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Empirical signatures of universality, hierarchy and clustering in culture
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Summary

Human societies exhibit a multitude of structural and dynamical properties that are interesting from a complex systems perspective. Such properties can be identified at two levels of analysis. On one hand, one is confronted with social networks, capturing patterns of connectivity and interactions between social agents – the "social" level of analysis. On the other hand, one is confronted with distributions of opinions, preferences and other cultural traits among the agents – the "cultural" level of analysis. The social level has seen a healthy mix of empirical, data-driven research and of theoretical, model-driven research, focusing on both the structure and the dynamics of social networks. By contrast, the cultural level has mostly seen theoretical, model-driven research, with little or no empirical input, with a strong emphasis on the dynamics of cultural traits, driven by social influence interactions between agents. This thesis can be seen as a step towards compensating for this imbalance, as it focuses on structural properties of culture, captured by static, multidimensional empirical data from large-scale social surveys.

As a first step, this data is converted into symbolic sequences of cultural traits, known as "cultural vectors," associated to different individuals, where different positions in each sequence correspond to different survey questions. Different empirical sources are used for constructing multiple sets of cultural vectors, where one such set is also called a "cultural state." These are analyzed with a previously developed technique, which combines two quantities whose definitions are independent of the set of survey questions: a measure of propensity to long-term cultural diversity and a measure of propensity to short-term social coordination, both of which are based on theoretical notions of social influence dynamics. The technique also incorporates a comparison between empirical data and appropriate randomized counterparts. The analysis shows clear deviations of empirical cultural states from randomized counterparts, as well as remarkable similarities across different datasets, suggesting that there are non-trivial, universal properties underlying the structure of culture.

As a second step, the mechanism behind the robust empirical properties is investigated. This leads to proposing a static, probabilistic model capable of generating cultural states that reproduce these properties. The model assumes that every individual's sequence of traits is partly dictated by one of several supposedly

universal "rationalities," whose existence is informally postulated by several social science theories. In addition, the model assumes that, apart from a dominant rationality, each individual also has some affinity with the other rationalities. It is shown that both assumptions are required for reproducing the empirical regularities. This implies that the generic structure of culture is compatible with the existence of several, mixing rationalities, providing indirect evidence for social science theories that are based on this idea.

As a third step, this thesis examines the constraints that empirical structure places on long-term cultural dynamics driven by social influence. More precisely, it evaluates the extent to which the contents of the final state groups (the subsets of agents whose cultural vectors are identical in the final state), produced by a simple model of cultural dynamics, can be predicted based on the cultural vectors that specify the initial cultural state, without explicitly running the dynamics. This predictability, which is rigorously defined in an information-theoretic sense, is shown to be significantly higher for empirical cultural states than for randomized counterparts, due to the hierarchical ultrametric-like organization of the former, which confines cultural convergence within the lower levels of the hierarchy. Moreover, higher predictability goes along with higher compatibility of short-term social coordination and long-term cultural diversity, which is an essential aspect of the empirical robustness mentioned above. In addition, a null model is introduced for generating initial cultural states that retain the ultrametric representation of real data. Using this ultrametric model, predictability is highly enhanced with respect to the randomized cases. This confirms the importance of the hierarchical organization of real culture for forecasting the outcome of social influence dynamics.

As a fourth and final step, the structure inherent in empirical cultural states is further investigated, using concepts from random matrix theory, applied to matrices of similarity between cultural vectors. For generating random matrices that are appropriate as a structureless reference, we propose a null model that enforces, on average, the empirical occurrence frequency of each possible trait. With respect to this null model, the empirical similarity matrices show deviating eigenvalues, which may be signatures of cultural groups or clusters that might not be recognizable by other means. However, they can conceivably also be artifacts of arbitrary, dataset-dependent correlations between cultural variables. This possibility is explicitly illustrated, with the help of two toy models, which implement the "groups scenario" and the "correlations scenario" respectively, in the simplest conceivable setting. It is also shown that, at least in this setting, the two scenarios can be distinguished by evaluating the uniformity of the entries of the eigenvector associated to a deviating eigenvalue, while checking if this uniformity is statistically compatible with the null model. For empirical data, the eigenvector uniformities of all deviating eigenvalues are shown to be compatible with the null model, suggesting that the apparent group structure is not genuine. However, deviating eigenvector uniformities might not be present for cultural groups induced by mixing rationalities (the plausible structural hypothesis mentioned above), so

further research is required for a decisive statement about the presence or absence of group structure in culture.