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HST.582J / 6.555J / 16.456J Biomedical Signal and Image Processing  
Spring 2007

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# Medical Image Modalities

HST 582

6.555

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# Overview

- Survey of Common Medical Image Modalities
  - Uses of Medical Images
  - Application of Image Processing
  - Medical Image Analysis
- 
- S. Webb (1988). *The Physics of Medical Imaging*.

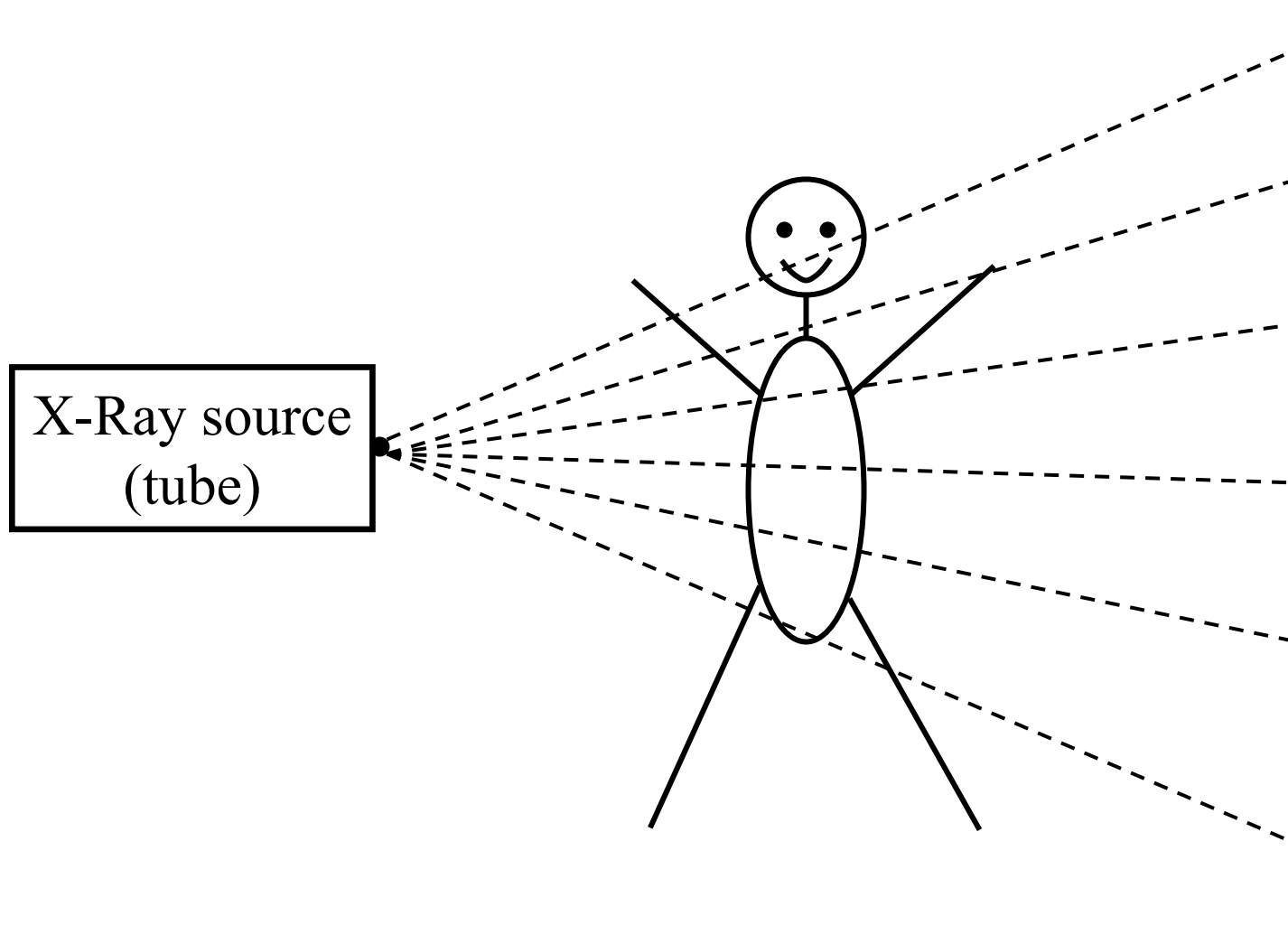
# Common Modalities

- X-Ray
- CT
- Nuclear Medicine
- Ultrasound
- MRI
- More Exotic
  - Optical Coherence Tomography (OCT)
  - Diffuse Optical Imaging
  - Modern EEG

# X-Ray

- Roentgen 1895
  - Low cost
  - Useful for fractures
  - Mammography
  - Chest films
  - Interventional guidance, needles, tubes, etc...
  - Some risk

Film (or detector array)



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# X-Ray Machines

The first ones...

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Photo removed due to copyright restrictions.

... from Philips.

... from Japan...

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<http://www.shimadzu.com/products/medical/oh80jt0000001x6x.html>  
<http://www.medical.philips.com/main/company/aboutus/history>

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# X-Ray Machines

Nowadays...

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<http://www1.shimadzu.com/products/medical/history.html>  
<http://www.medical.philips.com/main/company/aboutus/history>

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# X-Ray examples

The “first” acquisition



Fashionable image of the time...



Current medical applications:

X-Ray images removed due to copyright restrictions.

Skull - [http://www.gehealthcare.com/usen/xr/radio/images/skull\\_1\\_1\\_640\\_528.jpg](http://www.gehealthcare.com/usen/xr/radio/images/skull_1_1_640_528.jpg)

Chest - [http://www.gehealthcare.com/usen/xr/radio/images/chest\\_1\\_4\\_1\\_640\\_612.jpg](http://www.gehealthcare.com/usen/xr/radio/images/chest_1_4_1_640_612.jpg)

Hand - [http://www.gehealthcare.com/usen/xr/radio/images/hand\\_1\\_2\\_1\\_1\\_297\\_640.jpg](http://www.gehealthcare.com/usen/xr/radio/images/hand_1_2_1_1_297_640.jpg)

Courtesy of Radiology Centennial, Inc.

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# X-Ray sensing equipment

- Film
- Fluorescent screen
  - Fluoroscope danger!!
- Image intensifier tube + video camera

# *C-ARM* X-Ray machine

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<http://www.qdi.com.au>

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# Other C-ARM models...

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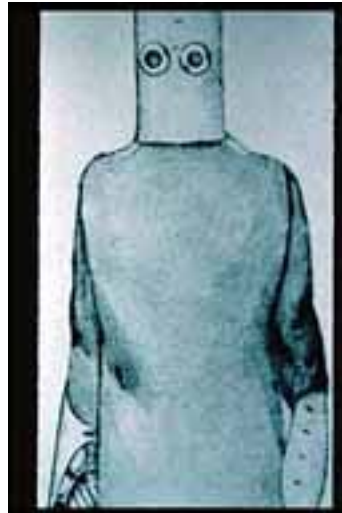
## Useful in the operating room

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<http://www.qdi.com.au>

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# X-ray risk...



Courtesy of Radiology Centennial, Inc.



<http://www.uihealthcare.com/depts/medmuseum/gallery/exhibits/trailoflight/03xraymartyrs.html>.  
1907 photo, courtesy of American College of Radiology

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# Digital Subtraction Angiography (DSA)

1. Acquire digital X-ray
2. Inject contrast agent into blood (x-ray absorber)
3. Acquire new digital x-ray
4. Subtract

⇒ vessels “stand out”

... often BI-PLANAR...

# DSA example



The pelvis of a patient who has had a kidney transplant and a stent placement.

Courtesy of Walter F. Block. Used with permission.

Spring 2007 [http://zoot.radiology.wisc.edu/~block/Med\\_Gallery/ia\\_dsa.html](http://zoot.radiology.wisc.edu/~block/Med_Gallery/ia_dsa.html)

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# Mammography

- Breast x-ray
- Cancer Screen
- Inexpensive
- Challenging to Read





## pleomorphic calcifications, malignant

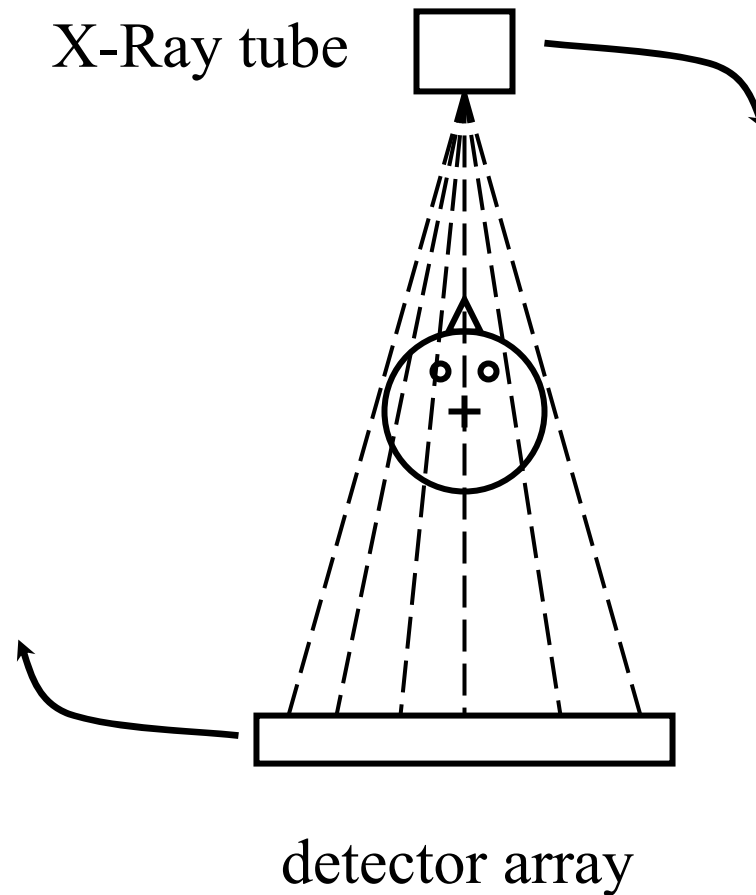
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Courtesy of DDSM: Digital Database for Screening Mammography

<http://marathon.csee.usf.edu/Mammography/Database.html>

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# Computed Tomography (CT) (1958)



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- Auto Rib Cage Projection ([DEMO](#))
- Fan Beam Systems

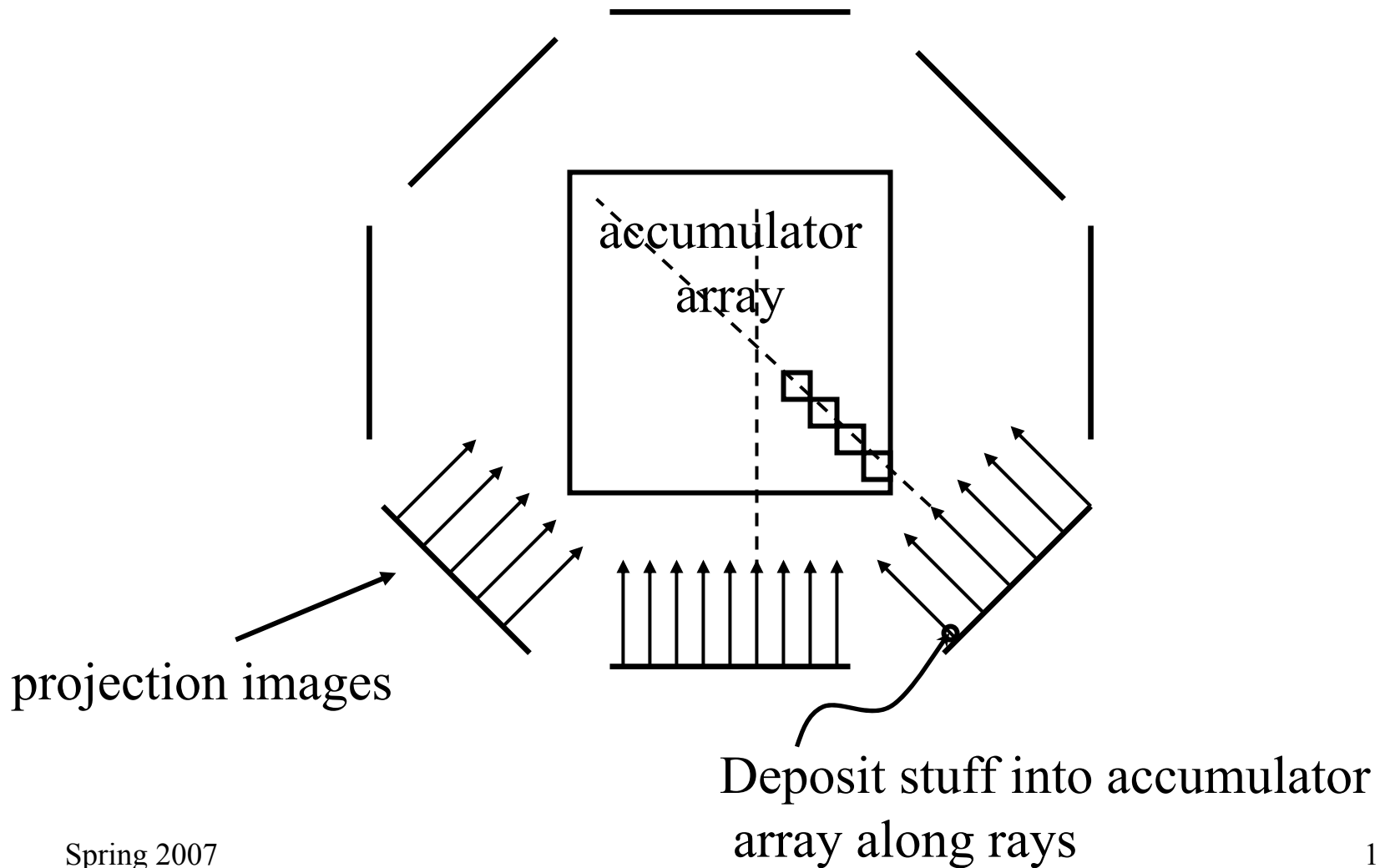
Figure removed due to copyright restrictions.

See <http://books.nap.edu/openbook.php?isbn=0309053870&page=25>

Fan beam systems employ a multicellular detector system rotating about the patient together with the x-ray tube.

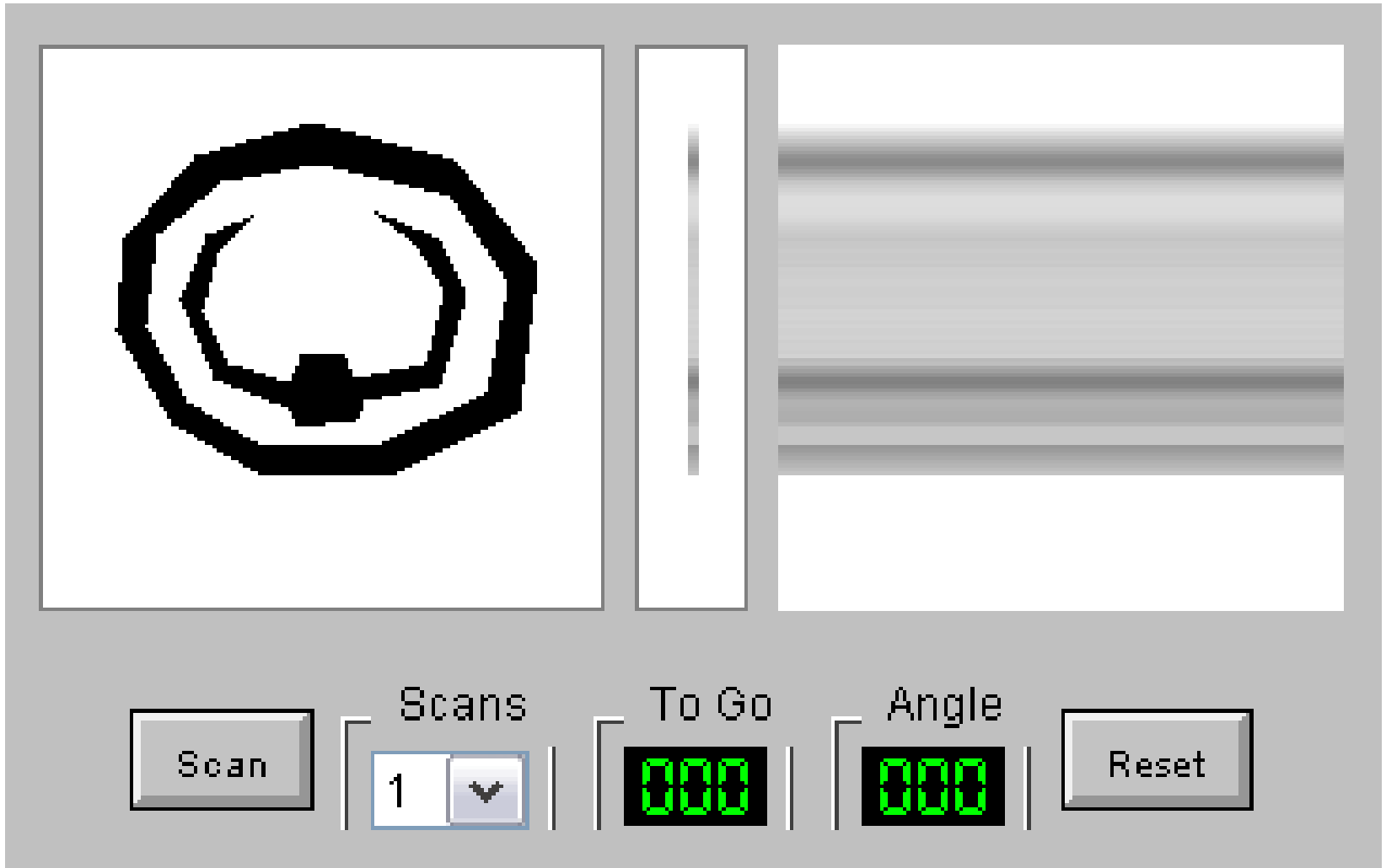
Ring detector based systems have a fixed detector ring, operate with a fan-shaped x-ray beam, and require only a rotational movement of the x-ray tube or the x-ray focal spot in the case of electron beam type x-ray generation.

# Backprojection Algorithm



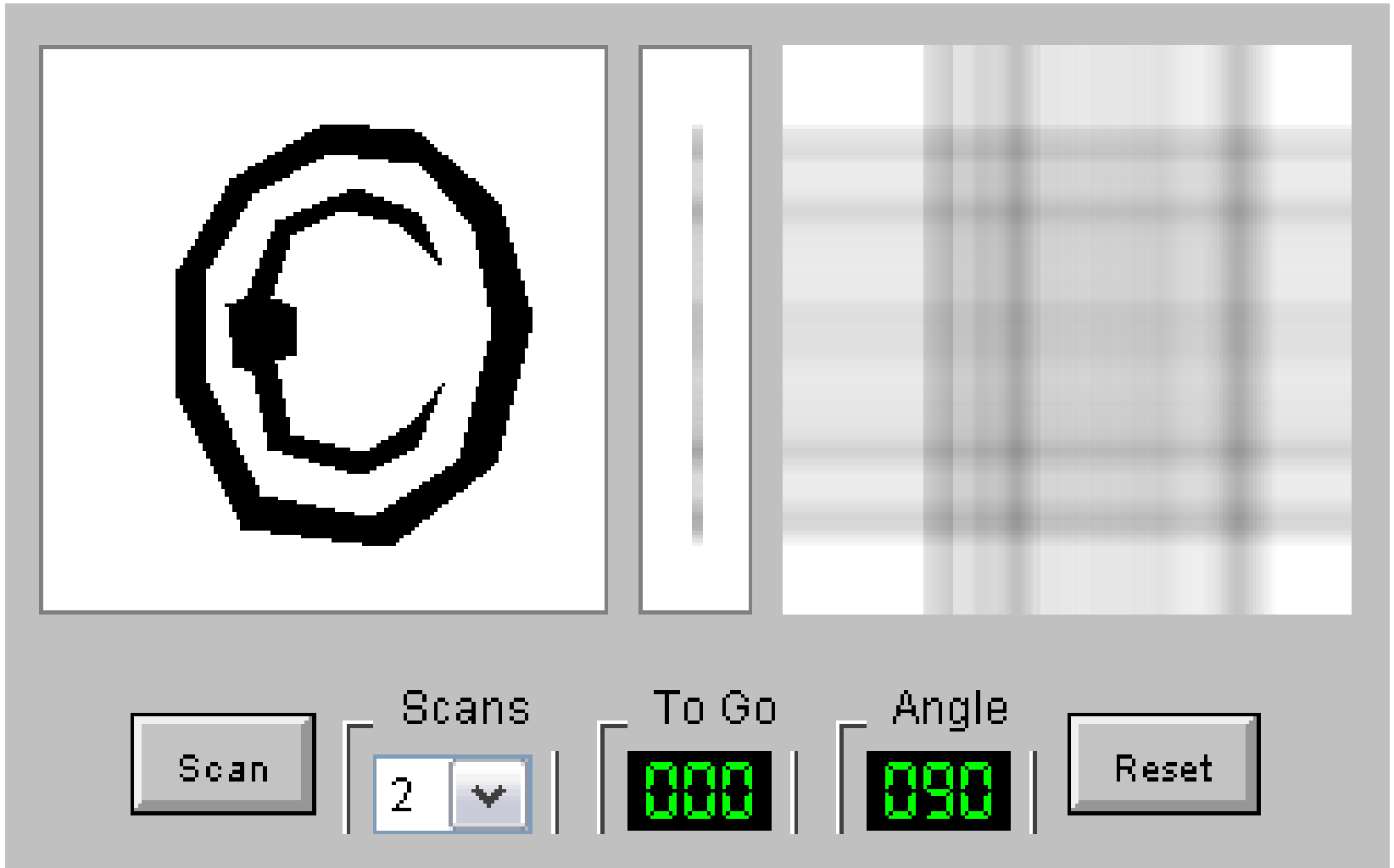
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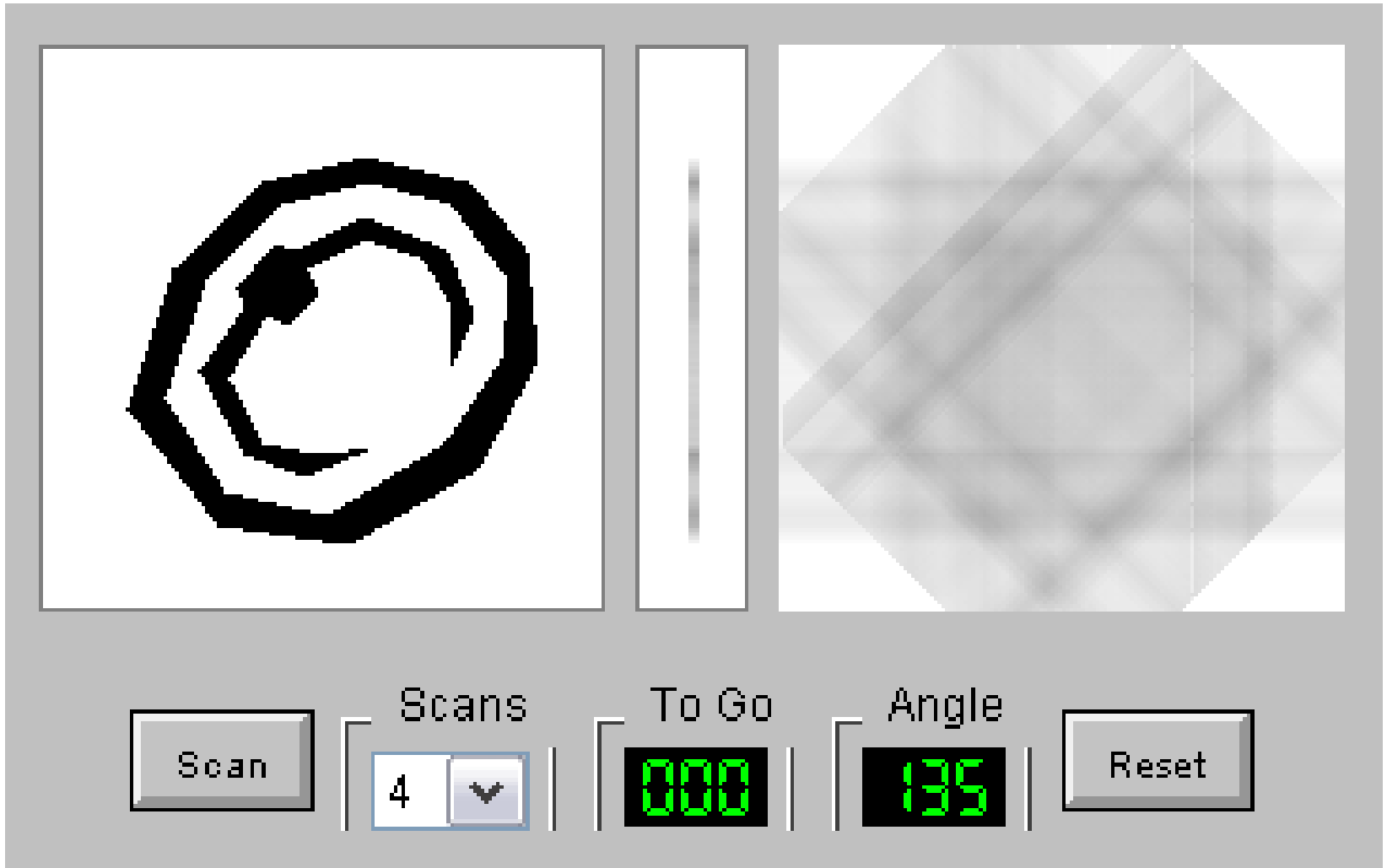
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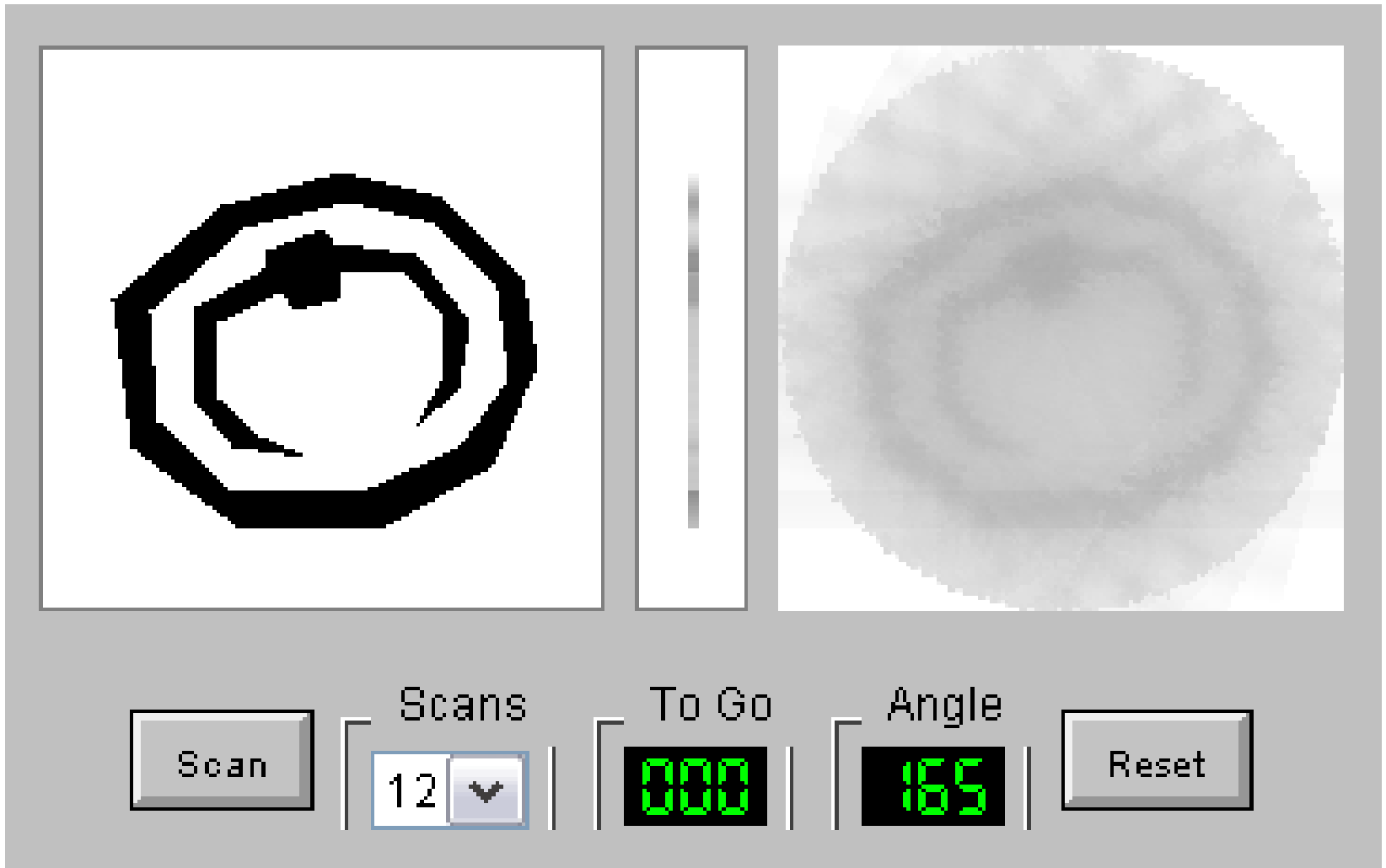
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# Backprojection...

- Backprojection (only) produces images that are blurred by  $1/r$  kernel
- Solution: *de-blur* with filter that is inverse of  $1/r$  (tricky to implement)
- Trick: de-blur filtering can be accomplished in space of projections before backprojection
  - *Filtered Backprojection*

# CT...

- Get hi-res cross sections
- Stack slices into 3D volumetric data set
- Great for bone

# CT example

Image removed due to copyright restrictions.

<http://www.gemedicalsystems.com/education/gallery/index.html>

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# CT scanners

Photo removed due to copyright restrictions.  
See <http://imaginis.com/faq/history.asp>.

Head-only CT scanner  
from 1974



Courtesy of NIH.

Current model

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# CT ...

- Soft tissue contrast not great
- Injected contrast agents can help
  - Tumors (disrupted circulation)
  - *wash-out* studies
  - Vascular imaging
- Moderate cost... ~\$300
- First screen for brain tumor?

# CT ...

- Useful for interventional guidance
- Reasonable access
  - needle placement
- Some risk (X-Rays...)

# Nuclear Medicine

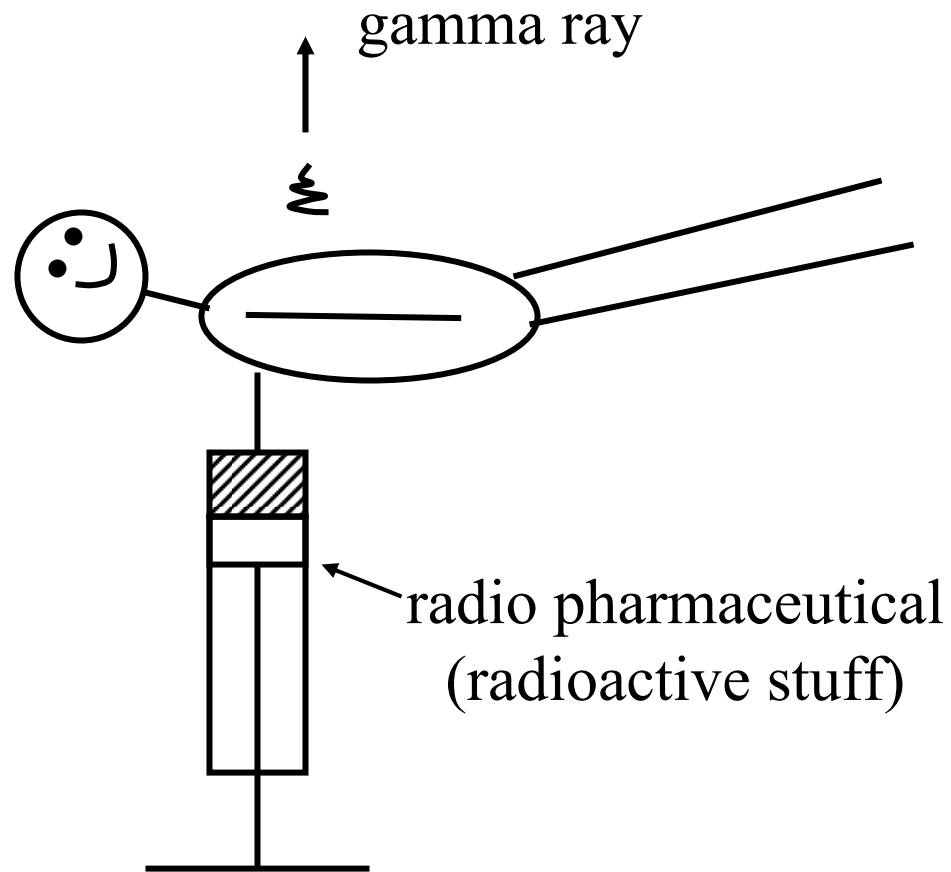


- PET 1953
- SPECT 1967

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# Inject *Radiopharmaceutical*



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# Positron-Emission Tomography (PET)

- Positron emitted
- Does not get far; annihilates with electron
- Producing pair of gamma rays
- Detected as coincidence in two detectors

# Positron Emission Tomography

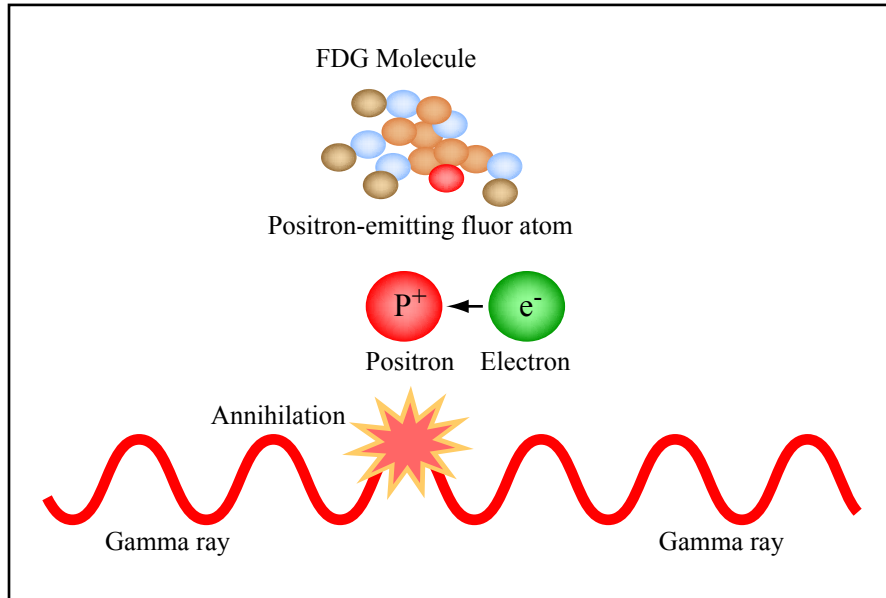
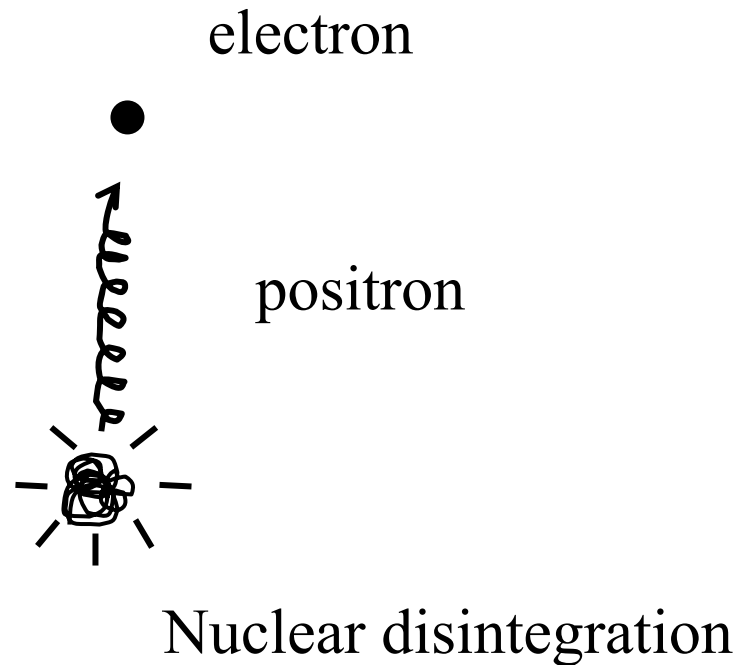


Figure by MIT OpenCourseWare.

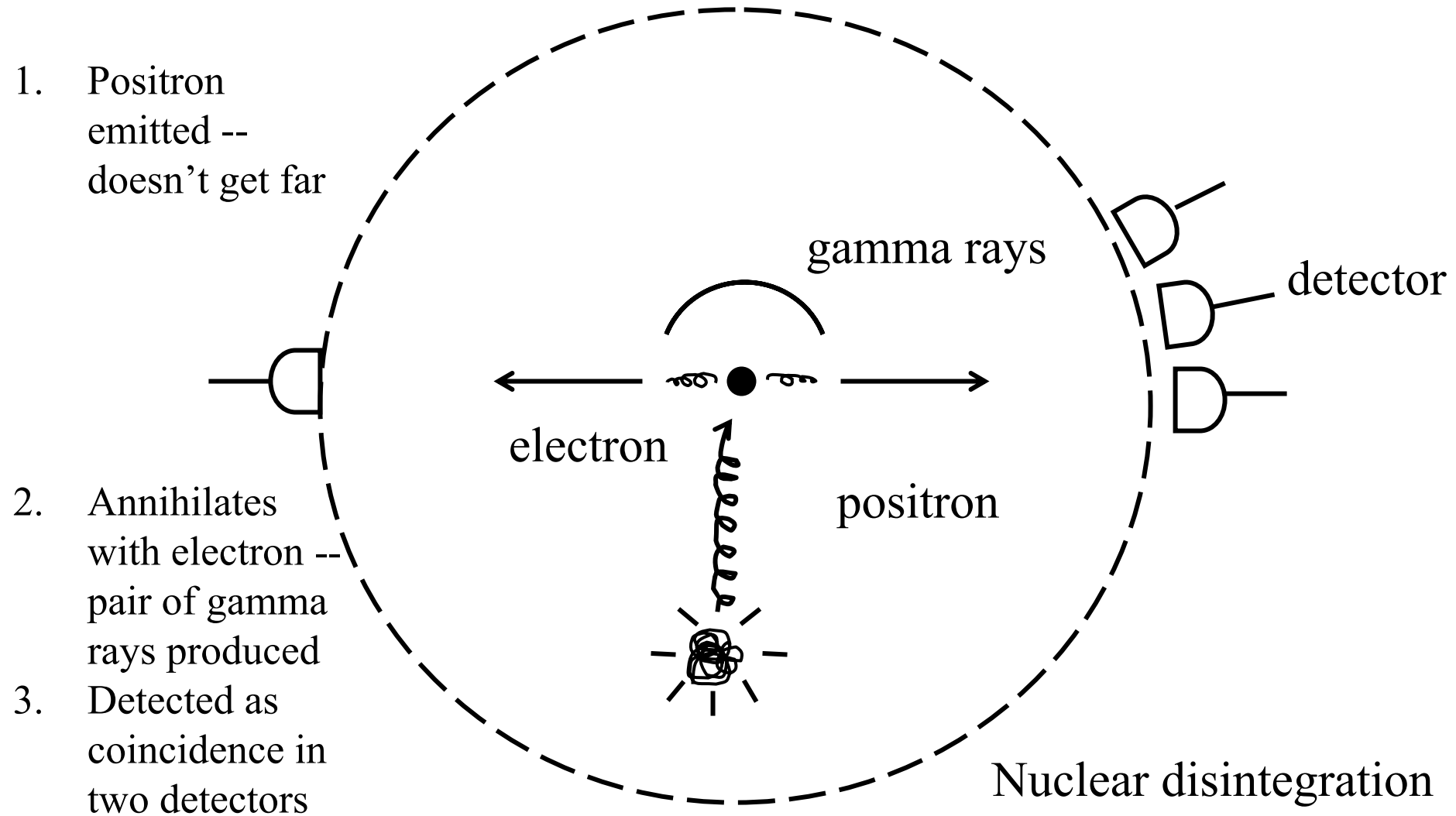
The fluor atom in the FDG (fluorodeoxyglucose) molecule undergoes radioactive decay, emitting a positron -- a form of electron with a positive electrical charge, so it's anti-matter.

The positron collides with an electron, and the resulting matter/anti-matter annihilation emits two gamma rays in opposite directions. The PET scanner registers these gamma rays and assembles the image.

# Positron Emission Tomography



# Positron Emission Tomography



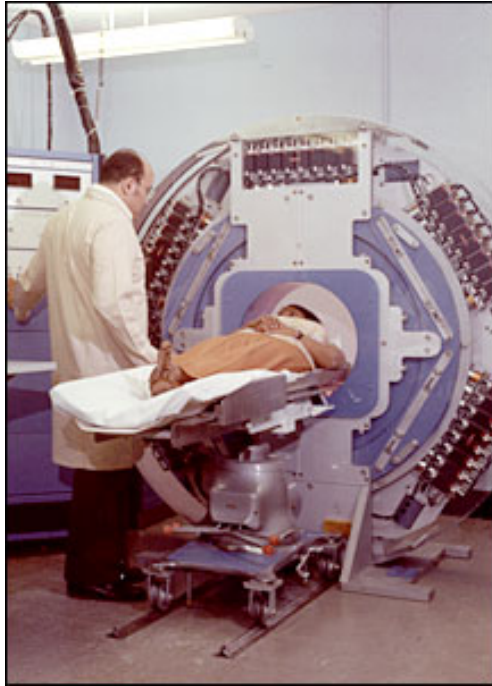
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Image removed due to copyright restrictions.

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# PET scanners



An early model ...

PET III, ca. 1977  
Courtesy of Brookhaven National Laboratory.



Current machines...

Courtesy of NIH.

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# Particle Accelerator needed for making Radiopharmaceuticals

Image removed due to copyright restrictions.

<http://www.crump.ucla.edu/lpp/radioisotopes/radioisoprod.html>

# PET history

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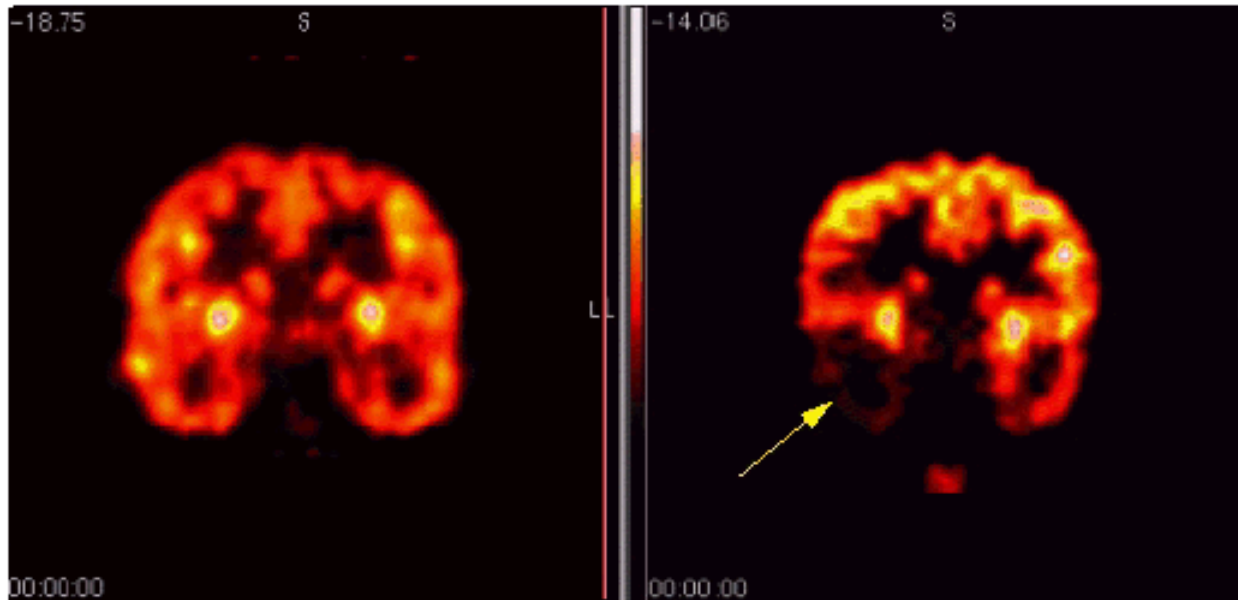
See [http://www.cerebromente.org.br/n01/pet/pet\\_hist.htm](http://www.cerebromente.org.br/n01/pet/pet_hist.htm)

Evolution of image quality from the first PET scanner, available in 1975, to the latest and most sophisticated model, ECAT Exact HR+. Improvement has been achieved with a larger number and better radiation sensors, better computer programs and the possibility of getting several slices at the same time (using many rings of sensors).



- Tracers show functional information
  - glucose metabolism
  - perfusion
  - ...
- Find tumors
- Show strokes
- Heart assessment
- Functional neuroscience
  - Ethical problems ...
- Some risk (radioactive stuff)

# PET images



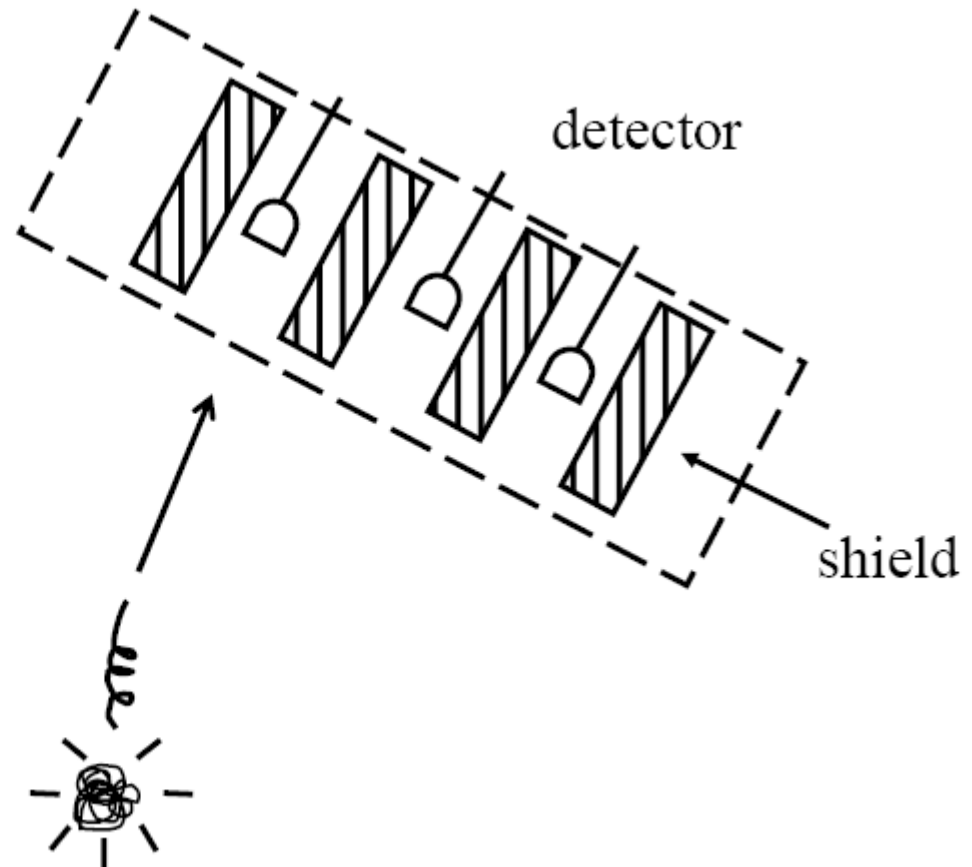
<http://www.biomed.org/pet.html>

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Images removed due to copyright restrictions.  
See <http://www.cerebromente.org.br/n01/pet/pet.htm>

# Single Photon Emission Computed Tomography



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# Gamma Camera

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Schematic of gamma camera.

Construction of a simple gamma camera (from Webb, *Physics of Medical Imaging*)

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# SPECT scanner

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# SPECT image

Image removed due to copyright restrictions.

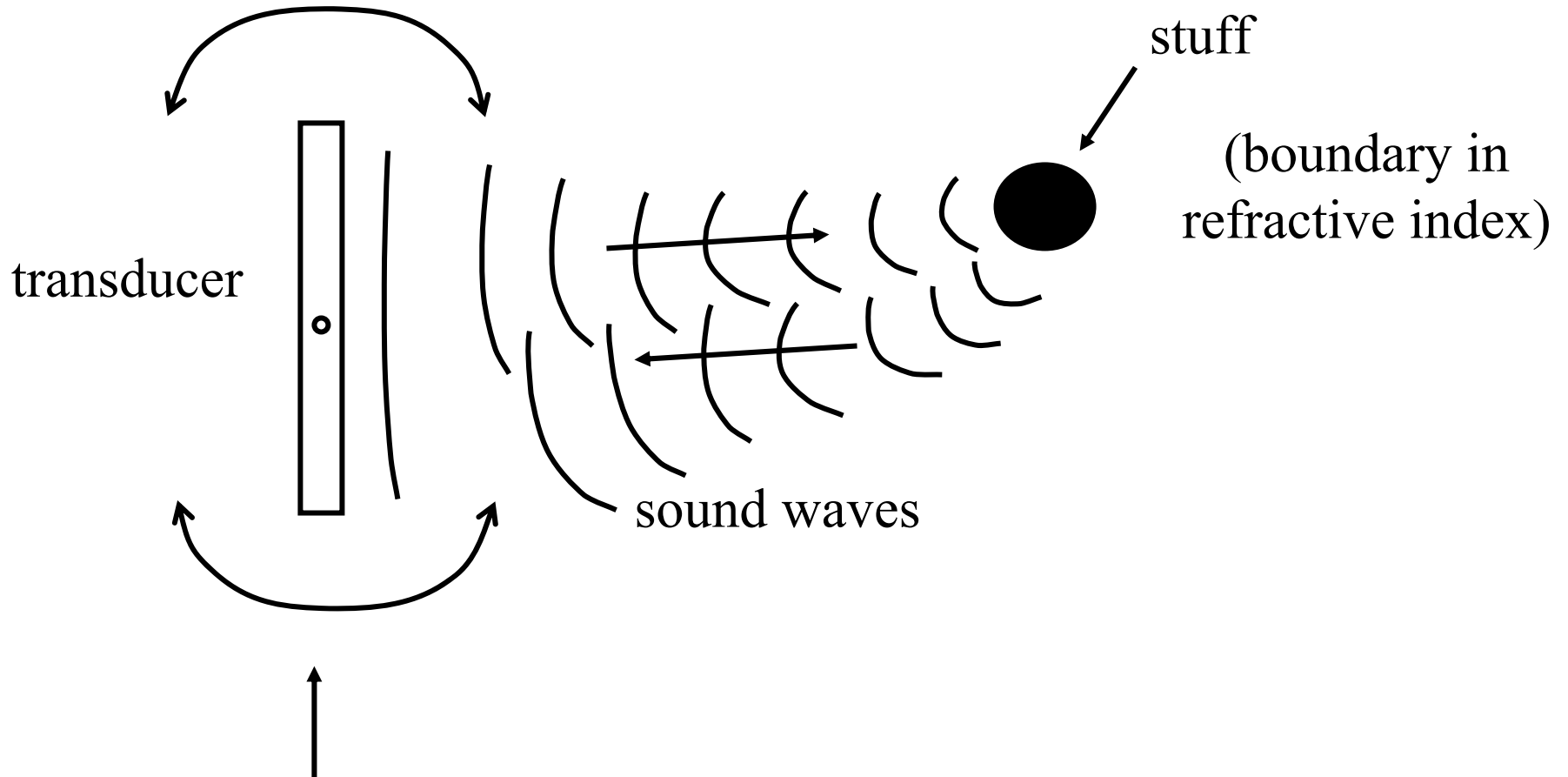
- PET
  - Expensive
  - Need nearby particle accelerator to make the tracers
  
- SPECT
  - Moderate \$
  - Do not need to be right by accelerator



# Ultrasound 1950's

- Low cost
- Safe
- Noisy images
  - Specularities

# Ultrasound...



in a hand-held probe?

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# Ultrasound...

- Boundary contrast
- Breast exams
- Useful for biopsies
- Some use in neurosurgery
  - For tumors with sharp margins
- Recent research
  - Amy Gieffers, HP Andover
  - Heart assessment
  - Blood contrast agent

# Ultrasound images

Images removed due to copyright restrictions.

[Ultrasound movies](#)

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# 3D Ultrasound image (1)

Images removed due to copyright restrictions.  
See <http://www.cs.uwa.edu.au/~bernard/us3d/people.html>

# 3D Ultrasound images (2)

Images removed due to copyright restrictions.

<http://tanya.ucsd.edu/>

Image removed due to copyright restrictions.

<http://www.cs.uwa.edu.au/~bernard/us3d/people.html>

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# ~~Nuclear~~ Magnetic Resonance Imaging

- 1978 first commercial
- Excellent soft tissue contrast
  - Tumors
  - White matter/ gray matter
  - MS lesions
  - Cartilage
    - Knees
    - Discs (spine)
  - Expensive ~\$1000

# MRI example

Image of human brain removed due to copyright restrictions.

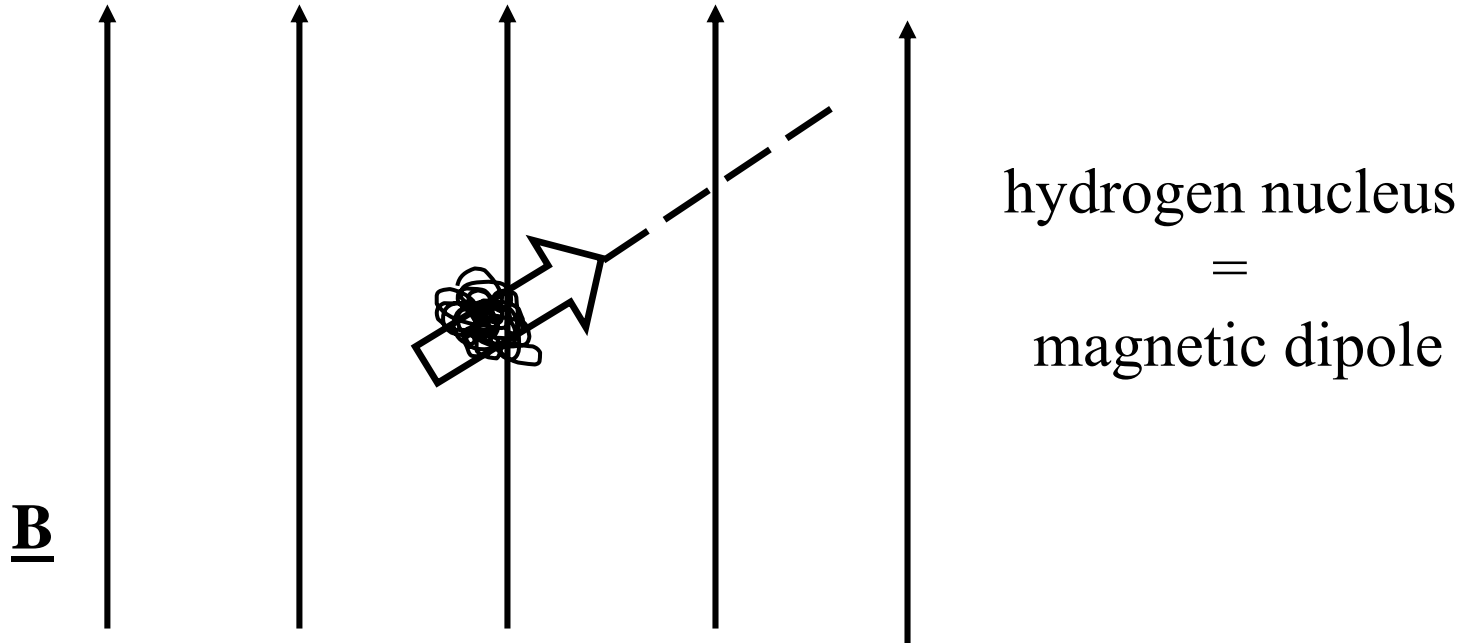
<http://www.gemedicalsystems.com/rad/mri/images/med/3t/>

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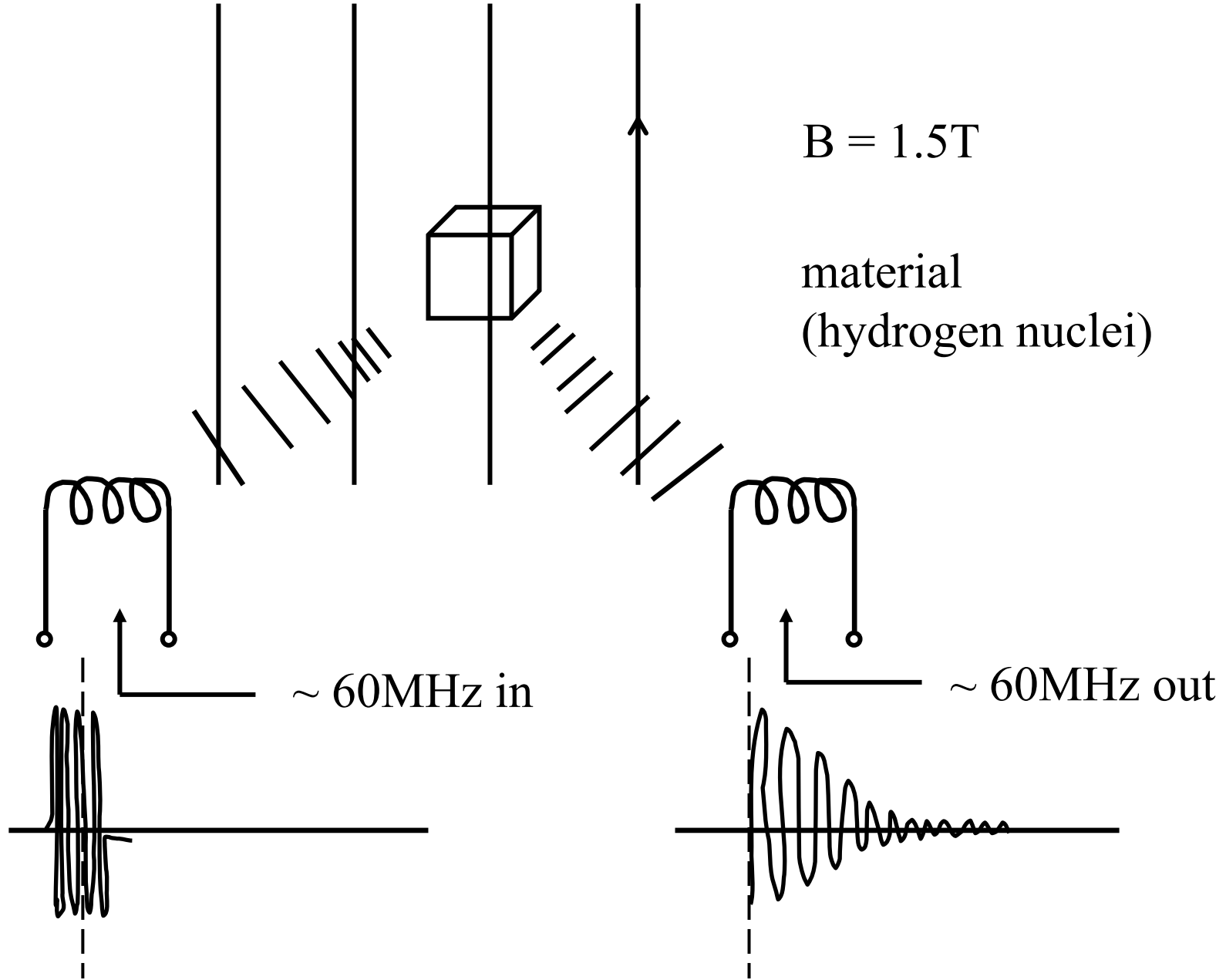
# NMR



- Hydrogen nuclei precess around an applied magnetic field
- 1.5 Tesla ~ 60 MHz Larmour frequency

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# How to image?

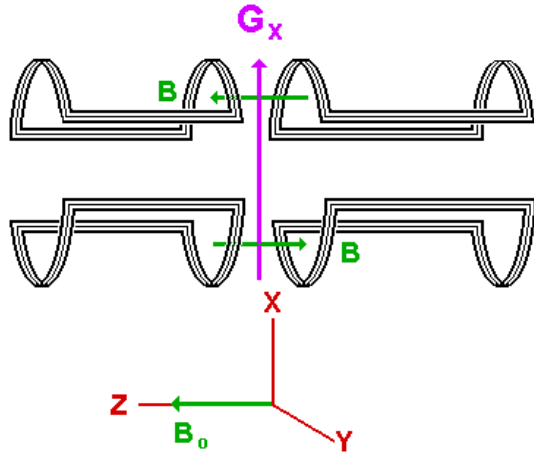
- = Nobel Prize
- Later lecture
- For now... what does the equipment look like? ...

# General Electric 3 Tesla Imager

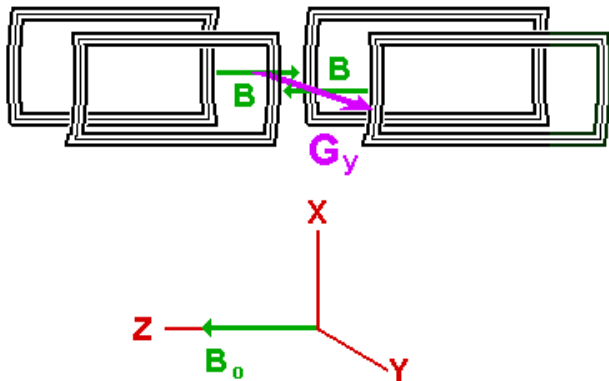
Photo removed due to copyright restrictions.

# Gradient subsystem

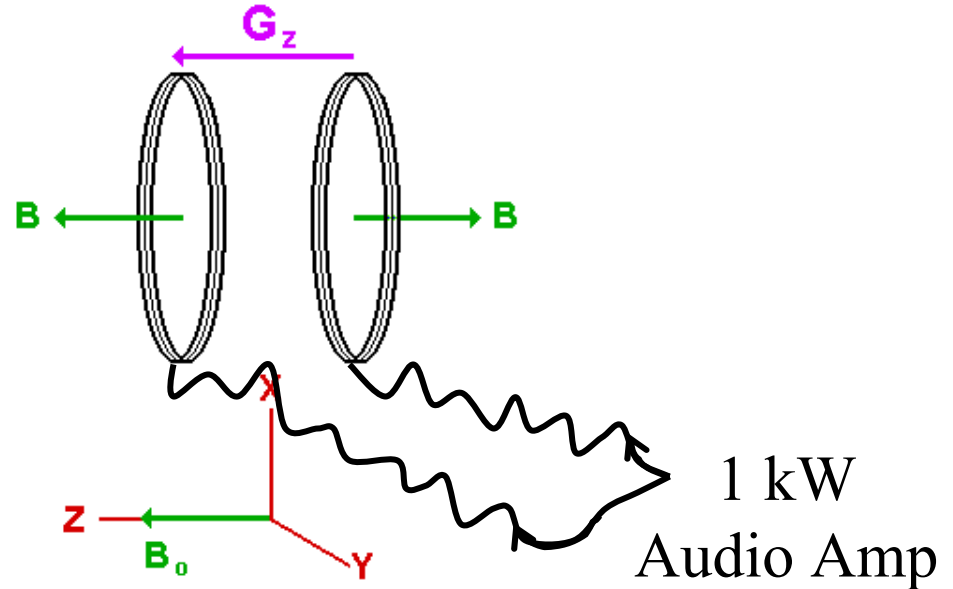
## X Gradient Coil



## Y Gradient Coil



## Z Gradient Coil



<http://www.cis.rit.edu/htbooks/mri/inside.htm>

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# Transmitter



200 W

60MHz

RF Transmitter

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# RF Receiving equipment

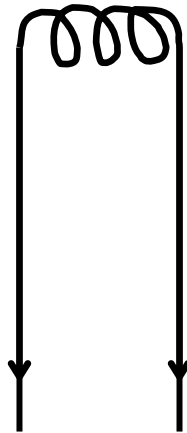


Image removed due to copyright restrictions.

Hornak, J. P. *The Basics of MRI*. <http://www.cis.rit.edu/htbooks/mri/inside.htm>

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# MRI equipment

Image removed due to copyright restrictions.

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Hornak, J. P. *The Basics of MRI*. <http://www.cis.rit.edu/htbooks/mri/inside.htm>

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# MRI...

- Provides cross-sectional images on volumetric data
- What does it see?
- ~ juiciness
- Proton density
- Relaxation time constants
  - T1: return to low energy state
  - T2: lose bulk transverse magnetization

# T1, T2 for Brain Tissues

Tissue	T1	T2 (ms)
WM	871	87
GM	515	74
CSF	1900	250

# MRI Imaging Protocols

- Proton Density
- T2-weighted
- T1-weighted
- ... many others
  
- “spectroscopy”

Image removed due to copyright restrictions.

Hornak, J. P. *The Basics of MRI*. <http://www.cis.rit.edu/htbooks/mri/inside.htm>

# Spinal MRI acquisition

Image removed due to copyright restrictions.

Hornak, J. P. *The Basics of MRI*. <http://www.cis.rit.edu/htbooks/mri/inside.htm>

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- Additional flexibility
  - Injectable (magnetic) contrast agent
  - MR angiography (safe)

# MR Angiography

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Hornak, J. P. *The Basics of MRI*. <http://www.cis.rit.edu/htbooks/mri/inside.htm>



# Functional MRI (fMRI)

- MGH >> 1
- Very fast acquisition
  - Do something different
- Another quick acquisition
  - ⇒ subtract, etc,
- Subtle intensity changes due to vascular responses ⇒ (fuzzy) activation images (SAFE!)

# fMRI Setup

Image removed due to copyright restrictions.

See: <http://www.arts.uwaterloo.ca/~jdancker/fMRI/Week%202%20-%20The%20Basic%20Story.ppt>

# Activation Statistics

Functional images

Region of interest (ROI)

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# Interventional MRI

- BWH >> 1
- Ferenc Jolesz
- GE Medical Sys., Milwaukee
- Open MRI, MRT

# MRT (interventional MR)

- Integrate MRI with Operating Room
- Non-magnetic patient monitor machine
- Non-Ferrous Anesthesia Machine

# Signa SP (GE Medical Systems)

Photos by Sam Ogden removed due to copyright restrictions.

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# Preoperative Image

Photo removed due to copyright restrictions.

# Intraoperative Image (end of procedure)

Photo removed due to copyright restrictions.



# MRT usage

- First: biopsies
- Now:
  - Craniotomies
  - Prostate Brachytherapy
  - Liver Tumor Ablation

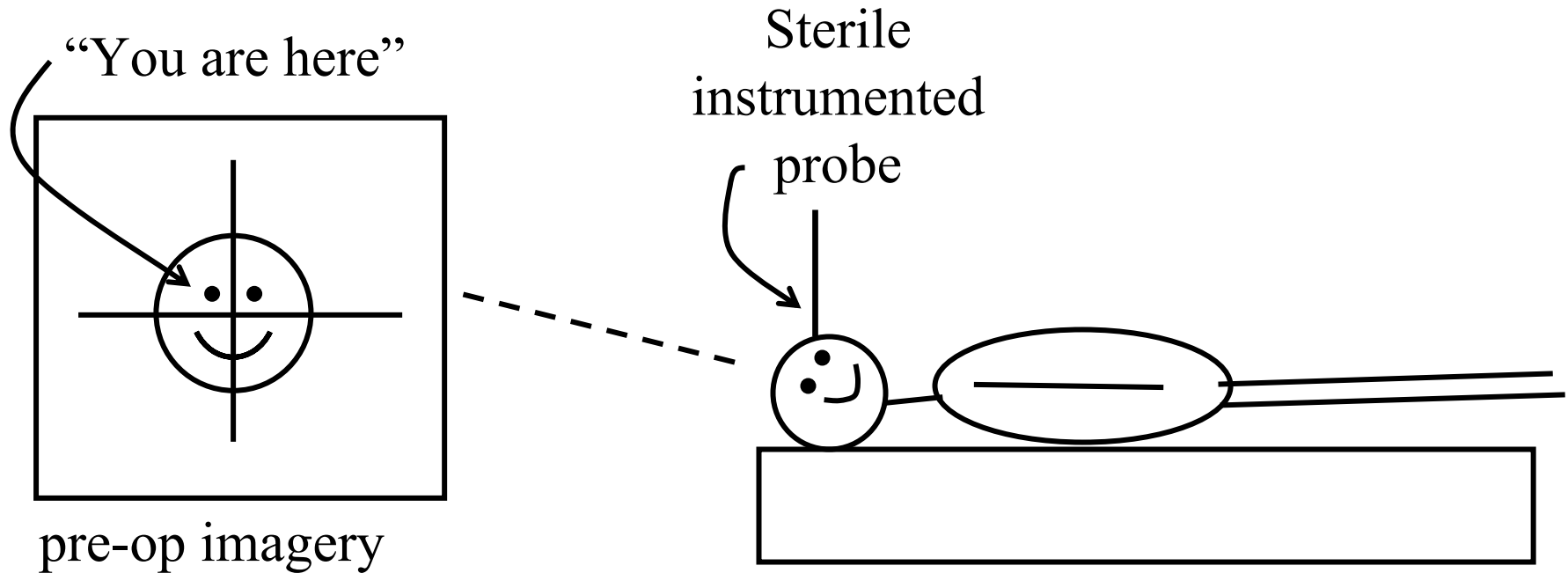
# Uses of Medical Images

- Diagnosis
  - Fracture, tumor, stroke
  - Eyeball + tape recorder
- Interventional guidance
  - Exploit spatial information “targeting”
- Scientific Research

# Interventional Applications

- Needle placement; catheterizations
- Image-guided “conventional” surgery
- Radiation therapy planning
  - Dosimetry
  - Portal imaging
- *stereotaxy*

# “Neuro Navigation”



- Mike Leventon, Eric Grimson, AI Lab...
- There are some commercial systems....
  - Brain Lab A.G. (German product)
  - GE NAV (General Electric)

# Science

- Neurological Diseases
  - MS
    - Drug trials
    - Quantify lesion burden
  - Schizophrenia
    - Temporal lobe anatomy
      - Measure volumes
  - Functional Neuroscience
    - Psychology experiments

# Medical Image Analysis

- Emerging field
- Elsevier journal
- Older technologies
  - Image reconstruction: CT, MRI (pretty mature)
  - SPECT still active
- Core technologies
  - Segmentation
  - Registration
- Applications
  - Visualization (surgery)
  - Anatomical studies

- Segmentation
  - current: more or less elaborate statistical classifiers + morphological operations
- Registration
  - Time series
  - Fuse modalities (surgery?)
  - Fuse anatomical reference (MRI) with activation (fMRI)

# Medical Image Analysis

## Current Research Areas

- Non-rigid registration
    - Computer simulation of tissue deformation + intra-op images
  - *computational anatomy*
  - ATLASSES --what are atlases?
    - Statistical characterization of shape in population
    - “warping” across people
- ⇒ integration of functional neuroscience experiments across subjects



the end

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