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TOWARDS NEW CLASSES OF INTELLIGENT COGNITIVE INFORMATION SYSTEMS FOR SEMANTIC PATTERN CLASSIFICATION

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Abstract. This paper introduces two new classes of specialised vision systems called UBIAS and E-UBIAS. Such systems belong to the group of cognitive reasoning systems and are designed for the semantic analysis of visual patterns in the form of medical images. Proposed systems are predecessors of a new generation of intelligent systems dedicated for understanding medical diagnostic visualization and using this data as biometric characteristics.

Keywords: Image understanding, intelligent systems, semantic analysis, cognitive reasoning

1 INTRODUCTION

The extremely fast development of computational intelligence algorithms has led to the recent appearance of a new field referred to as computational cognitive science or cognitive informatics. Cognitive science is a new branch of computer engineering originating from neurobiology and psychology, but is currently also developed by science (e.g. denotation mathematics) and technical disciplines (informatics). In this branch, cognitive process models have become the basis for designing various types of intelligent computer systems. In particular, this applies to information systems or systems of image recognition which make it possible to quickly access the needed information which contains a hidden meaning. Such systems, able to interpret the meaning of data they process, can also serve as decision-support systems helping people take decisions by acquiring knowledge adequate for the considered problem.

So it is obvious that modern solutions using state-of-the-art achievements of computer technologies with operations founded on complicated theoretical formalisms are moving in the direction of building new classes of information systems, called Cognitive Information Systems. These can process data at a very high level of abstraction and evaluate this data depending on its meaning. Such systems should also have autonomous learning capabilities, which will allow them to improve along with the extension of knowledge available to them, presented in the form of various patterns and data.

Before we present the directions of development of such systems and new classes of cognitive information systems, it is also worth noting that they will use theoretical bases and conceptual formalisms developed for cognitive science. Within informatics, attempts have already been made to create simpler information systems on this basis [6]. This is why elements of the cognitive approach are increasingly widespread in the structure of information systems of the new generation [15]. The general foundations for the design of such systems have been the subject of earlier publications by the authors. They have been broadly described in the following publications: [2, 15, 16]. However, it must be said that the methodology of designing universal systems of computational cognitive science (or cognitive informatics) has yet to be developed fully. This applies in particular to systems oriented towards the cognitive analysis of multimedia information. Overcoming the barrier between the form of multimedia information (e.g. the shape of objects in the picture or the tones of sounds) and the substance implicitly contained in this information requires more research oriented towards specific goals. These goals are mainly about moving away from the analysis of data describing single objects to a more general analysis of data presenting or describing various components. A very good example of such data is offered by medical images in the form of diagnostic pictures. So far, intelligent image recognition systems working on this kind of data could classify patterns showing single structures. Consequently, in new generation systems this functionality will be extended so they can analyse patterns showing many structures or single structures made up of several elements. Such capacities will be offered by the systems discussed below, which we have called UBIAS (Understanding-Based Image Analysis Systems) and E-UBIAS (Extended Understanding-Based Image Analysis Systems) [14]. In this paper we'll try to show, how to create and develop of cognitive information systems, and how it may affect further development of complex, intelligent and software intensive systems in various application areas [8, 9, 19]. Such systems will play increasingly important role in pervasive computing environments [11, 12, 17].

2 THE CONCEPT OF NEW CLASSES OF COGNITIVE INFORMATION SYSTEMS

In this section we would like to discuss two new classes of intelligent systems for analysing image patterns and supporting diagnostic decision-making. The novelty of the proposed approach is that these systems are targeted strictly at the semantically-oriented cognitive analysis supporting the semantic classification of selected types of medical images. The cognitive reasoning of these systems is conducted using suitably designed image languages allowing information constituting the meaning to be extracted. This approach is different from those traditionally used in artificial intelligence applications, based on decision trees, fuzzy sets or models of neural networks [1].

The methodology introduced below concerns two new classes of cognitive systems: UBIAS and Extended-UBIAS. Such systems are proposed based on the authors' previous achievements in designing CMDSS – Cognitive Medical Decision Support Systems [13]. However, the limited ability to use those systems only for some specialised types of images has driven the authors to propose somewhat more versatile classes of systems, namely UBIAS and E-UBIAS. Such systems will allow extending computer interpretation processes to handle model images showing multi-object structures. These systems will also be able to learn, which previous solutions could not do so, which particularly applies to cognitive pattern understanding systems [3]. The last important feature of the new system class will be the ability to create records of a biometric nature. This means that the semantic information which the UBIAS systems will be able to obtain by cognitive analysis will also be used to create a unique description having the character of a biometric identifier.

The proposed techniques of enhanced cognitive classification will be aimed at semantic reasoning about the meaning, which on the one hand will be used to conduct an automatic analysis of selected diagnostic images, and on the other to generate a description of the individual based on the detected lesions or other image characteristics of individual nature (dependent on the patient examined or case analysed).

These new systems will also be capable of learning, i.e. enhancing the reasoning rules used, and it will later be possible to use the semantic information obtained by applying these rules as specialised biometrics.

For the new UBIAS and E-UBIAS systems to have such characteristics, the following must be done first:

- enhanced mechanisms of semantic description must be developed for the analysed objects (e.g. medical images);
- cognitive reasoning procedures based on the model of cognitive resonance with learning must be defined;
- image languages must be applied to solve the problem of the semantic interpretation of a selected type of diagnostic images [5, 18].

This methodology enhancing cognitive categorisation processes will lead to the creation of new classes of information systems which will not only imitate natural thought processes, but will also be capable of learning.

When discussing the ideas for new systems below, we will present their functionality on the example of a selected class of medical images [4].

2.1 UBIAS Information Systems

The first groups of systems, of the UBIAS type, will be dedicated to the semantic analysis and recognition of lesions found in images showing multi-object structures. These include images of palms or feet. The purpose of these systems is mainly to recognise visible lesions and to enable their meaning (diagnostic) interpretation. These systems should therefore support detecting disease pathologies, traumatic lesions or inborn anomalies visible in X-ray images. These images may show either excessive numbers of structures (e.g. additional bones) or missing ones. They may also portray mechanical traumas or skeleton irregularities caused by disorders in the body's metabolism. Such lesions are frequently imaged on X-ray photographs of foot and palm bones.

Such systems interpret image patters in the following main stages:

- preliminary analysis of image types under consideration [7];
- linguistic modelling of recognised structures (using the appropriate graph languages);
- semantic reasoning with the use of cognitive resonance techniques;
- determining the significance of detected lesions.

Consequently, the most important step in these systems is to conduct the cognitive reasoning. As has been shown earlier in the case of diagnostic images, it can lead to understanding the meaning of such images [10]. Here, semantic reasoning and cognitive resonance processes are based on the knowledge collected earlier and recorded in the rules of the grammar defined. New patterns that the system records and analyses are compared to information contained in grammar rules. As a result of this confrontation, certain hypotheses preliminarily identifying the nature of the recognised changes are either confirmed or rejected. The ultimate stage of resonance procedures is to formulate the final identification, which is defined as the result of recognising a certain lesion, and semantic information determining its nature. A diagram representing this reasoning is shown in Figure 1.

We can see that UBIAS systems operating in the above way will be able to recognise and interpret visible lesions. However, we are assuming that the knowledge collected and represented in the form of grammar rules is very broad and allows most known diagnostic cases to be interpreted.

The situation is somewhat different in the case of E-UBIAS systems. These systems, in addition to the resonance modules, are also be equipped with procedures for learning from recognitions conducted earlier.

2.2 Extended UBIAS Systems

The second type of systems, namely E-UBIAS, will carry out enhanced cognitive reasoning, i.e. resonance with system learning. In the traditional approach, reasoning systems were not able to use the knowledge derived from previously analysed

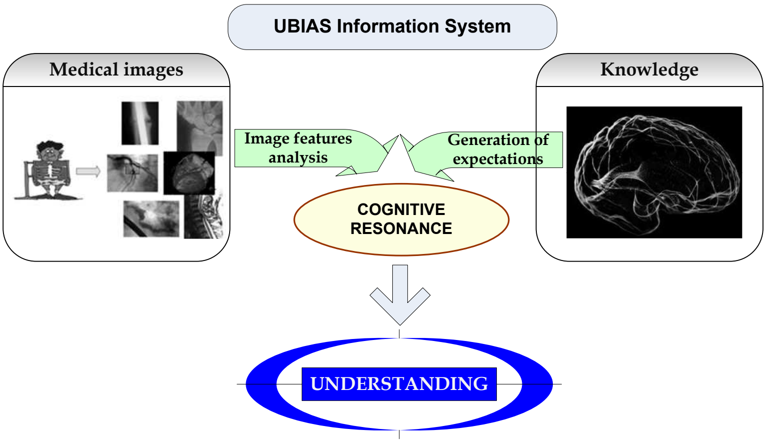

Fig. 1. A diagram of cognitive processes in UBIAS systems

patterns. In the case of these systems, we will strive to enhance the resonance by adding the ability to collect knowledge and extend reasoning rules. Such learning characteristics of the system will help improve the effectiveness of its operation, particularly for patterns whose initial number is very small.

In addition, extended semantic records containing data on individual characteristics of the palm bone layout can later be used as biometric information allowing patients or other persons to be identified. This second feature significantly enhances the functionality of these systems compared to classical UBIAS ones.

This way, cognitive analysis will help go deeper into the essence of the image data collected and processed. As we know, data in the form of medical images or photographs is extremely difficult to analyse because medical images (including those of feet and palms, for example) are characterised by the presence of many objects (bones) which frequently obscure one another. The analysis of such patterns is therefore a difficult job, which should additionally end in determining diagnostic information and elaborating personal characteristics allowing the examined individuals to be identified.

E-UBIAS systems interpret image patterns in the following main stages:

- preliminary analysis of image types under consideration;
- linguistic modelling of recognised structures (graph formalisms);
- semantic reasoning with the use of cognitive resonance techniques;
- the system learns by adding the recognition executed before to the knowledge base;
- defining the meaning of the lesions detected and creating a diagnostic record;
- using the linguistic representation to generate a biometric description of the palm (a biometric record).

We can see that in the case of E-UBIAS systems, the entire meaning analysis process now includes two additional stages. At the first of them, the system learns by collecting information about recognitions performed earlier. This stage can lead to the creation of a new type of resonance procedures, i.e. algorithms of extended cognitive resonance. As we know, the thought processes connected with human perception allow us to draw conclusions and collect knowledge from earlier experiences. Similar features would also be desirable in computer systems. As it is difficult to extend the sets of rules describing new patters for algorithms based on graph representations, the collecting of new knowledge (experience) must entail the creation of a new database for storing linguistic representations of cases not analysed before but recognised using semantic procedures. Thus we have a situation in which completely new (previously not considered) patterns appear, while the grammars and resonance procedures cannot unambiguously classify these patterns. However, based on semantic information or additional data about the patient's health, we can determine the type of lesion being recognised. If such a case comes up, then after the interpretation activities are completed, it will be stored as a new element in an additional knowledge base. This base will then be searched when subsequent patterns that are difficult to identify (based on grammar rules) appear. If the comparison of a new element to subsequent elements from the additional base shows that it is similar to one of them (with regard to the adopted similarity measure), it will be classified in a similar way. A diagram of the E-UBIAS system operation is presented in Figure 2.

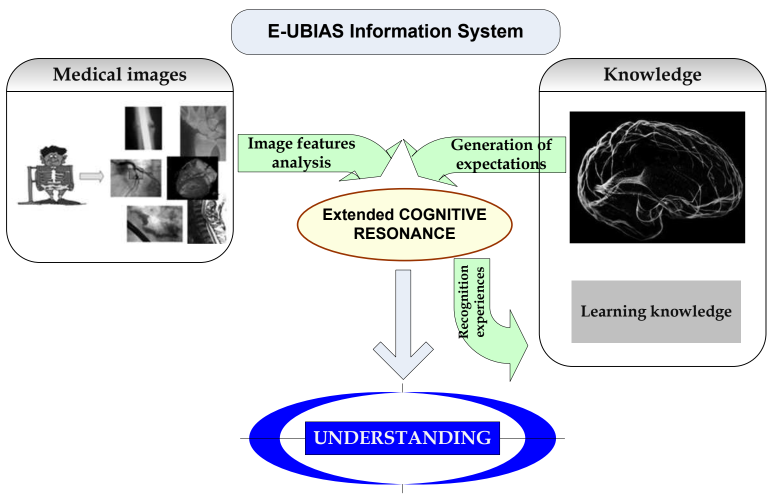

Fig. 2. A diagram of enhanced resonance processes taking place in E-UBIAS systems

The second new stage in the operation of E-UBIAS systems consists in generating the biometric description of the palm. This stage will be executed in the following way: once we have the given graph representation of the layout of the palm visible in the image, we can unambiguously determine the sequence of biometric information containing data about the nodes, labels and distances between particular components, i.e. the bones of the wrist, the metacarpus and fingers. Pathologies frequently lead to lesions in the form of losses, dislocations or delaminations of bones. This means that a description identifying the number of such bones and their mutual spatial relationships can unambiguously describe the characteristics of lesions for the given patient. This kind of characteristics can also be useful if there are no lesions. Due to the precision of the descriptions generated and the presence of certain individual differences in the dimensions and shapes of particular palm bones, such a description can be used as the biometric characteristic even for healthy individuals.

2.3 What Distinguishes an E-UBIAS from a UBIAS System?

Traditional data analysis processes based on cognitive resonance, characteristic for UBIAS systems, are extended to include stages at which the system learns using the knowledge collected in its knowledge bases and by analyzing situations it does not understand. Enhancing the system by adding the learning stage is characteristic for E-UBIAS systems. In addition, E-UBIAS systems recognize expectations, which in this class of systems are aimed at facilitating the addition of new analysis patterns learned by the system to the knowledge bases it uses to analyze data. If the system encounters a situation it does not understand, i.e. one undefined in its knowledge base, it cannot correctly classify it and match the pattern. In this situation, when the system cannot correctly interpret the data, it can supplement the knowledge base with new cases of classified patterns and strive to understand them. However, to execute such procedures, it is necessary to add new, undefined examples to the expert knowledge base. This situation is presented in Figure 3.

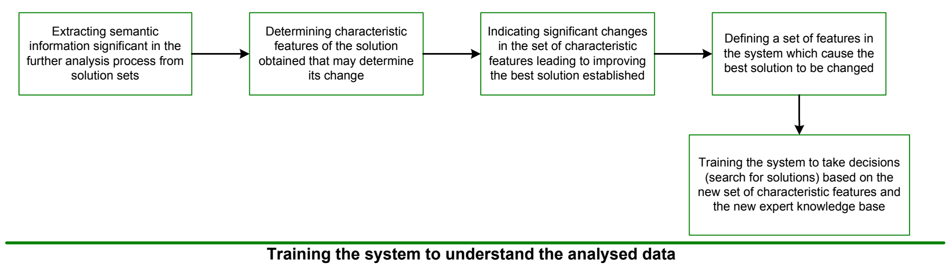

Fig. 3. Training the system to understand the analysed data

Extending data analysis by adding stages at which the system learns new solutions means that the cognitive resonance must frequently be repeated in the semantic data analysis process, and at the stage when the whole system learns, cognitive resonance must be repeated several times. UBIAS systems conducted the analysis based on 'closed' knowledge bases without the ability to teach new solutions to the system.

Adding new system training procedures to the data analysis process means that interpretation analysis processes of E-UBIAS systems are much more complex, but this allows an in-depth semantic interpretation of data to be completed (Figure 4).

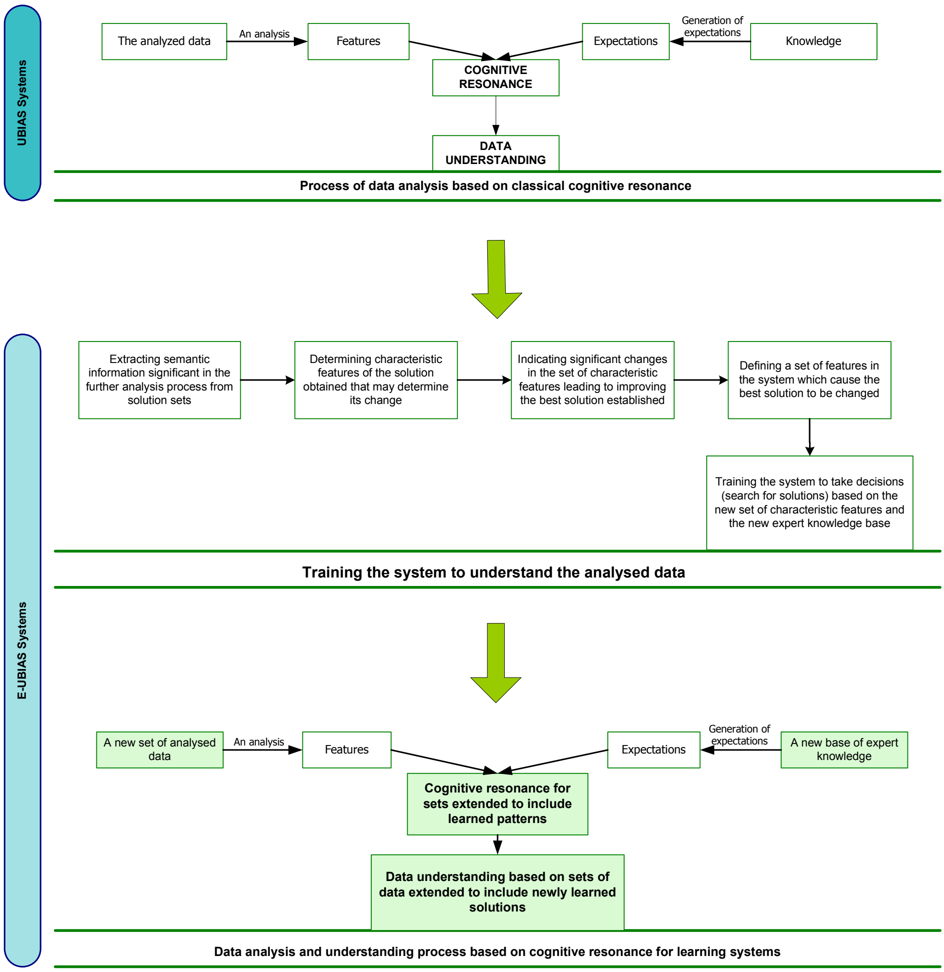

Fig. 4. Cognitive resonance in the new process of data analysis and understanding

Processes taking place in E-UBIAS systems when they analyze data also allow characteristic features of the recognized data to be defined, which leads to its full understanding as a result of the system's operation. This is because the process of learning situations, cases and solutions so far 'unknown' to the system facilitates the continuous supplementation and extending of knowledge bases used for the cognitive understanding of data.

3 POSSIBLE APPLICATIONS OF COGNITIVE INFORMATION SYSTEMS

As the presented systems execute processes aimed at determining the semantic significance of the analysed patterns, they can work together with consulting systems, diagnostic and decision-support systems or PACS systems [15]. Such systems are particularly versatile and can also be used for other jobs that require a cognitive categorisation or analysis to be conducted to obtain semantic knowledge components.

The idea of semantic data analysis processes executed by cognitive categorisation systems can be presented using the example of UBIAS systems which analyse medical image data. This section presents an example of UBIAS systems for semantic analysis of lesions in foot bones. Such lesions can be presented in three projection types: dorsoplanar, external lateral and internal lateral. For presentation we can focus on dorsoplanar projection, being most characteristic of the three possible types.

A graph showing the connections between foot bones (Figure 5) is created for the selected projection type.

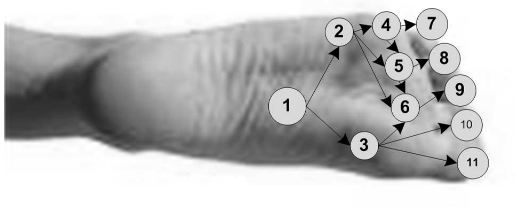

Fig. 5. A graph describing the foot bone skeleton in the dorsoplanar projection

Topographic relationships were introduced for the thus defined, spanned graph describing the foot bone skeleton in the dorsoplanar projection. These relationships describe the location of particular structures in relation to one another, as well as the possible pathological changes within the foot (Figure 6).

The introduction of such spatial relationships and the representation in the form of a graph spanned on the skeleton of foot bones were used to define the graph proper, in which all the adjacent foot bones were labeled as appropriate for the analysed dorsoplanar projection (Figure 7).

This graph shows bones that are already numbered and which have been assigned labels in line with searching the graph across. (bfs/wfs-wide first serach). Such a representation creates a description of foot bones using the so-called IE graph. This is an ordered and oriented graph for which the syntactic analysis will start from the distinguished apex number 1 (Figure 7).

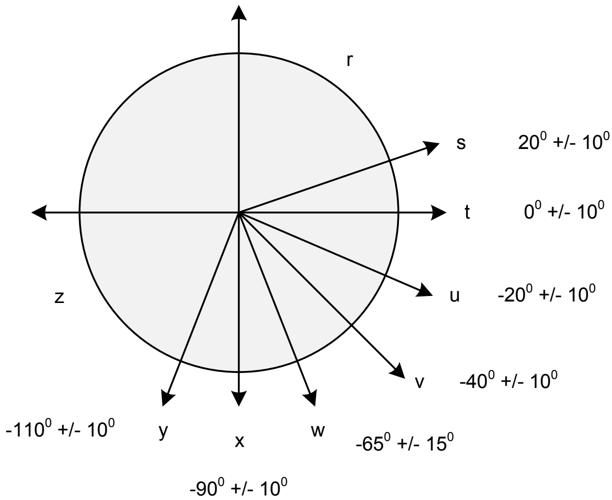

Fig. 6. A relation graph for the dorsoplanar projection of the feet

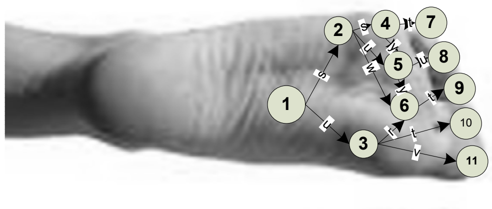

Fig. 7. A graph with numbers of adjacent bones marked based on the relation graph for the dorsoplanar foot projection

For the purposes of the analysis conducted, a formal definition of the graph grammar was introduced, which takes into account the developed linguistic description of correct connections between foot bones:

$$G_{dors} = (N, \Sigma, \Gamma, ST, P) \tag{1}$$

where:

- The set of non-terminal labels of apexes:

$$\begin{aligned} N = \{ & \mathtt{ST}, \mathtt{CALCANEUS}, \mathtt{OS\ NAVICULARE}, \mathtt{OS\ CUBOIDEUM}, \\ & \mathtt{OS\ CUNEIFORME\ MEDIALE}, \mathtt{OS\ CUNEIFORME\ INTERMEDIUM}, \\ & \mathtt{OS\ CUNEIFORME\ LATERALE}, \mathtt{M1}, \mathtt{M2}, \mathtt{M3}, \mathtt{M4}, \mathtt{M5}\} \end{aligned}$$

where individual names denote foot bone names and final nodes shown on the graph presented in Figure 8.

- The set of terminal labels of apexes:

$$\Sigma = \{s, t, u, v, w, x, y, c, on, oc, ocm, oci, ocl, m1, m2, m3, m4, m5\} \qquad (2)$$

where particular symbols denote the connections between individual nodes of the graph, shown in Figure 7 and the graph nodes shown in Figure 8.

- Γ – the graph shown in Figure 7.
- The start symbol $S = ST$.
- P – a finite set of productions shown in Figure 8.

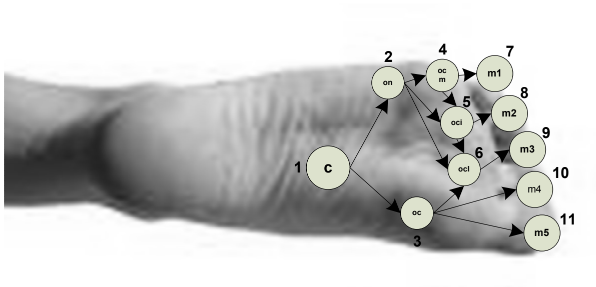

Fig. 8. A set of productions defining the interrelations between particular elements of the structure of foot bones for the dorsoplanar projection

Our analysis of image-type data understanding was aimed at an in-depth understanding of the images analysed, in this case also of specific lesions. Figure 9 shows the possibilities for describing various disease cases by expanding the set of linguistic rules to include additional grammatical rules.

The presented examples of the cognitive analysis and interpretation of data, describing the lesions appearing in foot bones, show possible cases, namely: foot fractures and deformations.

Semantic data analysis systems which present images of lesions found in foot bones are used to semantically understand the analysed medical images. This is because they present not just the recognition of the lesion, but also describe it, define directions in which necessary preventive treatment should go and project changes that may occur in the future.

The example presented above shows how UBIAS systems cognitively analyze selected medical images. At the same time, in this publication, such systems were enhanced by adding a stage of new solution learning, as a result of which the system performing the analysis is classified as E-UBIAS. This example will be characterized below by reference to the cognitive data analysis systems described above used for analyzing lesions occurring within foot bones.

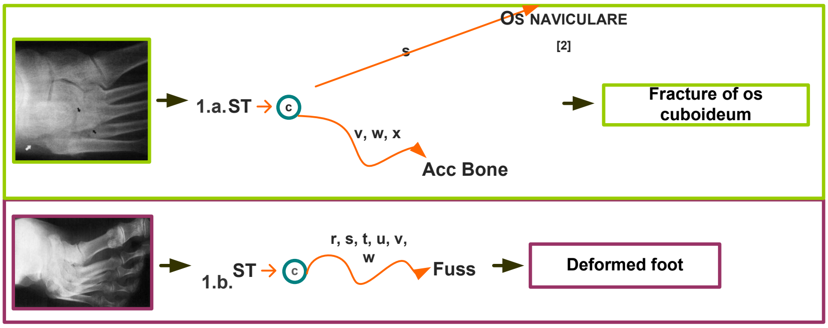

Fig. 9. Examples of using the automatic understanding of foot bone lesions detected by the system in the dorsoplanar projection

As a result of introducing new training solutions into the system, it is possible to conduct a cognitive analysis of images and a process of understanding images which were not correctly classified during the original analysis attempt. One of the reasons for this failure was the lack of the appropriate knowledge which could be used to correctly understand the data. The authors' research focuses on attempts to optimize the operation of E-UBIAS systems by equipping them with stages at which they learns new solutions. The results of their work are shown in Figure 10.

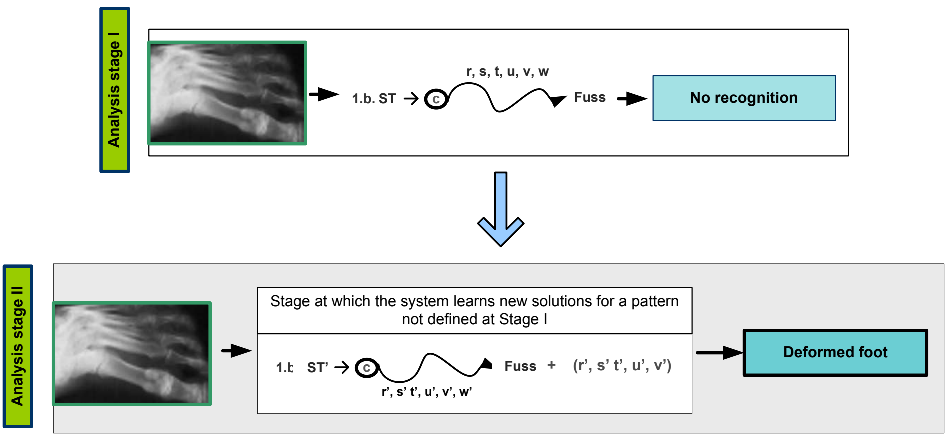

Fig. 10. Automatic data understanding in a E-UBIAS learning system

Figure 10 shows an example of a system analysis of an image showing a foot deformation; this image has been acquired in a layout different than image examples presented in Figure 9. This type of layout of input images has not been originally defined in the system base, but as a result of the system learning that it is possible to take images obtained from various input layouts for analysis, the diagnosis and the semantic analysis turned out to be correct.

Figure 10 shows how, as a result of the analysis conducted, the UBIAS system received an example for which there was no correctly defined pattern, so the system, without having a proper reference, compared the characteristic features of the analyzed image with expectations as to the image meaning using algorithms of semantic analysis of data defined in the form of a formal grammar, but did not complete the correct analysis. Consequently, it was necessary to input new definitions of patterns into the system and to extend the set of characteristic features to include those perceived in the analyzed case. As a result of this action, new classes of features characteristic for the analyzed images were obtained and the expert base has been supplemented with new characteristic patterns, and this has led to the correct analysis of data ending in the recognition and semantic understanding of data.

This publication presents a new approach to data understanding by correctly teaching new solutions to the system, which solutions are used to extend the knowledge bases constituting the foundation of the cognitive analysis conducted by E-UBIAS systems.

4 CONCLUSION

This paper proposes extending the techniques of the cognitive analysis and categorisation of image information used by intelligent cognitive systems previously developed by the authors. Such systems were mainly dedicated to semantic analysis of selected classes of 2D medical images. This publication proposes certain specialised classes of generalised cognitive systems, called UBIAS and E-UBIAS, designed for analysing complex images of multi-object structures. Such systems enable the machine understanding and extraction of semantic information from selected types of medical images, which makes it possible to develop procedures for composing semantic records. These records are used to support various decisions in the medical diagnostics and therapy field, but also for the purpose of structuring and systematising medical multimedia resources of various Internet services.

What is characteristic for such systems is that they also execute deeper semantic analysis processes for a broader class of input image information. This has become possible thanks to the development of a model for conducting deeper reasoning using cognitive resonance techniques. In previous solutions, this process could not use knowledge originating from objects classified earlier, but has now been enhanced to have this ability. This means that the newly proposed E-UBIAS systems allow the cognitive systems to learn while executing subsequent recognitions.

The second direction of proposed enhancements relates to using semantic records and linguistic representations generated for the analysed image information. As a result, it will be possible to use the linguistic representation as biometric indicators. The need for such systems has been mentioned for years by rescue services, the police, public prosecutors, welfare and other institutions. The capabilities offered as a result of the presented research will significantly contribute to extending the efficiency of intelligent information systems, which will achieve a completely new quality of operation when they are enhanced with modules for the cognitive interpretation of multimedia information and the biometric identification of people using images which have never been used for this purpose before .

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