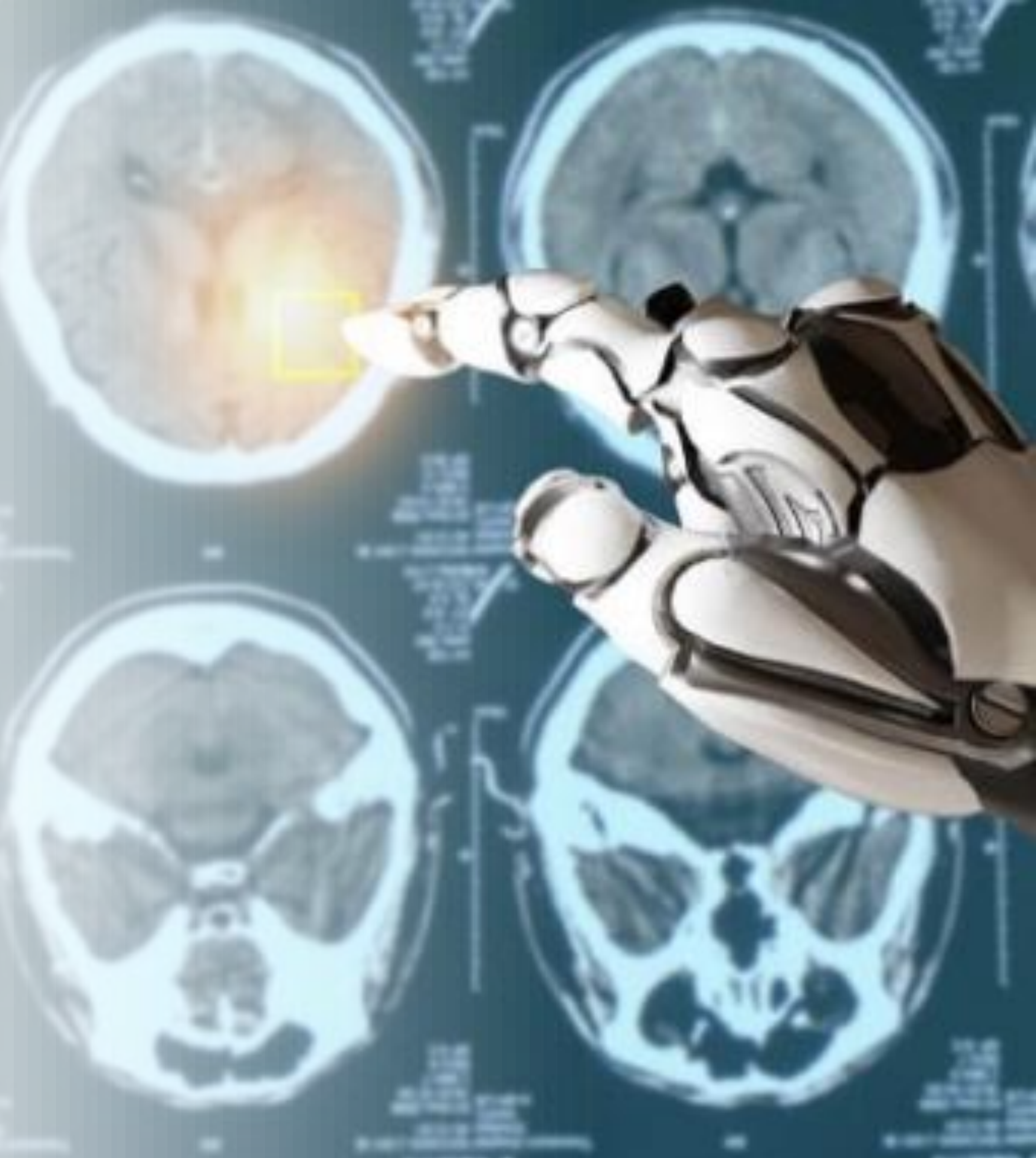
Medical Image Processing in Machine and Deep Learning



Presented by

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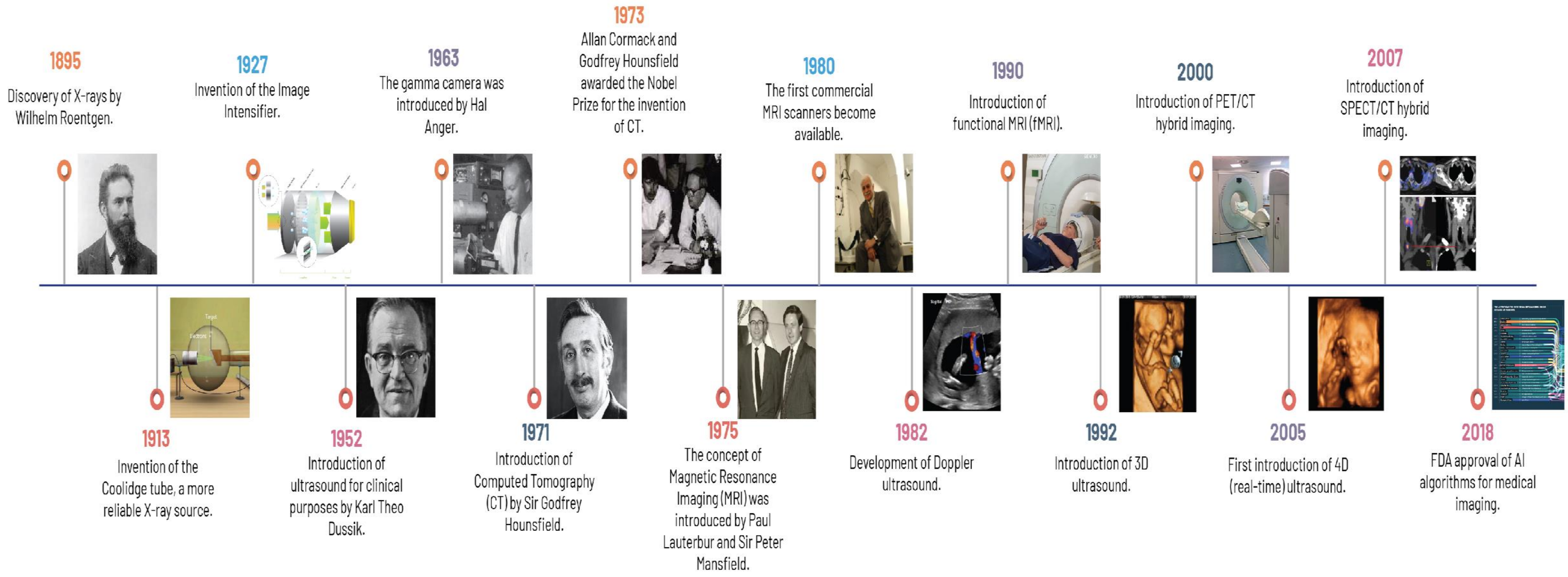
What is Medical Image?

Source: Google image

- Visual representations of the internal structures and functions of the human body or other living organisms, captured through various imaging modalities.
- To diagnose, monitor, or treat medical conditions.
- Medical imaging, also known as radiology
- Non-invasive tests that allow doctors to diagnose injuries and diseases without being intrusive.
- Procedures help determine whether surgery would be an effective treatment option; locate tumors for treatment and removal; find blood clots or other blockages
- Greatly reducing the amount of guesswork done by doctors, allowing them to more effectively deal with patients' injuries and diseases.

Source: Google image

A historical timeline of the key discoveries in medical imaging

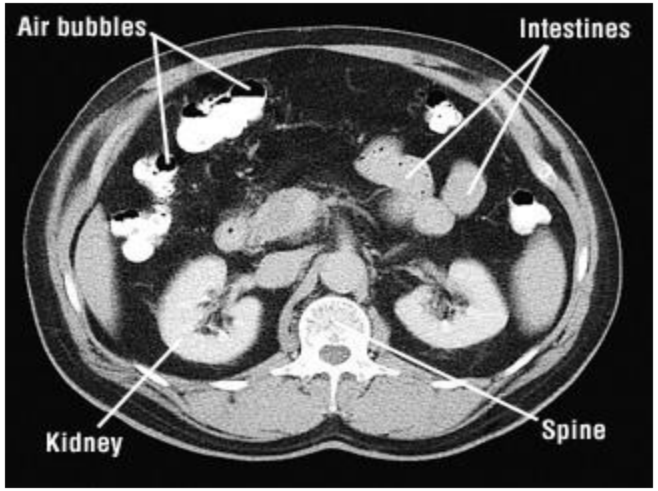


Source: Najjar R. Redefining Radiology: A Review of Artificial Intelligence Integration in Medical Imaging. *Diagnostics*. 2023; 13(17):2760. https://doi.org/10.3390/diagnostics13172760

Role of AI in Medical Image

Najjar, R. Redefining Radiology: A Review of Artificial Intelligence Integration in Medical Imaging. Diagnostics **2023**, 13, 2760.

Type of Medical Images



Source: Google image

MRI scan of brain

MRI scan of knee

X-ray imaging

- Create images of bones and some soft tissues.
- Used for detecting fractures, joint dislocations, and certain lung conditions.

Computed Tomography (CT) Scan

- Combines X-rays and computer processing to generate detailed cross-sectional images (slices) of the body.
- visualizing internal structures like organs, blood vessels, and bones.

Magnetic Resonance Imaging (MRI)

- Utilizes strong magnetic fields and radio waves to create detailed images of soft tissues, organs, and joints.
- Often preferred for imaging the brain, spinal cord, joints, and muscles.

Type of Medical Images (Cont.)

Ultrasound Imaging

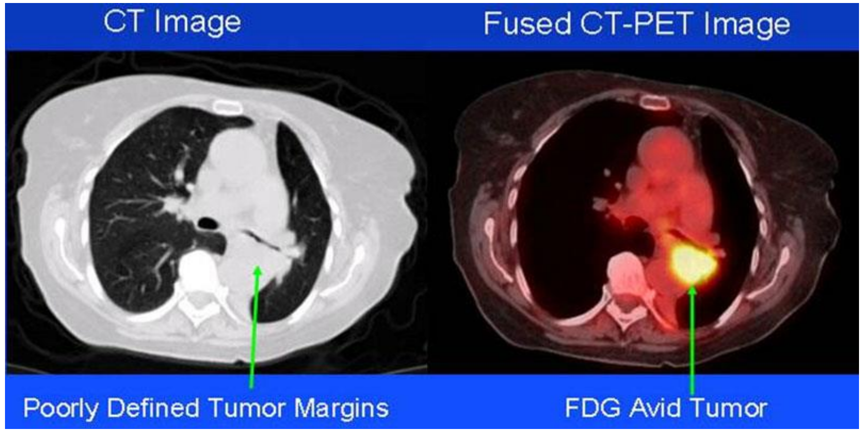
- High-frequency sound waves to create images of internal structures.
- Examining the abdomen, pelvis, and fetal development during pregnancy.

Nuclear Medicine Imaging

- Involves the administration of a radioactive substance (radiopharmaceutical) to visualize the distribution and function of organs and tissues.
- Techniques include Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET).

Mammography

- A specialized X-ray technique used for breast imaging to detect and diagnose breast diseases, including breast cancer.



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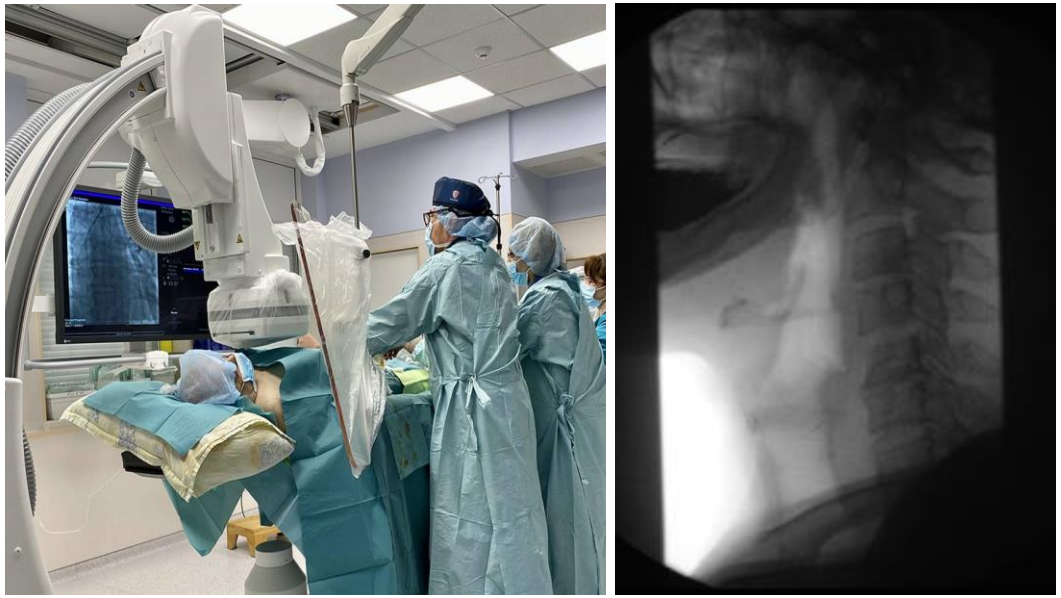
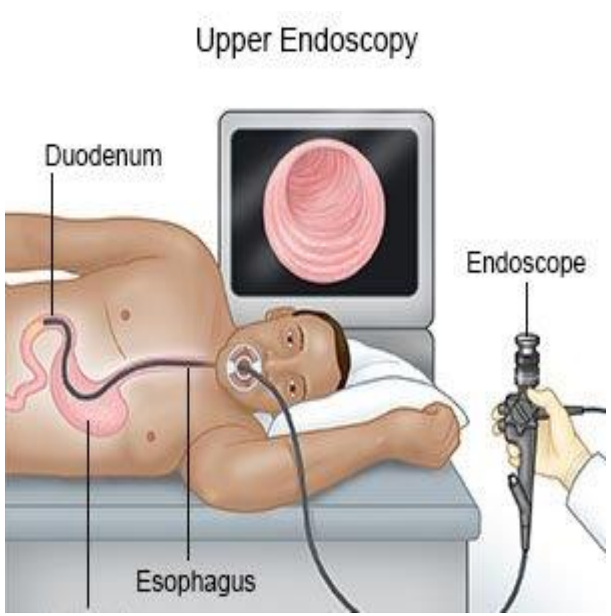
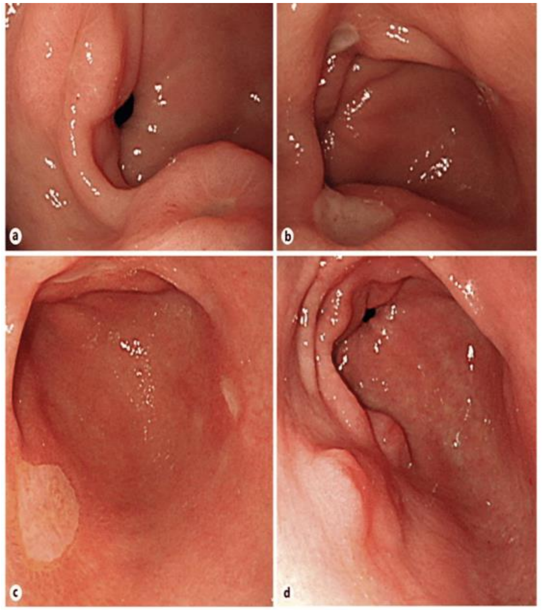


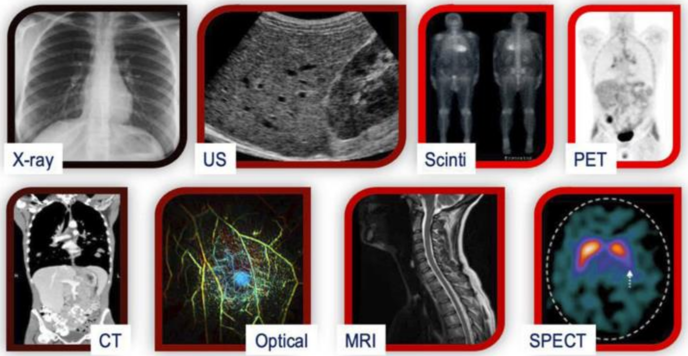
Fluoroscopy





Source: Google image

Type of Medical Images (Cont.)



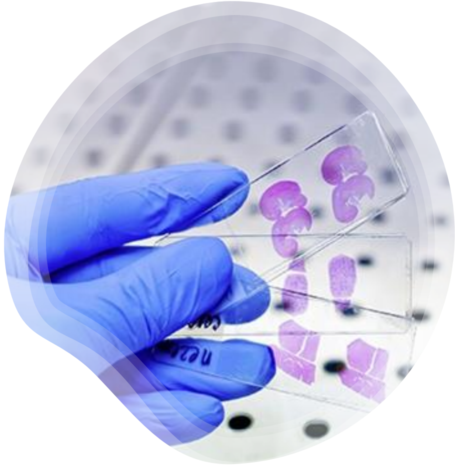
Fluoroscopy

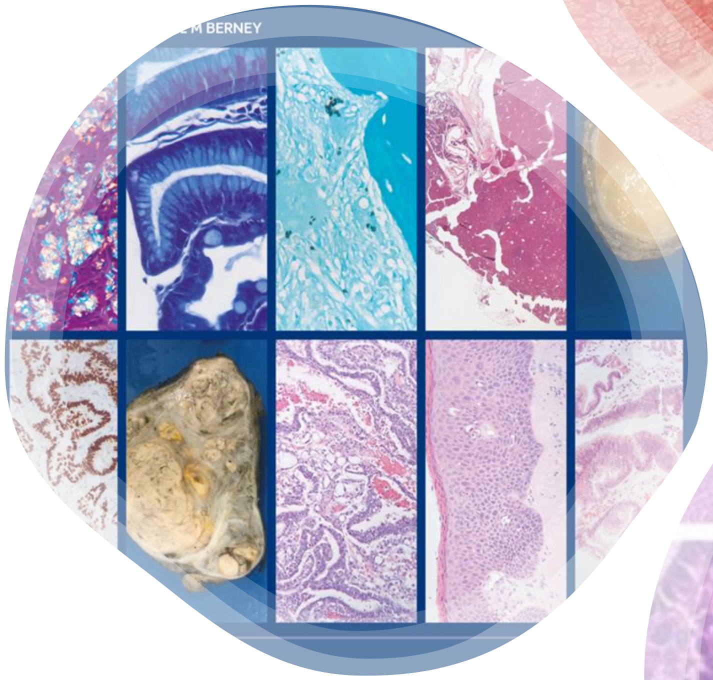
- Real-time X-ray imaging is used to observe the movement of internal structures, such as the gastrointestinal tract or blood vessels.
- Used for procedures such as angiography and gastrointestinal studies.

Endoscopy

- Involves the use of a flexible tube with a light and camera to visualize the interior of organs or body cavities.

Type of Medical Images (Cont.)





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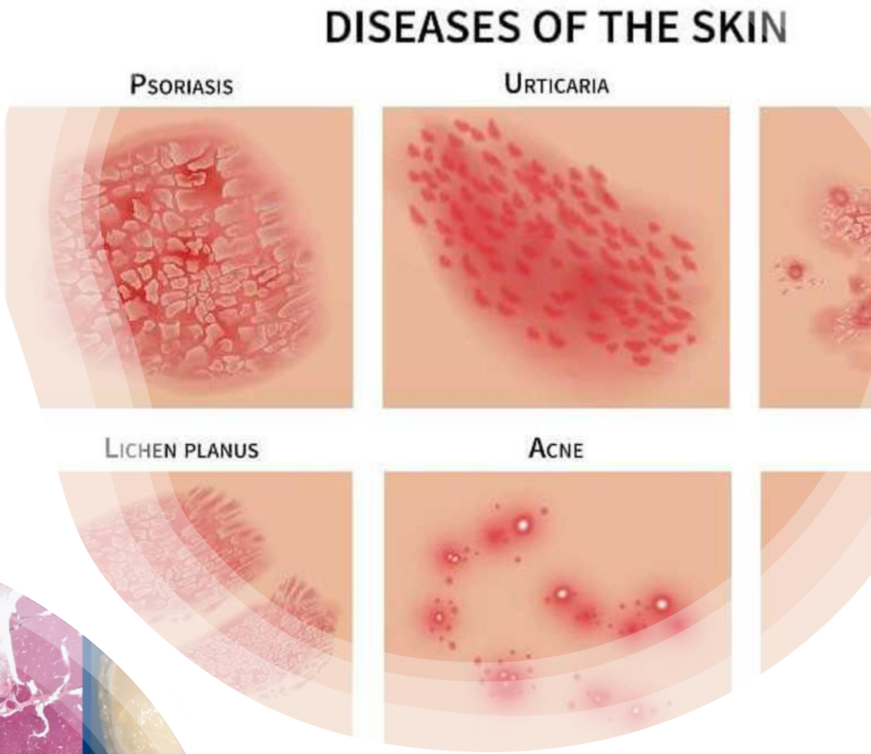

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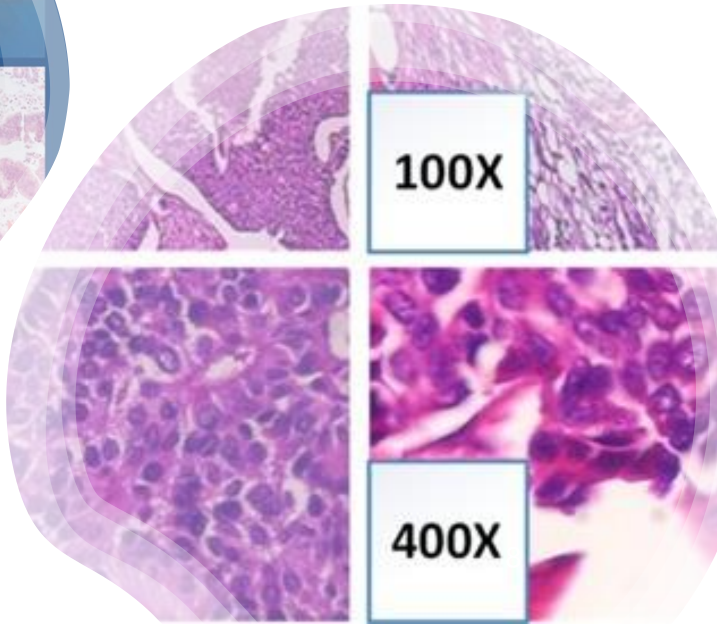


Histopathology Images

- Microscopic images of tissues obtained through staining techniques, such as Hematoxylin and Eosin (H&E), are used for pathological examination to diagnose diseases.

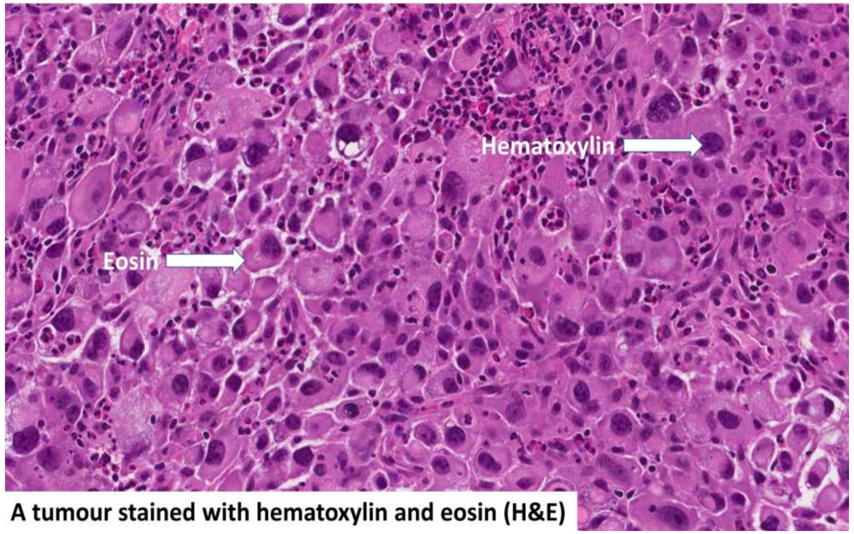
Dermatological Images:

- Images of skin conditions and lesions, often captured using dermoscopy or clinical photography.

Type of Medical Images (Cont.)

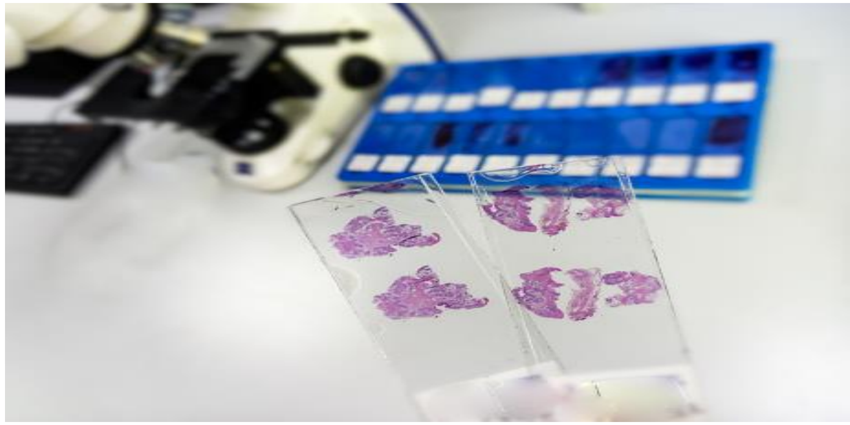
Hematoxylin & Eosin Histology Images

- Staining is a widely used technique in histology to colorize different cellular structures, making them visible under a microscope.
- Hematoxylin stains nuclei blue-purple, while Eosin stains cytoplasm and extracellular structures pink.
- Staining method provides a broad overview of tissue architecture and helps in the identification of various cellular components.
- Histology images stained with H&E are commonly used in pathology and medical research to study tissues, diagnose diseases, and understand the microscopic details of organs and structures.
- These images are often captured using a microscope and can be found in pathology reports, medical textbooks, and scientific publications.



A tumour stained with hematoxylin and eosin (H&E)

Source: Google image

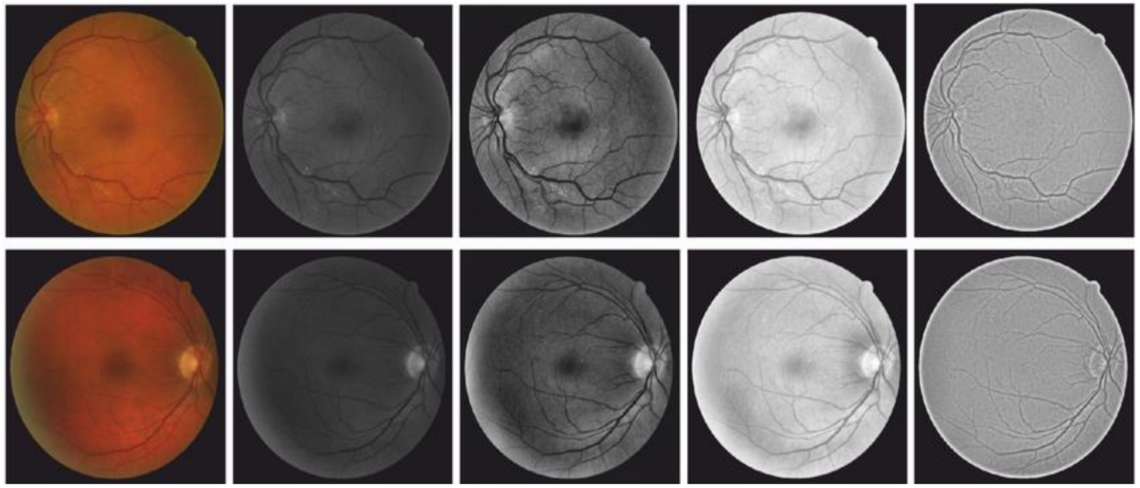


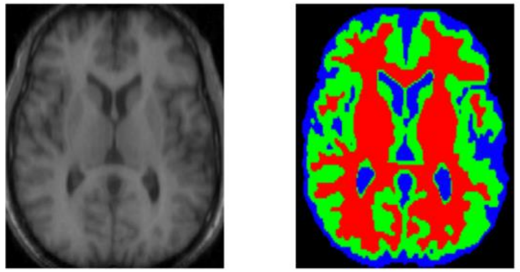
Want to be a master in this area?

Prerequisites	-	Type of Medical images
Basic Image Processing	-	Filtering, segmentation, feature extraction etc.,
Introduction to ML and DL	-	Supervised, unsupervised, Self-supervised
Specific ML / DL Models for Medical Imaging	-	CNN-image, U-Net-segment, RNN-sequence of image
Data Preparation and Augmentation	-	Cleaning and augmentation (New images – GAN)
Framework and Libraries	-	TensorFlow, PyTorch, Scikit-learn
Case Studies and Projects	-	Publicly available dataset, small projects
Stay Updated	-	Read recent ML/DL papers, Community Involvement
Course and Tutorials	-	Coursera, edX, or Udacity
Networking	-	Attend conferences, webinars, and meetups to network

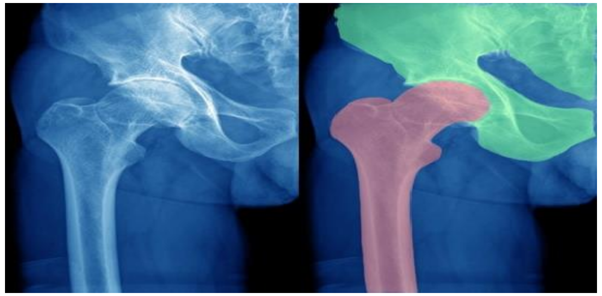
Medical Image Processing

Image Enhancement





(a) Axial slice (b) Tissue segmentation



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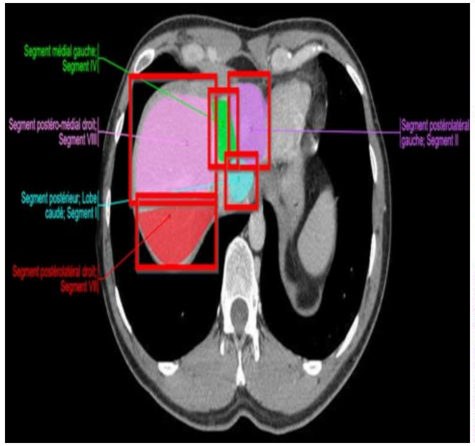


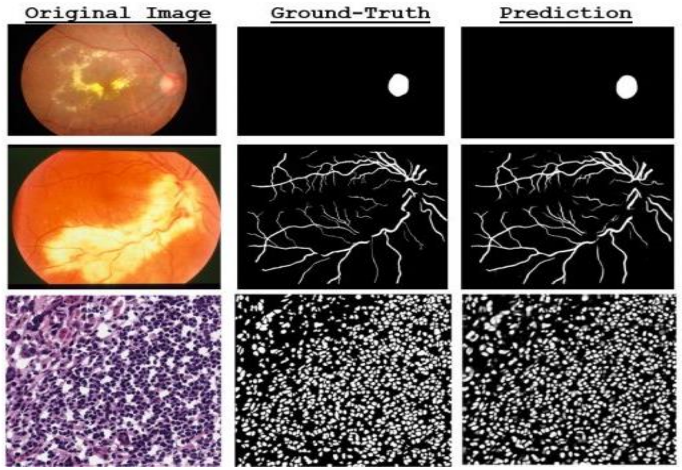


Image Enhancement

- **Contrast Enhancement:** Adjusting the pixel intensity to improve the visibility of structures within an image.
- **Histogram Equalization:** Enhancing the contrast by redistributing pixel intensities.

Image Segmentation

- **Thresholding:** Dividing an image into regions based on intensity thresholds.
- **Region Growing:** Grouping pixels based on similarity criteria.
- **Watershed Segmentation:** Separating overlapping objects using a topographical analogy.
- **DL-based Techniques:** U-Net, Mask-RCNN etc.,

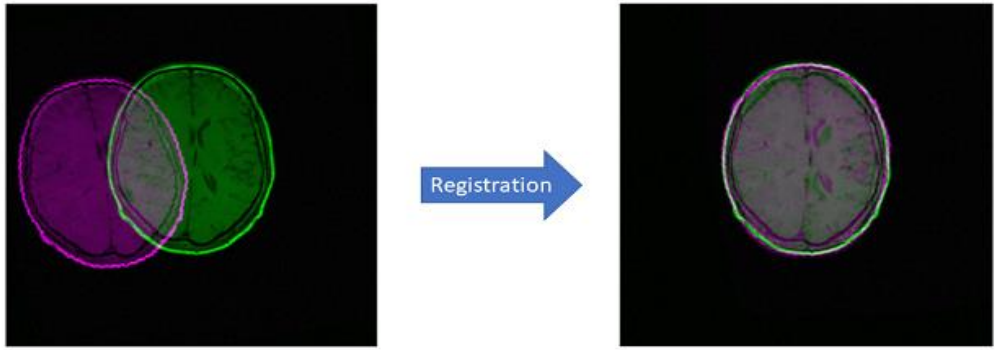
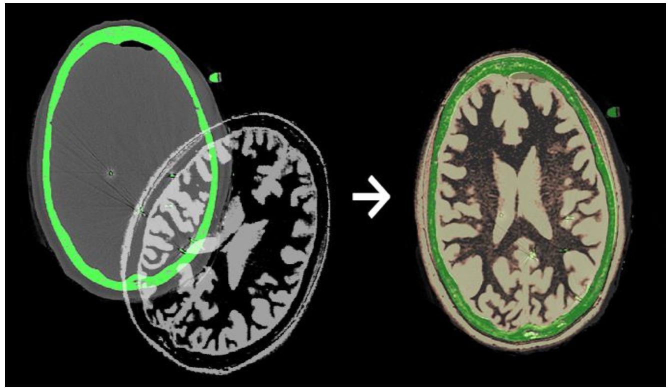


Image Registration



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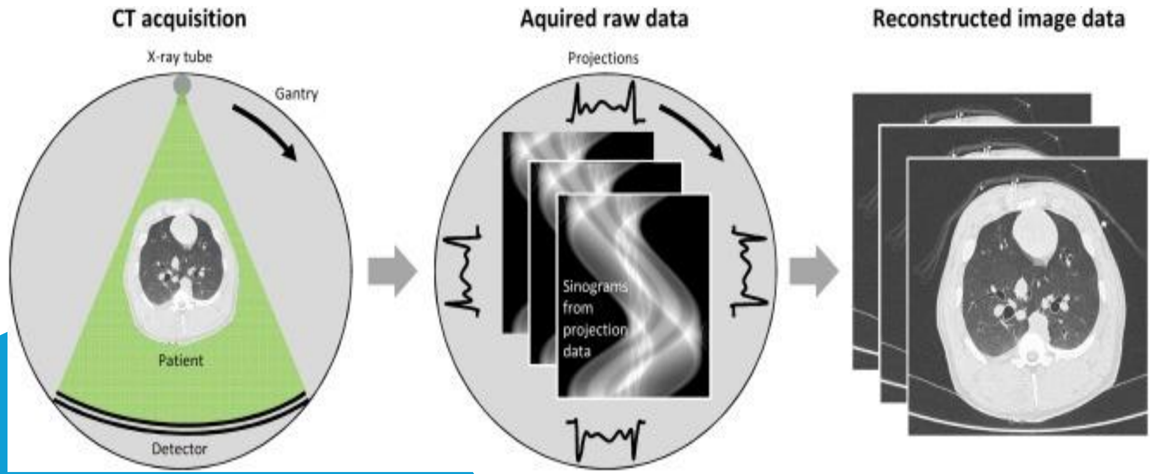


Medical Image Processing

Image Registration – fitting one images onto another

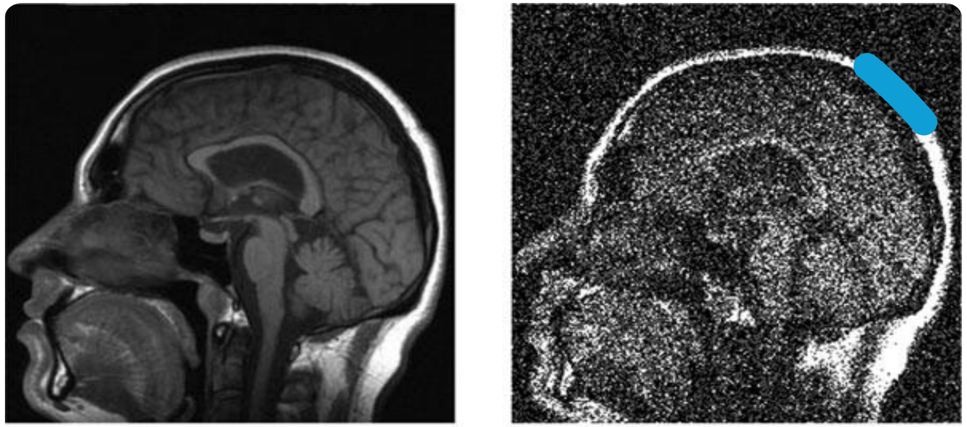
- **Spatial Registration:** Aligning images from different modalities or time points in space.
- **Intensity-Based Registration:** Aligning images based on pixel intensities.

Filtering Techniques

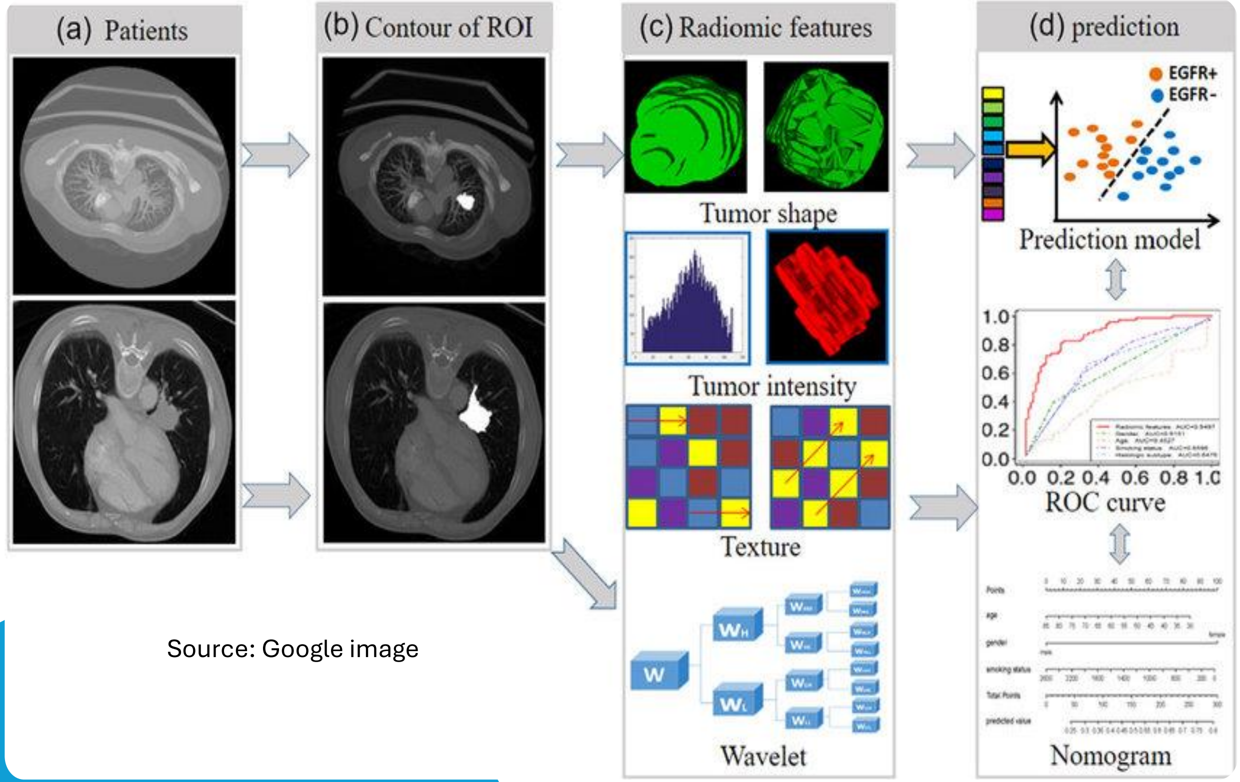
- **Spatial Filtering:** Applying filters (e.g., Gaussian, median) to enhance or suppress certain features.
- **Frequency Domain Filtering:** Using Fourier transforms for image filtering.

Image Reconstruction

- **Computed Tomography (CT) Reconstruction:** Creating cross-sectional images from X-ray projections.
- **Magnetic Resonance Imaging (MRI) Reconstruction:** Assembling images from raw MRI data.



(a) Brain MR Image without noise (b) Brain MR Image with noise



Source: Google image

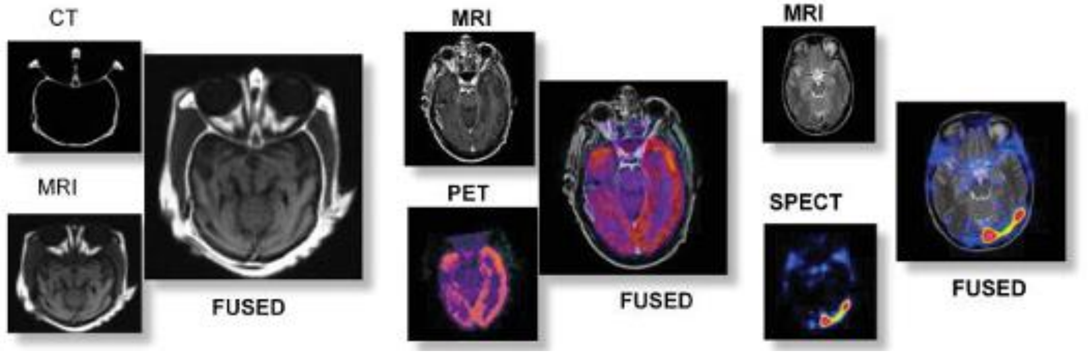
Medical Image Processing

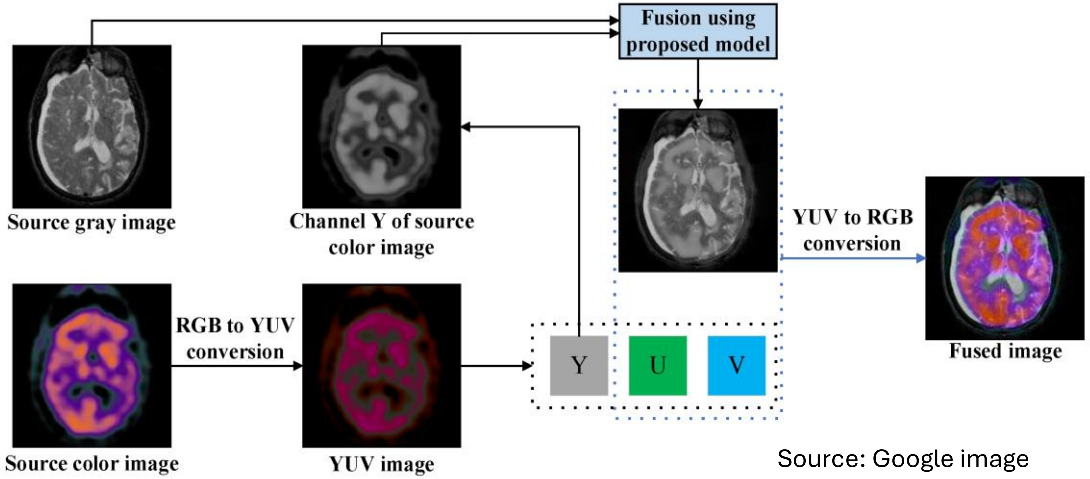
Noise Reduction

- **Median Filtering:** Replacing each pixel with the median value in its neighborhood.
- **Wavelet Denoising:** Decomposing images into frequency components for noise reduction.

Feature Extraction

- **Texture Analysis:** Extracting information related to the spatial arrangement of pixels.
- **Shape Analysis:** Quantifying geometric properties of structures within an image.





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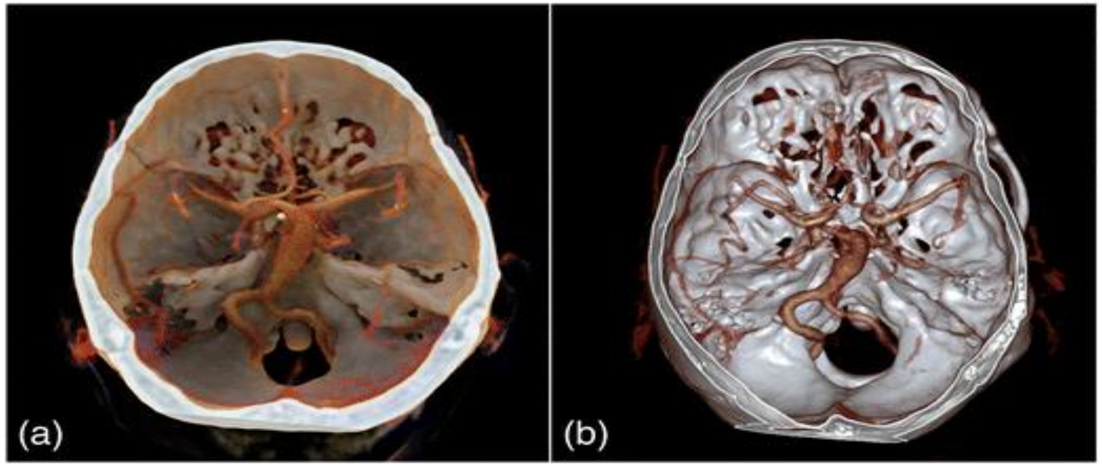


Medical Image Processing

Image Fusion

- **Multimodal Fusion:** Combining information from different imaging modalities.
- **Temporal Fusion:** Integrating information from images captured at different time points.

Machine Learning in Medical Imaging

- **Segmentation with Convolutional Neural Networks (CNNs):** Training deep learning models for accurate segmentation.
- **Classification with Support Vector Machines (SVM) or Random Forests:** Automated diagnosis based on image features.

3D Imaging Techniques

- **Volumetric Rendering:** Creating 3D representations of medical images.
- **3D Reconstruction from 2D Slices:** Reconstructing a 3D model from a series of 2D images.

Why computer vision and machine learning?

Automation & Time Efficiency

Accuracy and Consistency

Quantitative Analysis

Early Detection and Diagnosis

Personalized Medicine

Integration with Multi-model data

Research and Innovation

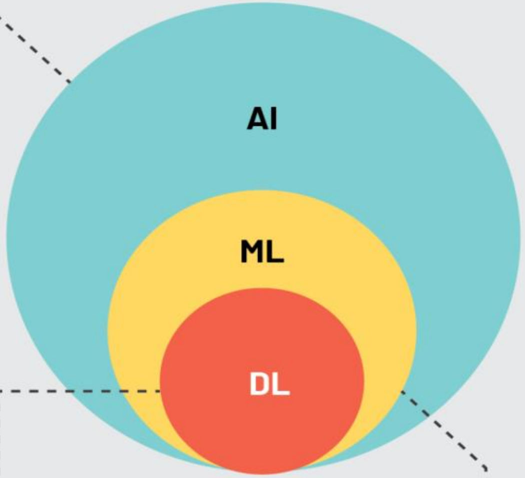
Challenges in Scale

Use of Computer Vision and Machine Learning in Bio-medical

Hierarchy of AI, ML, and DL

Artificial Intelligence (AI)

The development of intelligent machines capable of performing tasks that typically require human intelligence.



Machine Learning (ML)

Algorithms that enable computers to learn and improve from experience without explicit programming.

Deep Learning (DL)

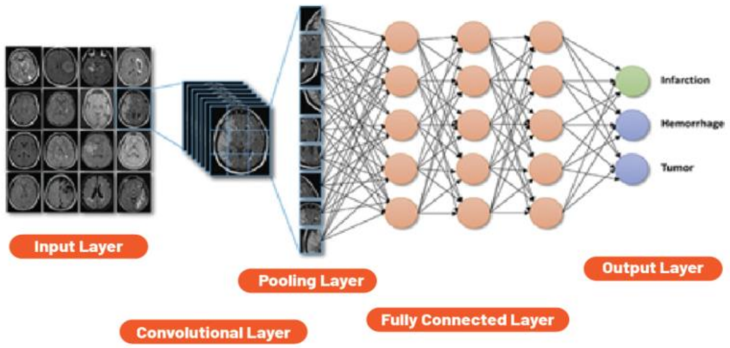
A subset of machine learning that utilises neural networks with multiple layers to automatically learn and extract intricate patterns and features from data.

Types of ML

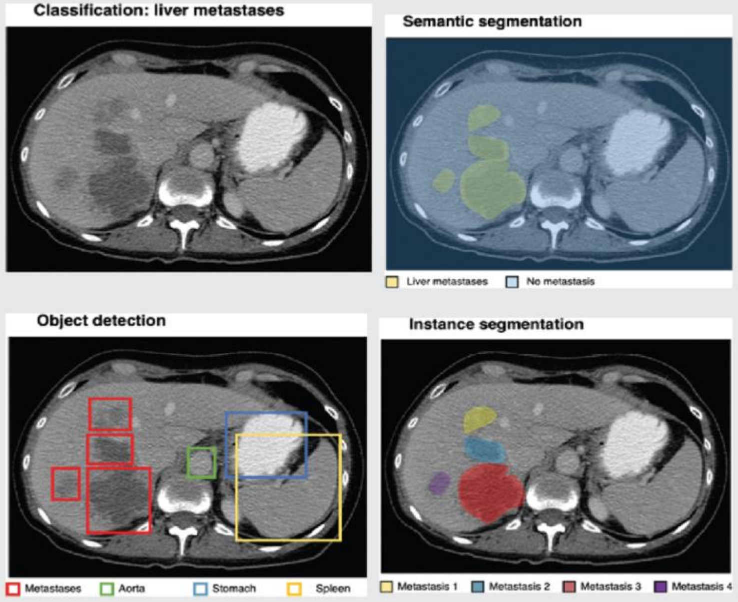
Supervised Learning: ML algorithm learns from labeled data with known input-output pairs.

Unsupervised Learning: ML algorithm learns patterns and structures from unlabeled data without predefined outputs.

Neural Network Layers



Four Key Computer Vision Tasks



Cheng, P et al. Retrieved from: https://doi.org/10.1148/rg.2021200210

Image Classification:
Assigning labels to images

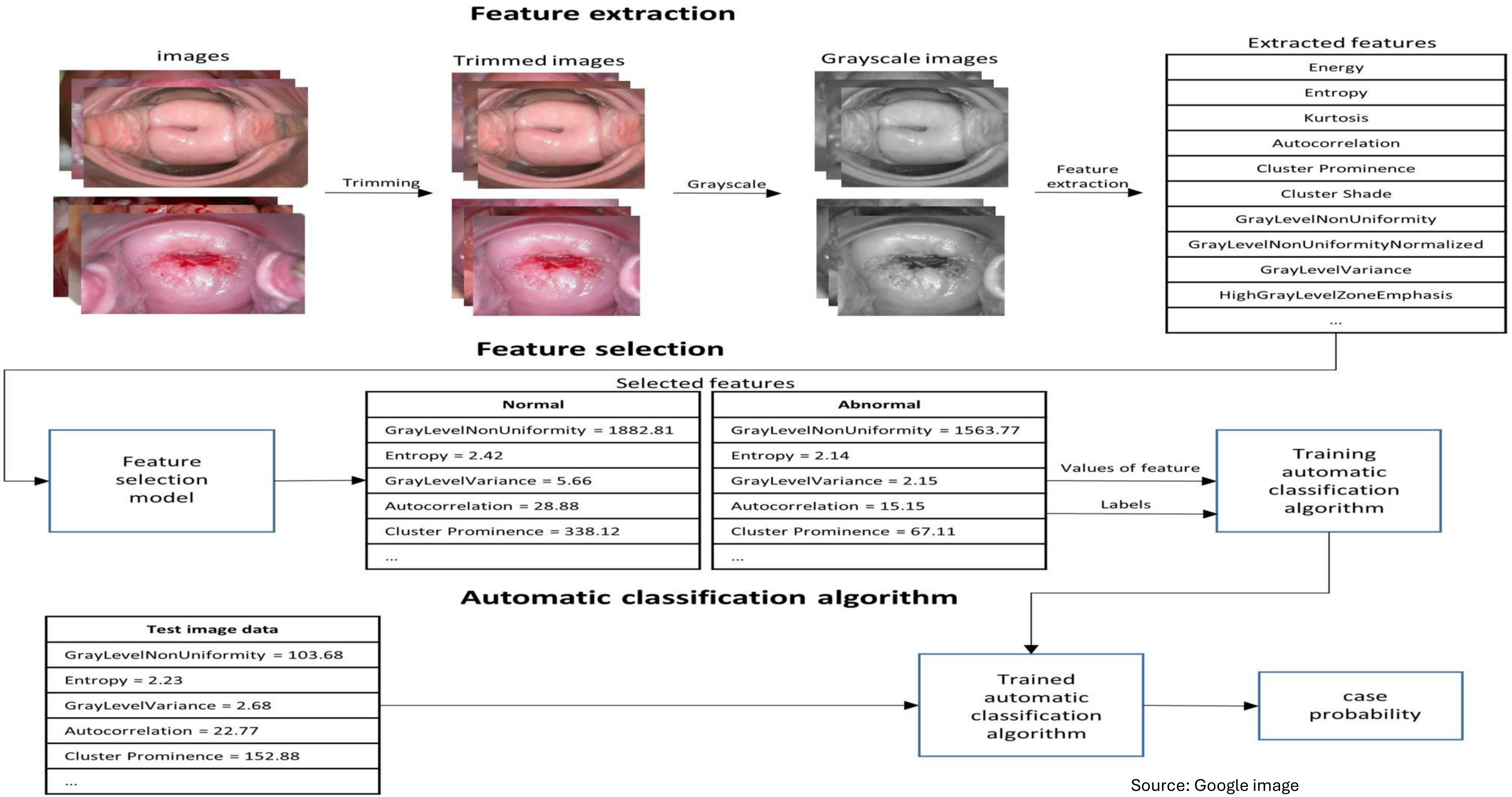
Object Detection:
Locating and outlining specific entities

Semantic Segmentation:
Assigning object category labels to each pixel in the image

Instance Segmentation:
Segmenting and labelling individual objects at the pixel level

Cheng, P.M.; Montagnon, E.; Yamashita, R.; Pan, I.; Cadrin-Chênevert, A.; Perdigón Romero, F.; Chartrand, G.; Kadoury, S.; Tang, A. Deep Learning: An Update for Radiologists. *Radiographics* **2021**, *41*, 1427–1445.

Machine Learning Process



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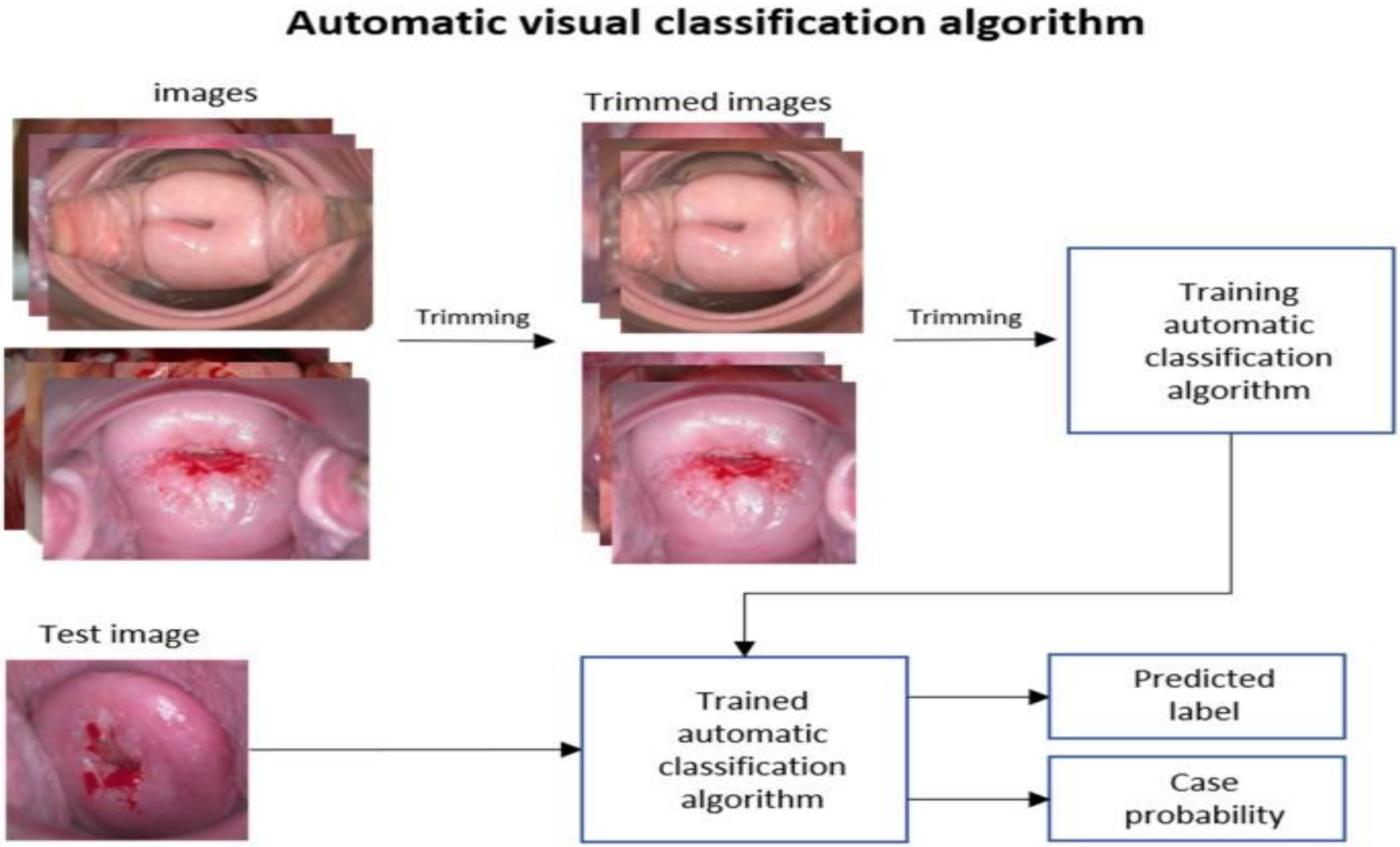
Deep Learning Process



Source: Google image

Basic Learning Foundations: Algorithms and Techniques

Learning Style	Common Algorithms Methods	Applied Ares of Medical Image
Supervised Learning	Linear or logistic regression, Decision trees and random forests, Support vector machines , Convolutional neural networks, Recurrent neural networks	Cancer diagnosis, Organ segmentation, Radiotherapy dose denoising, Radiotherapy dose prediction, Conversion between image modalities
Unsupervised Learning	Auto encoders, Dimensionality reduction (e.g., Principal component analysis), Clustering	Domain adaptation tasks, Classification of patient groups, Image reconstruction
Reinforcement Learning	Q-learning , Markov Decision Processes	Tumor segmentation, Image reconstruction, Treatment planning
Semi-supervised Learning	Generative Adversarial Networks	Tumor classification, Organ segmentation, Synthetic image generation
Self-Supervised Learning	Pretext task: distortion (e.g. rotation), color- or intensity-based, patch extraction	Image classification or segmentation
Transfer Learning	Inductive, Transductive, Unsupervised	Radiotherapy toxicity prediction, Adaptation to different clinical practices, Improving model generalization[
Ensemble Learning	Bagging - Bootstrap AGGregatING - (e.g. random forests), Boosting (e.g. AdaBoost, gradient boosting)	Radiotherapy dose prediction, Estimation of uncertainty , Stratification of patients

Barragán-Montero, Ana, et al. "Artificial intelligence and machine learning for medical imaging: A technology review." *Physica Medica* 83 (2021): 242-256.

Types of Learning in ML and Commonly Applied in Medical Image

Primary Type

- **Supervised Learning** → Uses **labeled datasets** to train algorithms to predict outcomes and recognize patterns. (Classification, Regression)
- **Unsupervised Learning** → Learns from data without human supervision, Unsupervised models are given **unlabeled data** and allowed to discover patterns and insights without any explicit guidance or instruction.
- **Reinforcement Learning** → Machine learning training methods based on **rewarding** desired behaviors and **punishing** undesired ones (Hit and trial)

Hybrid Type

- **Semi-Supervised Learning** → Combines supervised and unsupervised learning by using **both labeled and unlabeled data** to train models for classification and regression tasks.
- **Self-supervised Learning** → **Model is pre-trained using unlabelled data** and the data labels are generated automatically, which are further used in subsequent iterations as ground truths.

Learning Style

- **Transfer** → Reuse of a **pre-trained model** on a new task. This can be useful when the second task is similar to the first task, or when there is limited data available for the second task.
- **Ensample** → Enhances accuracy and resilience in forecasting by **merging predictions from multiple models.**

Tasks we need to know in DL process in Medical Image analysis

Classification

- Classification is sometimes also known as Computer-Aided Diagnosis (CADx). From the clinician's perspective, classification ascertains if a disease state is present or not, i.e., is blood present on this MRI brain scan signifying a hemorrhagic stroke?

Localization

- Localization implies the identification of normal anatomy, For example, where is the kidney in this ultrasound image?

Detection

- Detection, sometimes known as Computer-Aided Detection (CADe), This is in contrast to detection, which implies an abnormal, pathological state, for example, where are all the lung tumors in this CT scan of the lung?

Segmentation

- Segmenting the outline of a lung tumor helps the clinician determine its distance from major anatomical structures, and helps to answer a question such as, should this patient be operated on, and if so, what should be the extent of resection?

Registration

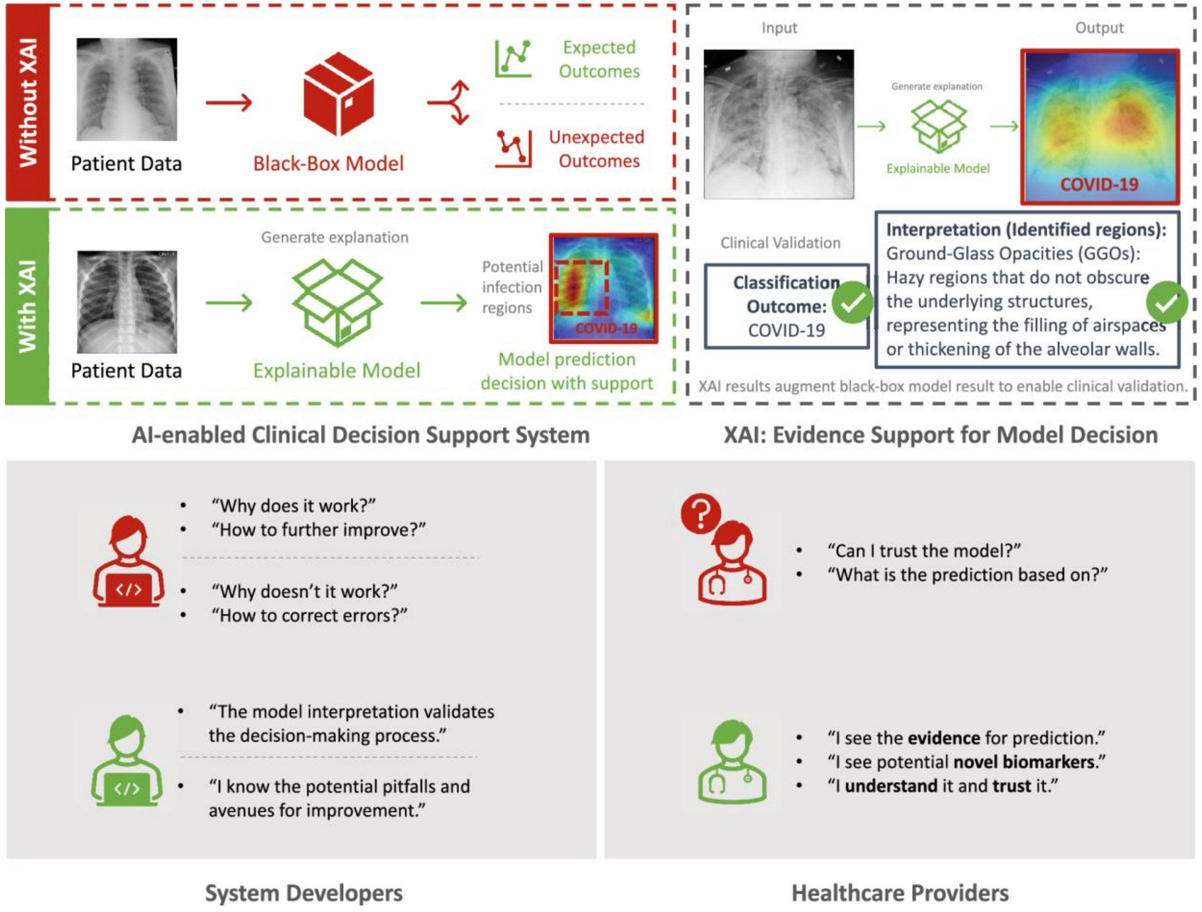
- Image registration is employed in neurosurgery or spinal surgery, to localize a tumor or spinal bony landmark, in order to facilitate surgical tumor removal or spinal screw implant placement.
- A reference image is aligned to a second image, called a sense image and various similarity measures and reference points are calculated to align the images, which can be 2 or 3-dimensional.
- The reference image may be a pre-operative MRI brain scan and the sense image may be an intraoperative MRI brain scan done after a first-pass resection, to determine if there is remnant tumor and if further resection is required.

Summary of Existing Research works in Medical Image analysis

Task	Organ	Modality	Performance Metrics	Network
Detection	Brain, Breast, Eyes, Chest Abdomen	MRI, ABUS, OCT, X-ray, CMR, WGD, US	AUC, True Positive Rate, VOI, False positive, Sensitivity, Area under ROC, F1-score, Shadow confidence	VAE, 3D-CNN, CNN, GAN, VGG-16, sCAE, AEE
Segmentation	Brain, Breast, Eyes, Chest Abdomen	MRI, DCE-MRI, OCT, CT, Mammograms	Dice score, Sensitivity, Specificity, PPV, Runtime, TS, Intensity normalization, Accuracy, ASSD, SP	AE, AD, FCNN +CRF, FCN, cGAN, GANs, CNN
Registration	Brain, Breast, Eyes, Chest Abdomen	MRI, OCT, MR-CT, CT-MRI	Dice Score, Computation time, Reliability, Runtime, Deformation field, DIR, HD, ASD run time, NRMSE	CNN, DFCN, GANs, 3D-CNN, U-Net
Classification	Brain, Breast, Eyes, Chest Abdomen	fMRI, MRI, Histopathology, Mammography, OCT, CT, MRI	ROIs, Classify ASD, Accuracy, VOIs, Sensitivity, Specificity, DR severity accuracy	DNN, 3D CNN, AlexNET, VGG-19, AE, AD, GANs, MIL

Dataset	Organ	Modality / Task
IDL, LIDC-IDRI,	Lung	CT (Classification / Detection
ADNI, BRATS, ACDC 2017, OASIS-3, ISLES 2018, Open Neuro, ABIDE	Brain	MRI, PET, Multiple (Classification, Segmentation, Diagnosis)
DDSM, MIAS,CAMELYON17, INbreast	Breast	Mammography, WSI (Segmentation, Classification/ Detection)
MESSIDOR-2, DRIVE, STARE, CHASEDB1	Eyes	SLO, OCT (Classification, Segmentation)
MURA	Musculoskeletal	X-ray (Detection)
ISIC 2018	Skin	JPEG (Detection)
HVSMR 2018	Heart	CMR (Segmentation)
ChestX-ray 14	Chest	X-ray (Multiple)
OAI	Knee	X-ray, MRI (Multiple)
TCIA	Multiple	Multiple

Altaf, F., Islam, S. M., Akhtar, N., & Janjua, N. K. (2019). Going deep in medical image analysis: concepts, methods, challenges, and future directions. *IEEE Access*, *7*, 99540-99572.



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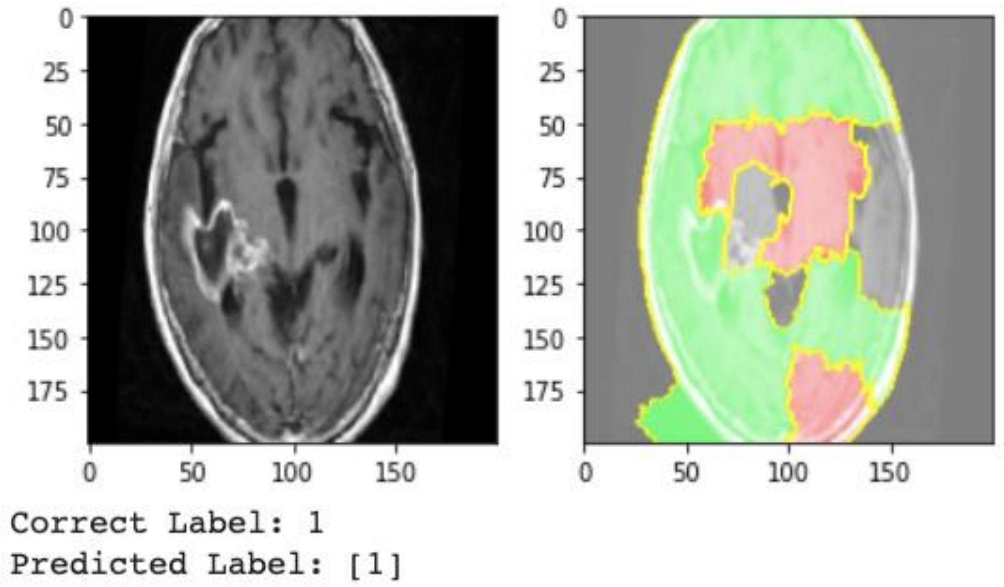
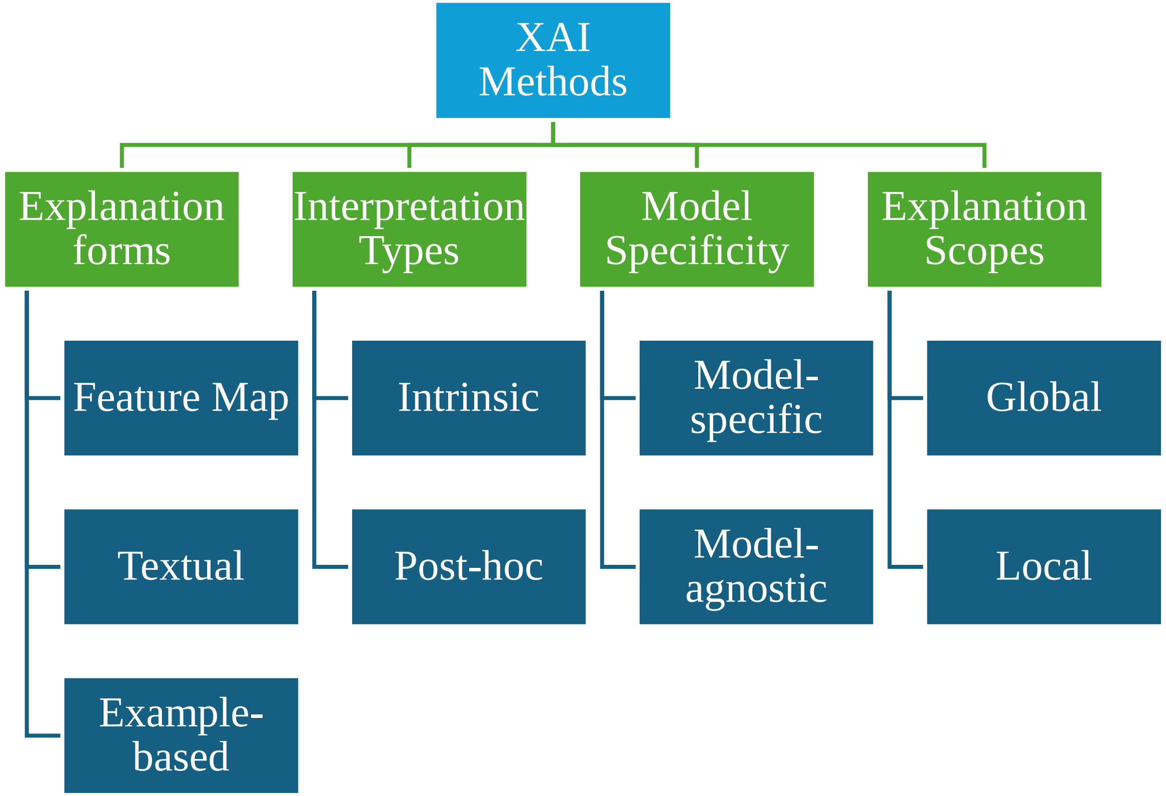


Source: Google image

XAI: Explainable AI Techniques

- XAI aims to explain the information behind the black-box model of deep learning that reveals how the decisions are made.
- Providing insights into how the predictions are made to achieve trustworthiness, causality, transferability, confidence, fairness, accessibility, and interactivity.

Criteria used to classify XAI methods



Explanation Type	Techniques
Feature (Highlights the feature contribution for making decisions, original image with an overlay of saliency map)	• Backpropagation (BP), Guided-BP, • Deconv Network, • Layer-wise relevance propagation (LRP), • Class activation map (CAM), • Grad-CAM, Local Interpretable model-agnostic explanations (LIME), • GraphLIME, • Shapley additive explanations (SHAP), • Attention
Example-based **(**Provide explanations by presenting similar instances or examples from the dataset that influenced the model's decision.**)**	• ProtoPNet, • Triplet Network • Explainable deep neural network (xDNN)
Textual (provide written descriptions of the factors influencing a model's decision)	• Testing with concepts activation vectors (TCAV), • Image Captioning

Criteria used to classify XAI methods (cont.)

Interpretation Type

- Intrinsic Explanation - Inherent to the model itself and built into its architecture or training process. (linear model, decision tree, etc.,)
- Post Hoc Explanation- Generated after the model has made predictions and is not inherently part of the model's architecture or training process (Deep learning techniques - CAM, Grad-CAM, LIME, SHAP)

Model Specificity

- Model-Specific Explanation - designed with the inner workings and assumptions of a particular model in mind. (Visualizing Feature Map or attention mechanism)
- Model-Agnostic Explanation - aim to provide insights into the model's behavior without relying on specific model characteristics. (LIME and SHAP)

Explanation Scopes

- Local Explanation - Providing insights into the decision-making process of a machine learning model at an individual prediction level (LIME and SHAP)
- Global Explanation - To provide insights into the overall behavior and functioning of a machine learning model across the entire dataset (SHAP)

XAI-Methods Used in Medical Images

XAI	Organ	Modality
CAM	Bone	X-ray
	Lung	Ultrasound, X-ray, CT
	Breast	X-ray
Grad-CAM	Lung	CT, X-ray
	Chest	Ultrasound
	Colon	Colonoscopy
Attention	Breast	X-ray
	Bone	CT
	Colon	Colonoscopy
Saliency	Lung, Skin	CT, X-ray
SHAP	Lung	HER, Radiomics, CT
	Chest	HER
LIME, SHAP	Chest	X-ray
SHAP, LIME, Scoped Rules	Lung	HER
Image Caption	Chest	CT

CAM (Class Activation Map)

- Highlights the most important regions of an image, and makes a specific prediction.

Grad-CAM (Gradient-weighted Class Activation Mapping)

- Provides more detailed and precise visualizations of which parts of an image are influencing the network's decision and output concerning its convolutional feature maps.

Saliency

- Highlights which parts of the input data are most crucial for a model's decision-making process.
- Saliency techniques may highlight important features across the entire input space, Grad-CAM specifically localizes the importance of features within the input image, offering more precise and detailed visualizations.

LIME and SHAP

- LIME focuses on providing local explanations by approximating the model's behavior around individual instances, while SHAP offers both local and global explanations by assigning feature contributions to model predictions using Shapley values.

Attention

- Pay more attention to important details when processing information

Challenges of AI Integration into Clinical Practice

Workflow Integration

- PACS and dictation software

Require

- Automation,
- Standardization
- Quality Control

Data Quality and Generalization

- Bias mitigation in data collection

Require

- Privacy
- Annotations

Disease Diversity

- Data-driven
- Domain-experts

Clinical Utility

- Check speed
- Accuracy
- Efficiency

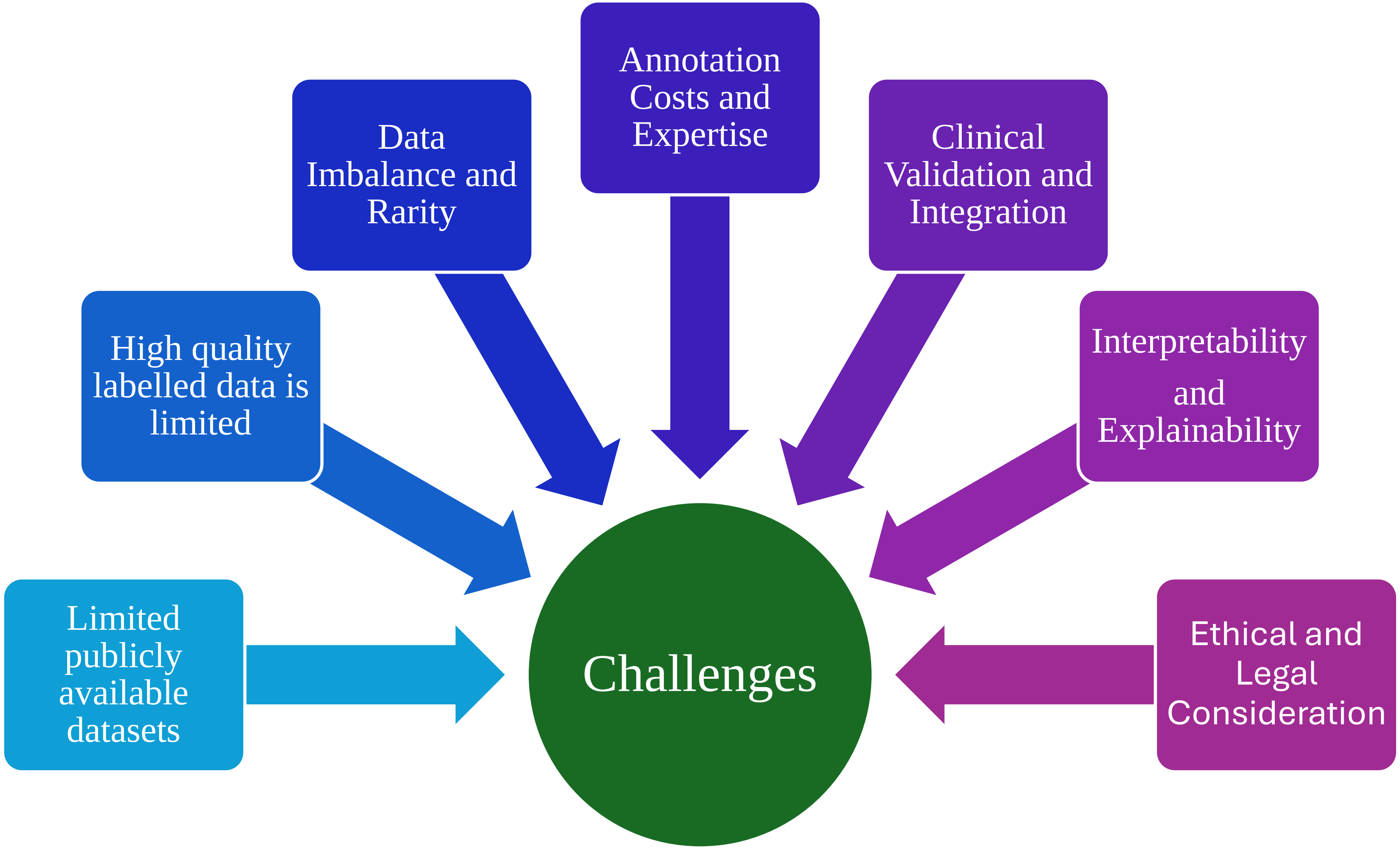
Ethical Consideration

- Informed consent
- Data privacy
- Prevention of Misdiagnoses
- Confidentially
- Guidelines

XAI: Explainability

- ‘Block box’ problem
- Explain how it was predicted

Existing Challenges in Medical Image analysis using ML and DL



Future Direction in Medical Image Analysis

Future Direction

- Wrapping deep features for medical image analysis
- Training partially Frozen deep networks
- Ensample deep models and Multi-task learning
- Using GAN for synthetic data generation
- Miscellaneous data augmentation techniques
- Dealing with small data size – use transfer learning

Source: Google image

Is it possible to achieve [this] with one expert in a particular field?

- Machine and Deep Learning methods, have reached important milestones in the last few years, demonstrating their potential to improve and automate the medical practice.
- A safe and full integration of these methods into the clinical workflow still requires a multidisciplinary effort (computer science, IT, medical experts, …) to enable the next generation of strong AI methods, ensuring robust and interpretable AI-based solutions.

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Notable Articles for Further Insights and Learning that I have used in my studies

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Thank You..!

Keep Learning and Upgrading Yourself until you reach where you want to be..!