Solidarity, synchronization and the emergence of cooperation

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Abstract

One of the big questions about social life is how people manage to cooperate for public goods. Current answers rely on individuals’ relations and reputations, but have difficulty explaining the beginning, when relations are sparse and reputations largely unknown. Moreover, actual situations are often characterized by uncertainties about the value and timing of the public good, such that established relations and reputations may not suffice. As a run up to cooperation, people can increase their solidarity and establish (or relay their) social ties through interaction rituals, which is done by groups ranging from hunter-gatherers to social movements. Kuramoto’s synchronization model is used to show that the network thereby formed should have sufficient algebraic connectivity to compensate for the differences between individuals’ commitments and psychological states. At a critical level of solidarity, a majority’s commitments and psychological states, respectively, synchronize in a phase transition, which yields a boost of motivation for a burst of collective action.

A remarkable feature of humans is that they can act collectively—and effectively at that—while individuals are tempted to defect and exploit the results of others’ efforts [1]. In contrast to current models and lab experiments, many of those situations are characterized by multi-fold uncertainty.

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For example, at defending settlements, mass protests and revolts against dictatorial regimes, contributing may be retaliated by the opponent, hence costs can be unexpectedly high, participants may be paralysed by fear [2], and benefits may differ from those expected or arrive later, if at all. Yet history shows that even under adverse conditions, which include hunting large animals by ancestral groups, people often cooperate [3, 4, 5].

Whether individuals know their costs and benefits or guess inaccurately, their decisions to contribute always depend on what they know about others in the same situation. It’s crucial for them to establish relatively stable ties and thereby form a group [1, 6]. Their relations provide access to reputations [7, 8, 9] that summarize others’ cooperativeness [10], but in a broader sense also encompass other’s interests, skills and behavior toward free riders. Reputations make possible to choose, reward, avoid, punish or ostracize specific individuals [8, 11, 12], thus feed back into the relations [9], and are to be backed up by cooperative norms to stabilize cooperation in the longer run [11, 13].

Here the question is how cooperation can get off the ground before relations, reputations and norms have been established, or when they do not suffice in the face of high uncertainties. Individuals then have to establish or relay social ties and, lacking (convincing) reputations, develop a shared intentionality [14] with respect to a given collective good. That means having the same emotions and thoughts about their action(s) to achieve it, the same level of commitment, and an awareness of this sharedness. Accordingly, the research question is narrowed down to how people can achieve this under adverse conditions. The problem is dealt with by interpreting shared intentionality in terms of psychological states and commitments, and by applying a well-studied model to analyze their synchronization. For a given group it turns out that if the pattern of social ties, or topology, of their network has a higher algebraic connectivity, they can synchronize more easily, i.e. at lower costs. Under favourable conditions, with uncertainty only about the number of contributors, the onset of cooperation can be explained without the model, discussed subsequently, but it still requires a certain level of algebraic connectivity. This measure therefore increases our understanding of networks in social movements and collective action [15] in general.
Results

To start out, members of a (becoming) group with a shared focus can perform certain *interaction rituals* [16][17], a subset of all rituals exercised by humans. Examples are marching and noise making at street demonstrations before physical confrontation with the incumbent power [18]; dance and religious ceremonies before a hunt or fight [17][19]; drill to prepare for combat [19]; and, team building activities in organizations to enhance workplace performance [20]. Many rituals involve rhythmic entrainment, which generates feedback that reinforces perceptions of similarity [21]. In experiments comparing treatments with asynchronous to synchronous movements, contributions to public goods were significantly higher in the latter [21][22][23]. Although these rituals cost time and energy, they can be accomplished at relatively low costs compared to contributions to the pertaining public good later on, and require no or few external resources, in contrast to many other solutions proposed in the literature such as individual incentives [12].

In some cases, the interaction ritual itself can already accomplish a collective goal, for example a mass demonstration that convinces a government to change a law. While this paper focuses on the hard cases, those easy cases can be largely explained in terms of the recruitment into those groups, which has been elaborated by others [4][24][25].

Interaction rituals increase solidarity [16][17][26], also called identification [27][28] or loyalty [29][30], which denotes the bonding strength of individuals to a group. It can be measured by the number and content of expressions of adherence to a group’s values, ideology or members. Moral justification, religion or sacred values [22][31] can enhance emotional intensity that further increases solidarity [16][19]. The higher or more numerous the uncertainties, the stronger group-directed emotions should be aroused. A competitive group [32] or an enemy [2][33] can give an extra push. Rare but emotionally intense rituals, e.g. initiation in the French Foreign Legion, have a stronger effect on solidarity than frequently occurring low arousal rituals such as prayers [34][35].

Because of heterogeneity of interests, $N$ participants of the interaction ritual will have a range of different commitments to the public good in question. These commitments are modelled as a symmetric single peaked distribution $g(\omega)$ mean-centred at 0, for example a Gaussian. During the ritual, these commitments may increase along with solidarity, sometimes under committed leadership [36] but collective action can also be self-organized without lead-
ers. However, high average commitments do not predict cooperation \[37\]: lowly committed may be tempted to free ride on the highly committed, who in turn may distrust the former and abstain from contributing. Cooperation is higher among equally committed, as was shown experimentally \[38\]. We therefore have to find out how heterogeneous commitments can synchronize into one.

For participants to learn about each other’s commitments, as well as to sense each others’ body language and emotions, they should interact in physical co-presence \[16, 39\], a key feature of interaction rituals. This makes possible for commitments to become (local) common knowledge \[40\], which is obviously not the same as making them equal. These interactions are modelled as symmetric ties \(a_{ij} = a_{ji} = 1\) (and absent ties \(a_{ij} = 0\)) among participants indexed \(i\) and \(j\), later generalized to (possibly asymmetric) \(a_{ij} \geq 0\). Participants have fluctuating emotions and thoughts about their collective action(s), modelled as psychological states \(\theta_i(t)\). The change of \(i\)’s state during the ritual is affected by \(i\)’s commitment \(\omega_i\) and, through empathy \[41\], by the psychological states of \(i\)’s social contacts \(j\) \[42\]. The effect size of the latter is determined by their difference, \(\theta_j(t) - \theta_i(t)\), multiplied by solidarity; at high solidarity, \(i\) is strongly influenced by \(j\), whereas if \(i\) hardly identifies with the group, (s)he is barely affected by \(j\)’s emotions and thoughts.

To analyse the effect of interaction rituals, Kuramoto’s well-studied model \[43, 44, 45\] is used. It has already solved numerous problems in physics, biology, engineering, complex networks and computer science \[46, 47, 48\], thereby establishing cross-disciplinary parsimony. By definition, the smaller a stable difference between \(\theta_j(t)\) and \(\theta_i(t)\), the higher their degree of synchronization \[49\]. This can be measured by heart rates in the field \[42\], or, less practical, by hyperscanning in a lab \[50\]. In Kuramoto’s original model, \(\omega\) is a frequency and \(\theta\) a phase. Obviously, people are no oscillators, but we can get tractability through these simplifications. The reading of coupling strength \(K\) as solidarity is straightforward. Having discussed the variables, writing \(\dot{\theta}_i\) as a shorthand for \(d\theta_i(t)/dt\), and dropping the time indices, Kuramoto’s model is,

\[
\dot{\theta}_i = \omega_i + \frac{K}{N} \sum_{j=1}^{N} a_{ij} \sin(\theta_j - \theta_i). \tag{1}
\]

In a minute, there will be variation of solidarity across individuals, \(K_i\), but in the simplest model version everybody has the same solidarity. The degree to which all group members are synchronized is indicated by an order
parameter $0 \leq r \leq 1$ (to be precise, a complex parameter $r(t)e^{i\phi(t)}$ where $\phi$ is the average phase \[45\]). Analytic solutions were derived for complete graphs, wherein every node is connected to every other node and $N$ is very large. When solidarity increases, nothing happens initially and psychological states remain incoherent ($r = 0$). At a critical threshold $K_c$, however, there is a sudden transition toward stable, although not perfect ($r < 1$), synchronization of a large majority, and Eq.1 implies that commitments synchronize in the same moment. This two-fold phase transition to synchronization becomes “explosive” when taking into account that solidarity varies across individuals and is correlated with commitments, and $K_i = K|\omega_i|$ is substituted for $K$ in Eq.(1) \[51\].

This phase transition has also been found for many sparse graphs with finite $N$ \[46\]. Social networks, except for very small groups, are sparse, clustered into subgroups, have skewed degree distributions (numbers of social contacts), and short network distances \[6, 52, 53\]. Solidarity is limited by the nervous system, and can’t reach arbitrarily high values. For a social network to synchronize at feasible solidarity, its connectivity has to compensate for the differences between individuals’ commitments, else $r$ jitters and synchronization is not achieved \[49, 47\]. Stability of $r$ is studied by means of the Laplacian matrix of the graph \[54\]. If in its spectrum, $0 = \lambda_1 \leq \lambda_2 \leq \ldots \leq \lambda_N$, there are $m$ (near) zero eigenvalues, they indicate the presence of $m$ (almost) disconnected graph components that won’t synchronize with each other. It turns out that increasing a network’s algebraic connectivity ($\lambda_2$) \[55\] yields synchronization at lower solidarity \[46, 47\], thus with less costly rituals. Density, average distance \[46\] and degree distribution \[56\] do not predict this in general.

To get an intuition, “round” graphs, for example the wheel in Fig.1, have higher algebraic connectivity than elongated graphs with the same size and density. To illustrate, Fig.1 compares a wheel ($\lambda_2 = 2$) to a bow tie ($\lambda_2 = 1$) topology, which are equal in size (7), density (0.57), average distance (1.43), degree distribution, degree centralization (0.6), and coreness \[57\] (both are 3-cores). For each draw of initial values (from a uniform distribution between $-\pi$ and $\pi$) and commitments (from a Gaussian with $\sigma = 2$), the wheel synchronizes at a lower threshold than the bow tie. Notice that in small graphs, such as these, small differences between these values have a large impact on the threshold.

Algebraic connectivity can increase by increasing tie strengths, but people have limited capability to do so, at the expense of other ties \[58\]. This
Figure 1: Wheel and bow tie graphs, and their synchronization $r$ as a function of solidarity $K$, indicated by triangles and dots, respectively. In large graphs at $K < K_c$, $r = 0$ but in our small graphs $r$ jitters with time (not shown) and there is no synchronization by definition. Depending on the initial values, here 20 draws, synchronization starts at a solidarity value between the dashed lines.
social homeostasis also constrains the number of ties that individuals can maintain. Members connecting by strong ties \((a_{ij} \gg 1)\) can only do this if their group is small, and usually for a limited time. In Fig.1, bow tie’s connectivity would double by a two-fold increase of all tie strengths, whereas relaying two ties to create a wheel has the same effect. Relaying a given number of ties (and keeping \(a_{ij} = 1\)) is generally more efficient. Alternatively, connectivity can increase by increasing group size, but as large groups inevitably cluster into subgroups, there is a—yet unknown—maximum connectivity. Well-connected subgroups synchronize at \(K_s < K_c\), and if there is assortment, or homophily, of commitments such that their variation \(||\omega_s||\) is relatively small, synchronization happens at lower solidarity, net of connectivity. Remainder group members may then be an audience that supports those subgroups, as in street protests.

In sum, if participant’s interaction ritual is in full swing and their algebraic connectivity is sufficient, the model predicts that their psychological states and commitments, respectively, fuse into one. The simultaneity of their synchronization will yield a stronger boost of motivation, experienced as “collective effervescence”, than if it were sequential, and collective protests, for example, are bursty indeed. Moreover, experiments show that when acting spontaneously, people are more cooperative than when they calculate their decisions.

At some point during or after a (series of) collective action(s), participants or their resources will be exhausted and their solidarity will decrease. If commitments are correlated with solidarity or with degree, there is hysteresis: the backward transition from synchrony to asynchrony happens at lower solidarity than the forward transition. In the end, when ties weaken or dissolve, initial differences are recovered. After a successful collective action, when reputations and norms are established, future actions by the same group will be easier to mount, and can be often explained by familiar mechanisms of cooperation.

Discussion

Cooperation under adverse conditions has a cold start problem, which can be solved by interaction rituals. When a group gets into collective action, it might look as if it’s members are set off by a spark—a minor event such as a police arrest of some protesters. The model, however, explains sparks’
effect in terms of a small increase of solidarity in a near-critical group, due to an emotional reaction that would not entail collective action well below the critical threshold. Another theory about the onset has it that if a sufficient number of initiators contribute, they will win over many others to do the same \cite{65, 66, 67}. The synchronization model contributes by explaining how a critical mass of initiators can be reached. Some scholars attempt to explain the onset in terms of individuals’ identities collapsing into one group identity \cite{37, 68}, but they have no model for it. If identity fusion is interpreted as achieving a shared intentionality, the synchronization model may provide an explanation for their findings.

When uncertainties and expected costs are relatively low, a mellow ritual will do or is not even necessary. People can then chat with each other about the public good \cite{69}, thereby establishing social ties and exchanging commitments \cite{70}, thoughts and emotions. As in interaction rituals, face to face contact is essential \cite{69, 71}, but high solidarity is not, and synchronization can be loosened to (approximate) consensus. Yet algebraic connectivity is important to achieve consensus fast, and for information transmission to be reliable, explained below. In a graph colouring experiment \cite{72}, algebraic connectivity turned out to be inversely proportional to the time to reach consensus. There, subjects had to choose the same colour as their network-neighbours, in highly clustered networks and in networks with randomly rewired edges which implies higher algebraic connectivity \cite{73}.

In cooperation experiments without communication, network topologies were unimportant for the level of contributions \cite{74, 75}. In those experiments, subjects could respond to others’ actions in previous rounds by either cooperating or defecting with everybody in their neighbourhood \cite{74} or group \cite{75}. For topology to have an effect, however, participants must be able to reciprocate the (in)actions of specific others \cite{76}, else free riding is inconsequential for some whereas others are punished for cooperating. This coarse grained behavior is clearly inefficient, whereas for fine grained reciprocity with specific individuals, and for the diffusion of reputations, topology does matter.

For the diffusion of reputations under realistic conditions, social networks should be robust against noise—misinterpreted, wrongly transmitted or manipulated information—and against node removal \cite{77, 78}. These requirements motivated a definition of social cohesion as the minimum number, $\kappa$, of independent paths (concatenation of ties) connecting arbitrary pairs of nodes in a network \cite{79}. This number is equivalent to the minimum number...
of nodes that has to be removed to make the network fall apart [80]. Only in very small networks, of say 7 members of a team, everyone can be connected directly to everyone else (in this example, $\kappa = 6$ and $\lambda_2 = 7$). It was proven for all incomplete networks (missing at least one tie) that $\lambda_2 \leq \kappa$ [55, 81]. Algebraic connectivity thus not only indicates synchronization potential in a broad sense, including consensus and robustness against small perturbations of psychological states [54], but also a lower bound for social cohesion and redundancy of information channels. It might even be important for other species. Orca’s, for example, can collectively catch a seal that sits on a slab of floating ice by swimming synchronously to create a wave that washes it off [82], hence they must exchange information in their network to pull this off. Low algebraic connectivity, in contrast, facilitates anti-coordination, e.g., choosing a different color for oneself than one’s neighbours in a graph coloring game [72], which is useful when group members want to differentiate themselves to exchange private goods instead of achieving public goods.

To study dynamic networks, the Kuramoto model has been generalized as follows [59]. Ties $a_{ij}(t) \geq 0$ strengthen between people who perceive each other as similar in terms of their $\theta$’s, which happens under the constraint of homeostasis. A tie that disappears is modeled as a fading tie, $a_{ij}(t) \rightarrow 0$. Starting out with a random network wherein solidarity increases from zero to a low value, subgroups emerge that are internally synchronous but mutually asynchronous. If solidarity continues to increase to $K \geq K_c$, those subgroups merge into one synchronized group [83]. When taking into account that solidarity varies across individuals, represented by a Gaussian distribution of $K_i$, it takes longer for synchronous subgroups to emerge, and individuals with very low $K_i$ stay solitary, out of sync with everyone else [84]. These loners set apart, the overall pattern is qualitatively the same as with one $K$ for all.

In this study on the onset of cooperation, Kuramoto’s model was used to predict that for a given group of people, a network with higher algebraic connectivity enables them to start at lower effort, hence faster. Under adverse conditions, the onset was explained by interaction rituals leading to shared intentionality. The latter is predicted to be reached in a phase transition that shows up in a burst of cooperation.
Methods

The synchronization model is elaborated in refs [45, 46, 49, 51, 47], and dynamic networks in refs [59, 83].

References


