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Intelligent Biosystems and the Idea of the Joint Synthesis of Goals and Means

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1. Introduction

Immediately after the appearance of first computers more than sixty years ago, the idea of the creation of artificial intelligence similar to that of humans has inspired activity of thousands of outstanding individuals. Interesting results have been achieved in this endeavor but the situation still seems unsatisfactory. With exception of very narrow domains such as chess playing, intelligent systems cannot compete with humans or even animals. Several factors may be the reason of this situation. In this chapter, I consider one of the most important reasons: there are serious problems in the theory of intelligent systems and, accordingly, in theoretical approaches to the building of artificial intelligence. Therefore, the consideration of fundamental principles of intelligence may be an appropriate method for constructing effective systems of AI.

Although there is no clear definition for the term ‘intelligence’, it is intuitively understandable that intelligence is an attribute of goal-directed systems. A goal-directed system has various goals, which the system attempts to achieve through interactions with the environment based on diverse methods or means. Intelligence characterizes the efficacy of such systems in the achievement of its goals (Russell & Norvig, 2003). Humans and animals undoubtedly are goal-directed systems and observations of their activities reveal two obvious classes of such systems.

One class that may underlie the activity of nonhuman animals contains goal-directed systems in which basic goals and means are determined jointly in the moment of the creation of a system. A system belonging to this class functions as follows: one or several basic goals are activated along with a broad diversity of means innately associated with those goals. In accordance with the requirements of the situation, one or several of such means are performed and then associations between those goals and means are changed through feedback loops using hard-wired relations between goals and the result of performance or/and those relations generate new means, which are consequences of some changes in ongoing means. It seems that various systems in neural nets, evolutionary computing, reinforcement learning, etc correspond to this class of goal-directed systems (Haykin, 1998; Bäck, 1996; Holland, 1975; Leslie et al, 1996; Sutton & Barto, 1998).

The observation of human actions and introspection allow us to define the other class in which goals and means can be constructed arbitrarily and independently from each other. If a goal is constructed arbitrarily, then searching through all of possible means is the only method for selecting one or several means appropriate to achieve the goal. The efficacy of those means may increase the probability of their usage in similar situations; however, this class does not suggest unequivocal methods based on feedback loops to construct novel means. Various, largely symbolic, systems can be related to this class (Bertino, Piero & Zarria, 2001; Jackson, 1998; Newell, 1990).

Because these classes are so obvious, it is very reasonable to assume that any AI project can be attributed to one of the classes (though some projects may combine characteristics of both). Like other technical systems, AI projects are not intended to imitate their natural counterparts but rather attempt to achieve "natural functionality". The fact that the objective of Artificial Intelligence as a scientific and engineering activity is the full-scale functionality of human intelligence means AI researchers implicitly suggest that humans can be attributed to one or both of these classes. However, in my opinion this supposition is doubtful.

Undoubtedly, like other animals humans have a complex structure of innate goals associated with survival and reproduction. As a result, some scholars attribute humans to the first class of goal-directed systems. For example, behaviorism suggested an innate motivation mechanism in order to establish connections between goals and means through reward and punishment (Heckhausen, 1980). Currently, evolutionary psychology is very explicit in supposing that humans have an innate repertoire of goals and domain-specific modules (Tooby &Cosmides 1992; Tooby, Cosmides & Barrett, 2005). However, the attribution of humans to the first class system is unable to explain the diversity and rapid alterations of actions either at the level of a single individual, or at that of a whole society (Buller, 1998).

This inability hints that humans belong to the second-class systems. The main problem, which faces such systems, is a combinatorial explosion owing to the need to search through the potentially infinite number of possible means. However, people regularly make effective and flexible decisions without being overwhelmed by their decision-making processes. Some ideas to explain how the mind avoids a combinatorial explosion have been suggested (Newell, 1990), but they do not seem satisfactory (Cooper & Shallice, 1995). Moreover, although people are able to apply the strategy of deliberately searching among several conscious alternatives, some problems demonstrate that the thinking system is reluctant to use searching.

Consider, for example the following simplest chess riddle: White: Ke1, Rf2, Rh1; Black: Ka1. White to play and mate in one. When the author (P.P.) was acquainted with the problem he found that many poor chess players (and P.P. himself), who were, of course, familiar with the chess rules, could not solve the riddle or solved it after many attempts. However, any chess program immediately finds the solution: castling O-O. Indeed, since White should mate in one, in order to solve this problem it is necessary to generate each formally possible move for White in the given position, and to test whether this move is the solution. Such a searching procedure is available for the computer program but often not available for a human.

Everyday experience seems to demonstrate that people seldom use searching among possible alternatives. Instead, they prefer (often unconsciously) a routine action. In accordance with this opinion, the dual-processes models (Stanovich & West, 2000; Evans, 2003) have supposed that the mind includes two components. One component uses searching procedures and accordingly is responsible for deliberate actions. The other component, which complies with the systems of the first class, underlies routine, automatic actions. It is suggested that in routine everyday situations, in which, according to such theories, the vast majority of actions is performed, the routine component effectively selects an appropriate action. Searching and planning are involved only in unusual situations. Some unspecified mechanisms constrain searching in those rare cases when the latter is necessary.

In my opinion, however, nonroutine and routine situations are intertwined more strongly than it may be consciously acknowledged. The mind cannot be separated into the two components. For example, if an individual is hungry, she may open her home refrigerator without the clear awareness of this process. However, people usually do not open somebody's refrigerators automatically even if they are hungry. No special intention to inhibit the wish "to open somebody's refrigerator" is necessary in such situations. Obviously, there is no universal routine "not to open somebody's refrigerator", simply because it is very difficult to define unequivocally and finally what refrigerators are permitted to open. Therefore, it is necessary to suggest that ongoing goals somehow control activity when an individual attends to the refrigerator, allowing or forbidding the opening of the latter. In the same manner, ongoing goals unconsciously involve in most of routine situations even when the individual believes that some component of her activity is automatic. With the involvement of ongoing goals in most of everyday situations, the problem of combinatorial explosion becomes unresolved for the dual-processes models.

Whereas, AI research is not intended directly to imitate human intelligence but it seems obvious that a certain view on human intelligence is a very important tacit heuristic to AI researchers and strongly influences AI studies. In my opinion, the analysis of the two conventional classes of goal-directed systems demonstrates that human activity hardly can be derived from these classes and this may be a very serious factor constraining AI research.

I suggest that the standard view on possible classes of goal-directed systems is incomplete and consider a more complex categorization below. I present, based on this classification, a new view on human goal-directed activity as a characteristic of a particular class of goal-directed systems. Some ideas on how this class can be represented in the brain are considered. These ideas form the basis for the simulation of simple models of goal-directed activity. Some proposals on how this novel understanding of humans as goal-directed systems can be used to create intelligent systems are also considered in the article.

2. Two-dimensional classification of goal-directed systems and the idea of joint synthesis

The two classes of goal-directed systems are usually considered as two poles of one axis and as a result, it seems that there are no other classes. However, a more profound view on the classes demonstrates that the situation may be more complex. Indeed, the first class contains goal-directed systems in which basic goals and means are constructed innately and together. In the systems of the second-class goals and means can be constructed arbitrarily and separately from each other. It is easy to discern that the words "innately" and "separately" are not antonyms neither are the words “together” and “arbitrarily”. This may mean that the two classes are only an apparent projection of a two-dimensional structure, in which one dimension can be characterized as “innate” versus “arbitrary” or “learned” and another dimension as “constructed together” versus “constructed separately”. With this assumption, a representation of this structure can be given as the following table.

	Together	Separately
Innately	Goals and means are constructed innately and together	Goals and means are constructed innately and separately
Arbitrarily	Goals and means are constructed arbitrarily and together	Goals and means are constructed arbitrarily and separately

Table 1. Classification of goal-directed systems

This results in a more complicated structure with four classes. Prior to the consideration of this structure, it seems useful to raise an issue of whether this classification is fundamental enough. Undoubtedly, there may be many various sources of classification: for example, the diversity of goals or the number of levels in the system can be used to classify. However, obviously, the most important classification should be based on key characteristics of goal-directed systems. In my view, the table reflects such fundamental characteristics because one axis is the capability of a goal-directed system to change and adjust and the second dimension is the relationship between the main components of any goal-directed system, i.e. its goals and means.

It is easy to discern that two cells in the table correspond to the conventional classes but two new classes emerge from the other cells. One new class is goal-directed systems, in which goals and means are constructed innately and separately. Such architecture is, however, logically impossible. Indeed, if basic goals and means of a certain goal-directed system are defined at the moment of the creation of the system, then a common configuration undoubtedly underlies them and they cannot be constructed separately.

The other new class is goal-directed systems, in which goals and means can be constructed arbitrarily and jointly. If one suggests that the construction of a goal and means in such a system is a self-organizing process, which is based on an extremal principle, e.g. that the costs on the synthesis should be minimal, then particular advantages of this class can be easily revealed. Indeed, because the goal and means in a system of this class are constructed jointly, there is no need to search among a potentially infinite set of means to satisfy the given goal; this is a simple solution to the problem of combinatorial explosion. On the other hand, the possibility to synthesize goals and means arbitrarily indicates the actions of the systems belonging to this class may be very flexible and adaptive. With such characteristics of this class, my main idea is that human beings are goal-directed systems in which arbitrary goals and means are synthesized jointly.

One may propose some objections to this hypothesis. First, if a goal and means are constructed together then the means ought to be appropriate for achieving the goal. However, people often understand what goal must be achieved but they cannot suggest appropriate means to achieve the goal. However, it is necessary to note that the joint synthesis is not a method to create the best action (this is impossible due to combinatorial explosion) but a method to create any action (because the number of possible actions is infinite, in principle). To a certain degree, an alternative to the action constructed by the ongoing joint synthesis is not another action but rather its absence. Therefore, the idea of joint synthesis is not hurt by the fact that people are able to imagine, plan, or pursue completely arbitrary even unachievable goals. Because even when the individual thinks that there is no method to achieve the goal, nevertheless an inappropriate method is chosen because the selection of a certain aspect of reality among the infinite number of other possible aspects occurred.

Second, experience teaches us that one goal can be achieved by various methods, ways (this is the principle of equifinality (Bertalanffy, 1968)) and that one method can be applied to achieve various goals. These obvious facts, which underlie one of the two conventional classes, seem inconsistent with the joint synthesis hypothesis (referred to as the JSH hereinafter). In my opinion, the idea that goals and means can be constructed separately is correct at the level of social practice but a psychological illusion at the level of psychological mechanisms of a particular action.

In order to clear this idea, imagine that one needs to achieve the 35th floor of a skyscraper. Firstly, this can be made by means of an elevator. If no elevator can be used (e.g. there is no voltage), it is possible to go upstairs. Finally, if the staircase is destroyed then one can climb on the wall using necessary tools. It seems one invariable goal can be combined with various methods to achieve it. However, the first method is available for everyone because it requires no concentration of mental recourses. The second one can be accepted when there is a serious need to reach the goal. In addition, the last one can be used only under extreme circumstances requiring the strongest concentration of will and energy. In other words, from the position of internal processes each way requires a certain psychological arrangement with special goals and this arrangement is acknowledged by any individual as distinctive from the others. Therefore, a change in the situation results in the alteration of goals at a particular level of the hierarchy of goals. It is reasonable to assume that the interaction between goals and means in the process of the construction of a goal-directed activity is a characteristic of any such activity.

In my opinion, like other psychological illusions, such as, for example, the illusion of the instantaneous reaction to an external stimulus (the understanding that the reaction is not instant, occurred in 1823 only (Corsini & Auerbach, 1998)), the illusion of the separate construction of goals and means results from the fact that it is very difficult to combine the involvement in a particular activity with the simultaneous introspective monitoring of this activity. Indeed, when an individual pursues a particular everyday goal (e.g., shopping at the supermarket) she usually does not pay attention to all variations in the intermediate goals and means necessary for this multi-stage pursuit. As a result, the complex interplay of these intermediate processes is reflected by consciousness and memory only partially, while the success or failure in the achievement of the main goal is usually in the focus of consciousness. In addition, the detailed awareness of each stage in a multi-staged activity is merely impossible because this is able to destroy the activity itself. The result of these circumstances is, in my opinion, a false feeling of the separate formation and change of goals and means.

It is necessary to note that the hypothesis that the mind constructs the goal and means together does not imply that an individual deliberately cannot search through possible options as a method to determine an appropriate means. Indeed, the conscious idea to apply searching along with the awareness of several possible options may be the result of the ongoing synthesis.

The validation of the JSH is easy. Indeed, because the hypothesis suggests that the mind constructs the goal and means of an action jointly following the criterion of minimal construction costs. This means that if there are no explicit preferences to choose among several possible actions then an action requiring minimal mental costs to be constructed is preferable. This action should be selected without intensive searching among probable alternatives. On the other hand, this choice should not be a result of the activation of a routine procedure and can be changed deliberately. A real experimentation to test these suppositions is possible but beyond the scope of this article (Prudkov &Rodina, 1999, Rodina &Prudkov, 2005). Instead, I consider a thought experiment, which, in my opinion, is sufficient to demonstrate the relevance of the JSH.

Imagine that two individuals participate in this experiment, one of them is Experimenter, the other is Subject, accordingly, and the experiment takes place in London. The participants are discussing some problem and at a certain moment, Experimenter asks Subject to give him a pen without specifying the location of the pen. Many people have a pen in their pockets, and it is very probable that Subject is among them. Subject takes the pen out of the pocket and gives it to Experimenter. It is very reasonable to suggest that the construction of this action needs minimal mental costs. In response, however, Experimenter asks, "why did Subject take the pen out of the pocket instead of calling New York?" Subject is astonished by this question and then Experimenter says that there are many pens in New York and Subject could find a pen there. The astonishment of Subject means that his mind did not find among possible alternatives of the pen's location but one may argue that this reflects the fact that Experimenter's request is performed by the activation of a corresponding routine. It is obvious, however, that if Experimenter would merely ask Subject to find a pen in New York then Subject could easily convert this idea to a sequence of actions. Such a rapid adjustment to the situation cannot be provided by a routine. This is the result of a special goal-directed process. In my opinion, this simple situation, which can be easily repeated in reality, demonstrates the appropriateness of the idea of joint synthesis.

Although the joint synthesis is a basic attribute of humans as goal-directed systems, the consideration of this characteristic alone may be insufficient to understand the whole diversity of human actions. Humans, of course, have innate mechanisms necessary for survival and reproduction and those, although are under control from more modern systems, influence actions and therefore, to a certain degree, humans can be considered as the goal-directed systems of the first class. On the other hand, using language and complex social skills, an individual can "emulate" the separation between goals and means. Indeed, by discussing some ideas with other people or by writing the ideas down and afterwards thinking about them, an individual can concentrate either on the goals or on the means of a goal-directed activity. The fact implies, to some extent, humans can be considered as systems with the separate and arbitrary construction of goals and means. However, it is the joint synthesis that determines the involvement of the other classes of goal-directed systems in human actions.

It is usually suggested that a goal-directed activity pursues a clear and unequivocal goal and when the individual acknowledges that the outcome of the process meets its goal then the activity completes. However, in my opinion, the idea of a clear and unequivocal goal seems doubtful. Consider, for example, the situation with Experimenter and Subject above. Obviously, that Subject unconsciously converted the goal "to find a pen" into the goal "to find a pen in the pockets" and as a result, he is astonished by the proposal "to search a pen in New York", though this proposal is consistent with the initial request. Obviously, the supposition "to search for a pen in another room" could astonish Subject to a lesser degree. Similarly, Experimenter would be stunned, if Subject could pull a giant pen (for example, 50 centimeters in length) out of his bag though such a pen meets his request. On the other hand, a pen of a very unusual design but a standard size could wonder Experimenter less. Therefore, it can be assumed that Experimenter and Subject have some distributions of anticipations regarding the result of their goal-directed activities rather than unambiguous goals, but they acknowledge those anticipations only partially.

I suggest that any goal-directed activity is a distribution of anticipations regarding the goal and means of the activity. The activation of some components of this distribution is determined by particular aspects of the situation and the changes in the situation results in the activation of slightly other components of the distribution. The construction and changes in the distribution are based on the criterion of minimal construction costs.

A suggestion that the goal and means of a goal-directed process are some distributions leads to two fundamental conclusions. First, this means that there is no simple procedure to define when the goal is achieved because it may be difficult to find an unequivocal compliance between the distributed representation of the goal and the output of the activity. Therefore, the completion of an ongoing process is the result of the interaction between this process, the situation, and the hierarchy of other processes. In other words, there is no special comparator always able to compare the goal and the output of the activity and as a result, people sometimes do not acknowledge that the result of an ongoing activity does not respond to its initial goal. In my opinion, everyday experience is consistent with this suggestion. Consider, for example, an individual who plans to buy necessary goods at the supermarket. Sometimes the result of such activity is that an individual misses several objects planned. Instead, she purchases other goods but thinks that the goal of the action is achieved.

Second, the vague representation of the goal and method implies that the sustainability of a goal-directed activity can be considered as its relatively autonomous attribute. Indeed, sustainability seems a one-dimensional parameter and hence less variable than multivariate distributions of goals and means that ought to meet the very complex structure of the situation. A proposal of the autonomy of sustainability seems unusual enough but perseveration, i.e., the involuntary and uncontrollable repetitions of a particular action, which is a very frequent attribute of disturbances in goal-directed behavior (Luria, 1966, 1972,1983; Joseph, 1999), clearly favors this proposal. Indeed, perseveration can be considered as the activation of a sustainable component, which, if the goal-directed system is damaged, persists regardless the influence of the situation or other processes.

3. Neural basis for the joint synthesis

If the goal and means of a goal-directed activity are constructed together then it is of great importance to understand how this can be implemented in the brain because similar mechanisms can be used to create artificial goal-directed systems. Undoubtedly, human goal-directed activity is very complex and a detailed understanding of it is the beyond scope of this article. Instead, I consider the neural basis of a certain "ideal" goal-directed process suggesting it includes three obvious stages, i.e. initiation, execution, and termination. My approach meets most of the contemporary hypotheses, which consider that the prefrontal cortex (PFC) plays a key role in goal-directed processes (E.K. Miller& Cohen, 2001; Wood& Grafman, 2003). In accordance with this position, I propose that the prefrontal cortex is heavily involved in the construction and maintenance of neural patterns representing goals and means.

It is suggested that the capacity of the PFC to construct and maintain sustainable neural patterns is based on possible reverberatory characteristics of neurons in this structure (Fuster 1997). It can be supposed that owing to such reverberatory properties the emergence of sustainable characteristics of a neural pattern is, to a certain extent, autonomous from the emergence of its other characteristics. In other words, relatively weak changes in neurons of the PFC may be sufficient to make a pattern sustainable but more serious alterations are necessary to form its other characteristics. This underlines a relative autonomy of the sustainability of goal-directed processes at the cognitive level.

It is suggested that the prefrontal cortex can be considered as blackboard architecture. Blackboard architecture consists of a set of specialized or stable processors that interact with each other using a blackboard, consisting of less stable, flexible elements. Some authors (van der Velde& de Kamps 2003, 2006) have suggested the idea that the prefrontal cortex uses this sort of architecture. This idea is consistent with the neural data. For example, this means that most of prefrontal neurons must flexibly adapt its activity to the ongoing task. And 30-80 percents of prefrontal neurons of the monkey show selective responses to some aspect of that task's events (Asaad et al 2000). However, it is necessary to emphasize a distinction between conventional views on blackboard architecture used in AI (Corkill 1991; Craig 1995) and that used in this text. Unlike conventional models, the given model does not suggest an absolute difference between stable processors and flexible elements, i.e. stable processors can be converted to flexible elements and vice versa because both groups comprise of similar neurons and only the level of stability distinguishes them.

It is reasonable to assume that a new goal-directed process emerges from the integration of various sources of information associated with the ongoing situation. So, it is hypothesized that prior to the construction of a new goal-directed process the prefrontal cortex can be considered as a blackboard system in which incoming sensory information and/or ongoing internal processes (emotions, innate drives, other goal-directed processes, especially those at higher levels, etc.) presented as spatiotemporal patterns of neural activity in the PFC and other brain structures are stable processors. Moreover, other ensembles of the PFC comprise a bulletin board with flexible elements. The construction of a new process started from interactions between stable processors and flexible elements and owing to such interactions, the characteristics of flexible elements become similar to some characteristics of stable processors. At the neural level, this means similar frequency or distribution of firing, etc.

and at the cognitive level this means some similar functions. After this, flexible elements with new functions start interacting with each other also exchanging its characteristics. It is reasonable to suggest that the more similar characteristics shared by some elements, the more probability of its interactions. For example, if neuron A has a synapse with neuron B then a probability that the discharge of neuron A results in the discharge of neuron B seems more than the same probability for two neurons that do not share a common synapse. The relationship between the similarity of elements and the probability of its interaction is the substantiation of the criterion of minimal construction costs.

It is reasonable to expect that owing to interactions between elements, the resemblance of elements can be increased. As a result, a pattern joining many elements with similar characteristics gradually emerges and this pattern becomes sustainable. This indicates that the construction of a new process is completed. Although, elements in the pattern have something in common but there are some distinctions among them and this is a prerequisite for the distributed representation for the goal and means.

It is suggested each pattern can be considered as a construction with two interconnected components: one component is responsible for the goal and the other for the means. Such a separation is based on the idea that some neurons in the pattern have mainly local connections within the prefrontal cortex (they comprise the goal component). Other neurons in the pattern are linked to other brain structures (those are the means component). Because the activity of neurons within the PFC is likely more reverberatory and self-sustained than that of neurons linked to other structures, the goal component can be more stable and persistent than the means component.

Once a goal-directed process is constructed, some activation from the means component propagates to other brain structures, which are able to carry out the process, and its performance is initiated (B.T. Miller& D'Esposito 2005). Simultaneously, the components interact with each other; this stabilizes the means component while it receives feedback because of performing the process. Therefore, the fact that the process pursues the goal is a result of the stability in the goal component produced by self-sustainable characteristics of the PFC. It is possible to say that goal-directed processes are self-sustained gates, which amplify appropriate information and diminish inappropriate one. The components are constructed together but their architecture is slightly different. The functioning of components gradually increases these differences and this change may be a basis for an autonomous representation of goals and means in consciousness.

As is emphasized above I do not suggest that the brain includes a special comparator, which monitors when the outcome of the process meets the goal, and then turns the process off. Simply, with the achievement of the goal, the current situation undergoes changes, thus not being able to support the ongoing process with appropriate information. To meet novel requirements of the situation, the construction of another process begins. Probably, more stable processes at a higher level of the goal-directed hierarchy supervising short-term ones also participate in the completion of the ongoing process. Free neural ensembles again become flexible components of the blackboard. It can be hypothesized that a real goal-directed process is a hierarchical multilevel structure joining many of such ideal processes.

4. Simulation of a goal-directed activity based on joint synthesis

The hypothesis of joint synthesis and its possible neural implementation can be considered a basis for computer models of goal-directed activity. It is necessary to point out that these models are neither models of a certain aspect of human or animal activity nor implementations of goal-directed activity in the brain. They are simply intended to demonstrate how a goal-directed process can be constructed. The models share a common basis but have certain distinctive characteristics.

4.1 A simple model of goal-directed activity (model 1)

The architecture of the model is presented in Figure 1.

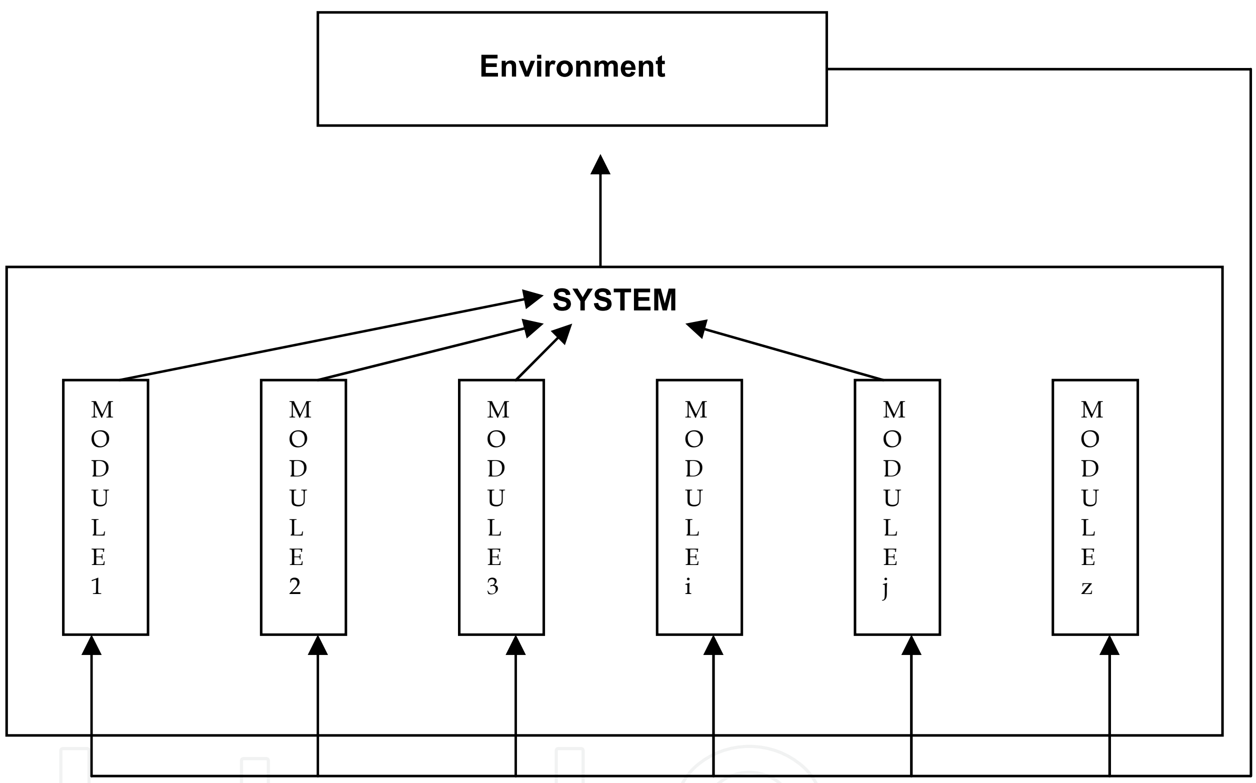

Fig. 1. Architecture of model 1

The model consists of two fractions; one is the system in which a goal-directed activity should be constructed and the other is the environment influencing the state of the system. At the beginning, a new goal-directed process emerges within the system under a certain state of the environment and after changing the environment, the process pursues its goal associated with the initial state of the environment using the means constructed.

The system includes one layer consisting of z autonomous modules and the output of the system is a summation of the outputs of its modules. Each module contains several n-dimension vectors with real numbers as its components. These vectors are an input vector (IV), which is filled by information from the environment (its k^{th} component is IV^k, accordingly), a vector of coefficients (CV), and an output vector (OV). The functioning of the vectors is described below. Also, each module has an activation level (AL), a real number from 0 to 1. With the idea of a relative autonomy of sustainability above, this parameter reflects the stability and activity of the module, i.e., as AL increases the functioning of the module becomes more stable.

A fundamental characteristic of modules is that they interact with each other. The functional proximity between two elements is calculated as follows. First, the following characteristic for module i (and j, accordingly) at iteration m is computed

$$me_{i,m} = \frac{\sum_{k=1}^{k=n} \left| IV_{i,m}{}^{k} - CV_{i,m-1}^{k} \right|}{n} \tag{1}$$

afterward another parameter is calculated

$$sd_{i,m} = \sqrt{\frac{\sum_{k=1}^{k=n} (\left| IV_{i,m}{}^{k} - CV_{i,m-1}^{k} \right| - me_{i,m})^2}{n}} \tag{2}$$

and then the functional proximity between i and j, fp(i,j) is

$$fp(i,j)_m = \left| \frac{sd_{i,m}}{AL_{i,m-1} * me_{i.m}} - \frac{sd_{j,m}}{AL_{j,m-1} * me_{j,m}} \right| \tag{3}$$

The interaction between module i and module j at iteration m occurs if fp(i,m) is less than a threshold (p1) plus a small noise. The fact that modules interacts only if its functional proximity is less than a threshold is an implementation of the idea of minimal construction costs. The result of the interaction between module i and module j is as follows:

$$CV_{i,m}^{k} = CV_{i,m-1}^{k} + \frac{(CV_{i,m-1}^{k} - (CV_{j,m-1}^{k} - IV_{j,m}^{k}) * (1 - AL_{i,m-1})) * p2}{z} \tag{4}$$

$$CV_{j,m}^{k} = CV_{j,m-1}^{k} + \frac{(CV_{j,m-1}^{k} - (CV_{i,m-1}^{k} - IV_{i,m}^{k}) * (1 - AL_{j,m-1})) * p2}{z} \tag{5}$$

It is suggested that modules interact in parallel and the formulae reflect this. Owing to interactions, the activation level of each module (for example, module i at iteration m) is also changed :

$$AL_{i,m} = p3 * AL_{i,m-1} + \frac{t_{i,m} * p4 * (1 - AL_{i,m-1})}{z} \tag{6}$$

where both p3 and p4 <1 and $t_{i,m}$ is the number of interactions between module i and the other modules of the system at iteration m.

It is easy to see that as the AL of a module increases, the components of the module become less prone to change. In addition, if a module did not interact with other modules at the last iteration, its AL should be decreased. Module i is able to influence the environment only if its AL exceeds a threshold (p5) at iteration m, then

$$OV_{i,m}^{k} = \frac{(IV_{i,m}^{k} - CV_{i,m}^{k})}{z}, \text{ otherwise } OV_{i,m}^{k} = 0 \qquad (7)$$

The environment is also a n-dimension vector (E) and its k^th component at iteration m is changed by the following formula:

$$E_{m}^{k} = constant_{m}^{k} + noise + \frac{\sum_{i=1}^{i=z} OV_{i,m-1}^{k}}{z} \qquad (8)$$

It is not difficult to see that, unlike the analysis of neural mechanisms above, this model does not include special layers to form output. The objective of such a design is to avoid unnecessary difficulties conditioned by complex relations between such layers. These difficulties are able to complicate the understanding of the model's functioning without clearing its main ideas. However, because each module has a complex structure with internal vectors such as CV and OV the model can be useful to understand the functioning of various goal-directed systems.

In all simulations, the number of modules in the system (z) was 300 and the vectors in each module were three-dimensional. Real numbers were used as the stuff of all vectors in the system. A goal-directed activity was constructed as follows. First, 40 modules were considered as stable processors. Its coefficient vectors were filled by a constant plus small noise and its active levels was more than p5 (0.3). The other modules of the system were flexible elements. Its coefficient vectors were randomly filled by numbers from 0 to 100 and its ALs were randomly established at 0,06 plus small noise. Following this initialization, interactions between stable processors and flexible elements started. Five iterations of this process took place and p1 was 0,3. At this stage (stage 1), no outputs from the system influenced the environment. This corresponded to the construction of a goal-directed activity. After this, novel constants were established and the interaction between the system and the environment became possible. This stage (stage 2) meant the functioning of a goal-directed activity.

It is necessary to emphasize that the architecture of the model means stable processors are not a necessary condition for the interaction between the system and the environment. In principle, flexible elements are sufficient to provide the functioning of the system but in this case, the activity of the system must be less stable and persistent. To test this suggestion a special simulation was carried out. In this simulation no stable processors were formed but five iterations similar to those in simulation 1 were performed (stage 1, accordingly). After this, certain constants were selected and the interaction between the system and the environment became possible (stage 2).

In both simulations all constants were 80, in other words, the goal of the activity in simulation 1 entirely met the initial state of its stable processors. After three iterations with such constants at stage 2, in both simulations the constants were forcefully established at 50 during one iteration to estimate the stability of the models to random fluctuations.

Afterwards, the constants were 80 again. Because at any moment all constants were identical, the components of input and coefficients vectors in modules could be averaged within each vector and across all modules. As a result, one number was sufficient to describe the state of coefficients vectors at any iteration. In addition, Al averaged across all modules also was used as a characteristic of the process.

It was suggested that owing to stable processors filled by 80 the coefficient vectors of the model with stable processors (CV-sp) should exceed those of the model without stable processors (CV-wsp) at stage 2. Moreover, CV-sp should be more stable after a sudden fluctuation in the constants of the environment. Also, AL-sp should be more than AL-wsp. The results of both simulations are in figure 2, where for convenience, ALs were multiplied by 100.

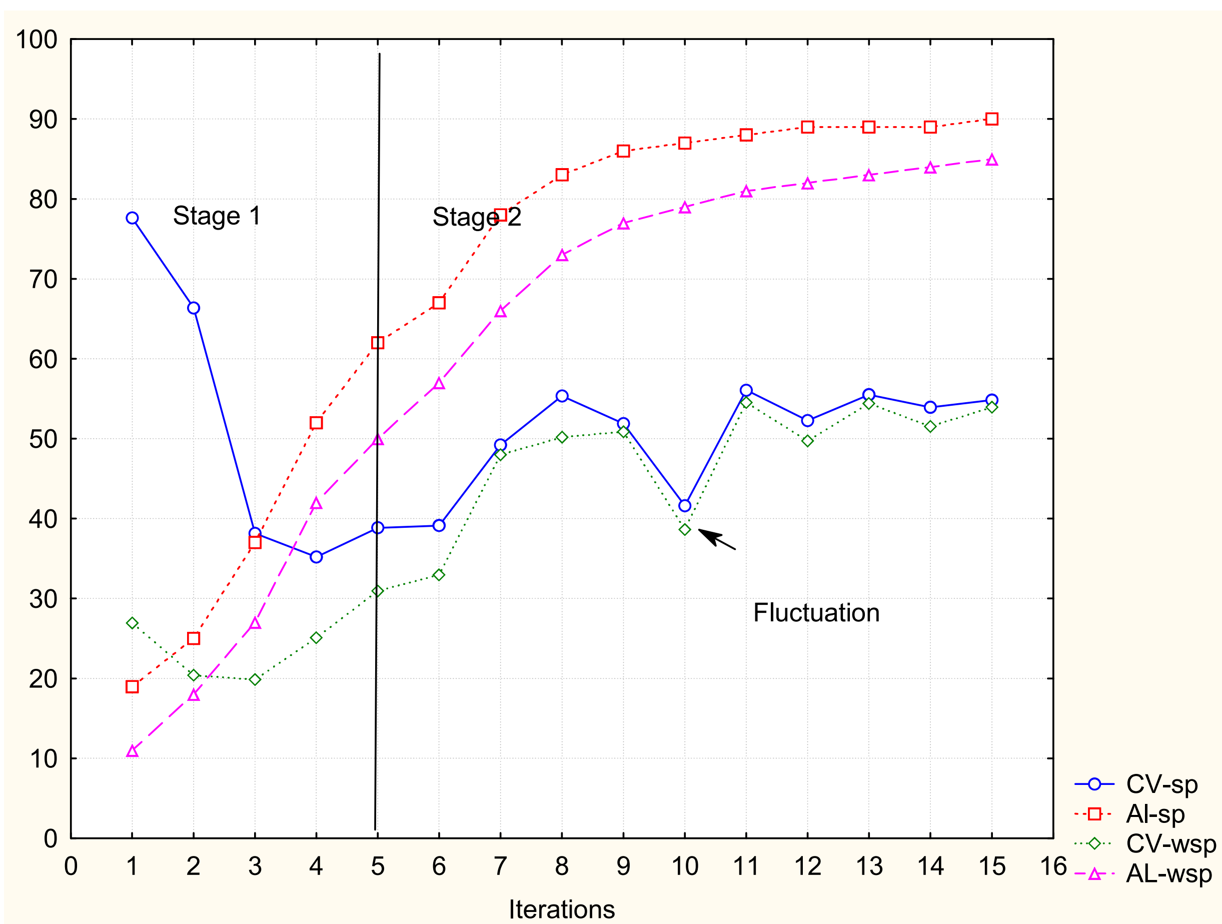

Fig. 2. The comparison of the results of two simulations.

4.2 A model with perceptive spot (model 2)

Though model 1 is able to demonstrate some characteristics of goal-directed activity, it seems too primitive for serious actions. Model 2 is more complex, its system has a perceptive spot, which includes the modules whose input vectors are filled by a useful signal from the environment while the input vectors of the other modules are filled by noise. Both a useful signal and noise are real numbers but the amplitude of noise is considerably less. The system is able to move the center of the spot but cannot change its size. The behavior of the system in model 1 is similar to the activity of an insect, which moves in the environment filled by a nutrient with variable concentration. Model 2 is, to some extent, similar to the action of an eye of an animal.

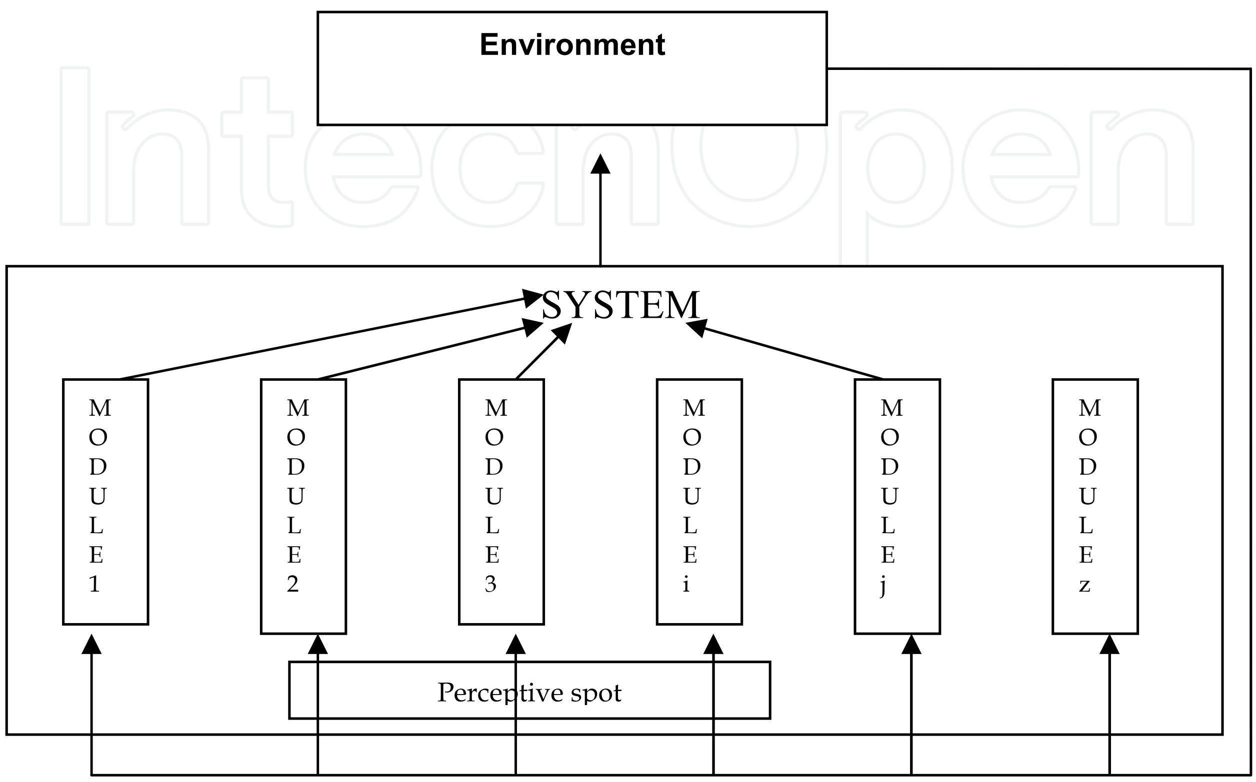

Fig. 3. Architecture of model 2

The modules in this model are similar to those in model 1 but also include a vector of differences (DV), its functioning is described below. In order to avoid the spurious activity of modules filled by noise, a threshold of perception is used, i.e. module i is able to participate in the activity of the system at iteration m only if

$$\frac{AL_{i,m-1} * \sum_{k=1}^{k=n} IV_{i,m}^{k}}{n} \geq p1 \tag{9}$$

The interaction between module *i* and module *j* at iteration *m* occurs if the distance between the modules, i.e. |(i-j)/z| is less than a certain parameter (p2) and the functional proximity i.e.

$$\frac{\sum_{k=1}^{k=n} \left| \left| IV_{i,m}{}^{k} - CV_{i,m-1}^{k} \right| - \left| IV_{j,m}^{k} - CV_{j,m-1}^{k} \right| \right|}{n} \tag{10}$$

is less than a threshold (p3) plus a small noise. The result of the interaction between module *i* and module *j* is as follows:

$$CV_{i,m}^{k} = CV_{i,m-1}^{k} + \frac{(CV_{i,m-1}^{k} - (CV_{j,m-1}^{k} - DV_{j,m-1}^{k}) * (1 - AL_{i,m-1})) * p4}{z} \quad (11)$$

$$CV_{j,m}^{k} = CV_{j,m-1}^{k} + \frac{(CV_{j,m-1}^{k} - (CV_{i,m-1}^{k} - DV_{i,m-1}^{k}) * (1 - AL_{j,m-1})) * p4}{z} \quad (12)$$

Owing to interactions, the characteristics of the vector of differences (DV) of module i at iteration m are also changed as follows :

$$DV_{i,m}^{k} = p5 * (CV_{i,m}^{k} - IV_{i,m}^{k}) + (1 - p5) * DV_{i,m-1}^{k},\ p5<1 \quad (13)$$

it is possible to say that CV is the long-term memory of a module and DV is its short-term memory.

The modules with AL exceeding a threshold (p8 in this model or p5 in the previous one) , also, influence the position of the center of perceptive spot. This position (center position or CP) is determined at iteration m as follows:

$$CP_m = CP_{m-1} + p10 * \sum_{i=1}^{i=z} (T_{i,m} - CP_{m-1})$$

and $T_{i,m} = i / z$ if $AL_{i,m} \rangle p8$, otherwise $T_{i,m} = CP_{m-1}$. (14)

It is suggested the position of the left boundary of the system is 0 and that of the right boundary is 1.

As is emphasized above, only the modules, which are within perceptive spot, are filled by information from the environment, i.e. if $|CP_m - i/z| \leq p11$, then for module i at iteration m+1

$$IV_{i,m+1}^{k} = E_m^k + noise$$

and for modules which do not meet this inequality (15)

$$IV_{i,m+1}^{k} = noise\ .$$

The formulae for computing activation level (AL), output vector OV, and the environment are identical those in model 1.

An idea underlying the usage of model is that under certain circumstances the input vectors of modules i.e. the state of the environment and the vectors of coefficients in the system ought to converge to each other. The results of a simulation intended to test this assumption are presented in table 2. In this simulation as well as in the simulations below, the number of modules in the system (z) was 300 and the vectors in each module were three-dimensional. The constants of environment vector in this simulation were 10, 50, and 90, accordingly. Perceptive spot covered all modules, and each module was able to interact with all of the rest i.e. p2 and p11 were 0,95. The threshold for interactions (p3) was 4,2. The other parameters are in Appendix, they were kept invariable through the other simulations. The values averaged across the components of input vectors were used as the description of the influence of the environment and the averaged components of the vectors of coefficients were considered as the characteristic of change in coefficients. The AL averaged across all modules reflected activity in the whole system.

Iteration	AL	IV^1	CV^1	IV^2	CV^2	IV^3	CV^3
1	0,3	15,03	-3,5	55,04	-3,78	94,87	-3,59
2	0,44	23,96	1,43	80,62	11,16	137,56	21,05
3	0,52	31,49	4,64	104,35	20,66	177,83	36,8
4	0,63	35,97	8,55	119,68	32,02	204,08	55,69
5	0,68	36,76	10,23	124,31	37,03	212,5	64,1
6	0,73	36,18	11,76	124,02	41,71	212,28	71,98
7	0,78	34,34	12,75	120,1	44,83	205,74	77,26
8	0,81	32,18	13,44	114,51	47,06	196,08	81,01
9	0,84	30,03	13,89	108,31	48,58	186,22	83,57
10	0,86	27,87	14,19	102,51	49,68	176,43	85,41
11	0,89	25,8	14,36	96,86	50,36	167,03	86,55
12	0,9	24,24	14,36	91,99	50,58	158,47	86,93
13	0,92	23,05	14,31	87,67	50,6	151,7	86,97
14	0,94	22,23	14,27	84,33	50,55	146,17	86,91
15	0,94	21,12	14,25	81,75	50,55	141,95	86,91
16	0,95	20,48	14,25	79,46	50,57	138,81	86,94
17	0,95	19,87	14,25	78,13	50,59	135,9	86,97
18	0,95	19,75	14,26	76,47	50,61	133,62	87,01

IV^1, IV^2, IV^3 are the first, second, and third averaged components of input vectors; CV^1, CV^2, CV^3 are the same components of the vectors of coefficients.

Table 2. Simulation of the convergence between input vectors and vectors of coefficients.

It is easy to see that input vectors and the vectors of coefficients indeed converged, though this process was incomplete probably because, as the mean AL approached to 1, changes in the system became practically impossible.

A goal-directed process was constructed as follows. First, one region of modules (or several regions consecutively) was considered as perceptive spot and the state of modules within this region was changed under a certain state of the environment. The position of the spot could not be changed during this stage. This corresponds to the formation of stable processors. And the modules beyond the spot were considered as flexible elements. At the second stage, perceptive spot covered all modules of the system, which obtained information from a neutral state of the environment. This stage, which corresponds to the interaction between stable processors and flexible elements and the formation of a goal-directed activity, is suggested to be rapid without interacting with the situation. Therefore, at the second stage there was no feedback loop between the system and the environment. A certain distribution of goals and means encoded by coefficient vectors and activation levels resulted from this stage. At the last stage, a new, local perceptive spot was established and the goal-directed process pursued its goal through interactions with the environment. The position of spot was able to change within the third stage.

First, consider the simulation of a goal-directed process with a simple goal. At stage 1, the constants of the environment were 80, 50, and 20. The center of perceptive spot was established at 0,85, the size of perceptive spot (p11) was 0,2. In addition, at this stage, p2 was 0,2 and p3 was 4,2. This stage lasted until the mean AL exceeded 0,2. At stage 2 all constants were 50 and the center of the spot was at 0,5 while p2 and p11 were 0,95 and p3 became 3 at this and last stages. At the start of the last stage all constants were 30, and the center was established at 0,25 while p2 and p11 were 0,2 again.

It was suggested that at stage 3 the process was to move perceptive spot to the right where there were stable processors, thus increasing CP. The state of the vectors of coefficients in the modules within the spot should meet the relationship between the components of coefficient vectors of stable processors caused by the different constants of the environment at stage 1. The components of input and coefficients vectors averaged across the modules within perceptive spot were used to describe the state of the process along with AL averaged across all modules. The results are in table 2

The table shows that at stage 3, the process was increasing CP and the relationship between the components of the vectors of coefficients gradually became similar to that between constants at stage 1. The opposite relationship between the components of input vectors results from formula 7, after inserting a constant as an input vector in it and taking the relationship between the components of CVs into account. Because the constants of the environment were equal at stage 3, the coefficient vectors of the system were influenced by these constants and, as a result, the relationship formed at stage 1 tended to disappear. This corresponds to the completion of the process owing to the influence of the situation. It is important to note that the action of the system cannot be explained by combination of the perseveratory activity of trained modules and the inactivity of untrained ones. The fact that at stage 3 the relationship between the components of the vectors of coefficients was already weakly present at 0,48, considerably beyond the area of modules changed at stage 1 means that a process including most modules indeed was formed at stage 2, while increasing the mean AL at stage 3 implies activity in modules untrained at stage 1.

In another simulation, a process with a complex goal, including two constituents, was formed. In this simulation, stage 1 was divided in two phases. At the first phase, all constants were 20, the center of perceptive spot was at 0, 85, p3 was 4,2 while p2 and p11 were 0,2. After eight iterations this phase was completed, all constants became 80 and the center of perceptive spot was moved to 0,65 without changing p2, p3, and p11. This was the second phase of stage 1 and four iterations were performed. Stage 2 in this simulation was the same as in the previous one. At the beginning of the last stage all constants were 10, and the center was established at 0, 25 while p2 and p11 were 0, 2 again.

It was suggested that the process was to move the center of spot to the right and because there could be two groups of stable processors. The components of the vectors of coefficients within the spot could firstly increase and later decrease but the components of input vectors might change in the opposite direction following formula 7. To some extent, this can be considered as a very primitive form of multilevel activity.

Because at any moment all constants were identical, the components of input and coefficients vectors in modules could be averaged within each vector and across all modules in the spot. As a result, one number was sufficient to describe the state of input or coefficients vectors within the spot at any iteration. In addition, AL averaged across all modules also was used as a characteristic of the process. The results of the simulation are in figure 2, where for convenience, CP and AL were multiplied by 100.

Iteration	CP	AL	Constant¹	Constant²	Constant³	IV¹	IV²	IV³	CV¹	CV²	CV³
					Stage 1						
1	0,85	0,11	80	50	20	85,19	54,83	24,83	3,64	3,64	3,92
2	0,85	0,13	80	50	20	84,91	55,2	25,02	11,95	8,27	4,56
3	0,85	0,14	80	50	20	84,37	55,07	24,86	22,51	14,76	6,63
4	0,85	0,16	80	50	20	88,36	57,55	25,88	29,22	19,01	8,32
5	0,85	0,17	80	50	20	91,84	59,46	27,14	33,77	22,06	9,67
6	0,85	0,18	80	50	20	94,44	61,1	28,59	37,65	24,72	10,98
7	0,85	0,18	80	50	20	95,65	62,54	28,69	40,13	26,32	11,8
8	0,85	0,19	80	50	20	95,82	61,48	28,09	42,11	27,62	12,48
9	0,85	0,19	80	50	20	95,86	61,5	27,57	43,29	28,36	12,92
10	0,85	0,21	80	50	20	95,51	61,68	28,58	44,13	28,86	13,19
					Stage 2						
11	0,5	0,27	50	50	50	55,13	55,24	55,43	15,9	10,55	5,24
12	0,5	0,31	50	50	50	55,02	55,03	55,36	18,53	13,46	8,5
13	0,5	0,35	50	50	50	54,98	55,26	55,23	22,69	18,16	13,69
14	0,5	0,39	50	50	50	55,16	55,16	55,37	25,41	21,35	17,43
					Stage 3						
15	0,25	0,4	30	30	30	35,15	35,25	35,34	19,74	19,79	19,89
16	0,33	0,4	30	30	30	32,36	33,76	35,65	19,42	19,55	19,73
17	0,39	0,41	30	30	30	32,49	33,77	35,07	18,99	19,19	19,23
18	0,43	0,41	30	30	30	33,1	34,59	35,79	17,86	17,96	18,18
19	0,48	0,42	30	30	30	33,38	34,52	35,28	17,75	17,44	17,12
20	0,51	0,42	30	30	30	34,03	34,19	36,29	17,85	17,1	16,35
21	0,55	0,42	30	30	30	34,42	35,37	36,28	18,04	16,88	15,55
22	0,57	0,43	30	30	30	35,72	36,51	38,02	17,82	16,49	14,83
23	0,6	0,43	30	30	30	36,07	37,1	38,73	18,05	16,49	14,58
24	0,61	0,43	30	30	30	35,94	37,92	38,61	18,34	16,68	14,82
25	0,62	0,43	30	30	30	37,52	38,04	39,53	18,4	16,77	14,98
26	0,63	0,44	30	30	30	37,32	38,14	39,41	18,66	16,96	15,26
27	0,64	0,44	30	30	30	38,42	39,43	40,34	18,65	17,11	15,68
28	0,64	0,44	30	30	30	38,17	39,83	40,62	18,8	17,32	16,08
29	0,65	0,44	30	30	30	38,59	39,65	40,52	19	17,66	16,55
30	0,65	0,45	30	30	30	39,41	40,04	40,87	19,28	17,99	16,95

IV¹, IV², IV³ are the first, second, and third averaged components of input vectors; CV¹, CV², CV³ are the same components of the vectors of coefficients.

Table 3. The simulation of a goal-directed process with a simple goal

In my opinion, all of these simulations demonstrate that the processes constructed can be considered as goal-directed in the sense that there was a state (or states), which each process attempted to achieve using certain means. It is important to note that no innate criterion of functioning was used to construct and perform the processes and that the goals of the processes treated as a source of sustainability and its means were constructed together.

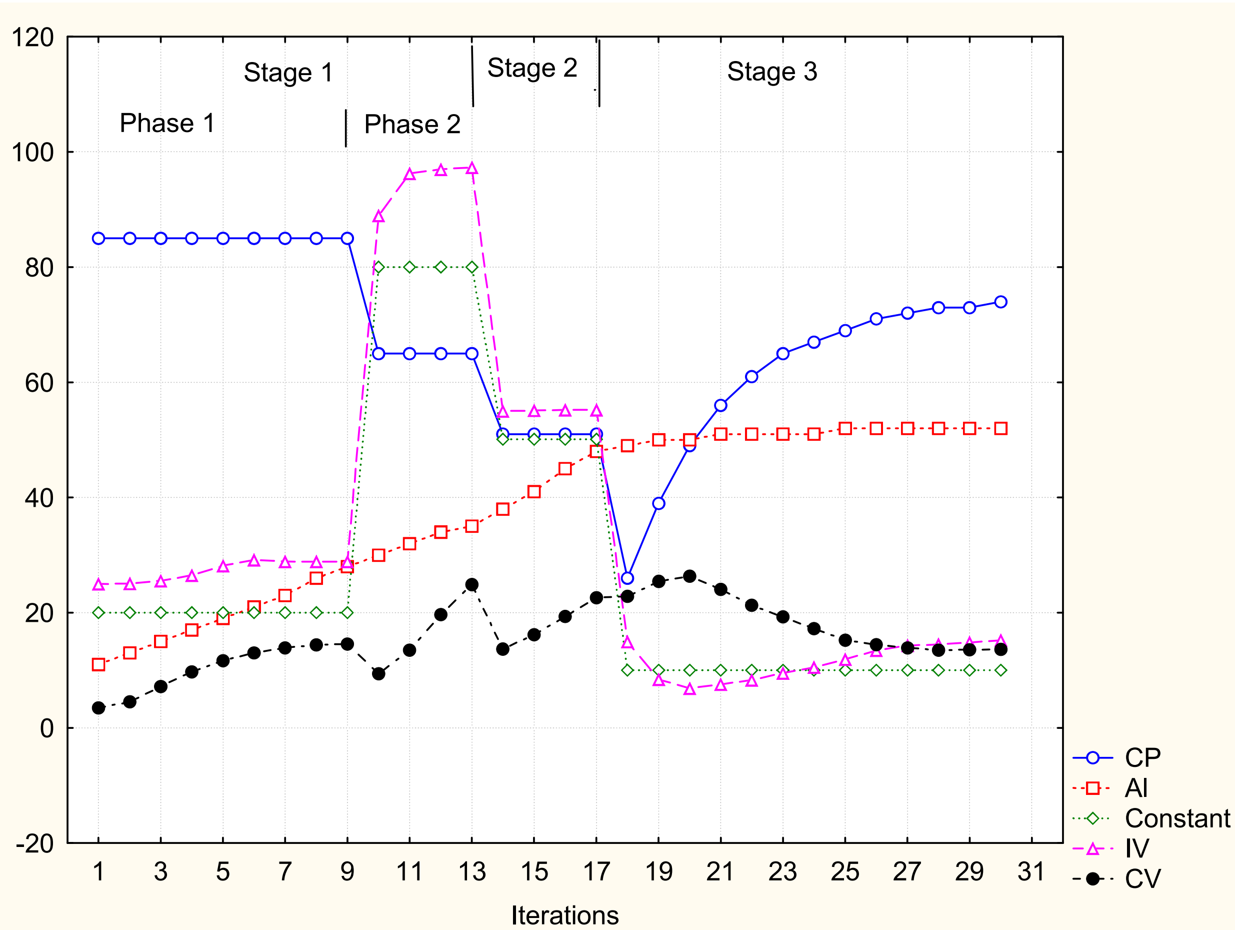

Fig. 4. The simulation of a goal-directed process with a two-constituent goal

Of course, it is easy to see certain shortcomings of the models. For example, the second process in model 2 was able to shift the center of the spot from one constituent to the other only because they were nearby. If the constituents would be established at opposite positions, such a shift would be impossible without changing the criterion of proximity. However, as is pointed out above the models simply are intended to demonstrate how the idea of joint synthesis can be applied to simulate goal-directed activity.

5. Future prospects

With the relevance of the idea of joint synthesis to simulate goal-directed activity as shown by the models above, it seems useful to consider some theoretical perspectives of this approach to the construction of intelligent systems. First, it is of importance to note that the consideration of the joint synthesis as the basic class of human activity and intelligence does not mean the abandonment of other classes and approaches. Indeed, successful attempts to achieve natural functionality often are not based on the imitation of a natural architecture – for example, cars can be considered as analogous to horses but cars have no legs, etc.

Similarly, it is not necessary that the joint synthesis is the only way to create full-scale artificial intelligence.

Though the joint synthesis seems appropriate to construct local projects like the models above, I will concentrate on the construction of general artificial intelligence. In my position, the construction of general AI should be a consequence of gradual changes within a system associated with its temporal functioning and complication, i.e. a result of a shift from short – term processes with simple goals and means to long-term processes with multilevel goals and complex methods. It is suggested that, although such a system may have complex innate architecture, the main source of its development is interactions with the system's environment via feedback loops.

The mechanism of joint synthesis is suggested to be a basis for such development. Indeed, because no innate criterion for the construction of goals is used, there are no constraints for the complication of goals. An appropriate means can be constructed for any goal because goals and means are constructed together,. As a result, the system is, in principle, able to adapt to any condition of training. It is suggested that the system can use blackboard architecture with flexible elements, then the formation and/or changes in elements can be considered as learning. The key component of the models above is the functional proximity that determines the possibility of the interaction between modules. It can be supposed that, in the hypothetical system, functional proximity can be dynamically changed in regard with the complexity and diversity of the system's components. The increase in the duration of goal-directed process may result from alterations in something similar to AL in the models above.

It can be suggested that the system should be able to create and use something similar to symbols. The generation of symbols may be performed as follows: because means in the system are constructed along with goals the system should be able to describe input and/or output information caused by these means in the terms consistent with goals and to prescribe a label associated with a goal to a sequence of such descriptions, thus creating symbols. The advantage of this method is that such symbols are grounded in the ongoing activity and therefore they can be used to construct novel goals and means through the involvement of symbols in the system's blackboard. Of course, this mechanism of symbolization can be gradual like changes in the duration of goal-directed processes. That is, at the beginning, the system will prescribe labels for the short sequences of ongoing states and gradually to for the longer and more complex ones.

It seems that the gradual increase in complexity and duration of goal-directed activities is a mechanism underlying human maturation. Indeed, in babyhood, the goal-directed activities of infants can be described as very short-term with primitive means but the activities of adults are long-lasting often life-ranging processes with very complex, hierarchical means and developed language. Therefore, the imitation of gradual human growth may be an effective way to achieve the human complexity of goal-directed activity and intelligence.

Of course, emphasis on the joint synthesis does not imply that other methods cannot be used within the given approach. For example, the criterion of minimal construction costs permits the system to synthesize a goal and means in any situation but if the minimum of costs found by the system is too local then the goal and means synthesized may be inappropriate to the situation. This mechanism seems to be an explanation for the fact that people sometimes are unable to solve simple problems, though their knowledge and skills are sufficient to find the right solution. To avoid similar difficulties an AI system may use the goals and means constructed jointly as a seed point in some cases and afterwards searches for goals and methods that are more suitable.

6. Conclusion

Since the advent of first computers, the idea of construction of artificial intelligence similar to that of human beings has driven the work of thousands of brilliant scientists and engineers. However, the result of their activity seems unsatisfactory as compared to, for example, advances in computer hardware. One of the most fundamental reasons for this situation may be that the mechanisms of human intelligence are unclear. Though the imitation of human intelligence is not a necessary characteristic of artificial intelligence, obviously a particular view on human intelligence is a very important heuristic. Therefore, an incorrect understanding of human intelligence can be a serious obstacle to construct intelligent systems. Intelligence is a characteristic of goal-directed systems and two classes of such systems can be easily derived from observations of animals and human beings. In my opinion, the classes that underlie most approaches to the construction of artificial intelligence are not sufficient to explain human activity. A broader classification of goal-directed activities suggests such processes can be described as a two-dimensional structure rather than a one-dimension one. In such structure there is a cell where in my opinion, humans can be located i.e., humans are goal-directed systems that synthesize arbitrary goals and means together. Though the idea of joint synthesis seems contradictory to some aspects of everyday experience, it is consistent with psychological evidence. In addition, there is neural evidence favoring this supposition. Simple computer models demonstrate that the idea of joint synthesis can be applied to simulate goal-directed activity. I suggest that the idea of joint synthesis can be a useful method to advance research in the construction of intelligent systems.

7. Appendix

Model 1
$p2=3*10^{-6}$; p3=0,99; p4=0,001
Model 2
p1=1; p4=2; p5=0, 3; p6=0,98; p7=0,5; p8=0,3; p9=0,8; p10=0,8

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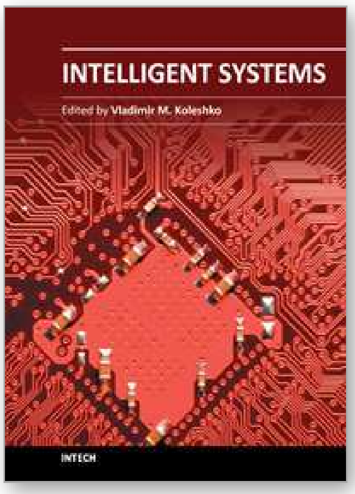

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This book is dedicated to intelligent systems of broad-spectrum application, such as personal and social biosafety or use of intelligent sensory micro-nanosystems such as "e-nose", "e-tongue" and "e-eye". In addition to that, effective acquiring information, knowledge management and improved knowledge transfer in any media, as well as modeling its information content using meta-and hyper heuristics and semantic reasoning all benefit from the systems covered in this book. Intelligent systems can also be applied in education and generating the intelligent distributed eLearning architecture, as well as in a large number of technical fields, such as industrial design, manufacturing and utilization, e.g., in precision agriculture, cartography, electric power distribution systems, intelligent building management systems, drilling operations etc. Furthermore, decision making using fuzzy logic models, computational recognition of comprehension uncertainty and the joint synthesis of goals and means of intelligent behavior biosystems, as well as diagnostic and human support in the healthcare environment have also been made easier.

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