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Introduction to Medical Imaging Part I

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What is “medical imaging”?

- Technique and process of creating visual representations (**images**) of the interior of a body, i.e., of internal structures that are hidden by the skin and bones

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- It is used for sake of **clinical analysis** (e.g., to diagnose a disease) and **medical intervention** (e.g., to treat a disease)
- It is used to establish a **database of normal anatomy and physiology** to facilitate the identification of abnormalities

Goals of medical imaging

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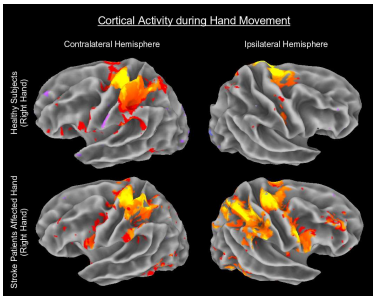

Functional Imaging

Goals of medical imaging

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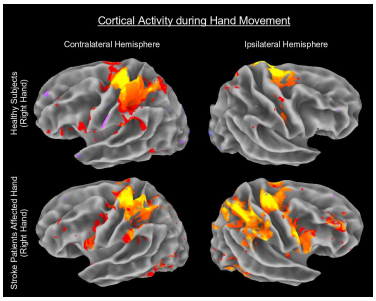

Functional Imaging

Goal: To visualize physiological processes in a living tissue (e.g., blood flow, oxygenation, etc.)

Goals of medical imaging

- Depending on the specific goal, two types of medical imaging are possible:

Structural Imaging

Goals of medical imaging

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Structural Imaging

Goal: To reconstruct the 3-D shape of an internal organ (e.g., to capture tumors, lesions, etc.)

Imaging modalities

- An **Imaging Modality** is the combination of type of probes and technologies used to acquire images of the body

Imaging modalities: signal

- Modalities can be grouped according to the type of signal used to probe:

Signal	Imaging Modality
Electromagnetic waves	*Radiography* *Thermography* *Computerized Tomography (CT)* *Magnetic Resonance Imaging (MRI)* *Positron Emission Tomography (PET)* *Single Photon Emission CT (SPECT)*
Ultrasound waves	*Doppler* *Echography* *Elastography*

Imaging modalities: image formation

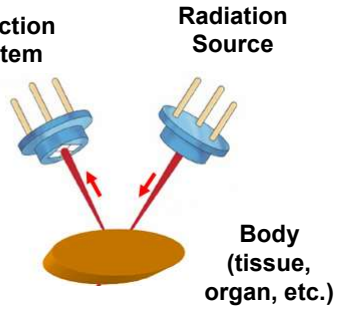
- Modalities can also be grouped according to how the image is recreated:

Imaging modalities: image formation

- Modalities can also be grouped according to how the image is recreated:

Reflection mode:

The image is recreated based on the amount of signal reflected by the tissue of interest

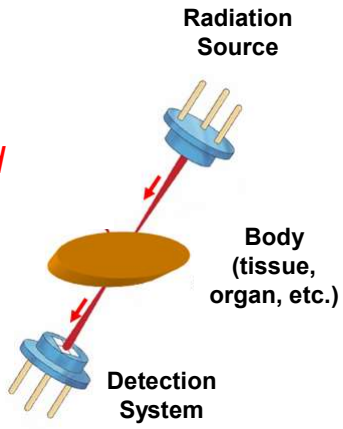


Imaging modalities: image formation

- Modalities can also be grouped according to how the image is recreated:

Transmission mode:

The image is recreated based on the amount of signal passing through the tissue of interest



How good is a medical image?

- Different imaging modalities produce images of different quality

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- One aspect that affects the choice of one modality over the others is the required image quality

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So, how do we define the **quality** of a medical image?

Quality of a medical image

Three parameters define the quality of a medical image:

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1) **Contrast**

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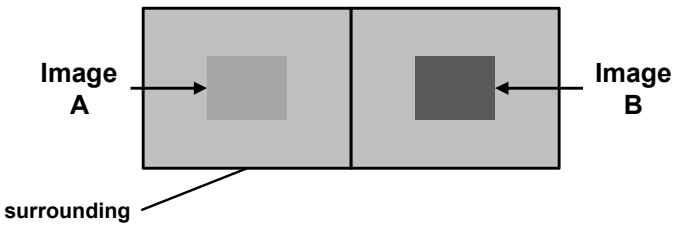
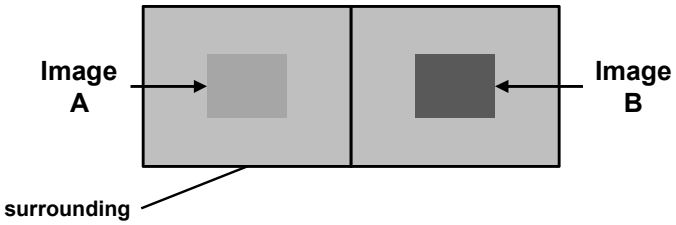


Quality of a medical image

Three parameters define the quality of a medical image:

Image A has **less contrast** (i.e., lower difference in intensity with the surrounding) than image B



Quality of a medical image

Three parameters define the quality of a medical image:

Image B has **less contrast** (i.e., lower difference in color with the surrounding) than image A

Image A

Image B

Quality of a medical image

Three parameters define the quality of a medical image:

2) **Resolution**

Quality of a medical image

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2) **Resolution** ⇒ It is the ability to resolve any two adjacent points of an image

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It defines the **smallest possible** dimensions of a point that can be detected

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Image A

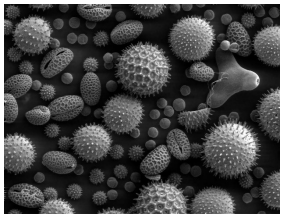

Image B

Quality of a medical image

Three parameters define the quality of a medical image:

Image A has **less resolution** (i.e., detectable points have larger dimensions) than image B

Image A

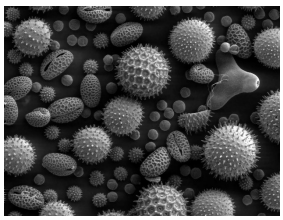

Image B

Quality of a medical image

Three parameters define the quality of a medical image:

3) **Signal-to-noise ratio (SNR)**

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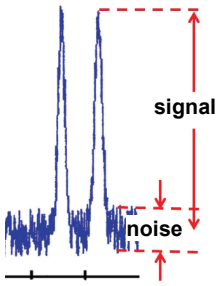
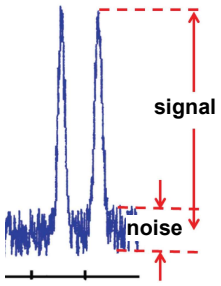


Quality of a medical image

Three parameters define the quality of a medical image:

3) **Signal-to-noise ratio (SNR)** ⇒ It is the ratio between the image signal and the noise from the instrument



Quality of a medical image

Three parameters define the quality of a medical image:

An estimation of the SNR is the ratio between the mean (μ_{sig}) and standard deviation (σ_{sig}) of the signal

$$\boldsymbol{SNR \cong \frac{\mu_{signal}}{\sigma_{signal}}}$$

Quality of a medical image

Three parameters define the quality of a medical image:

In general, the SNR is expressed in **decibels** (dB), i.e., it is computed as:

$$\boldsymbol{SNR = 20 \log_{10}\left(\frac{\mu_{signal}}{\sigma_{signal}}\right) \text{ dB}}$$

Quality of a medical image

Three parameters define the quality of a medical image:

Image A has **higher SNR** (i.e., the signal is much higher than the noise) than image B

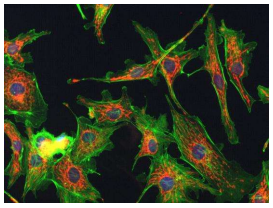


Image A

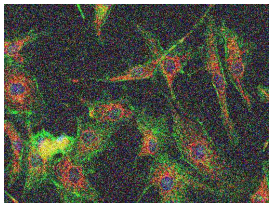


Image B

Quality of a medical image

- The quality of a medical image is largely affected by the type of signal used

Quality of a medical image

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- To understand what aspect of the signal is relevant, let us revise the notions of **electromagnetic** and **ultrasound waves**

What is a wave?

- First, let us recall the notion of **oscillation**

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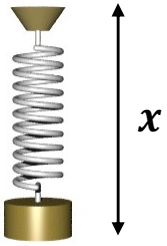
An oscillation is the **repetitive variation**, typically in time, of some measure about a central value or between two different states

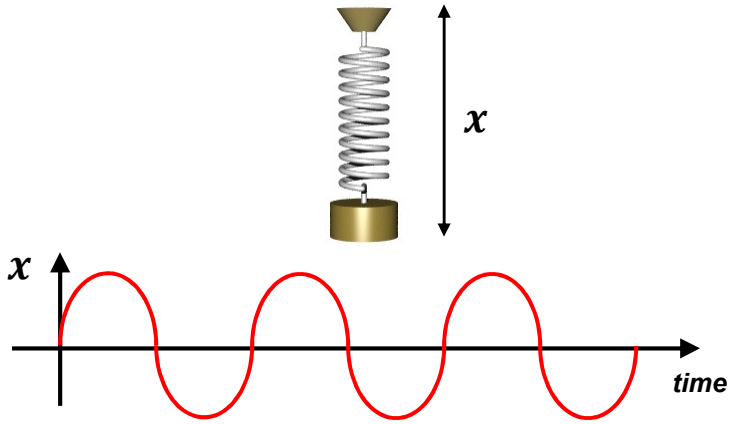
What is a wave?

- If we track the position of the free-moving end in time, we will see…



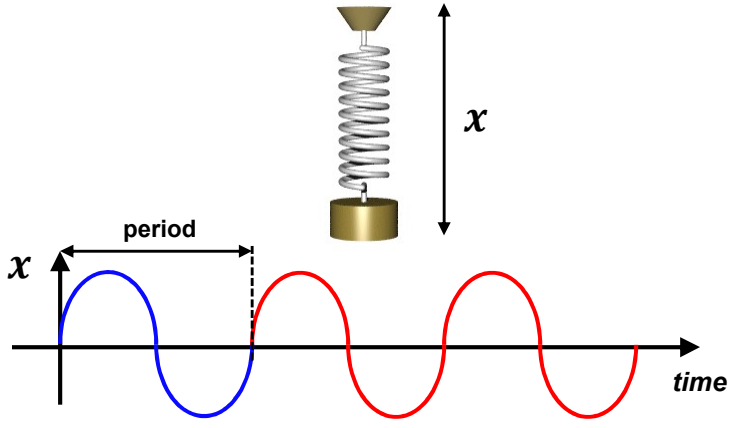
What is a wave?

- … **a sinusoidal-like signal**



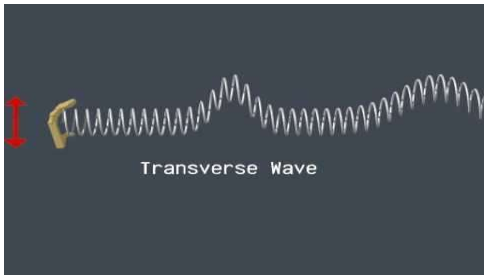
What is a wave?

- The time needed to complete one full cycle is the **period**



What is a wave?

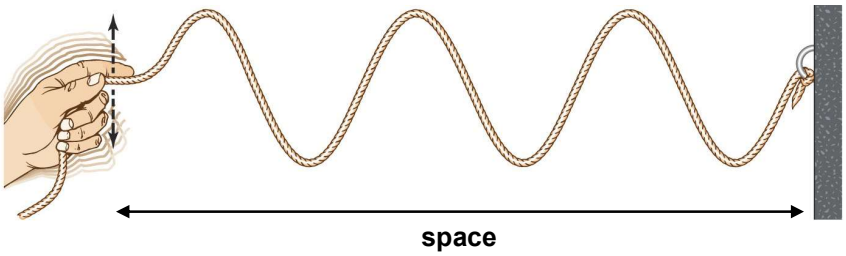
- Let us consider the vibration of a slinky due to vertical movements of the hand



source: *https://www.youtube.com/watch?v=UHcse1jJAto*

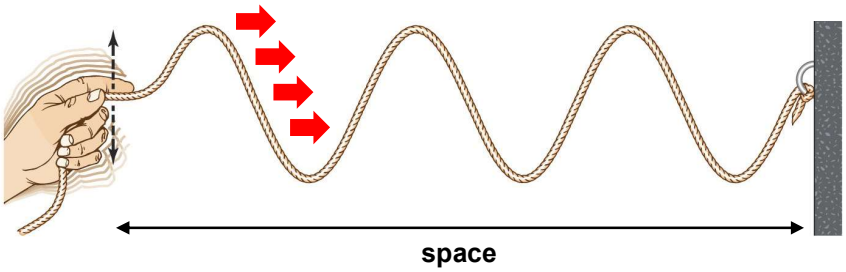
What is a wave?

- Now the sinusoidal-like shape is in space, i.e., if we take a snapshot at a given time ***t*** we may see something like this figure



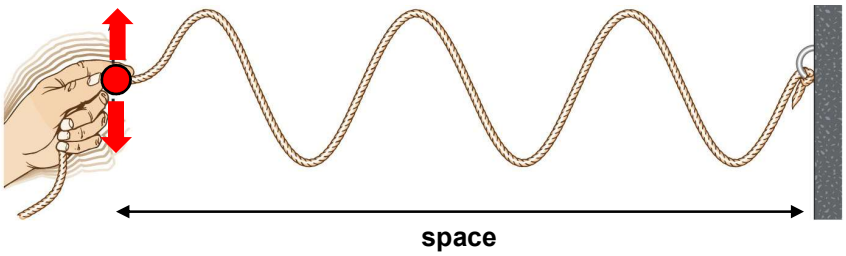
What is a wave?

- Moreover, the sinusoidal-like shape travels from left to right despite the fact that the slinky does not move in the same direction



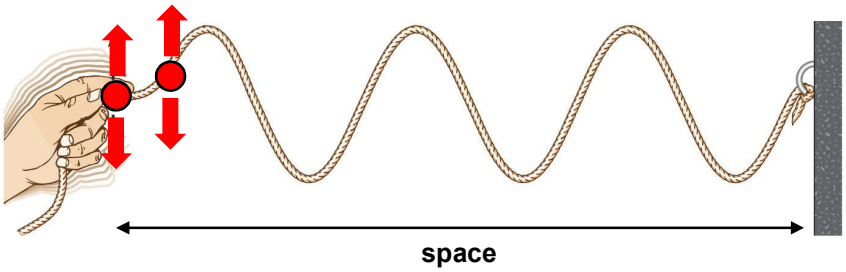
What is a wave?

- To obtain this, each particle of the slinky simply oscillates upward and downward…



What is a wave?

- … and in doing so, it pulls the particle next to it away from equilibrium (i.e., it transmits the oscillation)…



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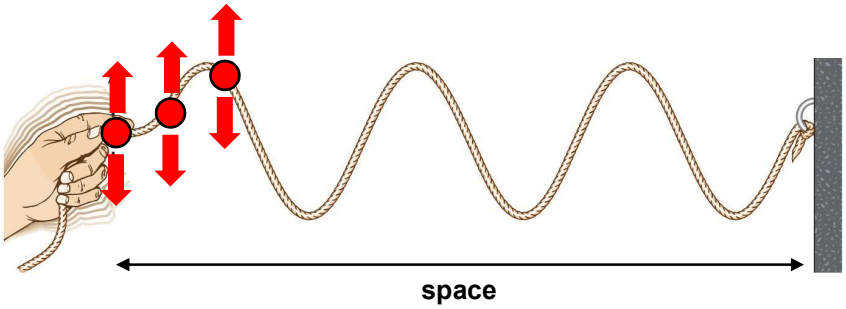
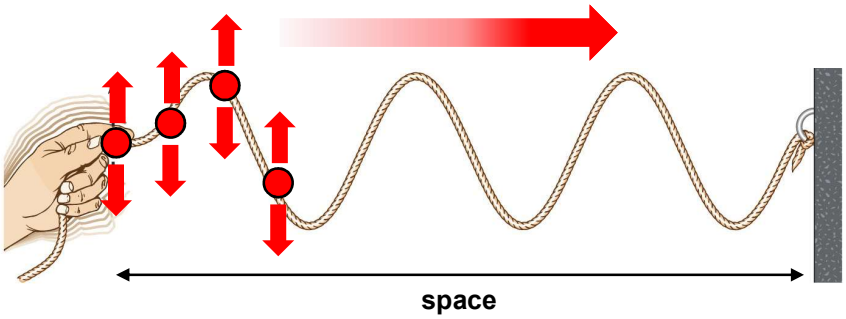


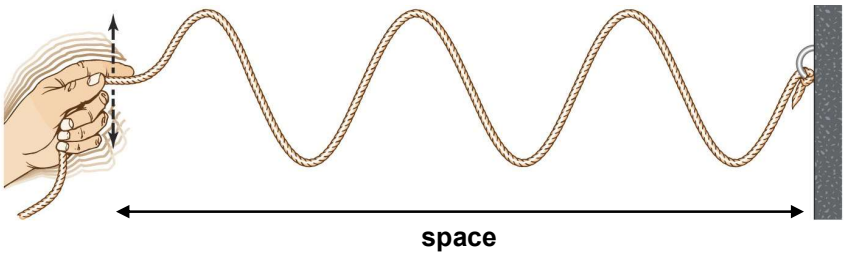
What is a wave?

- … and this makes the sinusoidal-like signal travel through the slinky



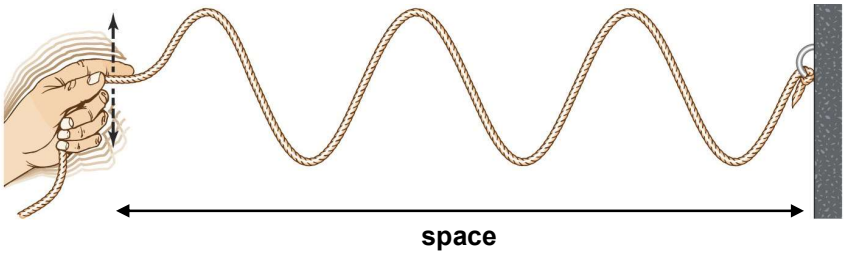
What is a wave?

- This is an example of wave, i.e., a wave is a disturbance or oscillation that travels through matter or space accompanied by a transfer of energy



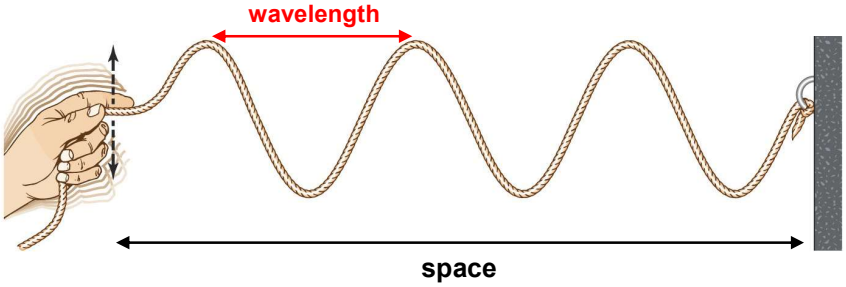
What is a wave?

- Two parameters characterize a wave:



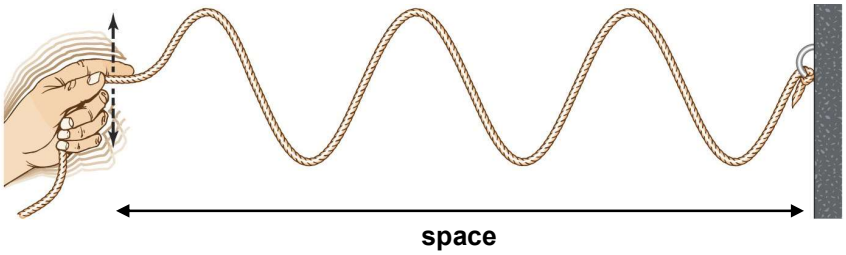
What is a wave?

- Two parameters characterize a wave:
  1) **wavelength (λ)**, i.e., the distance between two sequential crests or troughs



What is a wave?

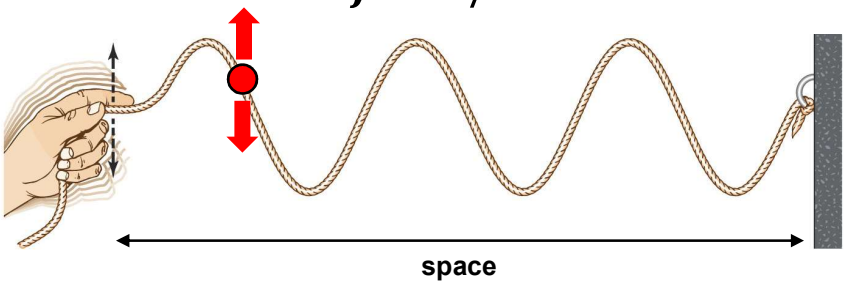
- Two parameters characterize a wave:
  2) **frequency (f)**, i.e., the number of full cycles completed in one second



What is a wave?

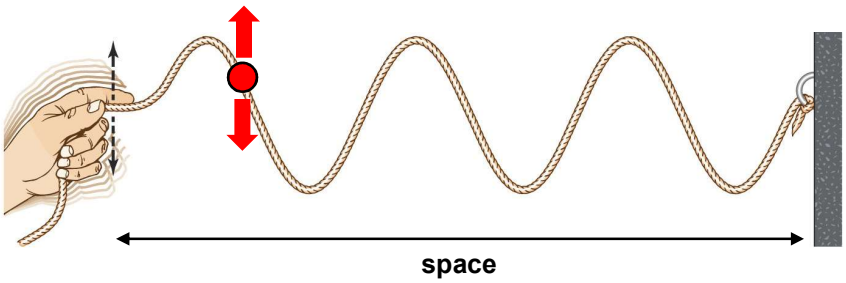
- Two parameters characterize a wave:
  2) Denoted with T the period of a full oscillation of a generic particle, it is:

$$f = 1/T$$



What is a wave?

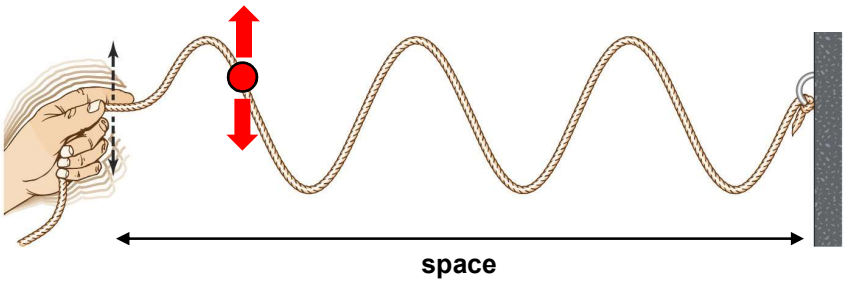
- Two parameters characterize a wave:
  2) Frequency f is measured in Hz, where 1Hz = 1 cycle/second



What is a wave?

- The speed with which a wave propagates through a medium results

$$v = \lambda \times f$$



Waves in medical imaging

- **Ultrasound waves**

Waves in medical imaging

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  Waves that propagate via air and tissue molecules colliding with their neighbors

Waves in medical imaging

- **Ultrasound waves**

  Waves that propagate via air and tissue molecules colliding with their neighbors

  Frequency: $\boldsymbol{f \in [1, 10]}$ **MHz**

  Wavelength: $\boldsymbol{\lambda \in [0.1, 1]}$ **mm**

M = mega, i.e., 10^6

Waves in medical imaging

- **Electromagnetic waves**

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  Waves that originate from the acceleration of charged particles and propagate at the speed of light

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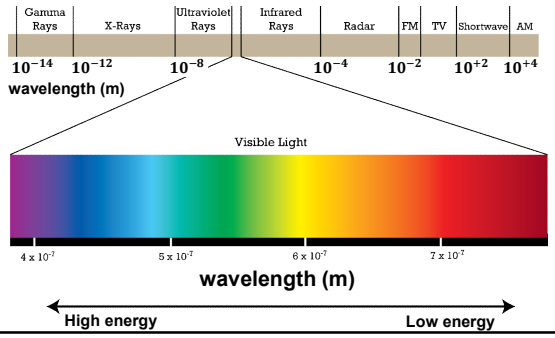
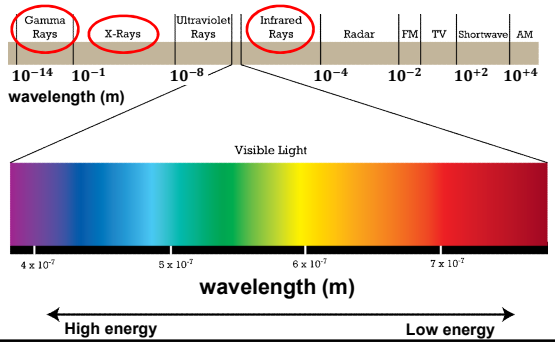


Waves in medical imaging

- **Electromagnetic waves**

  Waves that originate from the acceleration of charged particles and propagate at the speed of light



Wavelength and image quality

- **As a rule-of-thumb, if the wavelength of the probe signal increases…**

Wavelength and image quality

- **As a rule-of-thumb, if the wavelength of the probe signal increases…**
  - …Resolution decreases
  - …Contrast decreases
  - …SNR is non-trivially related to the wavelength