Gossip: Perspective Taking to Establish Cooperation

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Abstract

Problems of cooperation are frequent among living organisms, but they are difficult to solve. Humans have been able to produce large-scale cooperation among unrelated individuals through reputation systems. A challenging puzzle, however, is how reputation can guide behaviour if in most cases it is not shared publicly and is assigned to others privately. We confirm that it is difficult to obtain cooperation among agents playing the Prisoner's Dilemma when reputations are individually assigned. We propose that third-party communication (gossip) can overcome this difficulty, but only under specific conditions concerning its content, amount and persistence. We show that - in order to sustain cooperation - gossip should not only be about private evaluations of others but should also include perspective taking and exchange of information about tolerance thresholds to support cooperation. This perspective taking reputational strategy can propagate and establish cooperation in the population independent of gossip frequency and population size, under various selection mechanisms of communication partners and targets, and assumptions concerning agents' memory.

Keywords: Cooperation, Prisoner's Dilemma, Indirect Reciprocity, Gossip, Reputation

1 Introduction

In cooperation problems, mutual defection (or free riding on the effort of others) is worse for everyone than mutual cooperation. Cooperation is difficult to achieve since individual self-interest dictates defection, which is the most beneficial action given the possible actions of others. Cooperation problems are frequent among living organisms and can be solved in several ways even among unrelated individuals (Nowak, 2006). Direct reciprocity is a convenient solution when interactions are repeated frequently between the same partners (Axelrod, 1984). When this condition does not hold (e.g., in large groups), humans can still solve cooperation problems thanks to their exceptional social and cognitive capacities as well as through their enhanced communication skills (Gächter and Herrmann, 2009; Manrique et al., 2021; Számadó et al., 2021). Indirect reciprocity has been suggested as a mechanism to explain cooperation in these situations as individuals might cooperate with those who behaved fairly with others (Sugden et al., 2004; Alexander, 1987; Leimar and Hammerstein, 2001; Panchanathan and Boyd, 2003; Nowak and Sigmund, 1998b,a, 2005; Nowak, 2006; Sigmund, 2012; Rand and Nowak, 2013). Given this tendency, everyone strives to harvest future benefits of cooperative interactions with strangers by establishing a good reputation, which can be achieved by cooperation in current partnerships (Nowak and Sigmund, 1998b).

The solution to the problem of cooperation by reputation mechanisms has several prerequisites. First, individuals are supposed to form reputation images about others. Second, new partners should have access to information on previous play of others or a summary information about their actions. Public reputation systems, in which individual actions are aggregated to image scores and communicated unbiasedly to everyone, have been found to enhance cooperation in both theoretical models and empirical analyses (Nowak and Sigmund, 1998b, 2005; Wedekind and Milinski, 2000; Wedekind and Braithwaite, 2002; Ohtsuki and Iwasa, 2004, 2007; Suzuki and Akiyama, 2005; Seinen and Schram, 2006; Bshary and Grutter, 2006; Engelmann and Fischbacher, 2009; Barclay, 2012; Ohtsuki et al., 2015; Wu et al., 2016a; Santos et al., 2018; Podder et al., 2021). Specific social norms that are of higher complexity than image scoring (as they assign reputation to others and prescribe conditional action by taking into account the reputation of the donor along with the action and reputation of the focal actor) are able to sustain large-scale cooperation (Ohtsuki and Iwasa, 2004, 2007). Adding an empathetic element to social norms that evaluates actions from the perspective of the donor has been shown to be key for sustaining cooperation (Radzvilavicius et al., 2019).

Reputations, however, are rarely agreed upon in a large group (Abraham et al., 2016; Okada et al., 2017; Hilbe et al., 2018; Podder et al., 2021). Especially in the absence of a centralized communication platform, individuals maintain different views on others: there might be both agreement on the high reputation of certain persons and disagreements about the reputation of others. On the top of that, the absence of perfect information (Sigmund, 2012) and the disagreement about appropriate reputation scores (Abraham et al.,

2016) cause additional difficulties that make it very difficult for a reputation system to support cooperation.

Importantly, most *informal* human interactions lack a centralized communication platform. In fact, it has been found that a large part of human informal communications is *gossip* containing evaluative information exchange about third parties (Emler, 1994; Dunbar et al., 1997). Gossip as a third-party communication device enables the update of reputations (Goffman et al., 2002; Bromley, 1993; Sommerfeld et al., 2008; Giardini et al., 2019), and has been found to support cooperation in experimental situations (Milinski et al., 2002; Sommerfeld et al., 2007, 2008; Ellingsen and Johannesson, 2008; Piazza and Bering, 2008; Beersma and Van Kleef, 2011; Feinberg et al., 2012, 2014; Wu et al., 2015, 2016a, 2019; Milinski, 2019; Samu et al., 2020). At the same time, gossip is often considered idle talk that has a function of social bonding between the sender and the receiver (Dunbar, 1996, 2004; McDonald et al., 2007), and hence has no value concerning the reputation of the target.

Models of gossip and reputation consider simple assumptions and hence restrict the information that is transmitted in third-party communication (Suzuki and Akiyama, 2005; Brandt and Sigmund, 2005; Számadó et al., 2016; Giardini and Vilone, 2016; Vilone et al., 2016). Gossip, however, is not solely about a single reputation score of third parties. It is also about the motivations, intentions, morality, and expected reactions that are all relevant for choosing the right behavior in future encounters (Mills, 2010; Beersma and Van Kleef, 2011; Martinescu et al., 2019; Barclay and Barker, 2020). Humans have a highly elaborated theory of mind, an advanced ability to attribute beliefs and intentions to oneself and others (Dunbar and Dunbar, 1998; Preston and De Waal, 2002; Dunbar, 2004). This allows for the use of more nuanced conditional strategies than a simple judgment of who is good and who is bad conditional on a threshold value of reputation.

The theoretical assertion of this study is that gossip needs to be more than an exchange of information about the subjective reputation of third parties. The key element of gossip that makes it an efficient informal mechanism for the establishment of cooperation in large populations is its substantive content about the *perspectives* of others. Perspectives of others are collected in order to form proper expectations about behavior of future interaction partners. It is certainly important, if partners have good reputation or not, but it is also vital to assess how future interaction partners treat us. This is the information that is directly useful for selecting the appropriate action in a given interaction. Accordingly, a key feature of gossip is that it helps to evaluate the tolerance of others and consequently, provides the ground for preparing an appropriate action given the perspectives of the target.

Moreover, humans care about their own reputation and not just about the reputation of others. When they gossip, they exchange information in order to get information on how they themselves are evaluated by others (Greiff and Paetzel, 2016). Hence, gossip might serve also as a social mirror: individuals

infer from gossip the evaluation of themselves through the lens of others. Individuals try to maintain a positive reputation about themselves and they use gossip to monitor their own status, but also to improve their social position (Noon and Delbridge, 1993). We would like to impress others and we would like that a good impression is generally held about us. Impression management is a significant part of our communication (Goffman et al., 2002; Bromley, 1993; Giardini et al., 2019). The strive to maintain and improve on our own reputation could directly fuel cooperative action (Engelmann and Fischbacher, 2009; Greiff and Paetzel, 2016), as suggested also by the theory of competitive altruism (Roberts, 1998; Barclay, 2004; Barclay and Barker, 2020; Roberts et al., 2021).

In this paper, we build an agent-based model where populations of agents interact playing the Prisoner's dilemma and then engage in gossip with other members of the group. We study the conditions under which cooperation can be achieved and sustained through gossip. We show that, in absence of gossip, strategies that are cooperating conditionally on the subjective reputation score of the opponent have limited success in the establishment of cooperation. Similarly, the the large-scale dissemination of cooperation cannot be explained when gossip is an exchange of this subjective reputation information about third parties. The key for gossip to enable cooperation is that it should contain information about how the possible interaction partners will consider a given behaviour. In other terms, gossip should also contain discussions about the perspectives and tolerance of others. In our model, acquiring information about own's status does not result in sustainable cooperation by itself. These finding are robust to different assumption about the social structure of gossip, cognitive abilities (memory) of agents, and the amount of gossip being generated in a population.

In the next section, we discuss our agent-based model in details (Section 2). We then describe our key results (Section 3), before discussing them in Section 4.

2 The model

We build a model aimed at explaining cooperation through mechanisms of gossip and reputation. We first consider a simplistic view of gossip as an exchange of reputation information about third parties. We demonstrate that, with subjective and continuous reputation scores, little gossip-induced cooperation can be expected. We then extend the model of gossip with the operationalization of its content. Two further elements are added to the simple reputation score that can be exchanged in gossip: the information about the perspectives (tolerance) of others, and the reputational assessment made by third parties about the self. We analyze the consequences of different assumptions concerning the content of gossip on the establishment of cooperation through reputation formation.

Consider a set of $N \in \{1, 2...i, j...n\}$ individuals who are playing the two-person Prisoner's Dilemma (PD) game. Each individual can either defect (D)

or cooperate (C). The PD is characterized by the classical payoff structure, reported in Table 1.

	C	D
C	$R = 3, R = 3$	$S = 0, T = 5$
D	$S = 5, T = 0$	$P = 1, P = 1$

Table 1 The Prisoner's Dilemma $(T > R > P > S)$. The numerical payoffs used here are the same as in Axelrod (1984).

At each time step, every individual is matched to do exactly μ interactions with randomly chosen other players from the population. This choice is made in order to focus the model on gossip interactions. Individuals are characterized by an idiosyncratic opinion about the reputation of others in the population, $R_{iz} \in [0, 100]$ (the reputation that agent i has of agent z) and by a strategy for cooperation. In the simplest case and in the absence of further information, the strategy is defined by a threshold c_i and dictates cooperation if the reputation score of the opponent is above c_i (i.e. if $R_{iz} > c_i$) and implies defection otherwise. In each interaction, the individual i decides whether to cooperate using available information on thresholds and reputation. In this sense our model moves away from indirect reciprocity models (e.g., Nowak and Sigmund 1998b, 2005; Wedekind and Milinski 2000; Panchanathan and Boyd 2004) that consider a single – publicly known – reputation for each individual, toward a setup where each individual has a personal and fine-tuned opinion about each of the peers.

After an interaction, the subjective reputation score R_{iz} is updated upwards by a value θ if z cooperated and downwards if z defected, except the case of mutual defection when the reputation of z remains unaltered. Results discussed in this paper are robust to the change in the size of θ, provided that the latter is sufficiently large to allow the adaptation of behaviour to the result of past interactions (see SI, Section S3).

At the end of each time step, the threshold of cooperation of each agent is updated in the direction of a randomly chosen individual with strictly higher payoff (see Material and methods, section A, for details).

The social structure of gossip

Once all agents interacted, $\eta N \mu$ acts of gossip are initiated. In its simplest form, gossip is defined as individual i speaks to j about z, with z not being able to observe the communication. We assume that each gossip act is influential and as a result of each gossip, the receiver j updates its view on the target z. For baseline results, we will assume that the initiator of gossip i as well as the receiver j and the target z are all chosen from the population uniformly at random. This means that each individual will - on average - initiate η gossip

acts. We have analyzed other specifications for the selection of j and z, restricting the possible choices only to interaction partners and assuming a selection biased toward agents with certain reputations. These alternative choices are discussed in the *Materials and Methods* and reported in the SI, Section S1. All results reported there – in the large majority of cases – are qualitatively equivalent to those presented in the main text. It should be noted that increasing (resp. decreasing) the η variable is tantamount to slow down (resp. speed up) the evolutionary process (through which c_i threshold are changed) with respect to the speed of the gossip process (through which information about others and about others' perception is obtained).

The content of gossip

Receivers can acquire various information through gossip. Gossip is conceptualized as containing information to the receiver j on (1) the evaluation of the sender about the target (R_{iz}), (2) information on the reputation of the receiver (R_{zj}) in the perspective of the target, or (3) the target's threshold for cooperation (c_z). When such information is available, it can be employed for more elaborated conditional strategies. In order to clearly identify the impact of gossip content on cooperation, we analyze and compare different scenarios where one or more of the aforementioned informations constitute the "content of gossip" .

If gossip contains information only about the subjective opinion of the sender about the target R_{iz}, then this can be used to update the opinion that the receiver j has on the gossip target z, similarly to what would happen as a result of a direct interaction (*Pass R_{iz}* in the figures). In other terms, R_{jz} moves toward R_{iz} of an amount θ. If the same individual j receives information about the same target z multiple times after each other, then the effects are simply accumulated. This elementary component of gossip is assumed to be present also in other "content of gossip" scenarios described hereunder.

In the scenario in which gossip contains information both on R_{zi} and c_z, then after an update in the subjective evaluation R_{iz}, i cooperates if $R_{iz} \geq c_i$ & $R_{zi} > c_z$. In other terms, agents use a stricter condition for cooperation: they consider if the reputation of the opponent is above their tolerance threshold *and* if they can expect cooperation from the interacting partner (*Pass R_{zi} and c_z* in the figures). In the condition when information is kept fully up to date (see *Memory*), this information is sufficient to ensure that z will never defect unexpectedly against i.

Partial information can also be used to condition cooperative behavior. In case gossip contains information only about R_{zi}, then i conditionally cooperates if $R_{iz} \geq c_i$ & $R_{zi} > c_i$, i.e. individuals could project their own cooperation threshold on the partner (*Pass only R_{zi}* in the figures). Similarly, when gossip contains information only about c_z, i could conditionally cooperate if $R_{iz} \geq c_i$ & $R_{iz} > c_z$, i.e. individuals might base their decisions on a (possibly erroneous) projection of their own subjective reputation score to the subjective reputation of themselves by the partner (*Pass only c_z* in the figures). In all

these cases, if new information is received through successive acts of gossip, about the cooperation thresholds and/or his reputation with a given target, then the old information is disregarded and only the new values are used. This is a simplifying assumption meant to avoid the complication of merging information from different sources at different times, and can be done since we assume the absence of voluntary or accidental false reports of information. In this setup, new information is always more updated (and therefore relevant) than old one. In all simulations, at the outset, agents have no information on any agents' c_z or R_{zi}. These are gradually accrued through time with gossip. Only once the information is acquired it can be used to condition decisions, as described above.

It should be noted that, in this paper, we simulate the process of verbal gossip communication among humans with a focus on the gossip's content. While human communication can be very precise, in reality reputation cannot be reduced to a number, thus gossip information is less precise than what assumed here. The assumption that reputation information and cooperation thresholds are single numbers that can be known and communicated through gossip acts is made in this paper with the aim of providing the minimal conditions for the emergence of cooperation in context where different information types are conveyed through gossip.

Memory.

Given the amount of information that is passed on among individuals through gossip, we consider limitations on individual memory. We start by analyzing ideal-typical situations based on strong assumptions that we later relax. The first of such assumptions is that agents have infinitely sized memories, i.e. they never forget the information they learn from gossip. We relax this assumption by assuming that individuals only remember information from the last $\gamma \in \{1, \ldots, \infty\}$ periods. After γ periods since the last gossip received, the information is forgotten.

The second assumption is that once an agent acquires an information about R_{zi} and/or c_z, that information is kept *up-to-date* in successive time steps, regardless of the existence of further contacts or gossip. Thus if, R_{zi} and/or c_z change, agent i is made aware of it instantaneously. This is of course a strong assumption as both reputations and thresholds for cooperation evolve over time. In case of fully updated information, beliefs on reputations and thresholds are hence correct and universal for those who received gossip about it. We relax this assumption by considering that individuals use the information acquired at the moment of their last interaction (which information depends from the assumption made about the content of gossip) to guide their behavior. In this case, the latter is not updated and hence might be different from the current true value unless new gossip is received.

3 Results

Our model comprises two reputation processes through which agents can condition their behavior: one through direct interaction experience and another through third-party communication (gossip). In absence of gossip, little cooperation is observed. We demonstrate that it is difficult to obtain cooperation in the Prisoner's Dilemma when reputations are individually assigned and privately known. This is a strong departure from the case where reputation is common knowledge and such mechanism is able to sustain cooperation under a wide set of conditions and mechanisms (Nowak and Sigmund, 1998b; Panchanathan and Boyd, 2003; Ohtsuki and Iwasa, 2004). Reputation under privately assigned information has been studied also by Giardini and Vilone (2016), with a focus on the quantity and quality (namely the probability of errors in the information transmission), while assuming that gossip contains simply information about the observed behaviour of a target individual. In this paper, we instead focus on how the content of gossip type influence the sustainability and success of cooperation.

We propose that third-party communication (gossip) can overcome this difficulty, but only under specific conditions concerning its content, persistence, and frequency. If gossip is only used to exchange and adjust reputation scores, it is insufficient to establish cooperation. Fig. 1 shows that when gossip is only about reputations R_{iz}, cooperation disappears completely. Compared to direct observations, where individuals are able to discriminate at least their cooperative partners from past interactions and hence a minimum amount of cooperation is sustained, the exchange of privately formed reputations introduces criticism about the behavior of others and implies some unnecessary defections. These concern cases in which an individual would cooperate based on previous experience, but negative information received (which can be heavily noisy, especially at the beginning) implies a downgrade in subjective reputations and leads to the disappearance of cooperation consequently. Since defection is a beneficial strategy, this kind of divergence from private experience brings overall dynamics more likely towards zero cooperation.

When gossip contains only information about the subjective reputation of the self in the eyes of possible opponents, hence it operates as a social mirror, it still cannot support cooperation. In this case, individuals have a good idea of their image in the group but have no relevant information about others that would help them escape the social dilemma. Hence, seeking information solely about the self does not solve the cooperation problem.

Contrastingly, the key for success of reputation-based cooperation through gossip is perspective taking in the form of acquiring information on cooperation threshold of partners (c_z). Gossip about this threshold, or exchange of information about cooperation thresholds and the reputation of the self R_{zi}, are able to support cooperation under a wide variety of circumstances. In all other cases, very little cooperation is observed. After a random start, due to the

higher payoffs for defection, all scenarios undergo an initial decrease in cooperation. Perspective taking turns decline towards increase when information coming from gossip starts to sort cooperators and defectors effectively.

The variance of results is systematically very low, thus the distribution of outcomes is only reported in the SI (Section S1.2) and only average behavior is reported in Figure 1.
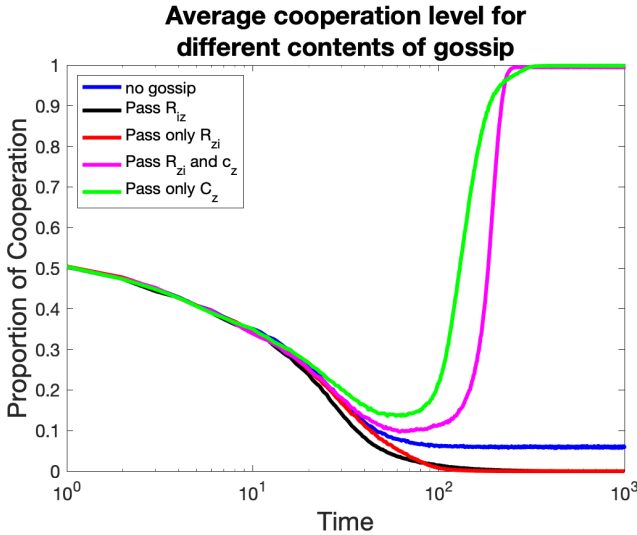
Fig. 1 Time evolution of cooperation under different assumptions concerning the content of gossip. Baseline model with perfect memory and updates. Averages computed at each time step over 100 simulations for each type of gossip. The distribution of outcomes is reported in the SI (Section S1.2).

In the following, we analyze in more detail the classes of gossip content that proved to be able to sustain cooperation in the baseline. We observe that when only threshold information c_z is passed on, then more cooperation is obtained for any amount of gossip. The general success of perspective taking through gossip is due to the relatively slow evolution of cooperation thresholds compared to reputation updates. When only c_z is passed, this can be regarded as a rather sound information for long periods of time. This means that information on the threshold of cooperation of the partner – together with a projection of what the individual thinks of the interacting partner – enable a good prediction of cooperation of the partner.

The reliability of information being vehiculated through gossip is important in determining its impact on cooperation (Fig 2). When the information acquired through gossip is kept up-to-date, we observe full cooperation regardless of the intensity η of gossip. If – as it is more realistic to assume – information is received only at the time of the gossip action, and is not updated

at every time step, then the amount of gossip essentially defines the level of cooperation observed.

When both R_{zi} and c_z are passed, they are both used to adjust the behavior to the predicted choice of the partner (in substitution of the projection of the decision maker's point of view about the reputation of the interacting partner). When the information is up to date, this is not a problem (Figure 2, red and green lines), but when information obsolescence is introduced, then the projection is a better predictor of partners' cooperativeness with respect to aging information about R_{zi}. This interpretation is supported by the fact that when both R_{zi} and c_z are passed on, cooperation increases with the amount of gossip, just slower than in the case of pure perspective taking gossip. In sum, more information in gossip does not necessarily yield better chances for cooperation. These results are robust (see SI, section S1.4) to all types of partner and target selection mechanisms where possible targets are chosen from the entire population. When instead the possible targets are restricted to only the last-period interacting partner, the information flow is too limited to guarantee cooperation, for any gossip intensity studied.

The behavior discussed concerns the case in which both the interaction partner and the target are selected from the population at random. As reported in SI (section S1.1), results are consistent and robust to a variety of different methods of selecting the gossip partners and the targets of gossip. The only apparent difference to the general pattern emerges when the gossip target is chosen based on how surprising is its behaviour with respect to the gossip initiator opinion. In this case, the results are bimodal. Where gossip concerns both the thresholds and self-reputation, in about 30% of the cases, cooperation disappears (SI, Section S1.3). With this type of target selection, when the information about reputations is the most useful, people with reputations around mid values (i.e. around 50), that frequently change behaviour from cooperation to defection and vice versa, are selected more often. While this allows efficient information about them to circulate, it limits the information diffusion about everyone else. In some simulations this lack of information leads to a collapse of cooperation with agents choosing the safer option of raising their cooperation threshold. This phenomena is present also when gossip contains information only about c_z, but in a much more limited fashion as this type of gossip content is stronger in sustaining cooperation.

A higher frequency of gossip exchange increases the chance that cooperation is established also with obsolescent information. Perspective taking in gossip can in general support cooperation. Jointly with self-mirroring information, cooperation can be established with most target selection mechanisms. Exceptions are if target selection is based on the surprisingness of actions, or if it is random but restricting the possible target choice to individuals with which there has been interactions in the previous step. It should be noted that, while these two target selection procedures appear different, they both strongly restrict choice to a small set of options. Such restriction effectively disable appropriate conditioning of action towards any individual in the group.

Robustness tests show that the amount of gossip is relevant when the target for gossip can be extracted from the whole population (the specific method doesn't matter).
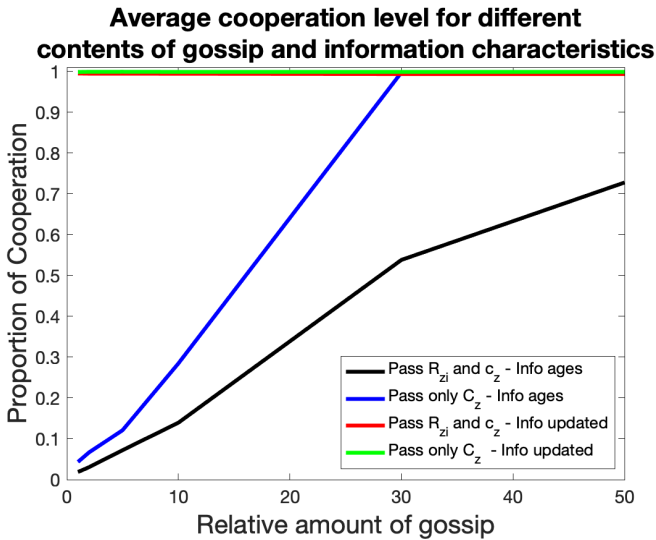
Fig. 2 The effect of different amounts of gossip η on cooperation under different assumptions concerning the content of gossip and the ability of individuals to keep the information they receive updated. Averages computed over 100 simulations for each parameter combination.

The length of memory (Fig. 3), i.e., the time after which one individual forgets the information received though gossip, has a straightforward impact on the level of cooperation. Further, the sustainability of cooperation derives from a combination of amount of gossip being made and ability to remember (i.e. memory length). The frequency of gossip acts as substitute for longer memory lengths when information does not age. Indeed, for each level of gossip, there is clearly a threshold of memory below which cooperation stays at the baseline level (observed for no gossip), and above which cooperation emerges. The threshold is lower when gossip is more frequent, as the increased frequency of communication guarantees a more up-to-date information about others. These results are qualitatively robust (see SI, section S1.5) to all procedures through which gossip partners and targets are selected.

Finally, by modifying population size (SI, section S2), we find that results are qualitatively robust in smaller populations, but in larger populations (600 individuals) the ability of gossip to sustain cooperation decreases. Still, even for larger populations we confirm that the superior way to establish reputation-based cooperation is perspective taking ensured by gossip about cooperation thresholds of others.
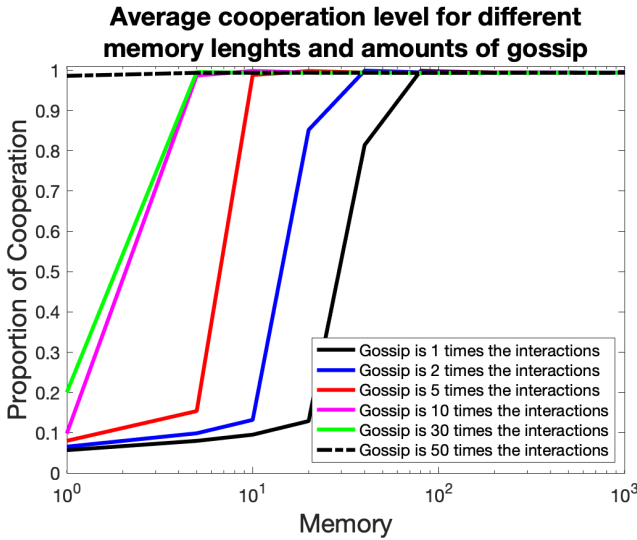
Fig. 3 The effect of different lengths of memory for different assumptions concerning the intensity of gossip η. Averages computed over 100 simulations for each parameter combination.

4 Discussion

Public reputation systems have been found to provide a solution to the problem of cooperation in both theoretical models and empirical analyses on human subjects (Nowak and Sigmund, 1998b, 2005; Wedekind and Milinski, 2000; Wedekind and Braithwaite, 2002; Ohtsuki and Iwasa, 2004, 2007; Suzuki and Akiyama, 2005; Seinen and Schram, 2006; Bshary and Grutter, 2006; Engelmann and Fischbacher, 2009; Barclay, 2012; Ohtsuki et al., 2015; Wu et al., 2016a; Santos et al., 2018). Centralized reputation systems based on perfect information, however, have not been available in human evolution. Reputations have been, and are in most situations, private attributions that are shaped by direct experience from interactions, observations of interactions, and sharing of reputational information about others. In particular, gossip, that is typically defined as an exchange of information about others who are not present, has been claimed as a potential candidate as an informal reputation-based mechanism that can explain cooperation among unrelated individuals in humans (Sommerfeld et al., 2007; Feinberg et al., 2014; Wu et al., 2016a).

There are, however, unresolved issues along these arguments. While the threat and the opportunity of gossip have been shown to increase cooperation (Milinski et al., 2002; Sommerfeld et al., 2007, 2008; Ellingsen and Johannesson, 2008; Piazza and Bering, 2008; Beersma and Van Kleef, 2011; Feinberg et al., 2012, 2014; Wu et al., 2015, 2016a, 2019; Milinski, 2019; Samu et al., 2020), the option to gossip has not sustained cooperation in the long run in laboratory settings (Samu et al., 2020; Samu and Takács, 2021).

There is also some discrepancy between models that typically simplify gossip as an exchange of (often binary) reputational information and empirical studies that highlight various dimensions and complexity of informal exchange in our everyday discussions (Rhee and Haunschild, 2006; Dafoe et al., 2014; Barclay and Barker, 2020). The conclusion of ethnographic work and text analyses of human conversations is that gossip is more than a simple exchange of reputational information (Romano et al., 2021; Garfield et al., 2021; Dores Cruz et al., 2021). It typically covers *perspective taking*, a discussion of the motivations and intentions of others (Ingram, 2019; Manrique et al., 2021).

Another shortcoming of models and experiments on reputation-based cooperation is the primary focus on the reputation of *others*. People care about their *own* reputation and not just about the reputation of others (Goffman et al., 2002; Wu et al., 2016b; Giardini et al., 2019). They care about their own image and like to monitor how it is shaped in the group (Romano et al., 2017). This is also crucially important to anticipate the actions of others towards them (Engelmann et al., 2013).

In this study, we are able to enrich the literature on how the content of gossip influences the establishment and sustainability of cooperation. As new elements compared to previous models, we incorporate perspective taking and information-seeking on the self in modeling gossip and cooperation. We show that perspective taking is a necessary element of gossip for the establishment of reputation-based cooperation. We highlight that perspective taking is more important than passing on a simple reputation score that is the usual and single content element of gossip in indirect reciprocity models. We make this contrast by different conceptualizations of the content of gossip. In the simplest case, following previous research (Giardini and Vilone, 2016; Vilone et al., 2016), gossip could be considered as a way to transmit privately assigned reputation scores about others. After the reception of such information, reputation scores are updated. We examine the evolution of strategies that are cooperating conditionally on the reputation of the opponent, such that a strategy with its threshold condition that is more successful in its local environment is adopted. We show that gossip about privately held reputation scores of others and the adjustment of reputation scores after receiving such evaluative information is not sufficient to establish cooperation.

Gossip can also have an element that helps to form the self-image by acquiring evaluative information about the self from others. However, no cooperation emerges if gossip contains only such an element. Hence, the problem of cooperation cannot be solved by a reputation-based mechanism that is driven by seeking self-centered information.

By contrast, we demonstrate that *perspective taking* can resolve the problem of cooperation. Gossip on perspectives of others is operationalized as an information exchange about subjective tolerance thresholds for reputation that would trigger cooperative behavior. Such information enables a better-informed choice of conditional action in an interaction because it does not only

take the reputation of the opponent into account but anticipates also expected action towards the self.

In sum, we find that perspective taking is highly effective and produces cooperation in a wide range of conditions where gossip with another content or the lack of gossip cannot. Our results are robust to a large variety of model specifications. We have explored different conditions regarding the extent of individual memory, the impact of gossip on reputation information, the size of population, and various mechanisms of selecting gossip partners and targets; and found our conclusions unaltered.

As a follow up of these findings, subsequent research could investigate perspective taking mechanisms in gossip theoretically and experimentally. Although we have considered population sizes where it is reasonable to assume that interactions and gossip can take place between any individuals, studies of reputation-based cooperation need to take into account that interaction and communication processes are embedded in the social network (Righi and Takács, 2014, 2018; Takács et al., 2021). Further, in order to focus on the role of different types of gossip content, we assumed that reputation information and gossip content can be acquired and communicated precisely, thus providing the minimal conditions for the emergence of cooperation. These assumptions could be relaxed in future work, to assess the chances of cooperation when only more vague information can be acquired through gossip. It is also the task of empirical work to find out more on the social and cognitive mechanisms that make us humans relatively good in the assessment of perspectives of others (Krauss and Fussell, 1991; Mascaro and Sperber, 2009).

Relatedly, a limitation of the present results concerns the fact that questions of honesty and strategic manipulation remain unanswered not just for the exchange of reputation information (Számadó et al., 2016) but also concerning the exchange of perspectives of others. This problem is mitigated as individuals seem to have a tendency to read misintentions of others, and although this sort of epistemic vigilance is imperfect, perspective taking of this kind implies high risks for dishonest behavior and restricts its manipulative use (Sperber et al., 2010; Haux et al., 2017; Liberman and Shaw, 2020; Fonseca and Peters, 2021).

Declarations

Funding

Conflicts of interest/Competing interests

Authors declare no conflicts of interests.

Availability of data and material

The data upon which all figures of this paper are generated are available at the link: https://github.com/simonerighi/Gossip/tree/main/Results

Code availability

All codes required to generate the simulation data used in this article, as well as a working demo and instructions on how to run the code are available at: https://github.com/simonerighi/Gossip.

Authors' contributions

Simone Righi (SR) and Károly Takács (KT) developed the model. SR implemented the model, wrote the code, and generated the numerical and graphical results. SR and KT analyzed the results and wrote the manuscript.

Ethics approval

No ethics concerns.

Consent to participate/Consent to publish

Not applicable.

Appendix A   Materials and Methods

The agent-based model presented in this paper has been built in Matlab 2020b and is fully available on Github: (https://github.com/simonerighi/Gossip). The pseudocode of the model is reported in Section S4 of SI. Results reported summarize results of 100 runs for each parameter combination. Including all robustness checks, about 315000 individual simulations have been run.

Initialization.

Population size N is fixed to 200 in the simulations reported in the figures and varied in the simulations reported in SI (Section S3), between 50 and 600. Initial strategies c_i, as well as the initial values for reputations R_{iz} are generated at random from an uniform distribution between 0 and 100.

Choice of gossip partner.

In the baseline model presented, an individual i chose to initiate gossip with an individual j chosen uniformly at random from the whole population. Other specifications of this process of partner selection are possible. In the supplementary material we analyze the following ones: (1) j is chosen with probability (linearly) proportional to subjective reputation R_{ij}. (2-3) j is chosen from

previous interaction partners uniformly at random or with probability proportional to R_{ij}. Options 1 and 3 imply that individuals have a preference to gossip with people to which they attribute high reputations. Options 2 and 3 simulate gossip based on recent interaction experience. All simulations presented in the main text are repeated in these setups and reported in SI, with nearly identical results.

Choice of gossip target.

In the baseline model presented, the target individual z for gossip is selected uniformly at random from the whole population. Also in this case, several other specifications of this processare possible. We consider the following ones: (1) z is selected at random from people that interacted with i in the last interactions, (2) z is someone that i interacted with and did something surprising, with the surprise being defined as a mis-alignement between expectations about agent z based on reputation R_{iz} and observed actions of z. In this case, the gossip target is chosen with probability proportional to R_{iz} if z defected, and to 100-R_{iz} if z cooperated. (3) z can be selected among individuals with similar reputation in the population, modeling status competition. Specifically, the probability of choosing the gossip target z is linearly proportional to $100 - |\overline{R_{\cdot,i}} - \overline{R_{\cdot,z}}|$ (4) z is selected with inverse - linear - proportionality to its social reputation $\overline{R_{\cdot,z}}$. All simulations presented in the main text are repeated in these setups and reported in SI, with nearly identical results.

Strategy (threshold) update.

Once all interactions and gossip has taken place, each individual i observes its interacting partners' payoffs and revises his threshold for cooperation c_i toward the one of a, randomly selected, agent among those with a strictly payoff higher than its own. The revision can imply a maximum change of 10 points. Such choice has been made in order to ensure a smoother dynamics.

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