Simulations of Disease Dissemination Using the Vidya Multi-Agent Systems Platform

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Abstract. This paper simulates the dynamics of a virtual disease disseminated on a population made of intelligent agents (called Jivas) in the Vidya multi-agent system platform. Vidya was originally proposed as a strategy and god game in which one player is responsible for supplying "intuitions" to a Jivas' clan, aiming at helping it to survive in a complex and changing environment. This environment is inhabited not only by Jivas, but also by many other types of artificial lives that compete by natural resources. This combination of characteristics motivated us to use the Vidya game as a social simulation and multi-agent systems platform, where fairly complex social phenomena and strategies can be investigated. In a previous work the Vidya platform has been used to simulate egoism and altruism, revealing interesting coherent dynamics for artificially motivated social behaviors. In this paper we have incorporated in the Jiva's intelligent decision module one additional decision variable, which is the presence (or lack) of disease. Results obtained in simulations have shown emergent change in social behaviors of Jivas' social aggregation, mostly related to the disease contamination and dissemination. We argue that this platform may be considered in the future as a test bed for plausible agent-based social simulations that might be used for supporting public policies in heath care and other relevant social areas.

Keywords: Agent-based social simulation, Disease dissemination simulation, Vidya, Heath care, Multi-agent system, Evolutionary computation.

1 Introduction

Scientific investigation of social phenomena is widely known as a hard task to be performed. Since reproducibility is almost impossible in such domain, there are no precise and complete mathematical models that are able to formally describe those phenomena. The very unlikely existence of a real controlled environment is a major experimental limitation. Besides that, some mathematical models were proposed as attempts to capture the essence of some social behavior, like the Neumann and Morgenstern's Game Theory [1]. However, the majority of these models are not always based on true or falseable premises (*e.g.* Game Theory considers perfectly rational players).

In the quest for reliable experimental alternatives for social sciences, we highlight the increasingly use of modeling and computer simulations in the field. Artificial social environments, besides the fact that real social environments are much more complex, supply an effective test-bed to understand and explore social phenomena. These types of computational applications are commonly referred as social simulations [2] [3]. A well-performed social simulation can be considered a reasonable approximation of the real phenomenon, with the advantages of flexible representation *in silico*, possibility to incorporate new features of the problem at any time, ability of forecasting future steps of the simulation and easily changeable control policies. To name just a few, applicability of social simulations are in public policies, management, and financial.

A class of computational modeling that has been widely explored in social simulations is the one in which individuals are instantiated from agents' models. These kinds of social simulations are known as agent-based social simulations (ABSS) [4]. There are many advantages in using agent-based models instead of analytical ones [2]. For example, agents can be heterogeneous, rules of interaction can be local and multi-dimensional spaces can be assumed.

Vidya was originally proposed as a strategy and god game in which the human player is responsible for supplying "intuitions" to Jivas' clans, aiming at helping them to survive in a complex and adaptive environment [5]. This environment is inhabited not only by Jivas, but also by many other types of artificial lives that compete by natural resources. This combination of characteristics motivated us to use the Vidya game as a social simulation and multi-agent systems platform, where interesting social phenomena and algorithms can be studied. In a previous work the Vidya platform has been used to simulate egoism and altruism, revealing interesting coherent dynamics for artificially motivated social behaviors [6].

In this paper we have incorporated in the Jiva's intelligent decision module one additional decision variable, that is the presence (or lack) of disease. Jivas are labeled with respect to its health (whether it is sick or not). This has an impact in its reputation and, consequently, the decision of others. The concept of Jivas' reputation abstracts a symbolic asset shared by the artificial society that partially guides its social behaviors. We observed in a previous work that reputation is an efficient mechanism for regulating open simulated societies [6]. Others researches also confirm this assertion [7][8].

There is a great variety of applications for ABSS systems. In this paper, we investigate the relevant problem of simulating the dynamics of disease dissemination on a population of agents using the Vidya ABSS platform. We have not focused on any specific transmissible disease. In addition to others social simulators that have already been used to simulate epidemics [9], this work aims solely at showing the ability of an ABSS platform such as Vidya in simulating contamination dynamics, as well as a candidate tool for providing insights to public policies..

Section 2 gives further explanations about the Vidya simulator. Section 3 explains how we have extended the Vidya platform to simulate disease dissemination. Section 4 presents the experiments carried out and the obtained results. Finally, section 5 concludes the paper and points out works that are in progress and other prospective ones.

2 The Vidya Multi-Agent Systems Platform

Vidya is an ABSS system that allows simulations of “primitive behaviors” of cognitive agents. By primitive behaviors we mean that they are directly responsible for the survival of agents, including searching food, eating, drinking, compete with each others and so on. The whole set of behaviors also consider the social ones, like the formation of clans, coercion-based leadership, formation and dissemination of reputations.

Subsection 2.1 explains the original Vidya application and some of its technical details. Subsection 2.2 highlights the extensions of the Vidya that make it an ABSS platform.

2.1 The Vidya Game

Vidya was initially designed to be a single-player strategy and god game, made of a world where virtual beings, such as sheep, wolves, cows etc., compete for available natural resources within a simulated ecosystem (see Figure 1). Among the many types of artificial lives that inhabit the virtual world, there is a special one called Jiva. Jivas are intelligent agents designed to be autonomous and to survive against all odds, whose actions are devised through evolutionary computation [10].

Figure 1. Screenshot of the Vidya game.

In the game mode of Vidya, two clans of Jivas dispute the supremacy in the game world. One of these clans obeys the player’s instructions. The player is invited to be the clan’s Deva (*i.e.* the clan’s god) – the one who provides guidance to the clan members. The intelligence of Jivas evolves over time and increases their knowledge about the world.

The task of the Jiva's intelligent decision module regards deciding the best action to be performed. This is achieved through genetic algorithms [11]. Actions are single-mapped to individuals (or chromosomes) of the GA population. The Jiva has a large set of available actions that can be performed, thus an exhaustive search for the best action can be very time consuming. By using GA, we narrow down the search space and the choices converge towards the best action with few generations.

The Jiva's perception consists of a set of world objects and their characteristics such as type and positioning relative to the Jiva. Next, the Jivas will select a good action considering all perceptive information. An action is defined as the destination cell to which the Jiva will move. Thus, we characterize an action by a coordinate pair (x, y), meaning that the Jiva will move to that position in the next time step, as shown in Figure 2.

Figure 2. Destination cell to which the Jiva will move. Note that there is a fruit highlighted at the destination, suggesting that Jiva may want to eat it.

When evaluating an action, the GA might care not only about its immediate cost, but also infers its long-term cost. The selection method used to choose pairs of actions that will crossover is the roulette wheel [12]. Pairs of actions are then selected and crossed-over, producing new actions that will comprise the next generation of the actions set. The mutation operator is also applied to the actions set. The mutation probability was arbitrarily set to 1/32, that is, on average, for every 32 actions one is likely to undergo mutation.

Initial experiments of the Vidya game have demonstrated that the best parameter setting is 192 chromosomes in the population and the ability to produce long term evaluation of only two steps in the future [5]. This setting is a compromise between the Jiva's intelligence and the computational performance of the algorithm.

2.2 Vidya as a Social Simulation Platform

The whole set of Jivas represents a society. This simulated society is an open multi-agent system, with the following restrictions: (*i*) it does not possess any kind of macro-level behavior control for promoting order and (*ii*) overall order emerges from the autonomous behaviors of individuals. Three specific social behaviors were added to the Jivas for implementing the above mentioned local order mechanism. They were: (i) reputation formation based on egoistic and altruistic actions of others; (ii) clan creation ability; (iii) coercion contexts based on leadership. Note that (ii) and (iii) are dependent of item (i).

A Jiva perceives other Jiva as egoistic or altruistic if the former benefits or not when in the presence of the latter, respectively. In addition to the Jiva's reputation be related to its selfishness, it is also related to its intelligence level, here indirectly ascribed by its vital condition (*i.e.* including vitality, energy, and hydration levels). Thus, the Jiva's reputation is increased if it becomes less egoistic and more intelligent.

In the Vidya social simulator, reputation is directly related to the egoistic and altruistic behaviors of the Jivas. Each Jiva store its opinion about all known Jivas and clans. This reputation is then communicated to others known Jivas, as well as it is received from them. The consideration of communicated reputation is also dependent on the communicator's reputation.

A Jiva tries to form a clan with other Jivas only if the former benefits somehow by the latter. If the benefited Jiva already belongs to a clan, he sends an association invitation to the other. In contrast, if the benefited Jiva does not belong to a clan, he sends a clan creation invitation to the other. The invitations to other Jivas, as well as the decisions of accepting and creating clans are highly dependent on the reputations of all Jivas involved.

A Jiva has an innate tendency to follow the actions performed by leaders. A leader is perceived as a Jiva of the same clan that possesses the greatest reputation. The Jiva's sociability will define how many others he considers influential to his own decisions. These kinds of social relations form coercion contexts, base for leadership. The leader Jiva is not influenced by other perceived Jivas, but distributes tasks to them based on their reputation. Jivas with higher reputations are designed to perform the most important tasks.

3 Simulation of Disease Dissemination in the Vidya Platform

We have used the Vidya ABSS platform to simulate the dissemination of a generic contagious disease with particular properties. The experiments aimed at validating the use of the Jiva's intelligent decision module with real problems, in this case, related to health and epidemics dynamics.

The two attributes added to each Jiva were: (*i*) a sickness label – that informs to others whether the Jiva is healthy or sick; (*ii*) contamination level – inform to others the contamination level of the sick Jiva. When an individual Jiva is sick, its vitality is decreased more rapidly, this also depending on its contamination level.

When Jivas encounter each other, they can disseminate disease if at last one of them is sick. The probability of disease transmission was proportional to the contamination level of the sick Jiva and if the other involved Jivas are of the same clan – meaning closer relation – it also increases the transmission probability. When all involved Jivas are sick they can increase each other's contamination level.

Jivas can cure their diseases by drinking water and/or eating fruits. These resources decrease the contamination level of a sick individual, and when their contamination level reaches 0 (zero), they are cured. In current simulations we did not considered any sort of immune memory. Therefore, a Jiva may be re-contaminated following the same above-mentioned probabilities.

As an important feature of the present set-up, contamination decreases substantially the vitality of Jivas; and they will decrease the reputation of all those involved in the contamination. This characteristic is orthogonal to the one that causes vitality losses, but indirectly reflects on the reputation of sick Jivas. Thus, is not strange that sick individuals possess lower reputations values. In the next section we investigate, through experimentation, the impacts of disease dissemination on the overall reputation and formation of clan involving sick Jivas.

4 Experiments and Results

The experiments carried out aimed at verifying the macro-level behavior of a society of Jivas facing a disease dissemination dynamics on the population. We are particularly interested in analyzing the influence of Jivas' health on the Jivas' aggregations, that is, what is the impact of the Jivas' health on the formation of clans. Therefore, three classes of data were analyzed: (*i*) disease dissemination dynamics; (*ii*) influence of disease on reputations; (*iii*) influence of disease and reputation on formation of clans.

The virtual world had 22500 cells distributed over a grid of 150 by 150. The world had 25 Jivas, of which 20 were healthy and 5 were sick. Obviously, at the end of simulations the number of Jivas has changed, since some of them may have died. Relative to the others elements of the simulated ecosystem, we have the following initial configuration: 7 sheep, 5 plants, 15 fruits, 10 trees, 5 wolfs, 5 cows, 10 water fonts. Similarly to the number of Jivas, the number of some of these components will be probably different at the end of simulation. The Jiva's intelligent decision module used a GA with optimal configuration according to previous work [5], which is 192 chromosomes and 2 generations ("steps seen ahead in the future").

Overall, we performed 20 executions, each one of 10 minutes, in a PC Pentium IV, 512 MB of RAM. We selected the 5 more representative executions based on the disease dissemination dynamics. The time 10 minutes was deemed to be sufficient to observe convergence or divergence in the disease dissemination process.

Obviously, the disease dissemination dynamics followed the particular characteristics of the simulated disease. In our case, we simulated a new and generic disease that is disseminated via superficial contact among individuals and treated through ingestion of water and fruits.

Figure 3 shows the percentage of sick individuals over time. In the executions where a stable configuration is reached (*i.e.* executions 1, 2 and 4) we verify two peaks of sick individuals' growth. The first peak is commonly stronger than the second, suggesting a periodic decreasing behavior. The first peak seems to be determinant for convergence or divergence of the disease dissemination process.

Executions 3 and 5 show divergent behavior for disease eradication and dissemination, respectively.

Figure 4 shows the average of contamination level of sick individuals over time. Notice the similarity in respect to disease stability with the executions of Figure 3, showing a direct relation between the number of sick individuals in a population and the contamination level of the current population.

Figure 5 shows the reputation average of healthy individuals over time. Notice the low values of reputation average of healthy individuals in execution 3, indicating that the simulated society is less selective in the presence of a large number of sick individuals. As reputation is also related to the egoism and altruism of individuals, this might suggest that in execution 3, where the percentage of sick individuals is large, the social pressure over the selfish individuals is weakened.

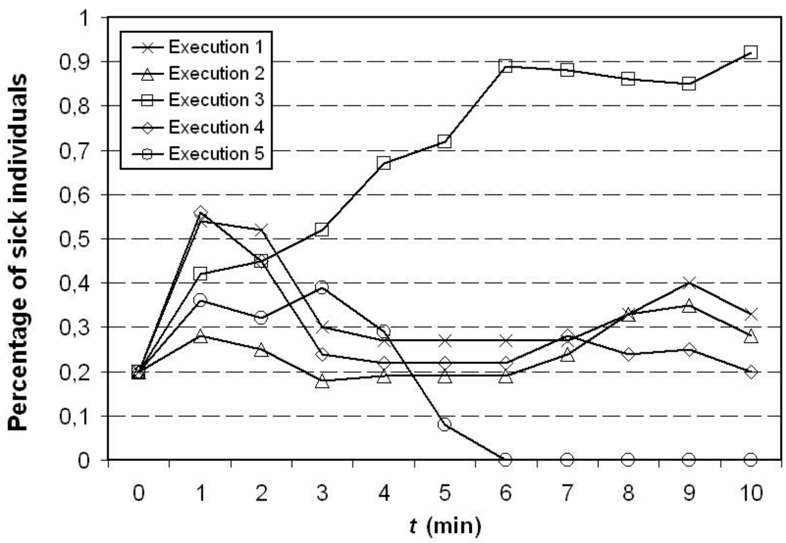

Figure 3. Evolution of percentage of sick individuals over time. All executions were initialized with 20% of sick individuals.

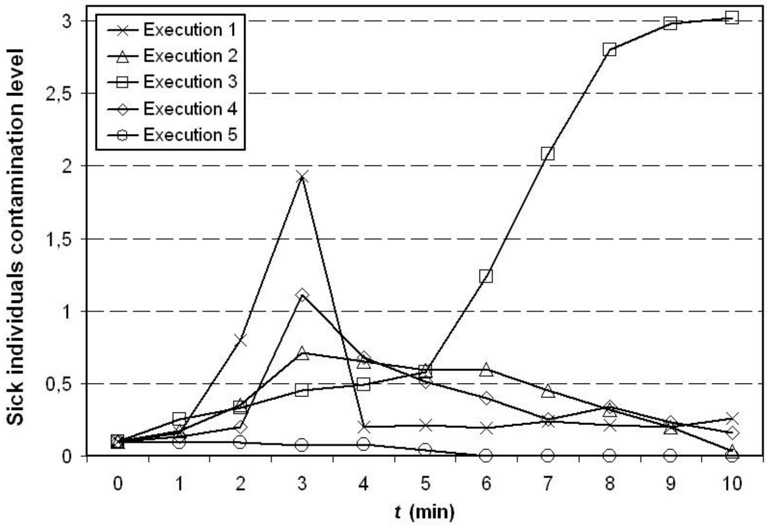

Figure 4. Evolution of contamination level average of sick individuals over time.

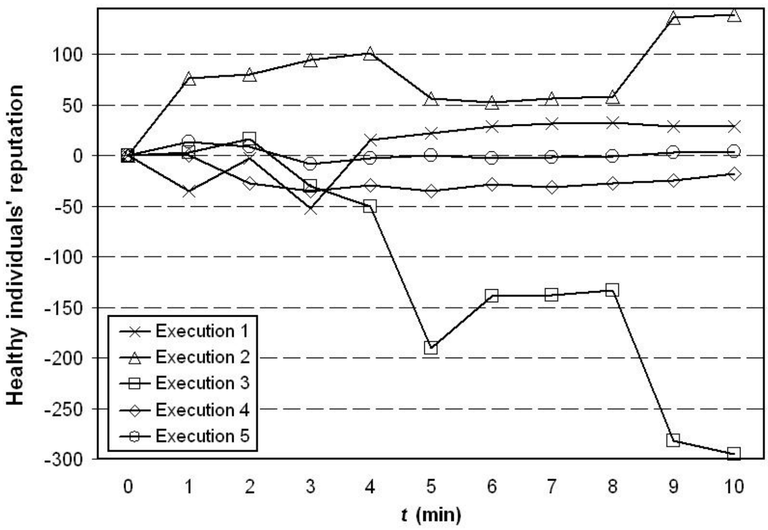

Figure 5. Evolution of reputation average of healthy individuals over time.

Figure 6 shows the reputation average of sick individuals over time. Here, we can see very clearly a social exclusion of sick individuals expressed as very low values of reputation. This is obviously coherent with the health problems after associations with sick individuals. Execution 3 shows the greatest contrast between reputations of healthy and sick individuals. Execution 5 had sick individuals until 5 minutes, after which all population became healthy.

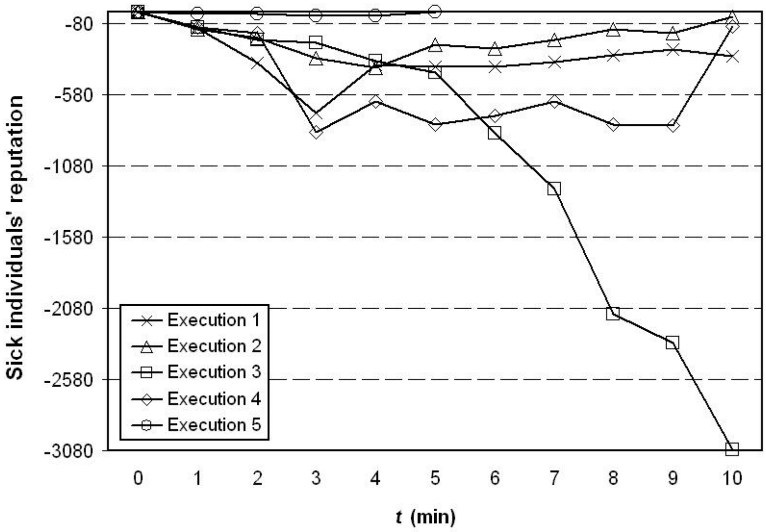

Figure 6. Evolution of reputation average of sick individuals over time.

Table 1, Table 2 and Table 3 show the number of healthy and sick individuals per clan for executions 1, 2 and 4, respectively, at 3 minutes of simulation; this is the immediate time after the first peak time where the number of sick individuals usually stabilizes and we observe the formation and stabilization of clans. Notice aggregations influenced by health of individuals and social exclusion of sick individuals that became without clan (*i.e.* in "No Clan" row).

Table 1. Number of healthy and sick individuals per clan for execution 1 at 3 minutes.

	HEALTHY	**SICK**
Clan 1	14	0
Clan 2	0	4
Clan 3	0	1
No Clan	0	1

Table 2. Number of healthy and sick individuals per clan for execution 2 at 3 minutes.

	HEALTHY	**SICK**
Clan 1	0	3
Clan 2	14	0
Clan 3	3	0
No Clan	0	1

Table 3. Number of healthy and sick individuals per clan for execution 4 at 3 minutes.

	HEALTHY	SICK
Clan 1	5	0
Clan 2	8	0
Clan 3	0	2
Clan 4	3	0
No Clan	0	3

Table 4 shows the number of healthy and sick individuals per clan for execution 3 at 3 minutes of simulation. This execution produced a large number of sick individuals. Even so, there is a clear influence of health on the aggregations and social exclusion of sick individuals. As the number of sick individuals is very large, there is an inevitable mixture of healthy and sick individuals (Clan 1), but as the Jivas' decisions are based also on contamination level of others, there is also a selection pressure in this sense. The contamination level of sick individuals of the Clan 1 is 0.02, which is relatively a very low value.

Table 5 shows the number of healthy and sick individuals per clan for execution 5 at 3 minutes of simulation. As the average contamination level of sick individuals is very low (0.07), there is a weak aggregation selection pressure based on health.

Table 4. Number of healthy and sick individuals per clan for execution 3 at 3 minutes.

	HEALTHY	SICK
Clan 1	10	6
Clan 2	0	1
No Clan	0	4

Table 5. Number of healthy and sick individuals per clan for execution 5 at 3 minutes.

	HEALTHY	SICK
Clan 1	2	0
Clan 2	4	3
Clan 3	0	1
Clan 4	3	2
Clan 5	0	1
No Clan	2	0

5 Conclusions and Future Work

This paper presented an extension of the Vidya multi-agent platform for simulations of disease dissemination on a population. The Vidya environment has the limitation of simulating societies of intelligent agents on a very primitive symbolic level, with action of agents based on their basic needs for survival.

The obtained results, besides not directly applicable to more culturally developed societies, shows the consistence of the cognitive agent's model used. Considering that this model is context independent, we can introduce aspects of more complex societies .

During simulations, we observe two peaks of sick individuals, the first one – the strongest – was found determinant for convergence in the process of disease dissemination. For the generic disease simulated, with its particular characteristics, the number of sick individuals increases substantially with the increasing of the contamination level of remaining sick individuals.

In respect to the reputation of healthy and sick individuals as function of disease dissemination, we observed that the increasing number of sick individuals reduce the selective pressure over selfish individuals. This means that reputations becomes dominated by health factors and not so by egoism and altruism of individuals (*i.e.* losses are diminished if agents prefer to relate with egoistic individuals as opposed to relate with the sick ones).

In executions 1, 2 and 4, where the percentage of sick individuals stabilized, we could observe the clear influence of individuals' health on social aggregations (*i.e.* clans). Sick individuals are biased to aggregate with each other, the same happening with healthy individuals. Very sick individuals are socially excluded (*i.e.* they became not associated to any clan).

When the number of sick individuals is large (*i.e.* the scenario of divergence in execution 3), mixture of healthy and sick individuals is inevitable, and selective pressure (based on reputation) is refined by variations on the contamination level of individuals. Therefore, clans of low and high contamination level are created.

When the number of sick individuals is small, the population average level of contamination is equally small, resulting in a mixture of healthy and sick individuals without a strong selective pressure in this sense. In this scenario, the selective pressure remains based on egoistic and altruistic characteristics of individuals.

All these observable results motivate us for pursue on future development of more plausible social simulation environments based on cognitive agents to support decision-making in public policies. These may be used in many social contexts and problems, mainly health care. Future works include the consideration of genetic and cultural evolution elements [13][14], producing more reliable social simulations by approximating them to real societies.

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