An affinity-based evolutionary model of the diffusion of knowledge

Modelo evolutivo de difusión del conocimiento basado en afinidad

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RECIBIDO: 29 de Mayo 2015

ACEPTADO: 15 de Julio 2015

Abstract

In this paper, we present a theoretical model that can simulate the diffusion of knowledge in social networks using an evolutionary approach. We assume that social networks built on processes of collaboration and cooperation among stakeholders (people and companies) evolve like living organisms, as described by Charles Darwin in The Origin of Species. We propose an evolutionary model of the diffusion of knowledge, in which stakeholders are knowledge propagators and/or receivers, depending on their customizable attributes. We consider each attribute as a gene that constitutes a chromosome. As in Darwin's theory, the proposed model achieves the processes of crossover and mutation between stakeholders for several generations, until a maximum number of generations is reached. The main contribution of the model is the creation of an environment that is conducive to the study of the dynamics of network cooperation, which uses the stakeholders' attributes as parameters.

Keywords

Social networks, cooperation networks, diffusion of knowledge, evolutionary model.

Resumen

En este artículo presentamos un modelo teórico capaz de simular la difusión del conocimiento en redes sociales, usando una aproximación evolutiva. Partimos del presupuesto que redes sociales constituidas por procesos de cooperación entre actores (e.g. personas, empresas, etc.) evolucionan de forma semejante a los organismos vivos, como ha sido descrito por Charles Darwin en *El Origen de las Especies*. Proponemos un modelo evolutivo de difusión del conocimiento, donde los actores son propagadores y/o retenedores de conocimiento, dependiendo de atributos ajustables que cada actor presenta. Consideramos cada atributo un gen que constituye a un cromosoma. Similar a la teoría de Darwin, el modelo propuesto realiza los procesos de crossover y mutación entre los actores por diversas generaciones, hasta que se obtiene un número máximo de generaciones. La principal contribución del modelo es la creación de un entorno favorable para estudiar la dinámica de cooperación en red teniendo como parámetros los atributos de cada uno de los actores.

Palabras clave

Redes sociales, redes de cooperación, difusión del conocimiento, modelo evolutivo.

1. INTRODUCTION

The complexity of relations of social interactions and the fact that it is possible to analyze them from different points of view lead to vast numbers of studies and results, which have sprung forth many efforts by researchers to create models that explain or predict the behavior of social networks.

From this perspective, this work presents a theoretical model that can simulate the diffusion of knowledge in social networks using an evolutionary approach. It comprises an evolutionary model of knowledge diffusion, where the actors (e.g., people, companies, etc.), depending on their attributes, are either knowledge propagators or receivers.

Affinity has been discussed in several studies as an important mechanism for collaborative processes between individuals (e.g., SILVEIRA 2006, PEREIRA et al. 2007, QUARTO et al. 2007, ZAMBANINI et al. 2012, CARNEIRO 2014, MONTEIRO et al. 2014). Quarto et al. (2007) highlighted the importance of social affinity in the teaching-learning process in a computer-aided environment. Silveira (2006) stated, based on Vygotsky, that when people count on their peers' help, they are able to solve problems or acquire new knowledge better than if they only relied on their own means. Zambanini et al. (2012) showed that individuals who possess a greater number of affinities with their colleagues are those who are more willing to collaborate. Pereira et al. (2007) studied the local clothing productivity arrangement in the city of Salvador in the state of Bahia (BA), Brazil and observed that there were minimal interactions for the arrangement to be efficient and, consequently, to be competitive. Carneiro (2014) presented a remote course management model based on affinity networks between course participants.

All of these works studied the impact of affinity on the relationships of cooperation and diffusion of knowledge. However, none of them discussed the impacts that the ensuing interactions of affinity can have on individuals or the ensuing impacts of this initial cooperation on future processes of cooperation.

To fill this gap, the present study presents a model of diffusion of knowledge based on affinity among individuals. The study verifies how the cooperation process between individuals impacts future processes of cooperation. With this article, the goal is to present a theoretical model that can simulate the diffusion of knowledge on the basis of collaboration and cooperation processes between actors of a certain social network using an evolutionary approach.

Considering that actors in a social network are propagators and/or receivers of knowledge, we begin from the premise that two actors interact when they have affinity. How then do we establish affinity between two actors? We used several fundamental principles on evolution from Charles Darwin's *The Origin of Species* to begin constructing the proposed model. We understood that the attributes of an actor can be represented as genes and its chromosome as a cluster of genes. In this way, we defined each actor to be a sequence of customizable attributes.

In general, the present study contributes by presenting a model capable of suggesting changes in the relationship of actors in a social network based on their attributes to potentiate the diffusion of knowledge. Specifically, we can say that the primary contribution of the proposed model is the creation of an environment conducive to studying the dynamics of network cooperation, which use customizable attributes of the actors as parameters. We can therefore investigate the processes of the diffusion of knowledge in terms of these attributes.

The present article is organized as follows. In Section 2, we present the concepts and definitions that lend theoretical support to the proposed model. In Section 3, we detail the latter with the description of the proposed model. In Section 4, we present the results and discuss them. In Section 5, we end our article with our conclusions.

2. THEORETICAL FOUNDATION

The theoretical foundation that sustains the present article was built on the basis of correlated studies that discuss social networks, diffusion of knowledge, and cooperation. Therefore, the following items are the relevant aspects of those theories that are necessary to understand the model proposed here.

2.1 SOCIAL NETWORKS AND THE DIFFUSION OF KNOWLEDGE

Currently, there is much discussion about social networks and the impact these networks have on interpersonal relationships and on the way their actors construct and spread knowledge. Essentially, a social network is made up of actors (e.g., people, companies, etc.) and connections (relations of interest) that the actors establish among each other. According to Frey (2003, p. 175), "social networks can be understood as independent forms of coordination of interactions. The central mark of the network is cooperation, based on trust between autonomous and independent actors". Still, according to the author, it appears that networks preserve the autonomy of partners and increase the capacity for individual and collective learning.

According to Fujino et al. (2009, p. 211), "the starting point of network analysis is the consideration that social networks structure the fields of several social dimensions". Networks are potentially democratic and participative systems that allow the gathering of individuals and institutions around a common purpose. For Castells (2000), this is one of its characteristics, i.e., horizontality and collaborative work, which endure due to the political will of the members involved.

In this context, it becomes relevant to attempt to understand, explain, or predict behaviors in networks based on formalizing and representing these interactions in models. There are several contributions towards this goal. We highlight those that have become epistemological landmarks due to their theoretical propositions (e.g., preparation of explanatory and predictive models) and practical applications: Erdös and Rényi (1960) presented two models of random networks and the existence of "democratic" networks; Milgram (1967) and Watts and Strogatz (1998) demonstrated how small the world is; Barabási and Albert (1999) formalized a scale-free network model that explains how the rich get richer.

From the beginning of 2000, the theory of networks reached virtually all fields of science, from social areas to exact and biological sciences.

2.2. PROCESSES OF COLLABORATION AND COOPERATION

In the context of the diffusion of knowledge on social networks, collaboration and cooperation processes that occur in these systems must be analyzed in light of the factors that determine them. These factors go far beyond understanding that all processes of collaboration and cooperation spring from a basic premise: the search for a result that represents a gain to all those involved.

According to Maçada and Tijiboy (1997), the existence of cooperation requires collaborative interaction, i.e., there must be common objectives and proper rules within that context that encourage and affect these processes. According to Barros (1994), collaboration is related to contribution, which may not reflect a situation of mutual gain. In contrast, cooperation requires collaboration because it involves common work around a joint objective.

However, it is necessary to consider that the propensity to collaborate and cooperate is the result of other factors, such as the efforts that will be needed for the actor who will collaborate, the efforts that the actors to be benefited will have, and the gains and losses of this collaborative process.

Based on the arguments of Brunet (2009), we decided to work with the theory of Spehr (2003) of Free Cooperation, which advocates that in free cooperation processes, all rules can be negotiated, there is no rigid formalization, there is no institutionalized determination that requires participants to collaborate, and the option for collaboration and cooperation is individual. This occurs because in a social network (e.g., a graduate program, sectors of an organization, etc.), all actors can position themselves as they wish according to their own needs, their profiles, and their availabilities and incentives to participate.

In other words, each actor has characteristics that may or may not lead him/her to have affinity with another actor and to collaborate/cooperate on the network. These characteristics are called attributes. With them, we will define the potential interaction of each actor in the network. For the present study, four attributes were determined:

- **knowledge** (i.e., expertise, know-how, or any knowledge that can be transferred to others);
- **willingness to socialize knowledge** with others;
- **desire to develop new knowledge** from other actors of the network;
- **ease to develop new specific knowledge**.

Such collaboration and cooperation processes also produce changes in the attributes that define actors' affinities. Because once an interaction is established, the actors influence and are influenced by other actors in the network, we consider the following premise: during the processes of cooperation, the interactions that occur between actors change the profile via the modification of the initial attributes of the actors.

We developed this proposition based on Darwin's theory of evolution (1859). This theory propounds that species evolve through natural selection of those individuals best adapted to the environment. In each generation, there are naturally selected individuals who pass their characteristics to their offspring. In our context, individuals are the actors present in social networks.

Thus, we believe that there could be cases of "crossover" (i.e., actors exchanging features that are unique to them due to the influence of other actors). For example, an actor who initially shows no willingness to pass its knowledge on can, when interacting with another actor that does have this disposition, develop the predisposition to socialize its knowledge. Furthermore, we admit the possible occurrence of processes of "mutation" (i.e., actors exchanging features that are unique to them without influence from other actors), which lead to changes in attributes that can make actors become separate or come together in terms of affinity. Similar evolutionary models can be found in literature (e.g., Moret et al., 2012; Monteiro et al., 2014).

3. MATERIALS AND METHODS

Our research focused on determining a model that could simulate the process of diffusion of knowledge in networks, where the motivation for the formation of cooperative relationships between the actors is affinity. Next, we will present the developed model and the elements that led to its construction.

3.1 PROPOSED MODEL

The proposed model admits, as a prerogative, that the **characteristics/attributes** of the actors determine the affinity, or likeness, between them and that this affinity determines a probability for establishing relations of **cooperation and diffusion of knowledge**, which is presented in the same way as in the studies by Monteiro (2012) and Carneiro (2014). Hence, the importance and need to determine a model that establishes the conditions for those relationships are settled.

For this, we chose to incorporate several concepts of genetic engineering (e.g., representation of chromosomes, genes, the use of **crossover** and **mutation**) and adapted them to the proposed model. The developed model is an evolutionary algorithm. Evolutionary algorithms consider that each actor is composed of one or more chromosomes, whose representation is determined on the basis of their genes. In the model proposed by Monteiro et al. (2014), these genes constitute the attributes that will define a larger or lesser affinity between the actors in a network with consequences for the success or failure of the formation of cooperation networks and subsequent dissemination of knowledge. In this model, a network evolves through several generations, modifying itself to become increasingly more efficient.

The authors also considered that individuals who stand out on the network are those with the highest **degree centrality** and, by analogy with the theories of evolution, are the more adapted (**elite** individuals) individuals because they establish the largest number of cooperative relationships in the last generation.

Monteiro et al. (2014) defined a chromosome as a sequence of binary numbers, where the value one (1) represents the existence of a given attribute and the value zero (0) represents its absence. Each binary number represents a gene on the chromosome. When considering a random company as an example, an actor X could have the following attributes:

- Actor X has difficulty in obtaining support from the public sector (value 1);
- Actor X has difficulty in hiring skilled labor (value 1);
- Actor X produces its own raw material (1);
- Actor X does not have its own transport to deliver its products to its customers (value 0).

In this case, its representation would be ActorX-[1,1,1,0]. From this, it is possible to establish the processes of **crossover** and **mutation**.

Considering the following interaction: Actor1-[1,1,1,0] interacts with Actor2-[0,1,0,1] (in this case, Actor2 has no difficulty in obtaining support from the public sector, has difficulty in hiring labor, does not produce its own raw material, and has its own transport to deliver its products). We can expect a **mutation** in the chromosome of one of the actors; for example, suppose Actor1-[1,1,1,0] ceases to produce its own raw material, and as a result of this event, this actor would then be represented by Actor1-[1,1,0,0]. This new structure of attributes leads the actor to have other affinity relationships and consequently, have a new configuration of relationships.

These interactions can and should occur over time, and new actors[11] may emerge in this context. To simulate this possibility, the model proposed by Monteiro et al. (2014) also allows simulating **crossover** processes. When two actors interact, they can exchange attributes among each other, which modifies their initial characteristics and creates a combination of features from both actors. For example, Actor1-[1,1,1,0] while interacting with Actor2-[0,1,0,1] could show a new set of genes or attributes, e.g., [1,1,0,1]. This would mean that Actor1 would continue to have difficulty in obtaining support from the public sector and would continue having difficulty hiring labor but would stop producing its own raw materials and would now possess its own transport to deliver its products due to the influence of Actor2.

11 In the context of the present scenario, a new actor can be a hostel, a restaurant, an inbound company, a commercial establishment, etc. Thus, it is possible that two companies unite to form a new company. For example, a hotel owner can have a partnership with the owners of a car rental and form a new inbound company.

In contrast, for there to be an interaction between actors, motivation is required. Thus, in the model of Monteiro et al. (2014), two actors establish a relationship of cooperation if there is a minimum **affinity** (i.e., or similarity of attributes) between them.

Similarly, in our model of diffusion of knowledge based on affinity, the network of relationships between actors forms from the affinity between them as set out in the aforementioned logical sequence. However, the process of diffusion of knowledge between these actors takes place according to new hypotheses, which are enumerated below:

1. Actors have knowledge (expertise);
2. Actors show resistance in transmitting certain knowledge;
3. Actors show difficulty in assimilating certain knowledge;
4. Actors show interest in acquiring certain knowledge;
5. The expertise, willingness to socialize certain knowledge, desire to develop the knowledge in question, and the ease in developing the new knowledge can all be quantified.

From these hypotheses, we extend the model of Monteiro et al. (2014) such that each actor now has four **chromosomes** (each chromosome consists of a number of **genes** or attributes): one referring to its knowledge or **expertise**; a second chromosome representing its **willingness** to socialize this knowledge; a third chromosome that represents its **desire** to further develop this knowledge; and a fourth chromosome representing its **ease** in doing so.

In this case, the new chromosomes will no longer be specified as binary numbers and are represented by **positive integers**. The **crossover** operation is also performed differently. Here, for the chromosomes representing the actors' expertise, crossover will occur at the **rate of the diffusion of knowledge** (RDK_j), determined by Equation 1.

$$RDK_j = \frac{EX_i + WSK_i + DDK_j + EDK_j}{4 \times MAX}, \qquad (1)$$

where EX_i is the **expertise** or knowledge of Actor *i*, WSK_i is the **willingness** of Actor *i* to socialize certain knowledge, DDK_j is the **desire** for Actor *j* to develop knowledge, EDK_j is the **ease** for Actor *j* to develop new knowledge, and *MAX* is the highest value an attribute can be assigned, e.g., 5 would be used if we want the attributes to range over the set of the following values: 0, 1, 2, 3, 4, and 5.

The *RDK* is incorporated by the model as one of the stages of the aforementioned logical sequence. Thus, the **diffusion of knowledge** will occur if two actors have sufficient affinity to establish cooperative relationships. Once connected, the actors shall exchange information according to the computed RDK_j. The new expertise (EX_j) of each actor is given by Equation 2.

$$EX_j = EX_j + EX_i \times RDK_j \qquad (2)$$

In Figure 1, we show how the process of the diffusion of knowledge is conducted between two actors (from Actor a1 to Actor a2). For this, we select a second **gene** or attribute of knowledge (expertise) of the two individuals. The *RDK* is calculated from the values of **expertise** (chromosome c1); **willingness** to socialize (chromosome c2) the specific knowledge of Actor a1; **desire** to develop knowledge (c3 chromosome); and the **ease** in learning this specific knowledge (chromosome c4) from Actor a2. The new knowledge is obtained through Equation 2 and then assigned to the second gene on chromosome c1 of Actor a2.

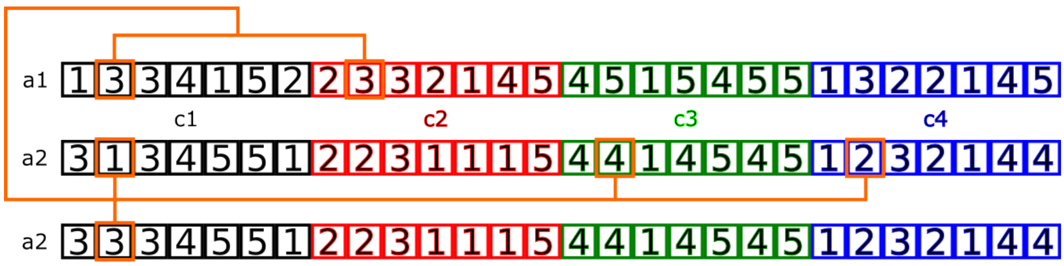

Figure 1: Process of the diffusion of knowledge between two actors, a1 and a2.

In Figure 2, we present graphically the steps in the evolutionary process of the diffusion of knowledge described earlier.

Based on this principle, we developed the following algorithm to simulate the diffusion of knowledge in social networks:

Step 1. Number of generations = 0;

Step 2. Increment the number of generations;

Step 3. If the number of generations reaches the specified maximum, go to Step 11; otherwise, go to Step 4;

Step 4. Determine the best adapted individuals (selection), calculate the **degree of centrality** of each, and select the actors with a centrality that is higher than the average network centrality;

Step 5. Perform crossover between the affinity attributes of connected individuals (leaving those best adapted unaltered);

Step 6. Perform **mutation** of the affinity attributes of individuals;

Step 7. Calculate the RDK_j using Equation 1;

Step 8. Calculate the new **expertise** of Actor j using Equation 2;

Step 9. Update the expertise of Actor j using the value obtained in the previous step;

Step 10. Connect individuals who have **affinity** (minimum specified quantity of equal attributes);

Step 11. Go to Step 2.

This algorithm was developed based on the flexibility of its application. Thus, any number of attributes or genes may be used provided that for each attribute of knowledge, there is a gene corresponding to the willingness to socialize the knowledge, a gene corresponding to the desire to acquire knowledge, and another one corresponding to the ease in developing this knowledge or expertise.

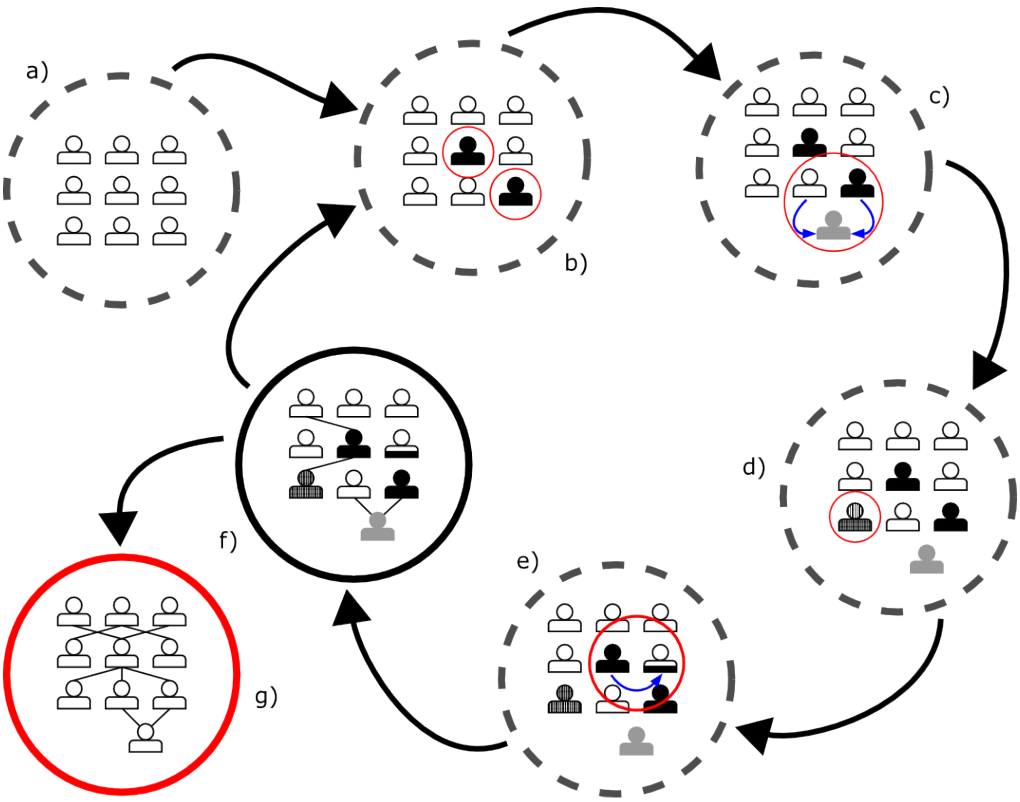

Figure 2: Evolutionary process of the diffusion of knowledge: a) initial population; b) selection of the best adapted individuals; c) crossover; d) mutation; e) diffusion of knowledge; f) connection between the actors based on the affinity between them; g) final network.

In the next section, we will present the results of applying this model to a hypothetical collaboration network based on affinity, where we considered each individual to have seven knowledge attributes.

4. DISCUSSION OF RESULTS

For the present article, we conducted *20* simulations divided into *2* groups. Each group was divided into *2* subgroups, and each subgroup was processed with 5 different settings, and thus, *10,000* networks were obtained. For each setting, we simulated the evolution of the network up to *500* generations. Our goal was to verify the optimal parameters to obtain an evolutionary process consistent with those observed in fossil records (REZNICK et al., 2009).

Initially, we created an artificial random network of affinity, which contained *100* actors, each with *4* chromosomes, as described in the computational model introduced in the previous section, where each knowledge chromosome contained *7* genes. Then, we calculated the frequency distribution of the actors' affinities and obtained an **average value** of *0.181043* with a **standard deviation** of *0.0755461* and **maximum value** of *0.464286*. The graph of the frequency distribution of affinities corresponding to the generated network is shown in Figure 3.

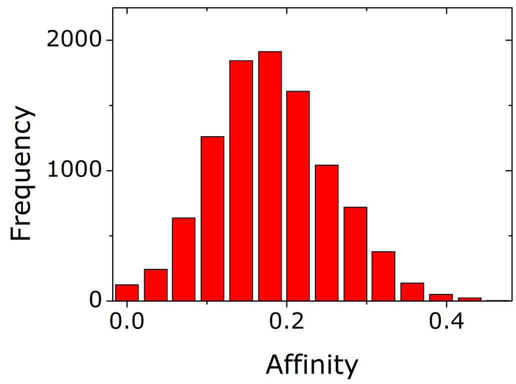

Figure 3: Frequency distribution of affinities in the initial network.

In the first two groups, we used the average affinity value (*~18%*) and the values *0.1%* and *1%* of mutation for each subgroup, respectively. In each subgroup, we used crossover percentages of *10%*, *20%*, *30%*, *40%,* and *50%*. At the end of each experiment, we calculated the overall efficiencies of each network generated in each generation and plotted the graph of the evolution of efficiency, as suggested in Monteiro et al. (2014) and based on Latora and Marchiori (2003). In the context of the present research, the efficiency shows how fast the diffusion of knowledge occurs in the network. In groups *3* and *4*, we used the maximum value of affinity (*~46%*) observed in the initial network.

The curve closest to the one obtained by Monteiro et al. (2014) in the simulations of their evolutionary algorithm based on affinity was a result from the simulation that used *1%* of mutation, *50%* of crossover, and *46%* of affinity. The reason for this is that due to the number of genes present in the chromosome (*28*), working with a lower affinity means that the network would rapidly converge to a clique or complete network because a large number of actors would have enough likeness (affinity) to create connections. Regarding mutation, lower values would lead to extremely long periods of stasis, which slows evolution. The meaning of the crossover value is the same as for mutation: to cause as many occurrences of punctuated equilibrium as possible. Figure 4 shows the result of the evolution of network efficiency using *1%* of mutation, *50%* of crossover, and *46%* of affinity.

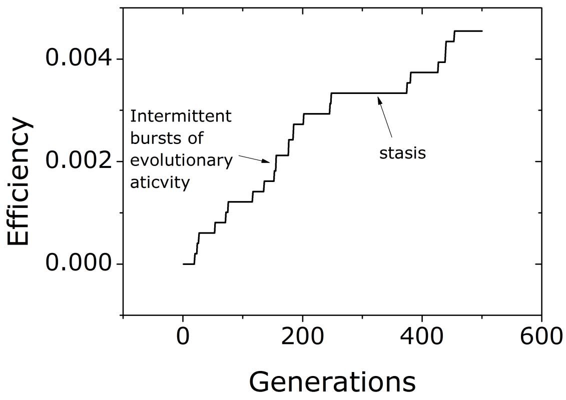

Figure 4: Evolution of network efficiency (punctuated equilibrium behavior).

This graph is consistent with the evolutionary curve observed in fossil records, as reported by Reznik and Ricklefs (2009). The vertical lines represent periods of punctuated equilibrium, where the actors undergo a sudden improvement in their characteristics, and the horizontal lines represent periods of stasis, where the actors remain without major genetic changes regarding their efficiencies as propagators of knowledge.

5. CONCLUSIONS

The proposed model proved to be suitable to simulate the diffusion of knowledge because it establishes more effective relationships based on the affinities of the network's actors. Furthermore, the model offers indications for understanding how cooperative processes may occur in social networks. Within this context, we believe that actors participate as propagators and/or receivers of knowledge depending on the attributes that each actor has and the interactions that it establishes. Thus, it is possible to obtain the level of cooperation and the dynamics of diffusion of information in a social network.

We further emphasize that the proposed model allows any researcher to establish their own scales for each of the attributes of the analyzed actors and possibly allows wide application within different studies on social networks (e.g., efficiency study of sectors in an organization).

Within this context, the model represents an innovation in the formalization of studies on the diffusion of knowledge within social networks because due to its generality, its applicability can be extended to several other studies (e.g., technology transfer in clusters of companies, cooperation in local productive arrangements and discussion forums, etc.).

ACKNOWLEDGMENTS

This work was partially supported by the State of Bahia Research Foundation (Fundação de Amparo à Pesquisa do Estado da Bahia - FAPESB).

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