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Understanding hunter–gatherer cultural evolution needs network thinking

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Hunter–gatherers past and present live in complex societies, and the structure of these can be assessed using social networks. We outline how the integration of new evidence from cultural evolution experiments, computer simulations, ethnography, and archaeology open new research horizons to understand the role of social networks in cultural evolution.

Cultural evolution: It is time for thinking about social networks

Social networks, referred to here as a structure in which individuals and groups of individuals are connected to each other through social ties, play a central but not yet well-understood role in human cultural evolution. Here, we advocate for the adoption of a '**network thinking**' (see Glossary) perspective in cultural evolutionary research when dealing with past and present hunter–gatherer populations. This approach necessarily requires (i) recognizing that social learning processes have involved the transmission of information throughout different levels of social interaction among individuals from the same residential group and between members of different residential groups; therefore, this information flow is embedded in large and complex social networks; (ii) understanding that population size scales up the complexity of these social networks from interactions among few individuals to direct and indirect interactions among hundreds of individuals in much larger metapopulations; and (iii) investigating the relationship between past social network dynamics and cultural change using archaeological datasets.

We argue the adoption of 'network thinking' in cultural evolution can only be adequately explored through a multidisciplinary combination of data, methodologies, and theoretical frameworks from archaeology, evolutionary anthropology, psychology, and network science. Specifically, this includes the evidence available from the archaeological record, ethnographic studies, computer simulations, and cultural evolution experiments on one side and the theoretical perspectives developed in cultural evolutionary and complex systems theories on the other. Here, we show how recent research has shifted the conceptual background of social connectivity in hunter–gatherer cultural evolution and discuss three major areas for prospective research: (i) the application of **social network analysis** to the archaeological record, (ii) the introduction of conceptual frameworks from network theory (Figure 1), and (iii) the interdependence between social networks and cultural evolution.

New perspectives on the role of social connectivity in hunter–gatherer cultural transmission

The core principle of cultural evolutionary theory is that individuals learn through a combination of individual and social learning. Under certain conditions, individuals' learning strategies can result in cumulative culture, which is recognized by the presence of traits that could not be invented by a single individual and that are gradually improved over time due to the inheritance of knowledge and

Glossary

Agent-based modelling: a family of computational models that simulates actions and interactions of autonomous agents under a previously defined set of rules. Agent-based modelling can be applied to simulate a wide range of phenomena, allowing the identification of emergent properties of a system.
Cumulative cultural evolution: the repeated modification and social learning of cultural traits from individual to individual and over successive generations, such that the cultural traits improve in some desired measure of efficiency (typically a proxy for fitness) over time.
Cultural taxonomy: the definition and description of taxonomic units that group assemblages according to their material culture and geographic and chronological distributions. Taxonomic structure itself is the outcome of social transmission processes over time and in relation to socioecological selection. By way of analogy to speciation, the diversification of lineages occurs as populations become isolated over time, so that vertical transmission dominates over oblique and horizontal transmission.
Network thinking in hunter–gatherer cultural evolution: a novel interdisciplinary approach to the study of cultural evolution in past and present hunter–gatherer societies. It uses the frameworks of the cultural evolutionary and complex systems theories to understand how social structure has influenced cumulative cultural evolution and other kinds of cultural evolutionary processes. It uses empirical datasets and methods from archaeology, evolutionary anthropology, psychology, and network science.
Radiocarbon chronological modelling: a suite of statistical techniques to produce time-series and/or spatiotemporal analyses of aggregated datasets of archaeological radiocarbon dates. Radiocarbon chronological modelling is often used to produce inferences about long-term population histories and settlement dynamics at regional scales.
Social network analysis: the process of investigating social structures through the use of networks and graph theories. It characterizes networked structures in terms of nodes (representing individual or collective actors, such as organizations or groups) and the links connecting them. Social network analysis encompasses a number of techniques to visualize social networks (through sociograms), identify their main structural characteristics, and study the relationship between the position of an actor in a network and its behaviour.
Taphonomic bias: the impact of different environments on the decomposition of artifacts and remains (e.g., caves and rock shelter have better bone preservation than open-air sites) and of different sedimentation rates on archaeological assemblage sizes and temporal ranges. This affects the type and quantity of objects found at archaeological sites and makes it difficult to compare aspects of archaeological assemblages to infer past social networks (e.g., researchers can underestimate the

extent of past social contacts if the objects that bear signs of those contacts did not preserve everywhere).

know-how from previous generations. We view social networks as a central but still understudied component of cultural evolution because, by definition, cultural transmission is information flow and retention through structured populations at multiple scales.

Recent research has applied social network analysis to explore the influence of social connectivity on cultural evolution using laboratory experiments, computer simulations, and ethnographic data [1–3]. Cultural evolution experiments in which participants can learn from each other to develop complex artifacts have demonstrated that populations subdivided into partially isolated subgroups produce more diverse cultural traits than fully connected populations and reach higher levels of cultural complexity when innovation depends on cultural diversity [1]. Computational modelling has investigated the effect of different human mobility strategies on information transmission through social networks and found that central place foraging, in which hunter–gatherers forage and bring food back to the campsite, improve the dissemination of social information in large populations [2].

Complementing these approaches, studies simulating cultural evolution over real

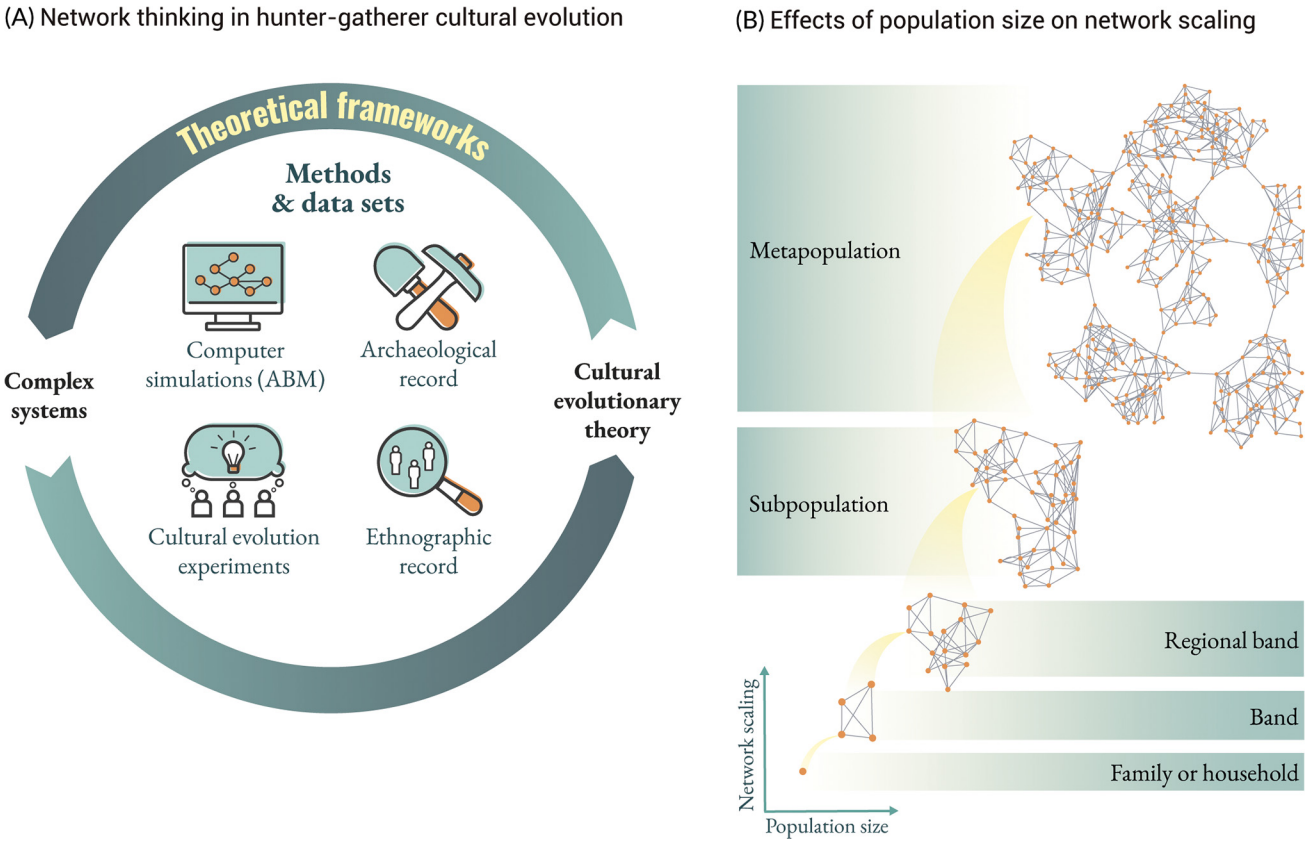

Figure 1. Network thinking in hunter–gatherer cultural evolution. (A) Crossing disciplinary boundaries to apply 'network thinking' in hunter–gatherer cultural evolution. Computational simulations including agent-based modelling (ABM), cultural evolution experiments, and ethnographic studies provide evidence for the effect of social connectivity on cultural evolution. Although laboratory studies offer insights into small-scale mechanisms operating between individuals, ethnographic studies allow the observation of social networks 'in the wild.' Yet, these approaches alone cannot reveal how networks change over long periods of time and how this impacts cultural evolutionary trajectories across generations and in relation to extrinsic factors such as between-group contact or climate change. Archaeological data fill this gap. (B) Scaling effects of population size in hunter–gatherer social networks. Populations are structured in nested levels of social organization (families or households, bands, regional bands, subpopulations, and metapopulations). The analysis of worldwide ethnographic datasets recurrently finds this nested self-similar structure characteristic of small-world, hierarchically modular networks. The information flow leads to the emergence of small-world networks where highly clustered local interactions are embedded within much larger but sparsely connected multilevel metapopulations forming decentralized knowledge systems [4]. Depicted networks have been produced by a network model combining constraints on module size at each hierarchical level and random wiring of links among families/nodes.

networks from extant hunter–gatherer communities have shown that social structures characterised by multiple levels of clustering of households within camps and camps within metapopulations can accelerate cultural evolution [3]. Furthermore, features such as coresidence, cooperation with unrelated individuals, multilocality, fluid sociality, and high between-camp mobility might have had a major influence on the cognitive mechanisms (e.g., high-fidelity transmission, innovation, teaching, and combinatorial innovation) underlying **cumulative cultural evolution**. This research has significantly contributed to replacing the long-held view of hunter–gatherers living in small-scale societies by a new perspective that highlights how small coresidence groups are dynamically connected to much larger populations, forming expansive networks of social interaction at large spatial scales [3,4]. In spite of contributing to a paradigm shift, experimental and ethnographic studies do not have the time depth to reveal how these changes might have impacted cultural evolution across generations. Archaeological data can step in here (Figure 2).

Applying social network analysis to the archaeological record

The archaeological record left by past hunter–gatherers provides long-term perspectives on the relationship between patterns of social interaction and cultural evolution. From the Upper Palaeolithic onward, archaeological evidence is often sufficiently representative to build spatio-temporal networks at regional scales. Studies applying formal social network analysis to the hunter–gatherer archaeological record have focused on a range of issues, including processes of cultural diversification, reconstructing network topologies, and the growth of settlement interconnectedness and its decline in relation to environmental hazards ([5,6] and references therein).

The application of social network analysis to archaeological datasets faces many challenges, including the low chronological resolution of the Palaeolithic record, with time scales of centuries and millennia, and research and **taphonomic biases**. These limitations are highly germane to the selection of appropriate classes of material culture to reconstruct archaeological networks, as well as in the selection of different statistical and modelling methods to evaluate their representativeness and robustness. Additional constraints come from the process of network construction itself, particularly when aggregating data over broader periods or when dividing the archaeological record into shorter subperiods

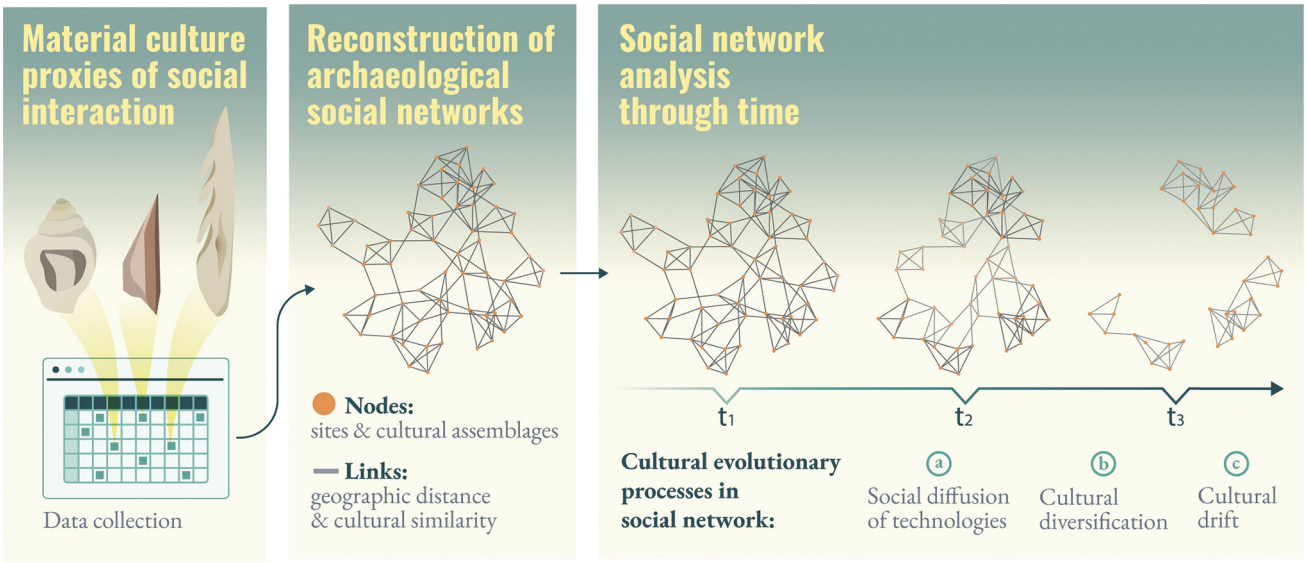

Figure 2. Network dynamics and archaeological social networks. The left panel depicts different kinds of material culture proxies of social interaction: pierced shells, used as personal ornaments, reflect broad social interactions in which long-distance circulation of materials is embedded, whereas lithic projectile points and harpoons are considered utilitarian objects whose formal and technological traits were transmitted in social learning contexts. The central panel represents the reconstruction of social networks using archaeological datasets. The right panel shows a theoretical social network changing through three time slices (t_1, t_2, and t_3), and potential consequences of such dynamics in terms of cultural evolutionary processes. At t_1, we find the complete social network, formed by interconnected regional bands within a subpopulation. At that moment, the density and strength of connections favour processes of social diffusion of technologies (a); at t_2, the social network presents fewer nodes than at t_1, and the strength among the connections is higher within each regional band than at subpopulation level. This sociospatial structural configuration privileges intraregional band information exchange, and inter-regional differentiation that can result in cultural diversification (b). Finally, at t_3, the network is significantly smaller and is fragmented, and connections are weak both within and across regional bands. This state increases the chances of cultural drift (c), a process by which random copying errors in smaller and/or less connected populations can lead to the disappearance of existing cultural variants.

for determining the spatial and temporal dynamics of those networks.

A set of recent developments in evolutionary archaeology – in particular, new forms of quantitative archaeological systematics as well as chronological and spatial modelling – open new prospects for finer-grained applications of social network analysis to cultural evolutionary processes. First, the re-evaluation of **cultural taxonomy** using cultural evolutionary theory–driven approaches seeks to capture population and network structure through artifact proxies [7]. Second, recent advances in **radiocarbon chronological modelling** have yielded new insights into the reconstruction of long-term changes in population size and spatiotemporal settlement dynamics at regional scales [8]. Third, coupling of geographic information systems and **agent-based modelling** allows a more realistic appreciation of the roles that geographic barriers and environmental constraints play in the formation of social networks in the archaeological record [9]. Importantly, the publication of archaeological datasets and methods accessible through online data infrastructures facilitates new data science approaches and reproducibility.

In sum, the application of social network analysis to the hunter–gatherer archaeological record opens vistas onto *longue durée* cultural evolutionary processes from a population perspective, such as the spread of new behaviours or technologies by social diffusion mechanisms; the diversification or decimation of culture; and the relationship between cultural changes with sociospatial structures, climatic and environmental changes, and population dynamics.

Hunter–gatherer social networks and cultural evolution interdependence

Studying the influence of social connectivity on cultural evolution is central, but it is only one side of the phenomenon we are interested in. We also need to better understand how cultural transmission might in turn condition the dynamics of social networks.

Indeed, recent research suggests the presence of feedback between network dynamics and cultural transmission and highlights the long-term role such feedback may play in long-term cultural evolution [1,10]. For instance, technological innovations may affect connectivity patterns through population increase or enhanced mobility, whereas cultural transmission rates or cultural trait stability might be conditioned by social structure. This interplay between network dynamics and cultural transmission is complex and likely to operate across multiple scales and with interactions of multiple factors (e.g., biogeography, environmental dynamics, and demography) that have not yet been fully explored in evolutionary archaeology [11]. Experimental and ethnographic studies can contribute to filling this gap because they provide insight on culture-mediated mechanisms underlying social network change. Future work may profitably focus on integrating these complementary approaches, as well as their articulation with archaeological data of different granularity.

For decades, network scientists have developed a growing body of methods and concepts to explore the dynamics of networks and their interplay with information transmission [12]. We can now use this knowledge to test evolutionary models of the interdependence of social structure and cultural change in hunter–gatherer societies.

A call for 'network thinking'

Our call for 'network thinking' in hunter–gatherer cultural evolution is based on growing evidence for the relationship between social connectivity and cultural change provided by recent ethnographic, computational, and experimental studies. Although research is beginning to show how hunter–gatherer sociality shapes cumulative culture today, the investigation of social structures in the past is required to fully understand cultural evolution. By using archaeological data to infer and analyse past social networks, we can offer unprecedented insight into how longitudinal changes in social connectivity interacted with human cultural evolution, in terms of both undergirding the remarkable accumulation of species-wide culture and the occasional shocks leading to demographic and cultural decline and extirpation. Network science naturally links interactions among individuals with emergent collective macrophenomena and so can be used to effectively integrate all these complementary perspectives. We believe that this cross-disciplinary application of network thinking will improve our understanding of the long-term interplay between human social structure and cultural change.

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Declaration of interests

No interests are declared.

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