More than the sum of their parts? Networks as methods and as heuristics in cognitive archaeology.

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Abstract

Network concepts and methods offer enormous potential for studying cognitive archaeology. They provide practical analytical methods for handling the archaeological and anthropological datasets that comprise the only hard evidence for cognitive evolution. In addition, they also offer valuable tools for understanding key features of hominin cognition and the selective pressures driving its evolution.

Recent work has emphasised cognition less as a static set of abilities determined by genotype and passively reflected in the archaeological dataset, but as highly sensitive to social and demographic factors. Cognitive evolution is now recognised as driven by network variables, including adaptive changes in group size, population density and effective population size, and the connectivity among individuals and groups. Interactions beyond conspecifics, with other species and aspects of the world around them, are also increasingly recognised as important in this respect. Traditional approaches have often focused narrowly on specific individual elements of the archaeological and anthropological record considered to demonstrate cognitive prowess, such as stone tools or brain size. However, from a network perspective such phenomena are better considered emergent properties of the complex social networking skills and patterns of social connectivity and organization which played a vital adaptive role in human evolution. This chapter will review the theoretical and practical bases for the application of network concepts and methods to investigate hominin and human cognition.

Introduction

'Network' is the buzzword of the 21st century. It can sometimes seem as though the term is used to describe everything from global trade and power and internet infrastructure to the fundamental structure of our ecosystems, our nervous systems and the molecules that surround us. The concept can seem so all-pervasive – and so recent, theoretically speaking – that one might be excused for writing it off as an epistemological fad. However, the network concept is in fact an extremely powerful one, particularly for cognitive archaeology, because it offers a mode of conceptualising, visualising and analysing *interactions*. As long as *something* can be conceptualised as connecting *some things* together, methods and analogies drawn from network science are likely to be appropriate.

One of the major attractions of these methods is that network approaches offer a mature and thorough field-tested set of quantitative methods for handling data on such interactions, derived from the surprisingly intuitive basic concepts of graph theory. In addition, network approaches allow for multi-scalar analyses, being largely agnostic as to the nature of the entities interacting, and the scale at which they operate. These entities can be qubits (quantum physics), molecules (the physical sciences), neurons (neurology), processors or computers (computer sciences), parts in machines (engineering), individual organisms, whether human (sociology), other- or more-than-human organisms (ecology), abiotic natural processes (earth sciences, meteorology), and many more.

Archaeology and anthropology have perhaps been slower to join the network party than some other disciplines. However, the basic concept of interactivity between different entities, from individual humans through to communities and nation states, is clearly central to both disciplines. Kinship (in its broadest, not simply strictly 'biological' or genetic sense), trade, exchange, inter-polity and human/environment interactions, etc. are key areas of research across the humanities and social sciences, precisely because they are of central importance in all human societies.

Conceptualising relations between humans and other social entities as networks is therefore highly intuitive and something common to many humanities and social science disciplines. However, there remains something of a divide between those fields that have historically embraced quantitative vs those pursuing more qualitative methods. For example, sociology has a long history of applying formal network methods such as social network analysis (see e.g. Peeples 2019; Brughmans and Peeples 2017 for useful historical overviews), while social anthropology tends to favour qualitative approaches.

But perhaps another reason for the resistance of anthropology and archaeology (until very recently) to network-based research is that in fact networks of humans are really only one aspect of the interactions that these disciplines study. Indeed, it could be argued of archaeology that it does not study networks of humans at all, or only by proxy. In any case, for archaeology and anthropology both, while interactions between humans are important, so are interactions between humans and other animal species. This includes interactions between humans and other biota such as plant species, and between humans and abiotic entities, such as natural and human-made objects and indeed places, elements of the landscape, and even intangible and supernatural entities such as spirits and gods. Such relationships have perhaps seemed more resistant to mapping using formal quantitative network methods. However, in other disciplines such as ecology, networks comprising multiple different plant and animal species, and indeed abiotic factors such as earth systems processes are routinely studied using network theory and methods despite focusing on flows of energy through ecosystems, rather than on 'social' relations per se (e.g Barnes et al. 2018).

More recently, such 'more-than-human' networks have increasingly become the focus of a more heuristic conceptualisation of networks and networking as part of the 'ontological turn' in the humanistic disciplines, including anthropology, geography etc. (e.g. Descola 2013; Emel and Urbanik 2010; Whatmore 2002), alongside other arguably related theoretical developments including Actor Network Theory (ANT; Latour 2005) etc. Indeed, some varieties of humanistic/social science 'network' thinking allow for the removal of humans from networks entirely, particularly focusing on object relations, for example Thing Theory (Brown 2004) and Assemblage Theory (Knutson 2021; DeLanda 2016).

This extension of 'social' networks beyond the simply human is key to the spread of such perspectives in anthropology and particularly archaeology. Since archaeologists deal almost exclusively with material remains and traces, a theoretical framework that explicitly theorises the relationships between *things* and between things and people provides an extremely attractive paradigm. And for those archaeologists with one foot in the sciences and welcoming of quantitative approaches, the availability of formal, quantitative analytical methods associated with such a useful theoretical framework is a handy bonus. Perhaps it is no surprise, then, that archaeological applications of both heuristic and formal network thinking have taken off in recent decades. And since interactions are the very stuff of human cognition and indeed lives, I suggest that networks are likely to remain a key concept across the humanities and social sciences for a long time to come.

Networks and cognitive archaeology

In some ways cognitive archaeology, obliged to confront the complex relationship between material culture and human cognition from the first, has been rather prescient compared to the broader cognitive sciences in its focus on *things*. However, the methods used historically are not without their flaws. Hypotheses about cognitive change over the evolutionary long durée have been constrained by an overly linear and species-focused conceptualisation of evolutionary 'progress' in cognition (Nowell 2010). In addition, some have questioned the extent to which it is possible to 'read off' cognitive processes from things and material traces (Currie and Killin 2019), arguing that reducing material culture to mere indices of cognitive complexity in this way prevents recognition of agency in the past (e.g. Barona 2021). To what extent is it possible to meaningfully assess and compare the cognitive demands of different manufacturing and material processes, from stone tool manufacture to art via jewellery and composite technologies (e.g. papers in Overmann and Coolidge 2019; Wynn and Coolidge 2008) in the abstract?

Nevertheless, cognitive archaeology's focus on the material in studying cognition has been at least partly vindicated as the cognitive sciences more generally have embraced new '4e' perspectives emphasising the 'extended' (or distributed), 'enactive', 'embedded' and 'embodied' etc. nature of cognition (Clark 1997; Clark and Chalmers 1998; Gallagher 2017; Gibson 1979; Hutchins 1995a, 1995b; Kirsh 1995, 1996; Newen et al. 2018; see e.g. Barona 2021 for discussion). Such approaches have informed work on material agency by a number of archaeologists and anthropologists (Coward and Gamble 2008, 2010; Gosden 2005, 2008; Knappett 2005; Malafouris and Renfrew 2010; Malafouris 2013; Roberts 2016) and represent inherently *networked* approaches, in which cognition, networks and things (in the very broadest sense, see below) form three points of the theoretical triangle – or three connected nodes within the conceptual network, if you prefer – within which cognitive archaeology operates (Figure 1). Each side of the triangle will be discussed in turn below.

Cognition and things …

The first edge in Figure 1 connects cognition and 'things'. While each of the various '4e' (extended, enactive, embedded and embodied) approaches represents a distinct theoretical paradigm, all to an extent emphasise an interactive and hence essentially *networked* component to cognition. *Thinking* becomes an emergent process arising from interactions not just between neurons but also between the central and peripheral nervous systems, and therefore between embodied nervous systems and the material environment of the individual concerned.

Thus the blind person's white stick is not simply an inert object but becomes an extension of their sensory apparatus (Malafouris 2013). Likewise, the shuffling of Scrabble tiles when trying to produce the perfect 7-letter word to fit on the triple-word score square is not simply nervous activity but a constitutive part of the cognitive process of recall and creation (Clark 1997). And the spatial arrangement of materials on a fishing boat, or of switches in an aircraft cockpit, likewise both reflect and structure the activities that take place there, and are thus part of cognitive processes in their broadest sense (Hutchins 1995a, 1995b).

Cognition thus becomes bio-cultural. Evolutionary 'environments' and the selective pressures they entail are normally considered primarily in terms of the physical/ecosystemic envionments of species. However, material culture is not just a product of humans but also goes on to become part of human environments and therefore to entail selective pressures that shape further material engagements.

Thus for example manufacture of a lithic tool is clearly partly reliant on the evolution of the requisite bodily and cognitive apparatus (e.g. Marzke 2013). However, as anyone who has ever tried to knap stone knows, the process of manufacture itself is not simply a process of 'imposing' a 'mental template' on a blank rock, but a more interactive process of negotiation with the materiality of raw materials (Roux and David 2005; Schlanger 1994, 1996). Furthermore, such material engagements are always further embedded in what are often, among modern humans at least, very complex socio-cultural conceptualisations of *how* such engagements should proceed (Stout 2002). In addition, new tools may 'open up' certain activities, ecological niches, and cognitive styles and innovations. The skills hominins required to use and create stone tools evolved as a key element of a new ecological niche relating to increased use of scavenged animal protein and/or other cryptic foods in Pleistocene Africa, perhaps in response to long-term changes in ecosystems at the time (Lewis and Harmand 2016). This new niche has arguably proved fundamental in shaping later hominin evolution. Further technological innovations later in human (pre)history – agricultural skills; pottery; writing; the wheel; the microchip – have likewise had enormous implications for our relationships with each other, with other species, and with the Earth itself (Sullivan et al. 2017; Mutekwe 2012).

It follows that, as cognitive archaeology has always maintained, things can be used as proxies for cognitive processes because they are inherently *part of*, not merely passive reflections of, those cognitive processes (Stade and Gamble 2019). And those things then constitute material environments which exert selective pressures of their own.

… Things and networks …

The principle that human cognition and things are interdependent should come as no great surprise to cognitive archaeologists; the next connection, of things to networks, may be less familiar, but is the foundation of a networked cognitive archaeology. This side of the triangle asserts that things are connected to one another to form networks – and that these networks are both the glue that holds human societies together, and simultaneously the stuff of which they are made.

To start with perhaps the most familiar form of 'things', archaeologically speaking, material culture forms networks because people form networks, and material culture is always inherently connected to persons of some form or another, e.g. manufacturers and/or users/owners. And because those manufacturers/users/owners etc. are social beings, those things also become linked to other people with whom those individuals interact, such as those people present and involved when the object was found, made, used, gifted etc. Things thus become entangled with and thus acquire and retain aspects of the people with whom they have been associated.

Things also have some valuable properties that make ‘material’ interactions different in kind than purely social interactions: notably, they are detachable and divisible, as well as durable and diverse. Because things are ‘detachable’ from their manufacturer/owner, they can travel away from them to other people (and places, see below), via processes of gifting, exchange and trade, entraining the participants in different sets of relationships with one another. Among contemporary *Homo sapiens*, objects being exchanged are often seen as carrying with them some intangible *aspect* of their former owner: the ‘spirit of the gift’ (Mauss 1925), or the ‘endowment effect’ (Morewedge and Giblin 2015). The effect is to create ‘partible’ persons (Strathern 1988) whose personhoods are distributed throughout their broader networks. The divisibility of many *things* further enhances this effect, as ‘whole’ objects can be broken into pieces which can follow very different pathways through human social networks, while retaining links to one another by virtue of a shared past wholeness (Chapman 2000; Chapman and Gaydarska 2010). ‘Places’ are thus also vital parts of these networks. Places where raw materials are sourced, where objects are manufactured, used, exchanged, gifted, purchased, found, deposited, and where persons interact with one another as part of these activities. The detachability and divisibility of objects allows them to move between, or become co-located across, multiple places, further linking them together in space and time.

The ways in which objects become intertwined in social relationships are partly structured by pre-existing ‘social’ relationships between people. For example, the manufacture of objects is typically part of a much broader and culturally-mediated process of ‘enskillment’ (Ingold 2000, 416) in materiality. Such cultural transmission is by definition both structured by, and creates and maintains, social relationships and interactions between people. In many traditional societies, cultural transmission occurs primarily between kin (Cantor and Whitehead 2013; Hosfield 2009; Tehrani and Riede 2008), but also takes place between people who are not related in the western biological sense. Here it not only reflects but also *creates* specific sets of social relations, e.g. teacher-pupil, master-apprentice, which may entrain further relationships between the individuals, families, and communities involved (Marchand 2008; Wolter and Ryan 2011). Note also, of course, that cultural transmission also relies on, and selects for, the many complex cognitive skills required for effective teaching and learning (see further discussion below). Material culture is therefore inextricably entangled in social networks from the start.

Material culture thus embodies and reifies complex sets of relationships and connections with other entities. These connections and relationships can grow, deepen, and intensify over time, to the point where objects have histories, and indeed arguably biographies (e.g. Gosden and Marshall 1999; Hoskins 1998; Appadurai 1986) or itineraries (Bauer 2019). In this respect, they can be considered not just passive *aides memoires* or souvenirs scaffolding human social networks, but as ‘persons’ (Hendon et al. 2012), active social agents in their own right (Barona 2021).

This is not to anthropomorphise things, or indeed to objectify persons, but recognises at a fundamental level that the agency recognised by the status of ‘person’ is an emergent property of entities’ enmeshment in broader networks. While here as a cognitive archaeologist I focus primarily on material objects, of course the principle of enmeshed agency can be extended much more broadly. Animals are already agentive beings and considered ‘persons’ in many traditional ontologies (including western ones). Likewise places and potentially also certain other aspects of the environment more often considered ‘natural’, such as weather or other aspects of the natural world, are also often ascribed agency, for example in animist ontologies (e.g. Bird-David 1999; Ingold 2000).

The recognition that human social networks are in fact always hybrid, comprising more-than-human entities and connections, is more than simply a thought exercise but has very real implications for human culture and society. The power of a hybrid network derives from the heterogeneity of agencies it encompasses: different entities/nodes in the network have different characteristics and hence distinctive forms of agency which have different effects.

The *diversity* of things’ materialities and hence affordances both practical and metaphorical (Coward and Gamble 2010; Tilley 1999) means that individual objects lend themselves to a range of different kinds of ‘uses’, metaphors and thus roles within social networks. Gold provides a very different resource for social networking than meat, for example. Thus objects also relate to one another, as well as to people and places. In juxtaposition with other things, objects acquire new nuances to their nature, meaning and effect, as emphasised for example in assemblage theory (DeLanda 2006, 2016; Deleuze and Guattari 1987 (2004); see e.g. Knutson 2021; Lucas and Robb 2021; Gosden 2008 for practical examples).

A further aspect of this is the variable *durability* of objects. While some are relatively short-lived, at least from an archaeological perspective, others survive long enough to not only connect people together across space, but also potentially through time, as for example when objects are passed down as family heirlooms or inheritances. Objects therefore act as *aide memoires*, souvenirs or metaphors bringing other entities to mind even in their absence, and thereby affecting ongoing behaviour in a complex variety of ways. Thus while material culture environments may be in part created by human behaviour, those material environments then go on to structure ongoing interactions and the wider network. The most obvious example is that of the built environment (papers in Parker-Pearson and Richards 1994; Bourdieu 1979; Hillier and Hanson 1984), but material culture is used in many more subtle ways to influence human interaction and behaviour (see e.g. Coward and Dunbar 2014 for discussion). Even simply accumulations of things in the landscape have the potential to become ‘persistent places’ affecting ongoing activity (Pollard 1999, 2001; Pope 2017; Shaw et al. 2016). In this way, things and people become increasingly co-dependent or ‘entangled’, to use Hodder’s term (2012).

Notably, this entanglement in hybrid networks does not appear to be a trait shared by our closest living relatives. All Great Apes and indeed most other primates are highly social, all are part of complex ecological networks of interaction e.g. via food chains, through processes of niche construction etc., and all also interact with and even occasionally make objects. Some do arguably engage with material culture to some extent, even thereby altering their environments in ways that affect future behaviour (Haslam et al. 2017; 2009; Kühl et al. 2016; Visalberghi et al. 2013). However. none seem to engage with material objects in anywhere near as geographically or temporally sustained a fashion as modern humans, let alone become quite as emotionally connected (Coward 2016). The fact that they also find it difficult to maintain social connections with other individuals over long periods of separation (Liszkowski et al. 2009) may also attest to the evolutionary role of such entanglements. This implies that the networking of and with things in which humans engage is at least partly the product of evolutionary processes which were subject to positive selection during hominin evolution.

… Networks and cognition

Thus well as being part of the cognitive processes of modern humans, things are also part of our social world, and these hybrid networks shape our cognitive processes (figure 1). Certainly it is clear that *Homo sapiens* are cognitively very different from our closest living relatives. Arguably, this reflects adaptation for more complex forms of interaction not just with conspecifics but a host of other entities. Debate continues as to whether the major selective pressures behind cognitive evolution were primarily ecological or social. However, a networked perspective highlights the extent to which the two are interlinked, since complex social cognitive skills evolved ultimately to solve ecological problems such as efficient resource procurement, and reproduction (Dunbar 2016). By definition, the ‘ecological niche’ of any species encompasses interactions with multiple other animal and plant species, as well as abiotic aspects of the landscape. Interactions with other species, from predator-prey relationships to mutualism, parasitism, commensalism and competition, can be significant co-evolutionary selective pressures. Modern human hunter-gatherers construe subsistence activities as fundamentally *social* interactions between human and other ‘persons’ and places (Ingold 2000). And those interactions and relationships are further entangled into networks firstly by the need for co-operation for many subsistence activities. As described above, the production of the necessary technologies relies on broader networks of cultural transmission, but also resource acquisition itself is often a cooperative activity, particularly the hunting of large animals (Balme 2018) and such co-operation may extend beyond the simply human to other animal species such as dogs or humans; Ruusila and Pesonen 2004).

Certainly neither co-operation in foraging nor in cultural transmission are unique to humans. Some elements of these abilities clearly not only have a long evolutionary history (Musgrave et al. 2020, though see also Whiten 2020), but have also evolved independently in multiple lineages, thus attesting to the adaptiveness of such cognitive abilities in a range of different evolutionary circumstances (Hoppitt et al. 2008). However, despite some debate it does seem clear that human co-operation may manifest in some uniquely complex forms, including complementary role-taking within teams, and teaching (Boyette and Hewlett 2018; Melis and Semmann 2010; Tennie et al. 2012; though see also Anderson and Franks 2001; see Krupenye and Call 2019 for review). The specific cognitive skills required for complex interactions with other social entities, potentially including joint attention, Theory of Mind, imitation etc. (Tomasello 2020), are therefore likely to have been subjected to positive selection since the separation of the hominin lineage from that of the chimpanzees (Carpenter et al. 2013).

In recent years, therefore, research has increasingly focused on the further adaptive significance of extensive hybrid social networks in hominin evolution. Extensive ethnographic research has documented that even where ecological conditions mandate low population densities, extensive networking via the ‘tuning’ of mobility (Grove 2016; Powell et al. 2009), and high levels of connectedness (Riede 2016, 2008; Premo 2012), nevertheless allow the maintenance of extensive networks. These allow for viable breeding demes (Birdsell 1958; Wobst 1974, 1976) and access to more extensive information about ecosystemic conditions and more effective risk-buffering in the face of ecosystemic unpredictability (Migliano et al. 2016; Whallon 2006; Gamble 1982; Wiessner 1982). They also translate into higher effective population sizes (Coward and Grove 2011; Henrich 2004; Shennan 2001, though see also

Fogarty and Creanza 2017), and therefore higher rates of innovation, faster spread of innovations, and better maintenance of complex technologies.

The hybrid nature of human social networks, and specifically the incorporation of material culture, contributes significantly to this adaptiveness of extensive social networking. As noted above, the *detachable, divisible*, *diverse* and *durable* nature of material objects provides valuable forms of agency that allow networks to expand further. A human proclivity to engage emotionally and socially with material objects provides a mechanism for a 'release from proximity' (Gamble 1998) whereby individuals can remember and hence maintain connections with other, absent network partners over longer geographical and social distances (Coward 2016; Coward and Gamble 2008). The semi-formalised exchange systems well-documented among many traditional societies, including the hxaro of the Ju'Hoansi (Wiessner 1982) and the Kula of the Trobriand Islanders (Malinowski 1920) provide well-documented examples of this phenomenon among contemporary humans, though many less formal networks have also been identified in the ethnographic literature.

Hybrid social networks and the cognitive skills than underpin them are thus tightly coupled on an evolutionary timescale and make *Homo sapiens* unique among extant species. For *Homo sapiens*, things are part of, not by-products of, many cognitive processes. Things are always part of human social networks, and these networks require, and select for, specific forms of cognition (figure 1). This makes a network approach an extremely valuable one for cognitive archaeology and anthropology, whether analysis is 'network' based at a purely heuristic, conceptual level, or whether the analysis utilises quantitative network methods.

Networks in practice in cognitive archaeology

The application of network analysis to archaeological datasets is a young but rapidly-growing field within archaeology. Their use in specifically cognitive studies has been more limited to date, but as discussed above, there is clearly considerable potential. Numerous excellent reviews of the basics of formal network analysis for archaeological and historical datasets are available (e.g. Peeples 2019; Brughmans and Peeples 2018; Mills 2017; Collar et al. 2015; Brughmans 2013a, 2013b). Beginners are directed towards some of the many guides which, although intended primarily for other disciplines, are nevertheless also extremely helpful for archaeological applications (Borgatti et al. 2002; Wasserman and Faust 1994). A helpful glossary of relevant network science terms is also provided by Collar et al. (2015). Rather than simply reiterate the basics, here I focus here on the broader issues and applications of network approaches to cognitive archaeology, including the more heuristic as well as the robustly formal and quantitative, and discuss some of the potential benefits and pitfalls of these approaches for the field of cognitive archaeology.

Perhaps one reason why network analysis has not been widely applied in cognitive archaeology is that the relationships between cognition, material culture and networks among modern-day *Homo sapiens* illustrated in figure 1 cannot be assumed for other hominin species. Indeed, perhaps they should also not be assumed even for the earliest *Homo sapiens*. But by the same token, arguably network methods therefore also offer a valuable means of investigating the process by which these hybrid networks evolved.

In the light of the perennial interest in evolutionary cognitive changes throughout the Palaeolithic, there is a strong argument that *all* applications of network concepts and theories in this period (certainly prior to the extinction of non-*sapiens* species of *Homo*) are almost by definition 'cognitive'. All work in these periods tests – whether implicitly or explicitly – whether the cognitive foundations for the uniquely hybrid networks of modern *Homo sapiens* are yet in place. In contrast, not all work taking a 'network' perspective in later periods is necessarily inherently 'cognitive', if the basic cognitive capacities for hybrid networking can be assumed to be in place. This is of course not to say that work on later prehistory can *not* be 'cognitive'. On the contrary, given the increasing recognition of the role of socio-cultural and developmental processes in cognition, work in later periods also offers significant potential for examining inter-cultural differences in cognitive styles in the past.

For example, one area of increasing attention from cognitive archaeologists is the cognitive implications of the adoption of increasingly sedentary and ultimately agricultural lifeways in the Epipalaeolithic and early Neolithic. Network approaches are increasingly demonstrating their worth in this area, documenting the processes via which some cultures became increasingly entangled in hybrid networks (Hodder 2018, 2017, 2011; Hodder and Mol 2016; Watkins 2016, 2004a, 2004b; Coward 2010). The ever-more complex interdependencies entrained by these developments, it is argued, ultimately ushered in the massively, globally interconnected world of today, with all its many unforeseen consequences.

Network analysis in these later periods is also of course potentially of considerable interest to cognitive archaeologists where methods and themes are valid for more explicitly 'cognitive' applications. Hence in the brief review below I cite a number of non-'cognitive' studies, including from later periods, where they have cognitive implications and/or where particular methodological developments may be relevant to cognitive applications.

Networks in practice

At its most basic, a network is simply a group of entities (or 'nodes'), some of which are connected in some way via links ('edges'). In Social Network Analysis (SNA), a major influence on archaeological applications of network analysis more common to the social sciences and especially sociology, nodes are usually individuals. These are linked by edges or connections where nodes/individuals have social relationships of different kinds, e.g. family ties, friendships, co-workers, gift-givers and gift receipt, political support (Borgatti et al. 2002; Wasserman and Faust 1994). Such links are often documented by self-report, or through empirical data such as measures of frequency and/or duration of interactions or proximity (Roberts and Dunbar 2011; Migliano et al. 2020; Üsküplü et al. 2020).

However, archaeologists do not typically access individuals in the archaeological record. Nor can we observe, or ask our subjects about, their social relationships with others. Thus in practice, most formal quantitative applications of network methods to archaeological data use archaeological sites, or phases of a site, as the 'nodes' of the network. To reconstruct links, measures of material culture similarity are interpreted as measures of the existence and potentially also the strength of connections between the communities based there. Spatial/geographic data such as distance or travel time have also been used, at both the regional (Coward 2013; Brughmans et al. 2014, 2015) and, where excavations have been sufficiently extensive, intra-site scales (Mazzucato 2019; Hodder and Mol 2016; Mol et al. 2015). In addition, biodistance data including aDNA (Terrell 2010a; Lulewicz and Coker

2018) and, for historical periods, textual and epigraphic data (Collar 2013; Graham 2014), have also been used to reconstruct connections between nodes.

Such proxies clearly provide a rather different perspective on social relationships to those documented by SNA. However even in the social sciences network analysis routinely uses measures of trade, transport etc. to reconstruct edges between nodes, especially where those nodes represent social entities at larger scales than the individual, such as nation states (Petridis et al. 2020; Knoke and Yang 2019; Smith et al. 2019; Choi et al. 2006; Smith and White 1992). Ethnoarchaeological surveys of material culture inventories also support the theoretical assumption that more frequent interactions between individuals or communities can perhaps be assumed to result in more shared types of material culture, and hence vice versa (e.g. Hodder 1982, 1979, 1977). Recent empirical work also suggests that archaeological distribution data is likely to be very valid for reconstructing some elements of social systems (Ladefoged et al. 2019).

Clearly, however, the choice of proxy requires careful consideration. Ethnoarchaeological work suggests that patterns of distribution of material culture vary depending on the objects themselves and on the ways in which they are enmeshed in different socio-economic processes, e.g. whether objects are participants in personal exchange, formalized 'gift' circulation, transactional market trade (Ruth et al. 1999; Gosden 1985). In other cases, material similarities between sites may be the result of observation or even hearsay, rather than direct exchange of the objects involved (Coward 2010). It remains unclear how such variation in socio-material interactions might affect the archaeological record and/or be identified or incorporated in network analysis (though see e.g. Fuentes et al. 2019; Mills et al. 2013a). Network methods might offer a potentially valuable means of exploring such variability in exchange contexts and socialities in the past, likely via 'thick descriptions' of the materials involved drawn from ethnographic analogy (e.g. Hodder and Mol 2016). Given the integral role such interactions play in cognition (figure 1), such work has significant potential for informing on processes of cognitive evolution in early humans and other hominins, and on the ongoing effects of socio-economic changes among later human populations.

Specific decisions about analysis will vary according to datasets, research objectives and the scope of the project. Analysts may choose to focus on a limited range, or even just one type, of material culture, the main examples including art (Gravel-Miguel 2017; Gravel-Miguel and Wren 2018 and references therein), raw material sources, for example of obsidian (Ladefoged et al. 2019; Golitko and Feinman 2015) and ceramics (Phillips and Gjesfjeld 2013), though other proxies have also been used (Langley and Street 2013; Lefebvre et al. 2021; Mizoguchi 2009, 2013). Alternatively, a range of different kinds of material culture may be used in combination (e.g. Blake 2014; Coward 2010). Analysts also need to decide how much information should be included in those edges, and indeed *when* an edge should be inferred at all. *Directed* edges specify their source and endpoint such that a connection from *a* to *b* need not imply a connection from *b* to *a*, although where such directionality is relevant specifically phylogenetic methods using an outgroup to identify an origin point may be more appropriate (e.g. Lyons-Weiler et al. 1998). *Valued* edges are not simply present/absent but incorporate information on the inferred strength of a connection between entities based on quantitative measures of similarity. Often, particularly where networks are very dense, a statistical threshold is chosen below which potential connections are discounted in order to reduce the ratio of noise to signal and thereby focus analysis on the most salient links (e.g.

Golitko and Feinman 2015; Gravel-Miguel 2016; Mills et al. 2013a; Mills et al. 2013b; Peeples and Roberts 2013; Terrell 2010b).

In any case, the major benefit of applying formal network methods in this way is that once a network or networks have been constructed, a robust and mature array of methods are available for analysis. Typically network analysts analysing social (or perhaps more accurately in the case of archaeologists, socio-material) networks might be interested in a range of measures (see table 1 for a brief summary). The mathematics behind these measures are often relatively intuitive and multiple social network analysis software packages are available for performing the analysis, many of which are open source (e.g. Gephi; Visone; UCINET; Pajek; Cytoscape; Node XL; packages in *R*, including igraph and statnet). A range of well-designed tutorials and discussions of the concepts behind the key analytical techniques are also readily available, which translate well to archaeological applications (e.g. Borgatti et al. 2002).

TABLE 1 ABOUT HERE

However, while the connectivity, density etc. of an individual network may well be of interest, in order to address questions about evolutionary variability in such networks, multiple such networks need to be reconstructed and compared. Cognitive archaeology is often interested, for example, in comparing the archaeological records created by different biological species, on the basis that disparities may imply evolutionary differences in cognition. A key benefit of network concepts specifically for such evolutionary applications is the fact that they provide an empirical, 'bottom up' style of analysis. Such methods therefore offer a valuable opportunity to test theories about differences in cognitive ability and style between species and populations, rather than assume them *a priori* (Gravel-Miguel and Coward, in press).

Comparing networks to identify evolutionary change over time

Network concepts thus offer a valuable corrective to the tendency for cognitive archaeology and anthropology to assume evolutionary, species-based differences in cognition. For example, the very different fates of *Homo sapiens* and other apparently very similar large-brained hominin species, most notably including *Homo neanderthalensis* have often been explained in terms of differences in our cognitive capacities. Debate continues as to whether such hypothetically distinct cognitive traits are seen as appearing very quickly and recently (in evolutionary terms; e.g. Klein 2008), or whether they have a longer and more gradual evolutionary history dating back to the earliest African origins of *Homo sapiens* (McBrearty and Brooks 2000). In any case, recent work has clearly demonstrated that *Homo neanderthalensis* and *Homo sapiens* were sufficiently closely related to interbreed (Villanea and Schraiber 2019), and also produced increasing evidence of complex behaviours implying advanced cognitive capacities among *Homo neanderthalensis* populations (e.g. Hoffmann et al. 2018a, 2018b). Such revelations have increasingly emphasised the long-recognised problem, particularly acute for cognitive archaeology and anthropology, of the potential gulf between cognitive capacity (what a species may be capable of) – and expressed cognitive style. Increasing recognition of the shortcomings of 'minimal capacity inferences' (Killin and Pain 2021) has focused attention instead on *contextual,* network-based explanations for differences in cognitive style detectable in the archaeological record. While cognitive differences between species are certainly known, developmental processes are also important (Coward and Howard-Jones 2021) and can result in considerable inter- and intra-cultural variation in cognition (Henrich et al. 2010), and the relationship between ontogeny and phylogeny is of course complex (Boyd and Richerson 2005, 1996; Potts 2013).

Thus much recent work in this area emphasises the bio-cultural nature of cognition, and the significant role played by socio-ecological and demographic context over (or perhaps more accurately, alongside) species boundaries for explaining any remaining differences in species' archaeological records (see references in Nowell 2010, 438; Henshilwood and Marean 2003). In combination with the selective pressures posed by periods of intense ecosystemic pressure on resources (e.g. Premo 2012; Powell et al. 2009; Ambrose 1998, though see also Yost et al. 2018; Gamble 1982), significant factors might include group and effective population size, population density, mobility, and the connectivity among individuals and groups. Indeed, inter-species interactions and networking have also recently been highlighted as driving rapid cultural change at the time (Carja and Creanza 2019; Creanza et al. 2017). It has thus become increasingly clear that hypotheses about genotypically-constrained differences in cognition between hominin species or populations, or indeed between cultural taxonomic units over time, need to be tested, not assumed. Network perspectives, being empirical, 'bottom-up' analytical methods that start from the data, offer invaluable methods for doing this.

Comparison of networks across species and/or over evolutionary timescales thus offers considerable potential for understanding long-term evolutionary processes. However as always, some pitfalls must also be acknowledged. While at one end of the scale, the Southwest Social Networks Project, working in the much more recent period of the prehispanic Southwest of the US, was able to compare sequential time slices of just ~50-years (Borck et al. 2015; Mills et al. 2013b; Mills et al. 2015; Mills 2017; Mills et al. 2018), Coward (2010) was restricted to time-slices of 1000 years in the Epipalaeolithic and early Neolithic of the Near East. More typically, especially in the Palaeolithic, limited numbers or even just a couple of pre-identified material 'culture' phases are compared, each of which may last hundreds, thousands or even tens of thousands of years (e.g. Gjesfjeld and Phillips 2013; Mizoguchi 2009; Rivero and Sauvet 2014). Not only do such timescales conflate multiple generations and processes of cultural transmission, but the use of pre-existing cultural (and indeed to a certain extent biological) taxonomies as a basis for comparison runs the risk of circular arguments. Nevertheless, as long as interpretation is sensitive to the scale of analysis, such comparison may be sufficient to identify gross differences between the networks of different temporal – and potentially biological – populations.

However, the problem of taphonomy must also be acknowledged. Destructive taphonomic processes are of course more pronounced at greater time depths, and this impact more substantially on the Palaeolithic than in later periods. Reconstructions of networks that rely on material culture are inevitably constrained by the low population densities and high mobility that characterised much of the period, as such a low-resolution archaeological record of course translates into very sparse reconstructed networks. Certainly sparse and missing data poses considerable problems for network analysis. However, network science does offer an increasingly broad range of methods for assessing and mitigating the impact of missing data (e.g. Bevan and Wilson 2013; Groenhuijzen and Verhagen 2016; Tsirogiannis and Tsirogiannis 2016). Most commonly, varying the thresholds of similarity at which 'edges' are reconstructed as connecting nodes (Peeples and Roberts 2013), and stress-testing empirical networks by the random removal of nodes and/or edges (Gjesfjeld 2015) provide sound methods for exploring the robustness of a reconstructed network. Such methods essentially bootstrap reconstructed networks to provide a measure of statistical reliability; where reconstructed networks retain their structure in the face of sizeable perturbations to the arrangement of nodes and edges, we can have more confidence that the network structures are ‘real’. Bayesian approaches also offer potential (Collins-Elliott 2017). In addition, modelling approaches can be used to better understand the effects taphonomic processes have on network formation (Davies et al. 2015; they can also of course inform on social, cultural and ecological processes, see below).

The perennial taphonomic challenges of Palaeolithic datasets are further exacerbated for comparative network analysis in particular because they are not uniform throughout the period. Where research covers long time periods, for example spanning parts of the Middle and Upper Palaeolithic to compare networks associated with *Homo neanderthalensis* and *Homo sapiens*, this differential impact of taphonomic processes becomes an increasingly significant confounding variable. There are also genuine patterns of socio-economic variability over time as well as between cultures that are not simply due to taphonomic variation. For example, later periods from the Upper Palaeolithic on, and among sedentary and/or farming communities (e.g. papers in Kent 1990) often yield much more expansive ranges of material culture. In part, of course, this is part of what needs investigating – *why* do some cultures incorporate more material culture into their networks than others? However, it also highlights the difficulties inherent in relying on material proxies for social processes, as earlier networks are likely to automatically look much less ‘complex’ than later ones. Gravel-Miguel and Coward (In press.) have recently suggested that one way of circumventing this problem could be to focus more research on the analysis of lithic networks, given that these provide a line of evidence that is arguably more ubiquitous and consistent (and better studied) throughout the Palaeolithic (and indeed later). They do however highlight a need to focus less on etic cultural taxonomy in favour of more quantitative data, perhaps morphometrics. Such approaches may also therefore help reassess the validity of those cultural taxonomic units themselves (e.g. Roberts et al. 2012).

Comparison of different networks also presents analytical problems for network methods. Typically, where applications of network methods in other disciplines aim to reconstruct social networks, one network, representing a single ‘point’ in time is reconstructed and studied. Where network change over time is the focus of study, typically the comparison is between changing configurations of the same network over time – i.e., same nodes, different edges. However archaeologically, comparison of networks across different time periods may comprise completely different nodes, and different *numbers* of nodes, as well as different edges (e.g. Middle vs Upper Palaeolithic sites, let alone Palaeolithic vs Iron Age sites). Since the number of nodes in a network can affect its quantitative properties in subtle ways (Fründ et al. 2016; Dormann et al. 2009), comparisons of unequal networks can thus potentially be problematic for traditional network methods, especially where samples are already biased, e.g. by variable taphonomic effects.

An alternative approach is simply to not compare empirical networks directly. Instead, simulation methods provide potentially valuable methods of hypothesis-testing using network approaches. One set of methods gaining traction in archaeological applications is the use of Exponential Random Graph Models (ERGMs) (Amati et al. 2020; Brughmans et al. 2014, 2015), which allow analysts to simulate the transformations a network will undergo according to specific hypotheses, then test the empirical networks against those simulated networks.

Despite the many confounding effects that must be ruled out, change over time in sequential networks is often considered evidence for long-term evolutionary adaptation, particularly when it is observed between groups hypothesised to be distinct biological species. The vastly increased scale of the networks that *Homo sapiens* can construct and maintain may be a key element of our global success as a species. However, size isn't everything: *variability* across populations and in different ecological and cultural contexts is vital for 'tuning' socio-economic strategies to environmental conditions, and networks are increasingly recognised as a key mechanism whereby populations are able to realize that flexibility. There is, however, no simple equation in which change over time is always biological, and spatial/ecosystemic variability is also developmental/cultural. Clearly, behavioural flexibility in the face of ecosystemic variability also has evolutionary cognitive foundations. Understanding how networks differ between contemporary populations of the same species, as well as between species and through time, is also therefore important for cognitive archaeology.

Comparing networks to understand socio-economic variability across space

Taphonomic bias in the Palaeolithic in particular presents further problems here. Not only has much artefactual data long since decayed, but most sites are heavily time-averaged palimpsest aggregations, biased towards caves and rockshelters over open air sites. Furthermore, where cultures pursued mobile hunter-gatherer lifeways, as in much of the Palaeolithic and indeed later, networks cannot be assumed to be discrete, bounded or emic social entities. Instead they potentially represent thousands (or tens or even hundreds of thousands) of years of sporadic accumulation by numerous different configurations of individuals and groups practising fission-fusion residential mobility over many generations (Gravel-Miguel & Coward, in press).

Such cross-cultural variability in demographics, mobility strategies and material practices clearly presents challenges for network analysis attempting to compare networks across space as well as through time. However, by the same token such methods offer valuable opportunities to explicitly study processes such as group formation, fission-fusion, risk buffering and social storage, in variable socio-ecological contexts (Bird et al. 2019; Coward 2016, 2013, 2010; Grove et al. 2012; Layton and O'Hara 2010). Much work espousing a 'network' perspective has thus been directed at examining the scale of connectivity and mobility of social groups by reconstructing the spatiality of human activity. Such work often takes data on the movement of raw materials and objects as a proxy for size of networks or 'territories' and the scale of mobility of groups (Gamble et al. 2011; Grove 2010; Moutsiou 2014; Pearce and Moutsiou 2014; though see e.g. Barona 2021). Ethnographic and culture ecology data are often used to calibrate empirical findings, in order to better understand how networks, mobility and group size are deployed as adaptations to new ecosystems and environmental conditions encountered due to climate variability or population dispersal/expansion (e.g. Wobst 1974; Gamble 1999; Kelly 2013; Binford 2001; Fuentes et al. 2019).

One such area of work relatively common in cognitive and Palaeolithic archaeology focuses particularly on networks of art and 'symbolic' objects (e.g. Álvarez-Fernandez 2009; Aubry et al. 2016; Buisson et al. 1996; Fritz et al. 2007; Fuentes et al. 2019; Gravel-Miguel 2017; Rivero and Sauvet 2014; and further references in Gravel-Miguel 2016, 2017). Aside from the cognitive implications of such objects in and of themselves, a rich ethnographic literature on symbolic communication networks links the 'use' of art and symbolism to the construction of multiscalar social identities. Such processes of identity construction vary in response to demographic selective pressures such as population pressure (e.g. Conkey 1980, 1982, 1995) at one end of the scale, and the long-distance maintenance of social networks in contexts of low population densities at the other (Gamble 1982, 1983). A particular benefit of network analysis for addressing such questions is that it allows for the consideration of multiscalar social processes, given that in network analysis the entities identified as 'nodes' can be almost anything. In archaeological analyses sites/phases are most commonly used as nodes. However, larger and smaller scales are of analysis are possible. At the one end of the scale, international and inter-regional, global-scale analyses of the relationships between larger political entities are also not uncommon in the social sciences. At the other, where preservation and scale of excavation allows, intra-site network analyses, e.g. between individual households (Mazzucato 2019) and burials (Wang and Marwick 2021; Mol et al. 2015; Sosna et al, 2012) has provided valuable information on how internal social interactions articulate with larger-scale processes. Such multiscalar work is of course challenging archaeologically and particularly in the Palaeolithic. However, it offers valuable opportunities to study the ways in which how intra- and inter-group social processes interrelate, and thus potentially also how cultures increase in scale and become socially 'complex'.

Further detail has been supplied in some of these studies by integrating other lines of evidence. These include faunal (Lefebvre et al. 2021) and lithic (Borić and Christiani 2016) data, GIS analysis of topography to better understand patterns of mobility and explore local catchments and routeways (e.g. Coward 2005; Gravel-Miguel and Wren 2018; Mackie 2001), and other demographic data such as site probability distributions (e.g. Maier 2017, see Crema and Bevan 2021 for further discussion). Such work does not always use explicitly formal network analysis, but alongside network approaches it potentially allows for more detailed considerations of the specific socio-materialities of hybrid networks. In addition, a range of other material culture studies focusing on the Palaeolithic and beyond have also accumulated detailed information on distributional data (e.g. Bahn 1982; Hours et al. 1994; Kozlowski and Aurenche 2005; Vanhaeren and d'Errico 2006), often used to formulate hypotheses about trade/exchange networks and connectivity between groups and regions. Such datasets also allow for potential applications of more formal social network approaches to formally test such hypotheses.

Further opportunities are afforded by the observation that in network analysis, nodes do not have to be 'human'. Given the hybrid nature of human networks and the agency of other-than-human elements of those networks discussed above, it is perhaps surprising that few network applications in archaeology have explored the considerable scope for integrating objects as nodes in what are known as multi-mode networks. These are networks which utilise different *types* of nodes, typically (in archaeological applications) sites/phases and different forms of material culture. Multi-mode networks are easily generated during the early stages of analysis, but typically analysts would proceed to use the same data to generate an affiliation network containing only those nodes representing sites/phases. The material culture data would thus be subsumed into the edges between those nodes. However, multi-mode networks can be extremely interesting and informative in and of themselves. Furthermore, in some cases there may also be merit in generating affiliation networks in which the nodes are *not* the human component but the more-than-human component, i.e. networks in which material culture nodes are viewed as connected via their common appearance at different sites/phases rather than vice versa. Interesting discussions and examples of such approaches can be seen in Lucas & Robb 2021; Lulewicz and Coker 2018; Blair 2015; Brughmans and Poblome 2016; Graham and Weingart 2015; Mills et al. 2013b; Knappett et al. 2011; Phillips 2011. This is an area with considerable potential for investigating the evolution of such hybrid networks and hence the cognitive abilities underpinning them.

In addition, the large body of work on simulation, other mathematical, and phylogenetic models is also worthy of mention here. These do not necessarily produce formal networks, but nevertheless provide valuable parallel lines of evidence on temporal trends in social connectivity and their implications. As noted above, modelling approaches including Agent-Based Models (ABM) can also be used to generate theoretical networks derived from explicit assumptions, against which empirical networks can then be compared. One common null model is simply a geographical network in which geolocated nodes are 'connected' by edges of weights inverse to their geographical or cost distance from one another. Empirical networks can then be compared to this network to determine whether the observed archaeological networks can be explained as simply the result of geographical 'friction', the energetic cost of interaction (e.g. Coward 2013). More complex hypotheses about social processes creating a single network, or driving change across multiple sequential networks, can also be explicitly modelled using a variety of approaches including gravity models (as explored by Knappett et al. for the Bronze Age Aegean; Evans et al. 2008; Knappett et al. 2008, 2011) and ABM (see Brughmans and Poblome 2016; Graham 2006; Graham and Weingart 2015; Gravel-Miguel and Coward In press.; Ossa 2013; Romanowska et al. 2017; Watts and Ossa 2016; Wren et al. 2019; see e.g. Evans 2016; Rivers 2016 for useful reviews of many models). ABMs in particular are already increasingly being used to study inter-species contacts and to infer demographic variability in Palaeolithic datasets (Barton et al. 2011; Greenbaum et al. 2019; Creanza et al. 2017; Perreault and Brantingham 2011).

Such models, especially where they explicitly incorporate material culture, often incorporate concepts developed in the cultural transmission/cultural evolution literature. Much of this is already at least network-adjacent; the existence of social networks, both in humans and in a variety of other species, is assumed, and the implications of different network structures for the innovation and dissemination of cultural traits explicitly foregrounded (Cantor and Whitehead 2013; Whiten 2017). Such work also offers a number of useful mathematical models for cultural transmission which could be applied alongside empirical, archaeological networks for hypothesis testing (Bentley and Ormerod 2012; Boyd and Richerson 2005; Derex et al. 2018; Grove 2016, 2018; Powell et al. 2010; Dodds and Watts 2005; Eerkens and Lipo 2005; Kandler and Caccioli 2016; Watts 2002). Phylogenetic approaches in particular differ from network analysis mainly in their directionality, thus ensuring considerable overlap in methods (Coward et al. 2008; d'Huy 2013; O'Brien et al. 2001; Straffon 2019) and offering potential for complementary work in this area.

Finally, while some tensions remain between proponents of formal and heuristic approaches, I would contend that both offer valuable theoretical and methodological tools for exploring hybrid networks in the past. Crossovers between heuristic/conceptual and formal approaches are also increasingly being developed, and include work by Knappett (2005, 2011, 2016), Van Oyen's 'work-nets' (2016), Hodder's 'tanglegrams' and Hodder and Mol's 'chainworks' (Hodder and Mol 2016), Pálsson's lineaology (2021), and Ingold's meshworks (2011). Such work demonstrates clearly the fact that the fundamental underlying principles can be applied in a rage of ways; researchers should thus consider the range of options available to them with reference to their data and research questions.

Conclusion

This chapter has firstly laid out the theoretical underpinnings of the importance of network approaches to cognitive archaeology, illustrated in figure 1. State of the art '4e' approaches in the cognitive sciences more generally provide firm empirical and theoretical foundations for arguing that things (in the broadest possible sense) form part of cognitive processes. Hence cognitive evolution is subject to selective pressure from human engagement with physical/material as well as social environments: landscapes and ecosystems, objects and persons (both conspecifics and members of other species).

These things, persons and places are further combined into networks because things are connected to people and to places, but also to one another. As material culture is the product of human social interactions, and by virtue of their circulation around people and places, things acquire biographies that can make them 'persons' in their own right. Things thus create, realise, and maintain connections between people and places. Furthermore, those material connections also then act to structure and guide further social interaction. The social nature and agency of things thus has adaptive consequences. The socio-material networks in which humans are enmeshed are not just shaped by cognition, but then go on to create their own selective pressures, both phylogenetically and ontogenetically. Development of cognitive processes in highly plastic infant brains is scaffolded by experience, and in *Homo sapiens*, this experience occurs within and as part of material and social as well as physical/natural environments.

The second part of the chapter builds on this theoretical foundation to highlight the potential of network approaches for specifically cognitive applications. The examples of questions and methods discussed here are not intended to be exhaustive but to demonstrate some of the general areas that can be addressed using network methods. Some of the challenges and pitfalls network analysts face are discussed, whether they use heuristic/conceptual or more formal approaches, but also the key benefits and potential of network techniques. A major benefit is the availability of (more or less) off-the-peg quantitative analytical methods for formal networks. Caution is always merited in their application to archaeological and especially Palaeolithic data in some instances. However, methods more specific to archaeological applications are continually being developed and refined. The 'bottom up' perspective of network approaches is another clear benefit which allows the rigorous testing of hypotheses about inter-species and inter-cultural differences. Such potential is particularly powerful given the potential for multiscalar applications of network methods, which can inform hypotheses about the comparative development of intra- and inter-societal social complexity. And finally, network methods allow us to de-centre the human (or hominin) and examine the ways in which we and other entities mutually 'fit' into the broader, co-evolutionary and hybrid communities which shaped our evolution. Ultimately, I argue, the ‘network’ concept is no fad but here to stay, a vital tool in furthering our understanding of the unique nature of human cognition.

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