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Research paper

Self-organizing cognitive model synthesis with deep learning support

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Abstract

Cognitive models are created by experts and the process takes a lot of time. Furthermore, the result of expert work needs to be verified especially in cases when experts do not have complete information and cannot understand the problem situation quickly. As was previously shown cognitive models' factors and their mutual relationships could be verified with applying Big Data analysis technology. This paper addresses the issue of automated cognitive models synthesis on the base of author's convergent methodology, artificial intelligence and deep learning technology.

Keywords: *automated synthesis; big data; cognitive modelling; deep learning; convergent methodology; monoidal category; tourist planning.*

1. Introduction

Cognitive modelling technologies as usual find its applications in the fields where nonmetric concept description is the prevailing way of representing a problem situation. The cognitive models are created by experts from different subjects' fields. They cannot quickly understand each other and are not able describing the problem situation with a high level of quality and integrity. For this reason the issuer of automated cognitive models synthesis is very important especially for the cases of collective decision making in emergency situations and in self-organized reflexive-active environment.

In our paper [1] it was shown that cognitive model components could be confirmed by the verification on the base of Big Data analysis. For this aims the corresponding requests has to be made to the special fragment of Big Data. The verification process consists of the automated analysis of the information from the Big Data that can prove the factors and connection between the factors of the cognitive model. The queries to Big Data contain keywords of both factors for proving the factors' connection or contain keywords only one of the factors for proving the presence of the factors in the verified cognitive model. If the documents are not found the Big Data experts have to confirm that the factor or factors' connection that experts have inserted in the model could be wrong. The task was solved; the good practical results have been got.

Our further researches identified the situations (especially emergency cases) when the special fragment of Big Data could be unavailable for the cognitive model verification and the shortage of time did not allow to construct the new model that is relevance to the situation. This could happen, for example, in the field during a railway accident when communication with Big Data is violated.

The task was set to find the substitution for Big Data analysis process. The solution was sought by applying the deep neural network (NN) which has to be previously trained on the base of the relevance training sample from Big Data. The high level results of cognitive model verification with this NN approach allowed developing the topic in the direction of automated synthesis the new cognitive model for the new situation, including emergency. The author's convergent methodology [2] supplemented by modified monoidal category and deep learning (DL) technology helped to do it.

2. New AI approaches review

In 2015-2017 years there has been the progress in the topics of Narrow AI (NAI) and General AI (GAI) [3]. The latter is considered as a future AI system, capable of replicating a wide range of human cognitive capabilities. But there is an impassable gap between NAI and GAI. In this direction, the topic of DL is developed with the use of multilevel neural networks, in which the number of levels can exceed 100. The direction of "man-machine teams (teaming)" appears when the AI system supplements human cognitive abilities (Artificial Augmentation). AI has a high potential for solving global issues such as predicting and eliminating the consequences of catastrophes and climate change, controlling the trade in wild animals, monitoring digital inequality, finding employment, and smart cities.

The paper [4] is devoted to the topic of verification of cognitive models using the Big Data analysis technology. It is asserted that without the analysis of Big Data, "cognitive calculations" are hardly useful for the development of business and organizations, since they do not allow high-quality analysis of trends and forecast of the future. To accelerate the analysis processes, a complex distributed organization and structuring of the data, high-level data

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abstraction, as well as consideration of volume factors, variability, and rate of change and reliability of data are required.

In the work [5] the concept of self-consistent field theory (or the theory of the median field) is considered, which involves the study of complex systems covering large sets of interacting elements. Parallel processes in neural structures of the brain are explored. The concept of the Hamiltonian of fluctuations and hydrodynamic analogies in this paper are used. The system is called organic, because it includes a person.

In the framework of the non-classical approach to the direction of weak (significative) semantics, it is worth noting the panpsychism provisions and especially the quantum approaches to brain research and thought processes (mind). Based on the analysis of existing works, for example [6], the following conclusions can be drawn.

The phenomenological aspects of the semantic interpretation of the thinking processes are associated primarily with the solution of the interaction problem of the human brain and the phenomenon of thinking (mind). In this case, the quantum nature of the process of thinking as a whole (brain and mind together) is not questioned, including by specialists in the physical and biological fields [7];

The behavior of the brain and the phenomenon of the mind are clearly different in nature, for example, the second can be subject of the quantum mechanical regularities. At the same time, the understanding of this interaction depends strongly on the philosophical concept accepted by the researcher: it can be a direct connection between matter and reason. For a long time an important argument against such a position was the statement of the impossibility of physical representability (calculation) of the phenomenon of quality of subjective experience - these are the problems of qualia and communication gap. The long-standing alternative position regarding the material-mental interrelation [8] requires the introduction of a third, neutral, category, namely the sign (name).

The neural network paradigm of thinking is not the only. The known concepts of complementarity and entanglement are under the attention of researchers, which are working in the field of thinking modelling, especially in resolving the conflict between physical determinism and free will, or the causal impact of the brain state on mental states [9];

The quantum chaos of the behavior of thought processes remains an actual subject of investigation of the purposeful phenomenon of free will. Unlike the classical approach to the nature of randomness, quantum chaos in the processes of light emission, radioactive decay, etc., is considered as a fundamental regularity characterizing an individual quantum event, while the behavior of an ensemble of events can be characterized by statistical laws.

In the study of human cognitive abilities, technologies from adjacent areas are used, for example, from the field of management (lean-technology) or medicine. So, lean-technologies are used to ensure profit growth, reduce risks and manage prices [10]. Data-mining allows keeping a watch on the health of patients, people identify diseases at an early stage, and insurers reduce losses from abuse and fraud. Mining includes six stages: understanding the problem, understanding the data, preparing the data, modelling, evaluation, and placement. The following analysis methods are used: classification, regression, association, clustering, and diagnosis of anomalies.

An approach with the construction of matrix semantics may be interesting. Thus, in [11] algorithms are investigated, which using the matrices characterizing the distribution of words in the body of a text; evaluate the connections of adjectives with verbs. The meaning of a word is determined by their contexts. The matrices are linear operators in the vector space of the context of words. Matrices are used to construct the values of compound expressions from the values of elementary components. A new matrix approach to the processing of these data is proposed, based on taking into account the symmetry of permutations with an estimate of the Gaussian weights and their perturbations.

In the above-mentioned examples the main focus is on processing retrospective information, regression and statistical style of analysis. On the contrary, cognitive modelling relies on the analysis of the future (goals) and through solving the inverse problem helps to find the way to the future. This path is unstable, since the inverse problems are incorrect. Therefore, in the present paper the approach is different: instead of a direct problem, the invers one is solved; instead of metric (quantitative) spaces non-metric (qualitative) spaces are used; instead of a regression mechanism an evolutionary (genetic algorithm) is used.

3. Significative and denotative semantic

It is known that the semantics of any sign model, including a cognitive model, can have a denotative and significative meaning (Fig. 1:. Denotative semantics mean the mapping of the cognitive model to real things, objects, relations, terms etc., which correspond to the signs of the model. It is also possible to represent the denotation of the sign through its connection with some images that have appeared in the mind of the decision-making participants. The subject matter of thought includes really perceived and verbally representable objects, thoughts, feelings, emotions, etc.

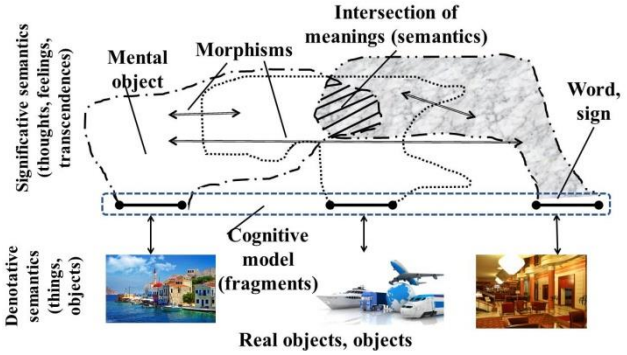

Fig. 1: Denotative and significative semantics

In the work [1**Error! Bookmark not defined.**] the rules were formulated, an algorithm was constructed, and a computer program was developed that make it possible to confirm the truth of the elements of the cognitive model by reflecting it on the world model represented in the form of systematized arrays of Big Data. At the same time, we note that Big Data contains mostly signs information, so verification of the cognitive model on its basis is denotative. The mental (thoughts, transcendental) aspects of cognitive model verification remain unconfirmed. There is a risk of limiting the completeness of its semantic interpretation.

It is obvious, an attempt to ensure full coverage of the semantic interpretation of the cognitive model with only denotative semantics will have a deficit of integrity (completeness), since mental processes are carried beyond the bounds of reasoning. Replenishment of this deficit should be sought in significative semantic interpretations. With significative semantics, the term (word, sign, factor of the cognitive model) represents the most important characteristics of some abstract and fundamentally non-formalized design. The sign reflects the result of rational and, most importantly, irrational, transcendental cognition, consisting in the formation of a set of characteristics abstracted from the real object (thing). This may also be an aspect of the conditions necessary and sufficient for the application of this sign. That is, the decision-making subject with his reflective cognitive abilities has to be directly included in the modelling process.

In these cases for taking into account the significative semantics of the cognitive model it was proposed to verify the model by solving on its basis direct and inverse problems under known initial conditions [2, 12]. It makes the cognitive modelling processes more convergent. But taking into account the significative semantics aspects required to develop the author's convergent approach by using the monoidal category theory.

4. Convergent monoid of self-organization

The groups' self-organizing decision-making in a reflexive-active environment combines the analytical-divergent and convergent-synthesis processes of participants' interests' consensus attaining. The divergent tendencies and nonmetric (no quantity) descriptions of the problem situation restrict the participants' attempts to speed-up decision-making processes.

Self-organization of decision-makers that occurs in a reflexively active environment implies the coordination of interests, goals, tasks, actions, resources. The participants' interests reflect free will, emotions, desires, thoughts, intentions, transcendental states of mind, etc. To accelerate the collective solution of any problem under these condition, it must be divided into many parts (divergent analysis), and then collect the results in a holistic solution (convergent synthesis). Cognitive simulation is used for decision-making support when the space of the problem description is conceptual in nature.

The cognitive models have as real semantic interpretations (strong, rigid semantics) that can be represented by formalized visual images, texts, logic, as mental (cognitive, weak semantics) interpretations that do not have the formalized representations. The greatest difficulty is the cognitive semantics.

Most of the semantic schools, including cognitive ones, proceed from the fact that in the texts' contents only texts' representations are to be studied and described. However, these schools do not take into account the mentality that immerses the decision-making processes in inverse problem and a weak semantics spaces. The former could be supported by convergent approach (see Section 5). The researches of mentality and weak semantics rely on various approaches to the study the brain and thinking. For example, it is necessary to take into account the mechanisms of brain behavior, in which the number of neurons is of the order of 10^{11}, and the number of atoms is of the order of 10^{26}. Atoms are under the influence of fields (electromagnetic, gravitational, strong and weak). The states of atoms can be teleported; they can be entangling with atoms from the outside. The quantum mechanics is used for consideration the influence of atomic on mentality processes [6].

The elements that provide a thought process for a certain object seem to form clusters, that is, holistic but informal objects. With this assumption, it is possible to identify a thought phenomenon. In this case, it must have a fuzzy boundary, and in the interpreting mathematical space, closedness of the set of the elements should be defined.

To ensure the integrity (holistic) of cognitive models the concepts of category theory and monads was applied. The categories help to study the properties of the relations of objects without consideration their structures. In this case, weak semantics corresponds to a certain category *C*, in which:

- Object *A* mean a certain closed mental phenomenon, corresponding to the word, factor or connection between the factors of the cognitive model;
- The set of morphisms $hom_C\ (A, B)$ is formed for each pair of objects *A* and *B* in order to determine the relationship between them in cognitive model. Between each pair of objects there can be a set of relations that characterize the difference of participants' understanding of different events, factors or connection between the factors;
- For a pair of morphisms $f \in hom_C\ (A, B)$ and $g \in hom_C\ (A, E)$, the composition $g \circ f \in hom_C\ (A, E)$ is defined. At the same time, such constructions do not always exist, for example, tolerant (nontransitive) relationships between objects are possible;
- The axiom of associativity for morphisms is fulfilled;
- For each object *A* the identity morphism $id_A \in hom_C\ (A, A)$ is given. This characterizes the natural desire to ensure the closure (self-reflection) of the mental phenomenon on oneself.

There is an experience of application the theory of categories for semantic interpretations of the language. For example, in [13] distributive categorical models of language are studied, and the limitations of the statistical estimations of vector spaces with quantum computing applications are shown.

The monads in category theory are used for reflexive encapsulation (representation of the assembly of a mental phenomenon) of information behavior of participants. Reflection is the mapping of some space onto itself; it is the monad that is the functor that maps the category *C* onto itself. The mathematical apparatus of the trigger (involution) compact closed categories helps to make identification the phenomena of interest from the texts [14]. Such categories can be used to express fundamental quantum information protocols such as teleportation, concatenation, complementarity, observable, etc. Accordingly, it is useful for the quantum-semantic interpretation of the cognitive model.

The monad fixes the closed field of discourse. Monad operators are used for: lifting - representing divergent processes; finite reinforcement - modeling of finite-bounded nondeterministic and non-empty lifting monads that prevent divergence; finite distributive monads used for probabilistic computations, and others.

In the group construction of the cognitive model the classical monad does not provide the necessary conditions for convergence [2]. Therefore, it is advisable to change the classical monad by applying the requirements for convergent support of a decision-making processes. In order to ensure convergence the concept of a "Convergent monad" $\mathcal{E}$ was introduced by adding the follow special axioms to the classical monoidal category:

- *D:* ***Set*** $\rightarrow$ ***Set***, and the number of elements in the system of the sets ***Set*** is infinite, and the maps of the objects are the maps with the closed graph;
- $\mathcal{B}$ – is a non-empty finite subcover of the monad $\mathcal{E}$ (*bicompactness*);
- Every neighborhood of the monad point $e \in \mathcal{E}$ can be associated with some neighborhood (in the topological sense every open set contains this point) such that for each two points there are always disjoint neighborhoods (*Hausdorffness*).

These axioms help to make the information processes in group decision-making more convergent.

5. Convergent cognitive modelling

The author's convergent approach helps to make the process of reconciling interests converging [2]. For this it is necessary to use methods of: cognitive psychology, invers problem solving in the topological spaces, fundamental thermodynamics, and genetic algorithm.

In a lot of problem areas the creation of formalized models is impossible. Such problems have characteristic: latency, randomness, quantization, uncertainty, qualitative description, ambiguity of consequences of decisions. During solving such problems, decision makers need to apply: intuition, experience, associativity of thinking, guesswork, expert judgment.

For such problem areas, cognitive modelling method is used [1]. It takes into account the qualitative aspects of the situation; make sure the complex semantic interpretation of models. Cognitive modelling is usually conducted by experts in the following order:

- The factors of the situation presentation are revealed;
- The mutual influences between factors are evaluated;
- The cognitive model (graph) is formed;
- Goals and management factors are identified;
- The direct and inverse problems on the cognitive graph are solved.

In this paper, the tourism field of activity has been chosen as a problem area. For cognitive modelling of tourist activity the relevance factors were considered, for example:

- The growth of Moscow's popularity (Goal);
- Number of tourists;
- The time of tourists staying in the city;
- Number of collective accommodation facilities;

- The number of events' activities;
- Easy entry visa;
- Quality of navigation and transport services, and etc.

The cognitive model allows obtaining a chain of "assessment of the state of the object - a diagnosis - a self-development forecast - a forecast of managed development taking into account environmental factors" at a qualitative level. This model gives an opportunity to monitor the current situation, assess the dynamics of changes in its state under various control actions, predict the development of the situation, assess the risks of decision-making, get the answer to the questions: "What will happen, if ...?", "What should be done for ...?" .

When using the cognitive modelling method the predictive parameters of the development of the situation are reduced to the automatic calculation of the numerical values of the selected factors at selectable moments of the model time.

The process of cognitive modelling has to be convergent to some goal. It should be purposeful, in spite of the goals could be ill defined. Convergent approach helps to create necessary formalized conditions for decision making acceleration. As it was shown in [2], for ensure the convergence of decision making process on the base of cognitive model the following simple recommendations have to be applied:

- Separate goals, resources and actions;
- Goals have to be arranged in hierarchy levels: main, internals and externals;
- Variety of resources should be separated into finite number of parts;
- Control all aspects of problem' solution, bindings between goals and resources;
- Never underestimate small factors, etc.
- These are necessary conditions for provision of purposefulness for decision making process.

6. Neural network instead Big Data

In this study, the choice of the NN method was carried out taking into account the requirements:

- Adequacy for verification of the cognitive model, consisting of factors and interactions;
- Availability of a relevant test case of documents;
- Using the standard software environment for a neural network learning;
- Accounting for cognitive, significative semantics.

In this paper, as an aid to the construction of significative semantics, an approach with the replacement of direct access to the Big Data by addressing to a NN is proposed. The choice of the most acceptable NN is substantiated and the idea of permanent training of the NN on examples with subsequent use in a concrete situation is worked out.

The expediency of using "Deep neural networks" [15] was shown, especially model type: LSTM (Long short-term memory), convolutional, recurrent. Unlike traditional recurrent NN, the LSTM-model is well suited to learning the tasks of classifying and predicting time series in cases where important events are separated by time lags with uncertain duration and boundaries.

The LSTM network is an artificial NN containing LSTM modules in place of or in addition to other network modules. The LSTM-module is a recurrent network module that can store values for both short and long periods of time. The key to this feature is that the LSTM-module does not use the activation function inside its recurrent components. Thus, the stored value is not blurred over time, and the gradient or penalty does not disappear when using the Backpropagation through time method in network training.

The test case of 16227 relevant documents was built on the basis of available data sets [16]. It is a working news collector, and there is also an online filter with samples, for example, news websites from the top 10000 news sites are taken from ready-made webhose.io/datasets "(291,584 doc's, 538 MB, Oct 2016). The DL was based on a set of factors for the cognitive model. The experiment involved cognitive models reflecting the situation related to tourist activities in the city of Moscow (income 500 billion rubles a year).

To vectorize the data, the Doc2Vec model was used [17]. This model has an important advantage that it could be learned from unlabeled data and thus can work well for tasks in which there is not enough labeled data. Doc2vec is an unsupervised algorithm to generate vectors for sentence/paragraphs/documents. The algorithm is an adaptation of word2vec [18] which can generate vectors for words. Unlike sequence models like RNN [19], where word sequence is captured in generated sentence vectors, doc2vec sentence vectors are word order independent.

Stages of creating the NN:

1. Download the categories of relevant document from available data sets [16];
2. Tokenization, lemmatization and filtering of texts for each document;
3. Constructing Doc2Vec model (Distributed representations of sentences and documents);
4. Converting the Doc2Vec model for training the LSTM-model;
5. Training the LSTM-model.

For every of abovementioned factors (Section 5) the request vector was constructed. For example, the factor "Number of tourists" took up the vector: "(number OR amount OR volume OR flow OR value OR size OR measurement) AND (tourist OR tourism OR traveler OR excursionist OR sightseer OR rest OR holidayer OR holiday OR visitor OR journeyer OR tripper OR voyager OR guests)".

After that the relevance documents for every factor were searched and downloaded from the data sets. The prefix for all queries was added: (Moscow OR ((Russia OR Russian Federation OR RF) AND capital))).

It should be noted that the syntax of search query can be complicated depending on subject domain. For example, task from technical sphere demands more than accuracy, than completeness of search results. On the contrary, the completeness of search results is more important for the legal or political sphere.

Than Doc2Vec model was constructed and converted for training the LSTM-model. For example, Fig. 2 illustrates the probability of occurrence the documents that was represented by testing sample of 10 documents distributed over 14 given factors (categories) of the analyzed cognitive model. These examples of the factors are: "Number of tourists", "Easy entry visa", "Quality of navigation and transport services".

The testing process was made with different numbers of documents in testing samples: 10, 100, 1000, and 4868. The model was trained on 70% of the total number of documents. The testing of the NN was conducted on 30% of the total number of documents.

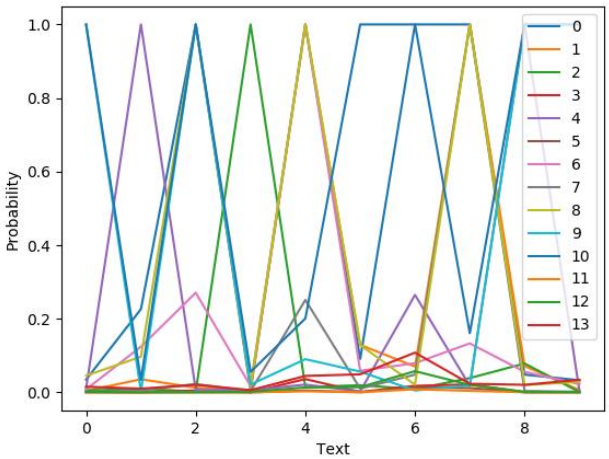

Fig. 2: The probability of distributing 10 testing documents

As an example, the diagram on Fig. 3 demonstrates the probability of distributing documents from a testing data for these 14 factors in case with 100 testing documents.

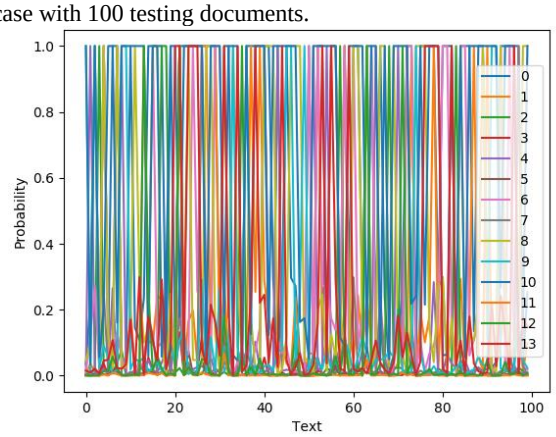

Fig. 3: The probability of distributing 100 testing documents

The result of the testing showed the accuracy of 93% for recognizing 14 abovementioned factors (categories).

7. Conclusion

Cognitive modelling technologies find its applications in the fields where nonmetric concept description is the prevailing way of representing a problem situation. The cognitive model could be confirmed by the verification on the base of Big Data analysis. But sometimes the Big Data could be unavailable and it was made the statement to find the substitution for Big Data. The solution was found with applying the deep neural network which has to be previously trained on the base of Big Data.

New AI approaches review showed that cognitive (weak, significative) semantic has to be taken into account. This semantic helps to reflect free will, emotions, desires, thoughts, intentions, transcendental states of mind. While denotative semantics mean the mapping of the cognitive model to real things, objects, relations, terms etc., which correspond to the signs of the model.

For ensure the integrity (holistic) of cognitive models and taking into account significative semantics it is useful to apply the Category theory and monads. The categories help to study the properties of the relations of objects without consideration their structures. But the classical monad has to be changed for ensuring the decision-making processes convergent. For this aim the concept of a "Convergent monad" was introduced by adding the special axioms to the classical monoidal category.

In this paper an approach with the replacement of direct access to the Big Data with addressing to a deep neural network is proposed. It was used the LSTM-model (Long short-term memory) that is convolutional, recurrent. It is well suited learning the tasks of classifying and predicting time series in cases where important events are separated by time lags with uncertain duration and boundaries.

The main results of the paper could be illustrated with the Fig. 4.

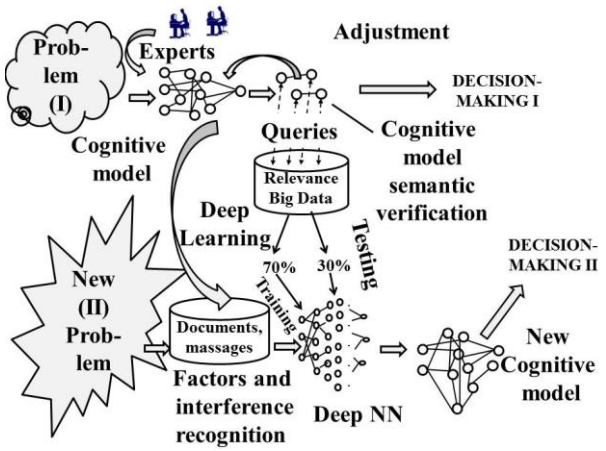

Fig. 4: Self-organized cognitive model synthesis with DL support

This result of testing the approach is so good that it allows raising the issuer to make an attempt of automating the cognitive model creating

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