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FEATURES OF A FREE MAMMOGRAPHY DATABASE TO MANAGE A RANDOM BREAST PHANTOM IMAGES DATASET INTENDED FOR TESTING CAD SCHEMES

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Abstract: A previous structured images database intended to be used as a tool to researchers testing developed image processing techniques in mammography is being upgraded with new tools and images sets. Its original management system allows to choose and download high quality mammographic images, as from old digitized films as well as from direct digital files acquired more recently. Its search engine is of freely access online, it has incorporated new features, and new types of images intended to aid performance tests of processing schemes. In this sense, we discuss here new tools implemented in the management system to be able to handle images of a new breast phantom with random distributions, exposed to different DR mammography equipment. We described some of the new database management system features to archive, search and download phantom images, together with an evaluation which compares these kind of images with those from actual breasts in order to validate this new set in terms of visual analysis. Previous results not only have indicated a reasonable level of similarity between phantom (ie., simulated) images and actual ones, but the utility of implement this dataset as a section of our mammography database in aiding performance tests of CADx schemes techniques addressed to detect and/or classify signals of interest in digital mammography.
Keywords: Digital mammography, breast phantom, breast images database, CAD scheme.

INTRODUCTION

The evaluation of computer-aided diagnosis (CADx) schemes in mammography [MALICH et al., 2006], [GILLIES et al., 2016], [KATZEN & DODELZON, 2018] is usually performed by applying the corresponding techniques to digital images stored in databases used as ground truth in statistical rate surveys of sensitivity and specificity rates. The relation between these rates using ROC [EVANS, 1981] or FROC curves gives an estimate of such schemes efficacy.

Such databases should have included large set of mammographic images showing as normal as suspicious cases, radiological reports (eventually with biopsy confirmation) for each case and preferably, images should be of high contrast and good quality, with adequate spatial resolution and no compression of the digital file. Moreover, for these bases of universal use, it would be useful free access to the files [NISHIKAWA, 1998].

Open mammographic databases widely used for testing processing schemes, as DDSM [HEAT, 2000] and MIAS [SUCKING et al., 1994], for example, have some limitations. MIAS contains low-contrast scanned images and unbalanced number of malignant and benign findings among its cases. Although extensive and well documented, DDSM is no longer being updated and their archives do not have sufficient accuracy in findings outline, making it difficult to validate lesion segmentation algorithms. In addition, both manage files from digitized film mammograms, quite far from the current state-of-art of direct digital mammographic images.

Many mammography datasets are hard to be available, since they were developed as researchers, radiology centers or hospitals properties. Therefore, researchers in the field often develop their own databases to evaluate computational schemes, often with restricted access to research team members [AMENDOLIA et al., 2001], [WARREN et al., 2007], [MOREIRA et al. 2012].

As an alternative, the use of both physical and computationally synthesized breast phantoms [CALDWELL & YAFFE, 1990], [CHEN et al., 2017], [ACCIAVATTI et al., 2017], [SOUZA et al., 2017], [BAKIC et al., 2018] may be useful for replacing datasets of images from actual breasts overcoming their restrictions and availability. In addition, this rules out the need for medical and/or biopsy reports to obtain the data requested in performance evaluation of computational schemes. However, similarity between images from typical actual breasts and those from the phantom, mainly in the inner regions (background) is an important requirement for the effectiveness of testing digital image processing techniques.

Indeed the main problem is that most of physical phantoms always correspond to the same type of structure [CALDWELL & YAFFE, 1990]. On one hand, it does not allow obtaining a significant number of different images and, on the other, it can induce the computational scheme to get adapted in the constant internal characteristics so that it always get detecting the existing structures of interest.

In order to overcome such limitations, we have developed in previous works [SIQUEIRA et al., 2015], [SOUZA et al., 2018] an innovative breast phantom, especially designed to be used in evaluating computational techniques designed either for detecting relevant findings or for their interpretation. Its main characteristic is the possibility of obtaining images of random distribution of simulated structures over many layers of random background distribution in order to simulate not only different thicknesses but also different densities. Many exposures of such phantom have provided a number of images as well as their corresponding gold standard, that is, the map information on the type and location of simulated internal structures.

As this phantom was previously validated according to physical characteristics [SOUZA et al., 2018], another required validation under investigation is the level of similarity with actual mammograms in terms of inner regions of interest according to the images visual perception. This could make it possible developing a breast phantom database to be incorporated to our previous structured "BancoWeb" mammographic database [MATHEUS & SCHIABEL, 2011] (freely available online), and designed to be a source of testing image processing schemes focused in digital mammography.

Therefore, the main goal of this work is to describe a set of new tools implemented in the management system of our database in order to incorporate handling the images of our breast phantom acquired in different DR mammography equipment, after considering those images validation in terms of physics and visual perception characteristics.

DATABASE MANAGEMENT SYSTEM AND COMPARISONS

"BancoWeb" is a public database containing images and information on mammography exams, requiring user registration (authorized by the system administrator). MIAS [SUCKING et al., 1994], DDSM [HEAT, 2000], INBreast [MOREIRA et al. 2012] and BCDR [AUGUSTO, 2014] are the most known public with free access. Others however, as LLNL from UCSF [LAWRENCE LIVERMORE NATIONAL LIBRARY], charges US$ 100 for 12 CDs but apparently is no longer available. Among the public databases, only "BancoWeb" currently is still an open project, which aims to keep developing for at least the next few years. For instance, MIAS [SUCKING et al., 1994] and DDSM [HEAT, 2000] will no longer perform updates and are not responsible for any technical issues they may present. A description of the main characteristics regarding such databases is shown in **Table 1** for comparative analysis.

	MIAS	DDSM	LLNL / UCSF	Mammo Grid (CALMa)	IN Breast	BCDR	*Banco Web*
Year	1994	1999	2010	2001	2013	2013	2010
Country	UK	USA	USA	Italy	Portugal	Portugal	Brazil
Number of images	322	10480	198	3369	410	1247	1700
Breast image type	Screen-film	Screen-film	Screen-film	Screen-film & FFDM	FFDM	FFDM	Screen-film & FFDM
Files	PGM	PNG	DICOM	?	DICOM	TIF	TIFF
Files access	Free	Free	Paid (US$ 100)	Only project members	Free	Free	Free after register
Contrast resolution (bits/pixel)	8	12 (80%) 16 (20%)	12	12	12	8	12
Searching tool	No	Yes (But not working)	*	*	*	*	Yes
CADx classifying	No	No	No	No	No	No	Yes
Phantom images	No	No	No	No	No	No	Yes
Maintenance and upgrade	No	No	Yes	Yes	Yes	Yes	Yes

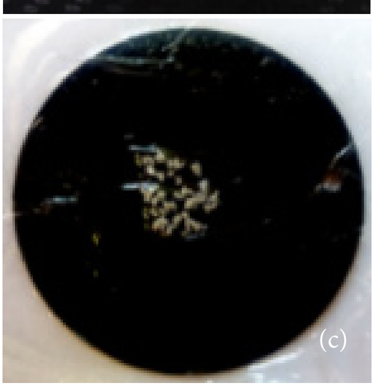
Table 1: Main mammography databases comparison.

Nowadays "BancoWeb" contains about 1,700 images for free access online corresponded to digitized films (by Lumiscan 50 and Lumiscan 75, Lumisys, Inc.) with 12 bits of contrast resolution and spatial resolution of 0.085mm or 0.150mm. There are also about 200 images from DR-type mammography systems. Currently about 600 images from the breast phantom [SOUZA et al., 2018] are also available for free downloading mainly aiming tests of image processing schemes in mammography. About 700 users are registered in the database.

The high versatility of configurations allowed by the phantom arrangement (and hence the very large amount of different images possible to produce, with or without signals of interest) is a unique tool in this field. Furthermore, this feature is important for the main purposes of this database, that is, providing support to tests of computational imaging techniques and schemes in mammography. "BancoWeb" is still a free access mammography database with a broad and functional search engine. Such a system displays image and patient information, clipping tools, and it enables classification by an associated CADx tool besides allowing complete mammogram download. In addition, it offers a variety of search options, enabling the user to search for a specific image or feature.

METHODS AND MATERIALS

An extra management system module was implemented in "BancoWeb" database regarding the possibility of archiving and handling (for later download by the users) images from the recently developed breast phantom [SOUZA et al., 2018]. Such a phantom consists of ten layers composed of paraffin gel with submerged PVC film in a non-uniform distribution, and four layers composed only of paraffin gel. The main layers distribution is to simulate more or less dense regions, according to the material concentration, resulting in the four BI-RADS® density classification categories. The nodules were simulated using two printed three-dimensional models, one for circumscribed lesions and other for spiculated lesions. For microcalcifications, granulated hydroxyapatite distributed in four clusters representing cases commonly found in actual breasts [SOUZA et al., 2015] was used. Each simulated structure (nodules or microcalcifications) may be inserted physically inside the phantom layers for the exposure or, additionally, over a phantom radiographic digital image also by using a computational tool. In this case, intensity and location of each lesion may vary depending on the user's choice. Fig. 1 illustrates the phantom structures and a typical image.



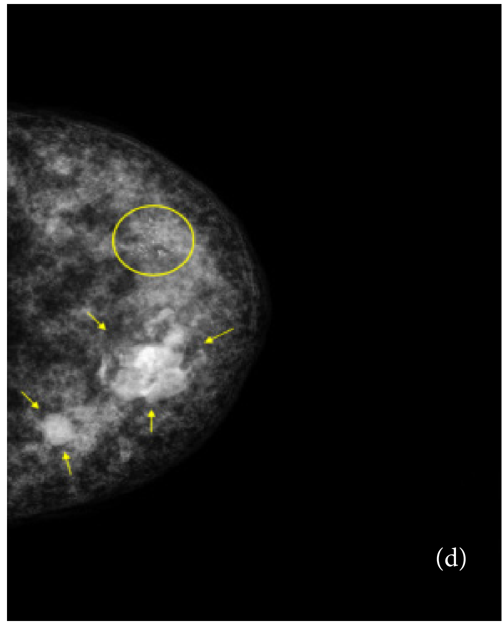
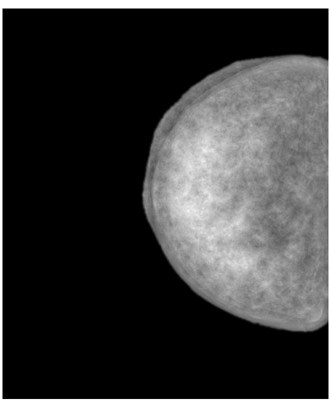


Fig. 1. (a) Phantom and its layers (paraffin gel, left, and paraffin + PVC film, right); (b) 3D models of nodules; (c) cluster of granulated hydroxyapatite simulating microcalcifications; (d) example of a phantom image with simulated lesions.

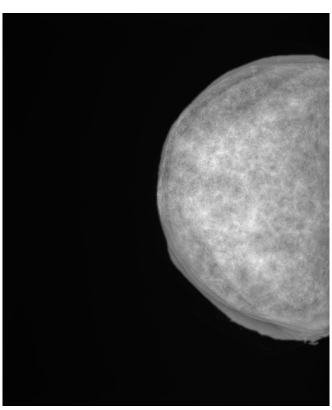
This phantom main characteristic is its flexibility in representing a large number of different radiographic projections, such as simulating a large number of different mammographic images. As a result, this feature makes it possible to generate a statistically significant amount of different images representing suspicious or normal signals of clinical interest [SOUZA et al., 2018].

Previously evaluated according to its main physical properties [SOUZA et al., 2018], the phantom applicability was also investigated according to the characteristics of images obtained with its exposure to FFDM mammography systems. Thus, extensive sets of images resulting from many phantom exposure tests were produced and stored with all the information templates regarding each image acquisition. Along with the many technical information relative to the acquisition process contained in the DICOM header of each image, other data such as the configuration of the phantom layers, and the location and type of simulated structure inserted are also recorded. Fig. 2 illustrates examples of some images obtained by exposures of such a phantom in a GE Essential mammography unit.

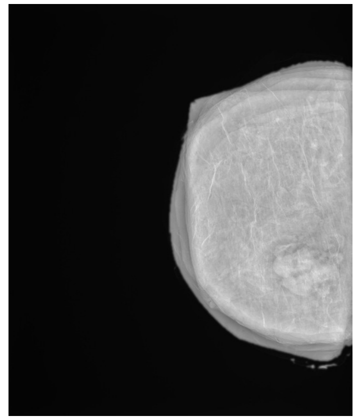
(a)



(b)



(c)



(d)

Fig. 2. Breast phantom layers positioned under the X-ray tube (simulating a compressed breast) of a DR mammography system (a), and 3 typical resulting images. Configurations: (b) 2 medium density layers + 2 paraffin gel layers + simulated round nodule (thickness of compression: 44 mm) ; (c) 2 different medium density layers + 2 paraffin gel layers + simulated round nodule (thickness of compression: 38 mm); (d) 2 low dense layers + 3 paraffin gel layers + simulated spiculated nodule (thickness of compression: 53mm). According to the registered template, the simulated nodule (indicated by the arrows) was located always at the middle of lower quadrant in the images and all the exposures were made in the CNT Auto mode.

With a view to design a module in our database exclusively to all the phantom images, menus were created to register equipment, findings, phantom image, and tools to phantom image searching with appropriate adjustments to the records and image profile. In addition to tables corresponding to such new menus, a field was added to register the type of finding in order to distinguish the common signals in actual breast images recorded in the database from the set of phantom images.

At the registration of each phantom image a set of information is recorded: (a) description, distribution and type of signal (nodule or clustered microcalcifications present at the referent image); (b) mammography equipment used during the phantom exposure – images were obtained from exposures in DR (as HOLOGIC Selenia Dimensions, and GE Essential) and CR systems (as LORAD M-IV with CR Agfa 85); (c) X-ray exposure characteristics, as selected target/filter at the tube, processing mode (when this information is available), kVp, mAs, compression; and (d) phantom characteristics during the exposure for each image, phantom configuration and the associate template – the image containing information on the precise location of each simulated lesion when inserted – for reference.

In order to discriminate the records corresponding to actual breast images from the phantom images, a “Belongs to” field has been created allowing to select whether the type of finding is part of an actual image or of a phantom image.

Image search menu allows exploring any set of information. The phantom image search has 4 sections divided into: equipment data, hospital data, phantom signal information and image data (target/filter combination, processing, image name, phantom configuration, kVp, mAs, compression, density and lesion). When using this menu, an internal procedure displays a list of results corresponding to the images with such chosen characteristics available within the database (see Fig. 3). When displaying a single image, all information recorded in the database about that exposure is displayed as a searching return. By selecting the template button a screen containing the template (reference) image corresponding to the phantom image displayed is exhibited. Alternatively the “More Information” button can be selected so that image, the respective template, and information on the equipment, image source, system, hospital, findings (with respective distribution and type), phantom layers configuration, target/filter combination, processing filter, kVp, mAs, compression, density and lesion, are displayed on the same screen as illustrated in Fig. 4. This same return screen allows downloading all the cases, that is, images and information (in .txt format), compressed into a .RAR file.

Some mammography databases have characteristics that do not adequately meet requirements for the development of CADx schemes [MATHEUS & SCHIABEL, 2011]. With this point in mind, our “BancoWeb” database has a tool implemented regarding integration with a single CADx scheme previously developed in our group [MATHEUS et al., 2015]. This is an extra feature provided by the management system which is being also integrated to the phantom images sets. It works as follows: when searching for a given image, there is an option called “Clipping”, allowing selecting part of such an image to download only this region instead of the whole image file. In addition, a classification of a given image is also possible from this clipping: once selected a single suspicious region, the system automatically sends the clipping to the integrated CADx tool that analyses it and returns information on the finding as “Suspect” or “Normal” as illustrated in Fig. 5.

A next step in the development of our phantom images set will be incorporating such a tool in the management system to evaluate its efficacy with those images by comparison with the templates containing the true information about the inserted simulated nodules and their correct locations.

Firstly to this CADx scheme integration however we had to investigate the visual perception behavior of such sets of images in order to assure some similarity to actual breast images regarding the main procedures applied by image processing techniques intended to detect and/or to interpret structures of clinical interest in mammography. The main approach

Fig. 3. Typical return screen from the phantom images searching.

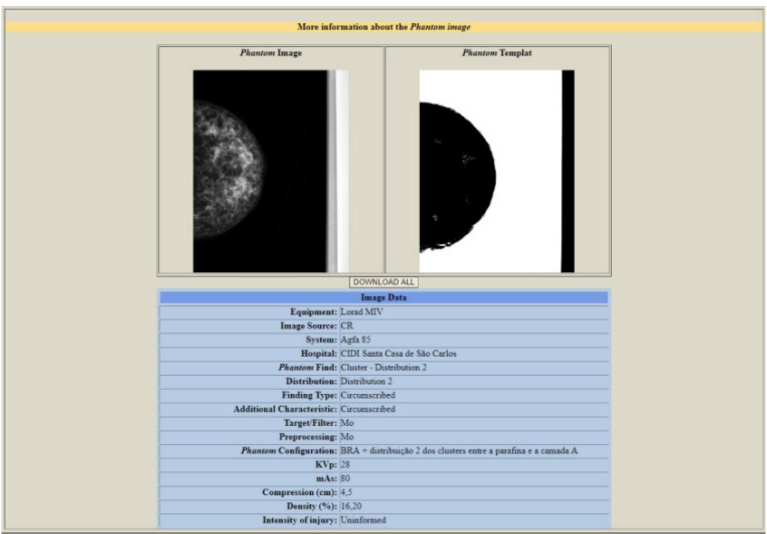


Fig. 4. Typical outcome screen when selected the "More Information" option in the menu.

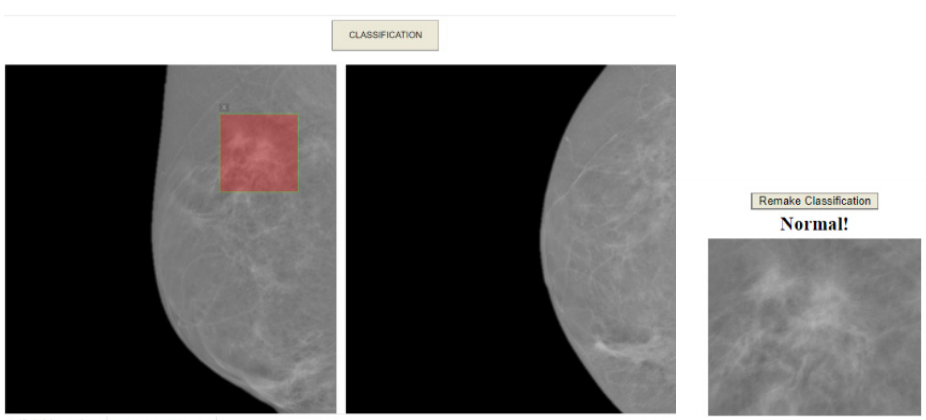


Fig. 5. Actual breast image clipping and respective CADx classification.

used in this investigation was divided in the following steps.

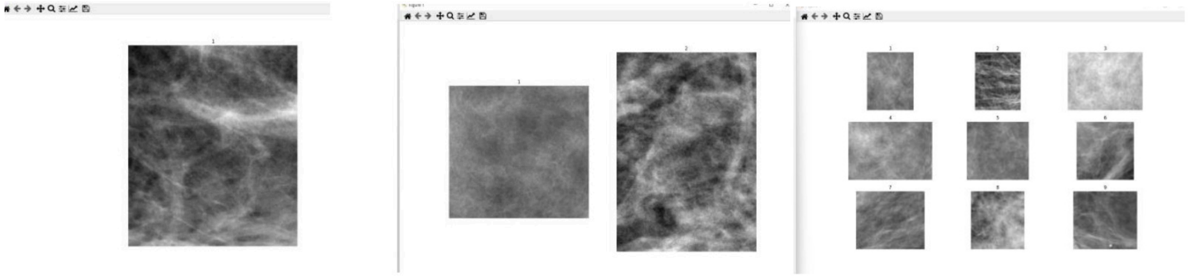
The first one was selecting a number of images from the phantom exposures as well as from actual breasts exposures preferably obtained in the same FFDM system. Then, regions of interest (ROIs) were cropped from these images, always considering areas corresponding to the background (depicting regions of the breast parenchyma), since these are the parts of the image where there is more interaction of the processing schemes seeking, for example, to segment possible lesions. All these ROIs (from actual and from simulated breast images) were stored in an internal database of a software designed to perform comparative tests.

Developed such a software, 3 experiments were possible to run in order to evaluate the level of confusion among the simulated and the actual images by collaborative observers: the first one shows on the display screen a total of 15 ROIs from the software database asking for the observer to set that ROI as from actual breast (or not); the second one shows 15 pairs of ROIs on the screen (each pair at a time), being necessarily one from an actual breast and the other from the phantom – the observer must determine which is which; and the third experiment displays 9 ROIs on the screen, asking for the observer to set which are from actual breasts; this procedure is repeated 6 times, yielding therefore 54 ROIs displayed from the internal database.

Two important features to enhance here is that (1) all ROIs are randomly displayed by the software (there are about 200 ROIs stored, half from actual and half from phantom images), and (2) there is a timer which limits the maximum time the observer has to give the opinion on each image, pair of images or set of ROIs shown. The first allows to the same observer performing many times the experiments with different images without being influenced by previous seen image or sequence. And the second assures a better differentiation on the accuracy of responses according to greater or lesser expertise of the participant, besides to speed up the tests execution. Fig. 6 illustrates typical ROIs displayed in each experiment.

RESULTS

All the features described here for managing the database were developed by using PHP and Java programming language, HTML as marking language to user interaction and database MySQL. Tests were performed with most of common browsers, as Google Chrome, Mozilla Firefox 59 or higher, Microsoft Edge 41 or higher and Safari, without the need of installing any extra software or plug-ins. All tools are also available for free access at the internet



(a) (b) (c)

Fig. 6. Example of ROIs displayed in: (a) experiment 1; (b) experiment 2; (c) experiment 3.

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database address: http://lapimo.sel.eesc.usp.br/bancoweb/.

One of the novelties in this project is the system to manage registering and searching for breast phantom images provided by exposures of the phantom previously developed in our group [SOUZA et al., 2018]. Capable of generating several image patterns obtained by random variations of size, shape, contrast and distribution of simulated lesions, this new set can be largely used for CADx schemes tests.

In fact, results from comparative tests corresponding to the 3 experiments previously described in section 3 performed with a number of collaborative observers have pointed out an important level of similarity among phantom and actual breast images, regarding intrinsic characteristics of background. They provided 45 evaluations, which were divided in 3 different groups for each one of the experiments, according to the observers degree of expertise in terms of visual assessment of mammographic images: expert, intermediate and with low experience.

The tests responses evaluation has primarily investigated the rate of success for each experiment and observer aiming to determine the number of hits between actual and simulated images. Data from such an analysis resulted in a rate of (64.1 ± 3.2)%, (59.6 ± 2.7)% and (63.8 ± 7.0)%, respectively, for the experiments 1, 2 and 3, for the subgroup relative to the expert observers. In average, all the rates for the same experiments were smaller for the other subgroups (intermediate and non-expert). Such rates – all lower than 65% - indicate a tendency of reasonable confusion between the two types of images, which allows us to deduce that the observers are having difficulty in clearly distinguishing the difference between actual and phantom images.

Such evaluation is a good result to validate in terms of visual perception the use of these phantom images to constitute a database suitable to be used in testing of image processing techniques in digital mammography. Even more tests needing to be carried out, the possibility of assuring that performance tests of different image processing schemes with our database of phantom images yield similar results when compared to their application to actual breast images is high. In fact all the data needed to evaluate sensitivity and specificity rates of these schemes in detecting and/or classifying signals of clinical interest are available through the images templates.

CONCLUSIONS

The current reorganization of our "BancoWeb" mammography database intends to provide registering, retrieving and downloading breast phantom images as well. Comparisons of "BancoWeb" with other databases have shown that requirements cited in the literature as important for a medical imaging database are met, but with the advantage of having features that other databases do not offer up to now. Among them there is the selection and clipping of ROIs for later classification with a CADx tool as well as the availability of a set of phantom images with randomly distribution of internal structures and backgrounds obtained from exposures to FFDM equipment. A continuous work regarding the database upgrading is being carried out with emphasis in the organization of phantom images set. Image searching has also been a major focus, enabling clear and objective user interaction.

In conclusion, the procedures considered in this work point out a promising resource for the constitution of a robust dataset of validated test images aiming to enable more generic evaluations of digital processing techniques and/or complete CAD schemes in digital mammography.

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