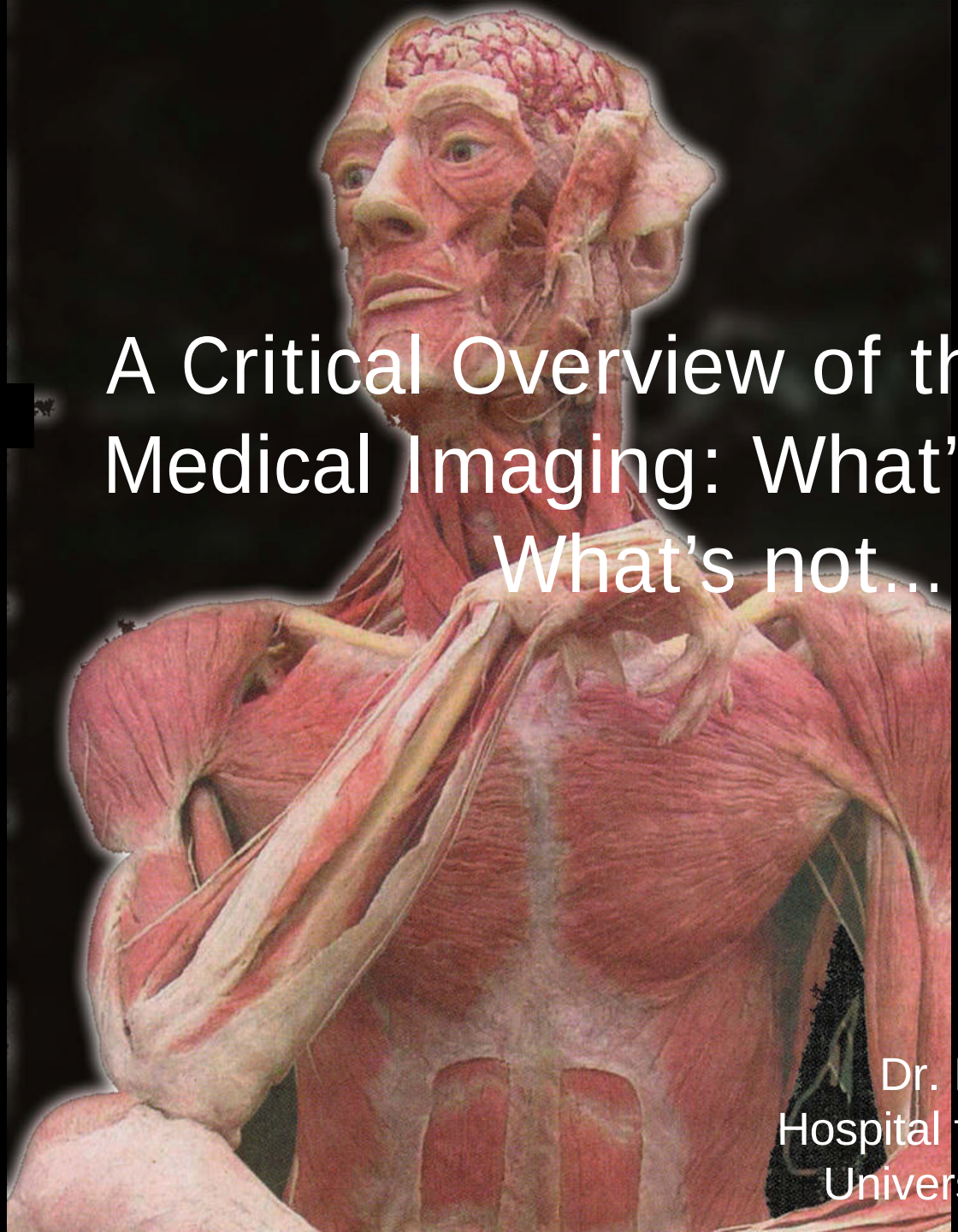


A Critical Overview of the State of Medical Imaging: What's working, What's not…

Dr. Paul Babyn
Hospital for Sick Children
University of Toronto

Outline

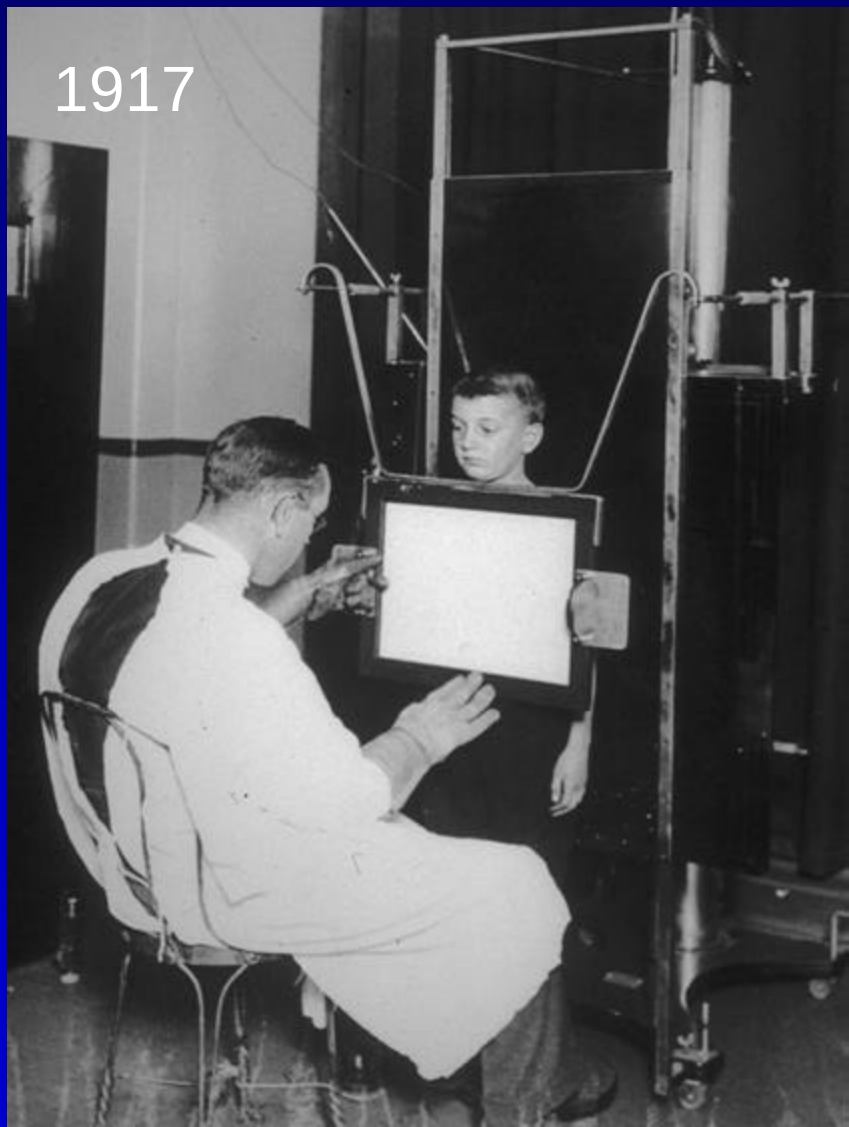
- Medical Imaging -Where are we today?
  - Goals, Acquisition modalities, Changing Practice
- How is image processing used today?
  - Review from data acquisition to surgical navigation
- How will image processing be used in the years ahead?
  - Illustrate areas where image processing will play an expanded role

The future is already here. It is just not evenly distributed.

Will Gibson

Medical Imaging
Medicine's Inner Vision

- Tremendous growth and development
- Estimated 35 million studies in Canada each year
- Information rich specialty
- Dramatic advances in imaging equipment



Example

- One of the first specialties to use computers
- Digital technology has led to exciting changes
- Each generation offering improved resolution, image quality, speed

Sagittal reconstruction 2005


Have a seat Kermit. What I'm about to tell you might come as big shock...
paisanolocos.com

Goals of Medical Imaging

Two-fold

1) Provide accurate and timely diagnosis of disease and anomalies
   - Evaluate progression or regression of disease and response to therapy

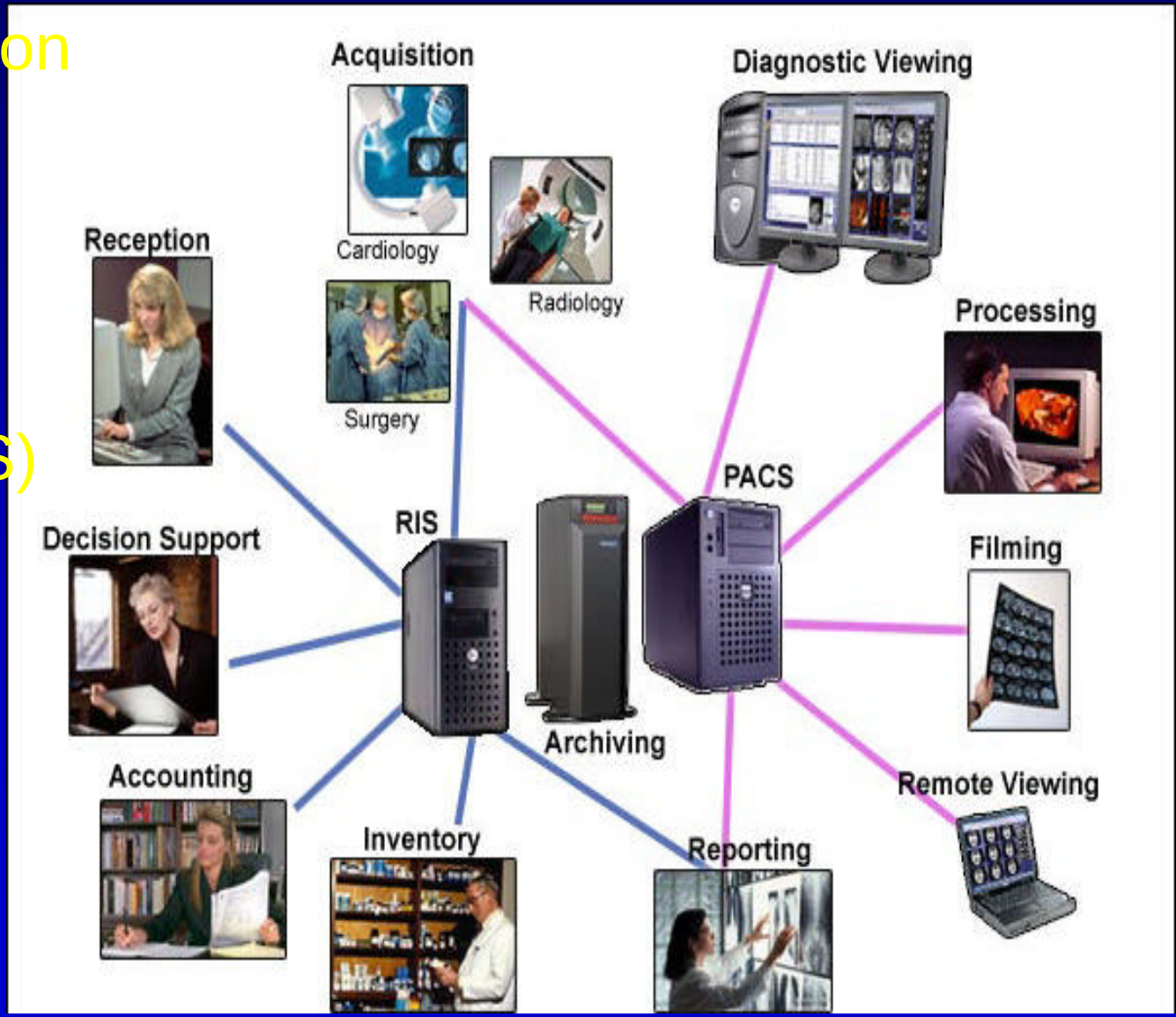
2) Provide image guidance for intervention

Accurate Diagnosis- Image and Interpreter

All while minimizing cost, complications, radiation and contrast use

Today's Radiology Department

- Digital information integral
- Picture Archiving Communication Systems (PACS)
- Reliance on complex computer systems



The Medical Imaging Work Environment

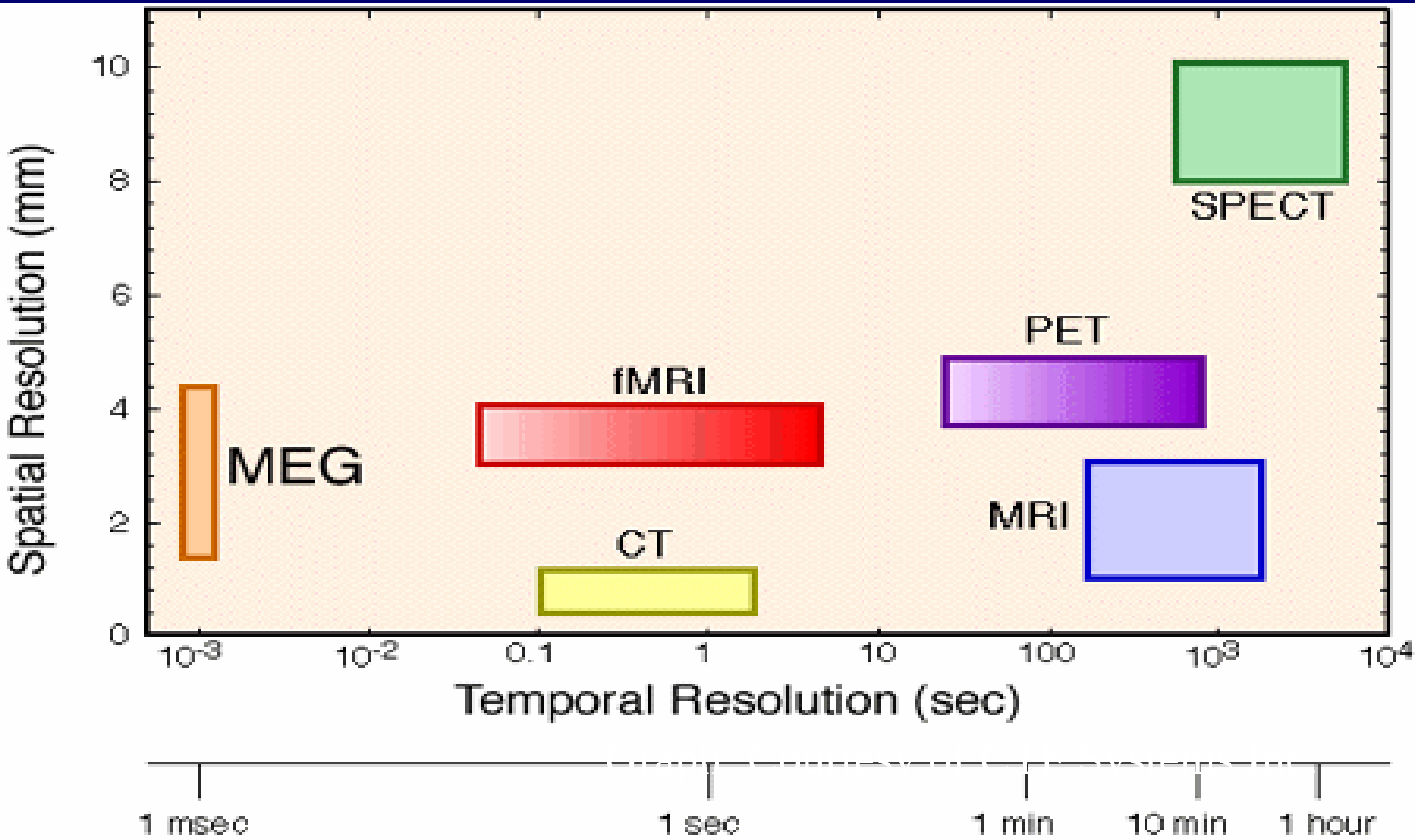
- Rapidity
  - Patients and physicians waiting for results
- Criticality
  - Treatment often changed by our findings
- Accuracy
  - High cost of error
    - Missing a lesion can have severe consequences
    - False positive results also not good!

Imaging Modalities- Image Acquisition

- X-Ray projection imaging, fluoroscopy, angiography
- X-Ray Computed Tomography
  - sensitive to tissue density, atomic composition
- Nuclear Medicine-SPECT, Positron Emitting Tomography (PET)
  - Functional evaluation, variable radiopharmaceuticals
- Magnetic Resonance, MR Spectroscopy, fMRI
  - proton density, T1,T2 relaxation times, flow, other parameters
- Ultrasound
- Magnetoencephalography

Spatial resolution 0.5-5 mm

Imaging Modalities



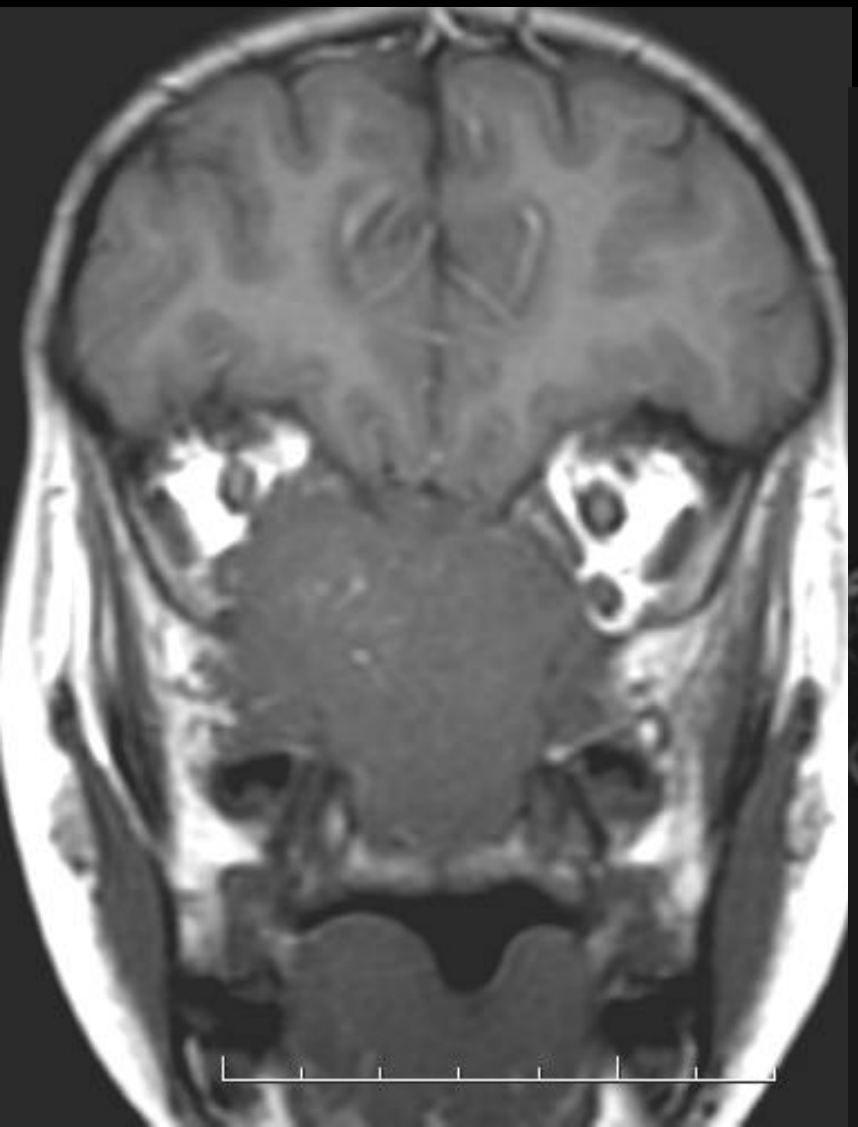
Basics of Medical Images

Analog or more commonly digital
- Conventional film/screen x-rays
- Digital images converted into matrix of smaller regions, numerical values
- Rows and columns of blocks called *pixels* or picture elements
  - 3D volume elements called *voxels*

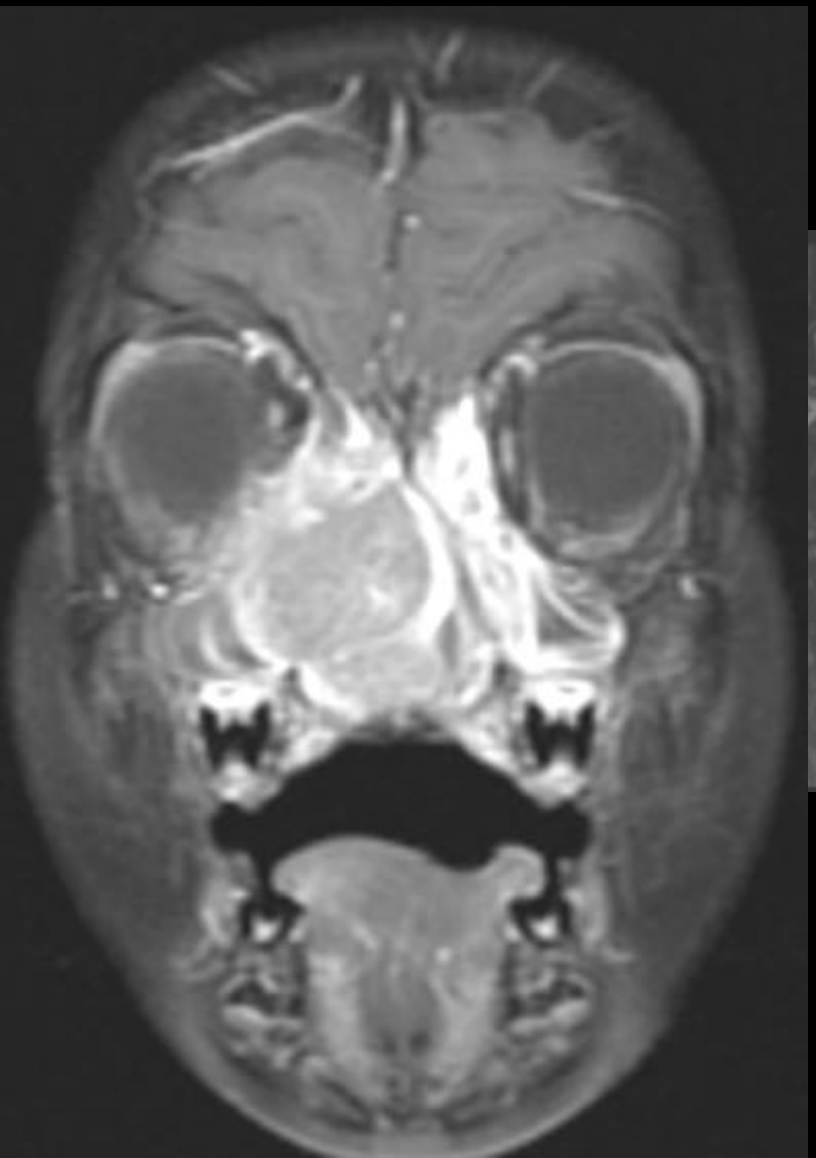
Resolution vs. Image Size
- The larger the array, the smaller the pixel but the larger the image file

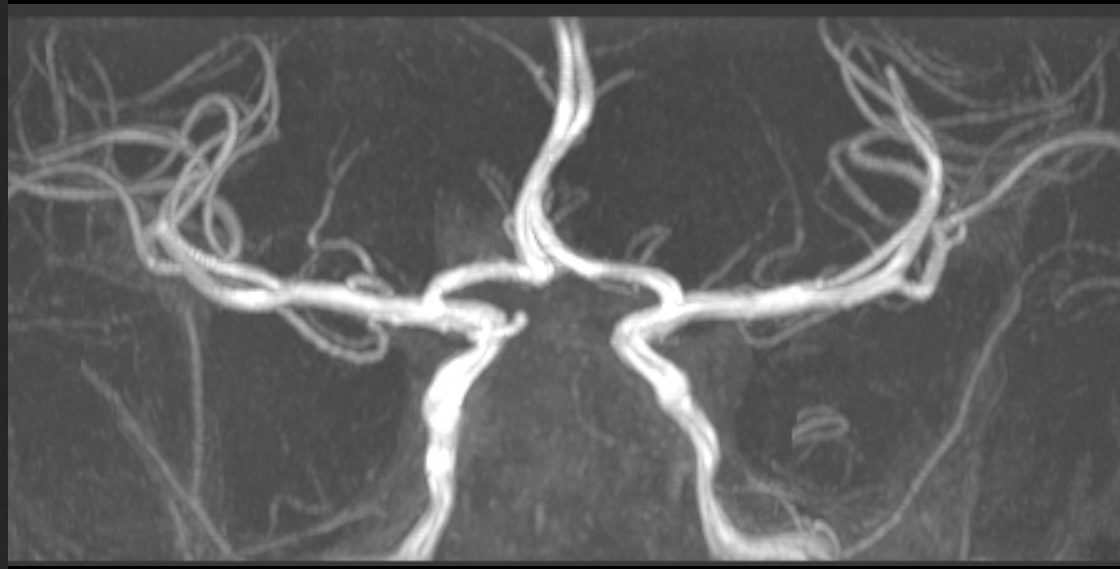
Typical matrix sizes
- **CT/MR -**512 x 512 x 12 bit depth or 1024 x 1024 x 12 bit
- **Computed Radiography**
  - 2048 x 2048 x 12 bit depth or 4096 x 4096 x 12 bit depth
- **Digital Mammography**
  - 50 micron pixels
  - 35-50 MB/image

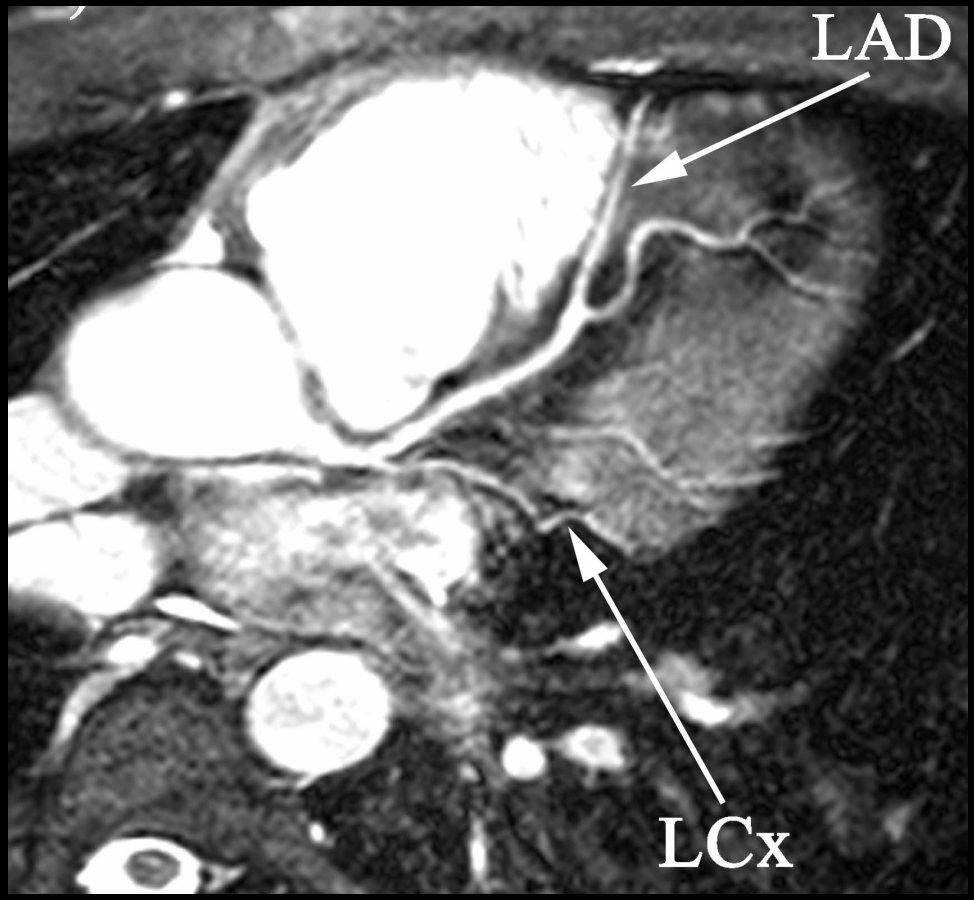
Morphologic Imaging



Contrast and Anatomic Imaging



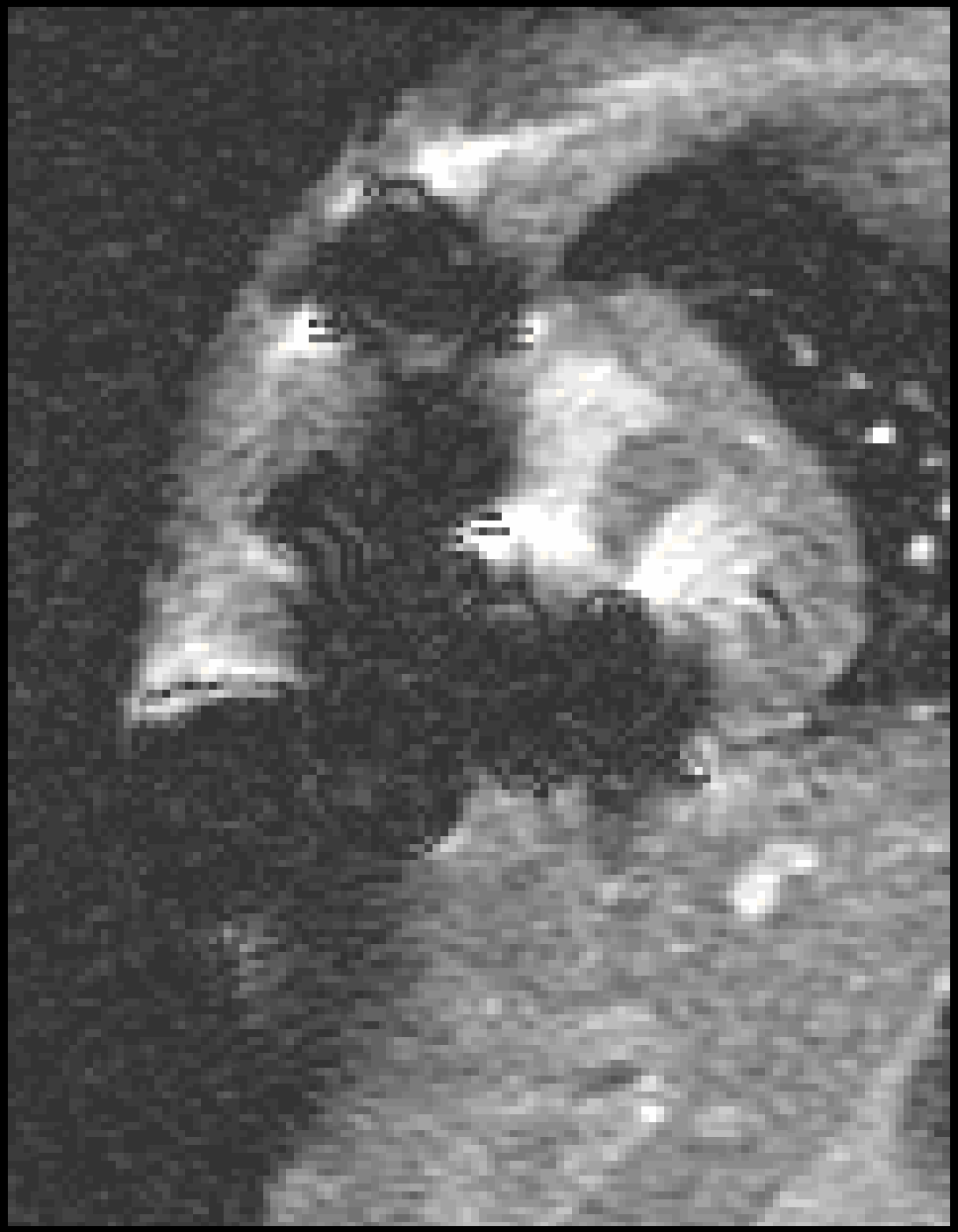




Courtesy of Dr. Gerald Greil, Germany

Working with Medical Images

- Complex!
- Data Limitations
  - Variable equipment, contrast mechanisms, data acquisition techniques, non-isotropic slice thickness, slice gaps, artifacts
- Safety limitations-dose, SNR
- Tremendous variability in Human Data within and between individuals
- Difficult to validate performance in many clinical areas
- Relationship between human perception and art of medicine poorly understood

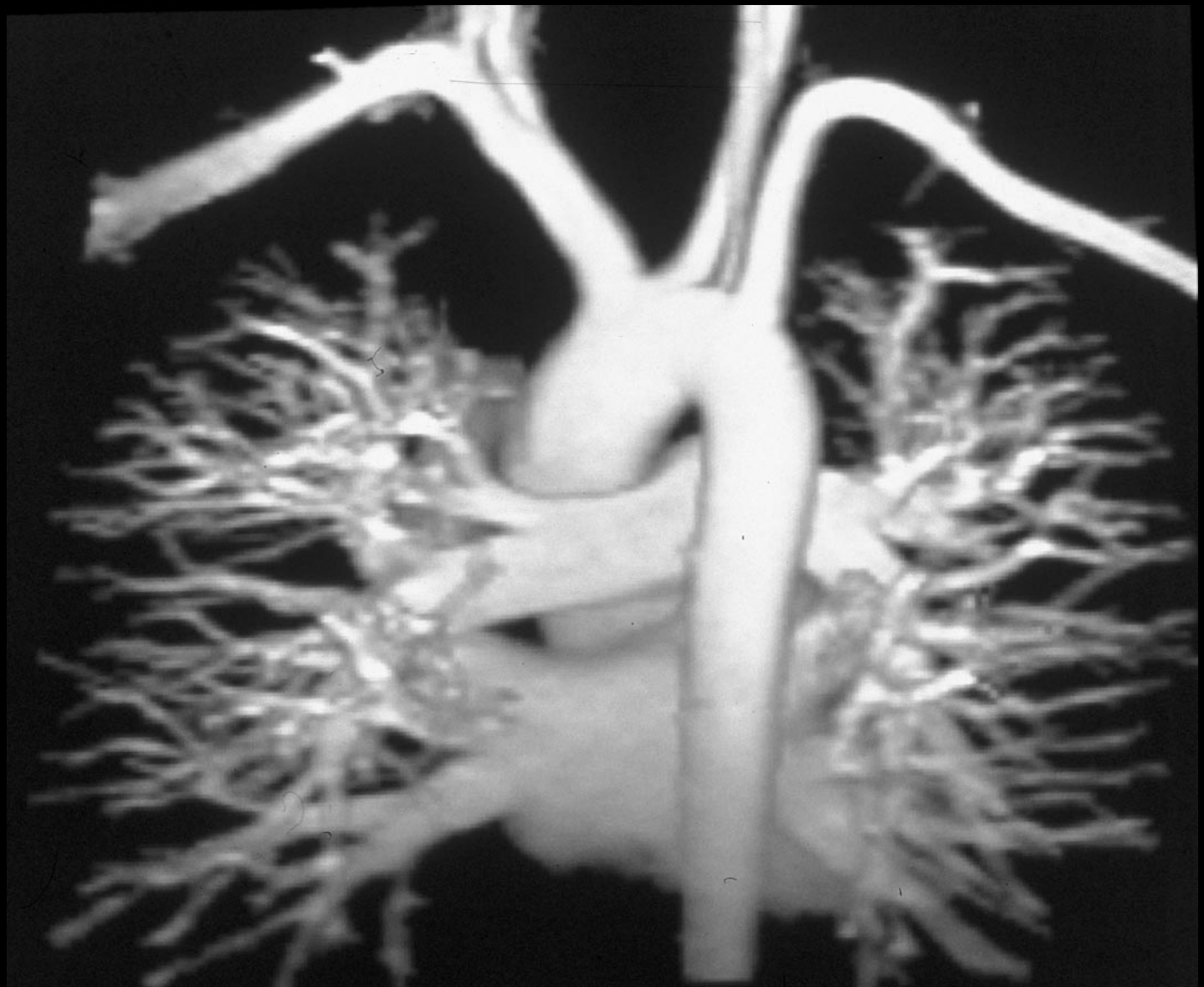


Artifact from multiple pacing wires

Increase in Imaging Modality Capabilities

- Image Reconstruction improvements
- Rapidity of scanning
- Volumetric coverage with isotropic voxels
- Screening
  - Whole Body CT
  - Whole Body MR
- Dynamic contrast studies
  - MR urography, temporally resolved angiography

Temporally Resolved MR Angiography



Volumetric MR collected every 4-6 secs

From Morphology to Biology

Anatomy

Perfusion

Diffusion

Metabolism

Receptors

Gene Expression

Signal Transduction

Cell-function

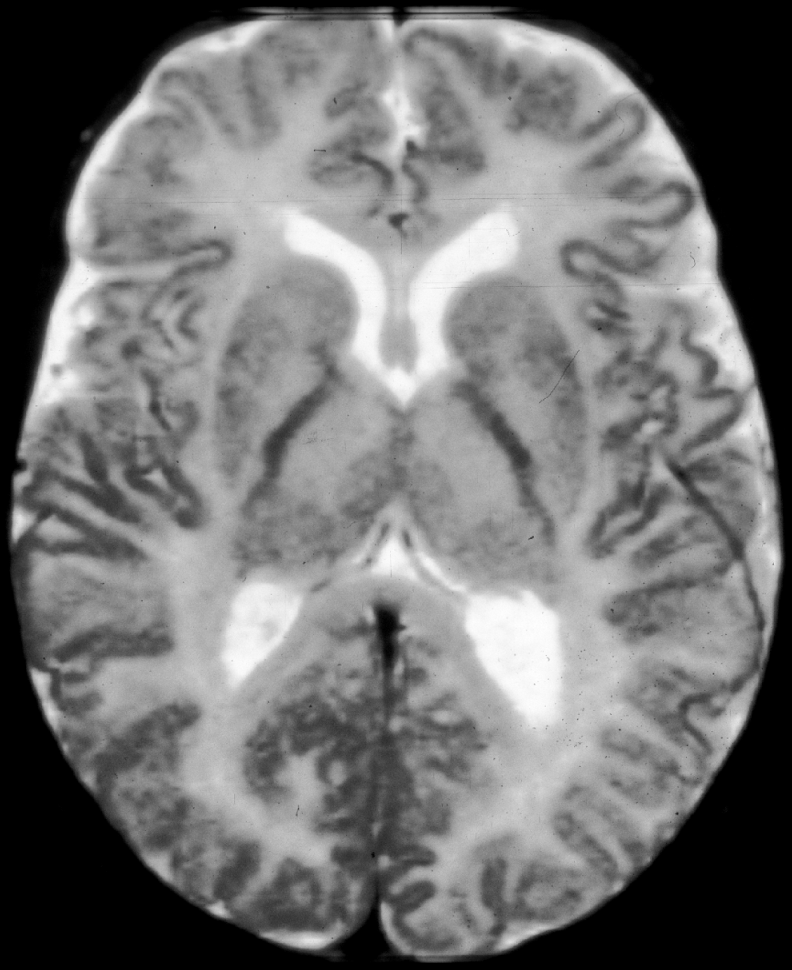
Biology

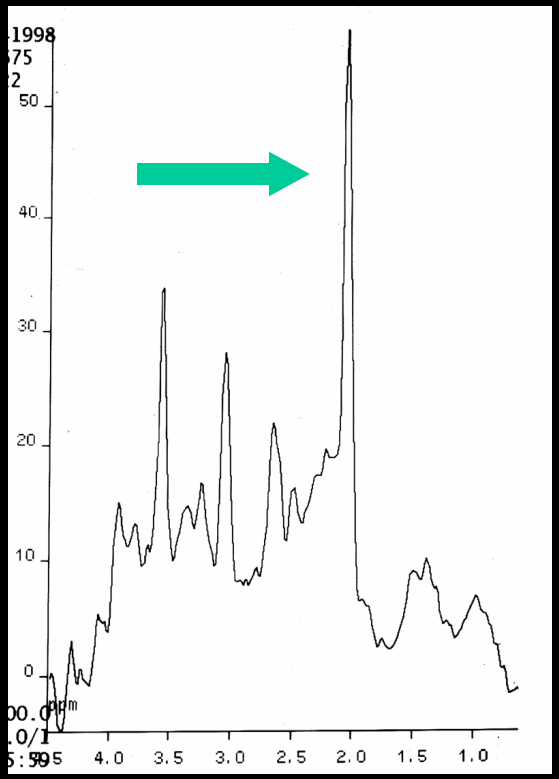
Growth of Physiologic and Functional Imaging

- Multitude of imaging tests now dedicated to providing physiologic, biochemical, structural data
- More than simple morphologic information, often abnormal before apparent on anatomic imaging
- MRI-remarkable growth
  - functional MRI, biochemical data from MR spectroscopy, diffusion, diffusion tensor imaging, permeability
- MEG, PET etc
- Quantification

Magnetic Resonance Spectroscopy

Canavan disease: asylaspartase deficiency

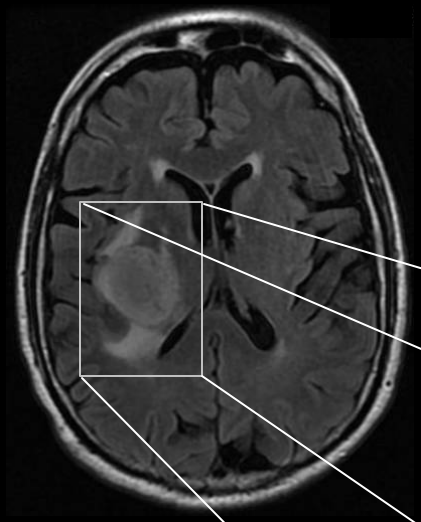




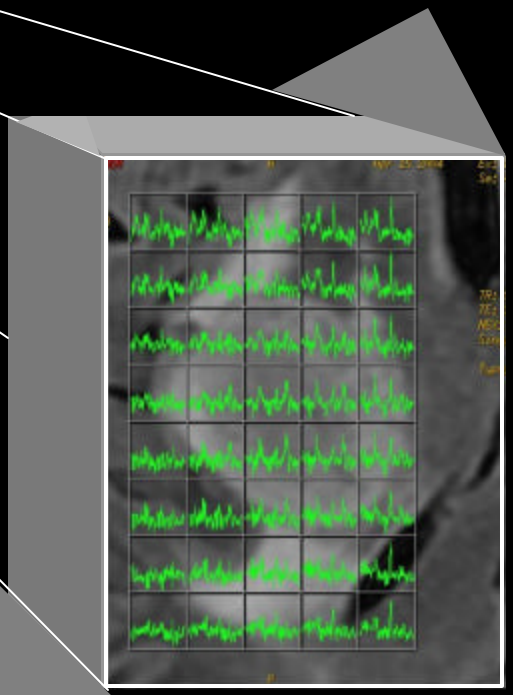
6 week old with macrocrania. Basal ganglia and thalami subtly abnormal in signal.

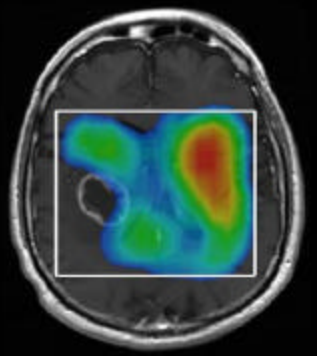
MRS shows markedly elevated NAA peak

Spectroscopic Imaging

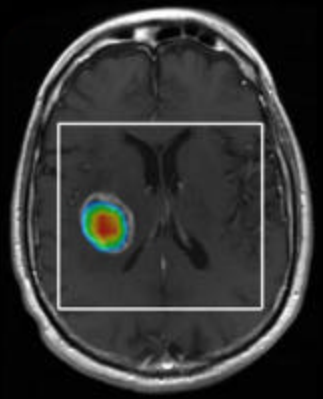


Multi voxel CSI





NAA overlay



Lipid Lactate overlay

CSI: MR spectroscopy with spatial encoding in 2 or 3 D; ∴ info can be displayed as images

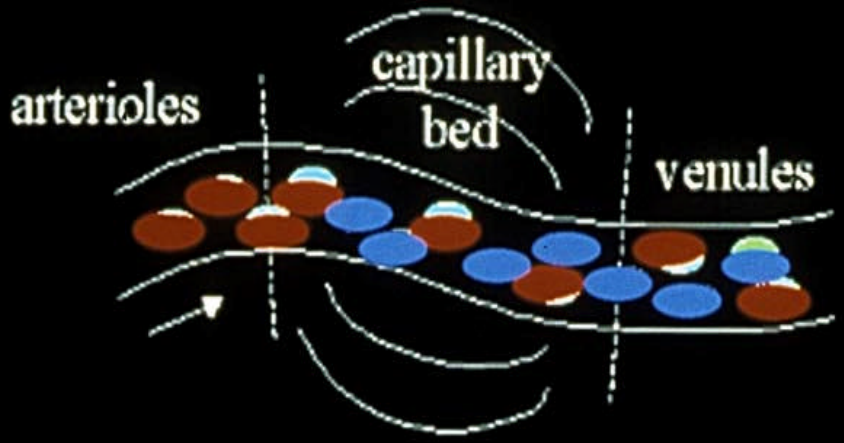
Infiltration

Functional Brain Imaging

- Noninvasive tool used in study of brain function
- Can be used to document sensory, motor or cognitive function
- With MR special sequence is performed which demonstrates the alterations in blood flow to the brain
- Active parts of the brain utilize more oxygen and receive more blood flow than less active regions
- Data is analyzed and superimposed onto detailed anatomic MRI images

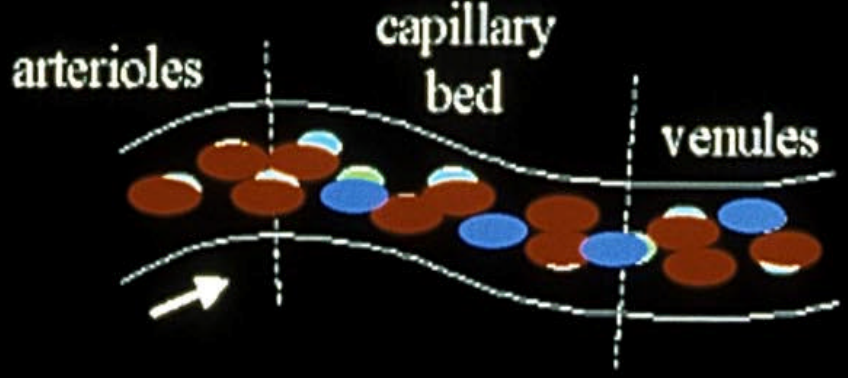
fMRI BOLD: Rapid Overview

Basal state



- normal flow
- basal level [Hbr]
- basal CBV
- normal MRI signal

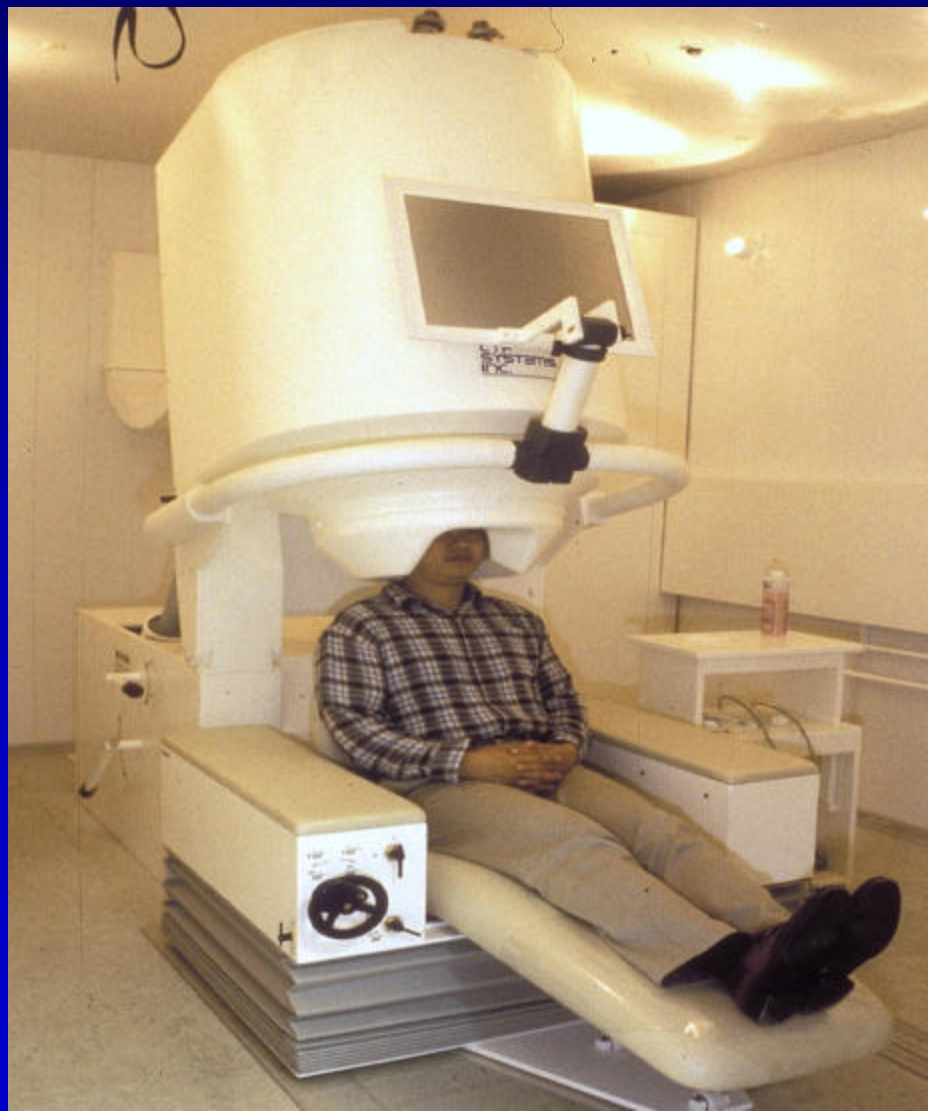
Activated state



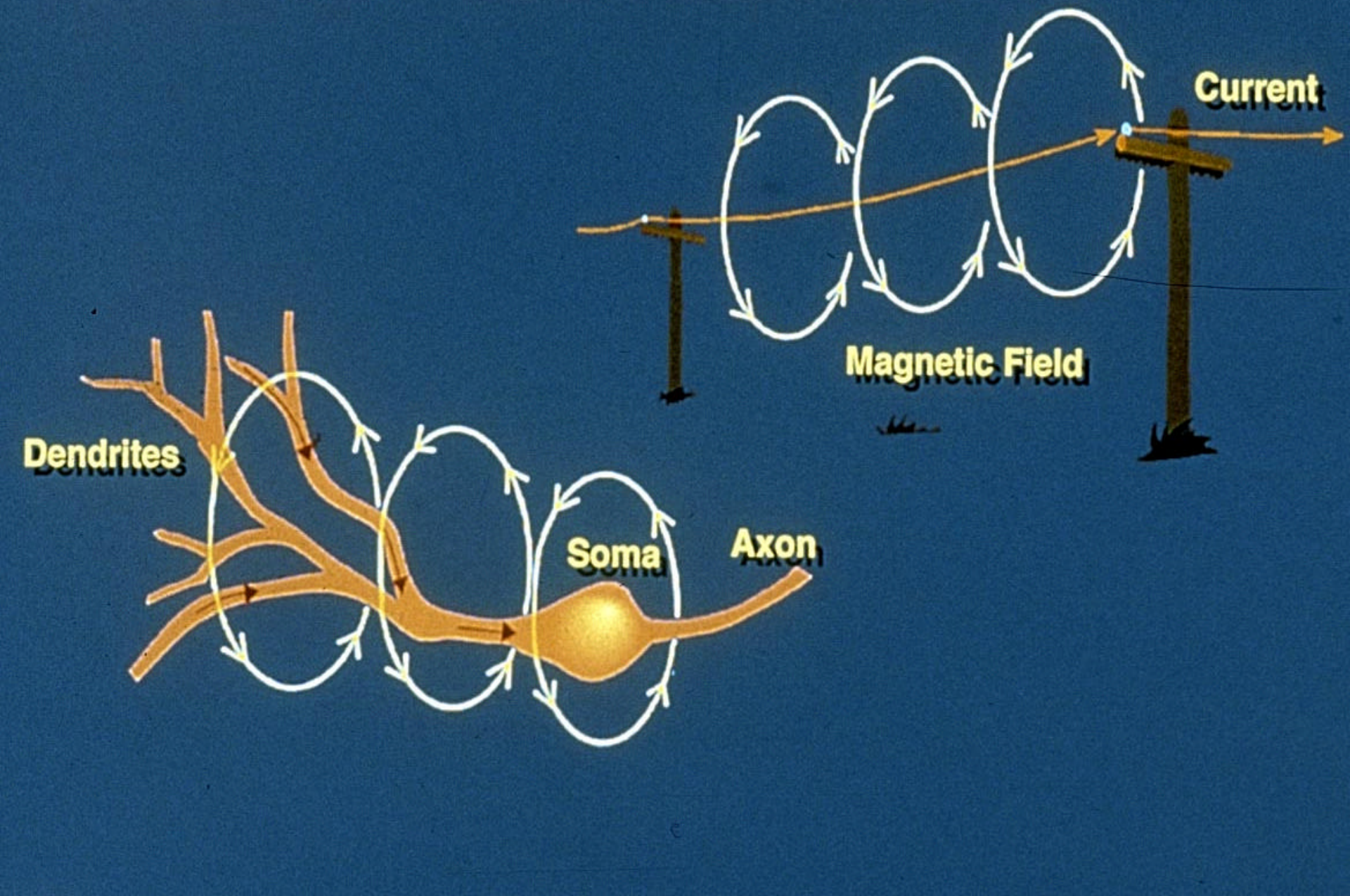
- increased flow
- decreased [Hbr] (*lower field gradients around vessels*)
- increased CBV
- increased MRI signal (*from lower field gradients*)

Magnetoencephalography (MEG)

- Also non-invasive test
- Measures magnetic fields produced by brain activity
- 3D image fusion of MEG mapped onto MR images known as Magnetic Source Imaging (MSI)

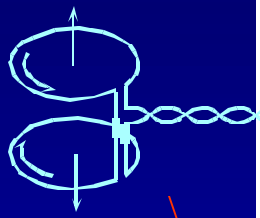


Magnetic Field Generation



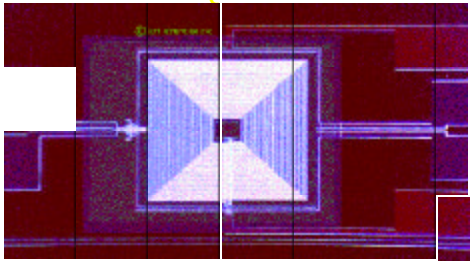
MEG

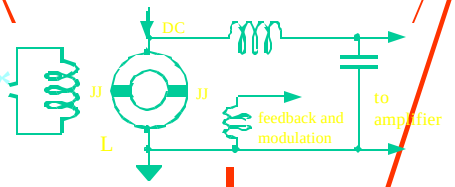
FirstOrder Radial
Flux Transformers

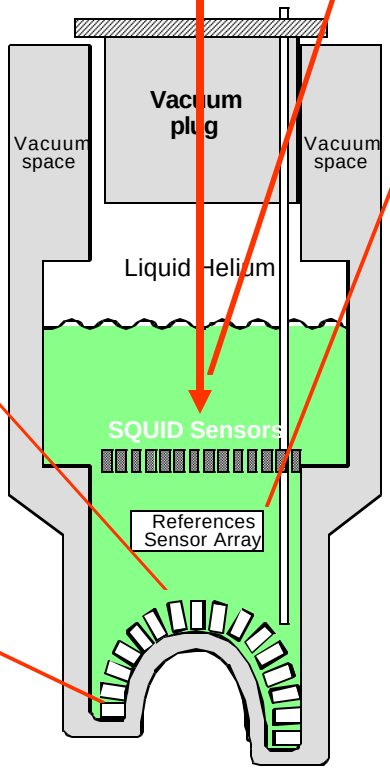


Sensing Coil Array
151-Sensing Locations

Planar SQUID Sensors

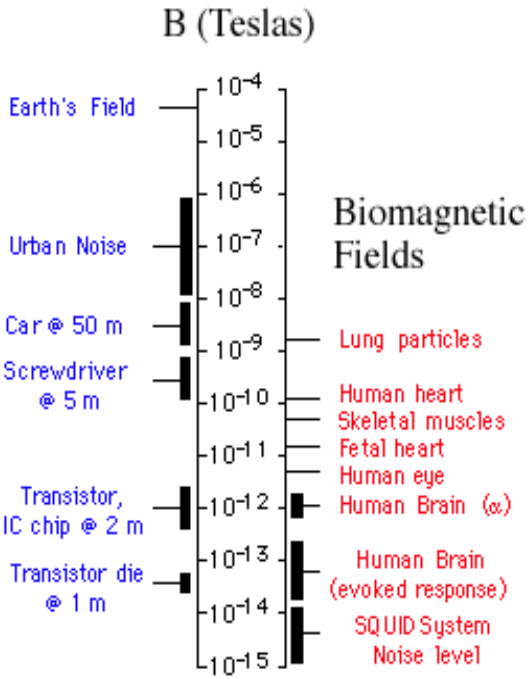




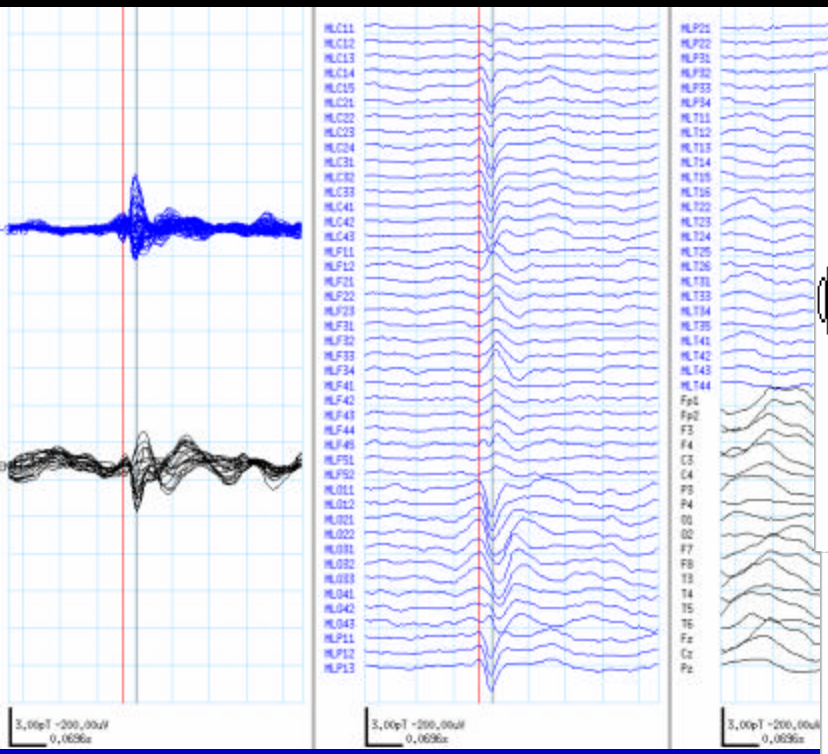


Whole-Cortex MEG System

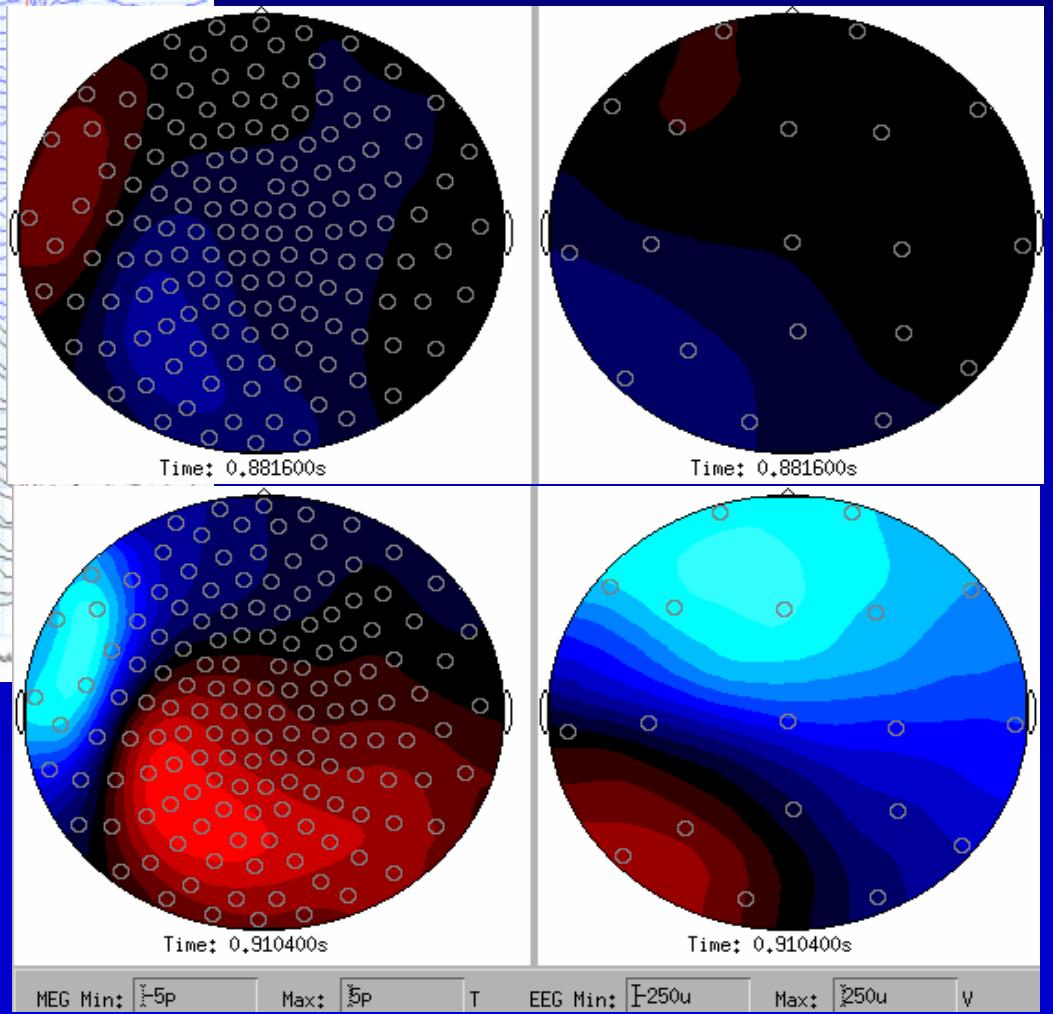
Magnetic Fields



Equivalent current dipole on MEG

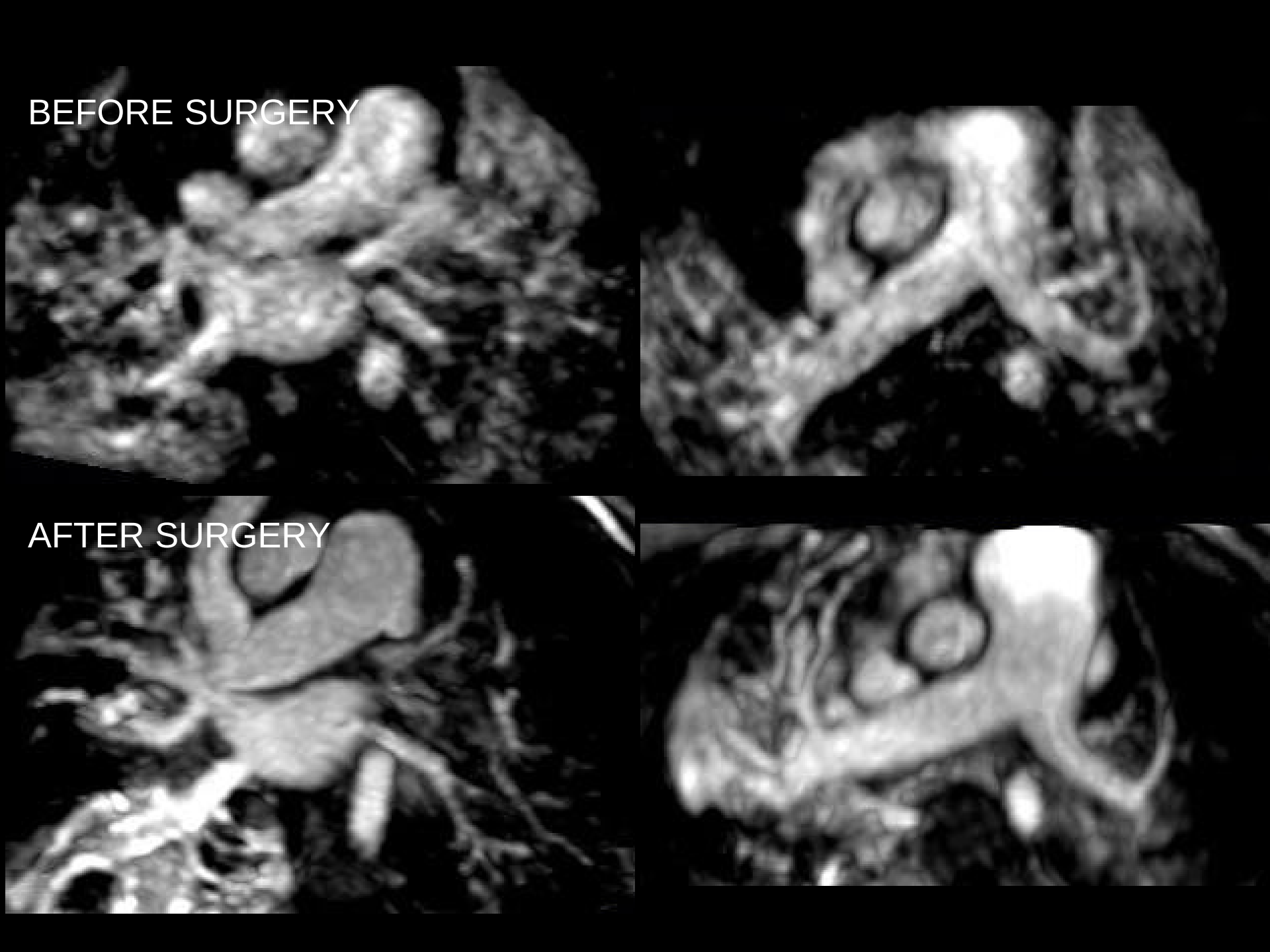


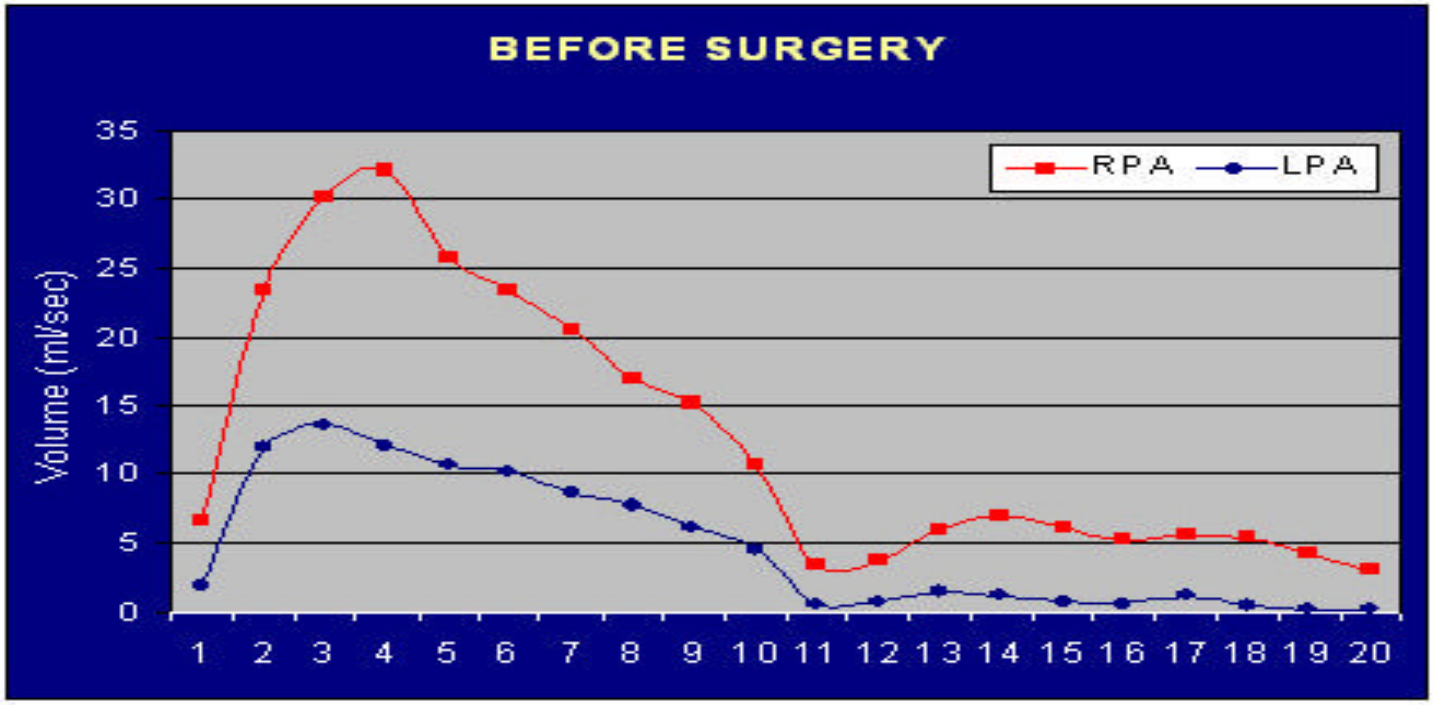
MEG wave forms



Quantification

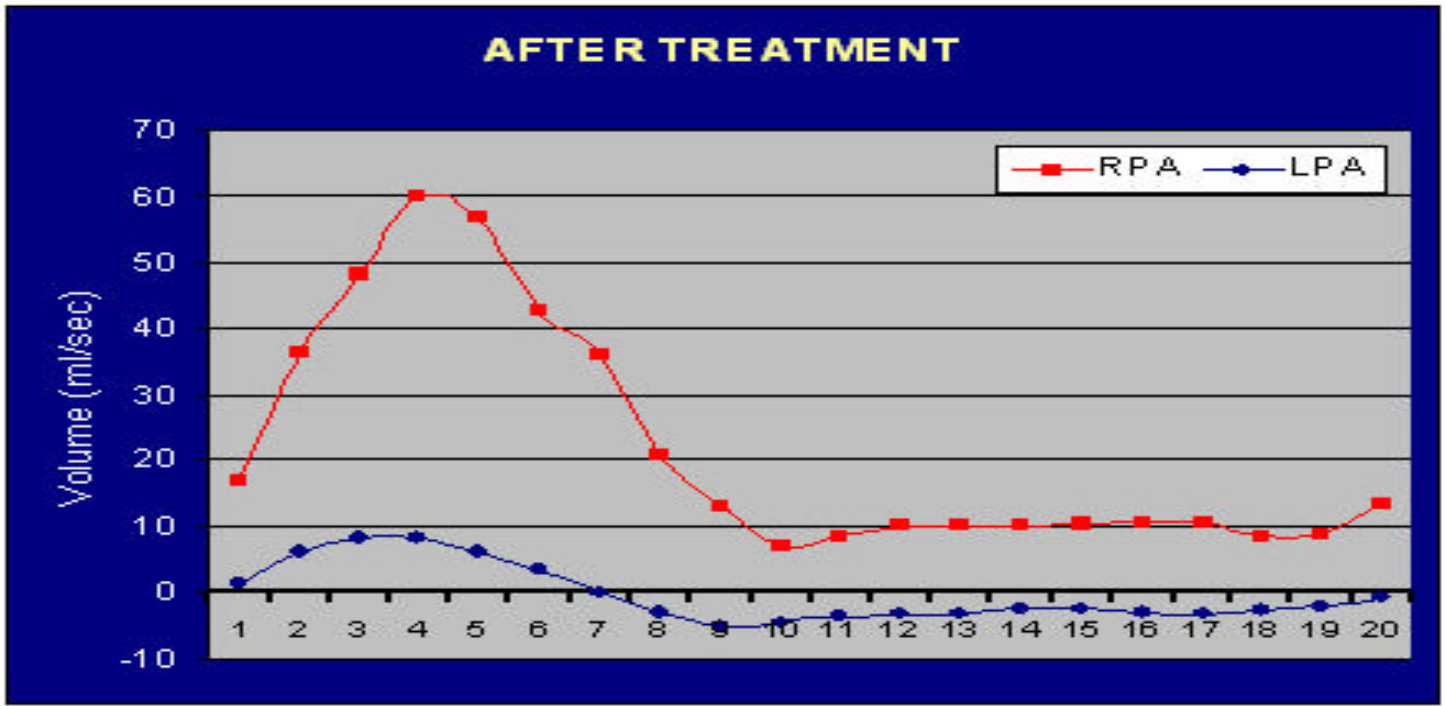
- Increasingly important aspect of care
- Little enthusiasm in radiologic community
  - Lack of standardization even for simple measurements- tumor areas, volumes
  - No consensus for how to display quantification with images
- Quantification already significant aspect of cardiac evaluation


BEFORE SURGERY
AFTER SURGERY



Relative Blood Volume over the cardiac cycle

R/L = 73/27



R/L = 99/1

Image Processing

- Medical image processing is the *manipulation* and *analysis* of medical image-based digital data to *enhance and illuminate* information within the data stream
- Processing may be automatic or interactive under human control

How is Image Processing Used in Medical Imaging Today?

- All throughout data stream
  - Data Acquisition, Transmission, Visualization
- Growing roles for Image Segmentation, Registration, Navigation and Image Analysis
  - Specialized evaluation - Dynamic contrast enhanced
  - Computer aided detection and diagnosis

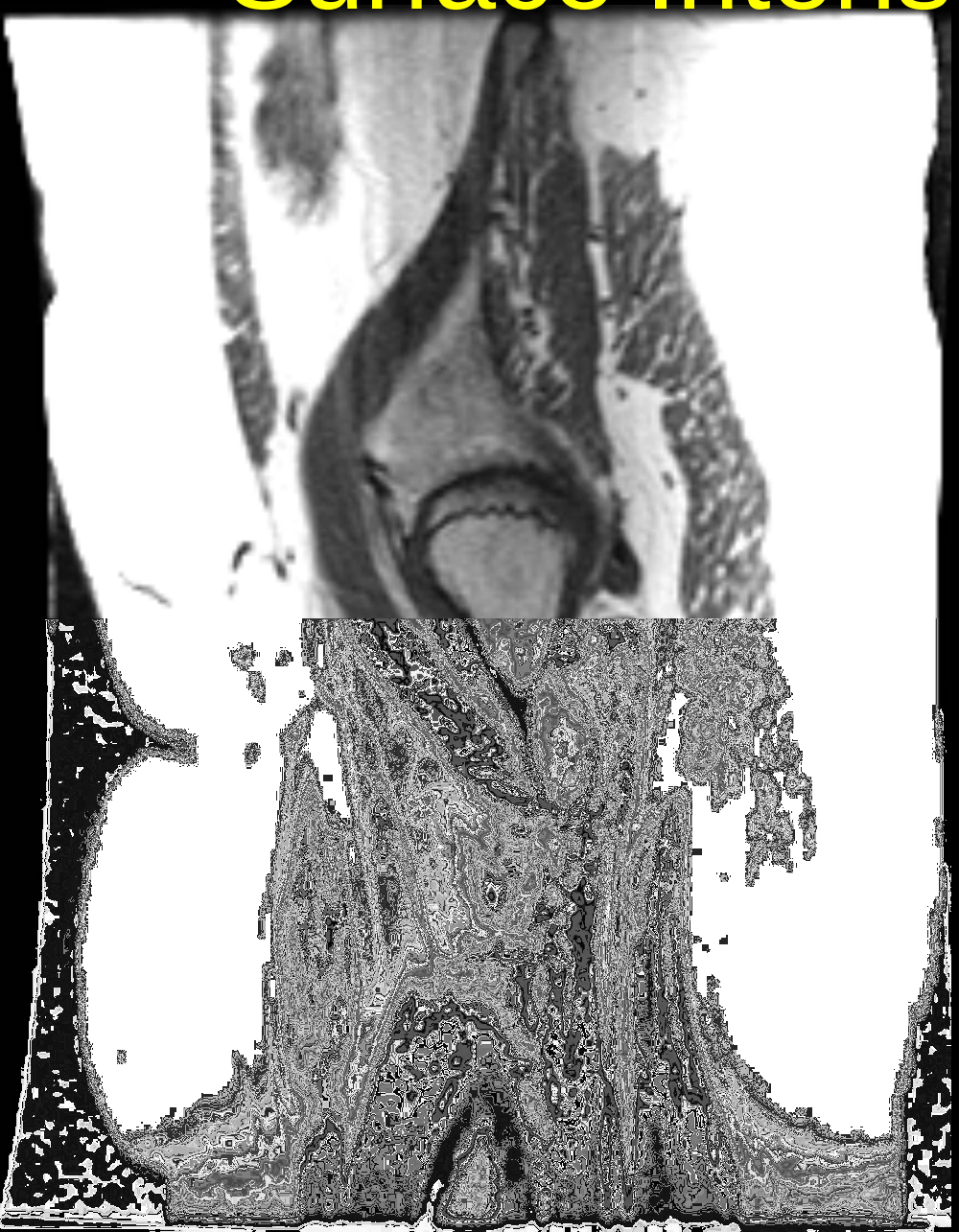
Common Digital Imaging Processing Operations Used in Digital Diagnostic Imaging Technologies

Digital Imaging Modality	Common Image Processing Operations
Computed tomography	Image reformatting, windowing, region of interest (ROI), magnification, surface and volume rendering, profile, histogram, collage, image synthesis
Magnetic resonance	Windowing, region of interest (ROI), magnification, surface and volume rendering, profile, histogram, collage, image synthesis
Digital subtraction angiography/digital fluoroscopy	Analytic processing, subtraction of images out of a sequence, gray scale processing, temporal frame averaging, edge enhancement, pixel shifting
Computed radiography/ digital radiography	Partitioned pattern recognition, exposure field recognition, histogram analysis, normalization of raw image data, gray scale processing, windowing, spatial filtering, dynamic range control, energy subtraction

Image Processing at Acquisition

- Black box
  - Generally not evident
  - Proprietary nature
- Basic tasks involved in filtering and preprocessing the data before detection and analysis by machine or human operator
    - noise removal, contrast and feature enhancement
- Opens new avenues for Digital Radiography
  - Dual energy subtraction
  - Temporal Subtraction
  - Tomosynthesis

Surface Intensity Correction



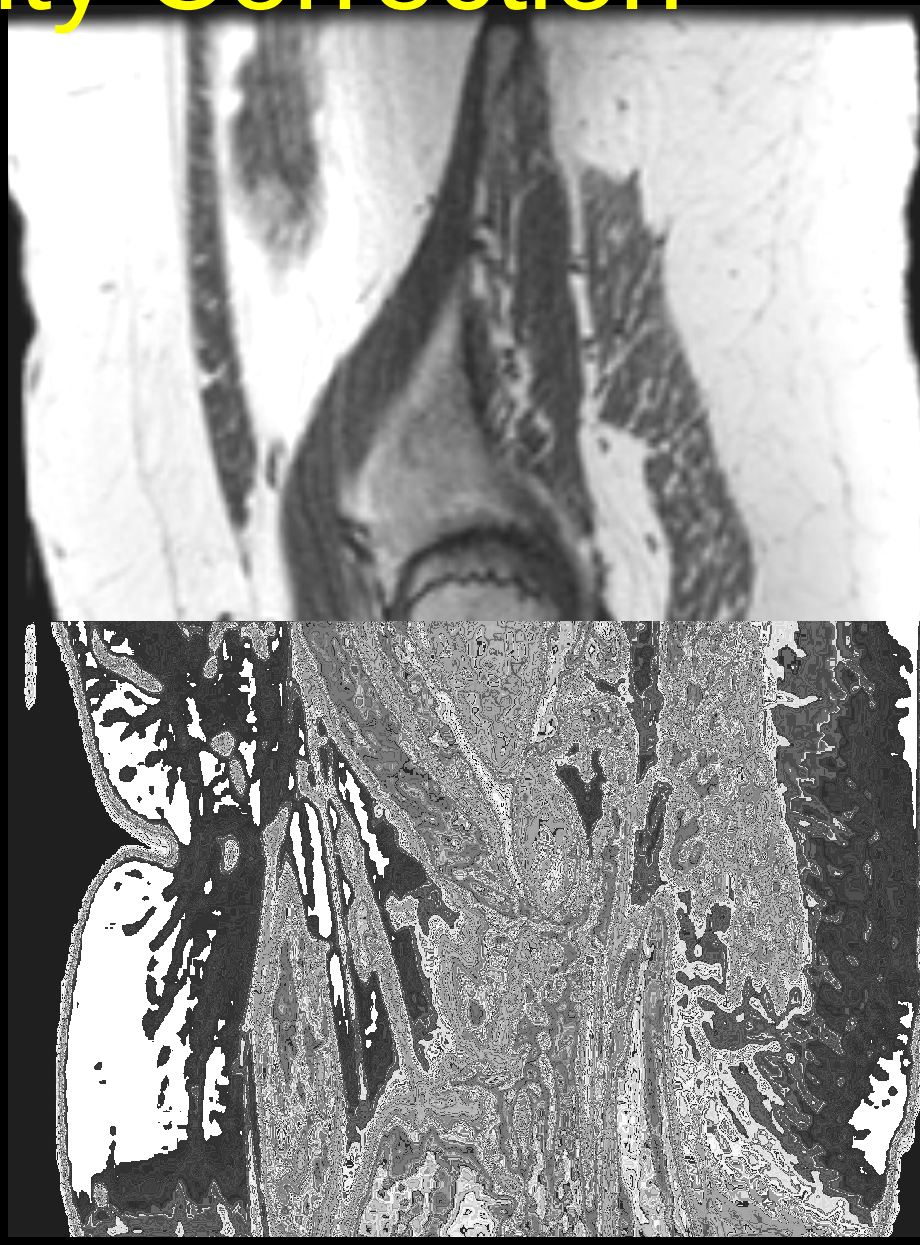


Image Processing:Contrast Enhancement in Computed Radiography

MUSICA® - Multi Scale Image Contrast Amplification

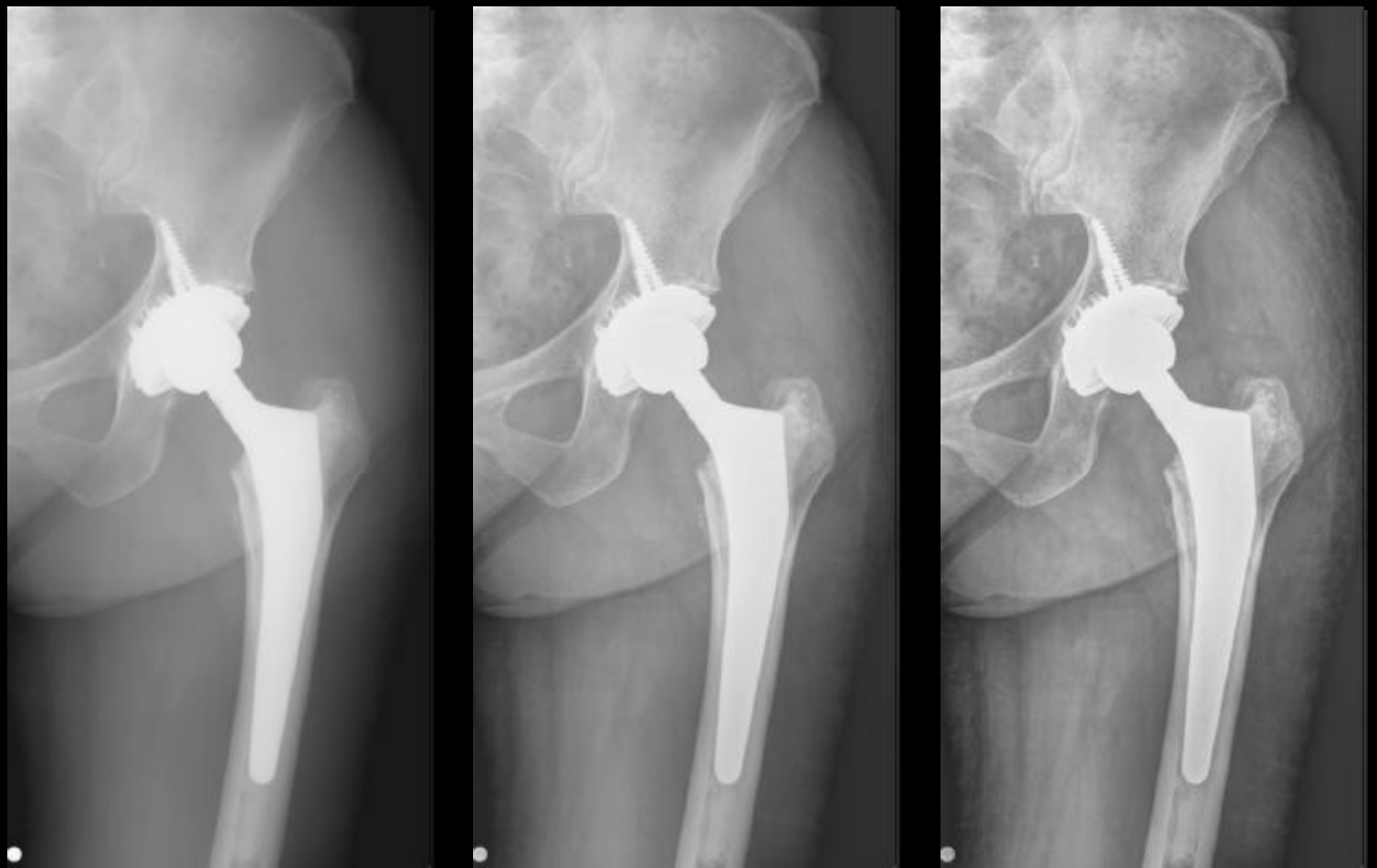


Image Visualization

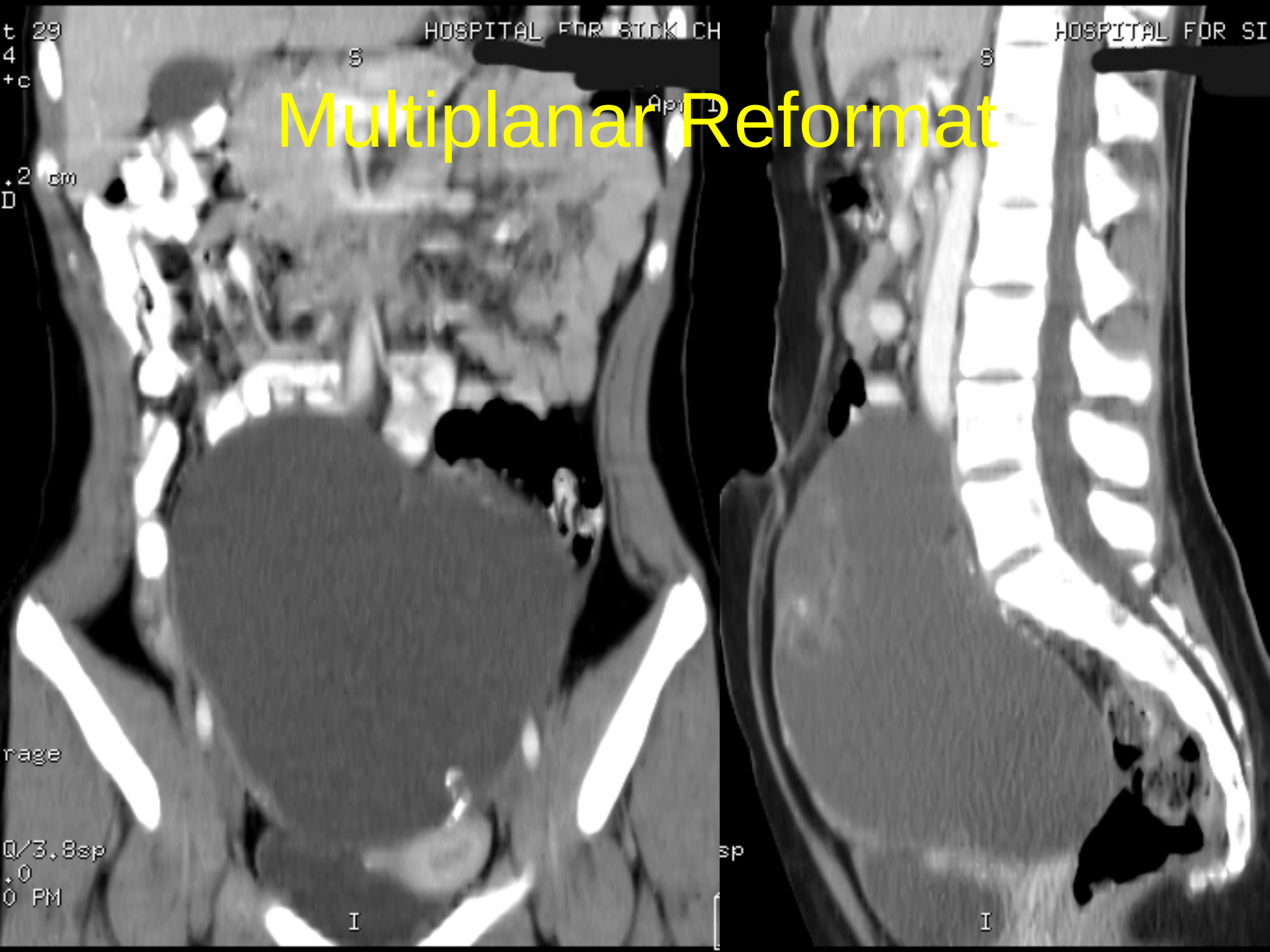
- Most recognized type of Image Processing by radiologist
- Originally displayed in static form on film
- Now dynamic display with soft copy viewing on PACS
- Often dedicated processing workstations
- Image manipulation now possible
  - Modification of contrast, brightness, magnification
  - Different presentation formats


MULTI
SLICE
CT

CT Axial images – often 1000+

Image Visualization

- 3D reconstruction techniques allow condensed representation of relevant information
- Variety of formats : Multiplanar reformat, MIP, Minip, Raysum etc
- Specific application depends on task needed and viewer
  - Surgeon and radiologist
- Two basic classes of volume visualization in use today
  - Surface extraction algorithm
  - Volume rendering algorithm
- May overcome some perceptive issues of structure shape and orientation

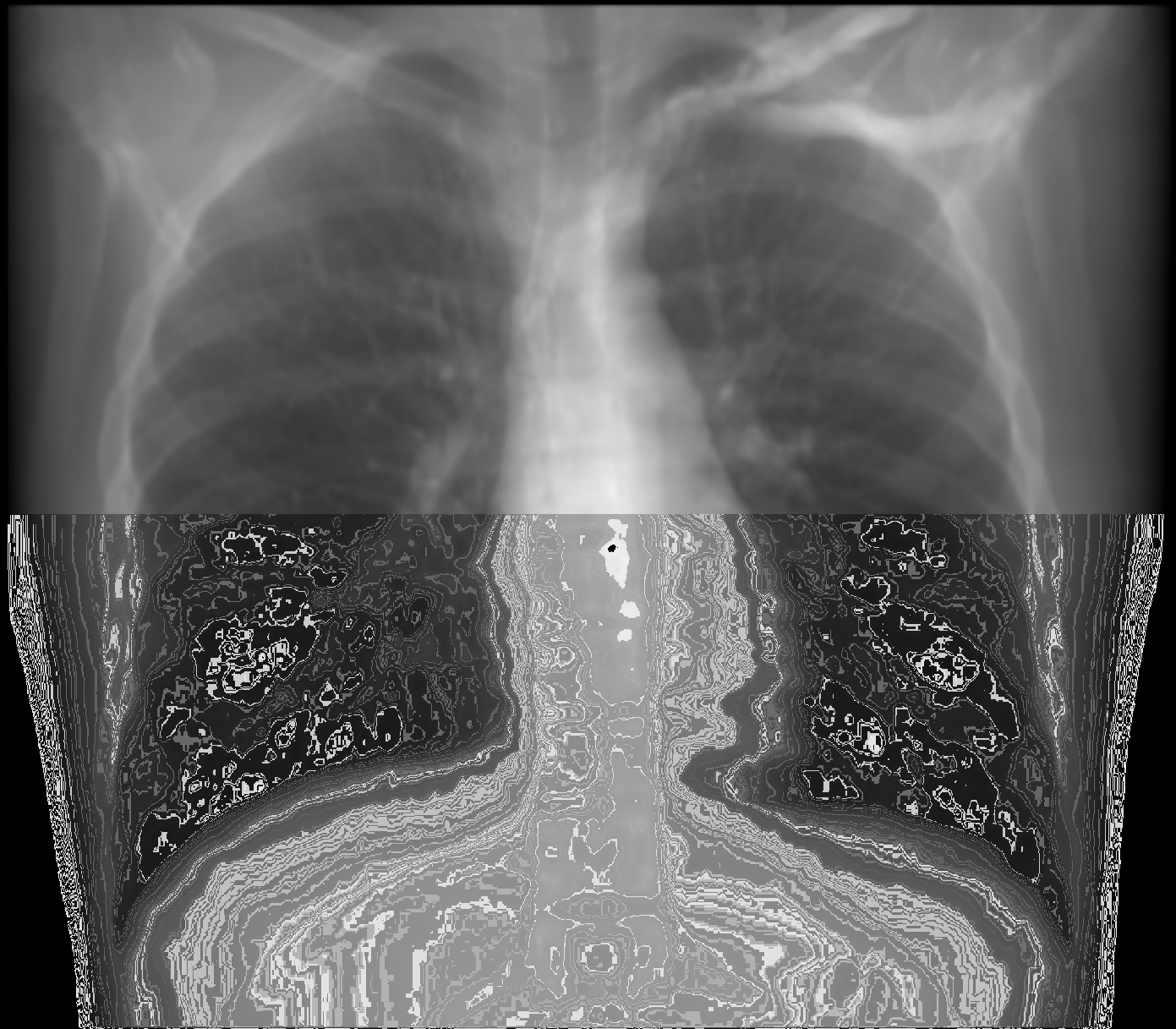

Multiplanar Reformat

Multiplanar Reformat

3D Display-Maximum Intensity Projection

- Maximum Intensity Projection
  - Collapses hundreds of images into 10-20
  - Cast rays perpendicular to viewing plane (along line of sight)
  - Pixel value is the value of the brightest voxel along that ray
  - Easy and objective to create
  - Artifacts from superimposition can be misleading
  - No quantitative info provided

Raysum



Shaded Surface Display

- Define the Surfaces of objects of interest. Assign color and opacity to each surface in the view, and the viewing angle
- Model light's interaction with object surfaces
- Strengths
  - Fast to render, clearest images if unhelpful parts edited out
  - Weaknesses
    - Requires segmentation and classification to define object surfaces
- Surface Extraction
  - Threshold dependence
  - Issues of noise, contrast level
  - Only surface information displayed

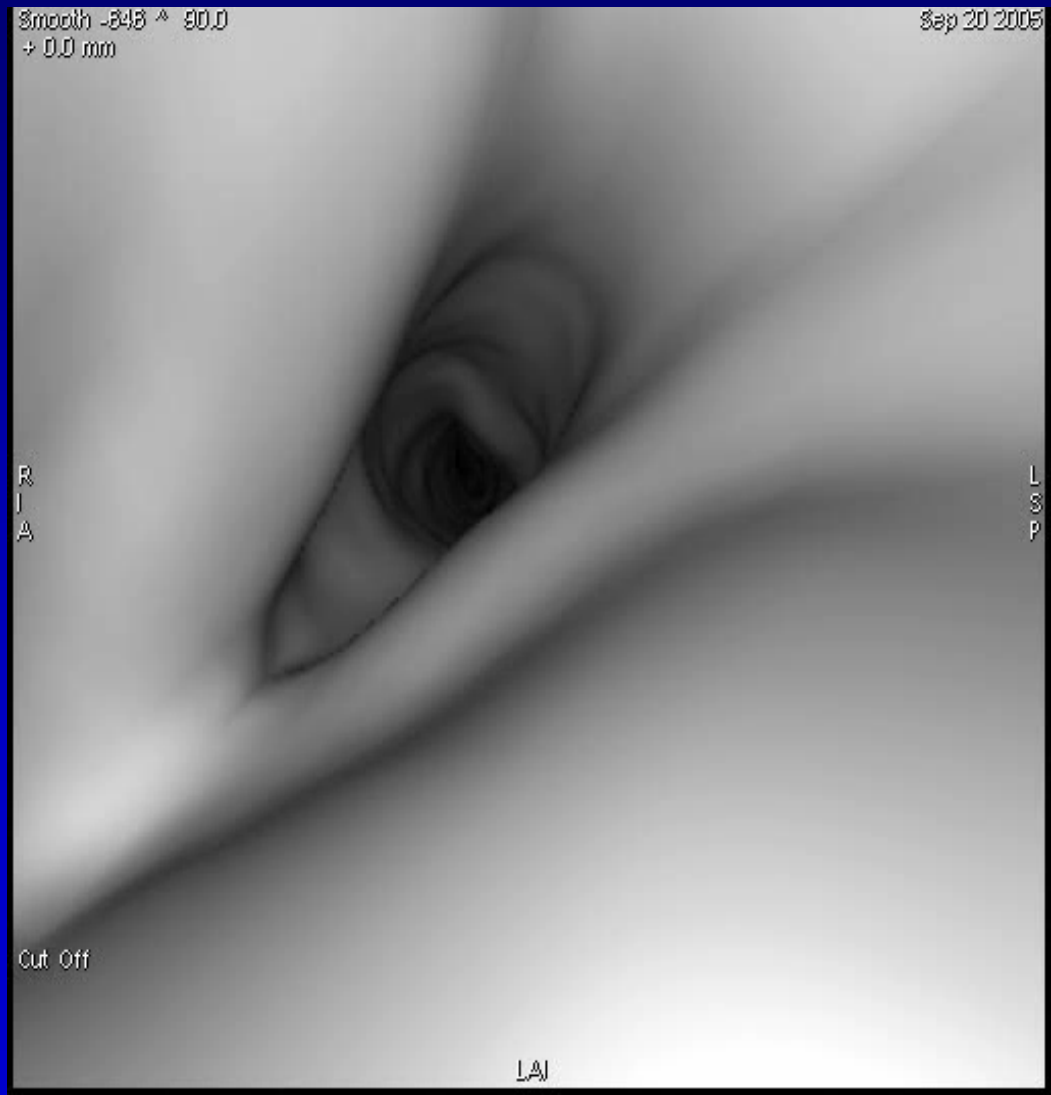
Shaded Surface Display

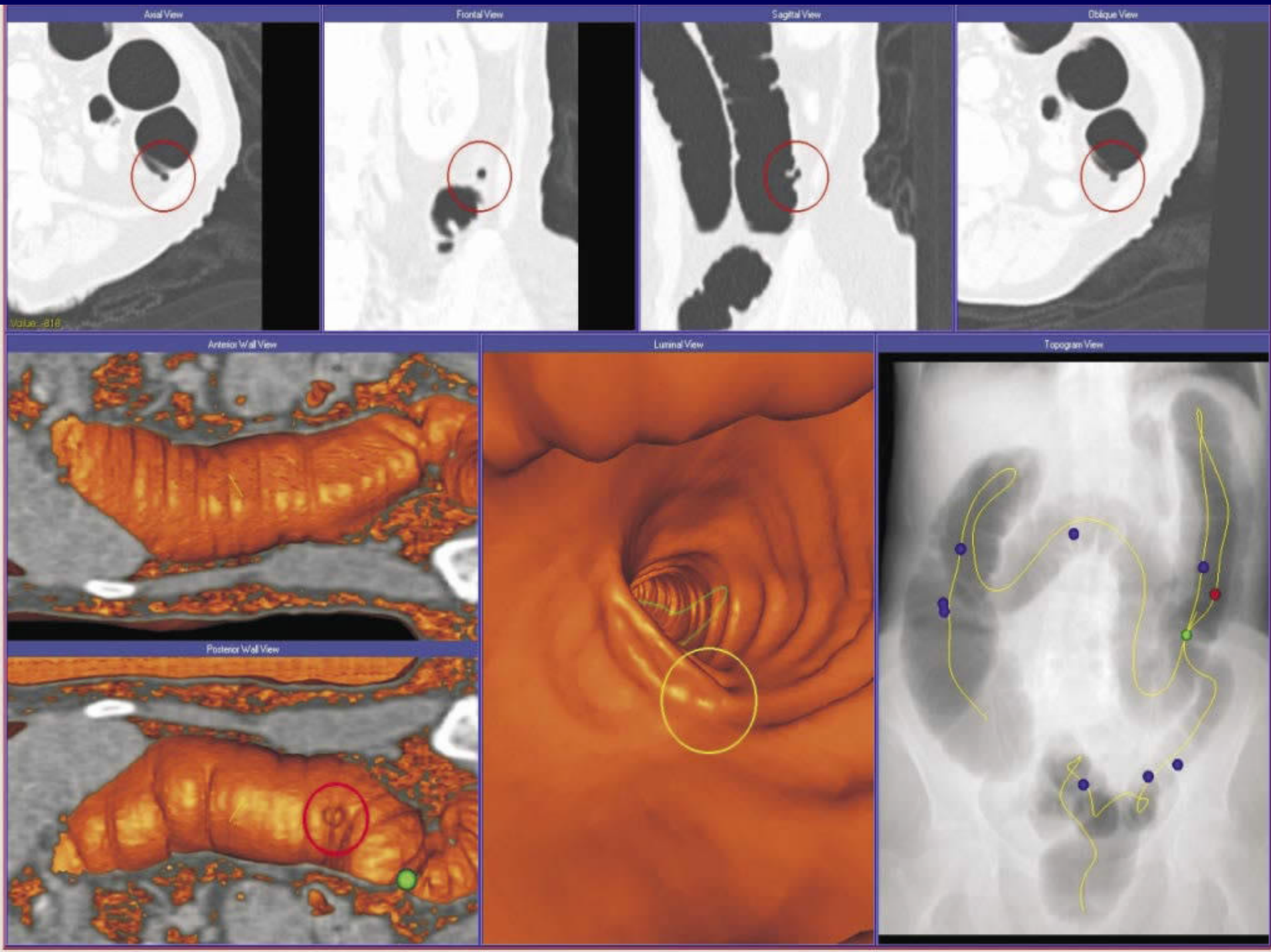
Volume Rendering

- Display objects of interest directly from the volume image
- Strengths
  - Versatile
  - No- presegmentation step
- Weaknesses
  - More computer intensive
  - Requires tissues that can be differentiated on the fly (intensity or other criteria)

Image Navigation

- Virtual environment becoming increasingly important in medicine reducing invasive risks
- Virtual endoscopy most prevalent
- Virtual bronchoscopy, colonoscopy, angioscopy



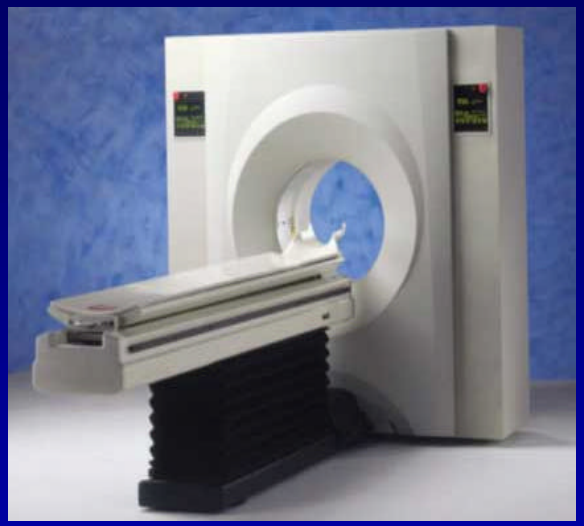

Axial View
Frontal View
Sagittal View
Oblique View
Anterior Wall View
Luminal View
Topogram View
Posterior Wall View

All these image techniques require dedicated time, effort, consideration of desired format and specific expertise to perform

Image Registration

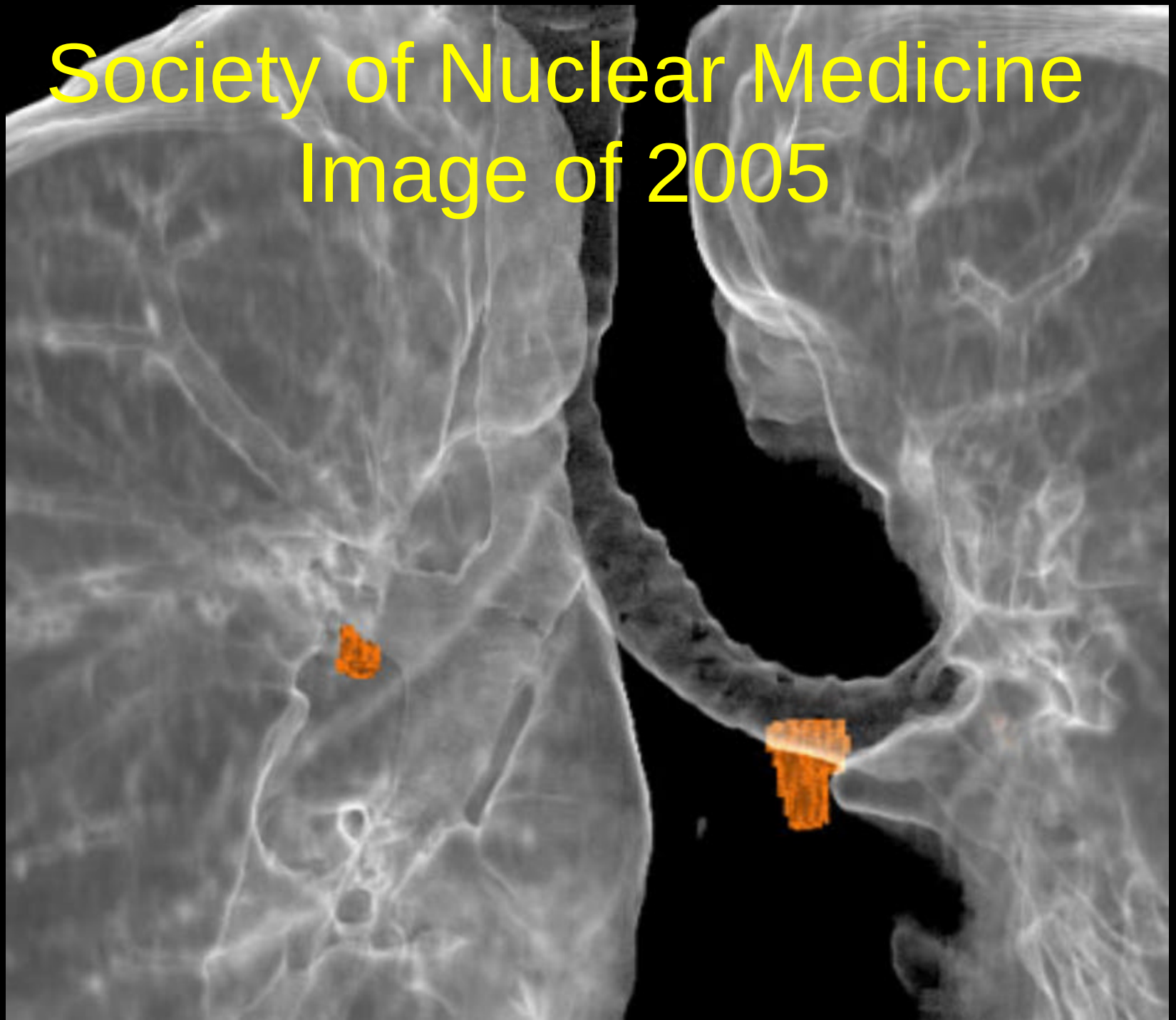
- Goal- align one image with base image
- Doesn’t need to be of the same type
- (e.g. register PET with CT or MRI)
- Monomodality vs Multimodality
- Temporal registration often used following contrast administration
- Inter subject matching- Telaraich

Positron Emission Tomography (PET)



- Glucose tagged with radioactive isotope and injected into patient demonstrates changes in body's usage of glucose
- PET can be now directly fused with CT Scan images acquired simultaneously

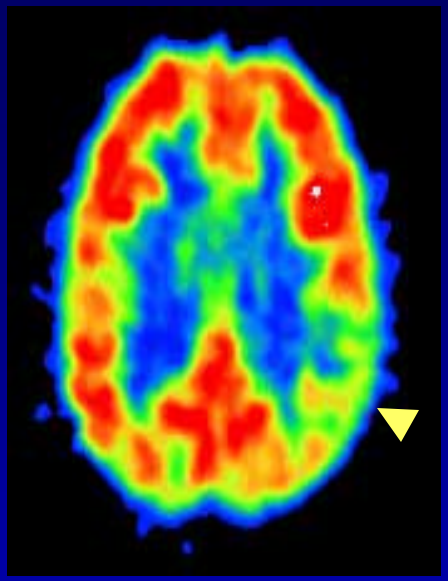
Society of Nuclear Medicine Image of 2005

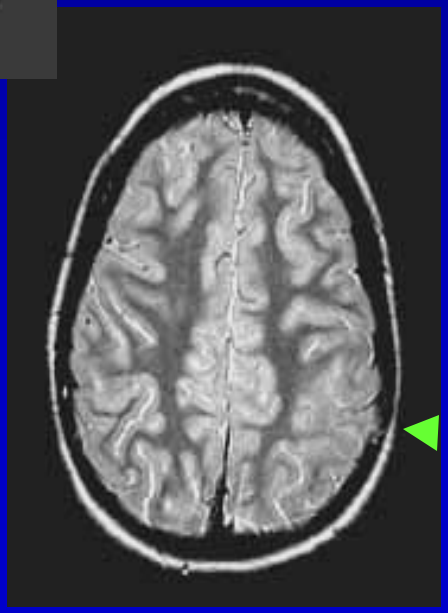


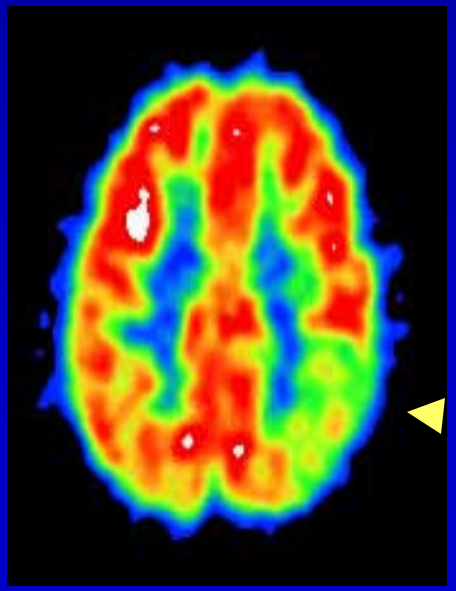
MRI, PET

Right

Left



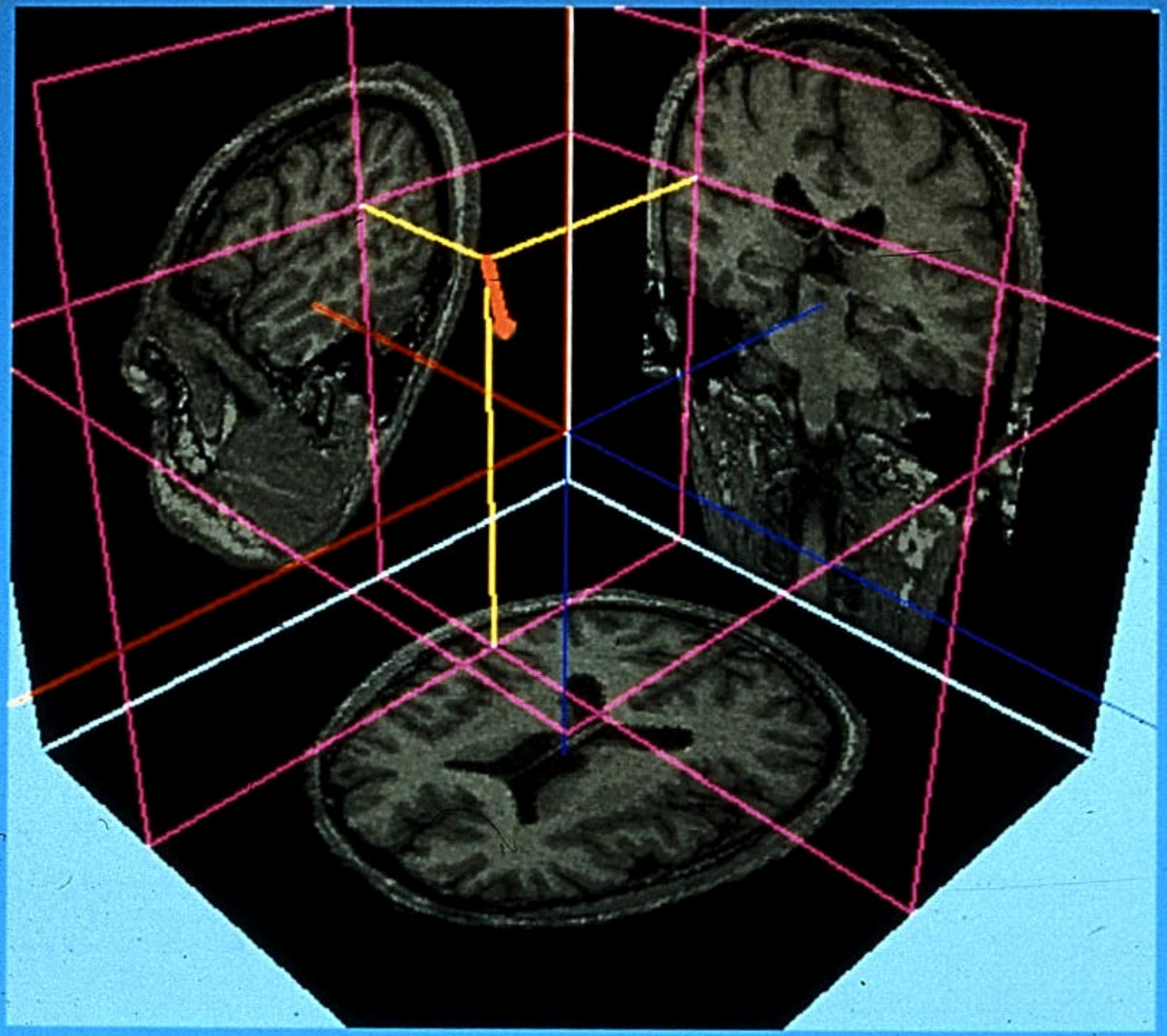




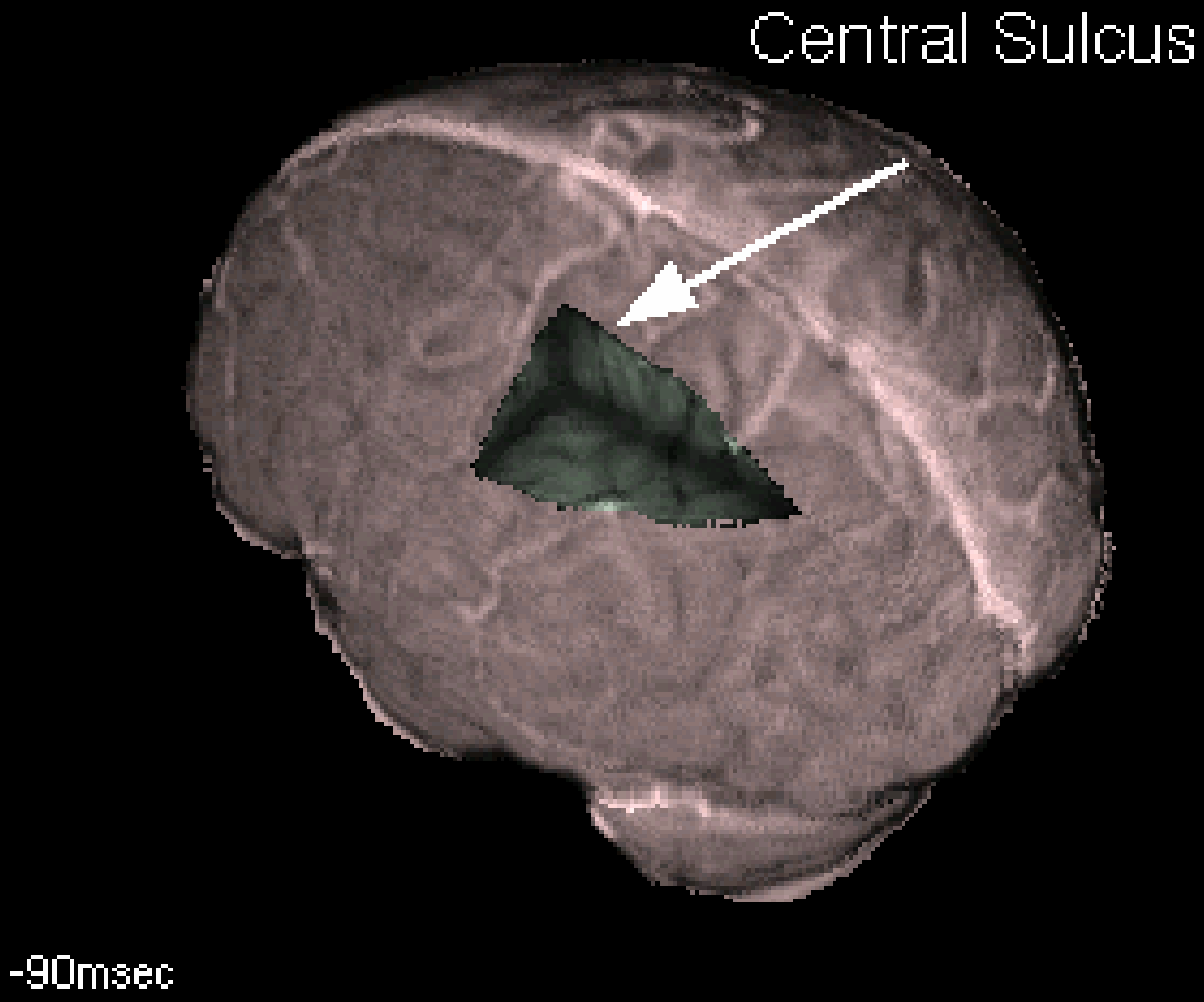
Images courtesy of
Dr. Ayako Ochi

KS

Dipole source localization on 3D MRI



Functional MSI




FREEZE

Surgical Navigation

- Key use for image registration, visualization tools
- Tracking of surgical navigation instruments, positions of surgical instruments within frame of reference of operating room and patient's 3D reconstruction
  - Neurosurgery
  - Long distance laparoscopic surgery
- Can allow patient specific pre-operative surgical planning

Laser Registration

Infra-Red Tracking system

Can utilize active or passive pointers

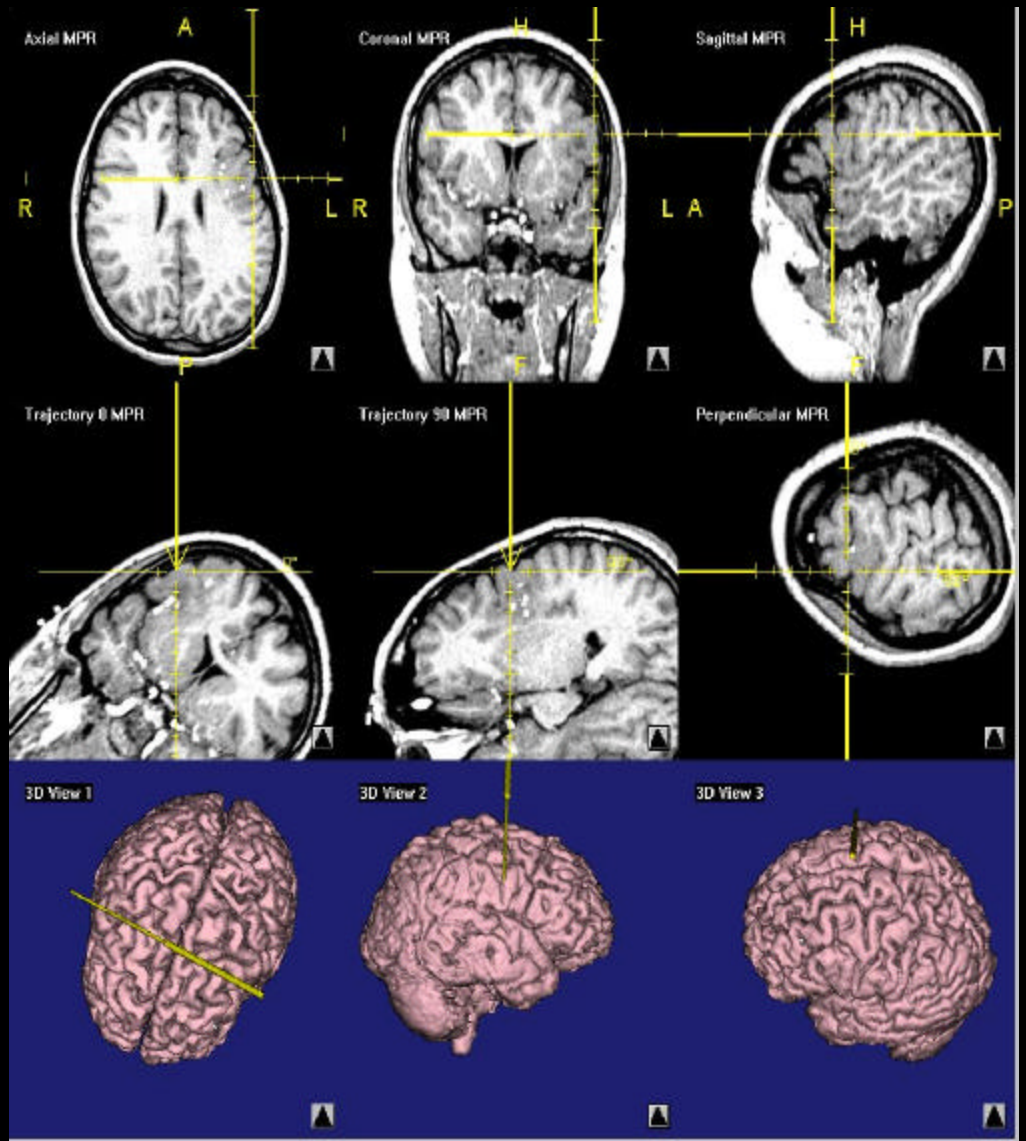
Referencing is created by a registration program correlated to a special frame.

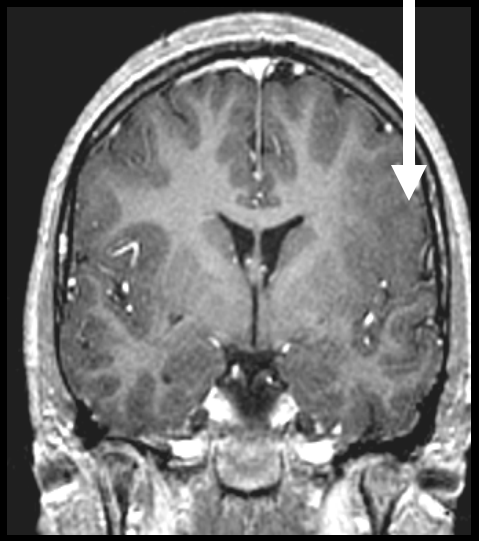
•System allows for correlation between multiplanar reformatted images and 3-D objects

Frameless stereotaxy

•Image courtesy of BrainLab A. Burwick

Frontal Cortical Dysplasia

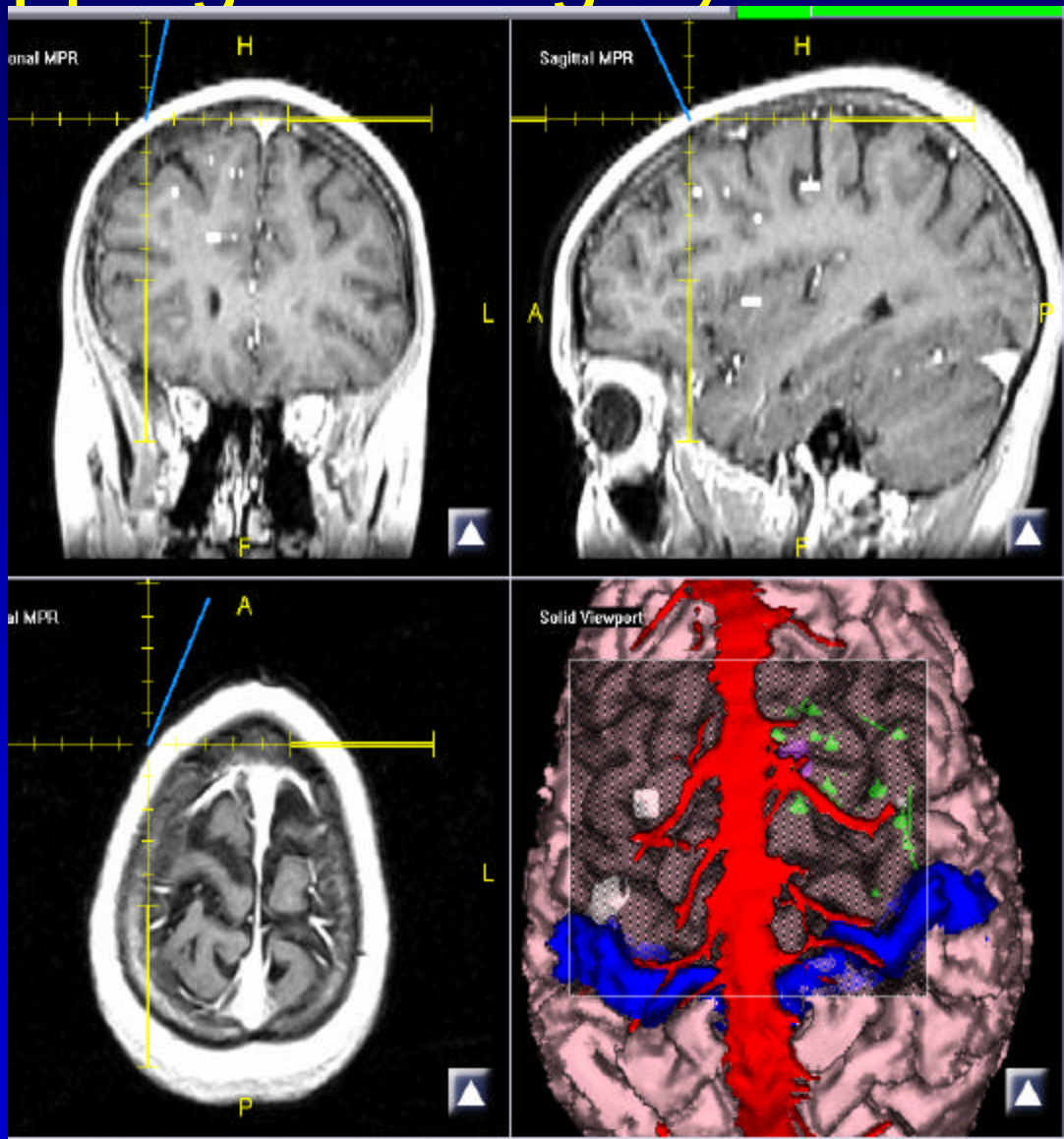




14 Yr old girl with cortical dysplasia -Surgery to insert and then monitor a subdural grid

MEG combined with 3-D Imaging Provides Accurate Mapping for Surgery

Patient with epilepsy, mapping to pre-motor cortex



Current Problems

- Growth of capabilities of image modalities generating thousands of images
- Creates problems in storage, viewing and interpretation
  - Example CT scan soft tissue windows, bone windows, lung windows

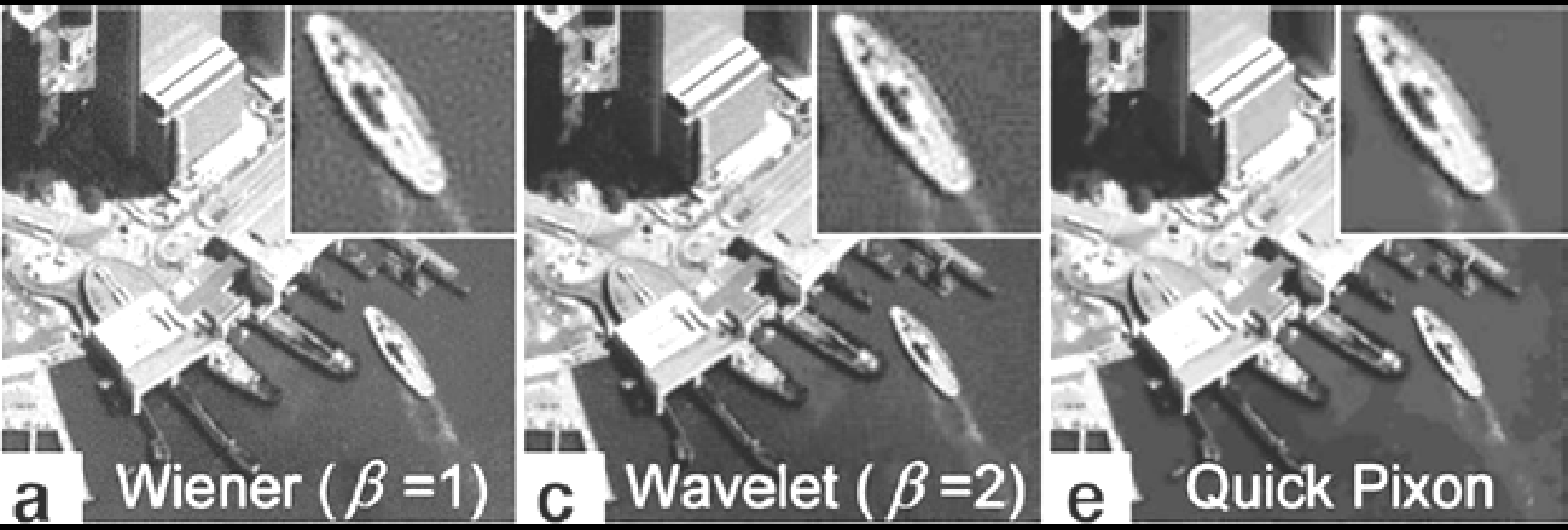
PACS and Image Processing

- Constraints
  - Closed system, hard to add features from outside the PACS vendor
- Limited tools on current PACS workstations
- Data pre-processed
  - E.g.-separate storage for bone, lung and soft tissue windows
- Improved workstation design needed to handle multimodality image display

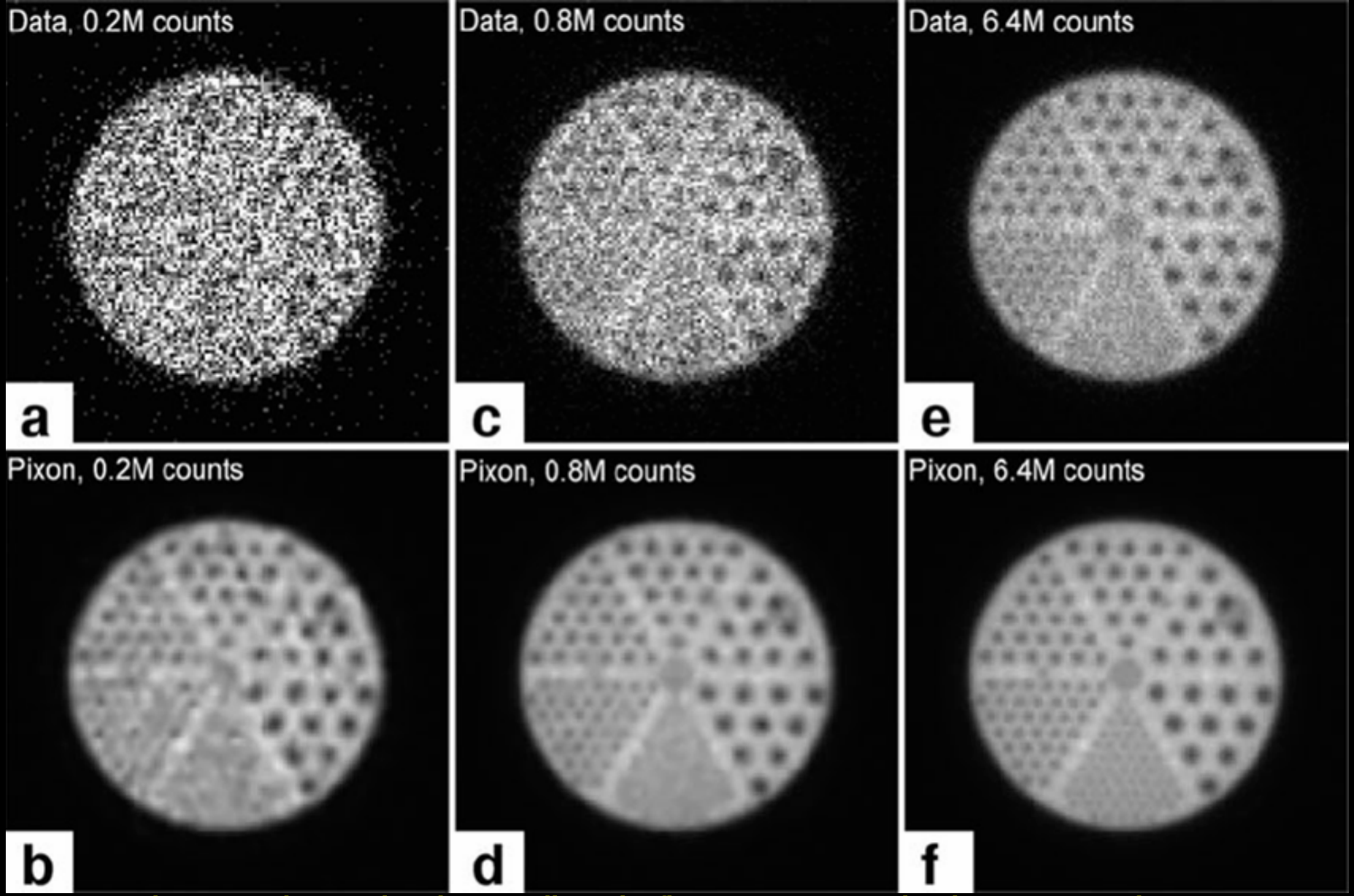
Areas for Improvement

- Throughout data stream
- At acquisition
  - All modalities increasingly digital acquisition allows new opportunities: Multidetector CT, Parallel imaging in MR
  - For example Digital Radiography can overcome altered radiographic appearance and reduce dose with introduction of copper filtering into data acquisition pathway

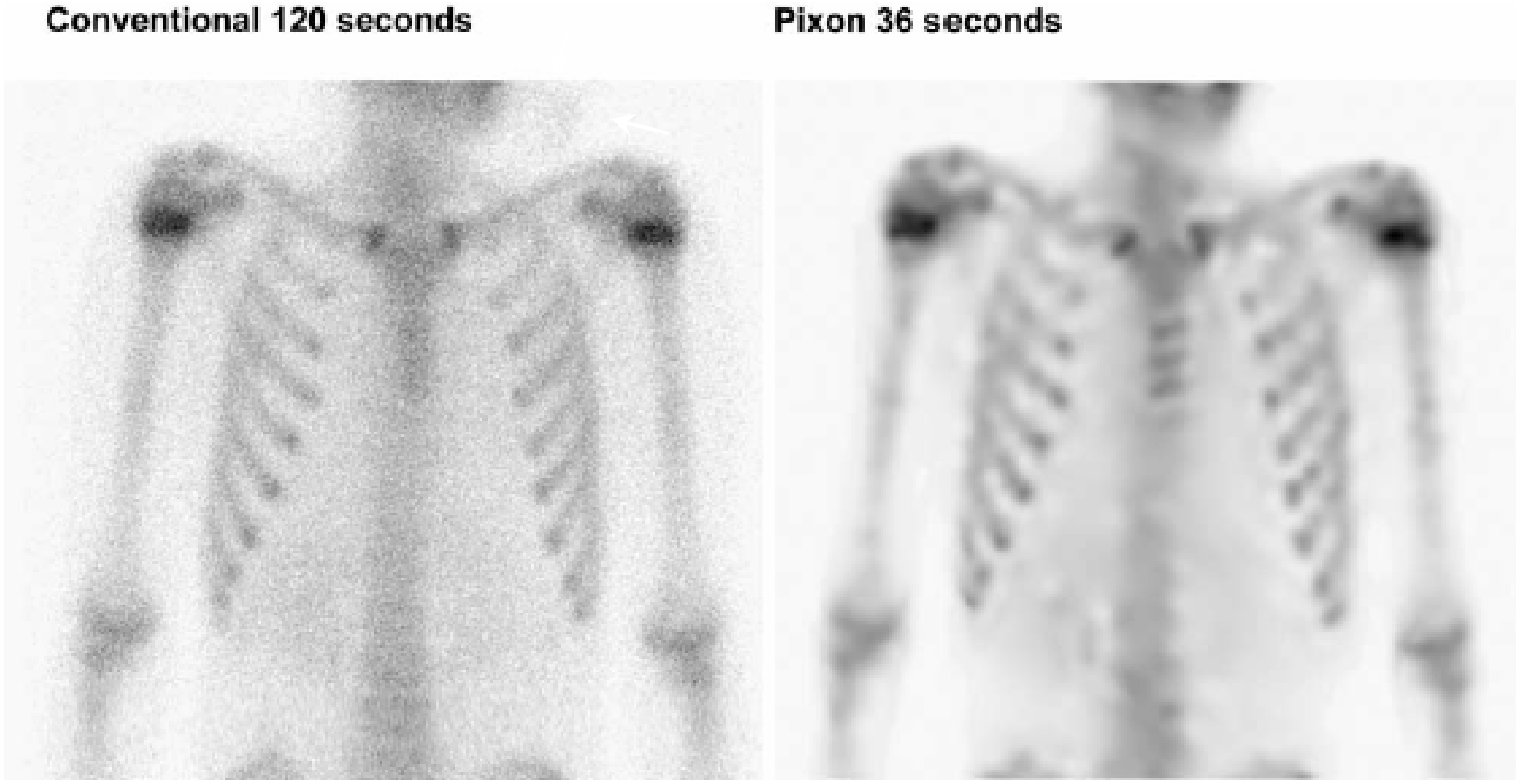
Filter algorithms



Puetter RC, Gosnell TR, Yahil A. Digital Image Reconstruction: Deblurring and Denoising. Annu. Rev. Astron. Astrophys. 2005. 43:5.1-5.56



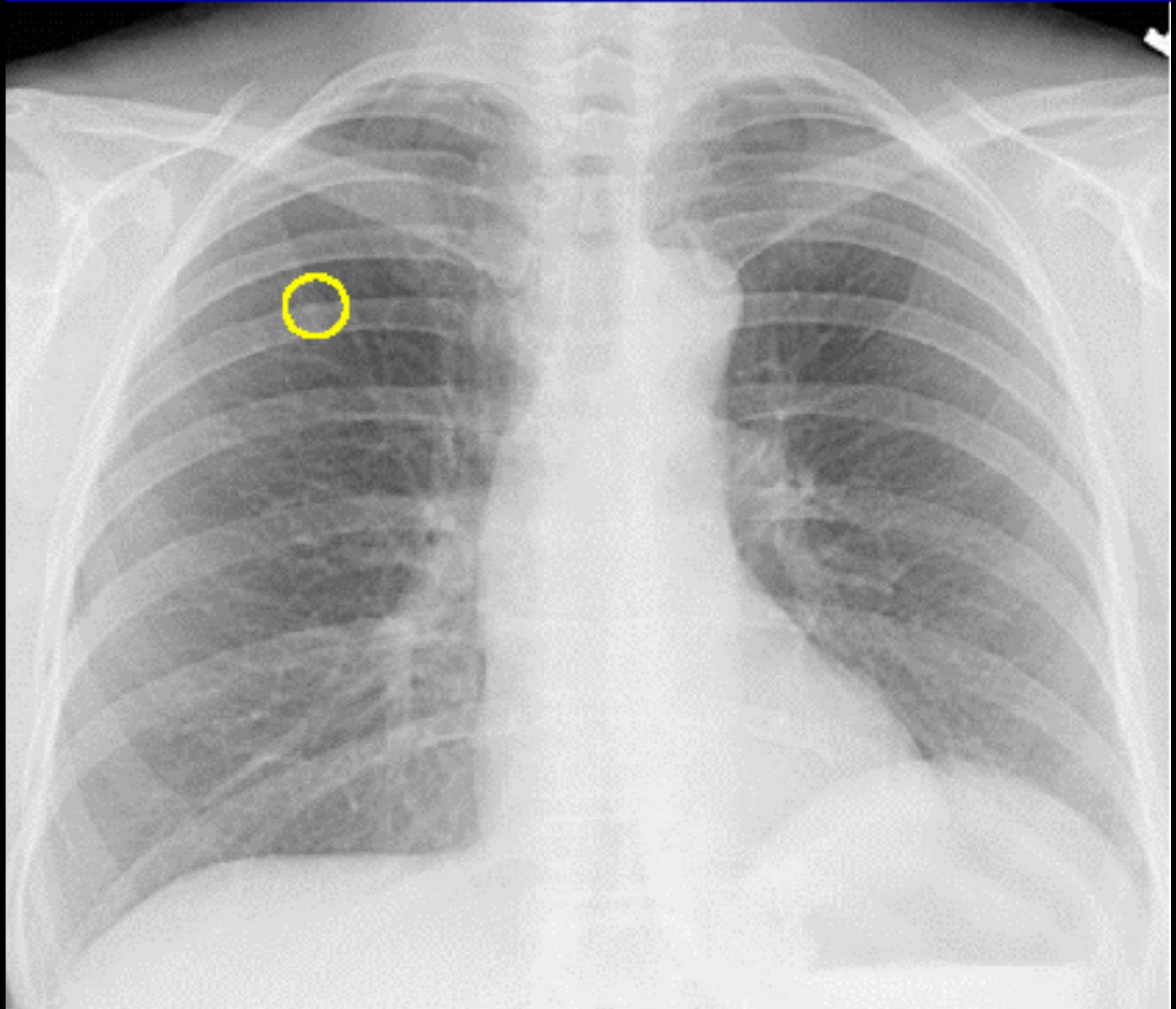
Raw (a, c, e) and Pixon (b, d, f) processed phantom data at three different count rates



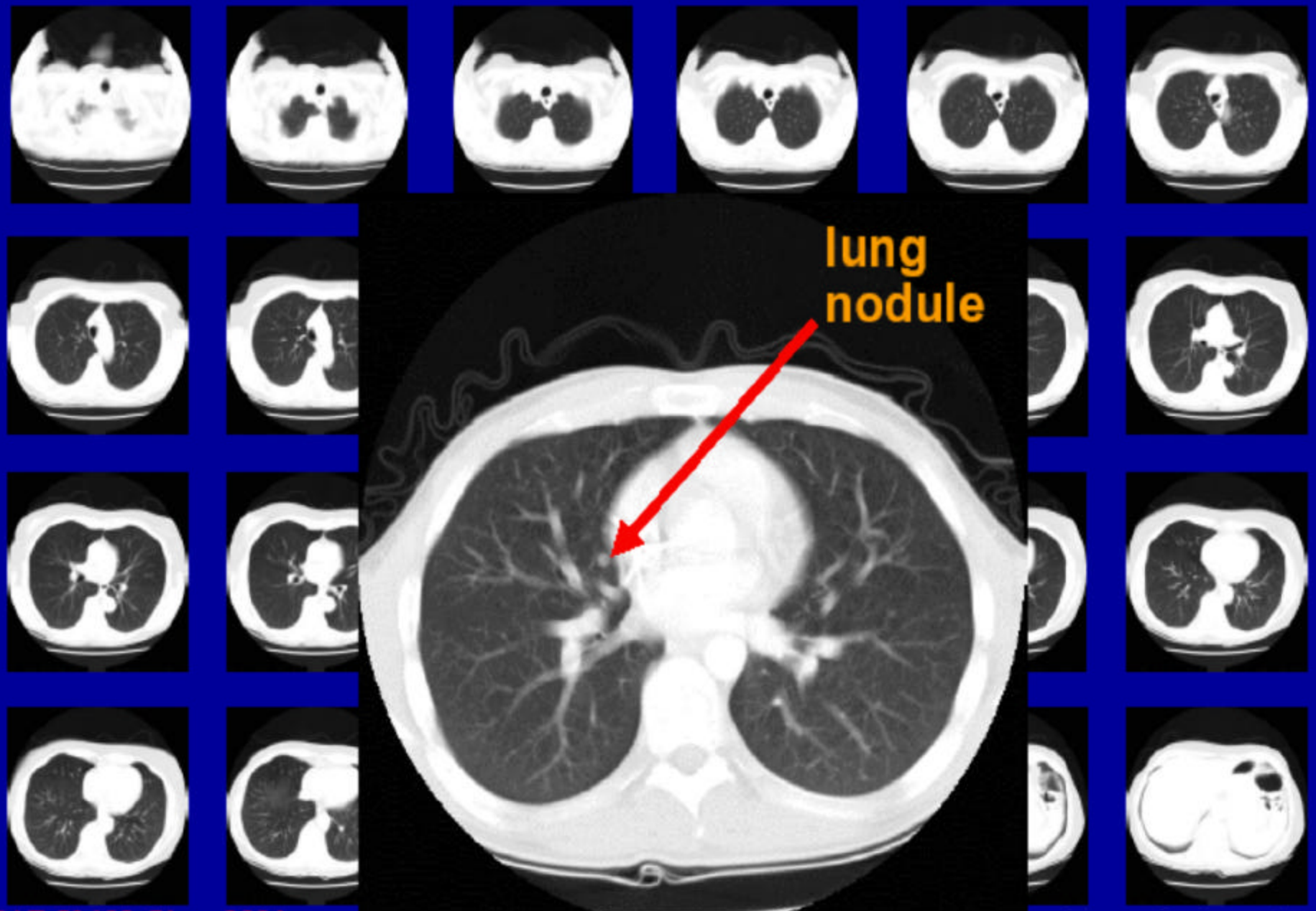
Unprocessed 120 second data versus Pixon processed data acquired for only 3 tenths of that time. Note improved visualization of sternal segments. Pixon processing may be used to reduce radiation exposure and/or reduce the likelihood of patient motion, without loss of imaging detail.

Improved Segmentation

- Removal of distracting overlying structural noise
- How best to display information?
- Anatomic depiction?
- Need standardized approach optimized for visual system of the radiologist



Vast Amount of Data



From S. Armato

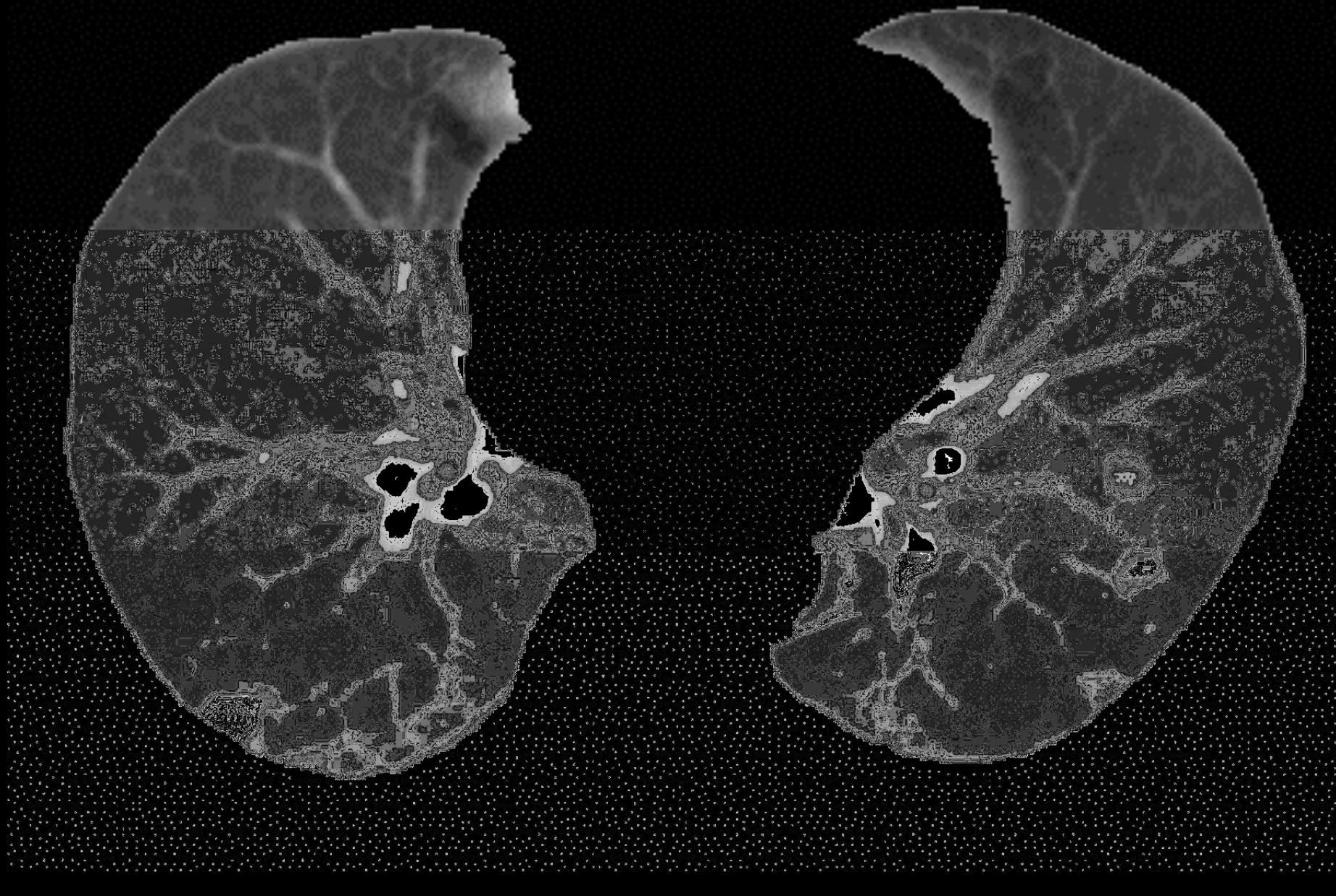
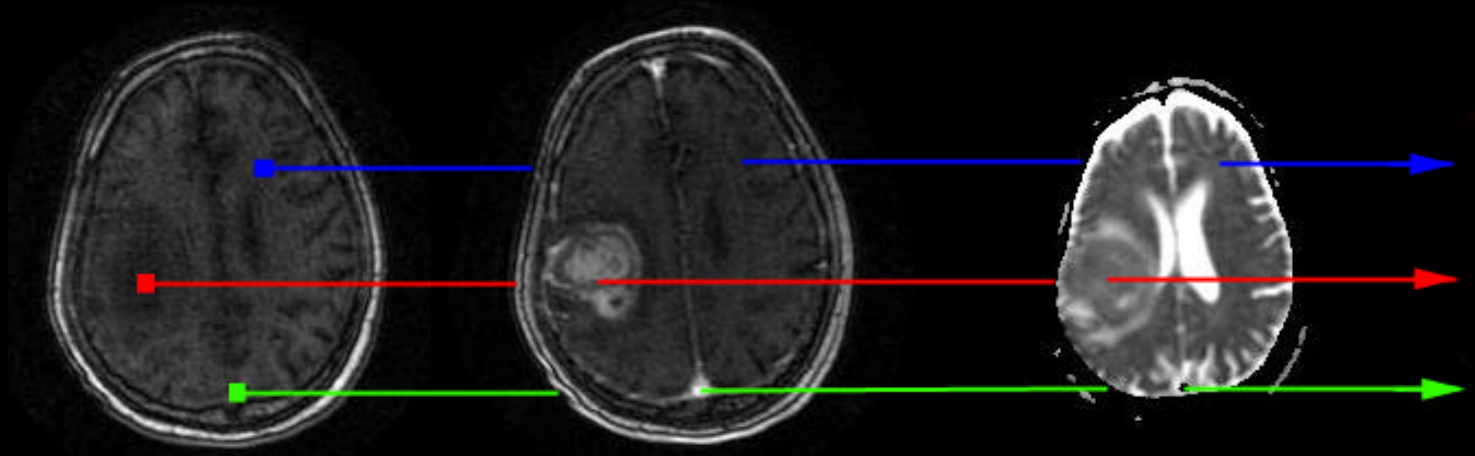
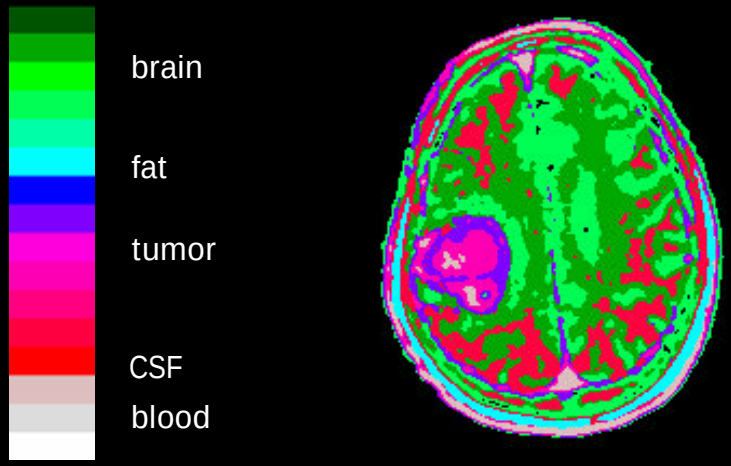


Image Visualization

- Improved aids in displaying information needed
- Standardization will be critical to reduce errors ensure all info looked at
- Improved integration of multiple modalities and better integration with surgical equipment
  - colors- abnormal, increased/decreased

Multispectral analysis - ISODATA

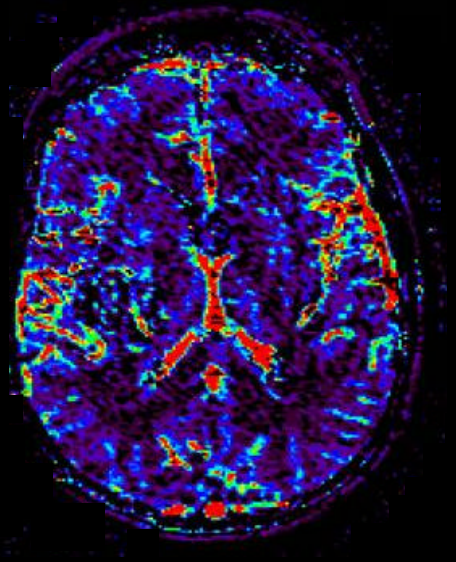




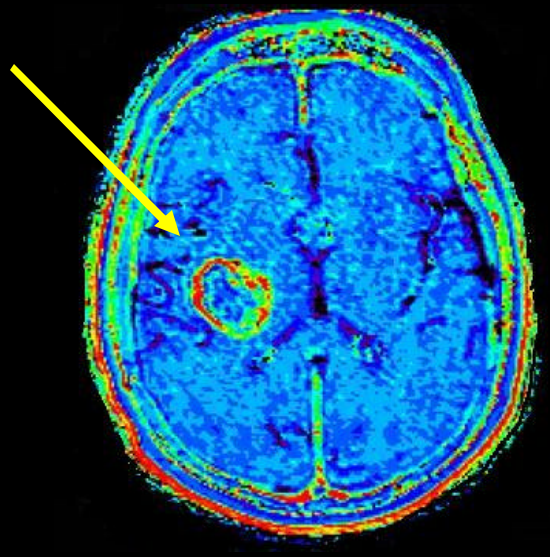
Isodata map from tissue vectors

Tissue signature vectors defined for each tissue class and assigned to cluster that most closely resembles vector elements for that tissue type

DCE permeability mapping



Blood
Volume



KPS

Permeability

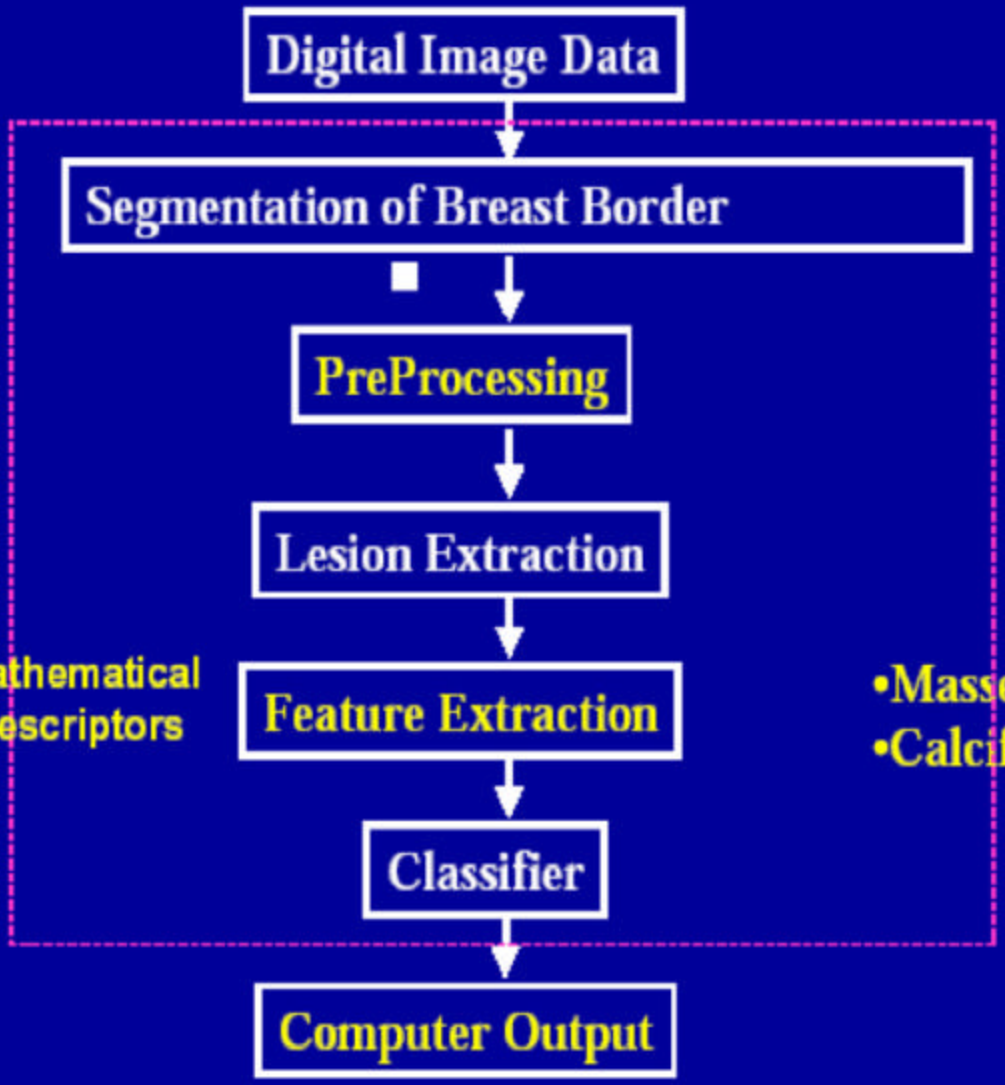
Computer-Aided Detection

- Many radiologic abnormalities are in fact recorded on the image with today's technologies but are not perceived by the observer
- Processing can be applied to optimize *detection* of these abnormalities
- Still in infancy
- Area of extensive research with application to multiple modalities and organs: Chest, Colon, Breast, Brain,Liver, Kidney, Vascular, Skeletal
- Commercialization Started for Breast masses, Lung Nodules

Computer-Aided Diagnosis

- Computer output utilized by radiologist as a second opinion
- With CAD the computer doesn't necessarily have to be better than the radiologist, but the combination should be better
- Goal is to reduce oversight error and reduce variation between observers

Generic Flowchart for the Computerized Analysis of Breast Images



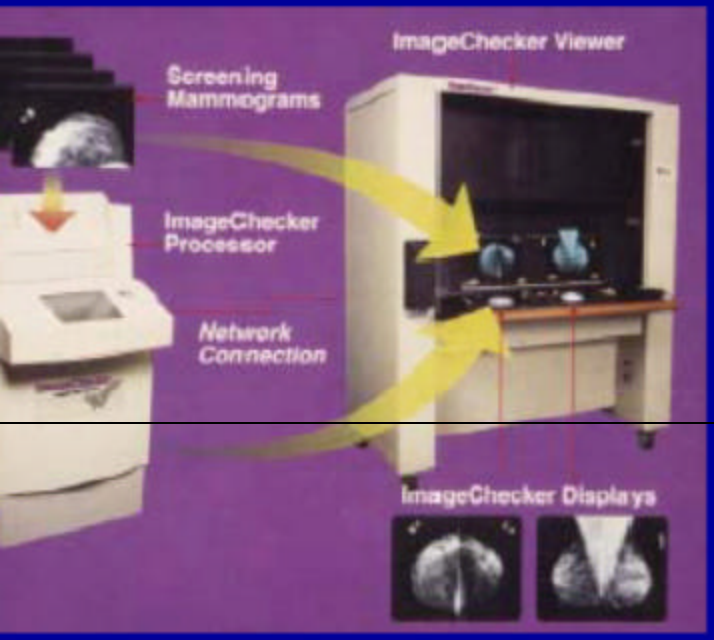
Examples

- Peripheral equalization
- Noise reduction
- Feature filter, e.g., spiculation
- Region growing
- Lesion segmentation

- Masses: spiculation, shape, asymmetry
- Calcifications: size, contrast, clustering

- LDA, ANN, rules, hybrid

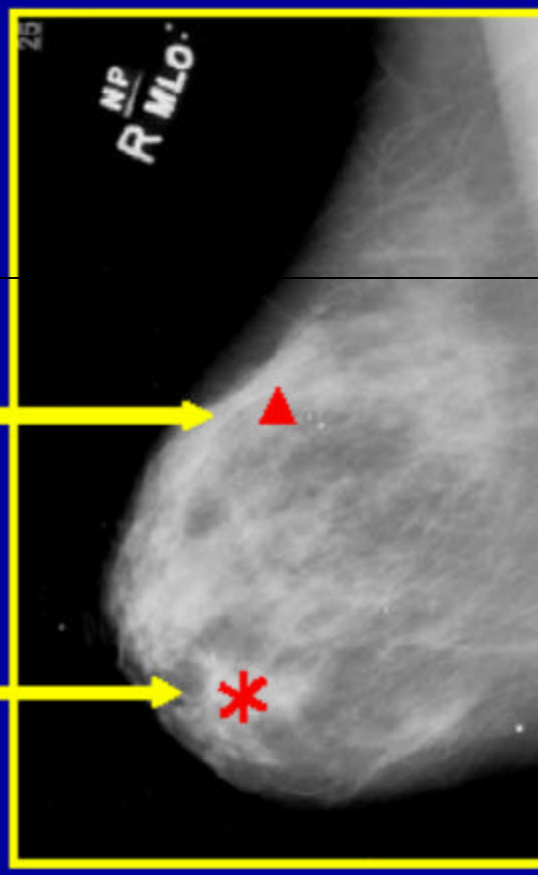
- Location of lesion
- Likelihood of malignancy

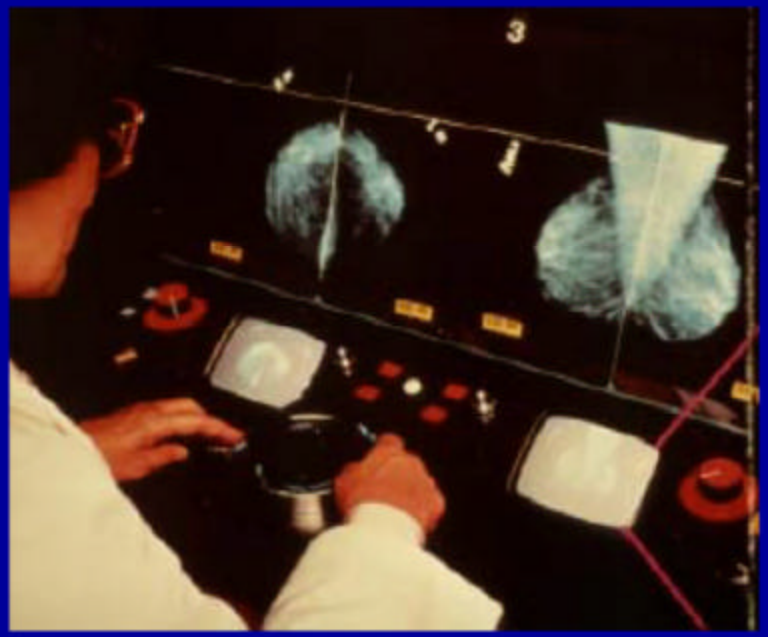


R2

A "▲" marks calcifications

A "*" marks masses or distortions.





Can be stored in DICOM fields or printed on paper for patient folder

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CAD for differential diagnosis

- CAD/ detection – reduces missed diagnosis
- CAD for differential diagnosis
- Improves quality of report, radiologist differential diagnosis
- Usefulness of Similar Images
- Need for large unique databases and sensitive tool for finding images similar to the unknown case
- It is difficult to construct feature sets of similarity

Intelligent Workstation For Breast CAD

CARS 2000
RSNA 2001
IWDM 2002
RSNA 2002
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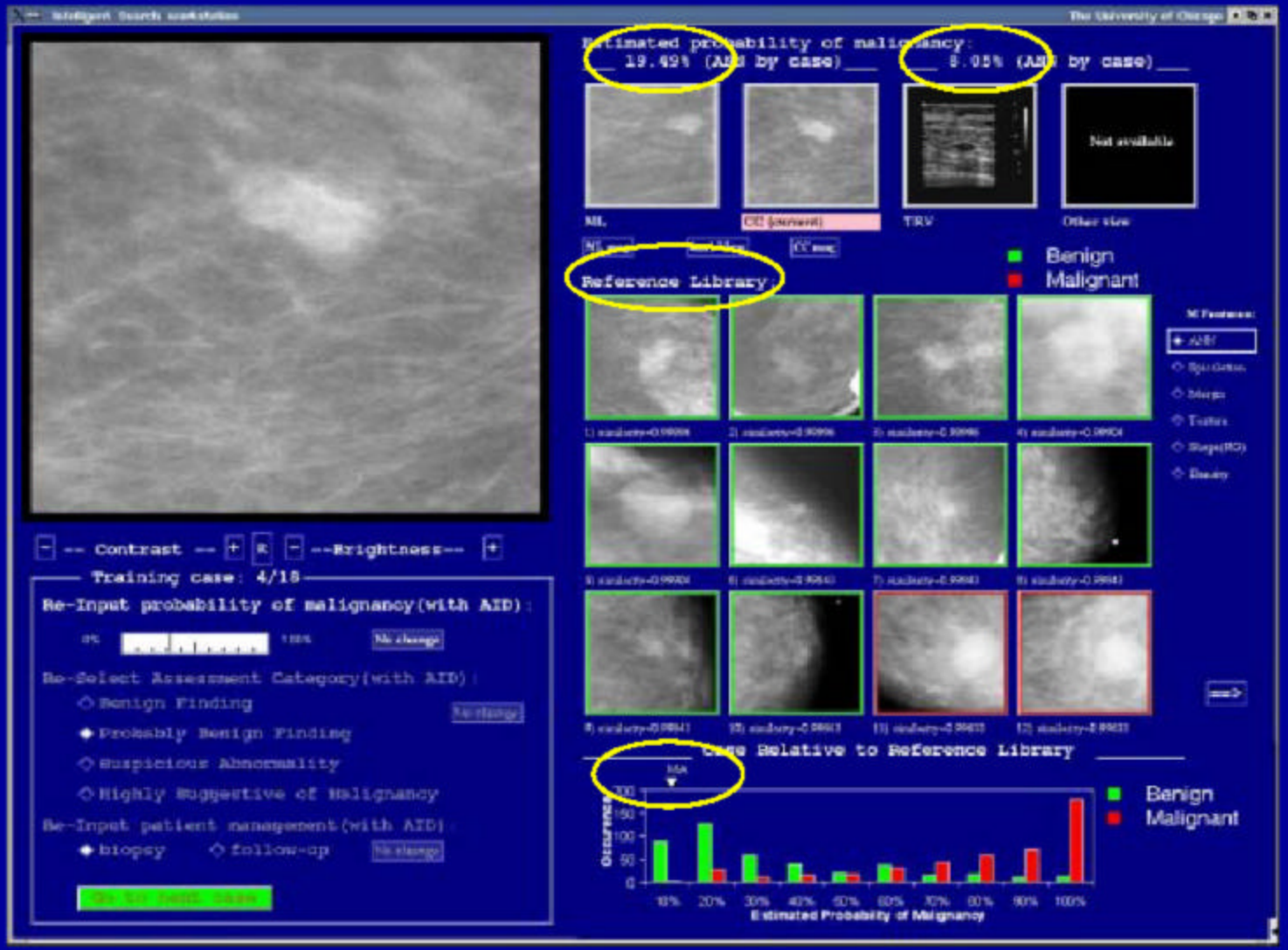
.
.
Giger et al.

Benign Case



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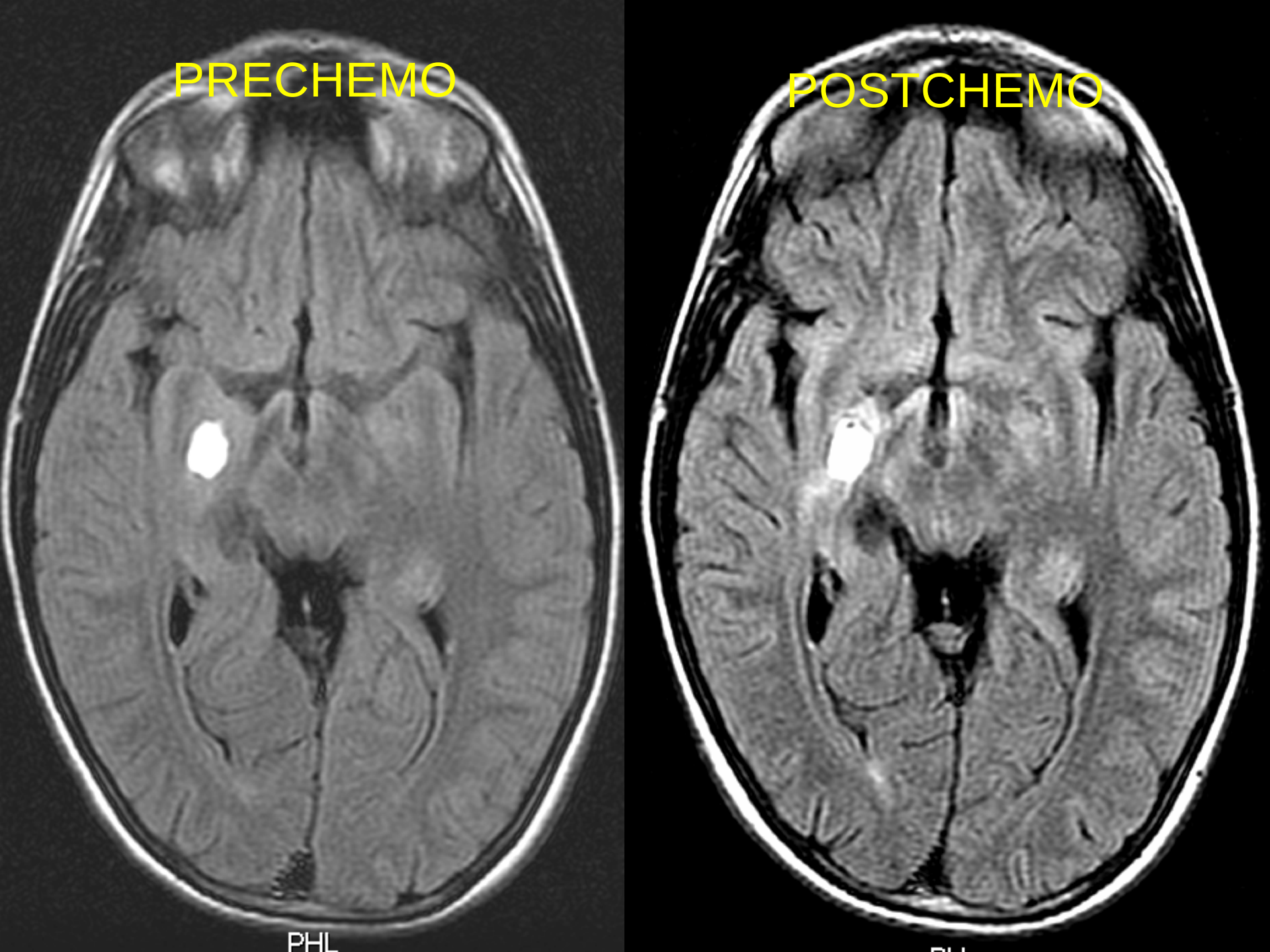
Change Detection

- Medical image comparison common aspect of daily practice
- Some tools exist for this but not yet widely available in clinical arena
- Hard to deal with extraneous effects
  - chemotherapy for example
- Image alignment for comparison would be great help
- Automated evaluation works best with volumetric datasets without gaps


PRECHEMO
POSTCHEMO
PHL

Additional points

- Exploitation of large databases which are being collected clinically
- Matching databases of normal anatomy, normal variants and pathology classification
- Training issues- general radiologist versus specialist

Conclusions

- Digital images with improved quality now available
- Computer capability now available for analysis
- Image Processing will be key aspect of most medical imaging studies in future
- Accuracy and efficiency can be improved
  - especially in detecting and interpreting abnormalities within large data sets
- Need to ensure image processing tools are optimized for the perceptual and cognitive skills of the radiologist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