Computer Science Journal of Moldova, vol.17, no.3(51), 2009

CASAD – Computer-Aided Sonography of Abdominal Diseases – the concept of joint technique impact

T. Deserno, L. Burtseva, Iu. Secrieru, O. Popcova

Abstract

Ultrasound image is the primary (input) information for every ultrasonic examination. Since being used in ultrasound images analysis the both knowledge-base decision support and content-based image retrieval techniques have their own restrictions, the combination of these techniques looks promissory for covering the restrictions of one by advances of another. In this work we have focused on implementation of the proposed combination in the frame of CASAD (Computer-Aided Sonography of Abdominal Diseases) system for supplying the ultrasound examiner with a diagnostic-assistant tool based on a data warehouse of standard referenced images. This warehouse serves:

i to manifest the diagnosis when the ecographist specifies the pathology and then looks through corresponding images to verify his opinion;

ii to suggest a second opinion by automatic analysis of the annotation of relevant images that were assessed from the repository using content-based image retrieval.

Keywords: warehouse, medical diagnostic, ultrasound, images classification, decision support system

1 Introduction

At the moment and in the near future too, using of image will remain a basic method of research on objects representation and estimation of information in decision-making in scientific research, medicine, physics, etc. The graphical representation is widely used in various diagnostic areas, including domain of medical diagnostics.

Ultrasound examination of patients, thanks to its non-invasive effect, is a basic technique of modern imaging. However, image collections in the ultrasound domain are isolated, incomplete and non-standardized. Besides this, the volume of information is in a continuous growth because new methods of patients examination appear. In particular, development of new transducers or improvement of old scanners doesnt simplify, but complicates the physicians diagnostic thinking, because he has to analyze a much larger number of diagnostic data, which typically reduces the accuracy and increases the time of diagnosis determination.

To increase the efficiency of decision making processes, based on large volume of information in this area, it is necessary to automize the storage, analysis and identification of imaging processes developing appropriate information technologies. For this purpose, we need to research methods and algorithms for effective storage, selection, analysis and estimation of results for ultrasound examination. The development of data warehouse of standard referenced images will facilitate the work of physician-ecographist in decision making [1].

The process of data warehouse development, without considering the particularities of the problem domain, can lead to various difficulties and inconveniences. The structural mismatching of input and output information as well as discrepancy between the users interface of medical system and the doctors diagnostic thinking may become the reason of different mistakes and may lead to rejection by the user to utilize such system in his medical practice.

Ultrasound image is the primary (input) information for every ultrasonic examination. The main characteristic of these images is two-layer structure of the information contained in it. The first layer is the image itself (graphical features), and the second layer is its textual description in medical terms (medical features).

Most often, to build a medical data warehouse based on image characteristics, the developers use content-based image retrieval (CBIR) methods [reference]. This approach consists of searching the image in a database, using information derived directly from its graphical content. The user annotates a region of interest (ROI) or a texture pattern on the image to obtain similar images from the image database. In the study of Datta et al., systematized methods were applied in several CBIR systems, which are designed for searching images with medical content [2].

To create a medical data warehouse that is based on textual descriptors of images, a formalization of the application domain is required, and its hierarchical structure (ontology) must be identified. The process of formalization includes identification of basic concepts and relationships between them.

Then, these selected concepts are used to describe medical images and ontology, which define the structure of data warehouse.

Obviously, the data warehouse in ultrasound investigation domain should contain a processing technology for both information layers of ultrasound images. In addition, the basic requirement for any medical system is its correspondence to the daily work and to the habits of the end-user. In ultrasound, the investigation domain predominates the case-based (precedent-based) reasoning. It is understandable, because this kind of reasoning is a pervasive behavior in everyday human problem solving.

The case-based reasoning is a four-step process [3]. In ultrasound investigation domain, the case (precedent) consists of: (i) the ultrasound image, (ii) its textual description in medical terms (annotation), (iii) a case solution, i.e. the diagnosis, and (iv) information about how the ultrasound image was obtained and the diagnosis was derived. This yields the following processing steps:

- Step 1 – Given a target ultrasound image, retrieve cases from memory that are relevant to solving it.

- Step 2 – Map the solution from the obtained case to the target ultrasound image. This involves adapting the solution as it is necessary to fit the new situation.

- Step 3 – Having mapped the obtained solution to the target situation, test the new solution and, if necessary, revise it (return to Step 2).
- Step 4 – After the solution has been successfully adapted to the target ultrasound image, store the resulting experience as a new case in memory.

Obviously, to avoid the discrepancy between the user's interface and the data warehouse with the form of the doctor's diagnostic reasoning, it is necessary that the process of adding new image(s) to the data warehouse should consist of the same four steps.

This article describes the concept of data warehouse establishment in the ultrasound investigation domain, merging case-based reasoning with knowledge-based and content-based image retrieval to form a system for Computer-Aided Sonography of Abdominal Diseases (CASAD).

2 Sonography of abdominal diseases

Ultrasound scanning is a wide used diagnostic technique, because of its non-invasive nature and possibility to visualize organs anatomy in real time. Another important advantage is that it is much cheaper than other imaging methods of diagnostics like MRI, CT, etc. Ultrasound helps in effective patient examination, especially in determination of processes of the internal organs of abdomen [4] – liver, gallbladder, spleen, pancreas, and kidneys – showing such pathologic states as cysts, abscesses, local infections, tumors, fibrosis, foreign bodies, and accumulations of fluid.

In many cases, abnormal state of an abdominal organ can be influenced by pathology of another organ, situated nearby. So, it is very important to investigate several abdominal organs simultaneously to clarify the clinical picture and to make accurately a definite diagnosis.

However, there are some important problems in ultrasound imaging. The skill of effective scanning lies in the operators ability to maximize the diagnostic information available and in being able to interpret the appearances properly [5]. So, the first problem is to obtain a good image, the most useful and relevant, that can be resolved by following general operating indications, specific for every particular organ, avoiding the pitfalls of scanning. The second and probably more important one is to interpret the resulting ultrasound images. This task is not easy to realize, because ultrasound images are noisy, blurred in shape, and suffer from echoes, etc. So, ultrasound diagnostics, based on interpretation of ultrasound images, widely depends on the physicians experience.

3 Decision making in sonography

3.1 Knowledge-based decision support

The conceptual description of knowledge-based decision support system (KB-DSS) was proposed in 1985 by Klein and Dusartre [6]. During the concept further development, the formal definition was proposed: a KB-DSS is a computer information system that provides information and methodological knowledge (domain knowledge and decision methodology knowledge) by means of analytical decision models and access to data base and knowledge base to support a decision maker in making decisions in complex and ill structured tasks. The idea was to combine the two frameworks and use knowledge-based technology to improve the decision support process [7].

For the deterministic reasoning that is a key type of decision-making process, DSS typically uses a decision rule. The knowledge-based technology can encapsulate both the flow of logic employed in deterministic reasoning and a representation of knowledge in a particular domain to make a decision [8]. When knowledge has been formalized under the form of rules and observed facts, the system can logically derive the conclusion from this knowledge stored, for example, in the knowledge base [9].

The rule induction algorithms are widely applied to extract general rules from a set of observed data. Decision trees are one of the most effective techniques for rule induction in classification problems because they easily lead to discrimination rules, which are well understood without a relevant loss in accuracy with respect to alternative classification approaches, such as neural networks or statistical discriminant analysis [10].

CASAD will use a knowledge base that has been created for the SONARES decision support system [11]. The knowledge pyramid for ultrasound investigation process of gallbladder, obtained during knowledge structurization and formalization stages, contains 335 nodes and 54 rules for logical inference procedure [12]. The following features are formalized:

- Information about the gallbladder localization (including the visualization methodology of the typical zone, the objective visualization conditions in the typical zone, the objective conditions of a non-reliable or difficult visualization in the typical zone, the reasons of possible non-visualization in this zone);
- Information about the pathological states of the gallbladder (acute gallbladder, compressed gallbladder, sclerotic gallbladder etc.);
- Main characteristics of the organ description (number, size/volume, form, tonicity, contour etc.);
- Information about the gallbladders anomalies and pathologies, each anomaly/pathology being determined by the main organs characteristics modifications (size anomalies, number anomalies, form anomalies etc.).

3.2 Content-based image retrieval

Starting with IBMs Query by Image Content (QBIC) approach [13], [14], content-based image retrieval (CBIR) has become an intensive field of research. Large repositories of images are represented by a small number of features, so called signature or feature vector, and during the retrieval, the features of the query image are extracted and compared to the pre-computed signatures of the archived images, using an appropriate distance measure. The signatures are usually designed to represent color, texture and shape of objects [15].

Since color has been shown to be the most distinguishable feature type, medical images have been excluded from CBIR for a long time. Automatic image annotation and data mining approaches have been established in biomedical imaging using CBIR techniques [16], [17], and nowadays, medical application of CBIR systems are developed and applied in routine [18]. The Image Retrieval in Medical Application (IRMA, `http://irma-project.org`) project is one of the rather general frameworks for medical CBIR [19], [20]. The IRMA system server components are presented in Fig.1 ([19]):

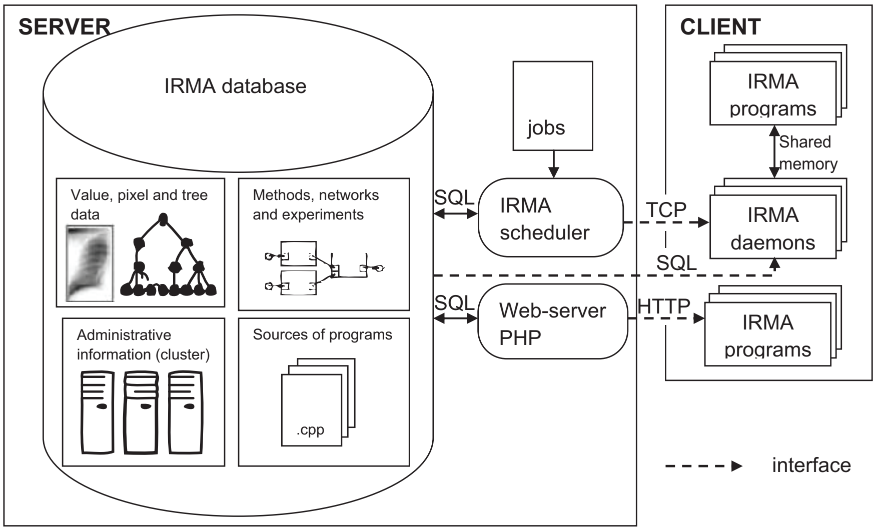

Figure 1. IRMA server components

- The database that holds images, features, and methods for feature transforms;

- The scheduler that provides tasks for computation to the computers within the cluster;

- The web server that provides an HTTP interface for application-specific user interfaces.

All IRMA graphical user interfaces (GUI) are built from the same Smarty Templates (`http://www.smarty.net`) and provide extended query refinement and relevance feedback using a complete history logging mechanism that again is connected to the IRMA database [21].

4 The CASAD approach

4.1 CASAD system architecture

The scheme of CASAD system architecture is presented in Fig.2. The detailed descriptions of modules and data flows of this scheme are given below in subsections of this section.

4.1.1 Functions and modules

The CASAD as data warehouse supposes two main functions:

1. To add new image to warehouse;

2. To retrieve images similar to the pattern image uploaded by user.

The meaning of both of these functions is image classification. In the case of new image adding function, classified image is added to warehouse. In the case of the system, output is the set of images belonging to the same class that the pattern image was classified.

From the implementation point of view the CASAD modules set is the following:

- Module of CASAD web-interface implementation;

- Module for ROI setting;

- Module of knowledge-based image classification;

- Module of knowledge-based image classification;

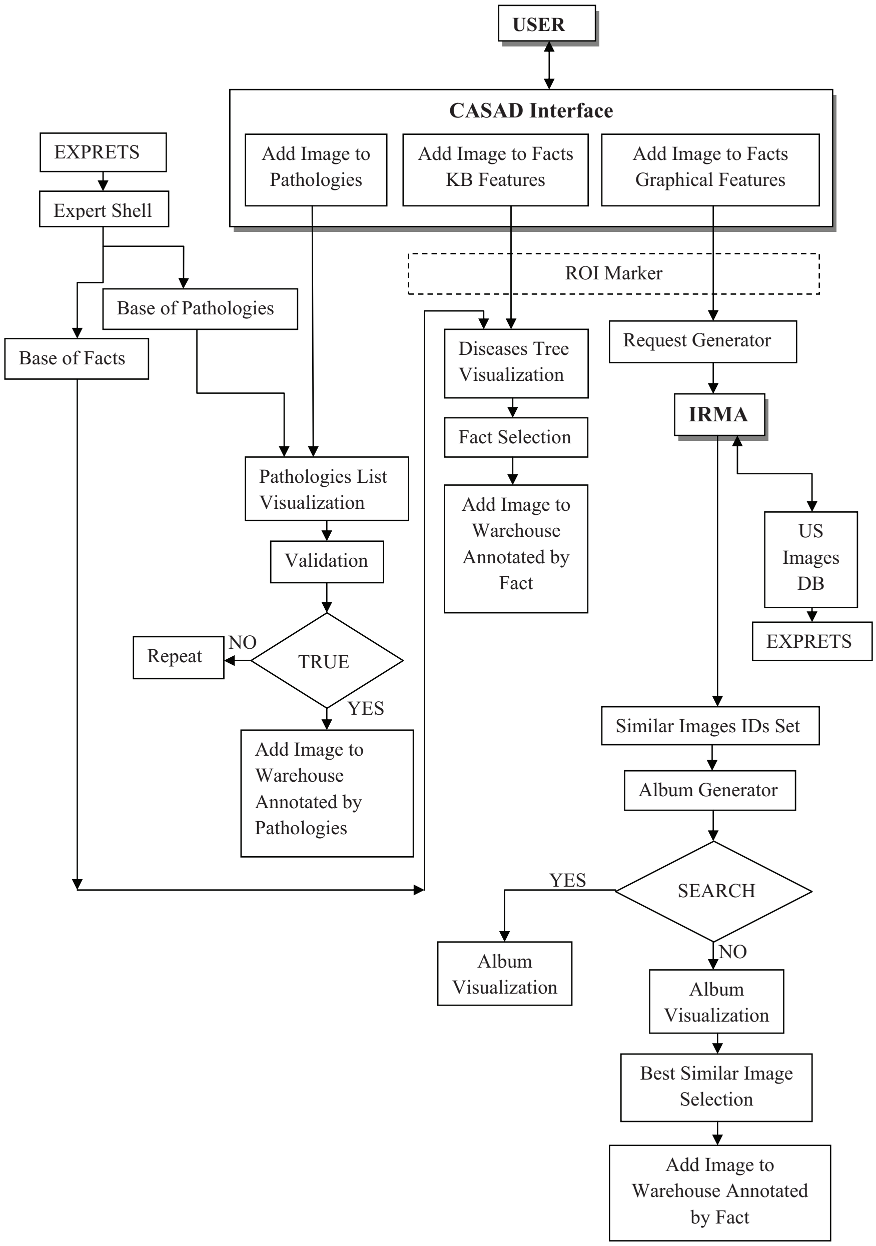

Figure 2. CASAD system architecture

- Module for database maintenance;
- Module of conversion of users input to data exchange XML file;
- Module of IRMA querying;
- Module for IRMA answer processing (translation table).

4.1.2 Input and output

The general input of CASAD system consists of the image bitmap and the code of function that has to be executed. The general output exists only for similar images retrieving function. This is the set of images from CASAD database together with their annotations.

Intermediate input/output between CASAD and IRMA systems is XML-file transmitted by HTTP protocol. The details of used XML extension will be described in due subsection further.

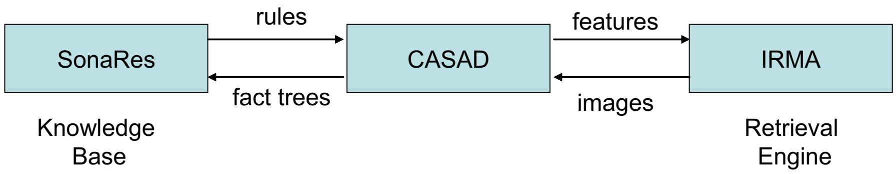

Figure 3. Scheme of interactions

4.2 Interfaces and Protocols

On application level of CASAD system contains pages of the web-interface and protocols of data exchange.

4.2.1 Users interface of CASAD

The implementation of both of CASAD main functions includes the use of the CBIR features of IRMA system. In this scheme of the functionality CASAD system works as server and IRMA is a client. This means that from the users point of view CASAD interface is a front-end. Both systems keep the images database, the rules of logical inference are kept by CASAD, the algorithms of CBIR are saved by IRMA. To provide due functionality CASAD web-application interface has two types of gates.

The interface gate for adding new image to warehouse also allows two start pages depending on the way the image supposed to be classified.

1. For classification according the pathology, the interface shows the pathologies list. After the particular pathology is selected the interface presents the set of questions answering which the user confirms that the image describes the selected pathology. Since the confirmation was made, the image is added to warehouse with respective annotation. In this case whole image is considered as the ROI.

2. For classification according to the rules tree, the interface has to present this tree, but the classification process is simpler. It consists only in selection of the fact at the tree and confirmation of the association.

In both cases user has the possibility to obtain classification help by CBIR using. The respective interface element will start the addressing to IRMA. After graphical features analysis is provided, the list of supposed pathologies (or facts) is presented to user for choice.

The interface gate for retrieving the images similar to the pattern image uploaded by user joints two blocks of elements for query building and start point for retrieval based only on graphical features. The query building elements represent the list of pathologies or facts and the options for joining like logical AND and OR.

The web interface modules are implemented by combination of PHP and JSP scripts.

4.2.2 Protocol of data transaction

The using of CBIR functionality of IRMA in CASAD classification process requires well structured and standardized format for

CASAD/IRMA data exchange. The XML format satisfies all requirements and has the convenient set of processing tools in every web-services framework. Basing on this we prefer the XML file as exchange data means. The corresponding DTD file has to be used for both CASAD/IRMA and IRMA/CASAD exchange directions.

Both CASAD and IRMA have the set of interface services for input and output of queries data. CASAD addresses to IRMA with information about image uploaded by user and retrieval algorithm ID. Information about image is tagged in XML file by: a) its URL on CASAD server, b) coordinates of the center of ROI, c) the ROI size (IRMA uses the squared ROI). IRMA input processing service obtains the image by its URL on CASAD server, uploads it and starts the retrieving procedure.

IRMA sends as the answer the list of images matched with the given conditions. Every image is tagged in XML file by its IRMA ID and similarity score. IRMA output also provides the information about the similarity score.

CASAD input processing service uses the translation table to find images IDs corresponding to IDs from results of IRMA XML answer. Then CASAD generates the web-page with matched images using their IDs and URLs on CASAD server.

The images in CASAD database are anonymized. There is also anonymization procedure for users uploaded image. Thus there should not be problems with private data keeping. The handshaking modules are implemented as Java servlets.

4.3 Image and case data

In the first attempt, a collection of 57 cases of gallbladder polyps has been collected from the Excellence Medical Center from Chisinau, Republic of Moldova. Ground truth was provided by physicians roughly indicating the position of the polyp shown in the ultrasound image. Fig.4 shows the Java-based interface that is used to mark the regions of interest (ROI). Each image can have one or more ROI that also might overlap.

Figure 4. SonaRes interfaces for manual ROI indication

According to the manually marked ground truth, the following processing steps have been performed when the image data is transferred to the IRMA system:

1. ROI extraction is performed according to the manually defined polygon. The ROI is assumed quadratic, and size as well as center coordinates are determined corresponding to the area of the manually marked polygon. These patterns form the true positive class.

2. In each reference image, the field of view is determined automatically using an algorithm based on morphological filtering [Sikka].

3. Within the field of view, four patterns of same size are extracted at positions where the respective ROI do not overlap with the ROI indicating the polyp. These were used to form the class of true negative examples (Fig.5).

In total, 255 cases associated to 57 ultrasound images are available which resulted in a database of 295 patterns of two classes: either showing a polyp or not. This data was applied to the first experiments.

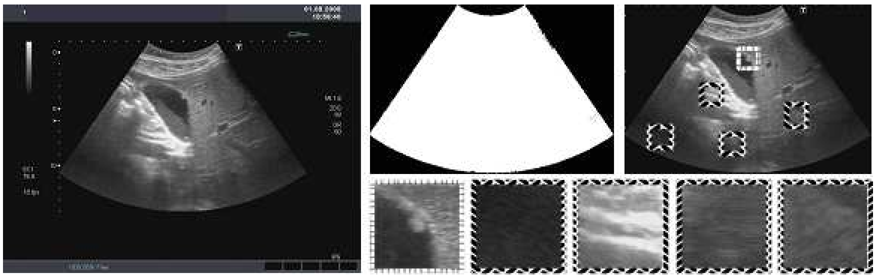

Figure 5. Steps of image processing for ground truth generation

5 Results

5.1 Fragment of DTD of XML transfer file

The interaction between two systems is successfully provided by transfer documents implemented as XML files. The detailed description of DTD presented in this subsection shows the adequacy of XML structures for CASAD information exchange.

Because of existing of several projects which use the IRMA services, the transfer XML document starts with root element that defines the addressing system:

```
<!ELEMENT casad_irma (query|queryresult)>
```

The following set of tags is used for request of IRMA service. This set contains: (i) element for transmission of URL of image supplied by user; (ii) elements keeping the information about ROI. Since the contour of ROI is set as the list of points, such structure can be mapped in XML directly:

```
<!ELEMENT query(image_url,contour)>
<!ELEMENT image_url (#PCDATA)>
<!ELEMENT contour (pointlist)>
<!ELEMENT pointlist (point+)>
<!ELEMENT point (x,y)>
<!ELEMENT x (#PCDATA)>
```

Figure 6. Screenshots of CASAD interface

```
<!ELEMENT y (#PCDATA)>
```

The XML file for transferring of IRMA service result contains the following set of tags. The result represented as list of pairs – image id, similarity score – meets the CASAD classification purposes:

```
<!ELEMENT queryresult (imagelist)>
<!ELEMENT imagelist (image_res*)>
<!ELEMENT image_res (image_id, similarityscore)>
<!ELEMENT image_id (#PCDATA)>
<!ELEMENT similarityscore (#PCDATA)>
```

5.2 Screenshots of CASAD interface

Web-interface of CASAD implements the user interaction with system modules. The ROI setting module is adopted from SonaRes web-interface. Thus the classification function in SonaRes is destined for experts, several modules from ExpertShell standalone application were remade as web-applications. The right snapshort in Fig.6 presents the example of such module: association of the ROI to the node of decision tree.

6 Discussion

The both, knowledge-base decision support and content-based image retrieval techniques, have their own restrictions when used for ultrasound images analysis. The ambiguous graphic features restrict the usage of the CBIR. Strong dependence on ecographist experience in medical features recognition makes difficult the KBDS usage. Thus, it looks promissory to combine those techniques for covering the restrictions of one by advances of another. In this work we have focused on implementation of proposed combination in the frame of CASAD – system of warehouse type. This ultrasound images warehouse can serve (i) to manifest the diagnosis when the ecographist specifies the pathology and then looks through corresponding images to verify his opinion, and (ii) to suggest a second opinion by automatic analysis of the annotation of relevant images. The ultrasound images have to be classified to provide main functions of warehouse maintenance: new image addition and similar image retrieval. Both KBDS and CBIR are used to help in the classification process. The usage of KBDS-based annotations serves to distinct graphically similar patterns corresponding to different medical features (polyps vs. gallstones). The annotations of images obtained by CBIR usage help the user to set the correspondence between visually seen graphical features and medical ones.

The main limitation of our approach consists in semi-automatic process of classification, since human participation in decision is required. Another important limitation is the high possibility of false positive/negative answer of CBIR component, because of hard noise that is peculiar to ultrasound images.

To develop our approach in future we plan to provide experiments with sets of images showing identical pathologies as well as the different ones. These experiments will allow to estimate the rate of false cases. After that the additional patterns will be defined for some pathologies including similar. The future experiments with such sets can reveal:

is it possible to correct false answers providing the pattern with the highest score of similarity.

The decision support systems of medical imaging domain mostly use one of approaches: based on knowledge or based on images. We propose to use the combined approach in the frame of one system. The process of images data warehouse filling, as well as retrieving, requires decision making. Supporting these processes by both KBDS and CBIR techniques, we can correlate their results and improve the decision adequacy.

Acknowledgments The research for this paper has been supported by common project of the Academy of Sciences of Moldova and Federal Ministry of Education and Research of FGR (BMBF) 09.820.08.02GA, and by the Science & Technology Center in Ukraine (STCU) grant 4035.

References

[1] W. H. Inmon, *Building the Data Warehouse*, Fourth Edition, Wiley Publishing, 2005.

[2] Ritendra Datta, Dhiraj Joshi, Jia Li, James Wang, *Image Retrieval: Ideas, Influences, and Trends of the New Age*, ACM Computing Surveys, 2008, to appear. (Also Penn State University Technical Report CSE 06-009, 2006).

[3] Agnar Aamodt, Enric Plaza, *Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches*, Artificial Intelligence Communications 7 (1994): 1, pp. 39–52.

[4] *Ultrasound Clinic 2*, xi–xii, Elsevier, 2007.

[5] Jane A. Bates, *Abdominal Ultrasound: How, Why and When*, Churchill Livingstone; 2 edition, 2004.

[6] Klein M. R., Dussartre D. *Introducing AI in OPTRANS a DSS generator.* In DSS theory and applications, NATO ASI serie vol 31, Springer, 1985.

[7] *Encyclopedia of Decision Making and Decision Support Technologies*, IGI Global, 2008.

[8] *Clinical decision support the road ahead*, ed. Robert A. Greenes, Elsevier, 2007.

[9] J. Lu, M. A. Quaddus, R. Williams, *Developing a Knowledge-Based Multi-Objective Decision Support System*, Proceedings of the 33rd Hawaii International Conference on System Sciences, 2000.

[10] *Data mining and knowledge discovery approaches based on rule induction techniques*, Ed. E. Triantaphyllou and G. Felici, 2006 Springer, Chapter 9: Rule induction through discrete support vector decision trees, by C. Orsenigo and C. Vercellis, pp. 305–325.

[11] L. Burtseva, S. Cojocaru, C. Gaindric, E. Jantuan, O. Popcova, I. Secrieru, D. Sologub, *SONARES – A decision support system in ultrasound investigations*, Computer Science Journal of Moldova, nr. 2 (44), vol. 15, 2007, Kishinev, pp. 153–177.

[12] Popcova O., Puiu S., Secrieru Iu., *Knowledge Structurization and Formalization for Gallbladder Ultrasound Investigation Domain*, Proceedings of II International ConferenceAdvanced Information And Telemedicine Technologies For Health, October 1-3, Minsk, 2008, pp. 98–102.

[13] Flickner M., Sawhney H., Niblack W. et al., *Query by image and video content: The QBIC system*, Computer 1995; 28(9), pp. 23–32.

[14] Faloutsos C., Barber R., Flickner M. et al., *Efficient and effective querying by image content*, Journal of Intelligent Information Systems 1994; 3(3-4), pp. 231–262.

[15] Smeulders AWM, Worring M., Santini S., Gupta A., Jain R., *Content-based image retrieval at the end of the early years*, IEEE Trans Pattern Anal Mach Intell 2000; 22(12), pp. 1349–1380.

[16] Lehmann T. M., Güld M. O., Deselaers T. et al., *Automatic categorization of medical images for content-based retrieval and data mining*, Comput Med Imaging Graph 2005; 29(2), pp. 143–155.

[17] Hersh W. R., Muller H., Jensen J. R. et al., *Advancing biomedical image retrieval: Development and analysis of a test collection*, J Am Med Inform Assoc 2006; 13(5):488–496.

[18] Muller H., Michoux N., Bandon D., Geissbuhler A., *A review of content-based image retrieval systems in medical applications-clinical benefits and future directions*, Int J Med Inform 2004; 73(1), pp. 1–23.

[19] Lehmann T. M., Güld M. O., Thies C. et al., *Content-based image retrieval in medical applications*, Methods Inf Med 2004; 43(4), pp. 354–361.

[20] Güld M. O., Thies C., Fischer B., Lehmann T. M., *A generic concept for the implementation of medical image retrieval systems*, Int J Med Inform 2007; 76(2-3), pp. 252–259.

[21] Deserno T. M., Güld M. O., Plodowski B. et al., *Extended query refinement for medical image retrieval*, J Digit Imaging 2008; 21(3), pp. 280–289.

[22] Sikka K., Deserno T. M., *Comparison of algorithms for ultrasound image segmentation without ground truth*, Proceedings of SPIE 2010, in press.

T. Deserno, L. Burtseva, Iu. Secrieru, O. Popcova Received February 9, 2010

T. Deserno
Aachen University of Technology (RWTH)
Department of Medical Informatics
Division of Medical Image Processing
Pauwelsstraße 30
52074 Aachen, Germany
Tel: +49 241 80-88793
Fax: +49 241 80-3388790
E–mail: *deserno@ieee.org*

L. Burtseva, Iu. Secrieru, O. Popcova
Institute of Mathematics and Computer Science,
Academy of Sciences of Moldova
Academiei 5, Chişinău MD-2028 Moldova
E–mail: *burtseva@math.md*,
secrieru@math.md,
oleapopcova@yahoo.com