

ANAMICA: A Medical Data Visualisation and Characterisation System

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ABSTRACT

This paper reports the design and implementation of ANAMICA, a three-dimensional (3-D) medical data visualisation and characterisation system which provides a complete set of image processing options. Constructions of internal surfaces from total or partial volume of 3-D data and cut-out views are supported by means of 'volume rendering' as well as object space methods. Arbitrary planar and curved sections of 3-D data can be obtained and processed subsequently as standard 2-D images. Volumetrics and a preliminary characterisation of tissues based on histograms are also supported. A window based user-interface provides convenient access to all these options.

1. INTRODUCTION

Widespread use of computed tomography (CT) and magnetic resonance imaging (MRI) has added a new dimension to the science of medical diagnosis. The basic image processing software which comes along with a standard CT or MRI system is adequate for routine diagnosis. Often these image processing options are only two-dimensional (2-D) in scope, though these imaging systems are capable of generating 3-D data by imaging a volume of interest in a series of sections. With the advent of high-speed computing and sophisticated techniques of graphical visualisation, it is now possible to view such medical data in a 3-D manner straightaway^{1,2}. This enables doctors to make mental models of the 3-D aspects in the data. Complex anatomical features could be brought out in a format which could be understood easily without prior training or experience. Besides leading to improved diagnosis, such 3-D visualisation can also help doctors in preparing for possible surgeries.

Unlike the case of 2-D data, visualising and characterising 3-D data is more complex and more computation intensive. It is only in the recent times that

they have become viable options, due to the availability of computers with high computational speeds and large memories. Research in this field has begun just a few years ago and the methods reported in the literature are yet to exhaust the ways in which one could view and characterise 3-D data. Also, there is a need for combining different methods that are already available so as to meet some special requirements of doctors. Pattern recognition techniques could be applied for comparing segments of the same or different medical images, which could lead to more quantitative diagnosis.

Anurag's Medical Imaging and Characterisation Aid (ANAMICA) represents an attempt to integrate existing methods of 3-D visualisation along with some newer ones for the use of doctors. It is not the first of its kind to be attempted though it differs from similar systems in terms of details. On the 2-D image processing side, it has a complete set of filters and editing tools. Explicit construction of isovalue surfaces, volume rendering by means of ray tracing and sectioning are three of the major options for visualising 3-D data and ANAMICA has modules to provide each one of these options. By a combination of the first and the third

options or by ray tracing alone one could rehearse surgeries using ANAMICA. Planar as well as curved sectioning of 3-D data is also possible. The results of sectioning 3-D data could be viewed either as surfaces in 3-D space or images. In the latter case they can be subjected to image processing options for improving their quality and contrast. While dealing with 3-D data, it is essential to provide for measuring volumes and surface areas of specific regions of interest inside the total volume. The volumetrics module in ANAMICA caters to this requirement. Using it, one could find out volumes and surface areas of tumours, internal injuries, etc. A reconfigurable graphical user-interface provides a friendly gateway to all these options in ANAMICA. An important feature of this interface is its multitasking capability. While one visualisation operation is being carried out, users could initiate another. Such a capability could be very useful if a parallel computer is used as a back-end for carrying out the computation intensive options.

2. GRAPHICAL USER-INTERFACE

The graphical user interface (GUI) in ANAMICA is characterised by a hierarchical menu structure, multitasking and easy reconfigurability. The basic components of the GUI are menus, dialog boxes, button boxes, sliders, icons and windows. There are three types of menus viz., toplevel, pulldown, and pop-up. Input parameters for various options can be specified graphically using dialog boxes and button boxes. Windows are used to display the results of computations on the screen. Icons are used as convenient and compact representations of options under execution, windows and operations on windows. There are three types of icons, namely, compute, stow and window. This section gives an overview of all these components followed by a discussion on the important features of GUI in ANAMICA.

All the options available under ANAMICA are accessible to the users by means of menus. A toplevel menu encompasses all these options, grouped suitably. Hierarchical pulldown menus are used to represent this grouping. Toplevel and pulldown menus can be invoked either by mouse clicks or by typing 'hot keys'. Pop-up menus are specific to windows and are discussed later.

Dialog boxes and button boxes are used to collect input from users before computations begin. A dialog

box is a collection of named fields, input for which can be through sliders or keyboard. Sliders can be used to input data, in cases where the range is known. Examples of dialog boxes and sliders are shown in Figs 1 & 2. A button box is a collection of named buttons, one of which can be selected by the user by means of a mouse click on the specific button.

Icons are used to represent an ongoing computation, a window, or an operation on a window. Whenever a menu option requires some computation, it is represented as a compute-icon with the option name as its title. This is very useful in a multitasking system such as ANAMICA as it gives a visible list of all the background tasks. It also enables the user to terminate a computation half-way through. Other types of icons are discussed later in this section. Windows are classified on the basis of the type of the picture they display. The basic types of pictures are surfaces, pixel images and volume rendered images. Each window type has its own set of operations applicable to it and they are available to users by means of popup menus. General window related operations like moving, resizing, and killing a window are available as window-icons on the title bar of every window. The same are available as popup menus also. All the windows displayed on the screen can be stowed away and stored as stow icons. By a mouse click inside the stow icon, the original window is brought back on the screen. With the multitasking capability of ANAMICA, presence of too many windows on the screen at a time is not unlikely and this option will help the user in better screen space management. Figure 1 gives an idea of multiple windows on the screen and the window icons.

The definition of the menu structure of ANAMICA is stored in a script file in a standard format. The script file defines the menu hierarchy, options to be invoked for menu items, dialog and button boxes associated with the options and hot keys. The file is a normal text file which can be created and modified using any standard editor. A translation program reads this script file, checks for the correctness of the syntax, and generates an executable module, which forms the menu interface of ANAMICA.

ANAMICA treats all computations as UNIX processes and by taking advantage of the multitasking capability of UNIX, several processes are executed concurrently. Processes, however need to share some

common tables and data, and shared memory is used for this interprocess communication.

3. IMAGE PROCESSING

ANAMICA has a set of image processing options for improving the quality and contrast of 2-D images and visualising them conveniently. These options can be broadly grouped as filters, image algebra, image editing and histogram equalization. The results of these options are again images and hence combinations of these options are possible on a single image. The resulting image can be displayed on a window of any size so that an effect of zooming can be realised. Typically medical images are of the size 256×256 or 512×512 pixels, and when they are displayed in windows of larger sizes, the additional pixels are generated by means of bilinear interpolation.

ANAMICA has a host of filters, namely Gaussian and low pass for smoothing, inverse Gaussian and high pass for sharpening, and Sobel and Laplacian for edge enhancement. The image algebra module enables users to perform algebraic operations such as addition, subtraction, etc, on images. Unary operations like applying a filter to an image can also be used in algebraic expressions. For example, users can perform an operation such as $\text{image 2} = \text{image 1} + \text{Sobel}(\text{image 1})$, which creates image 2 by adding image 1 with the Sobel filtered version of the same. An illustration of this operation is shown in the top window of Fig. 1(a).

The image editing option enables one to edit an image either in the intensity domain or in the spatial domain. In intensity domain editing, a window is selected from the range of intensities of the image and all the pixels that fall in that specified window are displayed after suitable normalisation. Invariably this option leads to an image of improved contrast in the chosen intensity range. An example of this option is given in the top middle window of Fig. 1(b). In spatial domain editing, a region of interest (ROI) is selected on the image itself and the pixels in that ROI are displayed in a separate window. The ROI can be a rectangle, an irregular polygon, a circle or a closed B-spline curve. For both the editing options mentioned above, apart from selecting pixels included in an intensity window or ROI, selecting pixels excluded from the window or ROI is also possible.

As a special case of histogram transformation, histogram equalisation can be used to enhance the

contrast of an image by equalising the entire image histogram or a selected range in it. An example of this operation is shown in the top left window in Fig. 1(b). The original image which has a much lower contrast is shown in the bottom centre window in Fig. 1(b).

A window related pop-up menu helps the user to see the intensity value and the intensity gradient at any given pixel. It is also possible to rotate the image in multiples of 90° . Users can see the intensity profile along any arbitrary line segment on an image. Histograms of various ROIs of an image can also be seen in separate windows.

4. ISOVALUE SURFACE CONSTRUCTION

Constructing and viewing meaningful surfaces inside volumes of 3-D data is a way of visualising the given data. Isovalue surfaces are a category of surfaces which can reveal the inner structure of 3-D data. These surfaces are obtained as loci of points in three dimensions over which the data values remain as user chosen constants. The explicit construction of such surfaces are carried out by identifying the surface segments inside the cells of the given volume of data. Since 3-D medical data is often organised in the form of a regular Cartesian grid of points, the piece-wise linear construction of the isovalue surface segments is carried out easily inside cubical subcells. Several methods for doing this are reported in the literature³⁻⁵ and one of the recent methods⁵ has been adapted and implemented as part of ANAMICA. Using this implementation, one can reconstruct, for instance, the outer skin of any part of a patient from the MRI or CT data corresponding to that part. This is done by constructing an isovalue surface over which the constant intensity value corresponds to that of skin. Such a reconstruction will be useful as a reference surface while rehearsing a surgery. By selecting different isovalues, one has the option of constructing various surfaces in the interior of 3-D medical data. However, since there is no unique mapping between the intensity values and the internal organs, in majority of cases the resulting isovalue surfaces will not be of much use. Research is currently progressing on the methods of preprocessing 3-D medical data, so that isovalue surfaces inside such preprocessed 3-D data could reveal the shape and structure of internal organs of interest.

The input to this option is a Cartesian grid of 3-D medical data. Figure 3 shows a set of 30 sagittal images

corresponding to a patient's head, acquired using the MRI system in the Institute of Nuclear Medicine and Allied Sciences (INMAS). A grid of 3-D data is prepared from these images by stacking them together in proper order. Figure 2 illustrates a result of facial reconstruction using this data set.

5. SECTIONING

A given volume of 3-D data can be made into smaller cross-sections using a planar or a curved surface. Viewing the intensity values on these surfaces is another important option provided in ANAMICA. In the case of a planar section, firstly users are shown a plane cutting through a representative template of the chosen 3-D data. The template is usually the isovalue surface corresponding to the intensity value of skin as shown in Fig. 4. The spatial orientation of the template can be selected later and then that of the cross-section plane by means of two pairs of sliders. The user-interface also displays an orthogonal section of the 3-D data and a point on it, such that the cross-section plane passes through that point. Both the position of the point and the sectional image on which the point lies can be varied as per the requirement of the user and the position of the plane will interactively reflect the user's choices. When all the options are frozen, intensity values on the selected sectioning plane are calculated and displayed either as a 2-D image or as a planar surface in three dimensions. Again the choice is left to the user; if the user chooses to see the result as a 2-D image, the image processing options available in ANAMICA can be applied to it. An illustration of this option is shown in Fig. 4.

Sectioning 3-D data with a curved surface is also possible using ANAMICA. This option will be useful in seeing the image of a curved organ such as the spinal cord. To exercise this option, the user first selects a suitable orthogonal section of the 3-D data and inputs a series of points on it. A B-spline curve is fit through all these points and a surface is generated by sweeping this curve inside the volume of interest. Bilinear interpolation is used to obtain the intensity values on this curved surface. The result is rendered as an image surface in three dimensions. Figure 5 illustrates the use of this option. An orthogonal section of a 3-D data set and a B-spline curve are shown in the top right window. The resulting curved surface and the intensity values on it are shown in the bottom right window.

By a combination of constructing isovalue surfaces and sectioning, cut-out views such as the one shown in Fig. 6 is also possible. The resulting combination of surfaces can be rotated and viewed from various angles interactively unlike that shown in Fig. 6 which has been generated using the volume rendering option available in ANAMICA.

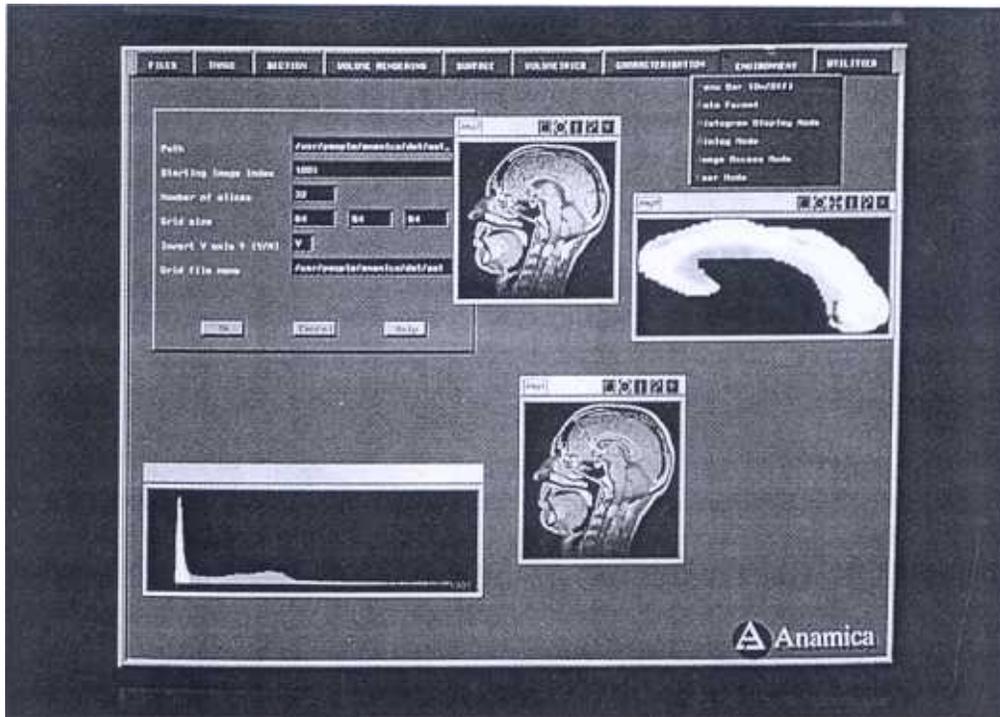
6. VOLUME RENDERING

Volume rendering is a technique for visualising 3-D data by means of ray tracing⁶. It differs from traditional polygon based rendering approaches, in that no intermediate surfaces are generated and a screen image of the volume is obtained directly on a pixel by pixel basis. A variety of visualisation options are possible using volume rendering. The images produced using this technique are also known to be more realistic. However, the technique is computation intensive and does not exploit the graphics hardware (each view of the same 3-D data, for example, has to be generated afresh). This section provides an overview of the volume rendering approach and the visualisation options supported in ANAMICA using this approach.

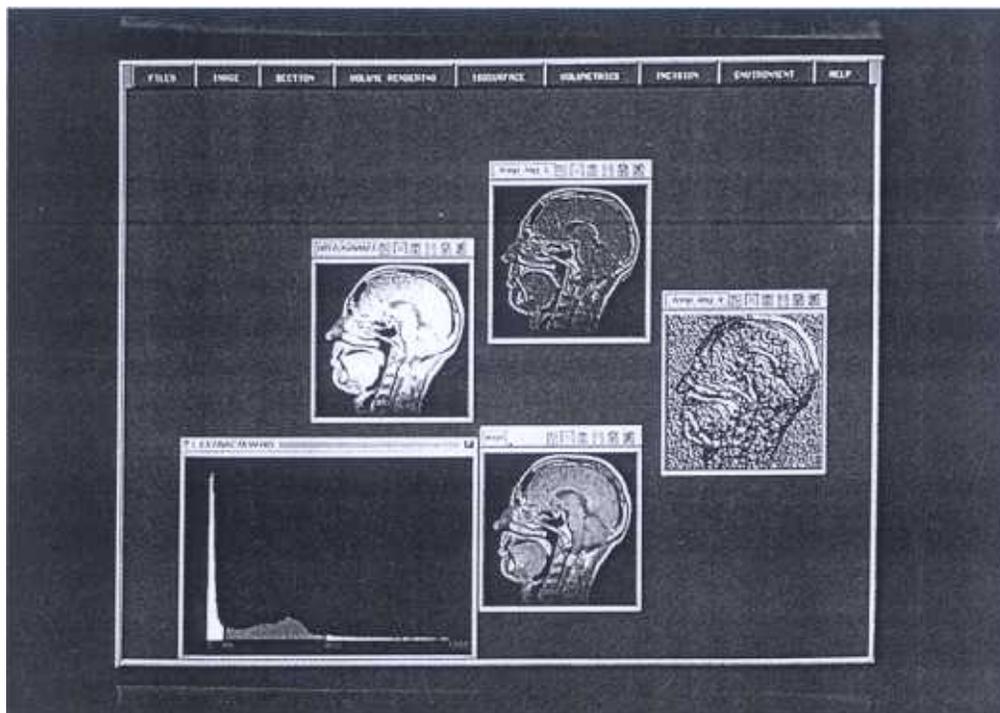
The basic input to the volume rendering technique is a Cartesian grid of 3-D data. The individual points of the 3-D grid are called voxels and the data value at a voxel is called intensity. The 3-D data is first subject to opacity assignment and shading, collectively known as classification, which assigns a colour value (a triplet with red, green, and blue components) and an opacity value (a measure of transparency) to each voxel. Classification stage makes use of the intensity gradients at each voxel. Many techniques have been suggested in the literature for computing the intensity gradients^{2,7}. The techniques implemented in ANAMICA are: (i) adaptive gray level gradient shading for visualising objects like skull, pelvis, face, etc; (ii) transparent gray level gradient shading for visualising thin or fuzzy objects like brain surface, and (iii) maximum intensity projection for visualising contrast enhanced objects like blood vessels in 3-D angio data.

During shading, a colour triplet is assigned to each voxel depending on the light source, view point and view direction. Phong shading model with ambient, diffuse and specular light components has been implemented.

Once the 3-D data is classified, in the rendering stage it is displayed using ray tracing. The data is



(a)



(b)

Figure Sample images obtained using image processing options.

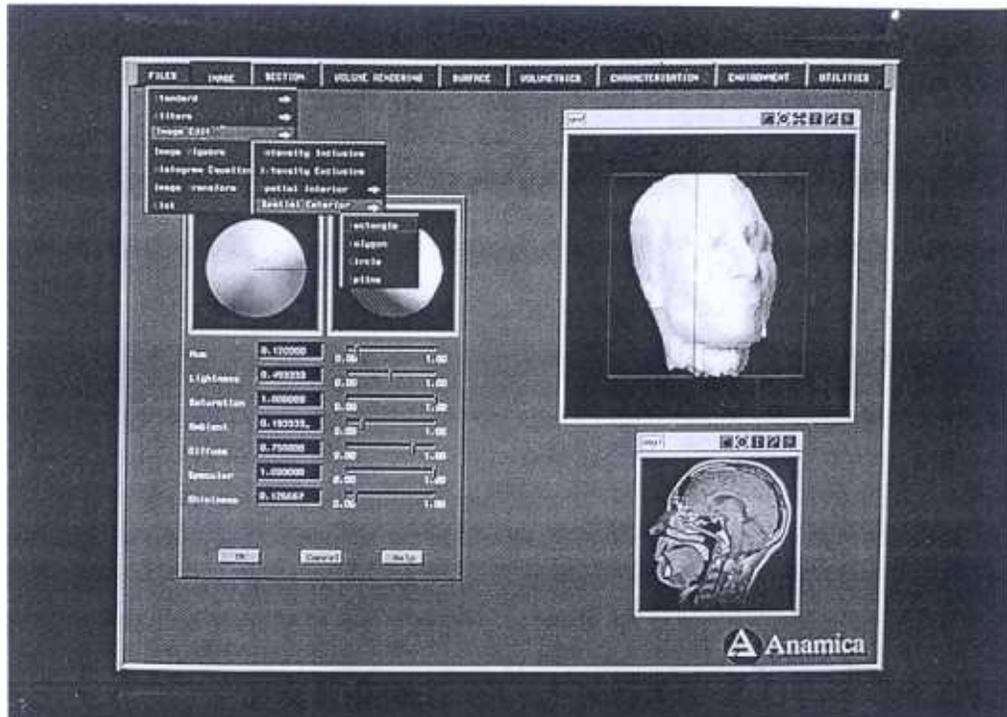


Figure 2. A result of applying the method of isovalue surface construction on a 3-D data set (the isovalue here corresponds to that of skin).

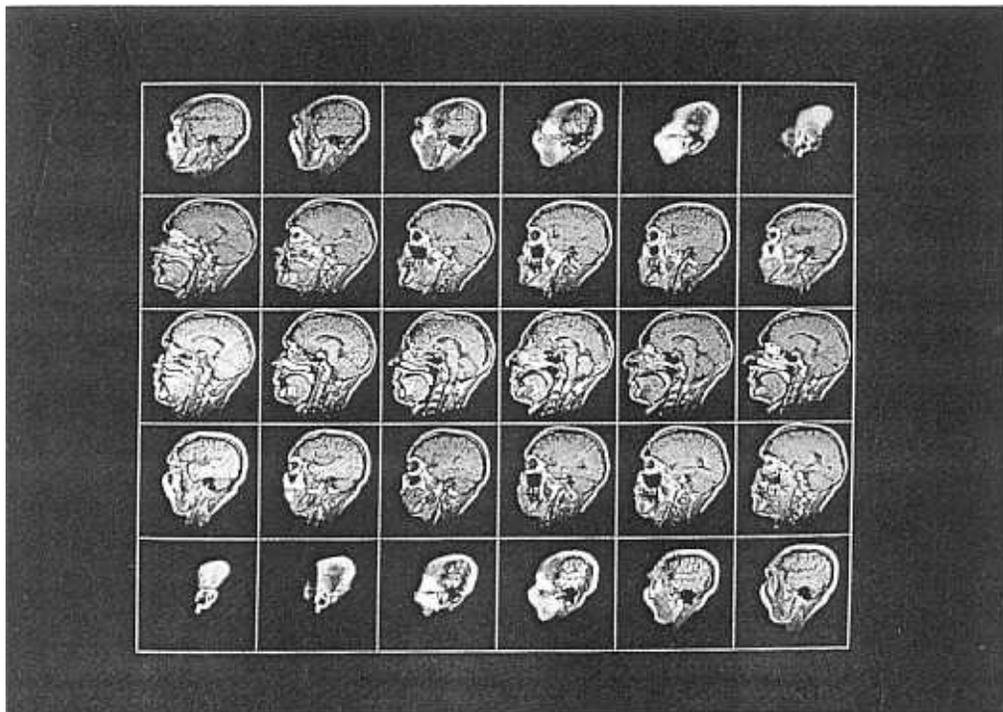


Figure 3. A set of 30 images of the patient's head obtained using the MRI system.

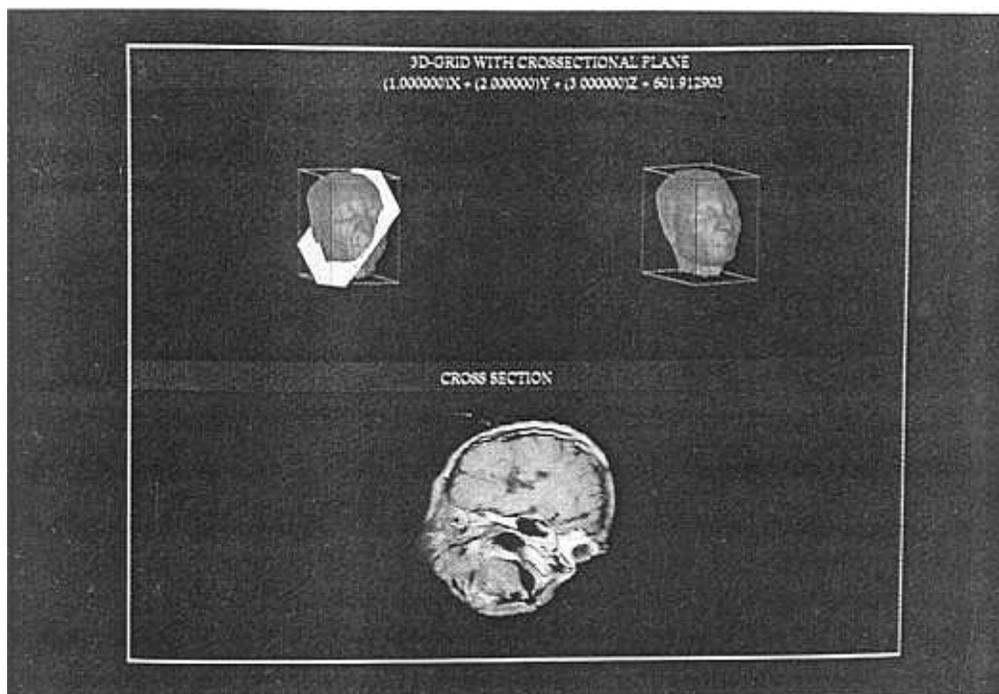


Figure 4. Illustration of sectioning 3-D medical data by means of a planar surface.

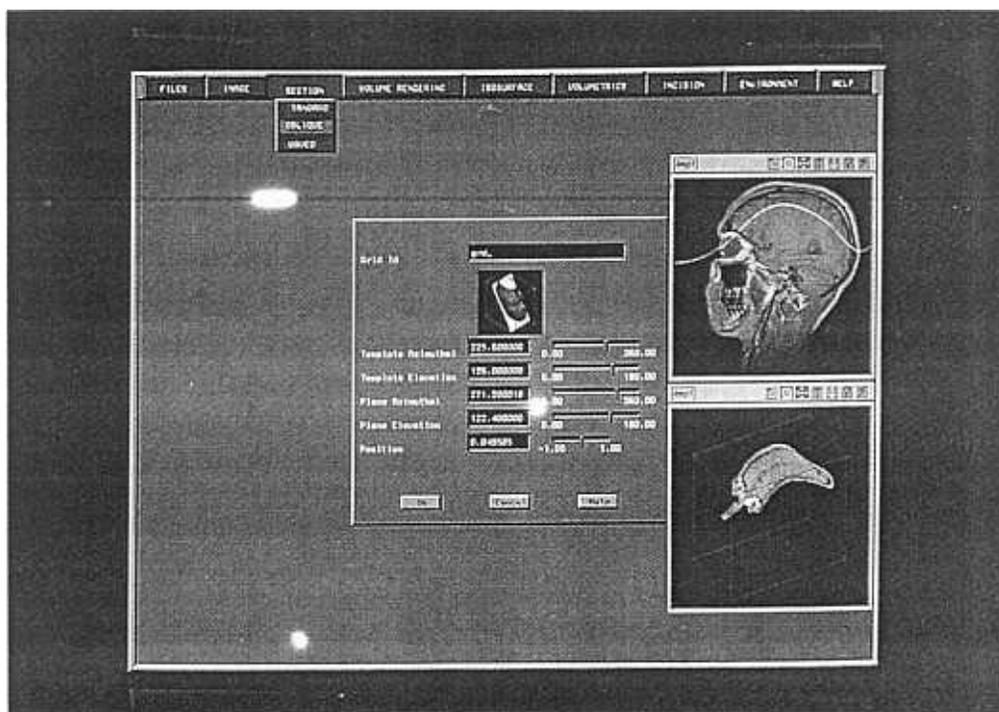


Figure 5. Illustration of sectioning 3-D medical data by means of a curved surface.

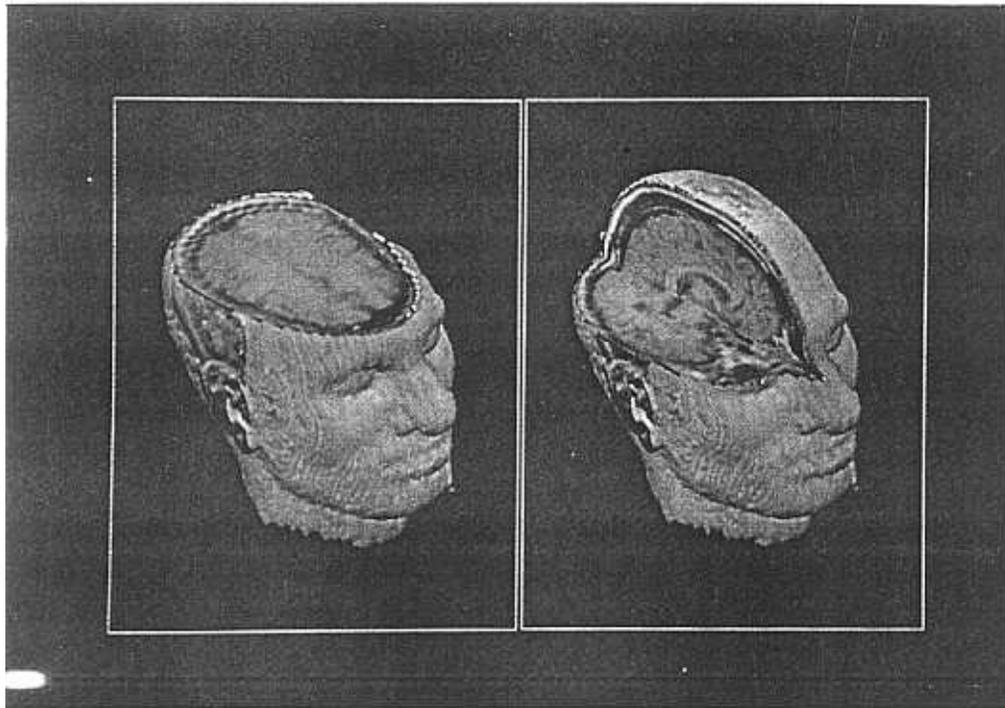


Figure 6. Two cutout views of 3-D medical data generated by the technique of volume rendering.

assumed to be seen through a view window, which is essentially a portion on the screen. A set of parallel rays are sent from the view window (one ray per pixel) along the viewing direction into the 3-D data. Along each ray, the data is sampled at regular intervals. At each sample point, opacity and colour values are computed by means of trilinear interpolation using the neighbouring eight voxels. From this array of opacity and colour values for a ray, a single colour is computed by the repeated use of the transparency formula suggested by Marc Levoy⁶.

The following visualisation options using volume rendering are implemented in ANAMICA.

Isovalue surface: The adaptive gray level gradient shading or transparent gray level gradient shading is used to assign high opacity to the voxels with a user selected intensity, called the isovalue⁶⁻⁸. Where possible, this isovalue may be carefully chosen to represent the surface of an object (like skull or face). The rendering stage will bring out this surface.

Maximum intensity projection: In the classification stage, opacity is assigned proportional to the voxel intensity⁸. During the rendering stage, the maximum intensity along a ray is picked up.

Partial volume rendering: Voxels in a block are assigned low opacity values so as to make them transparent. On the walls of the block, very high opacity values are assigned so that the ray stops there. This gives a feeling as though the block is cut away from the volume. Multiple blocks can be cut away from the volume. Figure 6 gives two examples of such cut-out views using this option.

Rehearsal of surgery: Using this option, the actual surgical procedure can be rehearsed on the computer. The doctor specifies a point inside the volume of data, which is to be reached for surgery. This point could lie, for example, inside a tumour. Also the surgeon specifies a suitable point on the outer surface, i.e., the skin, from where the surgery can be started. A rectangle appears on the surface that defines the size of the cut which can be modified interactively. Starting from the outer surface, in small increments, blocks are cut out and internal details are revealed till the inside point is reached. Using this option, the details of organ-encountered along the surgical direction can be shown, which will be helpful to surgeons in finding out the shortest and safest path to reach internal organs.

7. VOLUMETRICS AND CHARACTERISATION

Computing various metrical properties within the volume of 3-D data may be of interest to surgeons. For instance, information such as the distance of a certain tumour from a point on the outer skin or the angle subtended at a tumour by two points on the outer skin may be useful while preparing for a surgery. Radiologists may find it useful to be able to calculate areas of ROI in an image or volume inside 3-D data. The volumetrics module in ANAMICA supports these options.

For finding the area of an ROI in an image, the user is expected to give a series of points. A closed B-spline curve is fit through these points and the area is computed by an application of Green's formula. The region can be concave or convex but should be simply connected, i.e., without any holes. To calculate the volume of a region, a series of closed B-spline curves are defined on consecutive orthogonal slices of the 3-D data which span that region. These curves are connected together to generate the boundary of that region which is displayed as a surface for viewing. The required volume is computed using the trapezoidal rule taking the slice thickness and the interslice gap into account.

Characterisation of medical data is a complex task and a large volume of research in the field of medical diagnosis is devoted to it. In ANAMICA, we confine ourselves to a limited objective of comparing two ROIs in a given image to see if they are similar or dissimilar. The ROIs could also be selected from different images. The algorithm for comparison firstly computes the two histograms of the regions to be compared. Shape functions, which code angular shapes ignoring lengths are extracted from these histograms and a metric between these shape functions is evaluated⁹. If the shape functions are normalised, the value of the metric is bound to lie within a range of 0 to 1. A value less than 0.5 means that the regions are similar, otherwise they are dissimilar. This type of comparison will be able to characterise a region of tissue as normal or malignant and may be useful for a radiologist after some standardisation.

8. DISCUSSION

The primary users of ANAMICA will be radiologists and surgeons. ANAMICA can also be used as an educational tool in medical instruction, particularly for teaching anatomy. Conceived as an offline medical data

visualisation and characterisation system, ANAMICA is meant to handle data from different types of imaging systems. In this paper, the results of using ANAMICA for visualisation of MRI data only was discussed. However, visualisation of CT data is just as easy as that of MRI data. We are planning to extend ANAMICA to cover the processing and visualising of ultrasound medical images also. One major problem in the case of handling ultrasound images is the removal of noise which is practically non-existent in the case of CT and MRI images. Since ultrasound imaging systems are widely used due to their low cost, augmenting ANAMICA with the capability to handle ultrasound images will make it useful for a large number of diagnostic centers.

Two of the major issues in a visualisation package such as ANAMICA are the quality of its user-interface and the interaction speeds for its computation intensive options. In ANAMICA, we have tried to provide an imaginative and user-friendly graphical user-interface. To the extent possible, the terminology with which the radiologists and surgeons are familiar is used. Also the number of levels in the hierarchical menu structure is kept to a maximum of three. Currently, context-sensitive help messages are being incorporated at various points in the user-interface. However carefully crafted it may be, a user-interface would need modifications after trials at user sites and the reconfigurability of ANAMICA user-interface will make it easy for accommodating further requirements from users. As far as interactive speeds are concerned, with a one MFLOPS IRIS graphics workstation being used now, the 2-D options are carried out within a few seconds. However, the 3-D operations such as isovalue surface construction, cut-out views, etc take anywhere between ten to thirty minutes. So higher floating point computation speeds are required if the interactive response times are to be brought down to acceptable levels. To that end, we are planning to parallelise ANAMICA and port it onto the PACE-SPARC parallel computer which ANURAG has already developed. A four-node version of PACE-SPARC with a graphics accelerator card is expected to perform twenty times better than the workstation presently being used and so the consequent interaction speeds will be acceptable.

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