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Review

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Networks of reliable reputations and cooperation: a review

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Reputation has been shown to provide an informal solution to the problem of cooperation in human societies. After reviewing models that connect reputations and cooperation, we address how reputation results from information exchange embedded in a social network that changes endogenously itself. Theoretical studies highlight that network topologies have different effects on the extent of cooperation, since they can foster or hinder the flow of reputational information. Subsequently, we review models and empirical studies that intend to grasp the coevolution of reputations, cooperation and social networks. We identify open questions in the literature concerning how networks affect the accuracy of reputations, the honesty of shared information and the spread of reputational information. Certain network topologies may facilitate biased beliefs and intergroup competition or in-group identity formation that could lead to high cooperation within but conflicts between different subgroups of a network. Our review covers theoretical, experimental and field studies across various disciplines that target these questions and could explain how the dynamics of interactions and reputations help or prevent the establishment and sustainability of cooperation in small- and large-scale societies.

This article is part of the theme issue 'The language of cooperation: reputation and honest signalling'.

1. Introduction

Despite its obvious benefits, cooperation necessarily entails individual sacrifices, and so poses a fundamental puzzle for evolutionary theory, already alluded to by Darwin [1;2, pp. 5–8]. Many breakthroughs in evolution, however, have been achieved through cooperation and the formation of cooperative alliances [3]. For example, the transition from single-celled to multicellular organisms required the restriction of individual cell growth, cellular differentiation and the management of cheating—cooperation between cells to create a functioning organism [4–6]. Here, we focus our attention on cooperation in humans, as our species is particularly skilled in resolving cooperation problems and regularly cooperate with

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non-kin strangers [7,8]. It has been a major scientific achievement to realize and empirically demonstrate that humans are capable of solving the problem of cooperation through *reputation* [9–14]. Reputation can be defined as (shared) information about the qualities and attributes of an individual that also includes cooperativeness [15,16]. Reputational information can be used to condition behaviour towards an interaction partner. Furthermore, it can determine access to partner choice and reproduction as well as to material and to immaterial resources (e.g. to power). The benefits of having a 'good' reputation can deter individuals from defection and thereby foster the evolution of cooperation [17–19].

These processes do not take place in a social vacuum. Human interactions are complex, as they are embedded in social network structures. The local network ties that an individual has are important for solving the problem of cooperation for multiple reasons. First, the local network structure provides the context of social interdependencies, and large-scale cooperation is often scaled up from the successful establishment of local cooperation. Second, network ties provide the constraints of monitoring and controlling behaviour. Third, they are also the channels of communication. Communication is a device for coordination, but also for influence and persuasion towards doing the right thing for the larger group. The advanced communication capacities and social skills of humans allow us to disseminate third-party evaluations through *gossip* [14,20–22]. Gossip is the method through which one learns the reputations of others, and through which reputations are shared in the absence of direct experience and observation. These processes also sustain reputation-based cooperation in larger groups in which not every interaction can be monitored [23–25].

In short, network ties impact cooperation through multiple mechanisms. They can help the establishment of reputations that are aligned with group-beneficiary action but could potentially also be used to control the flow of, or strategically manipulate, reputational information [26].

After a short introduction to the problem of cooperation, we review work on the foundational elements of reputation-based cooperation in humans. We start from the simplest models that link reputation and cooperation, and then address the impact of networks on cooperation, before finally discussing more complex models of their coevolution. We conclude that the existing theoretical work on reputation and cooperation has not fully accounted for the possible complex interplay that emerges when social networks dynamically change as a function of gossip and reputation (e.g. [27]). While such dynamics pose many challenges, we argue that progressing the field towards investigating the interactions of reputation, gossip and network topology might help to overcome the remaining puzzles of how networks can ensure reliable reputation systems assisting the evolution of cooperation. Such a programme also promises explanations for when and why gossip and reputation dynamics have adverse effects on cooperation, by fostering dishonesty, strategic manipulation attempts, or by giving rise to parochial, group-bounded cooperation.

2. The problem of cooperation

Cooperation is defined as a costly action to benefit another individual, where the benefit b is higher than the cost c (with $b > c$ and $c > 0$) [7]. What follows is that mutual cooperation leads to higher social welfare than mutual defection. In other words, working together creates synergies that exceed what individuals alone are capable of. Yet, individuals are even better off by reaping the benefits of cooperation without paying the cost of cooperation themselves. This temptation to free-ride on the cooperation of others introduces a 'puzzle': How can cooperation emerge, given the risk of exploitation and, concomitantly, the temptation to exploit?

Prominent theories in biology explain cooperation based on kinship ([28,29], cf. [30]) and reciprocal interactions [31–33]. While these theories apply to human cooperation as well, the remarkable extent of large-scale cooperation among non-kin observed in humans has shifted the attention to the role of reputation, communication, and social networks for sustaining cooperation.

3. Reputation as a mechanism for solving the problem of cooperation

Humans are able to observe the actions of others and exchange information. This allows the evolution of cooperation through mechanisms such as indirect reciprocity and reputation [12]. Communication and the ability to track reputation enable decision rules like 'if someone told me that you cooperated with others in the past, I cooperate with you'. Cooperative decisions that are made conditional on transmitted information (i.e. 'reputation') also allow the extension of cooperation beyond dyadic relations. In a simple model, Nowak & Sigmund [11] showed that, if individuals base their decisions on the so-called image score of the interaction partner, simply operationalized as the number of times an individual helped others in the past, cooperators can avoid exploitation by identifying free-riders pre-emptively. Testing Nowak & Sigmund's model experimentally, Wedekind & Milinski [34] have shown that human participants are indeed sensitive to image scores and cooperate conditionally on whether the interaction partner has a good reputation (i.e. high image score).

Once good reputation pays off, individuals have an incentive to 'invest' in building it. Whether the expected benefits exceed the costs of investment depends on the size of the population, the reliability of the image score transmission, the number of future interactions and whether reputation provides a valid and reliable signal of cooperativeness in the first place [35]. The latter is open to exploitation as individuals may be able to increase their own reputation by buying 'fake' reputation (e.g. [36]). This means that reputation can be increased artificially without actually engaging in costly cooperation, enabling the exploitation of cooperators. Experimental results highlight how important the validity of reputation signals is and suggest that any reputation system has to mitigate the presence of adverse incentives to control and manipulate reputational information [37]. Recent studies have also shown that reputation scores can lose their ability to foster cooperation if they are assigned to groups rather than individuals or when cooperation takes place in groups rather than dyadic interactions [38,39].

Since the introduction of the 'image score' as a simplified concept of reputation, different rules on how to assign reputation based on past action have been proposed and analysed (see e.g. [40–46]). Not all rules can sustain cooperation. From all consensual attributions, only eight norms (the so-called

leading eight) that determine proper action and assignment of good reputation have been shown to maintain cooperation while being resistant to mutation and observation error [44,45]. The joint properties of the leading eight norms are that (i) they assign good reputation for cooperation by actors with good reputation against others with good reputation (maintenance of cooperation); (ii) they assign bad reputation for defection against individuals with good reputation (identification of defectors); (iii) they maintain good reputation for actors with good reputation after defection against individuals with bad reputation (justified punishment); and (iv) they assign good reputation for actors with bad reputation if they cooperated with individuals with good reputation (forgiveness) [44,45].

Reputation is an important mechanism for the emergence of cooperation not only because it might be the basis of conditional cooperation, but also because it could be the basis of whom to learn from [47]. When individuals with high reputation discount the behavioural strategies of individuals with low reputation, cooperation is further enhanced, especially if discounting is based on absolute rather than on relative reputation [47].

Most importantly, reputation can also be the basis of partner choice [25,48–51]. Under ideal circumstances, reputational information allows predictions about the likely action of other agents in the population. Partner choice or 'relational mobility' allows cooperative agents to seek out partners that have a 'good' reputation and avoid agents with a 'bad' reputation. This creates competition for the attention of other cooperators in so-called biological markets in which agents compete to be selected as interaction partners [52–56]. In theory, if reputation provides a valid and unambiguous signal of an agent's cooperativeness, cooperators have a competitive advantage over defectors, since they can exclusively interact with each other and gain from the mutual benefits of cooperation.

Reputation, however, is not necessarily available publicly or shared universally [57–62]. While individuals may observe the actions of others, reputational information in humans is often also transmitted through gossip [63–66]. Gossip allows people to sustain cooperative behaviours through the spread of negative reputation and the fear of retaliation [17], as well as through the creation of coalitions and the exercise of ostracism [16,22,25,67,68]. Yet, gossip can also be used strategically by sharing false information to damage the reputation of others, raising the question of how groups evaluate gossip and detect false accusations and strategic misinformation [69–72]. In addition to strategic lies, gossip might entail a non-negligible degree of noise (that is, unintended errors). Gossip information can be wrongly communicated, impeding the correct transmission of reputational information and leading to mistakes in updating reputation of others [69,73]. Receivers may also wrongly interpret gossip information, likewise increasing the noise of reputational information [74,75]. Hess & Hagen [69] provided evidence that people evaluate the veracity of gossip information, for example, by assigning more credibility to gossip information coming from multiple, independent sources or taking into account the relationship between the gossiper and the gossip target, which can increase the reliability and validity of gossip and reduce strategic gossip lies and unintended errors. Such complexities are often not incorporated in formalized theoretical models, but play an important role in social groups, extend the function of reputation beyond simply identifying free-riders or cooperators, and introduce noise and strategic signalling, and psychological mechanisms to prevent the spread of false gossip.

4. Networks and cooperation

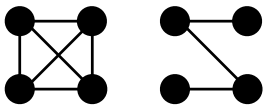
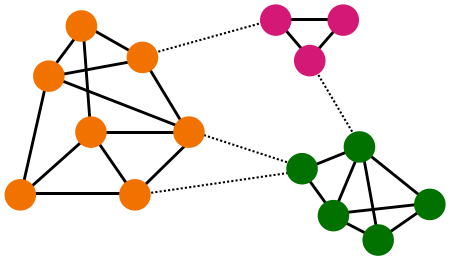
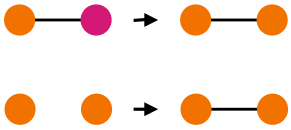
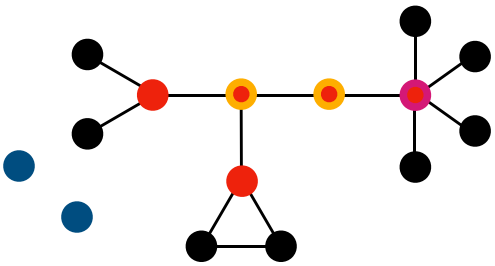
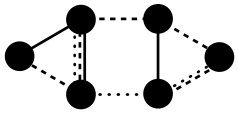
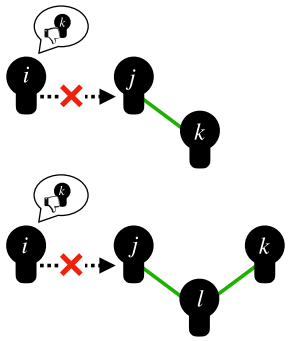
In large groups, people do not meet randomly, as assumed in some theoretical models for simplification. Human interactions are embedded in social networks that determine the likelihood with which two people meet, interact and exchange information. A logical implication is that the structure of a network could influence cooperation. Network topologies and features like how segmented, dense, close-knit or centralized a network is, might strongly facilitate or hinder the emergence of cooperation by constraining interactions or information transmission that might occur (table 1). In this section, we briefly review how networks can foster cooperation through mechanisms other than reputation.

When the likelihood to meet and interact with people remains unchanged over time, the ability to distinguish partners and act according to their previous actions can enable cooperation in networks [81–87]. A simple rule to foster cooperation in networks relates to the ratio between benefits b, costs c and individual degree d (d is the number of interaction partners that each agent has in the network). If $b/c > d$, the evolution of cooperation is theoretically possible without the need of reputation or strategic complexity [88].

People do not all occupy structurally identical positions and social networks often display skewed degree distributions [89]. Degree heterogeneity [90] and scale-free networks in particular have been shown to increase the chances of cooperation [81,84,91–93], though they are also highly vulnerable to error and deletion of nodes [94]. Realistic small-world structures [95] were also found to provide better conditions for cooperation [96]. Systematic investigations of topologies confirmed the superiority of structures in which hubs are integrated in cohesive cliques while they are also linked elsewhere [97]. Structural advantages are due to the benefits of cooperation for hubs and bridging individuals, their larger impact on the behaviour of others, the presence of ties and correlated behaviour among hubs, and high local clustering in small-world networks [98–100]. These results initiated the investigation of degree-based allocation policies that either decrease the required investments or increase the payoffs or aspirations of hubs in order to promote overall cooperation in public good games [100–104]. The strategic positioning of initial cooperators can shorten the time to achieve cooperation, but their placement is non-trivial and depends on the exact game and the network structure [105]. In addition, given their universal presence, highly centralized structures and hierarchical networks have been analysed and the underlying asymmetries found to maintain cooperation in models [106] and in experimental work [107]. Stable hierarchies, however, could imply the lack of motivation and investment in cooperation from lower ranked individuals [108].

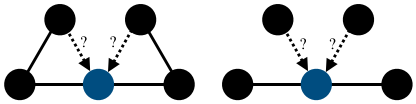
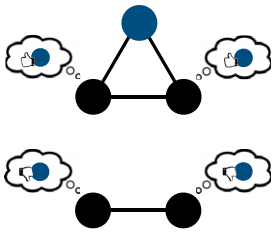
Theoretical models that investigated the evolution of cooperation in structured populations, such as in space or in lattices, observed the emergence of cooperation clusters in the population where cooperators meet other cooperators [109–115]. Experimental research, in contrast, suggests that a structured population in itself is not sufficient to solve the problem of cooperation in human groups ([116–119]; see also [120]). The mismatch could be caused by the low benefit to

Table 1. Key network concepts relevant for cooperation.

concept	definition/explanation	visual representation
network segmentation	the network can be partitioned into unconnected components; no influence on behaviour or on reputations is possible between the components	
network clustering/ modularity /segregation/ assortativity of nodes/the small-world phenomenon	human networks are characterized by dense and cohesive communities in which individuals show a large amount of similarity with each other (indicated by node colour). These cohesive clusters (modules) are loosely connected with each other through bridging ties (dotted lines), resulting in shorter network distances and a small world [76,77].	
influence and selection/ coevolution of networks and cooperation	the behavioural similarity of individuals in a community (cohesive subgraph) could be a result of social influence (assimilation, social learning) in informal relations or partner selection based on homophily [78,79]	
brokerage/betweenness/ centrality/power/social control	individuals may be in a distinguished network position such that they connect otherwise unconnected others (brokers, red), most information flows through them (betweenness, yellow), can influence many others (centrality, purple), or can exploit the cooperation of others (isolates, peripheral actors, blue)	
network multiplexity	human networks are multiplex, and networks of interdependence, communication and influence are just partially overlapping	
gossip	a sender *i* communicating to a receiver *j* about a target *k* who is absent or unaware of the content [66]	
structural constraints on the spread of reputations	the presence of certain network ties (e.g. friendship between the receiver *j* and target *k*, or a 2-path friendship tie of *j*–*l*–*k*) makes (negative) gossip about *k* by sender *i* to receiver *j* unlikely or forbidden	

(*Continued*.)

Table 1. (*Continued.*)

concept	definition/explanation	visual representation
triadic closure/structural holes	triadic closure (left) might be useful to cross-check the validity of reputational information received, while structural holes (right) enable the in-flow of information from independent sources [80]	
consensual reputation/ oppositional cultures	reputational information about an individual may (top) or may not (top versus bottom) be consensual as different subgroups may hold contradicting views about someone's reputation	

cost ratio in experiments [121], the share and positioning of initial cooperators in the network [105], the individual tendency to cooperate conditionally on the number of cooperative acts of others irrespective of payoff benefits [120] or learning the benefits of free-riding from others leading to a decay of cooperation in any structural setting.

Theoretical work and numerical simulations pinpoint dynamic strategy update rules that can promote cooperation in networks [98,122,123]. Unconditional, proportional or imperfect imitation strategies foster cooperation [109,124] more than innovative strategies, such as the myopic best response rule [125]. Mixing imitative and innovative dynamics is detrimental to cooperation near phase transitions and leads to the downfall of cooperation [126]. A general conclusion is that networks do not support or inhibit cooperation, but their impact depends on the micro-level mechanisms characterized by the strategy update rules individuals employ [124,127]. Results from statistical physics highlight the robust and universal features of phase transitions in problems of cooperation in networks [98,121,122,128,129], the impact of noise [130], mutations [131,132], punishment [129] and quenched distribution of types—which slows down relaxation towards the stationary state extremely [133]—therein.

This brings us to the role of dynamic social networks for the evolution of cooperation. People do not always interact or communicate with an unchanging set of partners. They can attempt to cut ties to previous interaction partners and form new ties (figure 1). This means not only that human interactions are embedded in social networks, but that social networks also change and evolve as a result of social interactions. Theoretical and experimental work has shown that dynamic social networks, labelled also as adaptive networks, in which agents can endogenously influence the network structure by cutting and forming social ties, foster cooperation [94,128,134,138–150] and the positive impact of tie dynamics could even spill over to static parts of the network [151]. The impact of network structure on cooperation depends on the rules and characteristics of dynamic network updates. Cooperation can prevail also in highly unfavourable conditions if strategy adaptation is paired with selective creation of ties [152] or with random creation but selective deletion of ties [153]. Selection of links that ensure higher payoffs in combination with adaptive strategy update offer good chances for cooperation, leading to a hierarchical network [138]. The endogenous development of a strongly heterogeneous topology through mechanisms of growth *and* preferential attachment [89] in which cooperators can secure an advantageous structural position supports cooperation [145,154]. While the role of hubs connected to other hubs is central in this process as their behaviour is imitated with high probability [93,154], cooperators might be located also on nodes of intermediate degree unlike in static networks [155]. The key for the success of cooperation is that the combination of tie updates and strategy updates must ensure that cooperators directly avoid defectors [91,153,156,157] or benefit from a self-organized informal leadership structure [128,138,139,145].

While most models assume that the network of interactions and the network of learning (strategy adoption) are identical and every relation is of equal strength, this is not necessarily the case [98,158,159]. Multiplex networks (cf. table 1) that represent the complex texture of relationships and model numerous layers that represent different social connections help cooperation endure even when the costs for exploitation are high [160]. Endogenous link updating in dynamic multiplex networks could lead to spontaneous symmetry breaking in cooperation levels across the layers [161–163].

The heterogeneity in human exchanges depends on both the diverse social circles people engage in (workplace, family, friends and neighbourhoods) and the strength of the relationships they create. The strength of social ties, meaning the intensity of the relationship and the frequency of communications, acts as a mediator between the maintenance of cooperation and network dynamics: the more robust the links between cooperative people, the more cohesive the cluster of cooperators and the lower the tolerance of defective behaviours [164,165]. That is, through the possibility to choose the interaction partners by strengthening or weakening ties to other agents in a dynamic social network, cooperation can be sustained in both large and small populations [154]. Natural self-organization patterns can dynamically change a social

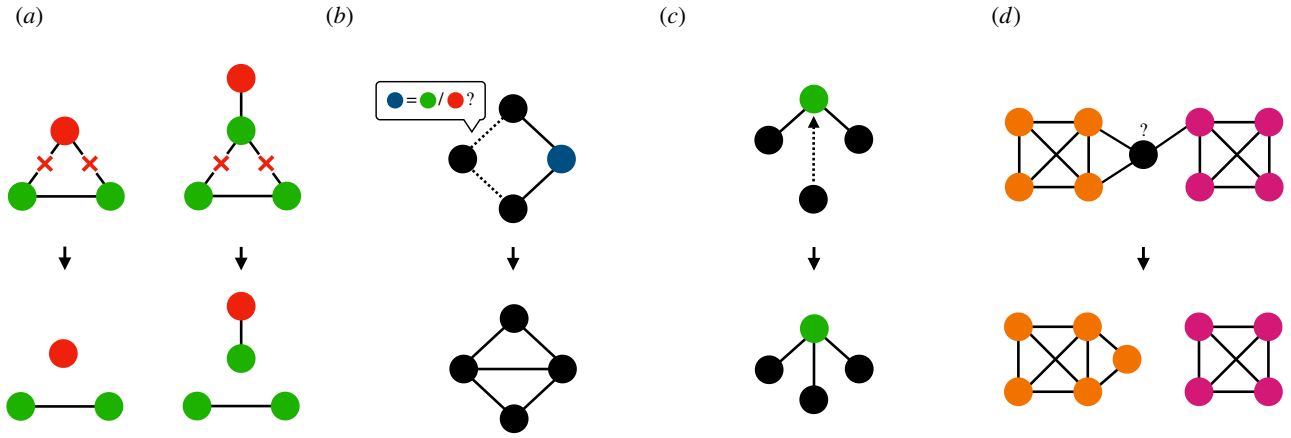


Figure 1. Examples of how network dynamics can relate to cooperation and reputation. (*a*) Breaking relations (crossed ties) can be a form of punishment for defection (left) [134,135] or low reputation (right) [136], which could also originate from cooperation with defectors; (*b*) asking for gossip about future interaction partners might lead to creation of new ties (selection based on access to reliable information); (*c*) preferential attachment to individuals with high reputation (green node); (*d*) cooperation within a cohesive group of individuals might have negative externalities for out-group members, sharpening group boundaries and creating parochial competition [137] which might force bridging individuals (black node) to choose sides.

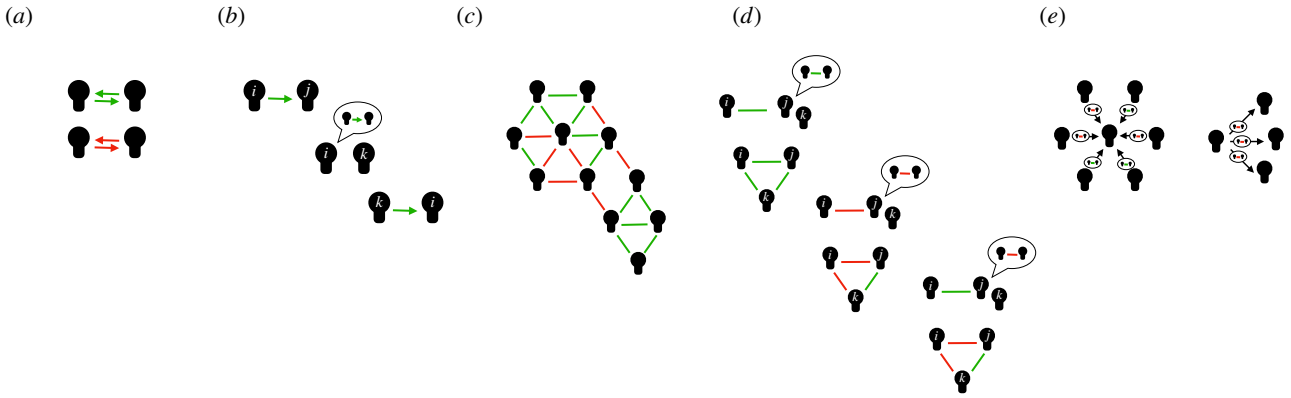


Figure 2. Cooperation in networks and reputation. (*a*) Cooperation can emerge through direct reciprocity in dyadic relationships. (*b*) Individuals can transmit information on past interaction partners to third parties, influencing their behaviour and allowing the evolution of cooperation through indirect reciprocity. (*c*) Often, individuals are engaged in complex social networks with cooperative or uncooperative relationships. (*d*) The transmission of information can influence actions and relationships. Importantly, information in the form of gossip does not need to be correct, allowing strategic (mis)information. The transmission of reputational information through network ties raises the question of how conflicting information from different sources is integrated. (*e*) Agents that have a central position in the network have more channels to transmit information and, hence, may have more influence on the ties of other agents and the evolution of the network.

network and induce the spontaneous emergence of cooperative clusters and help populations to become resistant to the invasion of free-riders [146,166,167]. Furthermore, when the network contains both positive and negative ties, network dynamics towards structural balance (e.g. 'a friend of a friend becomes a friend' and 'the enemy of a friend becomes an enemy') could efficiently drive the network towards in-group cooperation and cohesion [46,168–170].

5. Reputation transmission in networks

Beyond the direct relationship between networks and cooperation, reputation-based cooperation is also shaped by networks (figure 2) and networks also change as a result of reputation processes. Reputation affects both cooperation and network formation [120,171].

A useful framework to highlight how reputation is constructed in social networks comes from studies on the diffusion of information in networks [172], from the literature on learning in networks (e.g. [173]) and from network models of opinion dynamics (e.g. [174,175]). From this perspective, reputation in networks can be understood as arising from social influence, that is, as resulting from the communication between people that reinforces each other's views. A 'shared evaluation', as opposed to knowledge sharing, likely contains less certainty and requires more social proof, such as receiving the same information from multiple sources. This implies that for reputational information to get transmitted to others, a single source may not be sufficient [80]. Network models of reputation have been proposed to evaluate the reliability of multiple information sources [176–178]. In contrast with models on contagious diseases and information in general, which spread only by contact (a simple contagion), reputational information may be a 'complex contagion', i.e. it requires confirmation from multiple sources to be believed and potentially acted upon [172;179, p. 35].

This means that an exposure to reputational information does not immediately imply its acceptance and transmission to others; rather it requires multiple sources of confirmation. This is especially true when the source of reputational information is someone socially distant (several links away in the network). Such verification may be particularly important in situations in which those involved may have strategic

incentives to misrepresent reputational information (i.e. spread of false gossip). Therefore, networks that are characterized by high triadic closure, clustering and strong ties should facilitate complex contagions better than network structures with structural holes (open triads), low clustering and weak ties [179,180], because the former allow informational cross-checking and updating.

Extrapolating from this approach, it is likely that the transmission of reputational information might differ depending on the relevance and social (network) distance of the individual whose reputation is under discussion (target). Evidence shows that friendship and work ties influence individuals' propensity to engage in gossip [181,182]. Furthermore, the quantity and quality of the information shared shape individuals' reputation: high gossip activity decrease people's popularity in the network [183], while gossipers acquire a moral reputation when sharing diagnostic and adequate information that helps to identify others as trustworthy or not [184]. Thus, gossip not only influences the reputation of actors in a social network as 'good' or 'bad' interaction partners. Individuals in a network can also acquire a reputation as trustworthy or untrustworthy information providers. Such meta-reputations may help to avoid the spreading of false gossip and reduce noise. Our empirical knowledge, however, is still limited on how reputation is disseminated in the social network and to what extent contagion is susceptible to noise in various network topologies, and why an individual could have different reputations in different subsets of the population, as well as how individuals' reputations change based on the information they share.

6. The interplay of networks, reputation and cooperation

The complex interplay of networks, reputation and cooperation is such that no simple directionality can be assumed, since all three elements influence each other. Consequently, attempts to grasp the dynamic connections between networks and reputation mechanisms and their impact on cooperation so far have been limited. This holds for integrative theoretical agendas in general, and formal modelling efforts in particular. Both have to disentangle not only the multiplex social ties connecting and the reputational information flowing between the actors in the triad (sender, receiver and target), but also their differential effect on each actor's reputation and cooperative behaviour. A major challenge is capturing the multitude and interrelatedness of potential mechanisms through which networks and reputation may affect cooperation (see [16] for a fuller discussion). Here, we review recent efforts at capturing this dynamic interplay, whether with models or by observational work.

(a) Intragroup contexts

Some agent-based simulations, experimental studies and field studies have ventured into the coevolution of networks, reputations and cooperation. Partner selection plays a key role in these studies. For example, in a model where individuals interact in their local network, cut ties with individuals of low reputation and establish new relations with nearby individuals with the highest reputation (or with a random agent), free-riders get abandoned and stable and high levels of cooperation emerge parallel with a highly cohesive network structure [136]. This line of research follows up on early modelling work on 'prisoner's dilemma networks' [185,186] and matches with the results of analytical work that analyses equilibria in games on networks [187].

Experiments also found that dynamics of partner updates based on reputational information lead to high assortativity and stable cooperation [147]. The knowledge of the network structure along with reputational information may be a driver of cooperation and imply the emergence of dense and clustered networks [171]. Other studies have found that cooperation levels increase when more frequent partner updating is allowed (e.g. [134,156]). Large-scale online experiments have also attempted to dissect the complex interplay of network dynamics, reputations and cooperation. It has been found that while reputation information is important for partner choice, it might not even be necessary, and cooperation can be sustained by network dynamics alone [27].

It is important to note that these coevolution models show that the boundary between reputation and punishment mechanisms is fuzzy at best. Some interpret indirect reciprocity models as in line with (passive) punishment models, since the exclusion of low-reputation players from future exchanges can be seen as a sanction [136]. This is also seen in experimental models with dynamic networks, in which this mechanism is referred to as 'out-for-tat' [185,186].

Field studies portray a less straightforward picture, owing to intertwined processes of social influence and partner selection (table 1, third row), and in particular, the complex coevolution of networks of cooperation and social status [188], or networks, gossip and reputation [189,190]. For example, a series of studies among employees in Dutch organizations found that partner selection strongly depends on three partner characteristics: (i) the degree to which a potential partner has disclosed reputational information about others, i.e. individuals prefer to build ties to those colleagues who have shared negative third-party gossip with them [183], (ii) the power reputation of potential partners, i.e. individuals prefer to build close interpersonal relations with those colleagues whom they deem informally influential [191], and (iii) the degree to which a potential partner actually occupies an influential brokerage position in the informal network [192]. Finally, partner selection is also strongly influenced by self-monitoring capacity of the selecting party [193], with high self-monitors being more likely than low self-monitors to befriend those whom they or others perceive as powerful [191].

(b) Intergroup contexts

Intergroup contexts further complicate reputation dynamics and its role in establishing cooperation. A group is a bounded collection of interacting individuals who are interdependent to a certain degree [194]. In informal relations, group boundaries can be ambiguous, though they could be well approximated by detecting a relatively high density of network relations within the group and relatively few ties to members outside the group (e.g. [195–198]). Often, a shared identity binds in-group members together, excluding others. Group membership is associated with parochial cooperation, i.e. high in-group cooperation and low out-group cooperation [137,199–202]. These tendencies are supported by various theoretical accounts, such as social identity theory, self-categorization theory, bounded generalized reciprocity and parochial altruism ([203–207]; for an overview of these

theories, see [208]). Though several experiments have demonstrated the importance of social identification for in-group favouritism and in-group cooperation [200,201], experiments have also shown that people cooperate more both with in-group and out-group members when their reputation is at stake (e.g. [209–211]). Not only do people earn reputation from their cooperation, but their reputation may also be affected by their group membership and the actions of group members, as group reputation can be formed from the aggregate of individual reputations [38,39,212–214]. Such group reputations do not help to sustain cooperation with out-group members and generally lead to out-group discrimination [38,201].

One benefit of integrating network dynamics and cooperation is that groups do not have to be assumed to be exogenously given in the first place. Rather, models can allow for the dynamic emergence and dissolution of groups (e.g. [215]) and discrimination (e.g. [216]). Gross & De Dreu [46] provide an agent-based model where agents have personal information on others' cooperativeness, gossip and use the reputations learnt heuristically when deciding to cooperate with others. Applying the four reputation heuristics in structural balance theory, they found that groups emerged dynamically and displayed parochial cooperation; whereas reputation-based partner selection enhanced within-group cooperation, it impeded the emergence and stability of system-wide cooperation. Such models demonstrate that groups can emerge through learning, reputation and gossip, and that these constrain cooperation to certain clusters in a network.

These results are generally supported by behavioural experiments in the laboratory (e.g. [37,134]), and in real-world contexts (e.g. [217–219]). Parochial structures, echo chambers and subgroup polarization may arise when networks and reputations evolve endogenously, increasing the likelihood of in-group loyalty, group-exclusive cooperation and intergroup competition. Further modelling and experimental studies are required, which will help elucidate when parochial cooperation becomes entrenched in processes such as group polarization, and when intergroup tolerance and cooperation are sustained.

7. Outlook

Reputation and networks provide paths to large-scale cooperation. Much theoretical and empirical research has been dedicated to understanding the role of reputation and networks for cooperation in isolation and apart from each other. Human cooperation, reputation, and network formation are clearly interrelated. Consequently, the complex causal linkages between reputation, cooperation and networks have gained increasing attention in the literature recently. Investigating the interplay of dynamic social networks and reputation information that is (imperfectly) transmitted through gossip is challenging, from both a theoretical and an empirical perspective. What complicates matters is that individuals can have strategic incentives to spread false gossip [69–71], raising the question of how the validity of reputational information is secured in networks. As individuals associate with groups and attribute reputations also based on group stereotypes, group-bounded parochial cooperation could be the result of reputational dynamics. Investigating the complex interplay of social networks and reputation may, however, be fruitful as it could reveal unexpected emerging dynamics that help explain when or why cooperation remains group-bounded, in what situations networks 'polarize', or when cooperation may break down even under conditions that should theoretically favour cooperation. Here, we outline further avenues and open questions for future research, with a particular focus on the issue of complexity, which could be addressed by combining different methods, theoretical viewpoints and strengthening interdisciplinary collaborations.

One important open question is what determines the *stability and efficiency of reputations* and how eroding or developing reputations associates with the maintenance of cooperation. While cooperation has been associated with the convergence on consensual reputations, competition for reputation has also been shown to be an important driver of group-beneficial action. These two views are to a certain degree contradicting and could be reconciled in subsequent research. As competitive altruism theory suggests, competition could exhaust individual efforts and investments while the relative reputational positions remain unaltered, resulting in Red Queen dynamics [220] with the positive externality of large-scale cooperation [53,221–223]. At the other extreme, we also have limited knowledge on those network processes that contribute to the maintenance of false reputations, their reinforcement and the maintenance of suboptimal collective outcomes. The many examples of the Emperor's Clothes are illustrated by theoretical and empirical work [224,225], though these studies are more focused on the emergence and persistence of unpopular norms and beliefs than on cooperation.

Cooperative behaviour may also be *simultaneously motivated* by both network structure and reputational concern. Observational studies by behavioural ecologists of food sharing and other forms of cooperative behaviour have broadly found that multiple mechanisms appear to be operating simultaneously (e.g. [226–232]). Generous acts may help both to reinforce particular interpersonal relationships, and to build reputational standing [54,233–236]. Taking an explicit networks perspective, studies of Lamaleran whale hunters [230,231] and of Canadian Inuit [232] found evidence for reputational signalling, reciprocity and clustering. Ready & Power [232] particularly note how norms of giving and of reciprocity can help to entrench those who wield particularly influential network positions and hold political power.

Another issue is relational multiplexity. When considering real social systems, it is nearly impossible to separate communicative acts and communication networks that may spread reputational information from the underlying social relations the same individuals may be involved in. In other words, networks of exchange and networks of information sharing—both of which may foster cooperation—are co-occurring and mutually overlapping. Social relations are generally multiplex, such that the pathways through which reputational content may flow will often be the same ones through which cooperative exchanges occur [160,162]. This entanglement inevitably adds further complexity to the process by which cooperation may be fostered. A multiplex network perspective may offer a unifying framework for further empirical investigations into the study of cooperation, reputation and networks, by defining different layers of ties in the same system, e.g. 'who cooperates with whom', 'who attributes high/low reputation to whom' and/or 'who shares a reputation evaluation about a third party with whom', 'who is in a certain relationship (e.g. friendship, trust) with whom', respectively, so that they can be studied simultaneously.

Likewise, future research needs to consider the complex realities of group membership: individuals hold multiple identities [237] in multiplex social networks [238]. Appreciating this multiplexity—and the possibility for the same relationships to have both informational and material exchanges—will be crucial for further advancing our understanding of cooperation [238].

For all network and reputation processes in human cooperation, the social context, in particular, variations in the institutional and intergroup settings, matters. Cooperation is not only maintained through mechanisms of relational mobility and reputation, as outlined in this review. Groups also establish sanctioning systems based on implicit or explicit rules and develop norms of reciprocity [239–241], which can be enforced through partner choice and ostracism, revealing a link between institutions and dynamic social networks. The degree to which networks can sustain or undermine cooperation through reputation, therefore, also depends on the institutional context [242], and on the acceptance and stability of informal and formal institutions that safeguard the maintenance of cooperation [243]. The institutional safeguards themselves have developed on the fundamentals of informal networks and reputation through human history [244–247].

Individual differences are also important in understanding the adaptive function of reputation in networks. People differently manage their reputation depending on whether or not they value collective payoffs and the future [14], while there is also inter-individual variation in reputation domains (such as prosociality and competency, [248]), with concomitant effects on cooperation. Actors experience different socialization processes based on characteristics such as gender that influence the networks of exchange and information sharing described above. Although there is some evidence for overarching patterns, such as men are more likely to engage in competitive altruism than women (see [249] for a meta-analysis of sex differences), they might only hold for specific domains. What would also be informative is focusing on differences in status and relationship history within gender (e.g. [250]) or age group (e.g. [251]). Relatedly, research on the detection and recall of reputation and cooperative behaviours will elucidate proximate mechanisms underpinning the processes discussed in this review; see [46,120,252,253] for work on memory effects.

Finally, as our review has shown, empirical work in this field is based on a wide variety of methods. Agent-based simulation can extend analytical theoretical work in highlighting the macro consequences of micro mechanisms and structural dynamics (e.g. [68,254–256]). Laboratory and field experiments can provide tests for simple hypotheses in controlled environments (e.g. [60,120,257,258]). Field experiments can use games that consider the complexity of individual and group relations in real-world settings (see [259]). The analysis of reputation mechanisms in online markets can provide insights into the efficiency of regulatory practices and could be used to test hypotheses on a massive scale (e.g. [260–264]). Historical data and field observations (e.g. [218,235,265–267]) could provide detailed insights on the build-up and functioning of reputation mechanisms for cooperation in unique contexts and could highlight both the universal character and myriad variegations across human societies. This methodological variety of empirical work demonstrates the added value of cross-disciplinarity. Future research is likely to benefit not only from further embracing this *methodological pluralism*, but also from strengthening the field's methodological and empirical foundations through more powerful mixed-method research designs.

Data accessibility. This article has no additional data.

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References

1. Darwin C. 1859 *On the origin of species*. London, UK: John Murray.
2. Dugatkin LA. 1997 *Cooperation among animals: an evolutionary perspective*. Oxford, UK: Oxford University Press.
3. Maynard Smith J, Szathmáry E. 1997 *The major transitions in evolution*. Oxford, UK: Oxford University Press.
4. Strassmann JE, Queller DC. 2010 The social organism: congresses, parties, and committees. *Evolution* **64**, 605–616. (doi:10.1111/j.1558-5646.2009.00929.x)
5. Aktipis A, Maley CC. 2017 Cooperation and cheating as innovation: insights from cellular societies. *Phil. Trans. R. Soc. B* **372**, 20160421. (doi:10.1098/rstb.2016.0421)
6. Ratcliff WC, Herron M, Conlin PL, Libby E. 2017 Nascent life cycles and the emergence of higher-level individuality. *Phil. Trans. R. Soc. B* **372**, 20160420. (doi:10.1098/rstb.2016.0420)
7. Rand DG, Nowak MA. 2013 Human cooperation. *Trends Cogn. Sci.* **17**, 413–425. (doi:10.1016/j.tics.2013.06.003)
8. Raihani NJ, Bshary R. 2015 Why humans might help strangers. *Front. Behav. Neurosci.* **9**, 39. (doi:10.3389/fnbeh.2015.00039)
9. Alexander RD. 1979 *Darwinism and human affairs*. Seattle, WA: University of Washington Press.
10. Alexander RD. 1987 *The biology of moral systems*. New York, NY: Aldine de Gruyter.
11. Nowak MA, Sigmund K. 1998 Evolution of indirect reciprocity by image scoring. *Nature* **393**, 573–577. (doi:10.1038/31225)
12. Nowak MA, Sigmund K. 2005 Evolution of indirect reciprocity. *Nature* **437**, 1291–1298. (doi:10.1038/nature04131)
13. Wu J, Balliet D, Van Lange PA. 2016 Gossip versus punishment: the efficiency of reputation to promote and maintain cooperation. *Scient. Rep.* **6**, 23919. (doi:10.1038/srep23919)
14. Wu J, Balliet D, Van Lange PA. 2016 Reputation, gossip, and human cooperation. *Social Pers. Psychol. Compass* **10**, 350–364. (doi:10.1111/spc3.12255)
15. Tennie C, Frith U, Frith CD. 2010 Reputation management in the age of the world-wide web. *Trends Cogn. Sci.* **14**, 482–488. (doi:10.1016/j.tics.2010.07.003)
16. Giardini F, Wittek R. 2019 Gossip, reputation, and sustainable cooperation: sociological foundations. In *The Oxford handbook of gossip and reputation* (eds F Giardini, RPM Wittek), pp. 23–46. Oxford, UK: Oxford University Press.

17. Piazza J, Bering JM. 2008 Concerns about reputation via gossip promote generous allocations in an economic game. *Evol. Hum. Behav.* **29**, 172–178. (doi:10.1016/j.evolhumbehav.2007.12.002)
18. Giardini F. 2012 Deterrence and transmission as mechanisms ensuring reliability of gossip. *Cogn. Process*. **13**, 465–475. (doi:10.1007/s10339-011-0421-0)
19. Barclay P. 2015 Reputation. In *The handbook of evolutionary psychology* (ed. DM Buss). John Wiley and Sons. (doi:10.1002/9781119125563.evpsych233)
20. Dunbar RI. 2004 Gossip in evolutionary perspective. *Rev. Gen. Psychol.* **8**, 100–110. (doi:10.1037/1089-2680.8.2.100)
21. Baumeister RF, Zhang L, Vohs KD. 2004 Gossip as cultural learning. *Rev. Gen. Psychol.* **8**, 111–121. (doi:10.1037/1089-2680.8.2.111)
22. Sommerfeld RD, Krambeck HJ, Semmann D, Milinski M. 2007 Gossip as an alternative for direct observation in games of indirect reciprocity. *Proc. Natl Acad. Sci. USA* **104**, 17 435–17 440. (doi:10.1073/pnas.0704598104)
23. Beersma B, Van Kleef GA. 2011 How the grapevine keeps you in line: gossip increases contributions to the group. *Social Psychol. Pers. Sci.* **2**, 642–649. (doi:10.1177/1948550611405073)
24. Beersma B, Van Kleef GA. 2012 Why people gossip: an empirical analysis of social motives, antecedents, and consequences. *J. Appl. Social Psychol.* **42**, 2640–2670. (doi:10.1111/j.1559-1816.2012.00956.x)
25. Feinberg M, Willer R, Schultz M. 2014 Gossip and ostracism promote cooperation in groups. *Psychol. Sci.* **25**, 656–664. (doi:10.1177/0956797613510184)
26. Reynolds T, Baumeister RF, Maner JK. 2018 Competitive reputation manipulation: women strategically transmit social information about romantic rivals. *J. Exp. Social Psychol.* **78**, 195–209. (doi:10.1016/j.jesp.2018.03.011)
27. Melamed D, Harrell A, Simpson B. 2018 Cooperation, clustering, and assortative mixing in dynamic networks. *Proc. Natl Acad. Sci. USA* **115**, 951–956. (doi:10.1073/pnas.1715357115)
28. Hamilton WD. 1964 The genetical evolution of social behaviour I. *J. Theor. Biol.* **7**, 1–16. (doi:10.1016/0022-5193(64)90038-4)
29. Hamilton WD. 1964 The genetical evolution of social behaviour II. *J. Theor. Biol.* **7**, 17–52. (doi:10.1016/0022-5193(64)90039-6)
30. Kay T, Keller L, Lehmann L. 2020 The evolution of altruism and the serial rediscovery of the role of relatedness. *Proc. Natl Acad. Sci. USA* **117**, 28 894–28 898. (doi:10.1073/pnas.2013596117)
31. Trivers RL. 1971 The evolution of reciprocal altruism. *Q. Rev. Biol.* **46**, 35–57. (doi:10.1086/406755)
32. Axelrod R, Hamilton WD. 1981 The evolution of cooperation. *Science* **211**, 1390–1396. (doi:10.1126/science.7466396)
33. Axelrod R. 1984 *The evolution of cooperation*. New York, NY: Basic Books.
34. Wedekind C, Milinski M. 2000 Cooperation through image scoring in humans. *Science* **288**, 850–852. (doi:10.1126/science.288.5467.850)
35. Milinski M. 2016 Reputation, a universal currency for human social interactions. *Phil. Trans. R. Soc. B* **371**, 20150100. (doi:10.1098/rstb.2015.0100)
36. Diekmann A, Jann B, Wyder D. 2009 Trust and reputation in internet auctions. In *eTrust: forming relationships in the online world* (eds KS Cook, C Snijders, V Buskens, C Cheshire), pp. 139–165. New York, NY: Russel Sage Foundation.
37. Antonioni A, Sánchez A, Tomassini M. 2016 Cooperation survives and cheating pays in a dynamic network structure with unreliable reputation. *Scient. Rep.* **6**, 27160. (doi:10.1038/srep27160)
38. Duca S, Nax HH. 2018 Groups and scores: the decline of cooperation. *J. R. Soc. Interface* **15**, 20180158. (doi:10.1098/rsif.2018.0158)
39. Nax HH, Perc M, Szolnoki A, Helbing D. 2015 Stability of cooperation under image scoring in group interactions. *Scient. Rep.* **5**, 12145. (doi:10.1038/srep12145)
40. Milinski M, Semmann D, Bakker TC, Krambeck HJ. 2001 Cooperation through indirect reciprocity: image scoring or standing strategy? *Proc. R. Soc. Lond. B* **268**, 2495–2501. (doi:10.1098/rspb.2001.1809)
41. Panchanathan K, Boyd R. 2003 A tale of two defectors: the importance of standing for evolution of indirect reciprocity. *J. Theor. Biol.* **224**, 115–126. (doi:10.1016/S0022-5193(03)00154-1)
42. Pacheco JM, Santos FC, Chalub FAC. 2006 Stern-judging: a simple, successful norm which promotes cooperation under indirect reciprocity. *PLoS Comput. Biol.* **2**, e178. (doi:10.1371/journal.pcbi.0020178)
43. Santos FP, Santos FC, Pacheco JM. 2018 Social norm complexity and past reputations in the evolution of cooperation. *Nature* **555**, 242–245. (doi:10.1038/nature25763)
44. Ohtsuki H, Iwasa Y. 2004 How should we define goodness?—Reputation dynamics in indirect reciprocity. *J. Theor. Biol.* **231**, 107–120. (doi:10.1016/j.jtbi.2004.06.005)
45. Ohtsuki H, Iwasa Y. 2006 The leading eight: social norms that can maintain cooperation by indirect reciprocity. *J. Theor. Biol.* **239**, 435–444. (doi:10.1016/j.jtbi.2005.08.008)
46. Gross J, De Dreu CK. 2019 The rise and fall of cooperation through reputation and group polarization. *Nat. Commun.* **10**, 1. (doi:10.1038/s41467-018-07882-8)
47. Quan J, Tang C, Wang X. 2021 Reputation-based discount effect in imitation on the evolution of cooperation in spatial public goods games. *Physica A* **563**, 125488. (doi:10.1016/j.physa.2020.125488)
48. Ahn TK, Esarey J, Scholz JT. 2009 Reputation and cooperation in voluntary exchanges: comparing local and central institutions. *J. Polit.* **71**, 398–413. (doi:10.1017/s0022381609090355)
49. Sylwester K, Roberts G. 2013 Reputation-based partner choice is an effective alternative to indirect reciprocity in solving social dilemmas. *Evol. Hum. Behav.* **34**, 201–206. (doi:10.1016/j.evolhumbehav.2012.11.009)
50. Capraro V, Giardini F, Vilone D, Paolucci M. 2016 Partner selection supported by opaque reputation promotes cooperative behavior. *Judgm. Decis. Mak.* **11**, 589–600.
51. Wu J, Balliet D, Peperkoorn LS, Romano A, Van Lange PA. 2020 Cooperation in groups of different sizes: the effects of punishment and reputation-based partner choice. *Front. Psychol.* **10**, 2956. (doi:10.3389/fpsyg.2019.02956)
52. Noë R, Hammerstein P. 1994 Biological markets: supply and demand determine the effect of partner choice in cooperation, mutualism and mating. *Behav. Ecol. Sociobiol.* **35**, 1–11. (doi:10.1007/BF00167053)
53. Roberts G. 1998 Competitive altruism: from reciprocity to the handicap principle. *Proc. R. Soc. Lond. B* **265**, 427–431. (doi:10.1098/rspb.1998.0312)
54. Barclay P, Willer R. 2007 Partner choice creates competitive altruism in humans. *Proc. R. Soc. B* **274**, 749–753. (doi:10.1098/rspb.2006.0209)
55. Barclay P. 2013 Strategies for cooperation in biological markets, especially for humans. *Evol. Hum. Behav.* **34**, 164–175. (doi:10.1016/j.evolhumbehav.2013.02.002)
56. Barclay P. 2016 Biological markets and the effects of partner choice on cooperation and friendship. *Curr. Opin. Psychol.* **7**, 33–38. (doi:10.1016/j.copsyc.2015.07.012)
57. Ohtsuki H, Iwasa Y, Nowak MA. 2015 Reputation effects in public and private interactions. *PLoS Comput. Biol.* **11**, e1004527. (doi:10.1371/journal.pcbi.1004527)
58. Hilbe C, Schmid L, Tkadlec J, Chatterjee K, Nowak MA. 2018 Indirect reciprocity with private, noisy, and incomplete information. *Proc. Natl Acad. Sci. USA* **115**, 12 241–12 246. (doi:10.1073/pnas.1810565115)
59. Yang G, Csikász-Nagy A, Waites W, Cavaliere M. 2020 Information cascades and the collapse of cooperation. *Scient. Rep.* **10**, 8004. (doi:10.1038/s41598-020-64800-z)
60. Samu F, Számadó S, Takács K. 2020 Scarce and directly beneficial reputations support cooperation. *Scient. Rep.* **10**, 11486. (doi:10.1038/s41598-020-68123-x)
61. Samu F, Takács K. 2021 Evaluating mechanisms that could support credible reputations and cooperation: cross-checking and social bonding. *Phil. Trans. R. Soc. B* **376**, 20200302. (doi:10.1098/rstb.2020.0302)
62. Podder S, Righi S, Takács K. 2021 Local reputation, local selection, and the leading eight norms. *Scient. Rep*. **11**, 16560. (doi:10.1038/s41598-021-95130-3)
63. Sommerfeld RD, Krambeck HJ, Milinski M. 2008 Multiple gossip statements and their effect on reputation and trustworthiness. *Proc. R. Soc. B* **275**, 2529–2536. (doi:10.1098/rspb.2008.0762)
64. Feinberg M, Willer R, Stellar J, Keltner D. 2012 The virtues of gossip: reputational information sharing as prosocial behavior. *J. Pers. Social Psychol.* **102**, 1015. (doi:10.1037/a0026650)
65. Fehr D, Sutter M. 2019 Gossip and the efficiency of interactions. *Games Econ. Behav.* **113**, 448–460. (doi:10.1016/j.geb.2018.10.003)

66. Dores Cruz TD, Nieper AS, Testori M, Martinescu E, Beersma B. 2021 An integrative definition and framework to study gossip. *Group Org. Manage.* **46**, 252–285. (doi:10.1177/1059601121992887)
67. Wittek R, Wielers R. 1998 Gossip in organizations. *Comput. Math. Org. Theory* **4**, 189–204. (doi:10.1023/A:1009636325582)
68. Giardini F, Vilone D. 2016 Evolution of gossip-based indirect reciprocity on a bipartite network. *Scient. Rep.* **6**, 37931. (doi:10.1038/srep37931)
69. Hess NH, Hagen EH. 2006 Psychological adaptations for assessing gossip veracity. *Hum. Nat.* **17**, 337–354. (doi:10.1007/s12110-006-1013-z)
70. Giardini F, Wittek RPM. 2019 Silence is golden. Six reasons inhibiting the spread of third-party gossip. *Front. Psychol.* **10**, 1120. (doi:10.3389/fpsyg.2019.01120)
71. Peters K, Fonseca MA. 2020 Truth, lies, and gossip. *Psychol. Sci.* **31**, 702–714. (doi:10.1177/0956797620916708)
72. Hess NH, Hagen EH. 2021 Competitive gossip: the impact of domain, resource value, resource scarcity and coalitions. *Phil. Trans. R. Soc. B* **376**, 20200305. (doi:10.1098/rstb.2020.0305)
73. Wang Z, Wang L, Yin Z-Y, Xia C-Y. 2012 Inferring reputation promotes the evolution of cooperation in spatial social dilemma games. *PLoS ONE* **7**, e40218. (doi:10.1371/journal.pone.0040218)
74. Walmsley J, O'Madagain C. 2020 The worst-motive fallacy: a negativity bias in motive attribution. *Psychol. Sci.* **31**, 1430–1438. (doi:10.1177/0956797620954492)
75. Lee SH, Barnes CM. 2021 An attributional process model of workplace gossip. *J. Appl. Psychol.* **106**, 300–316. (doi:10.1037/apl0000504)
76. Watts DJ, Strogatz SH. 1988 Collective dynamics of 'small-world' networks. *Nature* **393**, 440–442. (doi:10.1038/30918)
77. Watts DJ. 1999 *Small worlds*. Princeton, NJ: Princeton University Press.
78. McPherson M, Smith-Lovin L, Cook JM. 2001 Birds of a feather: homophily in social networks. *Annu. Rev. Sociol.* **27**, 415–444. (doi:10.1146/annurev.soc.27.1.415)
79. Steglich C, Snijders TA, Pearson M. 2010 Dynamic networks and behavior: separating selection from influence. *Sociol. Methodol.* **40**, 329–393. (doi:10.1111/j.1467-9531.2010.01225.x)
80. Righi S, Takács K. 2018 Social closure and the evolution of cooperation via indirect reciprocity. *Scient. Rep.* **8**, 11149. (doi:10.1038/s41598-018-29290-0)
81. Santos FC, Pacheco JM. 2005 Scale-free networks provide a unifying framework for the emergence of cooperation. *Phys. Rev. Lett.* **95**, 098104. (doi:10.1103/PhysRevLett.95.098104)
82. Jansen VAA, van Baalen M. 2006 Altruism through beard chromodynamics. *Nature* **440**, 663–666. (doi:10.1038/nature04387)
83. Fu F, Chen X, Liu L, Wang L. 2007 Social dilemmas in an online social network: the structure and evolution of cooperation. *Phys. Lett. A* **371**, 58–64. (doi:10.1016/j.physleta.2007.05.116)
84. Vukov J, Santos FC, Pacheco JM. 2012 Cognitive strategies take advantage of the cooperative potential of heterogeneous networks. *New J. Phys.* **14**, 063031. (doi:10.1088/1367-2630/14/6/063031)
85. Rand DG, Nowak MA, Fowler JH, Christakis NA. 2014 Static network structure can stabilize human cooperation. *Proc. Natl Acad. Sci. USA* **111**, 17 093–17 098. (doi:10.1073/pnas.1400406111)
86. Lo Iacono S. 2018 Does community social embeddedness promote generalized trust? An experimental test of the spillover effect. *Social Sci. Res.* **73**, 126–145. (doi:10.1016/j.ssresearch.2018.03.001)
87. Testori M, Hoyle RB, Eisenbarth H. 2019 How group composition affects cooperation in fixed networks: can psychopathic traits influence group dynamics? *R. Soc. Open Sci.* **6**, 181329. (doi:10.1098/rsos.181329)
88. Ohtsuki H, Hauert C, Lieberman E, Nowak MA. 2006 A simple rule for the evolution of cooperation on graphs and social networks. *Nature* **441**, 502–505. (doi:10.1038/nature04605)
89. Barabási AL, Albert R. 1999 Emergence of scaling in random networks. *Science* **286**, 509–512. (doi:10.1126/science.286.5439.509)
90. Poncela J, Gómez-Gardeñes J, Floría LM, Moreno Y. 2007 Robustness of cooperation in the evolutionary prisoner's dilemma on complex networks. *New J. Phys.* **9**, 184. (doi:10.1088/1367-2630/9/6/184)
91. Santos FC, Pacheco JM, Lenaerts T. 2006 Evolutionary dynamics of social dilemmas in structured heterogeneous populations. *Proc. Natl Acad. Sci. USA* **103**, 3490–3494. (doi:10.1073/pnas.0508201103)
92. Gómez-Gardeñes J, Campillo M, Floría LM, Moreno Y. 2007 Dynamical organization of cooperation in complex topologies. *Phys. Rev. Lett.* **98**, 108103. (doi:10.1103/PhysRevLett.98.108103)
93. Santos FC, Santos MD, Pacheco JM. 2008 Social diversity promotes the emergence of cooperation in public goods games. *Nature* **454**, 213–216. (doi:10.1038/nature06940)
94. Perc M. 2009 Evolution of cooperation on scale-free networks subject to error and attack. *New J. Phys.* **11**, 033027. (doi:10.1088/1367-2630/11/3/033027)
95. Watts DJ, Strogatz SH. 1998 Collective dynamics of 'small-world' networks. *Nature* **393**, 440–442. (doi:10.1038/30918)
96. Santos FC, Rodrigues JF, Pacheco JM. 2005 Epidemic spreading and cooperation dynamics on homogeneous small-world networks. *Phys. Rev. E* **72**, 056128. (doi:10.1103/PhysRevE.72.056128)
97. Pavlogiannis A, Tkadlec J, Chatterjee K, Nowak MA. 2017 Amplification on undirected population structures: comets beat stars. *Scient. Rep.* **7**, 82. (doi:10.1038/s41598-017-00107-w)
98. Szabó G, Fáth G. 2007 Evolutionary games on graphs. *Phys. Rep.* **446**, 97–216. (doi:10.1016/j.physrep.2007.04.004)
99. Rong Z, Yang HX, Wang WX. 2010 Feedback reciprocity mechanism promotes the cooperation of highly clustered scale-free networks. *Phys. Rev. E* **82**, 047101. (doi:10.1103/PhysRevE.82.047101)
100. Perc M, Gómez-Gardeñes J, Szolnoki A, Floría LM, Moreno Y. 2013 Evolutionary dynamics of group interactions on structured populations: a review. *J. R. Soc. Interface* **10**, 20120997. (doi:10.1098/rsif.2012.0997)
101. Cao XB, Du WB, Rong ZH. 2010 The evolutionary public goods game on scale-free networks with heterogeneous investment. *Physica A* **389**, 1273–1280. (doi:10.1016/j.physa.2009.11.044)
102. Lei C, Wu T, Jia JY, Cong R, Wang L. 2010 Heterogeneity of allocation promotes cooperation in public goods games. *Physica A* **389**, 4708–4714. (doi:10.1016/j.physa.2010.06.002)
103. Zhang H, Yang H, Du W, Wang B, Cao X. 2010 Evolutionary public goods games on scale-free networks with unequal payoff allocation mechanism. *Physica A* **389**, 1099–1104. (doi:10.1016/j.physa.2009.11.029)
104. Yang HX, Rong Z, Lu PM, Zeng YZ. 2012 Effects of aspiration on public cooperation in structured populations. *Physica A* **391**, 4043–4049. (doi:10.1016/j.physa.2012.03.018)
105. Yang G, Cavaliere M, Zhu C, Perc M. 2021 Strategically positioning cooperators can facilitate the contagion of cooperation. *Scient. Rep.* **11**, 1. (doi:10.1038/s41598-020-79139-8)
106. Lieberman E, Hauert C, Nowak MA. 2005 Evolutionary dynamics on graphs. *Nature* **433**, 312–316. (doi:10.1038/nature03204)
107. Molho C, Balliet D, Wu J. 2019 Hierarchy, power, and strategies to promote cooperation in social dilemmas. *Games* **10**, 12. (doi:10.3390/g10010012)
108. Cronin KA, Acheson DJ, Hernández P, Sánchez A. 2015 Hierarchy is detrimental for human cooperation. *Scient. Rep.* **5**, 18634. (doi:10.1038/srep18634)
109. Nowak MA, May RM. 1992 Evolutionary games and spatial chaos. *Nature* **359**, 826–829. (doi:10.1038/359826a0)
110. Nowak MA, May RM. 1993 The spatial dilemmas of evolution. *Int. J. Bifurcation Chaos* **3**, 35–78. (doi:10.1142/S0218127493000040)
111. Szabó G, Vukov J, Szolnoki A. 2005 Phase diagrams for an evolutionary prisoner's dilemma game on two-dimensional lattices. *Phys. Rev. E* **72**, 047107. (doi:10.1103/PhysRevE.72.047107)
112. Vukov J, Szabó G. 2005 Evolutionary prisoner's dilemma game on hierarchical lattices. *Phys. Rev. E* **71**, 036133. (doi:10.1103/PhysRevE.71.036133)
113. Doebeli M, Hauert C. 2005 Models of cooperation based on the Prisoner's Dilemma and the Snowdrift game. *Ecol. Lett.* **8**, 748–766. (doi:10.1111/j.1461-0248.2005.00773.x)
114. Németh A, Takács K. 2007 The evolution of altruism in spatially structured populations. *J. Artif. Soc. Social Simul.* **10**, 4.
115. Nowak MA, Tarnita CE, Antal T. 2010 Evolutionary dynamics in structured populations. *Phil. Trans. R. Soc. B* **365**, 19–30. (doi:10.1098/rstb.2009.0215)

116. Traulsen A, Semmann D, Sommerfeld RD, Krambeck HJ, Milinski M. 2010 Human strategy updating in evolutionary games. *Proc. Natl Acad. Sci. USA* **107**, 2962–2966. (doi:10.1073/pnas.0912515107)
117. Grujić J, Fosco C, Araujo L, Cuesta JA, Sánchez A. 2010 Social experiments in the mesoscale: humans playing a spatial prisoner's dilemma. *PLoS ONE* **5**, e13749. (doi:10.1371/journal.pone.0013749)
118. Grujić J, Röhl T, Semmann D, Milinski M, Traulsen A. 2012 Consistent strategy updating in spatial and non-spatial behavioral experiments does not promote cooperation in social networks. *PLoS ONE* **7**, e47718. (doi:10.1371/journal.pone.0047718)
119. Gracia-Lázaro C, Ferrer A, Ruiz G, Tarancón A, Cuesta JA, Sánchez A, Moreno Y. 2012 Heterogeneous networks do not promote cooperation when humans play a Prisoner's Dilemma. *Proc. Natl Acad. Sci. USA* **109**, 12 922–12 926. (doi:10.1073/pnas.1206681109)
120. Cuesta JA, Gracia-Lázaro C, Ferrer A, Moreno Y, Sánchez A. 2015 Reputation drives cooperative behaviour and network formation in human groups. *Scient. Rep.* **5**, 7843. (doi:10.1038/srep07843)
121. Perc M, Jordan JJ, Rand DG, Wang Z, Boccaletti S, Szolnoki A. 2017 Statistical physics of human cooperation. *Phys. Rep.* **687**, 1–51. (doi:10.1016/j.physrep.2017.05.004)
122. Roca CP, Cuesta JA, Sánchez A. 2009 Evolutionary game theory: temporal and spatial effects beyond replicator dynamics. *Phys. Life Rev.* **6**, 208–249. (doi:10.1016/j.plrev.2009.08.001)
123. Amaral MA, Perc M, Wardil L, Szolnoki A, da Silva Júnior EJ, da Silva JK. 2017 Role-separating ordering in social dilemmas controlled by topological frustration. *Phys. Rev. E* **95**, 032307. (doi:10.1103/PhysRevE.95.032307)
124. Roca CP, Sánchez A, Cuesta JA. 2012 Individual strategy update and emergence of cooperation in social networks. *J. Math. Sociol.* **36**, 1–21. (doi:10.1080/0022250X.2010.520830)
125. Roca CP, Cuesta JA, Sánchez A. 2009 Promotion of cooperation on networks? The myopic best response case. *Eur. Phys. J. B* **71**, 587–595. (doi:10.1140/epjb/e2009-00189-0)
126. Amaral MA, Javarone MA. 2018 Heterogeneous update mechanisms in evolutionary games: mixing innovative and imitative dynamics. *Phys. Rev. E* **97**, 042305. (doi:10.1103/PhysRevE.97.042305)
127. Gómez-Gardeñes J, Vilone D, Sánchez A. 2011 Disentangling social and group heterogeneities: public goods games on complex networks. *EPL (Europhys. Lett.)* **95**, 68003. (doi:10.1209/0295-5075/95/68003)
128. Perc M, Szolnoki A. 2010 Coevolutionary games—a mini review. *Biosystems* **99**, 109–125. (doi:10.1016/j.biosystems.2009.10.003)
129. Perc M. 2016 Phase transitions in models of human cooperation. *Phys. Lett. A* **380**, 2803–2808. (doi:10.1016/j.physleta.2016.06.017)
130. Vukov J, Szabó G, Szolnoki A. 2006 Cooperation in the noisy case: prisoner's dilemma game on two types of regular random graphs. *Phys. Rev. E* **73**, 067103. (doi:10.1103/PhysRevE.73.067103)
131. Ichinose G, Satotani Y, Sayama H. 2018 How mutation alters the evolutionary dynamics of cooperation on networks. *New J. Phys.* **20**, 053049. (doi:10.1088/1367-2630/aac2a7)
132. Wang X, Duh M, Perc M. 2020 Robust cooperation against mutations via costly expulsion. *EPL (Europhys. Lett.)* **132**, 38001. (doi:10.1209/0295-5075/132/38001)
133. Droz M, Szwabiński J, Szabó G. 2009 Motion of influential players can support cooperation in prisoner's dilemma. *Eur. Phys. J. B* **71**, 579–585. (doi:10.1140/epjb/e2009-00160-1)
134. Rand DG, Arbesman S, Christakis NA. 2011 Dynamic social networks promote cooperation in experiments with humans. *Proc. Natl Acad. Sci. USA* **108**, 19 193–19 198. (doi:10.1073/pnas.1108243108)
135. Takács K, Janky B, Flache A. 2008 Collective action and network change. *Social Netw.* **30**, 177–189. (doi:10.1016/j.socnet.2008.02.003)
136. Fu F, Hauert C, Nowak MA, Wang L. 2008 Reputation-based partner choice promotes cooperation in social networks. *Phys. Rev. E* **78**, 026117. (doi:10.1103/PhysRevE.78.026117)
137. De Dreu CK, Gross J, Fariña A, Ma Y. 2020 Group cooperation, carrying-capacity stress, and intergroup conflict. *Trends Cogn. Sci.* **24**, 760–776. (doi:10.1016/j.tics.2020.06.005)
138. Zimmermann MG, Eguíluz VM, San Miguel M. 2004 Coevolution of dynamical states and interactions in dynamic networks. *Phys. Rev. E* **69**, 065102. (doi:10.1103/PhysRevE.69.065102)
139. Eguíluz VM, Zimmermann MG, Cela-Conde CJ, Miguel MS. 2005 Cooperation and the emergence of role differentiation in the dynamics of social networks. *Am. J. Sociol.* **110**, 977–1008. (doi:10.1086/428716)
140. Santos FC, Pacheco JM, Lenaerts T. 2006 Cooperation prevails when individuals adjust their social ties. *PLoS Comput. Biol.* **2**, e140. (doi:10.1371/journal.pcbi.0020140)
141. Pacheco JM, Traulsen A, Nowak MA. 2006 Coevolution of strategy and structure in complex networks with dynamical linking. *Phys. Rev. Lett.* **97**, 258103. (doi:10.1103/PhysRevLett.97.258103)
142. Masuda N. 2007 Participation costs dismiss the advantage of heterogeneous networks in evolution of cooperation. *Proc. R. Soc. B* **274**, 1815–1821. (doi:10.1098/rspb.2007.0294)
143. Wang S, Szalay MS, Zhang C, Csermely P. 2008 Learning and innovative elements of strategy adoption rules expand cooperative network topologies. *PLoS ONE* **3**, e1917. (doi:10.1371/journal.pone.0001917)
144. Pacheco JM, Pinheiro FL, Santos FC. 2009 Population structure induces a symmetry breaking favoring the emergence of cooperation. *PLoS Comput. Biol.* **5**, e1000596. (doi:10.1371/journal.pcbi.1000596)
145. Zschaler G, Traulsen A, Gross T. 2010 A homoclinic route to asymptotic full cooperation in adaptive networks and its failure. *New J. Phys.* **12**, 093015. (doi:10.1088/1367-2630/12/9/093015)
146. Fehl K, van der Post DJ, Semmann D. 2011 Co-evolution of behaviour and social network structure promotes human cooperation. *Ecol. Lett.* **14**, 546–551. (doi:10.1111/j.1461-0248.2011.01615.x)
147. Wang J, Suri S, Watts DJ. 2012 Cooperation and assortativity with dynamic partner updating. *Proc. Natl Acad. Sci. USA* **109**, 14 363–14 368. (doi:10.1073/pnas.1120867109)
148. Shirado H, Fu F, Fowler JH, Christakis NA. 2013 Quality versus quantity of social ties in experimental cooperative networks. *Nat. Commun.* **4**, 2814. (doi:10.1038/ncomms3814)
149. Wardil L, Hauert C. 2014 Origin and structure of dynamic cooperative networks. *Scient. Rep.* **4**, 5725. (doi:10.1038/srep05725)
150. McAvoy A, Allen B, Nowak MA. 2020 Social goods dilemmas in heterogeneous societies. *Nat. Hum. Behav.* **4**, 819–831. (doi:10.1038/s41562-020-0881-2)
151. Harrell A, Melamed D, Simpson B. 2018 The strength of dynamic ties: the ability to alter some ties promotes cooperation in those that cannot be altered. *Sci. Adv.* **4**, eaau9109. (doi:10.1126/sciadv.aau9109)
152. Szolnoki A, Perc M, Danku Z. 2008 Making new connections towards cooperation in the prisoner's dilemma game. *EPL (Europhys. Lett.)* **84**, 50007. (doi:10.1209/0295-5075/84/50007)
153. Szolnoki A, Perc M. 2009 Resolving social dilemmas on evolving random networks. *EPL (Europhys. Lett.)* **86**, 30007. (doi:10.1209/0295-5075/86/30007)
154. Santos FC, Rodrigues JF, Pacheco JM. 2006 Graph topology plays a determinant role in the evolution of cooperation. *Proc. R. Soc. B* **273**, 51–55. (doi:10.1098/rspb.2005.3272)
155. Poncela J, Gómez-Gardeñes J, Floría LM, Sánchez A, Moreno Y. 2008 Complex cooperative networks from evolutionary preferential attachment. *PLoS ONE* **3**, e2449. (doi:10.1371/journal.pone.0002449)
156. Hanaki N, Peterhansl A, Dodds PS, Watts DJ. 2007 Cooperation in evolving social networks. *Manage. Sci.* **53**, 1036–1050. (doi:10.1287/mnsc.1060.0625)
157. Fu F, Wu T, Wang L. 2009 Partner switching stabilizes cooperation in coevolutionary prisoner's dilemma. *Phys. Rev. E* **79**, 036101. (doi:10.1103/PhysRevE.79.036101)
158. Ohtsuki H, Nowak MA, Pacheco JM. 2007 Breaking the symmetry between interaction and replacement in evolutionary dynamics on graphs. *Phys. Rev. Lett.* **98**, 108106. (doi:10.1103/PhysRevLett.98.108106)
159. Ohtsuki H, Pacheco JM, Nowak MA. 2007 Evolutionary graph theory: breaking the symmetry between interaction and replacement. *J. Theor. Biol.* **246**, 681–694. (doi:10.1016/j.jtbi.2007.01.024)
160. Gómez-Gardeñes J, Reinares I, Arenas A, Floría LM. 2012 Evolution of cooperation in multiplex networks. *Scient. Rep.* **2**, 620. (doi:10.1038/srep00620)
161. Jin Q, Wang L, Xia CY, Wang Z. 2014 Spontaneous symmetry breaking in interdependent networked game. *Scient. Rep.* **4**, 4095. (doi:10.1038/srep04095)

162. Battiston F, Perc M, Latora V. 2017 Determinants of public cooperation in multiplex networks. *New J. Phys.* **19**, 073017. (doi:10.1088/1367-2630/aa6ea1)
163. Takesue H. 2021 Symmetry breaking in the Prisoner's Dilemma on two-layer dynamic multiplex networks. *Appl. Math. Comput.* **388**, 125543. (doi:10.1016/j.amc.2020.125543)
164. Wu B, Zhou D, Fu F, Luo Q, Wang L, Traulsen A. 2010 Evolution of cooperation on stochastic dynamical networks. *PLoS ONE* **5**, e11187. (doi:10.1371/journal.pone.0011187)
165. Melamed D, Simpson B. 2016 Strong ties promote the evolution of cooperation in dynamic networks. *Social Netw.* **45**, 32–44. (doi:10.1016/j.socnet.2015.11.001)
166. Szolnoki A, Perc M. 2009 Promoting cooperation in social dilemmas via simple coevolutionary rules. *Eur. Phys. J. B* **67**, 337–344. (doi:10.1140/epjb/e2008-00470-8)
167. Szolnoki A, Perc M. 2009 Emergence of multilevel selection in the Prisoner's Dilemma game on coevolving random networks. *New J. Phys.* **11**, 093033. (doi:10.1088/1367-2630/11/9/093033)
168. Traag VA, Van Dooren P, De Leenheer P. 2013 Dynamical models explaining social balance and evolution of cooperation. *PLoS ONE* **8**, e60063. (doi:10.1371/journal.pone.0060063)
169. Righi S, Takács K. 2014 Emotional strategies as catalysts for cooperation in signed networks. *Adv. Complex Syst.* **17**, 1450011. (doi:10.1142/S0219525914500118)
170. He X, Du H, Cai M, Feldman MW. 2018 The evolution of cooperation in signed networks under the impact of structural balance. *PloS ONE* **13**, e0205084. (doi:10.1371/journal.pone.0205084)
171. Gallo E, Yan C. 2015 The effects of reputational and social knowledge on cooperation. *Proc. Natl Acad. Sci. USA* **112**, 3647–3652. (doi:10.1073/pnas.1415883112)
172. Centola D. 2018 *How behavior spreads: the science of complex contagions*. Princeton, NJ: Princeton University Press.
173. Goyal S. 2011 Learning in networks. In *Handbook of social economics* (eds J Benhabib, A Bisin, MO Jackson), vol. 1, pp. 679–727. San Diego, CA: Elsevier North Holland. (doi:10.1016/B978-0-444-53187-2.00015-2)
174. DeGroot MH. 1974 Reaching a consensus. *J. Am. Stat. Assoc.* **69**, 118–121. (doi:10.1080/01621459.1974.10480137)
175. Quattrociocchi W, Caldarelli G, Scala A. 2014 Opinion dynamics on interacting networks: media competition and social influence. *Scient. Rep.* **4**, 4938. (doi:10.1038/srep04938)
176. Barber KS, Kim J. 2001 Belief revision process based on trust: agents evaluating reputation of information sources. In *Trust in cyber-societies* (eds R Falcone, M Singh, Y-H Tan), pp. 73–82. Berlin, Germany: Springer.
177. Teacey WL, Patel J, Jennings NR, Luck M. 2006 Travos: trust and reputation in the context of inaccurate information sources. *Auton. Agent. Multi-Agent Sys.* **12**, 183–198. (doi:10.1007/s10458-006-5952-x)
178. Craik KH. 2008 *Reputation: a network interpretation*. Oxford, UK: Oxford University Press.
179. Centola D, Macy M. 2007 Complex contagions and the weakness of long ties. *Am. J. Sociol.* **113**, 702–734. (doi:10.1086/521848)
180. Centola D. 2010 The spread of behavior in an online social network experiment. *Science* **329**, 1194–1197. (doi:10.1126/science.1185231)
181. Grosser TJ, Lopez-Kidwell V, Labianca G. 2010 A social network analysis of positive and negative gossip in organizational life. *Group Org. Manage.* **35**, 177–212. (doi:10.1177/1059601109360391)
182. Ellwardt L, Wittek RPM, Wielers R. 2012 Talking about the boss: effects of generalized and interpersonal trust on workplace gossip. *Group Org. Manage.* **37**, 521–549. (doi:10.1177/1059601112450607)
183. Ellwardt L, Steglich C, Wittek R. 2012 The co-evolution of gossip and friendship in workplace social networks. *Social Netw.* **34**, 623–633. (doi:10.1016/j.socnet.2012.07.002)
184. Peters K, Kashima Y. 2015 Bad habit or social good? How perceptions of gossiper morality are related to gossip content. *Eur. J. Soc. Psychol.* **45**, 784–798. (doi:10.1002/ejsp.2123)
185. Yamagishi T, Hayashi N, Jin N. 1994 Prisoner's dilemma networks: selection strategy versus action strategy. In *Social dilemmas and cooperation* (eds U Schulz, W Albers, U Mueller), pp. 233–250. Berlin, Germany: Springer.
186. Hayashi N, Yamagishi T. 1998 Selective play: choosing partners in an uncertain world. *Pers. Social Psychol. Rev.* **2**, 276. (doi:10.1207/s15327957pspr0204_4)
187. Jackson MO, Rodriguez-Barraquer T, Tan X. 2012 Social capital and social quilts: network patterns of favor exchange. *Am. Econ. Rev.* **102**, 1857–1897. (doi:10.1257/aer.102.5.1857)
188. von Rueden CR, Redhead D, O'Gorman R, Kaplan H, Gurven M. 2019 The dynamics of men's cooperation and social status in a small-scale society. *Proc. R. Soc. B* **286**, 20191367. (doi:10.1098/rspb.2019.1367)
189. Kisfalusi D, Takács K, Pál J. 2019 Gossip and reputation in adolescent networks. In *Oxford handbook on gossip and reputation* (eds F Giardini, RPM Wittek), pp. 359–379. Oxford, UK: Oxford University Press.
190. Ellwardt L. 2019 Gossip and reputation in social networks. In *Oxford handbook on gossip and reputation* (eds F Giardini, RPM Wittek), pp. 435–457. Oxford, UK: Oxford University Press.
191. Labun A, Wittek R, Steglich C. 2016 The co-evolution of power and friendship networks in an organization. *Netw. Sci.* **4**, 364–384. (doi:10.1017/nws.2016.7)
192. Van de Bunt GG, Wittek RP, de Klepper MC. 2005 The evolution of intra-organizational trust networks: the case of a German paper factory: an empirical test of six trust mechanisms. *Int. Sociol.* **20**, 339–369. (doi:10.1177/0268580905055480)
193. Kilduff M, Lee JW. 2020 The integration of people and networks. *Annu. Rev. Organ. Psychol. Organ. Behav.* **7**, 155–179. (doi:10.1146/annurev-orgpsych-012119-045357)
194. Lindenberg S. 2015 Groups, sociology of. In *International encyclopedia of the social & behavioral sciences*, 2nd edn (ed. JD Wright), pp. 434–440. Oxford, UK: Elsevier.
195. Freeman LC. 1992 The sociological concept of 'group': an empirical test of two models. *Am. J. Sociol.* **98**, 152–166. (doi:10.1086/229972)
196. Zeggelink EP, Stokman FN, Van De Bunt GG. 1996 The emergence of groups in the evolution of friendship networks. *J. Math. Sociol.* **21**, 29–55. (doi:10.1080/0022250X.1996.9990173)
197. Moody J, White DR. 2003 Structural cohesion and embeddedness: a hierarchical concept of social groups. *Am. Sociol. Rev.* **68**, 103–127. (doi:10.2307/3088904)
198. Newman ME. 2006 Modularity and community structure in networks. *Proc. Natl Acad. Sci. USA* **103**, 8577–8582. (doi:10.1073/pnas.0601602103)
199. Rusch H. 2014 The evolutionary interplay of intergroup conflict and altruism in humans: a review of parochial altruism theory and prospects for its extension. *Proc. R. Soc. B* **281**, 20141539. (doi:10.1098/rspb.2014.1539)
200. Balliet D, Wu J, De Dreu CK. 2014 Ingroup favoritism in cooperation: a meta-analysis. *Psychol. Bull.* **140**, 1556. (doi:10.1037/a0037737)
201. Lane T. 2016 Discrimination in the laboratory: a meta-analysis of economics experiments. *Eur. Econ. Rev.* **90**, 375–402. (doi:10.1016/j.euroecorev.2015.11.011)
202. De Dreu CK, Balliet D, Halevy N. 2014 Parochial cooperation in humans: forms and functions of self-sacrifice in intergroup conflict. *Adv. Motiv. Sci.* **1**, 1–47. (doi:10.1016/bs.adms.2014.08.001)
203. Mifune N, Hashimoto H, Yamagishi T. 2010 Altruism toward in-group members as a reputation mechanism. *Evol. Hum. Behav.* **31**, 109–117. (doi:10.1016/j.evolhumbehav.2009.09.004)
204. Tajfel H, Turner JC. 1986 The social identity theory of intergroup behavior. In *The social psychology of intergroup relations* (eds S Worchel, WG Austin). Chicago, IL: Nelson-Hall.
205. Turner JC, Brown RJ, Tajfel H. 1979 Social comparison and group interest in ingroup favouritism. *Eur. J. Soc. Psychol.* **9**, 187–204. (doi:10.1002/ejsp.2420090207)
206. Turner JC, Hogg MA, Oakes PJ, Reicher SD, Wetherell MS. 1987 *Rediscovering the social group: a self-categorization theory*. Oxford, UK: Basil Blackwell.
207. Yamagishi T, Jin N, Kiyonari T. 1999 Bounded generalized reciprocity: ingroup boasting and ingroup favoritism. *Adv. Group Process.* **16**, 161–197.
208. Böhm R, Rusch H, Baron J. 2020 The psychology of intergroup conflict: a review of theories and measures. *J. Econ. Behav. Organ.* **178**, 947–962. (10.1016/j.jebo.2018.01.020)
209. Romano A, Balliet D, Yamagishi T, Liu JH. 2017 Parochial trust and cooperation across 17 societies. *Proc. Natl Acad. Sci. USA* **114**, 12 702–12 707. (doi:10.1073/pnas.1712921114)

210. Romano A, Balliet D, Wu J. 2017 Unbounded indirect reciprocity: is reputation-based cooperation bounded by group membership? *J. Exp. Social Psychol.* **71**, 59–67. (doi:10.1016/j.jesp.2017.02.008)
211. Pisor AC, Gurven M. 2016 Risk buffering and resource access shape valuation of out-group strangers. *Scient. Rep.* **6**, 30435. (doi:10.1038/srep30435)
212. Baranski B *et al.* 2006 The impact of group reputation in multiagent environments. In *2006 IEEE Int. Conf. Evolutionary Computation, 16–21 July 2006, Vancouver, BC, Canada*, pp. 1224–1231. IEEE. (doi:10.1109/CEC.2006.1688449)
213. Masuda N. 2012 Ingroup favoritism and intergroup cooperation under indirect reciprocity based on group reputation. *J. Theor. Biol.* **311**, 8–18. (doi:10.1016/j.jtbi.2012.07.002)
214. Bedewi W, Whitaker RM, Colombo GB, Allen SM, Dunham Y. 2020 The implications of shared identity on indirect reciprocity. *J. Inform. Telecommun.* **4**, 405–424. (doi:10.1080/24751839.2020.1741858)
215. Stadtfeld C, Takács K, Vörös A. 2020 The emergence and stability of groups in social networks. *Social Netw.* **60**, 129–145. (doi:10.1016/j.socnet.2019.10.008)
216. Jensen GG, Tischel F, Bornholdt S. 2019 Discrimination emerging through spontaneous symmetry breaking in a spatial prisoner's dilemma model with multiple labels. *Phys. Rev. E* **100**, 062302. (doi:10.1103/PhysRevE.100.062302)
217. Apicella CL, Marlowe FW, Fowler JH, Christakis NA. 2012 Social networks and cooperation in hunter-gatherers. *Nature* **481**, 497–501. (doi:10.1038/nature10736)
218. Smith KM, Larroucau T, Mabulla IA, Apicella CL. 2018 Hunter-gatherers maintain assortativity in cooperation despite high levels of residential change and mixing. *Curr. Biol.* **28**, 3152–3157. (doi:10.1016/j.cub.2018.07.064)
219. Ehlert A, Kindschi M, Algesheimer R, Rauhut H. 2020 Human social preferences cluster and spread in the field. *Proc. Natl Acad. Sci. USA* **117**, 22 787–22 792. (doi:10.1073/pnas.2000824117)
220. Hauert C, De Monte S, Hofbauer J, Sigmund K. 2002 Volunteering as red queen mechanism for cooperation in public goods games. *Science* **296**, 1129–1132. (doi:10.1126/science.1070582)
221. Barclay P. 2004 Trustworthiness and competitive altruism can also solve the "tragedy of the commons". *Evol. Hum. Behav.* **25**, 209–220. (doi:10.1016/j.evolhumbehav.2004.04.002)
222. Hardy CL, Van Vugt M. 2006 Nice guys finish first: the competitive altruism hypothesis. *Pers. Social Psychol. Bull.* **32**, 1402–1413. (doi:10.1177/0146167206291006)
223. Van Vugt M, Roberts G, Hardy C. 2007 Competitive altruism: development of reputation-based cooperation in groups. In *Handbook of evolutionary psychology* (eds R Dunbar, L Barrett), pp. 531–540. Oxford, UK: Oxford University Press.
224. Kuran T. 1997 *Private truths, public lies*. Cambridge, MA: Harvard University Press.
225. Centola D, Willer R, Macy M. 2005 The emperor's dilemma: a computational model of self-enforcing norms. *Am. J. Sociol.* **110**, 1009–1040. (doi:10.1086/427321)
226. Gurven M, Allen-Arave W, Hill K, Hurtado M. 2000 "It's a wonderful life": signaling generosity among the Ache of Paraguay. *Evol. Hum. Behav.* **21**, 263–282. (doi:10.1016/S1090-5138(00)00032-5)
227. Wiessner P. 2002 Hunting, healing, and *hxaro* exchange: a long-term perspective on !Kung (Ju/'hoansi) large-game hunting. *Evol. Hum. Behav.* **23**, 407–436. (doi:10.1016/S1090-5138(02)00096-X)
228. Smith EA. 2004 Why do good hunters have higher reproductive success? *Hum. Nat.* **15**, 343–364. (doi:10.1007/s12110-004-1013-9)
229. Ziker J, Schnegg M. 2005 Food sharing at meals. *Hum. Nat.* **16**, 178–210. (doi:10.1007/s12110-005-1003-6)
230. Nolin DA. 2010 Food-sharing networks in Lamalera, Indonesia. *Hum. Nat.* **21**, 243–268. (doi:10.1007/s12110-010-9091-3)
231. Nolin DA. 2012 Food-sharing networks in Lamalera, Indonesia: status, sharing, and signaling. *Evol. Hum. Behav.* **33**, 334–345. (doi:10.1016/j.evolhumbehav.2011.11.003)
232. Ready E, Power EA. 2018 Why wage earners hunt: food sharing, social structure, and influence in an Arctic mixed economy. *Curr. Anthropol.* **59**, 74–97. (doi:10.1086/696018)
233. Barclay P. 2010 Altruism as a courtship display: some effects of third-party generosity on audience perceptions. *Br. J. Psychol.* **101**, 123–135. (doi:10.1348/000712609X435733)
234. Wu J, Balliet D, Van Lange PA. 2016 Reputation management: why and how gossip enhances generosity. *Evol. Hum. Behav.* **37**, 193–201. (doi:10.1016/j.evolhumbehav.2015.11.001)
235. Lyle HF, Smith EA. 2014 The reputational and social network benefits of prosociality in an Andean community. *Proc. Natl Acad. Sci. USA* **111**, 4820–4825. (doi:10.1073/pnas.1318372111)
236. Bliege Bird R, Ready E, Power EA. 2018 The social significance of subtle signals. *Nat. Hum. Behav.* **2**, 452–457. (doi:10.1038/s41562-018-0298-3)
237. Smaldino PE. 2019 Social identity and cooperation in cultural evolution. *Behav. Processes* **161**, 108–116. (doi:10.1016/j.beproc.2017.11.015)
238. Atkisson C, Górski PJ, Jackson MO, Hołyst JA, D'Souza RM. 2020 Why understanding multiplex social network structuring processes will help us better understand the evolution of human behavior. *Evol. Anthropol.* **29**, 102–107. (doi:10.1002/evan.21850)
239. Baldassarri D, Grossman G. 2011 Centralized sanctioning and legitimate authority promote cooperation in humans. *Proc. Natl Acad. Sci. USA* **108**, 11 023–11 027. (doi:10.1073/pnas.1105456108)
240. Baldassarri D. 2015 Cooperative networks: altruism, group solidarity, reciprocity, and sanctioning in Ugandan producer organizations. *Am. J. Sociol.* **121**, 355–395. (doi:10.1086/682418)
241. Fehr E, Schurtenberger I. 2018 Normative foundations of human cooperation. *Nat. Hum. Behav.* **2**, 458–468. (doi:10.1038/s41562-018-0385-5)
242. Diekmann A, Przepiorka W. 2019 Trust and reputation in markets. In *The Oxford handbook of gossip and reputation* (eds F Giardini, RPM Wittek). Oxford, UK: Oxford University Press.
243. Gürerk Ö, Irlenbusch B, Rockenbach B. 2006 The competitive advantage of sanctioning institutions. *Science* **312**, 108–111. (doi:10.1126/science.1123633)
244. Greif A. 1989 Reputation and coalitions in medieval trade: evidence on the Maghribi traders. *J. Econ. Hist.* **49**, 857–882. (doi:10.1017/S0022050700009475)
245. Greif A. 2005 Commitment, coercion, and markets: the nature and dynamics of institutions supporting exchange. In *Handbook of new institutional economics* (eds C Ménard, M Shirley), pp. 727–786. Boston, MA: Springer.
246. Milgrom PR, North DC, Weingast BR. 1990 The role of institutions in the revival of trade: the law merchant, private judges, and the champagne fairs. *Econ. Polit.* **2**, 1–23. (doi:10.1111/j.1468-0343.1990.tb00020.x)
247. Temin P. 2013 *The Roman market economy*. Princeton, NJ: Princeton University Press.
248. Macfarlan SJ, Lyle HF. 2015 Multiple reputation domains and cooperative behaviour in two Latin American communities. *Phil. Trans. R. Soc. B* **370**, 20150009. (doi:10.1098/rstb.2015.0009)
249. Balliet D, Li NP, Macfarlan SJ, Van Vugt M. 2011 Sex differences in cooperation: a meta-analytic review of social dilemmas. *Psychol. Bull.* **137**, 881–909. (doi:10.1037/a0025354)
250. Rucas SL, Gurven M, Kaplan H, Winking J. 2010 The social strategy game. *Hum. Nat.* **21**, 1–18. (doi:10.1007/s12110-010-9079-z)
251. Herrmann E, Engelmann JM, Tomasello M. 2019 Children engage in competitive altruism. *J. Exp. Child Psychol.* **179**, 176–189. (doi:10.1016/j.jecp.2018.11.008)
252. Stevens JR, Woike JK, Schooler LJ, Lindner S, Pachur T. 2018 Social contact patterns can buffer costs of forgetting in the evolution of cooperation. *Proc. R. Soc. B* **285**, 20180407. (doi:10.1098/rspb.2018.0407)
253. Winke T, Stevens JR. 2017 Is cooperative memory special? The role of costly errors, context, and social network size when remembering cooperative actions. *Front. Robot. AI* **4**, 52. (doi:10.3389/frobt.2017.00052)
254. Conte R, Paolucci M. 2002 *Reputation in artificial societies: social beliefs for social order*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
255. Bachrach Y, Parnes A, Procaccia AD, Rosenschein JS. 2009 Gossip-based aggregation of trust in decentralized reputation systems. *Auton. Agents Multi-Agent Syst.* **19**, 153–172. (doi:10.1007/s10458-008-9073-6)
256. Smith ER. 2014 Evil acts and malicious gossip: a multiagent model of the effects of gossip in socially

distributed person perception. *Pers. Social Psychol. Rev.* **18**, 311–325. (doi:10.1177/1088868314530515)
257. Rapoport A, Diekmann A, Franzen A. 1995 Experiments with social traps IV: reputation effects in the evolution of cooperation. *Rational. Soc.* **7**, 431–441. (doi:10.1177/104346319500700407)
258. Van Vugt M, Hardy CL. 2010 Cooperation for reputation: wasteful contributions as costly signals in public goods. *Group Process. Intergroup Relat.* **13**, 101–111. (doi:10.1177/1368430209342258)
259. Pisor AC, Gervais MM, Purzycki BG, Ross CT. 2020 Preferences and constraints: the value of economic games for studying human behaviour. *R. Soc. Open Sci.* **7**, 192090. (10.1098/rsos.192090)
260. Hogg T, Adamic L. 2004 Enhancing reputation mechanisms via online social networks. *EC '04: Proc. 5th ACM Conf. Electronic Commerce, New York, 17–20 May 2004,* pp. 236–237. New York, NY: Association for Computing Machinery. (doi:10.1145/988772.988811)
261. Diekmann A, Jann B, Przepiorka W, Wehrli S. 2014 Reputation formation and the evolution of cooperation in anonymous online markets. *Am. Sociol. Rev.* **79**, 65–85. (doi:10.1177/0003122413512316)
262. Przepiorka W, Norbutas L, Corten R. 2017 Order without law: reputation promotes cooperation in a cryptomarket for illegal drugs. *Eur. Sociol. Rev.* **33**, 752–764. (doi:10.1093/esr/jcx072)
263. Snijders C, Matzat U. 2019 Online reputation systems. In *The Oxford handbook of gossip and reputation* (eds F Giardini, RPM Wittek), pp. 479–495. Oxford, UK: Oxford University Press.
264. Al-Yazidi S, Berri J, Al-Qurishi M, Al-Alrubaian M. 2020 Measuring reputation and influence in online social networks: a systematic literature review. *IEEE Access* **8**, 105 824–105 851. (doi:10.1109/ACCESS.2020.2999033)
265. Lazega E. 2001 *The collegial phenomenon: the social mechanisms of cooperation among peers in a corporate law partnership*. Oxford, UK: Oxford University Press.
266. Power EA. 2017 Social support networks and religiosity in rural South India. *Nat. Hum. Behav.* **1**, 0057. (doi:10.1038/s41562-017-0057)
267. Power EA, Ready E. 2018 Building bigness: reputation, prominence, and social capital in rural South India. *Am. Anthropol.* **120**, 444–459. (doi:10.1111/aman.13100)