Robins, G. (2015). Doing social network research: Network-based research design for social scientists. Sage, Los Angeles.

TWO

Fundamental network concepts and ideas

This chapter is about ideas central to social network research and theory. It includes fundamental concepts and common theoretical argument. These ideas will inform the network-based research questions that you are going to formulate for your own research (Chapter 3). They will then affect the way you collect data (Chapters 4–6) and analyze it (Chapters 8 and 9).

In Chapter 1, we met a selection of social network elements, introduced in an intuitive manner:

- Social activity and popularity (degrees, centrality of actors)
- Structural position (e.g., being on the periphery of the network or in the core)
- Subgroups of actors
- Global network structure (e.g., centralization)
- Reciprocation
- Triangulation (network closure)
- Network brokerage
- Outcomes for the system as a whole, as against outcomes for individuals
- And the interplay of ties and attributes.

In this chapter, I want to return to these and other network features in a more precise way. To do so, I need to introduce the terminology and vocabulary that network researchers use. I present enough terminology so that I can then describe basic network elements more exactly. With these fundamental concepts in place, I can discuss important social network theoretical ideas, ideas about how *social* networks function and about the social processes that are implicated.

Then, in the next chapter, I will write about how to build from social network research questions, based on a specific theorization of a social system or of social structural processes, to your own network research design.

What is a social network?

A social network comprises (at least) a set of *social actors* and a relationship among them in the form of dyadic *relational ties*. A network can be represented as a mathematical object known as a *graph* with nodes and edges. The nodes represent social actors and the edges the ties between them. Network and graph terminology are often used interchangeably – as I did in Chapter 1 when introducing the collaboration network of Figure 1.1.

But it is important not to conflate social networks and graphs conceptually. Figure 1.1 visualizes a graph: it has nodes and edges. A graph is a way of presenting and using data: it is a mathematical object. For the purposes of Figure 1.1, the graph *represents* a collaboration network among a number of organizations, but it is not those collaborations. A social network is more than a graph.

It is also important not to conflate a network *visualization* (such as Figure 1.1) with the graph or the network itself. The same graph can be laid out in many different ways, so there are many possible visualizations of the one network or the one graph, just as there may be many different photographs of the one person. We will see this in Chapter 8.

So what distinguishes a social network from a graph? Importantly, a *social* network has social *actors*: they are involved in action in some way, often with motivations and strategies (whether we investigate these or not), and that action may be socially directed, not just individual responses. A graph, on the other hand, simply has nodes and edges. A relational tie in a social network may have many different qualities, positive or negative, with a past and presumably a future (whether we investigate these or not). A graph simply has edges between nodes. And of course a graph can represent many other types of networks – from electricity grids to subway systems to protein–protein interactions, none of which are *social* networks. It is possible that the same graph could represent both a social network and a subway system if it just so happened that they had exactly the same structure (not very likely!)

So the convenience in using a graph to represent a social network is the abstraction that simplifies the reality – but it is not the thing itself, any more than an IQ score used in a study of intelligence is a person. Our choice of a graphical abstraction – and there is more than one choice – is related to our network theory of the actual phenomenon.

That is the point: we have choices about how we represent our social system as a network and as a graph. This is not just pedantry. We need to give careful thought to how we will study social processes within a social system. As we will see later (Chapter 4), there is no 'automatic' graph representation to apply, no standard graphical pro-forma. Rather, we need to think about how best to abstract the observed social system in network form and on that basis represent it as a graph. That means we have to theorize carefully about the major elements of the system, related to the demands of the research question (Chapter 3).

Of course we should never ignore the possibility that networks may not yield good explanations for the phenomenon under study. This will always be an empirical question. In that case, the abstraction to graphical form will have proven of little value. So, just as we might ask other researchers to consider possible network effects, we need to be ready to test our network conceptualization against other explanations, including more individualized arguments.

All that said, we will indeed represent our social system using various graphical forms. So we had best answer our next question precisely:

What is a graph?

Many people, recalling secondary school mathematics classes, think of a graph as a two-dimensional chart with points plotted on *x*- and *y*-axes. In fact, that is only one type of graph. At its most general, dispense with the axes and think of a graph as simply a set of points (*nodes* or *vertices*) with *edges* between some of them. For those who like formal mathematical notation, a *graph* $G(N, E)$ has a *node set* $N = \{1,2,\dots, n\}$ and an *edge set* E comprising edges between some (not necessarily all) pairs of nodes. Look again at Figure 1.1: you will see that this is exactly what is depicted in the visualization.

So an edge may occur between a pair of nodes (i, j). In the social network literature, the letters i and j are quite popular to describe an arbitrary pair of actors. With your own network data, each actor will be identified by a distinct number, so that (1, 2) will then describe the pair of nodes 1 and 2. Depending on the data, there may or may not be an edge on this pair. The pair (i, j) can be taken to represent any pair of nodes, including (1, 2) in the graph.

Just because I have slipped into mathematical notation here does not mean that I intend to privilege quantitative research to the point of neglecting qualitative studies in this book. If you do qualitative network studies, you will still have pairs of actors (necessarily) and i and j may be a useful short-hand for you. And you cannot ignore the basic concepts that follow.

Most social network studies presuppose that people do not have social ties with themselves, so usually an edge on (i, i) is treated as impossible. In graph theory, when this restriction is not imposed, an edge on (i, i) is termed a *loop*.

As noted in Chapter 1, Figures 1.1 (the collaboration network) and 1.2 (the sporting team network) differ in that the edges are *undirected* for the collaboration network but *directed* for the sporting network (in which case they are called *arcs*). So, for an undirected network, an edge on (i, j) is the same as an edge on (j, i). In other words, the ordering of i and j in the pair does not matter. (If Tom is married to Mary, Mary is married to Tom.)

For a directed network, however, the ordering is important, and an arc on (i, j) is directed from the *sender* node i to the *receiver* node j. The direction is usually represented by an arrow on the arc, as in Figure 1.2. The presence of an arc from i to j does not imply that there need be an arc from j to i. (If Tom seeks advice from Mary, May need not seek advice from Tom.) Sometimes a directed graph is referred to as a *digraph*.

In Box 2.1, I present some basic terminology about graphs and networks. I know that lists of definitions can be tedious, but this terminology runs through this book and through social network analysis more generally. Do not neglect it.

BOX 2.1

Some important terminology for graphs and networks

- A graph can also be represented as an $n \times n$ *adjacency matrix* with a cell representing the presence or absence of an edge by 1 or 0, respectively. This can be the case even in qualitative research. I explain adjacency matrices further in Chapter 4.
- A *complete* graph has all possible ties present; an *empty* graph has no ties present.
- A *dyad* is a pair of actors and the state of the network tie between them (which may be the absence of a tie). Dyads, not single actors, are the fundamental unit for networks.
- A *triad*, on the other hand, is a triple of actors and the states of the network ties among them (which may include no ties – an *empty* triad).
- Often ties are assumed simply to present or absent (hence, 1 or 0), in which case the network is said to be *binary*. Sometimes network ties are weighted so that a tie has a *strength*. This can be represented in a graph with valued edges, usually termed a *weighted graph*, and visualized with edges of different thickness to depict the values. A *signed graph* has positive and negative signs attached to the edges, to represent positive and negative ties.
- A *whole network* study, sometimes called a *full network* study, examines a given set of actors and the ties among them.
- An *egocentric* network (*egonet*), or *personal network*, only includes the ties that a focal actor (called *ego*) has to network partners (called *alters*) as well as the ties among alters. An egonet study may include many egos, thereby examining the social environment of a sample of participants. There are important differences between whole and egocentric network studies that will become apparent in later chapters.
- A *two-mode network* has two different types of nodes, for instance, people and their organizations, sometimes called an *affiliation network* or *bipartite network*. Ties occur between different types of node (e.g., people are members of an organization) but not between the same type of node (in other words, a two-mode network only tracks the affiliations or memberships). I use the term *bipartite network* in this book and, where necessary, describe the usual one-mode network as *unipartite*.
- A *multilevel network* extends bipartite networks by also permitting ties between nodes of the same type.
- A *multiplex* or *multivariate* network has more than one type of relational tie possible between nodes. For instance, an organizational network study might include both advice and friendship. A multiplex network can be represented by a graph with two distinct edge sets. These are often visualized by edges of different colors.
- Social actors, of course, have many individual-level properties treated as variables in social science studies. These are termed *actor attributes*. Depending on the measurement of the attribute variables, these can be visualized as nodes of different sizes (for continuous attributes) or nodes of different colors (for binary or categorical variables).
- A *subgraph* is exactly what you expect it to be: a subset of nodes and a subset of the edges among those nodes. An *induced subgraph* includes all the edges from the original graph among the subset of nodes. See Figure 2.1.

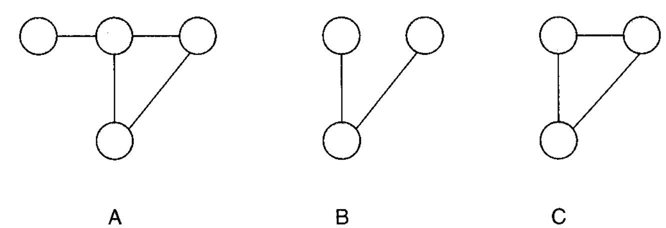

Figure 2.1 Graphs and subgraphs. Graph B is a subgraph (a subset of nodes and of edges between them) from graph A; graph C is an induced subgraph (including all edges in A among the subset of nodes)

Important graph and network concepts

Now, with basic terminology in place, let us turn to fundamental graph and network concepts, some of which you met in Chapter 1. These ideas describe some important features of graphs and networks, and as a network researcher, you need to understand them and the associated vocabulary. But this is a research design text, not a book of analysis, so I have deliberately provided only short descriptions. Robins (2013) provides more formal definitions, and there is greater detail in introductory texts such as Borgatti et al. (2013), Prell (2012), Scott (2013) and the now classic text by Wasserman and Faust (1994).

Once these fundamental features are described, we will have the vocabulary to talk about networks. Then we can turn to important social network theoretical ideas in the following section.

Box 2.2 distils some main points, with a little more detail in the ensuing text.

BOX 2.2

The bottom line in this section

- Network activity and degrees: *Density* and *degree distributions* are basic descriptive statistics of the network. You should examine these as a matter of course in your empirical studies.
- Network patterns: *Reciprocation* and *triangulation* invoke fundamental human social processes. They may prove to be important features of your empirical social network data.
- Connectivity: The essence of a network is that the actors are connected – hence are interdependent – and resources, information, disease or ideas (depending on your research topic) may flow through the *paths* in the network. The shortest path between two nodes is a *geodesic*.
- Centrality: Researchers often wish to understand which actors are most important in the network, but there are several different measures of *centrality*, each serving a different purpose. You need to choose centrality measures to suit your specific research questions.
- Cohesive subsets of nodes: The notion of a *clique* is important in both graph and social network theory, but nowadays there are fewer empirical social network studies using a clique analysis. The idea of a clique has been extended in different ways but without consensus on the best approach for empirical studies.
- Community structure: A more recent idea is to partition the network into regions of greater density. Although several algorithms exist to find community structure, empirically the method has mainly been used in large-scale social networks to simplify network description.
- Structural equivalence: An older idea, often used in smaller-scale network studies, is to partition the nodes into classes based on similar structural positions. Again, this approach can be used to simplify the network structure.

Network activity and degrees

The *density* of a network is a simple measure of the proportion of ties that are present, a description of how much social activity is occurring in the social system. The degree of a node is how much of that activity or popularity is due to the particular actor.

- *Density* is the most basic network measure. It is simply the number of ties in the network as a proportion of the total number of possible ties. A *complete* graph has all possible edges present (density = 1), and an *empty* graph has no edges (density = 0).

For a binary unipartite directed network with n nodes, each node may select any of $n - 1$ network partners, so the total possible ties is $n(n - 1)$. This assumes that loops (self-ties) are not permitted, the usual social network practice. With L arcs present, the density is then $L/n(n-1)$. For an undirected network, there are half as many possible ties because there is no difference between (i, j) and (j, i). With L edges, the density is then $2L/n(n-1)$. For a bipartite graph with two node sets of size n and m, the number of possible edges is nm so the density is L/nm.

- *Degrees*: I introduced the concept of degrees in Chapter 1. For an undirected graph, the degree of a node is the number of edges emanating from it. For a directed graph, the out-degree is the number of ties directed away from a node, and the in-degree the number of ties directed towards it. The out-degree and in-degree of a node are sometimes termed the *activity* (or *expansiveness*) and the *popularity* of the actor, respectively.
- The *degree distribution* is the number of nodes with each given degree, often depicted as a histogram. Figure 2.2 presents the degree distribution for the collaboration network of Figure 1.1. We can see that most nodes have degrees less than 10, but a couple have much higher degrees. Directed graphs have out-degree and in-degree distributions. The out- and in-degree distributions for the sporting team network of Figure 1.2 are presented in Figure 2.3.
- *Average degree*: is the average degree per node.

For a binary undirected network, the average degree is $2L/n$. Given the formula for the density above, average degree is given by $(n - 1) \times$ density. So, for constant average degree, the density must decrease as n increases. In other words, average degree and density do not *scale up* in the same way with the number of nodes. As a consequence, because humans often have only a limited number of network partners (except when it is cost-free to maintain 'friends' such as in Facebook), we often find that larger social networks have lower density.

Network patterns

The presence of small network patterns may reflect the underlying structural processes that are present in the network: for instance, how much reciprocation, how much cooperation in small groups (such as triangles).

- For a dyad (i, j) in a directed graph, if there is an arc from i to j and also from j to i, then the two arcs *reciprocate* each other. Sometimes, the dyad is referred to as *mutual*; with only one arc in the dyad, it is said to be *asymmetric*; and with no arcs, the dyad is *null*. See Figure 2.4(a).
- A *k-star* is a network subgraph centred on one node, with edges to k other nodes. Figure 2.4(b) depicts a 3-star. In a directed network, there can be *in-* and *out-stars*.

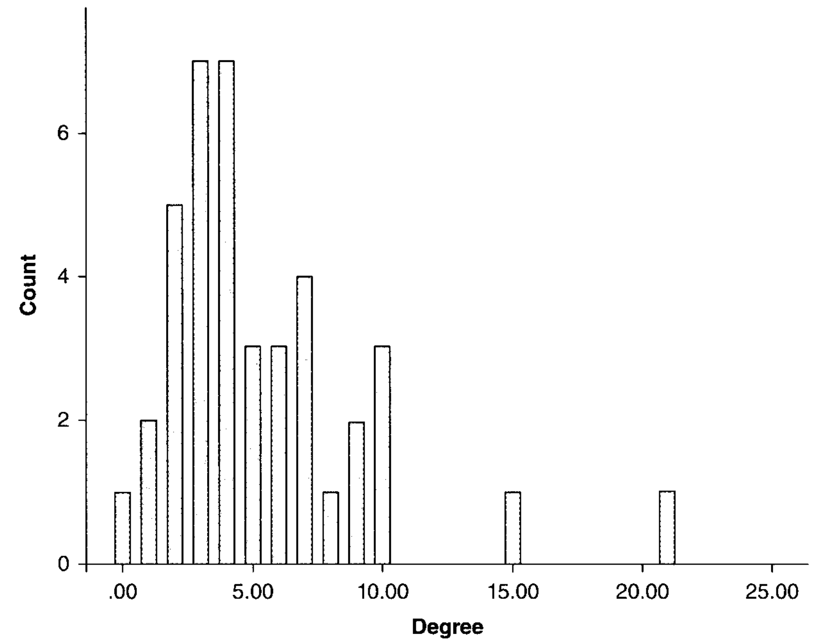

Figure 2.2 Degree distribution for the collaboration network

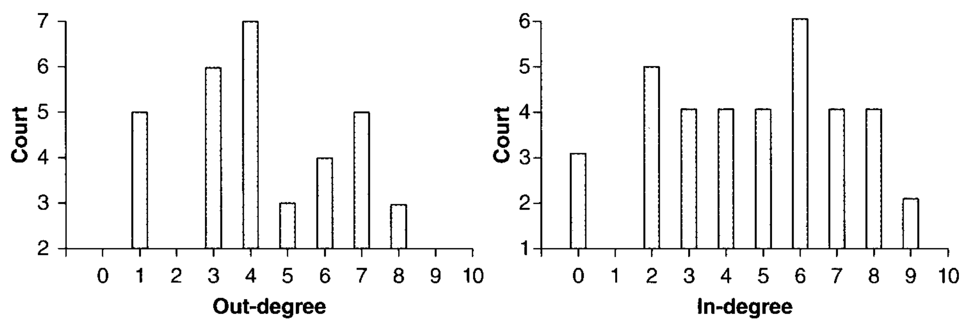

Figure 2.3 Out- and in-degree distributions for the sporting team network

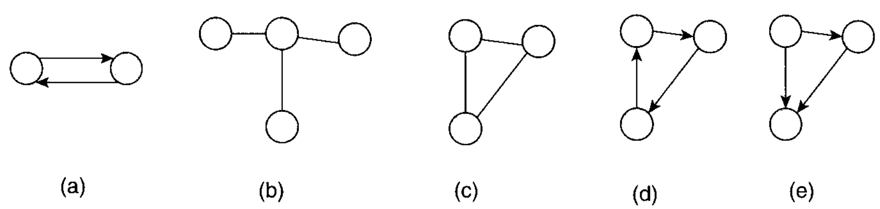

Figure 2.4 Some network patterns

(a) reciprocated arcs (mutual dyad); (b) undirected 3-star; (c) undirected triangle; (d) cyclic triad; (e) transitive triad.

- In an undirected graph, a *triangle* is a complete subgraph of three nodes (Figure 2.4(c)). In a directed graph, a *cyclic triad* is a cycle of length 3 where the arcs follow the same direction (Figure 2.4(d)). A *transitive triad*, however, is a subgraph of three arcs on three nodes where the arcs do not all follow the same direction, as in Figure 2.4(e).

Network connectivity

Network connectivity is at the heart of a network conceptualization. Paths are the network avenues through which information is passed and diseases spread.

- A *path* is a connected sequence of edges from nodes *i* to *j* to *k* and so on. The number of edges is the *length* of the path: if there are *k* edges, it is referred to as a *k*-path. For a directed network, a path requires consistent direction of the arcs; otherwise it is a *semipath*. Figure 2.5 depicts 3-paths and 3-semipaths.
- A *cycle* is a path of length greater than 2 for which the first and last nodes are the same and all other nodes are distinct. So the undirected triangle in Figure 2.4(c) is a 3-cycle, as is the cycle in Figure 2.4(d).
- If there is a path between two nodes, they are said to be *reachable*. A *geodesic* is the shortest length path between two nodes, and the *geodesic distance* is its length. If two nodes are not reachable, the geodesic distance is said to be infinite.
- A graph *component* is a maximal subgraph with paths between all nodes. Here, *maximal* means that adding another node will not make the component larger (i.e., there are no other nodes that are reachable from the nodes in the component). In other words, components divide up the graph into separated regions with no ties between them. For instance, the graph in Figure 2.5(d) has three components (an isolated node is formally a separate component, albeit a trivial one).

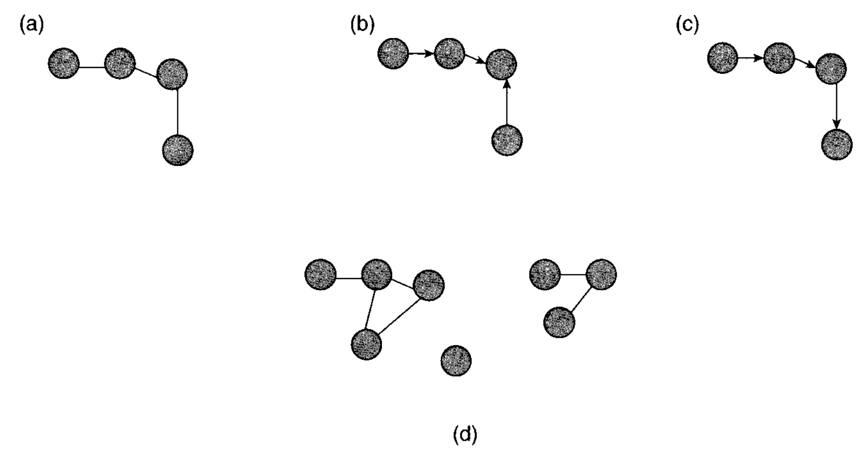

Figure 2.5 Connectivity

(a) undirected 3-path; (b) directed 3-semipath; (c) directed 3-path; (d) a graph with three components.

Centrality

The *centrality* of a node reflects its prominence or importance to the network structure, but there are several different ways to construe importance (Freeman, 1979). The most commonly used measure is *degree centrality*, simply measured by the degree of each node.

However, degree centrality focuses on the activity of a node, rather than its effect on the connectivity of the network. *Betweenness* centrality measures the presence of the node on geodesics, and so how important it is to short paths in the network. Such a node may or may not have high degree centrality. For instance, in Figure 2.6, node *i* has lower degree than other nodes, but if it were not present, the graph would collapse into two separate components, substantially decreasing connectivity.

In addition to degree and betweenness, a number of other centrality measures may be useful depending on the research question. I present some of these in Chapter 9.

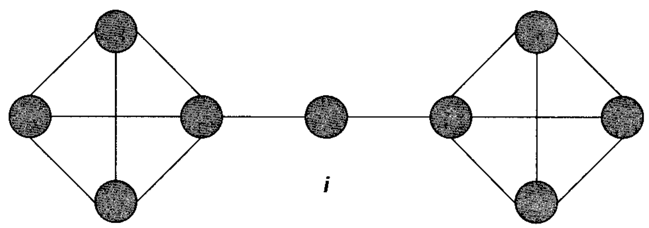

Figure 2.6 Centrality

Node *i* has the highest betweenness centrality, even though all other nodes have higher degree centrality.

Cohesive subsets of nodes

Actors can operate within small cohesive parts of the network with lots of ties, reflective of group or community processes.

A cohesive subset of nodes has an induced subgraph with substantially greater density than the graph as a whole. A *clique*, for instance, is a complete subgraph: a subset of nodes with all possible ties present. For instance, in Figure 2.6 the group of four nodes at the left (and indeed the right) of the visualization constitute a 4-clique, with ties between each pair of the four nodes. Many researchers, however, have seen the definition of a clique as too restrictive, so several extensions based on density and also on connectivity have been proposed. These are discussed in Chapter 7 of Wasserman and Faust (1994), Chapter 7 of Prell (2012) and Chapter 6 of Scott (2013). I note some of these extensions in Chapter 9.

The notion of a clique is an important idea in graph and social network theory. However, in empirical studies it may not be straightforward to use a clique analysis when there is a lot of overlap among cliques.

Community structure

In social networks there are often regions of the network, sometimes with many nodes, that have higher densities than the rest of the network (Girvan and Newman, 2002). These regions can be thought of as *communities*, and once these are identified (there are many current algorithms to do this) the description of the network can be simplified in terms of its *community structure*. One advantage of a community structure is that the nodes are partitioned into distinct sets, which aids the simplification.

Structural equivalence and positions

A social system can have a variety of different structural positions. Actors in the same position may face similar pressures or opportunities arising from that position. Structural equivalence is an approach to partitioning nodes into distinct sets, this time based on position in the network rather than community.

Two nodes are *structurally equivalent* if they occupy identical structural positions in the network. Lorrain and White (1971) defined *structural equivalent* nodes as a pair or subset of nodes connected to the same other nodes. A *position* is a set of structurally equivalent actors. Think of an army and the relationship 'commanded by'. Then all of the soldiers in one unit are structurally equivalent, because they are all commanded by the exact same officers.

Structural equivalence has been generalized in various ways, especially to *regular equivalence*. Nodes that are regularly equivalent do not have to be connected to the same other nodes but rather to other nodes that are regularly equivalent. In the army, all privates are commanded by a sergeant. Privates and sergeants then constitute two regular equivalence classes: every private is not tied to the same sergeant, but to one of a class of sergeants. If you are a private, you will have a sergeant.

Structural equivalence is useful empirically where the actors can be allocated to a smaller number of positions, so that the network can be simplified into a description or analysis of the relations within and between positions. This simplified description is known as a *blockmodel*, which I present in Chapter 9. In practice, depending on the data, equivalence classes may or may not differ from community structure. An important difference is that equivalent nodes do not have to be directly tied to each other, whereas the ties amongst nodes within communities are always relatively dense. In other words, it is an empirical question whether nodes in the same structural position are tied or not.

Some social network theoretical ideas

I now turn to some important social network theoretical arguments. The vocabulary from the previous sections is used to describe possible social network processes.

I want to emphasize that there is no one Grand Unified Network Theory that explains everything about networks (Brandes et al., 2013b). Just because a network idea is prominent (e.g., preferential attachment described below), this does not mean that it will necessarily apply in the particular social context that you are studying. The context counts; do not presume to know the empirical outcomes beforehand.

Box 2.3 summarizes key ideas. There are more extended descriptions in the following text, together with selected research examples. The goal here is not to review the entire corpus fully but to demonstrate social network theoretical thinking, including with illustrative empirical research examples. There is a wealth of work on any of these topics, so if an idea strikes a chord, check the current research literature.

BOX 2.3

Key social network theoretical ideas

- *Reciprocity*: Humans tend to reciprocate relationships, especially those involving positive affect.
- *Preferential attachment*: Popular actors often tend to become more popular because they have high visibility to begin with. In other words, the rich get richer. So degree distributions are often positively skewed, with a small number of actors with very high degree, and many actors with lower degrees.
- *Closure*: Network closure refers to triangulation in networks, reflecting human propensities to operate in small groups.
- *Small worlds*: Human social networks often exhibit short average path lengths (geodesics), at the same time as they exhibit closure. There is a balance here between security and efficiency.
- *Strong and weak ties*: Strong ties tend to exhibit network closure, closing into triangles, whereas weak ties do not, so that weak ties provide connectivity across the network.
- *Network brokerage*: Actors occupying *structural holes* – where they *bridge* (or broker between) different parts of the network – are in special positions. Often network brokers or *entrepreneurs* accrue advantages from their position. These actors do not need to be actors with high degree *status*.
- *Positive and negative ties* close in particular ways in triangles. These reflect old adages, such as 'The enemy of my enemy is my friend'. It can be important to understand the structure of negative ties among social network actors.
- *Actor attributes 1: Social selection*: Actors may select network partners based on attributes. One commonly observed possibility is *homophily*, where a tie is formed between actors with the same attribute.
- *Actor attributes 2: Social influence/diffusion*: Actors may be influenced by network partners, changing certain attributes (opinions, behaviors) to accord with those of their partners. Certain individual-level qualities (e.g., disease, innovation) may diffuse through the network.
- *Network self-organization*: Ties may come into being because of the presence of other ties. Reciprocity, preferential attachment, and closure are examples of network self-organization processes.
- *Dynamic network processes: Co-evolution of structure and attributes*: Networks are not static entities but are involved in dynamic processes as ties change. For a given set of actors, network structure (ties) and actor attributes may co-evolve in ways whereby influence, selection and network self-organization occur simultaneously.
- *Social capital*: The network can be viewed as a form of *capital* for the actors within it. In closed structures actors may benefit from strong, consistent support (bonding capital) but in structural holes, actors may gain brokerage advantages (bridging capital). Social capital may also be present when actors know others in a wide variety of social positions, or have access to a variety of social resources.
- *Embeddedness*: Social action (including markets) takes place within social network structures. The more embedded an actor is within a network, the more opportunities may be available at the same time that more constraints may operate.
- *Multiplexity*: Human relationships are not generic or of only one type. Social action invokes different types of relational ties, for different goals or purposes. *Multiplex relationships*, where dyadic partnerships have multiple types of relational ties, may have qualitatively different properties from uniplex dyadic partnerships. Social network studies often need to consider multiple types of tie, simultaneously.
- *Autocatalysis*: A radical new idea about how social innovation emerges from cycles of multiplex exchanges, where old network structures are adapted to new social goals.

Reciprocity

In directed networks, reciprocation of ties is often common, because reciprocation and exchange are fundamental human social processes. Reciprocation is especially likely to be present when the relationship involves positive emotions such as friendship. But do not expect that every tie will be reciprocated, even in such positive affect networks. Social networks are not deterministic, so there will usually be some unreciprocated ties. Furthermore, there are some types of relationships, often hierarchical, where reciprocity is less likely (e.g., leadership networks).

Research examples: Go way back to the start of social network analysis and look at Moreno and Jennings (1938) in the first issue of the journal *Sociometry*. Studying partner choice in a girls' school, they showed that the probability of reciprocated ties was 213% higher than expected by chance. (They also produced what they termed *sociograms*, one of the earliest examples of network visualizations.)

For more modern work on reciprocity, Lusher et al. (2012) showed that in the top management team of an organization, managers did not express much reciprocity in trust, but nevertheless believed that their own trust was reciprocated. Gaudeul and Giannetti (2013) studied reciprocation in social media, showing that reciprocity among bloggers was important to understand mentions between blogs. For a study of unreciprocated ties, see Ball and Newman (2013).

Preferential attachment

It is common for empirical social networks to have positively skewed degree distributions, with some actors having especially high degree (also shown by Moreno and Jennings back in 1938). Barabási and Albert (1999) proposed a particular degree distribution (*inverse power law* or *scale-free*) to describe these highly skewed degree distributions, especially for networks with a few very high-degree nodes (*hubs*). Albert and Barabási (2002) showed that a scale-free degree distribution could be achieved by a preferential attachment process: a 'new' actor in the network is more likely to connect to an existing actor, depending on that actor's current popularity. In other words, the highly popular are most likely to attract new fans (or 'the rich get richer'). The idea is in fact an old one, going back to Simon (1955), but has become an important element in modern network theory.

Obviously, whether a network can be fully scale-free depends on the type of relationship. If people cannot have a large number of network partners, then the network cannot be extremely skewed with hubs (e.g., ties based on immediate kinship). So, for instance, it may be possible for Facebook friends to exhibit a scale-free degree distribution, but perhaps not face-to-face friends. This does not mean that degree distributions will not be skewed, nor does it mean that the idea of preferential attachment is not useful in understanding network activity and popularity.

Research examples: Liljeros et al. (2001) argued that human sexual contacts exhibited scale-free degree distributions (presumably with hubs arising from prostitution), with important implications for the spread of sexually transmitted disease. In contrast, Jones and Handcock (2003) argued that when these degree distributions were fitted carefully with the best statistical approaches, evidence for scale-free distributions was not universal in sexual or other networks.

Closure

Many human social networks exhibit tendencies toward triangulation (Cartwright and Harary, 1956; Davis, 1970), often termed *network closure* as a 2-path *closes* with an extra edge to form a triangle. Other terms include network *clustering* and *transitivity*.

In some contexts, triangles can be thought of as archetypal small groups. Simmel (1908) observed that triads of individuals were more than just their constituent dyads – that, for instance, they were the smallest structure with a possible majority and a minority. Triangulated structures are often argued to assist in the establishment of group norms, to permit social monitoring and to provide cohesive support (Coleman, 1988).

In directed networks, there can be different types of network closure, in particular cyclic and transitive closure (Figure 2.4(d) and (e)). In a 3-cycle, all nodes have in- and out-degree 1 and in that sense are equivalent in this subgraph. So 3-cycles can be seen as a triadic version of reciprocity, encouraging exchange and cooperation (sometimes called *generalized exchange*). In a transitive triad, however, one node has in-degree 2 and is the most popular, so this may be an indication of local hierarchy. It is not uncommon to have negative cyclicity and positive transitivity effects in social networks, indicating local hierarchy as opposed to generalized exchange.

Research examples: Davis (1970) showed empirically that a large proportion of human social networks exhibit closure. Since then, pick up any issue of a journal such as *Social Networks* or *Network Science* and you are likely to find an example of an empirical study including network closure of some type.

Small worlds

A *small world* can be defined as a graph with low density, high closure but short average geodesic lengths (Watts and Strogatz, 1998). Translated into social terms, in such a network, actors tend to live in cohesive groups in the network (high closure) but can reach across the network in an efficient way (short geodesics). It is not obvious that this structure is possible when the density is low.

In an innovative and famous study, Milgram (1967) examined the connections among individuals in the United States. Participants communicated with acquaintances to try to reach a person of a given type. It is often forgotten that the majority of paths did not reach the target, but for those that did, the median path length was 6, leading to the popular notion of *six degrees of separation*. Watts and Strogatz (1998) reopened this issue by investigating small-world issues with computer simulations. They showed that the addition of a few random ties to a highly clustered graph with long geodesics could result in a rapid transition to a small-world graph.

Small-world ideas emphasize the balance between closure and connectivity and have become widely examined in the network literature. In real social network terms, this balance is between efficiency in the network (short paths) traded against the security and certainty of group cooperation (closure).

Research examples: Schnettler (2009a, 2009b) provided a fine review of the small world literature with guidance to those who wish to study small-world networks empirically. For those who want an even more comprehensive description, see Schnettler (2013).

Strong and weak ties

In a famous, much-cited article, Granovetter (1973) distinguished between strong and weak ties. He argued that strong social ties exhibited network closure, but weak ties did not. Weak ties, rather, provided connectivity between denser closed regions of strong ties. According to this well-known argument of the 'strength of weak ties', weak ties transmit new information and innovation across the network.

This idea has been prominent in network theory now for 40 years, but is not without its critics. Krackhardt (1992), for instance, pointed to the importance of strong ties, arguing that ties need to be conceptualized in more dimensions than just strong and weak. This argument about how best to characterize social ties continues today (e.g., Hite, 2003); but while strong and weak may seem somewhat simplified for many purposes, the distinction still serves a purpose.

Research examples: Granovetter's (1973) original empirical example related to finding a job. Bian (1997) gave a different sense to the argument, studying how strong ties also contributed to job search in China, invoking the Chinese cultural practice of *guanxi* relationships.

Network brokerage and structural holes

Drawing on Simmel's work on triads, Burt (1992) proposed *structural hole* theory, one of the most influential social network theories, especially in organizational contexts. Actors who bridge between different parts of the network are in a position to gain advantage as a *network entrepreneur* or *broker.* This hearkens back to Granovetter, although Burt ignores the distinction between strong and weak ties. The underlying idea is that ties that connect different sections of the network are particularly important and enable the spread of information and other resources. So actors involved in such ties have important advantages.

Again, structural hole theory is not without criticism. Krackhardt (1992) argued that actors in structural holes could experience more stress and, rather than reap reward, may find that competing pressures on them are too demanding. Nevertheless, Burt continues to extend and refine the theory (e.g., Burt, 2005).

Structural hole theory of course provides justification for the use of betweenness centrality. Actors in structural holes are likely to have higher betweenness centrality, irrespective of their degree centrality. So, the *status* of the actor in terms of degree centrality may not match the brokerage advantage that they can obtain from occupying a structural hole (Burt and Merluzzi, 2014).

Gould and Fernandez (1989) proposed five network patterns that indicated brokerage roles within and between groups. For instance, a person who brokers between two in-group members is termed a *coordinator,* while an actor brokering between two out-groups is a *liaison.* When the network study involves (say) two ethnic groups, actors may be classified into these different roles.

Notice how small worlds, strong/weak ties and structural hole theory each contrast closed structures and open paths in slightly different ways.

Research example: Burt (2004) argued that occupying structural holes in an organizational network enables managers to have better ideas.

Positive and negative ties: Structural balance

Frequently, social network researchers only measure what are termed *positive ties,* such as friendship, communication or collaboration. *Negative ties,* however, may be important in a social system: competition, dislike, working difficulty, and others. According to an old social network theory, *structural balance* (Cartwright and Harary, 1956), positive and negative ties tend to pattern into triangles in particular ways, reflecting old adages like 'My enemy's enemy is my friend', although the empirical support for balance theory is mixed (Doreian and Krackhardt, 2001).

Research examples: LaBianca and Brass (2006) set out good theoretical reasons to study negative relationships alongside positive ties. Good examples of negative tie research include research on bullying networks (e.g., Huitsing et al., 2012a study both positive and negative ties, including bullying).

Actor attributes 1: Social selection

Actors often choose network partners based on attributes, a process termed *social selection.* You choose a partner because you like that person's qualities. Network researchers frequently investigate selection process such as *homophily* where actors form a tie because they share one or more individual attributes (sometimes described by the old adage 'birds of a feather flock together'). *Generalized selection* (Wasserman and Robins, 2012) describes social processes where actors with certain attributes are predisposed to seek certain network positions (e.g., to have greater network activity or popularity, or to occupy structural holes).

Research examples: McPherson et al. (2001) set out theoretical arguments for homophily.

Actor attributes 2: Social influence and diffusion

For social selection, attribute values affect the presence of ties. In contrast, with *social influence*, actors change some attributes due to the influence of network partners. You may be influenced by your friends. This can often be seen as an individual-level quality or property 'flowing' through the network, for instance, network-based disease transmission, and is often also termed *network contagion* or *diffusion.*

Actors may change attributes because they occupy certain network positions – *generalized influence* (Wasserman and Robins, 2012). This is the nub of the structural hole argument, that network brokers gain personal advantage. Actors in the same structural equivalence class may also come to share certain attributes. For instance, Burt (1987) showed that innovations could spread through structural equivalent actors, not just through contagion by network partners.

Research examples: Those interested in network-based disease spread will want to read Morris's (2004) book which has plenty of good advice and examples about research design. There is a rapidly growing body of work on social influence in health behaviors. For instance, Christakis and Fowler (2007) made the controversial claim that obesity could be spread through friendship networks (more in Chapter 10). Diffusion of innovations has also been an important research area (Valente, 2005).

Network self-organization

Leaving aside attributes, network ties may also come into being because of the presence of other network ties. Reciprocity, closure and preferential attachment are all examples of *network self-organization* processes – processes that occur irrespective of attributes. So, these are *endogenous structural processes* (Wasserman and Robins, 2012), where the presence of some network ties sustains the ongoing presence of other network ties, or encourages them into existence. The structural outcomes are certain patterns (subgraphs) in the network (e.g., reciprocated arcs). So the presence of certain network patterns may be a clue about the structural processes that give rise to the network.

Research example: Again, let me refer right back to Moreno and Jennings (1938), who showed in a girls' school that mutual and triangulated ties were prominent network patterns, implying that the network self-organized through endogenous processes of reciprocation and network closure.

Dynamic network processes: Co-evolution of structure and attributes

Networks are seldom static; rather, they evolve as ties come into and out of existence. If strong network self-organization processes are present, however, cross-sectional data may give an indication of the mechanisms of evolution through the predominance of network patterns (e.g., reciprocated ties) typically associated with those processes.

Of course, there is no a priori reason why selection, influence and endogenous structural processes could not occur simultaneously. In that sense, network structure (i.e., the network ties) and actor attributes may co-evolve: network ties may change in line with selection and self-organization processes, at the same time that attributes may change due to influence. For instance, you can be influenced to like certain movies by your friends, and then choose new friends because they

like certain movies. It is an empirical question whether one or both of these processes are occurring within the network, but for confident conclusions longitudinal network data is required.

Research examples: If you are interested in social network co-evolution, check out the two special issues on network dynamics in *Social Networks* (Snijders and Doriean, 2010, 2012).

Social capital

The literature on *social capital* goes beyond networks (e.g., Putnam, 2000), but network theory has a particular approach to the topic. Lin (1999) defined social capital as the resources embedded in a social structure accessed or mobilized purposely by the actors. In short, a social network may provide social capital to the actors within it, a capacity for social action or personal advantage that would not be available in the absence of a social system. Such a general definition, however, has led to conceptual differences, with important implications for measurement. Some researchers concentrate on degree-based options: for instance, Lin (1999) studied an actor's range of acquaintances across a variety of different social or employment categories (e.g., doctor, banker) to assess the social resources an actor can access. Van der Gaag and Snijders (2005) more directly focused on the types of resources that could be accessed socially, rather than on the variety of network partners (more on the measurement of social capital in Chapter 5).

An alternative viewpoint is to consider local structural position as the essence of social capital, exemplified by Burt's structural holes theory. A brokerage position is taken as social capital because there are benefits to be reaped from occupying the position. Sometimes this is called *bridging capital*. In contrast, Coleman (1988) considered that closed structures were indicators of positive social capital because they enabled more social support from close partners (sometimes called *bonding capital*).

Research example: Van der Gaag and Snijders (2005) showed in a Dutch sample that there were four different elements to social capital: prestige and education; political and financial skills; personal skills; and personal support. In the physics literature, Latora et al. (2013) discussed different social capital conceptualizations based on open and closed network structures, and showed how various indices of social capital were related.

Embeddedness

The concept of embeddedness is most frequently invoked in economic sociology. *Embedded ties* are often considered to be network ties based on strong relationships rather than market mechanisms. Uzzi (1996, 1997) studied these from a dyadic perspective, distinguishing embedded ties and *arm's-length ties*. Granovetter (1985), on the other hand, defined *structural embeddedness* as the extent to which a dyadic tie existed within closed triads. The argument is that the structural embedding of a dyadic tie creates additional opportunities and constraints for the dyadic partners.

Research example: Uzzi (1999) investigated how social embeddedness affected the cost of an organization's financial capital in the banking sector.

Multiplexity

A *multiplex tie* is a dyadic relationship that involves more than one type of relational tie between the partners. A *multivariate* or *multiplex network* study involves the simultaneous examination of different types of relational ties on the one set of actors. Human relationships involve a number of motivations and purposes, so it is hardly a surprising claim that different types of tie exist and that there can be advantage in studying them together. I will talk more about this in Chapter 3.

Research example: Multiplexity is often examined in organizational network studies. For instance, Soltis et al. (2013) studied both work flow and advice ties in relation to organizational turnover.

Network autocatalysis

John Padgett has proposed a radical new theory of societal change whereby multiplex social networks co-evolve and, in a process akin to chemical autocatalysis, produce spillover effects that lead to the emergence of entirely new production flows. This theory is sufficiently novel and radical that it is still being debated. I include it here to illustrate an ambitious network theory of very wide scope and implication. It is no less than a social network theory of history.

Research examples: In their book, Padgett and Powell (2012) provided many different examples, both historical and modern. Whether you buy into autocatalysis or not, I suggest you still read Padgett and Ansell's (1993) classic network study of how the Medici came to power in medieval Florence. This is a *tour de force* of network theory and exploratory social network analysis, illustrating multiplex networks, closed versus open structures, and structural equivalence.

In conclusion: The key point

This brief purview of network arguments is neither exhaustive nor extended. New ideas and theories keep emerging as network research becomes increasingly popular. The point of this chapter is to direct you to network concepts, terminology and arguments that will become your basic tools. The goal is for you to start thinking 'network-like', not just adding a vague idea of networks to your existing social science terminology.

In your research, you want to avoid merely employing the concept of a 'network' as a metaphor, a term without precise meaning but one that might be tossed into the interpretational mix. There is plenty of research that does only that, but the use of the network metaphor is not sufficient to count as a network study. Do not be fooled into thinking that networks cannot be measured or observed, nor treated as the object of empirical study (as I have heard some non-network researchers argue). The theoretical ideas in this chapter all use networks as quite definite empirical constructs: the ideas are testable, and the data can be analyzed, using empirical data.

There are many possible processes that could be occurring in a networked social system. Do not assume that your data is determined by one factor alone. You may need to control for a variety of different network mechanisms in order to draw definitive conclusions about the concepts at the heart of your research.

BOX 2.4

Pulling back the curtain: What goes on in real network studies

For the organizational collaboration network study, we decided that the principal interest was the nature of the network structure and how well the system of organizations collaborated to manage the water resources. This fundamental question led us to think about network self-organization and system performance along the lines studied by Robins et al. (2011). We also wanted to study both positive and negative ties because we felt that effective collaboration can be impeded by work difficulty as much as enhanced by positive cooperation. We were interested in the flows of resources through the network, and in which organizations were central in the network, using degree and betweenness centrality to examine both status and brokerage by organizations. We speculated about whether there might be important structural positions we could identify, and wanted to know which type of organization might occupy them.

So at best we had some guidance from Robins et al. (2011), but beyond that we had rather eclectic ideas about how to get an understanding of the social system. Nevertheless, the types of network arguments that we drew on gave us directions to pursue in terms of both measurement and analysis.

Given that our hypotheses were not too firm, we also planned to conduct qualitative interviews with our respondents to get a richer understanding of what they understood by effective collaboration, and their perceptions of the effectiveness of the organizational system as a whole.

For the sporting team, we had always proposed to collect attitudinal data on certain key cultural issues. We believed that attitudes would be associated with network structures, so we knew from the start that we would be looking at selection, influence and possibly co-evolution mechanisms. But we did not have clear guidance as to which types of network tie would best associate with the attitudes, so we planned to collect data on multiple types of tie, with a view to a multiplex explanation.

Hot topics and further reading

There are a myriad of hot topics that could be derived from any of the network ideas in this chapter. Here are just a couple.

In a review of small-world research, Schnettler (2009a) argued that future directions might focus more precisely on network diffusion, in ways that could affect the definition of 'smallness'. For instance, 'with regard to infectious diseases, the whole world could be small – but with regard to solidarity, and mutual support, six degrees might be a whole universe apart' (p. 177). What types of tie might enable easy diffusion (and hence easily produce 'small worlds') as opposed to the types of ties that could produce 'large' worlds even with small path lengths?

Granovetter's strong and weak ties theory has been pervasive. But a recent argument occurred within the social network community: how to understand latent ties, those that may have been strong but have not been activated for a long time. Is an 'old, strong tie' a strong tie or not? Are there better ways to carve out the types of ties that we should study?

Further reading

Here are some further readings related to social network theory:

- Peter Monge and Nosh Contractor have long argued that social networks are best researched from a multilevel, multi-theoretical perspective: that is, not simply assuming one network mechanism ('multi-theoretical'), and taking into account the possible multiple levels of a human social system.

  Monge, P. and Contractor, N. (2003) *Theories of Communication Networks*. New York: Oxford University Press.

- Charles Kadushin's text provides a good coverage of current social network theory.

  Kadushin, C. (2012) *Understanding Social Networks: Theories, Concepts and Findings*. New York: Oxford University Press.

- Steve Borgatti is a leading writer about general social network theory.

  Borgatti, S. and Lopez-Kidwell, V. (2011) Network theory. In J. Scott and P. Carrington (eds), *The SAGE Handbook of Social Network Analysis* (pp. 40–54). London: Sage.

THREE

Thinking about networks: Research questions and study design

What does a network perspective bring to your social science research study? What are the novel questions that can be addressed?

Now, after Chapter 2, you have basic network terminology, concepts and ideas in place. In this chapter, I want to present typical broad research questions that can benefit from network-based research. I will describe how to think about the building blocks of a network study and then go on to discuss specific social network research designs.[1]

Thinking about networked social systems, processes and structures

Social network research explicitly measures or observes a social environment, social context or social system.

Consider an individualized study of bullying in a school class. Participants might be asked whether they are victims of bullying, how they respond to bullying, what are their personal traits and characteristics, and so on. The focus is on the participant's internal response to the social environment and perhaps on the individual characteristics that predispose towards bullying.

In contrast, in a whole network study of bullying, every student in the class also nominates the other students who bully them. The goal is to understand the overall pattern of bullying, not just to study the behaviors, characteristics and feelings of

[1]Parts of this chapter draw on earlier versions in Robins et al. (2010).