

ENG4BF3

Medical Image Processing

Image Visualization



Visualization Methods

- Visualization of medical images is for the determination of the quantitative information about the properties of anatomic tissues and their functions that relate to and are affected by disease
- For 2D visualization, three types of multiplanar sectioning and display, including orthogonal, oblique, and curved planes
- For 3D visualization, two types of display, including surface renderings and volume renderings (both projection and surface types)

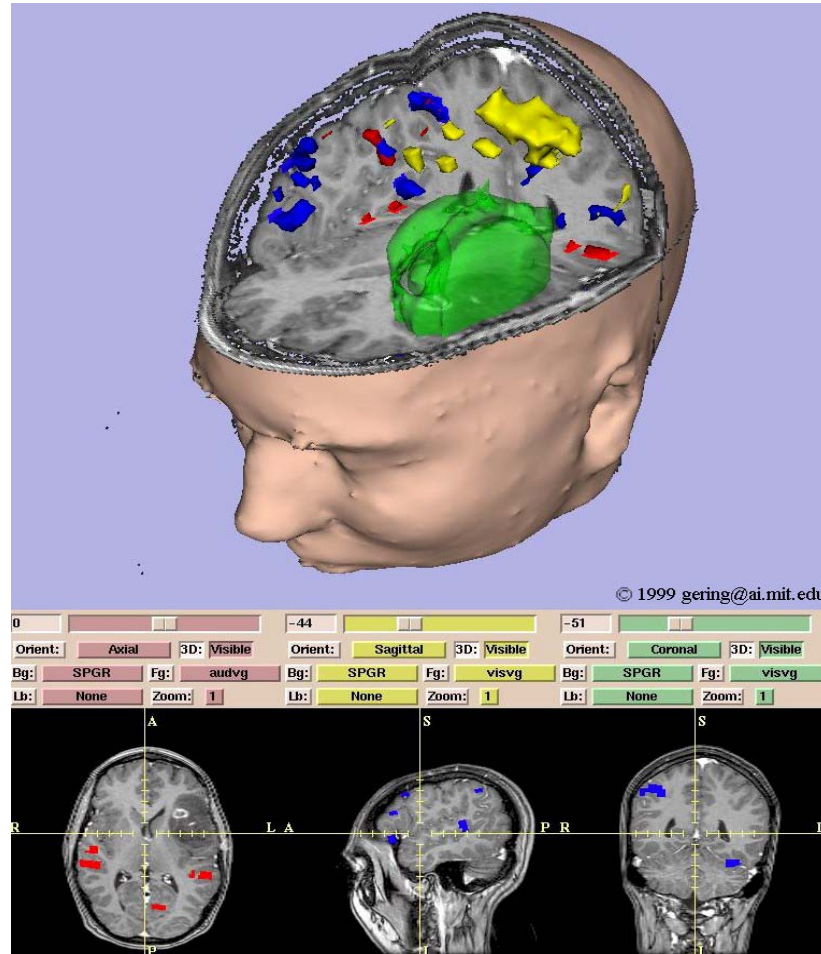
Two-dimensional Image Generation and Visualization

- The utility of 2D images depends on the physical orientation of the image plane with respect to the structure of interest
- Most biomedical imaging systems have limited capability to create optimal 2D image directly, as structure positioning and scanner orientation are generally restricted
- We need techniques to generate and display optimal 2D images from 3D images, and to allow the orientation of 2D image plane to ultimately result in clear, unrestricted view of important features

Multiplanar Reformating

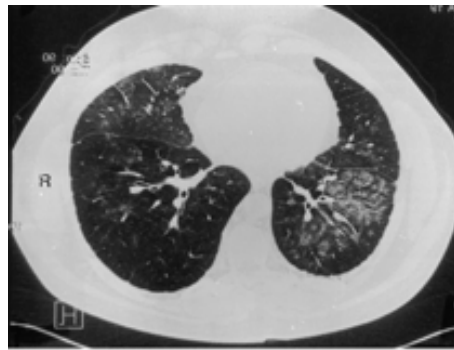
- 3D isotropic volume images allow for simple and efficient computation of images that lie along the nonacquired orthogonal orientations of the volume
- This is achieved by readdressing the order of voxels in the volume images
- With anatomic reference, the orthogonal planes can be depicted by the terms for orthogonal orientation: transaxial, coronal, and sagittal
- Display of multiplanar images usually consists of multipanel displays

Example of Multiplanar Images



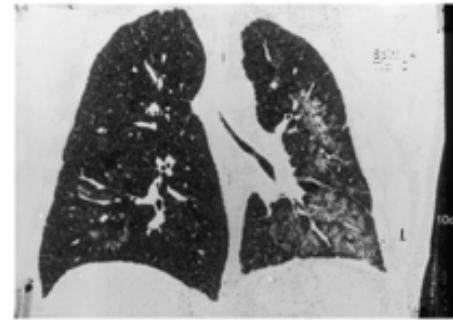
Multiplanar Image (Lung)

Axial



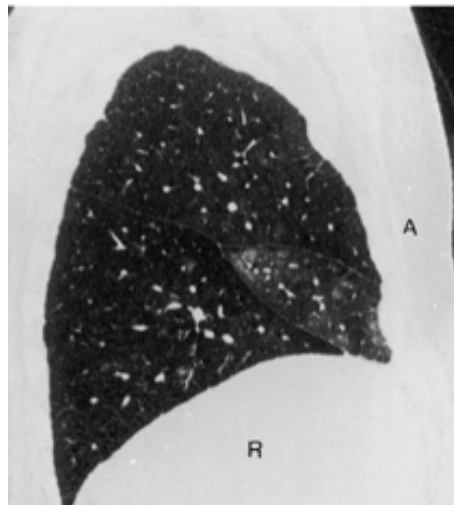
(a)

Coronal



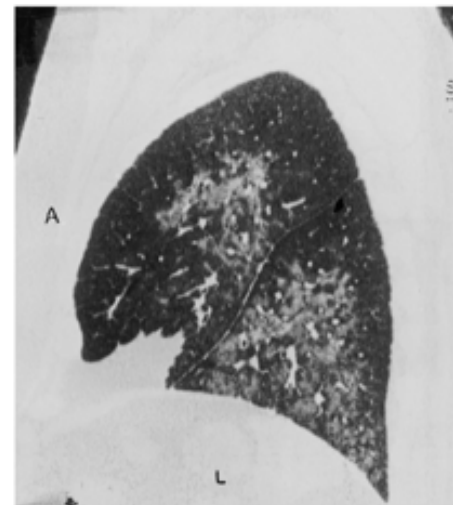
(b)

Sagittal-right



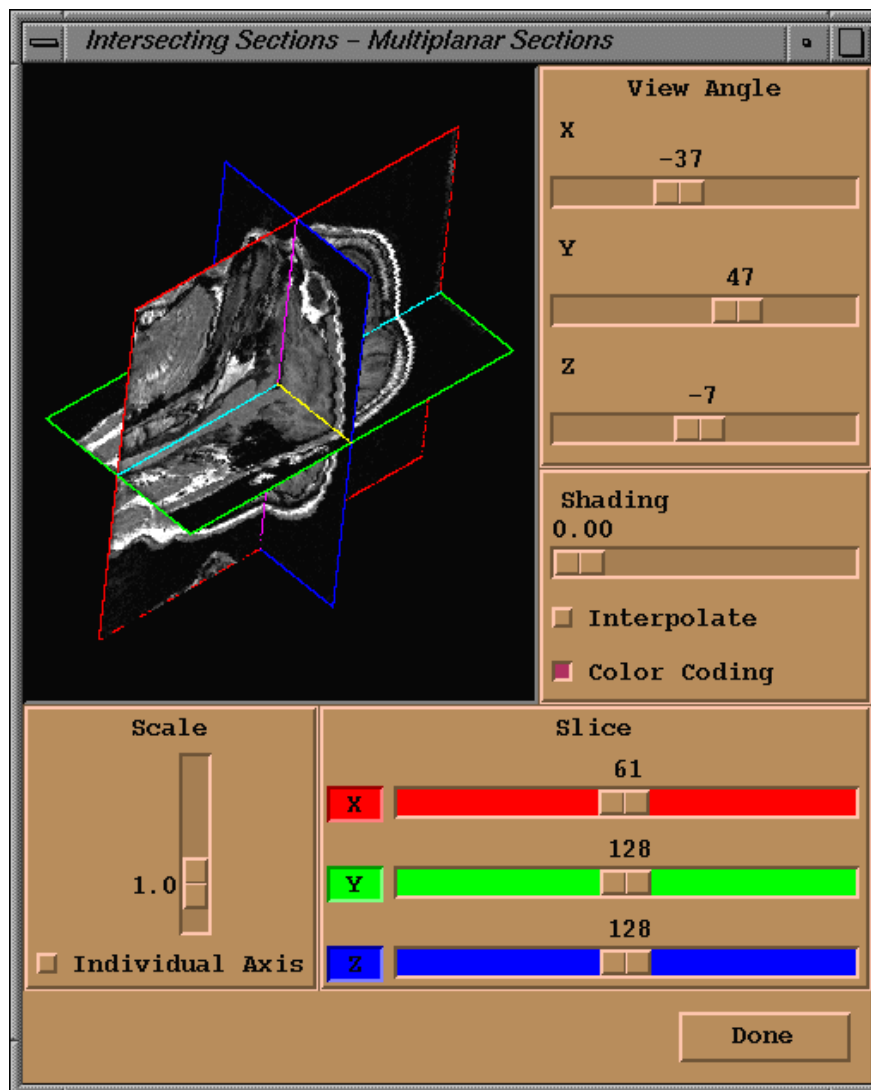
(c)

Sagittal-left



(d)

Multiplanar Sectioning



Oblique Sectioning (I)

- The desired 2D image may not be parallel to the orthogonal orientation of the 3D image
- Oblique images are less intuitive and harder to compute, as simple readdressing of the voxels in a given order will not generate the proper oblique image
- Specification of the orientation and efficient generation of the oblique image require additional visualization and computation techniques

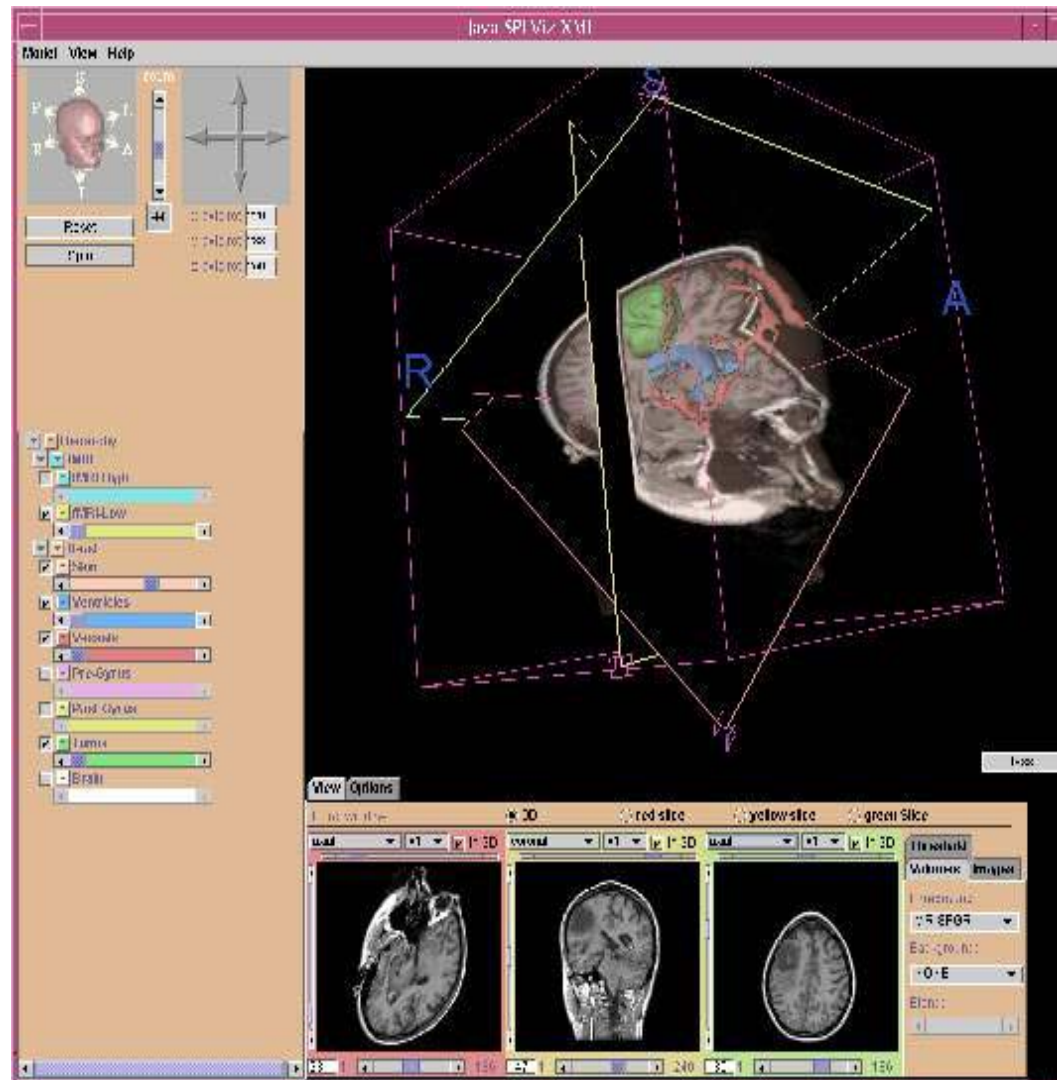
Oblique Sectioning (II)

- Specification and identification of oblique image can be done using structural landmarks in the orthogonal image data
- Several images need to be presented to allow unambiguous selection of landmarks, through multiplanar orthogonal images
- Selection of any three points or landmarks will uniquely define the orientation of the plane
- Two selected points define an axis along which oblique planes perpendicular to the axis can be generated (not uniquely)

Oblique Sectioning (III)

- Interactive oblique sectioning involves some method of visualization for plane placement and orientation verification
- One method is to superimpose a line on orthogonal images indicating the intersection of the oblique images with the orthogonal images
- Another depicts the intersection of oblique plane with a rendered surface image providing direct 3D visual feedback with familiar structural features

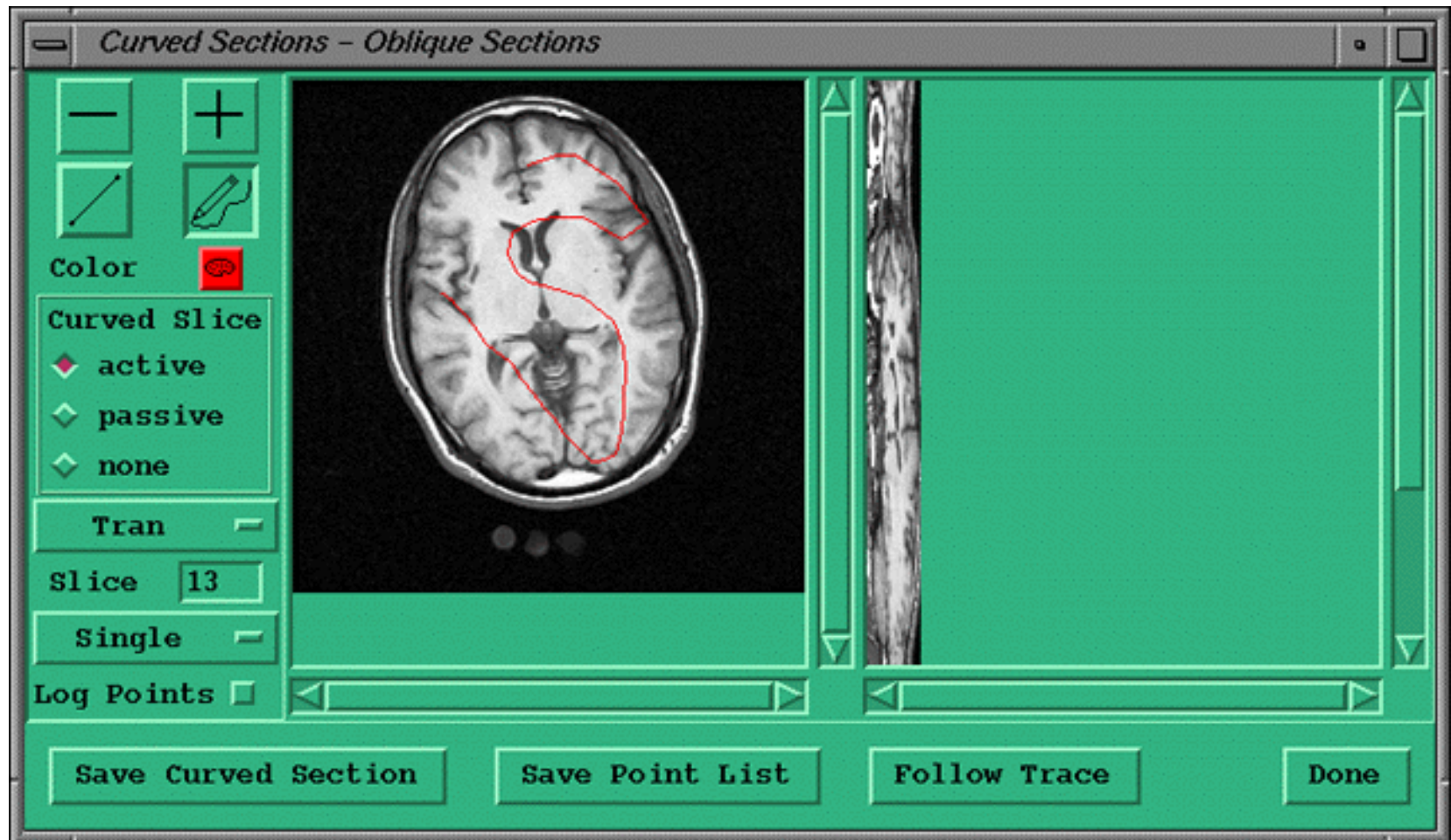
Example of Oblique Sectioning (II)



Curved Sectioning

- A trace along an arbitrary path on any orthogonal image defines a set of pixels in the orthogonal image that have a corresponding row of voxels through the volume image
- Each row of voxels for each pixel on the trace can be displayed as a line of a new image
- This is useful for curved structures that remain constant in shape through one orthogonal dimension, like the spinal canal, orbits of the eyes

Example of Curved Sectioning



Three-dimensional Image Generation and Display

- Visualization of 3D volume images can be divided into two techniques characteristically: **surface rendering and volume rendering**
- Both produce a visualization of selected structures in the 3D volume image, but the methods involved are quite different
- Selection of techniques is predicted on the particular nature of the biomedical image data, the application to which the visualization is being applied, and the desired result of visualization

Surface Rendering

- Surface rendering techniques require the extraction of contours (edges) that define the surface of the structure to be visualized
- An algorithm is applied to place surface patches or tiles at each contour point, and with hidden surface removal and shading, the surface is rendered visible
- They use a relatively small amount of contour data, resulting in fast rendering speeds

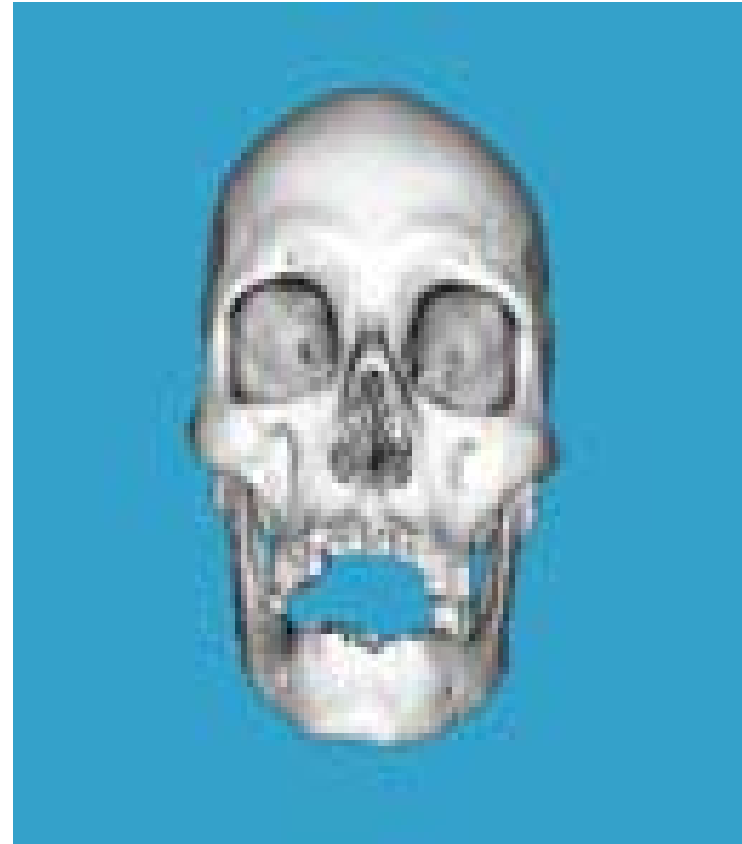
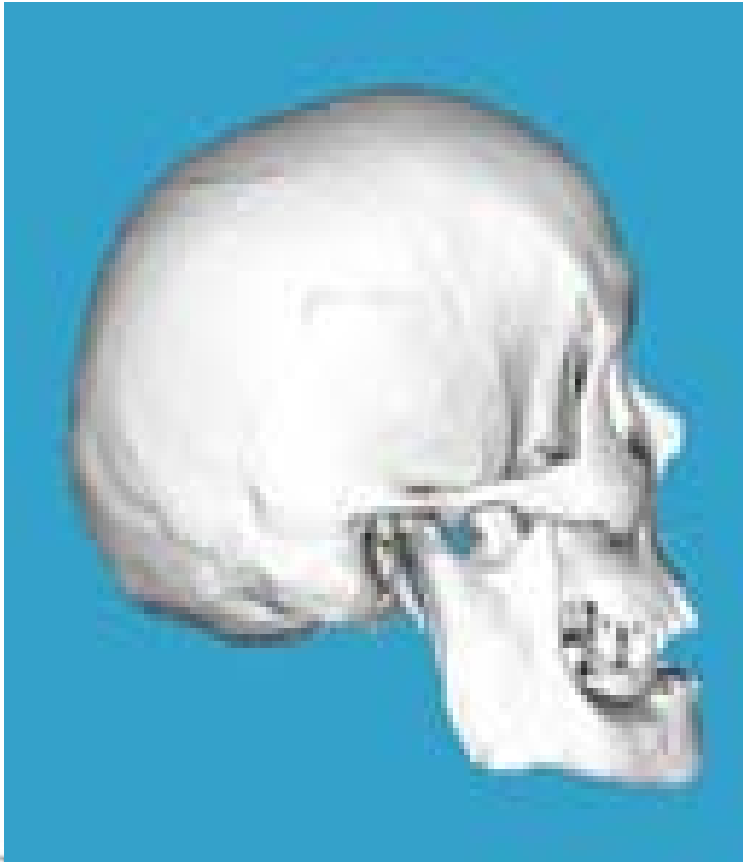
Surface Rendering (II)

- Standard computer graphics techniques can be applied, including shading models
- Particular graphics hardware of the computer can be utilized to speed up the geometric transformation and rendering processes
- Contour descriptions are transformed into analytical descriptions
- Other analytically defined structures can be easily superposed with the surface-rendered structures

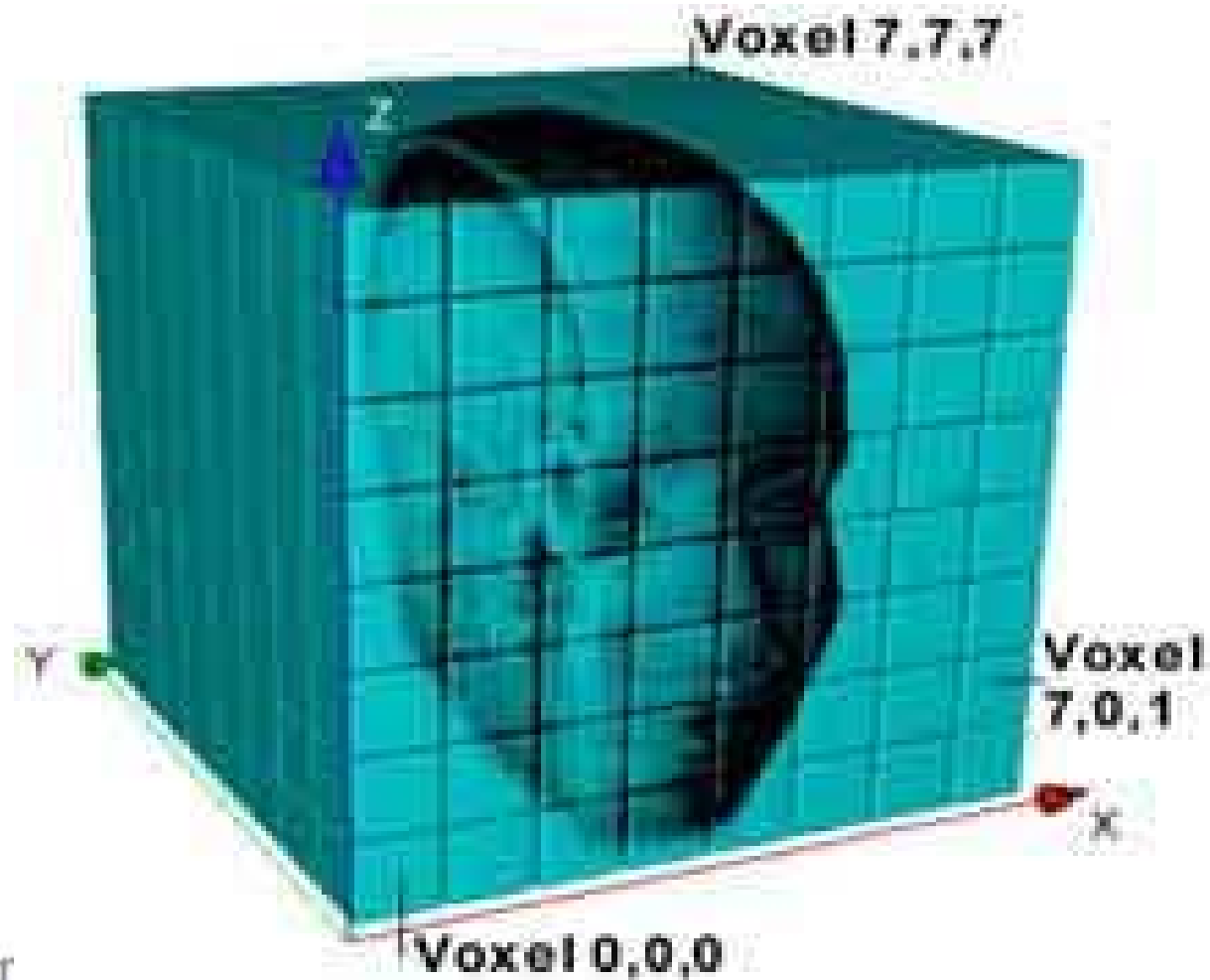
Surface Rendering - Drawbacks

- The need to discretely extract the contours defining the structures to be visualized
- Other volume image information may be lost in the extraction process, which may be important for slice generation or value measurement
- Difficult to interactive and dynamic determination of the surface to be rendered
- Prone to sampling and aliasing artifacts on the rendered surface due to the discrete nature of the surface patch placement

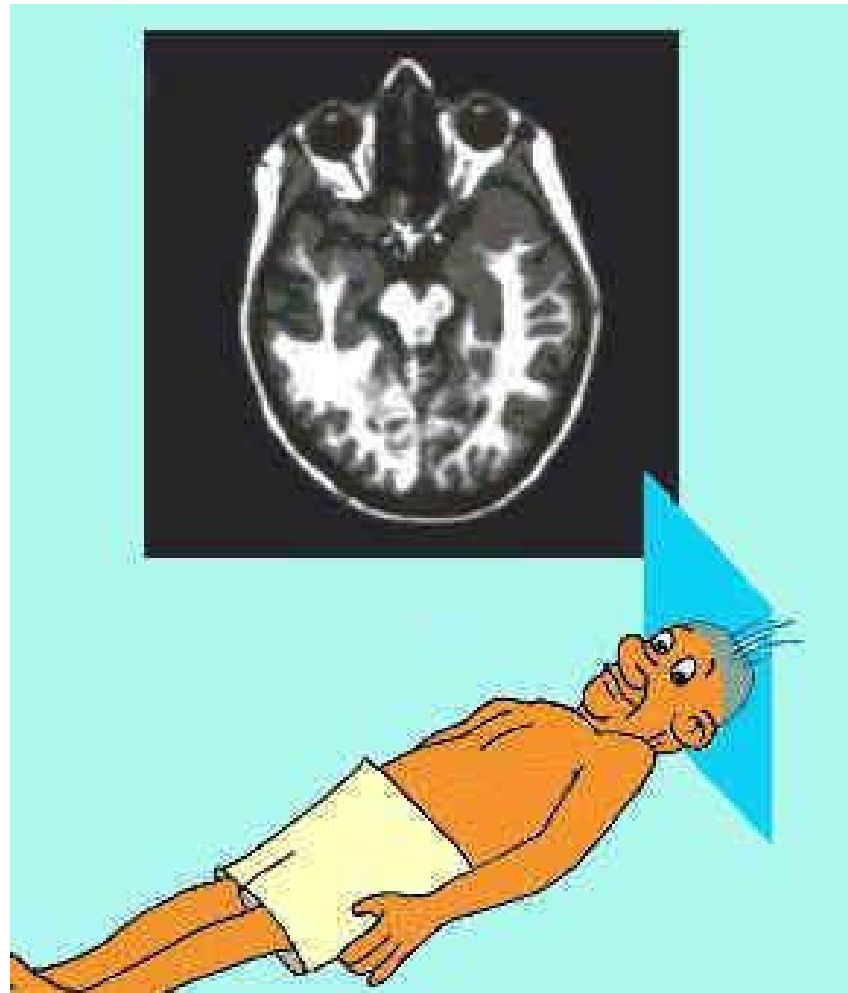
4.2e: Surface Rendering Examples



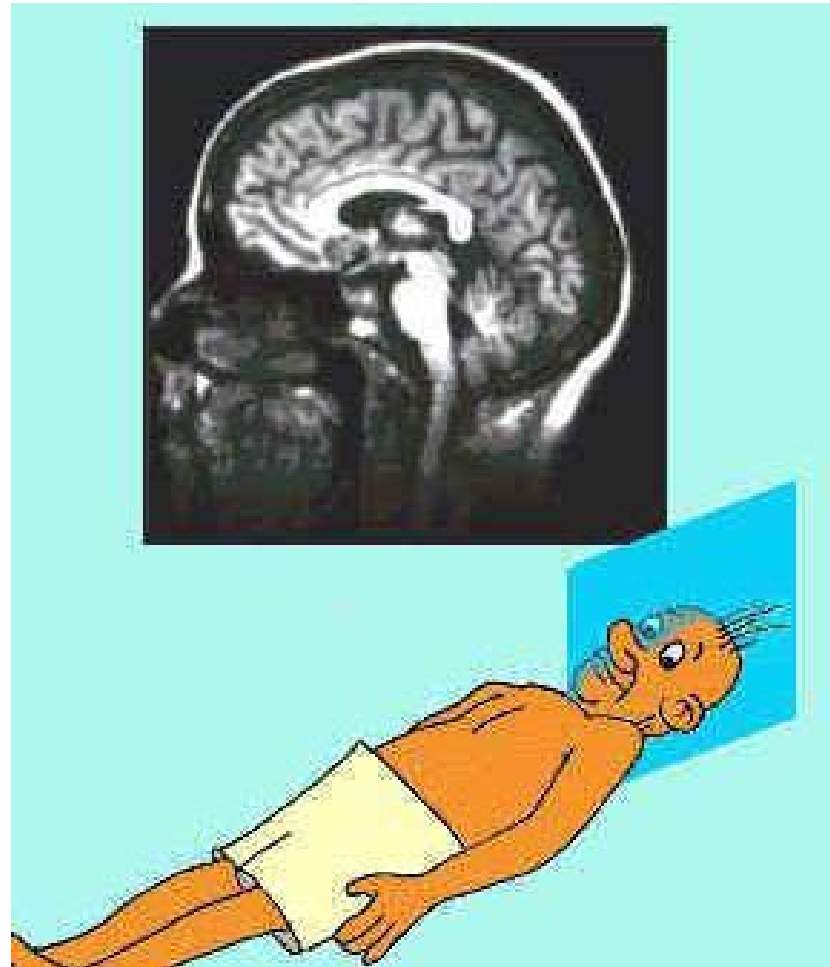
A Volume Data Set of Voxels



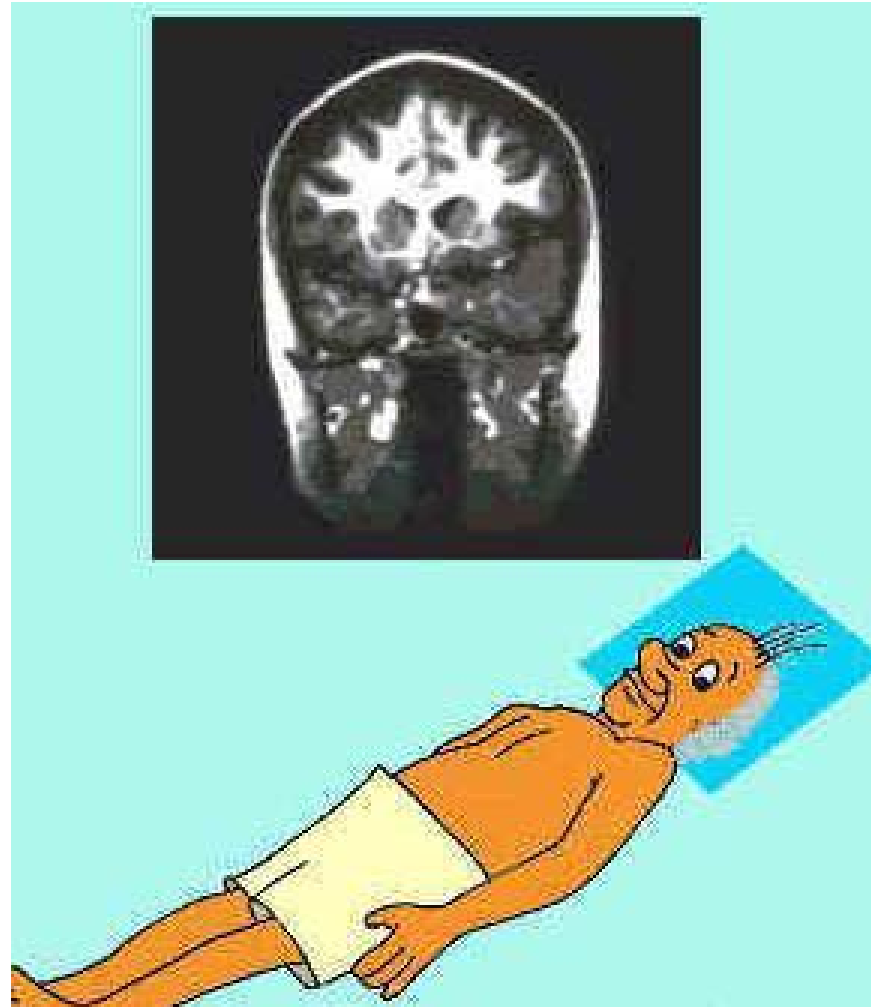
Transverse (Axial) Slices in the XY Plane



Sagittal Slices are in the ZY Plane

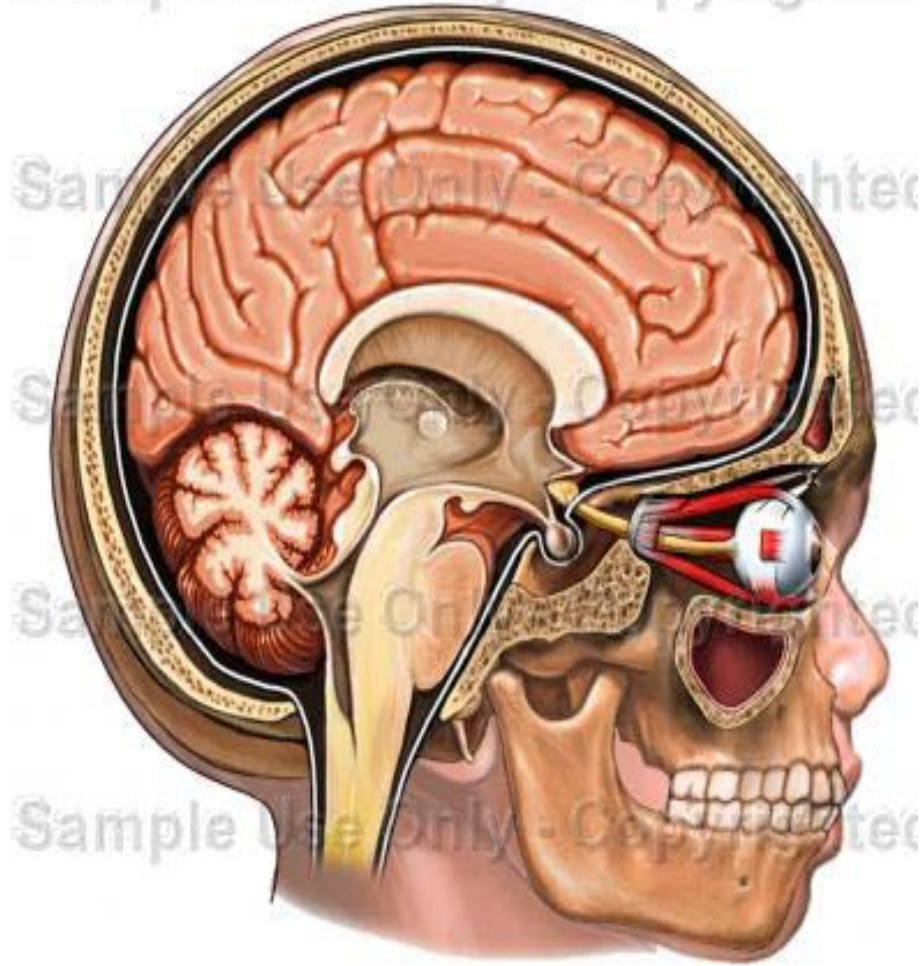


Coronal Slices are in the ZX Plane



What is the View of this Slice?

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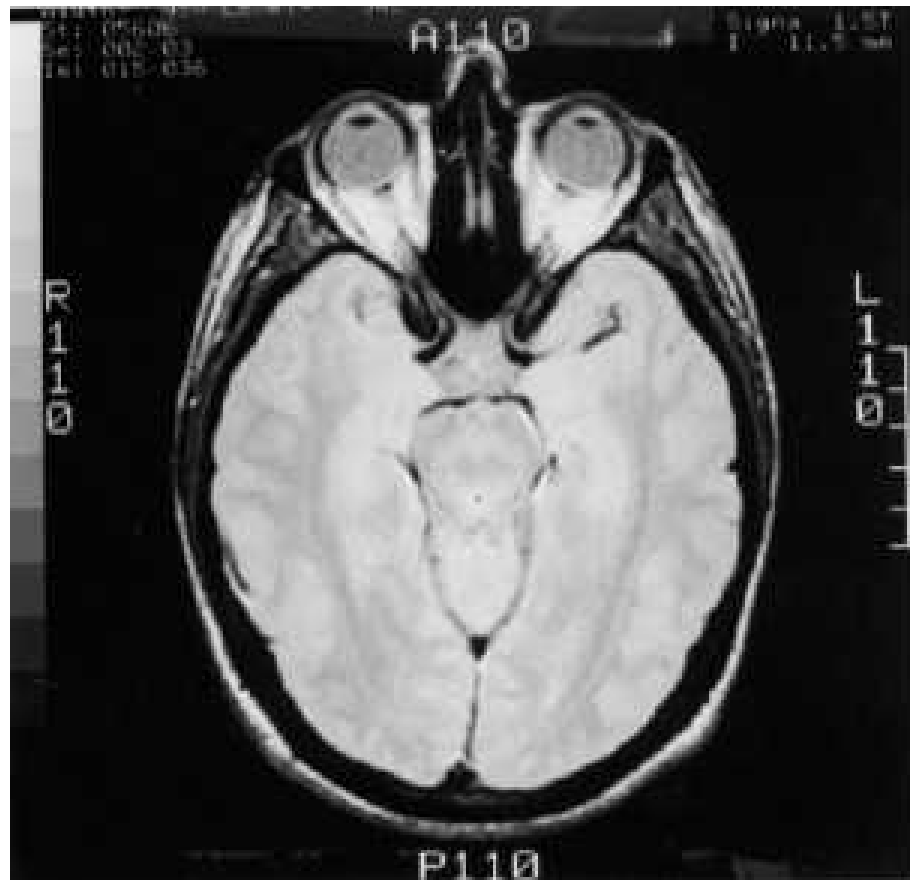
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What is the View of this Slice?



Interpolation and Transformation

- Most 3D biomedical volume images are sampled anisotropically, with the slice thickness often significantly greater than the in-plane pixel size
- Visualization and measurement usually require volume data to be isotropic, and the data must be post-processed before it can be used properly
- Possible problems for anisotropic data: incorrect aspect ratio along each dimension for visualization, and aliasing artifacts due to difference in sampling frequency

Interpolation

- First-order linear interpolation of the gray level values is commonly used for 3D volume image
- Values of “new pixels” between existing pixels are simply interpolated (averaged) values of the existing pixels. It is a tri-linear interpolation in 3D. The interpolation in each of the dimensions is completely separable
- Tri-linear interpolation works well for most biomedical images

High Order Interpolation

- When the ratio in size between any of the voxel dimensions in 3D becomes greater than approximately 5 to 1, tri-linear interpolation does not work well, which will provide poor approximations
- High order interpolation, such as cubic interpolation, may be used, with increased computational cost
- Cubic interpolation uses more than the immediate adjacent voxels and uses a cubic polynomial to estimate the intermediate values
- Shape-based interpolation methods may be used for certain particular (known) structure of interest

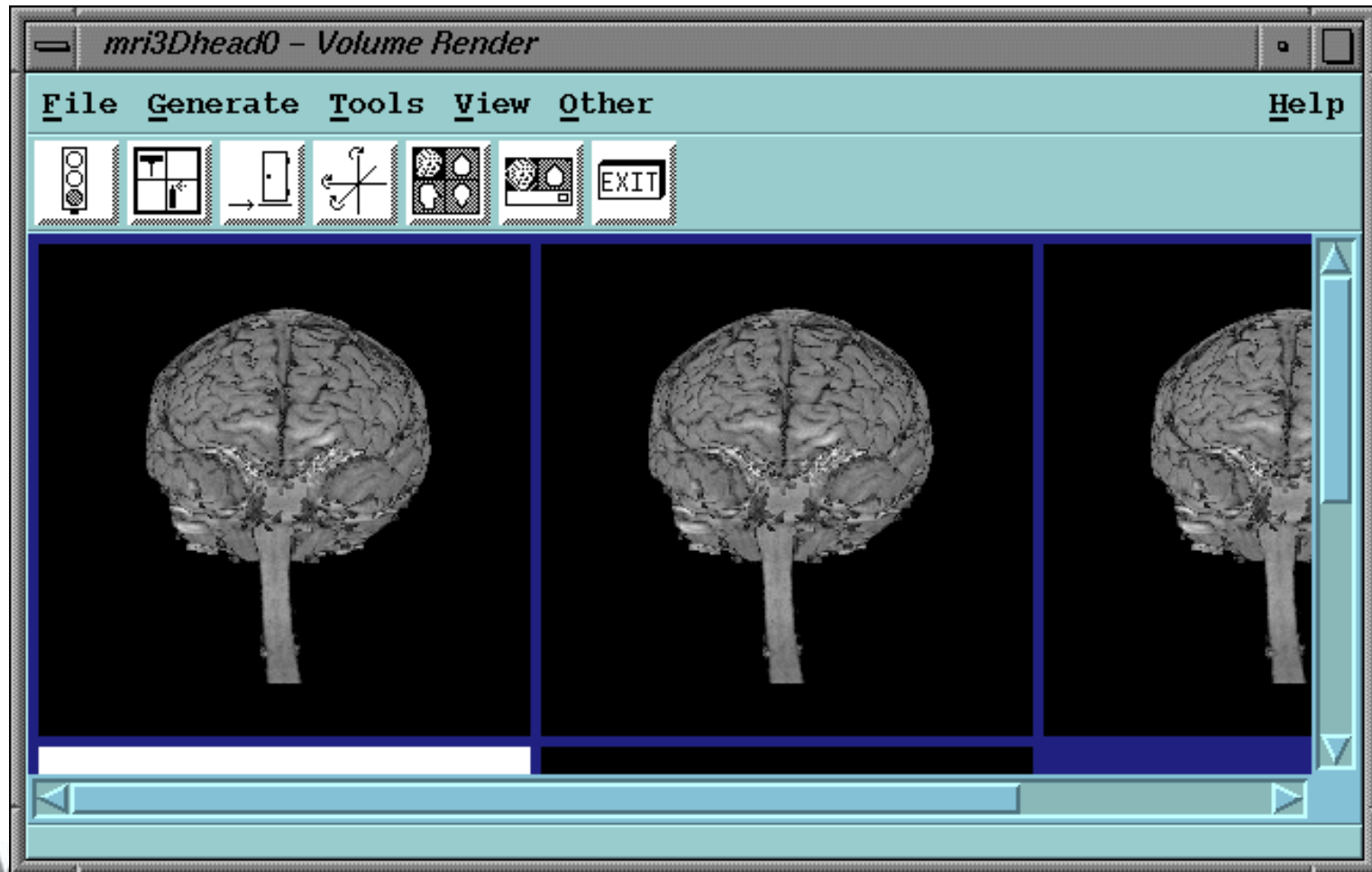
Volume Rendering (I)

- The most popular volume rendering methods in 3D biomedical image visualization are ray-casting algorithms
- They provide direct visualization of the volume images without the need for prior surface or object segmentation, preserving the values and context of the original image data
- The rendered surface can be dynamically determined by changing the ray-casting and surface recognition conditions during the rendering process

Volume Rendering (II)

- Volume rendering can display surfaces with shading and other parts of the volume simultaneously
- 3D biomedical volume image data sets are characteristically large, taxing the computation abilities of volume rendering algorithms and the computer systems
- Given the discrete voxel-based nature of the volume image, there is no direct connection to other geometric objects, which may be desired for inclusion in the rendering or for output of the rendered structure to other devices

Example Volume Rendering (I)



Example of Volume Rendering (II)

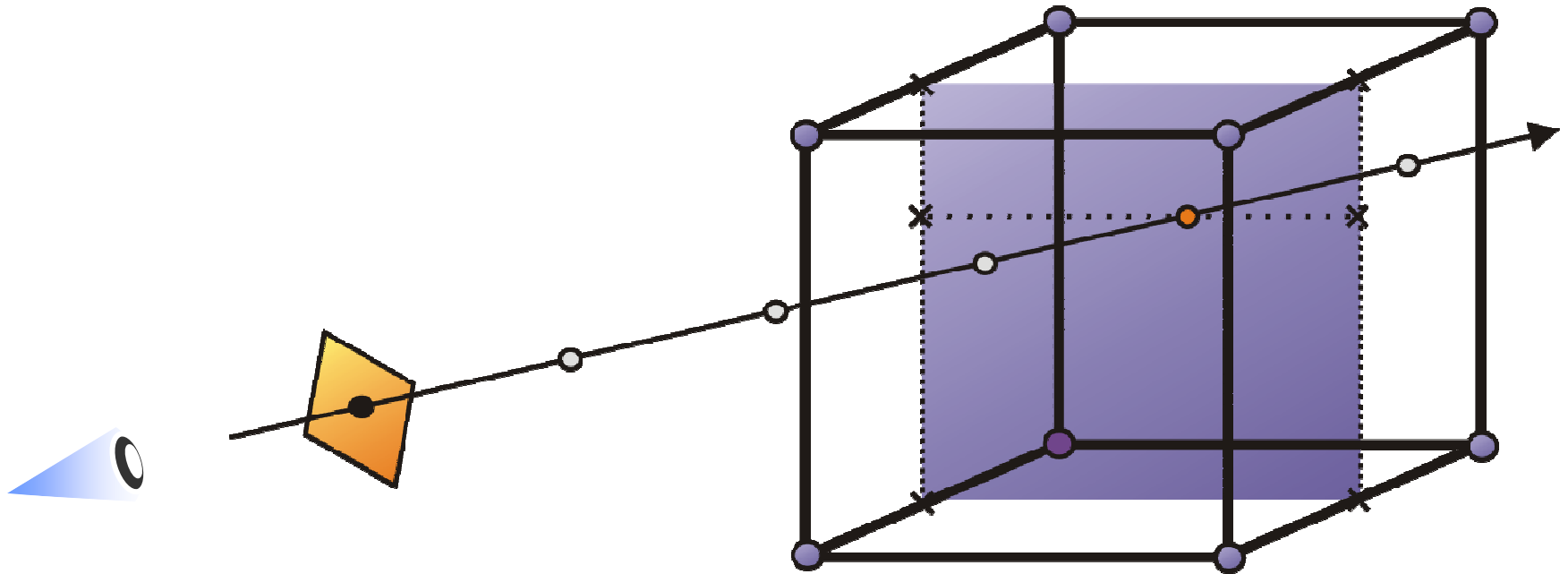


Rendered from CT scans
256X256X226

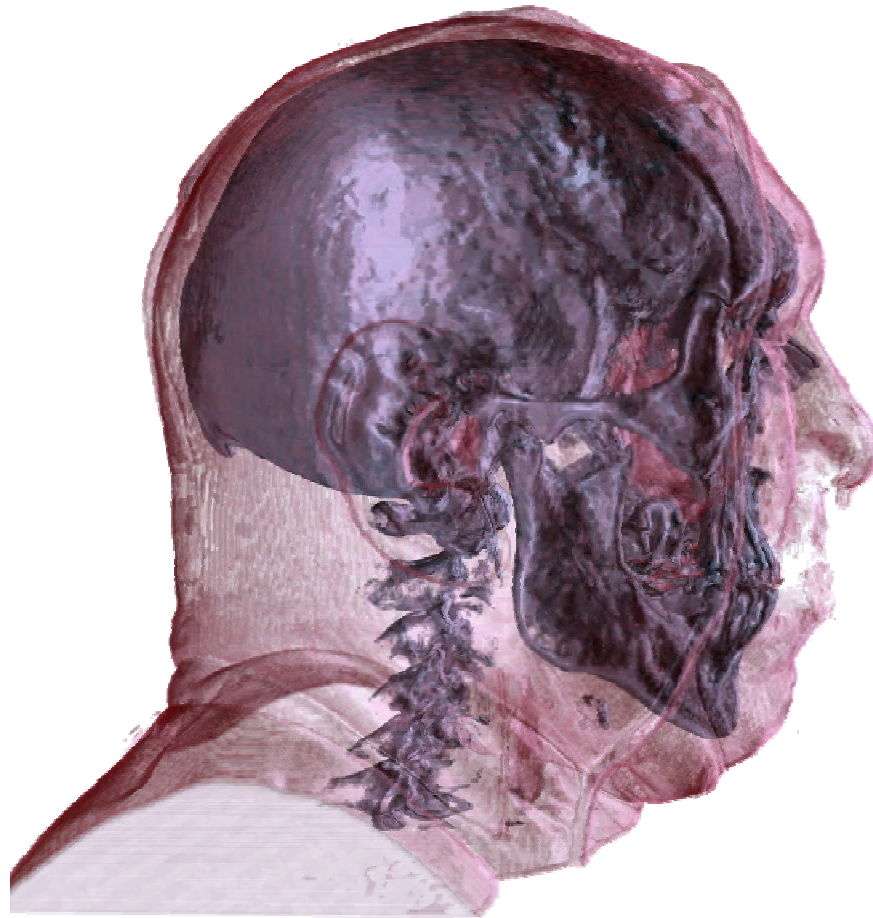
A Volume Rendering Model

- A source point (the *eye*)
- A focal point (where the eye is looking)
- A matrix of pixels (the *screen*)
- The visible object to display (*scene*) is in the projection path within a truncated volume (*viewing pyramid*)
- The purpose of a ray-tracing model is to define geometry of the rays cast through the scene
- A ray is defined as a straight line from the source point passing through the pixel

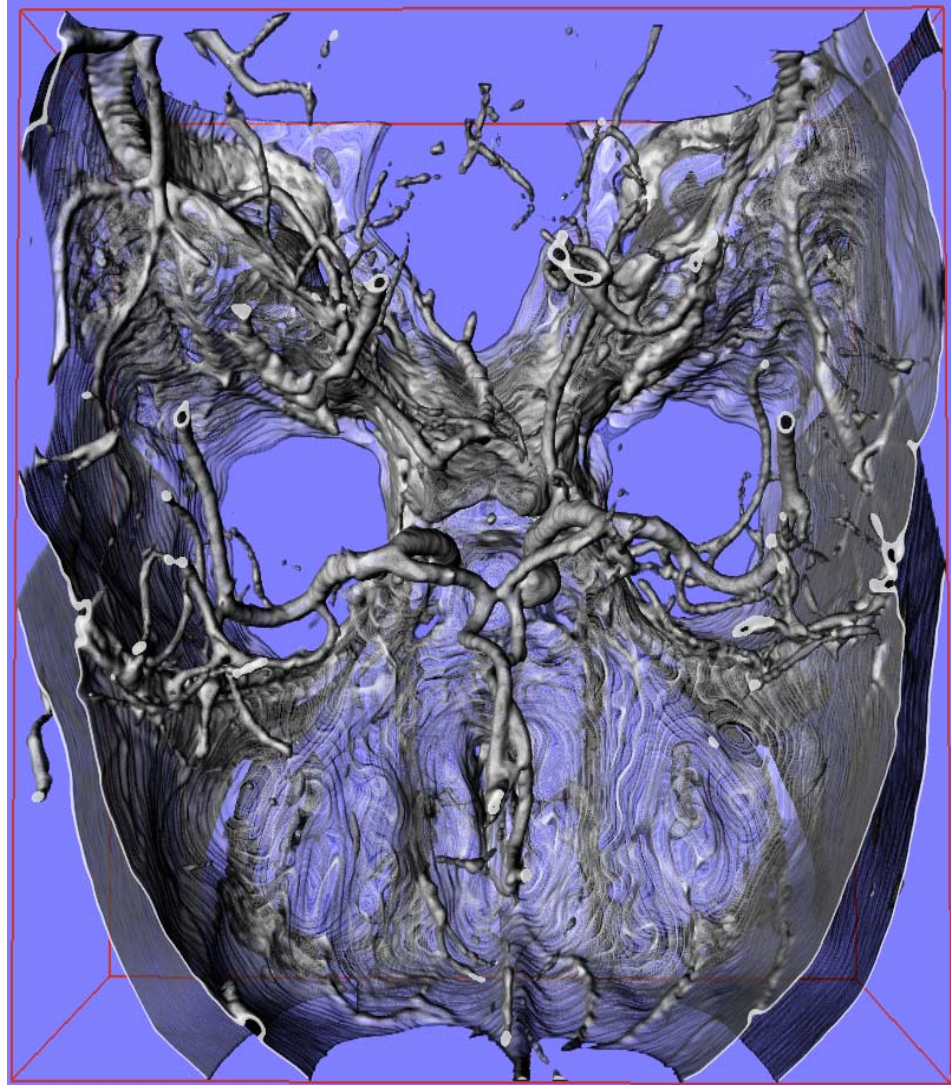
Diagram of Ray Casting Rendering



High Quality Volume Rendering



CT Angiography



Surgery Planning and Rehearsal

- Patients with brain tumors, arterial venous malformations, or other complicated internal brain pathology undergo multimodality image scanning preoperatively to help neurosurgeons understand the anatomy of interest
- Direct scans can be co-registered in order to produce single visualizations of complementary information
- Specific anatomical objects may be identified and segmented

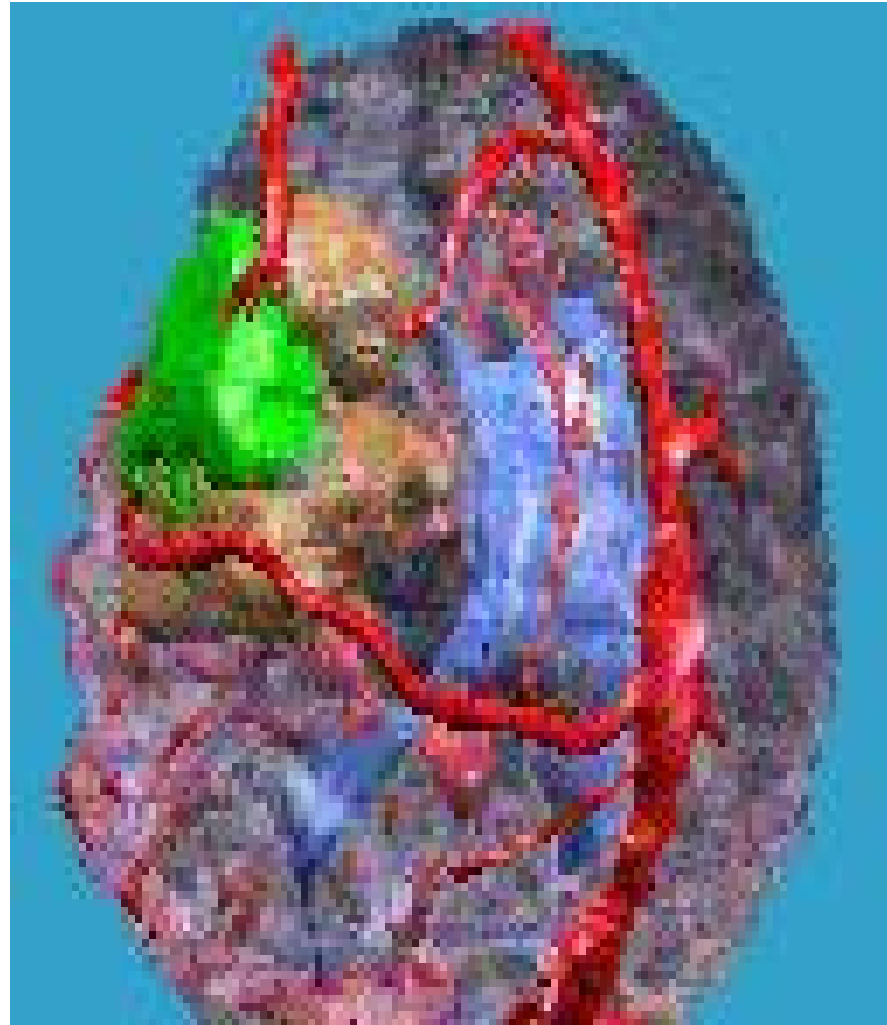
Neurosurgery

- Visualization procedures enable more precise and expedient navigation to the target site and provide more accurate delineation of margins for resection in brain surgery than traditional procedures
- It can provide online, updated information to accommodate any shifts in brain position during the operational procedure
- This results in significantly increased physician performance, reduction in time in the operating room, and an associated increase in patient throughput and decrease in healthcare costs

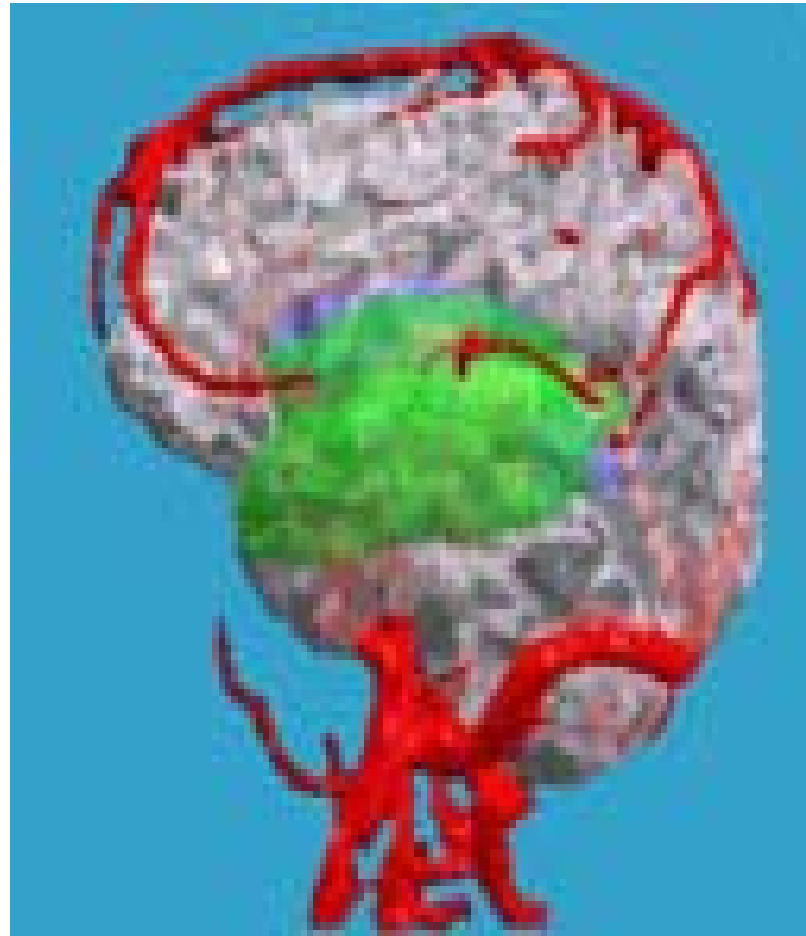
Brain Internal Tissues



Isolating Brain Tumor



Understanding Environment



Storage of Biomedical Images

- Biomedical images can usually be stored in slow storage media as they are not viewed frequently
- Design decisions for storage are based on the needs of the practitioners who use images, and balanced against the cost of data storage and software systems needed to make them accessible, reliable, and durable
- New standards, such as DICOM (Digital Imaging and Communications in Medicine), are evolving that will combine the universal access of film with the flexibility of digital imagery

DICOM

- DICOM (Digital Image Communications in Medicine) provides a protocol for transmission of image based on their modality, and incorporates metadata for each image within the message
- Each DICOM image message provides the basic information required to attach it to a patient or an imaging procedure, encoded information may be redundant
- DICOM requires the sending and receiving computers to agree on a common basic method of communication, and a set of well-defined services (such as image storage) specified before the message is sent

Metadata: The Image Header

- The first part of many image files provides a description of the image – file **header**
- The information in the header is called the **metadata** (the information about the image)
- Some file formats use formatted header fields to describe the image, e.g., information can be image type, height and width of the image
- Flexible fields such as TIFF (tagged image file format) defines a set of tags, or field definitions, that may be present or absent in an image file

DICOM File

- A saved DICOM transmission message file has a type of tagged file format. Everything has a tag, a size, and a value
- Image pixels are described as the value of a pixel tag
- There are a minimal set of standard tags required, followed by a minimal set of tags for each modality
- Many optional tagged values may be included, and the specification includes tags for proprietary data, allowing vendors or developers to encode data specific to their machines or process

Pixel/Voxel Packing

- Most pixel values are stored as binary numeric values with a fixed number of bits
- Monochrome data needs a single bit; gray scale data is stored as 8 bits, 12 bits, or 16 bits
- For images with multiple channels in each pixel, such as color encoded as RGB, image file formats may incorporate packed or planar schemes
- In packed scheme, pixels are grouped by pixel, such as RGB, RGB, RGB, etc
- In planar scheme, all of the pixels for one color are placed together as a 2D image, such as RRR, followed by GGG followed by BBB

Image Compression

- Image compression means to express in compact form the information contained in an image
- The resulting image should retain the salient (or exact) features necessary for the purpose for which it was captured
- For legal purpose, it is often necessary to insure that decompression restores the image to the same values by which any diagnosis was based
- Two main types of image compression algorithms: **lossless and lossy**

Lossless Image Compression

- Lossless compression perfectly recovers the original image after decompression, and works by simply taking advantage of any redundancy in the image, e.g., Huffman encoding, run-length encoding, etc.
- Most image data has pixel values or groups of pixels that repeat in a predictable pattern
- It typically achieves ratios of 2:1 or 3:1 on medical images

Run-length Encoding

- The image pixels are scanned by rows, and a count of successive pixel values along with one copy of the pixel are sent to the output
- Very effective for large area of constant color
- Not good for images containing many smooth gradations of gray or color values
- An example:

Original 2211333334333222 (16 characters)

Compressed 22 21 43 14 33 32 (12 characters)

Huffman and Lempel-Ziv Coding

- These schemes search for patterns in the data that can be represented by a smaller number of bits
- These patterns are mapped to a number of representative bytes and stored by probabilities
- Original 12334123343212334 (17 characters)
- Map 12334 = A, 32 = B
- Compressed AABA (13 characters)

Lossy Image Compression

- Lossy compression changes the image values, but attempts to do so in a way that is difficult to detect or has negligible effect on the purpose for which the image will be used
- It can accomplish 10:1 to 80:1 compression ratios before change in the image is detectable or deleterious
- Typical techniques are JPEG and wavelets
- Most often used to reduce bandwidth required to transmit image data over internet

JPEG

- The JPEG standard was developed for still images, and performs best on photographs of real-world scenes
- The first pass transforms the color space of the image to a luminance-dominated color space, and then downsamples the image and partitions it into selected blocks of pixels
- A discrete cosine transform is applied to the blocks
- The resulting DCT values for each block are divided by a quantization coefficients and rounded to integers
- The reduced data is encoded using Huffman etc

JPEG Lossy Compression



Wavelets

- Wavelet transform coefficients are partially localized in both space and frequency, and form a multiscale representation of the image with a constant scale factor, leading to localized frequency subbands with equal widths on a logarithmic scale
- Wavelet compression exploits the fact that real-world images tend to have internal morphological consistency, locally luminance values, oriented edge continuations, and higher order correlations, like textures
- For CT images, the compression ratio can be 80:1
- For chest X-rays, the ratio may be around 10:1

Example of Wavelet Compression

Original image
589824 bytes

JPEG image
45853 bytes

Wavelet image
45621 bytes



Image Database

- Basic requirements for an image database are a means to efficiently store and retrieve the images using an indexing method
- Hierarchical file systems, combine hard disk drives with optical or magnetic tape media, and through a file system database provide what appears to be a monolithic set of files to the users
- Frequent requests for a large number of files may swamp such a system

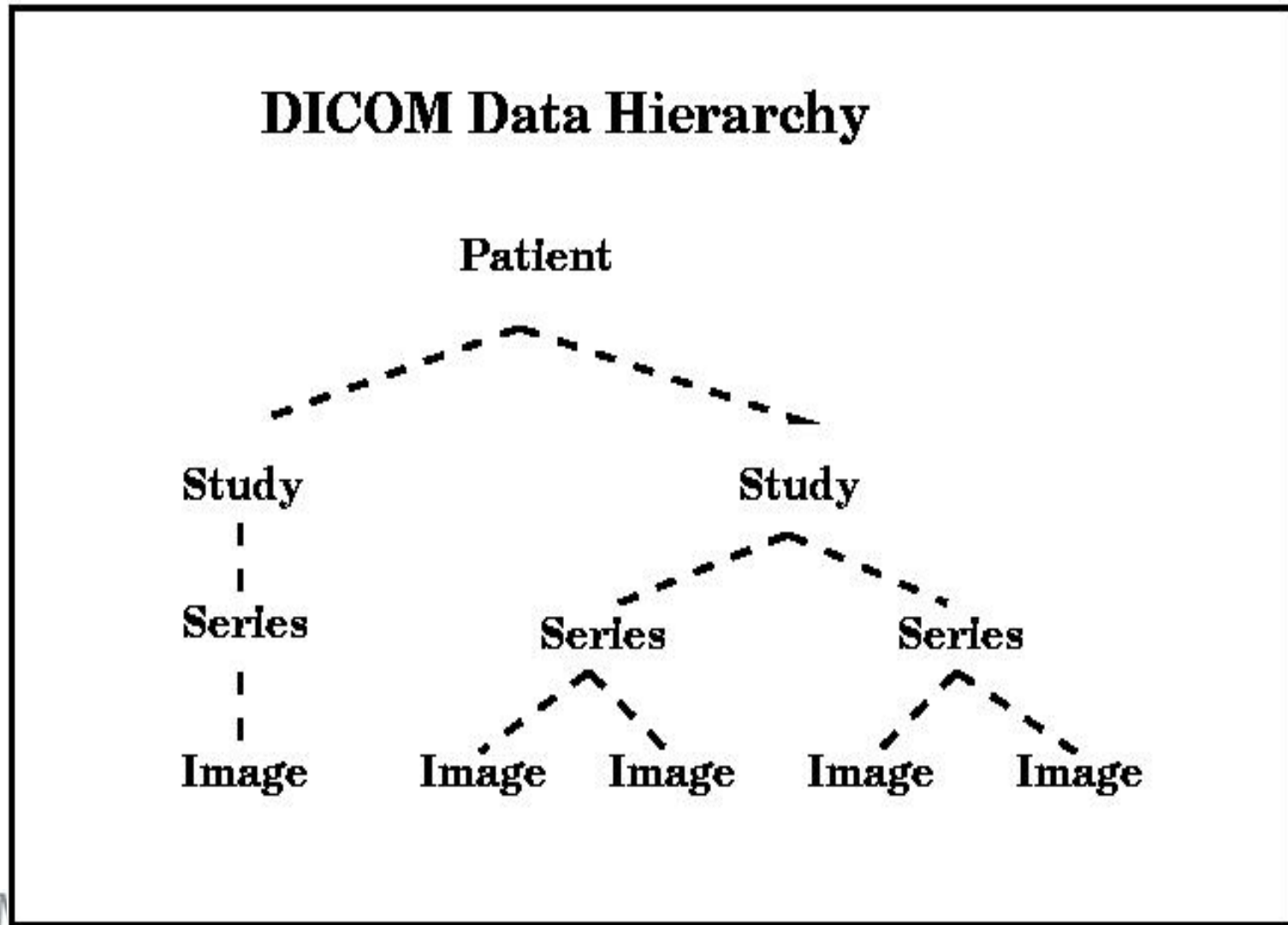
Where to Store the Images

- The images can be stored “inside” or “outside” of the databases
- A much smaller metadata about the image can be stored in the database
- A small-scale reference image, called “thumbnail”, extracted from the image can be used in a metadata. It is several orders of magnitude smaller than the original image
- An index is needed to link the metadata with the original image

DICOM Database

- DICOM database provides a hierarchical tree structure wherein the patient is at the top of the tree
- For each patient, there can be several studies, including an image examination by a given modality
- Within each study, there can be a series of images, where each series can represent different viewpoints of the patient within the study
- Each series may be a single or a set of images
- DICOM inherently organizes images in a most suitable way for use in a treatment setting

DICOM Data Hierarchy



DICOM Database (I)



DICOM Database (II)

PATIENT INFORMATION

Patient ID 987654321

Patient Name Smith, John

Birth Date 10/04/1975 Age 25

Sex M Weight 120 Lb 54 Kg

Rad Smith Refer Inflammation

Operator Status None

Exam Description Spine

History BACK PAIN, SOB, ?TB, FUNGAL OR BACTERIAL

Landmark

Patient Information

For Referring Physician:

Fill in ACR pathology code.

For Exam Description:

Fill in ACR anatomy code.