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Fractal Study and Space-scaled Pyramids for Biomedical Image Analysis

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***Abstract* — In this paper method of biological tissue image analysis is proposed. This method is based on scale properties of biological objects. Different characteristics of tissue are calculated on levels of scale image pyramid and allow defining more complete description for diagnostics or monitoring of disease.**

Keywords* — *fractal dimension; space-scaled pyramids; Computer Tomography; histology; image analysis; magnification

I. Introduction

Variety of types of biomedical diagnostics and specific of materials has been raising many questions for texture analysis. Even within the same diagnostic type it is quite complicated to describe textures. Thus for computer tomography (CT) there are an exact textures for certain organs or masses [1]. CT investigation measures a density of tissue through X-ray attenuation. Characteristics of such image type correspond to X-ray, so the principal drawback here is low contrast of soft tissues. For dense tissues these images differ with high contrast [2]. For histological investigation there are also questions due to "ability" of an image to change it properties against the magnification of examined specimen. Although here we have feature dependence which may vary according to magnification change and this dependence is keeping for different types of biomedical images.

Thus, for representation image information the data structure plays important role for the successful solution of an image processing task. The image pyramid is a data structure that is used for supporting of efficient multi-scaled convolution. It consists of a sequence of copies of original image where resolution is decreased by regular steps [3]. All structures, located on the histological images, have specific properties, which can greatly influence to the process of image processing and analysis.

As such, development of automated systems for image processing, analysis, estimation, and understanding is a significant branch of oriented fundamental and applied research. The essential prerequisites for development of such systems as well as automation of (i) selection of the solution method for the task at hand, (ii) provision of recommendations on selection of the solution method for the class of tasks, which includes the problem at hand, (iii) synthesis of algorithmic procedures for solution of the task at hand, (iv) provision of recommendations on synthesis of algorithmic procedures for solution of the task at hand.

Domain dictionary is known to be an efficient way of knowledge representation. Dictionary is used to provide explicit formal machine interpretable description of data semantics in a certain field. Consequently, it is an appropriate instrument for representation of knowledge used for information extraction from images.

The following are dictionary knowledge representation merits: (a) it provides the chance to establish a typical understanding of the considered field of knowledge, (b) it allows us to signify knowledge in a convenient form for processing by automated information processing and analysis systems, and (c) it provides the occasion for acquisition and accumulation of new knowledge and for multiple use of knowledge.

Fractal analysis is already well-established in the image processing apparatus. We have made the assumption that the fractal characteristics in combination with spatially scalable pyramidal representation of biomedical images will differentiate clearly individual classes of objects with fractal characteristics.

If for histological diagnostics pyramidal systematization of morphological characteristics is a very important (but still evident) element as it highly depends on image resolution, but for CT such an approach looks rather novel.

Somehow or other any analysis requires a specially prepared image with the explored objects displayed on by the binary data. The scale should be specified for the image (it can be determined by the calibration function) and calculated characteristics should be determined. Specialized object analysis requires preliminary calibration only. This process is divided into four steps: (1) preprocessing; (2) image segmentation; (3) shape correction; (4) image characteristics determination.

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Here is the specific description of the approach. Every image pyramid layer is analyzed and described by some value of the basal function. It is apparent that some descriptive statistic value can be associated with every level of the pyramid according to the values of basal function on this level. So, the dependence between the scale and pyramid level descriptive value can be analyzed and used for some conclusions or sometimes pattern recognition.

The subsequent sections are arranged as follows; brief description of the methodology of dictionary use in solution of image analysis problems and the structure of the experimental version of image analysis dictionary.

II. DAIA IN IMAGE ANALYSYS

A. Dictionary usage in image analysis

We developed a large number of automated image processing and analysis systems, able to carry out a wide range of operations over images. Nevertheless, efficient application of the recommended methods of working with images requires a highly qualified user having expert knowledge in the field. It is a contemporary problem to propose systems that would not only offer a certain set of tools for working with images to the user, but also provide him with tools modeling the strategies used by an expert in decision making. The major objective of designing image analysis and understanding systems is to offer maximum possible automation of all stages of working with images to minimize or completely reduce the expert's involvement and make the system accessible even to users who do not have special skills or knowledge in image processing and analysis.

The automated system ought to join the abilities of the development system of image processing and analysis with ones of the knowledge based system, in solving a broad class of tasks associated with analysis and evaluation of information represented by images. Accomplishment of these abilities depends on the accessibility of the knowledge base, which is necessary for accumulation and use of knowledge on image processing, analysis, recognition, and understanding.

Usually, it includes the following:

• modules of general knowledge not associated with any applied area (knowledge, which is needed for preparation and control over processing workflow, presentation of results, evaluation of processing quality, object recognition, and knowledge on image processing and analysis methods);

• modules of knowledge linked with the domain, which includes the specified problem (general and specialized methods and algorithmic schemes of segmentation, object description, attribute selection, extraction, and evaluation, and object recognition).

For solution of the following problems thesauri and dictionary are necessary:

(i) Creation of an identical manner for description and representation of image analysis tasks and methods of their solution;

(ii) Computerization of combining methods and synthesis of image analysis algorithmic schemes on the basis of semantic combination;

(iii) Linguistic support of knowledge bases for image processing and analysis automation (query formation, processing, and enhancement; navigation; knowledge representation structuring and optimization; knowledge storage organization; knowledge acquisition).

To give decision support in the area of image analysis and understanding, the subsequent dictionary is obligatory:

• image analysis dictionary, which describes (a) general (problem independent) tasks in the area of image analysis and recognition; (2) the existing methods (approaches, algorithms, operators, etc.) of image processing, analysis, recognition, and understanding;

• set of dictionary applied domains describing the field of knowledge, which includes the given problem.

B. Image features

Basic features of image analysis that can be used for purpose of a technique of processing are described as follows; Common processing sequence for histological samples image analysis. Usually, processing of histological images can be divided into several steps:

i) Input and image enhancement;

ii) Segmentation;

iii) Object detection (identification);

iv) Measuring;

v) Analysis.

All steps consist of execution of a set of functions. The application of a function depends on initial data or image estimations. It is possible to define such estimations in several cases, for instance, for contrast, noise or blurring, table of image processing functions and image estimations can construct be constructed.

Such as, in a case of histological images application of segmentation methods depends on global image characteristics. Usually, an image is decomposed into separate regions to analyze the histological sample. Consequently, the segmentation process (i.e., extraction of homogeneous regions in image) is considered as a basic step for formal scene description. It is necessary to define a correct set of features and feature characteristics for a suitable choice of segmentation methods. Based on the original image characteristics, it is possible to define a function for image processing and analysis (see Fig. 1). As a consequence, the table of connection functions and image estimation are constructed.

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In each step, functions are indicated by priorities. For instance, for the image improvement step the higher priority is defined for noise removal, next priority level includes contrast enhancement and correction of the borders. Priorities determine the order of the functions application and the need for re-analysis using neural network.

Image processing functions relate to basic computer vision topics. All functions changes properties of image and is applied for specific processing cases. Each function is introduced in an interpreter table and can be supported by additional information.

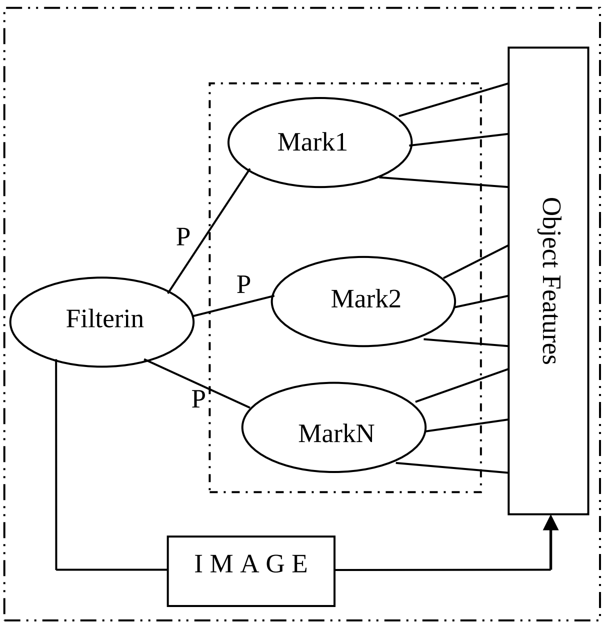
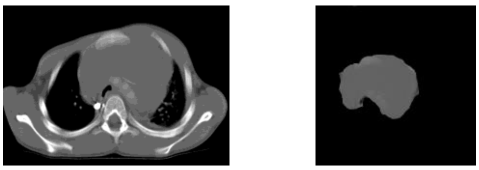


Figure 1. Scheme of homomorphic filtering definition based on image characteristics.

C. *The notion of a pyramidal representation of images*

At any diagnostics the objects under study one can decompose, but depending on imaging specific in the pyramid or laid-scale representation of image, or even a real optical zoom (magnification) of specimen. We have made the assumption that by calculating fractal characteristics of CT-images (Fig.2) it is possible to separate classes of objects that have their unique fractal features.

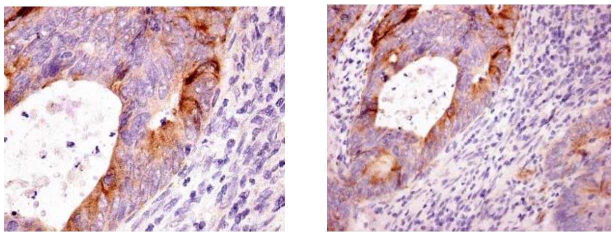


a) b)

Figure 2. CT-image of mediastinum and extracted image of a volume mass on it

Image pyramids have shown to be efficient data structures for digital images in a variety of vision applications. An image pyramid is a stack of images with exponentially decreasing resolutions. The bottom level of the pyramid is the original image. In the simplest case each successive level of the pyramid is obtained from the previous level by a filtering operation followed by a sampling operator. Image pyramids have the following merits [4]:

- the influence of noise is reduced in the lower resolution images by smoothing, so the regions of interest for correspondence analysis in levels of higher resolution can be found at low cost because irrelevant details are no longer available there (Fig.3).
- computational cost is reduced as the divide-and-conquer principle can be applied: in high resolution images, the region of interest can be split into several patches which can temporarily be handled individually. decomposition into sub-tasks, taking into account system properties, that is more efficient allocation of jobs between team members and program developers, simplifying the process of debugging.



a) b)

Figure 3. Histological images for different levels of pyramid.

Each layer of the pyramid can be processed and analyzed. And if the way of analysis is the same for all the levels, the sequence of descriptive data is received. This sequence of data provides an opportunity for the comprehensive image analysis leading to determination of some specific image characteristics which haven't been available before.

There are two ways to construct a regular pyramid:

1. Parallel graph contraction.
2. Decimation of the neighborhood graph.

The main purpose for the introduction of irregular pyramids was the rigid behavior (e.g. shift variance) of regular structures. Irregular pyramids offer greater flexibility for the price of less efficient access.

One can consider the contents of a cell as a model of the region which it represents. In the simplest case a cell stores only one (grey) value. We call such pyramids grey level pyramids. In more complicated cases several parameters of general models are stored in a cell. But the basic property that numeral values are stored in a cell remains. Subsequently we will call these pyramids numerical pyramids.

Besides numerical values it is possible to store symbolic information in a cell. In this case we have a finite number of symbols, and a cell stores a symbol relation among them. We call such pyramid symbolic pyramid.

The main property of processing in a pyramid is that it occurs only local, the brothers, and/or the parents a new value and transmits it to one or more cells of its pyramid neighborhood. In the bottom-up construction phase input comes from the sons but for some algorithms the flow of information is also in the top-down direction.

III. SCRIPTING AND SOFTWARE FLEXIBILITY

SCRIPTING AND SOFTWARE FLEXIBILITY

In software application, the script – is a program that automates certain task that user would perform manually using interface without script [4, 5]. Script languages allow developers to mix and "interlock" with different functions or packages, as well as to coordinate the results obtained by the system as a whole. To create a flexible environment, or a software system with an "open architecture", scripts are efficient in terms of their integrating level as a tool which modifies and extends functionality of developed software for image analysis. A material published by Guillaume Marceau [6] has been used to choose the best script language, which is planned to be a base core of software system with an "open architecture". Parameters of 72 implementation of programming language are compared in his study and applied to 19 special tests, which had been prepared in the frame of the project "The Computer Language Benchmarks Game". Different parameters were evaluated such as speed of code execution, code size, memory needed to implement certain functions.

The flexibility and particular functionality of a language Lua [7] has allowed to define it as the most suitable one for the task to be solved. Through the use of a core interpreter Lua, we have finally gained following advantages:

- Flexible integration of individual tasks in a single operating space. Implementation of the various components is invariant to assembling and adapting process for particular tasks.

- Problem decomposition into sub-tasks, taking into account system properties, that is more efficient allocation of jobs between team members and program developers, simplifying the process of debugging.

- Simple portability (without changings and recompiling) of already implemented and compiled components in new projects and their integration into the new connections system, circuit of functioning and information exchange between other components.

- The ability to use well-functioning compiled scenarios of build as a basis for new project with new or updated functionality.

- Designing a system based on the principle "from simple to complex", increasing gradually the functionality of system addressing the priorities of the project.

Depending on peculiarities of a problem the structure of software being developed is organized so that C + + as the base language of the majority functions can simultaneously extend Lua. C-functions call Lua-function and vice versa, for instance. The basis of the symbiotic relationship between Lua and its host language is a virtual stack, a LIFO-data structure ("last in-first out") which stores function arguments and results temporarily. To call base language from Lua (and vice versa), the caller side pushes values into the stack and calls target function. The recipient pops arguments from the stack, processes data and pushes result into the stack back. When control returns to the caller side, it retrieves values from the stack. Using C API, an application can also receive information from Lua-structure by calling any Lua-function of C. The reverse is similar. Lua can load and call functions on demand. As a result of Lua integration into the program it has been discovered the opportunity to write and export C-functions into Lua programs, and use it directly from the script of the program. In addition, such functions can be created and used as separate specialized DLL-modules (with Lua supporting interface). In view of high prevalence of language there are a large number of already developed modules. There is also an opportunity to use common dll-libraries with a specially designed interface functions.

Using described above methodology for flexible software environment we gain a simple management with a look of application and rapid interface adaptation to manifold tasks of image analysis. As a result, interactive part of application can be reduced to its minimum, which greatly simplifies the work with program and extend its usability.

A. Principles of flexible Grafic User Interface

Graphic User Interface (GUI) of an application consists of two sets of functions: basic static and extensible set of functions, which is controlled by Lua-scripts (Fig.1). Complex GUI-elements are programmed in C++ as a Lua-function as a single component. It covers such forms as a widget to display and edit images with the appropriate tools, interactive dialogues (for instance, interactive threshold segmentation or image histogram displaying), resulting tables and text editor for Lua-script. Simple elements are binding directly in Lua-functions so to cover: menu control, panels with control elements and universal dialogue that includes necessary elements to call Lua-functions.

The basic principles of working with such an application are as follows:

1. GUI - DLL is managed by Lua being a root element of the interface (all the elements sit here in the container).

2. Positioning of elements in the container is performed by using GUI. It locates and draws the element according to rules. Main containers are frame, vertical sizer, and horizontal sizer.

3. Events handlers are defined as functions that are attached to widgets.

4. Event loop is starting after creating a dialogue.

5. Universal dialogue covers all necessary elements to call Lua-function.

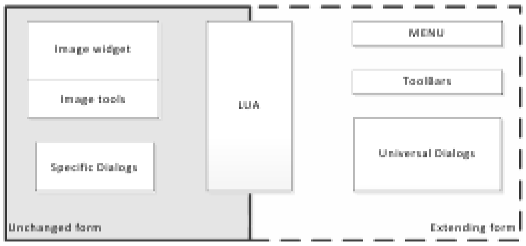


Figure 4. GUI of flexible application

The technology aimed at issues how to arrange process management so to:

- adapt interface to needs of certain specialist (user) and use available algorithmic experience of users;

- modify algorithms according to this or that task and then again provide appropriate interface to interact with user;

Adaptation of GUI is performed by using Recommending System or on the base of Intelligent Agent which can analyze features of processing images.

B. *Using intelligent agent to manage scripts*

When architecting a task-driven system using proposed conceptions we suppose that there are at least two different schemes for generating GUI with intelligent support.

Systems which are built by these schemes are described below. We also propose Intelligent Agent (IA) which is the Agent mentioned above [8]. It is embedded into next schemes.

Inherently, the engine of IA is the same for all schemes. The only difference is in fact that for one case the GUI script generation executes according to a pre-existing set of estimates of processing scripts based on extracted features of certain image. For another case estimates are formed adaptively with the number of users' interest with a different application (for us it is image processing domain). Thus quality of estimation increases with increasing of number of users or intensity of using the program (if system runs locally for one user).

1) *Intelligent Agent Without Collaborative Filtering*

GUI for this case is generated by Lua-scripts based on calculating characteristics of processed image (for example: display panel for texture characteristics if texture is under investigation).

System is running here in a fully autonomous mode and does not use any other information except the image, thus a set of guidelines (recommendations) is laid by developer in advance during its creation and distribution (Fig.2). For example, when photo images are to be downloading, algorithms for color correction, quality improving, and texture analysis will be actualized at GUI, and so on. When dealing with binary images morphological and distance transformations, skeletonization, blobs extraction will be at frontend of system interface.

One may see some restrictions for this scheme, but through the script-implementation of the intellectual part, advanced users have the ability to change both algorithmic (computational) functionality and interface. Also competitive versions of code and interface modifications can be easily distributed to users of the given application. Despite its apparent simplicity, the above approach has proved to be very functional in practice.

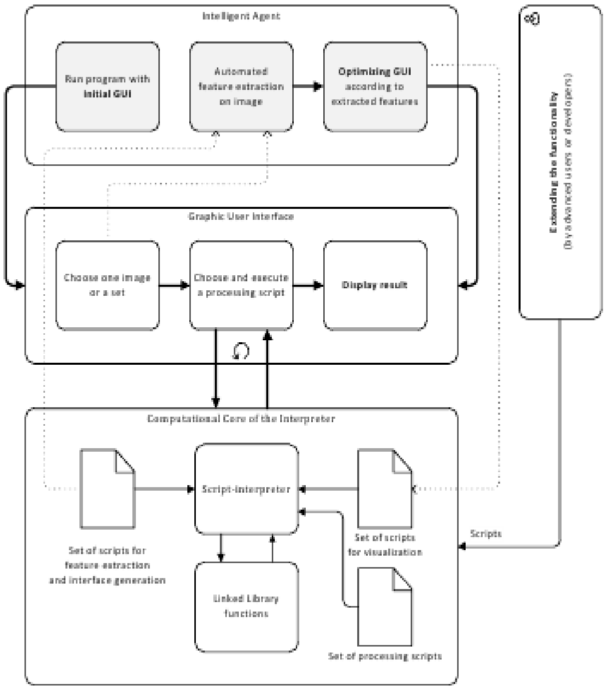


Figure 5. Baseline Image Processing System (Client) with Extensible Functionality without filtering

2) *Intelligent Agent With Collaborative Filtering*

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GUI for this case is generated by Lua-scripts based on calculating characteristics of processed image (for example: display panel for texture characteristics if texture is under investigation). GUI here is also generated by Lua-scripts based on calculating characteristics of used image together with IA. However, recommendations are being giving under Collaborative Filtering which collects and processes statistics of certain function usage (Fig.3). The main difficulty is still remained how to create a controlling script – IA which could support logic adaptation of GUI for a given type of images. This problem is easily and efficiently solved for a fixed set of image features and pre-set number of scripts through training on the test sample. However, we originally positioned the system as a flexible and scalable one, so a question arises to adapt IA for advanced feature sets and algorithms. To address these difficulties, it is proposed a method to adapt the logic of the Agent based on program usage history. IA calculates characteristics of a test images and puts into a local database a fact of using a specific set of algorithms and frequency of its use for a given characteristics (features). Further, this local database is analyzed to construct new user interface, to make it actual and personalized.

Thus local database with such statistics can not only recommend a unique interface for a given images with certain properties, but also to form a personalized basis (slightly variable backbone) GUI for the user, showing features for certain domain.

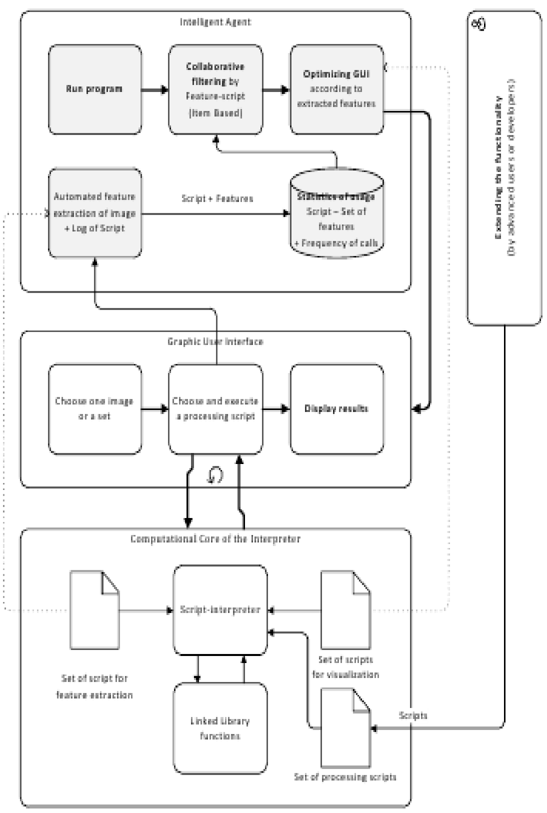

Figure 6. Baseline Image Processing System (Client) with Extensible Functionality supported with Collaborative Filtering

3) *Collaborative Filtering*

Collaborative filtering – this is one of approaches for forecasting in recommendation systems, which use known preferences and estimates of users' group to predict the unknown preferences of another person. [9] The system which is discussing here has properties similar with recommendation system. It basic assumption is following: those users who are assessed these or that objects of any kind in the past, could tend to give similar estimates for other subjects in the future. Decisions are made individually for each user, but used information gathered from database. Thus, collaborative filtering is different from a simple approach that gives the average score for each object of interest, for example, based on the number of votes cast. Research in this area is actively underway at the moment, so there are several methods which use different mathematical apparatus to solve such a problems. There are two main approaches for CF: item-based and user-based. Item-based strategy builds an item-to-item (image- to-image in our case) matrix, determining relationships between pairs of images and then recommends a set of the most suitable scenarios for current image (on the basis of image to scenario usage statistics) (Fig. 4).

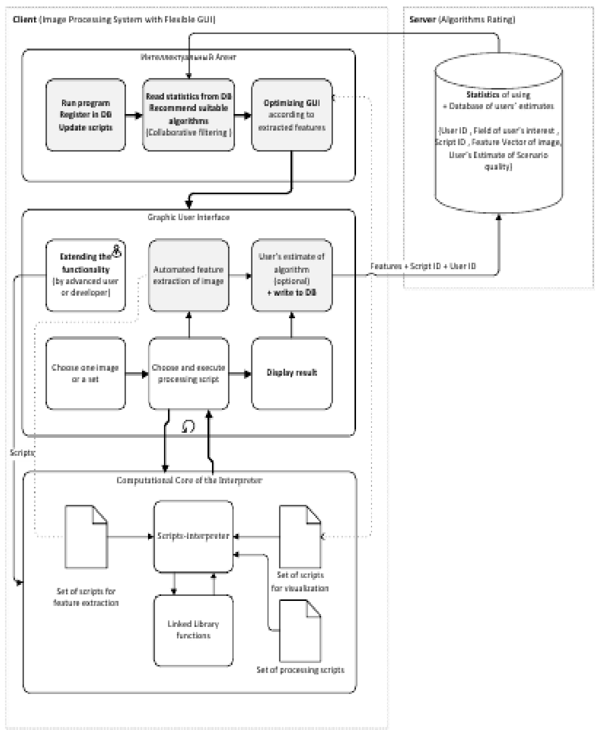

Figure 7. Client-Server architecture with remote server for user statistics collection

User-based strategy looks for users with similar rating patterns with the active user and makes recommendations based on their preferences. Describing these approaches more precisely is out of current topic so the only point here is to understand the difference between second and third scenarios which lies in counting user's action or not. Thus, "Item-to-Item" collaborative approach proposed by Amazon [10] is reasonable for passive feedback. Comparing to the original approach, we have been made a slight modification: the event of script is accepted for further processing if the same script has been executed at least 10 times. For active feedback a "Slope One" algorithm [11] is used since it is a well-proven algorithm for solution-based collaborative filtering for items (objects) with users' estimates.

4) Remote repository for extending functionality

Overall the server part of the proposed concept allows us to gather statistics of scripts' usage and effectively apply techniques of collaborative filtering to generate personalized user interface based on the Log (history) of his reviews (or statistics regarding scripts' use) as reflected in Fig.5.

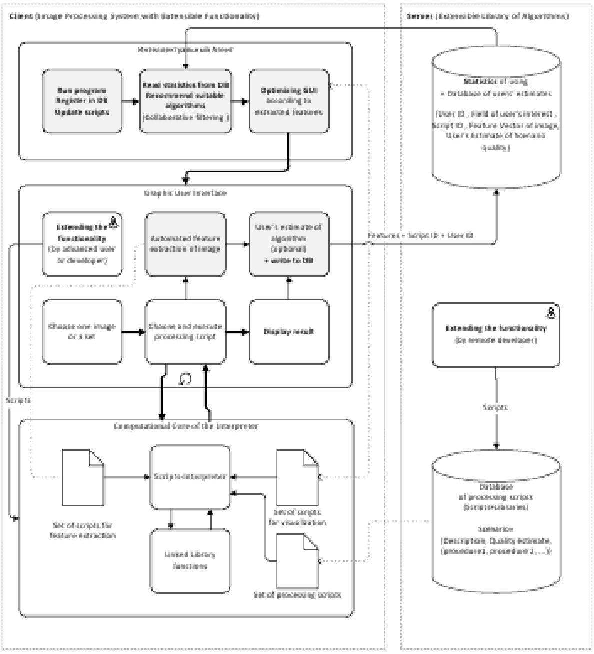

Figure 8. Client-Server architecture with remote repository supported with Intelligent Agent

However, developing the idea a convenient way of central storage (Repository) can be considered, so to apply simple mechanisms for update the database of image processing algorithms, for instance.

Central Repository of image processing algorithms has a number of advantages, among which:

- using actual scripts for imaging and image processing; - hot fix and add scripts;

- minimum cost for extending the functionality of a program;

- add new scripts without recompiling directly from the interface of the client part of the program;

- crowd-sourcing script developing and deployment.

Described methodology is based on using script language as a kernel of system to modify Graphic User Interface (GUI) and generate new functions to extend overall functionality, so to put a flexibility making work much more convenient. It is supposed that proposed conception can be extended to application of software as itself.

IV. INTELLECTUAL SOFTWARE ARCHITECTURE

A. *Inteligent agent for image analysis software*

We use three types of techniques for the intelligent agent for image processing software. Artificial neual networks id used for classification image processing function in scripts. ANNs are useful in information extraction from input image to be fed through the networks as its input parameters.[4,5]. We used backpropagation algorithm for weight change, the state of the system is doing gradient descent; moving in the direction opposite to the largest local slope on the performance surface. That is, the weights are being updated in a downward direction. Estimations of global setting on the image are used as weights in neural network. Adjusting of the input weights and vector signals quantization is intimately related to a simple basic algorithm for artificial neural network . System is aided by script generator module. This module makes use of LUA-metatable of function for image processing and corresponding table by means of estimations of image. Throughout such table, definition of function sets going by artificial neural network.

Also,we used Bayesian probability for image marks. Bayesian probability is used in image filtering for linking each mark to the image objects. Bayesian probability is one of the diverse interpretations of the notion of probability and belongs to the category of evidential probabilities. Mathematically, Bayes' theorem gives the relationship between the probabilities of *A* and *B*, *P(A)* and *P(B)*, and the conditional probabilities of *A* given *B* and *B* given *A*, *P(A|B)* and *P(B|A)*. In its most common form, it is:

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}.$$

The Bayesian probability is used in filtering the image marks for connection of the common marks [6]. The Bayesian interpretation gives a standard set of methods and formulae to perform this calculation. Bayesian probability interprets the idea of probability as "an abstract concept, a quantity that we allocate theoretically, for the reason of representing a state of knowledge, or that we calculate from beforehand assigned probabilities,"[7] in contrast to interpreting it as a frequency.
We then used Bayesian networks (BNs), also recognized as *belief networks* (or Bayes nets), fit in to the family of probabilistic *graphical models* (GMs) [8]. We used BNs to get the best object features of the image.

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Definition: Let BN be a Bayesian network over $U=\{A_1,\ldots.A_n\}$. Then BN specifies a unique joint probability distribution P(U) given by the product of all conditional probability tables specified in BN as in equation:

$$P(U)=\prod_{i=1}^{n} P(A_i|pa(A_i))$$

where $pa(A_i)$ are the parents of A_i in BN, and P(U) reflects the properties of BN.

The BNs formula in previos equation is used in getting the best image feature objects. As a result, the module proposed scripts for image processing and prediction as text file. Users can spend analysis of this script and change some in it. This software is supported by uses control and changing. There are a few version of user interface for managing of image processing and choosing of analysis type. Also the software has sets of interactive function for image prediction.

B. Features of software architecture

We carried out elaboration of structural scheme of software basis interface an inference of functionality and compatibility of existed software development tools. Tasks which can be solved with software to be developed, first data, diagnostic features and characteristics have been experimented.

In the first instance data are processed by temporary file, which permit to analyze records (images). In another instance a transfer by calling a run-time library is performed (Fig. 2). This software is based on the interpreter of Lua language. It was elaborated as the major module based on an communication of complex modules. It is made up of a graphical interface, global variables and image storage structure. Architecture of the graphical interface was carried out through linking the Highgui library [3] in the OpenCV package [3]. The image processing and function analysis are aided by OpenCV library except connection Lua with OpenCV are achieved by Lua-binding interface for a connection function of OpenCV with Lua.

An image organization is determined by a module of graphical interface keen on OpenCV library which is accountable for visualization and representation of images. Headers of image structures are made of global variables-pointer of interpreter Lua. They contain special type - userdata. Userdata corresponds to a pointer in the computer address space. This module also includes image read or write functions, essential functions of image processing and interactive contouring. Every interactive function return values in the event block, which changes global variables of the interpreter. A simultaneous usage of a number of modules is required for tasks of monitoring space occupying lesion. In this instance an interaction has been performed by means of global variables of the Lua interpreter and properties of the userdata type of Lua interpreter.

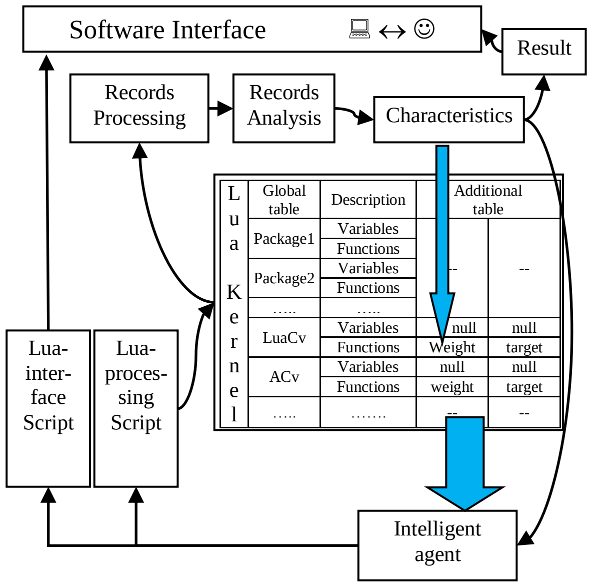


Figure 9. Script generation cycle for records processing and analysis

Nodes are the short sequences of functions, for solving essential problems. Through image processing a node of Lua can give image exchange through Lua-outlets. Primarily, it sends images to the highest Lua-outlet identifier. After that the processing is complete if the state of Lua-outlet was changed. The node changes the order of the processing functions and their parameters in accordance with his notifications. Loop notifications are sent finally from a slow thread at the end of the scripts processing. The observer notification is necessary during the path through the each of the nodes. It is called the notify event-slot. This slot calls node's state method to obtain a dictionary with the node's attributes. As well it sends these attributes to the observers. Communication among nodes in the same script is done through a direct function. This function is called via eventslots, either by means of a virtual method bang for the first inlet or a function pointer for other inlets. Images are processed by reference. Adding fresh complex functions of processing and analysis is carrying out by collection of developer's function. As an input new functions might get any global variable or text and numerical constants from the LUA interpreter.

All interior controlling of software is carrying out by text scripts of LUA, which are separated into two categories; (i) scripts for image sequences analysis; and (ii) scripts for operative functionality and setting up of software at workplace of medics. Every one of script are stored in a text form and easily accessible. However they are not for altering by user and might be edited for by developers only. Scripts administer to software organization and create new extra function for image analysis and processing. Preprocessing analysis of images sets of image let to define processing functions. Module of scripts generation defines such sets. It includes intellectual components for connections consequences of image functions processing and image distinctiveness. Of course such task can be solved only for specific task in our case for histology image analysis. Every interpreter defines function due to a specific table. We use it for explanation connection images characteristics by means of a function in our software. It includes a collection of feature vectors and variable of main concern. The set of feature vectors defines the utility function. The variable of priority determines the location of function in the generated script. In consequence such software has intelligent self-programming possibilities**.**

Image processing functions relate to basic computer vision topics. Every function changes properties of image and is applied for specific processing cases. Every function is introduced in an interpreter table and can be supported by additional. Inteligent agent manage to software processing by estimation of image characteristics. It extract of object from images. Then characteristics of such objects are calculated and define type of object. We divide objects for five basic types: blobs, front, needles, dendrites and nets. Using global fractal, texture characteristics software detect geometrical type of objects and formed characteristics sets for object description.

V. METHODICS OF IMAGE CHARACTERISTICS ANALYSIS

Characteristics of objects are the basis for any research. The high resolution of optical microscopes brings high accuracy in calculation of geometrical, topological and texture characteristics of objects. Most frequently measured parameters of magnetic structures are: area, perimeter, linear sizes, factor of elongation (the relation of two main moments), and other.

4. CALCULATION OF CHARACTERISTICS FOR INTALLIGENT AGENT

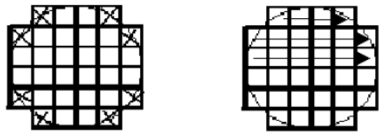
A. Calculation Characteristics by Connected Components

Initial image is commonly decomposed into two components: objects and background. While image is scanning each object gets its individual feature (color), thus classification is performed in such a way. There are more than object under consideration in the process. Therefore for classification certain components are marked and geometrical characteristic for each component are defined.

Lets two points (pixels) on image are connected if there is a path from one point to another and characteristic function is constant along the path. Connected component of image is a maximal set of connected points, i.e. set of points when any two of them have connected path.

Object marking on binary image lies in choosing of object's pixel from which growing starts. At the next step neighbors of these pixels are marked, then unmarked neighbors of neighbors and so on. When the recursion is finished one component must be marked, and the process may be continued then with new seed point. As non-zero pixel is appeared, we push to the stack coordinates of those neighbors which are equal to color of object. Then we proceed pixel-wise scanning of current line accompanied with coloring it into object's color. At the same time intermediate parameters which are required for further analysis is gathering. As background pixel is appeared next pixels of object is popped from the stack and corresponding line is started to scan. (see fig.1). Coordinates of binary eight neighbors of line edge pixels are pushed also to the stack. It recorded to an array described the border of object. These steps are performed until stack will get empty. As a result we bring a contour of object in coordinate representation.

Obviously, "background" may be decomposed to connected components also, since object may contain holes. Thus it may be marked by the same procedure but zero are also should be taken into account in the case. More often these regions correspond to components of object, so they need to be merged. Merging is performed by regions growing method.



a) b)

Figure 10. Scanning of object: a) pixels which are subtend the contour, b) direction of object's line scanning

The majority of modern methods for measurement by connected component look like region growing. Using such a method one may process edge pixels by some preset conditions, and if conditions are satisfied the pixel merged to initial region. This process is repeated until there are no suitable edge pixels. Merging of pixels may be brought by using very different properties and approaches depending on task, thus for measurement we may define such characteristics as mean values of intensity in regions, probability distribution [7], texture primitives [8], fractal dimensions [9], entropy and energy [6]. The method for connected component analysis to merge regions from pixels set. It should be noted that in spite of variety of methods for region growing, it either do not use a number of important local characteristics or work slowly. Therefore new analysis has been carried out to speed up the process.

B. Specialized Analysis of Global/local Information of Image

There is significant number of works in the discussed field where the method for connected component analysis starts from random definition of small regions with few pixels [10]. These regions are growing on-site of the algorithm and build informational regions. It is not effective solution in case of images with smoothed varying of intensity and texture, since result depends on type of image and number of pixels at the

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step of initialization. New analysis (called as quasi-optimization) is carried out at the expense of unification of local characteristics of neighborhood pixels subject to it differences in local region and non-uniformity of intensity distribution (see fig.2).

Unification is brought by calculation of characteristics of image regions. First and second derivates are found for each point using Sobel and Laplace filters. Based on results obtained a pseudo-color image is composed then (fig. 3).

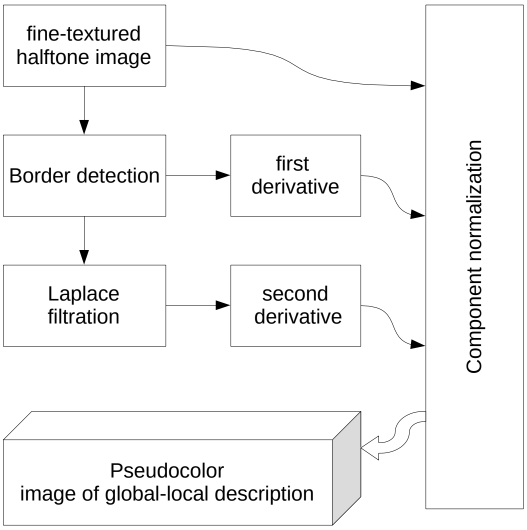
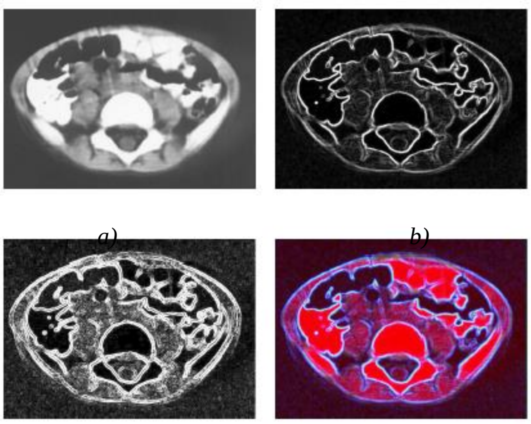


Figure 11. Algorithm of fine-textured image representation by local/global characteristics

Thus, each pixel contains both global and local information about image. So suffice it compare color value to analyze information about pixel and its neighborhood. Such a modification allows to run the algorithm of connected component analysis in much effective mode since it considers not only intensity characteristics but textural also.



a) *b)*

c) *d)*

Figure 12. Building a pseudo-color image based on global/local information: *a)* initial halftone image, *b)* first derivate, *c)* second derivate, *d)* combined pseudo-color (multiphase) image with certain properties

To speed up the calculation of three pseudo-color features we unify it into pseudo-vector of color. Color characteristics are changed along the vector [11]:

$$P = \sqrt{R^2 + G^2 + B^2} \quad ,$$

where *R*, *G*, and *B* – color components of image which reflect correspondingly initial values of pixel, characteristic of local changing in neighborhood and characteristic of nonlinearity of neighborhood.

Once we compose new pseudo-image, region characteristics are compared under by clauses:

- difference of dispersion for pseudo-color value should be equal or less that preset threshold (it differ organ from tissue);
- mean value of pseudo-color of each region should be in the interval limited by dispersion of another region.

If conditions are satisfied regions are merged by it redefining and by using of morphological closing operation which is applied for parental region on image. As a result identified region is colored with color of parental region. Edge lines which divide old related regions are deleted. New region is analyzed then again by image scanning to find neighbor unprocessed segments. If all regions are already processed, one of them is marked and analyzed as parental.

Finally, we obtain the set of regions corresponded to different parts of image. To classify regions of objects geometrical characteristics are calculated. Regions which are not corresponded to interested object are deleted, the rest of them colored in suitable way. Consequently, binary image of objects of interest is brought as a final result of the method. It may vary due dispersion threshold only, since we merge concrete regions which are independent on initial seed points on image.

C. Fractal dimensions at scale-based pyramids

The model to measure fractal dimension of image is two-dimensional scene with relief, the height of which is the brightness values of image pixels. Measure $S(x)$ is the square of the resulting relief. To measure the square of relief's surface a triangulation method may be used. Meanwhile four adjacent angles of sets-images are divided into two sets of three , and then , measure the square of a triangle "forward" – S_f and square "back" –. S_b Then the square of the surface bounded by the elements will be $S_1=S_f+S_b$ – for one scale and, similarly, for more detailed scale an estimate of the square will have a value of S_2. Therefore, in case of double scaling the fractal dimension *D* can be estimated by the formula [4]:

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$$D = -\log_s \frac{S_1}{S_2}.$$

Typically, analysis is carried out only with two scales. However, image may consist of several components, some of which become points at a scale greater than a certain number, while others still are sets at those scales. If we evaluate the fractal dimension of the whole image, the estimate *D* will not allow separate areas (clusters) of images, and moreover this estimate may be incorrect or distorted, since some image fragments might be unanalyzed. To compensate such an effect, it is sufficient to divide the image into small fragments where fractal dimensions to be estimated (Fig.3). If fragments are in the image of a fractal having the same dimension, the dimension and overall estimation of these fragments will remain constant. With this approach, we should talk about the local fractal dimension, as opposed to global, which is defined over the entire image.

Measuring local dimension question aroused: what is the size of image fragments? Obviously, this size should be no larger than the estimated size of the analyzed image elements.

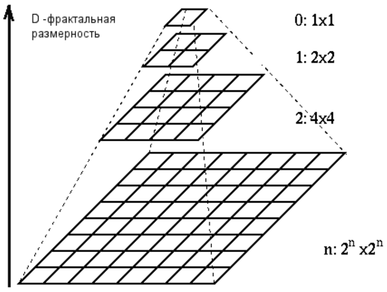
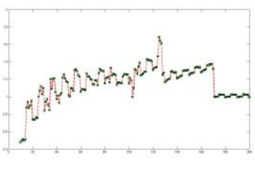
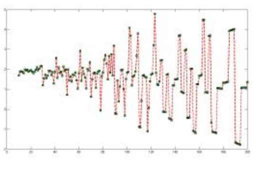


Figure 13. Pyramid for CT-image

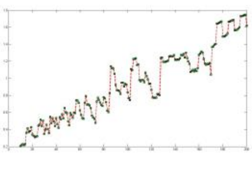
To determine the properties of CT-image of mediastinum the dependence of fractal dimension and size of the local area of analysis with size of fractal signature has built. As a result, the pyramids for the images have been built. Each layer is determined by sizes of local area and consists of fractal dimension's values. To simplify the perception of the material analyzed for each layer the value of fractal dimension is



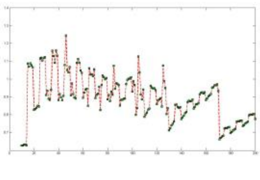
a)



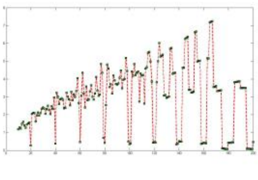
b)



c)



a)



b)

determined together with variance. Our studies are conducted for entire image, and for tumor fragment, both grayscale and on binarized image resulting from the halftoning using a threshold calculated with Otsu method adapted to local dimension. [5].

Figure 14. Dependence of mean value of fractal dimension for CT-image of lungs and localization size (size of aperture is 5): a) for binary image b) for halftone image, c) for binary image of tumor

Figure 15. Dependence of fractal dimension variance of CT-image of tumor and size of localization block (aperture value is 5): a) for binary image ,b) for halftone image

The fractal dimension of the halftone image was calculated by the method of triangulation, in case of binary image – using a standard way.

On charts of fractal signatures of objects one may observe periodic “jumps” (Fig.4) that characterize a selection of various objects in the image depending on the size of the aperture.

Charts for binary image are much smoother than similar one obtained by grayscale (halftone) image. This is due to the differences in the algorithms used to calculate the fractal dimension, as well as due to smoother structure of binary image. It is also worth noting that almost all charts have intervals with most adequate shape that were observed at a rate of localization blocks lying within the image being processed. Since the graphs of average fractal dimension depending on the size of the blocks could contain appropriate intervals so to assess which objects in the image at this stage influenced the shape of the graph.

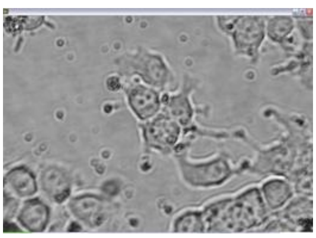
The dependence of the variance (Fig.5) of mean fractal dimension of the image resolution according to localization of the blocks has linear decreasing, that is because the larger unit's localization, the more uniform structure objects have that fall into it. Accordingly, the fractal dimension of these objects will not be much different. Moreover, the larger sizes of the aperture used in this processing, the less smooth been plotted. It is due to the progressive smoothing effect and thus increasing of smallest objects' size allocated during processing.

When the tumors image was processed it was found that the dependence of the mean fractal dimension and size of the localization blocks is almost linear. That is, the feature depends only on the size of the aperture in this case, as tumor has a rather homogeneous structure.

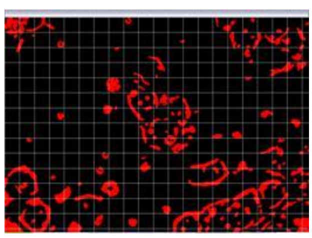
D. Topology features at magnification-based pyramids

Performing analysis of specimens (eg, histology) using optical images the pyramidal representation is perfectly suited for the determination of all the topological properties of objects, since every magnification has certain features group of tissue and its components: one king of objects is to be determined but other king of objects is not due to optical magnification of the image.

At different magnifications the subject of investigation is changing from cells to their conglomerates or tissue structures.



a)



b)

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So to determine characteristics we applied an approach [5] based on fractal dimension which is superimposed on the image and counting grid cells (Fig.6 and 7).

Figure 16. Elemental decomposition for fractal analysis: a) initial image; b) processed and decomposed image of cell boundaries

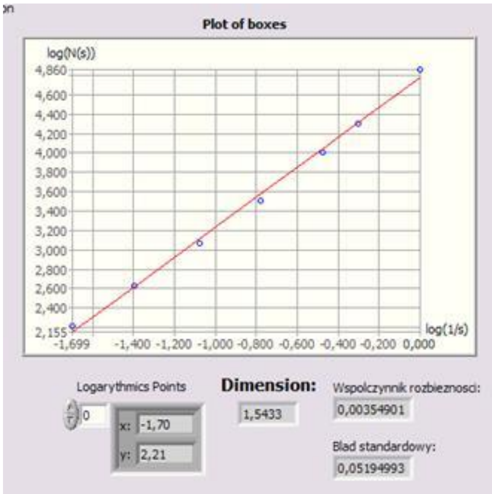

Figure 17. Dialog window of cells conglomerate fractal analysis

Rough boundaries lead to different values at different resolution/magnification. The higher the resolution, the greater the value of the dimension. Fractal dimension corresponds to the rate of change of the perimeter of the object in two-dimensional case; it also describes the changes at surface in three-dimensional case.

Firstly, after nucleus and cell structures objects are prevailing structure on the lower resolution images. After that cell conglomerates start to prevail. And finally, the structure which refers to the lowest resolution levels is tissue objects.

The dependency of the prevailing structures on the resolution levels of the image pyramids is represented at Fig.8. Where complex structures are represented by nucleus, cell structures or their combination and simple structures include conglomerates and tissue objects.

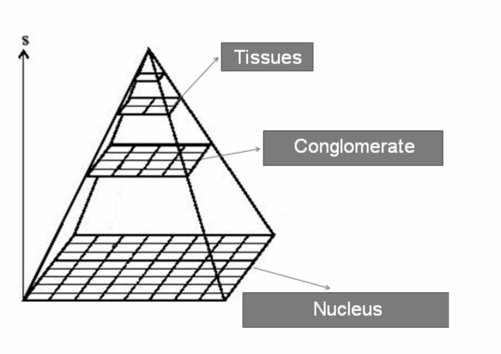

Figure 18. The dependency of the prevailing histological objects on the resolution levels of the image pyramid

According to the characteristics of the structures mentioned above and the corresponding pyramid layer resolutions it is possible to make conclusions about the specific physical or physiological characteristics of the observed histological objects. But this is a topic refers to another area and, therefore, is not to be covered in this article [5].

The scheme of histological objects and structures which is proposed above plays a key part in automated analysis of tissue and its components. So it is important when the methods for object extraction to be chosen

Histological objects varied depending on individuals. In general, its geometrical characteristics which are important for preliminary diagnostics are changing. Overall tissue characteristics are studied at low magnification which are: tissue structure and shape, presence of polyferation, tissue uniformity, etc. Characteristics of cells and its surrounding are determined at high magnification (500 - 2000 times). At low magnification a tissue fragments are visible (Fig.2), there are cells presented here as small contrast objects. Clusters of cells form tissue regions, which are different functionally from each other, so features of cell groups play a significant part to characterize a tissue structure. It is necessary to carry out the analysis of geometrical, topological and texture characteristics of cells to appreciate tissue fragment at oncological abnormalities (polymorphism, polychromism and anaplastics) [7].

Summarizing all aforesaid, we describe a morphological analysis, which is discovered in general as follows:

1. Low optical magnification (50-100 times, a presence of tumor is determined by studying of these characteristics and features of tissue and cell clusters:

- the Uniformity of tissue layer:

  i. Smoothness of layer edge;
  ii. Form-factor of layer edge;

- cells organization of layer in tissue:

  i. Distribution of cells by its area in layer;
  ii. Orientation of cells in layer;
  iii. Intercellular distance.

2. High optical magnification (500-2000 times). A diagnosis verification is provided by studying of cell characteristics:

- Cell morphometric parameters:

  i. Sizes;
  ii. Form;
  iii. Nucleocytoplasmic ratio.

- Nucleus parameters:

  i. Sizes;
  ii. Form;

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iii.Inner topological structure (Sulci; inclusions;mitoses - pathology in nucleolus organization.

For the qualitative specimens definition does work well for the most of features. Moreover it is very important to consider patterns of cells, vessels and fragments of tissue together for correct identification of object extracted from image.

E. Calculation of topological characteristics

There are several ways to describe an object's form. The most interesting characteristics is compactness. Compactness factor is a ratio of a particle area to the area of the smallest rectangle contained all points of objects. It is defined as

$$compactness = \frac{K \cdot AREA}{perimeter^2},$$

were AREA - is an area of dendrite, perimeter - is a perimeter of dendrite, K - is a calibration coefficient. The compactness factor belongs to the interval [0, 1]. The closer a shape of a particle to the rectangle, the nearer the compactness factor to 1. To define a topological features of the image a binarization of the images is carried out (as it is in the previous case).

Topological features of complex structures (bodes, gulfs, holes) are detected by operations of boolean logic and mathematical morphology smoothing. We defined three topological regions on dendrite images: body of dendrites, gulf and holes (fig. 3).

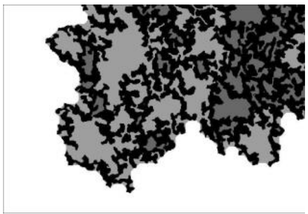

Figure 19. Hierarchical image after binarisation with topological features: black - body of dendrites, light gray - gulf, dark gray - holes

Gulf and holes are regions between dendrites. Gulf has connection with free space.

This regions are extracted by specific algorithm (fig.4).

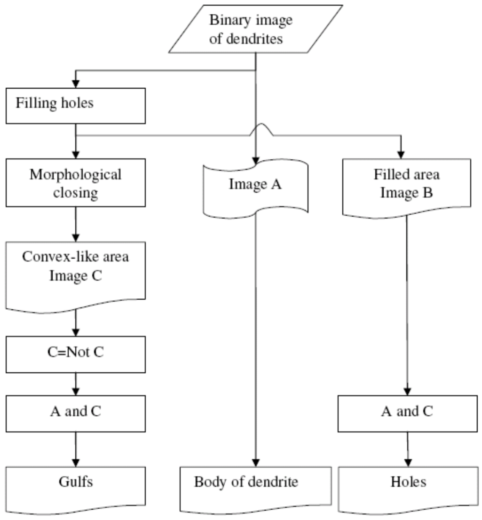

Figure 20. Algorithm extraction body of dendrite,gulfs and holes

The dendrites body encircled with holes. We propose next characteristic to describe these topological features: total area, gulf ratio, hole ratio, dendrite ratio. Total area is defined as a sum of all topological regions:

$$TotalArea = Area(gulf)$$
$$+Area(holes) + Area(dendrites),$$

were Area(gulf) - area of gulf regions, Area(holes) - area of holes regions, Area(dendrites) - area of regions of dendrite body. Others characteristics correspond to space filling and are defined as:

$$gulfratio = \frac{Area(gulf)}{TotalArea};$$
$$holeratio = \frac{Area(holes)}{TotalArea};$$

This characteristics describe rate of each type of region topology. For description of topological properties of dendrites it is necessary to extract a structures skeleton from a binary image.

This operation is realized by binary thinning operation (Zhang-Suen algorithm [5]). The basic definition for calculation are characteristics of body, skeleton, nodes and tails (fig. 5). A body corresponds to region of structures body. A skeleton is a centerline of geometrical object. Nodes are branchpoints of structure. Tails are last fingers of branch.

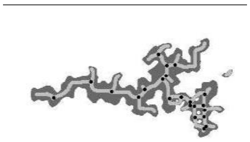

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Figure 21. Topological features of dendrites: gray - dendrites body, light gray - skeleton, black – nodes

For description of topology features of dendrite we define following characteristics:

branchiness, curliness, length, mean width of dendrite, tailness, tails curliness, tails ratio. Branchiness and curliness describe complexity of dendrite. They are defined by ratio of number of nodes to length of skeleton and number of skeletons segment correspondingly. The skeletons segment is a fragment of skeleton between nodepoints or endpoints.

$$Branchiness = \frac{count(nodes)}{length(skeleton)};$$
$$Curliness = \frac{count(nodes)}{count(segments)}.$$

Full length of structure corresponds to length of skeletons. Definition of tails allows to produce characteristics for description correlation termination properties with complexity of dendrites. They are tailness, tails curliness and tails ratio.

The most complex characteristic is structures width. It changes from point to point. We can’t define the width of skeleton in nodepoints and dendrites crossing. It is very complicated to distinguish skeleton’s endpoints from noise. For solution of this problem we proposed next approximation of mean dendrite’s width:

meanwidth=Area/length

This characteristic is just an approximation of real structures width. Construction of structures width distribution is very complex task, and small mistake appears when it performed. For magnetic complex structure this approximation is comparable with accuracies to real value.

VI. Definition of Structure

There are several different types of structures [4] determined on the magnetic images. We observe five basic configurations of image objects structures.

1. The object is characterized by many nucleation centers in observation area.

a. Blobs. They are the solid objects, without internal structure; a blob growing is isotropic.

2. The object is characterized by limited number of nucleation centers in observation area.

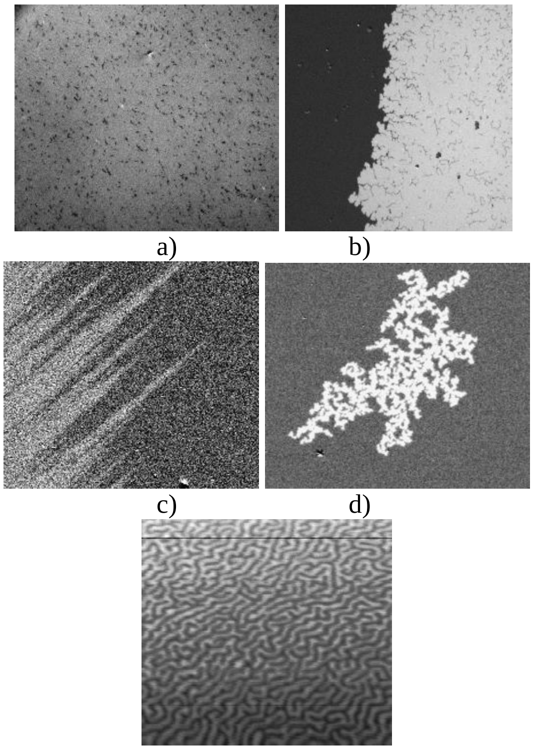
b. Front. This is a big object that is characterized by flat growing in one direction.

c. Needles. They are very elongated in one direction objects. Usually they have sharp terminations.

d. Dendrites. They are very complex objects. Dendrites represent connected structure of branch.

e. Nets are evolution of dendrite structures. They have all properties of dendrite structures expect preferential direction of growing. These structures appear in regions with filled band of structures blocks without global border conditions for convex region of structure. For this structure we cannot determine the center of nucleation. Nets have not border condition.

The basic image structures are represented in the Figure 3. Other objects are usually constructed by these four types of structures.



e)

Fig. 1 – The basic structures: a) blobs, b) fronts, c) needles, d) dendrites, e) nets

Static object analysis is divided into two categories. They are specialized object analysis and random object analysis.

Random object analysis requires a specially prepared binary image with the explored objects displayed on by the binary data. The scale should be specified for the image (it can be determined by the calibration function) and calculated characteristics should be determined. Specialized object analysis requires preliminary calibration only. This process is divided into four steps mentioned below.

1. Preprocessing
2. Image segmentation
3. Shape correction
4. Image characteristics determination.

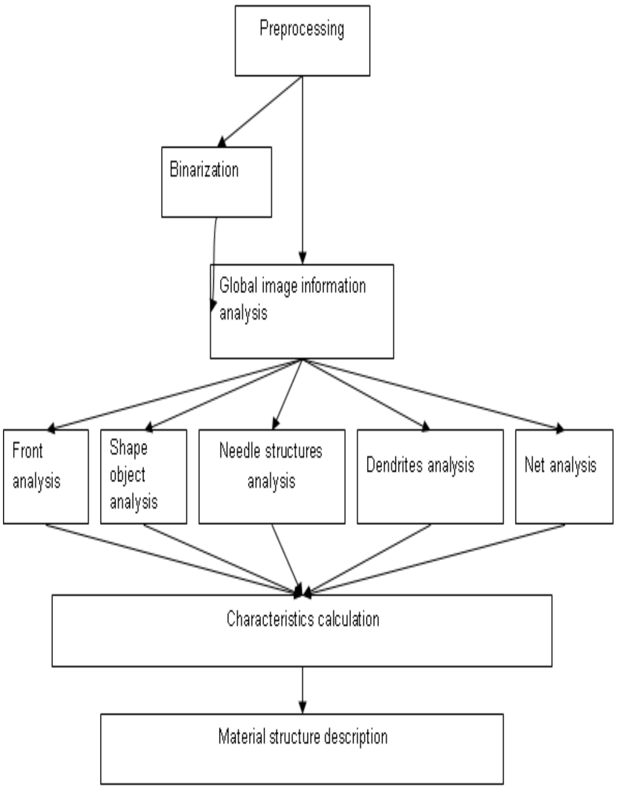


Fig. 2 – Specialized object analysis scheme.

Here is the specific description of the approach. Every image pyramid layer is analyzed and described by some value of the basal function. It is apparent that some descriptive statistic value can be associated with every level of the pyramid according to the values of basal function on this level. So, the dependence between the scale and pyramid level descriptive value can be analyzed and used for some conclusions or sometimes pattern recognition.

All these types of structures can be determined on different levels of the image pyramid of a magnetic image if the bottom level is represented by the nets or dendrites. The sequence of transformations is represented in Fig. 5.

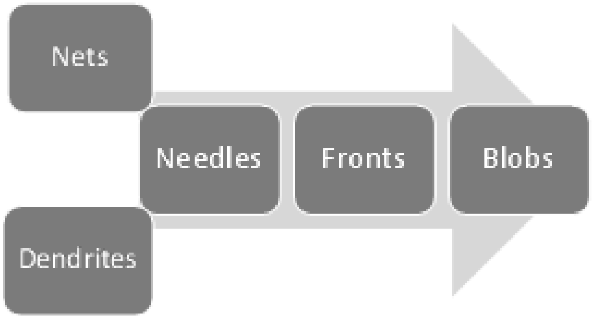


Fig. 5 – The way of prevailing magnetic structures transformations to each other on decreasing dimension levels of an image pyramid

Firstly, after dendrites or nets needles are prevailing structure on the lower resolution images. After that fronts start to prevail. And finally, the structure which refers to the lowest resolution levels is blobs.

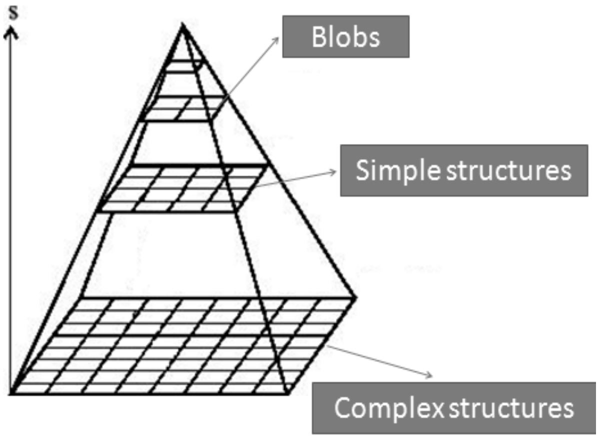


Fig. 6 – The dependency of the prevailing structures on the resolution levels of the image pyramid.

In the Figure 6 the dependency of the prevailing structures on the resolution levels of the image pyramids is represented. Where complex structures are represented by nets, dendrites or their combination and simple structures include needles and fronts.

According to the characteristics of the structures mentioned above and the corresponding pyramid layer resolutions it is possible to make conclusions about the specific physical characteristics of the observed magnetic objects. But this is a topic refers to another area and, therefore, is not to be covered in this article.

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Each of them has its own fractal characteristics which can be used for pattern recognition.

The study found that different organs have different fractal structure that allows the use of fractal characteristics in pattern recognition. By changing the size of the block of localization, we can determine the presence of various tissue structures. However, as the feature of the tumor the fractal characteristics for therapeutic or diagnostic purposes are not informative in computed tomography images so it well complemented by histological analysis methods. Thus, we recommend using a combination of research methods for one fragment of tissue at different medical images

6. TESTING INTELLECTUAL SOFTWARE FOR MEDICAL IMAGE ANALYSIS

At this time, the software has stage of developing. But we used a few tests for determination of essential possibilities. This software was tested on diverse kinds of histological and radiological images. Three types of histological images were used and two type of radiological image. Histological images were separated by cells density: high density - more than 68% image area for cells, middle density - between 38% and 72% image area for cells, low density - less than 40% image area for cells. Tested radiological images are separated into CT and MRI images. Once testing was constructed table with probability values of success image processing by generated scripts. A rate of success probability was defined by empirically method. The software was tested by 248 medical images.

Good marks for radiological images were taken. For histological images marks are insufficient.

7. CONCLUSION

In this paper, we proposed the system for automated generation of sets of medical image processing functions for analysis of image dictionary for prediction. Also, we developed method of software construction for image processing used intelligent software possibilities for reconstruction of itself depending from the task. We developed the solution using artificial neural networks and Bayesian networks. It was tested and the result shows that the intellectual software for medical image prediction can be used for medical image prediction. Such software can change your design and function and to adapt to the particular problem without reprogramming stage. As a result, it changes itself. Today, this software architecture is unique in the field of image processing and analysis, and has no analogs.

We proposed the system for automated generation of sets of image processing functions for image analysis and prediction. Also, we developed method of software construction for image processing used intelligent software possibilities for reconstruction of itself depending from the task. We developed the solution using artificial neural networks and Bayesian networks.

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