Community Structure and Its Implications for the Evolution of Cooperation

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Research Objectives

- Understand the role of network homophily [2] in supporting cooperative behavior.
- Develop algorithms to help explore this interaction
- Understand the relative importance of payoffs and network structure in reaching cooperative equilibria.
- Parameterize models with real world data and try to predict levels of cooperation.

Overview

This project began as a effort to replicate the results in a paper by Centola et al. "Homophily, Cultural Drift and the Co-Evolution of Cultural Groups" [2] where the authors develop a computational model of homophily and cultural diversity. I combined this model with a simple game theoretic model of the evolution of cooperation where cooperative outcomes are supported by high levels of community segmentation[1]. Results of computational experiments suggest that such a model may be a candidate for explaining real world observed levels of cooperation [3].

The General Process

1. **Begin with a network model algorithm as described in [2]:** Agents are initialized into a square von Neumann lattice. Every period an agent is selected at random from the population and paired with a neighbor. These agents compare on cultural traits and: break ties and select new neighbors at random if they share no commonalities; or probabilistically become more alike if they share any common traits.
2. **Incorporate a Prisoners Dilemma game:** Initialize a random assignment of traits as either cooperator or defector. Agents now play a game where they follow their strategy type and payoffs depend on pairings and network position.
3. **Incorporate network structured payoff updating and tie breaking rules:** Active player compares their payoff to an average payoff for their neighbors or to the payoffs of those who share community membership (defined as a trait), and applies a rule for tie breaking or tie creation.

An Evolutionary Game-Theoretic Model

We begin with a model of segmentation as a way of supporting cooperation in a heterogeneous society of both cooperators and defectors, where individuals play a one-shot prisoners dilemma game [1].

Market Norms and Segmentation

	Cooperate	Defect
Cooperate	b[3], b[3]	d[1], a[5]
Defect	a[5], d[1]	c[2], c[2]

[payoffs used for simulation]

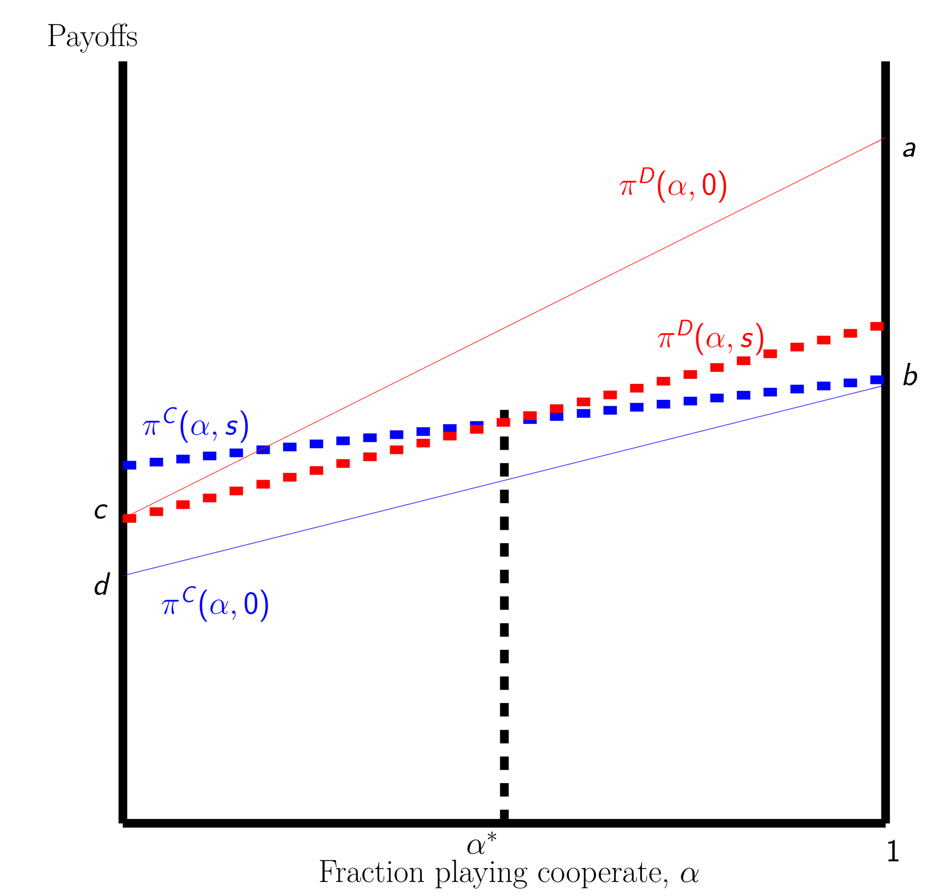
We have the following equations for the expected payoffs to cooperators and defectors:

$$\pi^C(\alpha, s) = sb + (1-s)\{\alpha b + (1-\alpha)d\} \tag{1}$$

$$\pi^D(\alpha, s) = sc + (1-s)\{\alpha a + (1-\alpha)c\} \tag{2}$$

We also have the following equation for α^*, the equilibrium level of cooperators in a society:

$$\alpha^* = \frac{s(d-b)+c-d}{(1-s)(b-d-a+c)} \tag{3}$$



Replication Simulation

This simulation replicates the results produced by Centola et al. (in the top two network graphs in the next collumn), but also uncovered some possible sensitivity to parameter selection in the model (bottom left network graph). In this simulation, t is the running time of the simulation in periods, F is the number of cultural features or categories on which agents compare themselves and q is the possible number of different values a trait in each category can take (these are uniformly distributed). As we can see, the model as originally specified does produce distinct cultural groups over time through the processes of homophily, influence and "network homophily".

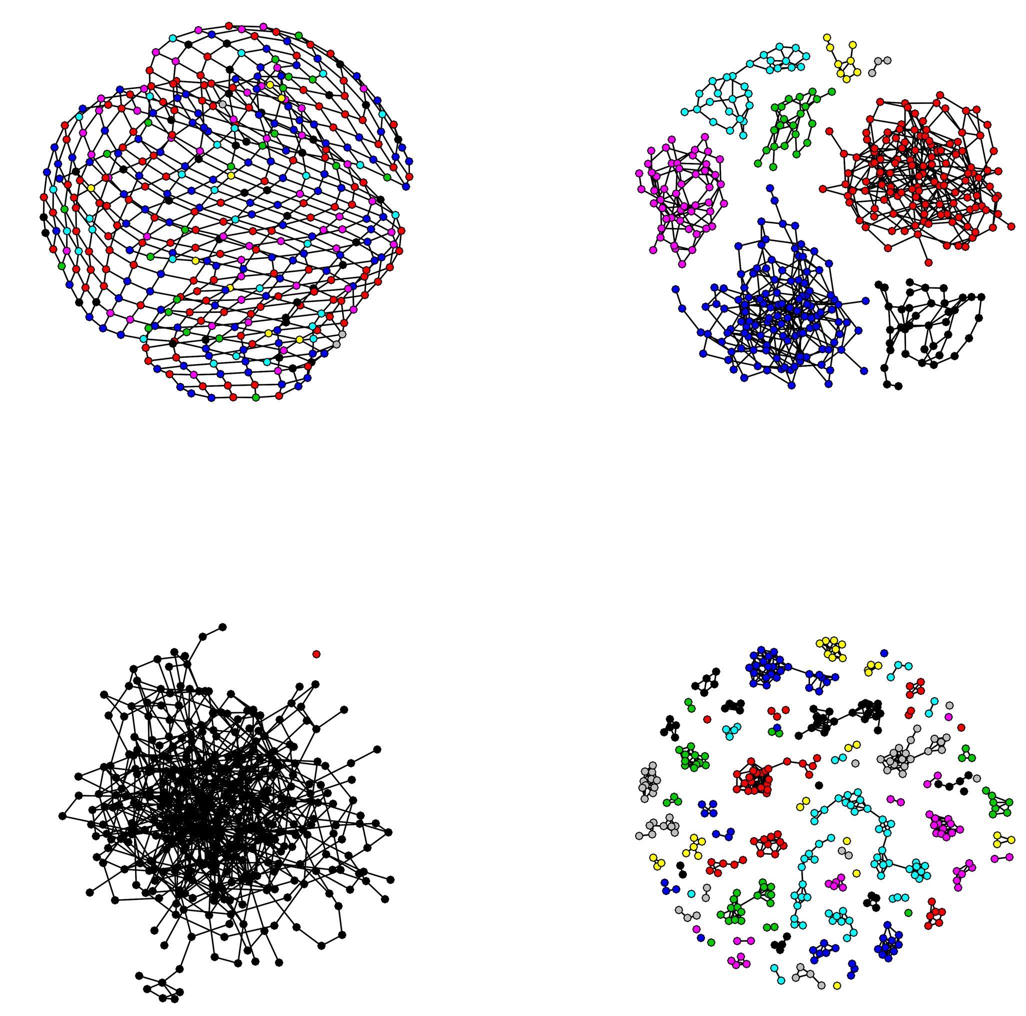


Figure: **From top-left to bottom-right: [t = 0, F= 3, q = 20], [t = 250,000, F= 3, q = 20], [t =250,000 , F= 4, q = 20] , [t = 500,000, , F= 3, q = 200]**

Extended Model

I extend the above model by implementing both an element of initial community membership (as a trait) and differential tie breaking and payoffs based on community membership. The network dynamics of this model are designed from the standpoint of supporting cooperation. Cooperators break ties with defectors and kick them out of their community every time they are paired. The new augmented model representation is shown in table form below:

	Community			
	Same		Different	
	Cooperate	Defect	Cooperate	Defect
Cooperate	3,3	3,2	3,3	1,5
Community Update?	No	Yes	Yes	No
Break Ties?	No	Yes	No	Yes
Defect	2,3	2,2	5,1	2,2
Community Update?	Yes	No	No	No
Break Ties?	Yes	No	Yes	No

The cooperator trait replicator dynamic for this model can be set up as follows:

- Let Φ be the fraction of an individual's community playing cooperate with $(1-\Phi)$ being the fraction playing defect.
- Let π^i be the payoff agent i experiences for the round and let $\underline{\pi}$ be the average payoff to the community for that round.

We then have the following probability that an individual will update based on payoffs:

$$p_i = \Phi(1-\Phi)(\pi^i - \underline{\pi}) \tag{4}$$

This equation is set up so that an agent is more likely to switch types if their community is more heterogeneous and will only switch if their payoff is below the community average. As a direction for future research, I would be interested to incorporate an algorithm which allows for some conversion between the segmentation parameter in the game-theoretic model and the initial community structure of the network in this extended model.

Preliminary Results

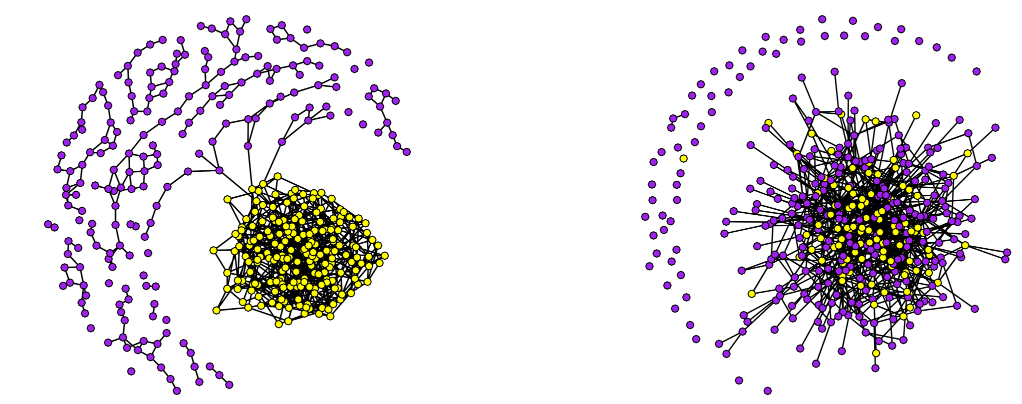


Figure: **From left to right: [t =50,000 , F= 3, N = 400], [t = 50,000, F= 3, N = 400]** I have so far ended up with some interesting (but also troubling) preliminary results. The graph on the left shows the community structure after 50,000 periods when cooperators simply break ties with defectors (and form a new tie with another cooperator) when they are paired with one and where those defectors form no new ties of their own. We get the almost trivial result that defectors will get pushed to the periphery of the community and cooperators will form a dense component. However, when I allow for payoff updating, preliminary results suggest that under almost all circumstances, network homophliy dynamics are dominated by payoff differentials.

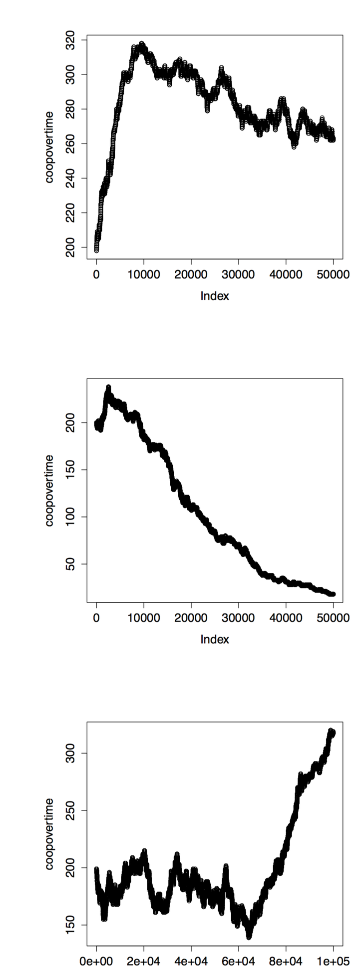


Figure: The three graphs shown here plot the number of cooperators in a simulated society (with a total population of 400) against periods with the top two running for 50,000 periods and the bottom for 100,000 periods. These plots presented here also highlight some interesting model dynamics. The top two plots support the conjecture that payoff differentials dominate homophily dynamics over time. In both cases, tie formation rules which advantage cooperators seem to support higher levels of cooperation in the short run (as evidenced by the initial spike in the number of cooperators), but this advantage seems to erode over time as in both cases, being a defector is always the payoff dominant strategy in the original game-theoretic model. The bottom plot is more interesting as the model parameters were adjusted so that being a cooperator is closer to being a defector, producing more unstable results. There seems to be quite a lot of work to do with this model, but it does miss some important factors like the importance of inequality, network position and power in supporting cooperation.

References

[1] Bowles, S. (2006). *Microeconomics: behavior, institutions, and evolution.* Princeton University Press.

[2] Centola, D., González-Avella, J., Eguíluz, V., and San Miguel, M. (2007). Homophily, cultural drift, and the co-evolution of cultural groups. *Journal of Conflict Resolution*, 51(6):905.

[3] Henrich, J., Boyd, R., Bowles, S., Camerer, C., Fehr, E., Gintis, H., McElreath, R., Alvard, M., Barr, A., Ensminger, J., et al. (2007). " economic man" in cross-cultural perspective: Behavioral experiments in 15 small-scale societies. *International Library of Critical Writings in Economics*, 204:343.

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