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Development of the Software for Recognition of Pathologies in the Images Obtained by the Wireless Endoscopic Capsule and the Atlas of Abnormalities

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Abstract: The wireless capsule endoscopy is a method of non-invasive examination of gastrointestinal tract widely used for screening purposes. The review of images taken by capsule usually takes several hours and requires a high degree of concentration by a doctor. To reduce the time and enhance the accuracy of data reviewing the special software for image processing is being developed. It is able to recognize abnormalities of the digestive tract. The study provides the information about the proposed software architecture and its implementation, the function it is to perform, user-friendly report interface development and the proposal for the creation of the digestive diseases' atlas that will provide information useful for both the professional community of physicians and for the developers of software for detection of pathologies and their symptoms in the images of gastrointestinal tract. The study provides the results of the software testing showing 94% accuracy. The research is underway to increase the accuracy of the algorithm to diversify the pathologies that can be identified in the images obtained by the wireless endoscopic capsule and to implement the atlas of diseases.

Key words: Software architecture implementation, report interface, ref channel, disease atlas, accuracy

INTRODUCTION

The wireless capsule endoscopy is the method of non-invasive examination of the digestive tract that nowadays is widely used for screening purposes. A patient swallows a tiny capsule that travels down the digestive tract taking photos (De Francis *et al*., 2012).

The endoscopic capsule helps gastroenterologists to diagnose sources of occult haemorrhage (Kukushkin *et al*., 2012), tumours (Li and Meng, 2012) or causes of abdominal pain such as Crohn's disease (Jebarani and Daisy, 2013) or peptic ulcers (Yu *et al*., 2012a). Timely identified pathology can not only shorten the time of treatment but also avoid surgical intervention or even save human's life.

The uniqueness of the method of capsule endoscopy of the gastrointestinal tract is believed by general public to be in the miniature camera and transmitter that allow taking images of the entire digestive tract. However, capsule endoscopic complex is not just the equipment it is also the specialized software that is constantly being improved becoming more convenient for the gastroenterologist (De Francis *et al*., 2012).

During the examination the wireless endoscopic capsule takes images of the gastrointestinal tract such as shown in Fig. 1.

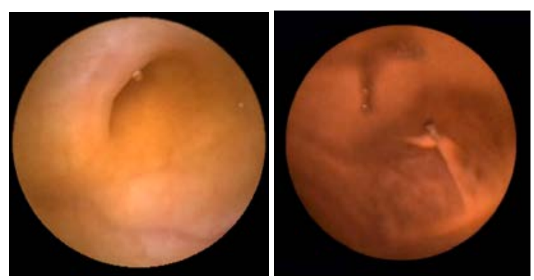

Fig. 1: Images of gastrointestinal tract obtained by the wireless endoscopic capsule

After the procedure some 57000 images of the digestive tract to be analysed are obtained (Yu *et al*., 2012b). Gastroenterologists usually spent several hours reviewing data array. Waiting for the capsule to reach various areas of interest in the gastrointestinal tract might also require several hours of a physician's time (De Francis *et al*., 2012).

This time-consuming process may be optimized by the software that provides automated pathology recognition significantly reducing the time of records reading and making the process more confident (Chen *et al*., 2011; Kukushkin *et al*., 2012; Dmitry *et al*., 2014).

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A number of developments (Bourbakis, 2005; Htwe *et al*., 2011; Fu *et al*., 2011; Chavez-Santiago *et al*., 2013) demonstrate the capabilities of decision-making systems to detect areas with pathologies in the images of gastrointestinal tract. For example, Chen *et al*. (2011) propose an approach to automatically detect the digestive tract pathologies in real time defining the Frame Abnormality Index using the ratio of training and testing data densities.

Nowadays, there are three major companies in the global market of capsule endoscopy equipment: given imaging (http://medical.olympusamerica.com/procedure/capsule-endoscopy), Olympus (http://www.givenimaging.com) and IntroMedic (http://www.intromedic.com/eng). Capsule complexes of these companies have quite similar software functionality: bleeding detection, screen multifunction, similar improvement goals (increasing the number of frames per second, image enhancement, viewing angle expansion), and others (Mikhaylov *et al*., 2013). Note that existing software is mostly focused on haemorrhage recognition.

However, it is not enough for the software to detect the location of the possible disease the data should be presented in a way comfortable for its reading and analysing.

The above companies propose different additional functions such as image adjustment function, displaying capsule track in 3D, bubble and debris image detection (OLYMPUS, 2013), capsule location detection (OLYMPUS, 2014), etc. (De Francis *et al*., 2012; Mikhaylov *et al*., 2013).

This study is devoted to the development of the special software for pathology recognition mainly focused on improving accuracy of pathologies recognition. The study also presents the user-friendly report interface development and the proposal for gastrointestinal diseases' atlas creation.

DEVELOPMENT OF THE SOFTWARE ARCHITECTURE

The proposed software for automated image processing should provide:

- Systematic storage and processing of data about patients
- Automatic data analysis
- Viewing and processing of analysis results
- Prior formation of report on the results of the survey in automated mode

The software will detect frames with abnormal parts of digestive tract the recognized pathology and suspected pathology on the basis of image analysis. In accordance with complete atlas of pathologies of the gastrointestinal tract the software identifies problem areas in the body such as tumours, ulcers, bleeding and polyps. Then, it creates a video-report with the most important frames from the point of diagnosis making (Fig. 2) which significantly reduces the time required and simplifies work on the patient's health record.

Unlike most of analogs (De Francis *et al*., 2012), (Mikhaylov *et al*., 2013) the proposed software is being developed with the function of automated detection of color, shape and texture anomalies (Alex *et al*., 2014), image editing such as labeling, resizing, scaling, image enhancement that increases the efficiency in the analysis of research materials. The software allows any

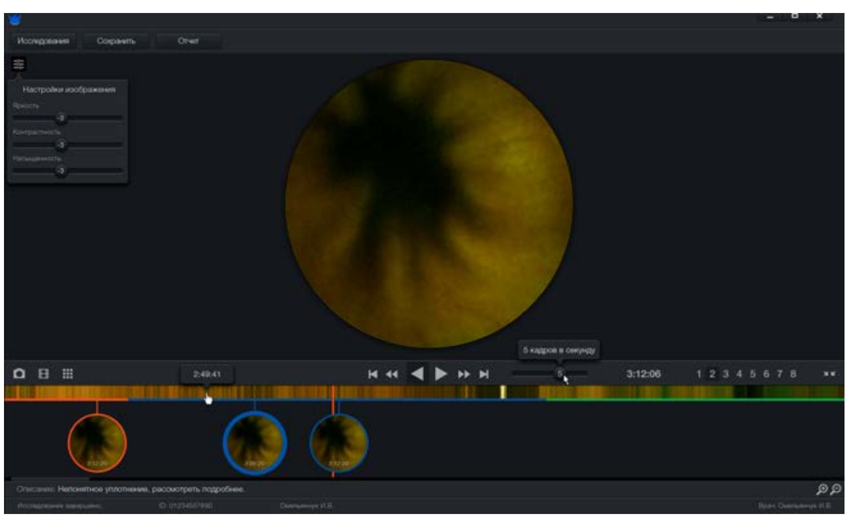

Fig. 2: Video-report of examination

type of report recording and can process data obtained by other capsule endoscopic complexes enabling by support of JPEG2000. Thus, the software for the wireless endoscopic capsule performs three consistent steps:

- Reads image of the gastrointestinal tract from an abstract repository (database, video, file system)
- Calculates the formal features indicating the possible presence of pathologies
- Submits the result to the input of the selected machine-learning algorithm

There is no need to implement the special machine-learning algorithm because existing solutions show good results and the appropriate one can be built into the developed software (Rapetov *et al.*, 2013). The developed software is based on three classes: bank, feature and output corresponding to the above mentioned steps.

Bank is an abstract class-iterator declaring two methods common for iterators: HasNextItem and GetNextItem. For different sources these two methods can perform different functions. For example, if the source is a video stream and it has frames, the HasNextItem will respond true, otherwise false and GetNextItem will return the next frame. The object returning by GetNextItem is the object of the BankItem class with two fields: image and its description (the table with string keys and their values).

Feature is an abstract base class determining the only one method GetValue that receives an image and calculates the set of formal features. Most features have large number of configuration parameters such as colour model, channel name, number of histogram cells for the “histogram channel” feature. For a homogeneous work with configuration parameters the class-table feature configuration with string keys and numeric values exists.

Output is also an abstract base class that accumulates the calculated features for all the images and converts the result into a format required by the selected machine-learning algorithm. Methods append and format are responsible for the two described steps (Alexander *et al.*, 2013).

COMPARISON OF MACHINE-LEARNING ALGORITHMS

As a part of the software development, consider the machine-learning algorithm (naive Bayes classifier, linear regression, logistic regression or Support Vector Machine (SVM)) (Table 1). In Table 1 contractions mean:

Table 1: Comparison of Machine-Learning Algorithms

Variables	Bayes	Linear	Logistic	SVM
CA	0.929	0.748	0.789	0.791
AP	0.912	0.606	0.680	0.791
TP	46.000	49.000	48.000	49.000
FP	1.000	17.000	13.000	14.000
FN	4.000	1.000	2.000	1.000
TN	20.000	4.000	8.000	7.000
Recall	0.920	0.980	0.960	0.980
Precision	0.979	0.742	0.787	0.778
F2	0.948	0.845	0.865	0.867

- CA (Classification Accuracy): the share of correctly classified images from the processed array of images
- AP (Average Probability): if the function does not give a binary response but estimates the probability, it is possible to calculate the average value by the probabilities to which correctly classified images were assigned
- TP (True Positive): the number of correctly classified suspicious images
- TN (True Negative): the number of correctly classified normal images
- FN (False Negative): the number of suspicious images that were classified as normal
- FP (False Positive): the number of normal images that were classified as suspicious
- Recall: the share of suspicious images shown to the physician relative to all suspicious images
- Precision: the share of suspicious images shown to the physician relative to all shown images
- F2: F-measure, the harmonic mean between precision and recall

According to Table 1, the naive Bayes classifier has the best indicators. However, it was decided that such a result comes from the particularity of the set of features on which the classifiers were tested. Therefore, the next algorithm according to F2 has been selected support vector machine.

SELECTION OF THE MACHINE-LEARNING ALGORITHM IMPLEMENTATION

Three different implementations of Support Vector Machine were considered: Orange, SVMLight (Thorsten, 2008) and LibSVM (Chang and Lin, 2001; Joachims, 2008).

Orange: Orange library not only implements many machine-learning algorithms but also includes a complete tool for data analysis. The library has an interface for the Python language (http://www.python.org/about/) that leads to poor integration into the developed software (written in C++). Orange library allows using the strengths of the Python language and simple calculation of basic performance parameters of several machine-learning algorithms at once. Indicators for Table 1 were calculated using the Orange library.

SVMLight: SVMLight implementation is written in C language and includes a variety of optimizations to speed up the calculations. For this reason, the implementation is well suited for large training samples. SVMLight utility provides a user-friendly console interface but is not well suited for integration into third-party code.

LibSVM: LibSVM is a set of libraries and basic tools that use these libraries. LibSVM as well as SVMLight is written in C and has good performance. At the same time, it is much easier to build LibSVM into the project developed in C or C++ than SVMLight. With source code of LibSVM the utility for the optimization of model parameters and the tool for cross validation are distributed.

Thus, as the support vector machine implementation LibSVM has been chosen. The results of the performance of utilities for optimization of parameters and cross validation are shown below.

SOFTWARE ARCHITECTURE IMPLEMENTATION

Before telling about data transmission software, consider the information exchange scheme of the endoscopic capsule (Fig. 3).

Upon completion of the endoscopic examination capsule reader is connected to a doctor's personal computer. When the data transmission is completed doctor launches software for automated image analysis. It performs automated analysis of digestive track images for signs of disease and gives the gastroenterologist the results of work with a note about the need to study the image in details by the specialist. This also solves the problem of determining the location of the capsule at the time of image taking.

The software architecture described above is well suited for the problem of pathology recognition. Figure 4 shows an abstract class bank and its successors. The successor DirectoriesBank implements the logic of the simple hierarchical database. Assume that a file system has the tree as presented below:

```
healthy
   healthy01.jpg
   healthy02.jpg
bleeding
bleeding01.png
```

Consistently fetching the HasNextItem and GetNextItem methods of DirectoriesBank class it is possible to get the output:

```
32healthy01.jpg healthy
healthy02.jpg healthy
bleeding01.png bleeding
```

This approach is very useful for storing the training sample. The file system can have a nested structure and the images can present a symbolic link to each other.

The successor VideoBank is designed to work with a video stream. The HasNextItem and GetNextItem Methods are implemented in such a way as HasNextItem returns true until it reaches the last video frame. With each fetch GetNextItem returns a new frame and if the video is over it returns the last image. Figure 5 shows an abstract class feature and its successors.

The successor ColorFeature implements the logic of plotting the histogram of image channel. It should be noted that the result of the performance is the non-normalized histogram. For normalization the NormalizeFeature class is used.

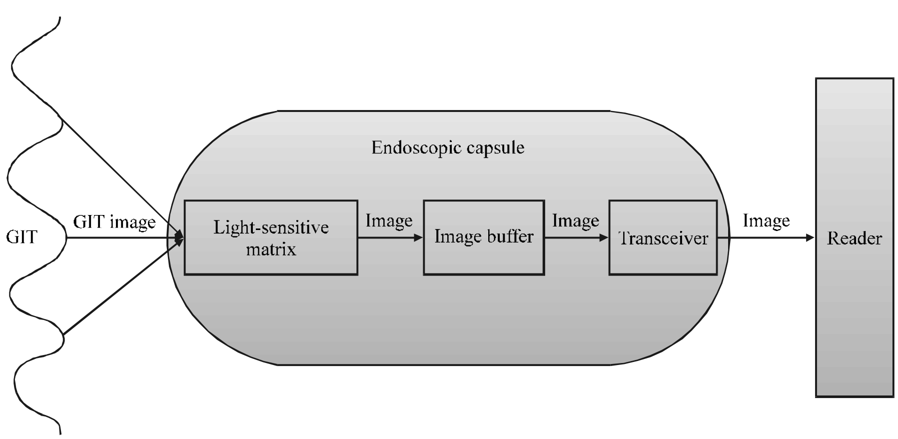

Fig. 3: Capsule information exchange scheme

The successor TextureFeature is used for plotting the texture histogram. The logic of this class is that for each image submitted for processing, the class calculates some 30 contractions that affect the performance effectiveness. Therefore, the use of this module when processing the video has been abandoned.

The NormalizedFeature and QuantedFeature classes implement the similar functionality they convert the already calculated histogram of some value.

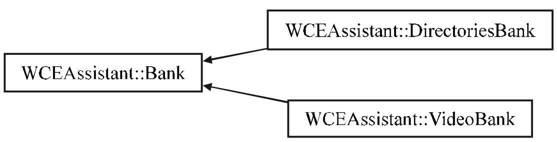

Fig. 4: Diagram of successors of an abstract class bank

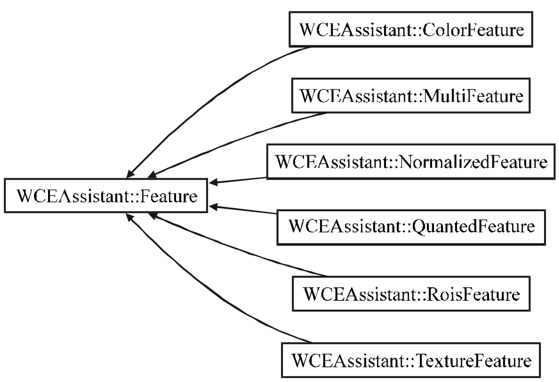

Fig. 5: Diagram of successors of an abstract class feature

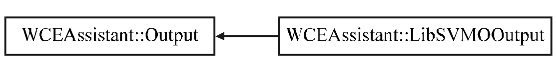

Fig. 6: Diagram of successors of an abstract class output

The RoisFeature and MultiFeature classes are also similar in the sense that the result of their work is the integration of feature values calculated by other modules.

An abstract class Output and its successors are presented in Fig. 6. LibSVMOutput is the only successor responsible for the presentation of features in the format with which LibSVM library works. The standard version of LibSVM works with sparse matrixes of features, i.e., in the description of the training sample some features for some objects may be missed.

REPORT INTERFACE DEVELOPMENT

The examination of the gastrointestinal tract with the wireless endoscopic capsule provides a large array of images (Yu *et al.*, 2012a, b). So, it is important that the developed software presents the data in the readable form. For this reason, it was decided (as an option to standard interface, shown in Fig. 2) to place all the images in a large two-dimensional matrix and give the user the ability to quickly change its size and position.

This interface is similar to the way of navigating through the internet maps when the user can easily change the map scale as well as latitude and longitude.

For the interface implementation it is rational to use one of the program maps solutions. It was decided to use the library of Yandex.Maps (http://api.yandex.ru/maps/) because they work in a browser and are provided with the Russian-language support.

Yandex.Maps like their competitors gives the ability to work with custom map layers and define the coordinate system different from the Mercator projection. Using these capabilities all images obtained by the wireless endoscopic capsule were placed in one large "map". The possibility of easy navigation became possible automatically. An example of the interface is shown in Fig. 7.

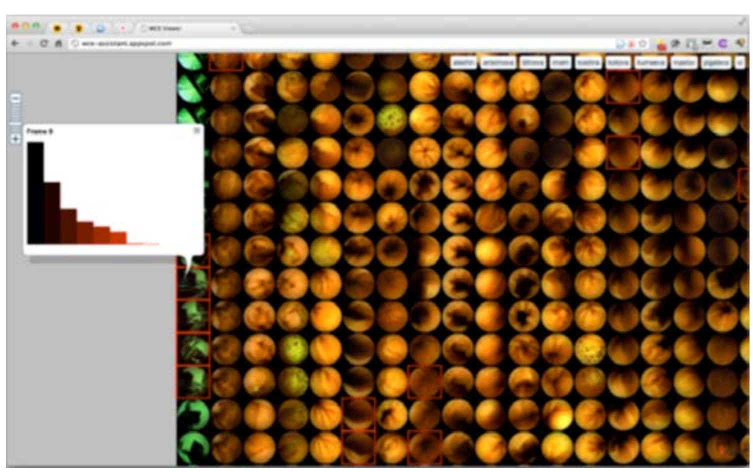

Fig. 7: The features calculated for each image are presented diagrammatically

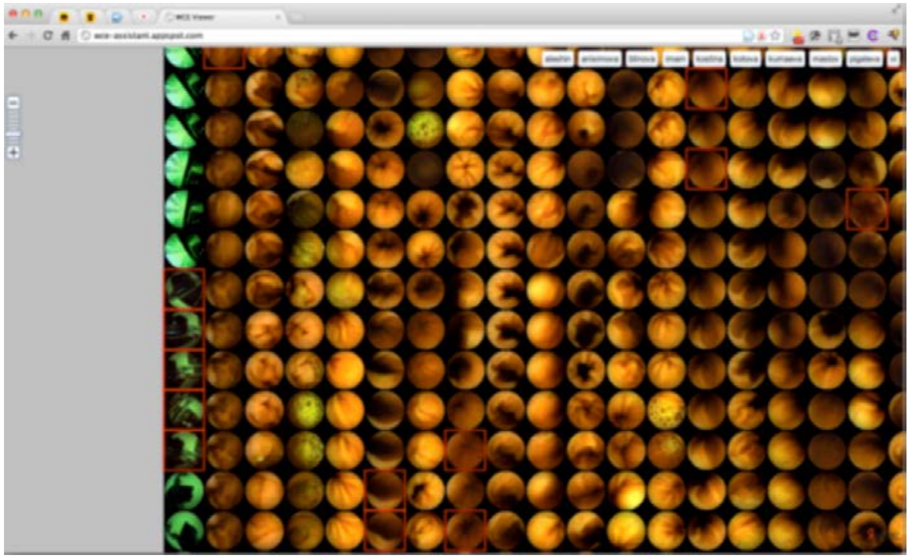

Fig. 8: The interface of work with arrays of images obtained by the wireless endoscopic capsule

Figure 7 shows that the image that were considered by the algorithm as abnormal are marked with a red frame. It is also possible to get a visual representation of the features calculated for each image. For this purpose, it is necessary to click on the image. An example of this function performance is shown in Fig. 8.

This feature is very useful when it is necessary to compare the value of a particular feature for the images containing healthy parts of the gastrointestinal tract and for those with pathologies or morphological changes.

Since, the interface is implemented in a browser, it has been put on the internet (Kukushkin *et al*., 2012). The hosting of the Google Company and file storage of the Amazon were used.

PROPOSAL FOR GASTROINTESTINAL DISEASES' ATLAS CREATION

As a part of the developed software for recognition of abnormalities and morphological changes of the digestive tract on the images obtained by the wireless endoscopic capsule it is proposed to create a service (atlas) that will provide information useful for both the professional community of gastroenterologists and for the developers of software for detection of pathologies and their symptoms in the gastrointestinal tract.

The idea is to create network storage of capsule findings. The software will enable physicians to save and annotate the images interesting from a medical point of view and send them into a common database accessible for the professional community. Along with the images the database will receive anonymous data about the patient sex and age.

The proposed network functionality will create a constantly updated atlas of diseases, assembled by the professionals that will allow physicians to quickly and effectively diagnose the patient. Gastroenterologists will be able to make queries on the supposed illness and compare the obtained image with those in the database.

There are two ways to find necessary images in the atlas: by terms describing the pathological changes or by diagnosis. The image of the pathology and the picture that interests the physician are demonstrated on the screen at once. The atlas will provide the opportunity to expand the knowledge of the gastroenterologists (even an experienced user) but will not serve as a substitution for the endoscopic experience.

Also, the atlas of pathologies is needed as a test set of images for the further development and debugging of the automated abnormality detection functions of the wireless capsule software.

TESTING

For the software testing the training sample from the 110 image received from the wireless endoscopic capsule was taken. Among them 50 images contained the healthy parts of the gastrointestinal tract and 60 with pathologies or their symptoms. On this sample, the training was conducted. The process was repeated for different parameters of the algorithm. The best result was selected by cross validation. The code for the red channel histogram generation (as an example) is presented as below:

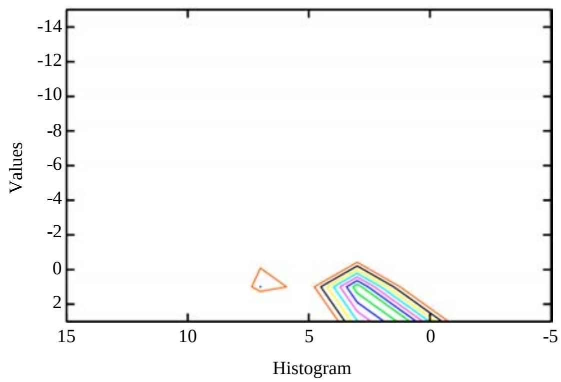

Fig. 9: Search grid of optimal parameters. Red channel histogram

```
FeatureConfiguration configuration;
configuration["Bins"] = 10;
configuration["Optimize histogram"] = 0;
configuration["Channel"] = 0; // Red
ColorFeature red(configuration);
NormalizedFeature redNormalized(red);
FeatureValue feature =
  redNormalized.GetValue(image);
```

The result of the search of pathology is shown in Fig. 9 (lines show localization of bleeding). The maximum algorithm accuracy (percent of correctly detected pathologies) is 94.337% (it means that out of 375 testing carried out in 352 the algorithm correctly identified abnormalities).

The maximum time required for primary video processing and automated formation of the preliminary report for a doctor is about 10 min. The average processing time in one study to generate the corresponding report by the physician does not exceed 5 min (Klokov *et al*., 2013)

CONCLUSION

The developed software for automated haemorrhage recognition in the gastrointestinal tract performs three consistent steps: image reading, feature indicating and result submission to the machine-learning algorithm. It provides the identification of pathologies and their suspicions and their presentation in a suitable for the reviewing way.

The software testing showed 94% abnormality prediction accuracy (percent of correctly detected pathologies). The research is underway to increase the accuracy of the algorithm to diversify the pathologies that can be identified in the images obtained by the wireless endoscopic capsule and to implement the atlas of diseases.

As a part of future software improvement it is planned to create a virtual model of the gastrointestinal tract which represents a new way of storing and analysing health information and creating a constantly updated database of processed images. Such a database can be filled from a plurality of remote computers via the internet. On the basis of the database an expert system of the gastrointestinal tract diagnostics according to the endoscopic examination which may operate in the online mode will be developed.

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