Synchronization of Management Strategies

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Abstract. Communication, learning and the diffusion of novel and new ideas is a fundamental feature of social systems and allows to develop flexible and adaptive strategies. This paper explores the role of authority in management communities and the role of an external authority that drives the communities towards a unified management path. This work finds that the authority distribution (exponential, normal or egalitarian) within and between management communities affects the synchronization (homogenization) of management strategies. Further, homogenization affects the overall resilience of a Social-Ecological System by reducing its adaptive capacity.

Keywords: synchronization, kuramoto model, strategy dynamics, authority distribution, resilience, management

1 Introduction

Communication is a fundamental feature for developing flexible strategies to adaptively manage a Social-Ecological system (SES). In this endeavor, humans have distinctive abilities: they are able to forecast, within the limits of prediction of a complex system, and to pursue different management paths. They communicate with one other ideas and experiences and are able to implement alternative strategies which can have sensible effects on the ecological components of the system. Human (inter)actions play a crucial role in influencing the resilience of a SES, and its capacity to absorb disturbances without undergoing disruptive processes [1]. More precisely, the ability to foresee and pursue different management paths and the technology used to implement different strategies depends on the ability to learn, interact

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and communicate. The ability to effectively communicate allows opinions, ideas and strategies to be exchanged and diffuse, and thus it enables humans to adaptively manage a SES.

Following Nelson et al. [2] adaptive capacity can be defined as the "preconditions necessary to enable adaptation, including social and physical elements, and the ability to mobilize these elements". Adaptive capacity is a crucial attribute of a resilient SES. It is the capacity to manage a system so that it can maintain itself in the same basin of attraction, despite internal and external disturbances affecting the ecological, the social or both component of the system. Adaptive capacity also allows managers to try to shift the SES towards a more desired basin of attraction, and, as the definition suggests, is time and space specific. This means that adaptive capacity is a local feature and depends on elements that are specific to a given community or environment at a given time. Nonetheless, it is possible to define preconditions necessary for adaptive capacity that are common to all communities and environments at all times. These preconditions, from here on named generic adaptive capacity, depend on ideas, opinions, and hence management strategies that exist in a given SES. Communication, as well as the existence of different management paths, is crucial for adaptive capacity and thus for adaptive management of a SES. Consequently it is important to understand under which conditions homogenization of management strategies is more likely to occur. More precisely, if authority is defined as the power to influence behaviors or opinions through reputation and legal means, two important questions arise:

- Are there different authority structures that favor the homogenization (or synchronization) of management strategies, thus reducing the adaptive capacity to manage a SES?
- What is the importance and what are the consequences of having an "external force" that pushes management towards a unified opinion, idea and consequently, towards the existence of one management path?

In order to answer these questions, it is necessary to understand what variables are fundamental in order to enable managers to synchronize their strategies. Societies where strategies are highly synchronized represent more homogeneous societies, where less room for experimenting with new ideas is allowed. If no or less room for novel strategies exists, imitation of strategies implemented by managers with higher authority may lead, in the long-run, to a reduced generic adaptive capacity, or in other words, a reduced ability to adapt to slow and fast changes in the surrounding environment [3]. As an example, consider a particular community or society that has the technology and the resources to deal with shocks affecting the environment in which they live, such as climatic changes, eutrophication of water bodies, and coral bleaching. The community is highly homogeneous, thus only "traditional" strategies are explored. If the traditional strategies fail, and no new management path is devised the society is bound to be unable to adapt and risks to collapse.

In highly synchronized, hence homogeneous societies, where strategies are highly similar and no room for novel experimentation is given, managers may be unable to identify the appropriate way to deal with a highly unpredictable environment, where extreme events have a non-zero probability to occur. Not being able to express new ideas that lead to new strategies lowers the generic adaptive capacity of the society itself, ultimately impacting on the resilience of the whole SES.

2 The Model

The model presented here aims to explain the conditions under which homogenization of management paths occurs, given few, crucial, social variables. Moreover, it addresses the extent to which external forces may influence this homogenization. Model details (specifics and numerical simulation) can be found in the supplementary material.

Let us assume that strategies used for dealing with our surrounding environment (ecological system in our case) vary with time. Further, a mechanism able to harmonize individual strategies exists. Under these conditions, the homogenization problem becomes a synchronization problem. The pioneering work of Kuramoto [4], with its subsequent modifications [5, 6], is highly relevant to this analysis. The model presented by Kuramoto [4] is very generic, but is still able to highlight the fundamental drivers of spontaneous synchronization. The model considers an ensemble of oscillators that have an intrinsic frequency; all oscillators influence one another, so that the frequency at time t is given by the intrinsic frequency of the single oscillator modified by the influence that oscillators have on one another. The influence, or coupling, can be thought of as a force that draws the oscillators towards a common frequency. Numerous applications of the Kuramoto model exist in biological sciences, engineering, and computer science [7]. Applications of the Kuramoto model can be also found in social sciences where they are applied to opinion formation [6] and economics and finance, where synchronization is normally assessed by looking at correlations [8, 9]. The Kuramoto model has also been widely analyzed in situations where the oscillators are connected by relationships that form networks of different topologies [7].

Humans communicate and exchange ideas and opinions through social networks [10-14]. These networks influence the possibility of synchronization. Although in a different context, Bodin and Norberg [15] have presented interesting findings relating the connectedness of the underlying social network and the ability of the social system to be flexible. The more a community behaves as a single entity, the higher the risk that the resilience of the overall SES is reduced, as no room for novelty and experimentation is allowed. Nonetheless, a degree of connectedness is necessary in order to foster novel ideas and flexibility in management.

The synchronization of strategies depends on how different individuals that have the authority to manage a given system (managers) are connected to each other, and on how different levels of authority influence the synchronization of strategies. Managers share information, ideas, opinions, and hence strategies based on a network of contacts. Since different management communities exist, the network on which managers act can be thought of as a highly modular network (i.e. a network whose density of edges within a module is fairly higher than the density of edges between modules). When acting on a modular network, every module represents a management community. Managers are able to share strategies along their connections within their community based on the authority they have within the community. They are also able to share strategies with managers from different communities; in the latter case, the synchronization of strategies will depend on the authority of the whole community to which a manager belongs. We assess how different authority distributions influence the homogenization of management paths existing in a given SES. Authority can be distributed in different ways: normally, representing a democratic setting; exponentially, representing a strong hierarchical configuration; and uniformly, representing an egalitarian situation.

3 Results

In order to assess whether different authority distributions lead to different synchronization states at the end of the simulation (tn = 1000), average "strategy values" of the 50 initializations are collected for every period t. To assess the synchronization degree at the end of every run, a synchronization parameter is calculated following Pluchino et al. [6].

$$r(t) = 1 - \sqrt{1/N \sum \left(x_i(t) - \overline{X_i(t)}\right)^2}$$

The system is fully synchronized when $r(t) = 1$. Once the synchronization parameter is calculated, the different distribution combinations shown in Table 1S are ranked from the most synchronized to the least one (ranking values from 1 to 6, with 1 being the authority distribution combination that leads to the most synchronized state and 6 the least synchronized one). Ranks are used as the focus is on how different authority distributions lead to different synchronization states, hence, the focus is on which authority distribution leads to the most synchronized state relatively to the other authority distributions, rather than in absolute terms. It is important to look at the relative synchronization in order to highlight how differences in authority distributions across and within management communities lead to relatively different synchronized states. Uncovering the relation between synchronization and authority distributions allows understanding how different structures of authority lead to different degrees of homogenization. Fig. 1 reports rank distribution and the type of authority distribution used. Fig. 2 reports the mean and median rank (r(t)) for different authority distributions.

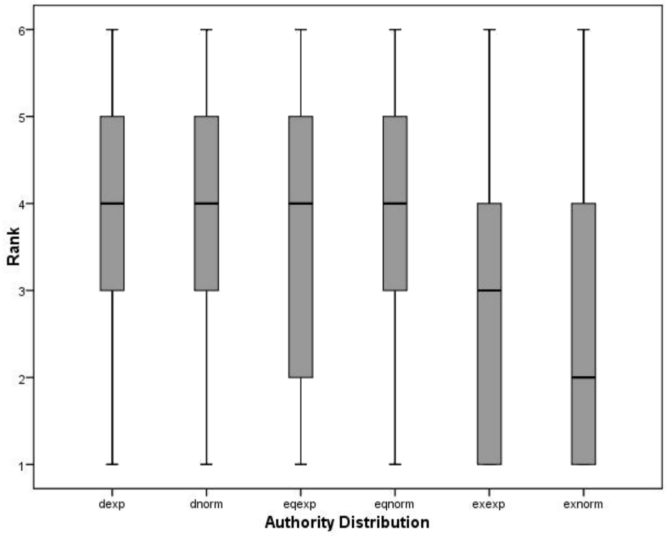

Fig. 1. Distribution of rank versus authority distribution Rank is displayed on the y axis, while different authority distributions are displayed on the x axis. Highest homogenization rank = 1, lowest = 6.

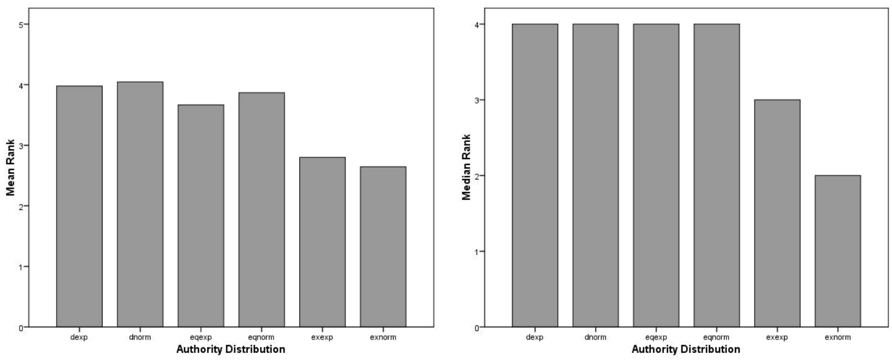

Fig. 2. Mean (right) and Median (left) rank versus authority distribution Rank for the different simulation performed is displayed on the y axis, while different authority distributions are displayed on the x axis. Highest homogenization rank = 1, lowest = 6.

Authority distributions have an important effect on the relative synchronization of strategies between managers and management communities. In other words, different distributions of authority give rise to different degrees of homogeneity. More precisely, exponential distributions are more prone to lead to the most homogeneous states as shown in the Fig. 1, and 2. Most of authority distributions result in higher synchronization when α is not present (= 0). Thus, it is possible, even if this result may seem counterintuitive, that an external force that pushes individuals towards synchronization, does actually generate more heterogeneity. In short, α does not seem to significantly alter the synchronization characteristics, as shown in Fig. 3.

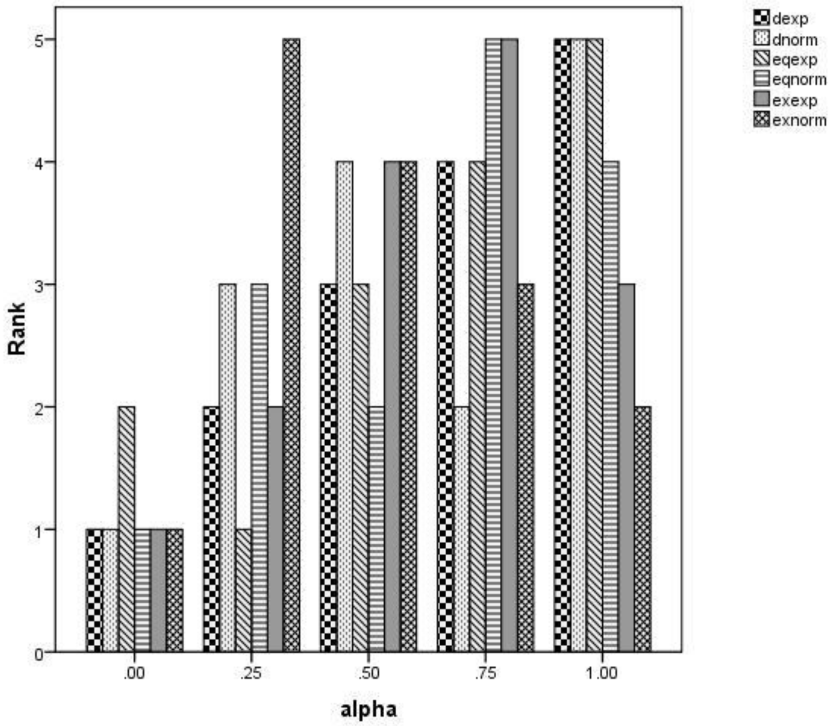

Fig. 3. Rank for different values of alfa. Ranks from 1 (highest ranking) to 5 (lowest ranking) for the six authority distributions given different alpha. Authority distributions are ranked according to alpha (i.e. which alpha value leads to the most homogeneous state in a particular authority distribution)

The fact that the external force gives results that are not aligned with our intuition is common in socio-physics [16]. A similar model (i.e. with respect to the role of external influence) that helps explaining the counterintuitive results of the α parameter has been proposed and studied in relation to opinion formation by Tessone et al. [17, 18]. The model differs from the one presented here as its coupling is not given by dissimilarities between individuals and the dynamics are qualitatively different since it does not take different phases (thus oscillating strategies) into account. However, the external force (social pressure, advertisement etc.) is modelled as periodic forcing (e.g. in the form $C * \sin(x)$) similarly to the model presented here. The external force acts upon the whole system and has different effects according to the homogeneity or heterogeneity of strategies, as in Tessone et al.[18] and Tessone & Toral [17]. Despite the differences in the synchronization of the various authority distributions, the proportion of non-synchronized individuals is very low (see Table 1 where minimum and maximum degrees of synchronization for every authority distribution given by [1] is reported), thus, given the relative high homogeneity resulting from the model, the external common driver is not able to act and force individuals towards a specific phase. Moreover, as Fig. 3 shows, α seems to significantly affect the results only when it is absent (i.e. $\alpha = 0$ thus $-\alpha * \sin(x_i) = 0$), leading almost in all cases to the most synchronized state.

Table 1. Min and max values of synchronization as resulted by the simulations performed

	r(t)	
variable	**min**	**max**
dexp	0.8048	0.9260
dnorm	0.8103	0.9226
eqexp	0.8042	0.9049
eqnorm	0.8108	0.9153
exexp	0.7942	0.9282
exnorm	0.8178	0.9188

This result, as previously mentioned, is not new in the socio-physics domain. External forces have a strong “homogenization” effect only if an intermediate degree of heterogeneity exists in the system [17, 18].

The relationship between heterogeneity and the effect of an external force can also be applied in other contexts. One example is the work of Nelson et al. [19]. In their paper the authors describe how villages in Mimbres (a region in the modern US Southwest), around the 12th century AD, went from a more centralized (thus more homogeneous society) to a decentralized (or more heterogeneous society). In that period the region underwent a transition from what is called the classic Mimbres period to the post-classic reorganization phase [19], where increased homogenization occurred when the Mimbres dispersed into hamlets (abandoning villages). The increased homogenization observed can be explained by the model presented here as the external force (e.g. common overarching state organization and strong cultural beliefs common to all the Mimbres villages) acting upon all members of the village becomes 0 (i.e. $\alpha = 0$), thus allowing for authority distributions to affect the homogenization of strategies between different households.

4 Discussion

Three main conclusions can be drawn from the results obtained here. First, the way in which authority is distributed within a community and between communities matters. Highly hierarchical societies tend to be more homogeneous. The second conclusion confirms that authority distributions between different management communities influence far more significantly the possibility of synchronization and thus homogenization of strategies than differences of authority distribution within the same management community. Differences between distributions of authority inside the very same community do not lead to significant differences (e.g. dexp vs dnorm, eqexp vs eqnorm and exexp vs exnorm), while variations of authority between communities seem to have a highly significant effect. Therefore, more effort should be put into examining cross-community relations, as these may as well be the main drivers of strategic decisions.

The third conclusion concerns the ambivalent effect of an external force that is able to homogenize different management paths. A high homogenization is responsible for narrowing the windows of opportunity for experimentation. Thus, high homogenization reduces what has been previously defined as generic adaptive capacity and leads to an “efficiency trap”, where no novel strategies are explored and managers concentrate on a single way of dealing with the environment [3, 20]. Managers that are able to devise only one type (or set) of strategies will refine the very strategies they are familiar with, at the expenses of other possible ones [3, 21]. In other words, thanks to the available technology, managers will become increasingly competent in changing the environment rather than adapting to it. In the long-run, different strategies are lost thus lowering the generic adaptive capacity. The reduction in generic adaptive capacity leads to a system that lacks the precondition necessary for adaptive capacity especially in case of novel disturbances. Such a system looses the ability to adapt to shocks that have not been previously experienced or that are not known or expected by the managers of a SES.

In order to be adaptive, the management of the SES should exhibit some degree of heterogeneity, if the management’s objective is to find the best possible strategy while maintaining flexibility and the possibility for novel ideas to emerge [20]. Given these results, highly hierarchical governance structure are less able to respond to fundamental shifts in the slow variables that cause the system to change its basin of attraction. This final consideration is also confirmed by a study on the resilience of three different archaeological cases in the U.S Southwest by Hegmon et al. [22]. The analysis of the three cases supports the conclusions presented here and allows for an understanding of the role of authority in the adaptive capacity and, in turn, in the resilience of a SES.

The three cases can be represented by different authority distributions of the model presented, and as such, they can be seen at different levels of homogenization. These levels of homogeneity have had an important effect on the outcome of the societal collapse, as the authors affirm, “the Mimbres transformation was clearly the least severe” while “Mesa Verde and Hohokam, evidenced much harsher conditions prior to their more severe transformations” [22], due to the rigidity imposed by a homogeneous society and the lack of new possible management paths that could have facilitated the adaptation or transformation of those societies.

To conclude, this paper has shown how different management systems may actually facilitate or hinder new management paths depending on hierarchies given by different authority distributions. Further light needs to be shed on the relationship between authority, management and the environment, in order to understand whether SES resilience is eroded or efficiency traps are formed.

5 References

1. Holling, C.S., Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, 1973. **4**: p. 1-23.
2. Nelson, D.R., W.N. Adger, and K. Brown, Adaptation to Environmental Change: Contributions of a Resilience Framework. Annual Review of Environment and Resources, 2007. **32**(395-419).
3. Levinthal, D.A. and J.G. March, The Myopia of Learning. Strategic Management Journal, 1993. **14**: p. 95-112.
4. Kuramoto, Y., Self-entrainment of a population of coupled non-linear oscillators, in International Symposium on Mathematical Problems in Theoretical Physics, H. Araki, Editor 1975, Springer: Berlin.
5. Arenas, A. and C.J. Pérez Vicente, Exact long-time behavior of a network of phase oscillators under random fields. Physical review E, 1994. **50**(2): p. 949-956.
6. Pluchino, A., et al., Opinion dynamics and synchronization in a network of scientific collaborations. Physica A, 2006. **372**(2): p. 316-325.
7. Arenas, A., et al., Synchronization in complex networks. Physics Reports, 2008. **469**(3): p. 93-153.
8. Forbes, K.J. and R. Rigobon, No Contagion, Only Interdependence: Measuring Stock Market Comovements. The Journal of Finance, 2002. **57**(5): p. 2223-2261.
9. Onnela, J.-P., et al., Dynamics of market correlations: Taxonomy and portfolio analysis. Physical Review E, 2003. **68**(5).
10. Boccaletti, S., et al., Complex networks: Structure and dynamics. Physics Reports, 2006. **424**(4-5): p. 175-308.
11. Bodin, Ö., B. Crona, and H. Ernstson, Social networks in natural resource management: What is there to learn from a structural perspective? Ecology and Society, 2006. **11**(2): p. r2.
12. Caldarelli, G., Scale-free Networks. Oxford Finance S.2007, Oxford: Oxford University Press.
13. Dorogovtsev, S.N. and J.F.F. Mendes, Evolution of networks. Advances In Physics, 2002. **51**(4): p. 1079-1187.
14. Galstyan, A. and P. Cohen, Cascading dynamics in modular networks. Physical review E, 2007. **75**(3): p. 036109-036113.

15. Bodin, Ö. and J. Norberg, Information Network Topologies for Enhanced Local Adaptive Management. Environmental Management, 2005. **35**(2): p. 175-193.
16. Castellano, C., S. Fortunato, and V. Loreto, Statistical physics of social dynamics. Reviews of Modern Physics, 2009. **81**(2): p. 591-646.
17. Tessone, C.J. and R. Toral, Diversity-induced resonance in a model for opinion formation. The European Physical Journal B, 2009. **71**(4): p. 549-555.
18. Tessone, C.J., et al., Diversity-Induced Resonance. Physical Review Letters, 2006. **97**(19): p. 194101
19. Nelson, M.C., et al., Archaeological and ecological perspectives on reorganization : A case study from the mimbres region of the U.S. Southwest. American Antiquity, 2006. **71**(3): p. 403-432.
20. Levinthal, D.A., Adaptation on Rugged Landscapes. Management Science, 1997. **42**(7): p. 934-950.
21. Scheffer, M. and F.R. Westley, The Evolutionary Basis of Rigidity: Locks in Cells, Minds, and Society. Ecology and Society, 2007. **12**(2): p. 36.
22. Hegmon, M., et al., Social Transformation and Its Human Costs in the Prehispanic U.S. Southwest. American Anthropologist, 2008. **110**(3): p. 313-324.

Supplementary material

Model Specifics

As mentioned above, managers act on a modular network. Every node of such a network represents a single manager. The modular network is created by joining different random networks that correspond to different management communities. More precisely, the modular networks, shown in Fig. 1, are created as follows:

1. Ten different random networks are generated with 20 nodes each, so as to represent a network of management communities made of 200 people (10 management communities, each having 20 managers).
2. Each node in these networks has a probability p_c to be connected to another node.
3. Each node of the ten networks has a probability p_{oc} to be connected to a node of an initially different network.
4. The connection probabilities given are as follows: $p_c > p_{oc}$, where p_c is drawn from a random uniform distribution between 0.9 and 1, while p_{oc} varies from 0 to 0.2 with a 0.025 increment.

Once the network is created, attributes are assigned to every manager as follows:

5. The community to which a manager belongs: ci
6. Initial strategy of manager i, represented by a number drawn from a random uniform distribution between -1 and 1: x_i
7. Authority that a manager has within the community: Pw_i that assumes values in the interval [0,1]
8. Authority that a management community has when deals with managers belonging to other communities: Pb_i that assumes values in the interval [0,1]

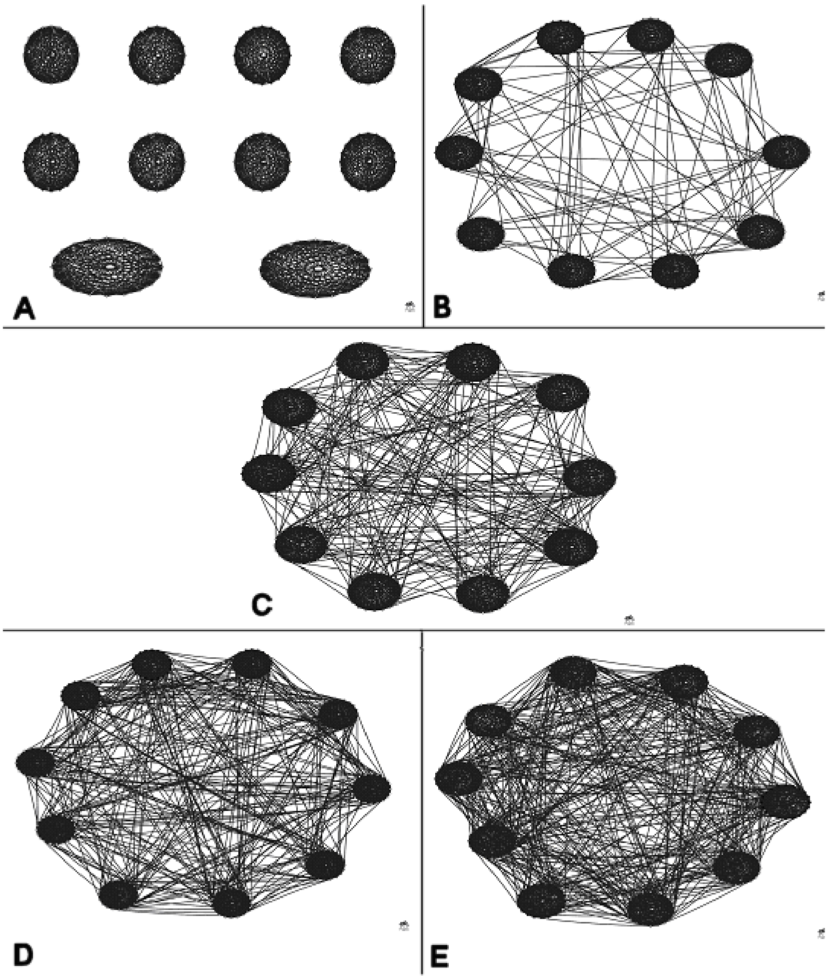

Fig. 4S. Networks visualization for different values of p_{oc} where $p_{oc} = 0$ (A), 0.05 (B), 0.1(C), 0.15(D), and 0.2(E).

The dynamics on the network can be expressed as follows:

$$\dot{x}_i = x_i + \sum_{j \in K} \sigma_{ij} * \sin(x_j - x_i) - \alpha * \sin(x_i) \tag{1}$$

where:

— x_i = is the strategy chosen by manager i
— K = first neighbors of node i
— σ_{ij} = differences in authorities between managers

– α = a general parameter representing the "strength" of an external force is proposed.

When $\alpha = 0$ no external force acts upon the system, while when $\alpha = 1$ a powerful external force pushes the whole system towards synchronization. This external force can be a homogenizing factor that exists in a given region of management communities such as strong cultural values or religious beliefs or the external influence of a powerful international organization.

Constraints on σ_{ij} are imposed as it is reasonable to assume that a manager will synchronize his own strategies only with those managers that have a higher degree of authority. The constraints can be stated as follows:

$\sigma_{ij} = Pw_j - Pw_i$ if $i, j \in ci$ AND $\sigma_{ij} = Pw_j - Pw_i \geq 0$

$\sigma_{ij} = Pb_j - Pb_i$ if $i, j \notin ci$ AND $\sigma_{ij} = Pb_j - Pb_i \geq 0$

$\sigma_{ij} = 0$ if $Pw_j - Pw_i < 0$ OR $Pb_j - Pb_i < 0$

Simulating the Model

Different modular networks with increasing p_{oc} are constructed. Manager's parameters are initialized 50 times for each network, and the dynamics represented by [1] are run for 1000 time steps (t_n).

The model is run for different authority distributions. Authority within communities is distributed as follows:

1. Pw is normally distributed with mean 0.5 and standard deviation 0.125 (this allows to have an upper limit = 1)
2. Pw is exponentially distributed with one agent having authority = 1

Authority between communities is distributed as follows:

3. Pb is equally distributed (every community has the same authority) with value 0.5

4. Pb represents a more "democratic" distribution of authority between communities, and thus is represented by a normal distribution with mean 0.5, and standard deviation 0.125
5. Pb represents a highly hierarchical system in which one community has $Pb = 1$ and the other communities have Pb exponentially distributed between 0 and 1.

Table 1S reports a summary of the different combinations explored and the symbols used to represent different authority distributions.

Table 2S. Symbols used and corresponding authority distributions

Symbol	Distribution of authority within community	Distribution of authority between communities
dexp	exponential	normal
dnorm	normal	normal
eqexp	exponential	equal
eqnorm	normal	equal
exexp	exponential	exponential
exnorm	normal	exponential

Simulations for eq. 1 are performed for different values of α (being α = 0, 0.25, 0.5, 0.75 and 1), for different values of p_{oc} (being p_{oc} = 0, 0.025, 0.05, 0.075, 0.1, 0.125, 0.150, 0.175, 0.2) and for the authority distributions described in Table 1S. It is important to note that all values that representing authority are not to be interpreted in absolute terms but only relatively to other values of the same attribute.