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GRASSlicer:A Medical Image Analysis and Visualization Tool

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Abstract

Medical imaging has become a powerful tool in diagnosis and surgical guidance. The new possibilities offered by computer systems and the development of accurate image processing algorithms enable the growing use of imaging application in clinical laboratories and hospitals.

A rich set of general purpose image processing tools exist within the GRASS geographic information system. In this paper we show their utility in the medical imaging field. We present a new medical image analysis and visualization tool based on the GRASS environment. Our software allows us to enhance, to classify and to rectify medical images, following the typical medical image processing pipeline of enhancement, segmentation and registration, respectively. This application is implemented as a graphical user interface allowing physicians to analyze medical data using GRASS modules and functions transparently.

Our work, following the line of research at the Center of Technology in Medicine, affiliate to University of Las Palmas de Gran Canaria, presents a new application which confirms that medical image analysis under GRASS is possible, and further capabilities of geographical softwares could be considered for medical images analysis and visualization.

Introduction

Medical Imaging Computational Environment

It was in 1895 when Roentgen discovered a new kind of ray, X-ray were born [1]. From then onwards, the existence of the border between human vision and the inside of opaque matter would begin to disappear.

In the 1970's, computed tomography (CT) was developed by Hounsfield, earning him the Nobel prize in Medicine in 1980 [2, 3]. The idea of getting transversal slices of human body had been in physicians minds years before, but it was due to capabilities of the new and raising digital computers that processing this information in a reasonable time became feasible. Hounsfield invent, hence, would reveal the importance of computers in generating new medical data, as well as the processing and analyzing of images.

Years later, the ultrasound imaging (US) was applied to the medical field. This technique is commonly used, not only because of a total lack of radiation, but also for providing information of a patient, even in motion. The resolution, however, is worse comparing to other methods.

Magnetic resonance (MR), was not used until the 1980's for medical and diagnostic purposes, although it was discovered much earlier. It represents a very important technique, as far as it provides different contrast between soft tissues. New sorts of magnetic resonance have been developed in order to get more information related to tissues nature and functional behavior.

The use of computer applications for medical data management and imaging, involving enhancement, classification and rectification, is becoming an important practice nowadays. It pursues a better diagnosis and minimization of surgical intervention, constantly seeking the improvement of public health system. There are several softwares and applications which have been developed by different Universities and research groups, such as 3D Slicer (Harvard Medical School) that analyze and process volume data from MR, CT and US scanners with the above mentioned purposes.

The challenge of medical imaging consists of obtaining, analyzing and delivering information from a patient, allowing a better diagnose and surgical planning. As far as we are concerned, geographic information systems (GIS) are also oriented to processing images but focused on a different scale, area of work, and aims. However, these systems have been developed separately from medical imaging softwares. This paper is aimed at illuminating that the two fields may benefit from a more close scientific interaction [4].

Objectives

The purpose of this work is programming an application with a graphical user interface (GRASSlicer, figure 1) which, making use of GRASS modules and tools, could be used by scientists who are not even familiarized with GIS environment for processing medical images. This application will create a confluence of knowledge that have been accumulated by both imaging fields. It will also provide some ideas of weaknesses and strengths of used methods, and how these systems could be improved by taking into account each others' tools and programming solutions. Likewise, if medical images may be processed under GRASS environment, it will be possible to interact with structured databases and statistical packages.

GRASSlicer only represents the initial step of this immense work and, by the moment, its capabilities concerning bi-dimensional images, although in the medical field, multidimensional data processing and rendering is the present focus.

Methodology

The development of the GRASSlicer followed three main steps:

1. GRASS modules were studied and classified by the functionality they offered in order to build useful tools for medical imaging pipeline of enhancement, segmentation and registration, which stand for enhancement, classification and rectification in GIS.

2. New code was written in tcl to bind GRASS modules accordingly to the needs of the new application and its structure. Images were analyzed for each of these tools, although we still don't have clinical validation.

3. The development and implementation of a graphical user interface (GUI) in tk programming language that takes the source code of these new tools, so that GRASS modules could run in a transparent way for the user.

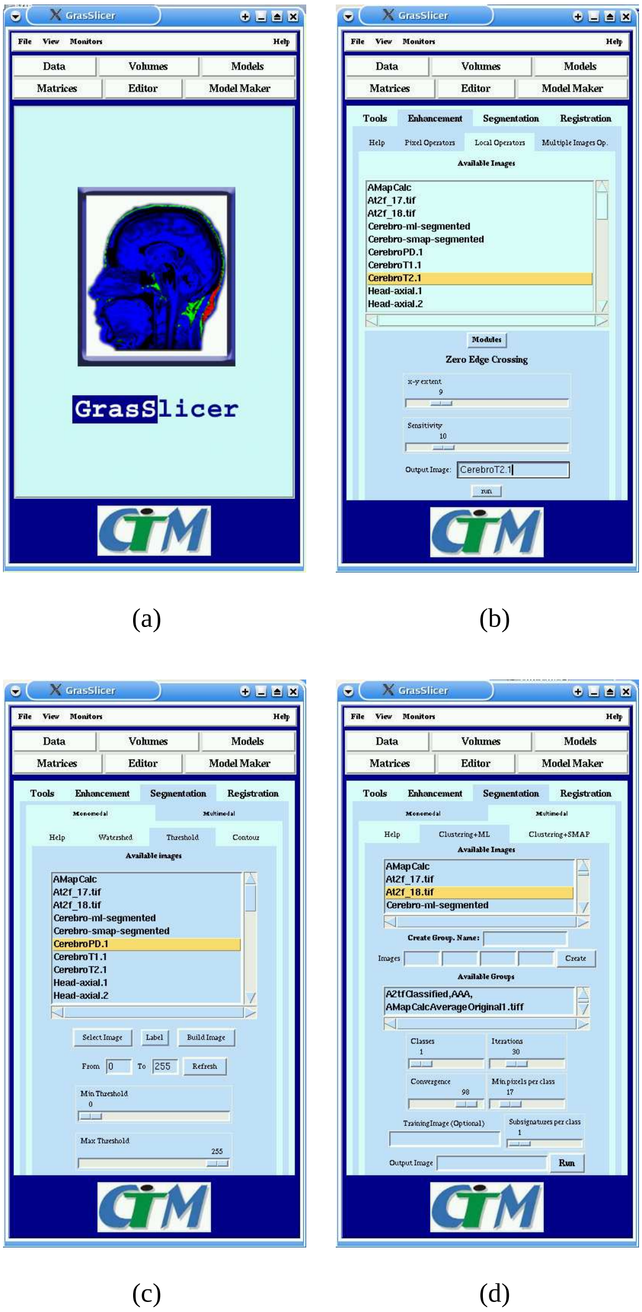


Figure 1: *Different graphics of GRASSlicer GUI. (a) Initializing GRASSlicer. (b) Zero edge crossing detector section. (c) Global Thresholding section of GRASSlicer. (d) Clustering + maximum likelihood classification section.*

Results

Enhancement

Image enhancement techniques are used to refine a given image, so that desired image features become easier to perceive for the human visual system or more likely to be detected by automated image analysis systems [5, 12]. Image enhancement allows the observer to see details in images that may not be immediately observable in the original image. The enhancement task is common in both GIS an medical imaging systems. Hence, GRASS modules for filtering and enhancement are used directly by GRASSlicer GUI for medical imaging. The enhancement section of the GUI is structured as is shown in figure 2.

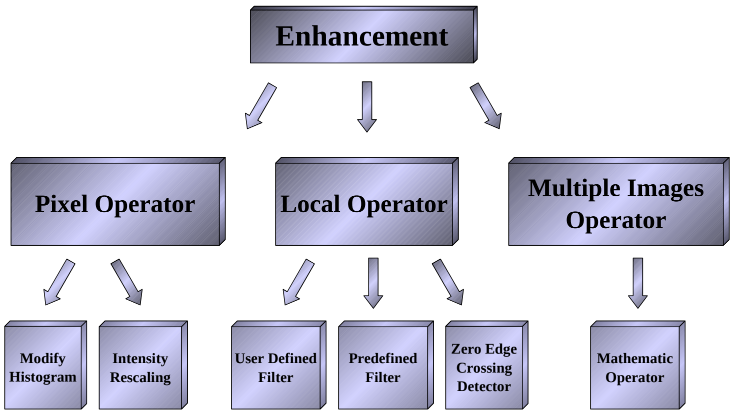


Figure 2: *Scheme of Enhancement section of GRASSlicer*

Pixel Operators

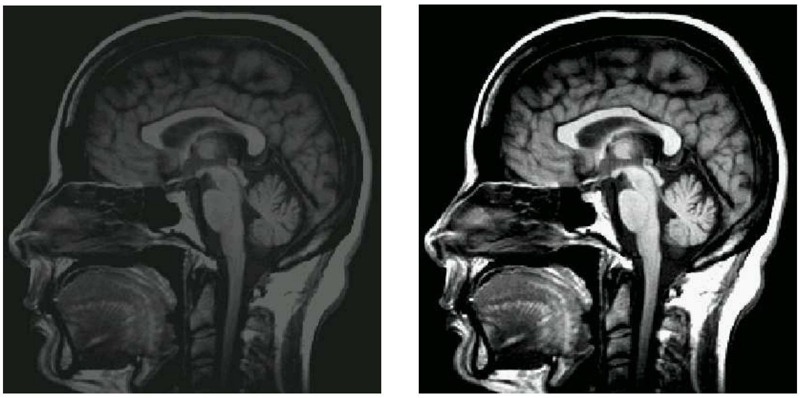
Pixel Operators are considered those that don't take into account the intensity value of the neighbors of the pixel that is being modified or analyzed. In this section, a 'Modify Histogram' tab and an 'Intensity Rescale' tab were added to the GUI. They call internally to *r.colors* and *r.rescale* GRASS modules.

With respect to intensity rescaling applied to medical images, it can be used when the dynamic range of the acquired image data significantly exceeds the characteristics of the display system, or vice versa. It may also be the case that image information is present in specific narrow intensity bands that may be of special interest to the observer. Intensity scaling allows the observer to focus on specific intensity bands in the image by modifying the image such that the intensity band of interest spans the range of the display [7, 8]. An example of intensity rescaling is shown in figure 3, where the contrast has been increased by rescaling intensities.

Local Operators

Local operators do take into account the neighbors' intensity value of the pixel that is being analyzed. In this group convolution filters are included, as well as a border detector which uses the zero edge crossing method with *i.zc* GRASS module. With respect to convolution filters, two possibilities were implemented in GRASSlicer GUI:

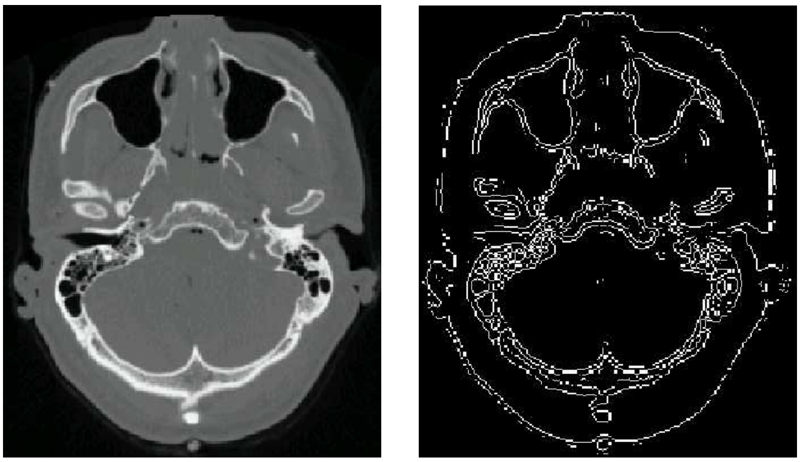
- Predefined filter, where the user chooses the method in a pop-up menu and the size of the matrix (*m.filter*).
- User defined filter. In this case, a filter must be edited and the user access a file browser GUI. *r.neighbors* GRASS module is run internally.



(a) (b)

Figure 3: *(a) Original Image. (b) Intensity rescaled image.*

Figure 4 shows an image which was applied a zero edge crossing detection filter. Borders of different objects in images play an important role in vision performance, and might be used in classification methods [6].



(a) (b)

Figure 4: *(a) Original Image. (b) Filtered Image with the local operator zero edge crossing detector.*

Operators with Multiple Images

Multiple images operators are filters that create a new image from arithmetic expressions between several images. One of the methods often applied for medical images is image subtraction, which is generally performed between two images that have significant similarities between them. The purpose of image subtraction is to enhance the differences between two images [9]. In figure 5 the Multiple Image Operator section of GRASSlicer GUI is shown with an example of contrast enhancement of differences between images by applying the image subtraction filter.

The aim of the GUI is that medical imaging under GRASS becomes straightforward and fast. GRASS modules used for filtering and enhancement are called by the GUI and, whatever method is being used, this GUI provides a list of available images in the database that is updated when a new image is created using

(a) (b) (c)

Figure 5: *Multiple Operator. (a) and (b) Original images. (c) Difference filter image.*

GRASS module *g.list*. The click of the mouse in one of the images of the list will display it -figure 1(b)-, using *d.rast* and *d.erase* GRASS modules. All these modules are used by the GUI seamlessly.

Classification or Segmentation

Classification of images has its origin in numerous psychological studies, which indicate the preference of human beings to group visual regions of a scene in terms of proximity, similarity and continuity to build an assembly of significant units [11]. The classification is made from intensity levels of the images that represent different characteristics of tissues or anatomical structures, depending on the acquisition technique.

In figure 6 the scheme for different classification methods implemented in GRASSlicer with GRASS modules is shown.

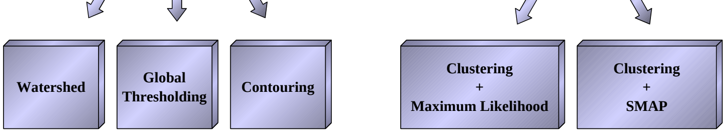


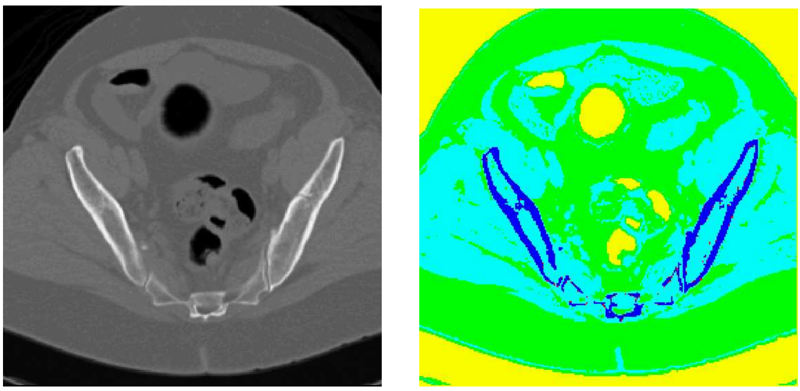
Figure 6: *Scheme of Classification section of GRASSlicer*

Monomodal classification works with one type of image at a time, while multimodal classification retrieves information from different kinds of images to create the groups. In a GIS environment, images may come from satellites in different bands or spectra. The analysis of multiple bands of the same scene provides valuable information. In medical imaging, as a matter of fact, these bands can be considered images from different acquisition devices, such as various modalities of MR and CT scanners, of the same scene; gathering information of medical images from different devices using GRASS modules could provide new and important records. Every classification method in GRASSlicer has its own tab in the GUI, and the original GRASS modules used for each of the methods are enumerated below. Additionally, a brief explanation of the contribution of these methods to medical imaging is given.

Monomodal Classification

- Watershed:
  Watershed classification has a specific module in GRASS, *r.watershed*. Several tests for medical images have been done, although no satisfactory results were obtained due to an over-segmentation of the images. This module is extremely sensitive to noise when there is not enough contrast between different tissues.

- Global Thresholding:
  Global thresholding classification is a common technique in medical imaging, and is based on the assumption that the image has a bimodal histogram and, therefore, the object can be extracted from the background by a simple operation that compares image values with a threshold value [10]. This threshold, or range of intensity level, divides the image in different groups of pixels; those whose intensity level is above the threshold, and those that are below. If an image contains more than two regions, it is possible to classify it by applying several individual thresholds [12], or using a multi-thresholding technique [13]
  In GRASSlicer GUI, the user may display the image and select the range of intensity levels of the pixels that he desires to remain in the display monitor. This selection is done with two sliders in the GUI -figure 1(c)-, one for setting the lower limit and the other for the upper limit. The pixels whose intensity levels are not inside the range of values are erased from the display monitor. This process is interactive, and after selecting a group of significant pixels, tagging the group may be done. Figure 7 shows an example of threshold classification. GRASS modules used in this method are *r.rescale, r.colors, r.mapcalc, g.remove, d.rast, g.list* and *type=rast*.

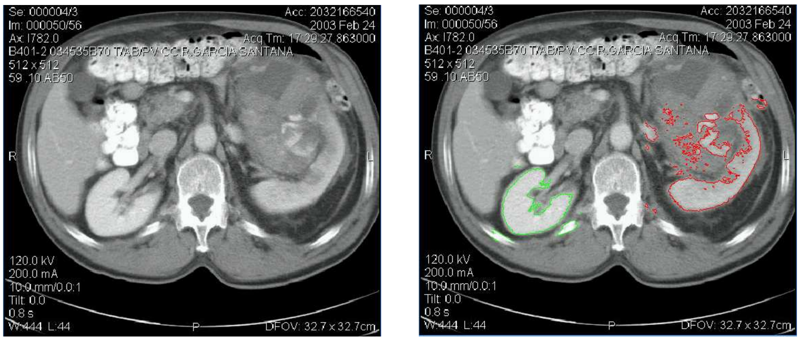


(a) (b)

Figure 7: *Threshold classification section of GRASSlicer. (a) Original image. (b) Classified image using thresholding method*

- Contouring:
  Contouring cannot be considered a proper classification method, but rather a method which applies colored contours overlaying the original image that surround pixels of intensity values below a given limit or border. This limit may be interactively modified with a slider in GRASSlicer. Contouring

provides only visual information, as far as the original image is not modified and no new image is created. The main GRASS module used in this section is *r.contour*. Tested images using GRASSlicer are shown in figure 8, where contouring was used to analyze dispersion of kidney tissue in presence of tumor.
Contouring technique in medical field was used before the implementation of GRASSlicer. One example of this was the measurement of ventricular volumes from a MR image which calculated the smaller number of pixels mixed in different distributions that had to be classified. The result was visualized as a map of overlayed contours to the original image [14].



(a) (b)

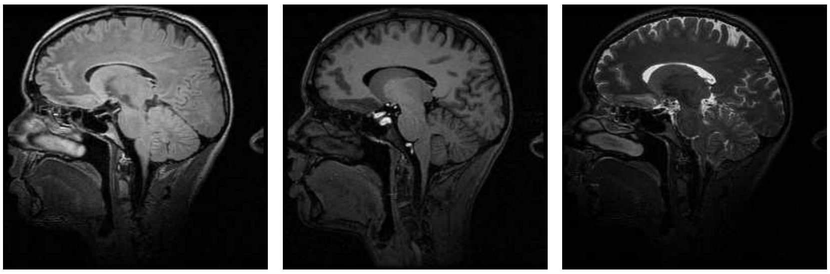
Figure 8: *Contour classification section of GRASSlicer. (a) Original image. (b) Contoured image.*

Multimodal Classification

- Clustering with Maximum Likelihood:
  This classification method, as was implemented in GRASSlicer, works in three steps: creation of a group of images, so that algorithms run in all of them; calculation of means and covariant matrices based on the number of clusters the image is being classified into; and designation of pixels to the group they have more probabilities of belonging, based on a statistic operator, which is in this case, a maximum likelihood method. The clustering may or may not be supervised, in terms of being guided by an image which is already classified or not. The main GRASS modules used by GRASSlicer code are *i.group*, *i.cluster*, *i.gensig* and *i.maxlik*. To run these algorithms in a transparent way, GRASSlicer GUI provides a section where only the selection of images, the number of classification groups and the adjustment of algorithms parameters through sliders are needed. The supervised classification field should be filled in, only if a supervised clustering is required, figure 1(d).

  Different kind of MR images from the same scene, figure 9, were classified automatically with clustering and maximum likelihood method as shown in Figure 10. In the figure, several groups of pixels that correspond to gray matter, white matter and cerebrospinal fluid can be perceived among others in the brain MR classified image.

- Clustering with Sequential Maximum a Posteriori:
  This classification method follows the same principle as the one above, but it makes use of a different clustering algorithm and statistic estimator. In this case the supervised calculation of means and covariance matrices uses the *gaussian mixture distribution* [15], while the probability of belonging to a group for each pixel is calculated with a *sequential maximum a posteriori* method based on Bayesian probability. The GRASS modules included in GRASSlicer are basically *i.group, i.cluster, i.gensigset* and *i.smap*. The purpose of the GUI is to run the algorithms automatically as the user selects images to classify and adjust parameters, making use of sliders and entries. Processing images turns out to be

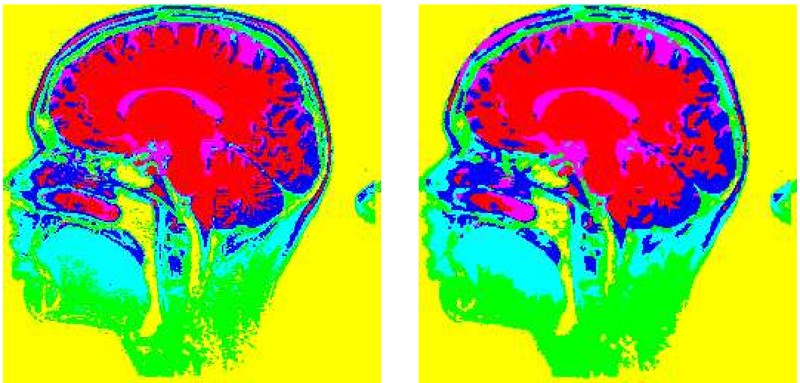


(a) (b) (c)

Figure 9: *Original images from different magnetic resonance acquisition techniques, used for multimodal segmentation. (a) PD MR. (b) T1 MR. (c) T2 MR*

very straightforward for those using this specific application.

An example of supervised maximum a posteriori classification from different MR images (figure 9), using as the reference image the one obtained with maximum likelihood method, is shown in figure 10. Results have improved in comparison to the maximum likelihood algorithm in terms of misclassified pixels quantity.



(a) (b)

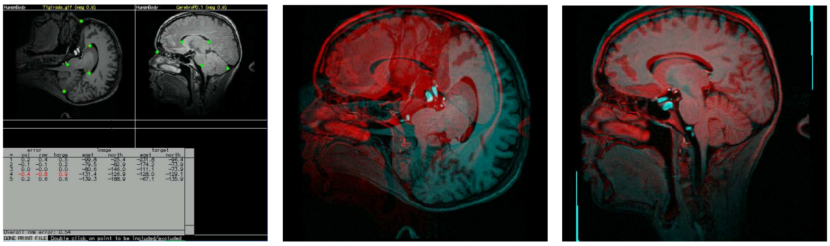
Figure 10: *Multimodal classification section of GRASSlicer. (a) Clustering and maximum likelihood. (b) Clustering and sequential maximum a posteriori.*

Rectification or Registration

GRASSlicer has implemented an interactive rectification method following GRASS modules *i.group*, *i.target*, *i.points*, *d.rgb* and *i.rectify*. The transformation may support first, second or third order and the points that will guide the transformation are selected manually. Pre- and post-processing images may be rendered jointly through different channels, as shown in figure 11, which allow the possibility of rectification evaluation.

Conclusion

We have shown that common medical image analysis operations is possible using GRASS algorithms, indicating that independent of the specific field studied, basic image processing needs are overlapping. This



(a) (b) (c)

Figure 11: *Rectification using GRASSlicer. (a) Setting points for transformation matrix. (b) Visualization through different channels before rectification. (c) Visualization through different channels after rectification.*

work may encourage scientists to bring together different frameworks and to gather research efforts.

Although there are already many powerful GRASS GIS image processing modules, several tools used in medical imaging are still desirable to add in this geographic system. Examples of modules that would be useful include:

- Semiautomatic registration modules using landmarks.
- Volume data loading, processing and rendering.
- Tensor data analysis.
- Manual classification module.

In summary, GRASSlicer provides useful tools for medical images analysis and the interaction with powerful statistical softwares such as R, and databases such as PostgreSQL. This is made possible by direct integration of our new software platform with the GRASS environment.

Acknowledgments

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