Aspects Concerning the Observation Process Modelling in the Framework of Cognition Processes

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Abstract: This paper presents results concerning the observation process modelling in the framework of cognition processes which belong to a new pattern of human knowledge. The cultural origin of the patterns is analyzed in terms of philosophical, psychological and linguistic points of view. A scenario concerning a robot integrated in a cognitive system is given in order to test the theoretical approaches. The definitions of signatures and of signature classes are given as one of the first steps in an alternative modelling approach to the observation process. An example that deals with the observation process modelling is offered.

Keywords: cognition process; observation process modelling; signature classes; signatures

1 Introduction

The pattern of human knowledge analyzed here represents a stage of the "Research on a new cognition system based on the experimentation of the causal relations" project. The big challenge regarding the studies on human cognition is to answer the question on how the human mind can obtain synthesis from experimental data. This deals in fact with how the human mind can build veridical models of reality only from apparently disturbed and unsubstantial data [1], the only information we can get through our senses.

The domain under investigation requires the solving of this problem as an interdisciplinary one. Two aspects are investigated in this context, the psychological and the technical. The psychological approach, known as Cognitive Psychology (CP), has in view as an objective the understanding of the human knowledge phenomenon, the obtaining of models of the processes which occur during this phenomenon. The technical approach, referred to as Machine Learning (ML), Robotics (R) and Artificial Intelligence (AI), aims to build a mathematical model and then to design and achieve a product.

The new results presented in this paper are supported by the proposal of a new pattern of human knowledge and by new definitions of signatures and of signature classes that emerge from the fuzzy signatures as convenient hierarchical symbolic representations of data [2], [3], [4]. With this regard this paper focuses on the better understanding of how natural cognitive processes can effectively coevolve with processes in artificially cognitive systems in the framework of Cognitive Infocommunications (CogInfoCom) [5], [6].

This paper is structured as follows: An analysis of the state-of-the-art in the field is presented in the next section. Section 3 highlights the results expressed as a new cognition model. The definitions of signatures and of signature classes are given in Section 4. Results obtained from the corroboration of the cognition model and of the signature classes are presented in Section 5. The conclusions and the directions for future research are pointed out in Section 6.

2 Literature Review

The research directions in CP from the point of view of patterns of human knowledge deal with attention, perception memory and reasoning [7].

The research concerning the attention aims to explain the following phenomenon: a human being has to deal with a great amount of information because of numerous stimuli from the environment, but only a small part of this information is used. The explanation has been given through the following models: the model of the selective attention (Broadbent), which explains the attention by the existence of a sensorial filter [8] (the model is limited regarding the explanation of the “cocktail party” phenomenon: a person who has focused on a conversation is still able to seize relevant information from another source as well); the model of attenuation [9] replaces the “all or nothing” principle of the previous model with the principle of selecting the main channel and the attenuation of the other channels (the main limit of the model consists of the fact that it does not specify clearly what is understood by the informational attenuation of the signal); the model of the selective attention, which relies on resources [10], and according to this model the selection takes place at different levels of processing, and the closer to the final point the processing takes place the more resources are used.

The research in perception deals with modelling the process in which the information supplied by environment is interpreted in order to find its significance and meaning. The perception consists of the interpretation of the information collected by using the sensations. Several approaches are suggested in the literature: the model of stamps [11], in which the information is compared to a set of models stored in the memory, and the limits of the model are given by the fact that the stamp must match perfectly and an infinite number of models would therefore be needed, and that the procedure is time-consuming; the prototype model, where the natural objects are approximations of idealized prototypes [8]; the model based on the analysis of the features [12], which suggests a hierarchy of remarkable features; the model of the scenic analysis [13], where patterns can be easily recognized because we expect to find certain forms in certain places; the cyclic model of perception [14], described as a combination of synthesis-analysis-synthesis, where synthesis elaborates the perceptive model and the analysis extracts the information from the environment in view of its further correction.

The research in memory is focused on the processes by which the storing and the updating of information are made. The processes investigated in this context are those which allow the storage of information only for the time needed to use it, i.e., the short-standing memory. The storage of the information for a longer period of time represents the long-standing memory, and the way in which the information is organized so as to be stored. The current approaches include: the constructivist model [11], which stresses the importance of memorizing the meaningful information and of the avoiding of meaningless association; the modal model of memory [15], which explains the way in which information is acquired, stored and updated; the model of the work memory [16], which states the existence of several parts: an articulator loop, which stores the information in a verbal form, a first acoustic storage with a limited capacity, a sensorial filter which permits the taking of the visual information, and a central instance at which the input is connected.

The reasoning is defined as representing the processes implied by symbolizing and manipulating the information [11]. It is also important to highlight here the following models: the Piage model, in which reasoning is seen as an equilibration process necessary to replace the lack of balance provoked by the new (the equilibration can be done by assimilation of the way in which the new is understood, based on the already existent concepts, or by accommodation, which implies the modifying of the concepts in order to understand the new); models that belong to the cognitive perspective (Miller, Newell and Simon), which state that the complexity of a problem can be reduced by solving a series of sub-problems; the models of the forming of concepts explain the way in which a person extracts the essential features from the stimulus and places the result in a category; the Bruner models [16], which use four types of strategies to identify the concepts: conservative focusing, the game of chance-type focusing, successive scanning, and simultaneous scanning; the Levine model [17] of successive hypotheses, which merges information into a working hypothesis; the behaviourist model [18], according to which reasoning is nothing else but a voiceless speaking that explains the fact that when a man is trying to solve a problem, he also solicits language to some extent; the rationalist model [19], which explains the language acquisitions by genetic endowment, stating that there are universal linguistic patterns in every language and that there are certain people who are genetically endowed to be able to recognize them.

From the technical point of view, according to EU's IST 2002 23.24, a cognitive system is a system that understands, learns and develops itself by social and individual interactions [7]. The desired objectives are based on achievements, referred to as the three components of a cognitive system: action, which is external (the robot control) [11] and internal [20] (the approaching of a behaviour through which the system focuses on a certain problem); perception, which supposes the interpreting of the signals obtained from the sensorial system and the using of this interpretation in describing a situation that triggers the reasoning; and reasoning, which co-ordinates the action and the perception. According to [11], reasoning consists of two functions, symbolizing and manipulating the symbols.

A cognitive system is a system which understands and learns by social and individual interactions. More precisely, the birth of cognitive systems has lead to a new generation of robots.

The main difference between an intelligent robot and a robot integrated in a cognitive system is that the latter can execute in time more tasks that it was programmed to do. More precisely, in the case of robots which have a tactical level of control, there are many solutions (known a priori) from which the robot will choose the one that fits the problem it has to solve; the knowledge (the set mentioned and the rules of their arbitration) is introduced by the designer and the development of knowledge is made by a procedure established a priori.

In the case of robots which have a strategic level of control, there is a set of behaviours which permit the planning of tasks. The knowledge (i.e., the behaviours and their rules of composition) is established a priori. The development of knowledge is conducted in accordance with a procedure which is established a priori.

While in the previous cases the knowledge was managed a priori by the designer (these rules do not change, regardless the knowledge of the robot), in the case of the cognitive system, the task of organizing the knowledge process becomes the task of the system itself. This task is a dynamic processing where its organization depends on the acquired knowledge, i.e., it modifies the rules according to the new knowledge.

The achievement of a cognitive system is an interdisciplinary problem dealing with CP, R and AI. The CP offers models of human reasoning, and the R & AI transform these models and combine them with its own knowledge. The complexity of the cognitive system is revealed in the fact that the achievement of such a system must benefit from the ML and AI algorithms. Such algorithms include several models [21]–[27], which include fuzzy models [28]–[33], neural networks [34]–[36] or hybrid models [37]–[40].

The following requirements are pointed out regarding the limitations of the domain and the more rarely approached directions (because of the novelty of the domain):

- Up to now, the research has focused on the organizing of the cognitive system. We consider in [41] that the auto-organizing of the knowledge process can be obtained by knowledge process itself. The mentioned process is controlled by a certain structure of knowledge which is modified because of the new knowledge. We consider that the mentioned dynamics can be known by using the basic level of knowledge in terms of [41]: the use of the experimentation of the causal relations as a source of knowledge.
- The necessity of defining the ratio between the initial knowledge of the system (a priori knowledge) and the knowledge the system can acquire (a posteriori knowledge).
- The necessity of determining the potential of the a priori knowledge and of the organization of this knowledge focuses the further performance of the cognitive system.

3 The Pattern-based Model and the Process of Knowledge

We focus on the following thesis: human knowledge – used as sources of inspiration in order to obtain systems of artificial knowledge – are cultural phenomena. Therefore the understanding of these phenomena requires the use of specific investigation methods. These specific methods are philosophy and psychology. Consequently, the first part of the project describes a pattern of human knowledge based on the investigation methods mentioned above. The phases of the project, discussed in the sequel, will take this model, transpose it into a mathematical language and, based on specific procedures, will turn it into an artificial system.

The knowledge process means that it is built on information acquisition. For the information definition, we accept the idea that the information is the "change which leads to a change". This means that an individual who performs information acquisition is able to react (change) to an external change.

We agree to name this reaction perception, and in conformity to Kantian philosophy, we agree that this reaction is possible based on schemas. The result of this reaction is the identification of the class and the concept.

We accept that observation means to extract the features of an object. This process is possible because the concept informs us as to what features to search. New information will trigger new reactions.

We accept that experience means to understand the observations, or more precisely, to corroborate the a priori knowledge with the new information. The experience generates new (understood, accepted) knowledge.

The external world is never unstructured for a human being. In agreement with Heidegger, the external world has a mundane character: it is the world of our perceptions and observations. In other words it is the world of changes which produce changes in our mind.

The structure of the external world has cultural sources: the expectations (which predict our experiences) and the goals (which select our schemas). The external world is culturally embedded, i.e., a particular object perception triggers a set of related phenomena. The object is not neutral. Even if we focus on objective knowledge, our culture polarizes the perception and gives it a meaning.

It is important to underline the difference between the concepts of information met in technical sciences and the concept of information, the source of change, met in knowledge phenomenon. The second has a cultural component. This means that the ability of human reactions and the reactions themselves are culturally dependent.

We have used in the previous paragraphs several times the term “schema”. Obvious it is due to a Kantian influence. Unfortunately, even the author of this term was vague about its definition. For “schema” we accept a simplified picture, a prototype image of the concept. In the next section we will propose an engineering solution for this term.

The originality of our approach is its operational nature. More precisely, specialized information [42] is systematized in order to obtain a pattern, which in the following phases can then be described mathematically, thus turned into an algorithm, and, eventually, transposed on a technical system.

Pattern description includes: expressing the initial principles of the pattern, the actual description of the pattern, describing how it works, and underlining the sources of knowledge and the specification of a priori elements required in order for the pattern to function.

The initial principles of this pattern are threefold:

- Knowledge is a cultural process, it belongs to a certain culture, and it takes place during a period of time. The human knowledge modes are facilitated by the interaction between culture and environment.
- The knowledge phenomenon can be described in two stages, upward (empiricist) and downward (rationalist).
- The mode of human knowledge is intelligence driven. Intelligence is a process which has as its goal to increase the space-temporary stability of the individual.

The elements that build the pattern are described as follows. First, the downward (rationalist) stage is characterized by the following aspects.

- Information is acquired by the individual due to his/her senses and structured by the schemes he/she owns.
- The schemes allow focusing on relevant information. The schemes are the basis of the arranging process that allows the general to incorporate the particular. Using the schemes, the information is arranged according to a system of classes.
- The mentioned process allows for perception, observation and, in the end, experience.

Second, the upward (empiricist) stage has the following features.

- Knowledge is the process through which the concepts are transformed based on experience. Learning stands for the basis of the transformation process, which allows the modification of the general for the purpose of incorporating a large variety of particulars.
- Experience allows for the establishment of the difference between the used schemes and the experimented structure (objects).
- The new structures allow for the building of new schemes and modifications of the concepts.

The operation mode of the pattern is described on the basis of the elements presented before. The description includes the next succession of stages:

- The object is a potential source of information. This potential can produce a reaction and, using the schemes, a perception.
- A perception means the ability to identify the class of the perceived object and the possibility of identifying the concept of this class.
- Each concept is related to a set of features and a set of compatible phenomena (phenomena which describe objects from the mentioned class). The mentioned features and phenomena have a cultural foundation. The phenomena involve (causal) rules (laws). The kernel of these rules is rational or heuristically.
- Knowing the concept, observations can be made. For example, an attractive possibility is to establish each of the 12 Kantian categories of the object.
- Experience will adapt the schemas and in the end the concepts.

The proposed pattern highlights the following aspects:

- Knowledge acquisition is a dynamic process (the process depends on its past states) that occurs during the interaction of the individual with the environment or with other individuals.
- There are three important states in this process: perception, observation, and experience.

- Each state is possible because of a prior knowledge: perception because of schemas, observations because of concepts, and experience because of observation.
- The dynamic character of the process is revealed by the transformation of the schemes and concepts after the experience.
- The first stages of education solve the problem of a prior knowledge. The individual learns to use the first schemes; the individual is taught how to recognize classes, categories, etc.; interaction with other individuals requires the individual to communicate through concepts.

The proposed pattern is thus: one perceives a phenomenon, observes its features, corroborates this information with the a priori knowledge, and adapts this knowledge. This structure of the information flow represents the basis for the concept of signatures.

4 Signatures and Signature Classes

The definitions of signatures and of signature classes are supported by the following recursive definition of the set $S^{(n)}$. Let R be the set of real numbers. The set $S^{(n)}$ is defined recursively as

$$S^{(n)} = \prod_{i=1}^{n} S_i \,, \tag{1}$$

where $S_i = R$, $i = \overline{1,n}$ (i.e., $i \in \{1,2,...,n\}$), or $S_i = S^{(m)}$, and $\prod$ is the Cartesian product. The *collection of signatures* is defined as the function $A: R^m \to S^{(n)}$, and the *signature* of the element $x \in R^m$ is $A(x)$

$$A(x) = \begin{bmatrix} \cdots \\ a_i \\ \begin{bmatrix} a_{i+1,1} \\ a_{i+1,2} \end{bmatrix} \\ \begin{bmatrix} a_{i+2,1} \\ \begin{bmatrix} a_{i+2,2,1} \\ a_{i+2,2,2} \end{bmatrix} \end{bmatrix} \\ \cdots \end{bmatrix}. \tag{2}$$

The matrix elements values which appear in the signature defined in (2), i.e.,

$$x = (a_1, a_2, ..., a_n, a_{i,1}, a_{i,2}, ..., a_{i,m}, ..., a_{j,k,l}, ...), \\ a_1, a_2, ..., a_n, a_{i,1}, a_{i,2}, ..., a_{i,m}, ..., a_{j,k,l}, ..., \tag{3}$$

are named the *signature values*. The transposition of the signature $A(x)$ leads to

$$A^T(x) = [\ldots \quad a_i \quad [a_{i+1,1} \quad a_{i+1,2}] \quad [a_{i+2,1} \quad [a_{i+2,2,1} \quad a_{i+2,2,2}]] \quad \ldots]. \tag{4}$$

The following notations are introduced to simplify the characterization of signatures:

- A signature $A(x)$ with the values $a_1, a_2, ..., a_n, a_{i,1}, a_{i,2}, ..., a_{i,m}, ..., a_{j,k,l}, ...,$ is expressed as $a^{\cdots}$.
- If $\exists x \in X$ and $A^T(x) = [a_1 \quad \ldots \quad a_n]$, then we will use the notation $A(x) = a^{1,\ldots,n}$.
- If $\exists y \in Y$ and $A^T(y) = [a_1 \quad \ldots \quad a_{i-1} \quad [a_{i,1} \quad \ldots \quad a_{i,m}] \quad a_{i+1} \quad \ldots \quad a_n]$, then we will use the notation $A(y) = a^{1,\ldots,[1,\ldots,m]_i,\ldots,n}$. In this case the sets are defined as $S_1 = S_2 = \ldots = S_{i-1} = S_{i+1} = \ldots = S_n = R$, and $S_i = \prod_{i=1}^{m} R = R^m$.
- A signature of type $[\ldots \quad [[a]] \quad \ldots]$ is the same as the signature $[a]$.

Two signatures $a^{\cdots}$ and $b^{\cdots}$ have the same structure if and only if for each value $a_{i_1,i_2,\ldots,i_s}$ of the signature $a^{\cdots}$ there exists the value $b_{i_1,i_2,\ldots,i_s}$ of the signature $b^{\cdots}$. A *signature class* is a set of signatures with the same structure. The notation $\hat{a}^{\cdots}$ will be used to indicate the signature class with the same structure as that of signature $a^{\cdots}$. The symbol S will be used to indicate *the set of all signatures* and the symbol $\hat{\mathrm{S}}$ will be used to indicate *the set of all signature classes*. For example, $a^{1,2,\ldots,n} \in \mathrm{S}$ and $\hat{a}^{1,2,\ldots,n} \in \hat{\mathrm{S}}$.

The *contraction* of a signature is defined as either the function

$$@ : \mathrm{S} \to \mathrm{S}, @(a^{1,2,\ldots,n}) = a^1 = [a], \tag{5}$$

where $a = f(a_1, a_2, \ldots, a_n),\ f : R^n \to R$, or the function

$$@_i : \mathrm{S} \to \mathrm{S}, \begin{cases} @_i(a^{1,\ldots,[\ldots]_i,\ldots,n}) = a^{1,2,\ldots,n}, & \text{if } i \le n, \\ @_i(a^{\cdots}) = a^{\cdots}, & \text{otherwise}, \end{cases} \tag{6}$$

where $a_i = f(a_{i1}, a_{i2}, \ldots, a_{im}),\ f : R^m \to R$. We use the following notation for the absolute value of a contraction:

$$|@(a^{1,2,\ldots,n})| = a. \tag{7}$$

The *extension* of a signature is defined as the function

$$\overline{@}_{i(p)}:\mathrm{S}\rightarrow\mathrm{S},\begin{cases}\overline{@}_{i(p)}(a^{1,\ldots,i,\ldots,n})=a^{1,\ldots[1,\ldots,p]_i,\ldots,n}, \\ \text{if } \ i\le n, \\ \overline{@}_{i(p)}(a^{1,\ldots,n})=\overline{@}_{n+r(p)}(a^{1,\ldots,n})=a^{1,\ldots,n,[1,\ldots,p]_{n+1},\ldots[1,\ldots,p]_{n+r}}, \\ \text{otherwise } \ (i=n+r)\end{cases} \tag{8}$$

where $[a_{i1},\ldots,a_{ip}]=g(a_i,p),\ g:R^2\rightarrow R^n$, and $[1,\ldots,p]_j,\ j=\overline{n+1,n+r}$, is an empty array of length *p*. The *two-step extension* of a signature is defined as the function

$$\overline{@}_{i(p),j(q)}:\mathrm{S}\rightarrow\mathrm{S},\begin{cases}\overline{@}_{i(p),j(q)}(\bullet)=\overline{@}_{ij(q)}(\overline{@}_{i(p)}(\bullet)), & \text{if } \ j\le p, \\ \overline{@}_{i(p),j(q)}(\bullet)=\overline{@}_{i(p)}(\bullet), & \text{otherwise.}\end{cases} \tag{9}$$

The *zero-step extension* of a signature is defined as the function

$$\overline{@}_{(p)}:\mathrm{S}\rightarrow\mathrm{S},\overline{@}_{(p)}(a^{1,2,\ldots,n})=\overline{@}_{1(p)}(\overline{@}_{2(p)}(\ldots(\overline{@}_{n(p)}(a^{1,2,\ldots,n}))))$$
$$=a^{[1,\ldots,p],[1,\ldots,p],\ldots,[1,\ldots,p]_n}, \tag{10}$$

where $[a_{j1},\ldots,a_{jp}]=g(a_j,p),\ j=\overline{1,n}$.

The *union* of two signatures is defined as the function

$$\cup:\mathrm{S}\times\mathrm{S}\rightarrow\mathrm{S},\ \cup(a^{1,2,\ldots,n},b^{1,2,\ldots,n})=c^{1,2,\ldots,n}, \tag{11}$$

where $c_i=f(a_i,b_i),\ f:R^2\rightarrow R$. The following notation will be used for the union of two signatures:

$$a^{1,2,\ldots,n}\cup b^{1,2,\ldots,n}=c^{1,2,\ldots,n}. \tag{12}$$

If $m<n$ then

$$a^{1,2,\ldots,m}\cup b^{1,2,\ldots,n}=\overline{@}_n(a^{1,2,\ldots,m})\cup b^{1,2,\ldots,n}, \tag{13}$$

$$a^{1,\ldots[1,\ldots,p]_j,\ldots,n}\cup b^{1,2,\ldots,n}=a^{1,\ldots[1,\ldots,p]_j,\ldots,n}\cup\overline{@}_{j(p)}(b^{1,2,\ldots,m}). \tag{14}$$

The *pruning* of a signature is defined as either the function

$$\varnothing_i:\mathrm{S}\rightarrow\mathrm{S},\begin{cases}\varnothing_i(a^{1,2,\ldots,i,\ldots,n})=a^{1,2,\ldots,i-1,i+1,\ldots,n},\varnothing_i(a^{1,2,\ldots[1,2,\ldots,m]_i,\ldots,n})= \\ =a^{1,2,\ldots,i-1,i+1,\ldots,n}, \\ \text{if } \ i\le n, \\ \varnothing_i(a^{1,2,\ldots,n})=a^{1,2,\ldots,n}, \\ \text{otherwise,}\end{cases} \tag{15}$$

or the function

$$\varnothing_{i,j}:\mathrm{S}\to\mathrm{S},\begin{cases}\varnothing_{i,j}(a^{1,2,\ldots[1,2,\ldots,m]_i,\ldots,n})=a^{1,2,\ldots[1,2,\ldots,j-1,j+1,\ldots,m]_i,\ldots,n},\\ \text{if } \ i\le n_x \ \text{ and } \ j\le m,\\ \varnothing_{i,j}(a^{\cdots})=a^{\cdots},\\ \text{otherwise.}\end{cases} \tag{16}$$

We will use the following notations for the pruning of a signature:

$$\begin{aligned}&a^{1,2,\ldots j,\ldots n}\varnothing_i=a^{1,2,\ldots j-1,i+1,\ldots n},\\ &a^{1,2,\ldots[1,2,\ldots m]_i,\ldots n}\varnothing_{i,(1,j,m)}=a^{1,2,\ldots[2,\ldots,j-1,j+1,\ldots m-1]_i,\ldots n}.\end{aligned} \tag{17}$$

The *intersection* of two signatures is defined as the function

$$\bigcap:\mathrm{S}\times\mathrm{S}\to\mathrm{S},\ \bigcap(a^{1,2,\ldots,n},b^{1,2,\ldots,n})=c^{1,2,\ldots,n}, \tag{18}$$

where $c_i=g(a_i,b_i), g:R^2\to R$. We will use the following notation for the intersection of two signatures:

$$a^{1,2,\ldots,n}\bigcap b^{1,2,\ldots,n}=c^{1,2,\ldots,n}. \tag{19}$$

If $m<n$ then

$$a^{1,2,\ldots,m}\bigcap b^{1,2,\ldots,n}=a^{1,2,\ldots m}\bigcap b^{1,2,\ldots,n}\varnothing_n\varnothing_{n-1}\ldots\varnothing_{m+1}, \tag{20}$$

$$a^{1,\ldots[1,\ldots,p]_j,\ldots,n}\bigcap b^{1,2,\ldots,n}=@_j(a^{1,\ldots[1,\ldots,p]_j,\ldots,n})\bigcap b^{1,2,\ldots,n}. \tag{21}$$

The *addition* of two signatures is defined as the function

$$\oplus_i:\mathrm{S}\times\mathrm{S}\to\mathrm{S},\ \oplus_i(a^{1,2,\ldots[1,\ldots,m]_i,\ldots,n},b^{1,2,\ldots,n})=c^{1,2,\ldots[1,\ldots,m]_i,\ldots,n}, \tag{22}$$

where $c_k=a_k\forall k\ne i, c_{ij}=f(a_{ij},b_j),\forall j=\overline{1,m}, f:R^2\to R$. We will use the following notation for the addition of two signatures:

$$a^{1,2,\ldots[1,\ldots,m]_i,\ldots,n}\oplus_i b^{1,2,\ldots,n}=c^{1,2,\ldots[1,\ldots,m]_i,\ldots,n}. \tag{23}$$

If $a^{1,2,\ldots,n},b^{1,2,\ldots,m}\in\mathrm{S}$ then

$$\begin{cases}a^{1,2,\ldots,n}\oplus_i b^{1,2,\ldots,m}\\ =\overline{@}_{i(m)}(a^{1,2,\ldots,n})\oplus_i b^{1,2,\ldots,m} & \text{if } \ i\le n,\\ =c^{1,2,\ldots[1,2,\ldots,m]_i,\ldots,n},\\ a^{1,2,\ldots,n}\oplus_i b^{1,2,\ldots,m}\\ =\overline{@}_{i(m)}(a^{1,2,\ldots,n})\oplus_i b^{1,2,\ldots,m} & \text{otherwise}\,(i=n+p),\\ =c^{1,2,\ldots,n,[1,2,\ldots m]_{n+1},\ldots[1,2,\ldots,m]_{n+p}},\end{cases} \tag{24}$$

where $c_{n+k,j}=b_j, j=\overline{1,m}, k=\overline{1,p},\ c_i=a_i, i=\overline{1,n}$.

The *multiplication* of two signatures is defined as the function

$$\otimes : \mathrm{S}\times\mathrm{S}\rightarrow\mathrm{S},\ \otimes(a^{1,2,..n}, b^{1,2,...,m}) = c^{[1,...,m]_1,[1,...,m]_2,...[1,...,m]_n}, \tag{25}$$

where $c_{ij} = g(a_i, b_j), i = \overline{1,n}, j = \overline{1,m}, g : R^2 \rightarrow R$. We will use the following notation for the multiplication of two signatures:

$$a^{1,2,..n} \otimes b^{1,2,...,m} = c^{[1,...m]_1,[1,...m]_2,...[1,...m]_n}. \tag{26}$$

The *grafting* of a signature is defined as the function

$$\Theta_i : \mathrm{S}\rightarrow\mathrm{S}, \begin{cases} \Theta_i(a^{1,2,...,n}) = b^{1,2,...,n+1}, & \text{if } i \le n, \\ \Theta_i(a^{1,2,...,n}) = \overline{@}_{i(1)}(a^{1,2,...,n}), & \text{otherwise,} \end{cases} \tag{27}$$

where $b_i = 0$ and $b_j = \begin{cases} a_j, & \text{if } j < i, \\ a_{j-1}, & \text{otherwise,} \end{cases}$ if $i \le n$.

The operations defined in this section are similar to the well-accepted contraction and extension in the framework of fuzzy sets. The formal background presented in this section can be used in several applications, including in the transformation of our proposed pattern in mathematical language, but also in fuzzy inference systems and in decision processes modelling, where the rule interpolation can be applied [30], [31], [43], [44].

5 Case Study

The analysis carried out in Section 2 highlights the fact that a cognitive system can be a new generation of robots. The main characteristic of this generation consists of its knowledge capacity. The analysis indicates one research direction: the study of the connections between the auto-organization of knowledge and the knowledge process itself. The following scenario is aimed (Fig. 1):

- The robot self-organizes its knowledge.
- This knowledge has two sources: the first refers to relations between phenomena that appear in the artificial environment in which the robot is immersed, and the second by dialog with its programmer.
- From the first source, in order to acquire experience, the robot takes action upon the objects and monitors, through a sensorial system, the phenomena that appear. This monitored information is transformed by the control system of the robot into perception which, in its turn, leads to learning.
- From the second source, in order to acquire experience, the robot constructs questions and asks its programmer about solutions. The answers are then analyzed and integrated.

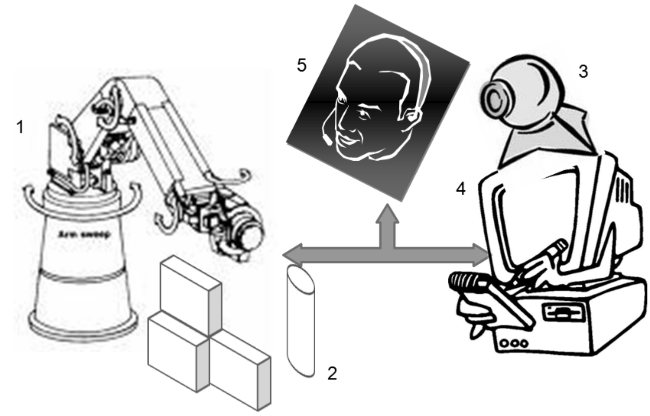

Figure 1
The scenario scene: 1 - the robot arm, 2 - the object in the artificial environment, 3 - the video camera, 4 - the computer, and 5 - the programmer

From this scenario we have implemented the observation process. Regarding the stages presented in Section 2, this case study involves the observed objects, the video camera and the computer. This robotics case study can be integrated in other challenging robotics control problems [45]–[47].

The two previous sections proposed a new pattern of human knowledge and a data structure which can be used to handle the complexity of the information involve in the knowledge process. Our idea is to corroborate and adapt these two results and to reduce their complexity as well, in order to design an agent able to acquire knowledge. First we have adapted the definitions concerning the three states of the knowledge acquisition process (perception, observation and experience), and we introduce new elements. We will define observation as a structured set of perceptions, and the following mechanisms are used in order to structure the perceptions:

- Using the concept of the object, this concept will highlight the observable features (the agent will know what to observe).
- Aggregation schemas if the concept of the object is not identified. This means that the perception failed and the agent must discover the object, for example aggregations based on opposite features (small – big, thin – thick etc) or on similarity (small – small, big – big, etc.) or on complementarily, etc.

A perception will be defined as a compatibility of a scene part with a known schema. We must continue by defining the scene as an unstructured data set (obtained from sensors) and a schema as a possible or an accepted data structure. This definition leads to the following chain, used in the observation process: scene (scene part), perception, and observation.

We have practical reasons to work with the above-mentioned chain. More precisely, our model uses the perception phase as a spontaneous process. The perception is imagined as an instantaneous process. The mentioned compatibility between a known schema and a focused part of the scene is not caused by feature recognition. For example, if a triangle shape is perceived, this process does not contain the three angels and three sides by counting and by analyzing them. Instead, the shape will be instantaneously identified as a triangle shape. The same solution is considered for the mentioned shape, colour, texture, etc.

A second practical reason is that the scene complexity is handled by structuring the perceptions. This means, for example, that a scene containing a triangle on top of a rectangle is observed by structuring the perception of the triangle, the perception of the rectangle and of the perception of the relative position, and the orientation of these two shapes. The perception also gives us the plausibility that this shape is a triangle or a rectangle. The observation gives us complex and particular information about the scene, expressed as: this scene contains two shapes, a triangle and a rectangle, which have a particular relative position: the triangle is on top of the rectangle as shown in Fig. 2.

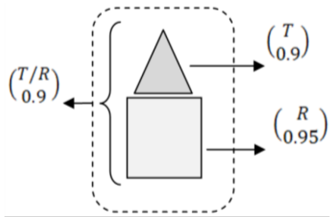

Figure 2
The scene and several perceptions

A third practical reason is the dynamic transformation of the mentioned chain. More precisely, if a particular observation is frequently performed, the tendency is to transfer this observation into a perception. This transformation can be denoted as experience. Inversely, if a perception is rarely performed, the tendency is to transform it into an observation based on several perception elements. The mathematical representation of the perception will use the signature concept, i.e.:

$$p : D \to S,\ p(X) = \begin{bmatrix} s_k \\ x_k \end{bmatrix}. \tag{28}$$

where $x_k = \max\{x_i \mid i = \overline{1,n}\}$, $X \in D$ is a data set, a scalar vector or a matrix, $\begin{bmatrix} s_k \\ x_k \end{bmatrix}$ is a signature which associate a particular structure s_k with a degree of plausibility, s_k is a signature, and x_k, $0 \le x_k \le 1$, is the plausibility value such that X matches s_k.

The function defined in (28) will select (from a set of signature) in fact the most plausible structure according to the input data, and it will graft the plausibility. The observation can be mathematical represented by:

$$o:\left\{\times\begin{bmatrix}s_k\\x_k\end{bmatrix}\right\}\to\{S_i\}_{i=\overline{1,r}},\ o:\left(\begin{bmatrix}s_k\\x_k\end{bmatrix}_{k=\overline{1,m}}\right)=S_i, \tag{29}$$

where $\begin{bmatrix}s_k\\x_k\end{bmatrix}_{k=\overline{1,m}}$ is a set of perceptions, and S_i is a structure of perceptions that consists of a signature.

To develop an observation it is considered that an observation is a structure of perceptions, and it is obvious that a perception is about "something". This means that the features which belong to the perceived entity are known. For example, after perceiving a triangle, we know that focusing on this shape we must identify three angles, three sides, etc. The features of an entity are represented with a signature. For example, the triangle can be characterized by the following signature:

$$\begin{aligned}T_1&=[[\alpha_1\quad\alpha_2\quad\alpha_3]\ \ [l_1\quad l_2\quad l_3]\ \ \ldots\ \ [c]]^T,\\T_1&=[[60\quad 60\quad 60]\ \ [10\quad 10\quad 10]\ \ \ldots\ \ [20\quad 35\quad 70]]^T.\end{aligned} \tag{30}$$

If the feature value is important for the knowledge process, a measurement must be performed. Otherwise, if it is not important or the measurement cannot be made, the information field remains empty. The first stage of an observation is illustrated in Fig. 3.

The development of an observation means to corroborate the feature's structures with the initial observation. Inside the signatures concepts, the development means to add the signatures. If we return to our example, the second stage of the observation is obtained by the addition of the first observation with the signature of the triangle. Let the observation be:

$$\begin{aligned}o_2&=o_1\oplus_{2,1}T_1\\&=[[[60\quad 60\quad 60]\ \ [10\quad 10\quad 10]\ \ \ldots\ \ [0.9]]\ \ [R\quad 0.95]\ \ [T/R\quad 0.9]]^T.\end{aligned} \tag{31}$$

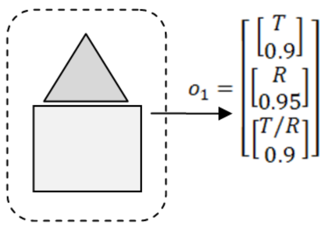

Figure 3
The stage 1 of an observation

The feature structure depends on the knowledge aspects. A feature can sometimes be neglected, and sometimes it is important. Using the signature concept, adding new feature means to graft another new structure. In our previous example, the line thickness was not important (from mathematical point of view, it is zero) but if it becomes important (for a graphical representation it is important) we can graft these features in accordance with:

$$\begin{aligned} T_1 &= T_1 \oplus_{1,3} [t_1 \quad t_2 \quad t_3] \\ &= [[60 \quad 60 \quad 60] \quad [10 \quad 10 \quad 10] \quad [t_1 \quad t_2 \quad t_3] \quad \ldots \quad [\ ]]^T. \end{aligned} \tag{32}$$

Proceeding the same way, a structure of features can be simplified by eluding non important features. This process can be modelled by the pruning operation.

The following development represents the experimentation of the previous triangle-rectangle observation example. Our goal has been to prove the signature data structuring efficacy to a real pattern recognition (classification) problem. The experiment is accomplished with a web cam, which acquires a set of data: a matrix contains the colour of each pixel of the image. From our point of view, this is an unstructured set of data.

Our observation model supposes the perception function (28) deduced from the signature associated function. For this example we have chosen a neural network (NN)-based function. This function has been trained to recognize the two mentioned shapes. The strategy of the experiment is presented in Fig. 4.

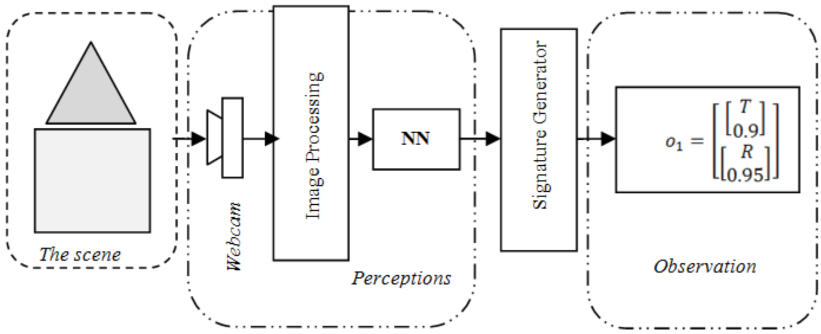

Figure 4

The strategy of the experiment

The observation development strategy is presented in Fig. 5. The perceived triangle is a known shape with known features. If the feature's values are demanded, measurements must be performed. We must stress the fact that using this model we know precisely what we must measure. If we add to the previous observation the fact that sensor data are unstructured, we can conclude that the measurement algorithms can be simplified.

In this case, the mentioned schema is embedded into the neural network object. It is a black box obtained in the training of the network. For training the neural network, we have used input vectors obtained from rotated Boolean matrixes. The mentioned matrixes have been obtained with the same signal processing procedures used in the perception process.

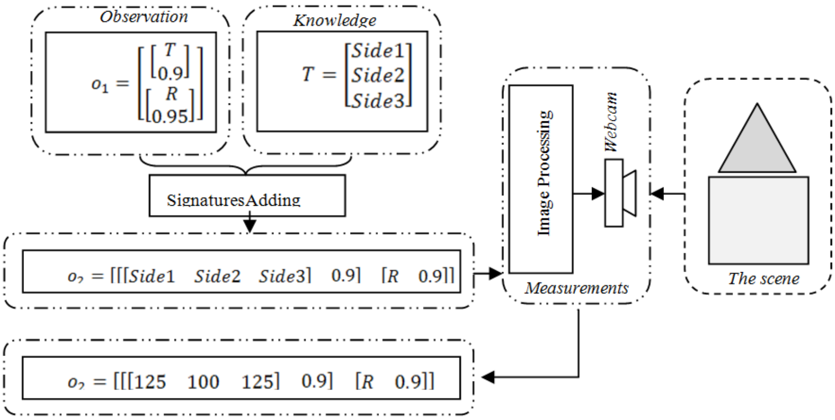

Figure 5
The strategy of the development

Conclusions

This paper has offered new results concerning a pattern of human knowledge proposed in [48]. Our model is advantageous with respect to the previous literature because it captures well the knowledge phenomenon as an ensemble from two phases: the building of experience and concept modification based on this experience.

We have underlined the fact that the cognition phenomena are cultural phenomena and we have created the possibility of building a data structure which stores the cultural aspects (related phenomena). We have highlighted the idea that a signature data structure offers access to various levels of knowledge representation. The elasticity of this data structure offers a good embedment for the dynamic representation of our knowledge. Using this representation, we can add or delete features. The signature can include data about an object or about several objects which belong to an observed scene.

The last part of our paper has demonstrated a part of the model operation focused on the observation process. Future research will deal with the mathematical formulation of the suggested model.

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