Toward a Theory and Agent-Based Model of the Networked Economy

July 1999

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Note: in this version of the text some quotations from English papers can differ a little from the original by its back translation from Russian.

Abstract:

What kind of information interactions among agents makes possible a functioning of socio-economic systems? What theory do we need to describe the fundamental principles of agents' information interactions? What is the model to simulate functioning of networked economy arisen in Information Society? How we should organize artificial environments where our "intelligent information agents" will interact with each other to help us in our online communications inside numerous human communities? The main purpose of this article is to suggest answers on these questions. Following statements are discussed in the article:

Rapid development of Information Society and its Networked Economy attracts attention to the role of information interactions in functioning of social systems. Information interactions are the more fundamental level to describe a functioning of a social and economic system then market or hierarchical interactions. Central element of agents' information interactions is "collective information model" of their environment. There are some limits on information interactions related with parameters of economic system. Institutional structures are able to channel information interactions beyond the limits. Market and hierarchical interactions are just special cases of such channels. Simplest model of economic system functioning with information interactions includes five types of objects (macro-technology, information space, institutional structures, collective information models, and human actors).

Introduction

What kind of information interactions among agents makes possible a functioning of socio-economic systems? What theory do we need to describe the fundamental principles of agents' information interactions? What is the model to simulate functioning of networked economy arisen in Information Society? How we should organize artificial environments where our "intelligent information agents" will interact with each other to help us in our online communications inside numerous human communities?

The main purpose of this article is to suggest answers on these questions. Practically we need to learn the basic principles of organizing of information interactions in real networked forms of organization and in artificial systems like community of negotiated and collaborated information robots, software agents and so on. It is
important for better realization of at least two tasks of modern social progress:
a) Development of Information Society and its "networked economy" for higher living conditions;
b) Development of the Internet technologies for more efficient cooperative work.

There are a lot of publications discussed modern changes in an economy related with Internet technology development. The modern (or near future) state of economy has several names:
- "New Economy" (Stephen B. Shepard),
- "Next Economy" (J. Bradford De Long, A. Michael Froomkin),
- "Hi-Tech Gift Economy" (Richard Barbrook),
- "Attention Economy" (Michael H. Goldhaber),
- "Digital Economy" (see The Emerging Digital Economy II),
- "E-conomy" (see the E-conomy site),
- "Network Economy" (Kevin Kelly),
and at last "Networked Economy" (see Status Report on European Telework).

There is also a whole "Encyclopedia of the New Economy" (http://www.hotwired.com/special/ene/). One of the most interesting features of these modern changes is that people get a principally new global environment for their interactions. So now actors can actually move their social, economic and so on interactions to the new environment, but social scientists know very few about mechanisms of interactions in socio-economic systems (Alan Kirman).

The problem is that research of socio-economic interactions based on market or hierarchical models of the system and so the human interactions look like commodity exchanges or principal-agent relations (S. Parinov). What about a picture of the economy based on pure information interactions?

In this article we propose a theoretical concept and a skeleton of agent-based model of economic system functioning with information interactions between agents. This concept could be useful not only in better understanding of Information Society and its networked economy development, but also for designing of artificial systems of interactive entities living into Internet technology environment. Such artificial systems, for example, are the next step of moving recent business infrastructure to the "e-business" (Business and the Internet Survey. The Economist, June 26th 1999) where some part of interactions business-to-business and business-to-customer serves by information robots and software agents (see as a sample Arie Segev, Carrie Beam).

In the first section of the article we reinterpreted institutional economics statements on interactions among economic agents as a start point of our analysis. The second section discusses theoretical limits on information interactions related with level of ICT development and intensity of changes of an economic system. Third section concludes that three types of information interactions (strong, medium and weak) of single agent with others exist and it could be roughly corresponded with interactions in small group, hierarchical organization and in a market. Fourth section shows how theoretical limits of information interactions can be overcame by using of institutional structures. In the fifth and sixth section propose a scheme of information interactions between agents. Seventh section shows an idea of general picture of economic system
functioning through information interactions between agents. Eighth section makes a first step to a computer model of an economic system based on our methodology.

1. Institutional Picture of Economic Interactions

Some parts of economic discipline have different points of view on what are interactions between economic objects and describe those by different kind of economic models (Alan Kirman). Below we will base on a picture of economic interactions accepted from New Institutional Economics approach. From the point of view of institutional economics, rules of behavior in a society or “to be more formal, the limitations created by man that organize interactions between human beings” (D. North, 1997, p.17), are society institutions. Those institutions set the pattern of stimulating motives and include various limitations, created by man in order to shape up human interactions (D. North, 1997, p. 18). Following this concept, we shall differentiate between, on the one hand, the institutions that form the opportunities for society members and acting as “limitations within which people interact with each other”, on the other hand – organizations that use those opportunities and “similar to institutions, structure the interaction between people (D. North, 1997, p. 19, 23).

Certain types of activity exist in the society that raise institutions as economic reality and maintain their efficiency. In this respect, specific human activity aimed at maintaining the performance of institutions can be presented as a certain mechanism that provides for interactions between organizations and individuals. At the “entrance” to this mechanism are economy participants in a free, unorganized state. At the “exit” – the same agents but connected via a system of established short- and long-term relationships. Thus, institutions and activity that supports them transfer a set of economic agents from free, “chaotic” state into a certain ordered institutional pattern (organization consisting of the above agents and relationships between them). Here, some types of relationships and corresponding organizations exist for quite a short period of time (e.g., acts of exchange at the market), other live for much longer periods (e.g., firms and corporations). We shall call this process as the action of “institutional mechanism” meaning that within internal environment of an organization a other mechanism is working that manages organization itself.

It is possible to depict the general institutional cross-section of economic world. At each given point in time the entire set of agents is broken down into 2 groups: 1) agents in free, “chaotic” state; 2) agents being in the bound state in the form of a set of organizations. Several types of institutional mechanisms are working in the economic system space that continuously transfer the multitude of free agents into a multitude of organizations (bound state). Due to certain reasons, relationships established between agents in the form of organizations, are regularly exhausted (they fail to correspond to objectives for the sake of which those relationships had been established). After that relationships are broken and agents resume to the free state. Thus, work cycles of the mechanisms are repeated time and again.

Fig. 1
Human interactions are mediated by their habitat in society; to a large extent it is established as the result of employing the technologies accumulated by the society. Maturity of technologies, particularly their information and communication constituents, is determined (in addition to institutional limitations) by one more – purely technical – type of limitations on human interactions within society. Similar as institutions set opportunities those are further used by organizations, information-communications technologies (ICT) determine the average level of information interactions (doing by information exchange) in a society and set their possible ceiling. Institutions structure interactions of the people within the framework of those technical limitations. The question is how we can describe the institution mechanism as information interactions between agents.

2. Theoretical limits of information interactions in economic space

In virtual space of Internet technologies being the base environment for the performance of network economy, human interactions are exercised as follows: 1) via dissemination of information flows over space; 2) in the form of collection and processing of information; and 3) via direct information exchange between economy participants. All these processes are implemented with the help of information and communications technologies being the technical means of interactions. Interaction carriers are information flows disseminating in the information environment of economic system. We will call the "information environment of economic system" as an "information space".

Let us consider how technical limitations on dissemination of information flows combined with the factor of gradual obsolescence of information will influence the structure of interactions of an individual agent with the rest of agents in economic system.

Information flows are disseminated over economic system with certain finite velocity. Upper limit of the latter depends on the current development level of ICT. Even if each given pair of agents can be connected with the fastest of existing information exchange channels, it is practically impossible to simultaneously ensure similar conditions for all the agents of economic system. Thus, from the viewpoint of each individual agent, there always will be groups of agents with whom there is an opportunity of fast information exchange as well as other groups with no such opportunity.

From theoretical point of view, the situation could be presented as follows:

1. Agents geographically distributed over the space of economic system have a certain network of information exchange channels. Information flows created by agents disseminated over the entire system via this network and gradually fade away. Development of information exchange channel topology can produce situations when individual agents have better conditions for interactions with remote agents then with immediate neighbors. Therefore, proximity or remoteness of agents in virtual
information space, in a general case, can differ from the similar geographical parameters.

2. For the time being, we exclude from consideration the parameters of geographical distribution of agents in the system and the technique of transforming geographical distances into information ones. Let us limit our analysis to the boundaries of virtual space. We shall proceed from the notion that all the multitude of agents is distributed in a certain fashion over the virtual (information) space of economic system. The distance in information space is defined as follows: the farther are the agents from each other, the more time is required for an information flow sent by one of them to reach the other.

3. Select a certain individual agent as the center from which information flows are emanated. The distance from the center to the rest of the agents in information space could be characterized by the time interval required for reception of information flows by each economic system agent (within this interval information travels from the source agent to the recipient). Thus, we are able to obtain a set of values of information remoteness of system agents from the “center” selected; in conjunction with particular points in space those values make it possible to define its topology.

It should be noted that within an economic system there is also a continuous flow of stochastic changes of its state that, in the general case, cannot be predicted by the agents. In our case this results in the fact that information flows disseminating over the system, gradually lose their adequacy to the current state of the system and therefore decrease in value. Usual situation: information sent by the source agent cannot be altered on the way to the addressee. During the time of information travel, the system can undergo changes that lead to the loss of actuality by information content.

Thus, such parameter as the intensity of stochastic changes within an economic system under constant information dissemination velocity defines the maximum possible duration of information dissemination. Exceeding this duration means loss of topicality of the given information. We have to keep in mind that the full-fledged agent interaction should presuppose mutual information exchange (recipient forms and relays back to the source its reaction to the information flow received). Consequently, the time interval of the maximum possible duration should incorporate also the reception of feedback by the agent source.

Limits of information interactions between agents depend on: a) remoteness of recipient from a source (on Fig. 2 - from the source at the right side to several recipients on the left one); b) average velocity of information dissemination through the system space (on Fig. 2 - zones from A to C); c) average velocity of changes of economic system state.

Let agent-source knows current state of agents-recipient (it’s upper line connected all agents). He can forecast states of agents-recipient

Fig. 2
(forecasted states located on the information flow line). Agent-source starts information flow to agent-recipient (blue and light blue arrows). Radial arrows show where should be future state of agents-recipient while information flow is disseminating. The flow content based on a forecast of the state of agents-recipient that agent-source could make. But to the moment when agents-recipient will receive an information from agent-source unpredictable changes make uncertain the real state of agent-recipient. The probability to shot the real state is lesser then farther agent-recipient from agent-source.

Division of the system space on three zones $A$, $B$ and $C$ has following legend:

Agents-recipient located inside zone $A$ have the best conditions to interact with agent-source. They are closed enough to the agent-source to receive and send back real time reactions on signals of information flow. Far from boundaries of zone $A$ locate a zone $B$. Agents-recipient from here can receive actual picture from the agent-source, but they are too far for real time reactions on the signals. Any agent-recipient from zone $C$ (located after zone $B$) receives only non-actual information flow.

In the next section we continue this analysis.

**3. Spatial boundaries of information interactions between agents**

One of outputs of previous section is a statement that the system space is divided into the zones of strong, medium, and weak interactions between the agents of the system. It's resulted from consideration of devaluation process of information flows content during the time of their propagation through the economic system space shown in the abstract picture above.

For the clearness of the further discussion, let us introduce the notion of “observer” (it was "agent-source" above) who can be any given agent of economic system located in a certain point of its information space. This will enable us to define the differentiation between the possible interactions of each individual agent of the system (“the observer”) with all the rest of the agents. (We use the concept of the “observer” approximately in the same manner as it done in the physical Relativistic Theory by Albert Einstein). It is necessary to stress that differentiation of agent subsets considered below belonging to certain information space zones should be interpreted as a phenomenon being purely relative for the observer selected. One and the same part of economic system can be the zone of different types of interactions depending on which agent is under consideration.
Now, if the observer is located in a certain point of information space, his interactions with other agents of the system can be divided into “strong”, “medium” and “weak”.

The zone of information space in the vicinity of the observer can be considered as that of strong interactions if his information exchange with the most remote agents of this zone (positioned at its boundary) takes time that does not exceed the period during which essential changes in the system occur. Let the border of this zone be distant from the observer location point by the length of radius $Ro$ (see Fig. 3 below). Thus, strong interactions are possible between closely positioned agents that have the opportunity of information exchange in the so-called real time mode; the subset of those agents is located inside the zone with radius $Ro$.

Among the agents, located at the distance more than $Ro$ from the observer, there is a subset for which information exchange with the observer can implement their interactions provided that information flows from the source agent do not presuppose considerable feedback from the recipient agent. This case is characterized by primarily unilateral information flows; this makes it possible to increase the number of agents (compared to the group of “strong interactions”) with whom the observer can interact but has to sacrifice the feedback reactions to the signals received. Let us consider that this group of agents is in the zone of medium interactions relative to the observer. The outermost boundary of this zone is equal to the time interval of the direct travel of information flows to the point where the information substantially loses its actuality. Let this boundary be distant from the observer location by radius $Re$. If we assume the velocity continuity of direct and backward travel of information flows, $Re$ should be approximately twice as long as radius $Ro$.

All those not included in the previous groups, and thus positioned at the distance longer than $Re$ relative to the observer, are in the zone of weak interactions with the observer. No one from this third group of agents can have information exchange with the observer in the real time mode. During the time necessary for information flows to travel from the observer to any point in the zone of weak interactions, the content of information flows fails to be adequate to the current state of the economic system due to unexpected changes accumulated during this period. Therefore, information flows in this case cannot be the basis for full-fledged interactions; however, there are situations when, even under such circumstances, certain types of interactions do take place.

Thus, due to technical limitations on information propagation velocity in a stochastic environment, interactions between economy participants have certain spatial structure which, in the first approximation, we characterized as zones of strong ($A$), medium ($B$), and weak ($C$) interactions. Interaction intensity in each of the above zones, naturally, can vary from zero to the upper possible limit for the given zone. So, all other intensities can be actually implemented in the zone of strong interactions. All the intensities can be implemented in the medium interaction zone except for the “strong intensity”, etc.
Analogies can be easily drawn between the three levels of interaction intensity with the main types of institutional structures. Strong interactions are characteristic of "small groups" and tribes (according D. North (1997) it is "personified links without control"); their participants can exchange information in real time. Medium interactions having mostly unilateral nature, are characteristic of hierarchy structures (D. North, 1997: "non- and personified links with control") where information flows go primarily from superiors to subordinates (from principal to agent). Weak interactions (D. North, 1997: "non-personified links without any control") correspond to market interactions.

As it was mentioned before, all the other institutional structures can work in the environment that exists in a small group. On the contrary, no other institutional structure than the market one, can function in the global market environment.

4. General pattern of information interactions beyond theoretical limits

When an agent interacts with someone other he receives and keeps an information image of current partner's state.

Interaction between the observer and a certain given agent is possible in principle when the information image of this agent corresponds to his real state with sufficient accuracy. Two-way interaction between observer and given agent is possible when both information images can be maintaining correctly. If information image reproduces the state of the corresponding agent inaccurately, the possibility that this pair of agents will find a mutually acceptable variant of their joint activity based on some incorrect models is rather low.

Remember a picture from above of general limitations on the agent interactions within the information space. Following this the observer has realistic images of the agents when and only when the given agent group can adjust the frequency of changes in its information images on appropriate level. If the frequency of changes fits well to the possibilities of data transfer without losing information actuality to the distance from the observer to the agents then the observer will be able to interact with the agents.

Due to objective reasons an economic system has non-ideal level of current ICT development and some level of stochastic changes in the system. So it is always possible to find groups of agents within the space of a large-scale economic system that do not have technical means to organize information exchange at the level required for their interaction. Persistent stochastic changes in all the parts and objects of economic system devalue the content of information flows disseminated. With the given velocity of the changes in the state of agents requiring appropriate coordination with the partners, and limitations on the information dissemination velocity, it is always possible to determine the maximum distances within the system space exceeding which means technical impossibility of agent interaction. In previous sections this fact was a reason for selecting zones A, B, and C (see Fig. 3). However, by decreasing the necessity to coordinate the changes in their state the agents are able to organize interactions at the distances that exceed theoretically possible values. So if
agents simultaneously slow down the level of their information image's changes, they will get conditions to interact each other in wider boundaries then before.

If information exchange level required for agent interactions cannot be attained by technical means (by changing information permeability of the environment), conditions necessary for the interaction can be created by institutional means. Agent can adopt behavior rules common for all of them; in accordance with the above their information images estranged to the outside environment, their information images should match certain standards. If the standards regulate the permissible upper limit of the degree of information image variability, then the set of agents that adhere to this standard, will form their own information images that will be uniform in their mutability extent. The totality of the latter uniform images can be considered as an independent sub-space for agent interaction; its content has certain relationship with the processes of change in the real space of economic system.

In fact, agents here should create a certain projection of real space. This projection has to differ from the reality in, at least, deceleration of the change processes. By designing institutional structures, agents can form projections of real space that reflect real processes with various decelerations. Each of these institutional limitations outlines the sub-spaces and makes for the establishment of new agent interaction conditions and channels. As a result, interactions become possible within broader spatial boundaries that would be unattainable without the use of appropriate institutional structures.

From the point of view of individual agent-observer (see a man at the left side on Fig. 4), his interaction with variously remote groups of potential partners (one or many men at the right side on Fig. 4) requires him to design and maintain a whole set of his information images made to the standards of the corresponding sub-spaces. So the observer has several parallel channels and sub-space to interact with other agents (four parallel sub-spaces on Fig. 4). To make a set of his potential partners wider he has to simplify his information image according rules and standards of appropriate institutional structures.

Fig. 4

Thus, certain set of institutional structures operating in an economy, segments the entire space of the system into a certain number of sub-spaces with their own rules and parameters of agent interactions. The more remote interactions are to be organized, the higher deceleration of real processes is to be implemented when designing the corresponding sub-space.

In similar vein, the more remote interactions those sub-spaces are mediating, the stronger are the discrepancies between real processes in an economic system and their reflection in sub-spaces. It would be logical to assume that long-term functioning of these sub-spaces should be completed by a procedure of bringing the state of subspaces into accord with the real state of the economic system.
Now we have a general picture of context where information interactions take place. The next step is to describe a scheme of interactions in details.

5. Scheme of Information Interactions: Causes and Motives of Interactions

The habitat defines basic configuration, parameters, and motives for agent interactions. Material world created in the preceding period of the economic system existence defines physical limits, provides the means and carriers for dissemination of signals and interactions. All these combined do form interaction opportunities. The structure and character of stimulating motives for economic activity of the agents formed in this world, defines which interaction topologies are realistically necessary and which of them will be further implemented.

We consider agent economic activity in its developed form. In this case it is based on a certain labor division (specialization) between agents in an economic system and implies collective use of a certain set of related technologies in the production process (let us call this set a macro-technology). We understand a macro-technology as a production apparatus created within an economic system; its individual elements are adapted to the existing labor division system and they form the “jobs” for the agents. At the “input” to macro-technology are natural resources. Material products for final consumption are located at the “output”. The structure and composition of a macro-technology, in the general case, is not a distinctly specified set. Its "job" items could be excessive, duplicating, etc. We cannot also exclude simultaneous existence of several macro-technology types that can be employed by the system both in parallel and on the alternative basis.

Macro-technology elements, similar to agents, are distributed in a certain fashion around the economic system space and can change their spatial location under certain circumstances. As a result of certain procedures (to be described below), agents take the “jobs” of the macro-technology and make it work: they implement the production process characteristic of the given macro-technology. The latter is a material foundation for the agent community to solve the problems of their socioeconomic existence and development. The structure and parameters of its jobs, as a rule, are more stable than the structure of agent possibilities and states. In a short-term aspect, agent community solves the problem of optimal allocation of agents for the given set of macro-technology jobs; it is oriented at individual differences in agent productivity relative to the set of jobs. In the long-term aspect, agent community improves the macro-technology and solves the problem of adapting agent capacities to its newly acquired characteristics.

In the process of macro-technology using the technological links appear and specific interactions do happen between agents. The links determine whom from does an individual agent receive the intermediate product of production process and who he transfers it to after completing its portion of this product transformation.

Technological network of links would have no economic sense if it would not be completed by distribution feedbacks that provide for dissemination and distribution of the final product among the agents of the economic system. Thus, agents create and
maintain among themselves another network of relationships that, in a general case, can happen not to coincide with topology of technological link network. Agent’s place in distribution network is defined by whom from he receives a certain portion of the final product and who he further transfers it to less what he can leave for himself to maintain his life activity necessities.

Having found his place in the system of technological links (a sub-space on the left side on Fig. 5) and distribution (a sub-space at the bottom on Fig. 5), the agent somewhat positions himself relative to the rest of the agents also involved with the above relationships. Those who he interacts with via direct links, are his closest neighbors in the given sub-spaces. The longer the chain of links between two given agents, the longer the distance between them, although geographically they can be located quite close to each other.

Apart from the activity mediated by the above relationship networks there is one more type. Before put themselves into technological and distribution networks agents search for the better place within those networks as well as coordinate their interests and capacities with each other. New kind of agent activity, as opposed to aforeconsidered, is not directly related to exchange of material substances. Its content is information exchange; it has the form of purely informational agent interaction.

David Leveers (1997) proposed some structurization of motives and causes of information exchanges between economy participants in the form of a “cognition cycle”. It makes a stress on the existence of various stages of information preparation and exchange between economy participants. Moves from stage to stage are exercised as a gradual transition from one type of agents' communication to another. In the networked economy this means the transition from one telecommunications service to another.

In metaphoric concepts that are essentially based on the contemporary capacities of the Internet technologies, cognition cycle has the following stages:

1. "Territory". Private "territory" for individual actions (here we recollect what we had just learned, adjust our existing mental model of the world in accord with the latest changes, rehearse the application of new skills and ideas, start formulating what we would like to do further, etc.).

2. "Map". Is used for initial orientation and navigation. When we dare to leave our private “territory”, we need a ‘map” which is a passive information in the form of references (newspapers, books, Yellow Pages, etc.).

3. "Landscape". Designed for other people and is a result of our intercourse as individuals, shows us how are we linked to communities and groups around us.
“Landscape” can be a real space such as a staff meeting at the office or a construction site where actions are visible, and intercourse is audible.

4. "Room". Is designed for meetings between individuals to conduct negotiations, brainstorming, and establishment of the base for future communication and cooperation.

5. "Table" Space for joint work on an agreement over individual provisions, problems and situations that require a planned cooperative approach.

6. "Theater". The space in which the results of joint activity become visible and socially available.

The Cycle of Cognition

Fig. 6. Source: David Leevers. Inner Space - the Final Frontier, 1997 <http://www.vers.co.uk/DLEEVERS/PAPERS/innerspace.htm>.

The intensity of human interactions at various stages of this cycle is quite different. At the first stage (see the above list) – “territory” – the needs in communication and information exchange are at the minimum. Then they reach the maximum at the “table” stage and somewhat decrease by the concluding stage of the cycle (“theater”).

Apparently, in the process of the above stages the participants solve the task of finding mutually acceptable variants of positioning themselves in the network of production and distribution relationships as well as bringing the optimal variants found to practical use.
6. Scheme of Information Interactions: The Main Blocks

Institutional structures set the limits of people’s interaction in the process of their socioeconomic activity (see above sections). Separate institutional structure could be imagined as a meta-model or a framework of a kind of interactions between individual agents that conduct activities “inside” it. The typical functions of such framework are the following three:

1. The switch of the joint activity participants (agents) from the “free” state that precedes their amalgamation within a certain organization, to a constrained state when they are already organization members and have formed the necessary relationships with its members. Here, institutional mechanism is working of coordination of opportunities and intentions of the agents relative to their potential joint activity.

2. The use of organizational relationships between agents for attaining the goals which were the reason for the establishment of the relationships. Coordination of the organization members’ activity in the process of joint activity which at this stage has been exercised via organizational mechanism.

3. Termination of membership in organization (breach of relationship) and agent return to the free state.

Further we shall examine the work principles of the first item in detail, and second – in general.

There arises a question: what is the content of specific human activity that creates an efficient institutional mechanism?

According a general picture of institutional structure, of direct information interactions, of "cognition cycle", and etc that was discussed in sections above, we can summarize the following:

By means of interaction exchange, agents participate in the collective formation of a certain information image (model) of their environment (Michael Lachmann, Guy Sella, end Eva Jablonka; Scott Moss and Bruce Edmonds) and possible joint activity. Agents use this information model for simulating different variants of their activity. Doing this they verify and coordinate their viewpoint of the content of their joint activity as well as define the place of each agent within the system of labor division between them. At a certain stage of coordination and specification the agents begin to consider the current state of information image of the joint activity to be acceptable for practical implementation. After that they are able to make the appropriate re-configuration of the links, and to readjust the type of their activity. In the process of re-configuration production relations are changed through which intermediate results of agent production activity are disseminated (in accordance with technological series). Also, distributive relationships can be changed through which the final results of the agent collective activity are fed back to them in the form of resources for maintaining their activity.

The outline of agents information interactions in a more detailed and formalized form is represented in following sub-sections:
**Interaction space**

1. Let us specify a set $A$ consisting of $n$ agents $A(i)$, where $i = 1 \ldots n$.

2. Specify space $P$ in which agents conduct their interactions and which contains the whole agent set $A$ as well as set $Z$ of the rest of economic system players different from the set $A$: Let $P\{A, Z\}$. More detailed description of the features of the space for economic interactions see in above sections.

**Macro-technology**

3. Set macro-technology $M$. Its description sees above in the previous section. Let the number of jobs in the macro-technology be $n$ and, consequently, it will coincide with the number of agents in set $A$. For each macro-technology job $M(j)$ (where $j = 1, \ldots, n$) its output is $V(j,i)$, defined for each agent $A(i)$ from the set $A$. Note that "output" here characterizes a production process result, “output” in the sense of final consumption is defined below. Thus, a certain agent $k$ has a coefficient vector $V(j,i=k)$ of his personal outputs that the macro-technology will produce if he takes each of the jobs $M(j)$. Assume that agents “know” their output values. E.g., they experimentally found those values in the past.

Surmise the existence of differences between agents in their skills relative to different jobs. Let there exist a clearly defined agent specialization within the macro-technology set of jobs for the existence of solutions for optimal agent distribution over the jobs. Thus, we do not tolerate that a large number of agents from the set $A$ hold maximum output values for the same macro-technology jobs. A small number of such coincidences will not, apparently, influence the existence of at least one optimal solution.

For the sake of simplicity, for the time being we ignore such variable as agent costs per unit of output. Let all the agents from set $A$ have equal cost values in the process of their activity.

4. At the start point of the interaction scheme, the set of agents will be randomly distributed over the jobs $M(j)$. As a result, for a certain current moment we recorded what output is “produced” by each job. Total output $V$ of the macro-technology $M$ is defined by the sum of values $V(j,i)$ for all the jobs, where $i$ is the number of the agent who took job $j$ (items in this sum are equal to the corresponding output of agents occupying certain jobs). Assume that there exists at least one distribution of agents by the jobs – any deviation from this distribution means diminution $V$ (Pareto optimum).

5. After the total output $V$ on the use of macro-technology $M$ is formed, this final product of the production process becomes a resource for maintaining living conditions and development. Now it is designed for distribution among agents. Let $V$ be distributed in a certain manner over the whole agent's set $A$. Denote the distribution function as $F$. Then the share of total return received by each agent in the process of distribution, is $F(V, A(i))$. Assume that function $F$ is linear by the agent return factors
(i.e., the higher the agent’s output, the higher share he receives in the process of distribution $V$).

**Mental model**

6. Each agent $A(i)$ has a mental model (D. North, 1994, p. 360) of space $P\{A,Z\}$, which we denote as $O(A(i),P)$. This model is initially created and exists in the human mind. The mental model as a result of psychological reflection of the environment by humans, is a copy (to a certain degree of accuracy) of the structure of real space $P$ (including the relationships between agents). The difference of mental model from its real prototype can be equal to zero (in this case, mental model identically reflects all the economic system components as well as their changes in time), or can have significant deviations. To describe the general case, let us introduce the distortion function $C(A(i))$ that can be individual for every agent. Then identity $O(A(i),P)=C(A(i))*P\{A,Z\}$ holds. Let us assume (for simplicity) that there are no distortions, i.e., $C(A(i))=1$.

In our description of the mental model we based on some related research:

According to D. North, “humans perceive the outside world by means of processing the information with the help of pre-existing mental patterns that enable for understanding of the environment and solving the problems arising (D. North, 1997, p.7). "Ideas and ideologies do form subjective mental patterns; with their assistance individuals interpret the surrounding world and make their choice” (D. North, 1997, p.143).

B. Edmonds in his article (Bruce Edmonds) using the techniques close to genetic programming, designs the simulation description of the agent behavior that includes the population of the agent internal models describing the environment that surrounds him. There is also similar research on sharing information to support an evolution of collective actions (Michael Lachmann, Guy Sella, Eva Jablonka).

Mental model will be wholly functional only when there is a mechanism that continuously keeps it in the actual state. For this purpose, information images of partner agents in the mental model should be sufficiently well fit with the state of real partners. Under small group conditions, a member of the group makes an actualization of his mental model via continuous direct information exchange with the other partners. Interactivity of actualization procedure enables to view the mental model as some collectively maintained substance that is not already the product of an individual agent; however, it can exists only in his consciousness. Starting from a certain level of information technology development, mental model can be estranged from the agent's mind to a certain information carrier; after that it becomes one of the objects in the agent information habitat.

Conceptions related to the agent mental model can be implemented as the following interaction scheme items.

7. Mental model $O(A(i),P\{A,Z\})$ is used by agent to design and simulate new configurations of relationships (to take a new "job" in macro-technology) with the
purpose to enhance its output. The deviation of the current agent distribution over the jobs from the theoretically optimal is a reserve of future output enhancement. In the process of using the model agents can find other variants of their distribution by jobs that are more preferable than the current variant by output of each of them. Thus, the agent generates a new configuration of the system’s space in his mental model $A(i): O(A(i),P\{A,Z\}) \to O'(A(i),P\{A,Z\})$.

In his mental model, an agent can construct the variants of changes in the current relationship pattern desirable for himself. This means that, as a result of accomplishing his local task of increasing the return from his activity, the agent is able to define a desirable version of reconfiguring the links between the agents. In the general case, those proposals can pertain not only to relations of a particular agent but any other combinations of relationships. Local optimization task of an agent can be written as: $\max F(V, A(i))$, by variable $V$ obtained by sorting out the set of possible variants $P\{A,Z\}$.

Rather similar approach to the study of social systems based on the agent computer modeling is proposed by S. Moss and B. Edmonds (Scott Moss and Bruce Edmonds). In their work "Modeling Learning as Modeling" they describe how agents can lower the errors in their forecasts via the change in the structural forms of the environment models used by them. This is attained by providing the agents with the opportunity to build the model of their habitat. "Specification of our agents’ models is based on their observations of the data and the success with which their models forecast the needed variables".

**Collective information model of the environment**

8. By definition, one of the aspects of agent interaction under direct information exchange consists in the mutual information on their capabilities and intentions. By means of such information exchange of the “everybody with everybody” type in the real time mode, mental images of capabilities and intentions of each of them become known to all the rest of the agents.

As a result, mental model of each agent is, actually, a certain combination of mental models of all the agents. Information activity of the partners creates their virtual presence in the private mental model of each agent from the set $A$.

Figuratively speaking, each of the partners is “responsible” for the content and actuality of a certain portion of the agent’s mental model. Each model fragment is filled and renovated (with certain accuracy and periodicity) as a result of information activity of one or several agents that have been reflected in the given fragment. Thus, the formal notation for a mental model should be rewritten as: $O(A(i),P\{O(A(l),P\{A,Z\}),Z\})$, for all values of $l = 1,\ldots,n$, but not equal to $i$. 

![Fig. 7.](image-url)
9. It has been already discussed above that there are several parameters that determine if a direct information exchange within the given agents' group is possible at all. In this connection, assume that information exchange intensity combined with the intensity of changes in the states of agents and other objects of space $P$, as well as the ability of each agent from set $A$ to process the information, are sufficient for the direct information exchange being necessary for maintaining the mental models of each of the players in the actual state. If this is feasible, than within the given agents' group there should be a tendency to the increased similarity of their private mental models.

Assume that the whole set of agents constructs and plays through the possible variants of reconfiguring the relationships between them in the form of a unified, collectively maintained information image of their habitat. Let us denote such image as “collective information model" of an economic system (their living environment). In the general case, this information model is stored in the mind of each agent; however, other variants are also possible.

Assume that the information technology development level makes it possible for the agents to estrange their mental models into the outside environment in the form of certain information objects. If this is done by a unified “standard”, then it is possible to make a composition of the set of such information objects. As a result, the agents receive information model of the system that exists as a substance being outside their consciousness. In a sense, internal models of the agents are materialized as an external model common for all the agents from set $A$. In this case, we can speak of the existence of a virtual variant of the model in addition to its mental variant.

It is characteristic of the interaction process under the direct relations between agents that they “discuss” their actions between themselves, “agree” upon mutually acceptable actions and then “coordinate” their joint activity that they agreed upon. Subject to our hypothesis on the existence of such a substance as “collective information model of a system”, the general outline of interactions described above could be specified as follows:

Agents estrange their proposals on the new variants of activity and preferable re-combinations of their relationships into the information space of an economic system. The totality of such proposals received from all the agents of the system constitutes the domain of choice that is accessible for each agent. Agents assess the acceptability of existing proposals and make their own that, in their turn, are also evaluated by the rest of the agents. If the agent community identified in its domain of choice a mutually acceptable variant of reconfiguring their relationships, then the above variants is moved to the implementation stage; the collective model of relationships formed here, is further used for the current coordination of practical activity.

**Organizational mechanism**

10. If the agents have built a new information model of their living system that would provide for the higher output from their activity compared to the current system, the real system is changed in accordance with this model. Here, the pattern of information
links established by the agents in the process of formation and coordination of the new information model of the system, becomes the prototype of organizational structure and the basis for organizational mechanism. This mechanism would ensure the maintenance and support of the new link system (organization) in the process of its practical use.

Thus, institutional mechanism having accomplished its function on moving the agents from the "free" to the "bound" state, as a final result of its work, provides possible all the necessary components that agents need for starting their joint activity within a particular established organization.

**Material and information sub-spaces of interactions**

Going back to the content above on institutional structures as sub-spaces of agents' interactions, we can note that there are also two another sub-spaces that mediate different kinds of agent activity:

First - material – includes real processes of creation, distribution and consumption of resources.

Second - information – is the result of mental (psychological) reflection of the first sub-space. It includes the processes of forming the information image of the environment as well as collective construction by the agents of a new information image of the first sub-space on this basis.

Agents form in the information sub-space the image of a new desirable material space and then rebuild the latter in accordance with this image. There is a certain cyclic recurrence in this process: information images of new links and types of agents' activity being born in the second sub-space, are partially materialized within the structure of the first sub-space changing its current state. On the other hand, the new state of the first sub-space being reflected in the agents' mind, becomes the basis for generation of new states and information images filling the second sub-space.

In compliance with those sub-spaces, agents network of links formed at the “exit” of institutional mechanism, can also be divided into two types: first – network of links for resource exchanges, second – for information exchanges.

7. **General picture of economic system functioning through information interactions**

It was concluded above that institutional frameworks shield the corresponding sub-space from the excessive mutability of the objects in real environment, filter information flows and set the space-forming rules common for all the participants. If the agent activity is localized mainly within the above limitations, he can have a wrong impression that this is the true reality. In principle, the differences between a sub-space and reality (e.g., degree of slow downing the real changes in it) can be noticed and assessed only by an outsider observer (here there are associations with
specific features of observer perception of the worlds in the relativism theory from physics).

The sub-spaces created by institutional structures can be ordered according to the multiplicity principle. Multiplicity of sub-spaces is explained by the fact that each new subspace is created as a means of forming the conditions for interactions that are technically impossible in the current sub-space. As mentioned above, there is a "natural" space for agent interaction corresponding to the internal environment of a small group. It would be logical to start from this natural space the examination of the necessity of creating the sub-spaces and their multiplicity. It was previously noted that it could be divided into 3 zones: 1) strong; 2) medium; and 3) weak interactions. The natural space is the first zone (strong interactions).

In the first zone, information exchange intensity for coordination of changes in the state of the participants of joint activity is kept within the current technical limitations on information exchange. Owing to this, agent can maintain the collective model of the environment in the actual state and rehearse possible variants of joint activity. The collective model of environment in this case coincides with the model of each individual participant in the first zone. By definition, group of agents located in the first zone does not need to create additional subspaces to interact between themselves.

Outside of the first zone agents can not build the real time collective model. Collective model of the environment for a certain agents group can form when the agent interaction intensity inside this group is not lower than intensity of the changes in the state of agents themselves. The conditions for existence of the collective model of environment in general looks as follows:

a) Each agent has a certain set of his own information images related with a set of institutional structures. These images have different quality of the picture of agent's capabilities and intentions. The images create a set of channels for agent interactions.

b) The set of private mono-quality information images belonged to the same institutional structure can be transformed into a collective model of the environment for the given group of agents. But only if the possible information exchange intensity between those agents is higher than the intensity of changing by the agents of their information images of the given quality.

In the second zone, technical limitations on information exchange make possible the interactions that are based on mainly unilateral information exchange, and, as a consequence, equal coordination of joint activity is already impossible. In this case, the agents positioned in the second zone relative to the observer receive from him the ready-to-use model of the environment (it could be, for instance, designed by the observer himself or by a group of agents from the first zone). Thus, for some agents the environment model coincides with their individual models (this agents group represents management); for another group their own models are defined by the “directives” and, therefore, correspond to certain fragments of the environment. In such situation, the capabilities of “subordinates” are underused; under certain circumstances, however, this can be compensated by substantial economic benefits owing to higher specialization of the participants of the given joint activity.

Interaction participants in the second zone can have significant gains from the joint
activity even without the introduction of additional sub-space. However, there is a reserve in their interactions related to the underused capabilities of a portion of participants; this represents a certain incentive for searching for the acceptable compromise between the three components:

1) costs of creation and maintenance of a sub-space that enables equal interactions between all the participants of the joint activity;

2) gains from the equal position of all the participants in the formation of environment model and coordination of their activity;

3) losses related to the inevitable partial inadequacy of the sub-space to the real processes of changes in the economic system.

Under certain conditions (e.g., with specialized education and training of managers, and under weak mutability and “standardization” of capabilities and intentions of the subordinates), a group of managers can create and maintain a model of environment that will be close to the best of the possible variants without introduction of a special sub-space. Thus, incentives of agents from 2nd zone for creation of new interaction subspaces theoretically exist, but they can happen to be insufficiently strong.

In the third zone, direct information exchange and, consequently, direct coordination of the agent joint activity, are not possible. Stochastic changes in the state of all the objects of economic system devalue information flows by the moment when they reach the border of zone three. Thus, particularly to organize the interaction between the observer and the agents located in zone three, it is necessary to establish a special sub-space. This is an artificial (compare with the "natural" space of interactions) sub-space created by an institutional structure. Functionally it is a projection of real space onto another, less mutable "coordinate axes". Therefore, the above sub-space can be considered as the first level of a hierarchy of the real space projections.

In the general case, it can happen that the first projection does not provide the agents with all the necessary prerequisites for interaction. Suppose that economic system has sufficiently large scale. Then the observer positioned in a certain point of the first sub-space has three zones of interaction (A', B' and C'). Their meaning is identical to the described above zones A, B and C. If the border of the third zone in the first sub-space is distant from the economic system boundaries, the agents have to construct institutional framework in order to create a projection of the second level. It is clear that this situation can be repeated to substantiate the necessity of the third sub-space, and so on.

Thus, the number of sub-spaces required for the agents to organize interactions between themselves within the framework of the entire economic system, depends on the following parameters:
1) the scale and scope of economic system;
2) ICT development level that ensures a certain degree of information exchange;
3) mutability extent of the objects in the system.
8. Economy as a complex system of agents with information interactions

In all cases before we understood the term "agent" as a human who is an actor of social processes. Now we should make the sense of the term a little wider because we are going to rewrite our scheme of information interactions under the "agent-based computational economics" method (Leigh Tesfatsion; Philip E. Agre).

According contents of previous sections we will describe "interactions of autonomous agents channeled through socio-economic institutions" (Leigh Tesfatsion) where types of agents include following:
1) Macro-technology;
2) Information space;
3) Institutional structure;
4) Collective information model of environment;
5) Human participant of interactions (he is an "agent" in narrow sense of this term).

From our point of view each of these five agents has much or less human component because they functioning realize through certain human activity. So when we define five types of agents here we distinguish some kind of specific human activity related with each of the agents.

To be more precise in terms let the fifth type of agents ("human participant") will be called as a "sizer". The same name has some similar models of self-replicated objects from mathematical genetics. See a survey on "self-replication" topics in (Moshe Sipper).

Summarize all above we can define the main functions and features of selected five types of agents ("what these agents produce in the system"). At the first step of building an agent-based model of the complex socio-economic system in the framework of our methodology we, of course, make some simplifications:

1. "Macro-technology" agent produces a resource for sizers' living. The quantity of the resource depends on parameters of sizers' distribution over the set of jobs belonged to the macro-technology. Sizers' optimizing behavior that looks in our case as their wish to find the best distribution leads the whole system of agents to an equilibrium state. In principal the system can have several parallel macro-technology agents.

2. "Information space" agent produces for each sizer in the system a perimeter of the zone of his environment where he can recognize a sub-set of sizers for interactions (choice area). The boundaries of the choice area depend on the ICT development level and on the strength of changes in the system (including sizers' states). So then more steady stable state sizers have then in average their choice area is wider. This agent makes local a sizer's searching of optimal distribution over the set of jobs. In general the system has only one agent of this type.

3. "Institutional structure" agent produces a sub-space for sizers interactions. Such sub-space defines rules of sizers' information images building and makes a certain simple projection of macro-technology set of jobs. By this way sizers can get wider
choice areas from the "information space" agent and in result they have more chances to find their optimal distribution over the set of jobs. The system can have several agents of this type.

4. "Collective information model" agent produces the best (and Pareto optimal) plan for changing current configuration of sizers' distribution over the set of jobs. It works similar to "how agents are learning about other agents" (Jose M. Vidal, Edmund H. Durfee). This agent appears for each group of sizers those "see" each other in their choice areas. The same picture takes place for each parallel sub-space created by "institutional structure" agents. Sizers exchange through the collective model by their suggestions on re-configuration of current distribution over jobs. The best (by output) suggestion registered in the collective model to the end of time for sizers' "discussions" becomes a real configuration of jobs distribution for the next production cycle.

5. "Sizer" agent produces the maximum of his output by changing his place in the macro-technology chain. He can also initiate the same changes for other sizers from his choice area. His suggestions will produce the real growth of his output if it approved by other sizers from his choice area (criterion is Pareto optimum). He can choose different sub-spaces to "discuss" with other sizers of the system how they can get a better output. The system can have many agents of this type.

General relations between these types of agents see at the Fig. 8.

Fig. 8.

Green boxes on the Fig. 8 mean types of agents. Yellow boxes – intermediate objects of the system that help to show relations between agents. As one can see on the Fig.8 the central element of the system is the "collective information model" agent. A set of
these agents provides the main process of the system functioning (information interactions between sizers) and reflects current states of macro-technology, institutional structures and sizers themselves. The "information space" agent specifies the precision of this reflection and its boundaries.

More detailed working out of the model should be plunged into a framework of the appropriate modeling method. It could be well-known SWARM method (http://www.soc.surrey.ac.uk/JASSS/1/2/4.html) or more mathematically well-developed TAO (http://www.rriai.org.ru/TAO/).

Conclusion

We suppose that following statements was enough argued in this article:

a) Rapid development of Information Society and its Networked Economy attracts attention to the role of information interactions in functioning of social systems. Information interactions are the more fundamental level to describe a functioning of a social and economic system then market or hierarchical interactions.

b) Central element of agents' information interactions is "collective information model" of their environment.

c) There are some limits on information interactions related with parameters of economic system.

d) Institutional structures are able to channel information interactions beyond the limits. Market and hierarchical interactions are just special cases of such channels.

e) Simplest model of economic system functioning with information interactions includes five types of objects (macro-technology, information space, institutional structures, collective information models, and human actors).

Now we are well prepared to make the second step to building of the general model of the socio-economic system and learn its features. The main target here is the general model of an economy functioning combined descriptions of different economic mechanisms (like market, hierarchy, small group and other) under common logical scheme. Research on "how institutional structures exist and work" has the special interest in this framework. It seems our concept can also help to get new responses on questions like "What is the role of institutions and how are they related to the aggregated performance of the socio-economic systems? What is the relation between institutions and the behavior of the agents?" (Jose Castro Caldas and Helder Coelho).

Another research direction in using of this methodology is the Agent-Based Social Simulation. This work should include "Methodologies and software engineering for agent systems" and "Intelligent information agents" topics. Research task is designing of more efficient "living environment" for information robots and software agents served some kind of online communities (like e-commerce, e-business, researchers networks, and so on).
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