Evolution of tag-based cooperation with emotion on complex networks

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Abstract. We study the evolution of the four strategies: Ethnocentric, altruistic, egoistic and cosmopolitan in one community of individuals through Monte Carlo simulations. Interactions and reproduction among computational agents are simulated on undirected Barabási-Albert (UBA) networks and Erdős-Rényi random graphs (ER). We study the Hammond-Axelrod model on both UBA networks and ER random graphs for the asexual reproduction case. We use a modified version of the traditional Hammond-Axelrod model and we also allow the agents’ decisions about one of the strategies to take into account the emotion among their equals. Our simulations showed that egoism and altruism win, differently from other results found in the literature where ethnocentric strategy is common.

1. Introduction
The tag-based cooperation [1, 2, 3, 4, 5, 6, 7, 8] has attracted considerable attention in the scientific community in recent years [9], also among physicists [10, 11, 12, 13, 14].

The scale-free Barabási-Albert (BA) networks[15] and game theory like the Prisoner’s Dilemma [16, 17, 18, 19] are important examples of social phenomena simulated by physicists [20]. The scale-free networks have heterogeneity of links among individual agents [15, 21]: A few have many neighbors and most have only few neighbors. The local interactions between computational agents in the prisoner-dilemma game lead to cooperation among similar agents [22], as well as non-cooperation with dissimilar agents (ethnocentrism) [5], even when there is no reciprocity and cooperation is expensive [23]. Sometimes good empirical data exist for comparison with simulations, in particular for political elections [24, 20]. Also economics has been simulated with evolutionary agent models, e.g. [25]. Hammond-Axelrod (HA) models of evolution of ethnocentrism [5] and contingent altruism [22] show that in-group favoritism among similar agents can evolve under a wide variety of conditions, even when there is no bias towards apparently similar agents. Four different types of agents (each labeled with a different color or other tag) compete via prisoner-dilemma-type interactions. For example, ethnocentric agents treat other agents with the same tag better than those with different tags. In addition, a mechanism for inheritance (genetic or cultural) of strategies is included. The ability to discriminate between the in-group and the out-groups through tags and local interactions can overcome egoism and promote cooperative behavior [5]. However, these models [22, 5] use simple square lattices, neglecting thus a plethora of biological or social real-world networks of contacts, complex and mostly heterogeneous [15, 26, 27, 18, 29].
Lima [28] has studied the HA model of ethnocentrism on both semi-directed and undirected scale-free networks [29, 30, 31]. Lima [28] was interested in how ethnocentrism and egoism emerge spontaneously at the global group-level from the local interactions of differently labeled individual agents. Its introduced a small change where only agents with reproductive potential $\alpha$ and a costly reduction of its $\alpha$ by $c$ obey the relation $\alpha > c$ can help, thus avoiding negative $\alpha$. Different from the traditional HA models of evolution of ethnocentrism, their results showed that egoism can win the ethnocentrism for some $m$ agent neighbors ($m = 1, 2, 5, 10, 20, 50$ and $100$) [28].

Our objective here is therefore to study the modified HA model of ethnocentrism [28] on both ER random graphs and UBA networks [29, 30, 31] and including now the emotion factor among the agents.

The “emotion” introduced in this paper is the fraction of neighbors of a central node having the same “strategy” as the central node, where strategy is ethnocentric, altruist, egoist or cosmopolitan. For example, the emotion is zero if an altruist finds no other altruists among its neighbors, and is unity if all its neighbors are altruists. The amount of help given and the amount of cost produced by this help is multiplied by this emotion factor.

![Figure 1](image_url)

**Figure 1.** (Color online) Outcomes of the competition of strategies in the modified AH model of tag-based ethnocentrism, showing ethnocentric (black), altruistic (red), egoistic (green), and cosmopolitan (blue) behaviors versus parameter $m$ on ER random graphs networks with emotion (left) and no-emotion (right).
![Graphs showing behaviors over time for different conditions](image)

**Figure 2.** (Color online) As Fig.1, but now on UBA networks.

### 2. Model and simulations

Our agent-based extension of the classical model of ethnocentrism [5], is simulated here with 1,000,000 nodes (or computational agents) on ER random graphs and UBA networks. We build on our previous model generalizations [35, 36, 37] by studying the effects of random network structure on the evolution of cooperative behavior of asexually reproducing agents with heritable and visually discernible tag and with four different interaction strategies. More specifically, agents are characterized in our model by one out of four possible arbitrary traits called tags, such as different skin colors. We systematically study an evolutionary model on ER random graphs and UBA networks, but with one modification in one of the four distinct steps called Interaction described below [28]. At each iteration, all agents interact pairwise with neighboring co-players and play Prisoner-Dilemma-like games and observe whether a given co-player displays the same or a different tag. Then each agent applies its fixed strategy. Thus, tags and strategies together will influence the final choice, cooperation (help) or defection, of an individual agent. Agents apply one of the four following strategies fixed at birth:

- **Ethnocentrism or intra-tag cooperation:** Agents help only those with the same tag;
- **Cosmopolitanism or extra-tag cooperation:** Agents help only those with a different tag;
- **Altruism or unconditional cooperation:** Agents always help;
Figure 3. (Color online) Display the behaviors versus time for UER random graphs and UBA networks. Boths for \( m = 100 \).

- Egoism or unconditional defection: Agents never help.

In our simulations, we started generating an empty network (UBA, ER) which remained static throughout the simulation. Then, an iteration (time step of the simulation) always contained updates consisting of four steps in the following order:

- 1) Immigration. One immigrant with randomly fixed traits (tag, strategy) lands on a randomly selected empty network node. It gets as reproductive potential \( \alpha \) the initial value 0.12.

- 2) Interaction. Each of \( N \) randomly drawn agents searches its connected neighborhood and determines whether to cooperate or to defect, depending on the tag of the neighbor and also considering now the emotion between the agents and its neighbors. After donating help, for the donor’s \( \alpha \) is reduced by the cost \( c = 0.01 \), while the donation recipient increases its \( \alpha \) by the benefit \( b = 0.03 \). Here, we used a small change where only agents with fitness \( \alpha > c \) can help, thus avoiding negative \( \alpha \) [28].

- 3) Reproduction. All agents in regular order check if at least one node in their neighborhood is empty; if yes then with probability \( \alpha \) they produce one offspring put on that empty node. The newborns inherit \( \alpha \), as well tag and strategy subject to random mutations with probability \( \mu = 0.05 \). Thus, reproduction is a simple cloning of the parent.
• 4) Death. As the final step, each agent is selected to die with probability $\delta = 0.10$. These four steps constitute one time step or iteration; $10^6$ such iterations are made in order to get stationarity. The stabilization procedure of [36] is used for the reproductive potential $\alpha$: At each time step, all values of $\alpha$ are multiplied by an identical factor such that the average reproductive potential of the population still remains the initial one $\alpha = 0.12$. Finally, for consistency with the original work on ethnocentric cooperation [5] we held this and (most) other parameters constant in accordance with the aforementioned values.

![Graph](image)

**Figure 4.** (Color online) Display the number of strategies in our modified AH model of tag-based ethnocentrism, showing ethnocentric (black), altruistic (red), egoistic (green), and cosmopolitan (blue) behaviors versus parameter $m$ on UER.
3. Results

Figs. 1 and 2 show the numbers of strategists (i.e. their observed behaviors: ethnocentrism, altruism, egoism, and cosmopolitanism) evolving on ER random graphs and UBA networks with parameter \( m = 4 \) and 10. For \( m = 4 \) and with emotion the altruism always wins and having ethnocentrism as the second winning strategy, Fig. 1(a). In Fig. 1(b), we observe that ethnocentrism wins after a brief victory in the early stages of altruism. For \( m = 10 \) and with emotion, Fig. 1(c), we observe a similar behavior of the Fig. 1(b). In the Fig. 1(d) the ethnocentrism always wins and having egoism as the second winning strategy. Fig. 3 compares UBA with ER, both for \( m = 100 \).

Figs. 4 and 5 show the numbers of strategists for \( N = 1,000,000 \) agents with \( m = 1, 2, 5, 10, 20, 50 \) and 100 on UER random graphs and UBA networks for two cases: with emotion and without emotion, respectively. We averaged over the last 500,000 iterations. In Fig. 4(a) already a parameter \( m \leq 4 \) makes altruism become the winning strategy on UER random graphs and for
There is intense competition between ethnocentrism and egoism. In Fig. 4(b) for $m \leq 5$ the ethnocentrism wins and for $m > 5$ the egoism is the winning strategy. Fig. 5(a) shows an intense competition between egoism and ethnocentrism. In Fig. 5(b) the ethnocentrism wins for $m \leq 5$ and $m > 5$ the winning strategy is the egoism.

4. Conclusion
Earlier work without emotion [11, 12, 35, 36, 37, 38] on Hammond-Axelrod models [5, 22] using complex networks showed dominance by ethnocentrics and/or altruists, but not by egoists or cosmopolitans. Here we introduced emotion, measuring the fraction of neighbors with the same strategy as the central node. Now, depending on parameters, also egoism can be the winning strategy. An explanation remains to be found.

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