Palaeolithic Social Networks and Behavioural Modernity

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Abstract: In this chapter, we discuss some of the challenges researchers face when using formal analysis methods to study Palaeolithic social networks. We also present alternative and complementary methods that can mitigate those challenges; in particular, we argue that agent-based models are useful tools to test formal methods and explore network questions that cannot be answered solely from the archaeological record. We use such a model to show how different social behaviours are reflected in material networks, and to evaluate the accuracy of a popular method to reconstruct Palaeolithic networks. Finally, we identify a number of fruitful areas that could be targeted by Palaeolithic network analysts, as well as questions for which social network analysis techniques may be particularly well suited.

Keywords: social networks, Palaeolithic, palimpsests, taphonomy, hominins, hunter-gatherers, agent-based model.

Introduction

Writing about Palaeolithic social networks is simultaneously easy and challenging because few formal network studies focus on this time period. This is surprising, because multiple studies have demonstrated that the concept of culture – and thus cultural transmission, an inherently 'networked' process – is at the root of key milestones in modern human evolution (Boyd and Richerson 1985, 2005; McBrearty and Brooks 2000). Moreover, some have argued that increases in inter-population connectivity may have led to the 'behavioural modernity' that increased modern humans' resilience to the ecosystemic changes that probably contributed to other hominins' extinctions (Cullen 1996; Greenbaum et al. 2019; Stiner and Kuhn 2006; Migliano et al. 2020). With this in mind, one would think that documenting how social interactions changed throughout the Palaeolithic should be central to research on human origins. Why, therefore, are Palaeolithic studies of social networks still so sparse?

In this chapter, we present some of the challenges that explain why formal network methods *alone* are difficult to apply to the Palaeolithic and thus, why such studies are still too few. These main challenges are: 1. the fact that we cannot assume that the non-*sapiens* hominins who created most of the Palaeolithic record shared the modern human behavioural capacities linked to social network formation; 2. the enormous time depth and resulting destructive effect of cumulative taphonomic processes on the Palaeolithic record, which creates palimpsests that are difficult to compare, and; 3. the nature of prehistoric hunter-gatherer lifeways, which typically left insufficient archaeological traces to reconstruct cultural interaction from material culture similarities. To mitigate these challenges, we suggest that researchers could combine formal network methods with a variety of new alternative and complementary approaches. In particular, we argue that agent-based models (ABM) offer enormous potential to test social network reconstruction methods and explore network questions that cannot be answered solely from the archaeological record. By way of illustration, we present such an ABM that demonstrates why archaeologists should use caution when interpreting the archaeological networks reconstructed from artefact similarities, especially for societies with low rates of artefact production and discard, as inferred for the Palaeolithic.

Problems and solutions to studying Palaeolithic social networks

Formal network analysis techniques – i.e. analyses that create sets of nodes connected by edges – have proven extremely useful analytical tools in archaeology, but remain rare in Palaeolithic studies. Artefact similarities among sites and regions have been used to explore the social relations of Palaeolithic populations (Rivero and Sauvet 2014; Buisson et al. 1996; Fritz et al. 2007) , but few have reconstructed formal nodes-and-edges networks (Gravel-Miguel 2017). In this section, we summarise some of the challenges that explain this discrepancy, but argue that they do not altogether invalidate the use of these techniques in this period.

Applying human experience concepts to species other than *Homo sapiens*

Much of the Palaeolithic was populated by species other than *Homo sapiens*, and thus we cannot uncritically assume that those hominins practiced the sociality, cultural transmission, and engagement with material culture that underpin the use of social network analysis in later periods.

However, conversely, we should not automatically assume that non-*sapiens* hominins *lacked* our cognitive facility and drive for material engagement. For example, the artistic/aesthetic capacities of Neanderthals, once assumed to be minimal, are currently undergoing a significant re-evaluation (e.g. Hoffmann et al. 2018). Moreover, recent research increasingly highlights the evolutionary importance of social structure and connectivity over biological boundaries. Those studies show that population density, mobility, encounter rate, and connectivity may have been more important than cognition to maintain and transmit complex cultural traditions (Grove 2016, 2018; Riede 2008; Shennan 2001). 'Behavioural modernity' may thus be less biological and more structural – perhaps even partly driven by inter-species contact, for example between Neanderthals and modern humans (Creanza et al. 2017; Carja and Creanza 2019). Such work highlights the potential of social network methods to better understand behavioural variability not just within but also between species.

However, since Palaeolithic hominins left sparse archaeologically visible material culture, we argue that, to analyse their networks, archaeologists should refer to research focusing on other social mammals such as chimpanzees (Whiten 2017) and cetaceans (Cantor and Whitehead 2013) that provide examples of social networks reconstructed without material culture. One could also turn to the body of literature on the emergence and evolution of culture. This work, which relies heavily on mathematical models, assumes the existence of cultural transmission and social networks as fundamental to human interaction and explicitly models the implications of such interactions without quantifying social networks *per se* (e.g. Bentley and Ormerod 2012; Boyd and Richerson 2005; Derex et al. 2018; Grove 2016, 2018; Powell et al. 2009). While this work has traditionally focused on demographic factors as drivers in innovation and cultural transmission, recent research focused on how cultural transmission and social network characteristics impact innovation and diffusion (Derex et al. 2018; Dodds and Watts 2005;

Eerkens and Lipo 2007; Kandler and Caccioli 2016; Watts 2002). Such models have considerable potential for exploring Palaeolithic social structure, interconnectivity, and the adaptiveness of variable social structures in changing ecological conditions, which could help test assumptions regarding the social organization of different hominins.

Limitations of Palaeolithic material culture

Formal methods to reconstruct social networks often rely on mapping inter-site assemblage similarities as a proxy for social interaction (Coward 2010; Graham and Weingart 2015). However, the Palaeolithic is notable for the sparseness of its archaeological record. Foraging, the major mode of subsistence for most of the period, entails mobile groups living at low population densities (Bird et al. 2019; Kelly 2013). These typically have less ‘stuff’ than settled groups (Coward in prep; Shott 1986; Testart et al. 1982), and what they do have is often not designed for longevity (and hence archaeological survival).

Taphonomic processes have further impoverished this material record, and unevenly so, with a more severe impact on earlier periods and on artefacts made from organic materials. The stone tools and animal bones that did survive are informative in many ways but using them to reconstruct networks inevitably provides only a partial, biased reflection of past social relations. However, it should be noted that some Holocene social network analyses also focus on a restricted range of artefact types (Golitko and Feinman 2015 [obsidian]; Phillips and Gjesfjeld 2013 [ceramic raw material]; Östborn and Gerding 2014 [Roman bricks]) and are nevertheless highly informative. With this in mind, we argue that the potential of lithic artefacts to inform on Palaeolithic social interaction (Tostevin 2012) should be revisited.

To date, most Upper Palaeolithic social network studies have focused on similarities in ‘symbolic’ objects (e.g. portable art objects and ornaments), rather than lithics (e.g. Buisson et al. 1996; Schwendler 2012). This may be because lithics’ utilitarian morphological constraints and restricted *chaînes opératoires* reduce the range of stylistic markers that may reflect social contact (Barton 1997; Conkey and Redman 1978; Eren et al. 2018), and because modern foraging communities often exchange ‘symbolic’ objects to solidify alliances (Wiessner 1982). However, as art only appears ~40kya and remains sparse until ~20kya, the restricted time-depth of networks reconstructed from ‘symbolic’ objects means that they cannot easily be compared over the *long durée* in the way that networks derived from more ubiquitous lithics could. In addition, ‘symbolic’ objects are not immune to the poor excavation practices of early 20th century research, which likely ignored artefacts now known to be markers of social contacts (Gravel-Miguel et al. 2017). Even for the most recent period of the Palaeolithic, the relevant ‘symbolic’ record still comprises small samples whose consistency across sites is difficult to establish, making it difficult to compare ‘symbolic’ assemblages between sites to recreate Palaeolithic social networks. Furthermore, the ABM model explored below suggests that consistency in the kind(s) of artefacts used to reconstruct social networks is important, as different rates of production and discard generate assemblages that differ considerably in the extent to which it is possible to reconstruct from them the underlying social network of which they were a part. Therefore, while ‘symbolic’ objects may seem to offer more scope for reconstructing social networks, a sounder strategy to examine long-term trends in social networks might be to base reconstructions on the more ubiquitous and consistent lithic evidence, or a combination of both.

When relying on ‘symbolic’ objects, we suggest that a heuristic approach to reconstructing networks might help circumvent the issue of low sample sizes in individual artefact types. For example, using multiple artefact types to establish links between contemporaneous sites could provide a more general overview of shared cultural practices (e.g. Bahn 1982; Coward 2010). This approach is challenging because each form of evidence is vulnerable to different taphonomic processes, but done carefully, it should facilitate the identification of general patterns across networks and allow other questions to be addressed. Moreover, such networks could also inform on different kinds of social interaction, as reflected by different artefact types (Coward 2010), or help test cultural taxonomies (e.g. Reynolds and Riede 2019).

Alternatives to formal network analytical methods can also be useful. Mathematical, agent-based, and phylogenetic models do not necessarily produce formal node-and-edges networks but can nevertheless provide valuable information on temporal trends in social connectivity and its ramifications. For example, ABM have been used to evaluate the mutual effect of direct contacts between Neanderthals and modern humans (Barton et al. 2011; Greenbaum et al. 2019), and to infer changes in network densities and cultural transmission patterns from rates of cultural innovations seen in archaeological assemblages (Creanza et al. 2017; Perreault and Brantingham 2011). Alternatively, d’Huy (2013) used phylogenetic analyses of similarities in myths alongside genetic data to map cultural transmission without reference to material culture. Such approaches use trait similarities between entities and mathematical analyses in ways similar to social networks methods, and are especially valuable for the long time-depths of Palaeolithic datasets in which evolutionary trends are more readily apparent.

Low resolution temporal and geographical datasets

The cumulative effects of taphonomy over the enormous time-depth of the Palaeolithic period and its inexact dating, coupled with Palaeolithic populations' low densities and limited reliance on material culture, often results in datasets whose resolution is both low and uneven, with older assemblages more time-averaged than younger ones (Perreault 2012). This makes it difficult to establish a sufficient number of even *roughly* contemporaneous sites to act as nodes linked into informative networks. While analyses have been able to model networks of ~50-year durations for more recent archaeological periods (Borck et al. 2015; Mills et al. 2013), time slices of ~1000-3000 years are more realistic for the Palaeolithic (Coward 2010; Rivero and Sauvet 2014). Such low resolution conflates hundreds of generations and reduces accuracy in the spatial distribution of cultural traits (Miller-Atkins and Premo 2018). Arguably, patterns seen at this low resolution reflect broad-scale evolutionary trends and may overlook shorter-term or local-scale heterogeneity in social and material practice reflecting variable 'solutions' (including 'unsuccessful' solutions that do not survive long enough to leave a strong signature in the archaeological record), potentially making temporal change look much more linear than it really is. Therefore, low resolution networks may be useful to answer broad-scale questions, but one should keep in mind that those cannot be used to infer social contact between specific individuals or even generations.

In addition to poor chronological resolution, poor *geographical* resolution also presents challenges. Taphonomy makes it difficult to identify meaningful and consistent 'nodes'. For example, many early 'sites' comprise palimpsest aggregations of materials derived from across the local landscape (see e.g. Schick and Toth 2006 re African Oldowan sites), while caves and rock shelters are over-represented in Palaeolithic archaeology in contrast to exposed open-air sites that were likely used more regularly, and thus may have contained sparse but important social network markers (Gravel-Miguel et al. in prep). Unfortunately, given the relational nature of social networks, any missing data can significantly bias the reconstructed networks and their interpretations, often in unpredictable ways (Kossinets 2006; Smith & Moody 2013).

Even simply identifying individual ‘nodes’ in a Palaeolithic archaeological network can be tricky. Many foragers practice fission-fusion strategies to map themselves onto variable ecosystems, making it difficult even for social anthropologists to determine what constitutes a meaningful ‘group’ (Layton and O’Hara 2010). High mobility also makes it notoriously difficult to determine archaeologically whether different sites represent different groups or repeated occupations by the same group. Nor is the determination of edges any simpler: distinguishing the material signatures of indirect, down-the-line trade (or cultural transmission) and direct procurement (or innovation) is a general problem for prehistoric applications of social network analysis, but one compounded for the Palaeolithic where rates of production and discard are usually low (see below).

To calibrate those ‘site-to-node’ expectations, Palaeolithic researchers can refer to ethnographic data on ranges and mobility patterns in comparable ecosystems, where they exist (e.g. Binford 2001; Kelly 2013), and isotopic studies, where geology and preservation conditions allow, to provide more direct insights into past group ‘territories’, the scale of mobility, and thus potential site contemporaneity and network boundaries. Recent methodological developments also provide new ways to mitigate some of the problems caused by poor resolution Palaeolithic datasets. For example, Gjesfjeld (2015) recommends stress-testing networks inferred directly from archaeological data by randomly removing nodes, edges, or both, to determine the robustness of the underlying trends and the networks' sensitivity to missing data.

ABM can also be used as an exploratory laboratory where archaeologists can control for many of the problems of real-world archaeological datasets enumerated here (Premo 2020). Complex systems can be generated based on parameters that mimic a variety of processes (taphonomic, social, cultural, and ecological), each of which can be controlled independently to understand their individual and combined impact on the overall system (Romanowska et al. 2019). Outputs can then be compared with the fragmentary and biased archaeological record to better understand the processes behind its formation; for example, modelled networks can be stress-tested to investigate the extent to which missing data reduce the accuracy of archaeological reconstructions, and hence allow archaeologists to understand the limitations of their datasets and interpretations (e.g. Davies et al. 2016).

While ABMs provide a suite of techniques distinct from social network analysis, their application to Palaeolithic and hunter-gatherer contexts have yielded exciting new insights which demonstrate the potential of combining the two (e.g. Graham and Weingart 2015; Romanowska et al. 2017; Wren et al. 2019). Here we use an ABM to show how different patterns of hominin behaviour are reflected in material networks, and to evaluate the accuracy of using artefact similarity between sites – perhaps the most common method of archaeological network analysis - to reconstruct Palaeolithic networks.

ABM case study:

Our model - written in NetLogo (Wilenski 1999) - uses simple assumptions to simulate cultural transmission and the production of archaeological objects within a network structure defined by the movement of agents among camps. This approach allows us to assess how changes in production and discard rates impact archaeologists' ability to reconstruct the network based on visits between camps. In particular, it allows the exploration of the effect of low production and discard rates associated with Palaeolithic societies (see discussion above) on the results of our network reconstructions. We summarize the model here; however, for more details, the reader should refer to the ODD protocol and the R code used for its analysis, available on the CoMSES.net repository at https://www.comses.net/codebase-release/ed04ffa8-6833-486b-b596-ebb78e0ff863/.

The model simulates two populations, equal in all other respects, but with dichotomous patterns of artefact production and discard, allowing us to focus on the impacts of those behaviors on the accuracy of our network reconstructions. One of these populations produces and discards culturally informed objects in low quantities – we call this the 'Palaeolithic' scenario, since Palaeolithic networks have often been studied using similarities between art objects, which are archaeologically scarce and thus inferred to have been produced and discarded in small quantities (e.g. Buisson et al. 1996; Rivero and Sauvet 2014). The other population produces and discards objects more frequently. For simplicity, we call this the 'Holocene' scenario, as Holocene networks are often reconstructed from decorated ceramics, which were produced – and thus presumably also discarded – in higher quantities than Palaeolithic art (Mills et al. 2013). We do, however, recognise that such a black-and-white distinction between Holocene and

Pleistocene groups is simplistic not just in terms of rates of production and discard but also in terms of other variables such as population size and density, mobility, social structure etc., as discussed above. Clearly some Holocene groups retained relatively low rates of production and discard, and/or also remained relatively mobile and retained foraging lifestyles etc.. Conversely, some Palaeolithic groups were relatively large and complex, pursued relatively settled lifestyles and produced considerable quantities of material goods. The model merely aims to present a simplified distinction between two highly generalized lifeways.

Model overview

A simulation follows 10 camps of 12 agents each - 6 travellers and 6 producers - who form social networks. At the beginning of a simulation, camps numbered 0-9 are randomly set on a flat landscape without real geographical characteristics. Potential alliances are randomly assigned between travellers and camps. To start, each traveller randomly chooses one of its allied camps to visit. As the simulation progresses, travellers use probabilities to choose which allied camp to visit based either on distance (i.e. often favouring the nearest camp), or on a desire to deepen already-created relationships (i.e. often favouring camps they have visited before). As they visit other camps, each traveller brings a producer with them.

The role of each producer is to produce artefacts, modelled as a set of ‘stylistic traits’, represented as integers. At the beginning of a simulation, each producer is assigned five such traits from a normal distribution centred around a value obtained from their camp’s number (0-9), thus representing a specific ‘style’ shared by all producers from a specific camp. Producers transfer cultural knowledge to one another at intervals chosen by the user. When a producer accompanies a traveller on a camp visit, they therefore have a certain probability of learning the ‘stylistic traits’ of the producers associated with that camp, which contributes to the widespread transmission of culture. Artefacts are discarded at frequencies controlled by the modeller, creating a proxy archaeological assemblage that can be analysed with formal social network techniques. At set intervals, the model calculates the Euclidean distance between all pairs of artefacts currently in use. The model creates artefact links (edges) between the camps of producers (nodes) who share statistically similar objects (artefacts with Euclidean distance below a statistically calculated threshold). At the end of a simulation, the model calculates two scores: the *network-score* calculates the ratio of inter-camp visits reflected in artefact links, and the *artefact-score* calculates the ratio of artefact links that represent inter-camp visits. Together, these two scores determine the degree to which simulated networks of direct contact can accurately be reconstructed from artefact similarities.

We ran the model with the variable settings presented in Table 1. Each combination was repeated 125 times, for a total of 2000 simulations, each run for 10,000 steps (values determined by preliminary analyses documented on CoMSES.net).

Table 1. Variable settings used for this research.

Variable	**Settings run**	**Meaning**
fitness?	True	Visits are based on previous visits
	False	Visits are based on distance
artefact-production	20	‘High producers’ learn from one another often (every 20 ticks)
	200	‘Low producers’ do not learn from one another often (every 200 ticks)

alliance-rate	3%	Producers go on visits often
	7%	Producers do not go on visits often
mode	Variable	Cultural transmission is done through a mix of conformism and prestige (see Eerkens and Lipo 2005)
alliance-output	200	'High producers' discard artefacts often (~ once every 200 ticks)
	1000	'Low producers' do not discard artefacts often (~ once every 1000 ticks)

Results

Model results suggest that archaeologists using stylistic similarities to reconstruct social networks face a trade-off between the accuracy of the network- and the artefact-scores, as these two display weak negative correlations (Spearman's $\rho = -0.20$ and -0.22 for 'Holocene' and 'Palaeolithic' respectively, p-value < 0.0001 for both). In other words, when artefact similarities correctly identify all inter-camp visits (high network-score), similar artefacts are also found between camps that were never in contact (low artefact-score). Data exploration shows that this is due in part to the indirect transmission of stylistic markers: e.g., when producers from camp *a* visit camp *b*, and then producers from camp *b* visit camp *c*, similarities between camps *a* and *c* can occur without direct contact between them. This inverse relationship is stronger when travellers favour camps based on previous interactions over distance (Table 2), suggesting that strong alliances lead to more indirect cultural transmission.

Table 2. How changing parameters impacts the average network- and artefact-scores. We tested the significance of the difference using non-parametric Wilcoxon two-sided tests on network-

*scores (skewed distribution); and Student's two-sided t-tests on artefact-scores (normal distribution). ***statistically significant difference, with p-value < 0.001. For all tests, the number of observations = 4000.*

Variable change	Changes in the mean (and 95% CI) of network score accuracy (estimate)	Changes in the mean (and 95% CI) of artefact score accuracy
Favouring nearby allies over already visited ones	-0.05*** CI: 0.04- - 0.05	+0.10*** CI: 0.09-0.11
Increasing artefact production rate	+0.04*** CI: 0.03-0.05	+0.10*** CI: 0.09-0.11
Increasing artefact discard rate	+0.05*** CI: 0.04-0.07	-0.06*** CI: -0.07- -0.06
Increasing visits' frequency	+ <0.01*** CI: -0.02-0.00	-0.07*** CI: -0.08- - 0.06
Increasing visits' length	+0.05*** CI: 0.04-0.06	-0.06*** CI: -0.07- -0.05

Changing the parameter settings of the model to produce the two scenarios discussed above shows that social networks reconstructed from stylistic similarities are less accurate for societies with low rates of artefact production and discard ('low producer' or 'Palaeolithic') than for those with high rates ('high producer' or 'Holocene') (Table 2 and Figure 1). Assuming perfectly preserved archaeological records, we could expect to accurately identify most inter-camp direct contacts of high-producers, with the significant caveat that many reconstructed links may connect camps that were never actually in contact. Conversely, in the alternative scenario of low artefact production and discard rates that best represents the Palaeolithic, researchers would be unlikely to identify all direct interactions even with a perfectly preserved archaeological record. In addition, they would also reconstruct many links that represent indirect rather than direct contacts.

[insert GravelMiguel_Coward_Fig1 here]

These show that there is no scenario that leads to perfect reconstructions of social networks through stylistic similarities. Therefore, we argue that archaeologists should use caution when they reconstruct networks from stylistic similarities, especially for populations or artefact types that have different rates of production and discard.

Prospects for the future:

Is it thus possible and advisable to conduct formal social network analyses in the Palaeolithic? We argue that, at least within the Upper Palaeolithic and perhaps also in earlier periods, network methods still hold considerable potential. Moreover, we think that some questions specific to the Palaeolithic can perhaps be answered *only* with social network methods, especially if archaeologists can draw from complementary alternative methods, including phylogenetic analysis, mathematical models of cultural transmission, and agent-based models.

Despite their relatively restricted temporal range and sample size, 'symbolic' artefacts such as ornaments and art objects offer potential for social network analysis. We suggest, however, that such networks should be recreated using *multiple* artefact types wherever possible, as the results of our ABM show that networks reconstructed from stylistic similarities of individual types of infrequently produced and discarded artefacts are often inaccurate. Relying on multiple artefact types would boost sample size and could offset variability in rates of production and discard across different types of material culture. The problems identified by our model could be further offset by calculating coefficient of similarities between contemporaneous sites based on the shared *frequencies* of different artefact types (see Mills et al. 2013) rather than by using simple presence/absence of stylistic traits within types and applying ‘thresholds’ to determine which edges should be included (Peeples and Roberts 2013).

Additionally, the more ubiquitous and consistent - albeit more stylistically constrained - lithics record should be included in such analyses to mitigate taphonomic bias and variability in production and discard rates across different artefact types. Some ‘classes’ of stone tools may already present opportunities to apply network methods to the Palaeolithic. For example, the substantial datasets on Acheulean handaxes offer valuable opportunities for carefully-designed network analyses to provide useful insights to the debate on the relative contributions of raw material, environment, phylogenetic, cultural, and social factors on the transmission of manufacturing skills (e.g. Key 2019; Lycett et al. 2016; Shipton and Nielsen 2018). Raw material sourcing data could also provide information that could be translated into formal social networks (e.g. Aubry et al. 2016; Fernandes et al. 2008). Most lithic material can be dated only indirectly, making site contemporaneity difficult to establish; however, this general archaeological problem extends beyond social network analysis and has not prevented lithic studies from providing robust insights (Tostevin 2012).

Furthermore, we believe that social network methods are particularly well suited to answer a few questions specific to the Palaeolithic. One of these is the general evolution of social networks, a ‘scaling up’ that culminated in the behavioural modernity that arguably distinguishes *Homo sapiens* from other hominins (Coward 2016; Gamble 1998). Some have argued that the temporally and geographically restricted networks of the Lower and Middle Palaeolithic resulted in frequent cultural extinctions and reinventions that prevented cumulative cultural innovation, and that the material culture changes widely interpreted as evidence of behavioural modernity became possible only when greater connectivity allowed the stabilization and widespread, rapid dissemination of technological innovations (Cullen 1996; Stiner and Kuhn 2006). Recent research has further suggested that inter-species connectivity may also have played a role in these changes (Greenbaum et al. 2019). We suggest that combining formal social network methods to techniques from allied disciplines offer considerable scope to test these different hypotheses on the emergence of behavioural modernity.

Social network methods are also ideal to investigate the question of Neanderthal extinction. As noted above, 'behavioural modernity', often invoked as an explanation for *Homo sapiens*' survival and the Neanderthals' demise, is increasingly related to variability in social network structure and cultural transmission rather than biology. *Homo sapiens*' greater inter-population connectivity is associated with improved ecological resilience, higher rates of innovation, and better diffusion of technological adaptations. Additionally, inter-regional exchange of material goods, information, and mates is an important risk-buffering mechanism among modern hunter-gatherers (Whallon 2006). While demographic models of past populations have typically assumed homogeneous, unstructured, and panmictic populations, such models clearly do not adequately explain the spread of new genetic traits and phenotypes in ancient populations (see e.g. recent work on the speciation of *Homo sapiens* in Africa by Scerri et al. 2018), nor the processes by which in-breeding among disconnected populations such as Neanderthals may have led to reduced resilience in the face of increasing environmental variability and ultimately extinction (Barton et al. 2011; Harris and Nielsen 2016; Sikora et al. 2017; Vaesen et al. 2019). Social network approaches, combined with ABMs and mathematical models, may thus be useful not just to archaeologists but also to geneticists investigating the complex patterns of interaction, interbreeding, and cultural and genetic exchange among Neanderthals, *Homo sapiens*, Denisovans, and potentially other, as-yet unknown species (Villanea and Schraiber 2019).

Conclusions:

The considerable challenges the Palaeolithic record poses to social network analysts may explain why these approaches remain under-utilised in this period. Nonetheless, we argue that such techniques have considerable potential to study social networks of the Palaeolithic when applied cautiously; indeed, in this chapter we identify some key Palaeolithic research questions for which social network methods are particularly well suited, as well as some potentially fruitful areas that could be targeted by Palaeolithic network analysts. While Upper Palaeolithic 'symbolic' objects are perhaps the most obvious source of data to reconstruct social networks, we suggest that lithic data or - better - a compilation of multiple artefact types may provide the best line of evidence for long-term comparisons of social networks throughout hominin evolution. We suggest that researchers should use concepts drawn from cultural transmission and evolution, social physics, and phylogenetic analyses among others to complement formal network analysis methods to model prehistoric networks. In addition, researchers should use methods designed to test the reliability and robustness of the reconstructed networks, such as stress-testing, exploring the effects of thresholds on edge inclusion, and statistical testing with bootstrapping. The ABM used here clearly shows the potential strength of models used alongside social network methods to gauge the robustness and significance of empirically-identified patterns, and thus improve our analytical methods.

The potential for such work is clear: understanding variability in social interaction and connectivity is central to some of the key questions in human origins research, informing on interbreeding, speciation, material engagement, creativity, and reliance on technology over the course of hominin evolution, and their implications for survival and resilience in challenging environments. The authors hope that an increase in connectivity among academic sub-populations in different disciplines and trained in a range of complementary techniques - as demonstrated by this volume - will have a significant impact on human origins research. We can but hope that we are at the beginning of a Palaeolithic social network 'gold rush', which will enable us to answer questions about prehistoric social interactions that might have been deemed unanswerable before.

Figure caption:

GravelMiguel_Coward_Fig1: Comparing the network- (grey) and artefact-scores (black) by scenario. Notches show the 95% Confidence Interval around the median.

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