Imaging

- Medical imaging is an important diagnostic tool
- It involves:
  - Image acquisition
  - Image reconstruction
  - Image Processing
  - Image Analysis
  - Image Interpretation

Image formation

- Physical properties are different, but fundamentally a 3 D object is being imaged:
  - let a tissue have a distribution of some property f = q (x,y,z)
  - Then the image g = T(f), where T is the transformation describing the imaging process.
  - Depending on the imaging modality, the distribution f only reflects one property of the object, ie linear attenuation or water content, not the real object.
  - The aim is to define some characteristics of the object using a specific T, and perhaps combine many T's (multi-modality imaging)

Where do we see images

- Film
- Monitors

Display Issues

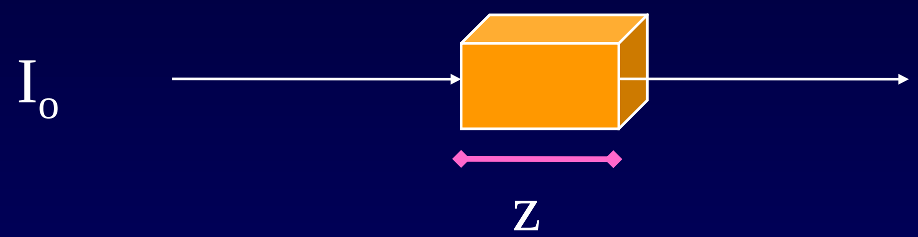
- Film properties: When images are transferred to film, the final product is affected- permanently
- Monitors: Several parameters govern the visualization

Physiological Properties Mapped

Modality	**Property**
X-ray: Radiographs Computed Tomography (CT)	Linear attenuation (μ) based on tissue density, atomic number
Ultrasound Doppler	Acoustic Impedence Motion
Radionuclide imaging,PET, SPECT	Distribution of chemically labelled γ emitters, receptors

RADIOGRAPHS AND COMPUTED TOMOGRAPHY (CT)

- Based on attenuation of x-rays.
  - Denser the tissue > attenuation (atomic number)
  - Muscle, soft tissue very similar



$$I = I_o\, e^{-\mu z}$$

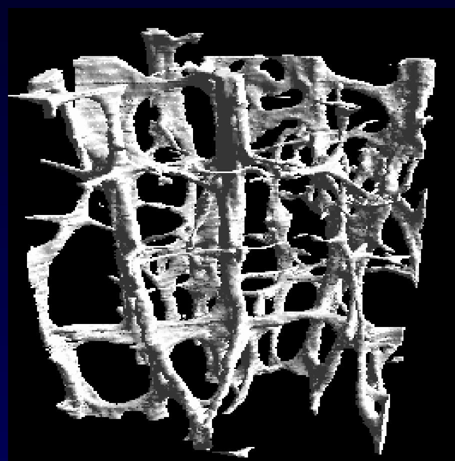
For multiple thicknesses with different attenuation: $I = I_o\, e^{-(\mu_1 z_1)}\, e^{-(\mu_2 z_2)}\, e^{-(\mu_3 z_3)}$

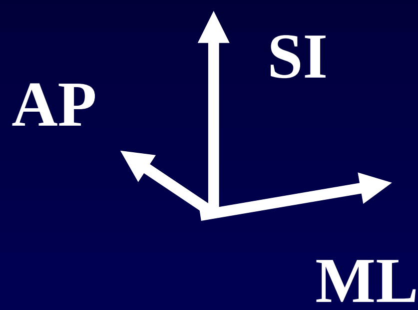
$P(x,y) = \text{Ln}\ I / I_o\ (x,y) = \text{Integral}\ \mu\ (x,y,z)$

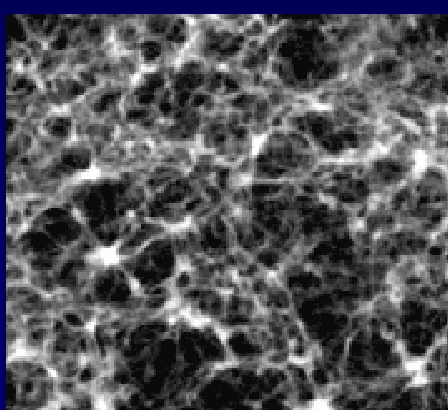
Projection theorem

RADIOGRAPHS : WRIST

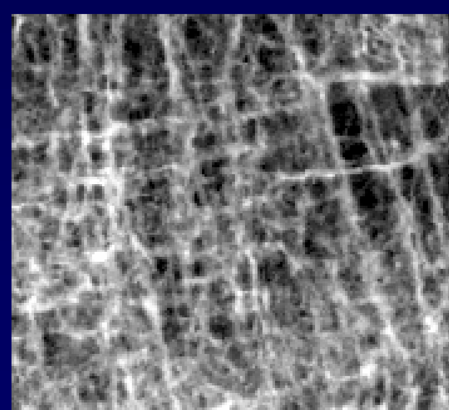
Radiographic Image of 3D Structure



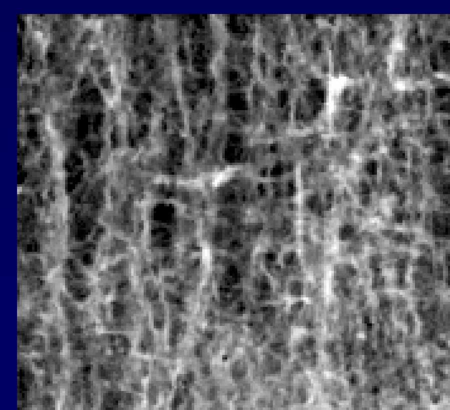




SI

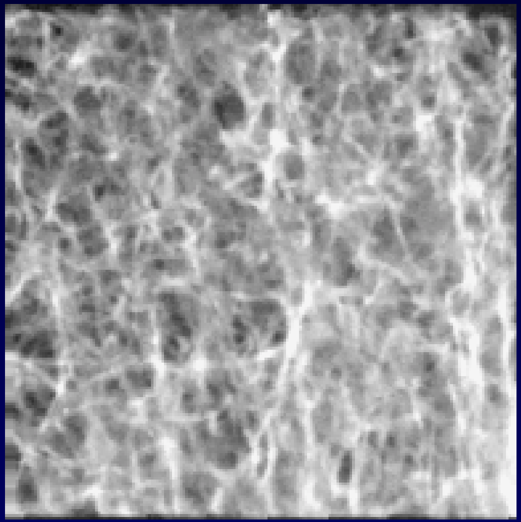


ML

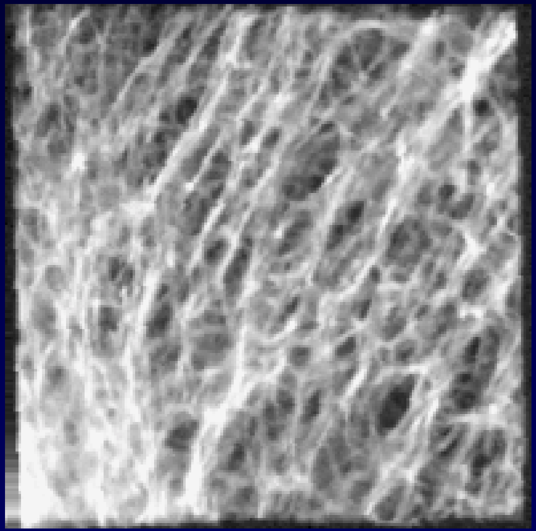


- AP

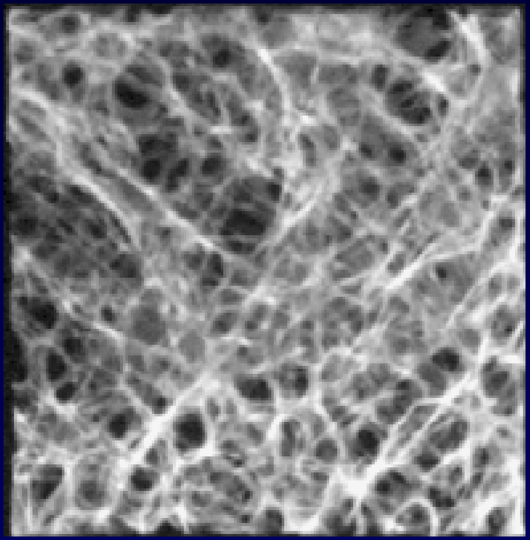
Examples of Radiographic Images of Trabecular Bone Pattern



Medial Lateral
Sagittal



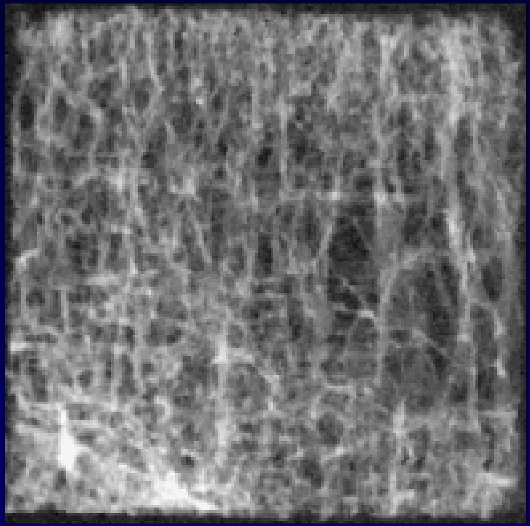
Anterior-Posterior
Coronal



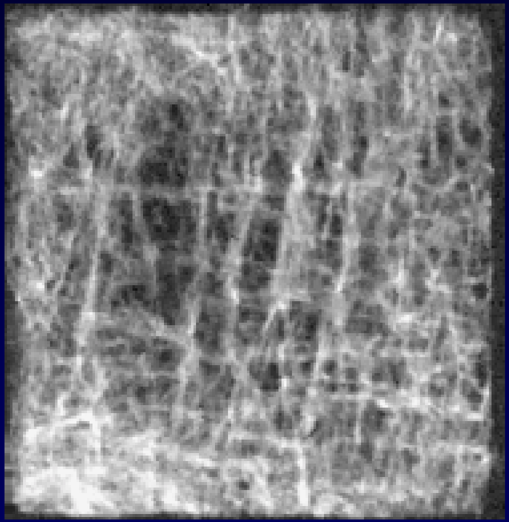
Superior-Inferior
Axial

Femur Sample: Density = 107.6 mg/cm^3

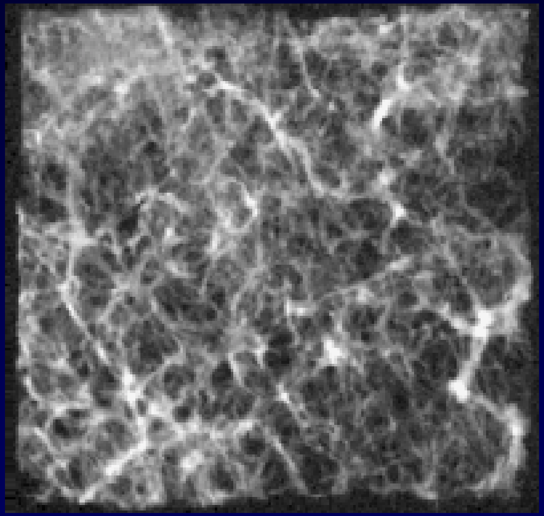
Examples of Radiographic Images of Trabecular Bone Pattern



Medial Lateral
Sagittal



Anterior-Posterior
Coronal



Superior-Inferior
Axial

Spine Sample: Density = 59.9 mg/cm^3

COMPUTED TOMOGRAPHY

QuickTime™ and a
GIF decompressor
are needed to see this picture.

COMPUTED TOMOGRAPHY : SKULL RENDERING

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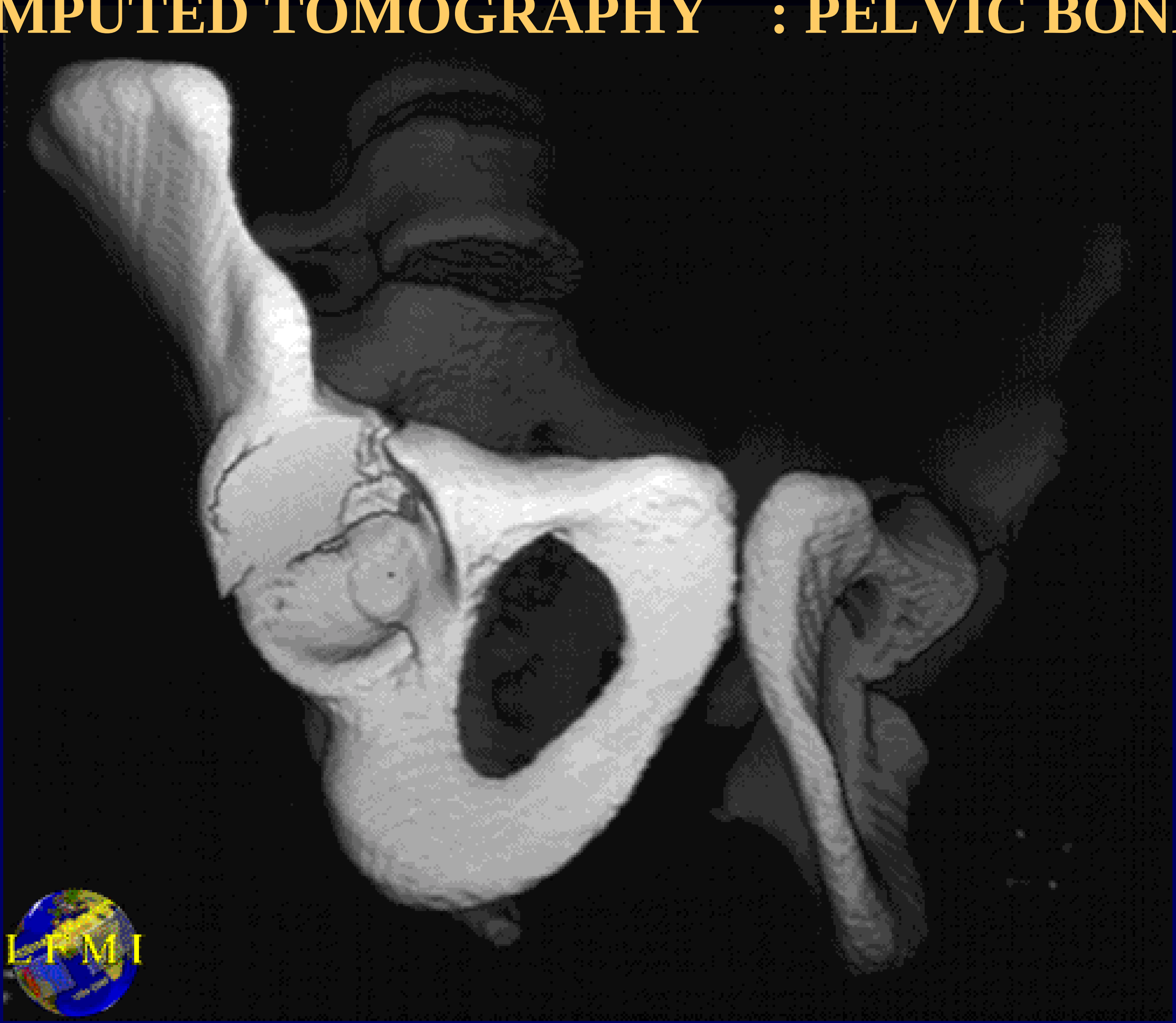
COMPUTED TOMOGRAPHY : PELVIC BONE



PRE-SURGERY

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POST - SURGERY

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COMPUTED TOMOGRAPHY : KNEE KINEMATIC

QuickTime™ and a
decompressor
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COMPUTED TOMOGRAPHY : HIP KINEMATIC

QuickTime™ and a
decompressor
are needed to see this picture.

COMPUTED TOMOGRAPHY : FINGER KINEMATIC

QuickTime™ and a
decompressor
are needed to see this pictu

DIGITAL SUBTRACTION ANGIOGRAPHY

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RADIONUCLIDE IMAGING

- Single Positron Emission Tomography: (SPECT)
- Positron emission tomography (PET)
- Images gamma emitters, nuclides administered to subject
- Resolution governed by detectors, signal to noise, etc.

SPECT

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QuickTime™ and a
decompressor
are needed to see this picture.

COMPUTED TOMOGRAPHY AND SPECT

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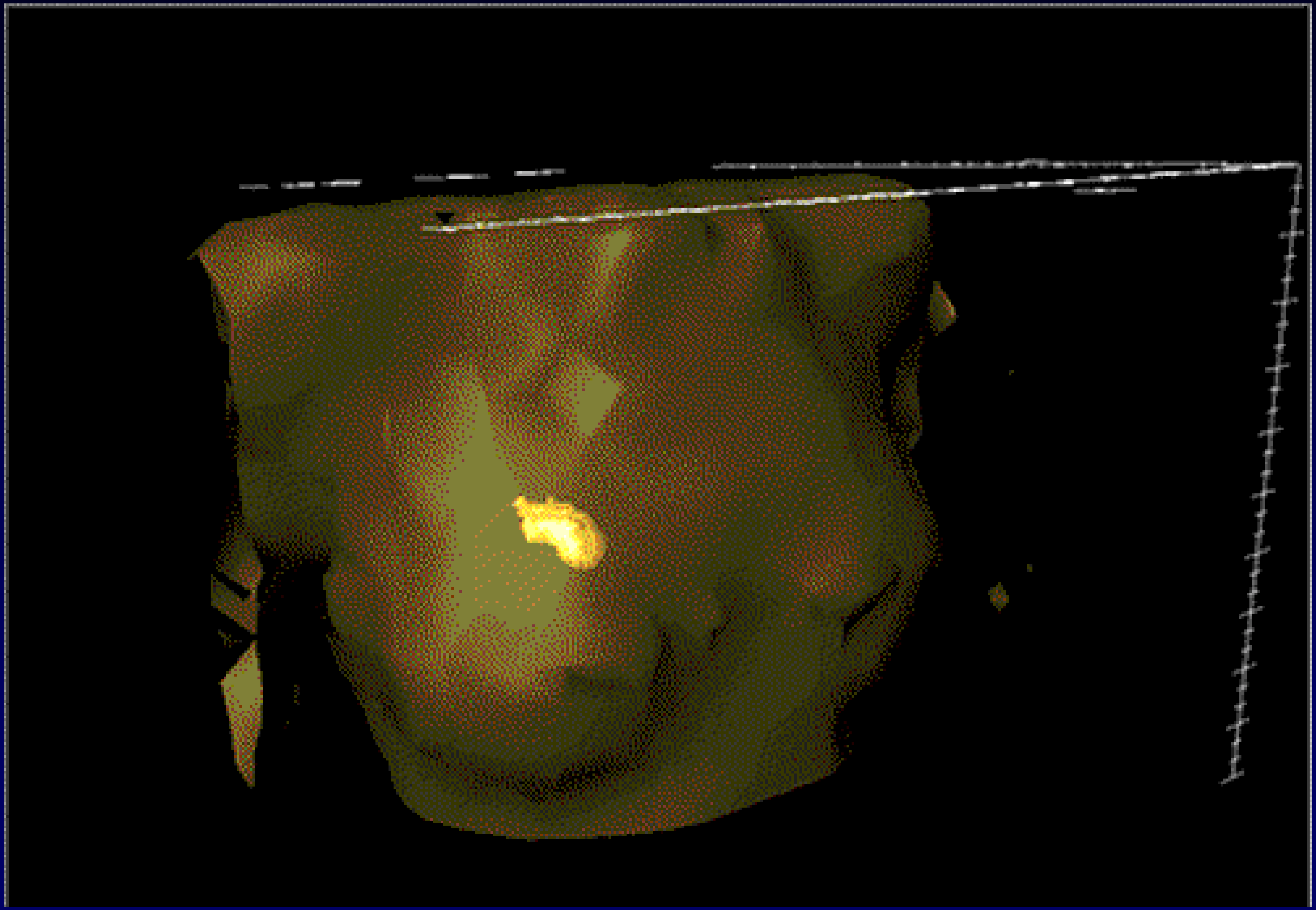
POSITRON EMISSION TOMOGRAPHY : BREAST TUMOR



POSITRON EMISSION TOMOGRAPHY : LUNG METASTASES

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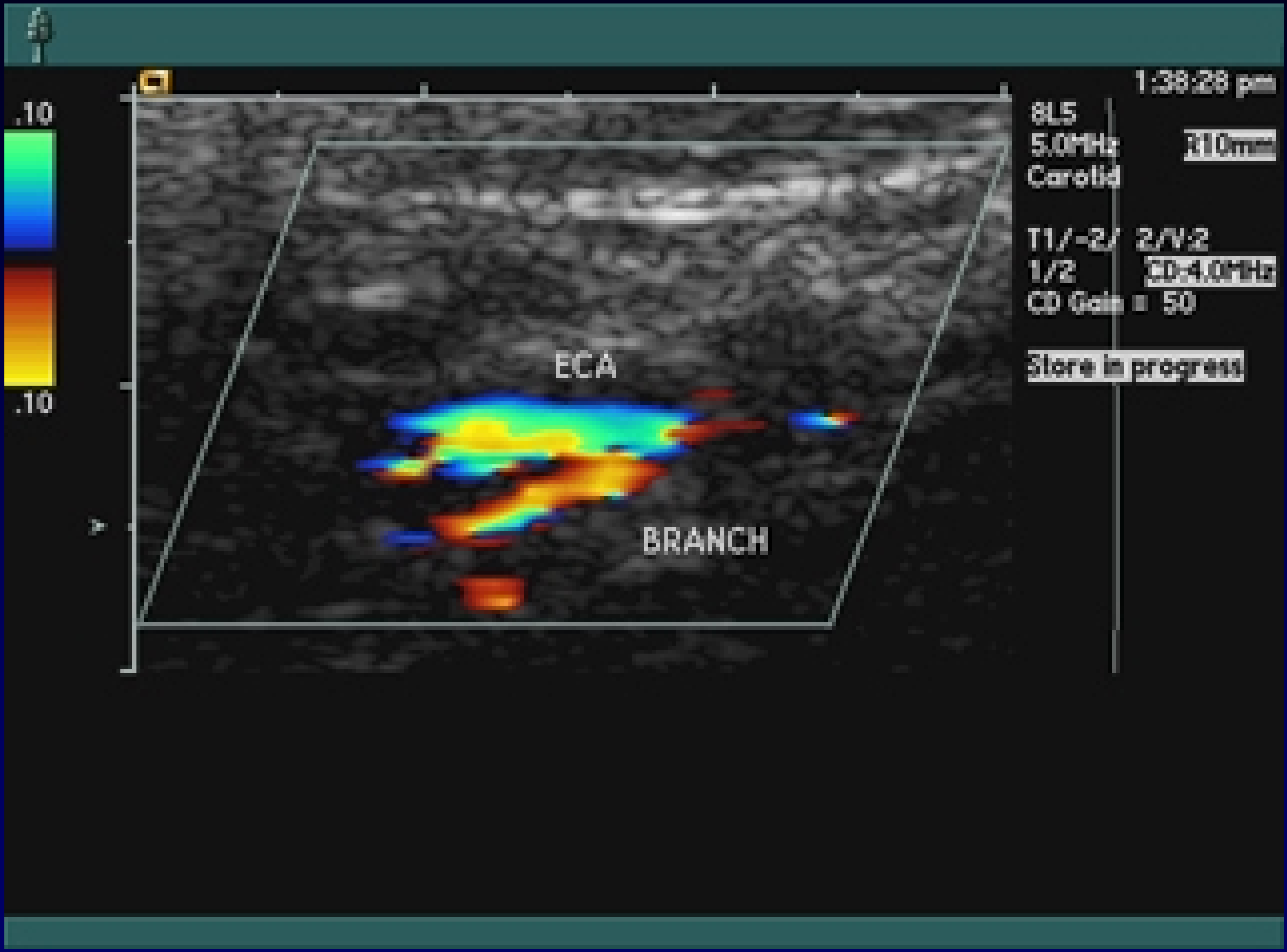
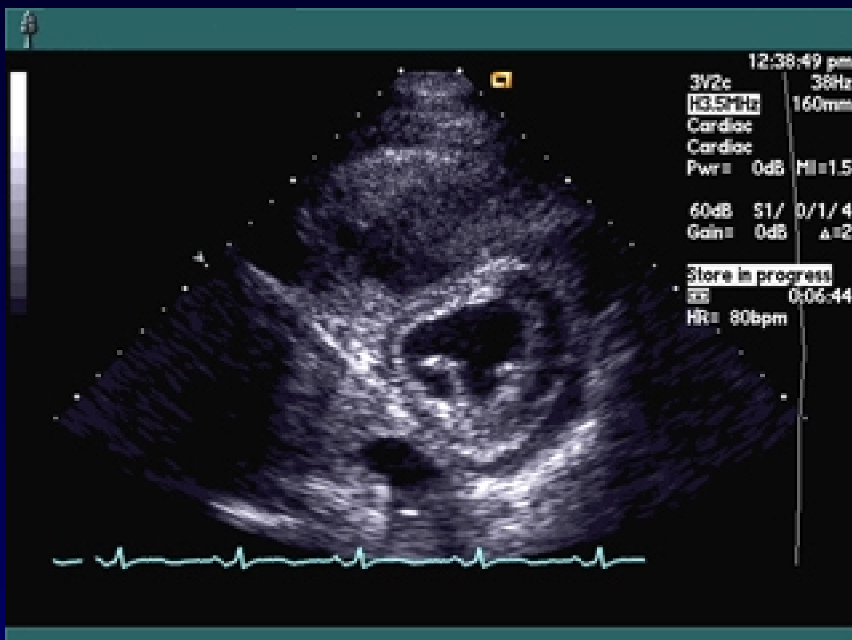
ULTRASOUND

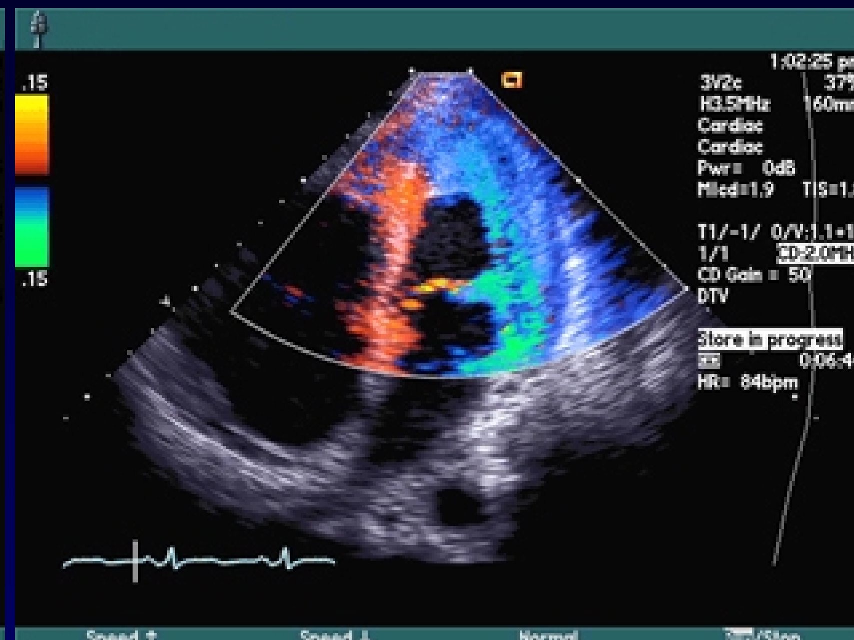
- Measures sound attributes: Acoustic Impedence = ρc c =speed of sound)
- Attenuation : $I_o e^{-\mu z}$
- Doppler shift measures moving objects such as blood. Ifr f is frequency of the US wave, then $\Delta f = -2vf\cos\theta$, v is velocity, θ angle of incidence
- For vessels: Flow volume = v Area of cross-section.

ULTRASOUND: CAROTID ARTERY



ULTRASOUND: CARDIAC





Modality	Property
Magnetic Resonance Imaging and Spectroscopy	Proton density (water content), relaxation times (environment of tissues), flow, diffusion, metabolic function
Electric Impedence Tomograph	Electrical properties, conductance, resistivity
Electrical and Magnetic Source Imaging	Emitted electrical and magnetic signals from the tissue
Optical imaging And spectroscopy	Optical properties, molecular status

MAGNETIC RESONANCE

- Water content
- Biochemistry
- Flow
- Diffusion
- Metabolic Activity

MR: BRAIN OVERLAID WITH PET

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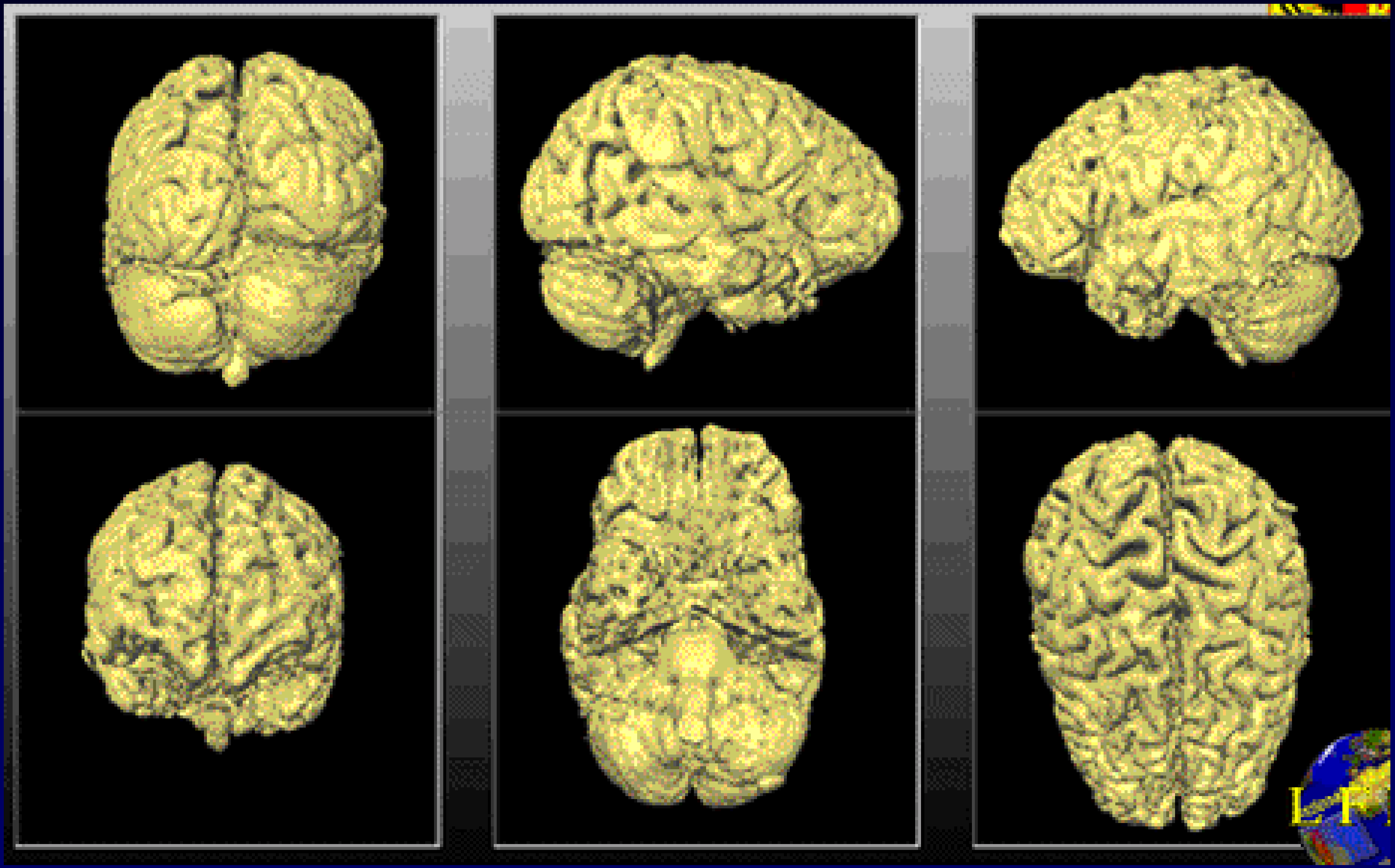
decompressor
are needed to see this picture.

MR: BRAIN VOLUME RENDERED



VISIBLE HUMAN

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GIF decompressor
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VISIBLE HUMAN

QuickTime™ and a
decompressor
are needed to see this picture.

MR BASED SEGMENTATION OF PORENCEPHALIC CAVITY

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MR AND SPECT

QuickTime™ and a
decompressor
are needed to see this picture.

MR SLICES FOR ANGIOGRAPHY

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GIF decompressor
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MAXIMUM INTENSITY PROJECTIONS

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MAXIMUM INTENSITY PROJECTIONS

QuickTime™ and a
decompressor
are needed to see this picture.

SURGICAL PLANNING

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MR BASED VASCULAR LIVER MODEL

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PRE OPERATIVE HEPATIC SURGERY

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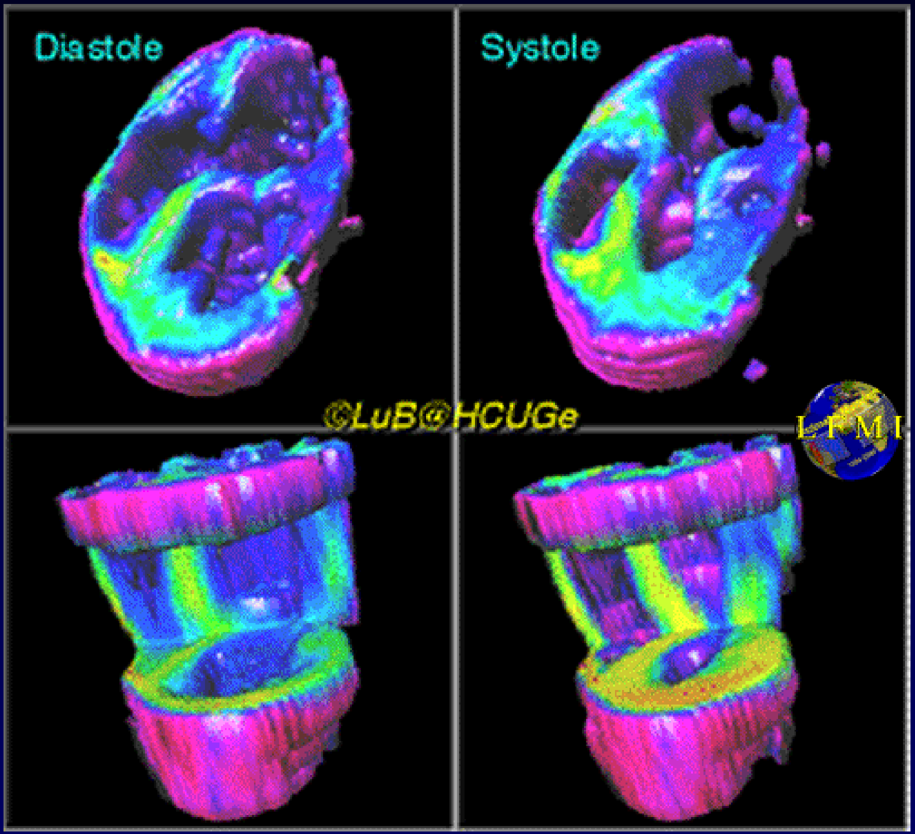
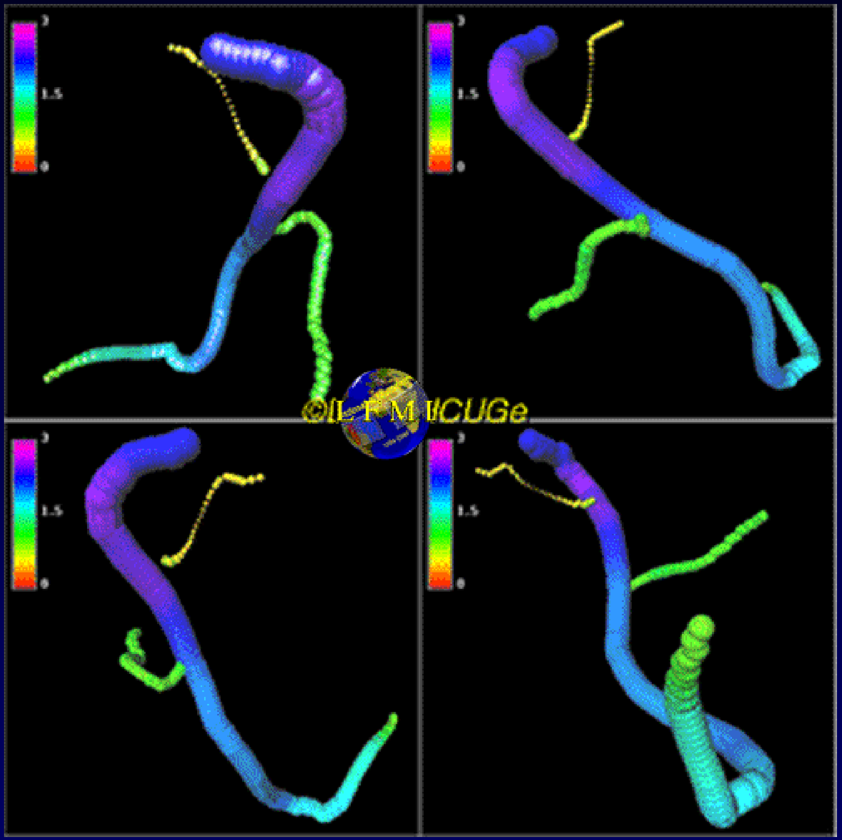
GATED CARDIAC MR

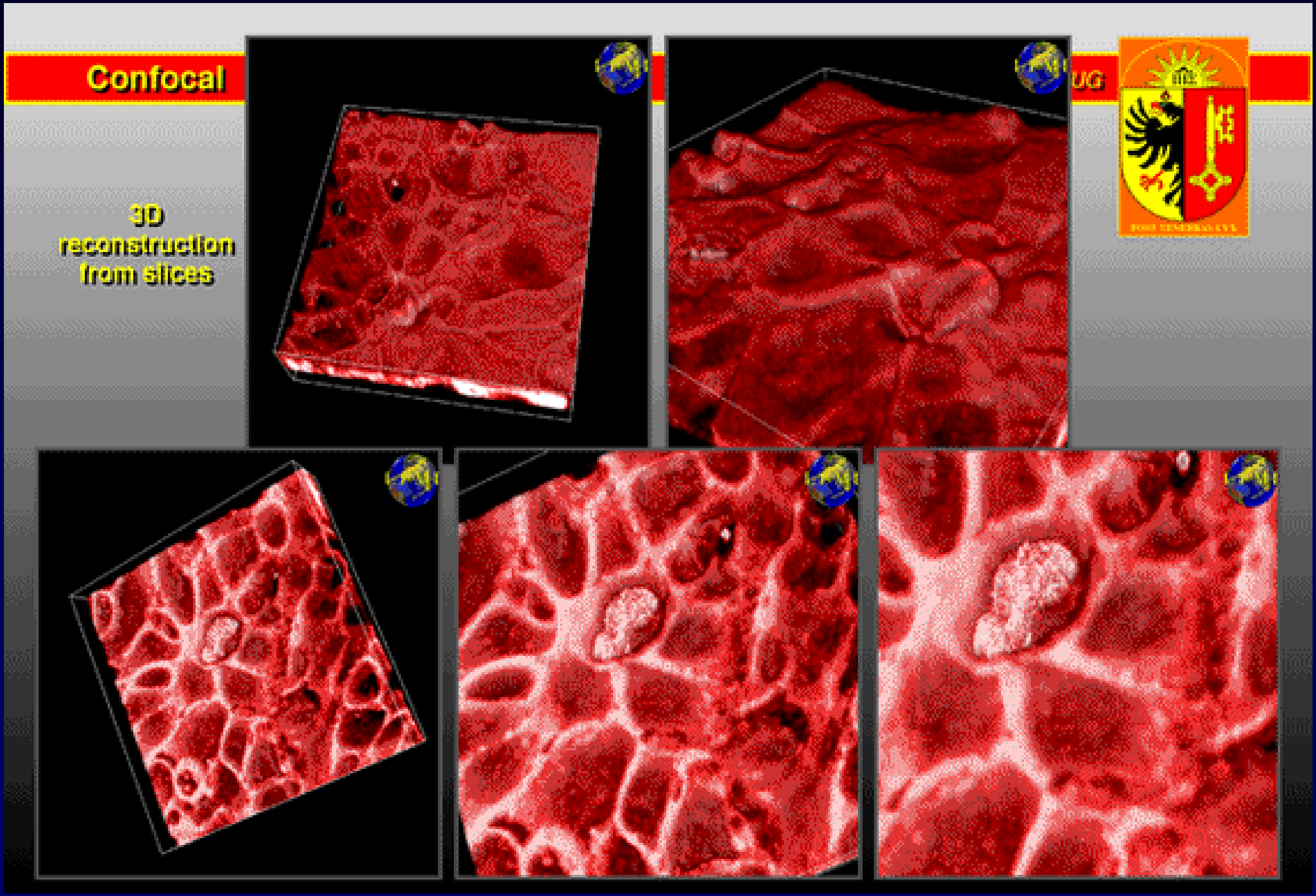




OPTICAL MICROSCOPY

- Impact on light

CONFOCAL MICROSCOPY:EPITHELIAL CELLS



ELECTRO-MAGNETIC TOMOGRAPHY

- Electro-Magnetic Tomography (EMT) from EEG or MEG:
  - data (electric potentials in EEG or biomagnetic fields in MEG + time) produced through an evoked potential experiment or an EEG-MEG monitoring are first acquired through a multichannel recorder (one channel per electrode/coil).
  - Accounting for the 3D location of every electrode/coil, the current density distribution inside the brain can be reconstructed in 4D space and time) by trying to assess the biological generators from the measurements.
  - Inverse problem there is no way at this time to take accurately into account every single piece of the puzzle which affects the path between biological generators and physical measurements.

ELECTRIC POTENTIAL TOMOGRAPHY:EPILEPSY

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decompressor
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MAXIMUM CURRENT DENSITY

ELECTRIC POTENTIAL TOMOGRAPHY:EPILEPSY

QuickTime™ and a
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VECTOR CURRENT DENSITY

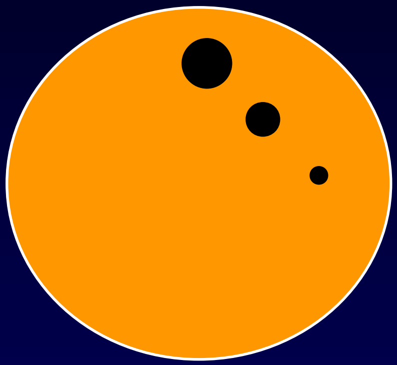
Linearity of Imaging systems

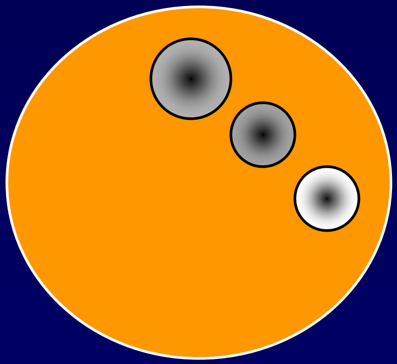
- $Ag = AT(f) = T(Af)$ Scaling the object property leads to scaling the image identically
- If $Bg= BT(g) = T(Bg)$ then
- $Ag+Bg = AT(f) + BT(g) = T(Af) + T(Bg)$
- This is linearity, is often assumed, but films sturate and have a curve associated and are non-linear.

Linearity of Imaging systems

- Radionuclide imaging examines concentrations and maps directly -- this is closest to being linear
- Xray attenuation: higher the atomic number, greater the attenuation, so it should be linear, but properties of xray attenuation (wavelength dependent) change as the tissue atomic number changes.
- MR: Higher the water content the brighter the signal, yes unless the magnetic field changes due to local changes….

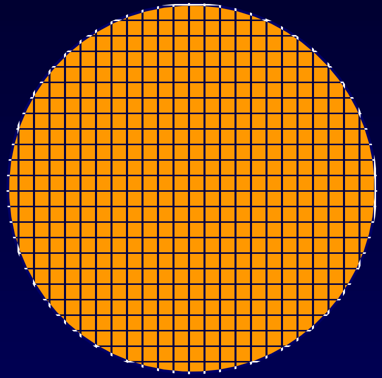
Point Spread Function

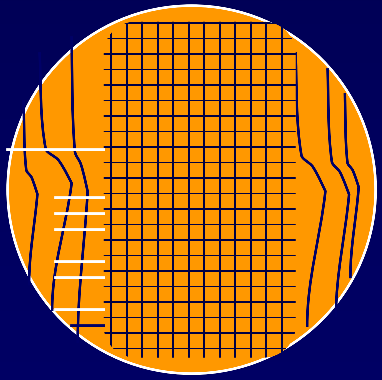




- All imaging systems produce a degradation of the image
- T(f) is not a delta function, it produces a blurring.
- The blurring effect is defined by the Point Spread Function, Point Response Function (PSF, PRF).
- PSF depends on the imaging system, and noise.

Properties of the Point Spread Function

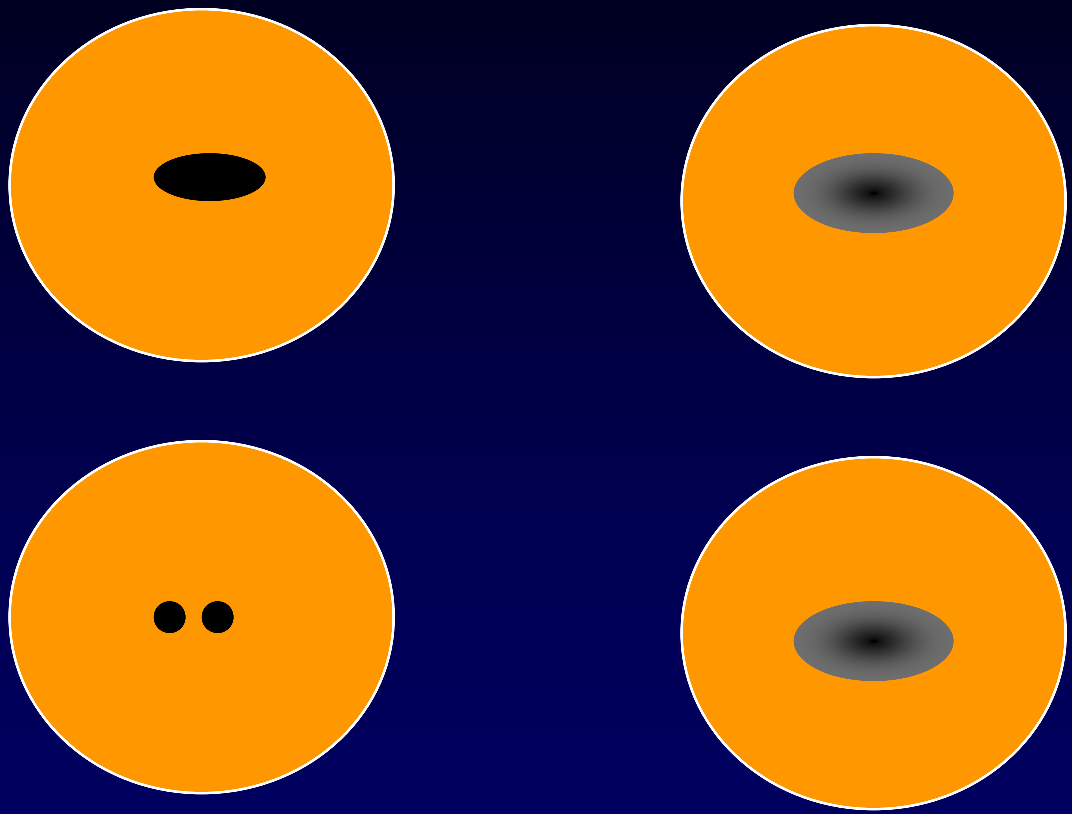




- Point Sensitivity: Is the total signal obtained from a point object the same in space?
- Spatial Linearity: Are all points depicted identically with respect to shape and geometry?

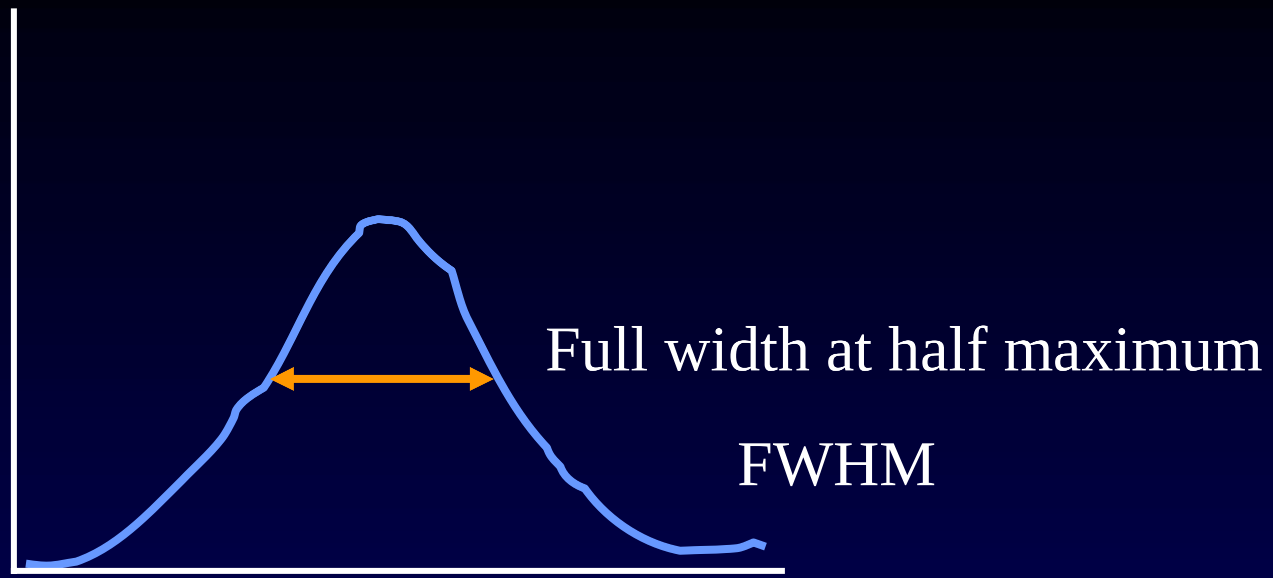
If one knows the point spread function, and the system is position independent the system can be characterized.

RESOLUTION



If two objects (points are close together can they be resolved.

Smallest object that can be visualized.



If the point spread function is a gaussian, for example, the point spread function governs how small an object can be seen, as well as how close they are before they cannot be resolved.

If two Gaussians of equal intensity are placed one FWHM apart then the intensity at the midpoint is 6% less than the maximum. The two points are then resolved.

RESOLUTION

- Set of parallel lines spaced different distances apart…gives resolution in line pairs per mm. With the advent with the digital imaging systems, people refer to the fullwidth at half maximum.
- Is the PSF isotropic, same in all directions?

RESOLUTION

- 2D images are visualizations of 3D objects.
  - A pixel is smallest unit in a 2D image
  - Voxel represents the volume of a pixel taking into account the thickness of the object (3D) that is projected onto the 2 D image
- Cross-sectional or tomographic images
  - Associated slice thickness
  - Pixel resolution
- Projection Images
  - Pixel resolution

- $F(x,y) = G(x,y) * H(x,y)$, where F is the image, G the object, and H the Point Spread Function.

- Convolution in the space is akin to multiplication in the Fourier domain.

CONTRAST

- Image Intensity in an image represents a magnitude of a given property.
- Difference in intensity between two tissues or entities is entitled the contrast between two entities
- No matter how high the resolution if two distinct entities have the same intensity of a given tissue property, the utility of the image is limited.

NOISE

- Every imaging system has associated noise
- This noise has different forms depending on the imaging (Gaussian, Poisson, Risean).
- The noise introduces random fluctuations in tissue intensity which reduce the detectability of different entities in an image.

SIGNAL TO NOISE AND CONTRAST TO NOISE

- Noise = <μ> (mean value often zero mean)
- Noise has a standard deviation σ^2
- Thus signal to noise ratio: I/Sqrt(σ^2)
- Two regions have intensity I_1 and I_2
- Thus contrast to noise ratio: I_1-I_2 /Sqrt(σ^2)