Socio-Economic Coordination Mechanisms Design: Conceptual Model

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Abstract

This study discusses socio-economic coordination mechanism design, which allows, in comparison with the classical mechanism design theory, to obtain a wider class of solutions, but with the loss of the ability to use the mechanism design's mathematical models and methods. The concepts of the coordinating activities and the basic forms of coordination of socio-economic agents are defined. The fundamental coordination process, which is present in all coordinated systems, is described. On this methodological basis the prerequisites, fundamentals and properties of socio-economic coordination are considered. A conceptual model of coordination is proposed, including a three-step algorithm for the coordination mechanism designing. As illustrations, based on the proposed algorithm some of the well-known coordination mechanisms are considered. Using the conceptual model of coordination, possible changes in the design and properties of coordination mechanisms because of the digitalization of socio-economic processes are analyzed. It is shown that digitalization leads to the convergence of the characteristics of basic forms of coordination and to the unification of their elements in digital form. This opens the possibility of creating a distributed computer system that performs the functions of a universal coordination mechanism. As one of the directions for the further development of this study, the creation of a computer agent-based simulation model of economy/society with the embedded coordination mechanisms is proposed. The possibility of creating a unified model and general theory of socio-economic coordination, which can serve as the methodological basis for creating a general theory of socio-economic activity, is discussed.

Keywords: mechanism design theory, coordination mechanism design, conceptual model

JEL: P0, O1, O3

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1. Introduction

Hurwicz and Reiter define economic mechanisms, including decentralized ones, as “a formal entity intended to represent a system for organizing and coordinating economic activity” (Hurwicz & Reiter, 2006, p. 14). There are no indications in the mechanism design theory that economic coordination mechanisms such as market, hierarchy, network (Adler, 2001; Powell, 1991; Provan and Kenis, 2008; Weigand at al., 2003) and their hybrids (Ménard, 2004) cannot

be considered as examples of the economic mechanisms. Therefore, the coordination mechanism, following the description of the economic mechanism (Hurwicz, 1973), should consist of the "response rules" and the "outcome rules". In addition, as Hurwicz points out, the "language" that is used to exchange information is important: "…in the Walrasian tatonnement process the language consists of prices and quantities demanded or supplied by various agents" (Hurwicz, 1973). He also mentions that to design a coordination mechanism, it is necessary to consider a class of environments, which should be covered.

This description, in general, corresponds to an intuitive understanding of how coordination mechanisms can work. However, such a description is a significant simplification of the essence of coordination, since it does not reflect important features that specify the content of, for example, well-known mechanisms such as the market, hierarchy, and network (Adler, 2001; Powell, 1991; Provan and Kenis, 2008; Weigand at al., 2003). If the mechanism design theory claims to be a complete description of economic mechanisms, including the coordination mechanisms, it must explain from the unified methodological basis the diversity of coordination processes and mechanisms observed in the economy.

In the mechanism design theory the rules of the auction and the metaphor of the auctioneer, which activate the coordinating function of the mechanism, are very important: "... any subject, observing the prices of all goods, determines its optimal volumes of production and consumption and reports them to the auctioneer. The auctioneer calculates the total supply and demand and informs all subjects of a new vector of prices for all goods..." (Izmalkov et al., 2008). However, it is more realistic to assume that the specific activity by which coordination occurs is performed by all agents and it is quite heterogeneous. For example, from a review of definitions of coordination (Weigand at al., 2003), it follows that this specific coordinating activity can mean: to perform "structuring"; "achieving the concerted actions" or "interconnecting differentiated sub-units"; "composing purposeful actions"; carry out "adaptation" or "integration"; perform the "reconciliation". Market coordination also requires coordinating activity from each agent, which involves collecting and analyzing various market information, using the "trial and error" method or "Walrasian tatonnement" to find the best market action. An important point is that the coordinating activity is an agent's individual costs, which reduce his benefits from economic activity.

The mechanism design theory ignores important features of socio-economic coordination. It does not take into account that, depending on the coordinating activity, the coordination mechanism may produce different characteristics of coordination. Differences in the characteristics of coordination, ceteris paribus, are manifested in different amounts of benefits for agents from their activities. For example, the greater number of participants can act in concert in their economic activity, the higher the likelihood of additional benefits for each participant due to the development of their specialization and division of labor. On the other hand, the higher the quality of coordination, measured, for example, by the completeness of taking into account the factors important for the joint activities of agents, the higher the probability of growth in the benefits of agents from their joint activities. Thus, by changing only the characteristics of coordination, agents can receive more benefits from their activities. These and other features of socioeconomic coordination that determine the research tasks for this study are considered in Section 2.

Proposed by Hurwicz (Hurwicz, 1973), developed in (Maskin & Sjöström, 2002; Jackson, 2001; Hurwicz & Reiter, 2006) and others, the mechanism design theory had a great influence on the development of Economics and with its help many important practical problems were solved (Izmalkov et al., 2008). However, when applied to the analysis and design of socio-economic coordination, it allows us to consider only particular problems. The fundamental scientific

problem, which is associated with the limited application of the mechanism design theory for designing coordination mechanisms, is the lack of a general methodological approach to the description of coordination. Almost 30 years ago, the authors of a study on coordination theory wrote: “Are there fundamental coordination processes that occur in all coordinated systems?” (Malone & Crowston, 1994). Thus, the first step towards creating a theory of the coordination mechanism design is to identify common methodological grounds for explaining the various manifestations of coordination.

The proposed study sets as one of its goals the identification and description of the fundamental process of coordination, which provides a general methodological basis for the analysis of various manifestations of coordination. The approach from (Parinov, 2023) was used as the basis for this analysis, in which socio-economic coordination is considered as the natural ability of agents to consider the activities of other agents.

Agents realize their natural ability to take into account the activities of other agents through their direct and/or indirect communications with each other. They use their consciousness as a tool to take into consideration the activities of other agents. The proposed study considers the agent's consciousness in the form of his individual and shared (collective) mental model, which concept is being developed in the Cognitive Sciences (Johnson-Laird, 1980; Mantzavinos et al., 2004; Badke-Schaub et al., 2007). The mental model in this case is a kind of "computer" in the mind of the agent, which, based on the information received, determines the content of his activity.

Depending on the communication modes, agents, due to the properties of their mental models, have the following abilities to take into account the activities of other agents (Parinov, 2023):

1) the ability to negotiate "who does what" in the presence of direct communications with each other;
2) the ability to stigmergy[1], if there are no direct communications, but indirect ones are possible;
3) the ability to use common rules in the complete absence of communication regarding the coordination of activities.

The proposed study is based on the hypothesis that the coordination of socio-economic activity of agents is created as a result of the use by agents of the three different-quality abilities of their mental models described above to take into account the activities of other agents. From this hypothesis follows the fundamental process of socio-economic coordination that occurs in all coordinated systems. Thus, the observed variety of methods and mechanisms of coordination is the result of the selection by agents of combinations of their three abilities for taking into account the activities of other agents (i.e., the basic coordination forms) in order to obtain the best result from coordination. The best combinations of the basic coordination forms are determined by the peculiarities of the types of coordinated activities of agents, differences in the goals of agents and in the conditions for the implementation of activities. This approach allows one to identify and analyze the fundamental foundations of socio-economic coordination, which are discussed in Section 3.

The considered fundamental foundations of coordination are used in Section 4 to create a verbal version of the conceptual model of socio-economic coordination, including a description of the algorithm for coordination mechanism designing. As illustrations, using the proposed conceptual model and algorithm, the design for some well-known coordination mechanisms have been considered (in a simplified form). Comparison of the proposed conceptual model with the

[1] Stigmergy is a mechanism of indirect coordination, through the environment, between agents. The traces left in the environment by an individual agents’ actions stimulate the performance of a succeeding action by different agents.

Hurwitz's mechanism design showed that the conceptual model provides a more detailed and accurate description of the economic mechanism in cases if it is the coordination mechanisms. With certain simplifications, the proposed conceptual model of the coordination mechanism can be reduced to a classical description of the mechanism design.

Section 5 considers one of the possible applications of the conceptual model of socio-economic coordination: analysis of changes in the properties of the coordination mechanism in connection with the digitalization of coordinating activities. The analysis showed that digitalization leads to convergence of the properties of the basic forms of coordination and to the unification of their elements in digital form. Under these conditions, the use of basic forms of coordination is largely determined by their unique characteristics. For example, the use of direct communications ensures the dominance of collaboration among agents. The use of indirect communications gives the dominance of competition. The use of common rules in the absence of communication means a neutral mode of joint activities. In addition, complex and deep digitalization opens the possibility of creating a distributed computer system that performs the functions of a universal coordination mechanism, common for all types of social and economic activities of agents.

Section 6 discusses possible methodological prospects for creating a unified model and a general theory of socio-economic coordination, the development of which is the contribution of this study. The conclusion is made about the primacy of coordination mechanisms in relation to the economy, from which it follows that the properties of economic coordination mechanisms determine a significant part of the properties of the economy. The methodological consequences of including in the scientific picture of the socio-economic world the activity of agents in designing the coordination mechanisms are discussed: clarification of the general structure of human activity, the hierarchy of motivations for maximizing human activity and the properties of an abstract socio-economic man.

In conclusion, directions for further research are briefly discussed, including the transformation of the conceptual model into a computer agent-based simulation model of coordination with the possibilities of endogenous design of coordination mechanisms. It is expected that such a computer model will make it possible to explore both ways to improve coordination mechanisms and related possible changes in the properties of the economic system. The results of this study in general provide a background for building a general model and a theory of socio-economic coordination. Given the important role of socio-economic coordination in human activity, the emergence of the general coordination theory makes it possible to discuss the possibility of creating a unified model of socio-economic man (Homo Socio-Economicus) and a general socio-economic theory.

2. Research problem statement

Considering the problem of designing the economic coordination mechanism, one may assume that the study of this problem should be based on the existing mechanism design theory, since the theory offers a rather abstract model of the economic mechanism. See, for example, (Izmalkov et al., 2008). However, it should be noted that in the key publications on the mechanism design, e.g., (Hurwicz, 1973; Jackson, 2001; Maskin & Sjöström, 2002; Hurwicz, & Reiter, 2006), the term "coordination mechanism" is not mentioned and coordination is not considered separately, although in in a certain sense is implied[2]. It can be assumed that the authors of this theory do not see the possibility within the framework of the proposed approach to take into account the observed features of various mechanisms of economic coordination, the

[2] The economic mechanism is "a formal entity intended to represent a system for organizing and coordinating economic activity" (Hurwicz & Reiter, 2006, p. 14)

most famous examples of which are the market, hierarchy, network (Adler, 2001; Powell, 1991; Provan and Kenis, 2008; Weigand at al., 2003) and their hybrids (Ménard, 2004).

At the same time, the initial message of the mechanism design theory, which Hurwitz formulated as "… finding a system that would be, in a sense to be specified, superior to the existing one" (Hurwicz, 1973), is currently extremely relevant in relation to existing mechanisms of coordination. It is intuitively clear that coordination mechanisms are largely based on the processes of exchange, collection, processing and analysis of information. All information processes are currently radically changing under the influence of modern information and communication technologies (ICT) due to its virtualization and digitalization. The ongoing deep and comprehensive digitalization of socio-economic processes means the inevitable digital transformation of existing coordination mechanisms. To understand and manage the digital transformation of coordination mechanisms, a theoretical tool is required that describes the fundamental nature of various manifestations of coordination and allows one to analyze the directions and methods of digital modernization of economic coordination mechanisms. In this case, it will be possible to solve the problems of designing "digital" versions of mechanisms that will, in a certain sense, superior to the existing coordination mechanisms. To create such a theoretical tool, it is required, among other things, to determine what features of the coordination and its mechanisms the theory of mechanism design does not take into account or does not fully take into account. Such an analysis will clarify the statement of the problem of this study.

It is important to note the significant methodological feature of this study in considering coordination. The proposed approach, in a sense, is between, on the one hand, the strictly formalized content of the mechanism design theory, and, on the other hand, quite general ideas about the economy and society developed in the publications of Yuval Harari (Harari, 2014; 2018), in which Harari refines and develop of the traditional picture of the socio-economic world. The proposed study of coordination is both: a conceptual refinement of how the mechanism design theory presents the economic coordination and an attempt to interpret and detail Harari's concept of the "imagined order" as the coordination. This is possible because Harari's "imagined order" is the only way in which vast human masses can cooperate effectively and forge a better society (Harari, 2014). This concept and its properties, as described by Harari, have much in common with the properties of the system of coordination of socio-economic activity in the form considered in this study.

From a comparison of coordination with the "imagined order" it follows that the scope of the proposed study should be extended to all types of socio-economic coordination. Economic coordination, in this study, is considered as a special case of socio-economic coordination.

2.1. Imagined order and socio-economic coordination

Imagined order arises in the same way as coordination: "The ability to create an imagined reality out of words enabled large numbers of strangers to cooperate effectively" (Harari, 2014). Regarding coordination, it must be added that the imagined reality that allows people to work together is created in their mental models through the information exchange, carried out in a variety of ways, and as a result of this making individual mental models in a certain sense shared (collective).

Harari notes: "… to safeguard an imagined order, continuous and strenuous efforts are imperative" (Harari, 2014). The same is true for maintaining coordination, since it requires constant human efforts, which in this study is considered as "coordinating activity".

Coordination, like the imagined order, arises and exists only in the imagination (consciousness) of people. It is a product of their mental models, which have evolved from individual to collective models by people's communications. At the same time, although coordination is a product of consciousness, it is closely connected with the real world, since in their mental models people operate with the mental reflection of the world. Harari argues in this regard that the "imagined order is embedded in the material world" (Harari, 2014).

Harari wrote: "The imagined order shapes our desires" (ibid.). The result of coordination, in turn, is a certain content of people's activities, which can be represented as a certain structure of desires associated with the implementation of this activity. Coordination, like the imagined order, is subjective in nature, but encompasses a multitude of interacting agents. For Harari, the imagined order is "inter-subjective", since it is "existing in the shared imagination of thousands and millions of people" (ibid.). Similarly, coordination, which as the coordinating activity is produced by the shared mental model of individuals.

Harari's reasoning why people usually fail to notice that "imagined order" exists only in their imagination also explains the popularity of Hayek's view that coordination is a spontaneous process leading to the emergence of spontaneous order (Hayek, 2006). The perception of coordination as the emergence of spontaneous order according to Hayek corresponds to what Harari defined as "artificial instincts that enabled millions of strangers to cooperate effectively". These instincts were formed in humans as a result of their training "to think in certain ways, to behave in accordance with certain standards, to want certain things, and to observe certain rules" (Harari, 2014). Performing coordinating activities by following the instincts, people often do not fix what their actions lead to coordination of their joint activity, and this gives them a feeling of the emergence of coordination as a spontaneous order.

The inter-subjectivity of the imagined order implies that it can be changed only by changing the consciousness of a billion people at once (Harari, 2014). The same can be said for the coordination process that serves large communities. For example, the global market or the system of the international division of labor. In this regard, the ubiquitous digital transformation of human activity promises a significant reduction in the complexity of the task of changing the "imagined order" and corresponding coordination processes. The digitalization of people's mental models and the transfer of their communications to a virtual environment opens the possibility of maintaining the imagined order and the coordination with the help of computer algorithms, changing which for any number of participants is a much simpler task. Network and computer algorithms can form some tools for all of humanity, which will collectively own all the data and manage the future development of life (Harari, 2018).

It should be noted that Harari also wrote about the high risks of possible negative consequences for the economy and society from uncontrolled changes in digitalization processes (Harari, 2018). It causes concern that the modern ICT, including artificial intelligence, increases the degree of connectivity and interdependence of socio-economic agents, which is needed to improve socio-economic coordination, but it can have possible negative consequences for socio-economic sustainability. With these concerns, building a model of socio-economic coordination would allow one to investigate such dangers and help find solutions acceptable to humanity.

The following parts of this section provide the research problem statement needed for building a model of socio-economic coordination. It includes the development of Harari's ideas about the imagined order in the spirit of socio-economic coordination and the discussion of important aspects of coordination that are not taken into account or not fully taken into account by the mechanism design theory.

2.2. The main and coordinating activity

One of the aspects of this study is the expansion of the field of analysis in comparison with the content of the mechanism design theory, which, for example, cannot describe by the single model all known mechanisms of coordination. Therefore, it is required to develop an approach that will allow one to explain the diversity of processes and mechanisms of coordination observed in the economy from a unified methodological basis.

A list of some definitions of the socio-economic coordination from (Weigand et al., 2003) can illustrate the variety of observed manifestations of coordination:

- Coordination is structuring and facilitating transactions between interdependent components;
- Coordination consists of the protocols, tasks and decision-making mechanisms designed to achieve concerted actions between interdependent units;
- Coordination describes the integrative devices for interconnecting differentiated sub-units;
- The joint efforts of independent communicating actors towards mutually defined goals;
- Networks of human action and commitments that are enabled by computer communications technologies;
- Composing purposeful actions into larger purposeful wholes;
- Actions and decisions of individual actors within an organization which need to be timely attuned for the organization as a whole to realize its aim;
- The integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal;
- Coordination is the act of managing interdependencies between activities performed to achieve a goal;
- Establishing attunement between tasks with the purpose of accomplishing that the execution of separate tasks is timely, in the right order and of the right quantity.

The list of the coordination definitions is certainly not complete without mentioning the "invisible hand" of the market coordination that regulates the supply and demand balance through the price changes. Another example of coordination, also not explicitly mentioned in the list above, is the coordination in accordance with common rules, which are developed, for example, by the mechanism design theory in the form of auction rules.

With the obvious heterogeneity of the noted manifestations of coordination, the mechanism design theory makes it possible to describe those in which the main principle of action is the implementation of established rules by agents (e.g., proposed by Hurwitz the rules of “responses” and “outcome”). An example of coordination, which this theory explains the worst, is the action of the network method of coordination (Parinov, 2023), in which the main principle of coordination is the agents’ negotiation based on the “all with all” direct communications about “who do what” in their joint activities.

As a first step towards creating an approach that will make it possible to explain the diversity of processes and coordination mechanisms observed in the economy from a unified methodological basis, we will make some clarifications on the nature of the activities carried out by socio-economic agents. We distinguish two types of socio-economic activity:

1. The main socio-economic activity, which is the object of coordination, and which brings agents a certain benefit.

2. The coordinating activity, which is certain specific efforts of agents necessary for the emergence of coordination.

If the first type of activity is obvious and self-explanatory, then the existence of the second type is often ignored. Examples of coordinating activities in the list of coordination definitions above are the mention that agents need to perform “structuring and facilitating”; "achieving the concerted actions" or "interconnecting differentiated sub-units"; “composing purposeful actions”; carry out "adaptation" or "integration"; perform the "reconciliation". Market coordination also requires certain coordinating activity from each agent, which involves collecting and analyzing various market information, using trial and error or "Walrasian tatonnement" method to find the best market action. Using the common rules, agents also make the coordination activity to bring their actions in accordance with the given rules, track when the rules change, etc.

The division of the agents’ activity into the main one, which brings them benefits, and the coordinating activity, which sets the coordination in motion, is important for describing the nature of socio-economic coordination. About this, Hurwitz and Reiter wrote: “... economic activity encompasses activities that are neither production, consumption nor exchange. … These activities include acquiring information, processing information, and communicating information to or from others. Resources used in these activities are not available for use in production or consumption” (Hurwicz, & Reiter, 2006, p. 15). These agents’ activities are additional to the main one, and called in this study as the coordinating activity, is necessary for agents to take into account the activities of other agents and determine the content of their main activity. Like the main activity, the coordinating one requires constant efforts from agents, because due to regular unpredictable changes in the conditions for the main activity, agents constantly must maintain the main activity in a coordinated state. Coordinating activity is the costs that reduce the overall benefit of agents from their main activity.

This study assumes that agents can consciously design and improve coordination mechanisms, which is another of their specific activities. By analogy with the imagined order, coordination is inter-subjective, i.e. changes in coordination methods must be preceded by a certain collective activity of agents. Collective improvement of coordination mechanisms means that agents need to perform two types of activities, which are also costs that reduce the overall benefit of agents: a) activity to design and improve coordination mechanisms, which can be constant for agents over time; and b) coordinating this collective design activity, i.e. the second order coordinating activities. In this study, these two additional types of agent activities and their associated costs are not considered.

Accounting for differences in the main and coordinating activities is necessary for a more complete reflection of the factors that form the benefits and costs of agents associated with coordination.

2.3. Main characteristics of coordination

Coordination as a process can have different characteristics. In this study the main characteristics are: 1) the number of participants whose coordination of activities is supported by a given coordination mechanism; and 2) the quality of coordination provided by the given coordination mechanism.

For example, in economic activity, the benefit of agents depends, among other things, on the deepening of their specialization and the development of the labor division by including as many participants as possible in economic activity. Under these conditions, coordination mechanisms

that differ in the number of participants for whom they provide coordination give agents different benefits, other things being equal. Therefore, the design of the coordination mechanism, which allows it to coordinate more participants and thereby provides additional benefits to each participant, is preferable to others.

Another example relates to the "quality of coordination" that the coordination mechanism can provide. Let the quality of coordination be measured by taking full account of important factors and conditions for the joint activities of agents. The higher the quality of coordination provided by the design of the coordination mechanism, the higher the degree of consideration in the process of coordination of the opportunities for joint activities that agents have and, consequently, the higher the likelihood that agents will receive additional benefits from their joint activities.

For economic activity, these two characteristics of the coordination mechanism directly affect the agents' benefits. Considering the desire of agents to maximize the benefit, these characteristics can be used as variables of the objective function in the coordination mechanism design model. The model of the mechanism of socio-economic coordination, which takes into account such characteristics, in comparison with the mechanism design theory, will allow a more complete analysis of the interdependence between the benefits of the main agents' activity and the values of the coordination mechanism characteristics by which the main activity is coordinated.

2.4. Dependence of coordination on ICT

The agents' benefit amount as a result of their main activity is traditionally presented as a certain production function, the arguments of which are various economic resources and factors. The result of the coordinating activity (CA) of agents, which consists of determining or clarifying the content of their main activity, is, among other things, a function of ICT characteristics. The role of ICT is to provide agents with the means of exchanging, collecting, processing and analyzing information both about the activities of other agents and about the conditions for their activities in general. Based on this, two main components can be distinguished in the composition of the CA:

1) communication with other agents to obtain up-to-date information about the conditions for their main activity;

2) determination, based on the information about conditions, of the content of the agents' main activity and its dynamic adjustment when the conditions change.

The first component of the CA is determined by the current capabilities of information exchange technologies, which set for each individual agent three main states of his communications with all other potential participants in the main activity:

a) direct communications are possible;
b) direct communications are impossible, but indirect ones are possible;
c) communication is impossible.

Let us assume that for each participant in the joint activity (let us call him an "observer") all other agents at each given moment of time are distributed among three groups with the communication states listed above. An observer has direct communications with one group of agents, indirect communications with another group, and no communications with all the others. The natural ability of a human person to negotiate in direct communications, to observe in

indirect communications, and to use common rules in the absence of communications allows the observer to obtain and use the information that he needs to determine the content of his activities with agents from all three groups, regardless of the total number of agents. Differences in the possibilities for exchanging information with agents from three different groups determine the differences in the characteristics of coordination of the observer's joint activities with participants from the corresponding groups.

The desire of agents to maximize the benefits from the main activity is manifested in this situation as their search for the Pareto optimal distribution of all participants in joint activities between three groups with different communication state and coordination methods. As a result of such Pareto optimal distribution, for any agent-observer each his group should contain agents the joint activity with whom produces benefit that cannot be increased without reducing the total benefit. An additional opportunity to increase the benefit is also the minimization of CA costs, which is discussed below.

The model of the coordination mechanism, which takes into account the existence of three main communication states, makes it possible to explain the differences in the characteristics of coordination. Such a model provides the unified methodological basis for explaining the different manifestations of coordination. The approach to consider the influence of the three main communication states on coordination complements and develops ideas about the role of information exchange processes that are used in the mechanism design theory.

2.5. Computing capabilities of agents and the intensity of stochastics

The second component of the CA noted above is responsible for determining (calculating) the content of the main activity of agents based on the information received from the first component of the CA. The performance of the second component of the CA depends on two factors:

1) the intensity of unpredictable changes (stochastics) in the conditions for the activities of agents, since such changes may invalidate the information used in calculations of their main activity content;

2) computational capabilities of agents that determine the minimum amount of time required to process incoming information flows into decisions about the content of the agents' main activity.

Unpredictable changes (factor 1 above) can destroy the already achieved coordination or make meaningless the current calculations of the agents' main activity content. In such a situation, agents must repeat the procedure for calculating the content of their main activity from the very beginning. The high intensity of such stochastic events, which does not allow agents with the available computational capabilities (factor 2 above) to get a decision on the content of their main activities, means the impossibility of achieving coordination.

The intensity of stochastics (unpredictable changes), as well as the computational capabilities of agents, at a given point in time, are exogenous parameters for agents. However, in order to achieve coordination, agents can adjust the quantity and quality of information they use to calculate the content of the main activity. By simplifying the information used in mental models, agents can reduce the time required for computation and thus ensure the coordination of the main activity and receive benefits from it. This is discussed in more detail in the next section.

The desire of agents to maximize the benefit in this case is manifested in the search for an acceptable level of information simplification. The degree of simplification in this case is

determined by two conditions: a) for a given simplification, coordination is still possible, and the main activity brings benefits to agents; b) the loss of a certain amount of benefit due to the simplification of the analyzed information is the minimum necessary, i.e. the more simplification reduces benefits, and the less simplification does not allow achieving the coordination.

The ratio between the computational capabilities of agents and the intensity of stochastics determines the conditions for the possibility/impossibility of coordination. This condition is not directly taken into account in the mechanism design theory.

2.6. General statement of the research problem

As noted above, this study presents an attempt to connect Harari's idea of an imagined order that governs the activities of people with ideas of the mechanism design theory, which describe how to design some types of economic regulatory mechanisms. In contrast to these two concepts, this study assumes a more complete and detailed consideration of the coordination features, some of which are discussed above in this section.

Coordination, like the "imagined order", exists and is realized in the mind of people (socio-economic agents). Diverse ways of coordination are combined in the agent's mind into a unified system of mental representation of his activity conditions. An agent uses this system to calculate and determine the content of various types of his socio-economic activities in order to obtain maximum benefits[3]. In cognitive science, such a system in the human mind is referred to as a "mental model" (Johnson-Laird, 1980; Mantzavinos et al., 2004; Badke-Schaub et al., 2007). Changes in the processes of coordination, as well as changes in the imagined order, require a uniform change in the consciousness of people, more precisely, a certain synchronization of the content of the mental models of all participants.

In this regard, it is required to study the mental models as a tool for coordination and its features to make some synchronous changes in mental models of all joint activity participants. It is also important to note that the coexistence of various modes of coordination in the human mental model means the theoretical possibility to build a unified methodological description of socioeconomic coordination.

To study how the mental model provides coordination it requires to separate the main and coordinating human activities. The main activity provides agents with a certain expected benefit, and the coordinating one is associated with the use of mental models and creates conditions for the main activity. Such a separation makes it possible to analyze the factors associated with coordination, which determine, on the one hand, the amount of the agents' benefit from the main activity, as well as their coordination costs, which reduce this benefit. In this formulation, the design of a coordination mechanism can be defined as a searching for an optimal solution for the task of maximizing the benefits from the main activity and minimizing the coordinating activity costs.

Designing a coordination mechanism as a solution to an optimization task requires determining the parameters of the corresponding objective function. Based on the characteristics of coordination mechanisms discussed above, agents can maximize the benefits associated with coordination by changing the following parameters:

[3] In this case, socio-economic activity means activity that gives its participants a benefit, the value of which, among other things, depends on the characteristics of coordination.

a) developing the agents' specialization and their labor division system, which become possible by increasing the number of participants in coordinated joint activities (not for all types of socio-economic activity);
b) increasing the quality of coordination, for example, by providing the higher completeness of the important factors' consideration in the joint activity coordination which can increase the benefits from it;
c) reducing the coordination costs, if this does not lead to decrease in benefits because of deterioration of the previous parameters.

The existing interdependencies between these three objective function parameters for the optimization task of the coordination mechanism design require research. To do this, it is necessary to consider the influence on these parameters of the communication states (direct communication, indirect and lack of communication) used by agents in the process of their coordination. It should determine the valid values of the objective function parameters "a" and "b", which depend on communication states, and for the parameter "c", which values depend on the method of formation of the coordination costs.

The conditions for the possibility or impossibility of the coordination require a deeper analysis. In this context, an important limitation is the computational capabilities of agents, which determine how complex the coordination task can be solved in their mental models and how much time agents need to achieve the coordination. When solving an optimization task for the coordination mechanism design, it is necessary to consider the relationship between:

a) the typical amount of time that agents need to determine the optimal, in a certain sense, content of their activities, and
b) the intensity of unpredictable critical changes (stochastics) in the conditions for their activities, which, if they happen, require starting from the beginning agents' calculations needed for achieving their coordination.

It is also necessary to explore the possibilities of ICT and computer technologies to improve the computational capabilities of agents, as well as the possibilities for agents to reduce the influence of stochastics on coordination processes.

The research problem of building a concept and a theoretical model for designing the coordination mechanism that discussed in this section, has also an important methodological aspect. Since humans can systematically combine all methods of coordination in their mind, there are two obvious research questions:

1) Can the heterogeneous manifestations and methods of coordination described in the literature be considered from a unified methodological basis as specific implementations of a general theory and a single model of socio-economic coordination?

2) How to design or improve not a separate method of coordination, what to some extent allows the mechanism design theory and some other approaches, but the entire system of coordination in the economy and society?

Consideration of these issues in this study is important for both economic theory and practice. The results of this study, if they are positive, will, on the one hand, fill in some gaps in understanding the nature of socio-economic coordination and get a more complete picture of the functioning of the economy and society. On the other hand, such study can provide tools for designing and constructing more advanced mechanisms of socio-economic coordination, including their digital transformation. The development of the unified methodological basis to

explain the various types of coordination creates the conditions for the emergence of a general theory of socio-economic coordination. Given the special place that coordination occupies in human activity, as well as its importance for the functioning of the economy and society, the presentation of different coordination processes as special cases of a single theoretical model, among other things, means a certain revision and refinement of the existing picture of the socio-economic world.

The next sections consider the defined research problem, including an analysis of the fundamentals of socio-economic coordination, from which I derive the conceptual model of coordination, as well as a concept of the algorithm for designing a mechanism for socio-economic coordination.

3. Fundamentals of socio-economic coordination

In this section, in more detail and completeness than in the previous one, the main properties of socio-economic coordination are considered, including a clarification of the definition of what constitutes coordination, as well as a description of the fundamental process of coordination that is present in all coordinated socio-economic systems. Accounting for these fundamentals of coordination is necessary to build its unified theoretical model, which should be valid for all observed manifestations of coordination.

In (Parinov, 2022), it was shown that the digitalization of the processes underlying socio-economic coordination changes some of its properties. Therefore, in this section possible changes in the properties of coordination under the influence of digitalization is discussed.

Coordination is inherent in any explicitly or implicitly joint or collective activity of people. Therefore, the fundamentals of coordination considered in this section are common to socio-economic activity in general. Further, we will consider the participants in such activity as socio-economic agents, separately explaining the purely economic cases.

In this study, only primary coordination is considered, the object of which is the activity of agents directly. Primary coordination can create secondary coordination between the results of agents' activities, which is not considered in this study.

The object of coordination is only socio-economic activity, the coordination of which gives the participants additional benefits. This requirement is intuitively obvious, since it makes it possible to exclude questions about the coordination of socio-economic activities, the benefit of each participant of which does not depend on the activities of the others. This restriction will also allow in the next section to consider the design of coordination mechanisms as a problem of maximizing the benefits from the joint activity of agents.

3.1. Definition of socio-economic coordination

Let us take as the basis definition of coordination proposed in (Parinov, 2023). In a slightly modified form, the definition of coordination, consistent with the objectives of this study, is as follows:

> *Socio-economic coordination is the mutual accounting by agents of the past, current or expected activities of other agents.*

This definition is based on the hypothesis that agents, depending on their possibilities for exchanging information with other agents use the abilities given to them by nature to take into account the activities of other agents in the following basic forms (Parinov, 2023):

- using the direct communication of the "all with all" type they negotiate to make agreement on how to act in concert, and also maintain these agreements in time;
- using the indirect communication each agent, based on observations of the activities of other agents, makes a decision about his activities (this method is described in the literature as the ability to stigmergy[4]);
- in the absence of communication, the agents act based on common to all rules of conduct, including predetermined roles behavior, traditions, habits or routines.

3.2. Mental model as a tool for coordination

The agent's consciousness performs the function of accounting for the activities of other agents. We will, as it is customary in cognitive sciences, call the corresponding part of the agent's consciousness a mental model. “By interacting with the environment, with other people, and with artifacts of technology, humans develop internal mental models of themselves and the things they interact with. These models provide predictive and explanatory power for understanding these interactions” (Badke-Schaub et al., 2007).

The mental model as a metaphor in research is well developed in various scientific disciplines (Johnson-Laird, 1980; Mantzavinos et al., 2004; Badke-Schaub et al., 2007). The literature contains mathematical descriptions of mental models for computer analysis of socio-economic systems (Fan and Yen, 2007; Stuit et al., 2007; Sayama et al., 2011). See some review in (Parinov, 2020, pp. 6–11). These results in total provide a good background for using the mental model metaphor in this study both at the conceptual level and as part of future mathematical models of economic coordination processes.

The mental model of an agent has certain computational capabilities, which include data processing methods, analytics, forecasting, etc. Computational capabilities of mental model allow the agent, based on the analysis of available information, to determine the best options for his main activity, taking into account the activities of other agents. Taking into account the activity of other agents in the mental model of an agent consists of processing information received from the common environment, as well as mental playback of various scenarios in order to determine the best (in a certain sense and in current conditions) content of his activity.

Hurwitz and Reiter wrote: " We take the cost of observation to be an increasing function of the precision with which the environment must be observed, and we take the cost of communication to be an increasing function of the size of messages that must be processed by the participants" (Hurwicz, & Reiter, 2006, p. 22). Considering these noted factors, it is natural to assume that the possibilities of mental models are obviously limited. They do not allow processing a large amount of information, the volume of which increases sharply if the agent operates with many participants. The mental models of agents usually fail to analyze the complex interdependencies that can arise between the activities of many different agents.

The development of ICT in recent decades has given rise to a new trend: the comprehensive digitalization of socio-economic processes, including the digital transformation of the ways in which mental models are used (Parinov, 2022). This means the emergence of opportunities for agents to use the analytical and computational resources of modern computer technologies

[4] See about stigmergy in (Elliott, 2006; Marsh and Onof, 2008; Elliott, 2016; Heylighen, 2016).

external to their consciousness to more fully account for the activities of other agents. Digitization is a potential source of improving the computational capabilities of mental models.

3.3. The influence of the communication states on coordination

In the general case, agents receive in their mental models the information necessary to take into account the activities of other agents, simultaneously in two ways: 1) directly from other agents, i.e. through direct communications; 2) monitoring changes in the common environment, i.e. through indirect communications. For cases where communication between agents is completely absent, which means that agents do not have up-to-date information to take into account the activities of other agents, the mental models of agents can make decisions based on the agents' own assumptions about activities of other agents. For example, based on the assumptions that other agents, in the absence of communications, act based on the common rules.

The mental model of an agent for all these three cases of obtaining information performs its coordination tool functions as follows:

1. In the case of direct communications, agents can exchange information about their capabilities and intentions for their joint activities in real time. Coordination, as a consideration of the capabilities and intentions of agents, includes the analysis by each agent of information about what he can give and what he wants from other agents in relation to their joint activities. Direct exchange of information between agents allows them to maintain their actual information images in each other's mental models. This leads to synchronization of the content of a certain part of the participants' mental models.

This content synchronization means creating the "… knowledge or belief structures that are shared by members of a team, which enable them to form accurate explanations and expectations about the task, and to coordinate their actions and adapt their behaviors to the demands of the task and other team members" (Badke-Schaub et al., 2007). As a result of synchronization of the individual mental models' content, a shared (collective) mental model is formed in their minds. Agents use the shared mental model to jointly simulate possible options for their activity and collectively choose the best decision about the content of each activity. As noted, "The main effect of the existence of shared mental models or shared knowledge … is a coordination of individual activities at the behavioral level" (Mantzavinos et al., 2004).

2. In the case of indirect communications, each agent individually updates the content of his mental model in observing changes in the common environment, which includes traces of the activities of other agents. Using their individual mental models, agents independently determine the content of their activities and implement it. Traces of agents' activities remain in the common environment and are reflected in each other's mental models. By trial and error, agents based on indirect communications find the content of their activities that best meets the expectations (demand) of other agents. This is how "stigmergy" works (Elliott, 2006; Marsh and Onof, 2008; Elliott, 2016; Heylighen, 2016).

Digitization and virtualization of the common environment through which agents carry out indirect communications, on the one hand, simplifies the processes for agents to track ongoing changes that they need to take into account when choosing the content of their activities. On the other hand, in a virtual environment, in comparison with a traditional one, agents can significantly more fully, accurately and timely express changes in their capabilities and intentions, which should be taken into account by other participants. As already mentioned, the development of ICT is changing the nature of agents' communications, bringing together the

characteristics of direct and indirect communications. Therefore, this reduces the differences in the functioning of mental models for these two communication states.

3. In the absence of communication, agents choose from the sets of common rules stored in their mental models those that are most suitable for performing the current type of activity. In this case, the agent uses some section of his mental model that collects, stores and updates the common rules applicable to his activities. The observance by the participants of the common rules gives rise to a certain coordination of their activity.

With the digitalization of the mental model and virtualization of communications, the common rules can, if necessary, be updated with a higher frequency, and agents can quickly switch to using new rules. The accuracy of the execution of common rules by agents, if the actions of agents taking place in the virtual common environment, can be controlled by computer algorithms and digital interfaces. As a result of such changes, rule-based coordination can move from being the most conservative method to being quite flexible and efficient, allowing agents to dynamically respond to changes in the conditions for their joint activity at minimal cost. In this case, the properties of coordination based on common rules to some extent approach the properties of coordination based on the direct or indirect communications.

These three ways in which mental models work as the coordination tool allow agents to achieve coordination of their main activity in the following way:

- Due to direct and/or indirect communications, the agent receives information from the common environment and from other agents that forms and updates in his mind a mental model of the existing and expected conditions for his activity;
- Using this mental model, the agent analyzes and mentally simulate the possible options for his activity. Depending on the communication state, this analysis can be collective or individual. Based on the results of this analysis, the agent decides on the content of his activity, which takes into account the activities of other agents in the following options:
    - as a result of a direct agreement between them "who does what";
    - as a result of observations and analysis of the information received about the past activities of agents, or about the traces of this activity left by agents in the common environment (stigmergy);
    - as a result of the assumption that all agents act according to established common rules.

In the agent's mental model, these different methods of communication and accounting for the activities of other agents are the part of a unified decision-making system on the content of the agent's main activity.

The digitalization of communications significantly changes the dependence of coordination characteristics on communication state that agents use. Direct and indirect digital communications take place in the same virtual environment and based on similar software technologies. In a virtual environment, the main difference between direct communication is that they are targeted, while indirect communication works as a broadcasting. However, indirect communications, with the help of, for example, software tools for automatically tracking the appearance of information corresponding to the profile of the agent's interests, can be functionally very similar to the direct communications. The common rules that are used by agents in the absence of communications can be quite easily changed by agents in the digital environment, dynamically adjusting to changing conditions in their activities, and almost instantly become known to all participants, regardless of their number.

3.4. Coordinating activity and basic forms of coordination

In this study the use of mental models by agents to determine the content of their main activity is interpreted as the performance by them of some coordinating activity (CA). With the help of CA, the content of which depends on the communication states used by agents, agents take into account the main activities of other agents, which leads to the emergence of coordination between all agents.

Let us define the three ways of how the mental model provides the coordination (described in section 3.3.) as the three basic forms of socio-economic coordination:

1) The *contractual* basic form of coordination. This basic form can work if agents have direct communications of the "all with all" type. In this case, CA manifests itself as the information exchange, using the mental model for collective simulations, negotiations and mutual agreement among agents.;

2) The *stigmergy* as the basic form of coordination. This basic form works if only indirect communications are possible between agents. With this form of coordination, CA means that agents independently make decisions about the content of their activities based on monitoring each other's activities.;

3) The *common rules* as the basic form of coordination. It does not need communications between agents. This form assumes a CA to select relevant common rules, according to which agents determine the content of their main activity.

Discussion of some general issues related to the basic forms of coordination moved into the Supplementary Material #1[5]. The material considers: a) how the common environment and the communication states available to agents in this environment affect the coordinating activity (behavior); b) why only three forms of the coordinating activity (behavior) can be distinguished and why these three forms are basic; c) what quantitative and qualitative characteristics have the basic forms of coordinating activity (behavior).

The purpose of agents in the implementation of the CA is to obtain (accounting their costs for the CA) more benefits from their main activities. However, if coordination does not ensure the use of factors or the capabilities of agents important for joint activity, then the benefits of agents from the main activity may be less than it could be. It is obvious that there is a direct relationship between the characteristics of the CA and the agents' benefit size from their main activities.

The desire of agents to obtain the maximum benefit from their joint activities, known in rational choice theory as the agents' maximizing behavior, motivates them to search for one the most suitable, or a combination of the basic forms of coordination, which, ceteris paribus, allow them to get a higher benefit from their main activity or to coordinate at a lower cost.

We will call, found by agents by trial and error, the single basic coordination form or its combination, which give agents the greatest benefit from their activities and therefore are used on an ongoing basis, as the method or mechanism of coordination. Examples of the representation of observed different coordination methods (market, hierarchy, and network) as combinations of basic coordination forms are given in (Parinov, 2023).

[5] Supplementary Material #1 - https://sparinov.wordpress.com/2022/08/01/conceptual-model-of-socio-economic-coordination-at-micro-level/

3.5. Fundamental coordination process

The concept of basic coordination forms as three use cases of the mental models for three communication states allows us to define the fundamental coordination process that is present in each basic form, in each method or mechanism of coordination formed from the basic forms, as well as in a coordinated socio-economic system:

> *The fundamental process of coordination consists in the transformation of the individual mental models of agents, based on which they determine the content of their main activity, into shared (collective) mental models.*

Each agent, using the first two basic coordination forms (contractual and stigmergy), regularly updates the content of his mental model based on direct of indirect communications. When using the third basic form (common rules), due to the lack of communications, the actualization of the mental model content does not occur. In this case, the agent uses in the mental model assumptions about the activities of other agents. In all three cases, the agent's mental model acquires the character of a collective model, since in his individual mental model, information images of other agents are formed and updated either on the basis of incoming information or on the basis of assumptions about their activities and/or intentions.

This fundamental coordination process allows agents to take into account the capabilities and intentions of all other agents when determining the content of their activity. Such mutual accounting by agents of each other's activities creates the effect of coordination of their joint activities. The results of the fundamental process of coordination can manifest themselves, i.e. becomes observable, in different forms, which depends on the nature of the most noticeable basic form of coordination in its combination.

Let us consider examples of the manifestation of the fundamental coordination process in the well-known methods of economic coordination: the market, hierarchy, and network.

The market. The fundamental process of coordination, which turns the individual mental models of agents into collective ones, in the case of market coordination manifests itself as follows: agents observe the activities of other agents in a common market environment, and the regularity of these observations gives the mental models of agents a collective character, because ensures the actualization of market’s information images of each other in their mental models.

The hierarchy. For hierarchical coordination, which is based on the use of the contractual basic form of coordination (Parinov, 2023), the fundamental process is implemented depending on the role of the agent "performer" or "manager". In the simplest case, the executing agent has direct communications only with his manager. The mental model of both becomes collective as a result of the appearance and regular updates of information images of each other in it. In addition, the manager may have direct communications with several other performers. Then the manager's mental model is collective with all his performers, and thus, through the manager's mental model, the performers' mental models also become connected to a certain extent.

The network. The fundamental process in the network method of coordination manifests itself most noticeably, because this method is based on the direct communications of the “all with all” type between the participants in joint activities. This mode of information exchange ensures constant updating of information images of agents in each other's mental models and gives these models a collective character.

3.5. Conditions for the possibility of coordination

The previously introduced assumption that coordination increases the benefit of each participant in the joint activity creates the motivation of agents for CA and for keeping coordination. However, the fact that agents have a desire for coordination does not guarantee the occurrence of coordination. This requires the fulfilment of some additional conditions:

a) For the emergence of coordination, the mental model of an agent must receive up-to-date and sufficiently complete information about the participants and the conditions of joint activity;
b) If "a" is fulfilled, then the computational capabilities of the agent's mental model should be sufficient to determine the content of his activity, which will allow him to receive additional benefits and cover the costs of the CA;
c) If “b” is satisfied, then the computational capabilities of the agent’s mental model should allow him to determine the content of his activity faster than unpredictable perturbations in the conditions of joint activity will violate the execution of “a”.

Conditions "a" - "b" are obvious. It follows from them that coordination is impossible if the participants in joint activities do not have the necessary characteristics of a collective mental model. The "c" condition is more complicated, so let us look at it in more detail.

The ability of agents to coordinate their activities is affected by the stochastic nature of the common environment and some unpredictability of agents’ behavior. In the conditions for joint activity, including the states of the agents themselves, unpredictable changes (perturbations) occur with a certain frequency. Under these conditions, for the emergence and maintenance of coordination, the ratio between the computational capabilities of agents and the intensity of the flow of perturbations is critical. Computational capabilities determine the amount of time that agents need to analyze the input information flow and decide on the content of their activities in the mental models. Among all disturbances there are critical ones, which devalue the coordination already achieved by agents and require coordination to be performed again (Parinov, 2020 pp. 15–17). We will consider only critical perturbations.

To occur the coordination, agents need to reach a coordinated state faster than the next critical disturbance occurs, which will require re-coordination of activity. Thus, coordination is possible if the time interval between critical disturbances is greater than the amount of time that agents need to achieve the coordination.

Coordination is impossible if unpredictable changes in the common environment devalue the content of the mental models of the participants in the activity faster than the agents, using their computational capabilities, manage to decide on the content of their activity, as well as to benefit from the activity.

The economic type of the joint activity, which considers the benefits of the activity in comparison with the costs of it, adds some additional conditions. The duration of the coordinated activity, which is determined by the time interval from the moment it starts until the moment it is interrupted by a critical disturbance, should be sufficient so that the benefits received from the joint activity during this time exceed the costs of it. Otherwise, the coordination of activities does not make economic sense.

Among the cases where coordination is possible can be situations where the CA is successful. This requires a long-term excess of the benefits from the joint coordinated activities of agents

over the costs, which include both the costs of coordination and the main activity[6]. For economic activity, the success of a CA means a steady excess of income from the main activity over total expenses. For non-economic activity, this is a steady approximation of agents in their joint activity to the set goals, despite the occasional disturbances that violate their coordination. See examples in (Parinov, 2021, p. 20).

3.6. Properties of the basic coordination forms

Consider the success of coordination for each of the basic forms, depending on two characteristics: a) the maximum possible number of participants in the main activity; and b) the highest possible quality of coordination, measured by the completeness of taking into account the capabilities and intentions of agents in their joint activities.

If for some type of the main activity agents receive additional benefits from the development of specialization and labor division, then an increase in the number of participants in joint activities is one of the key factors in increasing the benefits of agents from their joint activities. Economic activity is just such a type. In an economy, agents benefit from the increase in the number of participants, because this allows the development of specialization and division of labor. To use this factor of increasing benefits in a coordination mechanism designing, it is necessary to account for the following characteristics: upper acceptable threshold in the number of participants at which successful coordination is possible for each basic form of coordination.

The second characteristic - the quality of coordination - in this study is considered as the completeness of coordination, which can be provided by the corresponding basic coordination form. The literature also defines the quality of coordination as the "price of anarchy", which "measures the deterioration in performance of systems on which resources are allocated by selfish agents" (Christodoulou, et al., 2009). In the context of this study, the concept of "completeness of coordination" is a more adequate characteristic of the coordination quality, since it is related to the properties of agents' mental models and measures the degree to which the participants' capabilities and intentions are taken into account in the coordination process in their joint activities. In coordination, for various reasons, agents may not fully take into account (or not take into account at all) various important factors. This situation means the existence of a possible lost benefits. It arises because the participants in the joint activity do not receive the benefit in comparison with its values, if the information about the capabilities and intentions of the agents was taken into account in the mental models of the agents completely. For example, the less the possibilities of the participants, which can be useful for joint activities, are taken into account in the process of coordination, the less the potential of agents to increase the benefit is used, and vice versa.

Consider these two characteristics that determine the success of coordination, together. An increase in the number of participants increases the likelihood that agents will receive more benefits through the development of their labor division. Increasing the completeness of coordination means increasing the likelihood of participants receiving more benefits from the fuller use of their individual potentials in joint activities. Detailed analysis of the relationships between the coordination benefit and these characteristics is given in the Supplementary Material #2[7]. The analysis showed that three basic coordination forms have the following properties:

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[6] For comparison, in (Weigand, et al., 2003) coordination is considered successful when its participants are satisfied.

[7] Supplementary Material #2 - https://sparinov.wordpress.com/2022/08/02/main-characteristics-of-the-basic-forms-of-coordinating-behavior/

- the contractual basic form allows agents achieving high completeness of coordination and receiving by these additional benefits, but for a small group of participants in joint activities;
- the stigmergy basic form makes it possible, with less completeness and with the appearance of the lost benefits, to coordinate joint activities of a significantly larger, than contractual form, but a limited number of participants in joint activities;
- the common rules basic form has the lowest completeness of coordination and, accordingly, the largest amount of the lost benefits, but the number of participants is not limited.

The properties of these basic coordination forms complement each other. The common rules basic form allows one to coordinate an unlimited number of agents, while the contractual form is the best to achieve the maximum completeness of coordination. The maximizing behavior inherent in socioeconomic agents forces agents to look for combinations of the basic coordination forms and their settings that will allow them to get the maximum possible total gain from their joint activities both by increasing participants and by increasing the completeness of coordination. With respect to some given agent, each of the basic forms of coordination enables the agent to take into account the activities of different groups of agents with different levels of completeness of coordination. Together, these three basic forms allow an agent to coordinate its activities with all existing agents, regardless of their number.

The use by agents of the basic coordination forms implies a different level of costs for agents. Hurwicz and Reiter wrote: "… the evaluation of mechanisms should not avoid considering the real costs of creating, operating, and maintaining the institutions required for the existence and functioning of those mechanisms" (Hurwicz, & Reiter, 2006, p. 15).

In this study, the costs of agents associated with the use of the basic coordination forms are measured by the degree of use of communications. Obviously, the basic form with lowest cost is the common rules, since there is no communication here, and it is enough for agents to know the rules and follow them. The basic form with the highest costs is contractual, because in this case, agents are required to maintain a direct constant information exchange of the "all with all" type. The use of stigmergy is characterized by average costs because usual indirect communications require much less effort from agents than the direct ones.

Therefore, a way to reduce the cost of coordination, other things being equal, is to use less costly basic forms in the coordination mechanism. When designing a coordination mechanism, the implementation of this rule means: wherever it possible use the form "common rules", then stigmergy, and lastly - the contractual form.

3.7. Settings for the basic coordination forms

The basic coordination forms allow certain settings that help to use them in different modes, depending on the type of the main activity and the specific conditions.

The contractual basic form settings are:

- A choice of the direct communication mode. For example, the use of visual-speech communications, or communications in a virtual environment, etc.;

- A way of organizing a collective mental model. For example, delegating rights from performers to managers to decide on the content of performers' activity and thus creating a hierarchical way of coordination (see more in Supplementary Material #2).;

- A support of the mental model in the minds of each agent, or a creation of a virtual version of the collective model alienated from the minds of agents.;

- A determination of the special conditions for using the basic form. For example, agents determine that they use the contractual form only when there is a significant increase in the intensity of disturbances, or when the maximum possible completeness of coordination is required, etc.

Stigmergy settings include a special organization of the common environment. For example, the creation of a signal system, special labels and other devices that reduce the cost of indirect communications and/or increase the information value of indirect communications. Also, the special conditions for the use of this form can be specified.

The settings of the "common rules" basic form are the ways to update the rules and communicate information about the changed rules to agents and the specification of conditions for applying this form.

4. Conceptual model of coordination

Let us build a verbal version of the conceptual model of coordination that describes a set of concepts and relationships between them, as well as defining the semantic structure and individual elements of the coordinating activity of agents. The purpose of the conceptual model of coordination creation is a systematic representation of the fundamental principles of coordination, the rules for designing coordination mechanisms based on them, as well as a description of the model's main functionality. The verbal version of such a conceptual model is the basis for building mathematical models of socio-economic coordination in the future.

4.1. The coordination mechanism design model

This section discusses the relationship between concepts without their mathematical representation. Therefore, when discussing the relationship between concepts, the issues important for its mathematical representation, e.g., the coincidence of units of measure of compared concepts, are not considered.

4.1.1. The objective functions

Agents design the coordination mechanisms to get more benefits from their main activity. It was discussed above that coordination allows agents to get additional benefits from economic activity due to:

1. Increase in the number of participants in joint activities. This means that agents receive more benefits from involving as many participants as possible in joint activities due to the deepening of specialization and the development of their labor division (LD).

2. Improving the quality of coordination, which in this study is considered as the desire of agents to the fullest use of their potential and full self-realization in joint activities. This method of increasing benefits is associated with the completeness of coordination, the increase of which is the individual desire of each agent to use his capabilities and intentions to the fullest to obtain benefits. The more fully the possibilities and intentions of agents in their joint activities with each other are taken into account in the process of coordinating activity, the higher the probability of obtaining additional benefits due to this by each of them.

We will consider these two ways of increasing benefits as two objective functions for a conceptual description of the task of creating, in a certain sense, an optimal coordination mechanism.

4.1.2. The complexity of the coordination problem

Let us introduce the concept of complexity for the coordination problem, which is solved by the agent in the mental model to determine the optimal content of their main activity. The higher the complexity of the coordination problem, the higher the computational capabilities required by the agent to solve it in a conventional unit of time. The computational capabilities available to the agents limit the complexity of the coordination problems, in the solution of which successful coordination can be achieved.

Let us define the complexity of the coordination problem as a function of the following variables:

a) the number of participants in the joint main activity;
b) the completeness of coordination, which depends on the precision and detail of information images of the joint activity participants in their mental models;
c) the intensity of disturbances in the conditions for the joint activity.

An increase in the values of any of these variables leads to an increase in the complexity of the coordination problem.

4.1.3. Optimization of the conflicting objective functions

We assume that agents tend to simultaneously use all the methods they have for increasing their benefit. However, the objective functions of the coordination mechanism design, considered above, conflict with each other. For example, the desire of agents to expand the scope of activities means, ceteris paribus, an increase in the complexity of the coordination problem due to an increase in the number of its participants and a corresponding increase in the amount of information that needs to be analyzed. With limited computational capabilities of the mental models of agents, starting from reaching a certain number of participants, a further increase in the number of participants and an increase in the complexity of the coordination problem begins to exceed the computational capabilities available to the agents.

It is intuitively clear that a rapid increase in computing capabilities is a costly task for agents. However, the complexity of the coordination problem can be changed and adjusted by agents to suit their computational capabilities. For example, by reducing the precision and detail of information images of agents, i.e. a decrease of the coordination completeness. With an increase in the number of participants, maintaining the complexity of the coordination problem at a level that corresponds to computational capabilities is possible due to a decrease in the completeness of coordination, and vice versa. Thus, the complexity of the coordination problem can be maintained at the desired level.

When choosing the values of the variables of the objective functions, agents need to ensure that the complexity of the coordination problem is maintained at a level that does not exceed their computational capabilities, since this is a condition for obtaining benefits from the main activity. This condition sets constrains on the domain of variables. If these constrains are met, obtaining the maximum benefit through coordination can be achieved by selecting the values of the variables “number of participants” and “completeness of coordination”. Thus, the task of

designing a coordination mechanism is the simultaneous optimization of two conflicting objective functions in a common domain of variables.

4.1.4. Domain of variables and basic forms of coordination

The values of the coordination mechanism design objective function are the amounts of benefit Y from the activity of agents. Benefit Y arises as a result of the main activity, which becomes possible due to the coordinating activity of agents. Coordinating activity is carried out by agents by using the basic coordination forms within the constraints discussed above.

Since the production function of the main activity, which describes exactly how the agents create the benefit, is not considered in this study, for simplicity we will assume that the value of the benefit Y is some given function of two variables: 1) the number of participants in the main activity (N); and 2) the degree of completeness of coordination (P) of the participants in the main activity. It was noted above that there is a dependence between the values of the variables N and P, which determines their domain: from the set of pairs of values of N and P, only those are allowed for which the value of the benefit Y is greater than zero, i.e. in this case the coordination is successful.

Given this simplification, the benefit Y is determined by the characteristics of the basic coordination form BF that agents use to coordinate. The characteristics of the basic form determine the valid values of the number of participants N, the quality of coordination P, and the generated benefit Y. As stated above, each basic form of coordination BF_i, where i is the number of the basic form of coordination, has its own upper bounds for the number of participants and completeness of coordination ($\bar{N}_i$ and $\bar{P}_i$). The basic coordination form BF_i is used to coordinate a certain number of participants $N_i <= \bar{N}_i$, it provides a certain level of completeness of coordination $P_i <= \bar{P}_i$ and allows the participants to get a benefit $Y_i <= \bar{Y}_i$. The actual values N_i and P_i determine the actual value of benefit Y_i.

For each BF_i, the domain of the variables N_i and P_i is given by the condition that the complexity of the coordination problem CC_i corresponds to the computational capabilities CP of the agents. For simplicity, we assume that the computational capabilities of CP are the same in all cases and for all agents.

4.1.5. Types of the main activity of agents

The use of the basic coordination forms depends on the characteristics of the main socio-economic activity. For example, a feature of economic activity is that it consists of four relatively independent stages: production, distribution, exchange, and consumption. Each of these stages, from the point of view of coordination, has certain specifics and therefore requires a special coordination mechanism (Parinov, 2023). Further, we will consider the following important features of socio-economic activity, which are illustrated by examples from the economic activity of agents:

1. The activity requires the largest possible number of participants. For example, participants in the production of goods in the economy benefit from the development of specialization and the expansion of the labor division by including in this activity all existing participants of the global economy.

2. The activity requires the fullest possible coordination. For example, carrying out activity in extreme conditions and a dynamically changing environment. In response to an intense flow of perturbations, participants must use all their abilities to quickly find the optimal solution for

"who does what and in what sequence" and, thus, keep their activities in a coordinated state and benefit from it.

3. The activity requires the simultaneous execution of the previous cases 1 and 2. For example, the goods' distribution and exchange in the economy. We will consider these two types of activity as a process of exchange, since the distribution in the economy is the exchange of created goods for money, and the exchange is the exchange of money for the required goods. Thus, the exchange processes in the economy, on the one hand, require the participation of all agents in the economy, since this ensures they all can use the benefits created by the labor division system. On the other hand, traditional exchange processes require negotiations (bargaining) between sellers and buyers, which result in prices being set. The interests of participants in such a trade should be represented as fully as possible, which is equivalent to the requirement of the most complete coordination for this activity. So, the economic exchange activity is an example of the simultaneous execution of cases 1 and 2. Otherwise, there is a high probability that agents will not get the maximum benefit from the exchange activity.

4.1.6. Algorithm of the coordination mechanism designing

Let us define a coordination mechanism as a set of the basic coordination forms and their settings that allow one to get the maximum benefit from the main activity of some given type. The basic forms used in the designing of the coordination mechanism determine the upper possible limit for the values of $\bar{N}$, $\bar{P}$ and $\bar{Y}$. Thus, the task of coordination mechanism design is to choose one or more basic forms that, in combination, give agents the maximum $\bar{Y}$ for a given type of the agents' main activity.

For the existing coordination mechanisms, the agents selected the optimal set of basic forms of coordination by the trial-and-error procedure (Parinov, 2023). In the general case, the problem of choosing the optimal set of basic forms begins with determining the first suitable basic form of coordination: for the values of the variables N_i and P_i, given by the type of the main activity, the basic form BF_i is selected, the complexity of the coordination problem CC_i of which corresponds to the computational capabilities CP of agents. If several basic forms satisfy the constraint on CC_i, then the one that gives the maximum benefit max $Y_i(N_i, P_{i)}$ is chosen.

This the first algorithm stage for determining the optimal design of the coordination mechanism has some additions, because:

- Coordinating activity is associated with certain costs C. In the simplest case, these costs can be measured by the amount of time that agents spend on coordinating activities. The more time the agent spends on coordinating activity, the less time remains that the agent can spend on the main activity that creates benefit Y. Therefore, one of the ways to increase the value of benefit Y is to reduce the costs of agents C for coordinating activities.
- The use of the basic coordination form chosen at the first algorithm stage may mean the emergence of the lost benefit for agents. Therefore, another way to increase the value of benefit Y is to search for opportunities for agents to use lost benefits, if any.

Depending on the type of the main activity, which sets the requirements for the largest upper bounds on the number of participants $\bar{N}$ and completeness of coordination $\bar{P}$, determining the maximum upper bound on benefit $\bar{Y}$ is possible using the following algorithm, which represents the design of the coordination mechanism in three successive stages:

1. Searching for a given type of main activity that determines the values of the variables N and P, the basic coordination form BF_i and its settings that satisfies N <= $\bar{N}_i$, P <= $\bar{P}_i$ and gives the maximum value of $\bar{Y}$. As an illustration see example 1 in the next section.

2. Reducing the cost of coordination by partial and temporary replacement of the basic form selected at stage 1 with the less costly one, if this gives a final increase in Y. This is achieved by using together the form selected at the stage 1 and the less costly basic forms and their specific settings. In this case, the coordination mechanism is created as a sequential combination of several different basic coordination forms, at least one of which is more costly than the others. See example 2 in the next section as an illustration. This second stage is optional, because for the given type of main activity there may not be options for less expensive forms that will increase the benefit Y.

3. Increasing the completeness of coordination by using additional coordination mechanisms in parallel with the main coordination mechanism already established in stages 1 or 2, if the main coordination is incomplete. The incomplete coordination creates the lost benefit which means a missed opportunity for agents to obtain higher benefits from their activities. The creation of additional coordination mechanisms, which are used in parallel with the main one, is carried out according to the algorithm corresponding to stages 1 and 2. See example 3 in the next section as an illustration. This third stage is optional, because for the main coordination mechanism there may not be additional mechanisms that increase the total benefit Y.

Thus, when designing a set of the coordination mechanisms that maximizes the benefit for a given type of the main activity, the following are determined:

- the most appropriate basic coordination form and its settings, maximizing the benefits of agents from the main coordinated activities;
- the optimal addition of the main basic form with other less costly basic forms to create a consistent combination of the basic coordination forms to minimize the cost of coordination;
- the optimal set of parallel coordination mechanisms that maximize the completeness of coordination, which allows agents to receive additional benefits.

The proposed algorithm for constructing an optimal set of coordination mechanisms ensures the formation of a combination of the basic coordination forms that gives the maximum benefit for a given type of the main activity and provides:

- meeting the requirements for the maximum number of participants and the completeness of coordination, set by the main activity type;
- meeting the requirement for the success of the coordinating activity, which means balancing the current complexity of the coordination problem and computational capabilities.

The obtained optimal set of interconnected coordination mechanisms created by this algorithm has the Pareto optimality for obtaining benefits. Thus, when the optimal design is reached, an increase in the benefit by any individual variable must be accompanied by a decrease in the total benefit received by agents from their main activity.

4.2. Mental simulation of the algorithm: coordination mechanism examples

Let us conduct a thought simulation of some existing coordination mechanisms using the algorithm proposed above. To do this, consider the micro-level description of the coordination processes for some types of the main economic activity from (Parinov, 2023).

4.2.1. Example 1. Production activity

A specific feature of the production stage of economic activity is the creation by agents of economic benefits for their exchange for money. This activity requires the participation of the maximum number of agents (N -> max), because this allows the development of the labor division and specialization of agents, which gives each participant an additional benefit. Therefore, this type of activity illustrates the first case in the list of features of socio-economic activity (section 4.1.5.).

Let us assume that in the economy there is a large number of joint activity participants. Then, to fulfill the condition N -> max, which is true for production activity, the basic forms of "common rules" and/or "stigmergy" are required. However, the "common rules" form cannot be used because production activity involves communication between agents for the exchange of reactions to each other's actions, but the "common rules" do not imply this. Therefore, the condition max Y_i (N_i, P_i) for production activity can only be met with the help of the "stigmergy" form. And this form must be chosen in the first step of the coordination mechanism design algorithm.

To get max Yi (Ni, Pi) from using stigmergy, agents create various settings. Including carrying out the organization of indirect communications through the common market environment. To do this, agents present their information images in this common environment in the form of goods produced by them. The materialization of information images of agents in the form of goods on the market allows them to maintain the required complexity of the coordination problem regardless of the number of market participants. Adjusting the complexity of the coordination problem is possible both by narrowing/expanding the agent's contact area in the common environment, which allows him to regulate the number of participants with whom the agent maintains indirect communications, and by changing the detail and frequency of updating his information images presented in the form of goods on the market (Parinov, 2023).

The second stage of the algorithm is to increase the benefit by reducing the cost of coordination. Less costly compared to stigmergy is the "common rules" form. To reduce the cost of coordination, agents seek to replace stigmergy with the “common rules” in all market situations where indirect communications between them are not necessary. Therefore, in a real economy, the action of market coordination is supported by a large number of rules that determine, for example, standards for the presentation of information about goods, requirements for goods sold on the market, and so on.

The third stage of the algorithm is to increase the benefit by increasing the completeness of coordination. Coordination based on stigmergy, by definition, is characterized by a low completeness of taking into account the capabilities and intentions of agents. Consequently, with stigmergy agents have the lost benefit because it leaves the unused reserves in the capabilities and intentions of agents in relation to their production activities. These reserves can be used by creating additional production activities coordinated by the basic form with a higher completeness of coordination than stigmergy. This situation is discussed in more detail in Example 3 below.

By adjusting the number of participants, the costs of coordination and the completeness of coordination to maximize the benefits from the main activity, agents adjust the production

activity coordination mechanism based on stigmergy to the state of Pareto optimality. In this state, an increase in the benefit by any variable leads to a decrease in the total benefit.

4.2.2. Example 2. Exchange activity

Exchange activity consists in the exchange of agents of created goods for money, as well as the exchange of money for goods. This activity illustrates the third case in the list of features of socio-economic activity (section 4.1.5.). Exchange processes in the traditional form involve negotiations (bargaining) between sellers and buyers about the price and other parameters of the transaction. Coordination in the form of negotiations presupposes a high level of coordination completeness. For this, the "contractual" basic coordination form is best suited. Thus, at the first stage of the algorithm, it is necessary to choose the contractual basic form of coordination.

However, when coordination of a large number of participants is required, the use of a contractual basic form means very high costs. At the second stage of the algorithm, to reduce the cost of coordination, a less costly form is selected that will work in combination with the contractual one. In this combination, the contractual form provides the necessary quality of coordination, but it is used for a limited time and in certain situations. In addition to it, another less costly form is used, which, due to its special use, does not impair coordination as a whole, but will reduce the overall costs of coordination and, as a result, obtain a higher benefit from the main activity.

To include all participants in coordinating exchange activity, but with the eligible costs, agents created a combination of contractual form and stigmergy. Agents, as it is done with stigmergy, place information about their exchange proposals in the common environment of all participants. By this, agents share information on what conditions and at what prices they want to perform their acts of exchange. Based on this information, potential exchange participants are identified from all participants. When potential participants in the exchange are identified, then, assuming there are not many of them, the agents negotiate with them the parameters of the exchange in the contractual basic coordination form. As a result of using the combined process of coordination held the stigmergy and contractual form, the coordination of exchanges, on the one hand, includes all participants and this gives agents an additional benefit. On the other hand, the contractual part of this coordination process allows agents to benefit from a sufficiently high completeness of coordination (Parinov, 2023).

The third stage of the algorithm - increasing the benefit by increasing the completeness of coordination - in this case may not be required, because the contractual basic coordination form may not leave any reserves or has the lost benefit.

4.3.3. Example 3. Economic activity in general

As noted in example 1 above, the use of the basic form of stigmergy in the process of coordinating production activity entails the lost benefit which means existence of reserves for the emergence of additional production activities and related coordination processes. The use of such reserves means for agents the possibility of obtaining additional benefits from their main activity. To this end, by implementing the third stage of the coordination mechanism design algorithm, they create additional production activities that were not involved or not in demand when coordinating their production activities on the basis of stigmergy. To obtain additional benefits in this case, it is necessary to use a coordination mechanism that provides a more complete account of the capabilities and intentions of agents than stigmergy. Coordination mechanisms based on the contractual form, such as the network and the hierarchical methods of coordination, meet this requirement (Parinov, 2023).

As a result, many additional processes of the production activity appear in the economy, which are coordinated on the basis of the contractual form. The additional processes of coordination that arise in this way have relationships with the main process of coordination, since they take advantage of the stigmergy's lost benefit.

The agents' motivation to increase the benefits from their main activities by improving the characteristics of coordination creates a system of coordination mechanisms in the economy, which has the following structure:

1. The main coordination mechanism for the economy, which uses stigmergy to coordinate the production of goods, and the combination of contractual form and stigmergy to coordinate the exchanges (there is also a coordination of the consumption of public goods, which we do not consider).

2. Additional first-level coordination mechanisms created to implement agents' intentions and capabilities that were not taken into account within the framework of the main coordination mechanism based on stigmergy. These additional mechanisms use a hierarchical or network mode of coordination, as this gives more complete coordination than stigmergy. Such additional mechanisms apply only for the production activity coordination, since they use the stigmergy's lost benefits.

3. Additional second-level coordination mechanisms, created for the implementation by agents of their intentions and capabilities, which remained unaccounted for in their activities at the first level. Reserves for the emergence of the additional second-level mechanisms arise if the hierarchical method of coordination is used at the first level. The hierarchical method of coordination does not fully take into account the capabilities and intentions of agents, which creates a lost benefit. The layer two of additional coordination mechanisms compensate for this lost benefit if it uses the network coordination, which provides better coordination than the hierarchical method.

A more detailed description of the economic coordination system is given in (Parinov, 2023).

4.3. Comparison with the mechanism design theory

Hurwitz offered a general description of the economic mechanism: "The mechanism specifies rules according to which, given the information available to him at a given time, a participant sends messages to others. The information consists of messages previously received, as well as some (direct) knowledge of environment, and are called response rules because they govern the message response to messages previously received. … To provide for a transition from dialogue to decisions and actions, the mechanism must also have an outcome rule which specifies what actions are to be taken given the course of the dialogue" (Hurwicz, 1973).

Let us compare the description of the economic mechanism given by Hurwitz with the conceptual model of the coordination mechanism proposed in this study. To do this, generalizing what was described in the previous sections, we present the coordination mechanism as a system of two main parts, called "interface" and "calculator".

1. The interface of the coordination mechanism is a set of means, methods, rules of communication and information exchange between agents. The interface is responsible for ensuring that, as a result of direct and/or indirect information exchange, as well as in the absence of communications, agents have in their mental model information about the current conditions

for their main activity. This part of the coordination mechanism creates for each agent (observer) conditions that allow him to take into account the activities of other agents in the economy and to interact with them on this basis. The interface part of the mechanism, among other things, synchronizes the characteristics of data exchanged between agents. For example, it provides the same degree of simplification and the form of representation of information images of agents. Thanks to this, the mental model of each agent acquires the properties of the shared (collective) one, which makes it possible for the observer to coordinate activities with one group of agents on the basis of a contractual basic form of coordination, with another - in the form of stigmergy, with the rest - on the basis of common rules. The interface as a way of exchanging information is designed to give agents the maximum benefit from their main activity.

2. The calculator of the coordination mechanism is the agents' tool to calculate the content of their main activity. Calculations are performed in the mental model of agents based on information received from the interface part of the coordination mechanism. The characteristics of the information received, including the amount and variety of data, as well as the rate of their change over time, determine the complexity of the coordination problem that must be solved in the mental model of agents. The desire of agents to get the maximum benefit from their main activities requires solving the problem of coordination in the shortest possible time. However, mental models have limited computational capabilities. Simplification of information images of agents makes it possible to bring the level of complexity of the coordination problem in line with the computational capabilities of agents.

The goal of designing an optimal coordination mechanism is to create the first part of the mechanism (interface) in such a way that, satisfying the constraints of the second part (calculator), provides agents with the maximum benefit from their main activity. In this case, the limitation of the "calculator" is the requirement that the complexity of the coordination problem does not exceed the computational capabilities. The maximization of the agent's benefit from the main activity is carried out by the "calculator" by determining the values of three variables: 1) the number of participants in the main activity; 2) quality (completeness) of coordination; and 3) the cost of coordination.

It seems, Hurwitz's description of the economic mechanism is consistent with the "calculator", i.e. the second part of the coordination mechanism. Explaining the concept of the economic mechanism, Hurwitz and Reiter write: "... we present an "algorithmic process" or "machine" that accepts as inputs a set of agents, a set of possible environments, a distribution of information about the environments among the agents, and a goal function that expresses the desired outcomes of action" (Hurwicz & Reiter, 2006, p. 18). A similar thing happens in the "calculator": agents in their mental models analyze the information available to them at a given time, and on this basis determine the content of their activities, information about which becomes available to other agents. This part of the mental model work corresponds to the Hurwitz' concept of the "response rules". The mental model also ensures that an agent decides about the content of his main activity, which means the "transition from dialogue to decisions and actions" (Hurwicz, 1973). This functionality of the mental model corresponds to the Hurwitz' concept of the "outcome rule" (ibid).

With a certain similarity in the considered descriptions, the "calculator" concept developed in this study as part of the coordination mechanism offers a more detailed explanation of how the information received by agents turns into the coordination of socio-economic activity.

The first part of the coordination mechanism (the "interface") is also implied in the description of the Hurwitz economic mechanism since it "specifies rules". This implicitly assumes that the exchange of information occurs based on the basic form of coordination "common rules" and

stigmergy, since Hurwitz uses the concept of "environment". The description of the economic mechanism also mentions the "transition from dialogue to solutions", where "dialogue" corresponds to the basic contractual form of coordination.

It can be assumed that the classical Hurwitz's description implicitly implies the use of all three basic forms of coordination in the economic mechanism but ignores the possibility of manipulating them and selecting optimal combinations of basic forms to maximize the benefits from the main activity.

In general, the conceptual model proposed in this study provides a meaningful, more detailed and accurate description of the nature of the economic mechanism for cases where it is a coordination mechanism. By simplifications, the conceptual model of the coordination mechanism can be reduced to a classical description of the economic mechanism. The question of the possibility of an analytical model representation of coordination mechanisms, including in a game form, remains open. An obvious way to model the functioning of economic coordination mechanisms is the computer agent-based simulation.

5. Digital transformation of the coordination mechanism

The conceptual model of the socio-economic coordination mechanism makes it possible to analyze ways of using ICT for the digitalization of coordinating activities. It is important, since the possible consequences of the digitalization, manifested as changes both in individual coordination methods and in the structure of the economic coordination system. Such an analysis is an urgent modern task, because the ongoing deep and complex digitalization of human activity, and the associated gradual digital transformation of economic mechanisms and institutions, determine one of the most important modern directions in the development of the economy and society.

When considering the fundamentals of coordination (Section 3), it was noted that one of the results of the comprehensive digitalization of coordinating activities is the gradual erasure of some qualitative differences between the basic forms of coordination. This process is a consequence of digital unification, which occurs, on the one hand, because of the transfer of humans' communications to a digital virtual environment, and on the other hand, as a result of the acquisition of a digital form by the elements of coordinating activity (Parinov, 2022).

Consider the impact of digitalization on the two parts of the coordination mechanism described in the previous section: 1) "interface", which sets the conditions for communication between agents; 2) "calculator", responsible for determining the content of the main activities of agents.

5.1. The digitalization of communications and basic coordination forms

The "interface" part of the coordination mechanism, which is a set of means, methods, and rules for the exchange of information between agents, significantly changes its properties as a result of the digitalization of the relevant processes and their transfer to a virtual common environment.

The current level of ICT development allows agents in a virtual environment to maintain the intensity of direct communications necessary to use the basic contractual form, no worse than in a real environment. Taking into account the absence of geographic restrictions on communications in the virtual environment, and the possibility to use collective digital communications through instant messengers and social networks, the virtual environment provides agents with much more convenient and less costly opportunities for exchanging information than is possible in the real environment.

For stigmergy, used, for example, in the market mechanism of coordination, digitalization leads to a significant change in the characteristics of indirect communications. In a virtual environment, it is much easier for agents than in a real one to leave traces of activity or specially prepared labels, as well as to track and analyze them. Such indirect communications in digital form can significantly increase the intensity of information exchanges between agents, as well as unlimitedly increase the information content of traces and labels left in the virtual common environment. Thus, the indirect communications in the virtual environment by its characteristics approach to the direct communications. The communications as agents' action in this case require significantly lower costs compared to performing similar actions in a real environment.

The improvement of characteristics and a certain digital unification of direct and indirect communications in the virtual environment (Parinov, 2022) gives agents the opportunity to change the form of communications from direct to indirect and vice versa at a lower cost than in a real environment.

For the basic form of coordination "common rules", which works without communication between the participants, digitalization and virtualization of the common environment also significantly changes its properties. In this case, information about changing the common rules can quickly become available to all participants. The use of certain rules by participants, following the requirements of the activity and situation, can be controlled by computer algorithms and digital interfaces, allowing agents to dynamically respond to changes in the conditions for their joint activity. Under the influence of digitalization, the basic form of coordination "common rules" is turning from the most conservative method into a fairly flexible and efficient one, while remaining the least expensive.

The digitalization converges values of the characteristics of all basic forms of coordination, bringing them closer to the best values. This means that the differences in their characteristics, which determine the choice of one form or another in the process of coordination mechanism design for a given type of socio-economic activity, are reduced.

The overall result of the digitalization of communications and basic forms of coordination is the transformation of the interface part of the coordination mechanism into a distributed computer system. Such a computer system can select for each individual agent sets of basic forms of coordination and their settings, which are optimized for the specifics of the agent's main activity and the computing capabilities available to him, in order to determine the content of his main activity for maximum benefit.

Direct communication between agents ensures constant updating of their information images in each other's mental models, which transforms mental models from individual to collective. The transformation of the interface part of the coordination mechanism into a computer system suggests that the mental representations of information images of agents are converted into digital images that are alienated from the agents' mind and are the elements of some information systems. A similar thing happens with information images that agents create and alienate into the traditional common environment to perform indirect communications. The transfer of indirect communications to a common virtual environment assumes that agents create and update their digital information images in this environment.

The digital transformation of information images of agents into objects of a certain computer system leads to a situation where the agent, using computer interfaces, can maintain his digital image in this system in the most complete and up-to-date form. The computer algorithms of this virtual environment create variants of the agent's information image, which differ, for example,

in the degree of their simplification, for use in tasks of coordination with all participants in the economy and for all types of its main activities. In particular, this creates a much more efficient way of turning individual models into collective ones, which is a fundamental process of coordination.

5.2. The impact of digitalization on computations in mental models

The second part of the coordination mechanism "calculator" is responsible for determining the content of the main activity of agents. The digitalization of the "calculator" is primarily associated with the digital transformation of the mental models of agents.

The mental models of agents because of digitalization are to a large extent alienated from the consciousness of the agent and became a digital object of the common for all agents' virtual environment. Similarly, as for the interface part of the coordination mechanism, the process of digitalization of the "calculator", i.e. the mental models, means the creation of a distributed computer system. The algorithms of this system ensure the achievement of coordination between the activities of individual agents.

To do this, the computer system performs the processes of processing and analysis of the available information necessary to determine the optimal content of the agent's activity. Algorithms for coordinating the activities of agents, depending on the type of joint activity of the agent, select variants of dependencies between information images (for example, representing them as a hierarchical structure), and determine the optimal degree of simplification of information images necessary to solve the coordination problem. These results of transformation of information images of agents are used to find the best options for joint activities in computer solving problems of maximizing the total benefits of agents from their joint activities. As a result of solving this problem, agents receive proposals from the coordination system on options for their joint activities to decide and practically implement their contribution to joint activities.

Such digitalization of the "calculator" increases the computational capabilities of agents, which are one of the key constraints for designing coordination mechanisms.

5.3. The impact of digitalization on the coordinating activity

Agents' coordinating activity (CA) uses both parts of the coordination mechanism to achieve and maintain coordination over time.

As a result of the digitalization of both parts of the coordination mechanism, a digital transformation of the coordinating activity occurs, which manifests itself as the unification of its elements and a decrease in the diversity of the elements of coordinating activities. For example, due to the convergence of the properties of the basic forms of coordination "contractual" and "stigmergy", the corresponding elements of coordinating activity merge (Parinov, 2022).

For an individual agent, such a digital transformation of the CA significantly simplifies the process of coordinating his activities. Digitalization allows him to use the same actions to coordinate various types of his joint activities, which in the traditional case requires more complex and diverse actions from the agent. As a result of unification, the agent's coordinating actions are reduced to: 1) receiving information from the virtual and real environment; 2) actualization of his information image in the computer system of coordination; 3) making a decision on the practical implementation of options for joint activities offered to him by the computer coordination system. All other elements of coordinating activity, in this case, can be performed by software algorithms in the computer coordination system.

The convergence of the characteristics of the basic forms of coordination in their digitalization, by bringing them closer to the best the same values, means the appearance of serious advantages in the basic form "common rules". This basic form of coordination usage, ceteris paribus, is the least expensive. In such a situation, it becomes beneficial for agents to use the digital version of the “common rules” form instead of the contractual form and/or stigmergy.

Under conditions of convergence of the characteristics of the basic coordination forms, their use is determined by their unique properties. For the contractual form, such a unique property is the collective nature of the activity or the collective creativity of the participants, which is usually defined by the term "collaboration". For stigmergy, a unique property is the maximum manifestation of the individual character of agents, which quite accurately corresponds to the concept of "competition". Let us clarify that in this case, the concepts of "collaboration" and "competition" determine only the dominant nature of the relationship between agents, since in reality, these two types of relationships, as a rule, are present in the activities of agents simultaneously, but in different proportions.

The unique property of the "common rules" form is the exclusion of the influence of the factor of proximity and/or conflict of interests of agents on their main activities. Thus, the activity of agents based on the form of coordination "common rules" is neutral because it explicitly lacks both collaboration and competition.

As a result, a consequence of the digitalization of coordinating activity is the emergence of motivations for using the basic form of coordination "common rules" in all cases, except for situations where the type of activity and/or the conditions for its implementation require the presence of collaboration or competition of agents.

5.4. Radical digital transformation of coordination mechanisms

The convergence of the characteristics of the basic forms of coordination as a result of its digitalization, combined with the transformation of the coordination mechanism into a distributed computer system, allows one to consider the theoretical possibility of creating a unified coordination mechanism for all types of agents’ socio-economic activities. The fundamental possibility of the existence of the unified mechanism of coordination follows from the hypothesis considered in Section 3.5 of the existence of the fundamental process of coordination occurring in all coordinated systems. A logical result of the digitalization of this fundamental coordination process and the coordinating activity is the emergence of a mechanism for coordinating all humans’ socio-economic activities in the form of a global distributed computer coordination system.

The details of the unified coordination mechanism design and its properties are still to be studied (Parinov, 2022). However, it is already clear that the creation and use of the unified global coordination mechanism instead of existing separate ones has a number of clear advantages:

- the economy and its participants receive the unified adaptive coordination mechanism instead of several different ones, which provides more flexible and comprehensive coordination of activities, including for the global labor division system;
- computer technologies increase the quality of coordination and improve the ability to maintain coordination of actions over time;
- programming interfaces act as regulatory institutional structures, ensuring that agents comply with the specified rules at the level of interfaces;

- agents get the best chance for maximum self-fulfillment, since their potential partners are all other agents in the global economy, and their intentions and opportunities for joint activities are presented with the highest possible quality.

Such a global distributed computer coordination system supports the coordinating activity of humans, which is the basis of all types of coordination between socio-economic agents. In this form, this computer system can coordinate all types of activities of socio-economic agents, and not just economic ones. For an individual agent, this means the possibility of interconnected and systemic coordination of all types of his activities, including economic, scientific, socio-political, educational, security, etc. The computer system of the unified coordination mechanism allows a person to more fully coordinate and better link all his various activities with each other to achieve his goals. This creates unique opportunities for the best use of humanity's potential for economic and social development.

6. Methodological perspectives

The conceptual model, built in this study, describes the fundamental process of coordination, which is present in all processes and mechanisms of coordination. This allows one to consider this result as a contribution to the construction of a general theory of socio-economic coordination, which explains the observed diversity of coordination methods from the unified methodological basis. The principles and algorithms for coordination mechanism design, formed based on such a theory, can ensure the systematic creation and dynamic change of coordination mechanisms both for various types of human activity (for example, economic, social, political, etc.), and for socio-economic activity in general.

The prospect of creating a general theory of socio-economic coordination allows one to consider the possible methodological consequences of such changes for the scientific picture of the socio-economic world. Let us consider some ideas on the example of economic activity.

Taking into account the fact that the coordinating activity on the basis of coordination mechanisms creates conditions for the main economic activity, it follows from this that in the relationship between the coordination and the economy, coordination is primary. The economy is “nested” into the system of coordination mechanisms and its properties are partly determined by the properties of these mechanisms. By improving coordination mechanisms, we are creating new opportunities for economic growth and development. In this context, it is possible to raise the question of the existence of the coordination mechanism design, which is ideal for the economy, the country, and humanity.

The theoretical possibility of a conscious and decentralized design of coordination mechanisms for large communities (for example, humanity as a whole) leads to the need to clarify the structure of human socio-economic activity in the most general form. Bearing in mind the conscious collective construction of coordination mechanisms, the overall humans’ activity has the following levels:

1. The main economic activity, thanks to which humans maintain their livelihoods;
2. The coordinating activity for the main activity, creating conditions for humans to receive benefits from their main activity;
3. The activity to design and improve coordination mechanisms;
4. The coordinating activities to design and improve coordination mechanisms.

Each level in this structure, starting from the second, is based on the mental reflection by people of the conditions for their activities, which determine the content of the mental models of the

participants in the activity. The transformation of individual mental models into a collective means the formation of a more or less complete "map" of the conditions for activity and the environment in which people conduct their activity. Thus, the participants have a nested structure of mental representations, each next level of which includes a mental "map" of the previous level. In this case, the "map" of existing conditions at each next level is a partial recursion of the "map" of the previous level.

Assuming the existence of a general model of socio-economic coordination, we can make some refinements in the abstract model of an economic man (homo economicus) regarding his maximizing behavior. There are three successive stages in maximizing human behavior:

a) Economic man creates coordination mechanisms as a necessary condition for obtaining the maximum benefit from his main activity.
b) Economic man analyzes the conditions formed at stage "a" to determine the content of his main activity in order to get the maximum benefit within the boundaries defined by the design of the coordination mechanism.
c) Economic man implements the content of the main activity chosen at stage “b” in such a way as to get the maximum benefit from it.

The primacy of coordination processes in relation to the economic activity allows one to determine the hierarchy of properties of the economic man:

- The primary properties of economic man, allowing him to conduct joint activities with other people;
- The secondary properties that determine an economic man’s ability to conduct a particular type of activity. For example, human properties that allow him to conduct economic activities, scientific activities, movement in traffic, etc., including activities to create or use the coordination mechanisms;
- The tertiary properties defined by the coordination mechanism features that are used to coordinate a particular activity. For example, the market mechanism of coordination requires from an economic man the properties described as the market behavior.

The following set of properties of economic man is given in (Avtonomov, 2022): unlimited needs; the effect of preferences and restrictions; ability to evaluate; the presence of motivation; use of information and manifestation of rationality. Regarding the above, these properties can be classified as primary, because they list the properties that are manifested in the most diverse types of joint activities, and not just economic ones. To complete the picture of the properties of economic man, the properties given in (Avtonomov, 2022) should be added with secondary and tertiary properties, i.e. properties of a man who conducts precisely economic activity and is regulated by one of the mechanisms of economic coordination.

The methodological perspectives discussed in this section, which emerge as a result of presenting the processes of socio-economic coordination as the unified theoretical model, create, in our opinion, the conditions for the methodological integration of all socio-economic disciplines. A unified theoretical model of coordination allows one to consider the socio-economic world as a system of concepts about the properties of socio-economic man (Homo Socio-Economicus) who conducts various types of joint activities, the content of which is coordinated with each other by various, also interconnected, coordination mechanisms. On this methodological basis, the unified model of Homo Socio-Economicus and the general socio-economic theory can be created.

7. Conclusion

The presented conceptual model of socio-economic coordination has various directions for further development and many ways of its practical application. One of the most currently demanded directions in this approach development, which promises important both theoretical and applied results, is the study of the impact of the ongoing deep and complex digitalization on the coordination processes. The digitalization of the coordinating activity opens up the theoretical possibility of creating and using a universal global coordination mechanism that fully uses the capabilities of modern ICT and computer technologies (Parinov, 2022).

The proposed conceptual model of coordination can become a methodological basis for creating a mathematical model of coordination mechanisms, implemented, for example, as a computer agent-based simulation model. Such a model can become a tool for studying the properties of an economic system with built-in coordination mechanisms, including the analysis of scenarios for the digital transformation of coordinating activities and possible socio-economic consequences from improving coordination processes.

The creation of the agent-based simulation model will allow, in particular, to get an answer to an important question for modern society: how, on the basis of modern ICT, is it possible to rebuild the mechanisms for coordinating the joint activities of people so that they have a higher efficiency? In addition to this, computer experiments with such a model will allow one to study in detail the theoretical possibility of creating the unified adaptive coordination mechanism based on ICT, which adapts to the individual conditions of joint activities for individual participants. Such a prospect of digitalization of coordination processes promises a radical change in the usual socio-economic practice.

The results obtained in this study are methodologically significant for socio-economic theory development. The constructed conceptual model describes the fundamental process of coordination, which is present in all processes and mechanisms of coordination. This allows one to consider this result as a contribution to the construction of a general theory of socio-economic coordination, which explains the observed diversity of coordination methods from a unified methodological basis. The principles and algorithms for designing coordination mechanisms, based on such a theory, can ensure the systematic creation and dynamic change of coordination mechanisms for different types of human activity (for example, economic, social, political, etc.).

The prospect of being able to describe the processes of socio-economic coordination by the unified theoretical model creates conditions for the methodological integration of socio-economic disciplines. The unified theoretical model of coordination makes it possible to represent the socio-economic world as a single system of various types of joint human activities, which are interconnected by various, also interconnected, mechanisms of coordination. From these ideas follows the possibility of creating a unified model of socio-economic man and a general socio-economic theory.

Supplementary materials

1. Supplementary material #1 - https://sparinov.wordpress.com/2022/08/01/conceptual-model-of-socio-economic-coordination-at-micro-level/

2. Supplementary Material #2 - https://sparinov.wordpress.com/2022/08/02/main-characteristics-of-the-basic-forms-of-coordinating-behavior/

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