HUNTER-GATHERER FORAGING NETWORKS PROMOTE INFORMATION TRANSMISSION

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Abstract

Central-place foraging, where foragers return to a central location (or home-base), is a key feature of hunter-gatherer social organization. Although why or when our ancestors started returning to "home-bases" remains unclear, it likely had significant implications for many aspects of hominin evolution. For example, central-place foraging, by changing hunter-gatherers' use of space and mobility, could have altered social networks and increased opportunities for information exchange. We evaluated whether central-place foraging patterns facilitate information transmission and considered the potential roles of environmental conditions and mobility strategies. We built an agent-based central-place foraging model where agents move according to a simple optimal foraging rule, and can encounter other agents as they move across the environment. They either forage close to their home-bases within a given radius or move their home-bases to new areas. We analyzed the interaction networks arising across different environments and mobility strategies. We found that, at intermediate levels of environmental heterogeneity and mobility, central-place foraging increased global and local network efficiencies as well as the rate of contagion-based information transmission (simple and complex). Our findings suggest that the combination of foraging and movement strategies, as well as the underlying environmental conditions that characterized early human societies, may have been a crucial precursor in our species' unique capacity to innovate, accumulate and rely on complex culture.

Keywords Central-place foraging · Hunter-gatherer mobility · Social Networks · Movement Ecology · Human Behavioral Ecology · Agent-based Model

1 Introduction

One of the pivotal transitions in human evolution is our ability to innovate, accumulate and rely on complex, cumulative culture (1; 2; 3; 4). Recent evidence from hunter-gatherer societies (5; 6) has suggested that changes in our ancestors' social networks and connectivity could have promoted such a transition by facilitating an efficient exchange and transmission of cultural information. Given that the degree and strength of social interactions between hunter-gatherers would have been affected by their movement and spatial distribution patterns, researchers have proposed that divergences in foraging behavior, coupled with ecological changes, could have led to changes in social networks (7; 8; 9). However, the impact of changes in hunter-gatherer foraging and movement behavior on emergent social networks and their ability to transmit information is not thoroughly understood (but see 10; 11).

Central-place foraging marks a critical behavioral change between the foraging styles of early hominins and our closest great ape relatives (12; 13; 14) that would have modified their movement and spatial patterns. Our closest ape relatives mostly tend to consume food when they find it ('point-to-point' foraging) within smaller home-ranges, make sleeping

nests at variable locations and have shorter foraging trips. On the other hand, hunter-gatherers have been documented to have short-term residential camps or home-bases around which they systematically forage and bring the food they collect during foraging trips back to their camps to share and process it with camp members ('central-place foraging') (15). In addition, human foragers can make longer foraging trips and periodically move their residence to access new resource areas with little overlap in the range area between successive camps. These properties result in an expansion of their overall home-ranges (16) compared to other primates who spend most of their adult lives within the same area, resulting in more restricted use of space (17; 18; 19; 20; 21).

Such changes in mobility could have altered spatial patterns and dynamics of social interactions and led to more complex social structures. We hypothesize that central-place foraging could have played an essential role in the subsequent development of a multi-level social organization. In multi-level organizations, sets of multiple core units repeatedly coalesce, intermix and disperse, and can give rise to relatively fluid local bands that are embedded in higher-level interconnected regional networks(22; 23; 24; 25; 26; 27). These extended, flexible, and fluid social landscapes would have increased the likelihood of interactions, social learning, and information exchange compared to our closest Great Ape relatives (2; 28).

However, hunter-gatherer foraging and mobility (e.g. daily trips, residential movements) decisions are influenced by their resource environments and various costs (e.g., traveling costs) and benefits (e.g., resource abundance) of foraging activity (29; 30). Thus, hunter-gatherer mobility can vary widely across environments and is affected by ecological conditions and habitat quality (15; 31). For example,hunter-gatherer communities may be able to afford greater sedentarism in rich environments where there are plenty of resources available within home-range (32). In contrast, seasonal and patchy environments may require communities to move their camps multiple times a year due to resource depletion within home-range (33). Moreover, if resources are homogeneously distributed, bands might disperse into small units with reduced connectivity between them. Conversely, if resources are heterogeneously distributed where some areas are richer than others, bands may aggregate in a few places (29), potentially producing more opportunities for interactions (34).

In this paper, we model point-to-point and central-place foraging (with different home-range radii) behavior across a range of environments. We investigate whether and how mobility and subsequent interaction networks change when central-place foraging behavior is introduced. We then test the efficiency of information transmission in the networks that emerge from the different mobility regimes and environments. Previous computational models have explored the effects of environmental heterogeneity on social networks emerging from foraging behavior across different environments (35) and hunter-gatherer mobility on cultural transmission (10; 36). However, an explicit link between foraging strategies, environmental features, and hunter-gatherer interaction networks has not been made yet. Our work illustrates a direct connection between environmental conditions, foraging behavior, and information flow in hunter-gatherer social networks, thereby providing insights into the evolutionary origins of our species' unique ability to innovate, accumulate and rely on complex culture.

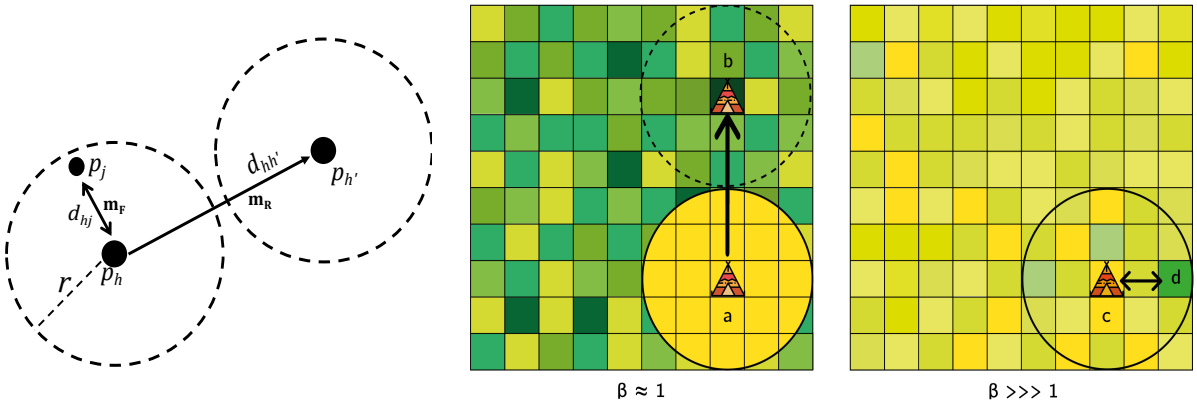
2 Methods

2.1 Model Description

We investigated how central-place-foraging behavior would affect the emergent interaction networks across environments. Previous work by Ramos-Fernández et al. (35) modeled the effect of environmental heterogeneity on the interaction networks that emerge from multiple agents foraging independently (representing spider monkeys). The authors showed that a complex social structure with fission-fusion properties, resembling those observed in field studies among real spider monkey societies, could emerge from optimal foraging rules in heterogeneous environments.

Our model (henceforth central-place model), like the model from Ramos-Fernández et al. (35) (henceforth point-to-point model), is executed in a two-dimensional environment that ranges from 0 to 1, and comprises 50,000 uniformly distributed patches. Each patch was initially assigned resource content, $k_i \geq 1$, drawn from a normalized power-law probability distribution, $P(k) \approx k^{-\beta}$ where the exponent β determines the distribution of resource content and the total resource abundance (see Methods section and Fig. 1). When $\beta \approx 1$, k has a broad range, patches vary widely in their resource content, and the environment is abundant. Conversely, $\beta \gg 1$ corresponds to smaller values of k, and scarcer resources that are homogeneously distributed across patches.

In the model, foragers followed a rule whereby they move to a new patch (p_j) from a depleted patch (p_i) such that it minimized the cost/gain ratio (d_{ij}/k_j), where d_{ij} is the distance between the patches and k_j is the resource content of p_j. Our model (Fig 1a) modified this resource-maximization rule to implement central-place foraging and distinguished between foraging and residential moves (15; 31). Every forager had complete knowledge of resources, a randomly allocated home-base, and a foraging area with a given radius, r. Foragers could forage and change their home-base



(a) (b)

Figure 1: Model Description. ***(a)***: A schematic representation of agent movement in the model. Agents can make foraging movements (m_F) within a radius r from their home-base (p_h) to a new patch (p_j) or residential movements (m_R) to a new home-base ($p_{h'}$). ***(b)***: An illustration of the variations in resource environments modulated by the parameter β. A low value of β results in a rich (dark-green patches) and heterogeneous environment (left), whereas a very high value of β results in a poor (yellow patches) and homogeneous environment (right). When food depletes within an agent's radius (yellow patches), it moves its residence ($a \rightarrow b$). Otherwise, it continues to forage within its radius ($c \leftrightarrow d$).

based on the following rules. When foragers were on a patch with no food left, they made foraging moves (m_F) to a patch (p_j) within r such that the cost/gain ratio (d_{hj}/k_j) was minimized, where d_{hj} is distance between home-base (p_h) and p_j, and k_j is the resource content of p_j (Fig 1b (right)). Before every move, foragers compared the cost/gain ratio of patches outside the radius to patches within the radius. When the resource quality within r diminished compared to the rest of the environment (Fig 1b (left)), instead of making a foraging move to profitable patches outside their radius, foragers made a residential move. Residential moves (m_R) allowed foragers to select a new home-base ($p_{h'}$) in a randomly chosen direction ($\theta \in [0, 360]$) that minimized ($d_{hh'}/k_{h'}$) but was far enough from the current base ($d_{hh'} \geq 2 * r$) to avoid overlap. Each time-step that a forager coincided with another forager on a patch, they formed a social network tie or added a unit of weight to an existing tie.

To assess how the combination of environmental heterogeneity and central-place foraging strategies affect the emergent social networks, we varied the resource exponent, β parameter to take values between 1.5 and 4.5 the foraging radius, r to assume values of 1, 0.1, 0.01, and 0.001. Furthermore, we tested the effect of population size by running the model with 50, 100, and 200 foragers (Fig. S1). We ran 50 simulations for each parameter combination and the point-to-point model and extracted the weighted social networks formed at the end of 100 time-steps.

2.2 Networks

We extracted the final networks formed from the sum of all interactions by the end of each run. We provide complete summary statistics of each parameter combination's resulting networks in the supplemental materials (Tables S4-S5).

2.2.1 Efficiency

We tested the networks for their ability to transmit information by measuring their global and local efficiencies (37). The efficiency measures have been used across various studies to investigate the transmission of social and cultural information in various networks, including hunter-gatherer social networks (5). Global efficiency indicates a network's ability to transmit information across the entire network and is inversely related to the characteristic path length (or the average distance between nodes). Latora and Marchiore (37) define a graph's global efficiency as the inverse of the sum of the shortest paths between all nodes i and j:

$$E = \frac{1}{n} \sum_{i \in N} \frac{\sum_{j \in N, j \neq i} d_{ij}^{-1}}{n-1}$$

Where N is the set of all nodes in the network, n is the total number of nodes, and d is the shortest distance between two nodes. On the other hand, local efficiency relates to the clustering coefficient of a network (i.e., the degree to which a node's local neighborhood is inter-connected). It measures the average global efficiency of subgraphs and denotes how well each local neighborhood can exchange information within itself. We modified the efficiency measures to incorporate weights (see SM). The original formulation of shortest distance calculations consider weights as distance (e.g. an edge of weight (w_{ij}) 4 between two nodes(i, j) will be considered to have a longer distance, $d_{ij} = 4$ than another edge with lower weight, $w_{ik} = 1$). In our model, weights represent social proximity, and larger weights should decrease path length and speed up information transmission. To correctly represent this, we take the inverse of edge weights and add a unit to the inverses (e.g., d_{ij} would change to $\frac{1}{4} + 1 = 1.25$, and $d_{ik} = 2$), such that each edge has a weight 1 and the maximum efficiency of an unweighted equivalent network is 1.

2.2.2 Contagion simulations

We calculated the proportion of agents in the network that acquired the diffusing information after 5000 time-steps through simple and complex contagion. Simple contagion models a perfect transmission of information independent of the number of novel interactions, where a single interacting event is sufficient for information transmission. Hence, an agent's probability of acquiring information is proportional to the number of its neighbors with the information and the strength of their connections. Accounting for edge weights, the probability of acquiring the information for individual i, in any given turn, is:

$$Pr(A)_i^{t+1} = \frac{\sum w_i \times d^t}{\sum w_i}$$

Where w_i is a vector of the edge weights that i shares with its neighbors and d is a vector of same length containing 1 if the corresponding neighbor has acquired the information or 0 otherwise at time, t.

Complex contagion, in contrast, represents a mode of transmission that is more well-suited to capture the diffusion of costly or difficult social behaviors that need reiterated affirmation (38; 39). Here, the probability of acquisition now rises exponentially as more neighbors acquire the information,

$$Pr(A)_i^{t+1} = \frac{\sum w_i \times d^t}{(\sum w_i)^2}$$

3 Results

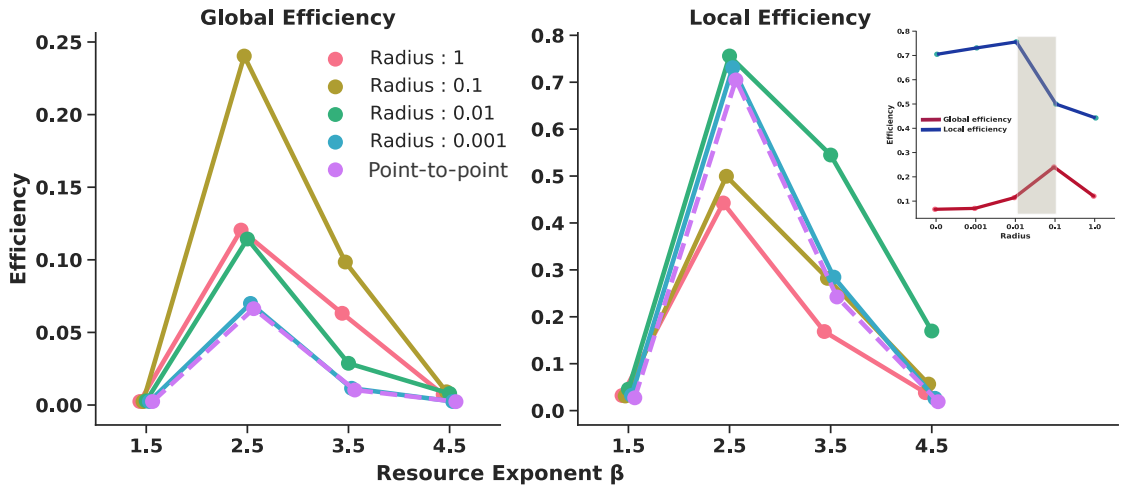


Figure 2: Network Efficiencies. The plot shows the average global (left) and local (right) efficiencies of the networks as a function of environmental heterogeneity for each radius. The inset shows the relationship between efficiencies and radius for $\beta = 2.5$. Shaded region corresponds to intermediate radii that balances global and local efficiencies.

3.1 Environmental factors affect the efficiency of information transmission in networks

In line with the results from Ramos-Fernández et al. (35), we found that environmental heterogeneity strongly influence the networks formed, with $\beta = 2.5$ generating the most efficient networks ($\overline{E}_{global} = 0.13, \overline{E}_{local} = 0.65$). In an environment ($\beta \approx 1$) where many rich resource patches are available, foragers had very low mobility (see next section for mobility results) and stayed fixed at a rich resource patch for long durations. In the resource-poor environment of $\beta = 4.5$, every patch had low resource value, and foragers depleted patches quickly. They frequently moved across the environment resulting in low interaction rates (as evidenced by density of connections) with other foragers. However, at intermediate heterogeneity and resource abundance, foragers coincided at the few rich patches available in the environment and formed stronger social ties. Increasing the population's size further increased the rate of interactions between the foragers and thus, the network efficiencies (Fig. S1).

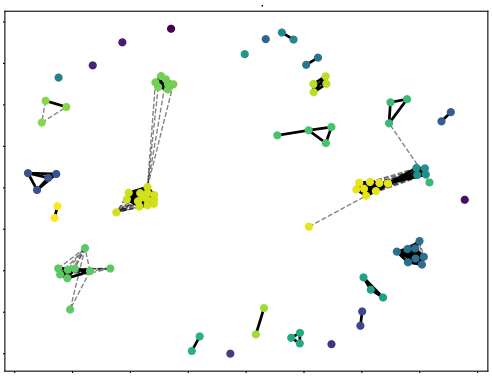
3.2 Central-place foraging increases global and local network efficiency

We found that point-to-point foraging created networks that resembled "small-scale societies" with very high local efficiency (or clustering) but low global efficiency. These networks contained strongly connected small sub-groups of foragers that were distributed across the environment with few to no connections between them. In contrast, central-place foraging created ties between otherwise unconnected sub-groups. We found that these ties increased networks' global efficiency while maintaining high local efficiency. On the one hand, this formed strongly bonded local groups, and on the other hand, large-scale, interconnected regional networks such as the ones observed among ethnographic hunter-gatherers (25; 2; 40; 5)

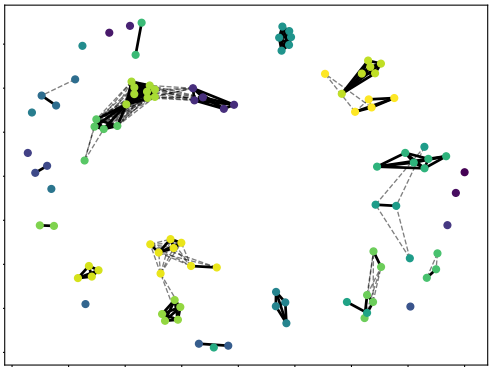
To explore the effect of different radii of central-place foraging, we compared the different mobility regimes (frequency and magnitude of residential and foraging moves) across environments and radii 4 (Tables S2-S3). We found that at intermediate levels of environmental heterogeneity ($\beta = 2.5$), when the home-range radius is small ($r = 0.001$), foragers primarily made short residential moves ($\overline{n}_r = 26, \overline{d}_r = 0.022$) with a few, shorter foraging moves ($\overline{n}_f = 3, \overline{d}_f = 0.001$). This mobility pattern closely resembled that of the point-to-point model, where foragers don't return to a central-place (16). The resulting networks from $r = 0.001$ comprised of many (≈ 24) densely connected sub-groups of high local efficiencies ($\overline{E}_{local} = 0.73$)(Table S4). But these dense sub-groups lacked connections between them with a maximum of 3 sub-groups connected to each other (Table S5).

Increasing the home-range radius to intermediate values ($r = 0.01$ and $r = 0.1$), resulted in foragers making longer, and more frequent foraging moves combined with longer but fewer residential moves. At $r = 0.01$, a small increase in residential mobility ($\overline{n}_r = 16$, $\overline{d}_r = 0.048$) created a few longer connections between the dense sub-groups. These connections resulted in more sub-groups being connected ($4 - 5$) and increased global efficiency ($\overline{E}_{global} = 0.11$). However, the network still remained highly cliquish with high local efficiency ($\overline{E}_{local} = 0.75$). As the home-range radius and use of space further increased ($r = 0.1$), foragers moved less frequently ($\overline{n}_f = 20$, $\overline{n}_r = 2$) but undertook longer moves ($\overline{d}_f = 0.03$, $\overline{d}_r = 0.23$). This change in mobility increased the long-range connections between fewer (≈ 15) but larger and interconnected sub-groups ($6 - 8$). This sub-group structure made the network substantially more efficient at the global scale ($\overline{E}_{global} = 0.24$) while maintaining considerable local efficiencies ($\overline{E}_{local} = 0.50$)(Tables S4-S5). However, we found that both efficiencies decreased compared to intermediate radii ($\overline{E}_{local} = 0.44$, $\overline{E}_{global} = 0.12$) when the foragers had a very large home-range radius ($r = 1$). In the absence of residential moves, the foragers remained tethered to their original home-bases and traversed longer foraging moves ($\overline{d}_f = 0.05$) to find food. The longer moves helped create long-range connections between foragers that resulted in a large number of connected sub-groups ($7 - 11$) and a more globally efficient network than the point-to-point model ($\overline{E}_{global} = 0.07$). But the strong tethering decreased the overall use of space and the probability of coinciding with others for longer durations, resulting in fewer and weaker connections between sub-groups (see Fig. S2-S3) with low local efficiencies.

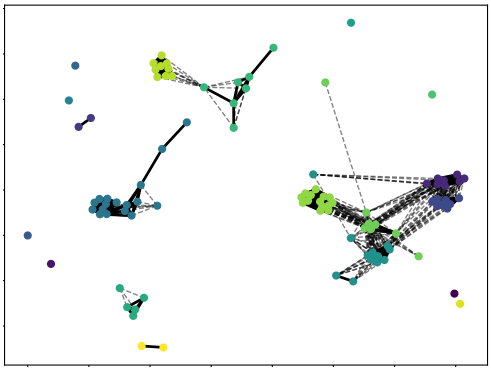
In environments where the habitat quality was low and patches were homogeneous in their resource content, foragers coincided on patches less frequently and for a shorter amount of time. At $\beta = 3.5$ when patches were less rich and homogeneous, foraging mobility increased with many shorter moves within home-ranges for all radii, while residential mobility increased with longer moves ($\overline{n}_r = 2$, $\overline{d}_r = 0.56$) for $r = 0.1$, but decreased for smaller radii with shorter and similar number of moves ($r = 0.01$: $\overline{n}_r = 15$, $\overline{d}_r = 0.041$), or shorter and more frequent moves ($r = 0.001$: $\overline{n}_r = 70$, $\overline{d}_r = 0.006$). This effect led to a decrease in both global and local efficiencies across radii ($\overline{E}_{global} = 0.04, \overline{E}_{local} = 0.3$) from $\beta = 2.5$. However, for radius $r = 0.01$, the decrease in the local efficiencies was lesser when compared to the other radii. For $r = 0.01$, foragers moved within a space that was small enough to increase the rate of interactions but large enough to find rich patches. When the radius increased ($r = 0.1, 1$) or decreased ($r = 0.001$), foragers either traveled longer distances and were dispersed in a larger area or were too restricted in their space use to find enough food and continually changed their residence.



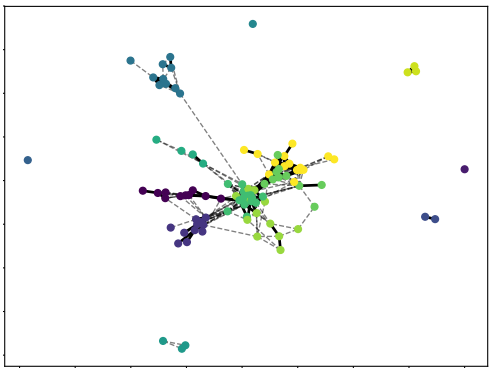
(a) Point-to-point foraging



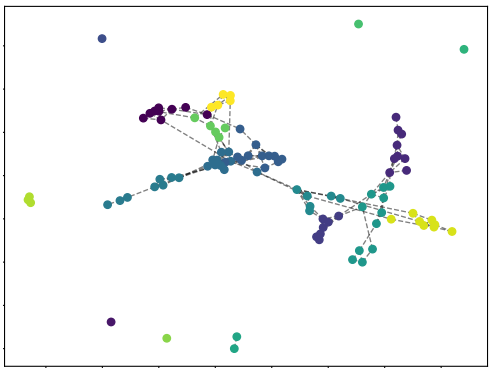
(b) Central-place foraging; $r = 0.001$



(c) Central-place foraging; $r = 0.01$



(d) Central-place foraging; $r = 0.1$



(e) Central-place foraging; $r = 1$

Figure 3: Emergent Networks from 100 foragers after 100 time-steps. The plot shows an example of weighted networks that emerge from different foraging behaviors in $\beta = 2.5$ environment (clockwise: *Point-to-point*, $r = 0.001, r = 0.01, r = 0.1, r = 1$). Node colors depict the different sub-groups detected by Louvain community-detection method (SI Text). Edge colors and style depict the edge weights: Solid back edges show strong bonds; dashed grey edges show weak bonds. Distance between nodes also depict the strength of connections. Networks were made using spring layout from *NetworkX* package in Python.

Taken together, these data illustrate that central-place foragers were restricted in their movements that led to strongly connected sub-groups. However, the longer residential moves allowed connections to form between the sub-groups to varying extents that were missing in the point-to-point model. We found that intermediate levels of overall mobility ($\overline{n} = 23$, $\overline{d} = 0.04$) with few long moves, and many shorter moves, for example in $\beta = 2.5$ and $r = 0.1$, created networks that are efficient at both global and local scales. As the frequency of overall movement decreased with longer moves($r = 1, \beta = 2.5 : \overline{n} = 15$, $\overline{d} = 0.05$) or increased with shorter moves ($r = 0.01, \beta = 2.5 : \overline{n} = 34$, $\overline{d} = 0.02$; $r = 0.001, \beta = 2.5 : \overline{n} = 28$, $\overline{d} = 0.02$,), networks lacked dense, long-range connections necessary for global efficiency with either highly locally efficient but fragmented networks or sparsely connected sub-groups. Finally,

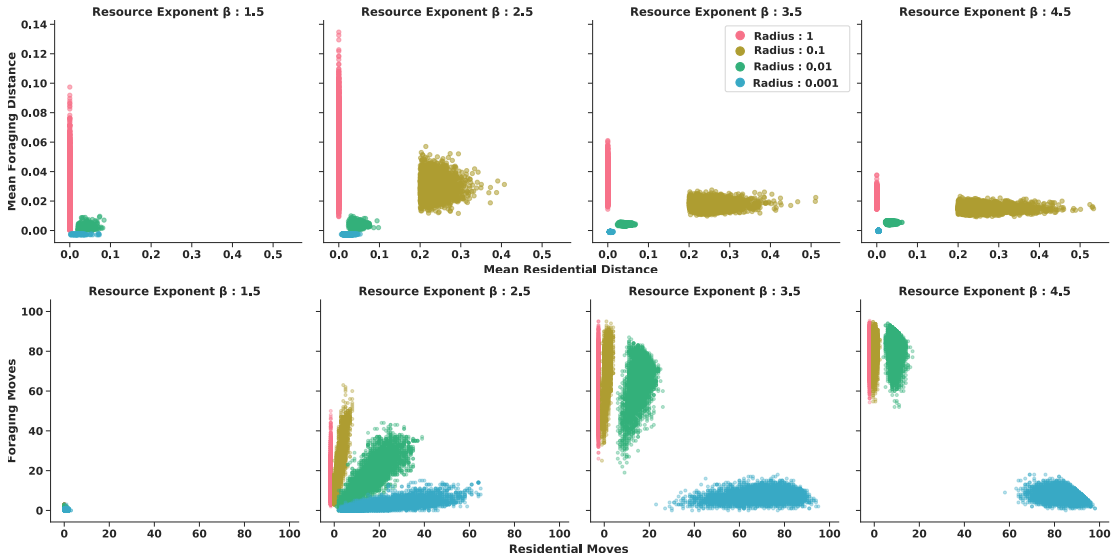


Figure 4: Mobility regimes across different environment and radii. ***Top***: The plot shows the mean distance moved in residential moves (d_r) against foraging moves(d_f). ***Bottom***: The plot shows the frequency of residential moves(n_r) and the frequency of foraging moves(n_f).

when rate of mobility was very low (highly frequent but very short moves, or rare and and short moves), for example in $\beta = 1.5$ and $\beta = 4.5$ (all radii), foragers rarely interacted with each other, and both global and local efficiencies tended to 0. Altogether, based on our results, we can predict that central-place foraging with an intermediate radius/mobility regime (between 0.01 - 0.1) should maximize both efficiencies (Fig 2 inset).

3.3 Central-place foraging networks are efficient at information transmission

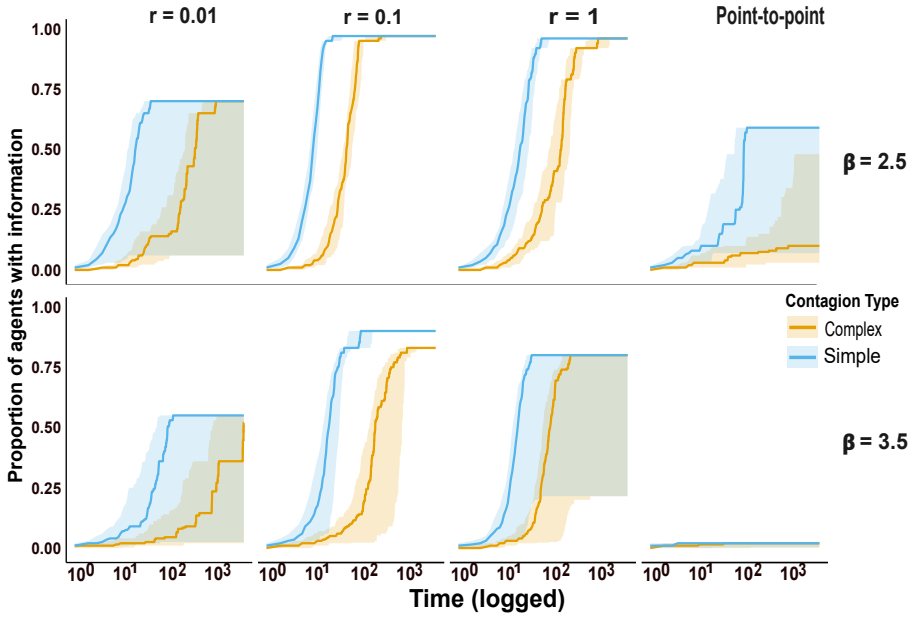


Figure 5: Simple and complex contagion trajectories. The plot shows the spread and speed of contagion over time for different radii (columns) and beta (rows). Shaded regions show the 25th and 75th percentiles of the distribution of trajectories at each time-step.

To directly test the networks for their capability of transmitting information, we conducted both simple and complex contagion simulations on the most globally efficient networks that resulted from each model and parameter combination (41).

In line with efficiency results (see previous section), we found that central-place foraging strategies characterized by a combination of residential and foraging moves (for $r = 0.1$ and $\beta = 2.5$) formed networks that allowed a rapid diffusion of information, reaching almost every node. We found that information spread more readily in networks with more extensive and well-connected subgroups instead of sparser or fragmented networks. For instance, in the point-to-point model, information reached a maximum of around 50% of the population across environments.

In complex contagion, where multiple novel interactions are required for successful transmission of information, we observed a greater effect of network structures and a slower rate of transmission across networks. For example, for $r = 0.1$ and $\beta = 2.5$, simple contagion tended to reach 75% of the nodes much faster and more reliably ($\pm$ SD) ($\bar{t} = 16 \pm 7$) than complex contagion which took longer time to reach similar proportions ($\bar{t} = 81 \pm 67$). This effect was magnified for less efficient networks (for example, $r = 1$) where the transmission was much slower and more variable ($\bar{t} = 207 \pm 299$) than in simple contagion ($\bar{t} = 33 \pm 16$) to reach the same proportion (75%) of nodes. In summary, we found that the networks that have high global and local efficiencies (such as those emerging from $\beta = 2.5$ and $r = 0.1$) can maximize both the reach and speed of contagions that resemble cultural transmission.

4 Discussion

Recent work on prehistoric and contemporary hunter-gatherer societies has shown that their social networks are efficient at information transmission and could have accelerated cultural evolution (5; 6; 42). However, the different factors that could have affected the formation of efficient social connectivity are not well understood. In this paper, we assessed how hunter-gatherer foraging patterns could have played a role in the emergence of such efficient social networks. We modeled spatial patterns and mobility regimes emerging from Central-Place foraging, a derived feature in our lineage, under different environments and tested their implications on forming social networks that are efficient at information transmission.

Central-place foraging is characterized by foragers bringing back food to home-bases while periodically changing the location of such home-bases according to the availability of resources. Our results reveal that this foraging pattern could have created social networks that are suited for information exchange. Previous works have suggested that a change in spatial and residence patterns could have caused unique expansions in early hominin social networks (1; 42). We modeled different space-use patterns by manipulating the home-range radius and found that social networks formed with larger radii and space-use are more expansive than those formed with smaller radii. We show that, compared to point-to-point foraging, central-place foraging could have modified spatial and residential patterns in ways that would have increased our ancestors' social interactions and their ability to exchange information (21).

We also find support for the idea that environment-driven variability between the mobility regimes employed by different hunter-gatherer societies has significant consequences for their social networks and hence cultural transmission (43; 44; 17; 10). Similar to Perreault and Brattingham (36), we find that mobility regimes which combine short-scale foraging and long-scale residential movements can create more efficient networks as opposed to regimes that are primarily residential or sedentary. In heterogeneous environments, When central-place foragers' movements are restricted within an intermediate radius with occasional long residential moves to richer resource patches, the networks formed contain densely connected sub-groups embedded in more extensive regional networks. Our results predict that an intermediate mobility regime (Fig 2 inset), thus, could balance the trade-off between networks that are highly cliquish at the expense of global efficiency and sparser large networks that have low clustering. Such networks, similar to small-world topologies, can support information processing at local and global scales (45; 46; 4).

Similar to previous research highlighting the importance of demography for cultural evolution, we find that an increase in population density can result in more efficient networks and a larger capacity for information exchange (47; 48; 49). Furthermore, our results indicate that central-place foraging can compensate for small population sizes to create networks that are as efficient as the networks from a large number of individuals engaged in 'point-to-point foraging' (SM). Thus, our results also emphasize the importance of optimal connectivity within a population to offset the adverse effects of demographic changes on cultural transmission (47; 34).

These findings hold significant implications for our species' evolutionary history and the ability to develop cumulative culture (50). The degree and strength of intra-and inter-regional group interactions among prehistoric hunter-gatherers and their spatial distribution have been proposed to be key factors for cultural transmission (26). Our model focuses on mobility and spatial patterns that can arise from hunter-gatherer foraging and does not consider other factors that could have shaped their mobility and networks. Nonetheless, it sheds light on the mechanisms by which the regional-scale

connectivity generated by central-place foraging despite low population sizes throughout our species history. Such connectivity could have maintained cultural diversity and complexity by allowing cultural recombinations, transmission of innovations, and preventing the loss of existing culture (11; 51; 2; 5; 52).

Future models could simulate more complex portrayals of physical (for example, resource distribution, traveling costs, seasonality) and social (for example, demography, inter-forager competition, cooperation, sociality, kinship, learning) environments that would have characterized early hunter-gatherer communities. These factors would have potentially interacted with foraging and mobility decisions and cultural complexity (53; 54; 55; 56; 28). Moreover, these factors would have also interacted with the cognitive capacities of our early ancestors (e.g. spatial memory, longer-range planning, larger neocortex, theory of mind, symbolic communication) (57; 58). Such cognitive factors would have affected the ability to explore larger spaces, engage in central-place foraging and maintain more extensive social networks, and possibly created selection pressures that paved the way for present-day human cognition and culture (59; 60; 61; 62).

Although future research should also address potential selection pressures experienced by our ancestors that would have led them to start using and returning to home-bases, our study corroborates early claims that central-place foraging would have had important implications for the accumulation and transmission of tools and other types of information (12). However, our work highlights the role of mobility and spatial patterns that stem from central-place foraging in our evolutionary history. We suggest that mobility-driven networks could have led to positive feedback whereby a more efficient transmission of social and/or ecological information, increased food-sharing, better resource-defenses, and a greater accumulation of material culture at a few places would have been advantageous to central-place foragers (63). This advantage could have further promoted reliance on increasingly complex culture and encouraged adaptations to social networks (for example, through kinship or trade) to efficiently generate, transmit and sustain such culture (64; 65; 11; 66; 67; 68).

Online Supporting Material

All code required to reproduce the results reported in the paper will be made available via GitHub.

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Author contributions

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