Reconstructing social networks: Transitional Changes from a Mobile Hunter-Gatherer to a Sedentary Neolithic Agrarian System.

Fiona Coward, Bournemouth University, fcoward@bournemouth.ac.uk

Word count: 5494

Abstract

The increasingly permanent, large-scale communities that developed in SW Asia in the early Neolithic, and that have been the norm in many societies ever since, mark a significant break with the highly mobile, fission-fusion forms of social organisation shared by all earlier human and indeed other primate forebears. While economic, ecological and cultural changes were clearly an important part of the transition, the social changes that accompanied them have received considerably less attention, despite the fact that they may have been critical elements of the transition. Network methods specifically designed for visualising and analysing changes in social structure thus offer enormous potential for examining the momentous social changes that occurred at this time.

Keywords:

Neolithic; sedentism; material culture; group size; social organisation; network analysis

Main text

[A]Introduction

The transition from mobile foraging to sedentary and agrarian societies ultimately proved one of the most significant transformations in human prehistory, foundational to the complex urban societies that dominate today's globalized world.

However, describing this as 'a transition' highlights a major issue in our ways of thinking about these changes. Traditional approaches to 'the origins of agriculture' have tended to identify a discrete 'event', and to foreground the economic changes involved, but more recent work suggests 'the origins of agriculture' is better considered a complex of more distinct and perhaps only loosely-interlinked processes. Any simplistic notion of a binary opposition between mobile foraging and sedentary agricultural lifeways is undermined by the enormous diversity of lifeways and socio-cultural practices and institutions demonstrated by communities across the globe even today (Finlayson and Warren 2017; Kelly 2013; Maher and Conkey 2019; Makarewicz 2013; Wengrow and Graeber 2015). While the earliest villages appear in the archaeological record of SW Asia from around 13,000BCE (Edwards 1991; Valla 1991), evidence of cultivation is rather later, around 9,500BCE (Willcox 2013), with farming villages only well-established by ~8000BCE (Bellwood 2005), suggesting a long and complex process of Neolithisation that was part of a much longer-term trend towards more mutually reliant ecological relationships between humans and plant and animal species (Asouti and Fuller 2013; Bogaard et al. 2021; Fuller et al. 2018; Zeder 2011).

Recent approaches have thus focused on investigating the various components of 'the transition' and the interrelationships between the processes involved, with many researchers increasingly

highlighting the fundamental significance of *social* change at this time (Asouti and Fuller 2013; Bender 1978; Benz 2010; Coward and Dunbar 2014; Hayden 1996; Hodder 1990; Kuijt 2000a; Rosenberg and Rocek 2019).

[A]Social changes in increasingly large and sedentary communities

Long considered important elements of Neolithisation, changing settlement and demographic patterns have primarily been studied as part of potentially positive feedback loops driving intensive food exploitation and ultimately production (Marshall 2006 and papers therein). However, they also have important implications for sociality.

Certainly the archaeological record of Epipalaeolithic and early Neolithic SW Asia demonstrates reduced mobility, more permanent co-residence, increasingly substantial settlement and demographic changes (the so-called Neolithic Demographic Transition; Bocquet-Appel 2011). The largest sites of the Late Epipalaeolithic (~10.5-10k BCE), may have housed 18-59 people, while by the Final PPNB/PPNC (~7.5-6k BCE) some could have boasted 1170-3822 people (Kuijt 2000b).

However, increasing community size is no simple project. Supportive coalitions may offset the physiological/psychological impact of social stress in larger groups (Benz 2010; Dunbar and Shultz 2021), but the increasingly detailed tracking of relationship histories needed to identify good allies and freeriders (Dunbar 2008), places demands on social cognition that increase exponentially as group sizes grow. Furthermore, larger social groups are inevitably more complex. Since close, or 'strong', social relationships still take the same amount of time and energy to maintain, individuals can only sustain so many such relationships (Roberts 2010). Social networks thus expand via the addition of 'layers' of others one knows only distantly, i.e. has only 'weak ties' with (Dunbar et al. 2018; Granovetter 1983; Roberts 2010). Even where local ecologies and economies allow aggregation, larger communities can only be maintained where new strategies are found to cope with the increased social complexity of larger groups.

[A] Strategies for social complexity

[B] Material culture, social roles and hierarchization

Understanding the specifically social implications of settlement and demographic change therefore also provides a new perspective on material culture change in the Neolithic: rather than simply being by-products of economic and settlement change, material culture may have played a much more important critical role in the development of larger-scale communities.

In small-scale societies, virtually by definition, most interactions occur between people who know one another well (Roberts 2010; Whitelaw 1991; Wilson 1988) and hence proceed relatively straightforwardly. However, as numbers grow, 'weak ties' proliferate, and interactions must now occur regularly between 'familiar strangers' with little or no personal knowledge of one another to guide them. To cope, individuals in larger-scale societies categorise those with whom they have 'weak ties' into a finite set of *roles* (Dunbar 2008; Read 2010): interaction can still proceed effectively as long as both parties are clear on the nature of the exchange, and on their respective 'roles' (Coward and Dunbar 2014). A key mechanism for establishing the crucial situational definition and thus 'cueing' appropriate behaviour is material culture e.g. via elaborated personal 'fronts' and 'settings' which signal roles and statuses (Goffman 1959; Kent 1990). While material signalling pre-dates the Epipalaeolithic, there is a notable increase in evidence for the signalling of social

distinctions at this time (Byrd 1994; Coward and Dunbar 2014; Kuijt 2000b; Molleson 2007; Wright and Garrard 2003), as people learned to navigate interactions with the ever-increasing number of familiar strangers characteristic of larger, more permanent settlements.

Larger communities also challenge the sharing ethos of many forager groups (Cashdan 1980; Woodburn 1982), especially where physical storage is used. Cultivation of domesticates is not the only economic strategy whose focus on large-scale but temporally 'bunched' resources promotes physical storage; however, surpluses such as seed and breeding stock are baked-in to agricultural lifeways. Such accumulation undermines 'sharing' in the classic forager sense, and is often associated with new roles around the organisation and management of stored resources (Benz 2010; Coward and Dunbar 2014). These provide opportunities for manipulation and differential accumulation of power (papers in Bogaard 2017; Hayden 2003).

The archaeological record of SW Asia has indeed been argued to demonstrate new forms of social integration increasingly supplementing and cross-cutting basic family relationships, for example 'household' or 'lineage' based systems of organization perhaps headed by venerated ancestors (c.f. Byrd 2000; Coward and Dunbar 2014; Kuijt 2000a, 2021). Elaborate 'special-purpose' buildings and communal structures (see e.g. Coward and Dunbar 2014) further suggest some level of communal cohesion and organisation among these communities.

[B] Ideology and religion

This emergence of distinct roles focused on maintaining 'order' at the group level may also relate to changes in religious and ideological practice and particularly the emergence of group ideologies, known to boost solidarity (Dunbar 2012). While small-scale societies may have very rich ideologies, these are typically very flexible and individualised in terms of 'practice', with specific 'rituals' most likely where social cohesion is felt to be threatened (Marshall 1999; Spencer and Gillen 1904).

Changing ideologies also may influence other aspects of Neolithisation. The 'animistic' views of most foragers position humans as just another one of many, equal though different, co-denizens of the world (papers in Harvey 2014; Ingold 2000). Foragers thus rarely consider themselves as 'owning' or controlling access to natural resources within the landscape (papers in Casimir and Rao 2021; Ingold 1987; Kelly 2013). In contrast, the ideologies of agriculturalists often ascribe human groups positions of power, responsibility and ownership of resources (Barnard 2002; Ingold 2000) that may encourage larger-scale interventions in their landscapes (Renfrew 1976; Tilley 2007).

Ideological change may therefore help drive economic and settlement change (Cauvin 2000; Hodder 1990), perhaps offering specifically religious specialists opportunities to monopolize spiritual power and parlay it into political power (Lucero 2003; Wickham 2019). An unusually rich burial identified as that of a shaman from Hilazon Tachtit dates to 12,000bp, relatively early in the establishment of village life, predating agriculture per se (Grosman et al. 2008), and ideologically oriented structures and facilities and symbolic artistic representations also appear during this period (Cauvin 2000; Verhoeven 2002), alongside increasingly complex funerary practices (Coward and Dunbar 2014; Croucher 2006) which hint at 'communal' activities but also at complex intra-group distinctions (Goring-Morris and Horwitz 2007; Hole 2000; Rosenberg and Rocek 2019).

This necessarily brief summary demonstrates the merits of a focus on the specifically social aspects of the transition from mobile foraging to settled farming, highlighting the need for approaches specifically designed for visualising and analysing social structure such as network methods.

[A] The role of network methods in studying the transition

Network concepts in archaeology span a spectrum; at one end, formal quantitative methods for constructing, visualising and analysing empirical data on social structure draw from sociological Social Network Analysis and network science (Peeples 2019). At the other end, a range of approaches espouse 'network' thinking in a more heuristic and ontological sense, typically emphasising 'more than human' networks of interaction comprising multiple different types of agents besides humans (Knappett 2011, 2016; Latour 2005; Pálsson 2021; Van Oyen 2016). While this chapter focuses primarily on quantitative network analysis, there is much of value in these more heuristic applications of network concepts, and indeed considerable potential for complementarity (e.g. Hodder and Mol 2016).

Network methods have a long history of use in archaeology (Peeples 2019), and are currently undergoing something of a growth phase with a burgeoning of method and theory specific to archaeological applications. They offer two main benefits for studying the adoption of increasingly sedentary and ultimately agricultural lifeways. Firstly, they are explicitly designed to investigate multi-scalar social interaction among and between individuals and communities. And secondly, they provide bottom-up methods for the visualisation and analysis of *empirical* networks, allowing research to move away from top-down theoretical models derived from culturally ingrained and often borderline racist assumptions about cultures based on outmoded socio-economic categories.

Some excellent reviews of the basics of quantitative archaeological network analysis are available (Brughmans 2013; Collar et al. 2015; Mills 2017; Peeples 2019): this chapter aims merely to review the basics and consider how these methods may be particularly relevant to the understanding the adoption of sedentary and agricultural lifeways.

[B] Archaeological proxies for networks

At heart, network methods are very simple. A group of entities (or 'nodes') are identified, some of which are construed as 'connected' in some way (via 'edges', in network terminology), and from these individual relationships between dyads, larger-scale social structure emerges which can be visualised and analysed.

Archaeologists, unlike researchers in disciplines studying contemporary social relations such as sociology and anthropology, are not typically able to observe and document individuals and their interactions. Archaeological applications of network methods thus use material proxies to reconstruct nodes and edges. Archaeological sites, or phases of sites, are most commonly used as nodes, though where data are sufficiently fine-grained, intra-site network analysis may be possible, e.g. between households (Barker et al. 2020; Mazzucato 2019) and burials (Mol et al. 2015; Sosna et al. 2012; Wang and Marwick 2021). Certainly none of these entities can be assumed to represent discrete, consistent or emic social entities (Gravel-Miguel and Coward In press.), but this potential for multi-scalar analysis is an important benefit of network methods, especially since further formal analysis can address the properties of the overall social structure (e.g. Coward 2010), compare and contrast the social 'position' of individual entities or clusters within it (e.g. Lulewicz and Coker 2018;

Mol et al. 2015), and/or consider how local interactions and broader social structure interrelate (Mizoguchi 2009). This makes network methods particularly valuable for understanding how small-scale social interactions and entities articulate with larger-scale cultural structures (and vice versa). Network methods may thus provide valuable insights into the ways in which the primarily bottom-up relationships between those connected by the strong ties that characterise small-scale societies, increasingly became supplemented by the more formal supra-familial, top-down forms of social organisation that are a defining feature of large-scale, complex societies during Neolithisation in SW Asia.

Once appropriate nodes are established, the most common way of reconstructing the edges connecting those nodes for archaeological applications is via some measure of similarity in material culture between pairs of nodes (Table 1; Figure 1). The underlying assumption is that entities with closer social relationships will demonstrate more overlap in cultural practice, and hence similarity in material culture, and conversely therefore that identifying closer similarity in material culture implies closer social relationships between nodes.

This reliance on material proxies raises important questions about the extent to which such archaeological networks really approximate sociological or anthropological 'social networks'. Probably the answer is simply that no, they are not the same, but that this does not necessarily matter. All human social networks are 'more-than-human' in nature, incorporating material culture along with many other forms of agent (see discussion and references in Coward In press), and even social scientists working on contemporary groups routinely analyse networks incorporating a range of entities as nodes, and using various measures of social interaction other than interactions observed between individuals as edges, including material measures of trade and transport (Bhattacharya et al. 2008; Carroll et al. 2018; Choi et al. 2006; De Benedictis and Tajoli 2011).

Probably a more pressing problem for archaeological applications is the impact of taphonomy, as sparse and missing data pose particular problems for network analysis given the inherent relationality of the methods. However, archaeologists are increasingly identifying ways of quantifying and mitigating the impact of missing data (Gjesfjeld 2015; Groenhuijzen and Verhagen 2016; Tsirogiannis and Tsirogiannis 2016).

Archaeological networks may therefore be better technically considered socio-*material* networks rather than purely social networks per se, and incomplete ones to boot. Nevertheless there is some evidence to show they can successfully reconstruct at least some aspects of past social systems (Ladefoged et al. 2019). Such methods thus offer considerable scope for understanding exactly how different kinds of social relationship may translate into material culture patterning, and vice versa, a question likely to be of pressing significance in these early village societies.

[B] Visualising and analysing networks

Even before any formal analysis is conducted, visualisation of networks can be extremely informative (Figure 1); while one-model networks (Figure 1(b), 1(c)) have perhaps been most commonly used to date, multi-modal networks also have a lot to offer (Figure 1(a)). Other, more heuristic forms of visualisation can also highlight different aspects of specific datasets for specific research questions (Deicke 2020; Hodder and Mol 2016; Mueller 2016; Pálsson 2021). Such visualisations allow for detailed consideration of the ways in which material culture connects individuals and/or

communities together, and vice versa, and how this might have changed during the development of larger and more complex social groups with the adoption of sedentism and/or agriculture.

A further dimension is however added by quantitative analysis of the reconstructed networks. A range of dedicated software options are available including UCINET and open-source options such as Gephi, Visone, Pajek, Cytoscape, and the Vistorian, packages in *R*, and add-ons for GIS programmes and Microsoft Excel (Node XL). As noted above, network analysis tends to focus either on the sub-network level or the level of the whole network (Coward In press). In the former, variability among the properties of individual nodes, dyads or clusters within the network is examined using measures such as degree, distance, centrality, clustering and brokerage to understand how well connected they are to one another and the level of influence (broadly conceived) they may be able to exert over other entities. Such measures can inform particularly on the development of social differentiation and hierarchization, and thus may be very useful for investigating early village societies.

At the level of the 'complete' network, measures such as density and fragmentation can inform on the ease (or otherwise) with which resources, innovations, information and ideas, such as those relating to new economic and cultural practices, may spread, and on the implications for the cultural and ecological resilience of communities and of the broader system (Collar et al. 2015; Crowe 2007). However, one issue with network-level measures is that they are difficult to evaluate in isolation. Comparator networks may be reconstructed for the same time period from other regions, or vice versa, thus potentially allowing comparison of the social structures that develop in different ecological and/or socio-historical contexts; successive networks may also be compared over time to identify patterns of temporal change, either as absolutely-dated chronological 'timeslices' (Coward 2010; Mills et al. 2013; Roberts et al. 2012), or as discrete cultural phases (e.g. Gjesfjeld and Phillips 2013; Mizoguchi 2009).

An alternative approach is to compare empirical archaeological networks to a theoretical network or networks, independently derived using geographical distance or travel distance/cost (Coward 2013), gravity models (Evans et al. 2008; Knappett et al. 2008; Knappett et al. 2011), Agent-Based Models (Brughmans and Poblome 2016; Graham 2006; Graham and Weingart 2015; Gravel-Miguel and Coward In press.; Watts and Ossa 2016) including Exponential Random Graph Models (ERGMs, Amati et al. 2020; Amati et al. 2018; Brughmans et al. 2014, 2015) or other modelling methods (see e.g. Evans 2016; Rivers 2016). Such approaches are likely to provide valuable opportunities to formally test hypotheses about the interplay between the multiple aspects of adoption of agriculture, sedentism and the development of social complexity (cf. Williams 2019).

[A] Conclusion

Transition from mobile foraging to sedentary and agrarian societies has been one of the most significant developments of human prehistory and directly foundational to the highly globalized world of the 21st century. While the economic and ecological aspects of the transition are of course extremely important, recent work suggests specifically social adaptations are likely to have been a critical part of the long-term success of sedentary, agrarian and ultimately urban lifeways, and hence deserve more attention.

Network analysis is a young but rapidly-growing field in archaeology that is well-suited to the empirical investigation of the multi-scalar socio-material interactions within and between communities that underpinned such long-term changes in social interaction and organisation structure. Network methods thus offer enormous potential for understanding the pivotal social changes that occurred among these earliest village societies, and their ongoing consequences.

References

Amati, V., Shafie, T. and Brandes, U. (2018). Reconstructing Archaeological Networks with Structural Holes. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-017-9335-1

Amati, V., Mol, A., Shafie, T., et al. (2020). A Framework for Reconstructing Archaeological Networks Using Exponential Random Graph Models. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-019-09423-z

Asouti, E. and Fuller, D.Q. (2013). A Contextual Approach to the Emergence of Agriculture in Southwest Asia: Reconstructing Early Neolithic Plant-Food Production. *Current Anthropology.* https://doi.org/10.1086/670679

Barker, S.J., Perna, S. and Ward, C.A. (2020). Marble networks: Social interaction in houses at Pompeii. In: *Archaeological Networks and Social Interaction* (ed. L. Donellan). Routledge.

Barnard, A. (2002). The foraging mode of thought. *Senri ethnological studies.* http://doi.org/10.15021/00002769

Bellwood, P. (2005). *First Farmers: the origins of agricultural societies.* Blackwell Publishing.

Bender, B. (1978). Gatherer-hunter to farmer: A social perspective. *World archaeology.* https://doi.org/10.1080/00438243.1978.9979731

Benz, M. (2010). Changing Landscapes - Changing societies? An Anthropological Perspective. In: *Landscapes in Transition* (ed. B. Finlayson and G. Warren). Oxbow Books/CBRL.

Bhattacharya, K., Mukherjee, G., Saramaki, J., et al. (2008). The International Trade Network: weighted network analysis and modelling. *Journal of Statistical Mechanics.* 2008 (2): P02002

Blake, E. (2014). *Social Networks and Regional Identity in Bronze Age Italy.* CUP.

Bocquet-Appel, J.P. (2011). When the World's Population Took Off: The Springboard of the Neolithic Demographic Transition. *Science.* https://doi.org/10.1126/science.1208880

Bogaard, A. (2017). The archaeology of food surplus. *World Archaeology.* https://doi.org/10.1080/00438243.2017.1294105

Bogaard, A., Allaby, R., Arbuckle, B.S., et al. (2021). Reconsidering domestication from a process archaeology perspective. *World Archaeology.* https://doi.org/10.1080/00438243.2021.1954990

Brughmans, T. (2013). Thinking through networks: a review of formal network methods in archaeology. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-012-9133-8

Brughmans, T., Keay, S. and Earl, G. (2014). Introducing exponential random graph models for visibility networks. *Journal of Archaeological Science.* https://doi.org/10.1016/j.jas.2014.05.027

Brughmans, T., Keay, S. and Earl, G. (2015). Understanding Inter-settlement Visibility in Iron Age and Roman Southern Spain with Exponential Random Graph Models for Visibility Networks. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-014-9231-x

Brughmans, T. and Poblome, J. (2016). Roman bazaar or market economy? Explaining tableware distributions through computational modelling. *Antiquity.* https://doi.org/10.15184/aqy.2016.35

Byrd, B.F. (1994). Public and Private, Domestic and Corporate: The emergence of the southwest Asian village. *American Antiquity.* https://doi.org/10.2307/282338

Byrd, B.F. (2000). Households in Transition: Neolithic social organization within Southwest Asia. In: *Life in Neolithic Farming Communities: social organization, identity, and differentiation* (ed. I. Kuijt). Kluwer Academic/Plenum Press.

Carroll, W., Graham, N., Lang, M.K., et al. (2018). The Corporate Elite and the Architecture of Climate Change Denial: A Network Analysis of Carbon Capital's Reach into Civil Society. *Canadian Review of Sociology/Revue canadienne de sociologie.* https://doi.org/10.1111/cars.12211

Cashdan, E.A. (1980). Egalitarianism among Hunters and Gatherers. *American Anthropologist.* 82 (1): 116-120

Casimir, M. and Rao, A. (2021). *Mobility and territoriality: social and spatial boundaries among foragers, fishers, pastoralists and peripatetics.* Berg.

Cauvin, J. (2000). *The Birth of the Gods and the Origins of Agriculture.* CUP.

Choi, J.H., Barnett, G.A. and Chon, B.-S. (2006). Comparing world city networks: a network analysis of Internet backbone and air transport intercity linkages. *Global Networks.* https://doi.org/10.1111/j.1471-0374.2006.00134.x

Collar, A. (2013). Re-thinking Jewish ethnicity through social network analysis. In: *Network Analysis in Archaeology: new approaches to regional interaction* (ed. C. Knappett). OUP.

Collar, A., Coward, F., Brughmans, T., et al. (2015). Networks in Archaeology: Phenomena, Abstraction, Representation. *Journal of Archaeological Method and Theory.* https://www.doi.org/10.1007/s10816-014-9235-6

Coward, F. (2010). Small worlds, material culture and ancient Near Eastern social networks. In: *Social Brain, Distributed Mind* (ed. R. Dunbar, C. Gamble and J. Gowlett). British Academy.

Coward, F. (2013). Grounding the net: social networks, material culture and geography in the Epipalaeolithic and early Neolithic of the Near East (~21,000-6,000 cal BCE). In: *Network Analysis in Archaeology* (ed. C. Knappett). OUP.

Coward, F. and Dunbar, R.I.M. (2014). Communities on the edge of civilisation. In: *Lucy to Language: the benchmark papers* (ed. R.I.M. Dunbar, C. Gamble and J.a.J. Gowlett). OUP.

Coward, F. (In press). more than the sum of their parts? Networks as methods and as heuristics in cognitive archaeology. In: *Oxford Handbook of Cognitive Archaeology* (ed. K.A. Overmann, T. Wynn and F. Coolidge). OUP.

Croucher, K. (2006). Getting ahead: exploring meanings of skulls in the Neolithic Near East. In: *Skull collection, modification and decoration* (ed. M. Bonogofsky). British Archaeological Reports International Series.

Crowe, J.A. (2007). In search of a happy medium: How the structure of interorganizational networks influence community economic development strategies. *Social Networks.* https://doi.org/10.1016/j.socnet.2007.02.002

De Benedictis, L. and Tajoli, L. (2011). The World Trade Network. *The World Economy.* https://doi.org/10.1111/j.1467-9701.2011.01360.x

Deicke, A.J. (2020). Entangled identities: Processes of status construction in late Urnfield burials. In: *Archaeological Networks and Social Interaction* (ed. L. Donellan). Routledge.

Dunbar, R.I.M. (2008). Mind the gap: or why humans aren't just great apes. *Proceedings of the British Academy.* 154 403-423

Dunbar, R.I.M. (2012). The origins of religion as a small-scale phenomenon. In: *Religion, Intolerance and Conflict: a scientific and conceptual investigation* (ed. S. Clark and R. Powell). OUP.

Dunbar, R.I.M., Mac Carron, P. and Shultz, S. (2018). Primate social group sizes exhibit a regular scaling pattern with natural attractors. *Biology Letters.* https://www.doi.org/10.1098/rsbl.2017.0490

Dunbar, R.I.M. and Shultz, S. (2021). The Infertility Trap: The Fertility Costs of Group-Living in Mammalian Social Evolution. *Frontiers in Ecology and Evolution.* https://doi.org/10.3389/fevo.2021.634664

Edwards, P.C. (1991). Wadi Hammeh 27: an Early Natufian site at Pella, Jordan. In: *The Natufian Culture in the Levant* (ed. O. Bar-Yosef and F.R. Valla). Ann Arbor.

Evans, T., Knappett, C. and Rivers, R. (2008). Using statistical physics to understand relational space: a case study from Mediterranean prehistory. In: *Complexity perspectives on Innovation and Social Change* (ed. D. Lane, D. Pumain, S.V.D. Leeuw, et al.). Springer.

Evans, T. (2016). Which network model should I use? Towards a quantitative comparison of spatial network models in archaeology. In: *The Connected Past: challenges to network studies in archaeology and history* (ed. T. Brughmans, A. Collar and F. Coward). OUP.

Finlayson, B. and Warren, G. (2017). The Diversity of Hunter-Gatherer Pasts: an introduction. In: *The Diversity of Hunter-Gatherers Pasts* (ed. B. Finlayson and G. Warren). Oxbow Books.

Fuller, D.Q., Lucas, L., González Carretero, L., et al. (2018). From intermediate economies to agriculture: trends in wild food use, domestication and cultivation among early villages in Southwest Asia. *Paléorient.* 44 (2): 59-74

Gjesfjeld, E. and Phillips, S.C. (2013). Evaluating adaptive network strategies with geochemical sourcing data: a case study from the Kuril Islands. In: *Network Analysis in Archaeology: new approaches to regional interaction* (ed. C. Knappett). OUP.

Gjesfjeld, E. (2015). Network Analysis of Archaeological Data from Hunter-Gatherers: Methodological Problems and Potential Solutions. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-014-9232-9

Goffman, E. (1959). *The Presentation of Self in Everyday Life.* Penguin.

Golitko, M. and Feinman, G.M. (2015). Procurement and Distribution of Pre-Hispanic Mesoamerican Obsidian 900 BC–AD 1520: a Social Network Analysis. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-014-9211-1

Goring-Morris, N. and Horwitz, L.K. (2007). Funerals and feasts during the Pre-Pottery Neolithic B of the Near East. *Antiquity.* https://www.doi.org/10.1017/S0003598X00095995

Graham, S. (2006). Networks, agent-based models and the Antonine itineraries: implications for Roman archaeology. *Journal of Mediterranean Archaeology.* https://doi.org/10.1558/jmea.2006.19.1.45

Graham, S. (2014). On connecting stamps–network analysis and epigraphy. *Les nouvelles de l'archéologie.* https://doi.org/10.4000/nda.2353

Graham, S. and Weingart, S. (2015). The Equifinality of Archaeological Networks: an Agent-Based Exploratory Lab Approach. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-014-9230-y

Granovetter, M.S. (1983). The Strength of Weak Ties: a network theory revisited. *Sociological Theory.* https://doi.org/10.2307/202051

Gravel-Miguel, C. 2017. *The impact of geography and climate change on Magdalenian social networks.* Ph.D., Arizona State University.

Gravel-Miguel, C. and Wren, C.D. (2018). Agent-based least-cost path analysis and the diffusion of Cantabrian Lower Magdalenian engraved scapulae. *Journal of Archaeological Science.* https://doi.org/10.1016/j.jas.2018.08.014

Gravel-Miguel, C. and Coward, F. (In press.). Palaeolithic Social Networks and Behavioural Modernity. In: *The Oxford Handbook of Archaeological Network Research* (ed. T. Brughmans, B. Mills, J. Munson, et al.). Oxford: OUP.

Groenhuijzen, M.R. and Verhagen, P. (2016). Testing the Robustness of Local Network Metrics in Research on Archeological Local Transport Networks. *Frontiers in Digital Humanities.* https://doi.org/10.3389/fdigh.2016.00006

Grosman, L., Munro, N.D. and Belfer-Cohen, A. (2008). A 12,000-year-old Shaman burial from the southern Levant (Israel). *Proceedings of the National Academy of Sciences.* https://doi.org/10.1073/pnas.0806030105

Hart, J.P. (2012). The effects of geographical distances on pottery assemblage similarities: a case study from Northern Iroquoia. *Journal of Archaeological Science.* https://doi.org/10.1016/j.jas.2011.09.010

Harvey, G. (2014). *The Handbook of Contemporary Animism.* Routledge.

Hayden, B. (1996). Competition, labor and complex hunter-gatherers. In: *Key Issues in Hunter-Gatherer Research* (ed. J. Ernest S. Burch and L.J. Ellanna). Berg.
Hayden, B. (2003). Were luxury foods the first domesticates? Ethnoarchaeological perspectives from Southeast Asia. *World Archaeology.* https://doi.org/10.1080/0043824021000026459a
Hodder, I. (1990). *The Domestication of Europe: structure and contingency in Neolithic societies.* Oxford: Blackwell.
Hodder, I. and Mol, A. (2016). Network Analysis and Entanglement. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-015-9259-6
Hole, F. (2000). Is Size Important? Function and hierarchy in Neolithic settlements. In: *Life in Neolithic Farming Communities: Social Organization, identity, and Differentiation* (ed. I. Kuijt). New York: Kluwer Academic/Plenum Press.
Ingold, T. (1987). *The Appropriation of Nature: essays on human ecology and social relations.* Manchester University Press.
Ingold, T. (2000). *The Perception of the Environment: Essays in Livelihood, Dwelling and Skill.*
Kelly, R.L. (2013). *The Lifeways of Hunter-Gatherers: the foraging spectrum.* CUP.
Kent, S. ed. (1990). *Domestic Architecture and the Use of Space: an interdisciplinary cross-cultural study.* Cambridge: CUP.
Knappett, C., Evans, T. and Rivers, R. (2008). Modelling maritime interaction in the Aegean Bronze Age. *Antiquity.* https://doi.org/10.1017/S0003598X0009774X
Knappett, C. (2011). *An Archaeology of Interaction: Network Perspectives on Material Culture and Society.* OUP.
Knappett, C., Rivers, R. and Evans, T. (2011). The Theran eruption and Minoan palatial collapse: new interpretations gained from modelling the maritime networks. *Antiquity.* https://doi.org/10.1017/S0003598X00068459
Knappett, C. (2016). Networks in Archaeology: between scientific method and humanistic metaphor. In: *The Connected Past: Challenges to network studies in archaeology and history* (ed. T. Brughmans, A. Collar and F. Coward). OUP.
Kuijt, I. ed. (2000a). *Life in Neolithic Farming Communities: social organization, identity, and differentiation.* Kluwer Academic/Plenum Publishers.
Kuijt, I. (2000b). People and Space in early Agricultural Villages: exploring daily lives, community size, and architecture in the late pre-pottery Neolithic. *Journal of Anthropological Archaeology.* https://doi.org/10.1006/jaar.1999.0352
Kuijt, I. (2021). The spaces and networks between households. In: *Archaeology of Households, Kinship, and Social Change* (ed. L.B. Carpenter and A.M. Prentiss). Routledge.
Ladefoged, T.N., Gemmell, C., Mccoy, M., et al. (2019). Social network analysis of obsidian artefacts and Māori interaction in northern Aotearoa New Zealand. *PLOS ONE.* https://doi.org/10.1371/journal.pone.0212941
Latour, B. (2005). *Reassembling the social: an introduction to actor-network-theory.* Oxford: OUP.
Lucero, L.J. (2003). The politics of ritual: The emergence of Classic Maya rulers. *Current Anthropology.* https://doi.org/10.1086/375870
Lulewicz, J. and Coker, A.B. (2018). The structure of the Mississippian world: A social network approach to the organization of sociopolitical interactions. *Journal of Anthropological Archaeology.* https://doi.org/10.1016/j.jaa.2018.04.003
Maher, L.A. and Conkey, M. (2019). Homes for Hunters?: Exploring the Concept of Home at Hunter-Gatherer Sites in Upper Paleolithic Europe and Epipaleolithic Southwest Asia. *Current Anthropology.* https://doi.org/10.1086/701523
Makarewicz, C.A. (2013). A pastoralist manifesto: breaking stereotypes and re-conceptualizing pastoralism in the Near Eastern Neolithic. *Levant.* https://doi.org/10.1179/0075891413Z.00000000023
Marshall, L. (1999). *Nyae Nyae! Kung beliefs and rites.* Peabody Museum Press.

Marshall, Y. (2006). Introduction: adopting a sedentary lifeway. *World Archaeology.* https://doi.org/10.1080/00438240600688364
Matsumoto, M.E. (2021). Archaeology and Epigraphy in the Digital Era. *Journal of Archaeological Research.* https://doi.org/10.1007/s10814-021-09162-4
Mazzucato, C. (2019). Socio-Material Archaeological Networks at Çatalhöyük a Community Detection Approach. https://doi.org/10.3389/fdigh.2019.00008
Mills, B.J., Clark, J.J., Peeples, M.A., et al. (2013). Transformation of social networks in the late pre-Hispanic US Southwest. *Proceedings of the National Academy of Sciences.* https://doi.org/10.1073/pnas.1219966110
Mills, B.J., Peeples, M.A., Haas, W.R., et al. (2015). Multiscalar Perspectives on Social Networks in the Late Prehispanic Southwest. *American Antiquity.* https://doi.org/10.7183/0002-7316.79.4.3
Mills, B.J. (2017). Social Network Analysis in Archaeology. *Annual Review of Anthropology.* https://doi.org/10.1146/annurev-anthro-102116-041423
Mizoguchi, K. (2009). Nodes and edges: A network approach to hierarchisation and state formation in Japan. *Journal of Anthropological Archaeology.* https://doi.org/10.1016/j.jaa.2008.12.001
Mol, A., Hoogland, A.A., P., M.L., et al. (2015). Remotely Local: Ego-networks of Late Pre-colonial (AD 1000–1450) Saba, North-eastern Caribbean. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-014-9234-7
Molleson, T. (2007). Bones of work at the origins of labour. In: *Archaeology and woman: ancient and modern issues* (ed. S. Hamilton, R.D. Whitehouse and K.I. Wright). Left Coast Press.
Mueller, A. (2016). Beyond ethnographic scriptocentrism: Modelling multi-scalar processes, networks, and relationships. *Anthropological Theory.* https://doi.org/10.1177/1463499615626621
Pálsson, G. (2021). Cutting the Network, Knotting the Line: a Linaeological Approach to Network Analysis. *Journal of Archaeological Method and Theory.* https://doi.org/10.1007/s10816-020-09450-1
Peeples, M.A. (2019). Finding a Place for Networks in Archaeology. *Journal of Archaeological Research.* https://doi.org/10.1007/s10814-019-09127-8
Read, D. (2010). From experiential-based to relational-based forms of social organization: A major transition in the evolution of Homo sapiens. In: *Social Brain, Distributed Mind* (ed. R. Dunbar, C. Gamble and J. Gowlett). OUP.
Renfrew, C. (1976). Megaliths, territories and populations. In: *Acculturation and continuity in Atlantic Europe* (ed. S.J.D. Laet). de Tempel.
Rivers, R. (2016). Can archaeological models always fulfil our prejudices? In: *The Connected Past: challenges to network studies in archaeology and history* (ed. T. Brughmans, A. Collar and F. Coward). OUP.
Roberts, J.M., Mills, B.J., Clark, J.J., et al. (2012). A method for chronological apportioning of ceramic assemblages. *Journal of Archaeological Science.* https://doi.org/10.1016/j.jas.2011.12.022
Roberts, S.G.B. (2010). Constraints on Social Networks. In: *Social Brain, Distributed Mind* (ed. R. Dunbar, C. Gamble and J. Gowlett). British Academy.
Rosenberg, M. and Rocek, T.R. (2019). Socio-political organization in the Aceramic Neolithic of southwestern Asia: The complex evolution of socio-political complexity. *Journal of Anthropological Archaeology.* https://doi.org/10.1016/j.jaa.2019.01.006
Sosna, D., Galeta, P., Šmejda, L., et al. (2012). Burials and Graphs: Relational Approach to Mortuary Analysis. *Social Science Computer Review.* https://doi.org/10.1177/0894439312453277
Spencer, B. and Gillen, F.J. (1904). *The northern tribes of Central Australia.* London: Macmillan and Company, limited.
Terrell, J.E. (2010). Social Network Analysis of the Genetic Structure of Pacific Islanders. *Annals of Human Genetics.* https://doi.org/10.1111/j.1469-1809.2010.00575.x
Tilley, C. (2007). The Neolithic sensory revolution: monumentality and the experience of landscape. *Proceedings of the British Academy,* 144: 329

Tsirogiannis, C. and Tsirogiannis, C. (2016). Uncovering the hidden routes: algorithms for identifying paths and missing links in trade networks. In: *The Connected Past: challenges to network studies in archaeology and history* (ed. T. Brughmans, A. Collar and F. Coward). OUP.
Valla, F.R. (1991). Les Natoufiens de Mallaha et l'espace. In: *The Natufian Culture in the Levant* (ed. O. Bar-Yosef and F.R. Valla). Ann Arbor.
Van Oyen, A. (2016). Networks or Work-nets? Actor-Network Theory and Multiple social topologies in the production of Roman *Terra Sigillata*. In: *The Connected Past: challenges to network studies in archaeology and history* (ed. T. Brughmans, A. Collar and F. Coward). OUP.
Verhoeven, M. (2002). Ritual and Ideology in the Pre-Pottery Neolithic B of the levant and southeast Anatolia. *Cambridge Archaeological Journal.* https://doi.org/10.1017/S0959774302000124
Wang, L.-Y. and Marwick, B. (2021). A Bayesian networks approach to infer social changes from burials in northeastern Taiwan during the European colonization period. *Journal of Archaeological Science.* https://doi.org/10.1016/j.jas.2021.105471
Watts, J. and Ossa, A. (2016). Exchange Network Topologies and Agent-Based Modeling: Economies of the Sedentary-Period Hohokam. *American Antiquity.* https://doi.org/10.1017/S0002731600101003
Wengrow, D. and Graeber, D. (2015). Farewell to the 'childhood of man': ritual, seasonality, and the origins of inequality. *Journal of the Royal Anthropological Institute.* https://doi.org/10.1111/1467-9655.12247
Whitelaw, T. (1991). Some dimensions of variability in the social organisation of community space among foragers. In: *Ethnoarchaeological approaches to mobile campsites: hunter-gatherer and pastoralist case studies* (ed. C.S.Gamble and W.A.Boismier). International Monographs in Prehistory.
Wickham, R.D. 2019. *Origins of sedentism: possible roles of ideology and shamanism in the transition.* PhD Thesis, Australian National University.
Willcox, G. (2013). The Roots of Cultivation in Southwestern Asia. *Science.* https://doi.org/10.1126/science.1240496
Williams, A. 2019. *Modelling the evolution of socio-political complexity.* PhD Thesis, University of Exeter.
Wilson, P. (1988). *The domestication of the human species.* Yale University Press.
Woodburn, J. (1982). Egalitarian Societies. *Man.* https://doi.org/10.2307/2801707
Wright, K. and Garrard, A. (2003). Social identities and the expansion of stone bead-making in Neolithic Western Asia: new evidence from Jordan. *Antiquity.* https://doi.org/10.1017/S0003598X00092267
Zeder, M.A. (2011). The Origins of Agriculture in the Near East. *Current Anthropology.* https://doi.org/10.1086/659307

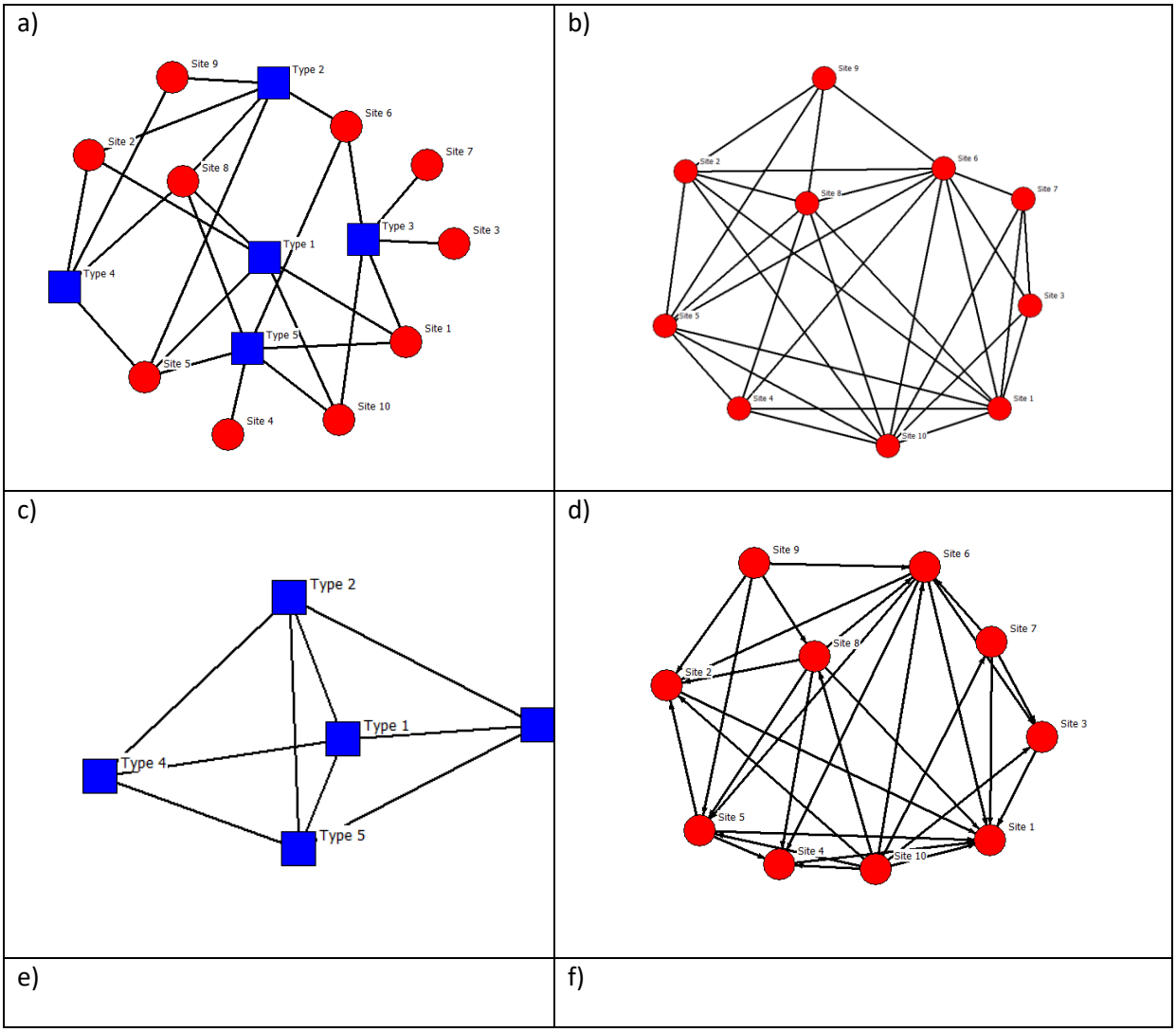
Tables and captions

Table 1: Some material proxies for similarity used to reconstruct edges in archaeological network analysis

Similarity	Specific data type	Example references
Typological similarity	'art' and iconographic objects	Gravel-Miguel 2017; Gravel-Miguel and Wren 2018; Lulewicz and Coker 2018
	Ceramics	Mills et al. 2013; Mills et al. 2015
Raw material similarity, e.g. geochemical analysis	Obsidian	Golitko and Feinman 2015; Ladefoged et al. 2019
	Ceramics	Gjesfjeld and Phillips 2013
Spatial/geographical data e.g. distance, travel time/cost		Blake 2014; Brughmans et al. 2014, 2015; Coward 2013; Mills et al. 2013; Mol et al.

		2015
Biodistance data	aDNA	Terrell 2010
Textual/epigraphic data (for historical periods)		Collar 2013; Graham 2014; see review and references in Matsumoto 2021
Combinations of different kinds of material culture		Blake 2014; Coward 2010; Hodder and Mol 2016; Mazzucato 2019

Figures and captions



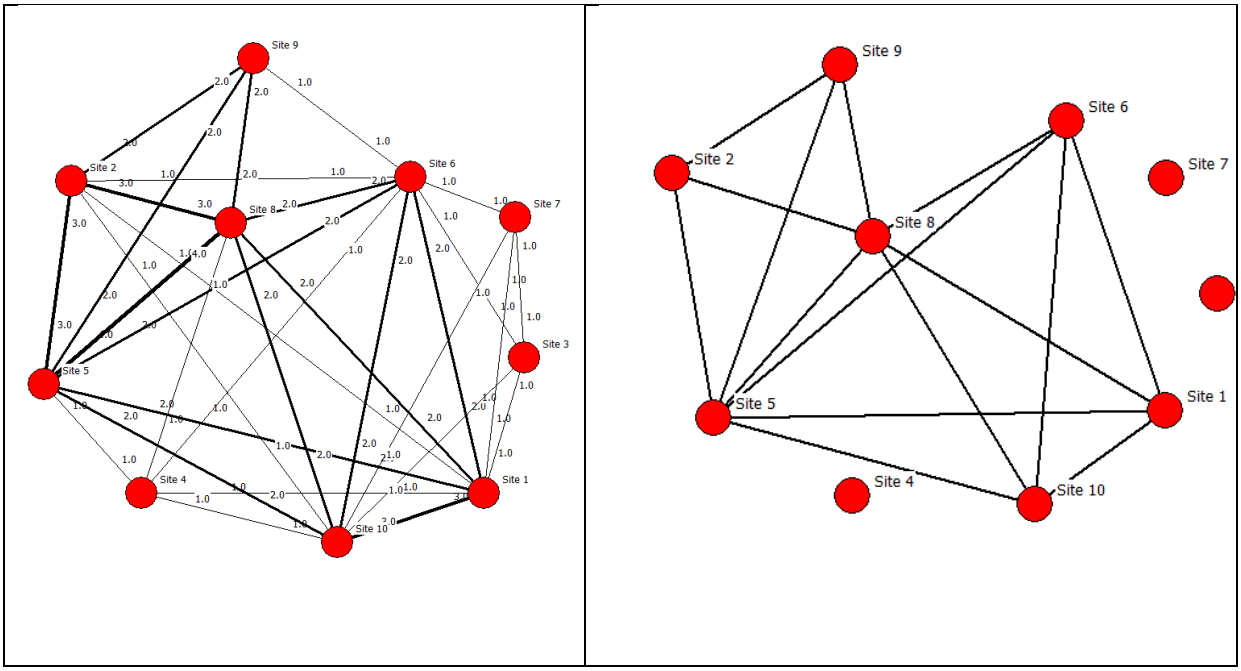


Figure 1

a) a two-mode network in which sites are seen as connected by shared material culture (and indeed, vice versa); b) affiliation network in which the nodes are sites and information on the material culture shared by each has been subsumed into edges connecting the sites; c) the same network, but with the material culture as nodes and the sites at which they appear in common transformed into edges. Note that the edges here are undirected, i.e. the direction of 'travel' of cultural or material transmission is not known (common in archaeological applications) or not considered relevant; d) network b with directed edges demonstrating reconstructed direction of transmission between sites; either a 'start' and 'end' point can be identified, for example where a raw material is sourced at one location but found at another; e) network b but with valued edges, i.e. where an edge is not simply present or absent but given a 'weight' referencing the inferred strength of the relationship between the entities – for example a statistical measure of material culture similarity between them, here simply the number of items of material culture each pair of sites shares; f) network b but with a 'threshold' applied whereby edges with an inferred weight below a certain level are removed from analysis and only the stronger and hence presumably more important relationships are considered - particularly helpful where networks are very dense. Here edges with a weight of less than 2 (i.e., they have 1 or 0 items in common) are ignored. Note that three sites, 3, 4 and 7 are no longer connected to the rest of the network here; g) the underlying data.

See Also:

wbiea2385, Agricultural Origins

wbiea1932, Demographic Transition

wbiea1983, Demography, Prehistoric Human

wbiea1789, Material Culture

wbiea2282, Ritual and religion, evolution of