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Cognitive Categorizing in UBIAS Intelligent Medical Information Systems

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Summary. This chapter will demonstrate that artificial intelligence methods based on linguistic mechanisms for semantic meaning reasoning can be used to develop new classes of intelligent information systems, and can be applied quite successfully to conduct in-depth meaning analyzes in the presented DSS (Diagnostic Support Systems) information systems as well as in a subclass of intelligent, cognitive systems used to analyze images: UBIAS (Understanding Based Image Analysis Systems). The study will present an IT mechanism for describing the meaning of analyzed objects using selected examples of analyzes of medical images, including those of the spinal cord and bone radiograms. The presented semantic reasoning procedures are based on the cognitive resonance model and have been applied for the job of interpreting the meaning of a selected type of diagnostic images of the central nervous system as well as images of the bone system. The solutions and applications presented here are of a research nature and show the directions in which modern IT systems as well as medical diagnostic support systems expand into the field of automatic, computer meaning interpretation of various patterns acquired in image diagnostics.

4.1 Introduction

Intelligent, cognitive information systems used to analyze varied, often extremely complex medical images have been developing extremely fast for many years as scientists and researchers try to answer the question how much the efficiency of this type of systems will allow humans to be replaced in making the final decision and whether this type of process is at all practicable. The whole class of computer systems designed for analyzing various types of images as well as the whole class of diagnostic support systems have overstepped their originally set functional limits which restricted the operation of such systems to visualizing and classifying patterns. At first it was thought that those systems would be used only for diagnostic jobs, so their operations

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would boil down to making simple statements without the practical possibility of verifying those. This type of IT systems were not sufficient for meaning interpretation jobs and for analyzing complex medical data, which would require imitating the thought processes of diagnosticians and taking steps towards understanding the semantics of the analyzed images. Consequently, within the broad class of IT systems, a subclass of systems was developed which were oriented towards jobs of analyzing various medical patterns, with the capability of conducting semantic reasoning based on the meaning information contained in the analyzed image. This is the UBIAS (Understanding Based Image Analysis Systems) class, the functional structure of which the authors have defined [11, 14].

DSS systems and UBIAS systems are currently very popular due to their wide diagnostic possibilities. In this paper we shall show an example of a system that was prepared not only to diagnose, but one that is also oriented towards the issues of cognitive analysis and the understanding pathological lesions taking place in the area of central nervous system. Particular attention is paid to disease lesions in the spinal cord.

Every medical image constituting a type of primary component for diagnostic IT systems is subject to analysis. The objective is to determine whether there is any important disease lesions observed in the patient's analyzed organ or whether there are no such changes (i.e. the patient is healthy). If there are any such lesions, their type is analyzed and the system directs its functions towards determining what disease the patient has. DSS systems operate on the basis of three main rules:

- Image transformation in order to obtain the best possible content quality and substance which the image carries,
- Image analysis in order to get the image properties in the form of a feature vector,
- Image recognition in order to classify all features of the analyzed image.

DSS systems proposed in earlier research were used, among others, for pancreas as well as for kidney and heart disease diagnosis. Their functioning is based on medical image recognition methods [10, 19] (Figure 4.1).

Due to the fact that DSS systems develop very rapidly, an attempt was made to construct a new class of such systems using in their operation the

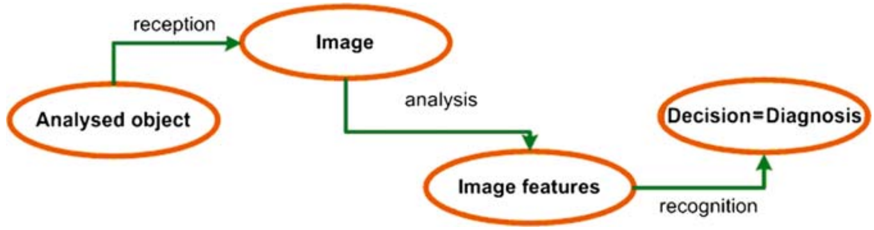

Fig. 4.1. Medical image recognition diagram

mechanisms of cognitive analysis (UBIAS systems). The said are to be directed at attempts to automatically understand the semantics of analyzed images, and therefore at their content meaning interpretation.

UBIAS cognitive information systems were thus developed on the basis of intelligent IT systems whose purpose was not just the simple analysis of data by storing, processing and interpreting it, but mainly an analysis based on understanding and reasoning of an about the semantic contents of the processed data. This is a significant extension of the capabilities of previous information systems.

Every information system which analyzes a selected image or information based on certain characteristic features of it contains in its database the knowledge indispensable for performing the correct analysis or reasoning, which forms the basis for generating the system's expectations of the analysis conducted. Combining the actual features of the analyzed image with the expectations of the semantic contents of the image generated based on the knowledge (about the pattern studied), brings about a phenomenon called the cognitive resonance. This phenomenon has been described more broadly in the publication [19, 24], but the notion behind it will also be presented in the next subsection.

UBIAS cognitive information systems are based on methods which lay down structural reasoning techniques to fit patterns [15,20,25]. Consequently, the structure of the image being analyzed is compared during the analysis process to the structure of the image representing such a pattern. The comparison is conducted using sequences of derivation rules which allow this pattern to be generated unanimously. These rules, sometimes called productions, are defined in a specially introduced grammar, which in turn defines a certain formal language or a so-called image language. The image (information) recognized in this way is assigned to the class which contains the pattern representing it. The analysis and reasoning process is conducted using the phenomenon of cognitive analysis, whose main element and also one of its foundations is the cognitive resonance phenomenon.

4.2 Using the Cognitive Analysis Method in the Medical Image Interpretation Process

Cognitive analysis is the main element of the correct operation of cognitive information systems designed for analyzing and drawing conclusions in the field of medical diagnostic systems.

Cognitive analysis used in IT systems is very often based on the syntactic approach [2, 7]. For the purpose of meaning image interpretation it first uses a pre-processing operation usually composed of:

- Image coding by means of terminal elements of the introduced language,
- Analyzed object shape approximation, as well as
- Filtration and pre-processing of the input image.

As a result of the execution of such stages it is possible to obtain a new image representation in the form of hierarchic semantic tree structures and subsequent production steps of this representation from the initial grammar symbol [6, 9]. An intelligent cognitive system distinguishing at the stage of pre-processing image data must, in the majority of cases, perform image segmentation, identify primitive components and determine spatial as well as semantic relations between them. An appropriate classification (also machine perception) is based on the recognition of whether a given representation of the actual image belongs to a class of images generated by languages defined by one of possible number of grammars. Such grammars can be considered to belong to sequential, tree and graph grammars while recognition with their application is made in the course of a syntactic analysis performed by the system [19].

In the most recent research on intelligent information systems it was observed that the recognition of an analyzed image alone is insufficient since more and more frequently there is a postulate to direct the intelligent information systems' possibilities so that they are able to perform the operation of automatically understanding image semantics. In order to enable such reasoning, the techniques of artificial intelligence are used. Apart from a simple recognition of an image they enable one that also extracts important semantic information allowing for a meaning interpretation, i.e. machine understanding.

This process relates only to cognitive information systems and it is a lot more complex than with pure recognition. This is due to the fact that in this case the flow of information goes clearly in two directions. In this model the stream of empirical data, as contained in the sub-system and aimed to register and analyze the image, interferes with the stream of generated expectations [10, 19] (Figure 4.2).

Between the stream expectation, generated for every hypothetical image and the data steam that is obtained by means of analysis of the currently considered image, there must be a special interference. As a result of this some coincidences (of expectations and features found on the image) gain on importance while others (both compliant and non compliant) lose their importance. This interference leads to a cognitive resonance, which confirms

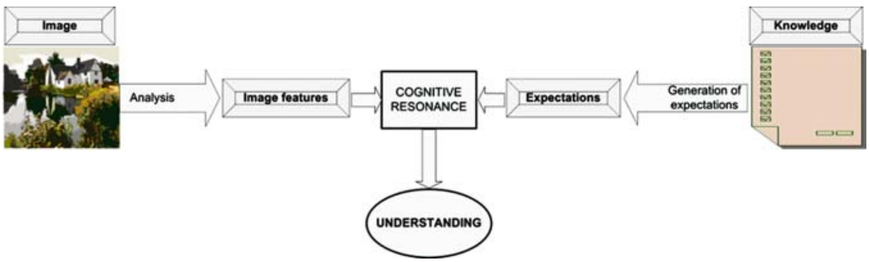

Fig. 4.2. Cognitive resonance in visual data analysis

one of certain possible hypotheses (in the case of an image whose content can be understood) or makes it possible to determine that there is a discordance, which cannot be removed, between the currently perceived image and all other gnostic hypotheses with an understandable interpretation. The second case stands for a failure of automatic image understanding.

Cognitive information systems function based on the cognitive resonance phenomenon which belongs only to these systems and differentiates them from other intelligent IT systems [8, 9, 24]. The application and use of such systems can be multiple due to wide possibilities offered to them by contemporary science. Nevertheless the greatest possibilities for the use of cognitive IT systems are currently offered by the medicine. This is due to the fact that there are more and more diseases in on-going pathological processes in individual organs and a growing number of detection cases as well as diagnosing these diseases. Medical images belong to some of the most varied data and they contain extremely deep and important (among others, for the patient's fate) meaning interpretation. Cognitive information systems could certainly also serve many other fields of science and everyday life, should an attempt be made to develop intelligent information systems in the field of economics, marketing, management, logistics, military affairs by adding the process of understanding the analyzed information or data.

Here it is worth noting another new class of systems developing very fast at present, which is used to analyze economic data. This class includes UBMSS (Understanding Based Managing Support Systems) which also use reasoning and cognitive resonance, but to analyze a specific type of data, namely that necessary to take strategic corporate decisions. The operation of UBMSS systems is presented in Figure 4.3, while the detailed description of the system presented is available in publications of [12, 23].

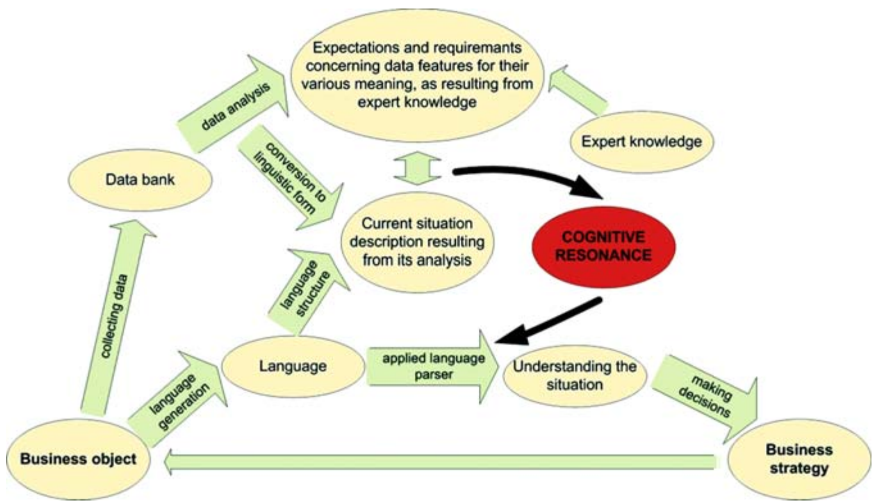

Fig. 4.3. Understanding Based Managing Support Systems

The idea of introducing UBMSS is based on the expansion of the already existing DSS (Decision Support Systems) in which the company must select the right economic strategy. A company, wanting to select the right economic strategy, collects a data pool of sufficient information to analyze the studied phenomenon. Simultaneously, it performs a number of operations aimed at selecting the right (from the IT point of view) language to describe the company's current situation. During data analysis the knowledge of experts generating certain expectations and requirements with regard to the studied phenomenon is included in the entire process. The characteristic features of the data described, which are yielded by the system, are confronted with the features produced by a panel of experts. This, as a consequence, leads to cognitive resonance which, as a result, leads to interference between the expectations generated by the system and the features produced for a given phenomenon. This interference, of course, aims to define important links between the features and the expectations, however, the entire process of analysis may yield irrelevant links. Cognitive resonance in the system leads to a stage of understanding the phenomenon, its causes, development and characteristic features. As a result, it becomes one of the most important stages in strategic decision-making for a given company. Cognitive analysis based on the process of cognition and understanding enables inference with regard to the future connected with the selection of the right economic strategy. Of course, such conclusions may be general and just indicate the weaknesses of the strategy implemented before as well as the benefits following another improved company strategy.

4.3 Artificial Intelligence Techniques in UBIAS Medical Systems

The information systems using cognitive data analysis, which are discussed in this chapter, vary due to the broad range of possible applications of individual techniques. Image-type data stored in information systems is nowadays broadly analyzed by signal processing aimed at improving the quality of data (e.g. images), their meaning analysis and classification.

The idea of introducing UBIAS is based on the expansion of the already existing DSS (Decision Support Systems) in which the pattern analysis tasks are transformed and expanded to the semantic description of the analyzed medical images leading to the understanding of such images. The human mind has incomparably greater perception capacities than a computer even with the best software so that it can reach such meanings appropriate for the observed objects or analyzed data infinitely better than a machine. Nevertheless also machine understanding techniques are slowly being improved and with time they could be used for the performance of a more complex reasoning process, one relating to the significance of data collected rather than just for their simple analysis. In order to enable IT systems such semantic reasoning based on data, advanced IT techniques are used. These techniques, apart from simple information analysis and possible classification (recognition) of data destined for analysis, make it possible also to extract important semantic information from them, ones that point to meaning interpretation. At the current stage of development, data semantic analysis is always set in some pre-determined context. It is impossible for a computer to discover simultaneously the analysis objective and its result. This means that systems currently built can undertake an attempt at understanding data with some a priori pre-definition of what the understanding is supposed to serve. This must be differentiated from a situation in which a human being, coming across a new situation analyzes it in many respects; the outcome of the analysis could be completely unexpected conclusions standing for a complete mental consideration of a given situation, i.e. its complete understanding. Referring to a frequently quoted example of semantic analysis of some specified medical images one can expect that the computer, after an analysis of X-ray image will 'understand' that the patient suffers from some kind of disease. This would not be achievable applying only the technique of automatic image recognition. On the other hand, a human being looking at the same image can, of course, do the same by diagnosing (the diagnosis being the same as the computer would have made or a different one). However, only a man can understand something totally unexpected, for example that an image is bad in quality because the X-ray machine was out of focus and that the examination must be repeated. The first type of understanding is well set in the context of medical examination. It is therefore available both for a medical doctor and for an appropriately programmed computer. The latter requires going outside the framework of an a priori defined scenario and for the time being it is available only for humans.

The main objective of the considerations presented in this paper is to focus the Reader's attention only at the first, easier way of interpreting data understanding process (for example, of images). Still even this process is a lot more complex than just data analysis and their possible recognition. Information flow in the second case is clearly two-sourced and two-directional (just like in the cognitive understanding process model, as taking place during eye perception). In the model considered here, the empirical data stream is collected and stored in a sub-system whose objective is to register and analyze the data the which the analyzed IT stores and processes in accordance with its destination; this interferes with a stream of automatically generated expectations concerning some selected features and data properties. The source of this expectation stream is the knowledge resources located in the system. It is a basis for the generation of semantic hypothesis while the knowledge source are people (experts), from whom the knowledge was obtained and adjusted appropriately for being used in automatic reasoning process.

The terms and conceptual basis of the above-defined approach is a new knowledge field, the so-called cognitive analysis. Currently it is better known in the context of psychological scientists' analyzes examining human cognitive processes. It is also known in the context of hypotheses about the nature of reason and rationality, as examined by philosophers dealing with the epistemology, gnoseology and semiotics foundations as well as criteriology by D. J. Mercier and other advanced intellectual trends. To a smaller degree, however, was it so far used in science itself [1, 10].

4.4 UBIAS System Model for Cognitive CNS Image Analysis

In this section we shall propose, as an example of intelligent IT system, a medical model of IT system supporting diagnosing. The selected system conducts intelligent analysis of image data relating to pathological lesions in the central nervous system, related both to selected disease units of the spinal cord [3, 4, 11]. This model will be based on the construction and the operating rule of UBIAS systems. Due to the fact that the issue of occurrence of disease units in the spinal cord is extremely extensive, some selected pathological phenomena, representative of central nervous system disease types will be presented.

The main element of a correctly functioning IT system supporting the medical image diagnostics is, in accordance with the concept presented in this paper, analysis preparation of a cognitive method of disease units and pathological lesions as occurring in the spinal cord. The cognitive analysis contained in the DSS-CNS system is aimed to propose an automatic correct interpretation method of these extremely complicated medical images, ones resulting from imaging parts of the nervous system. Such images are difficult to interpret due to the fact that various patients have various morphologies of the imaged organs. This is true both of the correct state and if there are any disease lesions. The nervous system, similarly as most elements of the human body, is not always correctly built and fully developed from the birth. The anatomy and pathomorphology differentiate between a number of developmental defects of the central nervous system. It often occurs that this system for the first couple of years functions correctly and only after some time there are some troubles with its functioning, demonstrated by the child's behaviour and feeling: seen either as a single symptom or as a widespread disease. All kinds of troubles occurring in the central nervous system, identified with disease units of the spinal cord are clinically diagnosed and subject to diagnostic procedure based mainly on image diagnostics. Due to small differentiation in the absorption of X-rays by the distinguished medical structures of the brain (for example, by the while and grey substance) as well as due to the fact that the whole central nervous system is hidden behind bones (of the scull and backbone) which strongly attenuate X-rays, the main role in image examinations of the central nervous system is customary assigned to NMR topography (Nuclear Magnetic Resonance) labelled also zeugmatography or most frequently the MRI method (Magnetic Resonance Imaging) – imaging based on the nuclear magnetic resonance phenomenon.

Magnetic resonance makes it possible to obtain maps of density distribution (the so-called topography) primarily of hydrogen atom nuclei (protons) and of these protons' relaxation time. Owing to the application of a projection corresponding to the tomography technique (computational reconstruction of the examined parameter distribution based on many multidirectional probing) the NMR image can be obtained on any cross-section of the body. Hydrogen is a constituent of water making up 60–70% of living organisms; it is also a constituent of all organic compounds. It is worth remembering that fats have an extremely high amount of hydrogen. Information obtained about its distribution inside the organism is the basis for image construction: the images differentiate tissues with regards to the degree of their hydration or fat content. Proton density and their relaxation times can be mirrored by brightness (i.e. greyness degree) of points on the given map. The method of magnetic resonance offers a lot more contrasting soft tissue images then X-ray images. In the case of many diseases it can also show more precisely the difference between a healthy tissue and one that was changed by disease.

All the analyzed images of spinal cord were, before their proper recognition, subject to segmentation and filtration procedures. Their aim was to extract from among other image elements important elements of the spinal cord [4, 10, 18]. Structures shown in this way were then subject to cognitive analysis stages using the grammar described below. In order to analyze disease lesions of the spinal cord, the following attributed grammar has been proposed – figure 4.4.

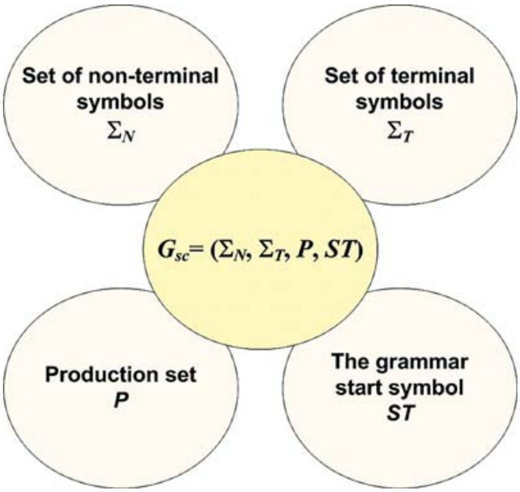

Fig. 4.4. Attributed grammar G_{SC} for spinal cord lesions analysis

The following definitions have been adopted for individual sets defined in G_{SC} sequence grammar:

$$\Sigma_N = \{SPINE\_LESION, SPINAL\_STENOSIS,$$
$$SPINAL\_DILATATION, SPINAL\_TUMOR, N, D, S\},$$
$$\Sigma_T = \{n, d, s\}$$

Apart from these, the following meaning was given to terminal elements present in the description: $n \in [-11°, 11°]$, $d \in (11°, 180°)$, $s \in (-180°, -11°)$,

$$ST = SPINE\_LESION$$

The production set P has been presented in fig. 4.5 where grammar rules and semantic actions have been defined for individual pathological changes.

The proposed grammar makes it possible to detect various kinds of spinal cord or meningeal stenoses characteristic for neoplastic lesions and inflammatory processes of the spinal cord. Figure 4.6a presents an image of the spinal cord with a visible deformation; figure 4.6b shows the spinal cord image after binarising while figure 4.6c depicts the diagram of the spinal cord. The red area represents the area of occurrence of the anomalies within the structure of the spinal cord. The set of yellow chords, cross-cutting the spinal cord in subsequent points perpendicularly to its axis, as shown on figure 4.6c which demonstrates how the width diagram was made.

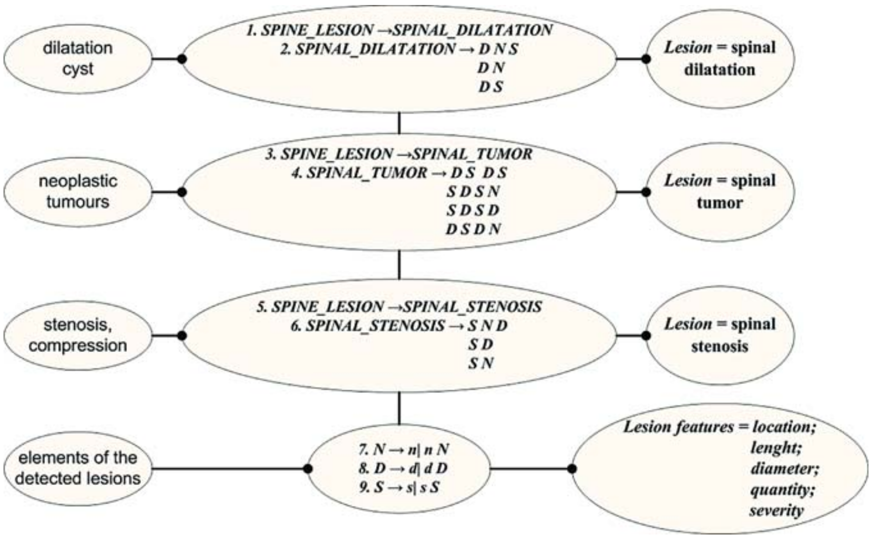

Fig. 4.5. The production set defining changes in the G_{SC} grammar

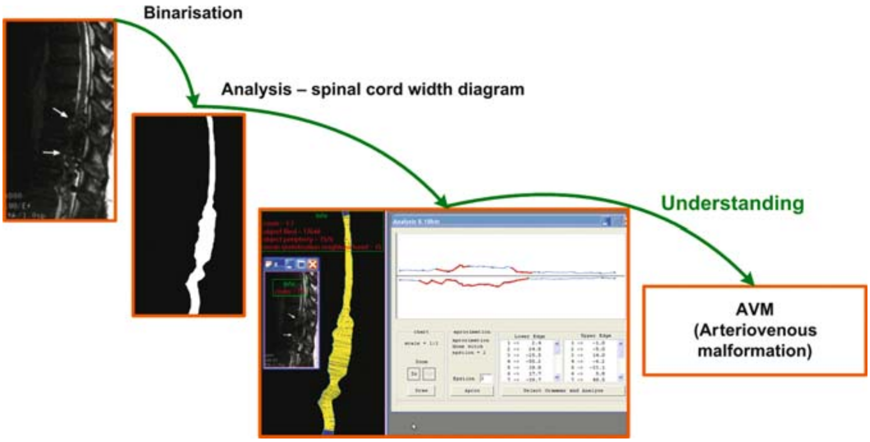

Fig. 4.6. Spinal cord: deformed, after binarising, spinal cord width diagram

Spinal cord width diagram (Figure 4.6) presents, in the most concise form, the results of spinal cord morphology analysis. It is the most precious source of information when one is looking for pathological lesions and it contains all-important data about the examined fragment of central nervous system. At the same time it ignores all spinal cord image details unimportant from the diagnostic point of view, as presented on figure 4.6.

To give an example, the spinal cord MR image, as presented above in figure 4.6 will be subject to (on Figure 4.7a) a diagnostic description of pathological lesions detected in the spinal cord. Image 4.7a presents an example of results obtained by the author in the course of examinations for a given disease case. The results presented here have been achieved by the application of attribute grammar and they are an example of the cognitive approach to the medical data considered here. The type of lesion detected here has been assigned based on its location and on morphometric parameters determined by the grammar semantic procedures.

Figure 4.7b shows an example diagnosis and a description of the lesion obtained by cognitive analysis and semantic reasoning which detects and describes the paraganglioma. This description, just as the description shown in Figure 4.7a, was generated using cognitive analysis applied in a UBIAS system.

The examples above (and many others, obtained as a result of research [13–17]) present the results of semantic meaning interpretation of the analyzed and detected pathological lesions occurring in the spinal cord.

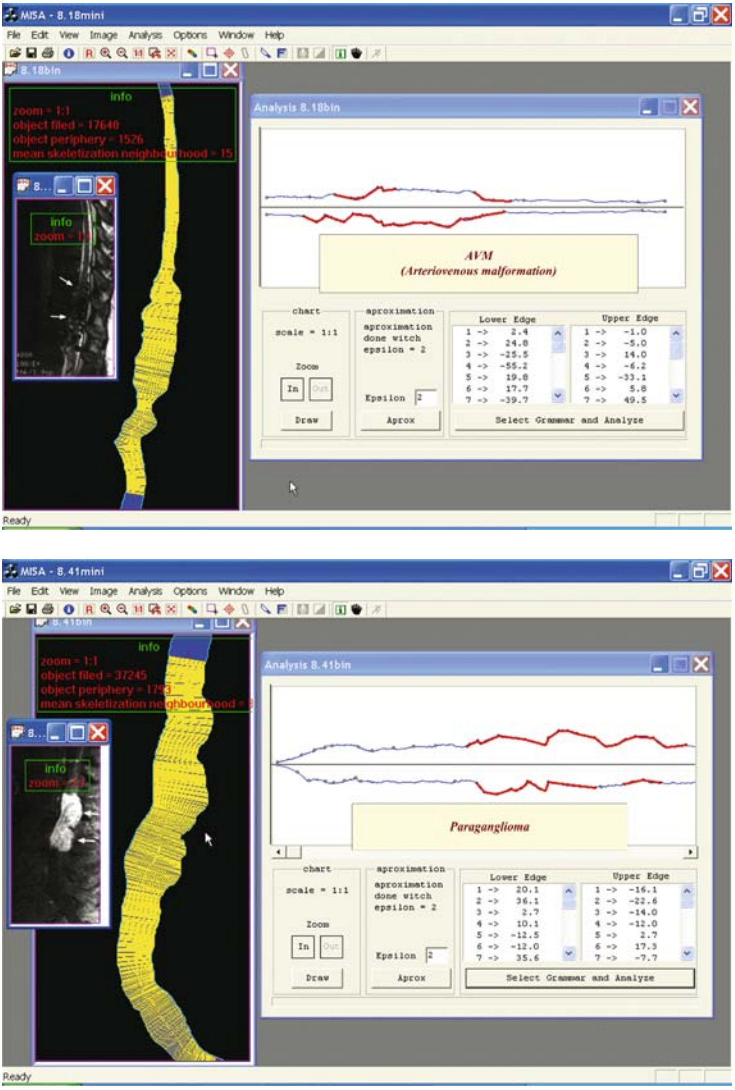

Fig. 4.7. Diagnostic descriptions of spinal cord lesions **A**) Spinal cord lesions with AVM syndrome detected as a result of cognitive analysis, **B**) Spinal cord with paraganglioma detected by the system

4.5 Cognitive Analysis Effectiveness in UBIAS Systems

In order to perform meaning analysis on spinal cord images with the use of a linguistic mechanism as described in this paper, the MISA (Medical Image Syntax Analyzer) computer system has been developed. This enables the analysis and classification of spinal cord images analyzed in this paper.

Table 4.1. The efficiency of cognitive analysis methods directed towards discovering and understanding selected disease phenomena in the central nervous system

Lesion	Number of images	Recognised images	Efficiency [%]
Spinal cord dilation	2	2	100
Cysts	18	17	94
Neoplastic tumours	27	25	93
Stenoses and compression	14	12	86
Degeneration	23	20	87
Total	84	76	**90,5**

The application efficiency of cognitive analysis procedures, using this system, has been presented in a table and it is directed towards comparing the results obtained from the use of this system with those that one can consider as a correct diagnosis (table 4.1).

These results are obtained as a result of the application of semantic analysis algorithms conducted in reasoning modules of the proposed system and based on semantic actions assigned to structural rules. The proposed approach exhibits significant scientific novelty features and is applied in diagnostic analysis using DSS medical information systems and UBIAS systems.

The research conducted by the authors, based on the analysis of images with pathological lesions in a part of the central nervous system, the spinal cord, have demonstrated that cognitive data analysis can be a factor that significantly enriches the possibilities of contemporary information systems. In particular, the described research has demonstrated that an appropriately built image grammar enables the conduct of precise analysis and the description of medical images from which important semantic information can be gained on the nature of processes and pathological lesions as found in the patient's spinal cord. It is worth emphasizing that the results described in this paper have been obtained following the cognitive process, simulating an experts' method of thinking: if one observes a deformation of the organ shown by the medical image used, then one tries to understand the pathological process that was the reason for the appearance of deformations found. One does not perform a mechanic classification for the purpose of pointing out more similar samples on the pathological image. Moreover, the research conducted has demonstrated that for cognitive analysis attempts (on the central nervous system) it is possible to apply it on sequential grammar-based linguistics.

4.6 An Example Application of Cognitive Analysis to Problems of Interpreting Long Bone Fractures

Another example of application of structural formalism for semantic categorization of medical images is lesion analysis in case of leg bones abnormalities or injuries interpretation. Such analysis is possible both for arm and leg bones, but further will be presented example of interpretation of various types (shapes) of leg bones fracture, and stages of theirs recovery. For detection of the most common leg bone fractures the following attributed grammar has been proposed (figure 4.8):

where:

VN = {RESULT, FRACTURE, FISSURE, TRANSVERSE, SPIRAL, ABHESION, DELAYED_UNION, DISPLACED_M1, DISPLACED_M2, DISPLACED1, DISPLACED2, LONGITUDINAL, A, B, C, D, E, F, G, H}

VT = {'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h'} where symbols defined as follows: a $\in [-10°, 10°]$, b $\in (10°, 70°]$, c $\in (70°, 110°]$, d $\in (110°, 170°]$, e $\in (170°, -170°)$, f $\in (-110°, -170°]$, g $\in (-70°, -110°]$, h $\in (-10°, -70°]$.

STS = RESULT. A production set SP is presented in Table 4.2.

The proposed grammar is designed not just for simple image analysis, but also becomes the starting point for conducting a semantic reasoning about the analyzed fractures. The examples of bone fractures described by the authors have been subjected to a descriptive analysis leading to making a medical diagnosis, but an attempt has also been made to reason out the substantive and semantic content of the analyzed image presenting a long bone fracture. An example result of bone fracture detection and analysis is presented in fig. 4.9.

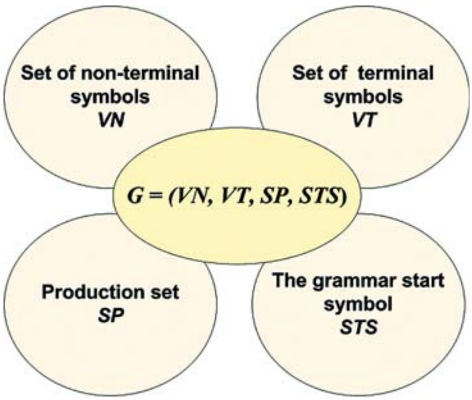

Fig. 4.8. Attributed grammar for leg bones fracture analysis

Table 4.2. Set of grammar rules defining types of fractures

Lesion	Grammar rules
Fissure fracture	RESULT → FRACTURE → A FISSURE A
	FISSURE → H B | H A B
Transverse fracture	RESULT → FRACTURE → A H E | A TRANSVERSE E | A G F E | A TRANSVERSE H E
	TRANSVERSE → H G | H F
Spiral fracture	RESULT → FRACTURE → A SPIRAL A
	SPIRAL → ABHESION F | ABHESION G F | ABHESION F E | ABHESION F G | H F | G F | F G | F H | F
	ABHESION → B A H | B H
Displaced fracture	RESULT → FRACTURE → DISPLACED_M1 F | DISPLACED1 F | DISPLACED_M2 D | DISPLACED2 D
	DISPLACED_M1 → B A | B G | B H
	DISPLACED_M2 → H G | H F | H E
	DISPLACED1 → B A H G | B A H | B A G | B A G H
	DISPLACED2 → H G F E | H G E
Delayed union fracture	RESULT → FRACTURE → A DELAYED_UNION A
	DELAYED_UNION → ABHESION ABHESION | ABHESION A ABHESION | ABHESION G ABHESION | ABHESION C ABHESION | ABHESION G A ABHESION | ABHESION G C ABHESION | ABHESION G A C ABHESION | ABHESION A C ABHESION | ABHESION B C ABHESION
	ABHESION → B A H | B H
Longitudinal fracture	RESULT →FRACTURE → A LONGITUDINAL E
	LONGITUDINAL → TRANSVERSE TRANSVERSE | TRANSVERSE E TRANSVERSE | TRANSVERSE E H | H E TRANSVERSE | H E H
Adhesion	RESULT → FRACTURE → A ABHESIONE
	ABHESION → B A H | B H
Elements of the detected lesions	A → ‘a’ A | ‘a’ B → ‘b’ B | ‘b’ C → ‘c’ C | ‘c’ D → ‘d’ D | ‘d’ E → ‘e’ E | ‘e’ F → ‘f’ F | ‘f’ G → ‘g’ G | ‘g’ H → ‘h’ H | ‘h’

Figure 4.9a presents a limb fracture after a certain time of union, together with the periosteum growing around it. The UBIAS system has recognised this lesion as a bone fracture at the phase of hard bone matter growth. The fracture is visible in the image, but the analyzed area is partially filled with periosteum. Figure 4.9b presents the bone fracture with the spiral fracture automatically detected by the UBIAS system.

The UBIAS systems presented here, designed for analyzing images of lower and upper limb fractures, serve to analyze various types of fractures, including spiral, longitudinal, displaced ones, factures at the phase of bone reconstruction and at the phase of hard bone matter growth. The jobs of analyzing the lesions and pathologies in the field of long bone fractures make use of cognitive

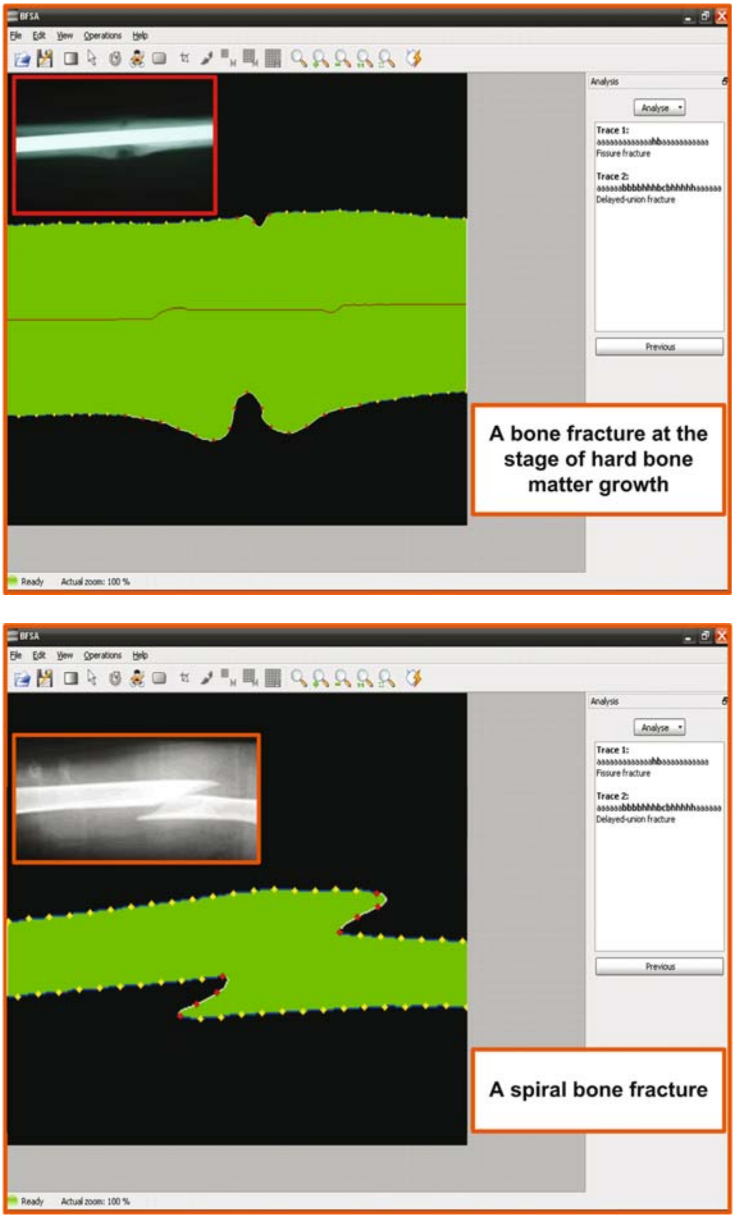

Fig. 4.9. Bone fracture analysis **A)** A description of a bone fracture; the marked fragment shows the bone fracture at the phase of hard bone matter growth detected by the system, **B)** Description of spiral fracture

analysis on the basis of which the system for cognitive analysis and interpretation of image-type data conducts reasoning and analysis using semantic information contained in the image under consideration.

4.7 Conclusions

The authors have illustrated the methodology of cognitive analysis presented in the publication as a tool supporting the development of new generation IT systems mainly with examples of problems of image analysis, particularly of medical images. Cognitive analysis applied in the context, presented here, of interpreting the meaning of selected types of medical images allows a new class of intelligent information systems to be developed, including the UBIAS class of systems described in this publication.

The cognitive analysis methods proposed here for pathological phenomena shown in medical images are a double achievement. Firstly, if we treat them literally and consider them only in the context of their utilitarian purpose, they are a successful attempt at developing medical information systems and systems helping to diagnose selected disease entities. Within this scope, the publication offers new results which can be considered and assessed with regards to their practical utility. However, a much more important objective of the authors was to show the capabilities offered by cognitive analysis treated as a tool for obtaining valuable knowledge components (and not just data) from modern information systems. By developing a system for the automatic understanding of medical images, it has been empirically proven that modern artificial intelligence methods make it possible to cross the barrier between the form of data collected in the information system and its substantive content necessary to understand its meaning. Obviously, the cognitive analysis of a different type of data (e.g. those needed by a UBMSS-class system presented in Chapter 4.2 for managing a corporation) will require a different type of preprocessing of this data, other procedures for its analysis and other languages in which this data will be described and which will later make it possible to extract itssubstantive sense. So using the results from this publication in a broader context requires solving many difficult specific problems.

Cognitive analysis methods proposed by the authors of this publication to develop cognitive information systems may represent an additional, precise tool very useful for many other purposes. It is worth noting the support for the early diagnosis of irregularities of the central nervous system in the medicine of developmental defects of children. The application of these systems in PACS (Picture Archiving and Communication Systems) is also worth considering.

The very high computational efficiency of the algorithms developed as part of this project for the semantic interpretation of images (which algorithms are of a multinomial complexity) makes the proposed cognitive analysis methods exceptionally useful in practice. It could be said that as a side effect of the scientific research, this publication offers medical practice a practical tool for extracting, recognising and understanding the diagnostic features of the analyzed medical image.

The semantic information on the disease factor extracted during the syntactic reasoning is mainly used to formulate the correct diagnosis, but it may also have further uses. In particular, it could be used to:

- follow the progress of the therapeutic process, including the definition of its direction and type;
- forecast the disease progress and the future condition of the patient;
- construct a description which indexes image data in a specialised medical database;
- streamline the processes of context-sensitive searching for semantic image information by a process of automatic formulation of queries to the system of multimedia database indexing.

The UBIAS systems presented here, which represent cognitive systems for the intelligent analysis and semantic reasoning on the basis of analyzed data, are applied not only in the broad and in-depth analysis of medical images, but are also quite successfully used for interpreting economic problems. These jobs are performed by another sub-class of DSS systems called UBMSS.

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