

ARTICLE

The Heterogeneity of Social Network and Institutional Covariance in the American Southeast

Jacob Holland-Lulewicz 

Department of Anthropology, Pennsylvania State University, University Park, PA, USA

Corresponding author: Jacob Holland-Lulewicz; Email: jhlulewicz@psu.edu

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Abstract

Social, political, and economic institutions covary with one another in heterogeneous ways across space and time. Social Network Analysis (SNA) offers a set of analytical tools and conceptual frameworks that have allowed for formal comparisons of interactions, affiliations, and relationships in reconstructing historical trajectories of institutional change. Although archaeologists have made full use of a range of metrics that describe the structural variation of social networks, formal approaches to analyzing the covariance of networks, and the institutions that structured networks in the past, remain undertheorized. In most cases, descriptive metrics are compared between networks built from different datasets or networks separated in time. Using quadratic assignment procedure (QAP) correlations to compare matrices of archaeological data, I draw on a ceramic dataset of approximately 350,000 sherds from the Southern Appalachian region to investigate how decisions related to manufacture choice and to stylistic design covaried with one another between roughly AD 800 and 1650. I explore how material attributes may or may not vary independently of one another and what that means for our analyses of the institutions they reflect. The results contribute to broader comparative analyses of institutional change and perennial discussions of social evolution.

Resumen

Las instituciones sociales, políticas y económicas covarían entre sí de formas heterogéneas en el espacio y el tiempo. El Análisis de Redes Sociales (SNA) ofrece un conjunto de herramientas analíticas y marcos conceptuales que han permitido comparaciones formales de interacciones, afiliaciones y relaciones en la reconstrucción de trayectorias históricas de cambio institucional. Si bien los arqueólogos han hecho un uso completo de una gama de métricas que describen la variación estructural de las redes sociales, los enfoques formales para analizar la covarianza de las redes y las instituciones que estructuraron las redes en el pasado siguen sin teorizarse. En la mayoría de los casos, las métricas descriptivas se comparan entre redes construidas a partir de diferentes conjuntos de datos o redes separadas en el tiempo. Usando correlaciones del procedimiento de asignación cuadrática (QAP) para comparar matrices de datos arqueológicos, me baso en un conjunto de datos cerámicos de c. 350.000 tuestos de la región sur de los Apalaches para investigar cómo las decisiones relacionadas con la elección de la fabricación y el diseño estilístico covariaron entre sí entre c. 800 y 1650 dC. Exploro cómo los atributos materiales pueden o no variar independientemente unos de otros y qué significa eso para nuestros análisis de las instituciones que reflejan. Los resultados contribuyen a análisis comparativos más amplios del cambio institucional y debates perennes sobre la evolución social.

Keywords: institutions; Mississippian; network analysis; social networks; southeastern United States

Palabras clave: instituciones; Mississippian; análisis de redes; redes sociales; sureste de Estados Unidos

Given that the materially based networks built by archaeologists are meant to reflect past institutions, it is critical to maintain a framework that allows for unique articulations, or covariations, between different kinds of networks. The conceptual logic behind this position is not new. For decades,

archaeologists have highlighted heterogeneity across both space and time in how different relationships and societal characteristics may covary (or not) with one another (e.g., Feinman and Neitzel 1984). These basic axioms continue to be expressed today in the analysis and comparisons of institutional arrangements (Bondarenko et al. 2020; Holland-Lulewicz et al. 2020; Kowalewski and Birch 2020) and in broader conversations about relational approaches to archaeological analysis and the lasting impacts of culture historic frameworks that do not generally allow for heterogeneity in models of social and cultural change (Feinman and Neitzel 2020; Holland-Lulewicz 2021). Despite this common recognition, archaeologists often treat multiple networks (reflecting different kinds of institutions) as a priori analytically independent of one another. Although network structures and network change are interpreted in relation to one another, there have been few attempts to evaluate correlations between material networks formally to determine how—and potentially why—different kinds of relationships and institutions might covary or not.

Past work from the Southern Appalachian Social Networks Project, which compared multiple networks built from different material categories, demonstrated unique historical trajectories of institutional change across two neighboring locales in the Southern Appalachian region of the American Southeast (Holland-Lulewicz and Roberts Thompson 2021; Lulewicz 2018, 2019a). Drawing on a compilation of over 350,000 ceramic sherds from across the Southern Appalachian region (Figure 1), multiple kinds of networks were analyzed over an 800-year period between approximately AD 800 and 1650 to track changes to sociopolitical organization and institutions and to compare how these changes unfolded heterogeneously over time and among distinct, yet interacting, communities. Although Lulewicz (2019a) demonstrated differences in the structures and histories of different kinds of social networks, there has been no formal assessment of how these network structures—and consequently

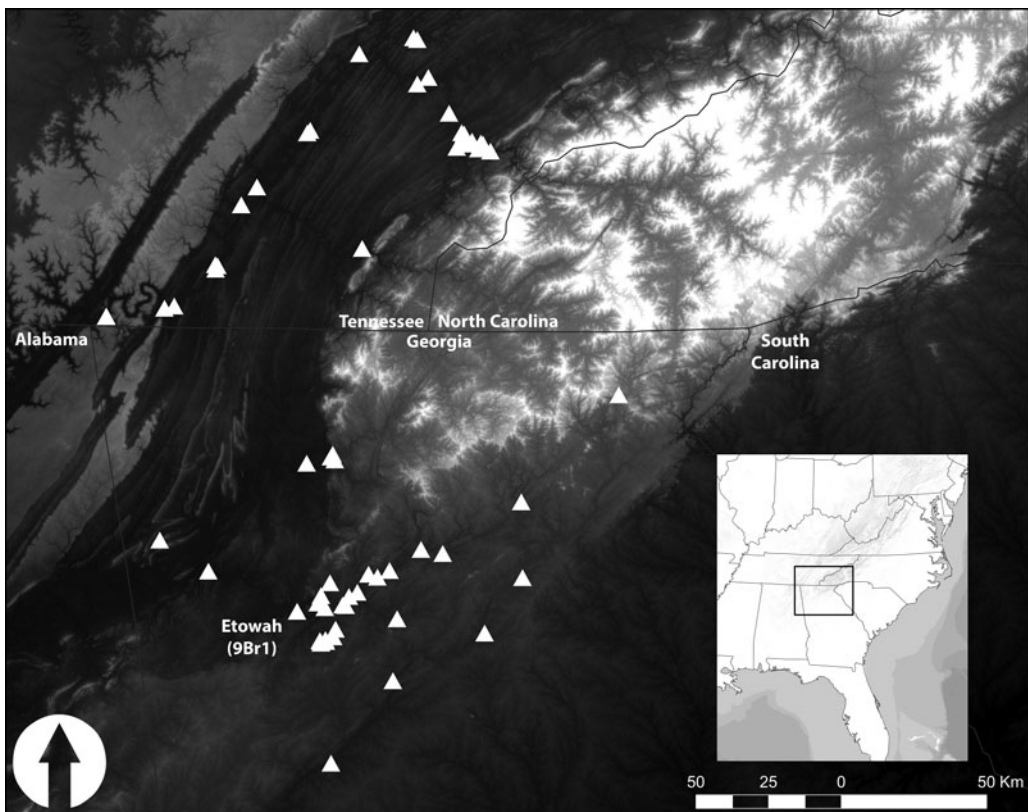


Figure 1. Map of the Southern Appalachian region considered here and sites yielding ceramic data used in the construction of material networks.

the substantive social institutions they reflect—covaried with one another across space and time. Given that the period of time considered here encompasses the initial emergence of villages and an increased degree of sedentism across the region, this study contributes to and expands on recent efforts to explain how and why we observe variability across institutional arrangements as people began to “settle down” at different places and different times around the globe (*sensu* Feinman and Neitzel 2023).

I begin by summarizing the historical trajectories of institutional and social network change across Southern Appalachia between approximately AD 800 and 1650. I then review how archaeologists have generally approached the comparative study of archaeological networks. I specifically highlight a formal method from the network sciences for assessing covariance between different kinds of networks and how this has been—and might be—used by archaeologists. Finally, I present the results of formal correlation procedures used to compare Southern Appalachian networks, begin to rethink local and regional histories of institutional change, and offer some final thoughts on how multilayer network analyses—the analysis of two or more overlapping networks—allow us to assess certain qualities of the material record.

Southern Appalachian Social Networks And Institutions

Institutions are defined here as organizations of people that carry out objectives using regularized practices and norms, labor, and resources (Holland-Lulewicz et al. 2020:1). A household, a village, a lineage, a secret society, a chiefdom, a moiety, a ritual sodality, or a confederacy can all be institutions in that they have defined membership, have a set of objectives, and articulate more broadly with overall institutional arrangements. Archaeologically, we search for material indicators to identify, define, and characterize institutions, institutional arrangements, and institutional diversity within and between societies. Social networks reconstructed from material proxies are one way that archaeologists have defined the extent and character of particular institutions.

Two kinds of networks have been analyzed by the Southern Appalachian Social Networks Project. The first kind of networks were built from data on a specific technological attribute, the kind of temper (aplastic material) added to clay in the production of pottery. These networks are argued to reflect intimate relationships of teaching and learning among specific potting communities, likely driven by intergenerational interactions among related women, which reflect broad patterns of intermarriage and institutions likely related to kinship. The second kind of networks were built from the modes of decorations adorning the exteriors of vessels, argued to reflect broad-scale participation in or affiliation with sociopolitical or sociocultural institutions (e.g., particular chiefdoms or extended symbolic communities). In this section, I will walk through the networks constructed and the interpretations offered through previous work of the Southern Appalachian Networks Project to give context to the new correlation analyses that form the bulk of the current study. For all networks, nodes represent components (assemblages from a single time period from a single site), and ties represent similarities between these assemblages. More detail on the formal network analyses is presented in the Data and Methods section and (more fully) in Lulewicz (2019a).

Previous results from the Southern Appalachian Social Networks Project indicate a general stability of both kinds of social networks across the approximately 850-year period considered (see Lulewicz 2019a). The networks built from temper—the low-visibility attribute—exhibit a clear geographic component to technological practices, with towns from northern Georgia clustering closely together, whereas towns from eastern Tennessee cluster opposite of the Georgia cluster. This pattern is apparent across all three time periods. In the second period (Figure 3), there are more ties between the two regions, but these are primarily funneled through central, politically important places that link the two regions together. Into the third period (Figure 4), the bipartite pattern remains, even as similarities between the two regions generally increase overall.

Similarly, the networks based on decorative practices generally retain their overall topological characteristics across all three time periods. These structures, however, are substantively different than the network structures built from temper. Instead of the strongly clustered nature of the temper networks, the networks built from decorative practices are long, strung-out networks without the clearly defined geographic subgroups identified through the temper networks. Although this pattern begins at least by

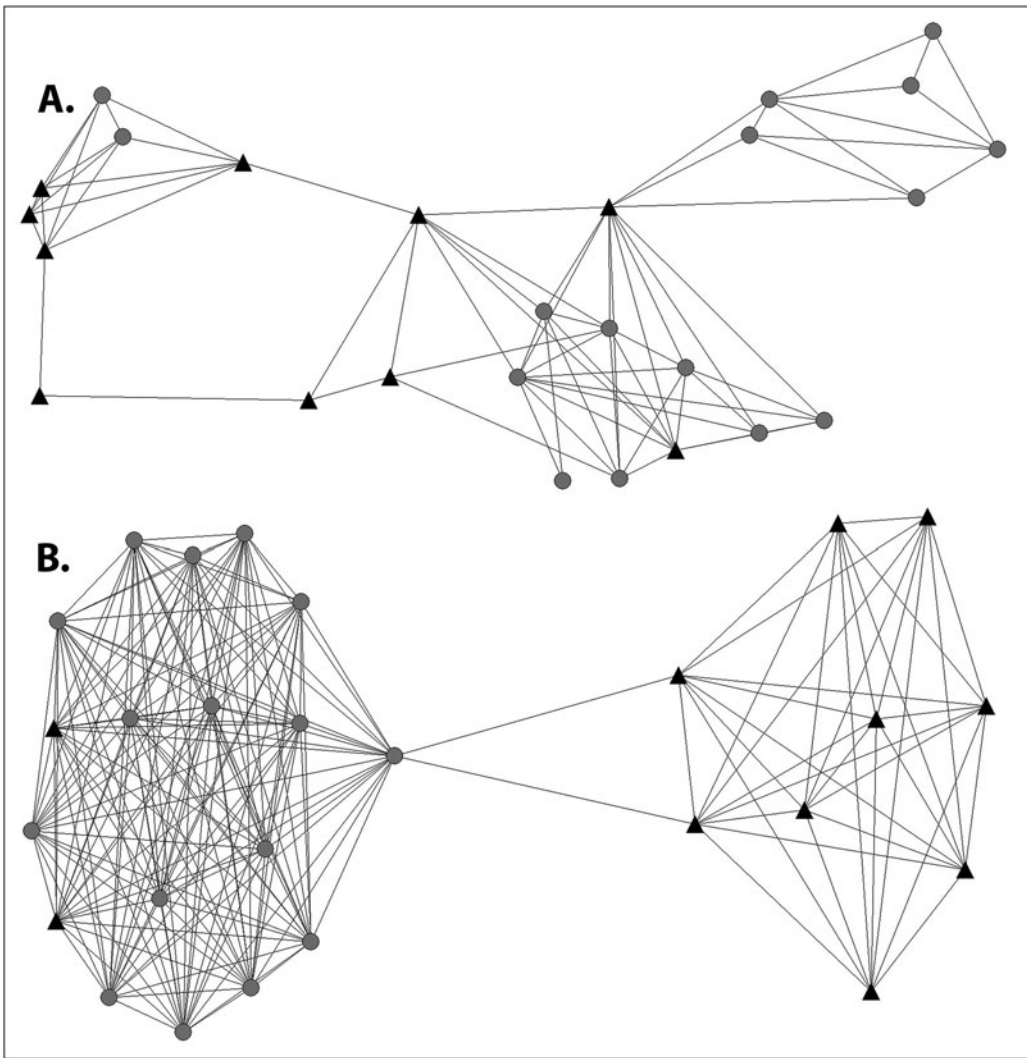


Figure 2. Material networks based on (A) decorative practices and (B) temper usage for the period between approximately AD 800 and 1050. Gray circles represent sites located in northern Georgia. Black triangles represent sites located in eastern Tennessee. Cutoff values for the binarization of the matrices used to produce each graph are included in [Table 2](#).

the earliest time period ([Figure 2](#)), the integration between towns across the region is even more enhanced into the second period ([Figure 3](#)), when powerful elites and towns emerge, driving similarities in decorative practices. Although overall integration increases across the region, we do see in this second time period a slight compartmentalization, as independent chiefdoms emerge across the landscape, at once vertically binding together local areas while horizontally binding the region together through elite interactions. After the collapse of this powerful elite system in the third period ([Figure 4](#)), strengths of ties across the region increase even more, indicating a continued sharing of decorative practices across the entire region and the overall drive toward a more cohesive network topology.

Although regional politics and networks extended across the Southern Appalachian region, and even beyond, the two subregions within Southern Appalachia, corresponding with what is today northern Georgia and eastern Tennessee, each have unique social and political histories. Regarding trajectories of changes to political institutions and organizations, sometime between circa AD 1050 and 1150, the Southern Appalachian region as a whole is characterized by the emergence of a hierarchical political system associated with broader changes that include widening socioeconomic inequality, the

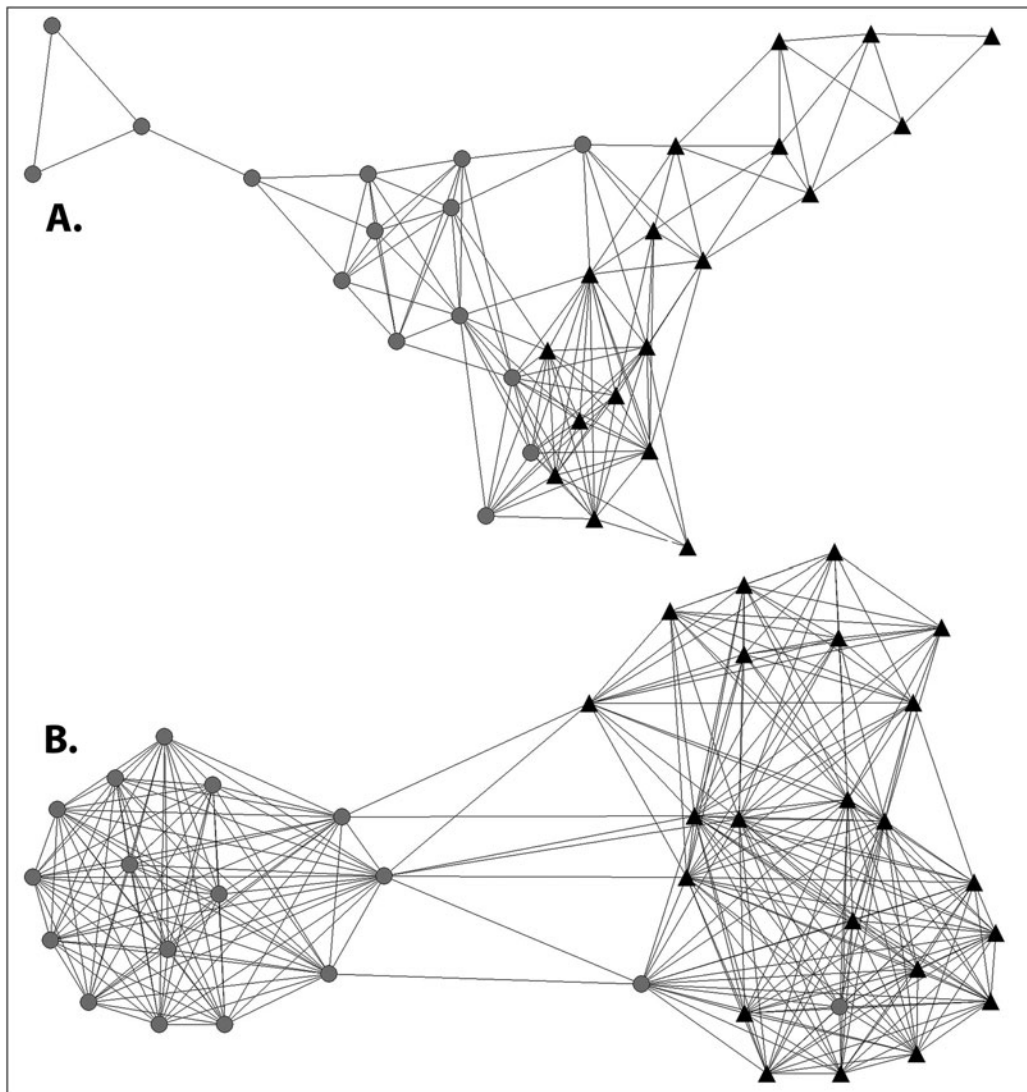


Figure 3. Material networks based on (A) decorative practices and (B) temper usage for the period between approximately AD 1050 and 1325. Gray circles represent sites located in northern Georgia. Black triangles represent sites located in eastern Tennessee. Cutoff values for the binarization of the matrices used to produce each graph are included in [Table 2](#).

diffusion of novel ritual and religious practices, and the intensification of agricultural economies (Anderson and Sassaman 2012). These developments unfolded across both northern Georgia and eastern Tennessee, although the contexts and manifestations of these changes—and their articulation with existing institutional arrangements—varied between the two.

In both locales, large towns emerge that represent politically, economically, and ritually important places across the region. The largest of these, Etowah, was located in northwestern Georgia (King 2003). Whereas the panregional networks indicate that interregional interactions between northern Georgia and eastern Tennessee were primarily funneled through Etowah during the second period, the role of Etowah varied locally. In northern Georgia, a hierarchical settlement system emerged, characterized by Etowah as the apical political actor connected to a series of lower political centers across northwestern Georgia. In contrast, across eastern Tennessee, no such local hierarchical organization or intensive community aggregation seems to have emerged (Schroedl 1998; Schroedl et al. 1990; Sullivan 2016). Instead, even with regional-scale integration through hierarchical politics centered at Etowah,

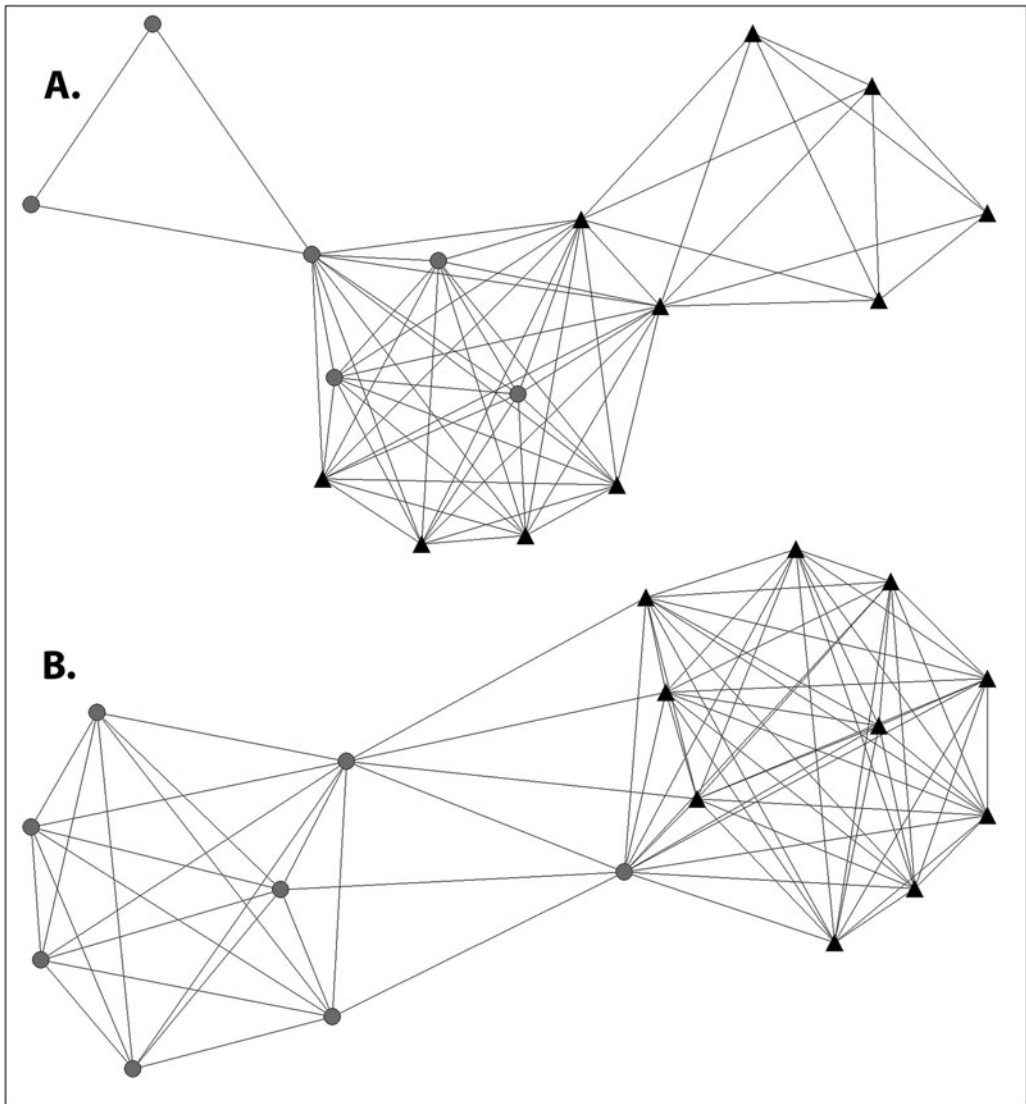


Figure 4. Material networks based on (A) decorative practices and (B) temper usage for the period between approximately AD 1325 and 1650. Gray circles represent sites located in northern Georgia. Black triangles represent sites located in eastern Tennessee. Cutoff values for the binarization of the matrices used to produce each graph are included in [Table 2](#).

local populations across Tennessee incorporated new political roles and practices into existing institutional structures that emphasized horizontal political relationships and collective local identities. Indeed, the resilience of these collective institutional arrangements can be seen in the endurance of the communal burial practices that long predate the emergence of important central political places. In this way, the institutional histories and contexts of social networks between northern Georgia and eastern Tennessee were tied to unique historical trajectories, within which institutions, practices, and relationships may have covaried in unique ways. The covariance analyses presented in this study aim to build on these results and formally assess patterns of covariance across these distinct historical trajectories.

Comparing Networks In Archaeology

Few network studies in archaeology consider just a single network. Indeed, most take as their focus the comparison of two or more networks. In many cases, these comparisons track differences between

contemporary network structures or between networks separated in time. In the southwestern United States, archaeologists have evaluated network change through time—usually in 50-year increments—to explore large-scale, long-term processes of migration and identity formation across the region (Mills et al. 2013; Peebles 2018). For each period of time, a range of metrics is calculated to compare how these processes unfolded through time and to compare which properties of networks were subject to transformation (e.g., increasing or decreasing connectivity, average path lengths, modularity, etc.). For the Northern Iroquoia region of southern Ontario and New York state, archaeologists have built networks for slices of time to understand histories of conflict, population movements, coalescence, and transformations to sociopolitical relationships (Birch and Hart 2021; Hart et al. 2017, 2019). The archaeological network research in Southern Appalachia similarly takes as its focus the comparison of networks assigned to different time periods, evaluating how and why networks were transformed or remained stable in the face of sociopolitical change (Lulewicz 2019a). Beyond temporal comparisons, Birch and Hart (2018), for the Northern Iroquoian region, compared two spatially discrete networks corresponding to distinct cultural groups to compare how contemporary political structures differed between the them.

In the network comparisons described above, including previous work in Southern Appalachia, none of the networks compared to one another are composed of the same sets of nodes. In comparing networks across time, for instance, networks consisting of sites dating to an earlier time period are compared to networks consisting of sites dating to a later time period. Although some sites may be included in both networks, having been occupied across both time periods, the sites included as nodes for each network do not necessarily match. True multilayer networks consist of two layers of the same nodes, with two different sets of ties depicting two unique kinds of connections—that is, the matrices underlying the two networks to be compared include the exact same nodes, whereas the values in the cells of each matrix depict the strength or presence of different sets of ties (Table 1). To use an archaeological sample, the same set of sites might be used to build one network based on ceramic similarity and another network based on similarity in stone tool assemblages. In the Southern Appalachian example used here, the same sets of sites are used to construct networks based on both ceramic decoration and temper material. Because the exact same dyads are present in each network within each time period (but not across different periods), formal statistical methods can be used to evaluate how different kinds of connections between dyads might covary with one another. In other words, how does one kind of relationship covary with another? Or rather, do relationships covary in regular and predictable ways, and do these relationships change through time?

A handful of archaeologists have employed formal methods to assess the relationships between two or more networks, the most commonly used method being the Quadratic Assignment Procedure, or QAP correlation, which is described in detail in the next section. One of the most straightforward of these uses is the comparison of an archaeological network built from material similarities to a matrix of geographic distances between these sites. Hart and colleagues (2019) used QAP to assess the relationships between geographic distance and the similarity of ceramic assemblages between regions across Northern Iroquoia. What they found was a significant, moderate negative correlation between geographic distance and assemblage similarity, indicating that increasing geographic distance meant increasing social distance. Put another way, assemblages were less similar between regions located farther from one another. In fact, when QAP was run on networks for a subsequent time period, these correlations grew stronger. This later period is characterized by the abandonment of towns in a key geographic region. As these towns were abandoned, the central brokerage once offered by these towns disappeared, further inflating the effects of geographic distance on social distance. Although the general relationship between geographic and social distance is well established archaeologically, the use of QAP in this case has value in its formal assessment of these kinds of assumptions. Although Hart et alia's (2019) case reaffirmed these patterns, other studies have used QAP to formally demonstrate that such relationships, between material similarity and geographic distance, are not necessarily always so straightforward, because geography may not always be able to explain material similarity and therefore substantive patterns of human interaction (Coward 2013).

Table 1. Example of Two Matrices of Brainerd-Robinson Similarity Values for Temper and Decorations across Southern Appalachian Assemblages.

Surface Similarities								
	40Ha1	40Ha10	40Ha2	40Ha210	9Ck1	9Ck4	9Ck46	9Ck5
40Ha1	200	149	57	43	42	40	40	41
40Ha10	149	200	81	64	54	62	66	63
40Ha2	57	81	200	85	60	82	100	73
40Ha210	43	64	85	200	58	98	79	77
9Ck1	42	54	60	58	200	151	77	180
9Ck4	40	62	82	98	151	200	93	166
9Ck46	40	66	100	79	77	93	200	91
9Ck5	41	63	73	77	180	166	91	200
Temper Similarities								
	40Ha1	40Ha10	40Ha2	40Ha210	9Ck1	9Ck4	9Ck46	9Ck5
40Ha1	200	200	177	9	5	0	0	0
40Ha10	200	200	177	9	5	0	0	0
40Ha2	177	177	200	31	7	3	2	6
40Ha210	9	9	31	200	5	1	0	4
9Ck1	5	5	7	5	200	195	195	195
9Ck4	0	0	3	1	195	200	199	197
9Ck46	0	0	2	0	195	199	200	196
9Ck5	0	0	6	4	195	197	196	200

Note: The matrices consist of the same rows and columns of assemblages, indicating the same nodes in each network.

Other archaeologists have used QAP to explore how networks might be correlated with other social phenomena, or how observed networks might fit with hypothesized models of interaction. Munson and colleagues (2014) used social networks to explore the practice of Maya bloodletting rituals. They used hieroglyphics to determine ties between Maya centers, and then they used QAP to determine whether or not certain kinds of ties or relationships enabled—or were correlated with—the spread, adoption, or frequency of bloodletting events. Partitioning their network into dyads that did and did not practice bloodletting, they showed that ties were more likely among centers engaging in the practice than ties between centers where the practice is not mentioned. The interpretation is that this ritual behavior was strongly correlated with social and political ties between places. In another example, Gjesfeld and Phillips (2013) compare observed networks based on geochemical sourcing of ceramics across the Kuril Islands with expected network structures based on three different models of exchange: local production, reciprocity, and central place. For each model, they produced matrices of expected ties, and they used QAP to assess the correlation between these modeled networks and the actual geochemical similarities between assemblages. Although these analyses yielded no correlation between proposed models and observed data, likely due to the highly generalized nature of the expected models, the study provides a useful example of how we might begin to formally assess hypotheses and undertake model testing in archaeological network research.

The use of formal correlation statistics in the Southern Appalachian case study considered here is used to assess how relationships, and therefore social and political institutions, covaried with one another through time. We know that institutions are layered, entangled, and articulated with one another in complex ways. For the Southern Appalachian networks, the goal is to understand if changes

to one kind of institution (such as a political system) will necessarily beget changes to other kinds of institutions or practices (such as kinship organization or marriage patterns). In other words, will changes to one kind of relationship tying two groups together correlate with changes to other kinds of relationships tying those same groups together?

Data and Methods

Archaeological network analysis has now been used to inform a range of research themes, including identity and affiliation (Hart and Engelbrecht 2012; Peeples 2018; Terrell 2010), social movements and migrations (Borck 2016; Borck et al. 2015; Mills et al. 2013, 2015), sociopolitical organization and roles (Birch and Hart 2018; Hart et al. 2016; Lulewicz 2019a; Mizoguchi 2009; Peeples and Haas 2013; Schortman and Ashmore 2012), and regional interaction and exchange (Golitzko and Feinman 2015; Golitzko et al. 2012; Thompson et al. 2017) to name just a few. Indeed, network analyses in archaeology have been subjected to robust methodological development over the last decade and continue to play a central role in addressing perennially important archaeological research questions (see Brughmans and Peeples 2023; Brughmans et al. 2016; Brughmans et al., ed. 2016; Mills 2017; Peeples et al. 2016). The study presented here explores the issue of institutional and material covariance, especially in regard to the interpretation of multilayer networks.

Multilayer networks refer simply to the multiplicity of relationships within which actors are embedded, or the “layering” of relational contexts into which they are linked—that is, actors or entities interact within one another in complex patterns that reflect multiple kinds of connections (Kivela et al. 2014). In the simplest terms, as Brughmans and Peeples (2023:91) state, a multilayer network is a network where a single set of nodes is connected by more than a single set of edges, each of which may represent a different kind of relationship. As they further note, the value in multilayer networks is that the analysis of multiple kinds of relationships or connections provides a more robust illustration of overall patterns and network topology than a single network would—which, by its nature, would describe just a single kind of interaction among nodes (Brughmans and Peeples 2023:91). In archaeology, the analysis of multiple networks side-by-side, built from different kinds of materials, is meant to reveal the different kinds of relationships, ties, or behaviors that produced those distinct material records (e.g., Giomi 2022; Gosselain 2000; Peeples 2018; Upton 2019).

Data and previous results from the Southern Appalachian Social Networks Project provide the basis and context for the current study. The Southern Appalachian Social Networks Project was designed and undertaken to explore long-term changes to social and political networks across the Southern Appalachian region of northern Georgia and eastern Tennessee between approximately AD 800 and 1650 (Lulewicz 2019a). To do so, networks were built from ceramic data (described below) from roughly 100 Ancestral Muskogean towns to assess different kinds of social capital that underwrote regional politics and how changes to these pools of capital were driven by changes to institutional dynamics. Comparisons between networks were made along two axes. The first was between different kinds of networks, built from different material categories, dating to the same time periods. These are essentially multiplex networks that have had the layers of connections parsed and compared to one another. The second axis of comparison is time. Networks were partitioned based on a regional ceramic seriation anchored in time via extensive AMS dating and Bayesian chronological modeling (Lulewicz 2019b). The result is three time periods (AD 800–1050, AD 1050–1325, and AD 1325–1650) across which changes to each network—and the similarities and differences between contemporary networks—were tracked (Figures 2–4). All matrices used to produce the networks, metrics, and figures are provided as both .csv and UCINET files, and these can be found archived at Zenodo (Holland-Lulewicz 2023). All analyses and visualizations were produced using UCINET (Borgatti et al. 2002).

Ceramic Data

The ceramic data used here totals to 365,331 sherds from 84 components across Southern Appalachia, including 276,626 sherds from 43 components across eastern Tennessee and 88,705 sherds from 41 components across northern Georgia that span between approximately AD 800

and 1650. A distinction is made between high-visibility (surface decoration) and low-visibility (temper) ceramic attributes. High-visibility attributes allow a wide range of people to be aware of a potter's behavior, thus potentially influencing the potter's choice of techniques (Gosselain 2000:191). In this way, we can understand the decisions that go into producing high-visibility attributes as part of a process of social signaling (e.g., Bliege Bird and Smith 2005; Bowser 2000; Degoy 2008; Dietler and Herbich 1998). Because these attributes are highly visible, the diversity of individuals who may potentially be influencing a potter's decisions is higher. High-visibility attributes are easily transmissible and allow for the identification of loose or situational networks of interaction that may or may not be highly influenced by geographic proximity or processes of conformity (Gosselain 2000; Wobst 1977).

Low-visibility attributes resulting from techniques related to raw material processing, temper sorting, and clay mixing may not be so easily "read" from a finished pot; consequently, those with the potential to influence a potter's behavior is more restricted (Gosselain 2000:192). This more restricted body of individuals may be referred to as a community of practice or identified as more local networks of interactions (DeBoer 1986; Gosselain 1995, 1998) materialized in participation in clay collection groups and communal firing parties, or in processes of teaching and learning likely through intergenerational and intrafamilial relationships.

The analytical separation of high- and low-visibility attributes allows for the separation between "surface cultural expressions and deep structural dispositions" (Jones 1997:92). At a more basic level, the distinction allows us to account for the possibility that cultural elements—including ceramic attributes, technical procedures, and variable social networks—do not necessarily covary or evolve in the same ways (Gosselain 2000:209). This is especially important if we are to determine what kinds of relationships and networks were transformed, or remained unaffected, by major sociopolitical change. Whereas situational networks or networks of broad political affiliation may exhibit a certain degree of flexibility in accounting for or driving institutional change, networks predicated on kinship and more frequent interaction may be characterized by more durable structures in the face of major social change. The evaluation of both high- and low-visibility attributes, used as proxies for two types of social networks, allows for these considerations.

Network Analysis

Using a matrix of Brainerd-Robinson values representing similarities between ceramic assemblages at the component level (an occupation at a single site dating to one of the three time periods), network graphs were produced. Each of the network graphs visualized throughout this study is based on binarized versions of the Brainerd-Robinson similarity matrices; that is, to pull out the most prominent features of the networks, data for each network were binarized by choosing a Brainerd-Robinson value as a cutoff point (Table 2). Cutoff points were chosen that highlighted the structure of the networks and that were just above the threshold of breaking the network into multiple, isolated subgraphs (see Lulewicz 2019a). In other words, chosen cutoffs represent the highest similarity values at which the integrity of the network as a single component could be maintained. This provides not only the most effective visualization of network structure but also valuable, generalized information on the degree of similarity between assemblages used in each network and the overall strengths of network ties. Whereas network graphs are produced using binarized data, as Peebles and Roberts (2013) have demonstrated, the underlying matrices of valued similarity scores should be used to calculate network metrics, including cohesion measures and node centralities. For this reason, all of the network measures described below were calculated using weighted data—or the actual Brainerd-Robinson values for each matrix, not binarized data.

Quadratic Assignment Procedure (QAP) Correlation

One of the methods that both network scientists, social scientists, and archaeologists have adopted to determine the character and significance of network and relational correlations is called the Quadratic Assignment Procedure, or QAP correlation (Hubert and Schultz 1976), which is similar to the Mantel test but designed for a regression framework. QAP correlation works directly on the comparison of two

Table 2. Metrics of Network Characteristics for Each of the Six Regional Networks Considered.

Measure	Temper			Surface		
	AD 800–1050	AD 1050–1325	AD 1325–1650	AD 800–1050	AD 1050–1325	AD 1325–1650
BR Cutoff for Graph	80	70	100	120	155	145
Average Tie Strength (BR)	75	72	108	116	116	127
Network Degree Centrality	13	6	10	13	9	11
Node Degree Centralities $>1\sigma$	0	7	0	3	0	0
Network Betweenness Centrality	2	1	8	3	0	7
Node Betweenness Centralities $>1\sigma$	0	2	0	3	4	1
Network Eigenvector Centrality	6	3	8	7	3	4
Node Eigenvector Centralities $>1\sigma$	1	2	1	3	0	0
Longest Geodesic Distance	11	18	13	14	21	9
Average Geodesic Distance	4.060	8.610	5.310	5.410	7.710	4.510
Compactness/ Cohesion	0.514	0.231	0.323	0.277	0.218	0.334
Fragmentation/ Breadth	0.486	0.769	0.677	0.723	0.782	0.666

Source: Adapted from Lulewicz 2019a.

similarity matrices of the same rows and columns, and it is used to assess the association between two networks. In this regard, as Tantardini and colleagues (2019) describe—and as it is understood across the broader network sciences—QAP is a comparative method based on known node correspondence as opposed to unknown node correspondence. First, Pearson’s correlation coefficient is computed between corresponding cells of the two matrices. Next, rows and columns of one of the matrices are randomly permuted (while maintaining cell dependencies in the underlying matrices being compared), and the correlation between the new randomized matrix and the second original matrix is recalculated. This second step of correlating randomized permutations is repeated a number of times (e.g., 1,000 runs) to determine the likelihood of achieving the correlation values of the comparison of the original matrices of observed data. In other words, how likely is it that the covariance patterns observed between the two networks could be the result of random chance? The QAP results reflect the proportion of times that a random measure is larger than or equal to the observed measure of correlation (Borgatti et al. 2002, 2019). A low proportion (e.g., <0.05) would indicate a strong, non-random correlation between the two matrices (Borgatti et al. 2002, 2019).

This study expands the use of the QAP statistic in archaeological network research by leveraging it toward the formal comparison of multiple layers of social relationships representing sociopolitical

institutions. In other words, the aim is to assess the covariance of institutional change across approximately 850 years of Southern Appalachian social histories. To these ends, QAP correlations are conducted on nine sets of networks. Each set or pair of networks refers to two networks consisting of the same nodes, with ties for one network built from temper similarities and ties for the other network built from decorative similarities. The first three sets—one set from each of the three time periods—were regional in scale and include all nodes from across the Southern Appalachian study area. The next three sets were for the same three time periods but included only nodes from the northern Georgia region. The last three sets included nodes only from the eastern Tennessee region. The goal here was to not only track the regional changes considered through previous work (Lulewicz 2019a) but understand how covariance in both institutions and ceramic attributes may have varied intraregionally.

It is prudent to provide a caveat regarding the interpretation of QAP results. Through the permutations conducted through QAP, we essentially produce an empirical sampling distribution. We then compare the coefficient of our observed data against this sampling distribution to determine what percentage of the hypothetical networks (or dyad sets) exhibit coefficients greater than or less than the value of our observed dataset. What we are equipped with is a p -value. Given that a QAP test simply reveals whether there is evidence that the correlation between two matrices excludes zero, the interpretations of resulting p -values must be approached with caution and without absolute certainty that these values definitively reflect strong patterns in the archaeological record. In this way, even small deviations could be significant—or, alternatively, given small sample sizes, returning a statistically significant result may be impossible. With this said, the QAP analyses conducted here, and those conducted across other archaeological studies, like many quantitative methods applied to incomplete and imperfect archaeological data, are meant to provide a conceptual foundation upon which to consider archaeological patterns, propose hypotheses, and construct archaeological narratives. The measures presented below certainly do not reflect truths or statistically “bullet-proof” narratives. They simply reveal limited characteristics about the archaeological record (in this case, ceramic datasets) that provide fodder for anthropological theory building.

Results

The presentation of results here, and the subsequent interpretation and discussion of these results in the next section, focuses primarily on the results of the QAP correlation applications. Although some context of overall network evolution, change, and comparison is provided, these results from previous work are discussed elsewhere extensively (Holland-Lulewicz and Roberts Thompson 2021; Lulewicz 2019a). The key results from this previous work are presented as a series of metrics in Table 2 for each of the regional-scale networks assigned to one of the three time periods. Previous results are discussed only briefly as context for the implications of the QAP correlation results. In general, the QAP correlations provide more nuanced information on the covariance between different networks and institutions, and they illuminate the finer mechanics of these network histories.

Regional Networks: Southern Appalachia

QAP correlations (Table 3) do not suggest a significant correlation between temper networks and decorative networks during the first time period, with over 50% of permutations yielding correlation coefficients similar to the observed data. In the second and third time periods, there is a significant correlation between the two kinds of relationships at the regional scale. In terms of the material dataset underlying the networks built here, in the period between approximately AD 800 and 1050, the similarity in temper occurrence between two ceramic assemblages is not significantly correlated with the occurrence of decorative practices. The two attribute categories vary independently of one another across the Southern Appalachian region. In the period between AD 1050 and 1325 and the period between AD 1325 and 1650, however, there is a significant, positive correlation between temper usage and decorative practices—that is, two assemblages that are similar in regard to temper usage are also generally similar in regard to decorative practices.

Table 3. Results of QAP Correlations Conducted Using UCINET Network Analysis Software.

	Pearson Correlation	Significance	Average	SD	Significant Correlation
Regional Networks (T ₁)	−0.007	0.534	0.000	0.076	
Regional Networks (T ₂)	0.238	0.000	0.000	0.033	*
Regional Networks (T ₃)	0.567	0.000	0.000	0.109	*
Northern Georgia (T ₁)	0.009	0.368	−0.004	0.884	
Northern Georgia (T ₂)	−0.278	0.012	0.001	0.189	*
Northern Georgia (T ₃)	0.403	0.039	−0.001	0.176	*
Eastern Tennessee (T ₁)	0.314	0.058	0.000	0.167	
Eastern Tennessee (T ₂)	0.015	0.339	0.000	0.069	
Eastern Tennessee (T ₃)	−0.066	0.358	−0.011	2.445	

Notes: Each row corresponds to a correlation calculation for a pair of networks—temper and decoration—from the same time period. Pairs that exhibit a significant correlation are highlighted in gray.

Local Networks: Northern Georgia and Eastern Tennessee

QAP correlations (Table 3) do not suggest a significant correlation between temper networks and decorative networks during the first time period across northern Georgia. In the second and third time periods, there is a significant correlation between the two kinds of relationships at this local scale. In terms of the material dataset underlying the networks built here, in the period between approximately AD 800 and 1050, the similarity in temper occurrence between two ceramic assemblages is not significantly correlated with the occurrence of decorative practices. The two attribute categories vary independently of one another across northern Georgia. In the period between AD 1050 and 1325 and the period between AD 1325 and 1650, however, there are statistically significant correlations between temper usage and decorative practices. In the third period, this correlation is positive. In other words, two assemblages that are similar in regard to temper usage are also generally similar in regard to decorative practices in the period of AD 1325–1650. For the second period, however, between approximately AD 1050 and 1325, this relationship is negative. As decorative similarity between two assemblages increases, the similarity between temper similarities can be expected to decrease.

For eastern Tennessee, QAP correlations (Table 3) indicate no significant correlation between temper networks and decorative networks during any of the three time periods. In terms of the material dataset underlying the networks built here, for all three time periods, the similarity in temper occurrence between two ceramic assemblages is not significantly correlated with the occurrence of decorative practices. These results, based on currently available data, would suggest that the two attribute categories varied independently of one another across eastern Tennessee for approximately 850 years.

Discussion

Previous work focused on long-term network histories of the Southern Appalachian region through a semiquantitative comparison of two different sets of social relationships (Lulewicz 2019a). Comparisons were made across quantitative metrics used to characterize each set of relationships. The comparisons themselves, however, were generally subjective, comparing general quantitative trends for each set of relationships through time. This work yielded interpretations that these different sets of relationships operated, on some level, independently of one another. This means that, in general, temper networks—those representing institutions of kinship and networks of closely related potters—were argued to operate independently of the decorative networks that represented broader political affiliation and participation that transcend close familial ties.

The analyses conducted here reveal that across both time and space there is heterogeneity in how these separate sets of relationships, representing different kinds of institutions, articulated with and covaried with one another. At the regional scale, for both of the later time periods, dyad-level

relationships based on temper use track consistently with dyad-level relationships based on decorative practices. Although broad, long-term, macro-scale changes to network structures do occur across these time periods, change happens consistently across different sets of relationships and institutions. For instance, when the political relationship between two towns shifted, maybe as a result of shared participation in new practices, more intimate relationships between members of those towns—namely, between women potters—concomitantly shifted. There is a simple interpretation for this that was generally overlooked by Lulewicz’s (2019a) previous work. Whereas Lulewicz (2019a) interpreted network results as suggesting that elite, political networks did not beget substantive changes to more intimate, strong networks of kinship, it may be suggested instead that the presence of strong ties between communities could be used to predict their shared participation in other kinds of relationships. This is the simple concept of homophily, in which nodes that are more similar to one another are likely to form similar kinds of relationships with one another. At the regional scale, it could be argued that strong relationships identified through the temper networks served as the basis of trust that encouraged communities to “buy in” to new social, political, economic, and religious institutions. In other words, membership in institutions in which strong bonding capital is accessed is a good predictor of choosing to participate in new, less intimate, and potentially risky institutions such as political or religious organizations.

When the network is partitioned into two separate localities—northern Georgia and eastern Tennessee—even more heterogeneity in institutional covariance is identified. Across eastern Tennessee, changes to intimate networks of teaching and learning among potters, tied to institutions of kinship and community and reflected in tempering practices, were not necessarily tied to or correlated with the political networks reflected in decorative practices. This tracks strongly with what we know about the social and political contexts of institutional arrangements across eastern Tennessee, especially the propensity for maintaining strong collective institutions and rejecting strictly hierarchical political systems like those that emerged in northern Georgia. Although the QAP analyses are simply a guide for identifying patterns in our ceramic datasets, the lack of significant correlation between the two sets of relationships, and the concomitance of these results with what we know about local social histories, thus reflects at once the increased participation of eastern Tennessee communities in emerging regional politics while maintaining deeply entrenched social institutions that were not allowed to be coopted by emerging elites.

In northern Georgia, like at the regional scale, there are significant correlations between temper networks and decorative networks. This is consistent with the social and political histories of institutional arrangements in this region in which there is more “buy in” by local populations and larger reorganizations of social institutions to support newly emerging, hierarchical political systems. Interestingly, however, the correlation between these two sets of relationships for the second period—between AD 1050 and 1325—is a negative correlation. In other words, where decorative practices between two assemblages are more similar, similarities in temper are less similar. This is interpreted as a result of regional interactions that were general one way. There is ample evidence that populations from eastern Tennessee and northern Georgia were coalescing at major central places in northern Georgia, especially at Etowah, whereas there is much less evidence for populations moving from northern Georgia up to eastern Tennessee. During this period of coalescence, there are large increases at places such as Etowah in temper variability. Yet new temper types were consistently associated with uniquely northern Georgian decorative practices, especially complicated stamping. As new populations moved into the region, they seem to have maintained technological practices while adopting signals that referenced their participation in the newly emerging political institutions of northern Georgia. Consequently, we see an increase in potential dissimilarity of temper between assemblages as diversity increases heterogeneously across northern Georgia, whereas complicated stamping dominates the decorative characteristics of these same assemblages.

Feinman and Neitzel (2023) recently proposed a social model for “settling down” that aims to describe processes of emergent sedentism and to provide a framework for explaining substantive variability in how these processes unfold globally. They list a few key characteristics of this model that are salient to, and indeed demonstrated by, the comparison of historical trajectories across northern Georgia and eastern Tennessee as populations coalesced and new villages emerged in each region.

Specifically, they note that there will be multiple pathways to sedentism, that the process will be non-linear nor uniform, that historical trajectories will oscillate over time, and that there will be divergent outcomes. The analysis of institutional covariance presented here lends a particularly apt example of the nonuniformity of these processes and of how historical trajectories may oscillate over time. In the case study presented here, this oscillation is represented by the ways that institutions do not uniformly transform or evolve over time, nor do they necessarily covary in predictable ways with related institutions or with broader changes to institutional arrangements. As demonstrated through the comparison of eastern Tennessee and northern Georgia trajectories, as Feinman and Neitzel (2023) further propose, although social adjustments to transitioning dynamics are critical, they are fundamentally variable, and new institutional arrangements that resulted from these adjustments were diverse. Most relevant to the Southern Appalachia case is the argument that new institutions, and indeed institutional change, come with associated costs. Depending on extant institutional arrangements—and on unique historical trajectories—what those costs are, how they are absorbed, and at what point the costs can be met will vary substantively and may be reflected in how changes to particular institutions covary with other societal changes.

Finally, beyond illuminating correlations between social networks, relationships, and institutions, methods of formally assessing covariance can also reveal the complexities of covariance between sets of materials or material attributes that are commonly used to interpret the past. For example, in the Southern Appalachian case study leveraged here, different attributes used to build distinct material networks were measured from the same ceramic sherds. These specific attributes—temper and decoration—are often neatly packaged with one another as “types.” Consequently, a formal measure of covariance between these material networks can begin to reveal the validity or usefulness of these attribute packages to constructing archaeological narratives and to highlight how distinct social relationships may drive materials or material attributes that are often collapsed by generalizing typologies.

For northern Georgia, at the scale of the assemblage, in the first time period, tempering practices and decorative practices do not significantly covary with one another. In the second two time periods, these attributes do vary with one another in predictable ways. Across eastern Tennessee, at the scale of the assemblage, the two ceramic attributes considered here never covary with one another in any kind of predictable or significant manner. These results indicate heterogeneity in how ceramics attributes covary with one another across both space and time. At any one point in time, temper may or may not covary with decorative practices, and patterns of covariance may change not only between regions but between individual sites. This poses a major challenge to the use of ceramic typologies—packages of expected attributes bounded in time and space—for conducting archaeological network analyses (Holland-Lulewicz 2021). Any analysis should fundamentally consider the covariance of attributes in the construction of materially based networks for archaeological research and should generally not rely on published ceramic types.

Conclusion

In this article, I have highlighted a framework and methodology for assessing the covariance of different sets of social relationships and institutional change in the past using multilayer network analyses. These procedures, of formally assessing the correlation and covariance between institutions, provide nuance to more generalized and subjective comparisons of network structures and characteristics built from archaeological data. In doing so, the finer mechanisms of relational change and the underlying articulations between different kinds of social networks can be more effectively illuminated. Institutional arrangements and the numerous, overlapping, multilayered networks underlying these relationships are complex. Institutions articulate with one another in unique ways that vary not only from society to society but also across time; that is, although we often focus on changes to institutions themselves, broader changes to how institutions articulate with one another are equally as critical. The case study provided here demonstrates how these changes to institutional arrangements may be heterogeneous, and that they cannot always be explained by models of change that do not account for the heterogeneity of covariance in institutional relationships.

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