# Machine Learning in Medical Image Analysis

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# Outline

- Introduction
- Medical imaging
- Medical image analysis with DL
- Applications of deep learning in medical image analysis
- Challenges, limitations, and opportunities
- Examples of our research
- Conclusion

# Medical imaging

## What is medical imaging?

Various technologies for creating images of the human body for diagnostic or therapeutic purposes.

## Importance of medical imaging

- Enables physicians to visualize internal body structures and functions in a non-invasive way
- Assists in early detection, diagnosis, and treatment of various diseases and conditions

# Medical imaging

## Common medical imaging techniques in clinical settings:

- Computed Tomography (CT)
- Magnetic Resonance Imaging (MRI)
- Positron Emission Tomography (PET)
- X-ray Imaging
- Ultrasound Imaging

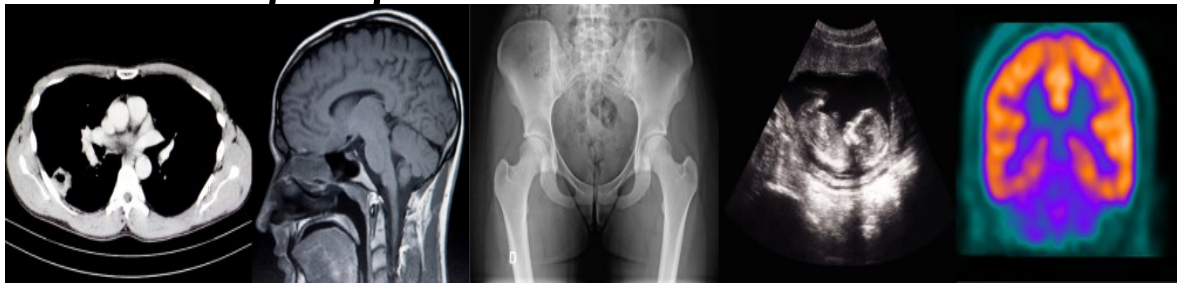

**Image 1.** **CT, MRI, X-ray, Ultrasound, PET**

# Medical image analysis with DL

## Deep neural networks with multiple layers

- Input layer
- Multiple hidden layers
- Output layer
- Learning hierarchical data representations

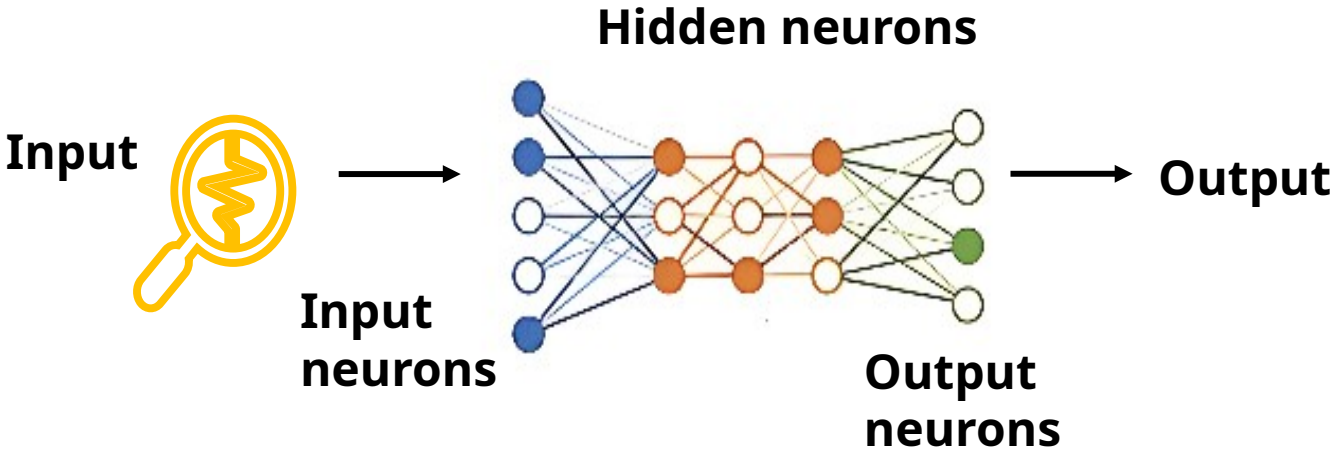


**Image 2.** CT, MRI, X-ray, Ultrasound, PET

# Medical image analysis with DL

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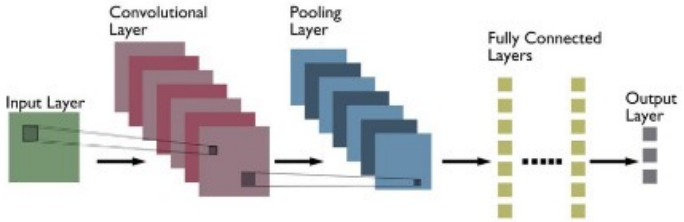
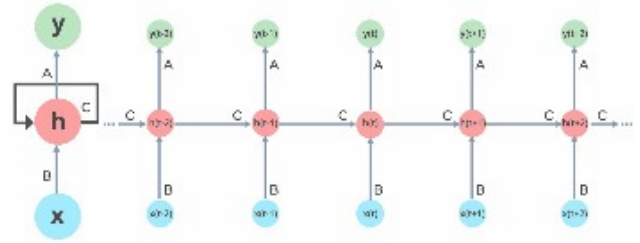
## Deep learning architectures

- Convolutional Neural Networks (CNNs)
- Recurrent Neural Networks (RNNs)
- Generative Neural Networks (GANs)
- Vision Transformers (ViTs)
- Reinforcement Learning (RL)
- Diffusion Models (DMs)

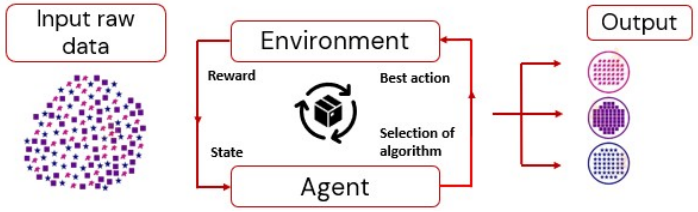
CNNs




RNNs

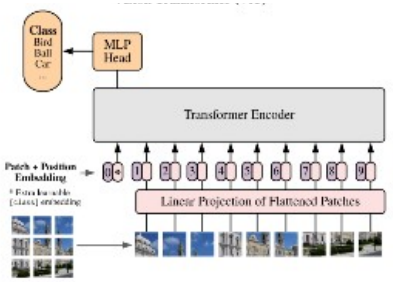



RL

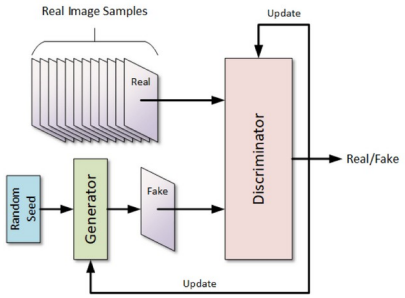




DMs




ViTs




GANs

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# Convolutional Neural Networks

## Filter layers define local features and form abstract representations in images

- Early layers detect low-level features such as edges and corners
- Later layers identify high-level features such as shapes and textures

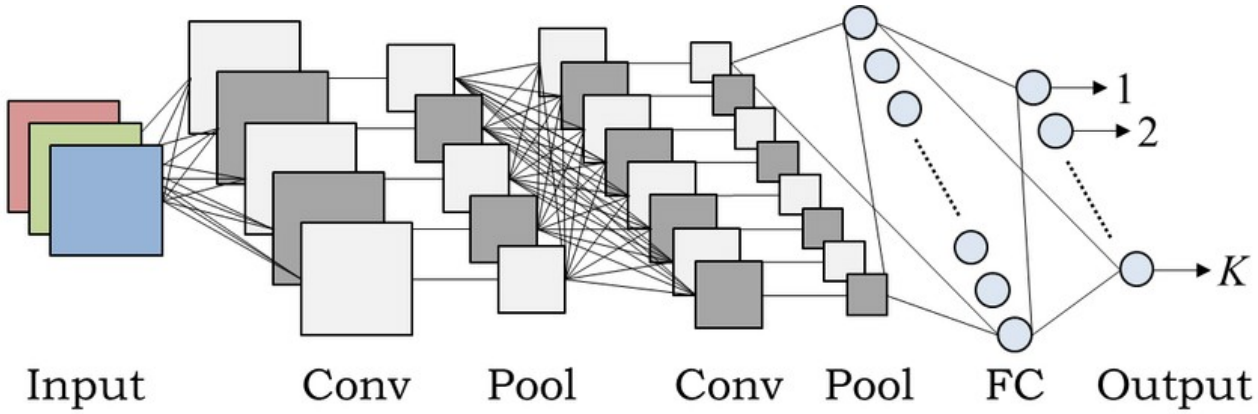



**Image 3.** CNN architecture

# Reccurent Neural Networks

## Suitable for processing sequential data such as time series or sequences

- Previous inputs influence the current output, making them ideal for temporal dependencies

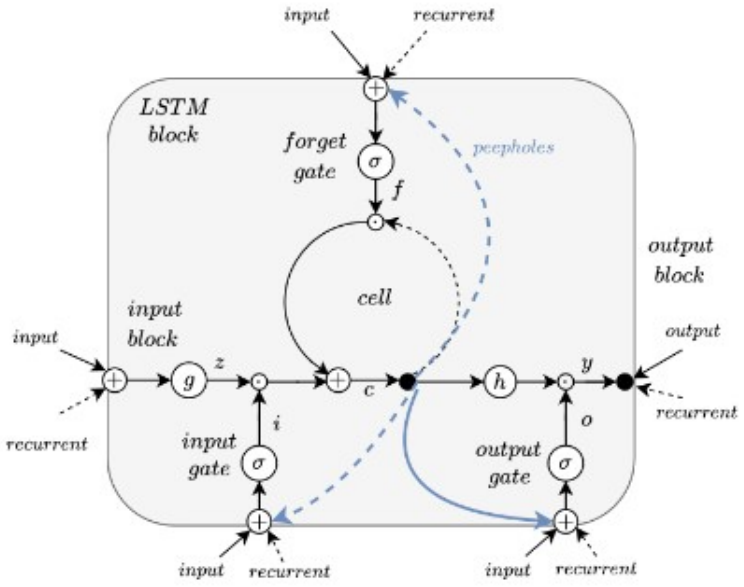



**Image 4.** Illustration of LSTM unit

# Generative Adversarial Neural Networks

## Consist of two networks

**Generator:** creates new samples similar to real data

**Discriminator:** distinguishes real samples from generated ones

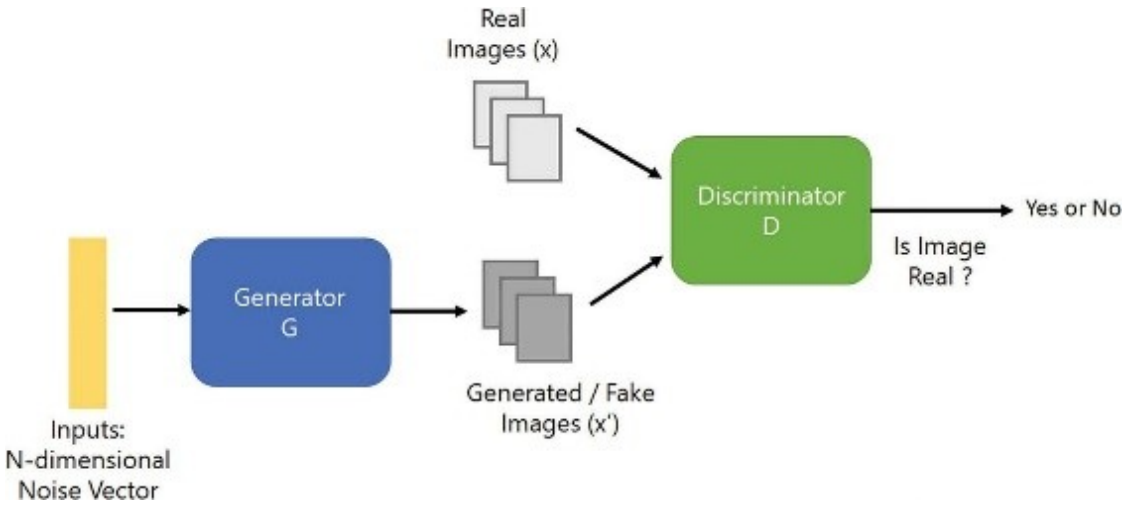



**Image 5.** Illustration of DCGAN architecture

# Vision Transformers

## Deep learning architecture adapted for visual data

Processes image patches instead of entire image

Self-attention mechanisms instead of convolutions

- for learning spatial relationships

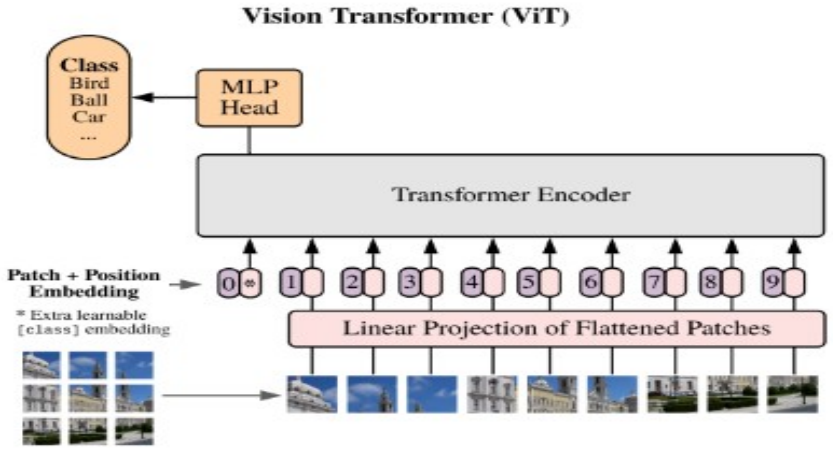



**Image 6.** Illustration of ViTs architecture

# Reinforcement learning

## Deep learning architecture adapted for visual data

- Agent learns by interacting with the environment
- Receives rewards or penalties based on actions
- Learns optimal strategies through trial and error

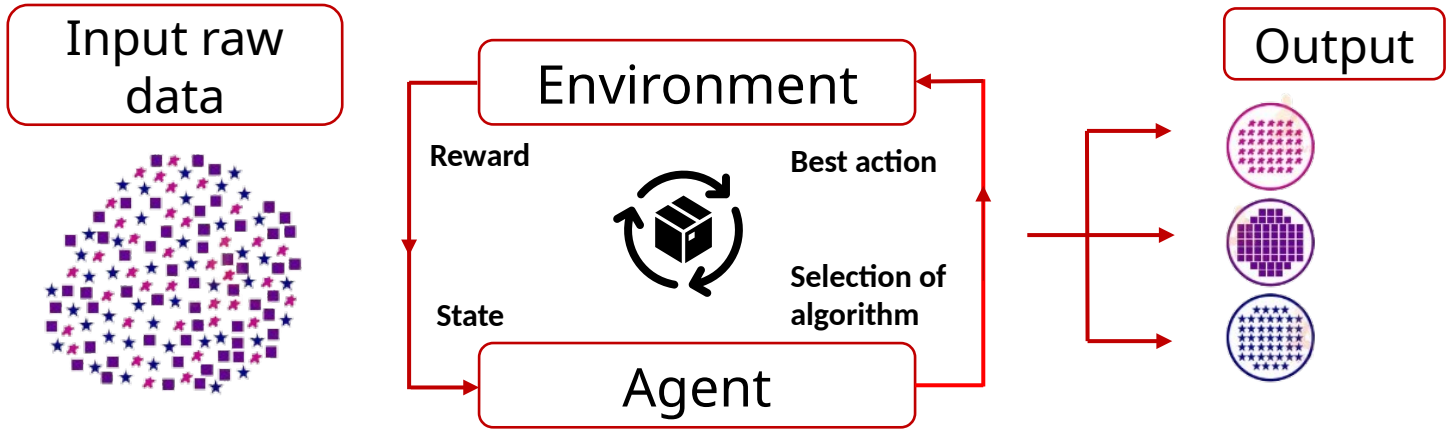



**Image 7. Illustration of reinforcement learning**

# Difussion models

## Deep learning architecture adapted for visual data

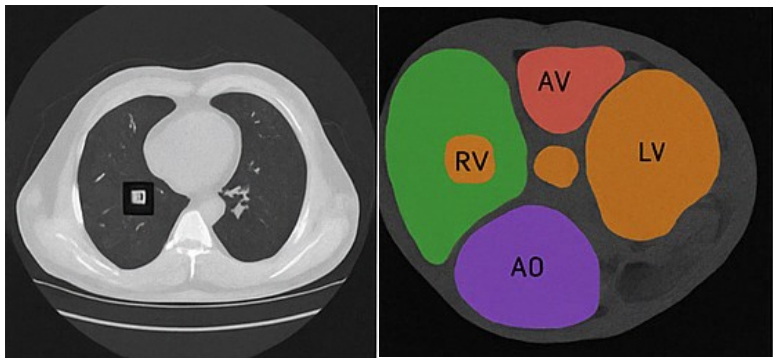
- Based on gradual noise addition and denoising process
- Capable of generating high-quality synthetic images
- Often outperform GANs in image realism and diversity

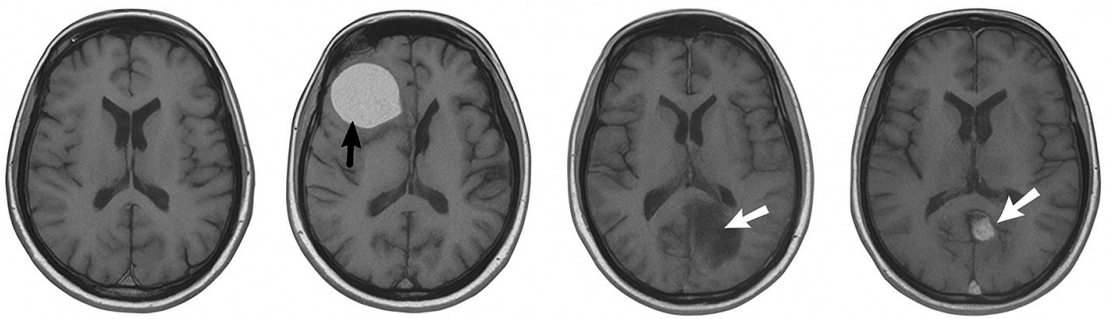

**Image 8.** Illustration of diffusion model

# Applications of deep learning in medical image analysis

## Common tasks in medical image analysis:

- Image classification
- Object localization and detection
- Image segmentation
- Image generation
- Image registration



# Applications of deep learning in medical image analysis

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## Image classification

Example: Lung nodule classification

**Image 9. Categories of lung nodules on CT scan: benign, primary malignant, and metastatic malignant (from left to right).**

# Applications of deep learning in medical image analysis

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## Object localization and detection

Example: Breast lesion detection

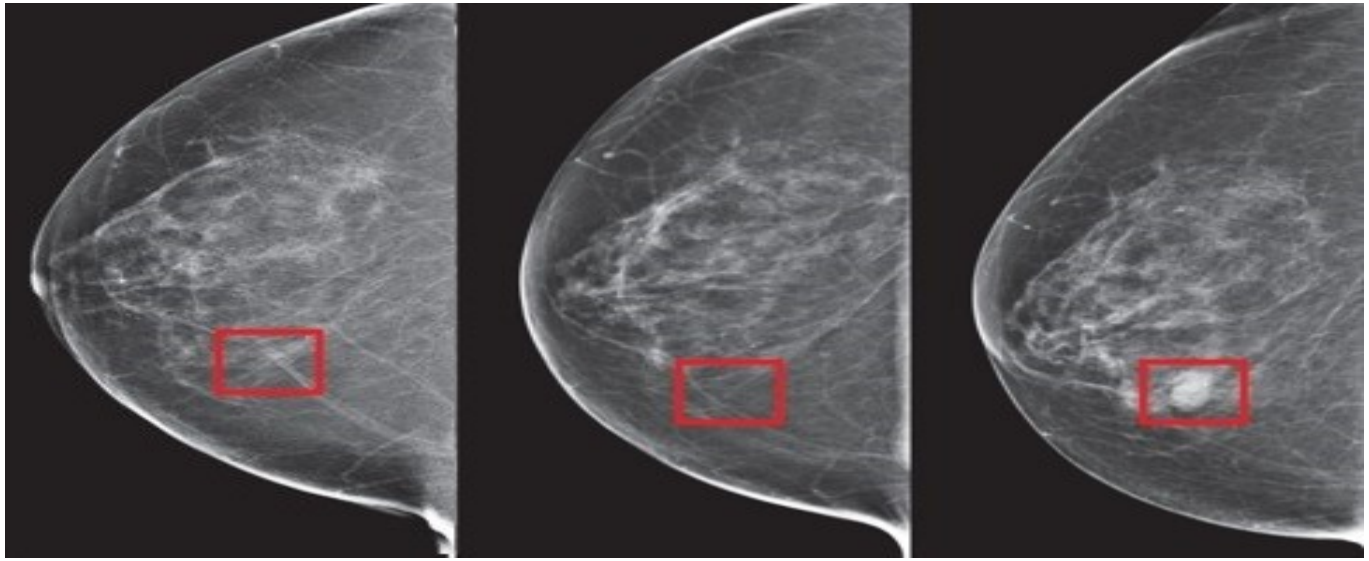

**Image 10.** **Categories of breast lesions on mammography: benign, primary malignant, and metastatic malignant (from left to right).**

# Applications of deep learning in medical image analysis

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## Image segmentation

Example: Heart and heart chamber segmentation

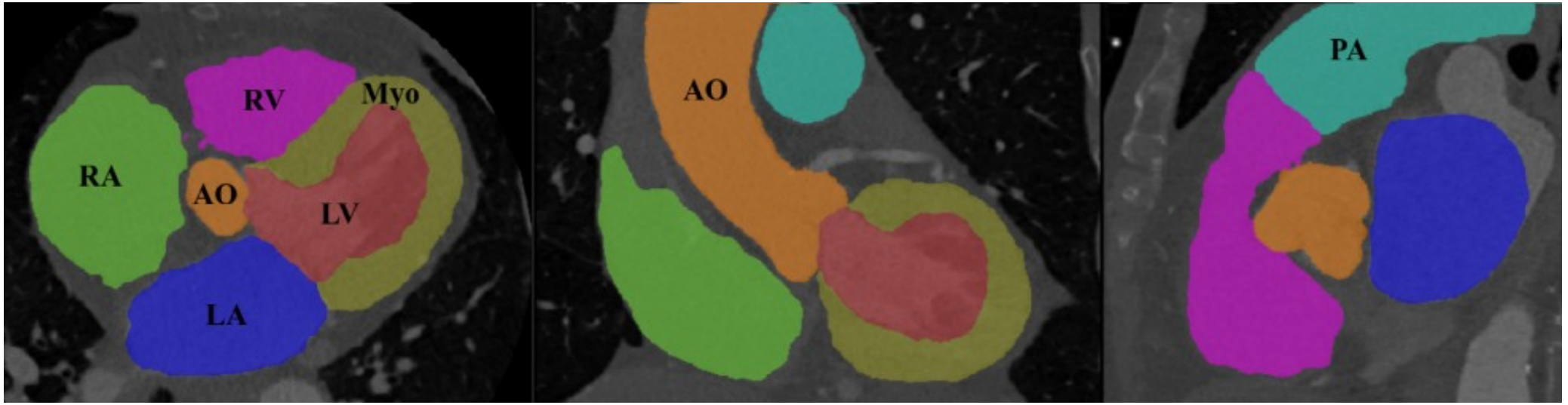


**Image 11. Categories of breast lesions on mammography: benign, primary malignant, and metastatic malignant (from left to right).**

# Applications of deep learning in medical image analysis

## Image generation

Example: Synthetic generation of CT images

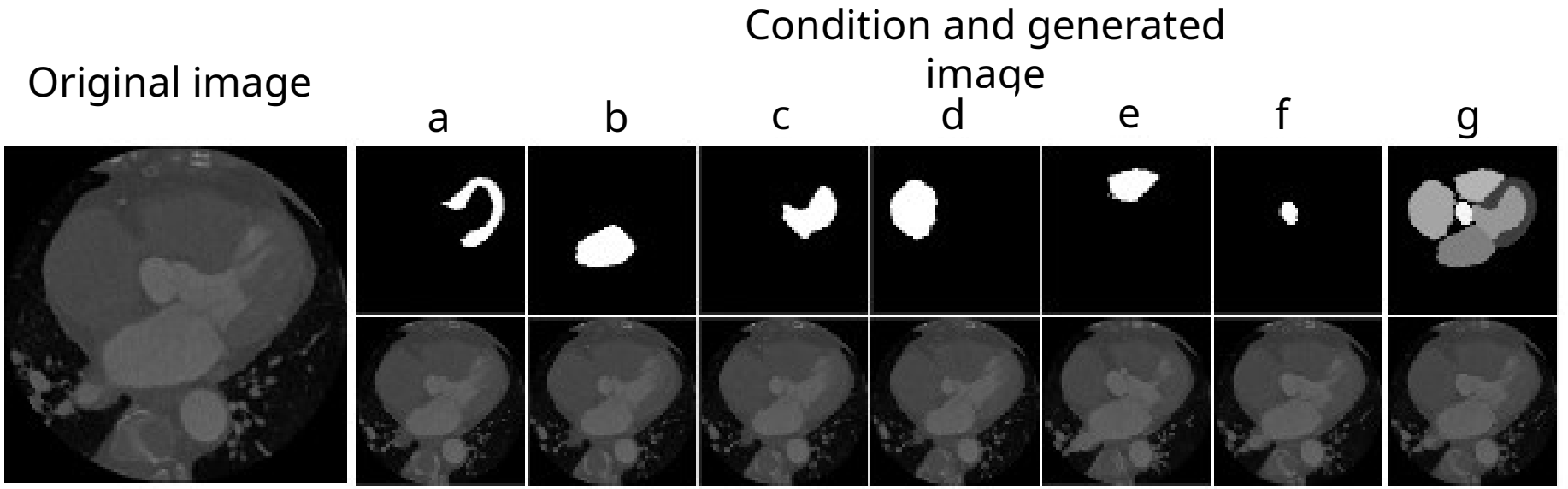


**Image 12. Categories of breast lesions on mammography: benign, primary malignant, and metastatic malignant (from left to right).**

# Applications of deep learning in medical image analysis

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## Image registration

Example: Brain image registration

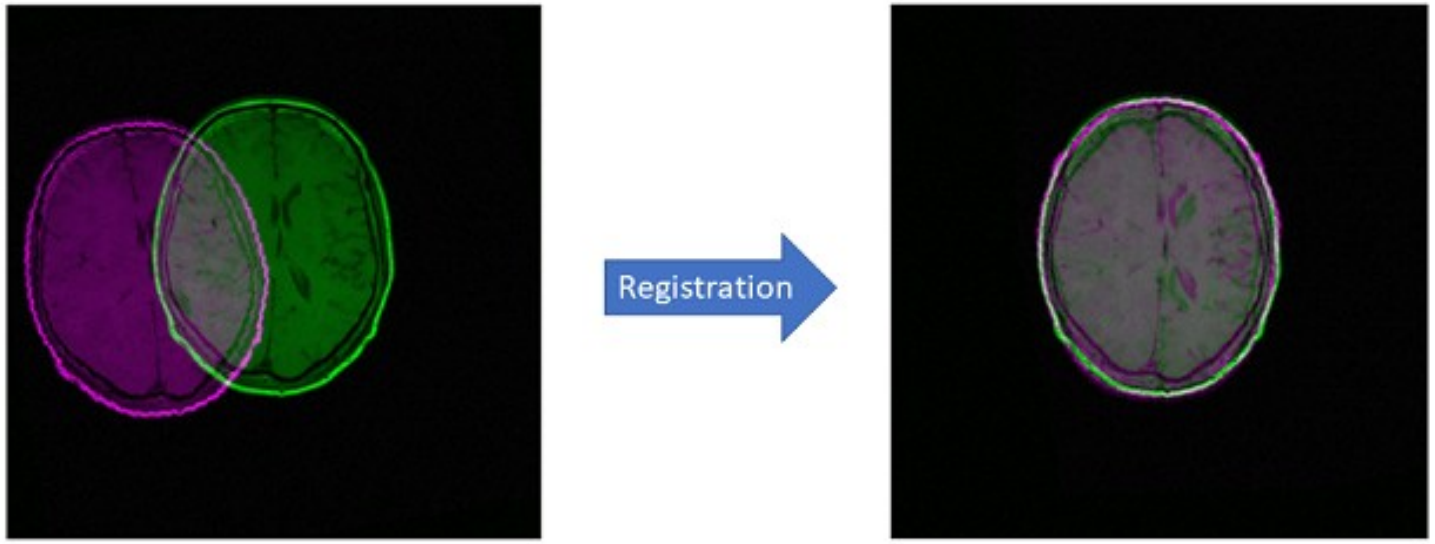


**Image 13.** **An example of image registration using CNNs.**

# Applications of deep learning in medical image analysis

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## Current challenges in the field of research

- Insufficient model interpretability
- Complex architectures
- Lack of transparency
- Lack of human-understandable data
- Difficulty in capturing causality

# Challenges, Limitations and Opportunities

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## Future research directions

- Development of explainable artificial intelligence (XAI) methods
- Model visualization
- Rule extraction
- Attention mechanisms
- Causal analysis
- Interpretable model architectures
- Explainable feature representations

# Examples of our research

## Medical Image Interpretation Methods for a Detailed Heart Health Analysis (IMAGINE HEART)

**Installation Research project by Croatia Science Foundation**

**Duration:** 1. 3. 2018. – 28. 2. 2023.

**Value:** 151 703.98 EUR

**Project team:**

- prof. dr. sc. Irena Galić
- doc. dr. sc. Hrvoje Leventić
- doc. dr. sc. Krešimir Romić
- dr. sc. Marija Habijan
- Marin Benčević, mag. ing. comp.
- doc. dr. sc. Dario Mužević
- Filip Novoselnik, mag. ing. comp.
- izv. prof. dr. sc. Zdravko Krpić
- doc. dr. sc. Tomislav Galba

imagineheart-online.github.io

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# Examples of our research

## Why cardiovascular system analysis?

**The main cause of death**

> 3.9M per year in Europe

> 1.8 in EU

47% in Europi

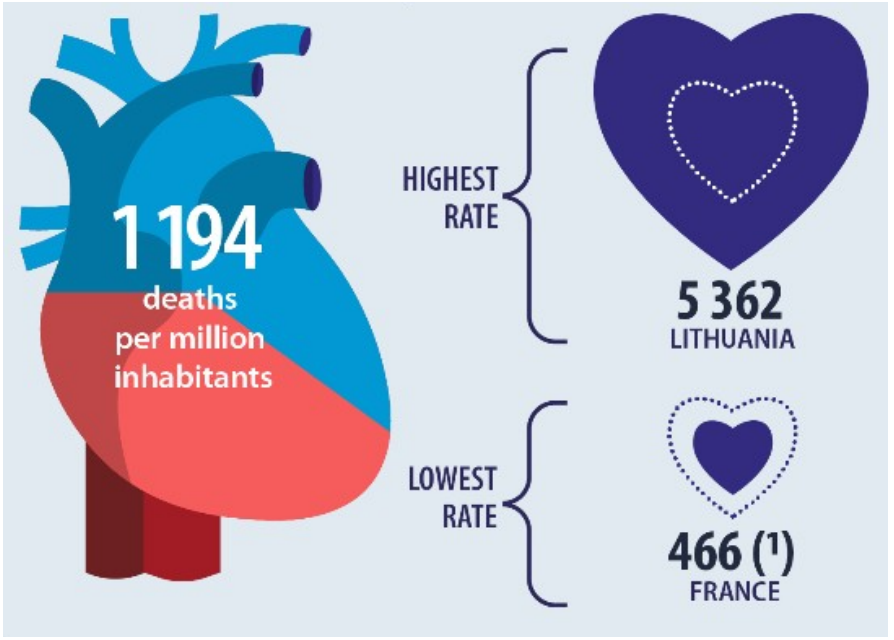
37% in EU

45% in Croatia

**Analysis based on gender in Croatia:**

> 50.1 % woman

> 39.7 % man

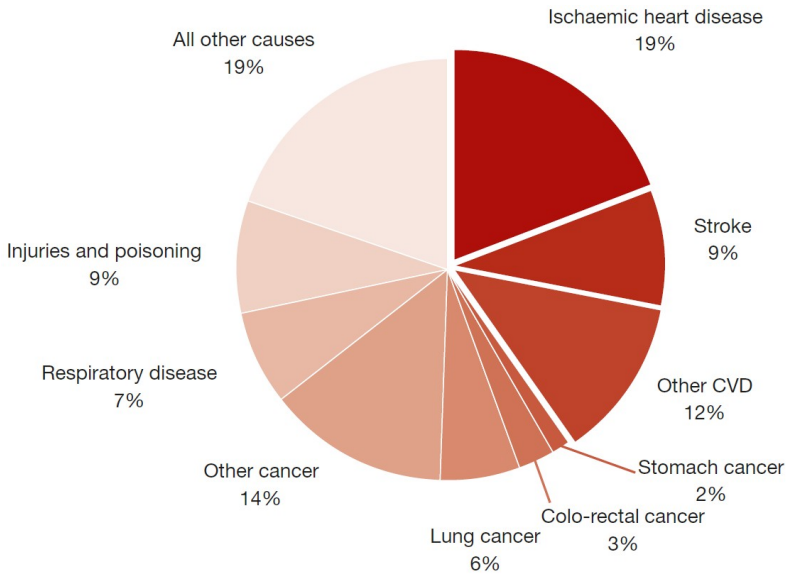



**Source**: European Cardiovascular Disease Statistics 2017

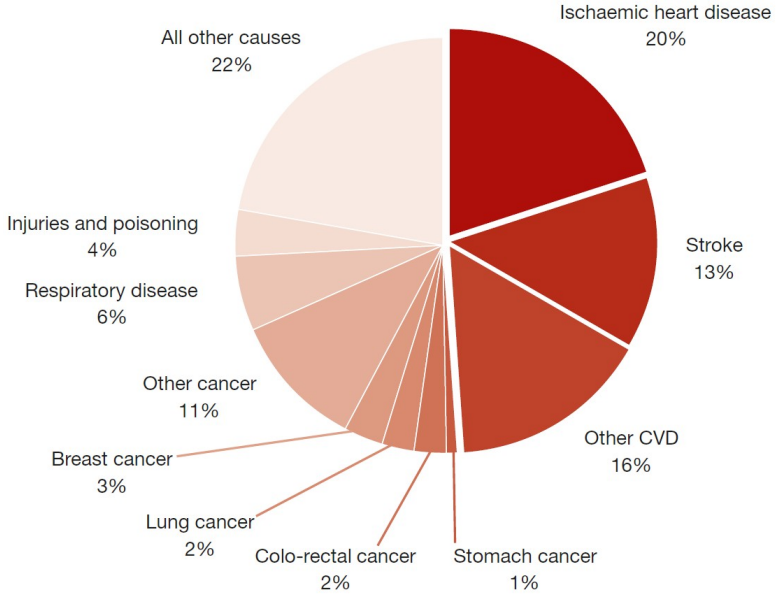
# Examples of our research

## IMAGINEHEART

### Causes of death for men




### Causes of death for women




~49M people in the EU suffer from cardiovascular diseases
~€210 million spent annually (EU)

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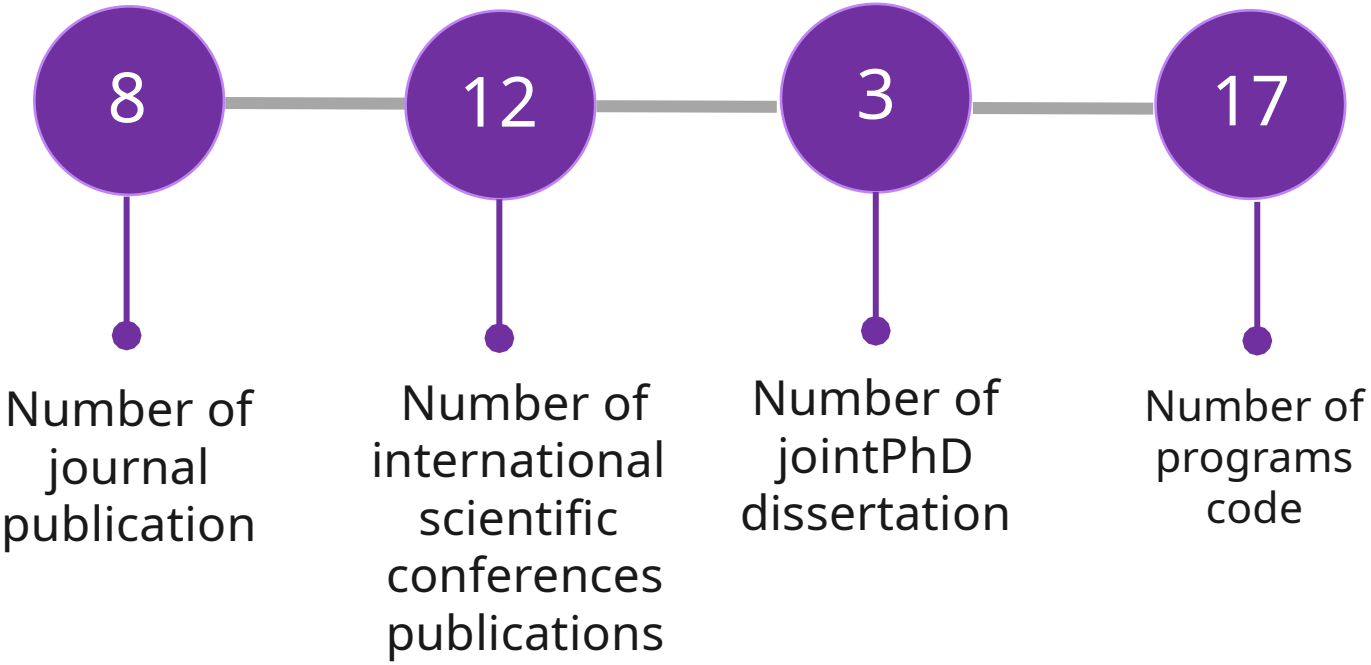
# Examples of our research

## IMAGINEHEART

**Results:**




https://imagineheart-online.github.io/

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## Medicinska edukacija i planiranje uz pomoć produžene stvarnosti

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**ANALIZA MEDICINSKIH SLIKA I SIMULACIJA EDUKATIVNIH MEDICINSKIH SADRŽAJA**

**URASLA POSTELJICA U TRUDNOĆI**
povećati iskustvo liječnika u zahvatima kod trudnica s uraslom posteljicom

**NEUROKIRURŠKI ZAHVATI**
povećati lakoću izvedbe i kvalitetu cerebrovaskularnih zahvata

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# Examples of our research

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- **Research project founded by Croatia Science Foundation**
- **Duration:** 16. 12. 2024. - 15. 12. 2027.
- **Value:** 197 800.00 EUR

### FERIT

- prof.dr.sc. Irena Galić
- doc. dr.sc. Hrvoje Leventić
- doc. dr.sc. Krešimir Romić
- doc. dr. sc. Ivana Hartmann Tolić
- dr. sc. Marija Habijan
- dr. sc. Marin Benčević
- Robert Šojo, mag. ing. comp.

### Klinički Bolnički Centar Osijek

- izv. prof. dr. sc. Dario Mužević, dr. med.
- dr.sc. Vjekoslav Kopačin, dr. med.
- Maja Košuta Petrović, dr. med.

### UGent, Faculty of Engineering and Architecture

- prof. dr. ir. Aleksandra Pižurica
- dr.sc. Danilo Babin

# Project goal

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## Physician Education

- Ultrasound examination simulations for early detection of placenta accreta

## Neurosurgical Navigation

- XR simulations to improve cerebrovascular procedure performance

## Synthetic Data Generation

- Generating medical images for education and diagnostics

# The main challenges

## Problems with traditional training methods

- Lack of realistic scenarios for practice
- Limited access to rare clinical cases
- High cost of commercial simulation systems
- Poor adaptability of existing VR systems
- Need for innovative and affordable solutions

# Key takeaway

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## Deep learning for medical image analysis

- Improves the accuracy and efficiency of diagnosis
- Enables effective identification of various medical conditions
- Enhances medical staff education supports personalized healthcare

**These technologies are not just the future —**
**they are a necessity.**

# Machine Learning in Medical Image Analysis

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