Shutter: Controls the time the sensor is exposed to light.

Aperture: Controls the amount of light entering through the lens.

- **PSF** is the system's response to a single point of light.
- It shows the **blurring** or spreading that occurs when capturing that point.
- It helps in understanding the **resolution** and **sharpness** of an imaging system.
- A smaller FWHM means the system produces sharper, more focused images, while a larger FWHM means more blurring.

FWHM tells you how wide a peak is at half its maximum height.

- **High-detail areas** (narrow dots, fine lines) in an image correspond to **high frequencies** in the spatial domain.
- If you capture an image at a lower frequency (like 50 instead of 100), it **undersamples** the fine details. This causes **aliasing**, where the high-frequency details are misrepresented, often appearing as **incorrect patterns** or **distortions**.

Contrast: (Image – Image_b)/(Image_b)

Clipping in imaging refers to the loss of detail in areas of an image where the sensor cannot capture variations in brightness. happens when pixel values exceed the sensor's dynamic range, causing all values in those regions to be rendered as either pure white (highlights) or pure black (shadows).

$$Ib + 2 \times (Ip - Ib)$$

Optical (Cameras Microscopy Histology) **X-rays (**Radiology CT Nuclear Medical Imaging) **Radio Frequency** (MRI) **Sound (**Ultrasound)

X_ray: Transmission of ionizing radiation(x-ray) through the body.

Optical Imaging (Cameras, Microscopy, Histology)	**Grayscale:** The pixel value represents light intensity **RGB:** The pixel value represents color intensity
Radiology (X-rays)	The pixel values represent the amount of X-ray absorption; denser tissues (like bones) appear white, and less dense tissues (like air) appear dark.
CT (Computed Tomography)	Pixel values are represented in **Hounsfield units (HU)**, which measure the relative density of tissues compared to water. Bones have high positive HU, while air has negative HU values.
Nuclear Medicine (PET, SPECT)	Pixel values represent the **radioactive tracer concentration** in tissues, reflecting metabolic activity. Radiotracer FDG used to emit gamma rays detected by the scanner. Cancer cells use more energy than healthy cells and use sugar to get this energy. Radioactive sugar binds with the tumor. PET can determine if it is cancer, if it has spread, what treatment is effective, is treatment working, relapse of cancer.
Radio Frequency Imaging (MRI) T2 relaxation: How quickly protons lose synchronization with each other (phase coherence). T1 relaxation: How quickly protons release energy and realign with the magnetic field.	Tissue properties based on proton relaxation times. T1 relaxation time (fat and anatomical structures) T2 relaxation time (fluid and edema) **fMRI**: Blood oxygenation level (BOLD signal) used for mapping brain activity.
Sound Imaging Ultrasound	**Acoustic impedance** of tissues. Pixel values reflect how sound waves are **reflected** or **absorbed** by different tissues, with denser structures like bones producing strong echoes (brighter pixels), while fluid-filled areas (like blood or cysts) appear darker.

Microscop	How it Works	What it Shows	Applications
Brightfield	Light passes through the sample; contrast comes from light absorption by the sample.	Best for stained specimens; shows absorption contrast.	Stained cells, tissues, bacteria, microorganisms.
Darkfield : Visualizes unstained samples with a dark background	Scattered light reaches the lens; the background is dark, and the sample is bright.	Great for unstained, transparent specimens with high contrast.	Live, unstained cells, bacteria, and small particles.
Phase Contrast Enhances contrast in transparent samples by converting phase shifts.	Enhances contrast by converting refractive index differences into brightness difference.	Reveals internal structures of transparent, unstained specimens.	Live cells, subcellular components, and tissues.
Polarization Contrast: Highlights birefringent materials.	Uses polarized light to highlight birefringent structures that change light polarization.	Highlights birefringent materials like crystals and fibrous structures.	Crystalline structures, fibrous tissues like collagen.
Fluorescence	A high-energy light is directed at the specimen. The fluorescent molecules in the specimen absorb this light and emit a lower-energy light, usually in the visible spectrum.	biological molecules, organelles, or even live processes with high specificity.	genetic studies for visualizing proteins, DNA, RNA

Most tissue specimens are stained with hematoxylin and eosin.
X-ray is transmission of ionized radiation through the body.

X-ray Attenuation = $I = I_0 \exp(-\mu \times \Delta x)$

Transmission of ultrasound into body where it reflects when hitting a soft tissue. The velocity of sounds will decrease depending on tissue type. A high freq will have high details but with less penetration, and low freq has high penet but low details. The time delay between the transmitted pulse and its echo is a measure of the depth of the tissue interface. Acoustic Impedance = density * acoustic velocity

Anatomical Imaging: Focuses on visualizing the **structure** of the body, showing the **physical details** of tissues, organs, and bones. It provides a static, detailed image of the body's anatomy. (X-ray, CT (Computed Tomography), MRI (Magnetic Resonance Imaging).)
Functional Imaging: Focuses on **physiological processes** in the body, showing how organs or tissues are functioning in real-time or over a period. fMRI (Functional MRI), PET (Positron Emission Tomography), SPECT (Single-Photon Emission Computed Tomography).

Contrast adjstment: f(a) = a_low + ((a – a_low) * ((a max – a min)/(a high – a low)))
Histogram Equalization – Gamma correction
Gamma correction adjusts the brightness of an image to match how we **see light** and how screens display it. **Human eyes/Sceens** don't see brightness in a straight line; we're more sensitive to **darker areas** than bright ones.
Edge Detection – Steps: (Smoothing – Noise reduction) (Enhancement – Edge sharpening) (Detection – which to discard and which to maintain Thresholding) (Localization – determine the exact location of an edge Edge thinning and linking)

Methods of Edge Detection: *Gradient method (First Order Derivative)* Local maxima and minima using first derivative in an image Compute gradient magnitude horizontally and vertically Localization – determine the exact location of an edge. *Zero-crossing methods (Second Order Derivative*) Locate zeros in the local derivative of an image – Laplacian of an image. $\left[\frac{\delta f}{\delta x} a,\ \frac{\delta f}{\delta y} b\right]$ dir: $\tan^{-1}\left(\frac{a}{b}\right)$ mag: $\sqrt{a^2 + b^2}$

Derivative filters are sensitive to noise, otherwhise edge cannot be detected,

Canny Edge Detector LoG filter image to enhance edges Detect edges with two threshold High threshold: definitely part of edge Low threshold: maybe part of edge Remaining pixels: not relevant Edge Tracking by Hysteresis: transforming weak pixels into strong ones, if a nearby pixel is strong

Unsharped mask -> blur + invert + scaled

Corners change of intensity with different viewpoint.

In the 1st derivative, an edge shows up as a peak (a sudden change in intensity). In the 2nd derivative, an edge appears as a zero-crossing (a point where the value changes from positive to negative or vice versa).

SNR = $\frac{(\mu_b - \mu_o)}{\sigma}$

The optimum threshold is that threshold which minimizes the within group variance. Sliding all possible theta and minimizing var. Sensitive to noisy images.

tradeoff between edge accuracy and edge complexity is needed. A = edge_acc + alpha * (Boundry Complexity) where we want to minimize A. For sharp boxes snake cannot benefit as it may not see the box, but applying a blurring filter helps it see it.

Parametric (Snakes)	**Non-parametric implicit models (**Graph-based) (Level-sets (mainly for Geometric Active Contours))

Snakes: $E_{total} = E_{in} + E_{ex}$

Increasing alpha, increases stiffness of curve

E_in: Internal energy encourages smoothness or any particular shape. Internal energy incorporates prior knowledge about object boundary allowing to extract boundary even if some image data is missing.

E_ex: External energy encourages curve onto image structures (e.g. image edges). The external energy describes how well the curve matches the image data locally. It can be image gradients $-\left|G_x^2 + G_y^2\right|$

Snake problem: Snakes originally developed for interactive image segmentation. They do not find' contours; the initial location must be provided either by other processing or by higher level knowledge. Initial snake result can be 'tweaked' where it goes wrong. It can be hard to segment two or more structures. Sensitive to initialization may get stuck in a local energy minimum near initial contour

The external energy describes how well the curve matches the image data locally.

- **Energy terms** (external) pull the contour toward **important features** (edges) in the image.
- **Curvature terms** (internal) enforce **smoothness** and prevent the contour from becoming too irregular or jagged

Level Set: can represent contours corresponding to objects with holes, isolated part.

- **Advantage of level set vs snakes representation**:
- **Level set** can handle **topological changes** (like splitting or merging regions) automatically, while **snakes** (active contours) need manual adjustments for such changes.
- **Significance of the hyperparameter adjusting edge energy**:
- The hyperparameter controls the **influence of edges** in the segmentation process, balancing between following strong edges and smoothing the contour.
- **Hyperparameters compared to Chan and Vese**:
- In **Chan-Vese**, hyperparameters control the weights for **region-based terms** (inside vs outside the contour). We may have adjusted **smoothing weights** or the **balancing of edge detection** vs region-based segmentation.

- **Why are Sobel filters not very sensitive to spatial directions?**
- **Sobel filters** are designed for detecting edges primarily in **horizontal** and **vertical** directions, but they are less effective for detecting edges at **other angles** because their kernel weights are fixed for these two directions.
- **Why are Gabor filters more sensitive?**
- **Gabor filters** are more sensitive because they can be tuned to specific **orientations** and **frequencies**, making them effective at detecting edges or textures in various **directions** and **scales**.
- **How does the size of the filter (and γ value) affect the direction sensitivity of a spatial filter?**
- A larger filter size and a smaller **γ** (aspect ratio) make the filter more **directionally sensitive**, as the filter captures more specific directional features and smooths less across different directions.
- **How does the Gabor filter with a spatial frequency component help identify texture?**
- The **spatial frequency** in a Gabor filter helps detect **repeating patterns** or **textures** by responding to certain **frequencies** in the image, which correspond to the periodicity or structure of the texture.

What does pixel intensity represent in an X-ray image? Microscope image? PET image?	X-ray: Absorption of X-rays (dense tissues like bones appear brighter). Microscope: Light intensity or staining. PET: Radioactive tracer concentration.

Difference between functional and anatomical imaging modality?	Functional: Shows biological activity (e.g., fMRI, PET). Anatomical: Shows structures (e.g., MRI, CT).
Contrast agent for X-ray images? Microscope images?	X-ray: Iodine or barium to enhance contrast. Microscope: Fluorescent dyes or stains to highlight structures.
Ways to define resolution?	Spatial resolution (detail), temporal resolution (time), contrast resolution (difference in intensity), spectral resolution (wavelengths/colors).
K-means processing	Clusters data by minimizing the distance between points and cluster centroids. Iterates until centroids stabilize.
Snakes algorithm: energy function and optimization?	Energy function has internal (smoothness) and external (image gradient) terms. Optimizes by moving the contour to minimize the energy.
Level-set algorithm (Chan, 2001): energy function and optimization?	Uses a level-set function to evolve a contour, minimizing energy related to region-based terms (inside/outside) of the contour. Iterates by updating the function.
Directional filters vs. Sobel filters?	Directional filters detect edges at specific angles. Sobel filters detect edges in horizontal and vertical directions.
Hough transform for lines and circles?	Lines: Converts edge points to parameter space (angle, distance). Circles: Uses center and radius parameters to detect circular shapes.
Block-based features?	Extract features from fixed-size image blocks, typically used for texture, edge, or pattern detection.
Hough features vs. block features?	Hough features detect global shapes like lines/circles. Block features detect local image details.