Physica A 388 (2009) 4999–5004

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Evolution of ethnocentrism on undirected and directed Barabási–Albert networks

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ARTICLE INFO

Article history:
Received 27 May 2009
Received in revised form 30 July 2009
Available online 1 September 2009

PACS:
05.10.Ln
87.23.Ge
89.75.Fb
64.60.aq

Keywords:
Monte Carlo simulation
Complex networks
In-group favoritism
Ethnocentrism
Agent-based model
Evolutionary model

ABSTRACT

Using Monte Carlo simulations, we study the evolution of contingent cooperation and ethnocentrism in the one-shot game. Interactions and reproduction among computational agents are simulated on *undirected* and *directed* Barabási–Albert (BA) networks. We first replicate the Hammond–Axelrod model of in-group favoritism on a square lattice and then generalize this model on *undirected* and *directed* BA networks for both asexual and sexual reproduction cases. Our simulations demonstrate that irrespective of the mode of reproduction, the ethnocentric strategy becomes common even though cooperation is individually costly and mechanisms such as reciprocity or conformity are absent. Moreover, our results indicate that the spread of favoritism towards similar others highly depends on the network topology and the associated heterogeneity of the studied population.

1. Introduction

Social phenomena among humans have been modelled extensively, also by physicists [1]. Scale-free networks have recently been claimed as effective promoters of cooperation in a variety of social dilemmas [2], especially in the prisoner's dilemma game [3–5] which has been one of the most widely applied games for studying how cooperative behavior emerges among unrelated individuals [6]. An important feature of scale-free networks causing sizeable effects in the evolution of cooperation is the heterogeneity of links among individual agents [2,7].

Recent research effort has been directed towards understanding how local interactions between computational agents in the prisoner's dilemma game lead to clustered in-group favoritism characterized by contingent altruism and cooperation among similar agents [8], as well as non-cooperation with out-groups and the emergence of global ethnocentrism [9], even when cooperation is individually costly and the necessary mechanisms such as reciprocity [10] and direct self-interested gain [11,12], leadership [13], reputation [14], trust [15], or conformity [16] are missing. Sometimes [17] good empirical data exist for comparison with simulations, in particular for political elections as started by Ref. [18] and reviewed in Ref. [1].

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doi:10.1016/j.physa.2009.08.029

Hammond–Axelrod (HA) models of evolution of ethnocentrism [9] and contingent altruism [8] show that in-group favoritism can evolve under a wide variety of conditions, even when there is no bias towards apparently similar agents. Instead, four different types of agents (each labeled with a different color) populate a simple square lattice and compete for limited space via prisoner's dilemma type interactions. "Ethnocentric" agents treat other agents within their group more beneficially than those outside of the group and in addition, a mechanism for inheritance (genetic or cultural) of strategies is included.

A remarkable outcome of these evolutionary model studies is that after a sufficient number of iterations, in-group favoritism emerges as a common strategy even though there is no built-in mechanism by which agents can recognize and favor those similar to them. Moreover, the emerging ability to discriminate between the in-group and the out-groups on the basis of different colors and local interactions was actually shown to overcome egoism and promote cooperative behavior, even when cost for cooperation is relatively high and the same-colored defectors that exploit cooperators need to be suppressed. Thus, in situations where cooperation among similar individuals is especially costly, ethnocentric behavior seems to become necessary to sustain cooperation [9].

However, a significant limitation of these studies [8,9] is that they have addressed the evolution of in-group favoritism only within the context of simplified square lattice based models, neglecting thus the fact that a plethora of biological, social, and technological real-world networks of contacts are complex and mostly heterogeneous in nature (e.g. scale-free or broad-scale networks) [2,19,20,5,21]. In addition, the populations studied in Refs. [8,9] were assumed to reproduce only asexually. However, sexual reproduction [22] in computational models is not just more realistic but it also allows for simulation of 'mixed marriages' between agents of different 'ethnicities'.

It is well known that in many racist societies, besides using in-group ideology as a control mechanism [23], there were laws against mixed marriages because they disturb ethnocentricity. Thus, by incorporating the sexual reproduction in the HA model, it might be possible to investigate how, as a function of the probability of mixed marriages, the emergence of ethnocentricity is first made more difficult and then eventually, totally prevented.

Another concern of the present work was that, with just a few notable exceptions (e.g. Refs. [24,25]), previous computational studies of complex networks have largely focused on undirected network systems, even though many real-world network structures such as the transcriptional regulatory network of the budding yeast (Saccharomyces cerevisiae) or Google's web pages [26,27], are actually directed [28].

Our objective here is therefore to generalize the HA model of ethnocentrism by including the sexual mode of reproduction among computational agents and by performing simulations on both *undirected* and *directed* scale-free networks [21,29–33]. More specifically, we first replicate the HA model on a square lattice where only asexual reproduction among agents is allowed. Next, we include the sexual mode of reproduction in the standard lattice based HA model. Finally – and this is the novel emphasis of the present work – we extend the HA model by simulating both reproduction modes separately on *undirected* and *directed* Barabási–Albert (BA) networks. These complex networks have been studied extensively by Lima et al. in the context of magnetism [34–40] and econophysics models [41,42].

While acknowledging the possibility of individual differences in cooperative behavior [43], we are interested here in how ethnocentric behavior, defined as preferential in-group favoritism and lack of cooperation with the out-groups, emerges spontaneously at the global group-level from the local interactions of differently labeled individual agents. Since our model is not analytically tractable, we employ extensive agent-based Monte Carlo simulations, detailed in the next section.

2. Model and simulations

Here, we study the effects of network structure and mode of reproduction (both asexual and sexual, respectively) in the standard (lattice based) and extended (scale-free network-based) HA model of ethnocentric behavior. Ethnocentrism is operationalized as preferential in-group cooperation and non-cooperation with any out-group members. Furthermore, cooperation is set to be an individually costly endeavour, due to implementation of a one-shot game dilemma framework. Moreover, any direct reciprocity is disabled by employing a one-shot game rather than its iterated version (repeated game).

In order to establish group differences and to enable their potential detectability, each agent is labeled by three traits: (a) color, (b) strategic behavior when interacting with same-colored agents, and (c) strategic behavior when interacting with differently-colored agents.

A color specifies the group membership of an agent and is interpreted as an observable feature (a "tag" [44]) that may be seen as socially relevant in a given population (e.g., skin color, religion, political orientation, or language). An "ethnocentric" agent is defined as one that cooperates with same-colored agents, but does not cooperate with individuals of different color.

Thus, the "ethnocentric" in-group preference and discrimination against the out-groups is only one out of four possible strategies. An "altruist" cooperates with all agents, while an "egoist" always defects. A "cosmopolitan" agent cooperates with agents of a different color but not with those of the same color. Given the fact that colors and strategies are not linked, the model allows for the existence of defectors that always exploit the cooperators. Thus, they are receiving help from same-colored ethnocentric agents and at the same time, provide help to no one at all [9].

In the present paper, each simulation begins with an empty lattice or an empty network. Generally, at each time step, the following events occur:

(a) Asexual reproduction mode:
  1. New agents with random traits invade at random empty lattice/network sites.