SIMULATING THE DIFUSION OF INNOVATION PROCESS: A MULTI-AGENT APPROACH

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ABSTRACT
Multi-agent based simulations provide tools and techniques to observe and analyze the emergent behavior that happens due to the interactions among agents. These agents could represent the actors in a real situation, or they could be used to test or to verify hypothesis, theories and to perform experiments in a controlled environment (e.g. virtual world). It is useful in certain cases, for instance when the event and its inner workings are hard to observe, which is common in social simulations. The diffusion of innovation theory, presented by Everett Rogers, provides a classification of the individuals in a social system related to how long an innovation takes to spread into the system. Also, it describes how people form clusters based on the homophily concept. This paper brings two hypotheses for the diffusion of innovation and puts them into test by a multi-agent based simulation, running in the Swarm multi-agent based framework. Rogers' theory, as well as multi-agent based simulations, is briefly presented so they become a background for the presented model. Also, the simulation and its results are shown. Finally, conclusions and future works are discussed.

Keywords: Multi-agent based simulation, diffusion of innovation, Roger´s model.

1. INTRODUCTION

The "diffusion" expression is widely used in literature, ranging from the knowledge diffusion up to the persuasion for the adoption of a certain innovation by the system's members. In a specific level, the innovation diffusion process happens when an innovation is communicated through the proper channels to the social system´s members. Thus, diffusion is a specific type of communication since it allows ideas, products and processes, among others to become known and shared in the society. Theories and models have been used to define the communication strategies.

Among the researchers that study diffusion and the innovation adoption's models, the early studies related to the homophily and performed by the French sociologist Gabriel Tarde is well known. For Tarde, social behaviors happen due to natural inclination of human beings to mimic other humans. Also, Tarde acknowledged that the interactions among individuals had a single purpose of spreading personal outcomes that emerge from imitation, and these outcomes were not created by those interactions. After the Functionalism studies began, Paul Lazarsfeld et al. (1944) analyzed how persuasion occurs in societies, especially by mass communication. DeFleur and Ball-Rokeach (1989) described the communication media theory by observing the strict bond between media, audience and society.

This paper focuses on Rogers' works (Rogers 2003). He was one of the top researchers on innovation and its diffusion in social systems. For Rogers, an innovation includes thoughts, procedures or objects that are perceived as new by a unit of adoption. The potential adopters assign the concept of originality and newness for information.

The diffusion of innovation phenomenon, in a social system, is a complex system because it displays some features such as unpredictable outcomes, emergent behaviors and an open and self-organized system. In this context, the Distributed Artificial Intelligence (DAI) field can be accepted as an option for modeling and simulating the diffusion of innovation phenomenon in a social system. One of the DAI's sub-fields is the Multi-Agent Based Simulation (MABS) that has as its main feature the modeling and the implementation of computational systems according to the social intelligence metaphor. In this approach, MABS is based on a collective building solution, which behaviors emerge due to interactions among its elements (the agents), by following local rules. The agents work autonomously since they are capable to perform certain actions independently. However, during certain moments, social interactions are required in order to promote collective actions, that lead to the development of apparatus for communication, cooperation, collaboration, negotiation, among others.

The MABS's theoretical-technical framework is suitable for modeling and simulate of complex systems. This work presents a multi agent-based system that models and simulates the diffusion of innovation phenomenon. The adopted approach is the one described in Rogers' model (Rogers 2003) and it is implemented in the Swarm multi-agent simulation framework.

This study is organized as follows. Section 2 describes the core concepts of Rogers' diffusion of innovation model. The Section 3 describes a proposed agent-based model for the diffusion of innovation phenomenon in a social system. The results found in the computational simulation, along with an analysis of such results, are shown in Section 4. Finally, Section 5 discusses the final statements of this work, including some propositions for future works.

2. THE ROGERS' DIFFUSION OF INNOVATIONS MODEL

According to Rogers (2003) "*An innovation is an idea, or object that is perceived as new by an individual or other unit of adoption*". There are two innovation profiles: (i) the hardware profile related to technological innovations, regarding tools or objects and (ii) the software profile that deals with information or new ideas. Research fields such as political philosophy, religious thoughts, norms and social conventions are instances of software innovations. On the other hand, a cell phone and the videogame consoles are concerned to hardware innovations. Usually, a hardware innovation leads to a software innovation as well (Rogers 2003).

Rogers (2003) defines diffusion as "... *the process in which an innovation is communicated through certain channels over time among the members of a social system*" and the concept that follows is that diffusion is a special kind of communication that covers: innovation, communication's channels, time and the social system. The perceived newness of an idea defines how it is related to the innovation. If an idea seems new to an individual, then it is an innovation, otherwise no. For the communication channels, Rogers´ theory states that the interpersonal channels are more effective to push an individual to accept an innovation. Thus, mass media communication channels are well suited for spreading an innovation. The time dimension on diffusion of innovation considers that the process of accepting or rejecting an innovation is composed of knowledge, persuasion, decision and confirmation.

According to Rogers (2003) a social system is: "*...a set of interrelated units that are engaged in joint problem solving to accomplish a common goal. The members or units of a social system may be individuals, informal groups, organizations, and/or subsystems*".

The decision process for adopting an innovation is based on a series of choices and actions that happen through time. In this process, an individual - or a system - evaluates a new idea and decides whether it adopts (or does not) the current innovation. This concept of new ideas in the messages' content provides a distinct feature to diffusion: it means that diffusion will have a certain degree of uncertainty. According to Rogers (2003) "*...uncertainty is the degree to which a number of alternatives are perceived with respect to the occurrence of an event and the relative probabilities of these alternatives. Uncertainty motivates individuals to seek information, as it is an uncomfortable state*".

A social system has aspects that induce the innovation diffusion process, among those it is possible to cite: social norms, social structure and opinion leaders. Social norms define the social system members' behavior pattern. On the other hand, the social structures are taken into consideration since the organization of the system's members, and components, either smoothes or hamper the diffusion of innovation. The opinion leaders are system members that might provide a formal or informal leadership on the innovation status. Also, the leadership directly affects the innovation's acceptance rate.

The model proposed by Rogers (2003) takes into consideration the homophily concept. For Rogers "*...homophily is the degree to which a pair of individuals who communicate are similar*". Such resemblance may appear in features such as beliefs, education and social-economical situation. Also, the basic communication principle is that the transferring of ideas occurs more often among individuals that share, the same values and meanings.

2.1. Classification of the Innovation Adopters

The model proposed by Rogers (2003) classifies the group members based on the time required to adopt an innovation. Rogers´ model begins by taking that individuals in a social system do not instantaneously adopt an innovation. Instead, such adoption happens in a certain period, so members of social system can be classified into categories based on the time they take to adopt the innovation. The system is based on a normal distribution of the number of individuals that adopt an innovation over the time. Figure 1 shows that this system has five categories: Innovators, Early Adopters, Early Majority, Late Majority and Laggards.

According to Figure 1 it is worth mentioning that the Innovators are the first ones to accept an innovation. Essentially, they are adventurers and cosmopolitans, their role is bringing external innovations into their social system. It is because of their cosmopolitan position - distinguished by their peripheral location in the network - usually, they are not called in or followed during the innovation-decision process. Also, their tendency of ignoring, or breaking, the social norms are influential to their low social reputation.

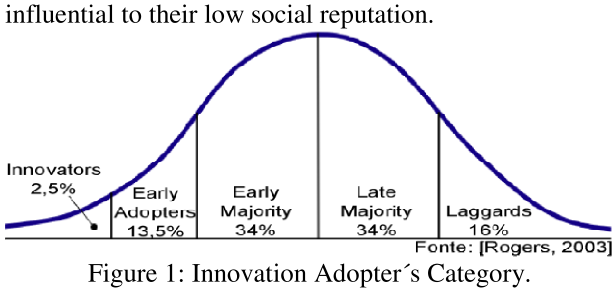

Figure 1: Innovation Adopter´s Category.

Going through the timeline of innovation's adoption, there are the following categories: Early

Adopters, Early Majority, Late Majority and Laggards. Each class takes more time to accept an innovation. The Early Adopters, also known as opinion leaders, have a great social reputation. They behave by the norms of the social system and they are quite integrated and mostly act as central nodes in social networks. Whenever they opt for an innovation, there is a growth in the number of followers. Thus, these individuals are potential opinion makers.

The Early Majority adopter frequently interacts with their peers, but rarely become an opinion leader in a social system (Rogers 2003). In this group the decision time for adoption of an innovation tends to be longer than the time required for Innovators or Early Adopters. The Late Majority is a group of skeptics that only accept an idea after half of the social system's adopters have already accepted that idea. Finally, the Laggard group's behavior shows that they are orthodox and conservative, and they adopt innovation when everybody in the system has accepted, after the peers' pressure.

3. MULTI-AGENT MODEL FOR THE DIFFUSION OF INNOVATION PHENOMENON

In order to have a better understanding of the diffusion of innovation process, this section proposes a Multi-Agent System based on Rogers' diffusion model, to be executed as a simulation. This MABS comprises four agent types: `Innovator`, `Opinion Leader`, `Laggard` and `Majority`.

The agents were defined considering the adopters' classes shown in Figure 1. Since there are no substantial differences between Early Majority and Late Majority classes, these two categories were combined in a single type of agent, the `Majority` one. To facilitate the comprehension of this model, the Early Adopter was renamed to `Opinion Leader` since this group, according to Rogers, presents leaders' exclusive features. Also, since the proposed MABS is based on Rogers' model, the percentage of each agent type fits in a normal distribution with the following values: `Innovator` (2.5%), `Opinion Leader` (13.5%), `Laggard` (16.0%) and `Majority` (68.0%).

The environment where the agents are inserted is modeled based on the Cellular Automata theory. Modeling and execution of this MABS model provides a theoretical-technical framework for the study of following hypotheses:

- The interactions among agents - generated during the innovation process and based on Rogers' theory - lead the `Majority` and `Laggard` agents to follow the `Opinion Leader` agents;
- The adopting agents follow their leaders in distinct ways, by applying patterns that were influenced by specific features of each follower type.

These hypotheses are reasonable suppositions, but they need to be analyzed to prove or disprove them. Thus, based on a conceptual model and further implementation of a computational simulation, it will be possible to confirm the feasibility and theoretical coherence of Rogers' proposition.

In the proposed MABS conceptual model each `Majority` and `Laggard` agent follows an `Opinion Leader`, called "optimal leader". In this context the relationship between agents is defined by the level of homophily, considering that the level helps in the formation of likeness or dissemblance relationships into the agency. It is assumed that higher the homophily is, higher the likeness between agents will be. For Rogers, that happens because there is a high level of homophily among individuals that belong to the same groups, social circles and share the same interests, common beliefs, and so on. On the other hand, the lower the homophily is, higher the differences among individuals are. Also, Rogers states that whenever the homophily is in a high level, the communication will likely reward both sides. Thus, agents that follow an opinion leader have a high level of homophily with such leader.

Based on such assumptions, on each simulation's iteration the agents attempt to find the group they belong, by a level of resemblance that is defined by homophily. To achieve that, the agents move in a social environment, and the decision to go to a certain place prioritizes the search for social groups with the highest level of available homophily. Which implies that the agent's priority is not to follow its optimal leader. For example, if such leader is close to the group with highest homophily, then the agent will follow its leader as an emergent outcome of the social interactions. The modeling of the proposed MABS model considers the following rule: if a `Majority` agent or `Laggard` agent follows its optimal leader (moving to a place that closer of such leader), then it means that this agent is adopting the innovation presented by the leader.

So far, the composition of the proposed MABS takes the following elements: (i) the `Social Environment`, which represents the place where the agents are physically located and where they interact with each other; (ii) the `Person` agent, which represents an individual that act according to innovation-decision process proposed by Rogers.

3.1. The Social Environment

The `Social Environment` represents the area where agents, and the other objects from the model are located and the social interactions happen. In order to model this environment, the Cellular Automata theory is applied using concepts such as: grid type, neighborhood definitions and local rules.

The topology is described as a two-dimensional grid. In the simulation, each cell can hold just a single agent. The agents' interaction with the `Social Environment` occurs by a reading mechanism, that defines how the agent's perception works. Such mechanism accepts that each agent has an optimal leader. The follower agents try to move to the same area of the optimal leader. However, this is not always possible because the movement priority is to go to an area where, on average, this agent has a higher level of homophily with the group. The choice of that area is based on the definition of four quadrants. Thus, at each simulation step there will be four directions possible to be chosen.

The width and length of each quadrant are established by agent's line of sight (scope) that defines its neighborhood, denoting the amount of cells that each agent can see in its surroundings.

3.2. The Person Agent's Architecture

The Person agent acts as an individual that follows Rogers' innovation-decision process, which has two main activities (Rogers 2003): the information seeking and information processing. By these two activities the individual, inside a social system, can decrease the uncertainty level of an innovation and choose, or not, to accept it effectively.

3.2.1. Information Seeking Module

In each simulation's iteration, agents keep on performing the innovation-decision process taking into consideration the readings from the neighborhood. For this task, the Information Seeking Module (ISM) performs a scan on the Social Environment, gathering the following data for each of the four observing quadrants: free cells, occupied cells, and the average level of homophily. This task requires the following four steps: (a) definition of the reference points (1, 2, 3 and 4, as it is shown in Figure 2), for establishing the quadrants; (b) a random choice of the reference point, to direct the reading of the neighborhood; (c) definition of the observation area as four quadrants; (d) data gathering from the neighborhood, based on the quadrants' division.

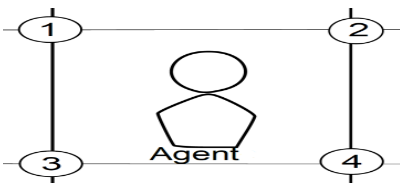

Figure 2: Reference Points for Quadrant Definition.

The topology is represented in the multiagent system in a 2D Grid and, in a given time, each cell can contain only one agent. The agent's interaction with the physical environment occurs by means of the grid reader mechanism delimited by quadrants. This mechanism considers that an agent is directed to an area where, on average, the agents has more degree of homophily with him. The choice of this area is based on the definition of four quadrants, and the length and width of each of this is determined by the radius of scope of the agent, defined by its category, as illustrated in the example of Figure 3.

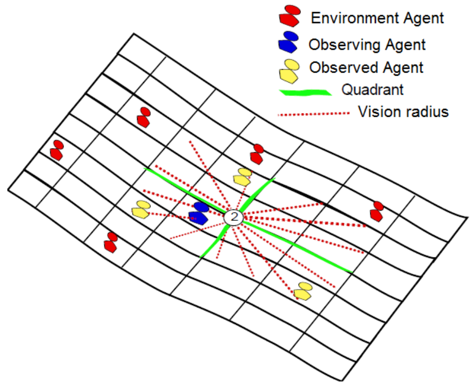

Figure 3: Referential Points to Establish of the Neighborhood..

3.2.2. Information Processing Module

The Information Processing Module (IPM) receives information from the Information Seeking Module, and then compares the homophily level between the agent and each neighborhood quadrant, by taking three steps: (1) the homophily level between the subject agent and each other simulation's agent is computed; (2) for each quadrant, an average of the homophily level from all agents of each quadrant is calculated, taking the subject agent as reference; (3) definition of the quadrant with the highest average homophily.

Information Processing Module: Single Features

The agents on this work are described through three main features: scope, groupCohesion and sociability. The scope describes the individual's social influence. In the model proposed in this paper, the scope is a constant value to indicate the agent's line of sight, that goes from 0 to 12. Therefore, the scope establishes the range of its neighborhood. Table 1 has the values for scope related to each agent type. The IN, OL, MAJ and LAG mean Innovator, Opinion Leader, Majority and Laggard agents, respectively.

Table 1: Scope Feature and Its Scale.

Scope		
Agent	**Level**	**Scale**
MAJ	0	3
LAG	1	6
IN	2	9
OL	3	12

Also, Table 1 defines the scales for the scope feature following the adopters' classes and features proposed by Rogers. In this case, if the number is high, the feature is high as well. For example, the Opinion Leader agents have a scope value of 12 due to their high power of social influence. And for the Innovator agents the value chosen is 9, since this group has less social influence than the Opinion

Leader, but considerable line of sight due to their ease of understanding the possible society's trends.

The groupCohesion feature describes how an agent perceives itself, compared to its group. This image defines a group bound that keep it strong and unite among its peers. The model proposed by this paper takes the groupCohesion feature as a random discrete variable that goes from 0 to 100. Table 2 shows how this variable is set for each agent type.

Table 2: Group Cohesion Feature and Its Scale.

groupCohesion		
Agent	**Level**	**Scale**
MAJ	0	0 to 25
LAG	1	26 to 50
OL	2	51 to 75
OL and IN	3	76 to 100

The Innovator and some Opinion Leader agents get the highest scale, between 76 and 100, since these groups have a great image of themselves into their social groups. This is explained, according to Rogers (2003) by their high level education, good funds and a high regard by peers. Most Opinion Leader has the groupCohesion feature in the 51–75 interval, because they have a great image of themselves into their groups, as well as keeping their leadership role in social systems. For the Laggard agents group, the groupCohesion value lies between 26 and 50. They have a good group cohesion, even considering that they are locked in traditional values and they are extremely cautious in adopting an innovation. Lastly, the Majority agents get the lowest scale of all (from 0 to 25), because they do not have a strong sense of group once they do not support their own ideas and have a strong tendency in following the majority.

The sociability feature indicates the agent's communication skills. This model describes this feature as a random discrete variable that ranges from 0 to 25. Table 3 displays how this feature is set for each agent type.

Table 3: Sociability Feature and Its Scale.

Sociability		
Agent	**Level**	**Scale**
IN	0	0 to 5
IN and LAG	1	6 to 10
LAG and MAJ	2	11 to 16
OL	3	17 to 25

For the sociability feature, the Innovator agents get the lowest values, between 0 and 5. Such agents have low affinity with other agents, and it can be partially explained by the fact that the Innovator agents break the social norms. Among the Innovators, a minority group receives a value between 6 and 10, considering the chance to model Innovator agents that want to communicate and spread their opinions about innovations. For the most part of the Laggard agents the sociability feature is defined in the range from 6 to 10. According to Rogers, the sociability of these agents is low, since many of them are almost isolated in their social group. However, there is a minority that has some influence on the others, and convinces them to adopt the innovations. To this minority it is set aside a sociability value from 11 to 16.

Information Processing Module: Defining the Homophily Level

The Information Processing Module takes care of the homophily level among the simulation agents, using a set of rules described in the tables 4, 5, 6 and 7. Based on these rules, each agent establishes a level of likeness, or difference, with other agents. In this case, homophily refers to the agent's preference in staying closer to another agent by comparing the scope, groupCohesion and sociability features.

These tables show how each agent category defines its homophily level among other agents in the society. Because of that, the terms "observing agent" and "observed agent" are chosen. The observing agent analyzes its neighborhood to establish the homophily level with them. During the homophily computing, for an observing agent each one of its neighbors is considered as an observed agent. After the observing agent establishes the homophily level between itself and each one of the simulation's agents, it computes the average of homophily for each one of the four quadrants of its neighborhood.

The rows from tables 4, 5, 6 and 7 denote how an observing agent should proceed to establish the homophily level, by looking at the scope (SCO), groupCohesion (GC) and sociability (SOC) features. On the other hand, the columns represent likeness classes, denoting how close (or far) the agents are among them. These classes go from -3 to 3. And the negative values (-3, -2, -1) indicate that the feature of the observed agents is lower than the value of the same feature of the observing agent. The positive values (1, 2 and 3) indicate that the feature of the observed agents is higher than the same feature of the observing agent. The zero value (0) states that the value of the analyzed feature is the same for both agents (observing and observed).

The values from the tables 4, 5, 6 and 7 show the homophily level among the observing and observed agents that range from zero (0.0) to one (1.0). The zero (0.0) means that there is no resemblance at all, while one (1.0) means a full resemblance.

Table 4: Opinion Leader´s Point of View.

Opinion Leader Agent							
	-3	-2	-1	0	1	2	3
SCO	1.00	0.75	0.50	0.00	0.25	0.00	0.00
GC	0.50	0.75	1.00	0.00	0.25	0.00	0.00
SOC	0.00	0.25	0.50	0.75	0.00	0.00	0.00

For instance, Table 4 is related to Opinion Leader agents. This agent category wants to be a central node in its influence area, avoiding getting closer to other `Opinion Leaders`. This happens because, if there is another `Opinion Leader` getting closer, its leadership is threatened, since the other simulation agents will have more than one leader to choose. For instance, about the scope feature, the homophily relationship among the `Opinion Leader` and the other agents works as follows:

- Column 0: If the scopes are the same, it implies that both agents share the same line of sight and the same influence scope. Therefore, as an opinion leader does not wish to share its followers with other leaders, the table considers that the likeness among them is zero;
- Columns -3, -2 and -1: If the observed agent scope is low, related to the `Opinion Leader` (the observing agent), it means that the observed has less social influence, which gets the `Opinion Leader` closer to this agent. This can be noticed by high homophily values;
- Columns 1, 2 e 3: If high the observed agent's scope is, related to `Opinion Leader`, it implies that the observed agent has a higher social influence, which pushes the `Opinion Leader` away from this agent, and it is denoted by low homophily values.

By looking at Table 5, which is related to `Innovator` agents, there are some features that are worth noticing. For instance, generally speaking the homophily levels are low because the `Innovator` agents tend to establish a low affinity with the other agents. This is related to their cosmopolitan nature that makes the `Innovator` agents to focus on the system's outskirts, in the border with other agents.

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Table 5: Innovator Agent´s Point of View.

`Innovator` Agent							
	-3	-2	-1	0	1	2	3
SCO	0.00	0.00	0.00	0.50	0.00	0.00	0.00
GC	0.25	0.50	0.75	1.00	0.00	0.00	0.00
SOC	0.00	0.00	0.00	1.00	0.25	0.50	0.75

The most important behavior feature of `Majority` and `Laggard` agents is the trend in forming groups around the `Opinion Leaders`. The values for the homophily level of these two categories are based on this trend. Table 6 and Table 7 represent the `Laggard` and `Majority` agents view, respectively.

Table 6: Laggard Agent´s Point of View.

`Laggard` Agent							
	-3	-2	-1	0	1	2	3
SCO	0.00	0.00	0.25	1.00	0.50	0.75	0.75
GC	0.50	0.75	1.00	0.00	0.25	0.00	0.00
SOC	0.00	0.25	0.50	0.75	1.00	0.75	0.75

Table 7: Majority Agent´s Point of View.

`Majority` Agent							
	-3	-2	-1	0	1	2	3
SCO	0.00	0.00	0.00	0.25	0.50	0.75	1.00
GC	0.00	0.00	0.00	0.25	0.50	0.75	1.00
SOC	0.00	0.25	0.50	0.75	1.00	0.00	0.00

4. COMPUTER SIMULATION AND RESULTS ANALYSIS

In this paper the conceptual model for the diffusion of innovation process, proposed in Section 3, was implemented in the Swarm multi-agent simulation platform. Based on this implementation two scenarios were modeled and executed.

4.1. Scenarios: Goals and Configuration

Two scenarios were modeled in order to investigate the two hypotheses presented in Section 4. The configurations of these scenarios are based on how many agents are allocated in the `Social Environment`. Table 8 shows the agents distribution for both scenarios.

Table 8: Configuration of Experiments.

Agent	**%**	**Color**	**Scenario 1**	**Scenario 2**
IN	2.5	White	07	02
OL	13.5	Red	20	06
MAJ	68.8	Green	98	26
LAG	16.0	Blue	22	07

The `Social Environment` is represented by a grid of 40x40. The first scenario presents a high density, with 147 agents. The second scenario has a low density of occupation, with forty-one (41) agents. Due to the architecture used by SWARM platform each agent occupies on cell of the grid, so it is not possible for two or more agents to stay on the same cell. The environment is also represented by cell, but it can hold an individual that move in.

4.2. The Results Analysis

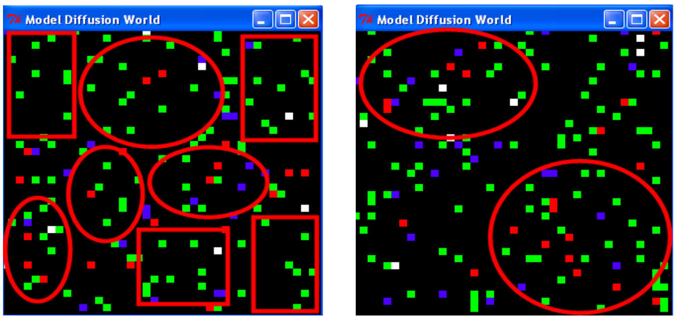
In order to obtain a better understanding related to the dynamics of the experiments, each of the hypotheses of this work is analyzed in this section.

4.2.1. First Hypothesis

"*The collective movement, created by agents that follow Rogers' innovation diffusion model, tends to direct followers to their opinion leaders*". In order to study this hypothesis the behavior of `Majority` and `Laggard` agents are analyzed.

The First Scenario

Figure 4 presents two situations that illustrate the `Majority` agents' behavior, related to the way that these agents follow their opinion leaders.



(a) Opinion Leader Agents Distributed in the Social Environment.

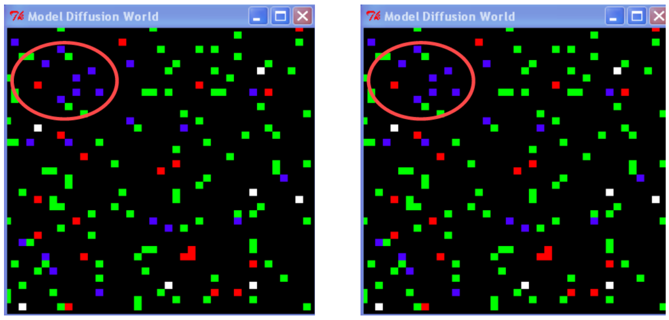
(b) Opinion Leader Agents Forming Clusters in the Social Environment.

Figure 4: The First Scenario: Visualization of the Majority Agents' Behavior.

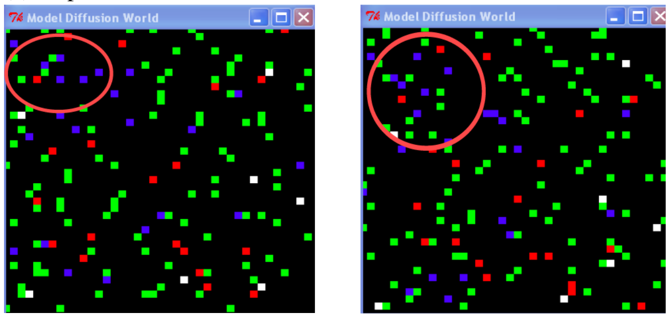
In Figure 4(a) the Opinion Leader agents (represented by red color) are more scattered in the Social Environment. The oval-circled areas emphasizes that, nearby the Opinion Leader agents, there is a substantial amount of Majority agents (depicted in green). Thus, it is clear that there is a pattern in which the Majority agents tend to follow the Opinion Leader agents. This result is consistent with the Rogers' diffusion model, which indicates that a large group of people follow a small group of leaders. Also, it is directly related to the Majority agents' characteristics, that tend to adopt positions held and disseminated by the opinion leaders.

In Figure 4(a), the Opinion Leader agents do not appear in the rectangle-surrounded areas. Thus, Majority agents tend to form clusters, because they look for areas with agents with a high degree of homophily. In Figure 4(b), the Opinion Leader agents are arranged in clusters, as highlighted by the oval-surrounded areas. It was noticed that the proximity to several opinion leaders led to an attraction of different types of followers, more specifically the Majority and Laggard agents. Since there is more than one leader, and they are all close, it is expected that different types of followers join them and increase the Opinion Leaders' social position. Another observation from Figure 4(b) is an increased presence of Laggard agents. This is partly explained by the fact that these agents are encouraged to follow a leader due to agglomeration of Majority and Opinion Leader agents.

Figure 5 illustrates the behavior of Laggard agents. In the surrounded-oval areas, in figures 5(a), 5(b) and 5(c), the Laggard agents (depicted in blue color) follow Opinion Leader agents (represented by red color). However, after a few steps the Laggard agents stop to follow the Opinion Leader (see Figure 5(d)). It is possible to conclude that Laggard agents act conservatively and with critical analysis, since they do not follow an opinion leader either unconditionally, or after several simulation steps.



(a) Step N. (b)Step N+1.



(c) Step N+2. (d) Step N+3.

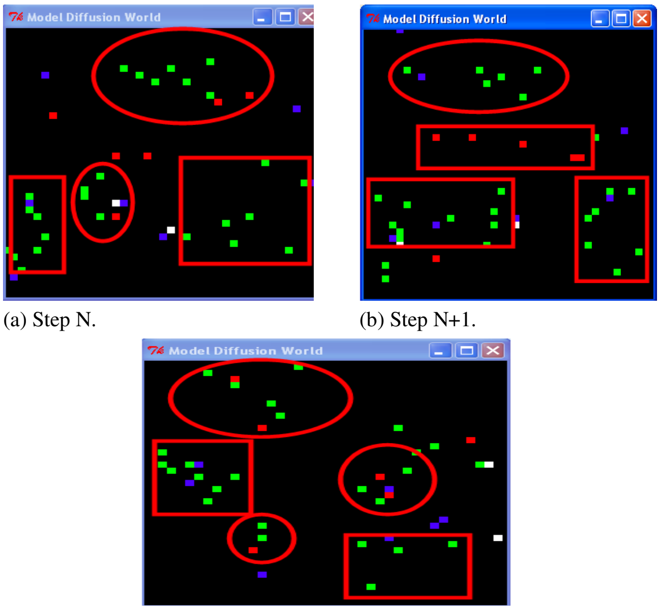
Figure 5: The First Scenario: Visualization of the Laggard Agents' Behavior.

The Second Scenario

The Figure 6 presents the agents' dynamics in a simulated environment with low population density. In Figure 6(a), the surrounded-oval areas indicate that Majority agents (represented by green color) follow their opinion leaders (represented by red color). This is the same behavior observed in the first Scenario, and it is clear that, indeed, Rogers' diffusion model represents adopter agents that follow their leaders.

In rectangle-surrounded areas, in figures 6(a), 6(b) and 6(c), the arrangement of clusters occurs. This result is more recurrent in second scenario because, in a low density, it is more difficult to find agents to change the quadrants' average homophily.

The Figure 6(b) shows the disposition of Majority agents clusters, due to the non-physical proximity with the leaders. Also, there are five opinion leaders forming a dividing line between the agents allocated on top, and agents allocated at the bottom of the Social Environment. This simulation stage is classified as an intermediate, in which the Majority agents are still organizing themselves to find the leaders, who have more affinity. After this step, in Figure 6(c) it is possible to observe that the opinion leaders are more scattered, and Majority agents begin to undo clusters. In fact, Majority agents clusters remain but with less elements. This happens because the leaders are more spread out, so they attract more groups of follower agents. At the end of the simulation, the Opinion Leader agents left their intermediate stage and became a part of more heterogeneous groups, as shown in Figure 6(c).



(a) Step N. (b) Step N+1.

(c) Step N+2.

Figure 6: The Second Scenario: Visualization of the `Majority` and `Laggard` Agents' Behavior.

In Figure 6(a), if the dynamics related to the `Laggard` agents are considered, it is hard not to notice the arrangement of large groups associated by their homophily. Therefore, these agents are dispersed. From the organization of `Majority` agents groups, shown in Figure 6(b), it is clear that `Laggard` agents begin to move around closeness. This is another result, also obtained in the first scenario, to indicate that the Rogers' diffusion model is robust in terms of scalarity.

Conclusions Related to the First Hypothesis

Based on the emergent behaviors, arising from the agents' interactions found in simulations of both scenarios, it is possible to conclude that the `Majority` and `Laggard` agents follow the `Opinion Leader` agents.

Each follower agent takes decisions based on its own characteristics, resulting in different behaviors in the innovation adoption process. Both agents (`Majority` and `Laggard`) aim to form clusters with the same type of agents. Also, they try to follow the leader with whom they identify. The `Majority` agents have low values for both scope and `groupCohesion` features (see tables 1 and 2, respectively). Thus, the `Majority` agents have a strong tendency to follow their opinion leaders. This happens because, according to Table 7, they have higher homophily with agents that have higher values for the scope and `groupCohesion` features. In turn, the `Laggard` agents also seek to be close to the `Opinion Leader` agents. But just do it (in most cases) when there is already different types of agents, such as `Majority` and `Opinion Leader` agents.

4.2.2. Second Hypothesis

"*Adopter agents follow their leaders differently, based on the features of each type of follower*". To examine this hypothesis, in each step of the simulation the following trace was done: the `Majority` and `Laggard` agents follow, or not, your opinion leader? It is worth recalling that each agent, in spite of its preferred leader, looks for a quadrant to move by choosing the area with the highest average homophily among the agents of its type.

The First Scenario

In the first and second scenarios, at each step of the simulation the average of the agents who followed their opinion leaders was calculated. In the first scenario these values are plotted in Figure 6, with the following structure: (i) the X-axis shows the simulation steps; (ii) the Y-axis shows the percentage of agents who followed their opinion leader, in each step; (iii) there are separate traces for each type of agent, `Majority` and `Laggard`, whose lines are represented by blue and orange color, respectively.

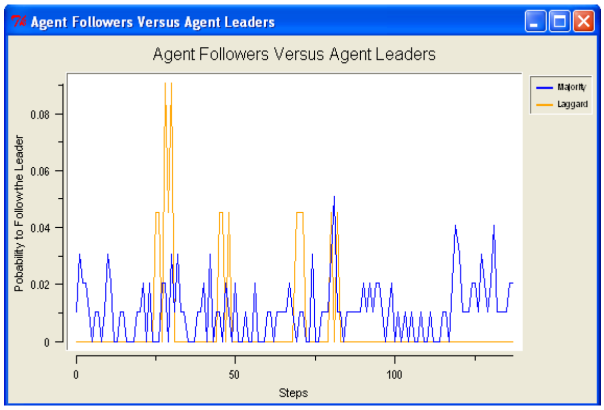


Figure 7: High Density Scenario: `Majority` and `Laggard` Agents' Innovation Adoption Patterns.

In Figure 7 it is possible to see that, from the start to the end of the simulation, the dissemination of innovation among `Majority` agents took place. These agents try to find out where are their leaders, and then follow this leader, as illustrated in the blue line. As there are many agents in the first scenario, it is expected a large oscillation in the dynamics related to the `Majority` agents, regarding how to follow their leaders. This is partially explained by the fact that, since in each step there are different averages of homophily in the quadrants, there is a frequent movement of these agents. Therefore, along all steps of the simulation, the `Majority` agents try to follow their leaders.

In Figure 7, the blue line indicates that the areas with low probability of `Majority` agents to follow their opinion leaders (the valleys) are punctual and almost instantaneous. After realizing that they are not following their leaders, these agents seek a quadrant that offers a better affinity with the agents of their type and, consequently, with their leader. Thus, the peaks are observed. Once found a quadrant that maximize their homophily, the `Majority` agents seek to move as close as possible to their leaders.

The orange line in Figure 7 shows that the `Laggard` agents follow the opinion leaders only at certain periods of the simulation. However, when these agents decide to adopt an innovation, they do together. These behaviors are observed in the same line, if it is analyzed the high probability peaks of these agents that follow their leaders.

The Second Scenario

The Figure 8 shows at the beginning of the simulation, the probability of `Majority` agents (represented in the blue line) follow their leaders is greater and more constant than in the previous scenario. Since the population is lower, in this scenario the tendency of maintaining clusters is greater. Observe that with fewer agents in the simulation, the trend to form distinct groups will decrease. Therefore, this feature makes the dynamics of `Majority` agents more effective in terms of finding their opinion leader.

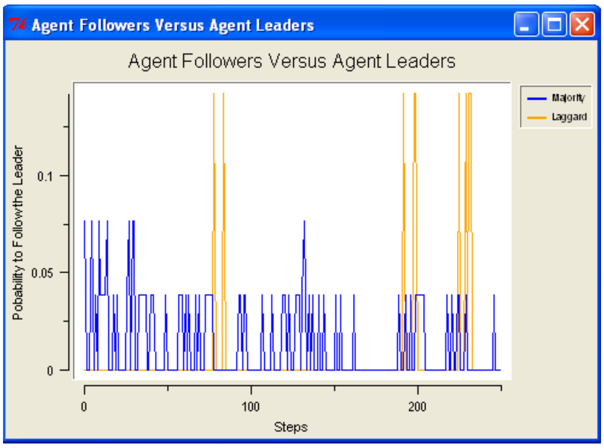


Figure 8: Low Density Scenario: `Majority` and `Laggard` Agents' Innovation Adoption Patterns.

Analyzing the orange line (see Figure 8), it is noticed that in the scenario with a lower population density, the `Laggard` agents also are more likely to follow their opinion leaders. This result points to the conclusion that smaller groups of adopters tend to make decisions with greater group cohesion. In other words, there is a greater mutual influence in the formed clusters.

Conclusions Related to the Second Hypothesis

The simulation results show that the adoption innovation process is different for each type of follower agent. Considering the elapsed time in the simulation, the `Majority` agents are quicker to adopt an innovation, and to follow their leaders for a long period. In turn, the `Laggard` agents take more time to decide to adopt an innovation. But once the decision is made, the entire group of `Laggard` agents tends to adopt together the novelty.

5. CONCLUSIONS AND FUTURE WORKS

In this paper a conceptual model for the diffusion of innovation phenomenon, based on the concepts of agent-based systems and on the Rogers' model theoretical ground (Rogers 2003) was proposed. The conceptual model was implemented as a simulation in the Swarm platform. Also, two scenarios were configured and simulated in order to verify the following hypothesis: (i) the interactions among agents lead the `Majority` and `Laggard` agents to follow the `Opinion Leader` agents, and (ii) the adopting agents follow their leaders in distinct ways.

According to the conclusions reached in the first hypothesis analysis, indeed the `Majority` and `Laggard` agents follow the `Opinion Leader` agents. In both scenarios this behavior can be observed. However, if the second hypothesis is considered, the simulation results show that the `Majority` agents are quicker to adopt an innovation, and follow their leaders for a long period. In turn, the `Laggard` agents take longer to decide to adopt an innovation. But once the decision is made, the entire group of `Laggard` tends to adopt together the novelty.

This work can be extended in the future to model even more realistic scenarios, including the diffusion of innovation in real-life situations. Some improvements could also be made on the agents' behavioral model, allowing them to react more realistically to the spread of innovation.

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