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Trends in Cognitive Sciences

Feature Review

Mapping the social landscape: tracking patterns of interpersonal relationships

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It is widely believed that the demands of living in large, complexly bonded social groups played a key role in the evolution of human cognition. This review focuses on a critical but understudied skillset in the social-living toolkit: the ability to acquire, maintain, and use knowledge of the interpersonal relationships among the people around oneself. We provide a multidisciplinary synthesis of a diverse set of relevant findings, including recent work on the neural encoding and cognitive and behavioral consequences of knowledge of real-world social networks, research on how third-party relationship knowledge is tracked and used by children and other highly social primates, and research examining how people's knowledge of their social networks can be leveraged to inform the design of interventions aiming to promote behavior change or to efficiently spread information. We also highlight important unanswered questions and avenues in need of further exploration.

Highlights

Successful living in a complex social environment requires individuals to track the interpersonal relationships between others that comprise their social networks.

Individuals track much information about their social networks, and others' positions within them, relatively accurately.

Mental shortcuts can reduce the cost of tracking social network information, but often lead to errors and biases.

Knowledge of patterns of ties in one's social network shapes social inferences and behavior.

Humans are keenly attuned to others' relationships

Recall the last time you met someone new at a professional or family event. As introductions were exchanged, the two of you likely tried to uncover any existing interpersonal ties connecting you to one another (e.g., friends-in-common, mutual acquaintances, or colleagues). This type of exchange allows people to place new individuals into an existing 'map' of their social landscape. In other words, it allows people to ascertain their locations relative to one another in their social networks. The observation that people often use their earliest conversations to search for shared social connections (then potentially marvel at how small the world is) led Stanley Milgram and collaborators to conduct their famous 'Small World Experiments', which showed that many pairs of strangers in the United States could be connected via a relatively small number of 'degrees of separation' [1].

Humans appear to be intrinsically interested in tracking interpersonal relationships among others. In addition to the tendency to use one's earliest conversations with new acquaintances to reveal shared social ties, this intrinsic interest is also reflected in the popularity of the six degrees of separation' game, where players try to come up with the shortest possible chain of connections linking two people. Humans pay close attention to interpersonal relationships between others, both real (e.g., everyday gossip) and fictional (e.g., in novels and films). In fact, roughly two-thirds of conversations involve gossip (e.g., discussing others' relationships and interactions [2]).

While much research on how people represent and are influenced by knowledge of interpersonal ties has focused on one's own relationships, tracking relationships between others, particularly in the large, complexly bonded social networks that humans build and inhabit, may require a distinct set of skills. Identifying, storing, and updating information about others' relationships with one another (e.g., who knows whom, who likes whom) poses a serious computational challenge, becoming exponentially more difficult with each increase in the number of tracked others.

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Nevertheless, tracking these relationships is essential to smoothly navigate one's complex social world. Indeed, agreeing to help a stranger in need can have vastly different consequences if the stranger is a friend-of-a-friend or a friend-of-an-enemy. As such, the pressure to learn about others' interpersonal relationships may have contributed to the evolution of humans' cognitive capacity [3,4].

Recently, increased interest in how individuals understand and are impacted by the patterns of relationships that constitute their social networks has resulted in a groundswell of research spanning multiple disciplines, including social and cognitive neuroscience, social and developmental psychology, applied economics, sociology, and behavioral ecology (e.g., [5–9]). Thus, there is a unique opportunity for future research to synthesize and build on these findings to advance our understanding of the acquisition, representation, and consequences of knowledge of interpersonal relationships between third parties and of characteristics of the social networks that those relationships comprise. To this end, the current review synthesizes relevant work on these topics, which has been scattered across disciplines and time periods [7,10–21], to work towards a cumulative science of such phenomena.

We consider knowledge of relationships between third parties from a social network perspective, first discussing findings related to knowledge of interpersonal relationships between pairs of people (i.e., network edges, Figure 1A), then turning attention to features of individuals' positions in their social networks (e.g., who is particularly well-connected, Figure 1C), and finally, to characteristics of broader network structure (Figure 1D). In so doing, we highlight assumptions that both support and bias the acquisition and representation of such knowledge, the cognitive and neural mechanisms supporting these processes, and how such knowledge shapes downstream processing and behavior. We also discuss research demonstrating how social network knowledge can have a real-world impact.

We note that it is important to distinguish between knowledge of interpersonal relationships and other forms of relational knowledge, including other forms of relational knowledge about people. Notably, knowledge of any characteristics (e.g., traits, preferences, physical characteristics, geographical location) of two or more people could be thought of as 'relational' if one considers how those people compare with one another in terms of those characteristics. Indeed, recent evidence suggests that knowledge of others' characteristics may be represented relationally, in a 'map-like' manner, by the brain [22]. Here, we focus specifically on knowledge of interpersonal relationships, a distinct (albeit related, Box 1) form of social knowledge that encompasses individuals' bonds with and/or feelings about one another. In particular, given the importance of affiliative interpersonal relationships between non-kin to everyday human thought and behavior and arguably, to the evolution of the human brain [3,23], we focus primarily on knowledge of affiliative interpersonal relationships between others (e.g., friendships) and the social networks that they comprise.

Building blocks of social networks: dyadic interpersonal relationships

Fundamentally, networks are made up of two 'ingredients': nodes (i.e., entities) and edges (i.e., the links between them, Box 2) [24,25]. In the context of the social networks considered in this review, each node is a person and each edge is an interpersonal relationship between two people (e.g., a friendship). In this section, we consider how people extract and represent information about the edges that constitute their social networks. In subsequent sections, we consider how this information may be aggregated to mentally represent the broader structure of social networks and others' positions within them, as well as the consequences of these phenomena.

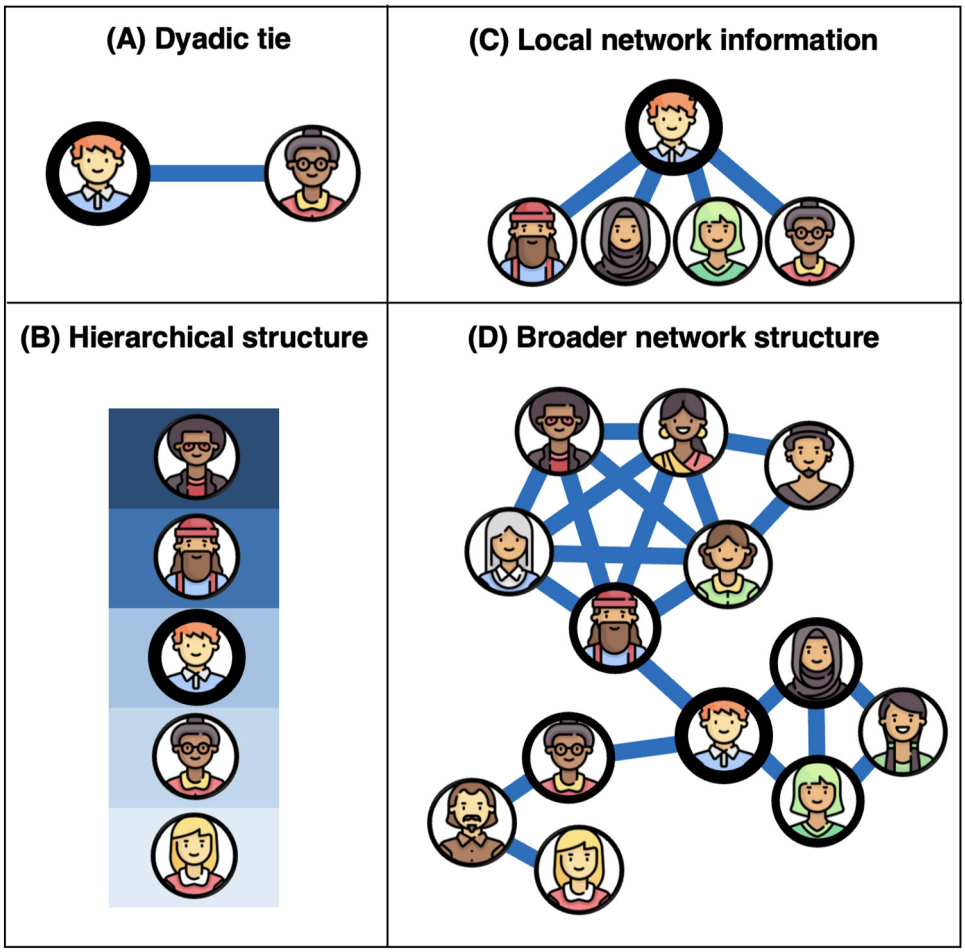

Figure 1. Simple and integrative representations of interpersonal relationships. In addition to tracking interpersonal relationships between pairs of individuals (A), perceivers can also construct more integrative representations that reveal others' relative levels of hierarchical forms of status (e.g., dominance-based status) (B) or facets of status based on local network information, such as how many social ties someone has (degree centrality) (C). Others' importance in one's social network can also depend on network-wide patterns of interpersonal relationships (D) (Box 2). However, such information can be challenging to acquire and track, as the number of possible ties in a network increases exponentially with each additional member. Icons were generated by Freepik (www.flaticon.com).

Humans and other highly social primates demonstrate considerable knowledge of interpersonal relationships between other members of their communities. Research probing mental representations of ties within real-world communities has found that people can somewhat accurately report on affiliative relationships between others (although not completely accurately [26–29]). Even in infancy, humans extract information about the nature of observed interactions between others (e.g., hindering versus helping [18,30]) and combine that information with actors' apparent intentions to infer their dispositions and attitudes towards one another [31,32]. Other highly social primates also track the valence of social interactions [33], and who knows whom in their environment [8], and leverage this knowledge to inform social behavior [8,34]. Thus, the ability to extract information about affiliative ties from observed interactions develops early in humans and extends to our close primate relatives. While these capacities may often be taken for granted in adult humans, examining the

Box 1. Linking interpersonal relationships to other forms of relational knowledge

In addition to tracking who knows whom in their social environment, individuals track a wealth of information about the people around them (e.g., demographic features, preferences, traits). While knowledge of these features and knowledge of interpersonal relationships (e.g., friendships) are conceptually distinct, they are often linked in the real world. Accordingly, people's knowledge of relations between others in terms of these various features sometimes influences their likelihood of remembering and inferring the existence of interpersonal relationships between others, likely reflecting an intuitive understanding of homophily [47–49,127] (i.e., the tendency for similar people to befriend one another [45]).

Given the link between these two kinds of social knowledge, examining prior findings regarding how individuals acquire and represent knowledge of similarities among others can provide clues about how people might acquire and represent networks of interpersonal relationships. For example, recent work suggests that by aggregating and comparing instances of similarity in traits and/or preferences between third parties, and between third parties and oneself, and combining those observations with beliefs about how social groups tend to be structured, humans probabilistically infer latent social groups that inform predictions of their future similarity to those individuals [103]. Considering the aforementioned tendency to associate similarity between third parties with the likelihood of an interpersonal relationship, this work suggests the possibility that similarity-based inferences about latent social categories (based on others' similarities to each other and oneself, as well as priors about social group structure) may shape or interact with inferences about the structure of social networks [112].

Relatedly, while previous work has examined how the ability to infer and remember dyadic relationships is related to similarity along different factors (e.g., traits, preferences, demographic categories) [47,48,127], recent work has begun to examine how individuals integrate aggregated knowledge of similarity across multiple different features with knowledge of interpersonal ties to determine which instances of similarity have a higher probability of predicting affiliative relationships among others [49]. Thus, people may combine veridical knowledge of dyadic ties with other types of relational knowledge to fine-tune their reliance on homophily and narrow down which information is used to probabilistically infer interpersonal relationships.

Future work can examine other ways that individuals leverage links between interpersonal relationship knowledge and other facets of relational knowledge (e.g., behavioral coordination, proximity) to guide social thought and behavior, and the extent to which reliance on these links varies across individuals and contexts.

acquisition and impact of knowledge of dyadic relationships can elucidate the foundations of knowledge of social networks. We next consider mechanisms that may support the acquisition of such knowledge and its impact on cognition and behavior.

Box 2. Social networks primer

Using network analysis to study social relationships has recently become increasingly popular among psychologists and neuroscientists. A network representation of social ties in a bounded community (e.g., a school, a village) can be constructed by representing each individual in the network as a node and representing interpersonal connections between these individuals as edges (Figure I).

A variety of consequential social information can be extracted from analyzing social networks, including characteristics of the overall network structure (e.g., whether there are densely interconnected communities or cliques), dyad-level attributes (e.g., relative 'degrees of separation' between people), and node-level attributes (e.g., measures of social network centrality, which quantify the importance of an individual in the network [25]). Measures of social network centrality include:

- Degree centrality: the number of connections an individual has. In Figure I, node *A*, who is connected to four others, has greater degree centrality than node *F*, who is only connected to two others.
- Eigenvector centrality: a prestige-based measure of centrality that captures the extent to which someone is connected to well-connected others in the network. In Figure I, although nodes *F* and *L* have equal degree centrality, node *F* has greater prestige, as their friends have more friends than node *L*'s friends.
- Betweenness centrality: the relative frequency with which shortest paths between others pass through an individual; this can capture the extent to which someone bridges between otherwise distant or disconnected nodes (i.e., brokerage). In Figure I, node *G*, who serves as a bridge between three otherwise separate communities (e.g., nodes *A*–*F*, *G*–*J*, and *K*–*M*), has a higher capacity for brokerage than node *I*, whose friends are already linked to one another.

Edges can be defined in wide-ranging ways across studies, even when only considering affiliative social ties (e.g., different ways of asking about friendships or other relationships, subjective ratings of liking or trust, observed interactions). Importantly, even relatively subtle differences in edge definitions can yield substantially different networks [28,113] and abilities to predict various behaviors and other outcomes [6,113,114]. Therefore, when studying individuals' ability to represent the structure of their social networks and the constituent interpersonal relationships, it is important to tailor edge definitions to best suit the research question at hand.

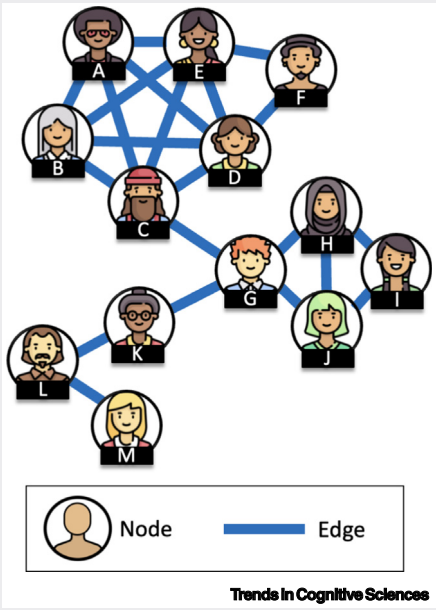

Figure I. Graphical representation of a social network. A social network consists of nodes (here, depicted as faces within circles, each depicting a person) connected by edges (here, depicted as blue lines). Edges can be defined in various ways (e.g., self-reported liking or friendships, professional relationships). Edges can also be directed (e.g., in a network of self-reported friendships, a directed edge could point from *L* to *M*, but not from *M* to *L*, if *L* considers *M* to be a friend, but this is not reciprocated) or undirected (e.g., only reflecting mutually-reported friendships), and they can be weighted (e.g., encode relationship strength or interaction frequency) or unweighted. Here, a network of undirected, unweighted ties is visualized for simplicity. For a thorough overview of social network analysis methods aimed at psychologists and neuroscientists, please see [24]. Icons were generated by Freepik (www.flaticon.com).

Inferring interpersonal relationships from observed and unobserved social interactions

Knowledge of dyadic interpersonal relationships in one's environment (i.e., of the edges that comprise one's social network) can be obtained by observing (or 'eavesdropping on') others' social interactions (Figure 2). Converging evidence from recent research on perception and cognition suggests that humans are highly attuned to others' social interactions. For example, interacting dyads attract more attention [35], are more accurately recognized [36], and are better remembered [37] than noninteracting dyads. From early in development, humans extract nuanced social information from observed interactions: infants disentangle intentions from outcomes to characterize the valence of others' interactions and use this knowledge to inform their social preferences [32]. By incorporating knowledge of intentions to understand interpersonal behavior, infants can distinguish between mutual behavioral coordination as a useful cue to affiliation (e.g., co-laughter [38]) and unidirectional imitation, which may not indicate a mutual bond [31]. Children also recognize preferential sharing of information and resources as a reliable cue to friendship [9,39,40]. Overall, these findings reflect humans' early understanding of affiliative relationships as mutual bonds that are based on intentionally directed prosocial behavior.

When perceivers cannot directly observe social interactions between others, they can sometimes learn about others' interpersonal relationships indirectly via second-hand accounts relayed during gossip (Figure 2). Recent work has looked beyond its negative connotations to study gossip as a means of acquiring information about others in one's social environment [6,41]. Yet, much remains to be understood about gossip as a tool for learning about interpersonal relationships. Considering the ubiquitous tendency to speak about others [2] and the salience of information acquired through gossip [42], gossip may provide an efficient means of detecting and characterizing interpersonal ties among others. For instance, the type of information being relayed can provide cues to the gossiper's relationship with the target in question [43] and that target's standing among other members of the community [16] (also see 'Heuristics guiding inferences about social network centrality'). Within the first decade of life, humans develop the social cognitive

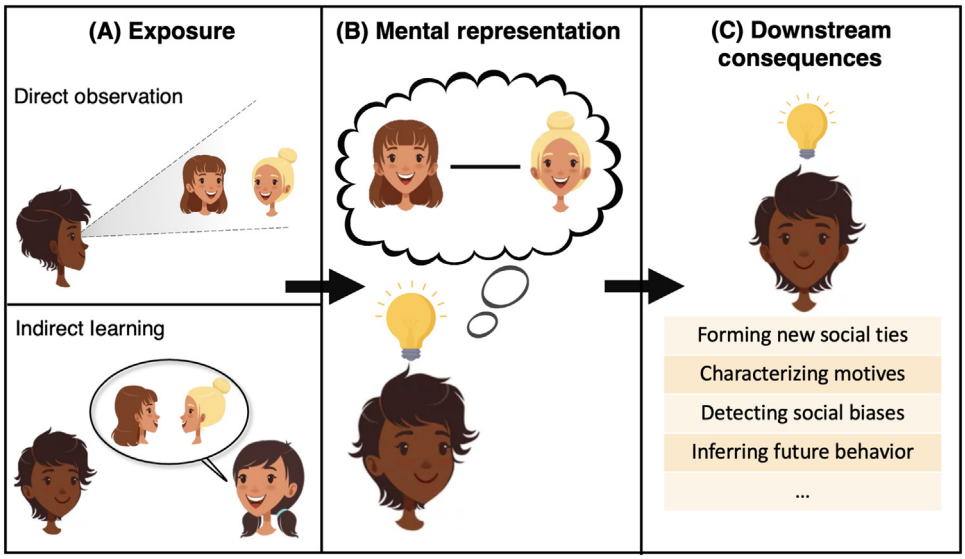

Figure 2. Acquiring, representing, and applying knowledge of interpersonal relationships. Information about others' interpersonal relationships can be acquired directly, from observing interactions between others, or indirectly, such as through gossip (A). Through direct and indirect learning about others' interactions and relationships, perceivers can form mental representations of others' social ties (B) and use this knowledge to inform their future social inferences and behavior (C). Icons were generated by DinosoftLabs (www.flaticon.com).

abilities necessary to effectively use gossip as a source of information about the people and relationships that constitute their social networks, recognizing the limited reliability of gossip compared with first-hand experience [44] and detecting potential biases in the information being relayed (e.g., recognizing that individuals tend to speak more favorably of friends than enemies [43]).

Heuristics and other shortcuts for inferring interpersonal relationships

Even with humans' remarkable capacity to extract information about dyadic relationships from direct observations and gossip, individuals' ability to track affiliative relationships is limited both by their ability to encode and recall observed pairings and by their access to information about these pairings. To cope with these challenges, individuals may rely on heuristics and other shortcuts that facilitate acquiring and representing knowledge of interpersonal relationships.

One such heuristic involves relying on other types of relational knowledge that could predict individuals' likelihood of sharing an affiliative tie. As mentioned previously, knowledge of interpersonal relationships (e.g., who is friends with whom) is conceptually distinct from other forms of relational knowledge (e.g., trait similarity). However, these phenomena are often linked in the real world, as similar people tend to befriend one another (i.e., homophily) and as social influence processes produce and further amplify similarities among people who frequently interact with one another [45,46]. By possessing an intuitive understanding of these phenomena, perceivers can leverage their knowledge of similarity to make inferences about interpersonal relationships [47–49,127] (Box 1). Indeed, similarity regarding a variety of attributes, such as sex [29], status [29], race [47], language [50], and preferences [48], may help people to infer and/or remember interpersonal ties, often from a young age.

Additional cognitive and perceptual shortcuts may further reduce the demands of tracking and representing knowledge of interpersonal relationships in one's social network. For example,

perceptual cues signaling affiliation (e.g., face-to-face interaction) may promote the perceptual grouping of the individuals who comprise a given dyad into a single attentional unit, facilitating the efficient appraisal of relationships among others [35]. This perceptual grouping of interacting individuals into dyads is mirrored in analogous social chunking effects in studies of working memory, where representations of individuals are bound into larger chunks when they are observed interacting with one another, reinforcing and expanding memory for individuals observed in interacting pairs [37,51,52]. Analogous chunking effects, where multiple dyadic relationships are further compressed into sets of ties, may scaffold mental representations of whole networks (see 'Heuristics facilitating efficient encoding of social network structure'). Notably, these processes are not unique to the social domain, consistent with the possibility that reasoning about interpersonal relationships may be at least partially supported by domain-general cognitive mechanisms (Box 3).

Consequences of dyadic relationship knowledge for social thought and behavior

Knowledge of interpersonal relationships (i.e., of the 'edges' that comprise social networks) can help people predict and explain others' patterns of social behavior, including selective sharing of knowledge [9] and other resources [53,54] and biased relaying of information about friends and enemies [43]. These predictions may have a wide-ranging impact, from supporting people's ability to seek/spread information (e.g., through inferences about who knows what [55]), to distinguishing dispositional (e.g., being rude in general) and situational (e.g., being rude towards an enemy) explanations of others' behavior [56] to arrive at more accurate trait inferences.

Tracking relationships involving one's direct social contacts (e.g., monitoring who is a friend-of-a-friend) may be particularly important. For example, people commonly rely on their close affiliates

Box 3. Does representing and reasoning about social network knowledge rely on mechanisms involved in representing and navigating space?

Does representing and 'navigating' social knowledge rely on mechanisms that support analogous operations in other domains (e.g., spatial cognition)? In line with this possibility, there is considerable overlap in the brain regions involved in processing spatial relationships and various kinds of social relations, including other people's positions in status hierarchies [115,116], levels of particular social traits [22], and closeness to each other [89] or to oneself in social ties [87] or intimacy [117,118]. These findings are consistent with suggestions that neural mechanisms that support aspects of spatial cognition (e.g., building world-centered cognitive maps in the hippocampal formation; representing information relative to oneself in inferior parietal cortex [119]) also support reasoning about social relations.

Importantly, such overlap does not necessarily imply the involvement of common mechanisms or that social and spatial relations are being encoded in the same way. Work examining fine-grained spatial response patterns within overlapping brain regions suggests that distinct neural response patterns signal analogous information (e.g., relative location [120]) and operations (e.g., shifts of attention [115]) for social and spatial relations. Consistent with the notion that processing spatial and social relations involves at least partially distinct mechanisms, the abilities to learn about social and nonsocial networks appear to be largely distinct [70].

Contrastingly, other work has found evidence for shared neural encoding of social and spatial distances from oneself [117], which could reflect shared meaning (e.g., self-relevance) across egocentric distances. Additional recent findings suggest that similar neural mechanisms may be involved in 'navigating' space and social knowledge: in entorhinal cortex (and other regions), knowledge of relations between people in terms of their levels of particular traits appears to be represented in a grid-like code, similar to that which supports spatial navigation [22]. The possibility that a grid-like code supports 'navigating' knowledge of friendship networks has not been tested. An alternative possibility is that a flexible, domain-general cluster-learning mechanism in medial temporal cortex produces grid-like representations when a two-dimensional space is learned via exhaustive and uniform sampling (e.g., in many spatial tasks and analogous tasks testing for grid-like coding of abstract knowledge), but also supports acquiring and 'navigating' knowledge of abstract concepts, without the generation of grid-like responses, when learning environments are more structured or 'clumpy' [121]. Testing if such a mechanism supports learning about social network structure would be an exciting avenue for future research, particularly given that mental representations of social networks are likely based on clusters of interrelated features (see 'Heuristics facilitating efficient encoding of social network structure').

to forge new connections (e.g., asking a friend to introduce them to a desirable romantic partner; pointing out common ties to gain the trust of a new contact). Other primate species may use similar strategies, leveraging common ties to facilitate attempts to affiliate with valuable social partners [8]. Monitoring others' dyadic relationships may also allow humans to recognize third-party threats to their existing relationships (e.g., through displacement), allowing them to intervene to protect those ties [57]. Similar findings have been found in studies of other highly social primates [34,58,59]. Thus, interrupting third-party bonding attempts, specifically ones that threaten to disrupt existing alliance networks, may be an important strategy for protecting one's social network position and its associated value (see Box 4 for further discussion of social niche construction).

Knowledge of others' interpersonal relationships may also extend the impact of a dyadic social interaction, such that it reaches other members of a community affiliated with one or both individuals in the interacting pair. Research on other group-living primates suggests that knowledge of interpersonal relationships can create a ripple effect, where the outcome of an affiliative [60,61] or agonistic [62] interaction with one individual shapes attitudes towards their kin and/or close affiliates (e.g., kin-mediated reconciliation, redirected aggression). Human parallels of these findings are found, for example, in studies of intergroup relations demonstrating that interactions with individual outgroup members can shape attitudes towards their group as a whole [63,64]. Similarly, social groups are expected to show accountability for the behavior of their members and to offer reconciliation to the group members of the wronged individuals [65,66]. In sum, individuals and their group members are often seen as potential substitutes for one another as targets of aggression or agents of reconciliation. Notably, given that friendships are also a prominent and consequential feature of the social world [23,67], friends may also act (or be perceived) as proxies for one another in such interactions. Indeed, humans expect that friends will share similar traits [127], preferences [48,49], and attitudes about others [68]. As such, the

Box 4. Social niche construction: strategically applying relationship knowledge

Individuals can strategically harness their knowledge of others' relationships as a tool for manipulating their social environment (or constructing a social niche [122]) by interfering in others' ability to form new alliances.

Parallel findings across the human and animal literatures suggest that individuals intervene to obstruct third-party alliances that have the potential to place them at a disadvantage. For example, individuals seem wary of affiliative attempts targeted at their close allies, as interlopers can increase demands on one's affiliative partners or threaten to entirely displace them [57]. To mitigate these potential risks, perceivers may engage in a variety of 'guarding' behaviors, such as closely monitoring their affiliates' interactions, and intervening to separate them from these third-party threats [57,58]. Individuals may also be wary of alliances formed by their close competitors. For example, in other highly social primate species, animals intervene to prevent alliance attempts by individuals who rank close to themselves [58], as well as alliances that have the potential to shift the balance of affiliative status in their community [58,59]. Relatedly, findings among human adolescents suggest that aggression is often targeted at individuals who occupy structurally equivalent network positions (i.e., who have the same ties), possibly suggesting that victimizing others can be used as a strategy of improving one's affiliative status [7]. In sum, blocking alliances among others may allow individuals to protect their existing relationships, and to maintain/improve their social standing [123].

In some ways, these findings suggest that individuals may engage in more costly behaviors when attempting to use their knowledge of others' relationships to maintain or increase their social standing (e.g., aggressing against competitors [7,124]) rather than to guard allies [57–59,123]. However, this distinction is complicated by the fact that perceivers' own allies are often also their closest competitors, often sharing many of the same interaction partners, or occupying network positions that are similar, or even structurally identical, to their own [7,124]. In other words, perceivers may be motivated to sabotage their allies' attempts to form new relationships, not only to monopolize their allies' support [57,59], but also to avoid being supplanted by them [7,124]. In line with this possibility, aggressive behaviors among adolescents appear to be commonly targeted at one's friends [7,124–126]. Accordingly, future work is needed to disentangle the different motivations driving individuals to sabotage their friends' alliances, as well as the extent to which these motivations predict the strategies used and the overall tendency to aggress towards friends.

proxy effects documented in the aforementioned studies of intergroup relations may have parallels based on more nuanced knowledge of specific interpersonal relationships. Yet, much remains to be understood about these phenomena and the cognitive mechanisms that support them in the context of individual ties. Future work examining this potential generalization along known dyadic ties may advance understanding of the cognitive foundations of alliances and group membership [69].

From edges to broader social networks

While being able to detect and track dyadic interpersonal relationships provides an important starting point for constructing representations of relationships among one's community members, dyadic ties do not exist in a vacuum. Instead, these ties make up the edges in larger networks of interpersonal relationships. Tracking characteristics of these networks and people's positions within them can reveal valuable information about community members (e.g., how well-connected they are) and the context of their ties (e.g., clique membership). Such information is not apparent when only considering individual dyadic relationships in isolation, but rather, requires considering patterns in the many relationships that surround oneself. Network approaches provide a framework for studying people's knowledge of these relationship patterns.

One approach often used to study mental representations of social networks in work on cognitive social structures [26] involves asking every member of a community to list their own ties and perceived ties connecting others in the community, then comparing respondents' perceptions of others' ties to those individuals' self-reported ties. Another approach involves the use of artificial networks, varying their properties to experimentally test individuals' ability to correctly encode and recall different relationship patterns [11,12,70]. Notably, while these approaches test individuals' knowledge of an underlying network structure, the mental representations used to store and query information about ties within a network may not mirror its veridical structure.

Indeed, mental representations of social networks based on complete knowledge of all of their constituent discrete relationships would be difficult to acquire, maintain, and utilize, both because of limits on information availability and because it would be highly cognitively taxing to do so. Moreover, simple strategies that allow humans to 'fill in the gaps' when it comes to other forms of social-relational knowledge, such as linearly structured social status hierarchies (e.g., based on relative dominance, Figure 2B), would not extend well to this domain. For example, in such hierarchies, the relationship between any pair of people can be inferred simply by knowing the relationships among a subset of people, then using transitive inference to deduce the rest (e.g., if Anne is higher status than Bob and Bob is higher status than Carlos, then Anne is higher status than Carlos) [71]. Conversely, networks of affiliative ties have complex structures and variable configurations that limit the utility of simple strategies like transitive inference in using one's knowledge of a subset of ties to make inferences about other ties and others' positions in the broader network.

Given these challenges, how can individuals effectively acquire and apply knowledge of patterns of relationships in their social networks without tracking every single dyadic relationship in those networks? Recent findings suggest that individuals may supplement their knowledge of individual ties with assumptions about how social networks tend to be structured (e.g., affective balance [68]) and by tracking features that covary with characteristics of others' network positions (e.g., frequency of mention in gossip [6], impressions of certain personality traits [5,72]). In the next sections, we discuss evidence that perceivers can ascertain aspects of others' social network positions and patterns of relationships in their networks, mechanisms that may support these capacities, and the value of tracking this information.

Social network centrality

Social network centrality as a consequential facet of social status

Viewed collectively, an individuals' affiliative ties are a valuable resource that can be leveraged for emotional and instrumental social support. Characteristics of one's social network are related to wellbeing [73–75], academic and professional success [76,77], and the ability to make new social connections [78]. Relatedly, research using network approaches has identified several social advantages of occupying central (i.e., important) social network positions. Across different measures of centrality (which capture different ways that a node can be important, Box 2), central network positions have been associated with influence on others' reputations [79], social norms [80,81], and how information and other resources spread in networks [6], as well as protection from maltreatment (e.g., scapegoating, negative gossip) [16]. These findings suggest that measures of social network centrality, such as how many affiliative ties one has with others (i.e., degree centrality) and how well-connected someone is to well-connected others (i.e., eigenvector centrality), capture an affiliative facet of social status associated with the number and patterning of interpersonal relationships surrounding an individual.

Affiliative forms of social status based on network measures have received comparatively little attention in psychology and neuroscience compared with other forms of status (e.g., dominance, prestige based on talent/skill) [82]. While dominance- and prestige-based status are impactful and important to understand [83,84], the aforementioned findings highlight the importance of social network centrality as a consequential component of social status. Indeed, endeavors that can be effectively bolstered by an understanding of others' centralities (such as reputation management, effectively seeking and spreading information, and ascertaining group norms) are prevalent in day-to-day life. Thus, the social status afforded by others' social relationships is a ubiquitous and consequential facet of social life that may contribute to humans' proclivity to track configurations of interpersonal relationships.

Tracking social network centrality

Does the ability to track interpersonal relationships among others extend to being able to identify central members of one's community? Recent work suggests that people recognize and respond to familiar others' social network centralities: perceivers preferentially attend to central targets [85] and are more motivated to display positive qualities when observed by them [79]. Research integrating social network and neuroscientific approaches [24] has found that people spontaneously track familiar others' centralities, even when passively viewing faces or performing unrelated tasks [86–89]. Spontaneous neural encoding of centrality has been demonstrated in brain areas associated with mentalizing and valuation even when controlling for potentially confounding factors, including attractiveness and perceivers' ties to and liking of targets [86–89]. These findings suggest testable hypotheses for future behavioral studies (e.g., that individuals may intrinsically value people who are well-connected in their social networks and pay particularly close attention to those individuals' apparent mental states).

Thus, people can identify central members of their communities and this knowledge shapes downstream processing and behavior. How do people overcome the challenges associated with tracking social network structure (see 'From edges to broader social networks') to ascertain others' centralities? Next, we consider heuristics that might support such inferences and their behavioral and cognitive consequences.

Heuristics guiding inferences about social network centrality

Interestingly, characteristics of individuals' positions in their social networks, including measures of social network centrality, and naive observers' perceptions thereof, are associated with certain

personality traits (e.g., extraversion, competence) [5,72]. Perceivers can leverage these associations, relying on trait impressions from pictures of faces [5] or brief videos [72] to infer complete strangers' social network characteristics. As such, information in these 'thin slices' of others' behavior and appearance, including trait impressions and factors such as gender [72] and attractiveness [5], can allow perceivers to instantly identify individuals who are likely to occupy central positions, even before acquiring knowledge of any of their interpersonal relationships. While these inferences are likely characterized by some degree of systematic error (as trait impressions from faces are not completely accurate [90]), they may reduce the cognitive burden associated with aggregating dyadic ties across an entire community and allow individuals to make inferences about someone's importance in a network when other information is not available (e.g., when first entering a community).

Future research can explore how individuals may leverage other types of information to infer others' centralities. For example, simulations suggest that by monitoring patterns in someone's social interactions, such as the extent to which they are observed among small versus large groups or have stable versus varied interaction partners, perceivers may be able to make inferences about their centrality without tracking the specific identities of their interaction partners [91]. Similarly, perceivers may also be able to identify central individuals based on how frequently they are mentioned in gossip [6]. While some work shows that central individuals tend not to be the targets of negative gossip [16], they may be more likely to be mentioned in general, with information about them reaching more network members. Accordingly, some have suggested that perceivers may be able to detect complex forms of social network centrality (e.g., who is well-connected to well-connected others, Box 2) by tracking the identity of individuals they hear about most often [6]. Empirical tests of these possibilities are needed to determine whether individuals attend to these patterns in the behavior of those around them and use such observations to probabilistically infer the identity of central people in their community.

Implications of recognizing central community members

What are the cognitive and behavioral consequences of accurately identifying central members of one's community? Prior findings from studies of real-world networks suggest implications for reputation management. For example, knowledge of others' centrality may engender wariness of potential reputational consequences when being observed by highly central individuals [79] or sharing information about them [16]. Modifying behavior in the presence of central individuals and their potential allies affords perceivers control over the information that becomes accessible to the rest of their community. Given these findings, additional research is needed to examine whether the capacity to accurately ascertain others' centralities (and to modify one's behavior accordingly) can impact individuals' ability to form and sustain affiliative relationships. Research on this topic may have important implications, particularly given other work showing that there is significant variability in attunement to others' social network positions depending on perceivers' age [28,29], sex [11,29,68], and social status [88,92]. Interestingly high-centrality perceivers seem particularly attuned to others' relative centralities [88]. It is possible that attending to others' social network centralities allows individuals to improve their own affiliative social status. However, future research is needed to eliminate other possibilities, as this could also reflect central individuals' increased access to information about other community members.

Future research can also examine whether knowledge of others' centralities can provide a motivational explanation of findings [93–95] linking centrality to social influence on other community members. This link is often attributed to the objective properties of highly central network positions, such as the capacity for one's behavior to be observed by many people/interaction partners. Whereas this explanation attributes central individuals' heightened influence to others'

frequent exposure to them, an alternative explanation can be proposed based on central individuals' documented attentional salience [85]; in addition to having more encounters with others, central individuals may be perceived as particularly worthy of 'tuning into' during any social encounter, which could, in turn, explain their outsized ability to shape the behavior of their community members. While some findings do suggest that perceivers may place greater weight on central individuals' behaviors when inferring norms in their community [80,81], the extent to which this is driven by perceivers' knowledge of others' centrality (rather than their frequency of exposure to central individuals) is unclear. Considering the significant impact of norm perceptions on behavior [81,96], future work distinguishing the effects of exposure frequency and attentional salience has the potential to advance interventions that target central individuals as agents of normative change (e.g., by determining whether facilitating direct encounters with central individuals can improve the efficacy of these interventions).

Social network structure

Effectively navigating one's social environment also requires individuals to detect broader characteristics of its structure, such as the existence of cliques and the identity of individuals who bridge between them (often referred to as 'brokers', Box 2). To understand these characteristics, perceivers need to build mental representations that capture information about broader patterns in how interpersonal ties in their network are structured (Figure 2D). Next, we examine individuals' ability to construct such representations and the various ways in which they may be structured. Additionally, we consider prevalent biases in perceptions of social network structure and the potential sources and implications of such biases.

We note that the preceding section on social network centrality focused on knowledge of individuals' importance in one's social network based on how many connections they have (i.e., degree centrality) and how many connections they have to well-connected people (i.e., eigenvector centrality). While some measures of network centrality are related to brokerage (e.g., betweenness centrality [24]), we consider findings pertaining to knowledge of others' brokerage in this section ('Social network structure'), rather than in the preceding section, to facilitate linking social network features to relevant research on human cognition.

Heuristics facilitating efficient encoding of social network structure

As discussed previously (see 'From edges to broader social networks'), acquiring, maintaining, and utilizing mental representations of social networks composed of all of their constituent discrete ties would be costly and sometimes unfeasible. What other types of representational strategies might help individuals to track, infer, and use information about cliques and other structural patterns in the networks that surround them?

One possibility is that perceivers simplify information about interpersonal ties into categorical groupings. Research using artificial social categories suggests that from early on in development, people use social categories to group individuals [97] and predict affiliative relationships [98]. Similarly, perceivers may bin people into *ad hoc* social categories (e.g., friend group A; friend group B) based on knowledge of a limited number of affiliative relationships (e.g., that Anne is friends with someone in friend group A) and infer unobserved relationships amongst members of those categories (e.g., presume friendships between Anne and other people in friend group A). Accordingly, perceivers would only need to track each individual's categorical assignments to form predictions about who their close affiliates might be. Perceivers may make similar inferences (i.e., assign people to categories or cliques whose members are likely to be friends) based on other factors, such as interpersonal similarities. Notably, perceivers' experience in their social networks may dictate which features (i.e., which dimensions of similarity) are used to infer the existence of

affiliative ties. For example, while demographic characteristics (e.g., gender, race) can aid in the recall and inference of dyadic pairings [29,47], the boundaries and salience of these and other social categories can evolve over time and shift across contexts. As such, individuals' tendency to rely on these characteristics to support inferences about social structure may depend on observed patterns in their community [69,99,100]. Indeed, recent work has shown that perceivers may use their existing knowledge of affiliative ties to detect highly predictive features and use those community-specific features to inform future inferences about ties among other community members [49].

Capturing more granular information about social network structure may require more nuanced strategies. For example, people may use complex cognitive maps that encode statistical relationships between features and friendships (although the use of such maps may depend on individuals' ability to recognize when simpler strategies, such as a homophily heuristic, are not effective for predicting friendships) [49]. Another strategy may entail remembering and 'chunking' people who are all affiliated with a specific well-connected individual [101]. Paying particularly close attention to relationships involving well-connected individuals may be adaptive, not only because of well-connected individuals' social value and behavioral relevance, but also because in human social networks, a small number of people account for a large proportion of the total number of ties [102].

Related strategies involve the use of priors about how social networks are typically structured. For example, studies using real and artificial networks suggest that people expect social networks to exhibit a 'small world' organization, in which nodes cluster together into a few densely connected communities with a small number of connections between them [20,101]. People also expect interpersonal ties to exhibit a tendency towards triadic closure (i.e., if Anne and Bob are connected, and Bob and Carlos are connected, then Anne and Carlos are connected) [11] and affective balance (i.e., if Anne and Bob are friends, and Bob and Carlos are friends, then Anne and Carlos are more likely to be friends than enemies) [68]. While such heuristics are often studied at the triadic level, they may scaffold expectations about broader social network structure [12,20].

Overall, the aforementioned strategies may facilitate the efficient construction of a rough representation of the structure of one's social network while only tracking (or being able to observe) a subset of interpersonal relationships. The degrees to which individuals rely on these various strategies can be difficult to disentangle, as different strategies often make convergent predictions about which relationships are most likely to be inferred and remembered. Future work can examine the possibility that the aforementioned heuristics, and the sources of evidence on which they draw, are combined to produce a single probabilistic representation of a social network. Relatedly, recent work shows that people probabilistically assign others to latent social groups based on patterns of observed similarities to them (i.e., how a target's attributes relate to one's own), as well as among them (e.g., if a target has much in common with an additional third party who is known to be dissimilar to oneself). As a result, knowledge of relations between others shapes who is mentally assigned to one's ingroup in an inferred social structure [103]. Future work can examine whether similar mechanisms are used to combine knowledge of affiliative interpersonal relationships, and predictors thereof, to probabilistically assign individuals to cliques within mental representations of social networks.

Biases in the perception of social network structure

While relying on cognitive 'shortcuts' such as those described in the preceding section (as opposed to fine-grained, comprehensive network representations) provides an efficient means of uncovering structural features of social networks, such strategies can produce systematic biases

and errors in network perceptions. More specifically, while such heuristics may effectively support inferences about structures that align with perceivers' expectations, they can otherwise produce inaccuracies, both through the inference of nonexistent ties and the omission of existing ones. For example, the assumption of triadic closure can lead to false inferences of nonexistent ties, causing perceivers to fail to recognize structural holes and associated opportunities for brokerage [104]. Conversely, perceivers may also omit ties across communities in compressed representations of networks, thereby exaggerating the extent to which networks are clustered into distinct subgroups [101] (Figure 3).

What factors might lead individuals to rely particularly heavily on heuristics to represent patterns of interpersonal relationships? Perceivers may be forced to do so when information about individual ties is difficult to access. The accuracy of perceptions of individual attributes [10,17] and dyadic relationships [27,105] decays with increasing social distance between perceivers and targets. Thus, whereas people may have an easier time acquiring and activating knowledge about their frequent interaction partners [106], they may rely primarily on heuristics to infer distant ties. Indeed, recent evidence suggests that when attempting to reconstruct relationships in social networks from memory, people begin with a limited number of directly remembered dyadic ties, then use heuristics about how social networks tend to be structured to impute the remaining relationships [101].

Some individuals may also be more prone to relying on such heuristics. For instance, social power, which is associated with increased reliance on abstract cognition, decreases perceivers' ability to detect structural holes [104]. Similarly, individuals with a high need for closure are more

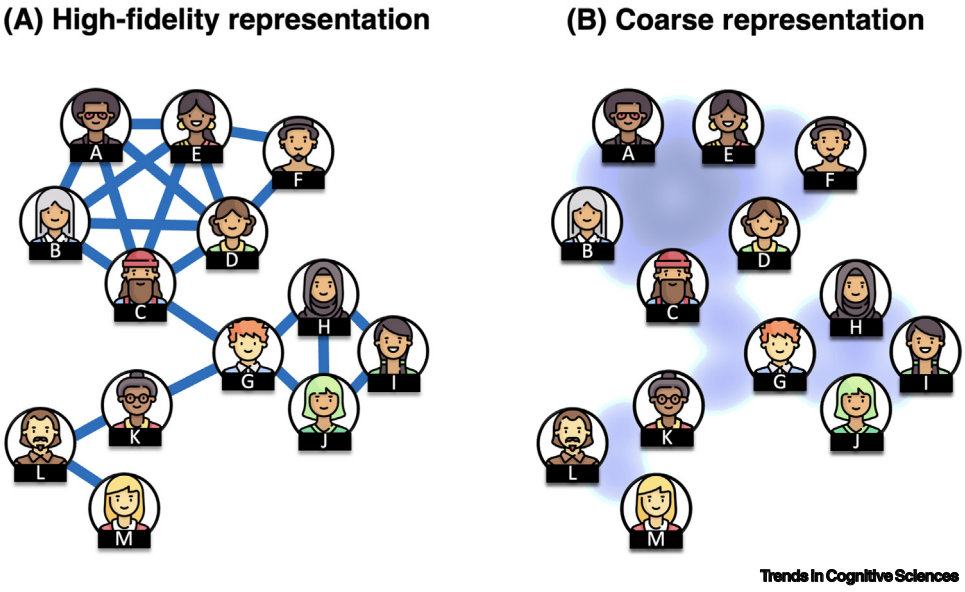

Figure 3. Fine-grained and coarse representations of social networks. Instead of constructing fine-grained, high-fidelity mental representations of all of the interpersonal relationships in their social networks (A), people can rely on cognitive shortcuts to efficiently build relatively coarse mental representations of their social networks (B) (e.g., compressing multiple individuals together as a unit, such as the triad composed of nodes *K*–*L*). Such shortcuts can allow perceivers to impute missing information about others' social ties to guide their social inferences and behaviors; they can also reduce the cognitive demands of tracking and encoding others' relationships. However, they can also contribute to the emergence of errors and biases in which social ties are omitted or falsely inferred (e.g., assuming that nodes *K* and *M* are friends with one another because they are both friends with node *L*). In particular, relatively coarse mental representations of social networks can exaggerate the extent to which individuals are clustered in densely interconnected cliques or subgroups (e.g., *A*–*F*, *G*–*J*, and *K*–*L*). Icons were generated by Freepik (www.flaticon.com).

likely to utilize priors about homophily and triadic closure when inferring affiliative ties [47]. Additionally, affective states may also shape the structure of mentally represented interpersonal ties. Negativity is associated with the activation of small and dense networks, whereas positivity is associated with the activation of large and sparse networks [13,107,108]. Interestingly, these biases may have a functional role; in times of negativity, they help orient individuals to cohesive networks that provide a better source of social support [109]. These biases also allow individuals to make the most of positive mental states, expanding their range of interaction partners, and allowing them to make new connections that can help them accomplish their goals [13].

Implications of knowledge of social network structure

While social network structure impacts members' access to various resources, the ability to take advantage of such access can be limited by individuals' perceptions of network structure and associated opportunities. For instance, the ability to occupy brokerage positions, which entail several advantages [110], is limited by both the availability of such positions and one's ability to recognize structural holes [104] and the potential advantages of being the person to bridge them [111]. Relatedly, in contexts characterized by competition over affiliation-based status, the ability to acquire and maintain advantageous social network positions can depend on one's capacity to identify structurally identical others who are potential rivals for attaining such positions and the status they can impart [7] (Box 4). Knowledge of social network structure may also facilitate the recognition of key community members who bridge between disparate people or groups. Individuals who occupy these types of bridging positions can serve as 'brokers' of information and other resources and are the target of much basic and applied research [110].

Overall, despite the many limitations and biases characterizing mental representations of social networks, people are remarkably adept at tracking and inferring wide-ranging information about the structure of their social world. In fact, recent work suggests that perceivers' social network knowledge can be harnessed to identify community members who are particularly well-positioned to diffuse information (i.e., high in a form of eigenvector centrality [6]). Doing so has the potential to confer much real-world benefit, such as bypassing the need for costly collection of full-network data to inform network interventions (which aim to accelerate behavior change by targeting people in influential social network positions). By relying on community members' own social network knowledge, researchers can identify key people to target for spreading information or modeling prosocial or healthy behaviors, making network interventions easier and more cost-effective. Thus, studying network phenomena and the human propensity to track the social ties around oneself has the potential to not only advance understanding of important aspects of everyday social thought and behavior, but also to create tangible social impact.

Concluding remarks

Humans are remarkably attuned to the interpersonal relationships that comprise their social networks, demonstrate substantial knowledge about their social networks, and apply that knowledge on a day-to-day basis to make social inferences and strategically navigate their social environment. Recent work spanning a wide range of disciplines has shed light on these phenomena, but many questions remain (see Outstanding questions). Future work that continues to integrate perspectives and findings across disciplines promises to advance understanding of how social network knowledge is acquired and integrated with other kinds of social information and how such knowledge shapes how people think, feel, and behave.

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Outstanding questions

To what extent does acquiring and representing knowledge of interpersonal relationships in one's social network rely on mechanisms that support other kinds of relational knowledge processing?

How does gossip contribute to learning about others' interpersonal relationships and network positions? Can perceivers detect when the information about others' relationships conveyed in gossip is likely to be biased or inaccurate and what strategies guide such distinctions?

How does knowledge of others' interpersonal relationships and social network position characteristics (e.g., brokerage) shape goal-directed behavior (e.g., strategically seeking and spreading information) and other outcomes (e.g., the ability to maintain and promote one's own social status)?

How is knowledge of interpersonal relationships combined with other types of relational knowledge and other person knowledge to construct cohesive mental representations of the people in one's social environment? How do these different kinds of social knowledge interact?

How is the ability to track affiliation-based forms of status impacted when cues that can typically guide heuristic-based inferences about others' social network positions are unavailable, such that perceivers must rely solely on acquiring and integrating knowledge of others' relationships (e.g., when learning networks that deviate from the typical structure of natural social networks or where visual cues linked to social network centrality are unavailable)?

How do perceivers identify brokers? Are there individual differences in the ability to do so and what other social or cognitive abilities is this capacity linked to?

How do social cognitive biases distort perceptions of social networks? Biased perceptions of others' relationships could stem not only from biased informational availability (e.g., having more chances to observe interactions among one's friends), but also from

social cognitive biases (e.g., the tendency to ascribe more positive attributes to one's ingroup).

Declaration of interests

No interests are declared.

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