METHODS FOR RECONSTRUCTION OF THREE-DIMENSIONAL STRUCTURES

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Abstract

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The aim of the contribution is to provide the reader with an account of methods for creating computer reconstructions of medical data acquired in the form of planar cross sectional slices. This kind of data is frequently obtained from various medical scanners like computed tomography and magnetic resonance imaging. The models of data are created by small volume elements in the shape of cube, called voxels. The voxels arranged in a regular space grid envoy information about the relevant volume of modeled object. Relating individual voxels to different parts of modeled objects we define space structures (classification). The structures can be also chosen with thresholding. To visualize data we can chose two different approaches: volume or surface rendering. In the case of volume rendering the whole data set is visualized regardless to the classification and threshold. We described several methods: summed, averaged and maximum intensity projection. These methods are suitable for visualization of contrast structures. The second approach, surface methods, requires as the first step to define object - visualized structure either by thresholding (definition of voxels with intensity in given interval) or by the classification (definition of voxels with given volumetric properties). We described two simple algorithms (Voxel value shading, Depth shading) and several more complex shading ones (Z-buffer gradient shading, Voxel gradient shading and Gray level gradient shading). The setting of color and transparency to particular structures enables to visualize hidden or inner objects. The best quality of visualization is reached by Gray level gradient shading, where small surface details are visible well.

Medical visualization, computer graphics, voxel, 3D reconstruction, shading

Increasing capabilities in computer processing power and advances in image processing allow users to analyze sequences of 2D cross sectional slices and describe the shape and morphology of anatomical structures. Since computer tomography (CT), magnetic resonance (MR) and confocal microscopy were introduced, many of different methods to visualize 3D geometry of such structures have been developed. Much of the early work dealt with tracing and connecting contours. These methods were not so much computationally demanding and offered acceptable idea about the shape for reasonable costs. On the other hand complex structures with branches were visualized with difficulties. New techniques were based on voxels - cuberille (Chen 1985), marching cubes (Lorensen 1987), dividing cubes (Cline 1988), isosurfaces (Wallin 1991).

The process of visualization of volumetric data can be divided into six steps (Ney 1990).

Volume formation

A volume consists of a set of planar cross-sectional slices one on the top of the other. The pixels are in a equidistant grid. The space between corresponding pixels of neighbour slices become cubic or rectangular volume elements of equal size (voxels). In other words a pixel is extended into the 3rd dimension. The value assigned to each voxel in according with material property of modeled object. The physical interpretation depends on the scanning method (e.g.,CT, MR).

Segmentation/Classification

Segmentation forms substantial step of data visualization. The datasets are difficult to understand because the data values for different objects may overlay, the data is noisy, the image has not balanced brightness and a low amount of clear edges (surfaces) can be found in an image. In such a case, 3D view of an examined organ is needed. Nowadays only basic tools are utilized for segmentation step. The easiest way of segmentation is intensity thresholding followed by cutting of parts we are not interested in and manual error correction. The lack of knowledge, from which simple algorithms suffer, is substituted by experience and knowledge of the researcher. In case of CT it is suitable for determination of bone and outer skin as well as for soft tissues in case of MR.

During classification, information about membership to segmented parts is assigned to voxels. By this operation sets of voxels are created that represents particular organs. As an extension, each voxel may contain not only a gray value but also other colours, transparency or an intensity value delivered by an additional imaging modality (Hoehne at al. 1990).

Transformation

The model is usually not intended to be viewed only from one direction but in various positions with different level of magnification. On the voxel model (both classified or unclassified) we can perform space transformations - rotation and translation. Rotating the object about axis we can view it in arbitrary orientation.

Surface detection

In case we want to visualize the shape of the object we have to define its surface. One of the approaches assumes that surface can be defined as an interface among sets of differently classified voxels. Voxel is assigned to surface if one of its neighbor voxels has different classification. The number of voxels for comparison is 6 (faces are included), 18 (faces and edges) or 26 (faces, edges and vertexes are included).

Projection

Projection is a transformation of 3D space of voxel model into 2D space of an image. The final image in viewing plane depends on type of used method projection and shading as shown in Fig. 1.

Methods

Surface detection and classification can be omitted and in this case we can use three methods:

Maximum intensity projection. MIP. The value of the brightest voxel along the ray is displayed. It means that structures with the highest intensity are showed (Fig. 1e).

$$I = \max (I_i)$$

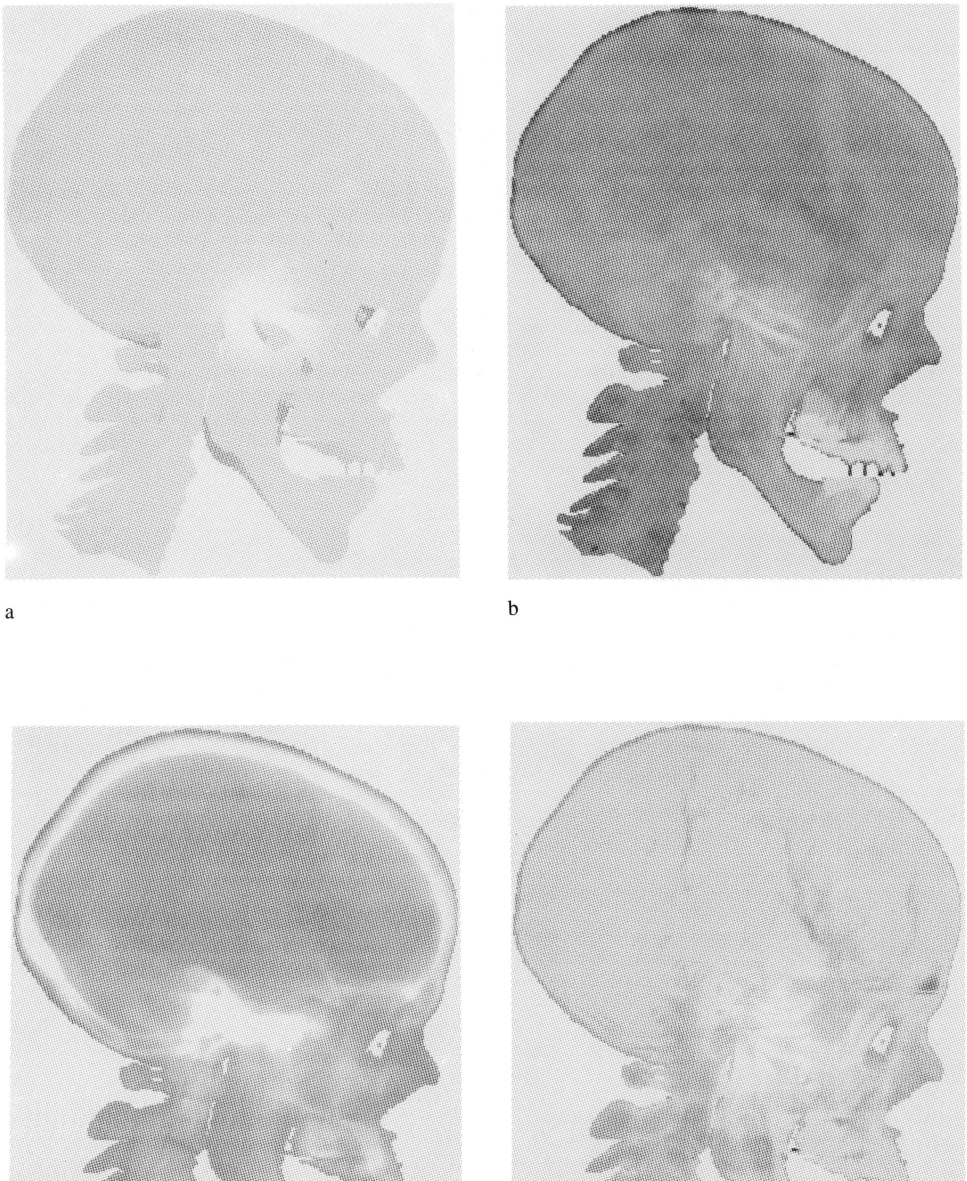
Summed intensity projection. SIP. The displayed pixel is computed as a sum of all voxels on the ray falling in a specific threshold range (Fig. 1c).

$$I = \Sigma (I_i)$$

Average voxel projection (or Additive reprojection) (Hoehne 1987).The method is a modification of previous one. A displayed pixel is computed as an average of all voxels on the ray falling in a specific threshold range (Fig. 1d).

$$I = \frac{\Sigma (I_i)}{i}$$

Methods mentioned above are fast and not demanding for pre-processing. We can use them for the pre-view in the data set. The Additive reprojection technique has the effect of simulating an x - ray image.



a b

c d

Fig. 1. Examples of rendering techniques. a) Voxel value; b) Depth shading; c) Summed intensity projection; d) Averaged intensity projection;

In case we perform surface detection we can use following methods:
Voxel value projection. The actual value of intensity or color of the detected surface voxel is projected. This method doesn't show the shape of the object, but colors on the surface (Fig. 1a).

$$I = I_i$$

Z buffer Shading (or Depth / distance-only Shading). ZS (Hoehne 1990). The value of the display pixel is a function of depth only (distance between the screen and the intersected voxel on the surface); the surface normal is completely ignored. The depth at which the first surface voxel is found is used to determine the initial brightness of the pixel in the shaded surface image. Although this technique smoothes out sampling noise, it suppresses edges and object discontinuities that are essential to human comprehension of the 3D scene (Fig. 1b).

$$I = Z(I_i)$$

Methods with higher quality of image are based on shading. The realistic display of 3D objects on a 2D surface requires several depth- cues to create illusion of the third dimension. Shading techniques are used to simulate both the object surface characteristics and the position and orientation of object surfaces with respect to light sources. Very good results are obtained from the model developed by Phong (Tiede 1990). The model is based on computing color and intensity of surface voxels with knowledge of intensity and direction of light sources, vector of observer and surface normal at voxel location. There are several methods to resolve normal at voxel location. In this case we can choose one of the following methods:
Z buffer gradient shading ZGS (Tiede 1990; Hoehne 1990; Gordon 1985).

The gradient is approximated from 2D distance map of the visible voxels. Given the Z-buffer, Z(x,y), the components of the surface normal are approximated from the gradient vector (Fig. 1f).

$$n_x = Z(x+1,y) - Z(x-1,y)$$

$$n_y = Z(x,y+1) - Z(x,y-1)$$

$$n_z = 1$$

Voxel Gradient Shading estimates the surface orientation by a gradient of tresholded or classified voxel. The function f is defined as a function that returns 1 (true) or 0 (false) if voxel is or is not showed. Particular components of the surface normal are derived from the difference of the function f of neighbour voxels in direction of axes x, y, and z (Fig. 1g).

$$n_x = f(x+1,y,z) - f(x-1,y,z)$$

$$n_y = f(x,y+1,z) - f(x,y-1,z)$$

$$n_z = f(x,y,z+1) - f(x,y,z-1)$$

As well as in previous method we can see on the resulting image the shape of the object but there is strong disturbance from artifacts.

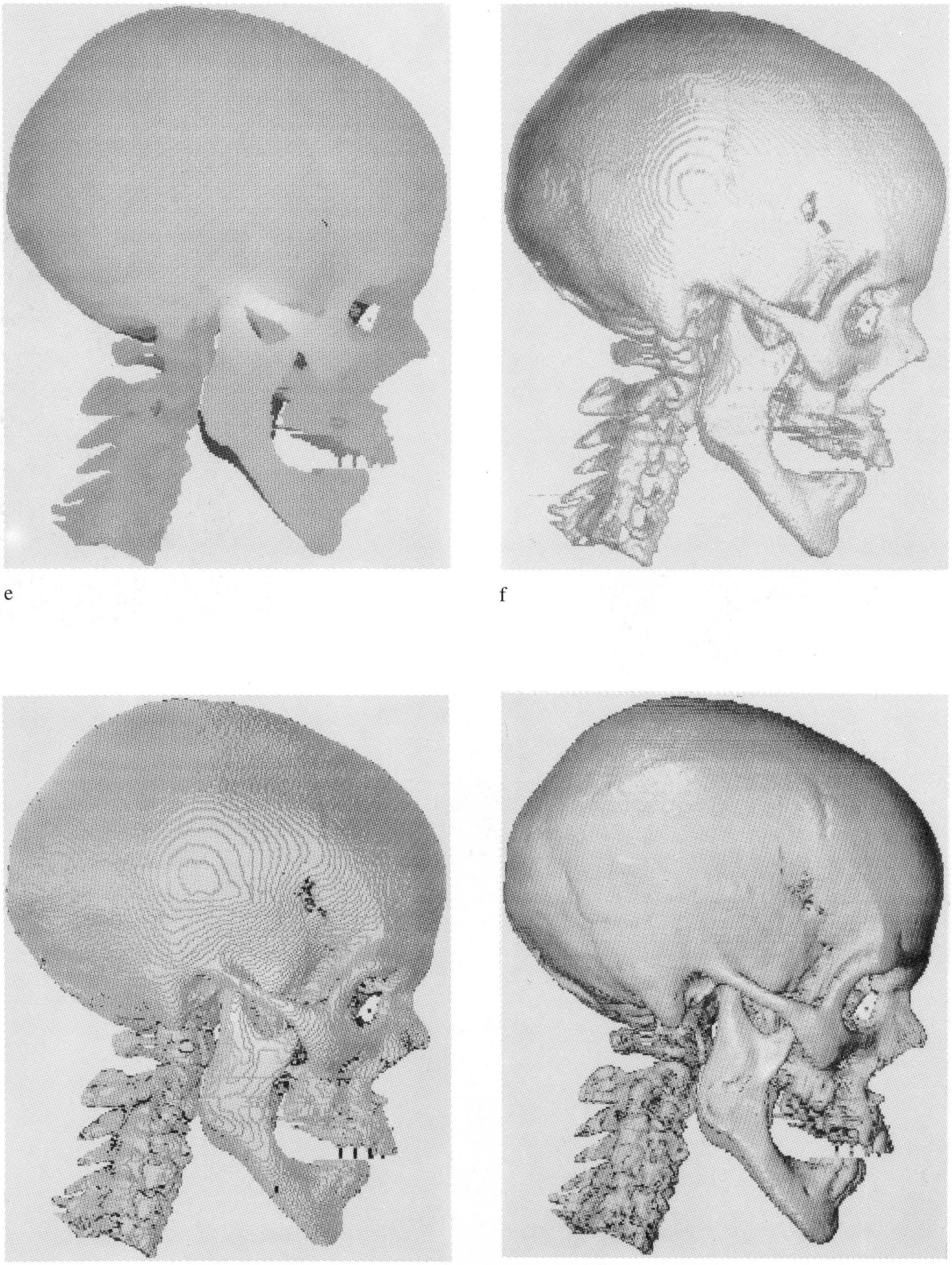
Gray-level Gradient Shading (Density gradient shading) GGS (Levoy 1988; Cline 1988; Tiede 1990). This approach uses the value of the voxels in a 3D neighbourhood. The method is based on the assumption that voxel values can be used to indicate the correspondence between surface inclination and density value gradient. Due to the high resolution range of the voxel values, this method produces a smooth shading of high quality. The gradient is estimated from the density function by taking differences between the densities, g(x,y,z), (Fig. 1h).

$$n_x = g(x+1,y,z) - g(x-1,y,z)$$

$$n_y = g(x,y+1,z) - g(x,y-1,z)$$

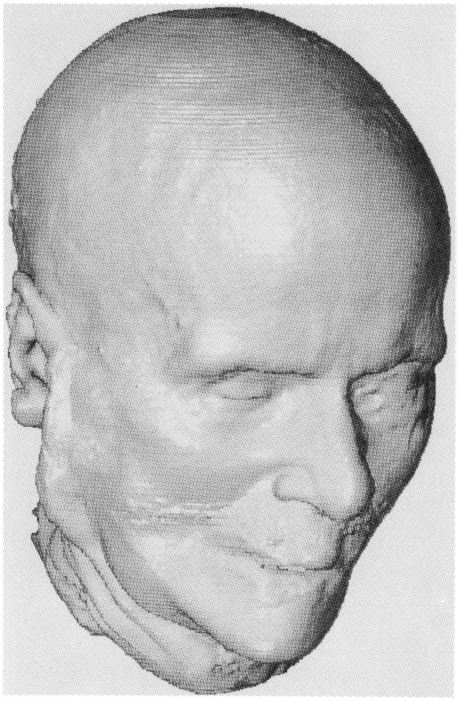
$$n_z = g(x,y,z+1) - g(x,y,z-1)$$

The dataset used in this survey is a CT scan of a cadaver and was acquired as 341 slices of 226 x 272 samples each.

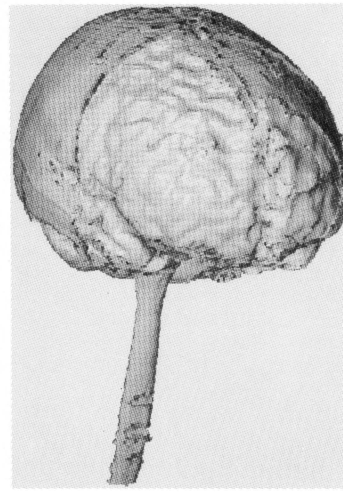


e f g h

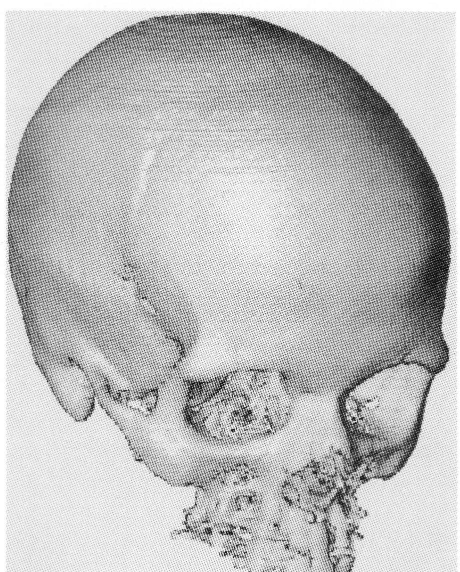
Fig. 1. Examples of rendering techniques. e) Maximum intensity; f) Z-buffer gradient shading; g) Voxel gradient shading; h) Gray-level gradient shading



a

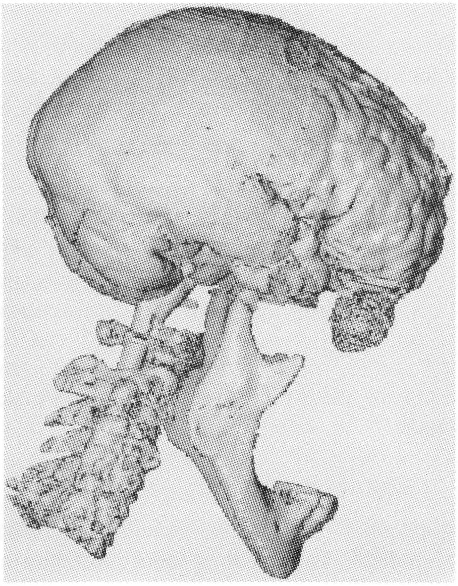


b



c

Fig. 2. Results of Gray-level gradient shading in different types of processing. a-c) Cutis, Cerebrum, Cranium;



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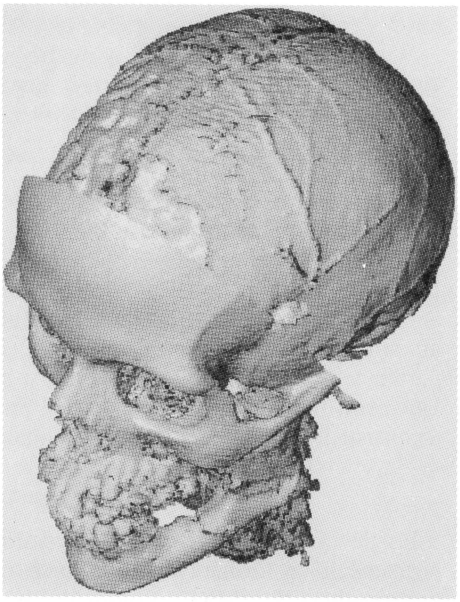
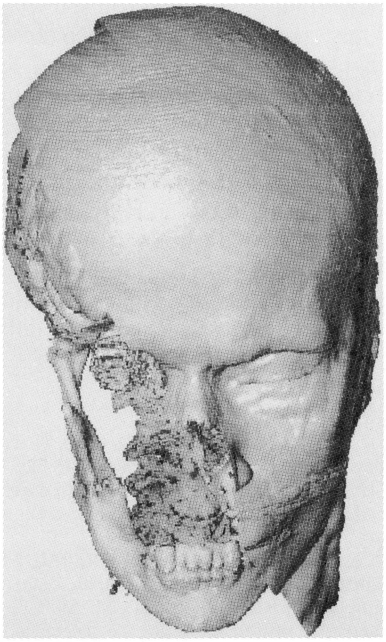


e



f

Fig. 2. Results of Gray-level gradient shading in different types of processing d-f) combination of classified objects with set cutting planes.

Conclusions

We have presented a survey of methods for 3D visualization of serial sections that provide researchers with ability to extract new information from existing collections of data. Methods differ in demands for hardware and in quality of results. The methods can be divided into three groups:
- without classification and shading
- with classification and without shading
- with classification and shading.

We have described and implemented eight visualizing methods. The best results were obtained from Gray Level Gradient Shading. The results of implementation are encoring and show that with the present knowledge of algorithms and appropriate hardware we can choose an optimal strategy for visualization. Except for imaging whole objects we can set parameters of cutting planes as shown in Fig. 2 and set transparency of classified parts. However, in visualizing of histology preparations we are limited by our ability to make a consistent voxel model from individual sections.

Metody pro rekonstrukci prostorových struktur

Příspěvek popisuje metody pro vytváření počítačových rekonstrukcí z medicínských dat pořízených ve formátu rovnoběžných rastrových řezů. Taková data jsou získávána na zařízeních CT, MRI, konfokálních mikroskopech nebo přímým snímkováním a skenováním. Modely těchto dat jsou složeny z malých objemových elementů, nazývaných voxely, majících tvar krychle nebo kvádru. Voxely uspořádané v pravidelné prostorové mřížce, obsahují informaci o odpovídajícím objemu modelovaného objektu. Přiřazením jednotlivých voxelů k různým oblastem modelovaného objektu (klasifikací) definujeme prostorové struktury. Struktury lze také vybrat pomocí intervalu intenzity šedi, který určuje práh zobrazovaných hodnot (prahování). Při zobrazení se používají objemové nebo povrchové metody. Objemové metody zobrazují celý objem voxelů, bez ohledu na klasifikaci a práh. Je popsána sumační, průměrová a maximalizační metoda. Tyto metody jsou vhodné pro zobrazování velmi kontrastních struktur. U povrchových metod je nejdříve nutné vymezit zobrazovanou strukturu pomocí klasifikace nebo prahování. Algoritmy mohou zobrazovat hodnoty intenzit šedi, hodnoty vzdálenosti od pozorovatele nebo používají některou z metod stínování podle normály funkce povrchu, normály zobrazovací funkce nebo normály funkce intenzity šedi. Nastavením barevných odstínů a průhledností lze zobrazit vnitřní, jinak neviditelné struktury. Nejlepší kvalitu zobrazení poskytuje metoda stínování podle normály funkce intenzity šedi, kde jsou dobře zřetelné i malé detaily na povrchu struktur.

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