# 3D AND 4D ULTRASOUND

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# OUTLINE

- Introduction to Ultrasound
- Why 3D / 4D is used
- Clinical Uses
- Concept of 3D ultrasound
  - Acquisition
    - 3 methods
  - Rendering / Reconstruction
  - Navigation
    - 3 types of images
- 4D ultrasound
- History of Ultrasound
- Future
- Ethics

# INTRODUCTION TO ULTRASOUND

- High-frequency sound waves (MHz)
- Medical imaging technique: use of sound waves to visualize internal structures
- Basic concept:
  - *transducer* sends out sound waves
  - Sound waves reflect off of internal structures
  - Image generated from data:
    - Time for the echo to be received
    - Intensity of echo
    - Depends on density of material, location in body
- Different types:
  - 1D, 2D, Doppler, 3D, 4D

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# WHY 3D / 4D?

- Accuracy and repeatability
  - Less dependent on technician's ability to visualize 2D images in 3D setting
  - Easier to track growth of tumours /diseases, lesions
- No health risks from moderate use
  - Potential health problems
    - Too intense
    - Over-usage
- Useful to see structures in motion
  - Surgery
  - Diagnosis

Traditional 2D Image

3D Image

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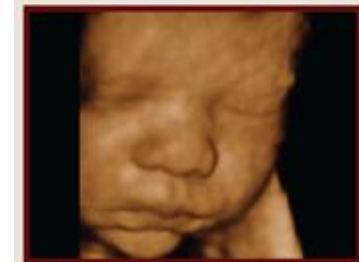
# CLINICAL USES

- 3D
  - Imaging during surgery, radiotherapy planning
    - Find instruments with respect to structures in the body
  - Looking at structures / sections of larger structures
  - Eg: fetal screening, breast biopsy, carotid artery, intestine, eye, intravascular, rectal, gynaecological

- 4D
  - Fetal screening
  - Echocardiography
  - Pelvic floor surgery
  - Venous system imaging



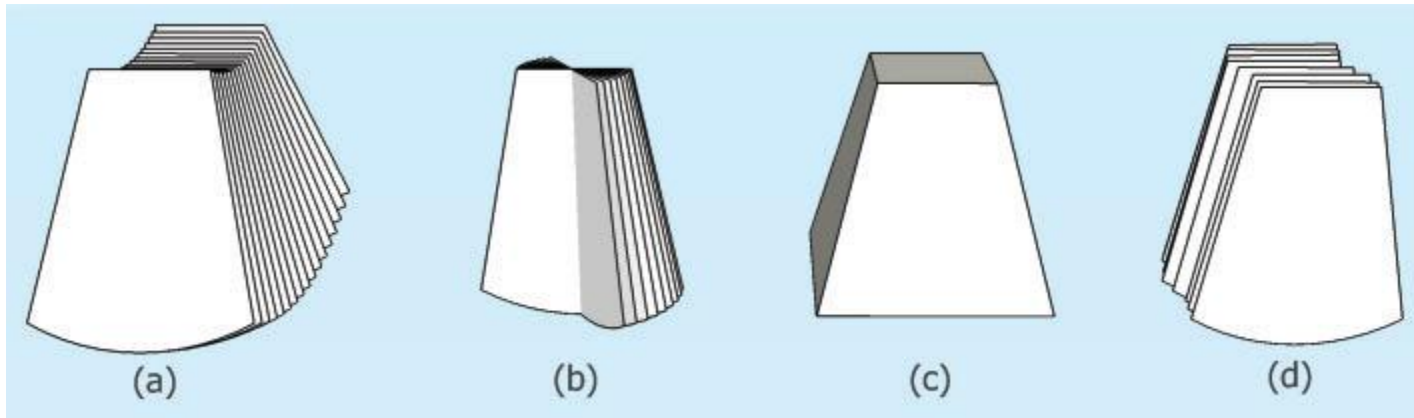(a)    (b)    (c)

(d)    (e)

(f)    (g)    (h)

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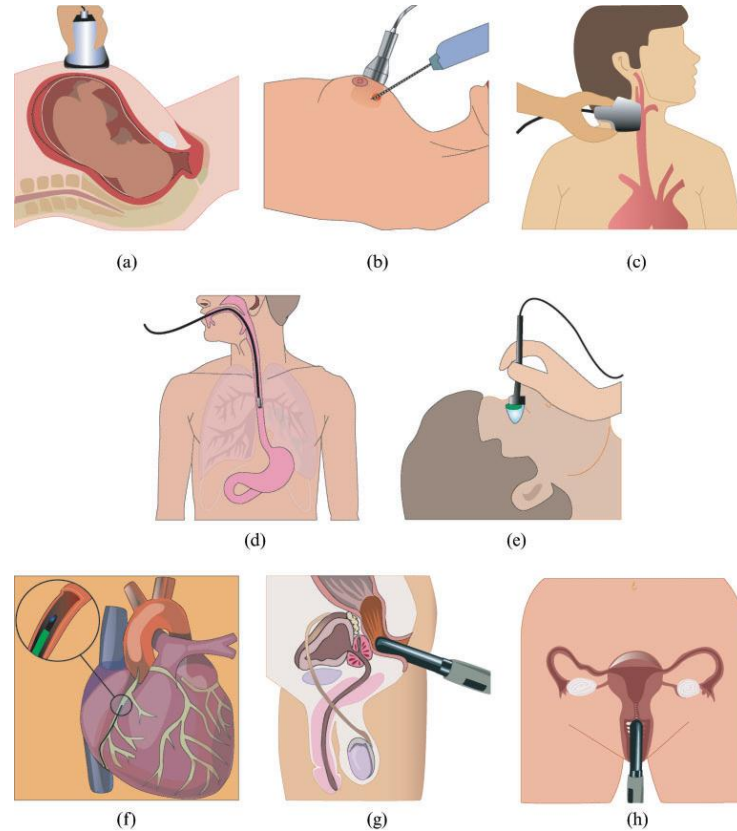
# CONCEPT OF 3D ULTRASOUND

- Take 2D images, process with position to form 3D visualization

- Processes:
    1. Acquisition
    2. Rendering / Reconstruction
    3. Navigation

# 1. ACQUISITION

- 3 types of transducers:
  - Mechanically-swept (a and b)
  - 2D transducer array (c)
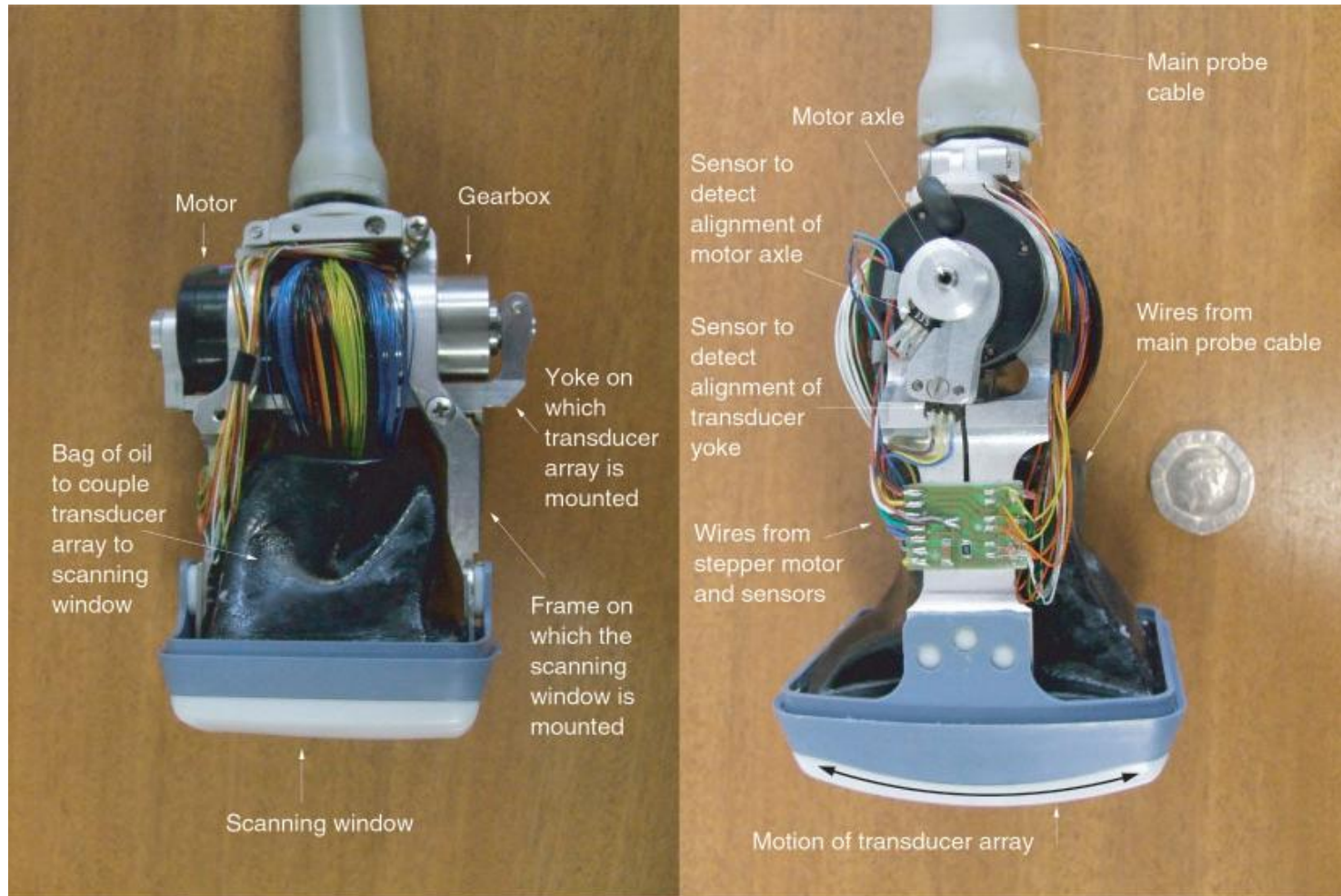  - Freehand acquisition (d)

# MECHANICALLY-SWEPT

- Transducer is mounted
- Moved along a specified path by a motor
  - Consistent
- As motor moves, transducer array takes B-scans (2D scans)
  - The faster the motion, the less exact the image
    - Image could be distorted
    - Method mainly being used in clinical applications where nothing is moving rapidly
- Fetal screening usually uses this

# MECHANICALLY-SWEPT PROBE

(a)

(b)

Motor

Gearbox

Bag of oil to couple transducer array to scanning window

Yoke on which transducer array is mounted

Frame on which the scanning window is mounted

Scanning window

Main probe cable

Motor axle

Sensor to detect alignment of motor axle

Sensor to detect alignment of transducer yoke

Wires from main probe cable

Wires from stepper motor and sensors

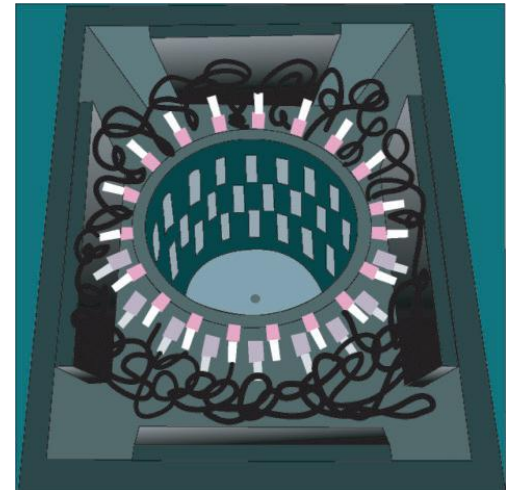Motion of transducer array

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# 2D Transducer Array

- Grid of 128 x 128 transducer elements
  - The more the better (better resolution)
  - 20 x 20 in the 90's
- Alignment of transducer elements is difficult
  - Lots of transducer elements in small space
  - Wiring large number of transducers in small area
- Speed
  - Need to use transducers in parallel
  - 128 sound beams travelling 10 cm in and out →1/60s at speed of 1540 m/s
    - 16384 beams would take 2.1 seconds: too slow!

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# 2D Transducer Array Arrangement

- Align transducers in a grid
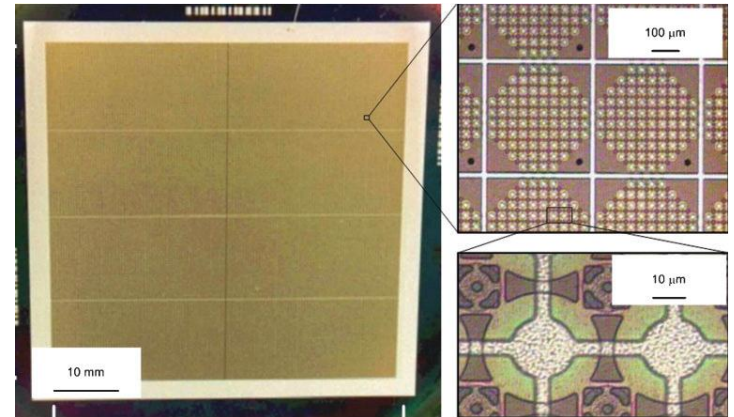
- Align transducers in ring around patient
  - Only image things that fit in it
  - Slow data processing with larger ring

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# FREEHAND

- 1D transducer array with external position sensor
  - Position sensor measures 6 degrees of freedom (calibration)
- Path and image measured
  - Put together to obtain data
- Technician must operate transducer by hand
  - More labour intensive (move smoothly and slowly)
  - More sources of error: not taking same path each time
- 2 types of position sensors: optical and magnetic
  - Optical: calibrated cameras
  - Magnetic: magnetic field
- Can modify a transducer used for 2D ultrasound

# FREEHAND TRANSDUCER OPERATION

Transmitter for spatial locator

Magnetic coupling

Sensor
$(x, y, z, \alpha, \eta, \rho)$

Probe

Patient

(a)  (b)  (c)  (d)
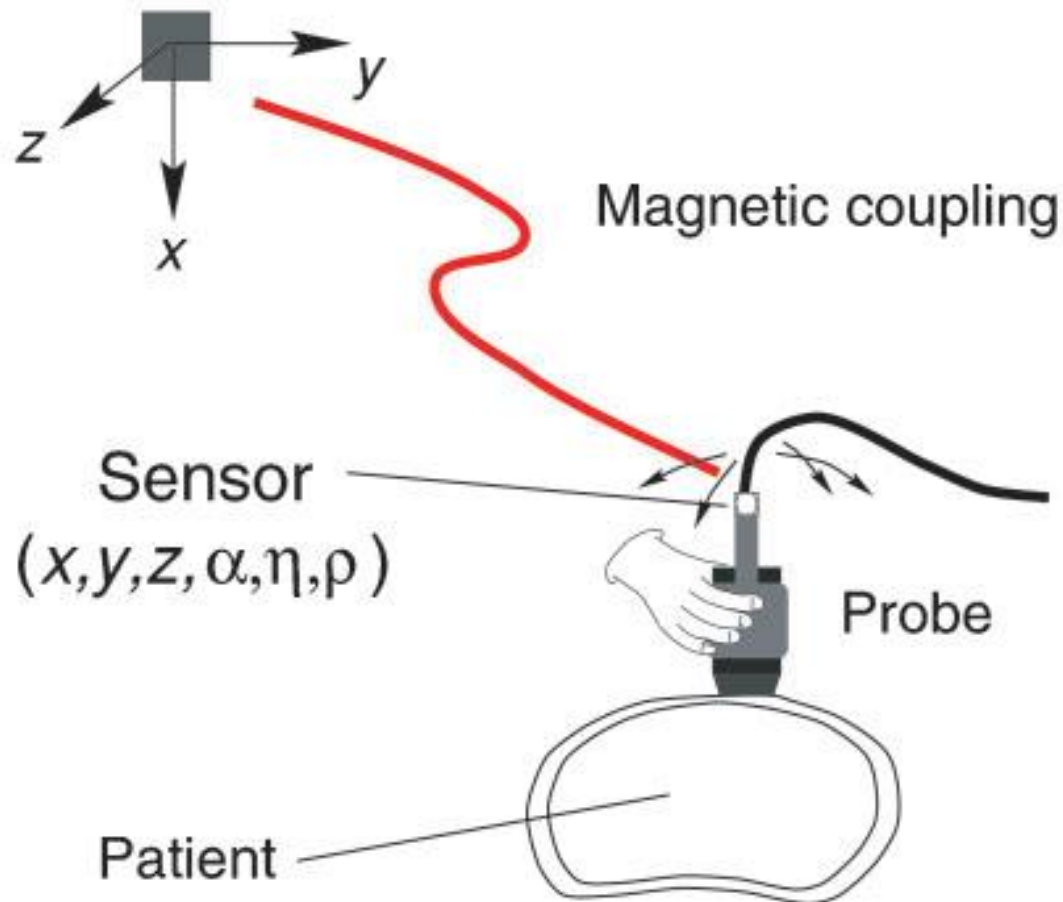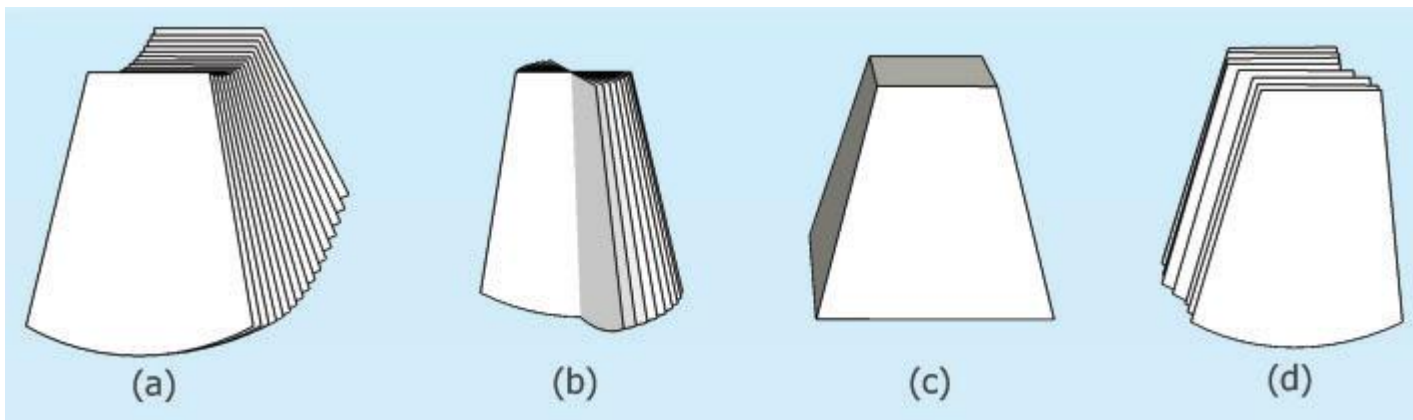
# 2. RENDERING / RECONSTRUCTION

- Done by a computer program
- Rendering
  - Make image more clear, detailed
  - Volume Rendering / Reconstruction
    - Adjust 3D image to be viewed on 2D screen
    - Ray casting
    - Plane composing
  - Surface Rendering
    - Smoothing and texturing
    - Lighting
    - Transparency

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# SURFACE RENDERING

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# Volume Rendering / Reconstruction

Image plane

Voxel array
(arbitrary rotation)
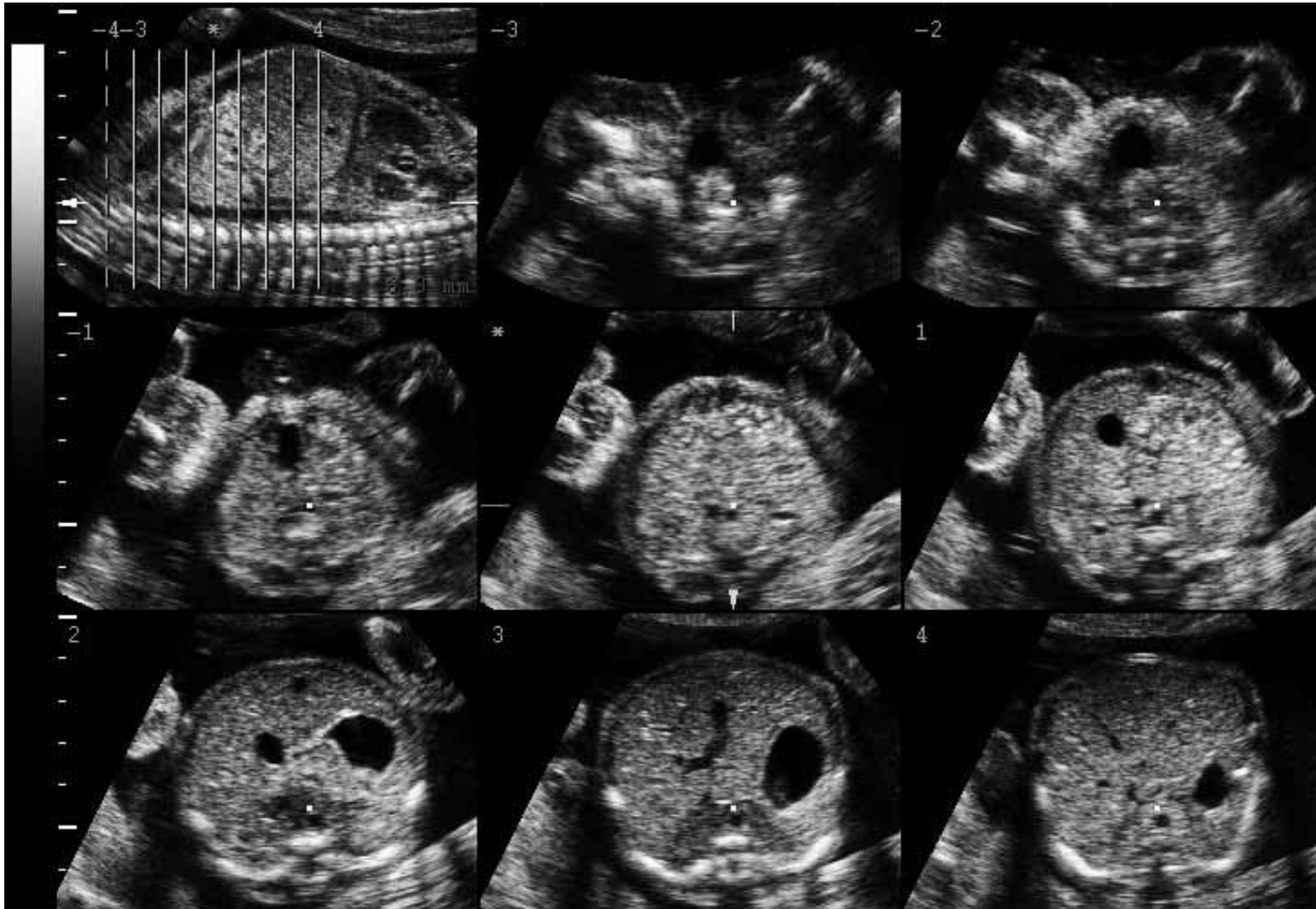
Rays
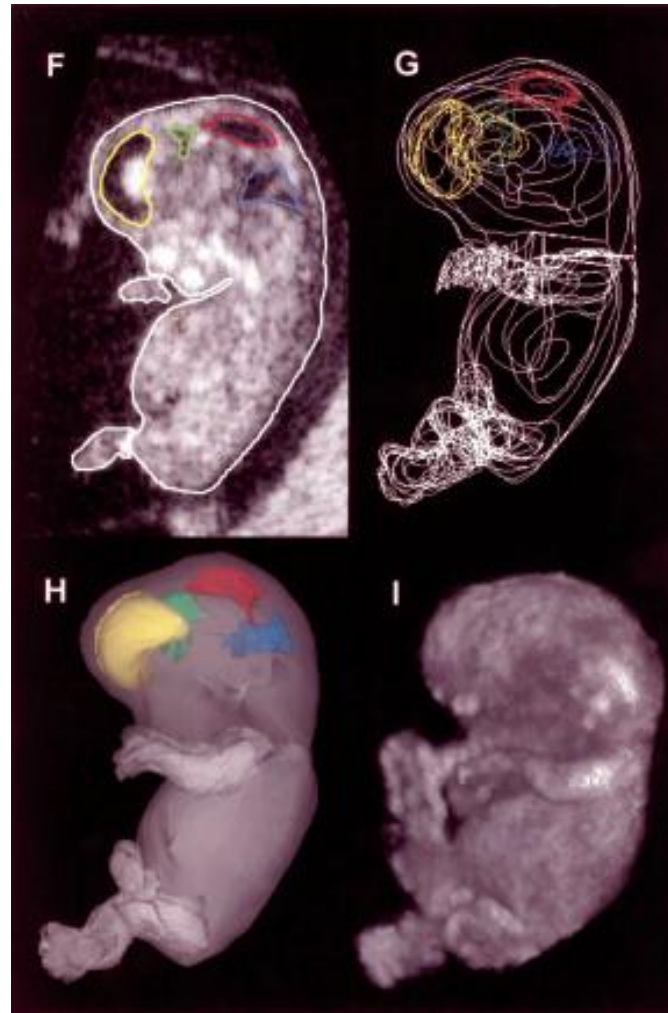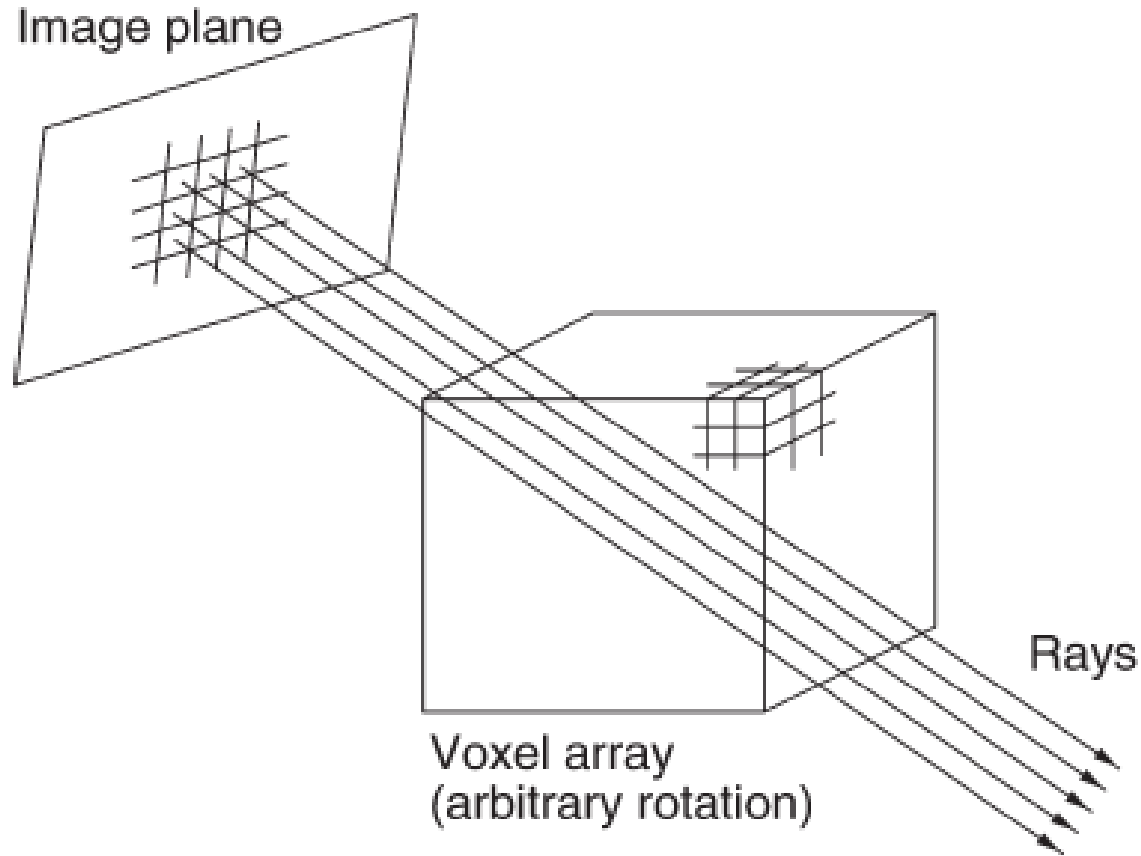
# 3. Navigation

- Done by a computer
- Manipulation of images
  - Surface
    - Used for organs, arteries
  - Slices
    - Multi-plane view
    - Not the same as B-scans
  - Voxel
    - Locating structures, volume measurements
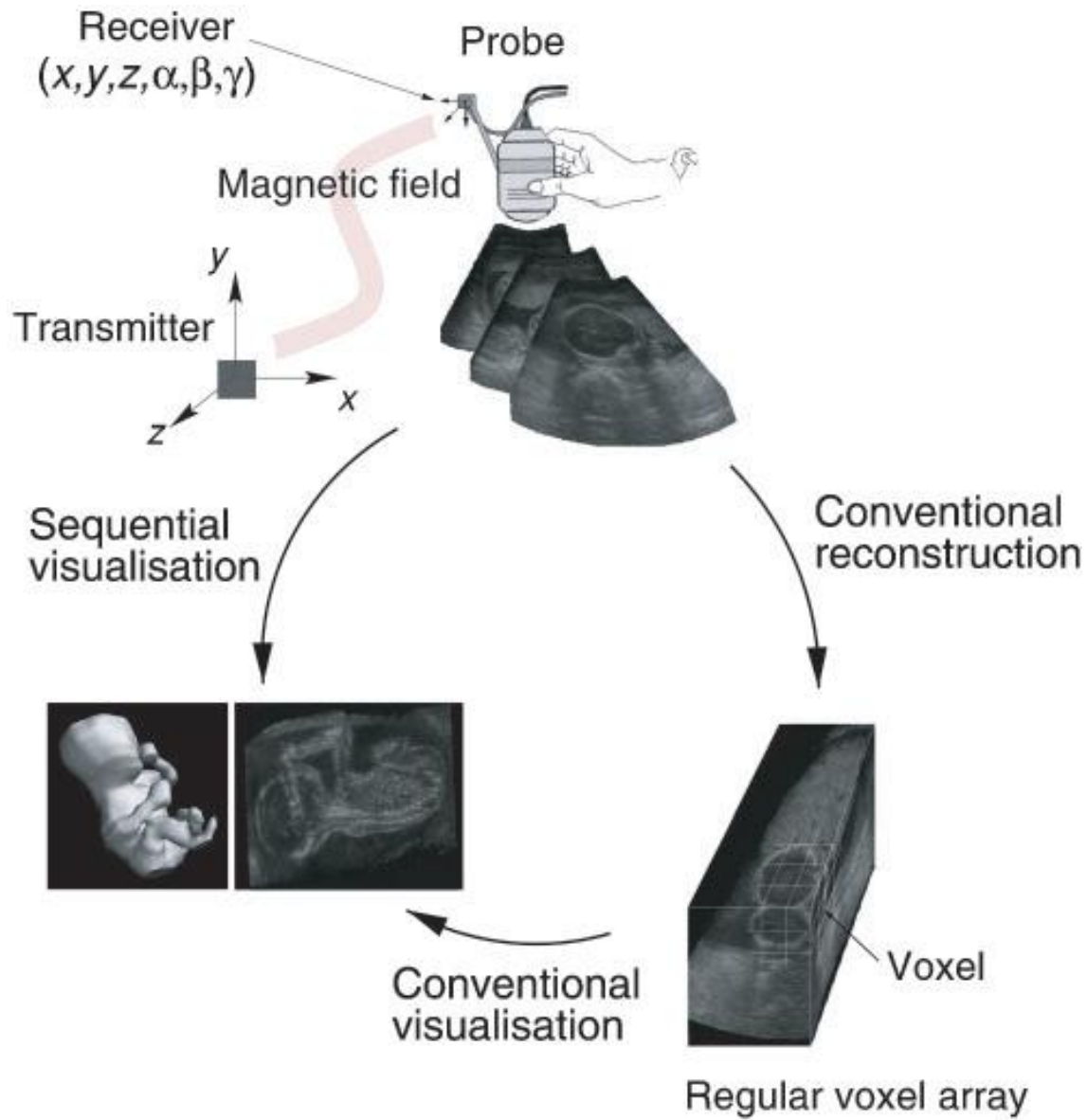    - Ray casting

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# Surface

# Slices

# VOXEL



Receiver $(x,y,z,\alpha,\beta,\gamma)$

Probe

Magnetic field

Transmitter

Sequential visualisation

Conventional reconstruction
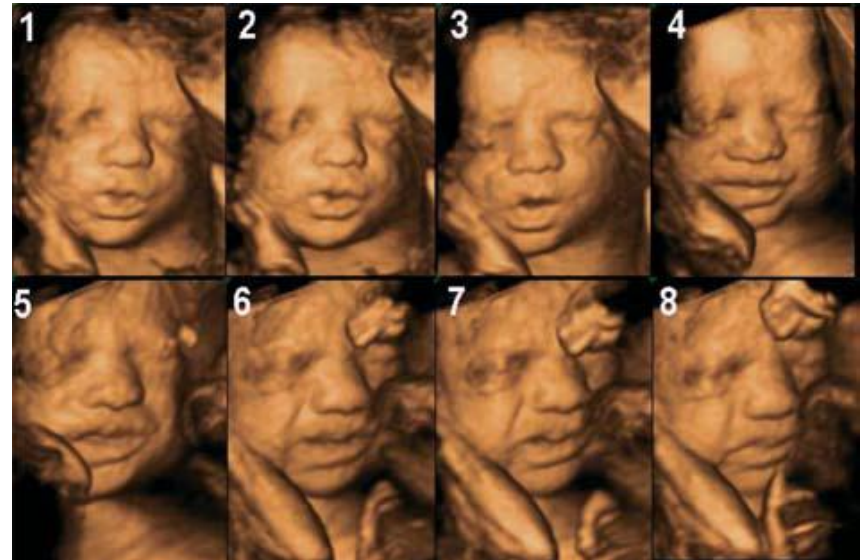
Conventional visualisation

Voxel

Regular voxel array

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# 4D Ultrasound

- Multiple 3D images within a short period of time put together for a moving picture
- Speed of images depends on what is being viewed
  - Fetal imaging vs. echocardiography

http://www.youtube.com/watch?v=KPkliidHlP4

# HISTORY

- Multiplanar scanner developed in 1973 by Tom Brown in Glasgow



- Three-dimensional visualization began developing in the early 1980's
- A lot of the early work came from cardiologists in an attempt to find a method of measuring the volume of cardiac chambers



- Scanners mounted on articulated arms to track path
- Early images not as clear as 2D and very time-consuming
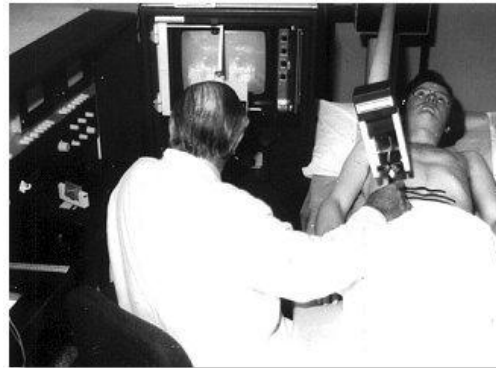


Baba's Early 3-D image of a 19 weeks fetus

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# HISTORY (CONTINUED...)

- 1991 – matrix array scanner to image cardiac structures in real-time and 3D
- 1994 – development of Medical Ultrasound Imaging integrated circuits (MUsIC)
  - process signals from multiple images
  - basis for first electronically steered matrix-array 3D ultrasound imager
- Many of the pioneering volume rendering algorithms were developed by Pixar Animation Studios
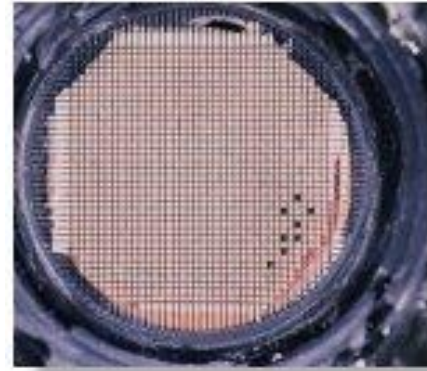


2-D matrix-array at Duke

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# FUTURE

- Current problems:
  - Speed and resolution compromise
  - Size of equipment
  - Cost
- Future development
  - Develop 2D transducers
    - Different alignments
    - Cheaper cost, more compact
  - Research shows that 3D is promising
    - Not being used as widely: cost, size
    - Resolution, speed have already been improved
  - 4D is very intense (time-sensitive)
    - Make safer
    - Increase speed without sacrificing quality

Intrauterine
Sport Activities

פעילות ספורט ברחם

[http://www.youtube.com/watch?v=sVB0qTiq5jU](http://www.youtube.com/watch?v=sVB0qTiq5jU)

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# ETHICS

- A commercial practice?
  - Peek-a-boo Ultrasound
  - My Sunshine Baby
  - Womb with a View
  - Access to ultrasound → $
- Pro-life movement
  - Nebraska LB 657
  - 2009
  - Women about to abort must have an ultrasound within one hour before abortion

# QUESTIONS?

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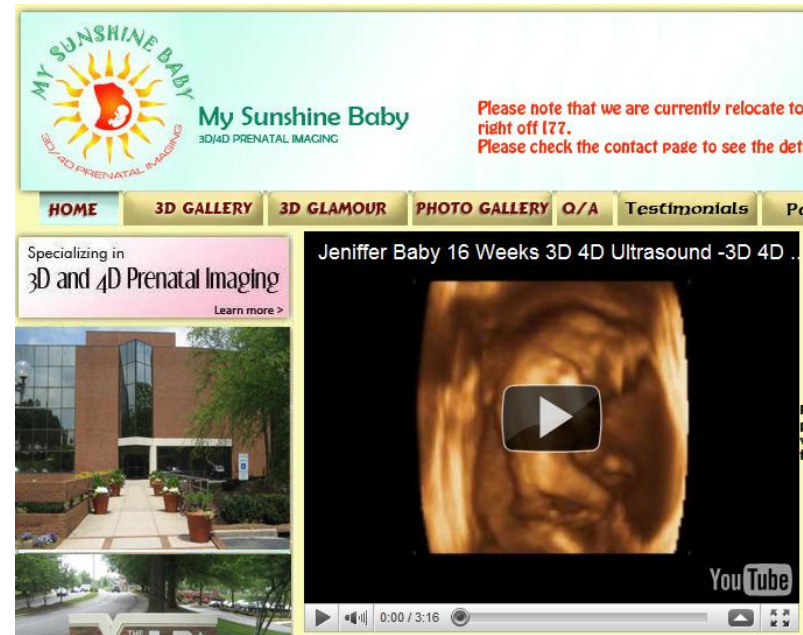
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- http://nebraskalegislature.gov/FloorDocs/Current/PDF/Intro/LB675.pdf