- HW 7 (LAST ONE) DUE NEXT TUESDAY
- HW 6 SOLUTIONS AND GRADED HW 6 BY NEXT MONDAY
- PROJECT PROPOSALS => FEEDBACK BY EOD TOMORROW
- LECTURES: TODAY, NEXT WEEK, AND 12/1 (4 LEFT)
- PRESENTATIONS: 12/3, 12/8, 12/10 ← SHORT => SEE ME IF YOU ARE WILLING.
- FINAL WRITE-UPS DUE 12/10 (LAST DAY OF CLASS)
- FIELD TRIP WEEK OF THANKSGIVING??

TUESDAY 6-9 PM

ULTRASOUND IMAGING

- CONSIDERED TO BE FULLY NON-INVASIVE AND RISK FREE
- IN RADIOGRAPHY AND CT, WE LOOKED AT TRANSMISSION OF IONIZING RADIATION. W/ ULTRASOUND, WE LOOK AT REFLECTION OF SOUND WAVES.
- IN ADDITION TO DEPICTING SOUND REFLECTANCE, ULTRASOUND IS CAPABLE OF PORTRAYING VELOCITIES ("DOPPLER" IMAGING)
- VERY POPULAR AND CHEAP => COMBINATION OF ANATOMICAL & FUNCTIONAL

SYSTEM CONSISTS OF:

- TRANSDUCER & ASSOCIATED ELECTRONICS, DISPLAY
- TRANSDUCER IS BOTH A TRANSMITTER AND RECEIVER

ELECTRONICS STEER THE BEAM SO THAT AN ARC IS COVERED, YIELDING 2D IMAGE.

MOST COMMON APPLICATIONS:

- IMAGING IN UTERO OF THE DEVELOPING FETUS
- 2D ECHOCARDIOGRAPHY (~~HEART~~ IMAGING)

PHYSICS OF ULTRASOUND

- ULTRASOUND => ANYTHING ABOVE 20kHz IS CONSIDERED ULTRASONIC.
- MEDICAL ULTRASOUND OPERATES AT 1 TO 10 MHz (EXPERIMENTAL SYSTEMS UP TO 70 MHz => WHY?)
- PRESSURE WAVES: CAN BE ABSORBED, REFRACTED, FOCUSED, REFLECTED, AND SCATTERED.

STEPS IN ULTRASOUND:

① TRANSDUCER CONVERTS ELECTRICAL SIGNALS TO ACOUSTIC SIGNALS, AND GENERATES PULSES OF SIGNALS WHICH ARE SENT THROUGH THE BODY.

② ORGAN BOUNDARIES AND COMPLEX TISSUES PRODUCE ECHOES (REFLECTION OR SCATTERING)

③ ECHOES ARE DETECTED BY TRANSDUCER, AND CONVERTED BACK TO ELECTRICAL SIGNALS

④ IMAGING SYSTEM PROCESSES THE ECHOES AND PRESENTS A GRAYSCALE IMAGE. EACH POINT IN IMAGE CORRESPONDS TO ECHO STRENGTH AT ANATOMIC LOCATION OF AN ECHO-GENERATING STRUCTURE.

HISTORY:

- STARTED IN 1950's
- RAPID EXPANSION IN 1970s, W/ 20 REAL-TIME SYSTEMS
- PHASED ARRAY SYSTEMS IN EARLY 1980s
- COLOR FLOW IMAGING IN THE MID 1980s
- 30 SYSTEMS IN THE 1990s.

THE WAVE EQUATION;

- PRESSURE WAVES ⇐ ACOUSTIC WAVES
- RELY ON ELASTIC PROPERTIES OF MATERIAL

LONGITUDINAL ⇐ PARTICLES OSCILLATE IN DIRECTION OF PROPAGATION, SHEAR WAVES CAN FORM TOO IN HARDER MATERIALS, BUT WE DON'T CONSIDER IN ULTRASOUND.

COMPRESSIBILITY OF MATERIAL ⟹ K $\left[\frac{m \cdot s^2}{kg}\right]$ ← $B = \frac{1}{K}$ "BULK MODULUS"

DENSITY OF MATERIAL ⟹ ρ $\left[\frac{kg}{m^3}\right]$

SOUND TRAVELS AT: ~330 m/s IN AIR

~1540 m/s IN TISSUE

SPEED OF SOUND: $c = \sqrt{\frac{1}{K\rho}}$ $\left[\sqrt{\frac{m^3}{m \cdot s^2 / kg \cdot kg}}\right]$ $\frac{m}{s}$

- CONSERVATION OF MASS, MOMENTUM IMPLY EXISTENCE OF ACOUSTIC WAVES

TO DERIVE, LET'S LOOK AT MAGNITUDE OF PARTICLE DISPLACEMENT & VELOCITY IN DIRECTION OF PROPAGATION:

$u(x,y,z,t)$ ⇐ DISPLACEMENT

$v(x,y,z,t)$ ⇐ VELOCITY

WE INTRODUCE THE CONCEPT OF AN ACOUSTIC PRESSURE: (0 IN THE ABSENCE OF AN ACOUSTIC WAVE)

$$p = Z v$$

(v: VELOCITY)

CHARACTERISTIC IMPEDANCE = $Z = \rho c$ (SPEED OF SOUND) (NOT SAME AS v!)

ACOUSTIC PRESSURE IS ANALOGOUS TO VOLTAGE, PARTICLE SPEED IS ANALOGOUS TO CURRENT

Z UNITS ⇒ $\frac{kg}{m^2 \cdot s}$ "RAYLS" (AFTER LORD RAYLEIGH)

ACOUSTIC PRESSURE p MUST SATISFY:

$$\nabla^2 p = \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2}$$

(WAVE EQUATION)

∇^2 IS 3D LAPLACIAN OPERATOR

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

- RELATES SPATIAL PARTIAL DERIVATIVES OF PRESSURE TO TEMPORAL PARTIAL DERIVATIVES OF PRESSURE!

$p = p(x,y,z,t)$

PLANE WAVES:

- VARY IN ONLY ONE SPATIAL DIRECTION AND TIME.

IF $p(x,y,z,t)$ IS CONSTANT FOR ANY PARTICULAR x, y GIVEN A FIXED z, WE HAVE A PLANE WAVE. (MOVING IN $+z$ OR $-z$ DIRECTION).

SO:

$$p(x,y,z,t) = p(z,t)$$

1D WAVE EQN.

$$\frac{\partial^2 p}{\partial z^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

GENERAL SOLUTION IS:

$$p(z,t) = \underbrace{\phi_f\left(t - \frac{z}{c}\right)}_{\text{FORWARD TRAVELING WAVE}} + \underbrace{\phi_b\left(t + \frac{z}{c}\right)}_{\text{BACKWARD-TRAVELING WAVE}}$$

- ONLY CONSTRAINT ON ϕ_f AND ϕ_b IS THAT THEY ARE TWICE DIFFERENTIABLE.

ONE SUCH FUNCTION:

$$p(z,t) = \cos\left[k(z-ct)\right]$$