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SEARCH FOR MEANING: AN EVOLUTIONARY AGENTS APPROACH

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ABSTRACT

To build intelligent systems it is crucial to understand what the phenomenon of meaning is, how can such phenomenon arise and what is the process behind it. The meaning is peculiar to living organisms and only for the living organisms things in the surrounding world mean something. It is proposed that the meaning arises when an agent starts to distinguish things that are positive or negative in a sense of survival and behaves accordingly—preferring desirable and avoiding undesirable states. As the life is a process so is the meaning. In this paper a simulation of evolutionary agents is proposed to find out whether a configuration can arise from a random initial state or trough the evolutionary process that allows an agent to distinguish good things form bad ones and to choose appropriate action**.**

1. INTRODUCTION

For living organisms things in the surrounding environment mean something. Everything an organism senses signifies something to it: food, fight, reproduction (Hoffmeyer, 1996). The meaning is usually considered in relations with language and symbolic systems and the meaning of one symbol is given by a set of other symbols. Harnad (1990) raised a question how an arbitrary symbol system can be grounded in the other meaningless symbols and how words actually get their meaning and he names this problem the symbol grounding problem. It is proposed that the symbols and their meaning can be grounded through sensorimotor activity when reference between objects or events and symbols is built up (Harnad, 1990). But such a grounding to the external world has some difficulties to explain abstract concepts (Barsalou, 2008).

Symbols are regarded in a connection with concepts and concepts are said to be mental symbols. A concept unifies the classification of things and their meaning. But explaining what a concept is faces with the same problems as the symbol grounding. The classical theory of concepts expects that a concept is defined as a set of necessary and sufficient features (Laurence & Margolis, 1999), but usually there is difficult to describe all the features that are important in a certain contexts. Therefore Barsalou (2003) has proposed a so-called situated simulation theory to explain the essence of a concept and in this theory conceptual representation is highly contextualized and dynamical. The concept is formed in an interaction between perception and action during a goal achievement (Barsalou, 2008). Things in the world can afford to achieve some desired state (Gibson, 1979). The meaning of an object or event depends on what it makes possible and also on the observer and situation. Nehaniv (1999) also points out that the information gathered through the channels of perception and actions turns to be meaningful for an agent since it is useful in achieving goals of homoeostasis, survival, and reproduction. Therefore the observation of the surrounding world is always selective (Popper, 1991) and it needs some point of view or a problem why a certain thing is important.

The meaning is not a static relationship between a thing and its meaning but it is continuously changing and therefore it can be regarded as a process, like the life is process too. To explain the idea of meaning Cisek (1999) proposed the control metaphor explaining how living organisms behave so that they could get the right stimulus. Objects and events mean to an agent whether they support survival or not and whether they enable to achieve a desirable or avoid undesirable state (simply by making a distinction between good and bad). A simple process that enables simple organisms to migrate towards good things (nutrients) and away from bad things (toxins) is chemotaxis (Bray, Lewin, & Lipkow, 2007). A comprehensive overview of chemotaxis is given by Wadhams and Armitage (2004), a general overview of living cells (Harold, 2001) and the chemotaxis process is imitated in a computer environment by Bray et al. (2007).

Every level described beforehand explains somehow the phenomenon of meaning and as Millikan (2004) has pointed out the term "meaning" moves freely among the described levels and the meaning can be understood in relation to one another. The different levels of meaning can be regarded as forming an hierarchical structure of interacting processes. The meaning occurred with the transition from a non-life to life state of early life and continued to become more complex when the interaction between organisms and their environment turned more sophisticated.

The aim of this study is to move closer to the origin of meaning, it means closer to the origin of the life and to discover what might be the process that first gave rise to the phenomenon of meaning. As there was not a very sharp boundary between non-life and life even despite some step-like phase transition (Popa, 2004) the structure of the meaning followed similar complexity—from the basic chemical reactions till complicated conceptual structures.

In this paper a simulation is proposed that analyses the simplest form of meaning—how an agent interacts with the environment. The simulation takes into account a generalized model of chemotaxis and the aim is to find

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an answer how distinction between good and bad arose to explain the emergence of meaning. There are performed a number of experiments where similar organization is used (e.g., a simulation is proposed where agent try to find some common vocabulary to describe things in the environment (Honkela & Winter, 2003), an approach to use neural networks to train agents for distinguishing good and bad things in the environment (Ruppin, 2002)). In this paper the idea of artificial chemistry (Dittrich, Ziegler, & Banzhaf, 2001) is used and the behavior of agents is a result of chemical reactions. The simulation rather follows the idea how generally processes of perception and interaction with environment takes place and chemical networks are used as a signaling pathways. The aim of the simulation is to find out whether from a random configuration and through the evolutionary process a successful configuration can arise that enables a population of agents to survive. If the agents are able to properly react in the environment then it would give some indication how the phenomenon of meaning could have been arisen.

The paper is divided into four main parts. In the first part a theoretical and philosophical background is introduced. Next part the simulation environment is described. Thereafter the main results of experiments are given and the final part of the paper includes the discussion and conclusions.

2. THEORETICAL FRAMEWORK

As it is noted the meaning is peculiar to living organisms and it arises from the continuous interaction between an agent and its environment. Karl Popper has proposed a three-world model (see Popper & Eccles, 1977) which consists of the physical world with its objects and events, the individual and unique subjective world, and the world of artefacts. Knowledge acquisition is the interaction between the three worlds.

The aim of a subject in this world is to survive and therefore he must be able to find out regularities within this world and categorize things according to the impact on survival. The purpose of the categorization system of an organism is to provide maximum information about the environment with the least cognitive effort (Rosch, 1978). Categorization must use features that maximize similarity between the samples in the cluster and at the same time separate different clusters as well as possible. An organism must not differentiate stimulus that is irrelevant to the purpose at hand. (Rosch, 1978)

At first an agent can use only a trial and error approach to study the regularities within the world, because it does not have any a priori knowledge about the world. As Popper (1991) noted, the method of learning by trial and error is learning from our mistakes and it seems to be practiced by lower and higher animals. From the Popper's idea that the knowledge acquisitions is trial and error search the idea of evolutionary epistemology has grown out. Evolutionary epistemology emphasizes the importance of the natural selection. It has two main roles, first, to ensure fit between an organism and environment and second, the trial and error learning is a way to acquire knowledge. The trial and error learning requires a mechanism for variation, for selection (fitness) and for preserving and propagating the selected variations (Campbell, 1990). Even if there seems to be some shortcuts to avoid trial and error approach, such approach is still needed at some level. The knowledge and meaning are an outcome of evolutionary process.

To understand what the meaning is it is reasonable to turn back to the beginning of the life or to study some simple organisms that are ancestors of current natural diversity. There are several theories how the first living pieces of matter came into existence, like 'autocatalytic sets' described by Kauffman (1993). The self retaining cycle is the basis of life. It corresponds to a definition called the NASA definition of life: life is a self-sustained chemical system capable of undergoing Darwinian evolution (Shapiro, 2007). The main property of the living system ensures that the conditions to continue their existence are met. Living systems should keep certain critical variables within an acceptable range and this mechanism is called "homeostasis". The variables are kept in the desired range by feedback loops forming a control cycle. If a certain variable is out of the desired range a cascade of chemical reactions follows that brings the system back to the desired situation and the trigger of the reactions ceases.

For example, several hours after eating the blood sugar level drops and it activates certain neuronal activity. Activation of the pertinent innate pattern makes the brain alter the body state so that the probability for correction can be increased (Damasio, 2006). You feel hungry and that makes you take steps to get some food. After eating the blood sugar level increases and the feeling of satiety follows.

The control cycles also help an organism to classify things or events as "good" or "bad" because of their possible impact on survival (Damasio, 2006). All the things are categorized as good or bad and the process of defining new good and bad things grows exponentially. The internal and external signals are triggers of a certain response or behavioral pattern. Animals distinguish inherently some input; some of them are "desirable" and some "undesirable" (Cisek, 1999). The desirable situations are preferred, like a full stomach, and undesirable are avoidable, like danger. Such a distinction gives the meaning to the perception—whether the perceived object or event enables to achieve a favorable situation or must be avoided. Control is gained by studying the regularities within the environment and defining reliable rules of interaction.

Cisek (1999) states that in the living systems the meaning comes long before symbols because organisms have interacted with their living environment long before they started to use symbols. Some sophisticated unicellular organisms were present on Earth for about 2.5 billion years before the first multicellular organisms appeared (Alberts et al., 2007). The reason, why arise of multicellular organisms was slow, was a missing communication mechanism. These communication mechanisms depend heavily on extracellular signal molecules, which are pro-

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duced by cells to signal to their neighbors (Alberts et al., 2007). Through the random search and evolutionary process cells had to associate the same meaning to the signaling molecules that we can regard as pre-symbols.

3. SIMULATION DESIGN

A fundamental starting point to design the experiment is that organisms or agents need some energy to function. Consumption of energy is an important factor because it is needed to keep an entropy level of a living organism low. Without continuous flow of additional energy and resources the process will reach equilibrium when all the stored resources are used. If an organism is successful in finding new energy sources, he will survive and otherwise he dies out. The use of energy instead of fitness function makes the simulation more lifelike and the selection procedure of successful agents is easier.

The simulation is based on the idea that energy-driven networks of small molecules were the initiators of life. Shapiro (2007) supports the theory of metabolism first and argues that life began as a combination of simple organic molecules that stored information for duplication and passing it to their descendants. Multiplication took place through catalyzed reaction cycles and some external source of energy was needed (Figure 1). Based on the Shapiro's assumptions the simulation was constructed as a very simple one and agents have only simple drives to gather external sources of energy and to replicate. The simulation was also inspired by the process of chemotaxis—a network of chemical reactions that lead a simple organism to move toward favorable and away from unfavorable environments (Bray et al., 2007).

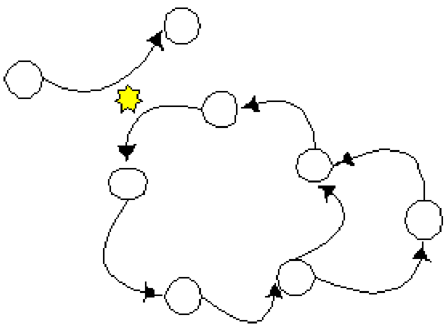

Figure 1. A network of chemical reactions releasing energy (Shapiro, 2007)

Based on those presumptions an agent based simulation has been built. The aim of the simulation is to test whether it is possible that first, a random configuration, a set of reaction rules, occurs which allows an agent to recognize energy sources, and second, a system starting from a random configuration is able to reconfigure and to adapt the surrounding environment and generate rules to distinguish good things from bad ones and to behave meaningfully.

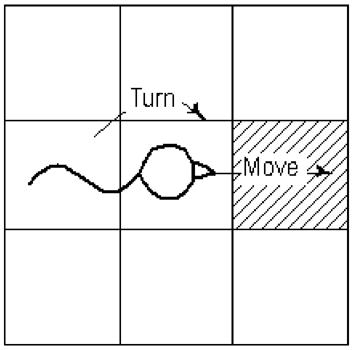

Figure 2. An agent in the world

The simulation consists of a world where initially a number of agents and resources—good energy rich things and bad poisonous things—are distributed randomly. At the beginning of an experiment the agents get some initial energy. Time in the simulation is discrete and at each time step the reaction rules are applied for each agents and based their results an agent can move forward, turn or stand still. An agent splits into two parts when it has gathered enough energy. At the end of each time step the number of resources in the world is restored.

Agents are separated entities that can interact with the surrounding environment by sensing elements in front of it and by moving (Figure 2). An agent consist of a set of molecules $S = (s_1, \ldots, s_n)$ that follow a set of reaction rules $R = (r_1, \ldots, r_m)$. In the experiments at least 11 different type of molecules are used (see also Figure 5) that can follow one of the four defined reaction rules. The first four molecules define what substance is sensed by a perception receptor in front of an agent whether there is an empty space or ground – Gr, an energy rich and good substance – G, or a bad substance – B, or another agent – A. Next two molecules define the level of energy rich substance inside an agent – E and the level of a bad substance that increases the energy consumption – NE. Next two molecules define whether an agent needs to move forward – M or to turn – T. Those first eight molecules follow only the reaction rule of perception – P. Last three set of molecules are signaling molecules defined through reaction they are connected with. The first of them causes increase of a product molecule – I, the second one decreases the level of a product molecule – D, and the last one cancels a product molecule out – C. The number of signaling molecules can be higher and therefore they are numbered.

In this simulation four reaction rules are defined (Figure 3). The first rule is called a reaction of perception—the signaling molecules created by the receptor for internal or external substances. During the perception the same amount of output molecules are created as perceived input, the number of input molecules is not changed. The second rule is a reaction of increase—this rule transforms input molecules to output molecules and during the process all the input molecules are consumed. The third rule is a reaction of decrease—during the reaction the number of input and output molecules is decreased until one of them reaches to zero level. The fourth rule is a reaction of cancellation—during the reac-

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tion if there is any input molecule the number of input and output molecules is reduced to zero.

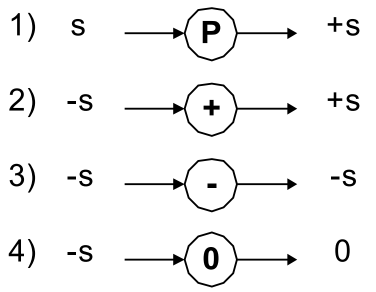

Figure 3. Four reaction rules 1) perception, 2) increase, 3) decrease, 4) clear

An agent behaves continuously in a cycle (Figure 4). Within a cycle an agent perceives surrounding environment and internal states, generates signaling molecules and finally takes an action. An action can be whether a move or a rotation depending on which of the signaling molecules is dominating. At each step an agent consumes energy and consumption is increased when an agent has consumed some bad things or it has too many reaction rules. Reactions in this cycle are formed by a evolutionary process. Feedback is provided by a natural selection and all unsuccessful configurations become extinct.

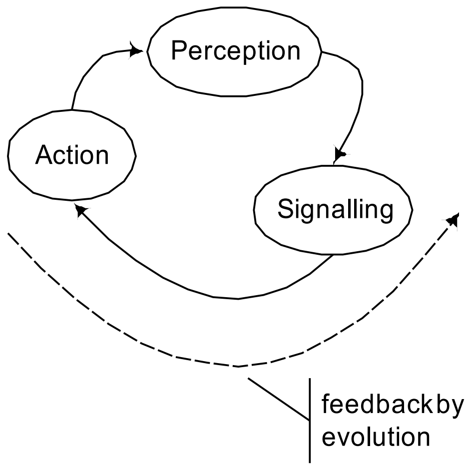

Figure 4. The cycle of behavior and feedback

In this simulation an evolutionary algorithm is used to continuously adapt agents with the surrounding environment. To make changes in the reaction rules of an agent the crossover and several mutation operators are applied after a predefined number of steps. During a crossover the agents can change part of their chemical reaction rules. Next mutations are applied with a small probability and reaction rules of an agent can change their location or order and appear or disappear. The main difference with traditional algorithms of evolutionary computation is that instead of using a fitness function and retaining minimal population size, a natural selection is used. Agents that are not able to find some energy source die after using their energy.

4. RESULTS OF THE EXPERIMENTS AND DISCUSSION

To test the hypothesis several experiments were performed. All the experiments were made in the continuous world with the size of 30 x 20 units. The initial number of agents was 150 and the world contained 840 units of good and 250 units of bad things that all were distributed randomly. The simulation ended when it had performed 850 steps or all the agents had become dead. After each 9 steps an evolutionary algorithm was applied for survived agents and crossover and mutation operators were applied to the configuration of agents with a probability of 0.15. The evolutionary algorithm was applied 60 timed during an experiment.

Table 1. A set of predefined reaction rules

Input molecule	Reaction rule	Output molecule
Increase$_1$	+	Move
Energy	P	Increase$_1$
Energy	P	Decrease$_1$
Decrease$_1$	-	Move
Good	P	Move
Bad	P	Turn
Ground	P	Turn
Ground	P	Increase$_1$
Bad	P	Clear$_1$
Clear$_1$	0	Move

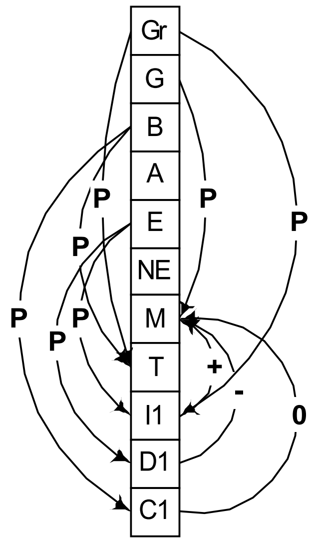

Figure 5. Visualization of reaction rules

Before using random configurations a set of rules was developed to test whether the environment is applicable to solve the task. The predefined set of rules consists of three parts (Table 1 and Figure 5), the first four rules increase possibility that an agent starts to move when the value of energy is decreasing. Next three rules define behavior when an agent perceives good or bad things. Next rule increases possibility that an agent starts to move when there is an empty space in front of the agent. And two final rules ensure that an agent never moves towards a bad thing. The rules were used to adjust the parameters

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of simulation environment. Thereafter experiments with random configurations were performed. As the evolutionary rules were very strict only one experiment of 100 was successful where some agents survived till the end of experiment. But the successful configurations gave interesting results.

The successful set of reaction rules were not as complicated as was expected beforehand. There were two main types of successful rules that varied a bit. The first set consisted of a rule to move towards an energy source and a rule ensuring continuous movement (Table 2). As we take this set of rules from the point of an individual then those rules do not seem to be very rational, but from the viewpoint of the population as a whole it was effective because even if some agents died the majority of agents were able to find some energy sources. The second set of rules was more agent oriented and a contact with the bad things was excluded (Table 3). As such a set of rules appeared during the evolutionary process it was more successful than the previous one and it became dominating if the number of agents was rather low.

Table 2. A set of rules successful in the case a big number of agents

Input molecule	Reaction rule	Output molecule
Energy	P	Move
Good	P	Move

In general the population was successful when it was able to quickly exceed certain threshold. In this case the population behaved more like a whole than a set of separate individuals. The configuration of agents reaction rules was not ideal but good enough to be effective within constraints defined in this world.

Table 3. Simple set of successful rules

Input molecule	Reaction rule	Output molecule
Ground	P	Move
Good	P	Move
Bad	P	Turn
Agent	P	Turn

The performed experiments gave some indication that from a random initial state a configuration can emerge that is able to survive and reproduce. To find a successful configuration a variety of initial states was needed to test. As several configurations appeared that were able to distinguish good and bad things it could be regarded as appearance of an agent's subjective sight into the world. As Kauffman (2007) has pointed the reception by the receptor of a food molecule is information about food and it is a presence of proto-semantic. The perception of a food source or a bad thing is not just a perception but it is connected with the probability of surviving and therefore are meaningful for an agent.

During the experiments an interesting phenomenon was observable. When a successful configuration appeared then it became soon dominant and if there were not any big disturbances then the configuration lasted till the end of experiment. Such a phenomenon has also been observable in earlier experiments where once a successful configuration was found it turned out to be unstoppable when there was a continuous flow of additional energy and resources (Kirt, 2007).

It was noticeable in several experiments that the successful configuration was not the best from the viewpoint of an single agent but a population as a whole. The behavior of the agents did not support survival of a single agent but the whole population. It is like in a multicellular organism where some cells (e.g., the skin cells) has to be sacrificed to keep an organism alive. The population was able to predict what the best behavior is in this world. It is noticed in earlier experiments of evolutionary systems that the organisms and environment form a single dynamical system (Taylor, 2004).

The experiments indicated that the evolution did not do anything extraordinary but just found an optimal solution that suits with the constraints defined by the environment. Even if the initial set of reaction rules was defined rather complex it turned out that evolutionary process simplified them very rapidly. In accordance with the evolutionary epistemology the search for rules was random because there was no knowledge beforehand to make predictions.

The evolution seems to be rather an emergent property of a system that functions in changing environment. The evolution appears when the environment changes and agents are able to mutate. If there are some changes in the environment then successful are those agents that are able to mutate accordingly to the change in the environment and agents not adapting with the changes just die out. Such a rule prefers agents that are able to change and it can lead to the rise of evolution. It ensures that the agents adapt with the changing environment.

5. CONCLUSIONS

In this paper the results of performed experiments for studying the emergence of meaning are presented. The aim of the study is to find what might be the basic process behind the meaning and how to implement it. In the experiments the evolutionary process generated reaction rules that enabled an agent to identify perceived substances and to choose a appropriate reaction depending on the effect on survival.

For further research there are several possibilities for improving the simulation environment. One idea is not to use crossover and mutation operators but just to let agents to join when they are close to each other. It would be another improvement to the traditional approach of evolutionary algorithms. Concerning reaction rules in this simulations too much randomness was used and the degree of freedom was rather high. Some restrictions should be enforced to allow only certain reaction cycles to evolve.

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