miller and Page 2009).

A third approach could be to interpret the nature of tie strength based on logics of *appropriateness* (March and Olsen 2009). Whether a tie is strong or weak may depend on an institution's formal and informal rules. Certain types of contact may be considered routine or perfunctory. Others may be viewed as obsequious or unseemly. Still others may be a reflection of true intimacy. Institutions elaborate on these distinctions as new cases arise and as they evolve.

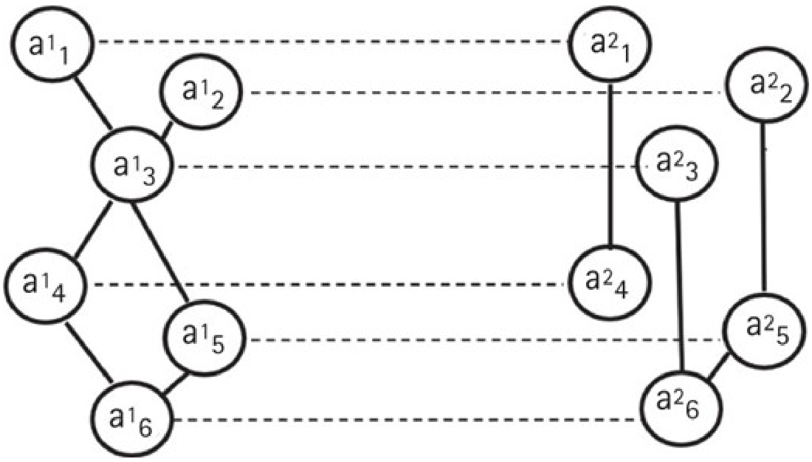
The potential value of adopting one or more of these approaches (*dimensionality*, *thresholds*, or *appropriateness*) can be gleaned by considering the example of campaign finance networks in the United States. First, dimensionality of ties could be relevant to differentiating between the significance of dollars given by alternative entities—individual citizens, industry Political Action Committees, or other politicians—or in races for distinct offices—president, senator, representative, governor, state legislator, and so on. Second, thresholds could be applicable in thinking about the legal restrictions on certain types of contributions. The strength of contribution might be thought of as a function of the difference between the contribution and the legal maximum, or possibly between the contribution and the average amount given. Such differences might hint at how actors are likely to interpret levels of giving; a contribution that is closer to the legal maximum could indicate a stronger relationship, while a contribution below the overall average might not. Third, appropriateness might differentiate between the strength attributed to contributions made by a party leader (who might be expected to give to all vulnerable members of their caucus) and a rank-and-file member (who might only be expected to give to party allies in their region). In this case, the effective strength of the contribution depends on what is appropriate for the giver and recipient's institutional roles. Building a theory based on one or more of these approaches could help to use network analysis to deepen what is known about campaign finance institutions.

Recent advances in network methods would readily accommodate testing hypotheses derived from such theories. Of particular note is the development of Generalized Exponential Random Graph Models (GERGMs) (Desmarais and Cranmer 2012; Wilson et al. 2017). These models combine standard regression analysis with dichotomous Exponential Random Graph Models (ERGMs) in order to consider dependent variables composed of a network's edges that may assume any value on the real line (positive or negative). Clearer theories about the strength of edges would enhance the value of these methods that model edge variation. Relevant applications could include trade balances, body counts in war, frequency of political discussion, co-occurrence of lobbying coalitions, or campaign finance contributions.

Types of Network Ties

Rather than specifying $G=(V, E)$ as connected only through a single adjacency matrix, a, it is possible (following Bianconi 2018, 101) to specify a set of interrelated graphs, $\vec{G}=(G_1,G_2, \ldots, G_\alpha, \ldots, G_M)$ such that $G_\alpha=(V_\alpha,E_\alpha)$ where each α represents a different type of tie. For example, we could imagine that M = 5 such that the graphs are connected by friendship (G_1), family (G_2), communication (G_3), common workplace (G_4), and party membership (G_5), each of which has its own distinct adjacency matrix, a. In this multiplex setup, node i and j might be connected in G_1, G_3, and G_5 but not in G_2 and G_4. Figure 3 illustrates this approach where M = 2, with G_1 on the left and G_2 on the right. The solid lines reflect ties within a single G_α and the dotted lines draw attention to the same node's presence in both graphs.

Figure 3



A multiplex network

Source: Author's conceptualization.

A variety of questions immediately spring to mind when viewing Figure 3. Is there a difference between the node pairs (i.e., dyads) that share a tie in both graphs (in this case, a_5 and a_6) and those that do not? Do ties in G_1 affect ties in G_2, and vice versa? Is behavior in the system governed more by G_1 or by G_2? Is there some interactive effect stemming from the copresence of G_1 and G_2? Do G_1 and G_2 operate according to similar or different logics? These questions sketch an initial agenda for the study of multiplexity.

The foundational study applying multiplexity to political phenomena is John Padgett and Christopher Ansell's (1993) article on "Robust Action and the Rise of the Medici, 1400–1434." They demonstrated that the rise to power of the Medici family in Renaissance Florence was the result of the family's skillful navigation among multiple elite networks based on marriage, economics, friendship, and politics. John Padgett and Walter Powell's (2012) treatise on *The Emergence of Organizations and Markets* further builds multiplex theory by rooting exchange between networks in autocatalytic processes among nodes. Applications of these ideas are found in studies of political discussion (Minozzi, Song, Lazer, Neblo, and Ognyanova 2020), lobbying influence (Heaney 2014), local government service provision (Shrestha and Feiock 2009), and Czech political corruption (Diviák, Dijkstra, and Snijders 2019).

Methodological advances have facilitated the analysis of multiplex data within a common statistical framework. For example, it is possible to use Multilayer ERGMs to estimate the formation of ties across multiplex networks (Caimo and Gollini 2020). Similarly, multiplex stochastic actor-based models can be adopted to estimate multiplex endogenous network effects (Labun, Wittek, and Steglich 2016), which rely on somewhat different modeling assumptions from Multilayer ERGMs. Scholars who wish to investigate multiplexity should be able to tailor one of these approaches to the statistical requirements of their research.

Yet, political theories rooted in multiplex networks are still limited in depth. Perhaps the most obvious opportunities for progress rest in theorizing the relationships among the various G_α in $\vec{G}$. Some non-mutually exclusive possibilities include (with labels in italics):

1. *Independence:* G_i and G_j are not meaningfully related to one another. For example, an activist's network of business associates has few to no implications for their hobbyist network.
2. *Comparability:* G_i and G_j are equally important to an actor. For example, an elected official's network of grassroots political supporters is equally important to their network of legislative allies.
3. *Asymmetry:* G_i is significantly more important to an actor than G_j. For example, a nation-state's network of weapons suppliers is more important than its tourism network.
4. *Nesting:* G_i is a subset of G_j such that $G_i \subseteq G_j$. For example, the prime minister's network of close advisors is a subset of their party network.
5. *Overlap:* G_i and G_j have a high degree (or, alternatively, a low degree) of overlap with one another. For example, an interest group's network of coalition allies is nearly identical to the lobbyists with which it regularly exchanges information. Alternatively, an interest group makes its formal alliances in coalitions quite separately from the close confidants with which it exchanges information.
6. *Isomorphism:* G_i and G_j exhibit isomorphism such that $G_i \cong G_j$ (or, alternatively, anti-isomorphism) with respect to their key network configurations. For example, G_i and G_j are both highly hierarchical. Alternatively, G_i is highly hierarchical while G_j is highly decentralized.

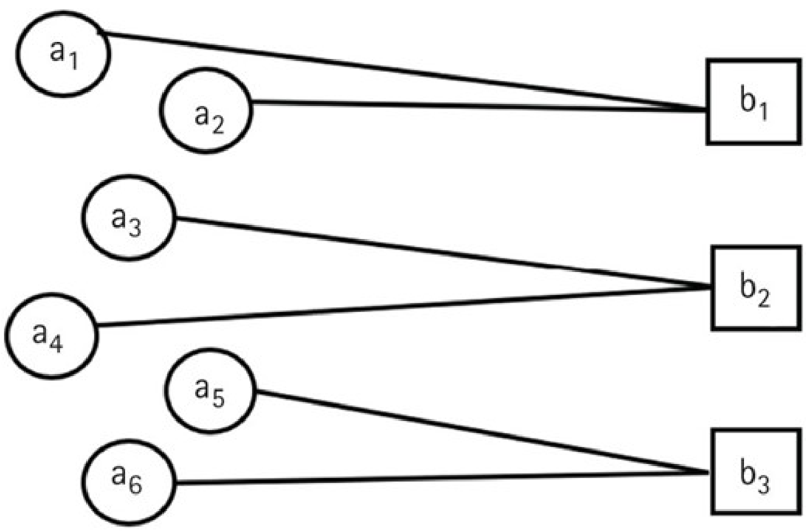
The above list is not exhaustive, but it does clarify some of the options for theoretical consideration. Consider option (6) and its associated examples. It is reasonable to hypothesize that the effects of multiplexity differ when G_i and G_j are isomorphic as opposed to anti-isomorphic. If G_i and G_j are both hierarchical, it is likely that the two networks would be in close competition with one another; actors might be compelled to side with either G_i or G_j when there is a conflict—perhaps depending on resource levels—making compromise difficult. On the other hand, if G_j is decentralized, it might be harder to control, leading to less competition between the actors when G_i and G_j conflict. Further, there is mileage to be gained from theorizing the conditions under which these patterns are expected to hold. Should competition between hierarchical networks be a universal tendency? Or are there reasons to expect divergent results depending on the case?

Another pathway would be to focus on the kinds of multiplex patterns that recur frequently in network models. For example, coalitions (or alliances) and communication is a common multiplex pair (Heaney and Leifeld 2018; Simpson 2015; Wang et al. 2016). Given this recurrence, can some general propositions be stated about the nature of multiplexity? For example, the degree of overlap between the coalition network and the communication network may be influenced by the level of formality of the coalition network. When coalitions are highly formal, coalition networks and communications may differ more from one another because coalition membership is more strategic, symbolic, or rigid. But when coalitions lean toward informality, closer ties with communication are expected, since coalitions members can leave more easily when their partners no longer appear to serve their cause. Other common multiplex pairs include networks of trade and war (Jackson and Nei 2015) and networks of migration and commerce (McKeown 2001). These regularities suggest likely intellectual benefits in building theoretically systematic knowledge in these domains, if possible, with the aspiration of pushing toward a more general network theory of multiplexity.

Types of Network Actors

Rather than assuming that any a_i can connect with any a_j in a, it is possible to partition the elements of V into related sets $\vec{V} = (V_1, V_2, \ldots, V_\alpha, V_\beta, \ldots, V_K)$ such that the elements of V_α can connect with the elements of V_β (and vice versa), but connections are not permitted among the elements of V_α or among the elements of V_β. For example, a partition might be created between nation-states and treaties to which they are signatories; a nation-state may sign a treaty, but a nation-state may not sign another nation-state and a treaty may not sign another treaty. These partitions are referred to as the *modes* of V. It is common to set $K = 2$, which creates a *bipartite* graph. However, higher-order partitions are possible (Fararo and Doreian 1984). For example, imagine a network in which V_1 is composed of individuals, V_2 of organizations, and V_3 of events (Knoke et al. 2021, 143). Figure 4 illustrates a multimodal network with $K = 2$ (two mode/bipartite).

Figure 4



A multimodal network

Source: Author's conceptualization.

The study of two-mode/bipartite networks drew considerable inspiration from the work of Ronald Breiger (1974), which demonstrated the analytical value of mapping two-mode data into a one-mode space. That is, a network of individuals and organizations can be projected into a network of individuals to individuals or a network of organizations to organizations. From these projections, it is possible to know how individuals become interlinked through the bipartite network, as well as how organizations are similarly interlinked. Thus, it is readily possible to analyze how individuals are related to one another by being part of the same activist groups (Heaney and Rojas 2015) or how nongovernmental organizations are related through participating in the same coalitions (Hadden 2015).

Some readers may be inclined to conflate *multiplex* and *multimodal* networks. The key difference is that a *multiplex* network has different types of *ties*, while a *multimodal* network has different types of *actors* (or partitions among the actors that it does have). Of course, it is possible for a network to be *both* multimodal and multiplex. For example, imagine a situation in which the types of nodes were *legislators* and *policy committees*, while ties consisted of *membership* on the committee and *appearance* before the committee. In this case, legislators have the potential to connect to a policy committee in one of two ways (membership or appearance). It might be relatively uncommon—but possible—for some legislators to both appear before the committee and serve as a member of it. Some legislators are members of a committee but do not appear before it; some appear before a committee but are not members of it; while others are neither members nor do they appear before the committee. Such a situation might call for analysis using a model that is both multiplex and multimodal.

Methodological innovations have facilitated research on multimodal networks, especially bipartite networks. Peng Wang and his colleagues (2009) derived ERGMs for bipartite networks, thus facilitating statistical studies of these structures. Other scholars have contributed by extending concepts and measures used in the basic model to bipartite networks. Of particular use has been Lorien Jasny and Mark Lubell's (2015) two-mode operationalization of Gould and Fernandez's (1989) models of brokerage. They illustrated the value of this approach using data from water policy networks in California. By drawing on these and related statistical tools, research has used multimodal analysis to interpret phenomena such as Brazilian youth activist networks (Mische 2009), engagement in civil society in Western Europe (Knoke et al. 2021), city politics (Diani 2015; Neal 2013), and terrorism (Spelta, Pecora, and Pagnottoni 2023).

Much of the existing research on multimodal networks treats this feature of the data primarily as a methodological wrinkle; a way of accounting for the complexity of a system. To move beyond this perspective, a starting point is to think of modes as the result of *institutional rules*. While this conceptual move may not be applicable in every multimodal network, it makes sense for many networks that are relevant to politics.

Consider three examples of two-mode networks: (1) a Twitter network of accounts and the hashtags they post; (2) a parliamentary network of staffers assigned to Members of Parliament (MPs); and (3) a public policy network of government regulations and the businesses that are subject to them. The existence of nodes in each of these modes is subject to institutional rules. A Twitter account has to follow the platform's rules, otherwise it is subject to suspension, while a hashtag is meaningful only if it follows the system's specifications. A staffer must be hired through human resources procedures, while MPs are officially selected in elections. A regulation is created after proper rounds of review, while a business is incorporated under the laws of the state. Given these relationships, the extensive literatures on how institutions operate could be used to theorize about multimodal networks (Fioretos, Falleti, and Sheingate 2016; March and Olsen 1989; Moe 1990).

Institutional rules may set some of the following non-mutually exclusive parameters for tie formation in multimodal networks (with parameter labels in italics):

1. *Nodal preferences*: Are there institutional restrictions on, or preferences for, which nodes connect within a mode?

2. *Degree restrictions*: Do the institutions set minimums or maximums on how many nodes may connect

within a mode?

3. *Duration restrictions*: Do the institutions set minimum or maximum lengths of time that the connection within a mode must be maintained?

4. *Flexibility*: Do the institutions permit a mode's connections to be easily changed or is there significant rigidity?

5. *Publicity*: To what extent do institutions allow a mode's connections to be advertised publicly? Is it easy or difficult to obtain information about the connections?

6. *Sanctions/rewards*: Do the institutions impose costs, or provide benefits, for connecting within the mode?

7. *Governance gap*: Are there differences within or between the modes in the degree to which they are governed by institutional rules?

Attention to the parameters outlined above could help to initiate more general theorizing about how different types of multimodal networks operate. They could facilitate generalization across multimodal networks that had previously been considered unrelated to one another. For example, if V_1 and V_2 both impose *duration restrictions*, they might exhibit patterns not evident in V_3 and V_4, which are more reliant on *sanctions/rewards* in their governance processes. There is also the possibility that certain parameters tend to couple with one another, but not with other parameters. For example, degree restrictions and duration restrictions may tend to co-occur because they both reflect the institutions' imperatives to control membership in the network. On the other hand, high flexibility and high publicity may tend not to co-occur because institutions have an interest in limiting publicity when they allow flexibility, given the risks of indiscretion in tie formation.

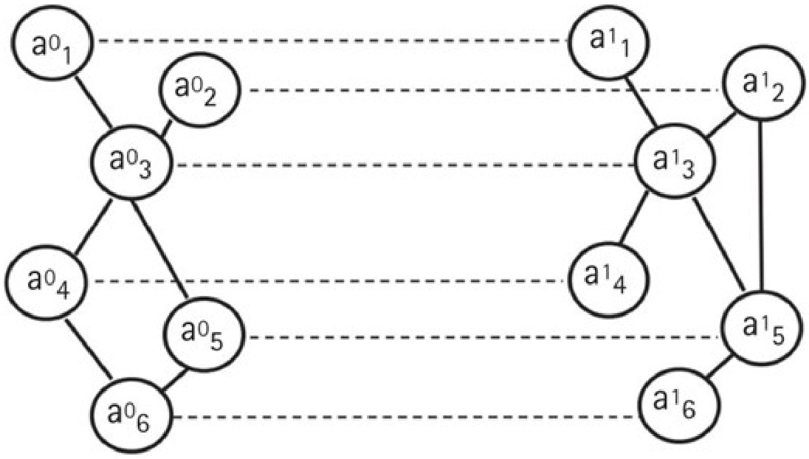
The central argument in this section is *not* that a particular configuration of parameters is particularly likely or unlikely. Instead, it is that network theory should develop around understanding the parameters of modes in multimodal networks. This approach would promote the development of knowledge about how seemingly unrelated multimodal networks in fact follow similar principles.

Temporality

The metatheory underlying social network analysis assumes that networks are constructed over time; all the ties in a network do not appear in an instant (Robins and Lusher 2013). Yet the temporal unfolding of tie formation is not routinely incorporated into network models. In order to do so, a basic choice must be made about whether to measure time as a discrete phenomenon (e.g., year 1, year 2, year 3, etc.) or as a continuous phenomenon (e.g., 01:05.77, 06:21.36, 11:55.49, etc.).

When a discrete-time approach is selected, a straightforward extension of the basic model can be easily represented. The graph can be partitioned into time slices where $\overrightarrow{G} = (G^t, G^{t-1}, \ldots, G^{t-L})$ such that t represents the current time period and L represents the number of periods (see Cranmer, Desmarais, and Morgan 2021, 123). This specification is similar to the multiplex model with the nontrivial difference that the order of the partitions matters; time travel is not possible. In a multiplex network, it is trivial and inconsequential to swap the order of G_α and G_β. But in a temporal model, it would be highly problematic to swap G^{t-4} and G^{t-9}. Figure 5 illustrates a discrete temporal network with L = 2. The solid lines reflect ties within a single period and the dotted lines draw attention to the same node's presence in both time periods.

Figure 5



A discrete-time temporal network

Source: Author's conceptualization.

The simple example presented in Figure 5 represents a fair amount of temporal stability as the network evolves from period t-1 to period t. The two periods are identical save two changes. The tie from a_4 to a_6 has dissolved such that $a^{t-1}_{46} = 1$ and $a^{t}_{46} = 0$. At the same time a_2 and a_5 have formed a new relationship such that $a^{t-1}_{25} = 0$ and $a^{t}_{25} = 1$. These observations naturally lead to questions about tie dissolution, formation, and overall temporal network stability (or instability). For example, how was tie formation between a_2 and a_5 influenced by their common tie with a_3? Analysis of discrete temporal networks branches out from these types of question.

Continuous-time approaches require a somewhat different model setup, so they are not presented in detail here due to space constraints. Excellent explanations of these models are given by Tom Snijders (2001) for Stochastic Actor-Oriented Models (SAOMs) and by Carter Butts (2008) for Relational Event Models (REMs). Philip Leifeld and Skyler Cranmer (2019) offer an instructive comparison of the discrete-time and continuous-time approaches.

Political scientists have adopted temporal network models in numerous empirical studies. An early application of Temporal Exponential Random Graph Models (TERGMs) by Skyler Cranmer and Bruce Desmarais (2011) found that the longstanding democratic peace hypothesis (i.e., democratic nations tend not to fight one another) is not supported when network structure is taken into account. Philip Leifeld (2013) analyzed the discourse in German pension politics to show how transition among advocacy coalitions over time can be attributed to polarization of policy beliefs and policy learning. Seth Masket and Boris Shor (2015) turned to a TERGM to reveal that newly established term limits led to polarization of the state legislature in Nebraska. Scholars have adopted continuous-time network models in their examinations of reciprocity in congressional collaborations (Brandenberger 2018), tweeting about a Hindu religious festival (Heaney 2021), and the Syrian civil war (Fritz et al. 2023).

Prior research has identified numerous mechanisms for network change over time. They include:

1. *Preferential attachment*: Actors have a preference for forming new ties with actors that already have a large number of ties where $p(a^{t}_{ij} = 1 \mid a^{t-1}_{ij} = 0) = f(\text{degree}(a^{t-1}_{i}))$ such that $\frac{df}{da} > 0$ (Barabási and Albert 1999). For example, voters who begin to pay attention to an election contest late in the campaign have a tendency to attach their support to the leading candidate.

2. *Triadic closure*: If $a_{ij} = 1$, $a_{jk} = 1$, and $a_{ik} = 0$, there will be pressure to complete the triad such that $a_{ik} = 1$ (Rapoport 1953). For example, if *i* is in alliance with *j*, and *j* is in alliance with *k*, then there is a

tendency for *i* and *k* to also form an alliance.

3. *Balance*: In cases of triangles where $a_{ij} = 1$, $a_{jk} = 1$, and $a_{ik} = 1$, each tie has a valence that is either positive ($v_{ij} = 1$) or negative ($v_{ij}=-1$). If product of the valences is positive ($v_{ij}v_{jk}v_{ik} > 0$), then the triangular relationship is stable. If the product of the valences is negative ($v_{ij}v_{jk}v_{ik} < 0$), then there is pressure on the network to change one or more of the valences to create a positive product (Heider 1946). For example, if three nations are all at war with one another then there is pressure for two of the nations to set aside their differences and form an alliance against the third (i.e., the enemy of my enemy is my friend).

4. *Homophily/Heterophily*: For each set of vertices, $V \in G$, there exists a set of characteristics, $\vec{C} = (C_1, C_2, \ldots, C_\gamma, \ldots, C_H)$, where H is the number of characteristics. *Homophily* is the pressure to switch from $a_{ij} = 0$ to $a_{ij} = 1$ if *i* and *j* share a characteristic C_γ (McPherson, Smith-Lovin, and Cook 2001). For example, there may be a tendency for friendships to form among children of the same sex. *Heterophily* is the pressure to switch from $a_{ij} = 0$ to $a_{ij} = 1$ if *i* and *j* do *not* share a characteristic C_γ. For example, there may be a tendency for sexual relations to take place among people of different sexes.

5. *Reciprocity*: In a directed network, if $a_{ij} = 1$ and $a_{ji} = 0$ in the period t-1, then there is a tendency to establish $a_{ji} = 1$ in period t. For example, if politician *i* makes a campaign contribution to politician *j* in the first quarter of the year, then there is pressure for politician *j* to make a campaign contribution to politician *i* in the second quarter of the year.

6. *Decay:* The rate of decay, δ, is the probability that a tie that exists in period t-1 dissolved by period t such that $\delta = p(a^{t}_{ij} = 0 \mid a^{t-1}_{ij} = 1)$ where $\delta \in [0,1]$ (Burt 2000). For example, a coalition may typically lose five percent of its members in any given year, $\delta = 0.05$.

The above network mechanisms offer a non-exhaustive but well-established list of correlates of network dynamics. An opportunity for theoretical advance rests in the potential to combine these mechanisms with non-network-related theories of political time. Paul Pierson's (2004) discussion of temporal processes in politics could serve as a starting point for such an endeavor.

Temporal networks have features such as preferential attachment that are *path dependent* because they may be unpredictable, inflexible, potentially inefficient, and feedback prone (Arthur 1994; Pierson 2004, 18). Given these similarities, it is reasonable to speculate that network dynamics follow some of the same patterns that Pierson observed about institutions, such as linkage to electoral cycles, stickiness from actors' needs to make credible commitments and satisfy supermajority requirements, and the persistent relevance of historical events. For example, an election outcome (such as the 2000 American presidential election resulting from a Supreme Court decision) could shape the structure of political discussion networks for many years to come. Relatedly, individuals' decisions about new friendships and joining groups could have temporal effects on the evolution of their political attitudes (Santoro 2023). Theorizing networks as path-dependent phenomena, then, could be a way of deepening theories of temporal networks.

Sequencing is another aspect of time that may be relevant for temporal networks (Abbott 2001; Pierson 2004). In a simple example, the tone of the relationship between *i* and *j* may depend in part on whether *i* initially reaches out to *j* ($a_{ij} = 1$), or whether *j* reaches out to *i* ($a_{ji} = 1$). Suppose there is a considerable status difference between them such that at $s(a_i) > s(a_j)$. In this situation, *i* may take the relationship more seriously in event that they did the initiating than if they experienced the receiving. This difference could be a factor in transitive closure with *k* from period t-1 to t. If $a_{jk} = 1$, then triadic closure with *i* may be more likely if *i* initiated the relationship with the lower status *j* than if *j* initiated the relationship with the higher status *i*. An application to politics could be in the domain of coalition formation, offering one mechanism (of several) for why coalitions brokered by higher status individuals may grow more quickly than coalitions brokered by lower status individuals.

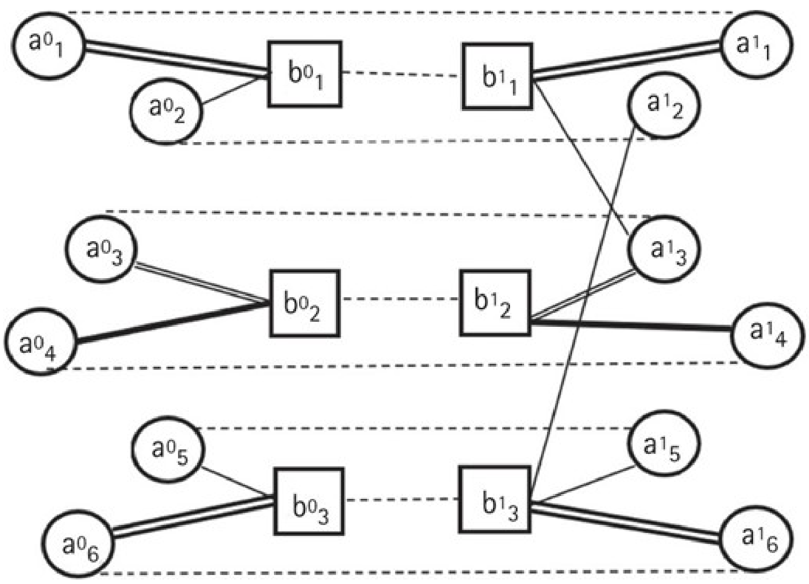
The features of *long-term political processes* are a third element that could be theorized in conjunction with temporal networks. Pierson (2004, 97) categorizes these processes as combining either *long* or *short* time frames with respect to either *causes* or *outcomes*. These processes could be thought of as congruent or incongruent with network temporality. For example, institutions might produce long-term outcomes while network temporality is biased toward the short term. An application to politics could be in the domain of international military alliances. These alliances are working toward long-term outcomes such as regional hegemony. But tensions among allies are created by shorter-term decay in national-level political networks. An instance of these dynamics is found in Europe, which confronted tensions as it tries to establish its collective security vis-à-vis Russia while the American posture has vacillated between pro-Europe (under President Barack Obama and President Joe Biden) and pro-Russia (under President Donald Trump).

Time is a vital consideration across varied social-scientific approaches. The above discussion suggests that there is potential to combine theories path dependence, sequencing, and long-term processes with theories of network temporality. At the same time, these suggestions only scratch the surface of ways to enhance theories in this area.

Traversing the Extensions

The four extensions in this chapter can be combined into a single, grand network model. Figure 6 illustrates this combination. Strength of ties is indicated by the thickness of the lines. Type of tie is noted by single or double lines. Type of actors is shown as circles or squares. The linkage of nodes across time is traced with dashed lines. Thus, the model accounts simultaneously for tie strength, multiplexity, multimodality, and temporality.

Figure 6



A grand network model

Source: Author’s conceptualization.

Combining all these network features in a single model may not necessarily be theoretically desirable in any particular application. Instead, this figure makes the point that it is possible—and not too difficult—to bring them together. Recently developed computer packages such as **xergm** make it feasible to estimate statistical models of this ilk (Leifeld, Cranmer, and Desmarais 2018). Now the key challenge is to build theories that demonstrate the relevance of these models to empirical political phenomena.

This chapter outlines more than thirty concepts relevant to the logic of networks. Combining any two of these could provide an avenue for theoretical advance. Some scholarship has already moved in this direction. For example, Dingding Chao and colleagues (2019) theorized mechanisms for the unfolding of multimodal networks over time. Labun, Wittek, and Steglich (2016) articulate a theory that looks at endogenous multiplexity in a temporal network. Paul Smaldino, D'Souza, and Maoz (2018) blend theories of path dependence and multiplexity to develop a concept of *structural entrenchment*.

As it is not possible to discuss all the possible combinations here, consider the investigation of the politics of brokerage as one path forward that is consistent with the argument of this chapter. As mentioned above, Jasny and Lubell (2015) have shown how the Gould-Fernandez perspective on brokerage can be interpreted within multimodal networks. It now seems important to think also about brokerage taking place across multiplex networks and over time.

Many brokerage situations are likely to involve the complexity encompassed in multimodality, multiplexity, and temporality. The negotiation of Northern Ireland's trading relationship with Europe in the aftermath of Brexit, for example, encompasses all these elements. Multiple modes include supranational institutions (e.g., the European Union), independent nations (e.g., the United Kingdom (U.K.), the Republic of Ireland), and devolved nations (e.g., Northern Ireland, Scotland). Multiple ties consist of trade flows, security guarantees, and cultural exchanges. Time has brought out a series of different proposals and changing leaders (especially several prime ministers of the U.K.). How do strategic brokers manage the flow of interaction and concatenation of interests in this system? Under what conditions does a British prime minister actually lead? Can the European Union protect its member nations (e.g., Ireland) while sustaining the principles of its union? Network theory has the potential to help tackle these kinds of challenges.

Conclusion

Over more than a century, social network theory has risen to aid in understanding the complexity of an increasingly interconnected world. The next century promises expanded dimensions of connectivity, as well as the growth of computational tools, statistical methods, and big data. At the same time, the world is facing unprecedented challenges on matters of security and the place of humans in the natural environment. Political scientists can be a part of the solution to these problems and social network analysis can be a valuable tool to them. The chapter makes the case that greater attention to network theory would complement and enhance recent (and future) methodological advances for the analysis of social networks.

The effects of building and extending theories of political networks would likely reverberate beyond the study of politics into other social sciences. Politics has a tendency to bring together disparate fields of social action – such as family, friendship, and business – in striving toward political goals. Thus, it presents distinct opportunities to understand the concatenation of multiple networks. Complexity and variation in political institutional rules likely creates new ways to appreciate network change over time. Shifting political issues and alignments may spark unexpected adjustments in tie strength. Political innovations may manifest through the emergence of new forms of actors that require theorizing the burgeoning modes of a network. Political scientists should strive to harness their knowledge of these phenomena to yield more general insights on social networks.

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