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OPINION FORMATION AND SELF-ORGANIZATION IN A SOCIAL NETWORK IN AN INTELLIGENT AGENT SYSTEM

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Intelligent agent systems are relatively new approach to modelling social phenomena. In particular, such systems are descriptions and simplified representation of human interactions occurring in real world. In the paper, a model of intelligent agents system, in which the agents interact with environment and change their opinions as a result of mutual contacts, is presented. A network of inter-agents contacts was constructed to investigate the process of self-organization in the system resulting from agents motion and their opinion formation. The relations between the properties of this network, properties of environment and opinion formation rules were discussed. It is worth noting that in contrast to other papers, we examined two general threads studied so far separately: opinion dynamics of autonomous agents, and the relation between agents and resources distribution in the environment.

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1. Introduction

The subject of intelligent agent system is a relatively new, still developing topic, based on the knowledge from fields such as: computer science, physics, sociology, biology or chemistry. In the last few years, intelligent agent systems [1] have become a powerful tool for studying phenomena occurring in the human societies. This kind of systems refers to a particular type of simulation, where moving agents situated in some environment with assumed properties, are considered. Both — agents and the environment — are described by the set of simple rules. An intelligent agent is an autonomous entity which perceives its environment and may have impact on it. Moreover, agents have control over their own behaviour to a certain extent, including deciding about direction of motion. Interactions of agents occur in two ways:

— directly by the environment in which they are set (agents observe resources in the environment and change it);

— indirectly through interactions with each other.

The subject of intelligent agent system was presented in many different papers in the field of sociophysics and social science. An example is "Sugarscape" model proposed for first time by Epstein and Axtell in 1996 [2, 11]. Authors present a model where a heterogeneous population of autonomous agents compete for renewable resources distributed over a 2-dimensional grid. The "Sugarscape" scenario can be modified in many different ways by introducing into the model: opinion dynamics, pollution, diseases trade, markets or different additional resources. This property of the model makes it possible to use it in different fields of science like social or economic sciences. Other model proposed by Epstein in 2002 is a model of civil violence [3, 4], where agents (called here citizens and police officers) are placed on a square lattice grid. In the paper, two variants of civil violence model were proposed: (1) a central authority seeks to suppress decentralized rebellion; (2) a central authority seeks to suppress communal violence between two fighting ethnic groups. In earlier works, the subject of using environment of agents to build social network was presented. For example, in paper [11] authors present model in which social network changes over time due to the allocation and redistribution of resources. Presented model allows: to add new links between nodes and to remove outgoing links. Also, the subject of population of agents in a changing environment was studied (see [12]). In this paper, modelling biological evolution of agents was presented. Authors, using numerical simulations, try to determine the fate of a population, that at the beginning is adapted to a given environment and after certain time the conditions change for the worse. Unlike to papers mentioned above — in our model, the processes of opinion formation and self-organization in a social network for population of agents in a changing environment were examined. The changing environment and mutual contacts of agents (involving the exchange of opinion according to bounded confidence model) was used to construct social network.

For modelling opinion formation, in our model we used simplified version of Deffuant Model [5, 6], where new opinion of interacting agents is the average value of their opinions before the discussion. Deffuant Model is based on a compromise strategy. It means that, after a constructive debate, the opinions of the interacting agents get closer to each other. Most results on Deffuant dynamics are derived through numerical simulations and there are three possible distributions of final opinions: one cluster of opinions (consens), two clusters of opinions (opinion polarization), more than two clusters (opinion division). In this point, it is worth to mention, that in the special case, Deffuant Model is analytically solvable for $\varepsilon = 1$, $\mu = 0.5$ (where μ is called convergence parameter, and its value lies in the interval $[0, 1/2]$) and for fully mixed population where everybody interacts with everybody else [14]. Furthermore, since the publication of Deffuant Model, the general properties of the model were examined. For example [15, 16], it was shown that for the agents located in the networks with the topologies: complete graphs, regular lattices, random graphs and scale-free networks, for $\varepsilon > 1/2$, all agents tend to the same opinion, so the complete consensus in the considered population is reached. For $\varepsilon < 1/2$, more clusters of opinion emerge. In order to obtain more information about the time evolution of opinions, an order parameter based on the number of interfaces in the network was introduced. Based on this parameter, it was found that for the Barabási–Albert networks, near $\varepsilon = 0.22$, phenomenon similar to the phase transition is observed [10]. Moreover, in the Monte Carlo simulations it was shown that for ε value from interval $(0; 1/2]$, the number of clusters n_{c} can be approximated by equation $\frac{1}{2\varepsilon}$ in the stationary state.

In this paper, we have considered a model of intelligent agents system in which the agents interact with environment and change their opinions as a result of mutual contacts. Agents move in a rectangular grid consisted of cells with different levels of resources — necessary for the life of agents. Level of resources can be treated as a determinant of the standard of agents life. During motion of agents, resources are consumed by agents. Resources are renewed with the defined intensity n which depends on the initial state of the system. In each time step, an agent moves to one of neighbouring cells which are in its range of vision defined with the parameter d. Agents have also an opinion represented by the variable $x_i(t)$. According to bounded confidence model [5, 6] the pair of neighbouring, random chosen agents i and j may change their opinions, provided the difference between $x_i(t)$ and $x_j(t)$ is less than a threshold value ε.

The paper is organized as follows. In Sec. 2, a description of the intelligent agent system, where agents interact with environment and change their opinions in accordance with the rules of the bounded confidence model is presented. In Sec. 3, a network formed during the time evolution of the system of inter-agents contacts for different parameters of the model was constructed. It enables to investigate the process of self-organization in the system resulting from agents motion and their opinion formation. Some general conclusions are given in Sec. 4.

2. The model

We considered a model of intelligent agents system, where there are four kinds of rules concerning: environment, agents, opinion and social network. In our model, agents move in a rectangular grid consisted of cells with different levels of resources, necessary for agents survival. Furthermore, agents have the set of characteristics and rules governing its behaviour. For example: opinion (represented as a continuous variable), metabolism level (rate of resources consumption per one time step) or range of vision (how far they can see). In our model, each cell can be occupied by only one agent. During the time evolution of the system, each agent can move in the environment, meet other agents (according to Von Neumann neighbourhood) and exchange their opinions as a results of the properties of the environment and mutual contacts. This kind of interactions are very interesting from the point of view of the social networks and the social sciences. It is worth noting, that in the presented model, there is no initial network of contacts between agents. For a better understanding of the processes occurring in the population of agents and their opinion formation, social networks formed during the time evolution of the system were examined. A detailed description of the rules used in our model is given below.

2.1. Environmental rules [E_n]

— square lattice grid (50×50) specified for each location (x, y);

— resources in the environment can be treated as determinants of the standard of life of agents *i.e.* economical, social and cultural aspects of life;

— in the cells there are different levels of resource r, ranging from 0 to 4 (see Fig. 1);

— higher level of resource in the cell results in higher standard of life for the agent occupying the cell. Below, for convenience, the resource is called sugar;

— in the time evolution of the system, the level of resources in each cell is renewed with the intensity n units per one steps to the capacity at that position (where $0 < n < 4$);

— boundary conditions: reflecting.

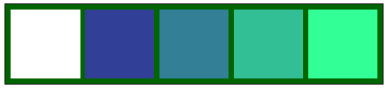

Fig. 1. Different levels of resource r, from left to right ranging from 0 to 4.

2.2. Agent movement rules [M]

— in each time step, an agent look around and its vision have the range d in four directions: up–down, left–right (see Fig. 2);

— each agent in his range of vision identifies the cell which is not occupied by other agent, has the highest level of sugar, and moves in its direction;

— in each time step, an agent demands p portions of sugar. This can be called metabolism level and is a parameter of the model;

— each agent can carry 25 portions of sugar, it is also the initial amount of sugar assigned to each agent;

— each agent collects all sugar located in the cell which he has reached.

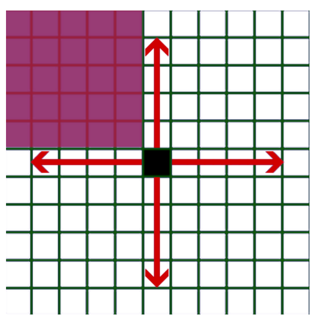

Fig. 2. Range of vision of agents. Agents can only see in four direction: north, south, east and west. Intermediate directions are forbidden.

2.3. Agent opinion rules [O]

— each agent has an opinion represented by the variable $x_i(t)$ with the values lying in the range between 0 and 1;

— in each time step, an agent can exchange opinions with one of his randomly chosen neighbours [5]. The opinions of the pair of agents (i and j) in the time t, are represented by $x_i(t)$ and $x_j(t)$. As a result of their discussion, opinion of the agents may change, if $|x_j(t) - x_i(t)| < \varepsilon$, where ε (bounded confidence) is a threshold value from interval [0, 1]. Their new opinions are [5–10]

$$x_i(t+1) = x_j(t+1) = \frac{[x_j(t) + x_i(t)]}{2}\,.$$

2.4. Parameters used for the description of a self-organization in a social network

— the number and the locations of agents with initial opinions in a rectangular grid represented with the number of nodes;

— the properties of the network depend on the properties of the environment and the interactions between agents;

— the network of contacts between agents. New links are added to the network only in the time when the exchange of opinions between agents occurs.

3. Results and discussion

In the first case, we have examined the processes of migration of agents, their opinion formation and self-organization in the system of $N = 130$ agents with the rules $[E_1]$, $[M]$, $[O]$. Agents are located in the environment with heterogeneously distributed resources (see Fig. 3). Initial state of the system, shown in Fig. 3 (a), was used for all simulations. Area located near the left lower corner is the "poor" area with $r = 2$ and opinions of agents from interval $[0, 0.2]$, area located in the upper part of the picture is the "rich" one with $r = 4$ and opinions from interval $[0, 1]$ (in relation to the areas where the agents are located, in the "poor" areas agents have lower

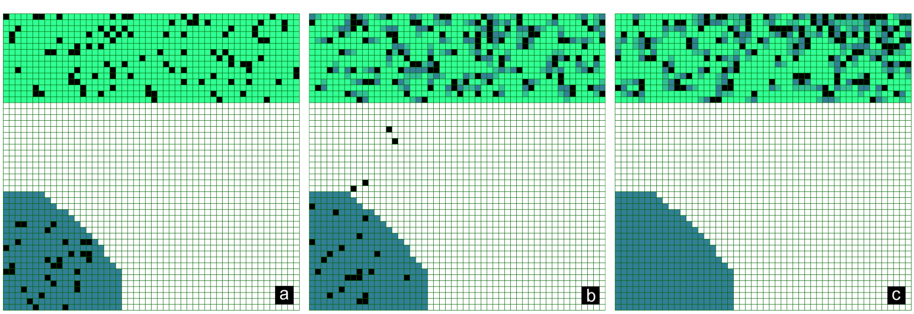

Fig. 3. Time evolution of the $N = 130$ agents with the rules $[E_1]$, $[M]$, $[O]$; (a) initial state of the system; (b) migration of agents; (c) last stage of simulation, all agents are in the rich area.

range of opinion, on the other hand, in the "rich" one, agents have the full range of opinions). These areas are separated by the desert area with $r = 0$ (agents try to avoid this area).

For the first simulation, we used the following parameters of the model:

— $p = 1$ (metabolism level); it means that each agent consumes one unit of sugar per time step;

— $d = 30$ (range of vision). The value of the parameter $d = 30$ allows the agents from the "poor" area to see upper "rich" area, thus the migration process is possible;

— $\varepsilon = 1$ (bounded confidence); it means that we have considered population of open-minded agents (exchange of opinions between interacting agents always occurs).

For $t = 2000$, simulation was stopped — all agents share the same opinion $x = 0.3$ (one cluster of opinions — consensus was obtained) — see Fig 4 (a). As we can see, as a consequence of migration process, average value of opinion decreases slightly in time as a result of the influence of agents arriving to the "rich" area and coming from the "poor" area, where the agents opinions are lower. In the population of agents under consideration, the group of permanent emigrants was observed. Agents from the "poor" area after the migration process will not return to the areas where they were in the initial state of simulations — those agents establish their permanent residence in the upper "rich" area (unidirectional migration of agents). It is an interesting result which is also observed in the real processes of people migration.

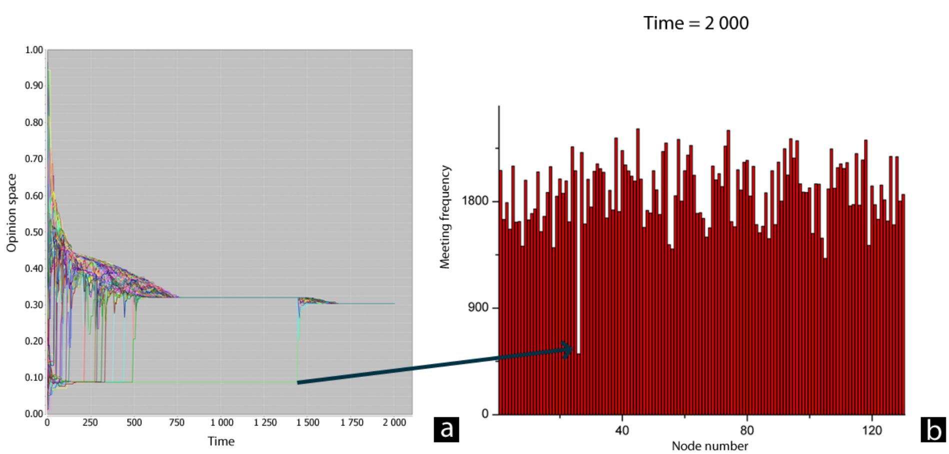

Fig. 4. Time evolution of the system for $\varepsilon = 1$; (a) opinion formation in the agents system; (b) meeting frequency of agents. Last emigrant with the lowest value of frequency of meetings was marked.

For time values from interval $[0, 2000]$, the dependence of the meeting frequency as a function of node number (Fig. 4 (b)) and social network formed during the time evolution of the system (Fig. 5) was shown. Figure 4 also shows last emigrant with the lowest value of frequency of meeting. Properties of this agent are caused by a relatively smallest number of contacts with other agents (see Fig. 4 (a)). Approximately at the time $t = 1400$ migration of the last agent was observed.

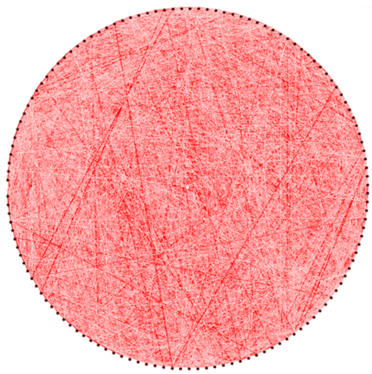

Fig. 5. Social network formed during the time evolution of the system. It is a result of the properties of the environment and the interactions between agents.

Figure 6 shows degree distribution for social network formed during the time evolution of the system for different values of time. Degree distribution for $t = 2000$ represents a social network from Fig. 5. As we can see, for this case, all agents are "open-minded" and for time $t \to \infty$, the social network tends to complete graph.

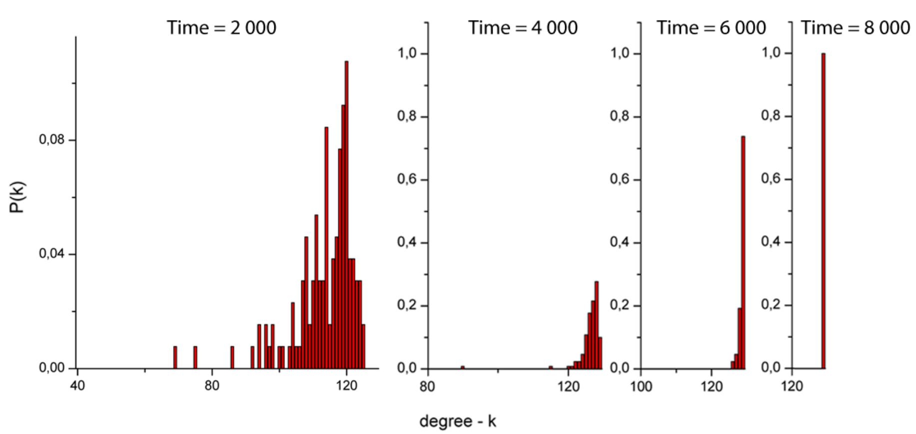

Fig. 6. Degree distribution for social network formed during the time evolution of the system for different values of time. For $t \to \infty$, network tends to complete graph.

In the next case, we considered population of "closed-minded" agents, where bounded confidence $\varepsilon = 0.1$. We used here the same configuration of environment as in the previous case (Fig. 3), also the parameters of the model like metabolism level, range of vision, agents movement, opinion and environment rules are the same. Opinion dynamics for this case was shown in Fig. 7 (a).

As we can see, for the time $t = 2000$, the division of opinion is observed. At the end of simulation, when all agents reach "rich" area, five groups of agents having five different opinions were formed during the time evolution of the systems. Moreover, one agent with extremely isolated opinion (agent with constant value of opinion in time) was marked (see Fig. 7 (c)). If we compare the dependencies shown in figures 7 (b) and 4 (b), we can see, that with decreasing value of ε, decrease the values of meeting frequency of agents and average values of degree of the nodes (see Fig. 8). It means that, in the cases of "closed-minded" agents, less connections between nodes are generated.

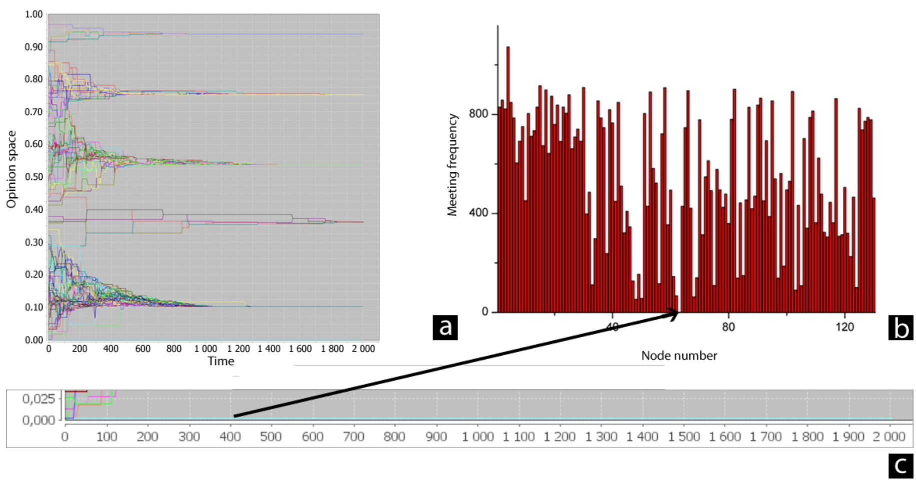

Fig. 7. Time evolution of the system for $\varepsilon = 0.1$; (a) opinion formation in the agents system; (b) meeting frequency of agents; (c) shows in detail the agent with extremely isolated opinion. The scales in the both axes are magnified.

In the next simulation, we have examined the process of agents opinion formation for the cases of "close-minded" agents (bounded confidence $\varepsilon = 0.1$) and the smaller value of range of vision $d = 5$. Initial state of the system is shown in Fig. 3 (a). During the time evolution of the system all agents move randomly in the area where they were initially located — the process of migration does not occur in this case. For agents located in the "poor" area, more connections between nodes and higher values of meeting

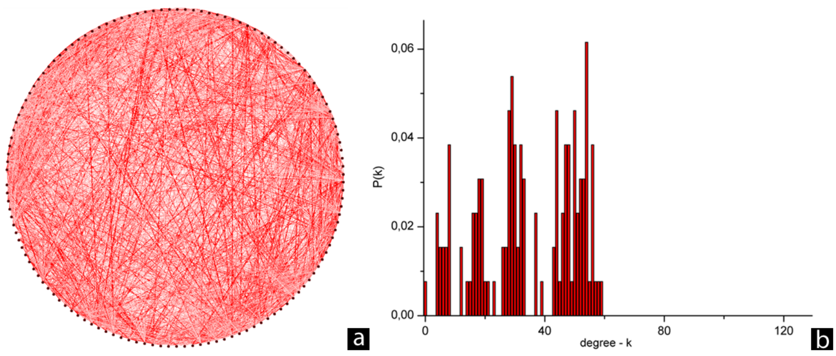

Fig. 8. (a) social network formed during the time evolution of the system; (b) degree distribution for social network presented in the left part of the picture.

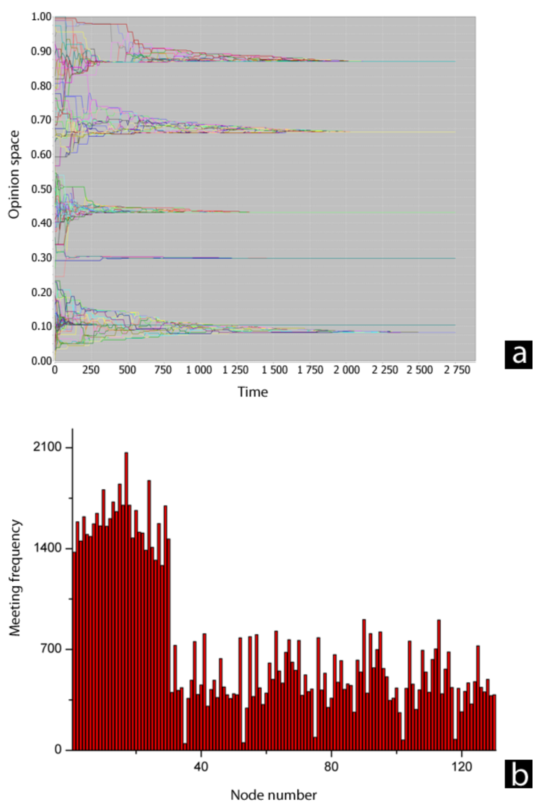

Fig. 9. Time evolution of the system for $\varepsilon = 0.1$; (a) opinion formation in the agents system. The division of opinion in the last stage of simulation is observed; (b) meeting frequency of agents. In the "poor" area (first 30 nodes), highest values of meeting frequency were observed.

frequency were observed (see Fig. 9 (b) — first thirty nodes). This is a result of a smaller range of opinion and more limited living space — agents meet with higher probability. Figure 10 shows that in the social network two independent areas are formed. In the "poor" area (*cf.* Fig. 3 (a)), all agents share the same opinion $x = 0.1$ (see Fig. 9 (a)) — consensus has been reached and social network tends to complete graph. On the other hand, in the "rich" area, opinion division was obtained (see Fig. 9 (a)).

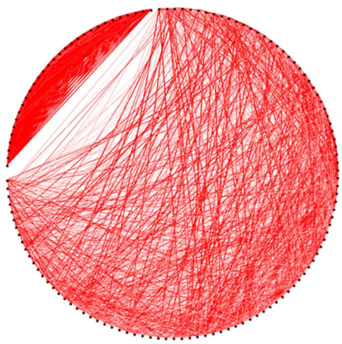

Fig. 10. Social network formed during the time evolution of the system. Two independent areas are visible. In the part of network, corresponding to the "poor" area, complete graph is visible.

4. Conclusions

In this paper, we investigate the important issue of opinion dynamics and self-organization in a social network in an intelligent agent system. In particular, using the model presented here, we showed some general relations between autonomous agents, their environment and their impact on the opinion dynamics. Also the network of contacts occurring in the real processes of human interactions was discussed. For example, it was shown that the agents try to increase their social status by migration to the "rich" areas at the expense of changing their opinions. We investigate two cases of migration of agents, for "open-minded" and "close-minded" agents. It was found that, with decreasing value of bounded confidence ε, decrease the values of meeting frequency of agents and average values of the degree of nodes. Moreover, through numerical simulations we were able to found some general properties of the model. For the case of the population of "open-minded" agents and for the distribution of resources that allows to everybody interacts with everybody else, social network tends to the complete graph for time $t \to \infty$.

We believe that the model presented here, where intelligent agents can migrate between areas with different levels of resources and change their opinion in mutual contacts, can be extended to more detailed models that manifest also other phenomena occurring in the social sciences.

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