A Model for the Evolution of Society Based on the Principles of Communicative Links Formation

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In this paper a model for the evolution of society based on the principles of communicative links formation is suggested and modified. One of the main principles of links formation suggested is closely related to altruism, the other to selfishness.

The numerical study of the model and its modifications has revealed that the selfish strategy is more robust. Although the altruistic society, under the same environmental conditions, is able to achieve a higher level of prosperity and seems to be in some sense, more rational. Eventually underlying laws of evolution lead to a dominant role of the selfish.

1. Introduction

During conditions of being materially well-provided and in a stable situation the majority of people live in small groups and families and depend little on each other. During times of change and uncertainty people unite.

One of the interesting problems engaging sociologists of our century is urbanization as the means of existence for city residents. L. Wers pointed out the fragmentary structure of human relations. He wrote [1]:

> Characteristically, urbanites meet one another in highly segmental roles. . . . Their dependence upon one another is confined to a highly fractionalized aspect of the round of activity.

He tried to prove that supporting often superficial contacts with some people is necessary rather than understanding the characteristic features of each human met [1].

> We are interested only in the efficiency of the shoe salesman in meeting our needs; we couldn't care less that his wife is an alcoholic.

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A. Toffler wrote [2]:

> Continuing urbanization is merely one of a number of pressures driving us towards greater 'temporariness' in our human relationships... The increase in travel brings with it a sharp increase in the number of transient, casual relationships with fellow passengers, with hotel clerks, taxi drivers, airline-reservation people...and countless others. The greater the mobility of the individual, the greater the number of brief face-to-face encounters, human contacts, each one a relationship of sorts, fragmentary and above all compressed in time.

So questions about people relations and interactions and how they influence processes inside society seem to be quite actual.

The problem of structure investigation and structure formation processes has recently acquired more interest in different fields of science from physics and engineering to biology [3, 4, 5]. From the viewpoint of the evolution of a system, dynamics undoubtedly depend on the geometry of a system [4, 5] and includes structure formation as well. Moreover, this property has to be regarded as fundamental and general for a wide class of phenomena, for instance, the atomic structure in physics, the structure of the universe in cosmology, evolution and morphogenesis in biology, and the formation of different social groups in social sciences. Thus the process of structure formation is one of the most important in the world.

From the standpoint of theoretical physics, it is out of the question that topology influences crucially the phenomena that can take place in a system under study. So it would be interesting to construct a model in which a topology (a structure of interaction) arises in the course of dynamics. Let us attempt to apply a similar structural approach to the problem of social evolution. For this we must consider society as a system of interacting elements and relationships among individuals as a structure, forming within it. So the main objects of our study will be the processes of organization and structure formation in a system consisting of a large number of interacting elements. Let us stress that our aim is not the question of how elements in the system interact. (The number of papers devoted to this theme is huge [6].) Neither do we try to find the optimal variants of networks. In this paper we propose a model describing structure emergence in the process of society evolution and report the results of the study.

2. The model

It is unlikely that someone could claim to know the exact principles of community structure formation and what the main governed factors are. Let us propose some ideas about it.

We take as basic notions for the model such terms as *altruism* and *selfishness*, and in addition suggestions about the special role of the poorest individual.

- *Altruism* is unselfish care about the benefit of other people.
- *Selfishness* must be understood as behavior of an individual that is totally determined by thoughts about personal advantage, preferencing one's own interests to those of other people.

Why do we pay the most attention to the poorest individual? In the context of the proposed model, the poorest individual is the one that has the minimum fitness value, in other words, the one who satisfies environmental requirements the least. One can see a variety of examples where the least fit element gives origin to many crucial processes (especially of catastrophic character). A chain breaks in the least durable circle, a panic emerges when a single individual starts behaving inadequately. The least fit element is the trigger of many important processes.

In the framework of the proposed investigation a society is represented as a system of N elements, each of them characterized by the number $b : b \in [0, 1]$, which corresponds to individual fitness on the landscape of its environment.

Let all individuals have random values of fitness in the beginning (distributed with uniform probability) and let links in the system be absent, that is, let it be a random free landscape. At each time step the individual with the minimum fitness value is found and this value is randomly changed. If there are no neighbors of the individual (a neighbor is an element having a link with the former), another individual is randomly chosen and their fitness is also changed, that is, a single interaction occurs. If there are some neighbors of the individual, the same procedure is performed for each of them. As a result of the occurring changes links among individuals can be preserved, appear, or vanish. (From the formal viewpoint, some features of this model are analogous to those proposed in [7].)

The experience of interactions of individuals must constitute the basis for links formation. In our case the experience is the result of change in the fitness value after a single interaction. Let us enter the following estimate of the interaction experience. If the fitness of an individual increases then the result is regarded as positive (1), otherwise as negative (0). The simplest rules for the organization of links can be formulated mathematically as the operations of boolean addition and multiplication.

Boolean addition is defined as:

$$1 + 1 = 1, \qquad 1 + 0 = 1, \qquad 0 + 0 = 0.$$

In our case this means that if the fitness of at least one of the interacting individuals increased, then the link appears or is preserved.

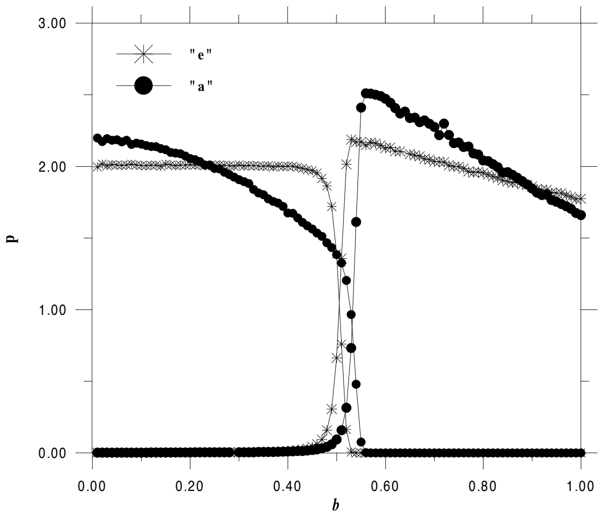

Figure 1. The probability distributions of minimum fitness value (left) and the probability distributions of fitness value (right) for the **a** case of link formation (circles) and for the **e** case (stars). Size of the system $N = 1023$.

This means of link formation is in good agreement with the idea of altruism, in other words, a link appears if it is profitable for at least one of the interacting individuals. Below we will denote such interactions and the society built up on this principle by **a**.

Boolean multiplication is defined as:

$$1 * 1 = 1, \qquad 1 * 0 = 0, \qquad 0 * 0 = 0,$$

meaning the appearance or persistence of a link only in the case that fitness of both individuals increase.

This means of link formation is in good agreement with the idea of selfishness, namely if the link is not advantageous for the selfish one, it does not appear or vanish. Below we will denote such interactions and society built up on this principle by **e**.

It is known that the prosperity (development) level of a society is defined as prosperity of all and each of its residents. It is also possible to take the viewpoint that the well-being of a society is defined as that of its poorest member. Following both these views, let us pay attention to the distribution of minimum fitness values and the distribution of the fitness value itself.

As one can see in Figure 1 the graphs for both of these distributions have a step shape and cross at a single point, which is the point of rising for some and the point of dropping for others. We call it a critical point. For **a** interactions the value is $b = 0.54$ and for **e** interactions $b = 0.51$.

For **e** interactions the graph of minimum fitness values is more convex than for **a** ones. The results of the distribution of fitness in our model show a linear drop after the critical point. Moreover, in the **a** case the rate of decrease is greater than in the case of **e** interactions.

The critical fitness values obtained can be interpreted as a boundary of the middle class, which is present in any society. It is created by the system itself. As it is easy to see, in the system where all individuals are altruists, the critical fitness value is greater than in the selfish system.

From the minimum fitness distributions one can make the suggestion that the altruistic society is more humanistic. The smaller a fitness value is, the more probable is its change, hence the chance of its increase is also greater. In this case changes occur with an individual who is more in need of them. As for the selfish society, it is harsher, that is, if a fitness value is less than the critical one an individual turns out to be in a "group of risk," now the real fitness is not essential and the probabilities of becoming better or worse are almost equal. This shows a deep difference between the societies.

From the fitness distributions one can notice that for both societies a fitness value close to the boundary of the middle class is the most probable, in other words, the majority of individuals belong to this category. Moreover, in the altruistic society there are more individuals having such a level of prosperity than in the selfish one. Nevertheless, let us stress that for an individual in the selfish society there are more chances to achieve higher fitness.

For a complete picture we calculated the average fitness value $\langle b \rangle$ as $\langle b \rangle = 0.745$ for the **a** society and $\langle b \rangle = 0.738$ for the **e** society, as well as the average number of interactions at a moment for the whole society $\langle k_s \rangle$:

$$\langle k_s \rangle = \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=0}^{T} k_i(t)$$

and for the i individual $\langle k_i \rangle$:

$$\langle k_i \rangle = \frac{1}{T} \sum_{t=0}^{T} k_i(t).$$

We obtained $k_s = 1.185$; $k_i = 1.75 \cdot 10^{-3}$ for the **a** case and $k_s = 1.00891$; $k_i = 0.222 \cdot 10^{-3}$ for the **e** case.

We also found that $\langle b \rangle$, k_s, and k_i are greater in the **a** society, that is, on average, the prosperity level of the altruistic society is higher.

Since we use the principles of link formation as the basis for our model we must pay attention to a distribution of the number of links in the system. We will call this the *connectivity* of the system. In our case it is defined as the ratio of the number of links to the number of

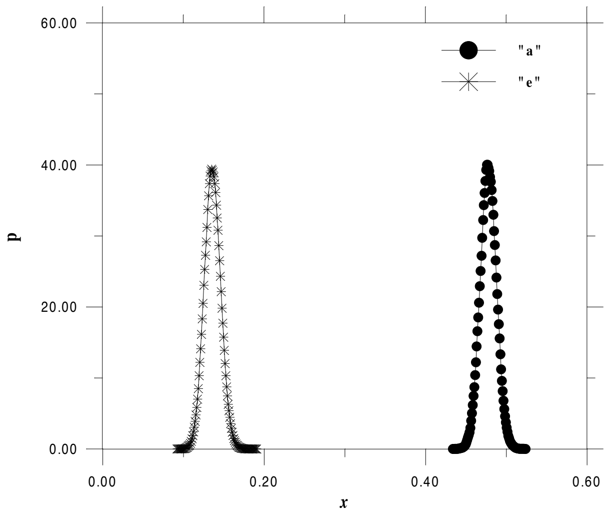

Figure 2. The probability distributions of system connectivity $p(x)$ for the **a** case of link formation (circles) and for the **e** case (stars). Size of the system $N = 1023$.

elements in the system and is a characteristic of structure that emerged from the system.

A graph of the probability distribution of connectivity of the system demonstrates localization on a narrow region of values as shown in Figure 2. For the interactions of type **e** it is from 0.09 to 0.19. For the **a** case it is from 0.43 to 0.53, hence one can see that the last case corresponds to a stronger connected system.

It turns out that the probability distribution of the system connectivity obeys the gaussian law

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-a)^2}{2\sigma^2}}.$$

In our model $a = 0.1456$ and $\sigma = 0.01$ for the **e** case for the **a** case $a = 0.4771$ and $\sigma = 0.01$. As one can see the deviations are equal in both cases.

Taking into account that there are more links in the altruistic society than in the selfish one we regard that the members of the altruistic society help each other to a greater extent. Personality has a greater meaning. At the same time links in the **e** society are short in duration and unstable. There one can observe frequent changes of partners, this is in accordance with the definition of selfishness. Previous experience is not taken into account, the society "lives for the present moment." Moreover, one can point out that links in an altruistic society are not only longer and more stable, but also that interactions are more local.

3. Modifications of the model

Since we never have an ideal society, where all members are of the same type, we have also investigated different intermediate cases. Namely, we considered mixed systems, which contain both **a** and **e** type individuals. In such systems conflict situations are possible, when the elements of different types interact and changes of fitness occur in opposite directions (as one can see from the definitions of **a** and **e** interactions, if fitness changes occur in the same direction, the result is equal for both cases).

Let us consider all possible means of link formation.

- *Variant 1*: A link appears if the fitness of an **e** element increases.
- *Variant 2*: A link appears if the fitness of an **a** element increases.
- *Variant 3*: A link does not appear.
- *Variant 4*: Existence of a link is defined arbitrarily for each conflict situation taking place.

We considered that the systems consist of almost equal numbers of elements of the different types. (We use the term "almost" as the number of elements in our system is odd and at the same time it is big enough.)

As one can see from the numerical simulations the different variants of link formation give similar results. As can be seen in Figures 3 and 4 the distribution of fitness for all the variants and its minimum value demonstrate intermediate behavior between pure **a** and **e** interactions, moreover, all the results are very close to each other.

As for the system connectivity, its most probable value is 0.28 ± 0.01 varying from $0.22 \div 0.25$ to $0.32 \div 0.34$ for the first, the second, and the fourth variants, and it is 0.24 inside the range from 0.19 to 0.28 for the third variant. This confirms an intermediate result among **a** and **e** interactions: the size and shape of the distribution are almost the same for all cases as can be seen in Figure 5.

Since evolution is the process, investigation of only its permanent characteristics gives an incomplete picture. So, besides the characteristics of emergent structures we also investigated the dynamics of its formation. Namely, we studied the duration of deviation of a fraction of free elements in the system from the average.

After some transient period, the system comes to the stationary regime, so one can count the average fraction of the free elements in it:

$$\lambda = \frac{1}{NT} \sum_{i=1}^{T} n_i$$

where T is the total time of counting and n_i is the number of free elements at moment i. Since each state of the system is not stable,

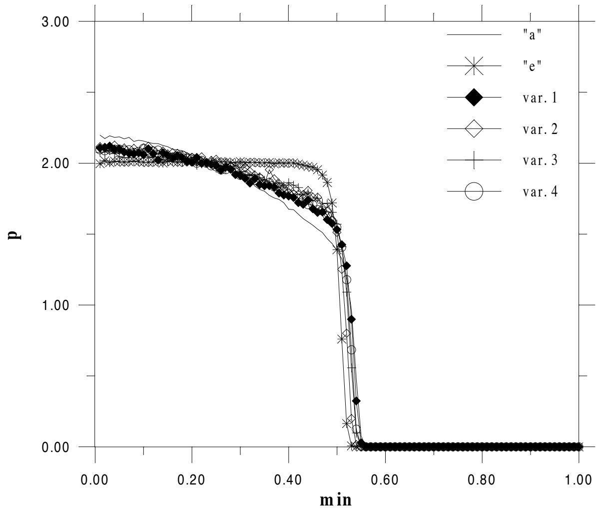

Figure 3. The probability distributions of minimum fitness value $p(\min)$ for the investigated intermediate variants of link formation: the **a** case (line only), the **e** case (stars), the first variant of link formation (diamonds), the second variant of link formation (squares), the third variant of link formation (cross), and the fourth variant of link formation (circles). Size of the system $N = 1023$.

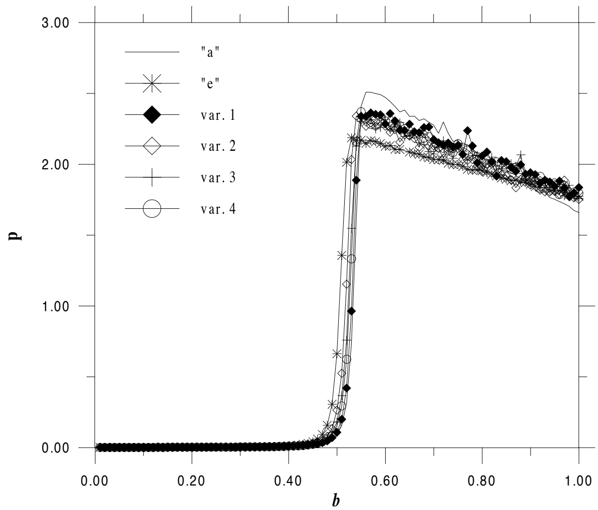

Figure 4. The probability distributions of fitness value $p(b)$ for the investigated intermediate variants of link formation: the **a** case (line only), the **e** case (stars), the first variant of link formation (diamonds), the second variant of link formation (squares), the third variant of link formation (cross), and the fourth variant of link formation (circles). Size of the system $N = 1023$.

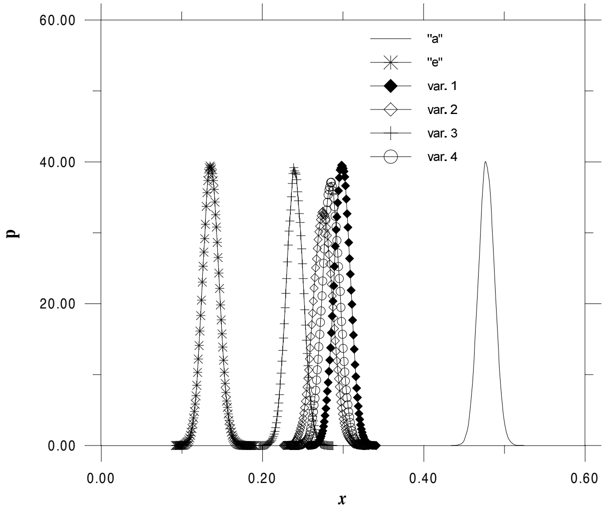

Figure 5. The probability distributions of system connectivity $p(x)$ for the investigated intermediate variants of link formation: the **a** case (line only), the **e** case (stars), the first variant of link formation (diamonds), the second variant of link formation (squares), the third variant of link formation (cross), and the fourth variant of link formation (circles). Size of the system $N = 1023$.

that is, processes of appearing and vanishing links continuously occur, stability is reflected by the change of the fraction of free elements in the system *dl* (deviation from λ). Namely, when a link appears then *dl* decreases, if it vanishes *dl* increases. Let us emphasize that deviations of different duration can be observed: both increase and decrease of *dl*. One can think of such deviation as avalanches in models of self-organized criticality [7, 8]. We investigated the structure destruction processes, that is, the probability of the *dl* deviation from the average to larger values as a function of its duration. In so doing, moments $t = n/N > \lambda$ and $t = n/N < \lambda$ are guessed by the start and the end of the event correspondingly.

As demonstrated by computer simulations, this characteristic obeys the power law distribution

$$y \sim t^{\gamma}$$

with the exponent $\gamma = -1.56$, which is the same for all systems investigated. At the same time the average value of the fraction of the free elements (a free element has no links with any other) in the systems are different, namely for the **a** case it is equal to 0.19, for the **e** case it is 0.75, and for the intermediate cases approximately 0.5. (See Figure 6.)

This means that structure destructions of any duration are admitted.

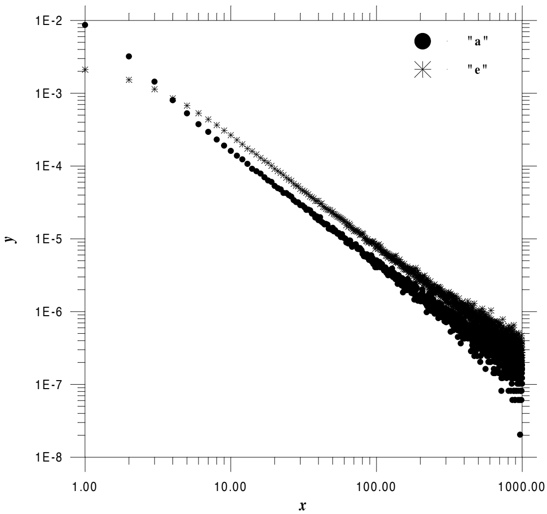

Figure 6. The distributions of deviation from the average of free elements in the system $y(x)$: for the **a** case of link formation (circles) and for the **e** case (stars). Size of the system $N = 1023$.

3.1 The model with memory

Very often an individual making a decision is governed not only by the advantage of the present situation but also takes into account previous experience. In order to reflect this in our model we incorporate memory. This can be done if we characterize a link between individuals by a positive integer number, which can be changed in the process of system evolution according to the rule: If after an interaction the fitness change result is positive, then the number is increased by a unit, otherwise it is decreased by a unit. If the number is equal to zero, this means that the link is absent. Thus each interaction with a positive result leads to an increase in stability of the link and *vice versa*.

Our numerical study demonstrates that in the **e** case the distributions are the same as before, while in the **a** case essential changes have taken place, namely the system does not come to a stationary regime, instead a process of slow monotonous directed change occurs. Almost all the elements of the system have a fitness value very close to one. So we can conclude that for interactions of the **e** type, as before, links in the system are very mobile (short in time). Previous experience does not matter and a human is used to living alone. The case of interactions of the **a** type corresponds to very stable links. The emergent structure represents a great number of stable small groups. In this case the distribution of minimum fitness is almost linear, namely the probability of change of an individual's status linearly decreases with its value. The change in status of an individual who is in most need of this is more probable than in the earlier case.

It seems obvious that during life an individual can demonstrate fairly different behavior (according to our definitions, altruistic or selfish). Probably life experience, especially stress situations (in our model this is a fitness change), plays a very important role here. So the next modification suggested by our method is the opportunity to change the type of an element at the same time its fitness changes.

We choose a different type for an individual with uniform probability. Let us consider the third and the fourth variants of link formation.

The tendency of system characteristics shifting to the **e** case distribution was revealed in both variants. This is well explained by the fact that the percentage of **e** type elements is always greater. Thus a selfish individual is more adaptive to the environment independent from the evolution rules.

The first version of our model, where only formation of a single link at a moment is possible, is the simplest case and a very rough description of a real community. For this reason we put into our model an opportunity for more than one link formation at a time, when the element with the minimum fitness value is free, a number of interactions is defined randomly inside the range from 1 to N with uniform probability (the principles of link formation are the same as above).

As in the previous cases, a probability distribution of the system connectivity obeys the gaussian law, that is, the structure formation processes do not reveal any new fluctuations or behavior changes.

Here are the parameters of the distributions (see Figure 7).

- For the **e** case $a = 0.189$ and $\sigma = 0.011$.
- For the **a** case $a = 2.92$ and $\sigma = 0.15$.

Looking at these values of parameters, one can say that in the **a** case connectivity and deviation essentially increase. On average each **a** individual has approximately three links and this number can change in essentially wider ranges than above. As for the **e** case robustness of the structure changed very insignificantly (the range of values was [0.139; 0.235]), the average increased only to 0.044 (let us point out that it is, as above, less than one). Thus a selfish individual lives alone in spite of a greater number of contacts and the opportunity for creating bigger communities.

Critical points in this case for **a** interactions is $b = 0.09$ and for **e** interactions $b = 0.03$.

As can be seen, the boundary of the middle class essentially shifts to the left. The difference of these values for **a** and **e** societies increased.

One can say that the step shape is preserved in the distributions of fitness but that for the **e** case after the critical point it became uniform.

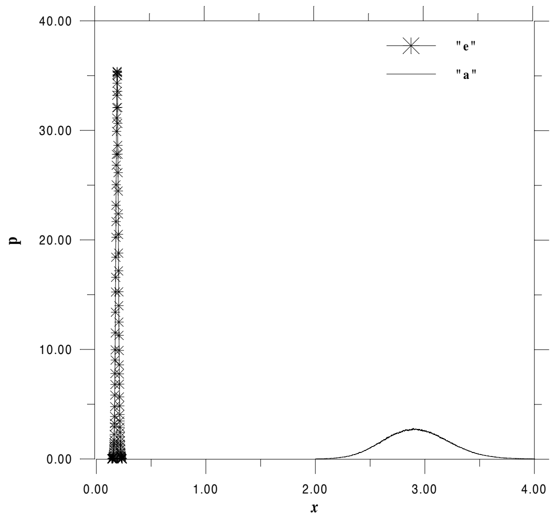

Figure 7. The probability distributions of system connectivity $p(x)$ for the investigated model's modification with an opportunity of more than one link formation at a time, where the **a** case of link formation is represented by circles and the **e** case by stars. Size of the system $N = 1023$.

For the **a** case it has, as previously, a linear drop but less rapid. For the **e** society one can interpret this result as if both the poor part and the rich part vanished, the society becomes more homogeneous. In the **a** case this tendency is present also but many features of the previous one are still preserved. An increase in stability leads to an increase of fitness, as a result, almost all members of the **a** community have very high fitness.

4. Conclusion

From the study of the model and its modifications we make the following conclusions.

1. A modern individual as well as, it is possible, a human in the future is very mobile, having many different contacts. At the same time, in less developed countries (as well as in the past) a human has a lower level of interactions with the environment and is not so mobile. Life in a big family is more appropriate. One of the principles of surviving in a rapidly changing society consists of decreasing the number of relationships while at the same time keeping a great number of contacts. Doing so allows an individual to be better adapted to the environment, that is, the communicative links lower the adaptive ability of an individual [2]. This is in good agreement with our model results.

2. As one can see from the distributions of connectivity in the system, the statistically robust structure builds up after the transient time. The most

probable value of connectivity for the **a** society is greater than for the **e** one. Excluding the variant of the model with the opportunity of more than one link formation at a time, the number of links is always less than the number of elements, so for good functionality system connectivity should be less than one. To clarify this idea we emphasize that there is an essential distinction between links and interactions. The interactions are short contacts, the links are long and robust relationships. Society is based on a great number of interactions. The connectivity in our understanding is something more cardinal, it is a deep mutual dependence. If something essential occurs to an individual, something essential occurs to those having links with them. Random encounters with fellow passengers, a variety of clerks, and so forth are interactions. As an example of links one can take family. Just links (in some rough description) form the structure of society. If we consider a society as a combination of families, its connectivity is indeed quite low, but at the same time the percentage of interactions between its members may be sufficiently great. Interactions unite individuals in a society, connected collectives (families) form its structure. In reality we do not have societies with a high level of connectivity.

3. There are correlations between connectivity of the system and the choice of an individual who has to be affected. In the case of greater connectivity, the choice of an individual, who is in need of the transformation is more probable. So one can say that the choice of an individual, who will be affected, in the **a** society is in some sense more adequate.

4. According to our model's modifications one can conclude that the **e** type of interactions are more robust, that is, in most of the cases our modifications do not change the main characteristics of the system corresponding to the selfish society.

5. As it is easy to see from the model modification, when there is an opportunity of forming more than one link at a time, the altruistic society is able to achieve a higher level of prosperity than the selfish one and seems under the same environmental conditions, in some sense, more rational. Why is it our world seems to be represented by the selfish communities? Consider the model modification where we studied the mixed system. It was obtained there that the percentage of the **e** type individual is greater, so one can conclude that the selfish strategy is more robust. This suggests that the environment, and not our desires, forms society. A selfish community stays the same, this has to be according to evolution.

Acknowledgment

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