Reflection Tomography

$\rightarrow$ ultrasound $\leftarrow$ reflections governed by amplitude of return signals

$\rightarrow$ optical $\leftarrow$ absorption of particular wavelengths provide compositional information

$\rightarrow$ near-infrared spectroscopy

- CAN be non-invasive
  (most ultrasound is completely non-invasive)

- Non-ionizing
  \( \Rightarrow \) serial imaging is completely okay
Anatomical/Structural

- Signal of interest is produced by variable reflectance
- US ⇒ acoustic energy reflected/transmitted at a tissue boundary

- Optical ⇒ absorption tells us about composition

Functional

- Can measure dynamic behavior of tissue
  ⇒ observe motion (e.g. heart valves)
  ⇒ observe physiology (HbO or HbR)
  ⇒ quantify flow (Doppler)
  ⇒ diffusion, % O₂
Ultrasound ... basic principles/concepts

- Energy put into the system to be measured at super-sonic frequencies (>20 kHz)
  - Typically 1-10 MHz ... not up to 70 MHz.

- Energy represents **longitudinal waves**
- Propagation of energy is via compression & rarefaction
- Waves can propagate, be attenuated, be absorbed, reflected, refracted & scattered.
Concept of Operation

What happens at the boundary, given propagation in tissue 1 at velocity $v_1$?

propagated distance $\propto$ time
At a tissue boundary, some energy is reflected (R) and some is transmitted (T). The reflected wave will be incident on the tissue at time $t_1 = \frac{2d}{v_1}$. Return times are directly related to distances to tissue boundaries. Also velocities.
\[ \text{time is } f(\text{distance, velocity}) \]

\[ \text{amplitude related to attenuation within the traversed tissues and any T/T coefficients at traversed encountered boundaries.} \]
\[ \begin{align*}
\tau_1 &= \frac{2d_1}{v_1} \\
\tau_2 &= \frac{2d_1}{v_1} + \frac{2(d_2-d_1)}{v_2}
\end{align*} \]
Propagation Velocity:

\[ C = \sqrt{\frac{1}{\kappa \rho}} \]

\[ K = \text{Compressibility of medium} \]

bulk modulus \( B = \frac{1}{K} \)

\[ \rho = \text{density of medium} \]

Longitudinal waves...

Air Cas \( \sim 330 \text{ m/s @ STP} \)

Tissue Cas \( \sim 1500 \text{ m/s @ body} \)

- Blood: 1570 m/s
- Fat: 1450 m/s
- Kidney: 1560 m/s
- Liver: 1570 m/s

Pulse rates near kHz work well...

Typical distances in body \( \sim 10 \text{ cm or less} \)
Waves

Defined as a change over space & time

\[ p(x,y,z,t) \]

Treated as a relative measure

\[ p \neq 0 \text{ in the absence of a propagating wave} \]

\[ \rightarrow \text{Pressure is related to the velocity of the particles that define the wave} \quad [\vec{v}(x,y,z,t)] \]

Pressure-Voltage analogy \[ p = Zv \quad Z = \rho c \quad \text{"characteristic impedance"} \]
Waves in Ultrasound

⇒ Assume plane waves incident on all tissue boundaries [source waves]

⇒ Assuming A is small relative to the dimensions over which the curvature of the tissue changes

C = 1500 m/s so @ f = 1 MHz, \( \lambda \approx 1.5 \text{mm} \)

C = 10 MHz, \( \lambda = 0.15 \text{mm} \)

C = 20 MHz, \( \lambda = 0.75 \text{mm} \)

⇒ Works OK!
Assume all reflections produce spherical waves.

⇒ Treat all reflection boundaries as "point sources".