Virtual Reality in Medicine

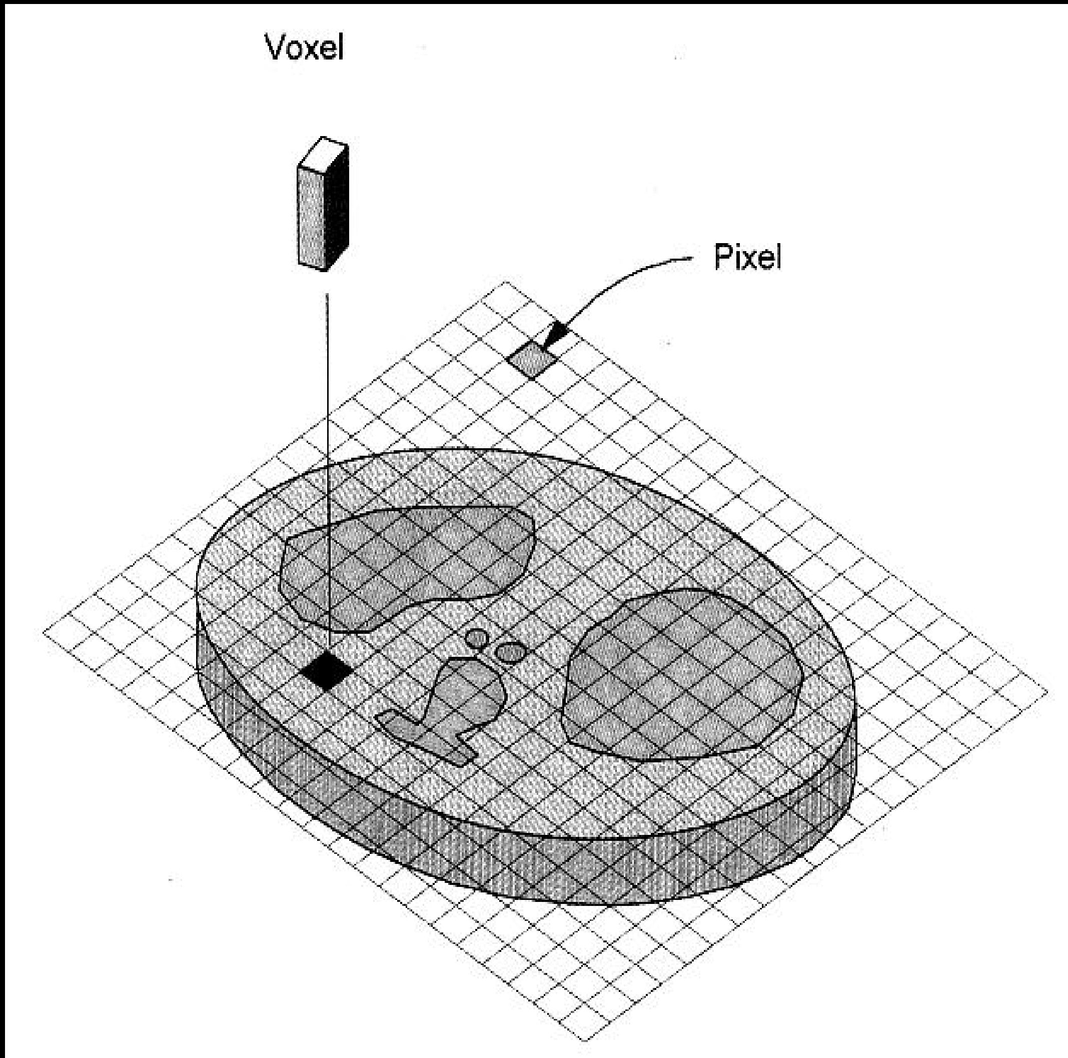
16-17 March 2000
Johns Hopkins University

Terry S. Yoo, HPCC Office
National Library of Medicine, NIH

Data

- Image generation from clinical data.
- Obligation to representing the truth.
- Precision, accuracy, repeatability.

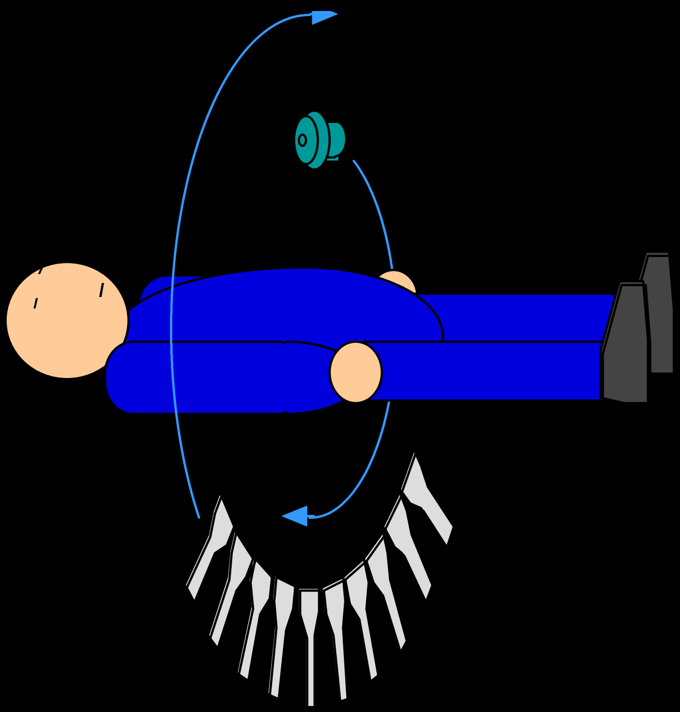
- Where does it come from?


Voxel
Pixel

X-ray Computed Tomography (CT)

– Also known as CAT Scan.
– Tomographic cross-sectional imaging
– Typically uses relatively high energy X-rays (120-140 kVp) filtered to include the high energy part of the spectrum.
– Fan beams and thin slices (collimation!).
– A detector array is placed opposite a tube that revolves around the patient.
– The cross-section is reconstructed from the projections.

“Third Generation” CT Technology



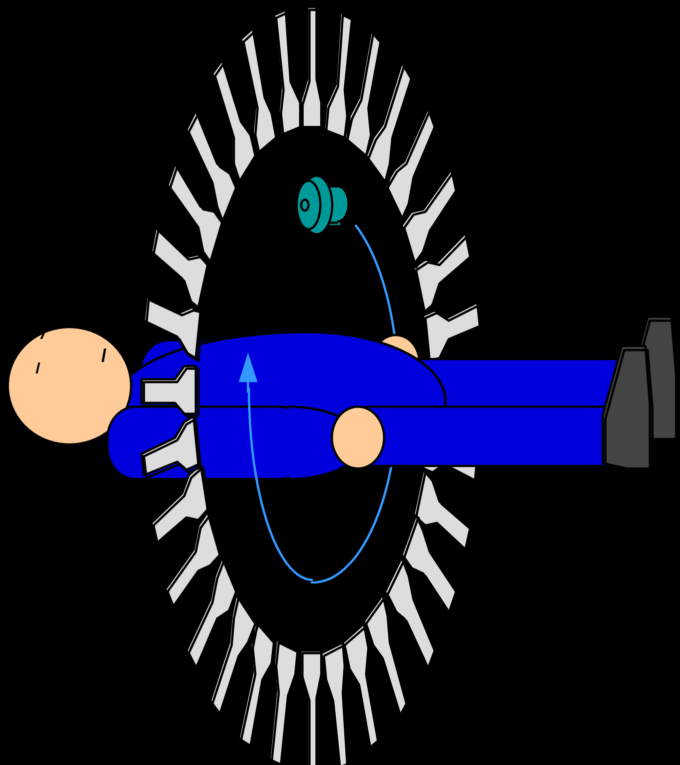
– Revolving array of detectors.

– Revolving X-ray tube.

– Moving bed allows multiple slices.

– Cabling harness usually limited the rotation of the detector array and tube to 180° to 360°

“Fourth Generation” CT Technology

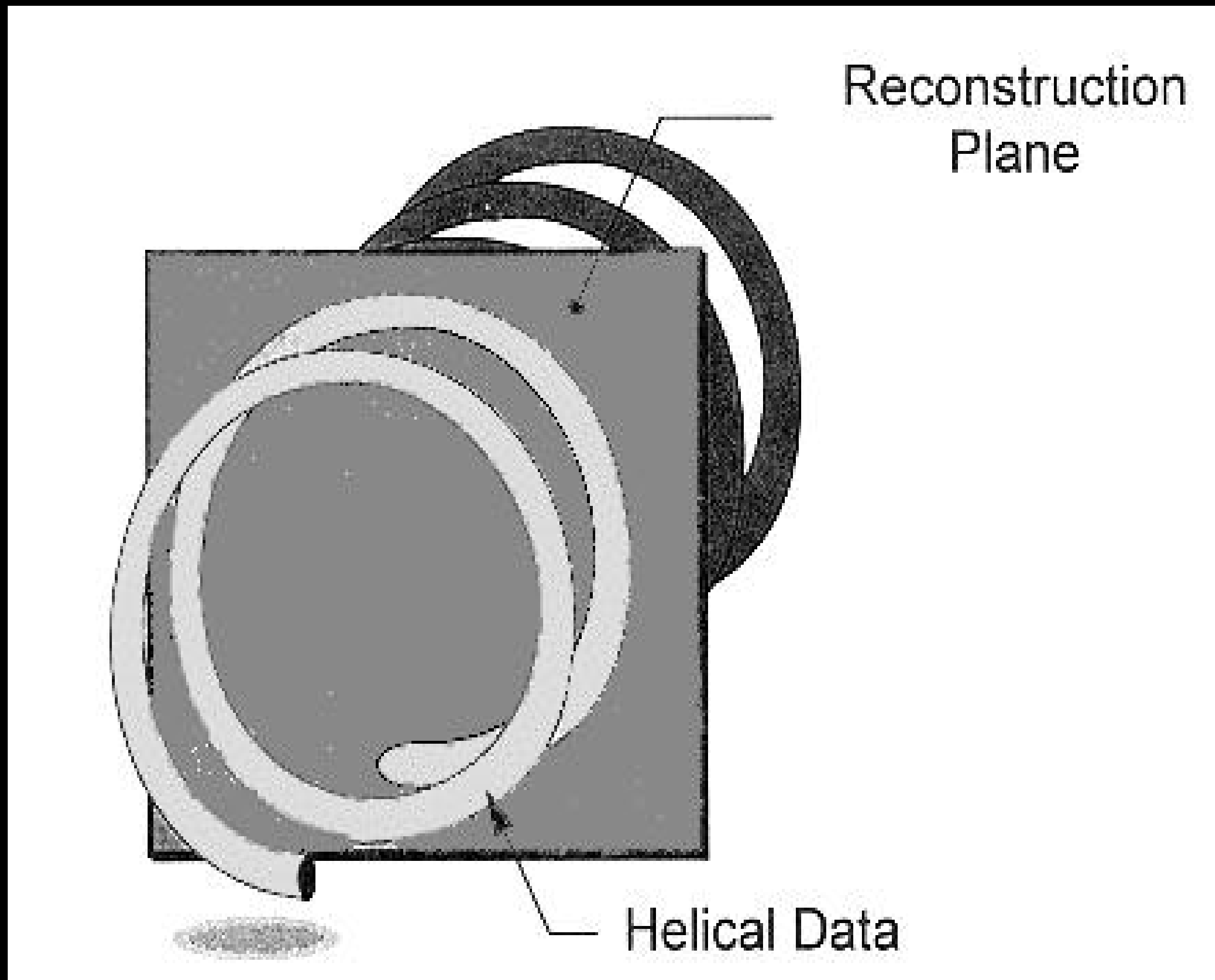


- Fixed array of detectors.
- Revolving X-ray tube.
- Can be constructed using slip-rings, allowing continuous tube rotation.
- Simultaneous patient motion and continuous tube revolution enables helical CT scanning (also called spiral CT).

CT

Spiral Computed Tomography

- AKA Helical CT
- The table is moved simultaneously with gantry rotation and X-ray exposure
- Helical data is interpolated to form conventional projections
- An entire volume is scanned in 30 seconds
- Equivalent to 30 individual slices
- Ideal for organs that move during respiration

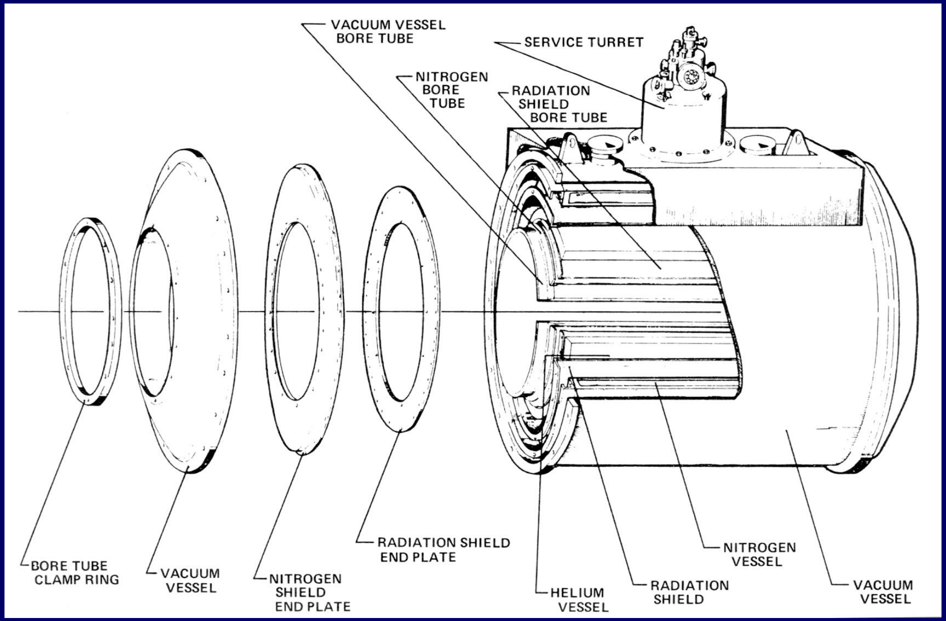

Reconstruction
Plane
Helical Data

MRI

- Magnetic
- Resonance
- Relaxation
  - a.k.a. Nuclear Magnetic Resonance
  - A big magnet, a microwave oven, a radio antenna, and a fast computer.

MRI

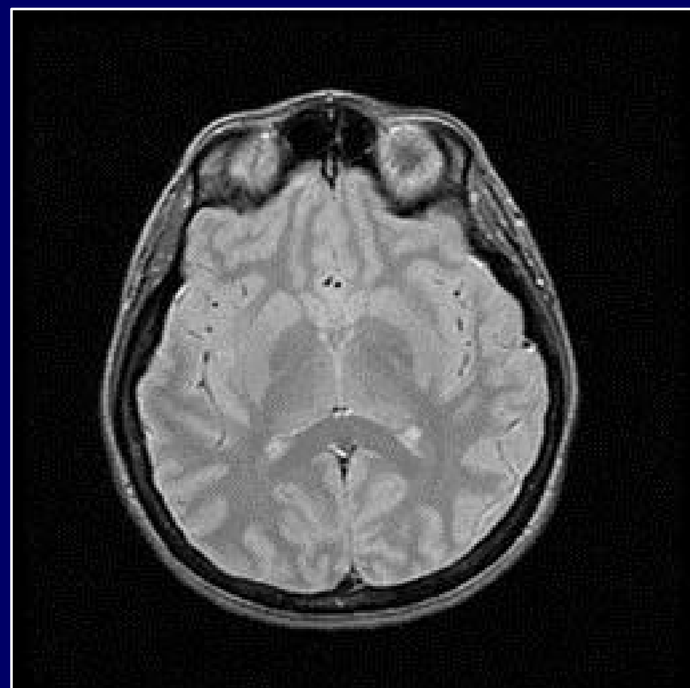
- Acquire any plane or an entire volume
- Images generally 512x512 or 256x256 pixels
- Voxels as small as 0.5x0.5x2 mm, but variable
- Sometimes gaps in between slices
- 5-10 minutes for one sequence
- No absolute scale for the signal (10 bits)



Assembly diagram of a 1.5 T cryostat vessel (Toshiba)

View of a 1.5 T diagnostic MRI magnet (GE Medical)

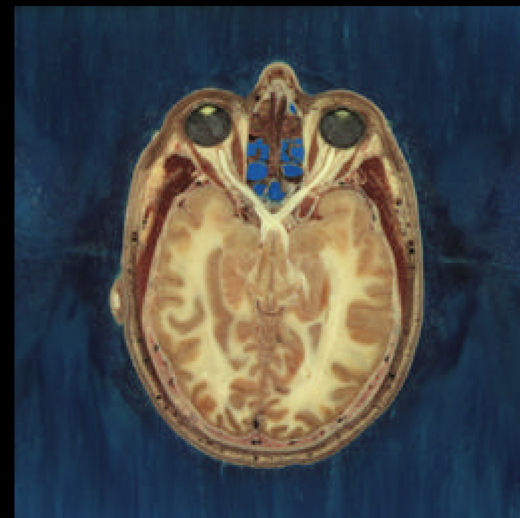
Magnet Safety - (courtesy of GE Medical Systems)



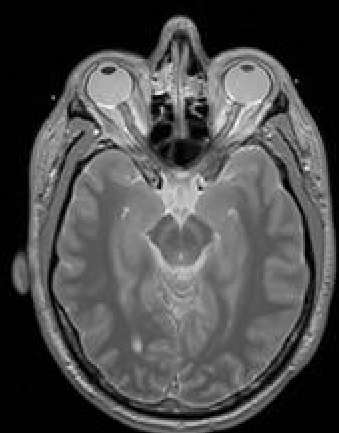
The Visible Human Project Data

- Multiple modalities
  - MRI
  - X-ray CT
  - Photographic cryosections
- Unique study in anatomy
- High spatial resolution
- Male: 17 GB, Female: 50+ GB

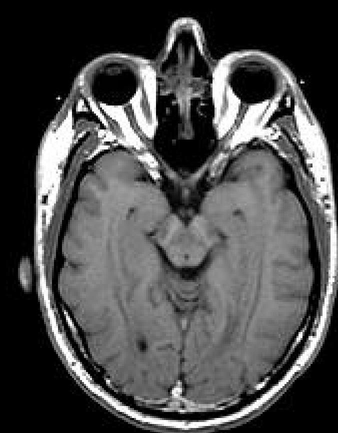
CT



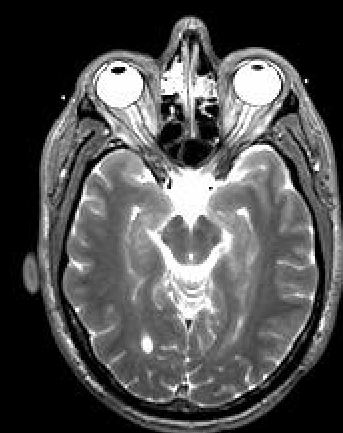
Cryosection



MRI - PD



MRI - T1



MRI - T2

Visible Human Data Acquisition

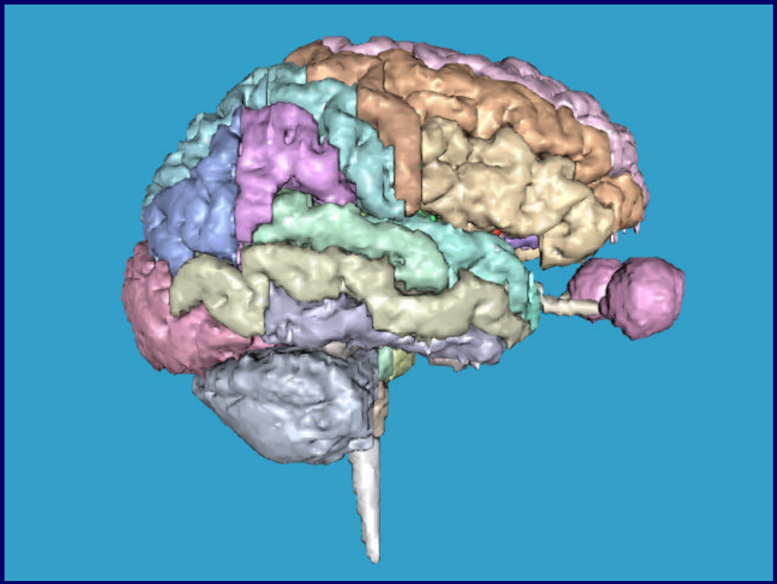
Medicine in Virtual Reality

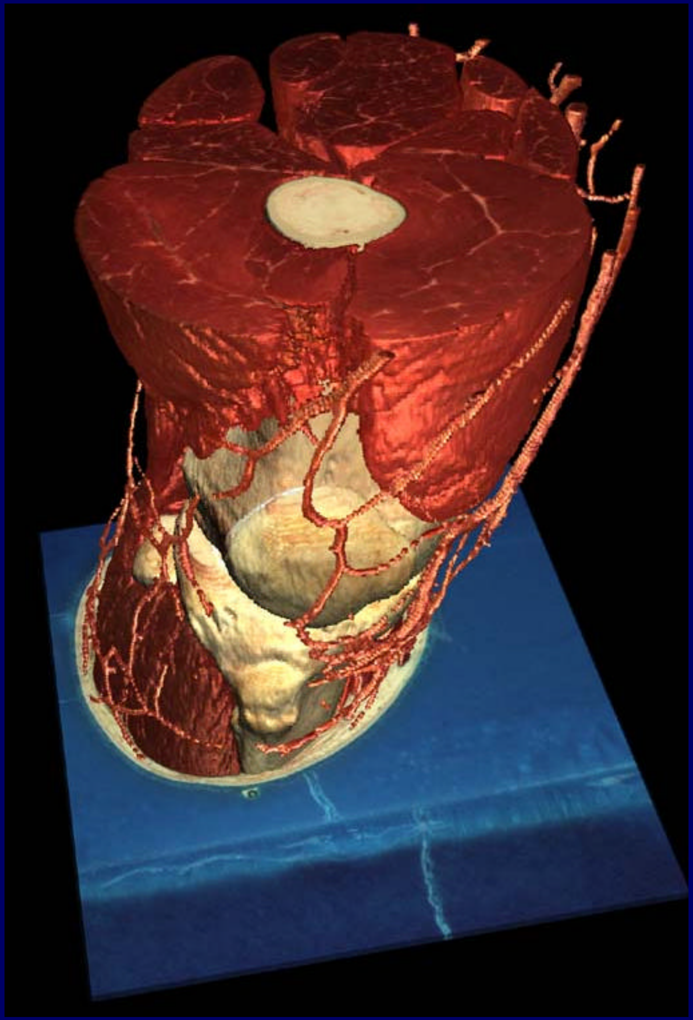
- CAD
- Telemedicine
  - filerooms
  - image storage/retrieval
  - EMR
  - remote diagnosis/ treatment.

Medicine in Virtual Reality (continued)

- Training / education
- Surgical Planning
- Computer assisted therapy
- Image guided therapy
- Treatment (e.g., mental health)

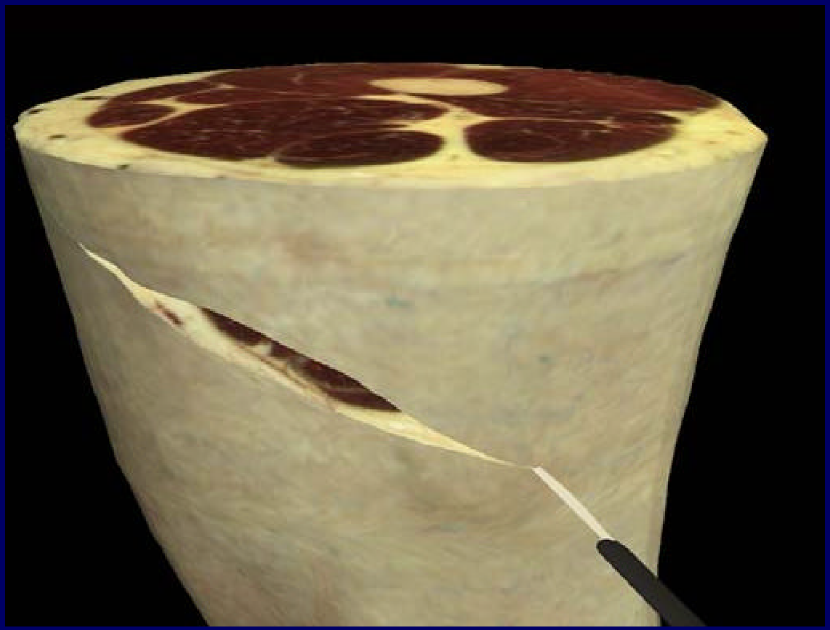
Visualization / Education





Visualization / Education

Simulation / Training

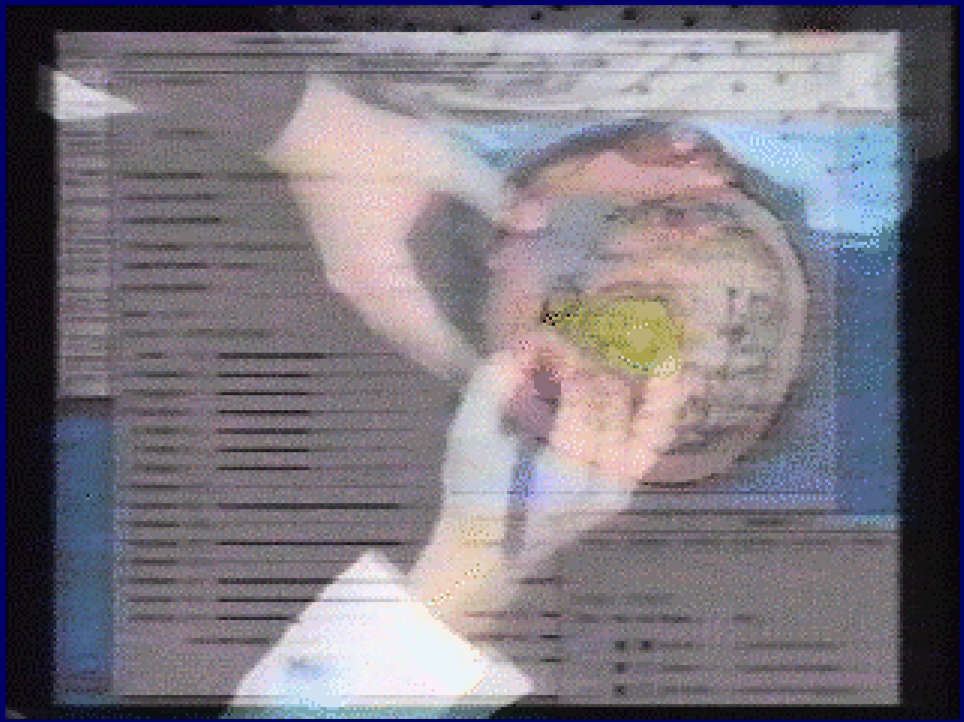


Simulation - Univ. of Colorado

Haptic Training Simulator - Univ. of Colorado

Computer Assisted Therapy

Augmented Reality - BWH



Augmented Reality - Harvard BWH

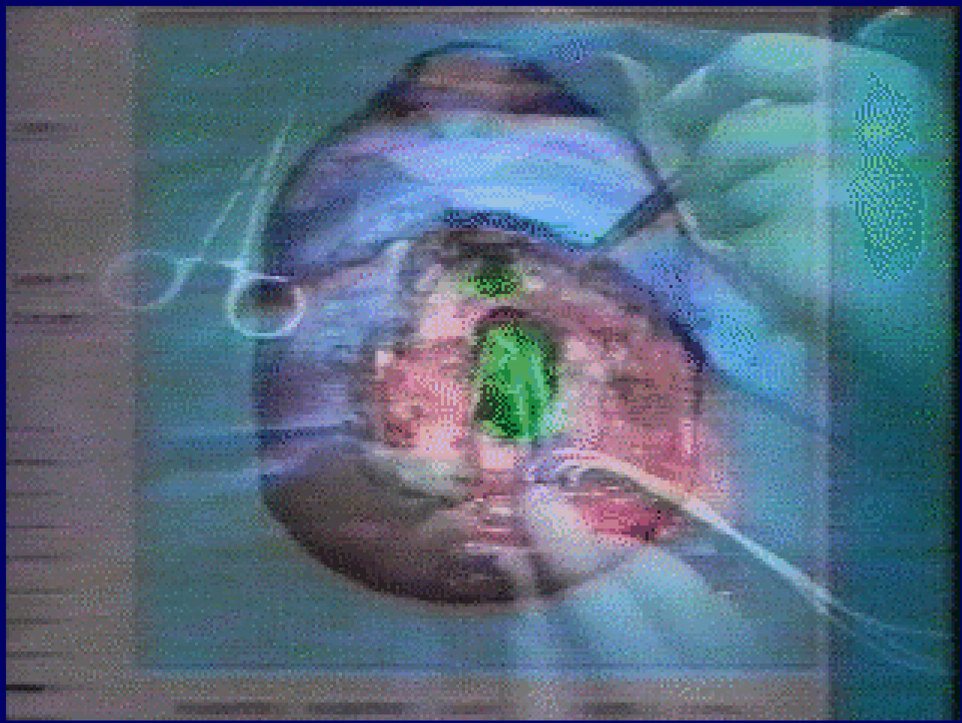
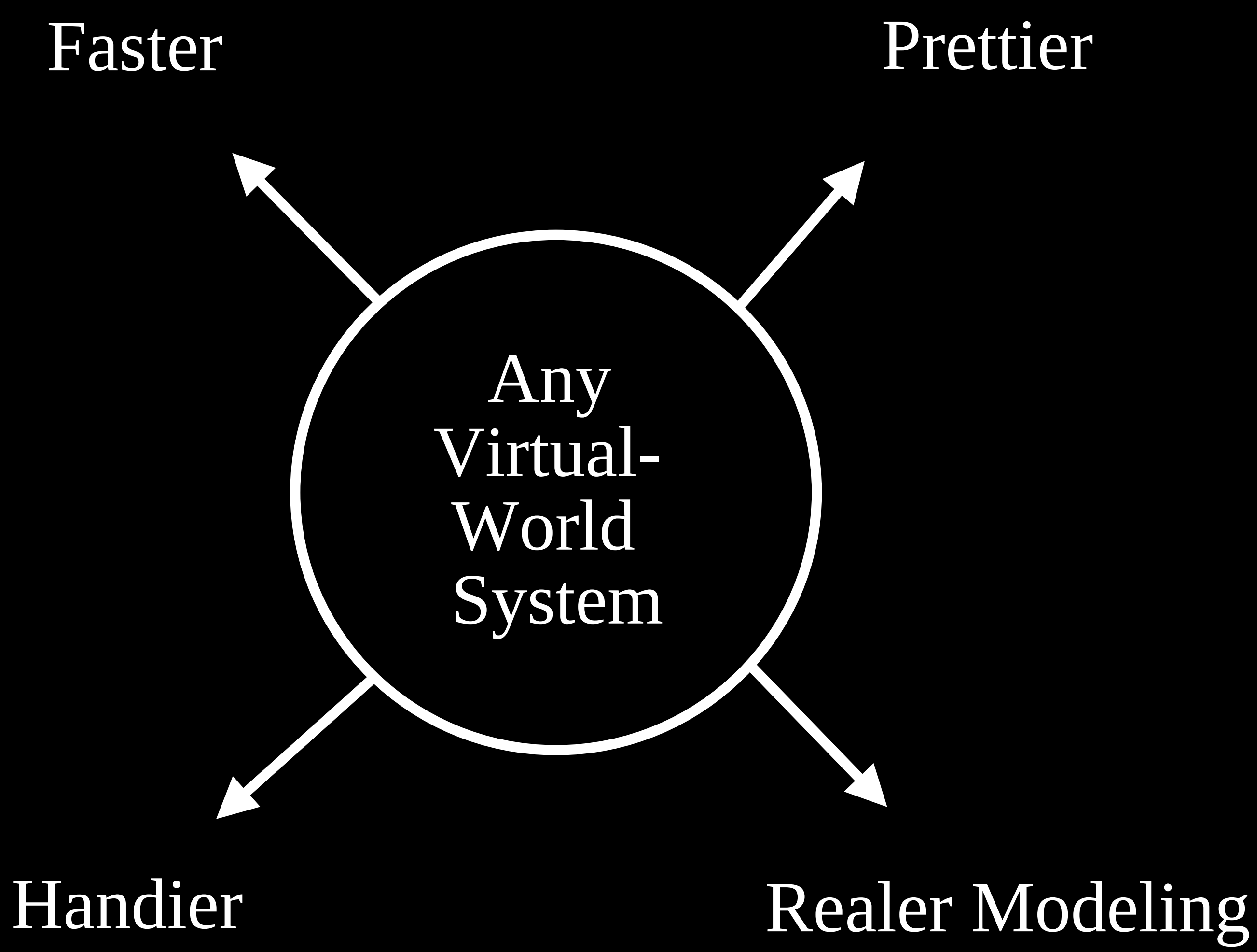


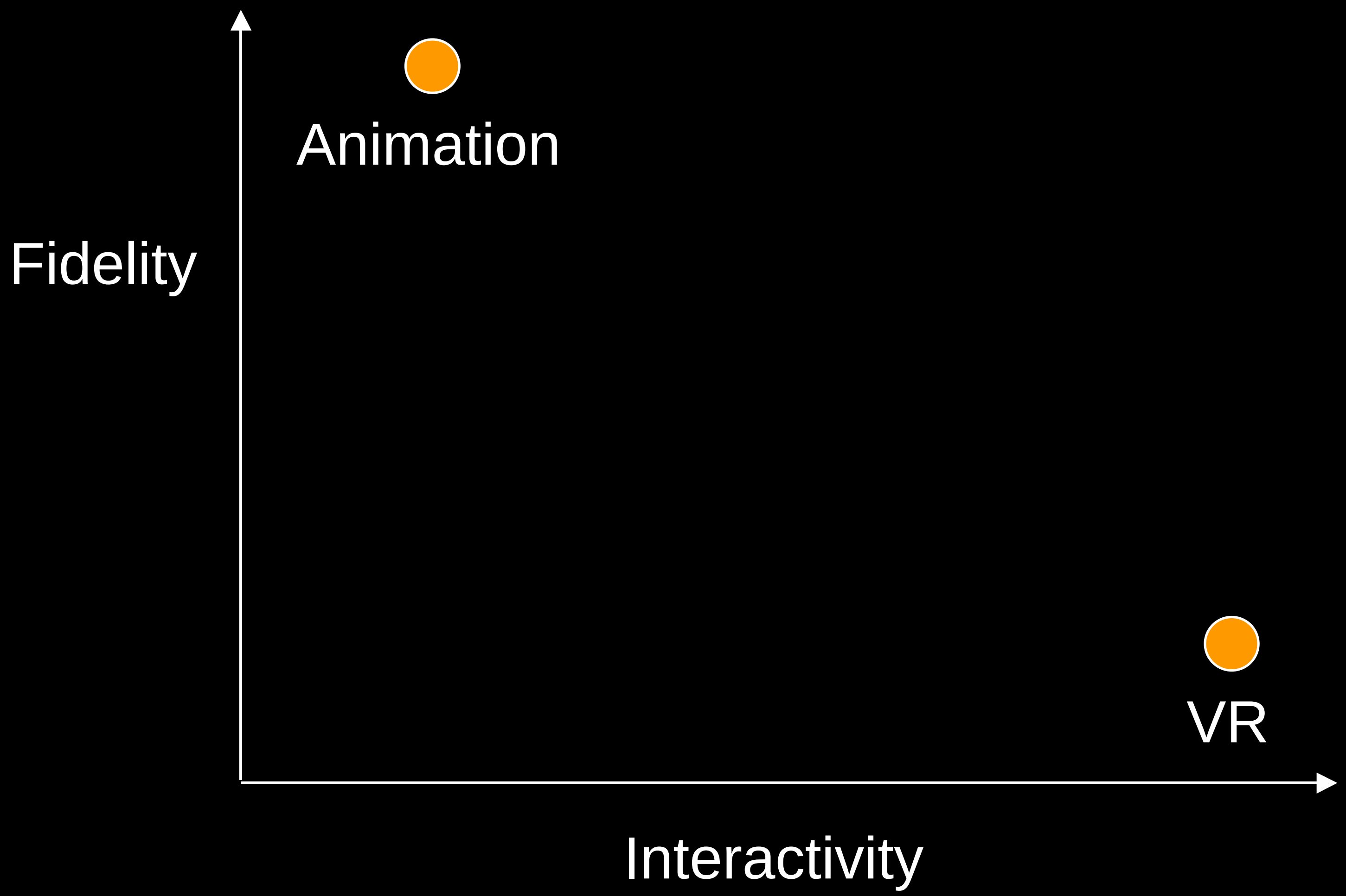
Image Guided Therapy

Treatment - Georgia Tech

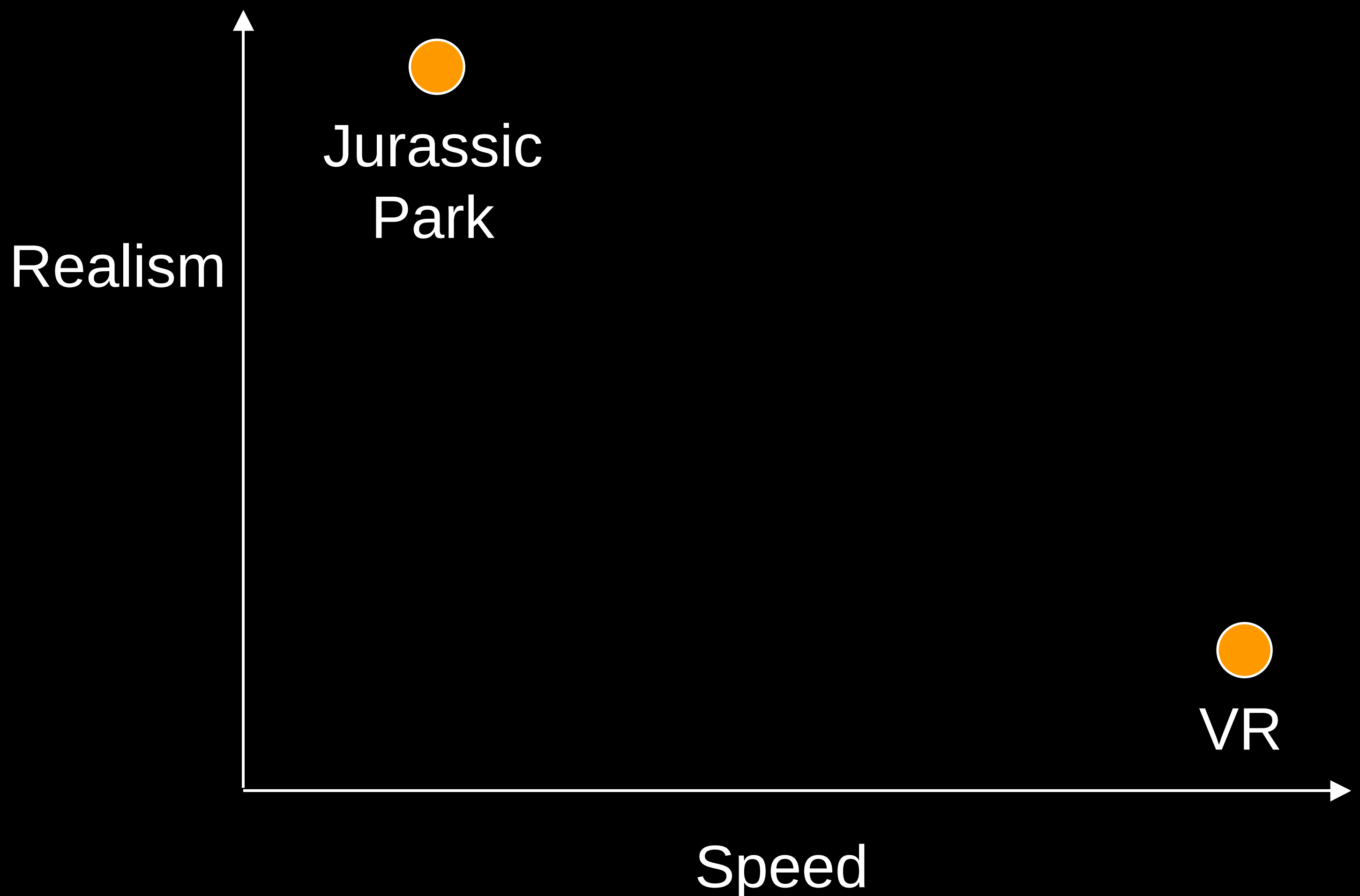
How To Make VR Work?



Simulation vs. Interaction



Simulation vs. Interaction



Model Size: 1-100 Million Triangles

Virtual Reality - It Almost Works

- Swimming due to lag
- Limited precision
  - Poor registration with real world
- Limited model complexity
- Bad ergonomics

Hardware Required for VR

- Image Generation: Speed, textures
  - PixelFlow (1995) 20 M textured, shaded tri/sec
  - SGI (1998) 13-100 M textured, shaded tri/sec
- Image Delivery: See-through, resolution, wide angle
  - Virtual Research - V8
- Tracking: Lag, range, lag, precision
  - UNC optical ceiling tracker — 5.5 m x 7.5 m

640 x 480 Pixel, stereo, HMD

Required Hardware (continued)

- Networking — Speed, usefulness models
  - Vistanet testbed for 1 Ghz fibre application
- Haptics: Fidelity, speed, flexibility
  - Sensable 1999: Phantom 6-degree-of-freedom arm, electrical, 1 mm.

Haptic devices by Sensable

Latency

- Frame rates are not latency.
- Delays are measured from end-to-end.
- Affects simulator sickness.
- Rates:
  - IBR (Siggraph 99): minimum JND = 7 msec.
  - Haptics: minimum JND = 1 msec.

Precision

- Accuracy required in medicine: 1 mm?
- Computational precision? Error?
- Outcomes? Evaluation?

Augmented Reality Ultrasound circa 1991

Latency - some approaches

- Mechanical tracking
- Commercial hardware.

Precision - an Approach

- Video registration
- Predictive tracking
- Mechanical tracking

[redacted]

Virtual Reality in Medicine

Terry S. Yoo, HPCC Office
National Library of Medicine, NIH

Designing a Digital Surgical Simulator for Interventional MRI

Terry S. Yoo, HPCC Office
National Library of Medicine, NIH

Acknowledgements

- Penny Rheingans, CSEE Dept.
  - Univ. of Maryland Baltimore County
- University of Mississippi Medical Center
  - Dr. S. Crawford, Dr. B. Harrison, Dr. G. Dhillon.
- University of Mississippi Computer Science
  - A. Rodden, C. Bland, B. Fox

Support

- The Institute for Technology Development
- Sun Microsystems
- GE Medical Systems

Minimally Invasive Surgery

- Surgery through small openings.
- Reduced trauma.
- Reduced chances for infection.
- Shortened recovery times.
- Shortened stays in ICU.

- Consider - minimally invasive knee surgery

Interventional MRI

- Simultaneous imaging and surgery with MRI technology.
- Immediate 3D verification of procedure success.
- Does not use ionizing radiation (x-rays).
- Better for patient and practitioner.
- Latest advance for physics in medicine.

NMR and Medicine: MRI

- A non-invasive cross-sectional imaging modality.
- Does not employ ionizing radiation.
- Good soft-tissue definition.
- Advances in functional MRI allow imaging of physiology as well as anatomy.
- EPI techniques enable heat imaging.

Limitations of Conventional MRI Scanning Equipment

- Superconducting magnets
  - 10,000 Gauss = 1 Tesla
  - Earth’s magnetic field = 0.5 Gauss
- Cryogen chambers required.
- Limited access to patient during procedures.
- Claustrophobia inducing environment.

Pros in MRI

- Non-ionizing radiation
- Good imaging characterisitics.
- Operates in acoustically opaque regions of the body.
- Good soft-tissue definition.
- New advances in functional MRI allow imaging of physiology as well as anatomy.

Cons in MRI

- Projectile or “missile effect.”
- Requires liquid helium.
- Radiofrequency and strong magnetic fields create concerns for patients with pacemakers or other instruments.
- Image artifacts introduced by steel plates or other magnetically susceptible prostheses. (also scalpels, clamps, …)

Three Interventional Designs

- Philips - Conventional magnet
  - Long patient table, One end: Angiography suite
  - Conventional 1.5T MRI system
- Siemens - Low Field magnet
  - Swing arm table, angiography suite
  - 0.35T Open Fixed Field MRI system
- GE - Medium Field surgical magnet.

Philips: Hybrid System

- Full Angiography suite (catheters).
- Higher field strength.
  - Use spin echo - not gradient echo - sequences
  - Higher susceptibility - except when biopsy along the B_0 direction.
- Restricted access to patients in the bore.
- U Minnesota, and UCSF (planned).

U. Minnesota Reports

- 15-20 minutes for an intraoperative scan
- Diagnostic Tissue Rate.
  - IMR 80/80 cases (100%)
  - Frame stereotaxy 129/134 cases (96%).
- Infection.
  - IMR = 1/80 (1.25%)
  - OR = 2%

U. Minnesota Reports Brain Biopsy

	IMR	Conventional OR
Length of Stay	3.3 Days	6.4 days
Cost/Charge Ratio	71.77%	74.10%
	Cost reduction IMR	32%
	Charge Reduction	29.60%

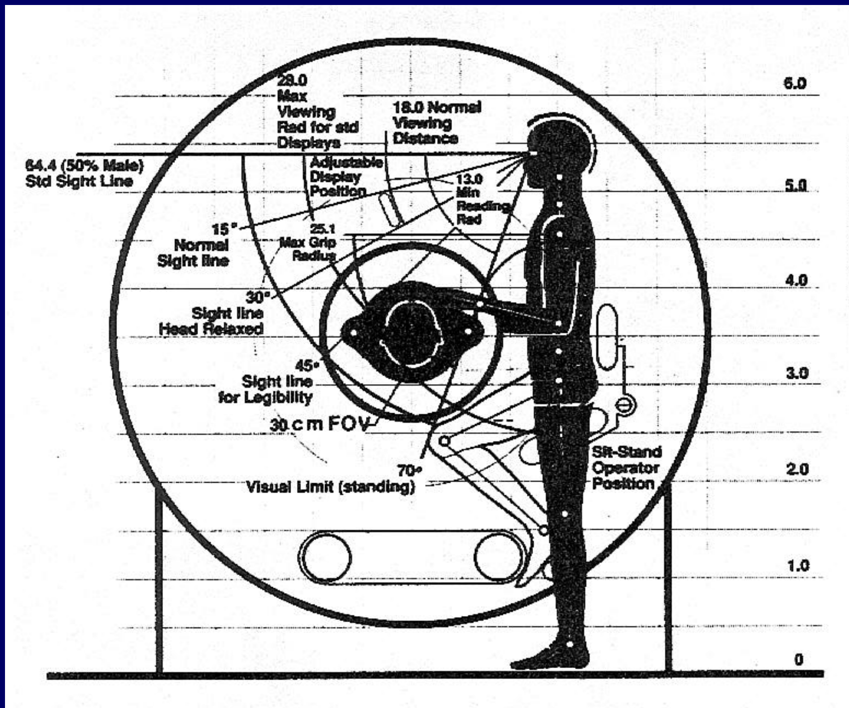
- Occasionally discharge biopsy same day

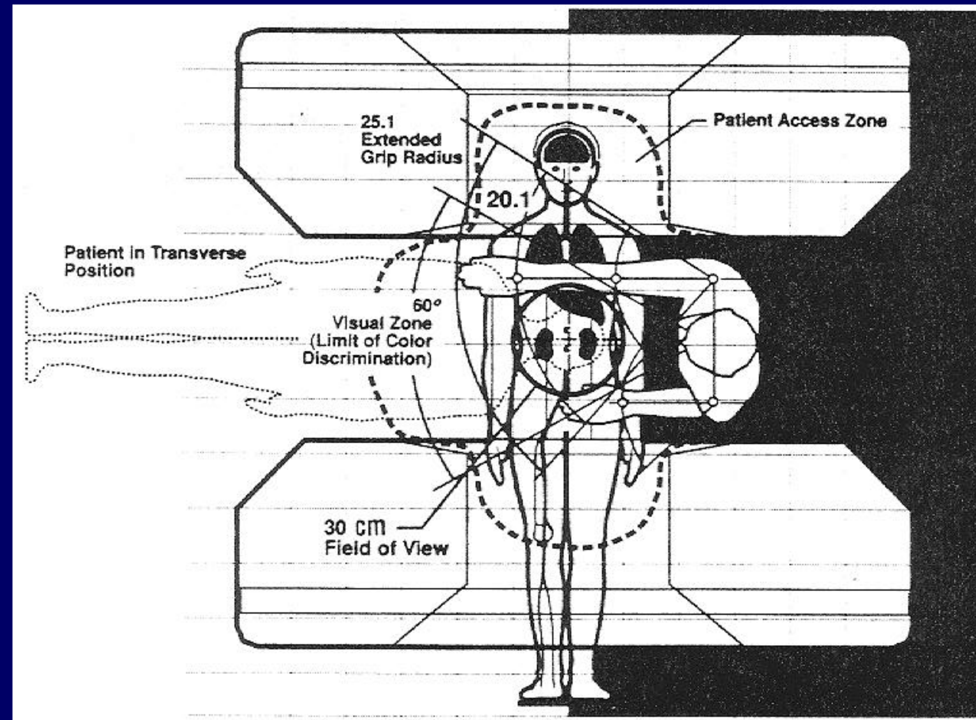
U. Minnesota Reports Retreat Tumor Resection Rate

	IMR	Conventional OR
Adults		
Primary	0%	18%
Recurrent	7%	45%
Pediatric		
Primary	0%	32%
Recurrent	33%	50%

GE Design: Open Magnet

- Based on Nb-Sn compounds – No cryogens required.
- Open configurations permit a variety of scanning orientations.
- Patient access allows interventional procedures – surgery.
- Less confining environment offers patients alternatives.

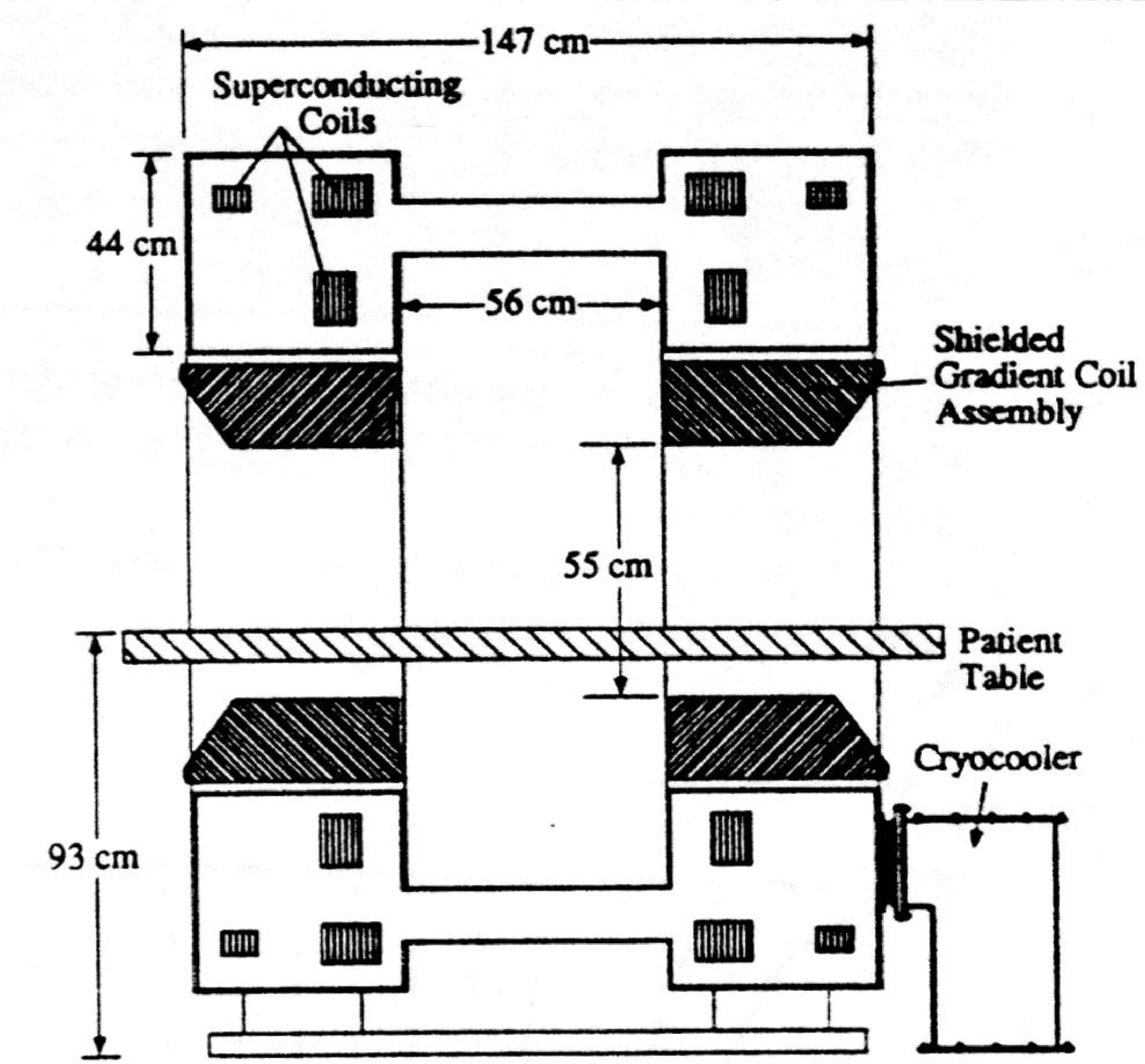




Interventional MRI
axial view

Interventional MRI
overhead view

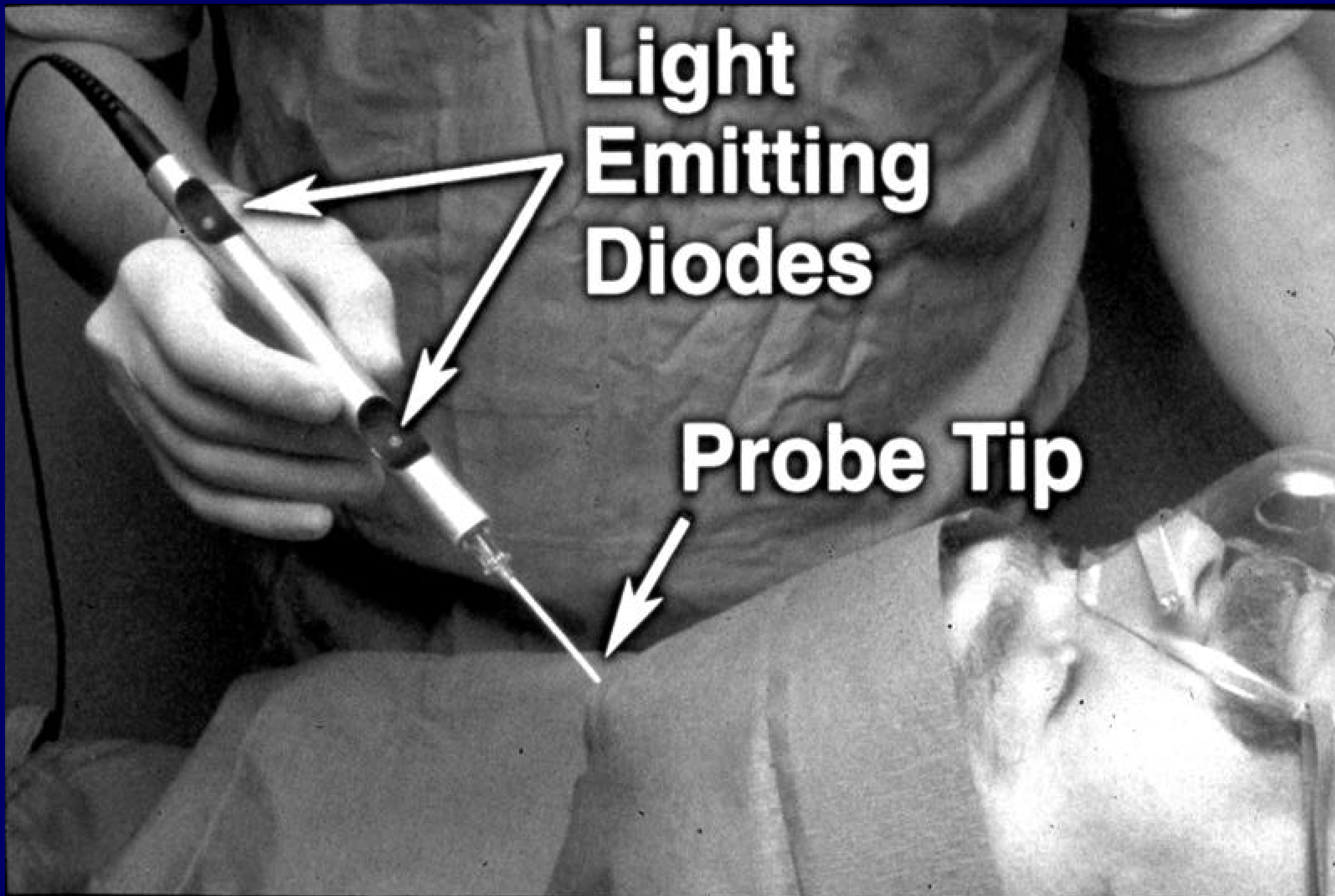
Cross-sectional schematic of the open magnet

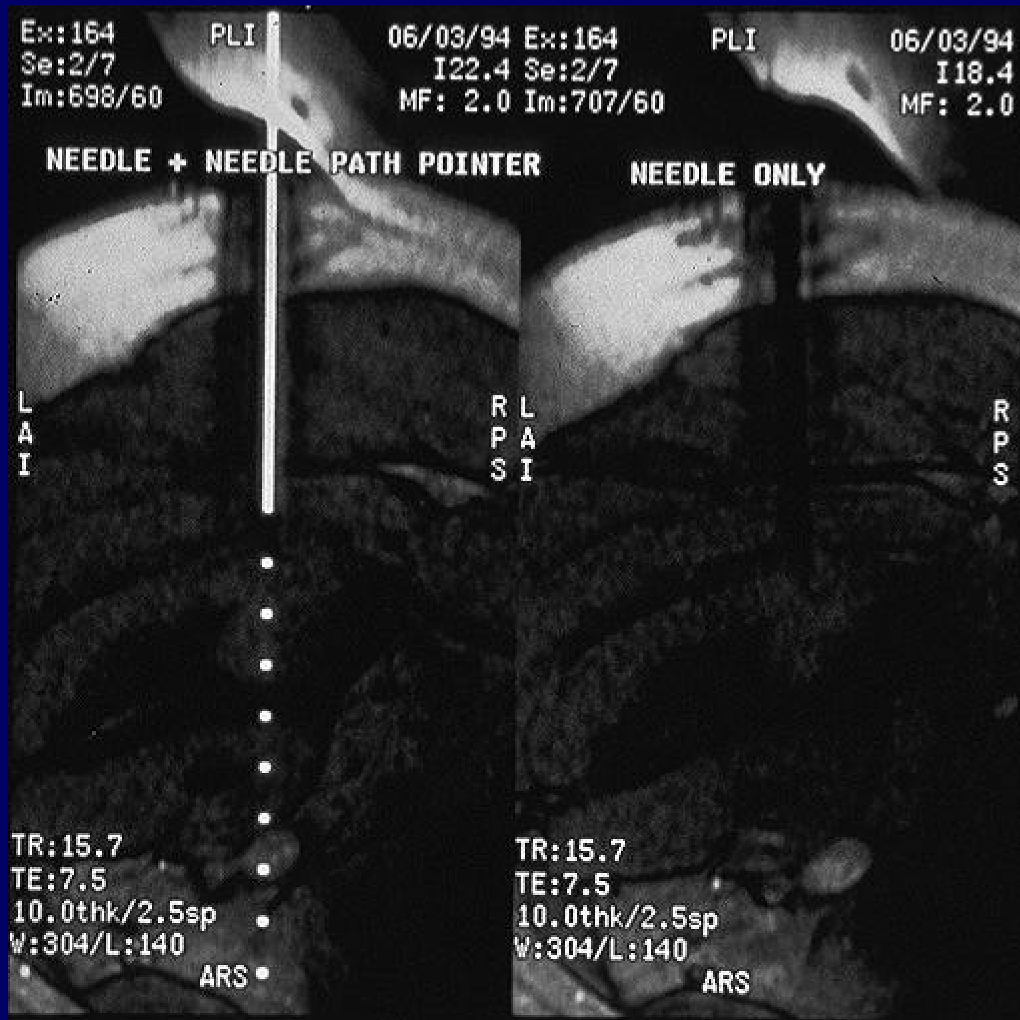



Signa 0.5T SYS#BWS30C0
BRIGHAM WOMENS HARVARD MRT
Ex:134
Se:2/4
Im:15/18
Sag R6.0
SE
TR:600
TE:19
EC:1/1 12.5kHz
NECK
FOV:24x24
5.0thk/1.0sp
9/02:42
256x128/2 NEX
St:p/NP/VB/ED
= 684 L = 359

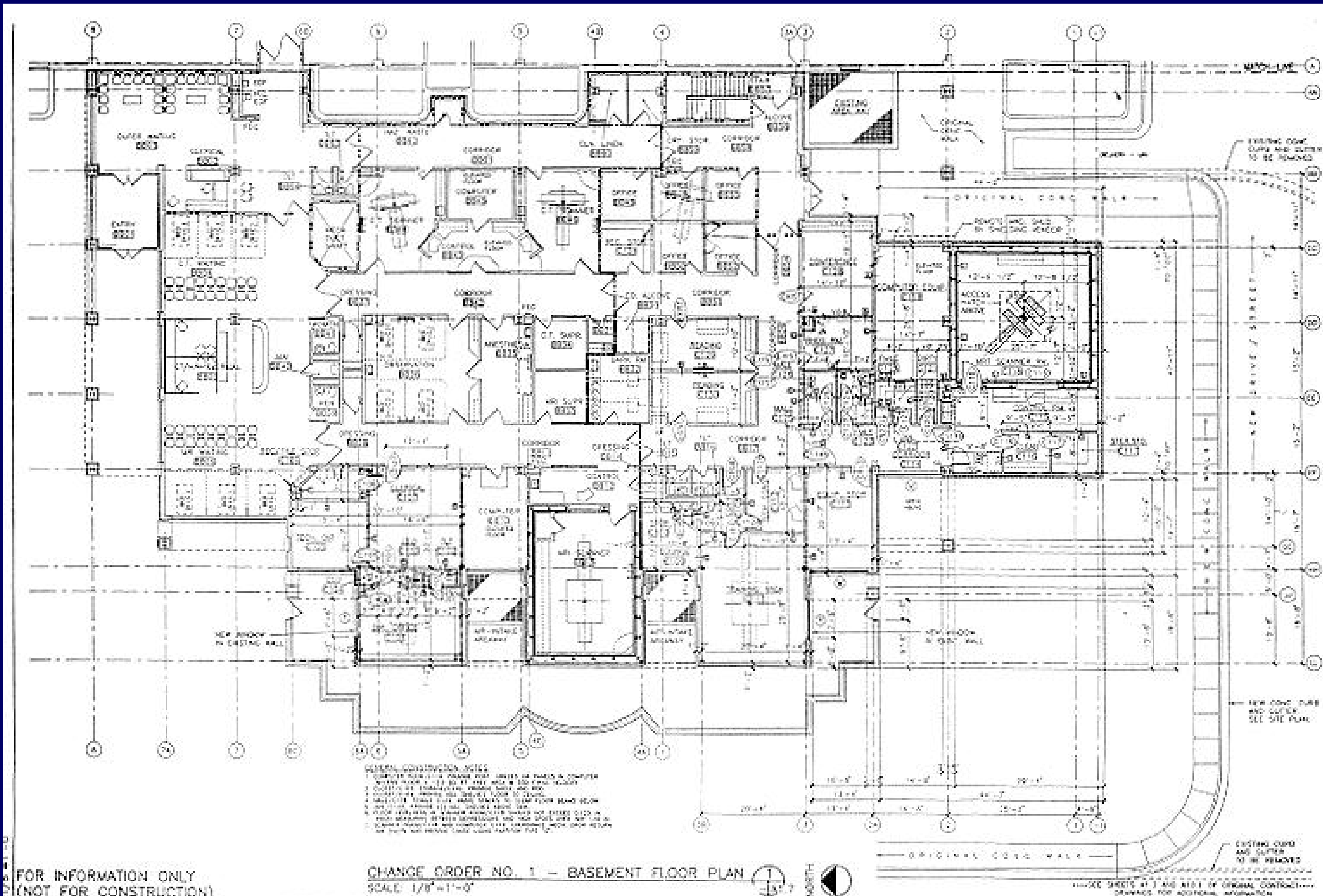
Why a Simulator?

- Rapid instrument and procedure development (outside the O.R.).
- Beyond surgical planning.
  - "No battle plan survives first contact with the enemy." -Wellington
- Develop the use of image guided therapies.
- Safety.

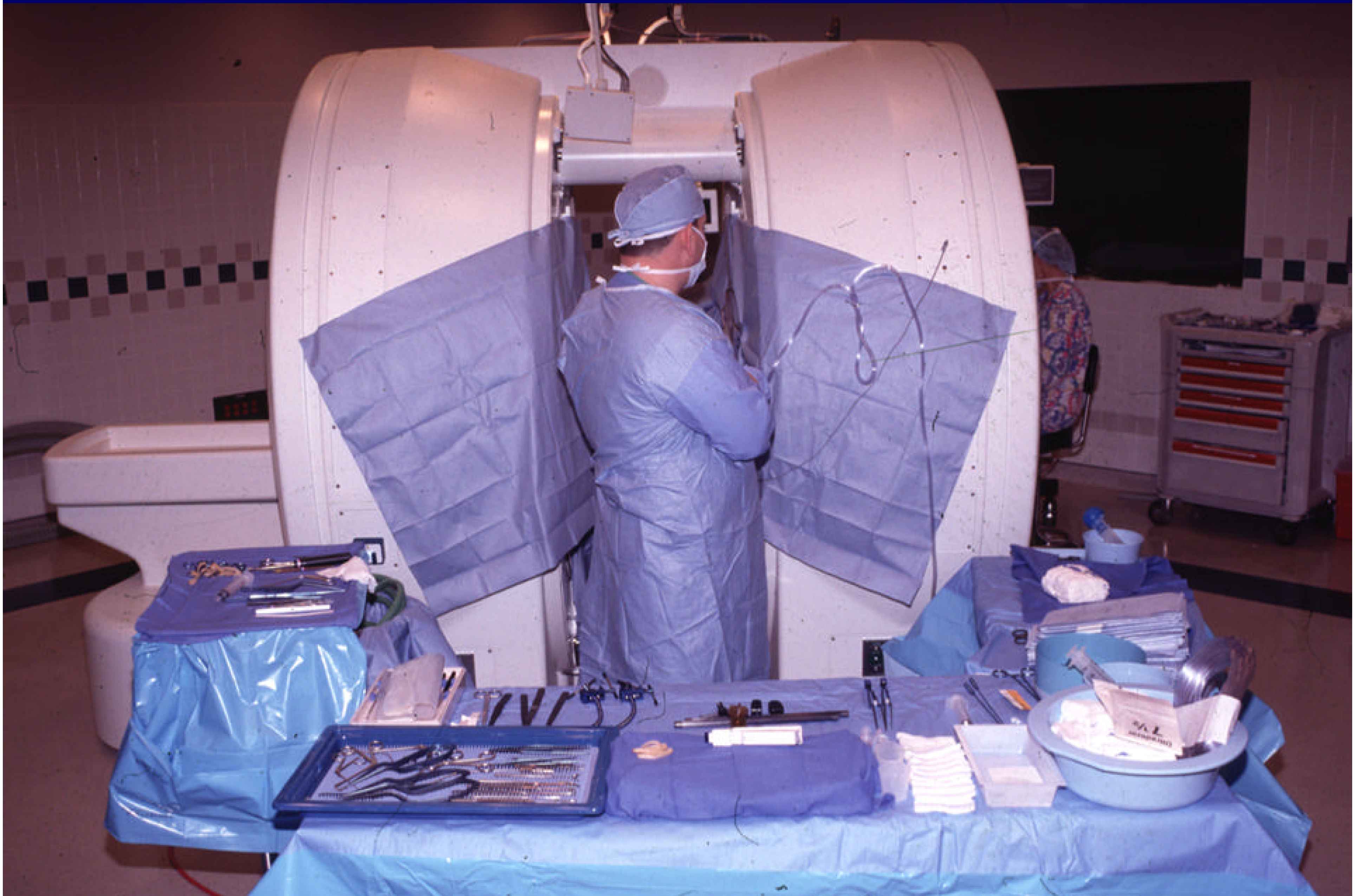

Light
Emitting
Diodes
Probe Tip

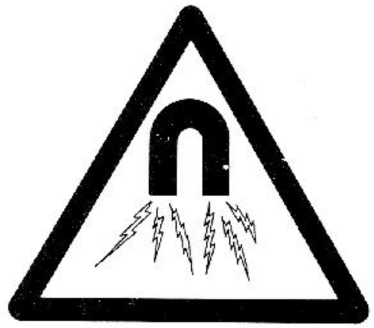


Ex:164
Se:2/7
Im:698/60
PLI
06/03/94
I22.4
MF: 2.0
NEEDLE + NEEDLE PATH POINTER
L A I
R P S
TR:15.7
TE:7.5
10.0thk/2.5sp
W:304/L:140
ARS
Ex:164
Se:2/7
Im:707/60
PLI
06/03/94
I18.4
MF: 2.0
NEEDLE ONLY
L A I
R P S
TR:15.7
TE:7.5
10.0thk/2.5sp
W:304/L:140
ARS



Floorplan for the new MRI/CT facility at UMMC





WARNING

MAGNETIC FIELD

THE FIELD OF THIS MAGNET ATTRACTS OBJECTS CONTAINING IRON, STEEL, NICKEL OR COBALT. SUCH OBJECTS MUST NOT BE BROUGHT INTO THIS AREA. LARGE OBJECTS CANNOT BE RESTRAINED.

PERSONS WITH IMPLANTS OR PROSTHETIC DEVICES SHOULD NOT ENTER THIS AREA. PACEMAKERS MAY BE DISABLED.

DATA ON CREDIT CARDS AND MAGNETIC STORAGE MEDIA CAN BE ERASED. WATCHES, CAMERAS, AND INSTRUMENTS CAN BE DAMAGED.

Visualization Issues

- Exact GUI reconstruction
- Texture reflects radiologic data
- Surface rendering for anatomical references
- Dynamic (near-real-time) update

Early view of the Surgical Simulator laboratory.

Infrared photodiode array

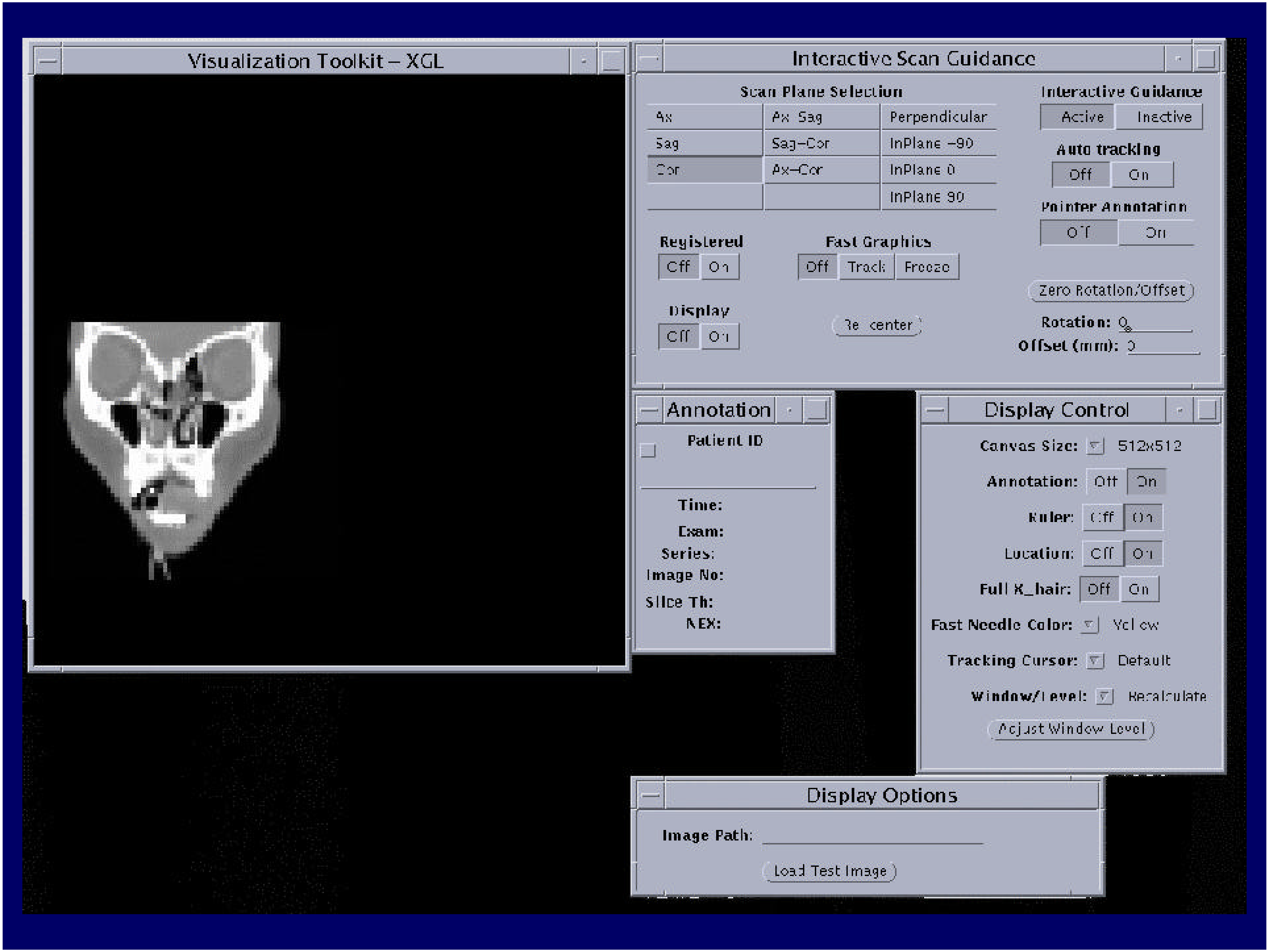
Sun Ultrasparc 2: console and simulation system

3D Tracking base unit

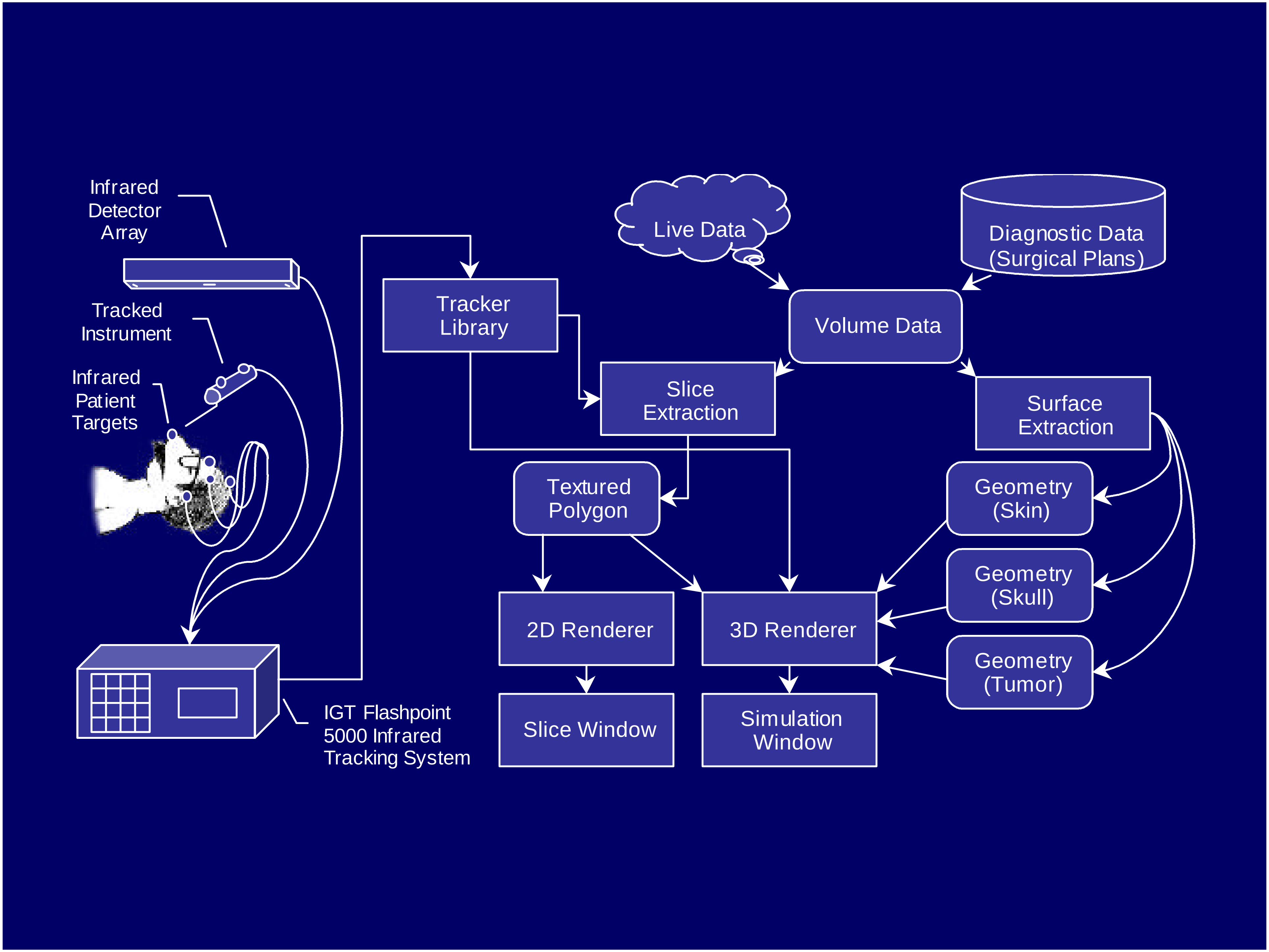
3D Tracking target

Software Design

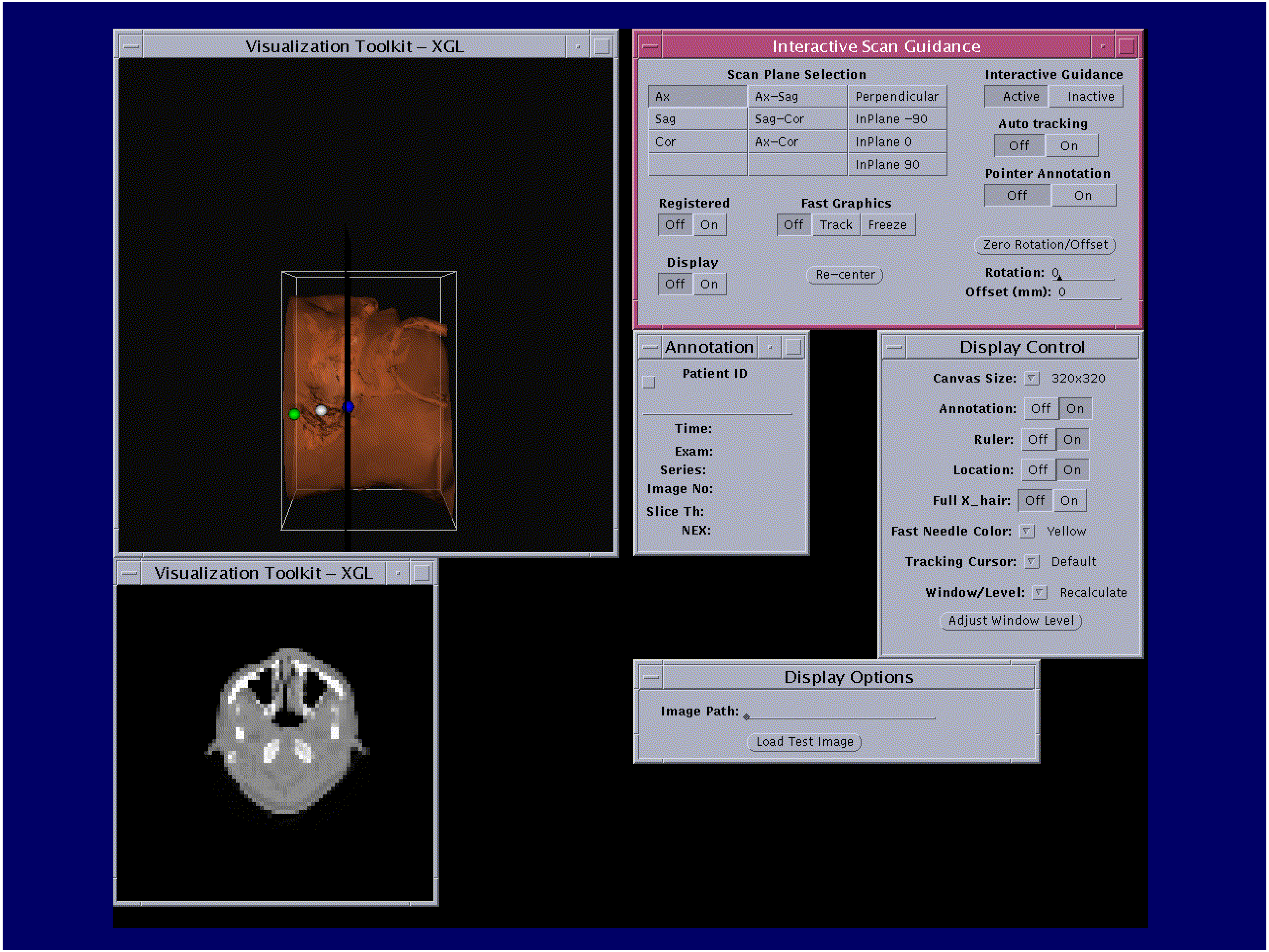
- Generated GUI from SDK configuration files from GE Medical Systems.
- Leveraged existing visualization tools (VTK).
- Hand coded the serial interface to the Flashpoint™ 5000 tracker.
- Combined texture information with 3D surface renderings.



Visualization Toolkit – XGL
Interactive Scan Guidance
Scan Plane Selection
Ax
Ax–Sag
Perpendicular
Sag
Sag–Cor
InPlane –90
Cor
Ax–Cor
InPlane 0
InPlane 90
Interactive Guidance
Active
Inactive
Auto tracking
Off
On
Pointer Annotation
Registered
Fast Graphics
Track
Freeze
Display
Zero Rotation/Offset
Re center
Rotation:
Offset (mm):
Annotation
Patient ID
Time:
Exam:
Series:
Image No:
Slice Th:
NEX:
Display Control
Canvas Size:
512x512
Annotation:
Ruler:
Location:
Full X_hair:
Fast Needle Color:
Yellow
Tracking Cursor:
Default
Window/Level:
Recalculate
Adjust Window Level
Display Options
Image Path:
Load Test Image



Infrared Detector Array
Tracked Instrument
Infrared Patient Targets
IGT Flashpoint 5000 Infrared Tracking System
Tracker Library
Live Data
Diagnostic Data (Surgical Plans)
Volume Data
Slice Extraction
Surface Extraction
Textured Polygon
Geometry (Skin)
Geometry (Skull)
Geometry (Tumor)
2D Renderer
3D Renderer
Slice Window
Simulation Window



Visualization Toolkit – XGL
Interactive Scan Guidance
Scan Plane Selection
Ax
Ax–Sag
Perpendicular
Sag
Sag–Cor
InPlane –90
Cor
Ax–Cor
InPlane 0
InPlane 90
Interactive Guidance
Active
Inactive
Auto tracking
Off
On
Pointer Annotation
Off
On
Registered
Off
On
Fast Graphics
Off
Track
Freeze
Display
Off
On
Re–center
Zero Rotation/Offset
Rotation: 0
Offset (mm): 0
Annotation
Patient ID
Time:
Exam:
Series:
Image No:
Slice Th:
NEX:
Display Control
Canvas Size: 320x320
Annotation: Off On
Ruler: Off On
Location: Off On
Full X_hair: Off On
Fast Needle Color: Yellow
Tracking Cursor: Default
Window/Level: Recalculate
Adjust Window Level
Visualization Toolkit – XGL
Display Options
Image Path:
Load Test Image

Results

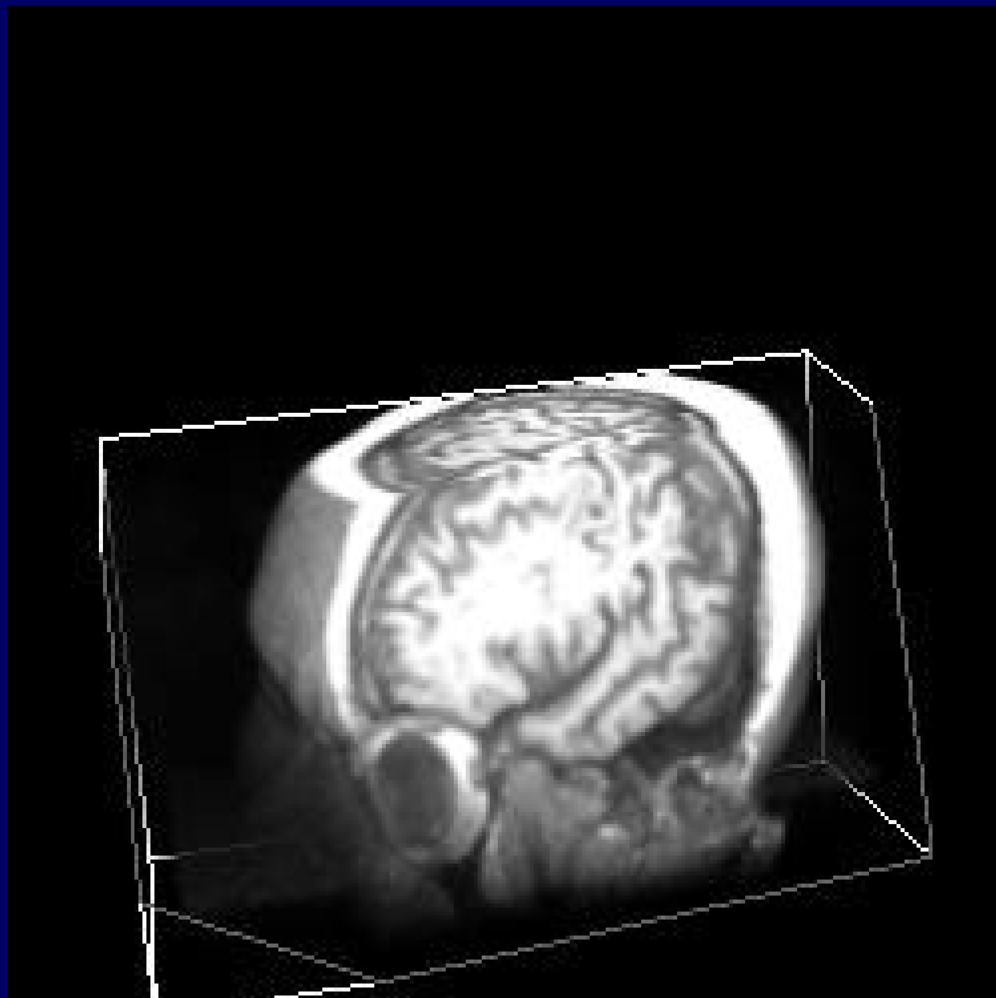
- Fast, dynamic simulation (10 fps) - faster than the actual scanner (.7 fps)
- Surgeons preferred the simulator for planning. Lack of tissue dynamics limited use as a training tool.
- Anatomical references preferred for inexperienced users.
- Simulator use suggested tool modifications.

Visualization Extensions

- Physical gap simulation (not completed).
- Adapted to texture based volume rendering.
- Direct rendering to the iMRI suite.
- Integration with the PACS network.
- Fused MRI and CT data.
- Segmentation, segmentation, segmentation.

Volume Rendering

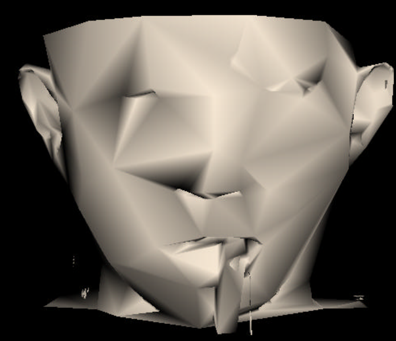
- Requires better segmentation.
- Unlike CT data, MR data has not direct mapping to density.
- Can use alternate pulse sequences to suppress dermal fat and increase contrast between white and grey matter.
  - Inversion recovery
  - Phase contrast angiography

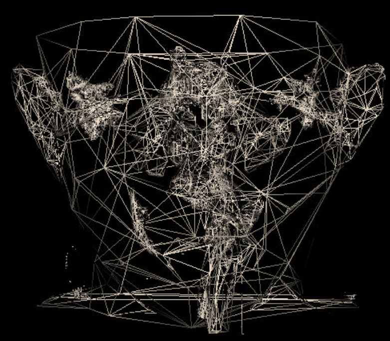


Lessons

- Dynamic control essential.
- Discard unwanted anatomy.
- MRI data, especially those collected with surface coils represent significant challenges to most visualization systems.
- Surface geometry is less essential than high fidelity reconstruction of radiologic images.
- Segmentation is critical.

Discard Unwanted Anatomy



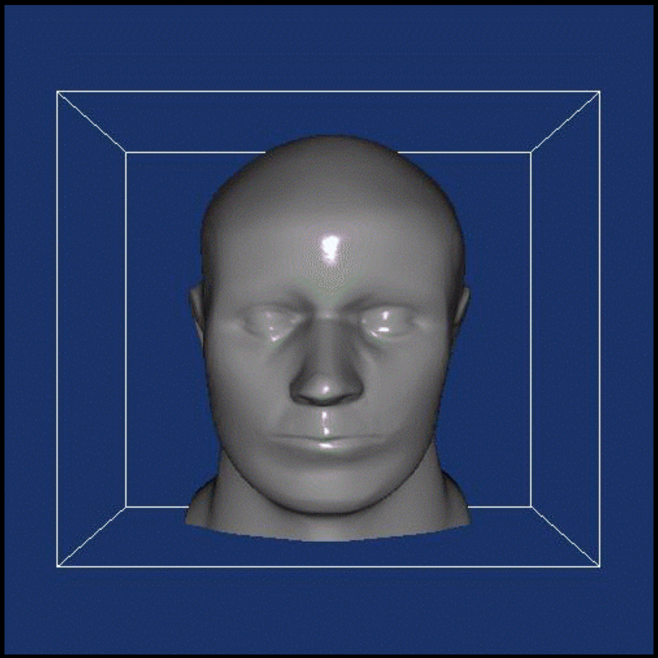


Original (surface)

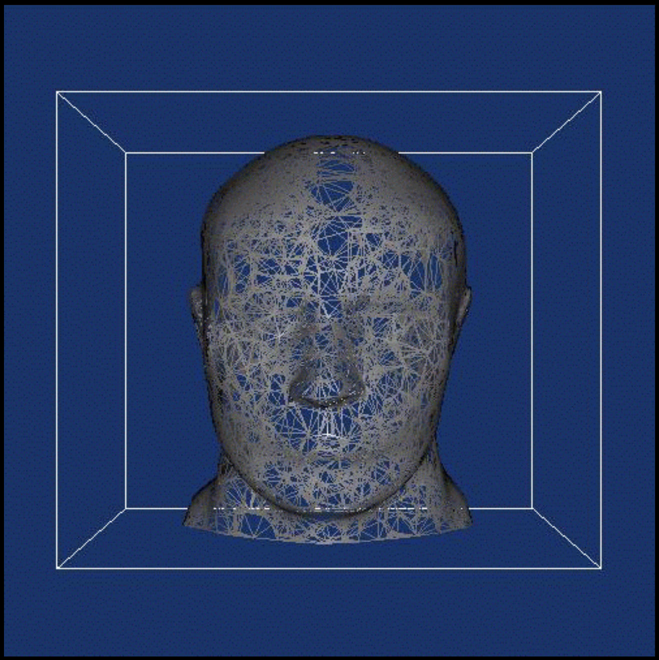
98% decimated

(shaded surface) (wireframe)

Discard Unwanted Anatomy (continued)



Original (surface)



98% decimated (wireframe)

MRI Challenges

MRI Challenges (continued)

Segmentation

- Quality of the visualization hinges on segmentation.
- Segmentation can be aided by registration of data compiled from multiple modalities.

Visible Human Toolkits (watch this space)

- A new, 3-year research initiative in segmentation and registration by the National Library of Medicine.
- Software consortium meets next week.
- Publicly available implementations of segmentation and registration algorithms.
- Open-source public software resource.
- No-cost licenses.

Summary

- Simultaneous MR imaging and surgery.
- Clinical challenge is to make it effective in medical care today.
- Engineering and clinical challenges in:
  - Materials Science
  - Antenna and instrument design
  - Pharmaceuticals

Summary (continued)

- Visualization research opportunities in:
  - Image processing.
  - Real-time data processing.
  - Dynamic interactive visualization techniques.
  - Segmentation and Registration.
    - Deformable multimodal registration.
    - Segmentation of non-homogeneous image data.

[redacted]