Beyond the individual: A social foraging framework to study decisions in groups

Ketika Garg✉[1], Wenning Deng[1] & Dean Mobbs[1,2]

[1]Department of Humanities and Social Sciences and Computation and [2]Neural Systems Program at the California Institute of Technology, 1200 E California Blvd, HSS 228–77, Pasadena, California 91125, USA.

✉kgarg@caltech.edu

Abstract

A key goal of the behavioral sciences is to understand how agents decide between rewarding, hazardous, and conflicting options. Foraging theory, which is rooted in ecology and evolutionary theory, has helped advance this pursuit but has largely been limited to the study of the individual. In this Perspective, we extend beyond an individual. We propose social foraging as a promising avenue to study social decisions, or decisions within a social context. Recent research has already applied similar paradigms to study social behavior in naturalistic conditions. We synthesize the key socio-cognitive elements involved in social foraging that can be further studied through foraging paradigms. We then propose a social foraging framework that distinguishes between the asocial and social components involved in the decision-making process and describes their integration. Our framework bridges research across disciplines to provide a promising new avenue for the study of social behavior by linking decisions across different scales, from individuals to collectives.

Introduction

Sociality has been a distinguishing and essential feature in our species' history and success. From the beginning of our time as hunter-gatherers to the present day, we rarely make our decisions in isolation. Instead, we make decisions as part of a group, and even collectively as a group. Foraging theory has helped study and situate human decision-making within ecologically and evolutionary valid contexts (1). However, its applications have been largely limited to individuals and overlooked the social aspect of decisions such as social inference, learning, coordination and collective behavior. In this Perspective, we introduce a social foraging framework that can help extend decision-making beyond the individual and towards a richer understanding of behavior and decision-making in groups, especially in naturalistic settings.

Since the early theories of optimal foraging (2–4), foraging paradigms have been a staple across the behavioral sciences. Optimal foraging models provide naturalistic and ecologically valid contexts to examine decision-making under conditions that test an individual's ability to balance costs and benefits (1) to maximize their energy intake. They also provide tractable ways to simulate different conditions like uncertainty, threat, and risk, to induce fundamental trade-offs that underlie many decisions. For example, many foraging studies have investigated how individuals balance trade-offs between exploration and exploitation [e.g., (5–7), speed and accuracy (8,9) and risk and safety (10) to maximize their fitness, and how environmental conditions, state-dependent factors, emotions, and individual differences affect these decisions.

Many species, including humans, forage in groups, where they either compete for resources, or share relevant information and act collaboratively, or a mixture of the two. When compared to solitary foraging, foraging in social groups poses new challenges like coordination or competition and opportunities like risk dilution and resource sharing. In the broader context of evolution, social foraging has arguably been a key driver of social intelligence and general cognition (11) and a primary contributor to the evolution of sociality. Social foraging may have even acted as a selective pressure on several cognitive processes like theory of mind, sophisticated planning, and social learning to successfully navigate social environments (12,13). At a basic level, others' presence, whether in a competitive or collaborative context, could necessitate accounting for and improving the efficiency of one's own decisions (14). At a more complex level, individual agents would engage in social learning, and infer and predict others' actions and intentions like directions of movement to inform their own decisions.

In this Perspective, we propose a social foraging framework to study how individuals make decisions in and as a group. Social foraging builds upon general decision-making, where a sequence of decisions leads the forager to achieve a certain goal, but adds a layer of social interaction. It also extends to the collective level, where foragers act as a group, allowing for the examination of decision-making across multiple scales, from the individuals to groups. We begin by reviewing different conceptual models and types of social foraging. We then outline the key socio-cognitive components that underlie or manifest in social foraging. We end with an integrative framework that distinguishes between the asocial and social components of social foraging and how they integrate. Our framework can open new avenues for the study of social and collective decisions, help compare them with individual decisions, and uncover how they integrate with each other.

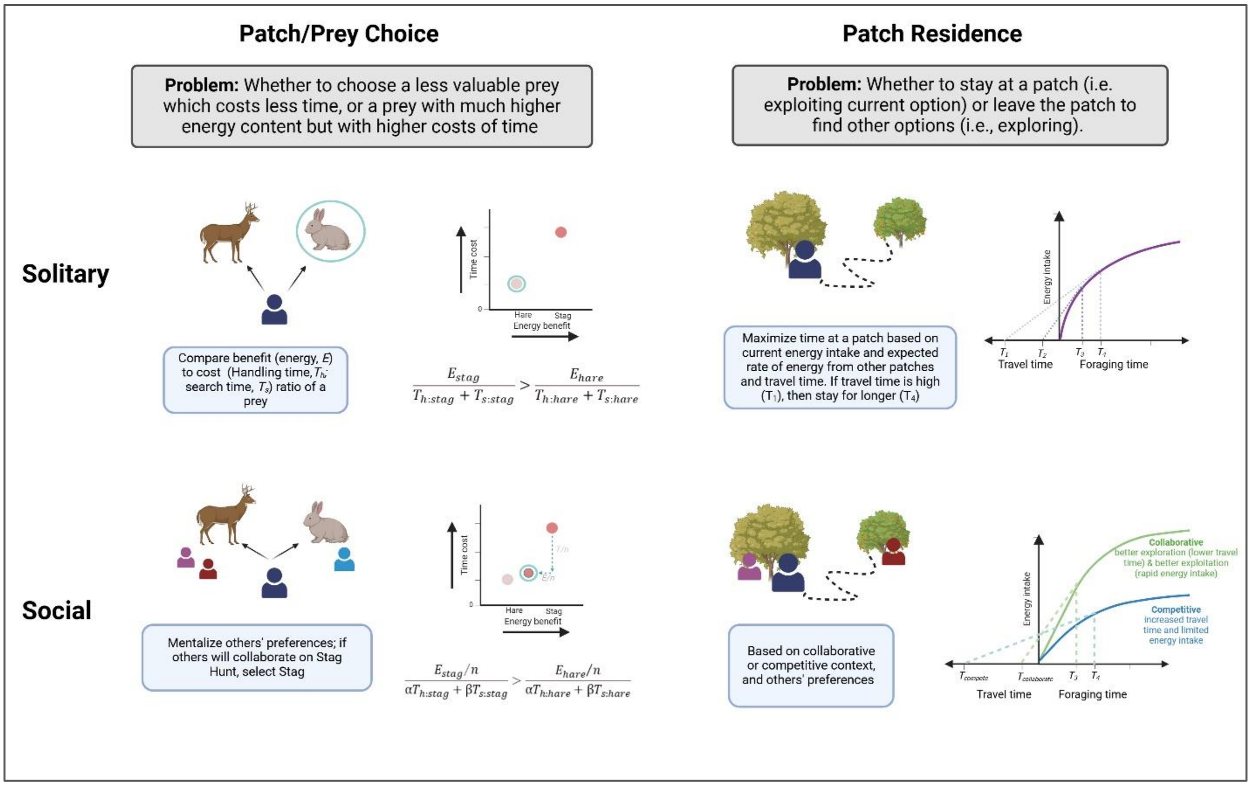

Fig 1. Social modifications to classical solitary foraging paradigms: Prey-choice and patch-residence are classic decisions in optimal foraging theory. In solitary foraging, decisions are driven by the energetic value of each option and the cost to attain it. In social foraging, the social environment (other agents' preferences, group size, social context) will scale these values and costs and modify the decisions. For instance, in a collaborative context, travel time between patches can be reduced if foragers share information about the patch availability. They can also exploit a patch better by coordinating their efforts. These changes will then affect the marginal value of staying in or leaving a patch.

What is Social Foraging? Conceptual Models of Social Foraging and Existing Work

To survive in the natural world, an individual forager needs to decide which resource to consume, and optimally search for resources, while avoiding dangers (e.g., predation or starvation risk). In many species, including humans, foraging often occurs in groups. The natural world is riddled with different forms and types of social foraging, from quorum-sensing bacteria (15), and eusocial insects (16,17) to hunter-gatherers (18). We conceptualize social foraging as a phenomenon where individuals forage in each other's presence. The presence of other foragers can create new phenomena like competition, collaboration, cooperation, etc., that are uniquely social. This added layer of social phenomenon can introduce new trade-offs and modify optimal decisions. On one hand, if competing for limited resources, social foraging can be detrimental to the survival of an individual. On the other hand, foraging with others can unlock a suite of benefits and possibilities unattainable by a single forager, such as safety against predators (e.g., risk dilution and protection), collective pooling of information, distributed energy expenditure, and division of tasks (19,20). In this section, we outline two different contexts of social foraging.: competitive and collaborative. Each of these context introduces trade-offs that do not exist in individual foraging. Yet, each builds upon the individual foraging decisions like finding food, selecting between patches, optimizing the time spent on a patch, and avoiding predators. (see Fig. 1 for how classical foraging models can be modified to accommodate social foraging).

Competitive foraging: Competition between foragers, where an individual's success decreases in the presence of others, provides the simplest case of social foraging where individual decisions change based on other foragers. Given an option to choose between two patches, an optimal forager will prefer the one with more resources. In the presence of others, the decision should tilt towards the patch where there is less competition. *Ideal-free distribution* models how foragers distribute themselves among resource patches to minimize competition and maximize fitness(21). Studies have shown that when deciding between two patches or rewards, humans tend to choose options that minimize competition (22–26). In one study, Mobbs, Hassabis, et al. (26) showed that people choose to stay in a patch or leave based on how they balance the number of competitors and the reward rate.

Minimizing competition often needs to be weight against the benefits of *risk dilution* (27), which can also affect how foragers distribute themselves (28). Being in a group can reduce the chances of being caught by a predator and therefore downregulate fear (29). Silston et al. (10) provided evidence of this trade-off between risk dilution and competition avoidance during group foraging. They showed that based on the level of threat, people flexibly choose the optimal option by computing both the safety benefits and the competition costs of foraging in the group. They found that under high threat levels, people are more likely to forego the cost of competition and choose a patch with more foragers to reduce the chance of being attacked by predators.

Social information can also influence decisions to join or avoid others, as has been suggested by *information-sharing* models (30). The presence (or absence) of others on a patch can be a valuable source of information about the patch quality. Goldstone et al (2005) showed that when people could see which patch others preferred, they chose that over the risk of overcrowding. In a recent study, Wu et al (31) designed an immersive social foraging experiment based on Minecraft and showed that people adaptively decide whether to forage away or near others and whom to forage with. They found that people continually integrate individual reward rates with others' successes to make these decisions: following successful people when they are unable to find rewards by themselves. The opportunity to glean information from others' decisions and efforts can give rise to social dynamics, such as producer-scrounger (32,33) whereby not every individual contributes equally and takes advantage of others' efforts.

Collaborative foraging: We define collaborative foraging as an umbrella term where two or more can benefit from others' success. They may share some or all goals or coordinate their actions to produce mutually beneficial outcomes (34). Foraging in a group provides several benefits such as vigilance, risk dilution, and social learning (20). However, collaborating with others can also pose a trade-off between short-term individual goals and long-term incentives for groups.

Searching for unknown resources, prey or information is a central problem in foraging. Optimal search decisions require foragers to find resources under the costs of movement, effort, time, uncertainty, and predation risk (2,6,35,36). In collaborative groups, foragers can share information about resource locations with others and *collectively search*. Collective search can reduce search costs, and improve search efficiency (37). With effective use of social information, foragers can coordinate better (38). Hawkins et al. (39) developed a collective sensing task where participants moved around in an area with hidden rewards. They found that individuals flexibly infer other's rewards and copy their behavior to enhance the collective performance. In another recent study, Deffner et al. (40) designed an immersive collective search experiment and showed that selective use of social information improves performance.

Compared to searching for multiple, static rewards, *hunting* for a single, mobile resource requires more complex inferences and coordination. From catching and chasing to blocking the prey (41–43), it often requires individuals to take on different roles within the group. Such effective spatial and temporal coordination can require complex processes such as theory of mind (44) and shared intentionality. While foraging or hunting together, there is often the risk of predators or other competing individuals. Individuals can work together to collectively defend themselves against other groups or predators (27) or coordinate to be jointly vigilant. Experiments on foraging under threat in humans showed that individuals attend less to threats in a group and adopt collective vigilance strategies (45,46).

In the context of human evolution, social foraging occupies a special place (47,48). Successful collaboration and the ability to achieve goals by coordinating with others is considered a significant step in human evolution (49). It also likely facilitated human socio-cognitive "niche" with elements, such as cooperation, coordination, theory of mind, and communication.

Box 1: Game Theory, Social Decisions, and Social Foraging

Social foraging and social decision-making literature have shared roots in game theory. Traditionally, it has been useful to invoke game theory when individual fitness is dependent on the actions of other individuals in a group (50). When viewed as a "game," different strategies or actions can lead to different payoffs. By simulating these strategies, we can explore their outcomes and interdependence. In behavioral economics and psychology, economic games have been widely used to study coordination, cooperation, selfish behavior, social preferences, etc., leading to the development of many standardized 2-player games like trust games, hawk-dove, prisoner's dilemma, and stag-hunt. Other games, like the Public Goods Game, extend beyond 2-person interactions and study how a person strategically interacts within a group.

Similar dynamics occur in social foraging, too, because of an inherent interdependence between an individual and others' decisions (51). Many economic games are indeed an abstraction of foraging economics. For example, the stag-hunt game is a simplified hunting dilemma: two people need to coordinate to hunt for a bigger reward, and miscoordination will lead to a loss (52). Social foraging paradigms can further build upon game-theoretic models by situating economic games in naturalistic and complex settings to gain data beyond what two-choice paradigms can afford (e.g., movement data, synchronization, multi-agent coordination, threat). It can help create dynamic, continuous tasks that probe state-dependent actions (53–55) and deviations from expected or "rational" behavior.

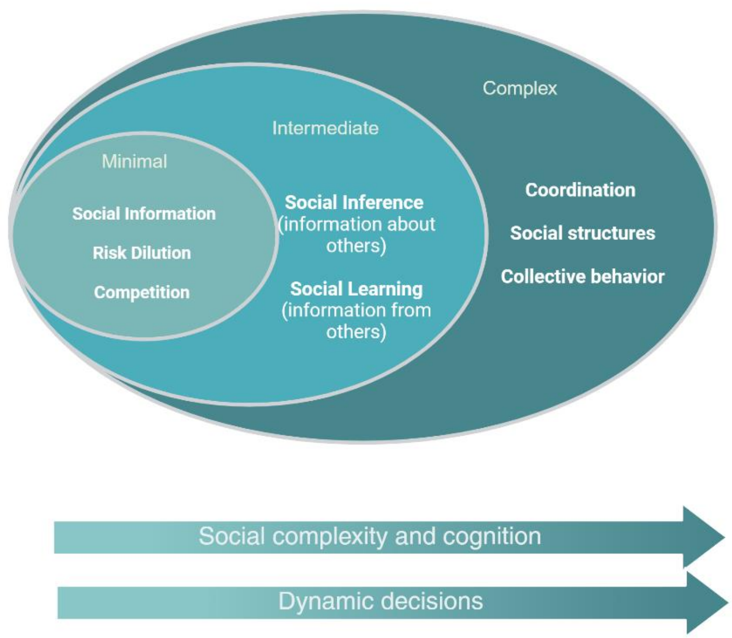

Fig 2. Three Levels of Social Foraging: At a *minimal* level, social foraging introduces the possibility of competition for resources, social information, and risk dilution against predators. At an *intermediate level*, for e.g. in small group foraging, there are processes like active social inference and learning at play. At a more *complex* level, for e.g. in large groups, dynamics involving coordination, social structures, networks, and collective behavior can be present.

Socio-Cognitive Elements of Social Foraging

For an individual forager, the decisions to find resources depend on the conditions of their external environment, such as resource distributions, costs of travel, predation threat, etc. In a group, the external environment includes the social group, and foraging decisions must also account for the behavior and decisions of others in the group. Constraints from the social environment can modify optimal decisions. Compared to resource environments, social environments can be more complex due to multiple interacting components. They can also be more dynamic and uncertain, where individuals and interactions between them are liable to more frequent and even more rapid changes. Social foraging can therefore present an inherently greater intellectual challenge than individual foraging (41). This complexity can necessitate individuals to develop and apply various socio-cognitive processes (56,57).

We review selective general elements of social behavior that are particularly relevant in social foraging, either as drivers of foraging decisions or their consequences These elements can build on top of each other and lead to complex forms of social foraging (Fig 2). We outline these elements separately but decisions in social foraging are likely driven by an integration of these processes ((58), see next section).

Social Inference: Theory of mind

To succeed in both competitive and cooperative interactions, individuals need to interpret and predict the intentions, beliefs, and motivations of their foraging partners, or at the very least predict their actions. Examinations across species have shown that how social a species is can affect its ability to form a theory of mind, i.e., representation of others' beliefs. Some deeply social primates utilize behavioral features such as gaze or movement direction, to infer others' goals and to modify their own behavior to tactically deceive in competitive tasks (59). They may also need to mentalize recursively about others' beliefs (60) for a review), and recursive in a dynamic way. (61–63). A spatial foraging task, modeled on the stag-hunt game, showed that people engage in rapid online assessment of other's actions and intentions and recursive reasoning about others' actions drives cooperation (64). Decisions to coordinate or compete, or flexible adjustment of the degree of competitiveness is driven by inferring others' intentions and regularly updating those predictions (65). Knowledge about other agents' preferences and goals can help predict their actions and be especially important for survival and foraging decisions (66).

Social learning

When foraging alone, individuals must learn about an environment, its resources and dangers, by themselves, often at considerable risk. But in a group, they can socially learn from others and avoid facing personal costs (19). Social learning can guide important foraging decisions like when to depart a patch, and which patch to choose or avoid. When alone, foragers need to continuously assess the quality of a patch as they exploit it, but in groups, they can estimate the quality of a patch based on others' estimations (31,67). They can directly copy others' actions to learn where to seek rewards and where to avoid threats or choose to selectively copy based on their social partner's behavior or status. Or, they can infer the hidden reward structure of the environment from observing other's behavior, as has been evidenced through tasks employing tasks like multi-arm bandit (68,69). A spatially correlated multi-armed bandit task that resembled a foraging task showed that people learned latent, generative rules of the reward landscape via social learning(37). To decide who and what to socially learn from, foragers need to attend to salient social information, i.e., information about their foraging partners (70). Not all forms of social learning are beneficial. Direct copying can be maladaptive if social information is inaccurate or non-generalizable (68), over-relying on social information can lead to herding and adaptive social learning can make groups more efficient (38,71,72). Social foraging models and tasks have further shown that environmental structure and social partners affect the selection of optimal social learning strategies (31,38,39,73).

Coordination and Social Role-Taking

Social inference paves the way for coordinating or aligning with each other. Coordination is especially adaptive in the face of multiple, mutually exclusive, and costly activities. Foraging for food requires effort, energy, and time. Simultaneously expending time and effort on other crucial activities, like avoiding predators, can limit the physical and mental energy available to the forager (74–76). Coordinating with others and distributing some of the tasks among a group can thus be beneficial. Coordination becomes even more important in tasks like hunting. To hunt a moving prey, individuals need to plan their actions to coordinate with others, and to do so they need to predict the future location of their prey and the decisions of their group members (64,77,78). A shared risk (79) or benefit (80) between foragers motivates the emergence of coordination, and even the act of coordinating together can be motivating (81). Socio-cognitive mechanisms such as joint attention, shared goals, social norms and small group sizes (49,82,83) can further support coordination .

Social Interactions and Social Structures

Foraging with others gives a chance to exchange information and use it optimally to coordinate (83,84) and cooperate (as shown in hunter-gatherers (85). Decisions about movement and patch selection can affect the opportunity of interactions (86) and dynamically change the social networks over time (31). Research in social animals has increasingly emphasized that social interactions in foraging are guided by a forager's representation of its social network. In bats, social interactions during foraging induce inter-brain coupling whose strength depends on the forager's position within the social network (87). Another study further highlighted how individuals keep track of social interactions not just with others but also between other group members (88) and use that to inform their social foraging decisions. Research from other animal studies has demonstrated the interplay of social network structure and group composition (i.e., the characteristics of individual foragers) in foraging decisions (89). In humans, economic paradigms have shown that people weigh social information based on the social network structure (90) and that the social network structure affects collective dynamics like the spread of cooperation (91). Integrating network science into social foraging can enrich these findings.

Group Decisions and Collective Intelligence

Social foraging affords an opportunity for individuals to act *collectively,* i.e., as a group. Multiple and coupled social interactions can give rise to collective intelligence that exceeds the capability of any individual (92,93). Collective decisions about where and when to move can increase a group's accuracy and performance (94). Collective problem-solving can generate more novel solutions in a more efficient manner (95). Whether a group is collectively efficient can depend on many factors, such as the environment structure (31), the knowledge and skill of group members (96), the incentive structures (40,97), and the interactions between group members (38,95). Experimental research on human collective foraging shows that collective performance is driven by flexible adaptation of foraging and social learning strategies (31,40,98). Further research on collective behavior can explicitly link foraging theory to generate easily testable predictions (99).

Behavioral Flexibility and Dynamic Decisions

In many of the examples above, two key features seem to underline social decisions: flexibility and dynamic updating. To deal with rapidly changing task conditions, decisions and the processes underlying need to be flexible. Physical environments are mostly predictable and change over slow timescales. However, adding other foragers can increase the level of complexity and dynamic nature, and transform the decision space into a dynamic *seascape* (100). The presence of other, often moving, individuals with continually changing behavior and intentions requires faster and more flexible decision-making (56). Foragers need to keep track of others' behaviors, goals, etc., and update actions flexibly at a more dynamic pace. It can necessitate rapid cognition in terms of perception, learning, memory retrieval, and decision-making, and may engage neural circuits distinct from non-social behavior (101).

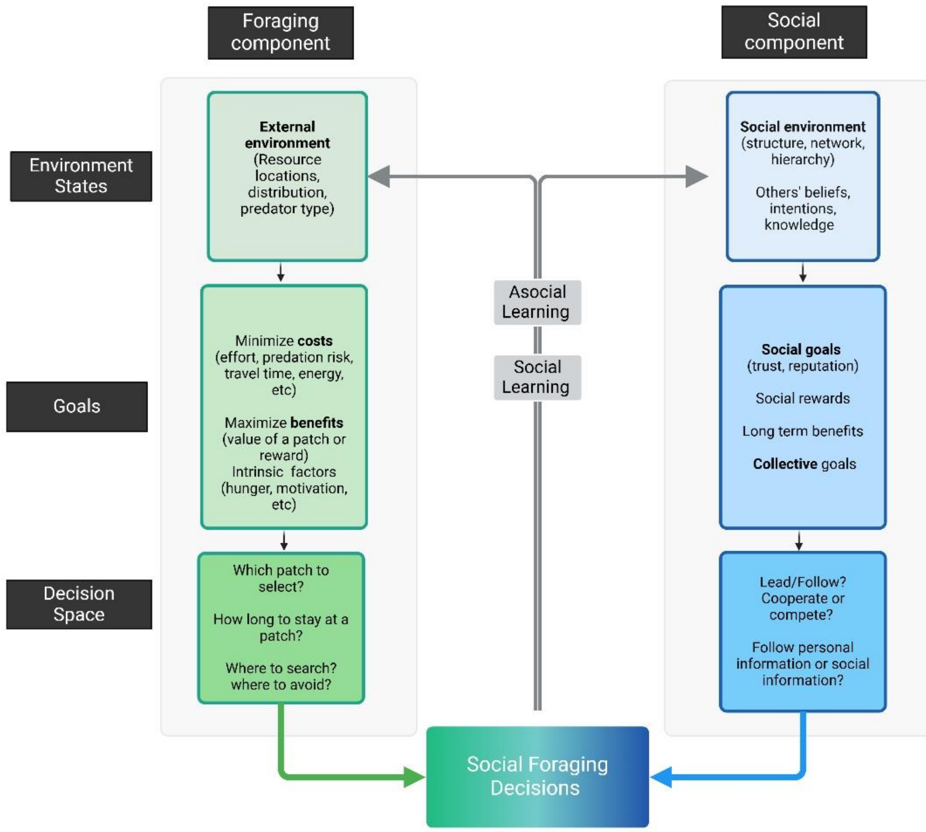

Fig 3. Social Foraging Framework: Social foraging decisions can be broken down into two components: foraging (left) and social (right). Within each component, we further distinguish between *Environmental States*, (i.e., the external states like reward distribution), and social information that inform decisions; external and internal states then frame the *Goals* of an agent and the possible actions available in the *Decision Space*. These processes finally inform social foraging decisions through an integration function that weighs different goals and selects an action. The outcome of a selected action can then update the external states and goals via *Asocial Learning* or *Social Learning* based on others' actions and outcomes.

Social Foraging: An Integrative and Unifying Framework

In summary, the three effects of social foraging become clear. It modifies foraging decisions associated with risk and reward. It introduces new decisions that are uniquely social, such as who to learn from, or who to follow. Lastly, it gives rise to decisions that are driven by an socio-cognitive mechanisms. We introduce a social foraging framework that can integrate these various concepts and contextualize them within the usual framework of decision-making models (102).

We conceptualize the social foraging process as a combination of two, interrelated components: foraging and social (Fig 3). The *Foraging* component characterizes the commonly studied decisions that an individual is confronted with regarding foraging activities like finding food or avoiding predators. The *Social* component conceptualizes the unique additions of being in a group and engaging with others. The social addition layers the foraging component, compounds its environmental states, its goals, and expands its decision space. The objective of the framework is to highlight the differences between social and solitary foraging and to describe how they influence social foraging decisions. We offer a formal account of the framework in Box 2.

Environmental State: Foraging decisions are informed by the known state of the physical environment like resource distribution or predator sighting. The social component is driven by the social environment; information *about* social partners, their beliefs, knowledge, and intentions, and the structure of the social environment like social network positions, and dominance hierarchies (87,88). Social environmental states can be represented by employing the theory of mind or accessing social information about others, which can then be updated by learning. A social environment can be richer, more dynamic, and more uncertain than a physical one. While a solitary forager can only learn about the environment state by trial and error, a social forager can socially learn from others about both the physical and social environment.

Goals: A forager's primary goal is to maximize their energy returns against costs of energy or time (1,103), which can be further affected by intrinsic factors like hunger or motivation. For social decisions, a forager needs to account for social goals like coordination, and social rewards like trust or reputation (49,104). Other agents' states, goals, and predictions about their actions can affect social foraging goals (64,66). The time horizon of social foraging goals can be longer than that of solitary foraging; a social forager may need to give up short-term maximizing goals to achieve long-term benefits and stabilize rather than maximize. The foraging and social goals can influence each other and integrate given their respective weights to define the value of a given decision (31). In collective foraging, the group-level or collective goals can influence other goals (40).

Decision Space: Foraging decisions revolve around where to search, which patch to exploit, when to leave a patch, and the trade-offs between different choices. Being a part of a group widens this decision space. Foragers also need to make decisions related to how to engage with others. For example, they face additional trade-offs like deciding between following others towards a location or not, who to follow, to share resources or not, to compete or cooperate, or which social role to take. High-level social decisions like competition or cooperation can affect other decisions in a hierarchical manner (105) and pre-select the foraging decisions. For example, decisions to cooperate with others may increase the likelihood of sharing food with others.

Integrated Social Foraging: We argue that decisions in social foraging are a result of an integration of both foraging and social components. On one hand, physical environment states and foraging goals can affect social goals. For example, grouping or cooperation becomes more likely under high levels of environmental risk and uncertainty (10,29,106). Silston et al. showed that participants weigh others' presence and external threats to evaluate the appropriate patch to select. In the absence of threat, they prefer patches with fewer competitors, while with high levels of threat, they prefer patches with others. On the other hand, social environment, i.e., information about and from others can influence asocial goals and decisions such as which patch to select (107), how much effort to apply (108), or optimal movement strategies (31,33,40,66).

Such integration may be driven either by overlapping computational mechanisms of asocial and social components, or by different and specialized mechanisms that eventually integrate to guide behavior. There is growing evidence for overlaps between how we represent spatial and social environments and navigate through them (109). Information about others' positions relative to each other in a social network is represented in a similar fashion as information about physical locations in space (110). Social rewards and social threats appear to elicit similar mechanisms as foraging-based rewards or predator-based threats (111).

Other evidence suggests specialized mechanisms underlying social processes. An experiment, where participants had to locate a hidden reward under social and asocial cues, showed that social cues were processed in a different manner than asocial cues. People processed social cues based on interaction history and placed more weight on them than they did on asocial cues (112). Although, social learning has been shown to share general computational mechanisms with asocial learning, while being implemented differently at the neural level (113). Even at the computational level, learning processes in a social context can be different than in asocial context, and need an additional accounting for others' actions (62,114). The social foraging framework, with its ecological and evolutionary lens, can further such investigations on the integration between the asocial and social components of decision-making.

Box 2. Social Foraging Framework: A formal account

We first consider a solitary agent. An agent's foraging decisions to be represented by a set of environmental states, (S_{f} $= s_1, s_2, .., s_n$), goals ($\mathcal{G}_{f} = \mathrm{g}_1, \mathrm{g}_2, .. \mathrm{g}_\mathrm{m}$) over a set of possible actions that an agent can take, ($\mathcal{A}_{f} = \mathrm{a}_1, \mathrm{a}_2, .. \mathrm{a}_\mathrm{k}$). We can now consider a social foraging agent, whose actions will be defined by the foraging component, layered by a social component. A social agent's environmental states will include ($S = s_{s1}, s_{s2}, .., s_{sn},\ \mathcal{S}_{f}$), goals ($\mathcal{G}_{=}\mathrm{g}_{s1}, \mathrm{g}_{s2}, .. \mathrm{g}_{\mathrm{sm}},\ \mathcal{G}_{s}$) over a set of possible actions that an agent can take, ($\mathcal{A}_{=}\mathrm{a}_{1\mathrm{s}}, \mathrm{a}_{2\mathrm{s}}, .. \mathrm{a}, \mathcal{A}_{f}$). The policy function of a social agent, $\Pi_{\square}$, can select a decision based on different weighting of foraging and social goals.

$$Q^{\pi}(s, a|g) = \sum_{s'} P(s'|s, a, g)[U(s', s, a|g) + \gamma max_{a'} Q^{\pi}(s', a'|g)]$$

$$Q^{\pi}(s, a) = \sum_{i} w(g_i) Q^{\pi}(s, a|g_i)$$

$$\mathrm{U}(.\,|g) = \theta(g)U_{\mathrm{self}}(.) + \big(1-\theta(g)\big)U_{\mathrm{others}}(.)$$
$$\text{Social foraging decision, } \pi_*(s) = \mathrm{argmax}_\pi Q^\pi(s,a)$$

where g_i denotes each goal an agent has, and w_i denotes the weight the agent puts on achieving each goal. π denotes the policy of taking an action, a at state, s. $Q^\pi(s,a,|g)$ denotes the value function of policy π given the goal. U denotes the immediate utility gain of transferring from state s to s'. Here the agent calculates the utility as a weighted average of self-utility and other-utilities, and the agent is trying to pick an action that maximizes the overall value function given how much they value each goal.

We can consider four cases of social influence:

Case 1: Minimal social influence. When an agent is foraging with a group, the agent can modify their decisions based on others' actions. The agent will use social information to calculate the utility of a patch, but only utility for the self (θ = 1). The goal will only be to maximize self-reward against costs.

Case 2: Influential social goal. In many scenarios, the agent has a social goal, such as cooperation or competition, and must make decisions to achieve the social goal. Then $\mathrm{W}(i) = 1$ for that specific goal and 0 for others. Depending on the social goal, the agent can assign different utilities to the self and others.

Case 3: Dynamic social integration. In more complex social scenarios, an agent will dynamically select both social and nonsocial goals to maximize overall utility. For example, an agent may choose to compete or cooperate based on the scarcity of the environment, or the intention of social partners. In this case, the agent will dynamically update the $\mathrm{W}(i)$ that they assign to each goal.

Case 4: Collective decisions. In collective foraging where everyone shares the same goal of maximizing group benefits, we can assume a shared collective goal $g_{collective}$ and collective utility $\mathrm{U}_{\mathrm{collective}}$ drive decisions. We can also assume that the weights of other goals will depend on $g_{collective}$ and can vary to influence the correlation between agents' weights. A weight function like $W_{homogenous}(g_i|g_{collective})$ would lead all agents to converge towards a similar behavior, maximizing the Q-values that align with the collective goal. $W_{complementary}(g_i|g_{collective})$would allow for coordination or division of tasks, where different agents prioritize different individual goals that complement each other under the collective goal.

Concluding Remarks

Integrating various strands of research under a broader paradigm has been a longstanding challenge in the behavioral sciences. Newell (1973) advised focusing on a single complex task. Rather than designing specific, small, disparate experiments aimed at specific, small, disjointed questions, he advocated for framing research pursuits around a single complex task, for example, chess. But how to choose a model or research paradigm to achieve this goal? Biological sciences, where research is usually focused on a model organism, can offer insights. A good model organism should be tractable to study in labs, be evolutionarily related to the target interest, be well-defined in its properties, and be complex enough to spur various lines of investigation (116). In many ways, foraging paradigms check these boxes.

Social foraging paradigms can build on the established framework of foraging theory and afford mechanistic insights into social behavior (117). Similar to how foraging studies have driven comparative research across species (118,119), social foraging can extend these pursuits further. Similarities in asocial and social foraging can pinpoint fundamental computations in social decision-making, while differences can reveal unique behavioral or neural adaptations. Recent advances in experimental design and computational modeling bode well for the study of social foraging. Gamification of experiments (6,10,31,39,40,120) can target rich, naturalistic social behavior with continuous decision-making. Theoretical approaches can employ agent-based models to focus on emergent social behavior or underlying cognitive computations (33,38,73,86). Advances in computational modeling of behavioral and neural data can further yield mechanistic insights (92), for example, hyperscanning can dig into the workings of real-time social interactions (121) or how social environment is encoded (122).

In conclusion, we live in highly complex social environments and have evolved within them. Foraging theory has helped contextualize adaptive decisions and underlying cognitive processes. We propose that social foraging is a complex “super-task” (115) that can substantially integrate smaller tasks and make them commensurate amongst themselves to yield a detailed picture of social behavior (123). It can help go beyond the individual and study behavior across scales—from individuals to dyads, groups, and collectives.

Table 1. Extensions to decision making in social foraging. Foraging paradigms have shed light on important aspects of decision-making. We offer future research questions that can extend these findings in the social context through social foraging paradigms.

Aspects of decision-making	Examples from foraging paradigms	Modifications in a social foraging paradigm
Exploration vs Exploitation	How do individuals balance between exploration and exploitation in patch choices (7,124–127)? How much resources like time, energy, effort should be expended on these activities?	How do competitive or cooperative social contexts affect this trade-off? How do groups manage this trade-off? (33,38,40) How does the presence of others change allocation of time or energy? (108) How do groups distribute effort amongst themselves for different activities? (45)
Risk sensitivity	How does probability distributions of reward affect expected utility and choices? How do individuals balance between risks and rewards in foraging? (128–132)	How does risk sensitivity change as a function of group size? (10) How do people coordinate with other who differ in risk preferences? Do differences in risk manifest in or lead to different social roles?(133)
Learning	How do foragers learn about the properties of resource environment? Do model-free or model-based learning rules describe foraging decisions? (5,134,135)	How do people integrate social and asocial learning and selectively learn from others? How does social learning inform movement and social interactions? (31,40) How does social context (competition or cooperation) affect learning rates? (14)
Memory	How do individuals navigate new environments, and learn the location of resources or predators? How does spatial memory affect foraging decisions? How do goals affect attention and memory? (136–139)	How do people construct cognitive maps of dynamic social agents? How does social learning or social integration affect spatial memory? (66,140,141)
Continuous decisions	How do foraging decisions like when or where to move unfold over time (6,142,143)?	How does movement towards social partners unfold over real time naturalistic interactions? How do others' movements affect decisions? (31,64,144,145)

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