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Introducing Network Science for Archaeology

1.1 WHAT ARE NETWORKS AND WHAT IS NETWORK SCIENCE?

Networks are nothing more than a set of entities and the pairwise connections among them. This simple definition encompasses a tremendous amount of variation from communication systems like the internet to power grids to neurons in the brain to road systems and flights between airports to our own social networks defined through familial ties, acquaintance, or any manner of interaction one could imagine. Over the last 20 years or so, academic interest in networks and the complex properties of network systems has grown by leaps and bounds. This has been mirrored by a growing excitement by the public in general (see best-selling works including Barabási and Frangos 2014 and Watts 2004). It is not uncommon these days to see networks and network visuals used as explanatory tools in news stories or popular articles shared across social media (another kind of network) exploring the complicated connections among characters in television shows, books, or people and organizations involved in news stories. Everyone, it seems, is excited about networks and networks are everywhere.

So, what is the big deal? Why have networks captured so much academic attention if the basic concept of a network is seemingly so simple? The real power of networks for researchers lies in their explanatory and predictive power across a wide variety of social and natural phenomena. There is a long tradition of social network analysis in the social sciences, and in particular sociology, going all the way back to the 1930s (see Freeman 2004 for a historical account). This work has shown that formally defining and measuring the properties and structure of social relationships often reveals features of social systems that are otherwise hidden if we only consider the attitudes and attributes of the people or other units involved. Since the late 1990s, a different set of network concepts have also taken hold among

researchers interested in complex systems in physics, biology, and related fields (see Newman 2010). The excitement in this realm is largely focused on the availability of massive datasets and the emerging realization that networks comprising phenomena as diverse as the internet, the human brain, and even human and animal social networks are apparently governed by some common organizing principles and sometimes exhibit similar dynamics. Network science is a rapidly growing interdisciplinary field sitting at the intersection of these traditions of research, which promises to provide new insights along the edges of traditional disciplinary inquiry.

By way of example, showing the potential power of networks and what we can learn from them, we can turn to a classic study focused on one famous political dynasty, the House of Medici in the early Renaissance. Over the course of the first few decades of the 15th century, the House of Medici in the Republic of Florence rose from one of a number of wealthy families vying for power to a dynasty wielding unprecedented political, economic, and religious authority for centuries. The Medicis' influence eventually extended well beyond Florence, producing three Popes and numerous other high-ranking officials across the Italian peninsula and Europe. So, what explains the meteoric rise of the Medici dynasty? Was it purely their wealth? While the Medici family was among the wealthy families in Florence, there were many other rivals who equaled or surpassed them. Were the Medicis simply master strategists? To the contrary, historic accounts from the period describe Cosimo de' Medici in particular as enigmatic, reactive, and passive in dealings both public and private, with no apparent specific overarching goals (Padgett and Ansell 1993:1262–1263). Why, then, did the Medici dynasty rise so dramatically when so many others fell?

In the early 1990s John Padgett and Christopher Ansell set out to answer this question in an innovative and influential historical study focused on understanding the potential role of networks in the rise of the Medicis' political power and social influence (Padgett and Ansell 1993). Relying on the detailed work of historians outlining the business and personal dealings of the Florentine elite, Padgett and Ansell were able to reconstruct networks of marriage, economic relationships/ business co-ventures, and patronage among the prominent 15th-century Florentine families (Fig. 1.1). This research revealed something surprising. While most of the prominent families were mutually connected in a single dense set of complex and overlapping relations, the Medici family consistently fell in a more intermediate position for different kinds of relations. Indeed, the Medicis had both more diverse connections (they married and created business ventures with many different families) and they tended to interact with families that were not otherwise interacting. Padgett and Ansell argue that this allowed the Medici family to develop

Network of Business Relationships
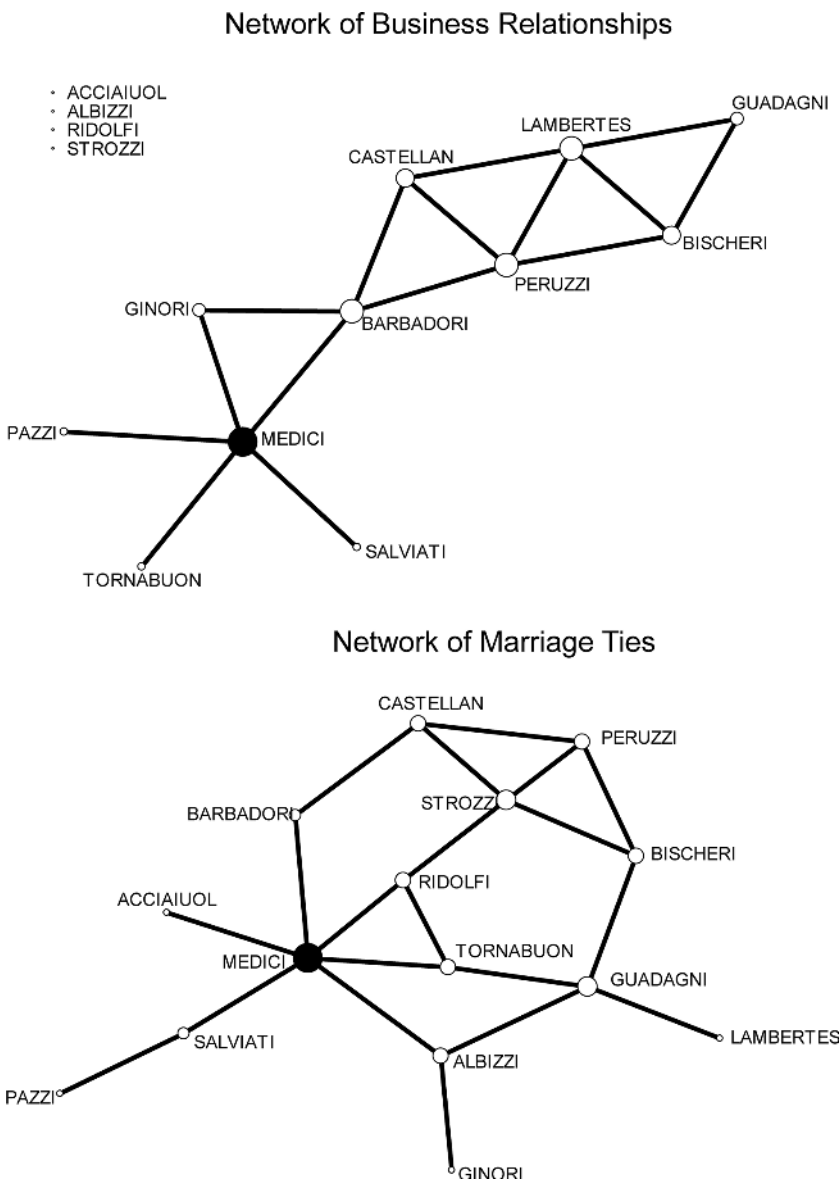

Network of Marriage Ties

FIG. 1.1 Network diagrams showing business relationships and marriage ties among prominent families in 15th-century Florence based on data published by Padgett and Ansell (1993). Note that the Medici family in both networks has both more connections than other families and connects many families that are otherwise not connected.

a coalition where everyone involved was connected *through* them, and thus they became the center of their socioeconomic sphere. Padgett and Ansell use historical accounts to convincingly argue that the individual decisions in this process leading toward the dominance of Medici authority were largely unintentional and were the product of dynamics common to a wide variety of network systems. Only after they were well established did the Medici family learn the true potential of what they had built.

The rise of the Medici family underscores a few important features about the nature of networks in general. First, networks and positions within them matter in a real, material sense. Beyond this, thinking about and formally tracking relations can often reveal surprising patterns that would otherwise be difficult or impossible to recognize through analyses focused on the attributes of the people or entities involved alone. The formal study of networks can tell us much about the relative importance and influence of the actors within that network as well as the processes behind significant changes in interaction over time. For archaeologists, the use of network concepts and network methods pushes us to think about the *relationships* driving social change in addition to exogenous processes that have often been given priority. The application of network science approaches to archaeological data has a great deal of potential to develop new insights into old questions as well as a whole body of well-developed and interesting research questions that are new to archaeology.

In this book, our goal is to both introduce network science and a wide variety of network methods for an archaeological audience, and also to make an argument for the importance of *relations* and *relational data* for understanding many natural and social phenomena that are of interest to archaeologists. In the remainder of this chapter, we set the stage by providing some basic definitions and concepts as well as a brief overview of the history of networks in archaeology, the place of network science in archaeological research, and the organization of this book.

1.1.1 *Basic Concepts*

For the purposes of this book, we define a **network** as a formal system of interdependent pairwise relationships among a set of entities (or actors). Networks are often represented and visualized as *graphs* with the actors in question depicted as a set of *nodes* or *vertices*, and the relationships among them drawn as lines, typically referred to as *edges* or *ties* (see Fig. 1.2). In this book we will use the term **node** to
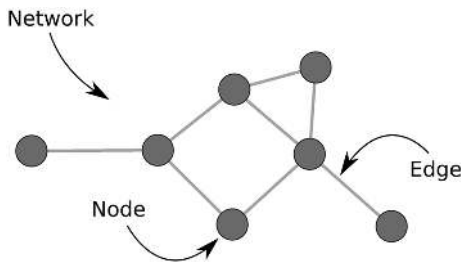
FIG. 1.2 Example network showing nodes and edges.

refer to the entities in a network and the term **edge** to refer to relationships between node pairs. In practice, many network researchers use the term *network* to refer to various kinds of network representations (like graphs and other mathematical notations), and for the sake of simplicity, we follow that general rule here. We do wish to note, however, the subtle but extremely important distinction between a network as a system of relations and a network representation as a formal abstraction of that system (see Chapter 3 for an in-depth discussion of the connection between networks, network data, and network representations).

A *network* is a formal system of interdependent pairwise relationships among a set of entities.

Networks involve the formal definition of *nodes* as the entities in question and *edges* as the relationships among them.

A *network representation* is a formal abstraction of a network created for the purposes of visualization or analysis. In this book, network representations are simply referred to as networks.

In this book we consistently use the terms *network*, *node*, and *edge*. However, alternative terms are common in other disciplines:

- A *network* is often called a *graph* in mathematics and computer science.
- A *node* is often called a *vertex* in physics, mathematics, and computer science, and an *actor* in sociology.
- An *edge* is often called a *link* in computer science, a *bond* in physics, and a *tie* or a *relationship* in sociology.

The nodes in a network can represent almost any kind of entity, from individuals or larger collectives (lineages, villages, corporations, nations, etc.) to objects,

geographic locations, or even events. Likewise, the kinds of relationships that can be used to define edges are virtually endless, ranging from all manner of direct social interactions to biological relationships; flows of information, influence, or goods; shared participation in organizations or trends; and geographic proximity. Although the nature of nodes and edges in any given network representation can be quite variable, the important point is that they are defined using consistent criteria across all actors and relations within a given context.

Formal network research typically involves both the visualization of networks as well as the calculation of a broad range of statistics designed to quantify various aspects of network structure and node or edge position. **Network structure** is a general concept referring to the form and properties of a network. Are all actors connected or are there many isolated nodes? Is there a tendency for clustering or subgroup formation, or are all nodes connected in one dense set of relations? Are there intermediate nodes between otherwise separate clusters or are clusters wholly isolated from one another? Are some nodes more central to certain kinds of flows than others? There are a variety of network analytical tools designed both to represent such features of network structure (and many, many others we will discuss in the coming chapters) and to explain variation in such features at both the local (node/edge) and global (network-level) scales.

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Network structure refers to the general properties of a network including the overall patterns of relations, the presence/absence and nature of subgroups, the variation in the positions of actors within that network, and a broad range of other potentially salient features of organization.

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1.1.2 *The Relational Perspective*

So, what makes networks special? Creating a network representation of some system of pairwise relationships can often be quite informative in and of itself. Network visuals are striking and can reveal important organizational principles of a system that are not otherwise apparent (see Chapter 6). We argue, however, that the true utility of network approaches lies in the **relational perspective** fundamental to the study of networks, that is, the underlying assumption that the nature and structure of *relationships* among actors are as important (or in some cases, more important) for understanding and predicting the behavior of actors in a network than the attributes of those actors themselves (see Chapter 8 for an extended argument). For example,

the relational perspective suggests that in order to understand the role and importance in the Roman Empire of the province of Baetica in southern Spain, we cannot simply refer to the mineral wealth or agricultural potential of the region. Rather, we must consider how the region's position in the Roman transport system and the social relationships of its inhabitants that tied it to the capital of Rome were likely crucial in making it one of the most important and affluent regions in the Roman empire that eventually provided the first non-Italian emperors. Network methods and models help us formally describe and analyze such relational patterns.

Over the last two decades many archaeologists and material cultural specialists working in a variety of contexts have begun to shape what they see as a new direction in investigations of objects and identities sometimes glossed as "the relational turn" across many areas in the social sciences and humanities (see Harrison-Buck and Hendon 2018; Selg and Ventsel 2020; Van Oyen 2016). In our view, this relational turn does not represent a single paradigm but generally groups works that focus on the primacy of relations not just as drivers of social change but as constitutive components of persons and objects themselves. Within such perspectives entities and relations cannot be wholly separated and the agency of nonhuman entities is explicitly considered. Such relational perspectives draw on diverse theories and concepts including interpretive models like Actor-Network Theory (Latour 2005), entanglement theory (Hodder 2012; Hodder and Mol 2016), relational notions of personhood (Strathern 1988), and assemblage theory (DeLanda 2016), among many approaches. Some researchers have begun to consider the potential connections between such theoretical models and formal network methods and data (Knappett 2011, 2018, 2020; Knutson 2021; Van Oyen 2015, 2016) though empirical evaluations of such perspectives have been rare as of yet. In this book, we use the concept of the "relational perspective" in a somewhat narrower sense, focusing explicitly on the material role that relations in networks play in generating outcomes for actors within those networks. There is clearly overlap between formal network methods and broader notions of relationality that will likely continue to be explored (e.g., chapters in Donnellan 2020).

> The *relational perspective* at the core of formal network approaches is the notion that the structural properties of networks and variation in the positions of nodes and edges in a network are just as important for explaining or predicting the behavior of the actors of that network as the attributes of the social actors themselves.

1.1.3 *Network Science and Network Theory*

One criticism often directed toward network research is that it is simply a loosely defined set of methods and mathematical tools and does not constitute an explicit approach with its own unique theoretical underpinnings, research agendas, and insights (see discussion in Borgatti and Halgin 2011b; Borgatti et al. 2009). Are networks simply tools to get a job done or do networks also offer a fundamentally new theoretical perspective? In this book, we argue that we can have it both ways to a certain extent (see also Peeples 2019). Network approaches can be profitably used as analytical tools to address a number of traditional archaeological research concerns (a hammer and some nails), but network approaches also offer exciting novel research agendas beyond the realm of traditional archaeological questions (the plans to build a fancy new gazebo). In this book, we attempt to walk the fine line between these two perspectives, exploring both the practical methodological aspects of the network approach as well as what we see as the deeper theoretical insights the approach has to offer. We suggest that network perspectives and network methods have the potential to open up archaeological investigations to a broad array of important topics that have, as of yet, seen considerably less attention than they deserve (see also discussions in Brughmans 2013b; Mills 2017; Peeples 2019).

So, what then is the "network science" where this book gets its title? Here we borrow a useful definition from the inaugural issue of the journal *Network Science*. Brandes et al. (2013:2) define **network science** as "the study of the collection, management, analysis, interpretation, and presentation of relational data." That seems simple enough: network science offers specific methods and tools to deal with relational data consisting of entities and relations, and relations are important for understanding a broad range of phenomena. Network science provides tools to collect the data necessary to create formal network representations and explore and interpret network structures. For example, in one recent study, Golitko and Feinman (2015) used network science methods and visualization tools to explore the procurement and distribution of pre-Hispanic Mesoamerican obsidian (see also Golitko et al. 2012). This involved collecting data on the frequency of occurrence of objects made from different obsidian sources at a number of important sites and creating a network representation based on the shared frequencies of objects from those sources. In this network representation, sites were defined as nodes and strong similarities in site assemblages based on obsidian sources were represented as edges. They subsequently used this network to explore the relative centrality (importance) of specific sites and areas for directing flows of obsidian across the region, producing results that led to new archaeological insights.

As this brief example illustrates, network science *methods* are certainly useful, but we argue that where the rubber really meets the road when it comes to network

science is when we use these methods to explicitly explore network theories. **Network theories** are formalizable and testable expressions of dependencies (or contingencies) among nodes, edges, attributes, outcomes, or global network structures, or any combination thereof (see Chapter 8). In other words, network theories are formal statements about how one part of a network system or one kind of relationship in a network can influence the development, spread, or decline of some other salient feature of that system or the actors within it (see Chapter 3). As with any theoretical concept in archaeology, network theories can come from traditional archaeological concerns or may be derived from expectations based on the properties of networks themselves. In either case, the application of network theories in archaeology (or any field for that matter) typically involves two basic components: (1) the development of a model for abstracting network concepts and techniques to study a real-world phenomenon as network data and (2) a formal evaluation of the network dependencies, contingencies, and/or relational processes described by a network theory using network data.

This process of abstraction is, of course, not unique to network research. As archaeologists we study diverse phenomena involving past human behavior, but we typically cannot study these phenomena directly. Instead, we must always abstract the phenomenon we are interested in exploring using archaeological concepts and develop tools for representing such concepts using archaeological data. Network approaches to archaeology are no different. For example, let's say we are interested in exploring how the position of a settlement within a regional transportation system influenced the growth of that settlement. In this case, the general archaeological concept we are interested in exploring is the movement of people and resources across a region using transportation corridors, and the implications of this movement for settlement growth. The notion of the "position" of a settlement in relation to such flows can be abstracted using the network concept of "centrality," which refers to a broad set of approaches used to describe the relative importance of nodes for directing or receiving flows across a network (see Chapter 4 for further discussion). In order to represent this concept using archaeological data we could then define a simple point-to-point (settlement-to-settlement) network using sites as nodes and roads connecting them as edges, perhaps with some additional considerations of the length or formality of road segments. From here we have got our network data (derived from archaeological data) and the path ahead is relatively straightforward. We can calculate and evaluate relative differences in network centrality and compare these to attributes of settlements including their size or rates of growth to evaluate our relational theories.

As the discussion above suggests, modeling and abstracting archaeological data into network data is therefore a fundamentally archaeological thing to do. It involves a constant dialogue among archaeological data, disciplinary knowledge, archaeological theory, and network concepts (see also Section 1.2). In archaeological applications of

network science, network theories can include theories about how a network structure evolves, how processes and flows take place in relation to the network structure, how all aspects of the network affect the behavior and opportunities of the nodes and edges, or many more relational questions. Network theories can describe how relational aspects of the past phenomenon of interest functioned, or they can be theoretical arguments about why it is appropriate to use network concepts and data to abstract and represent a given phenomenon. Both of these are network theories. For example, in Golitko and Feinman's (2015) study described above, the authors theorize that top-down control of obsidian production and distribution by major settlements resulted in the important positions of these settlements in the obsidian distribution network: this is an archaeological theory about relational aspects of a past phenomenon. They also suggest that network centrality measures are appropriate representations of these relative importance positions of major centers: this is a theoretical argument about the appropriateness of using particular network methods and representations to address the question at hand in a given context.

To put it simply, **network science in archaeology** is the study of network models and network theories developed for an archaeological research context, and formally expressed and tested using network methods. Although network science techniques without explicit network theories may sometimes offer useful analytical explorations, the ability of such methods to lead to new insights into past human behavior is significantly enhanced *when theory and method are combined*. We cannot emphasize enough that network science can only make unique contributions to our understanding of past human behavior when archaeologists let their use of network science be guided by the specific nature of archaeological research contexts, critical evaluations of archaeological data, and careful considerations of relational theories (see Chapter 8).

Network science is the study of the collection, management, analysis, interpretation, and presentation of relational data.

Network theories are formal and testable expressions of dependencies among nodes, edges, attributes, outcomes, or global network structures or any combination thereof. They express why and how relationships matter in a certain research context.

Network science in archaeology is the study of network models and network theories developed for an archaeological research context, and formally expressed and tested using network science methods.