# Computer vision in medicine and life science

Sonja Aits

*Lund University, 2023-12-13*

# Computer Vision

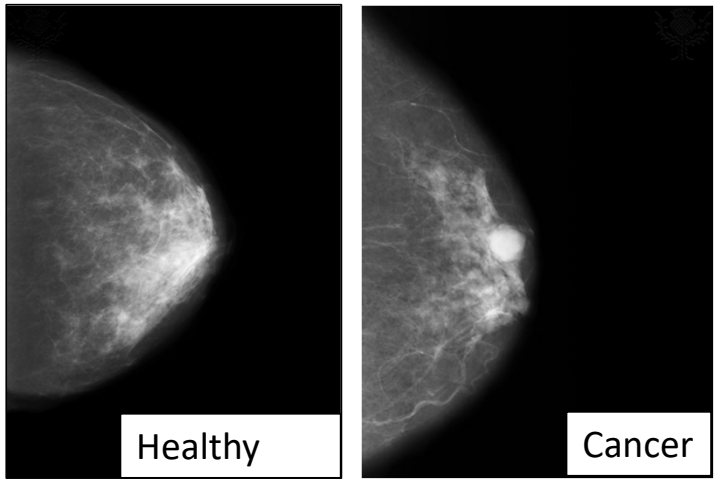
= AI for processing, analysis or generation of images or videos

# Computer vision tasks

# Examples of images and videos used in medicine and life sciences?

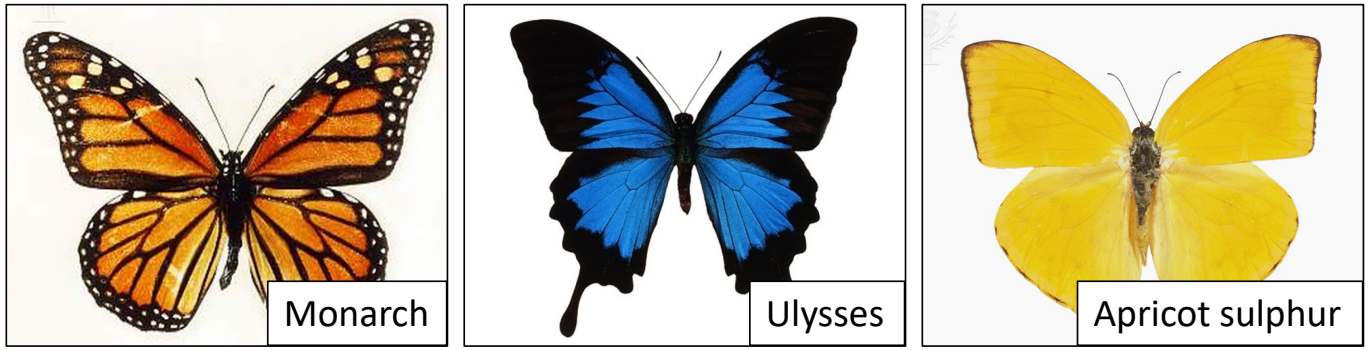
# Image classification

**Binary**

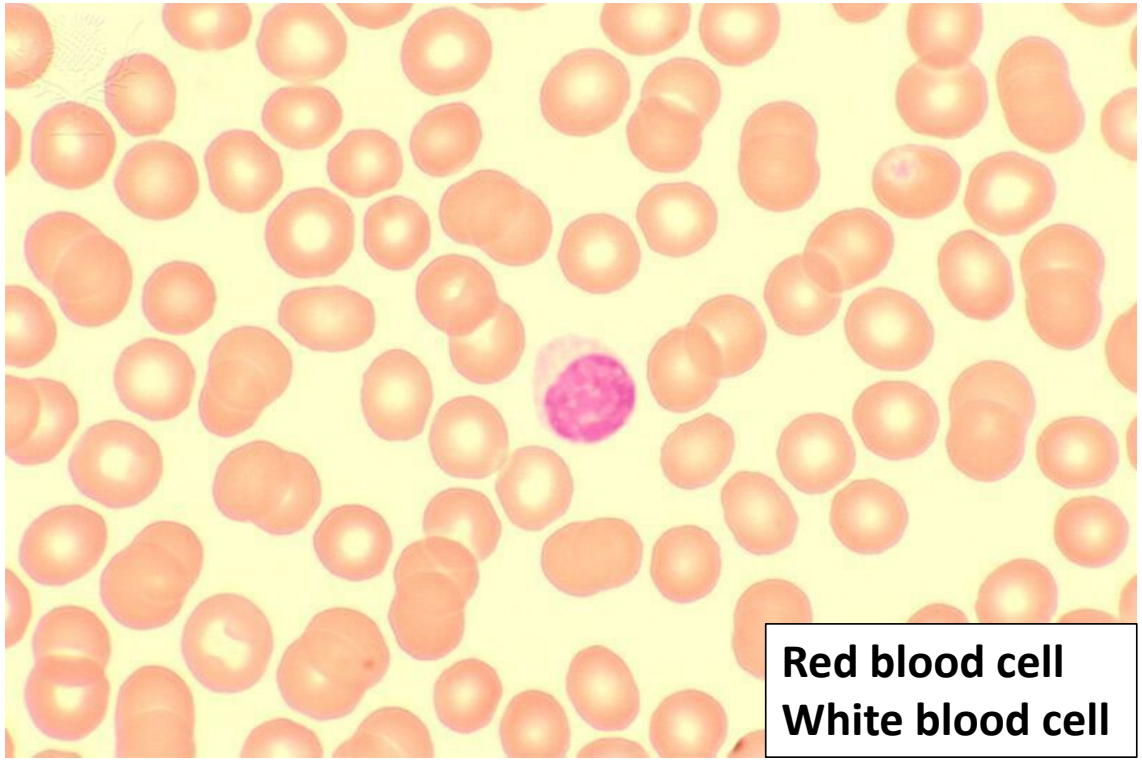



**Output:**
Image class

**Multi-class**

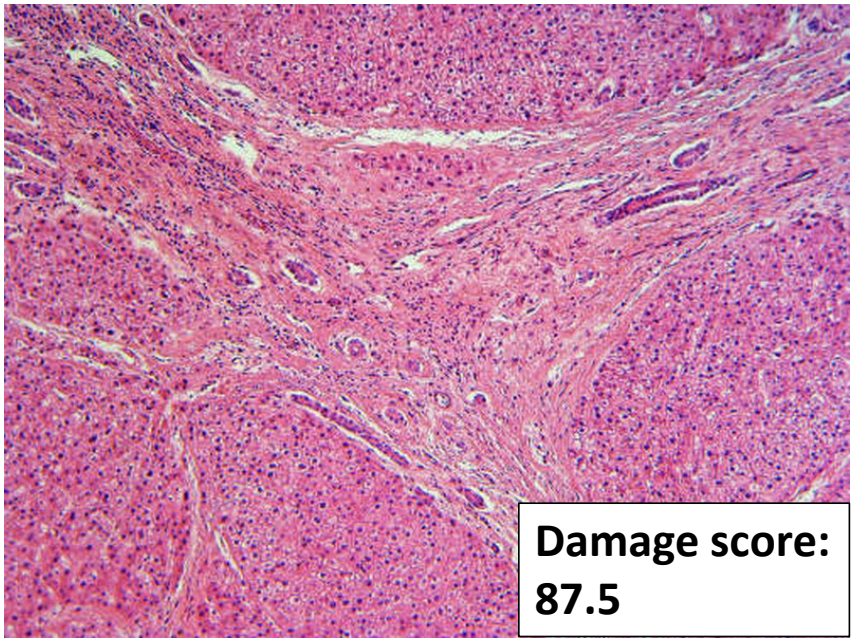


# Multi-label image classification




**Output:**
Multiple
image classes

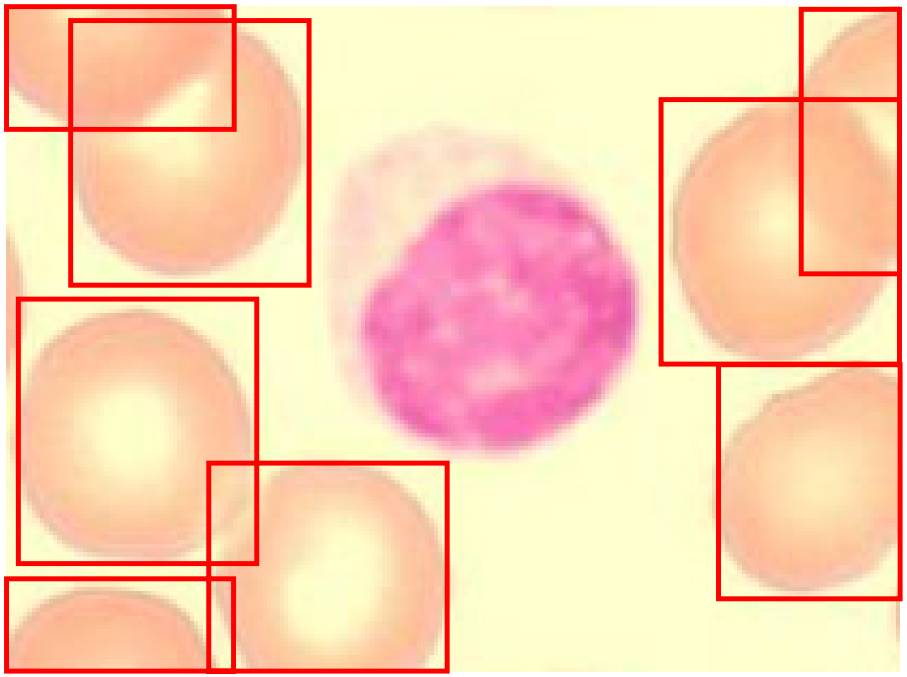
# Image regression




**Output:**
Continuous value

# Object detection

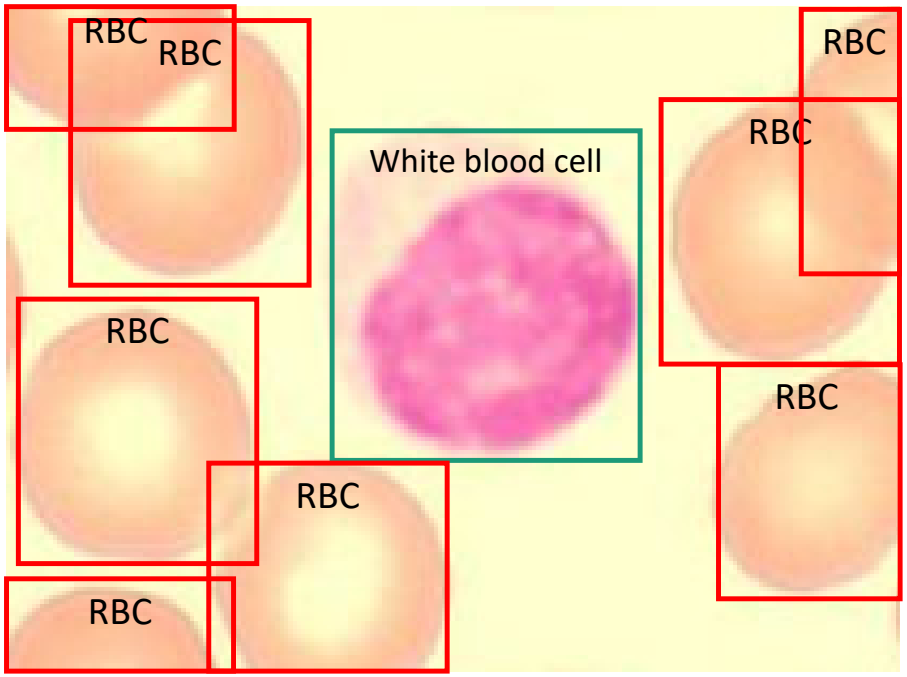
**Single-class**



**Output:**
Set of bounding boxes
(x, y, width, height)

# Object detection

**Multi-class**

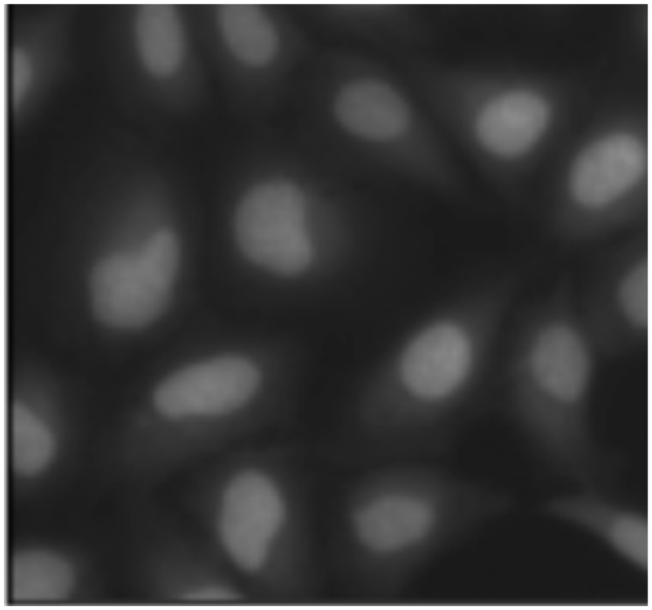


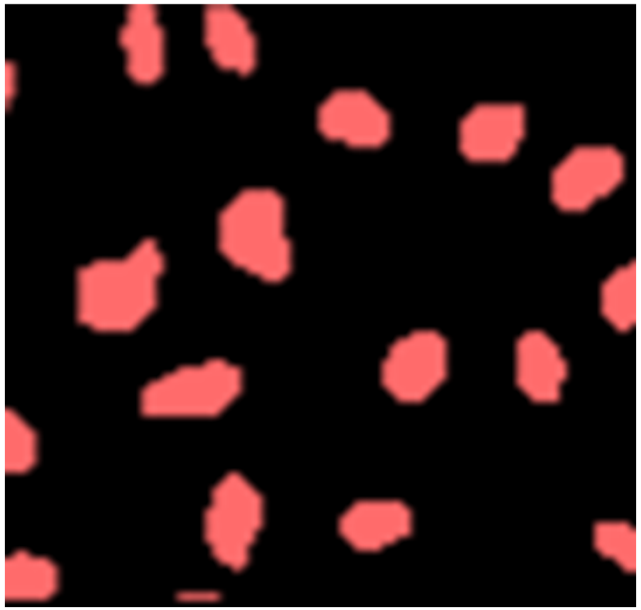

**Output:**
Set of bounding boxes with object class

# Object tracking


https://www.youtube.com/watch?v=2Pq5upuFtrA

# Semantic segmentation





**Background**

**Cells**

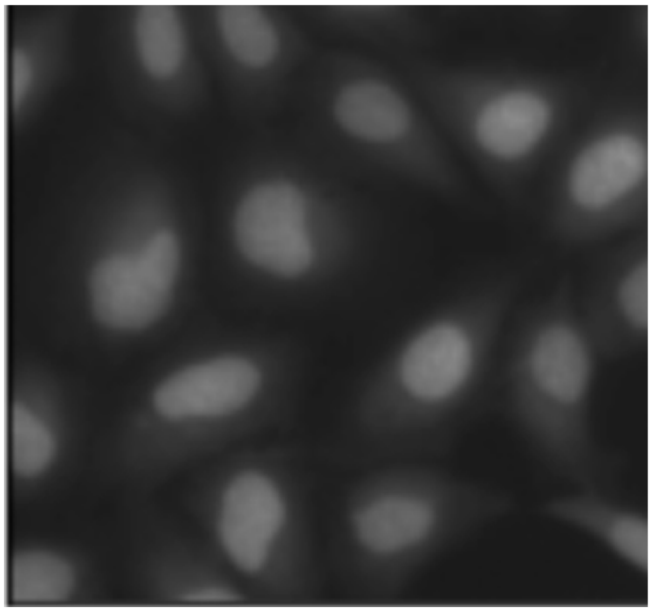
**Output:**
Class of each pixel

No information on individual objects!

## Slide 11

**SA1** Sonja Aits, 2021-10-16

# Instance segmentation



**Output:**
Outlined objects

## Slide 12

**SA2** Sonja Aits, 2021-10-16

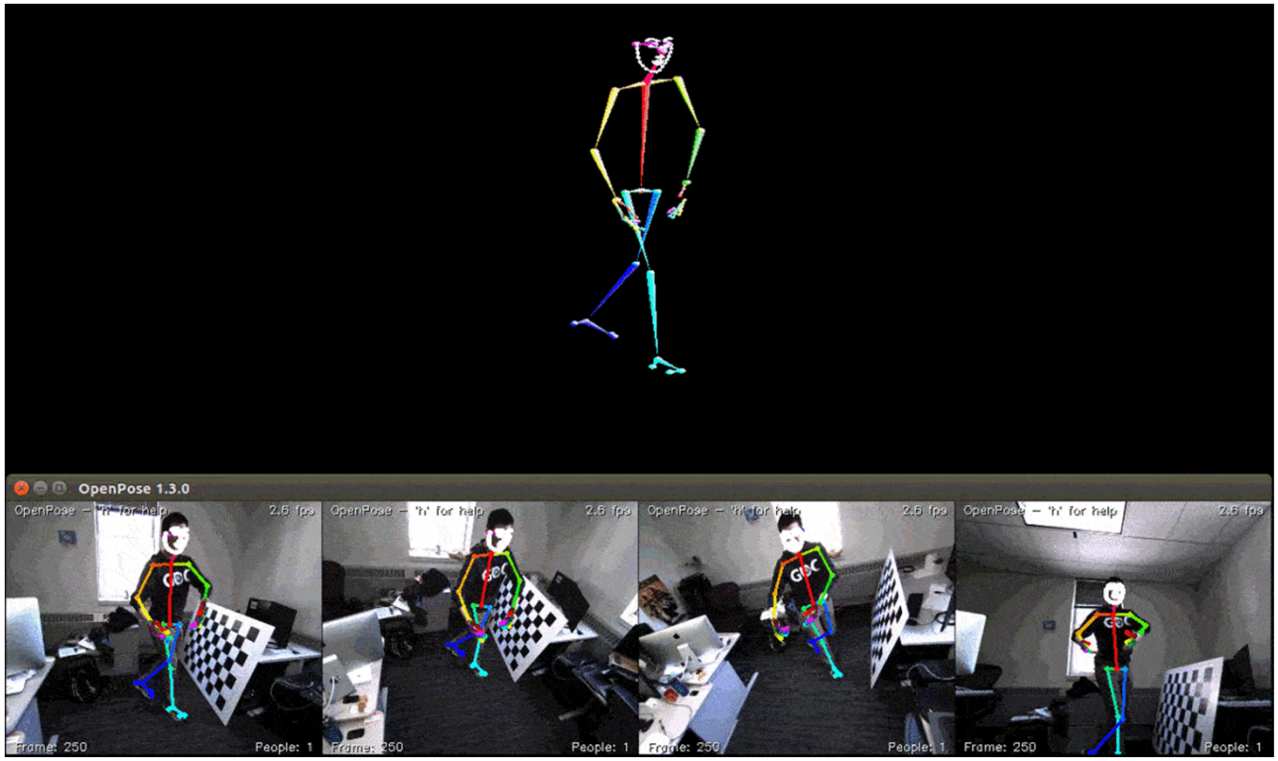
# Mini quiz: Object detection, Instance segmentation, Semantic segmentation

- Counting bees in a photograph
- Calculating the area covered by forest in a satellite image
- Determining the average size of bacterial colonies in a photograph
- Determining the average level of green fluorescent protein in cells
- Calculating the circularity of cell nuclei
- Determining how many types of vegetation can be seen in drone images

# Pose estimation

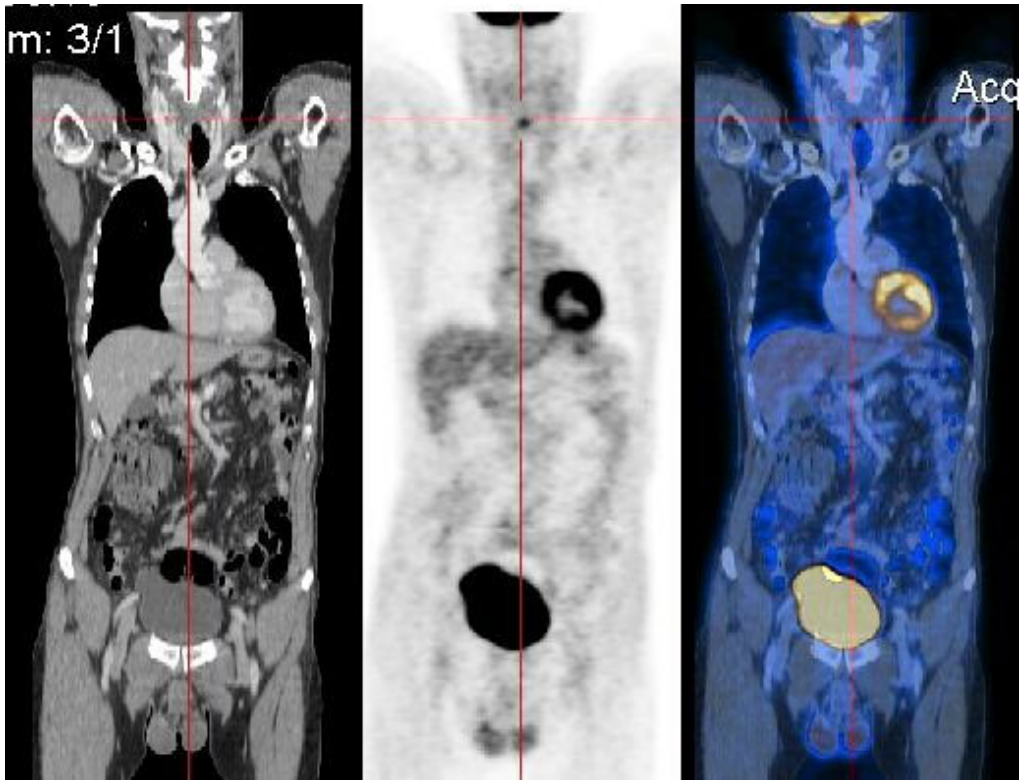
https://github.com/CMU-Perceptual-Computing-Lab/openpose/

# Pose estimation: 3D



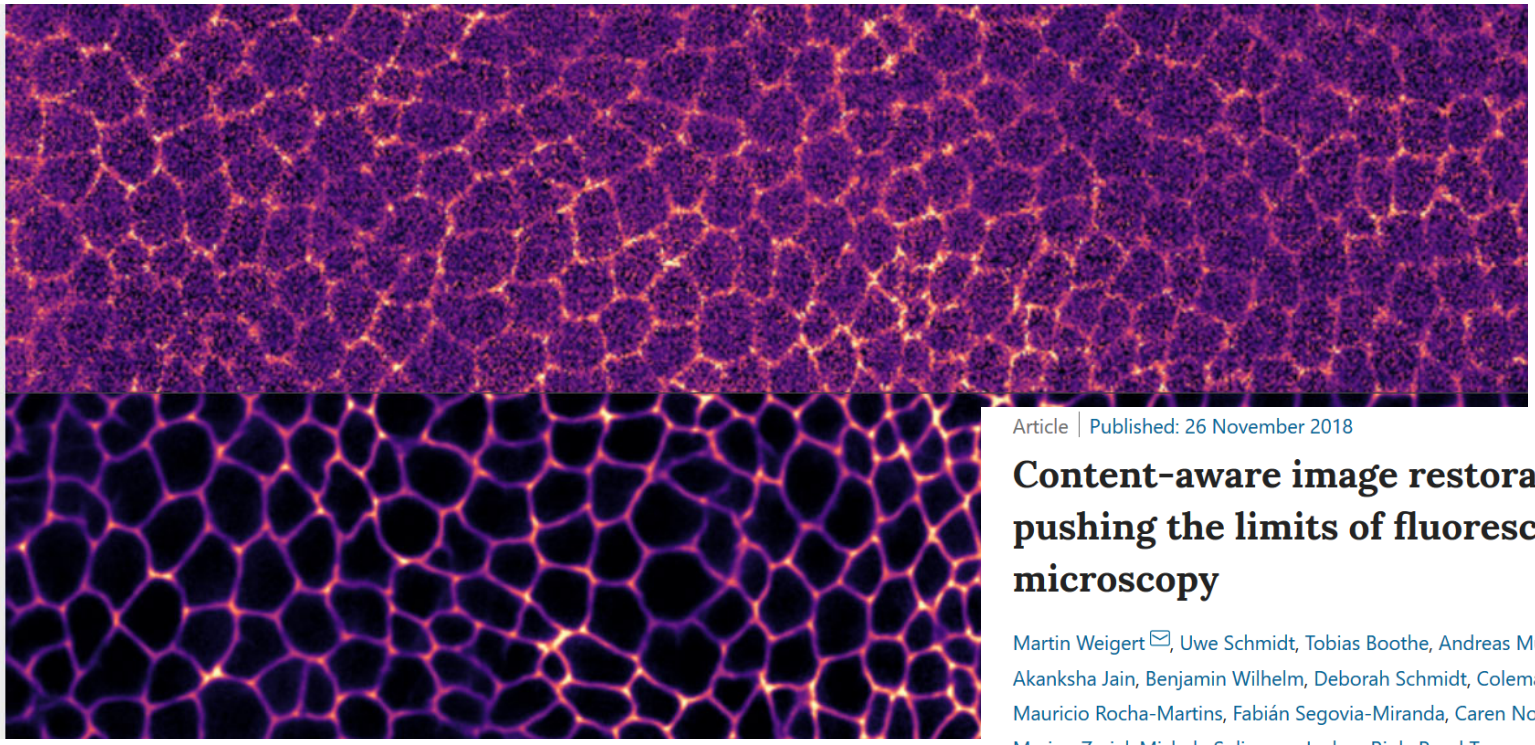

https://github.com/CMU-Perceptual-Computing-Lab/openpose/

# Image registration




https://commons.wikimedia.org/w/index.php?curid=20682407

# Image restoration



combined surface prediction + denoising

Article | Published: 26 November 2018

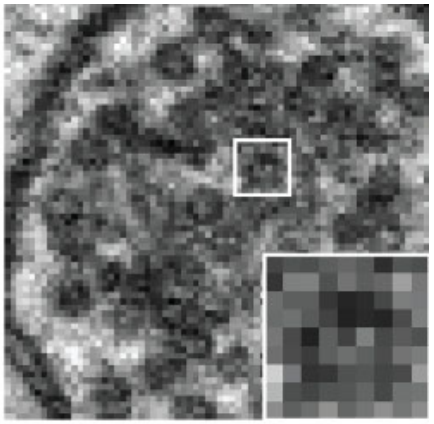
## Content-aware image restoration: pushing the limits of fluorescence microscopy

Martin Weigert, Uwe Schmidt, Tobias Boothe, Andreas Müller, Alexandr Dibrov, Akanksha Jain, Benjamin Wilhelm, Deborah Schmidt, Coleman Broaddus, Siân Culley, Mauricio Rocha-Martins, Fabián Segovia-Miranda, Caren Norden, Ricardo Henriques, Marino Zerial, Michele Solimena, Jochen Rink, Pavel Tomancak, Loic Royer, Florian Jug & Eugene W. Myers

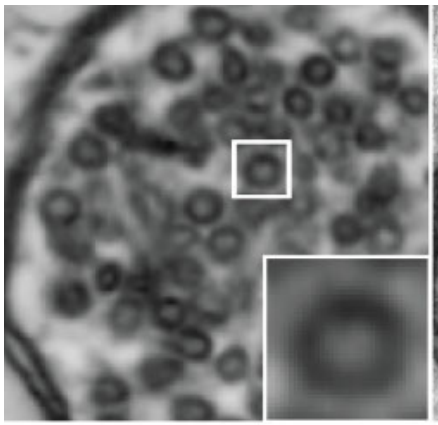
*Nature Methods* **15**, 1090–1097(2018) | Cite this article

# Super-resolution

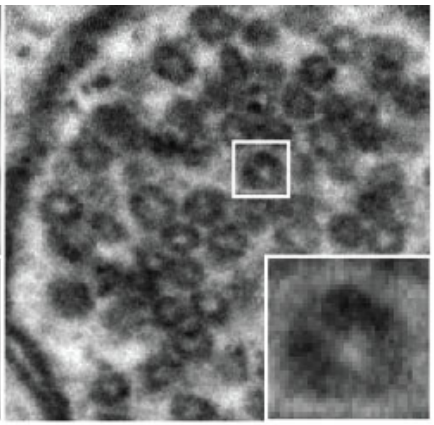
**Low resolution (input)**



**High resolution (output)**

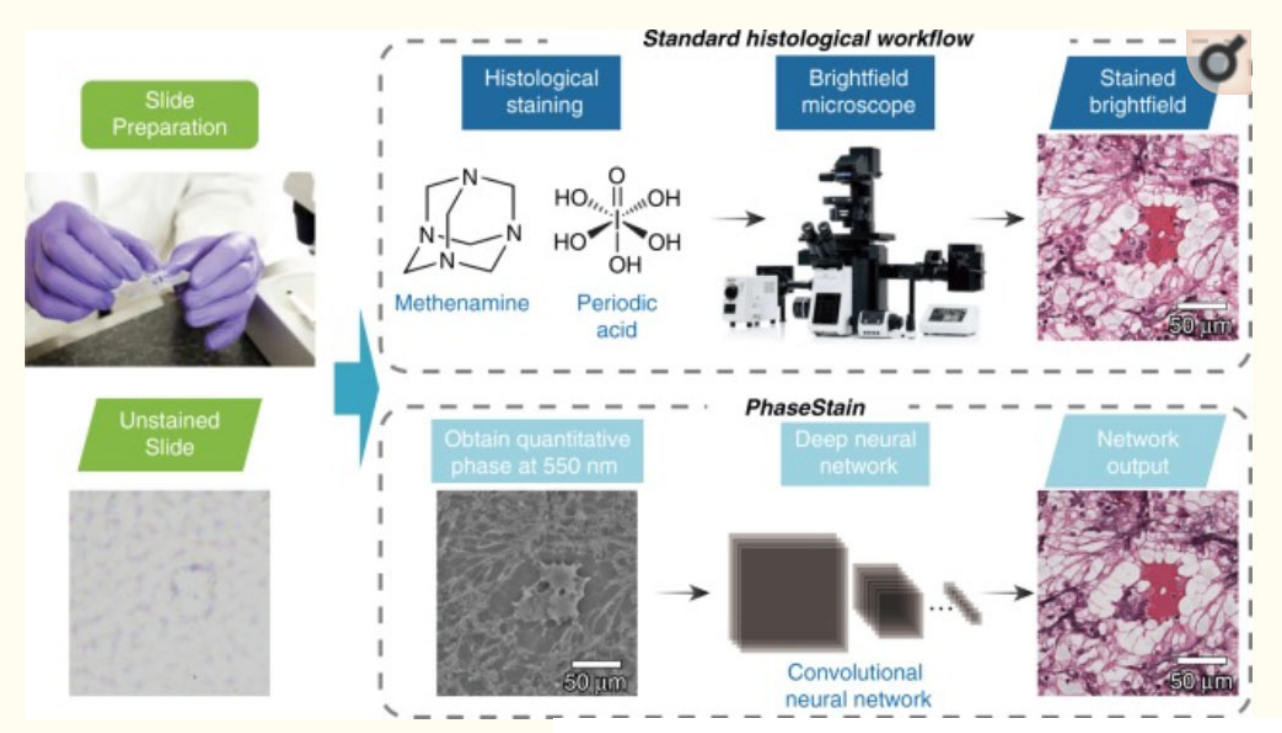


**High resolution (truth)**



https://www.biorxiv.org/content/10.1101/740548v7.full

# Virtual staining

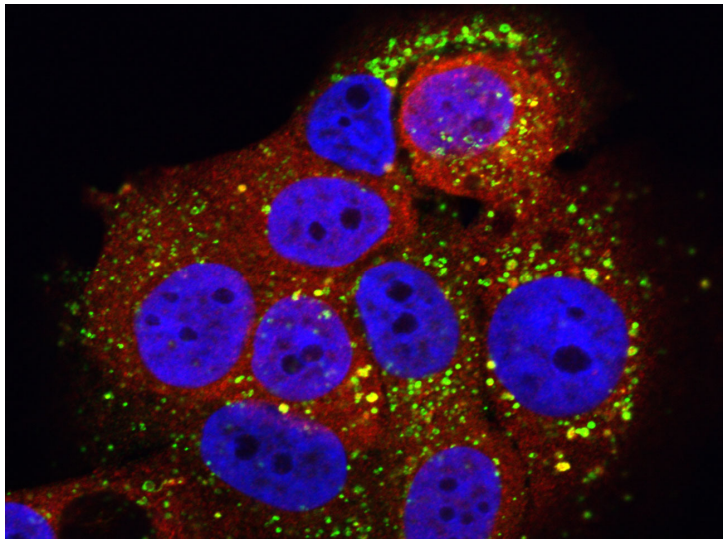



PhaseStain: the digital **staining** of label-free quantitative **phase** microscopy images using deep learning.

Rivenson Y, Liu T, Wei Z, Zhang Y, de Haan K, **Ozcan** A.

Light Sci Appl. 2019 Feb 6;8:23. doi: 10.1038/s41377-019-0129-y. eCollection 2019.

# Image captioning



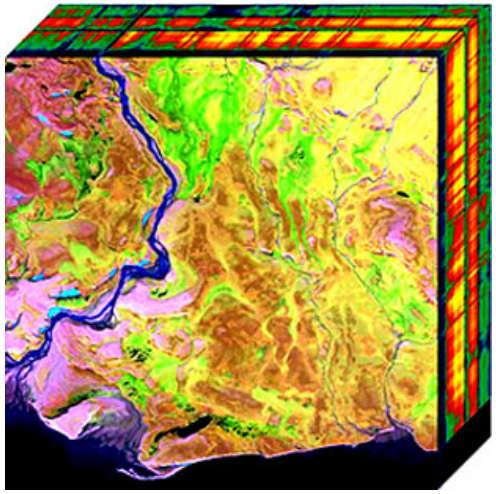
**Output:**
Descriptive word sequence

"a fluorescence microscopy image showing a group of cells with blue nuclei and bright green cytosolic spots"

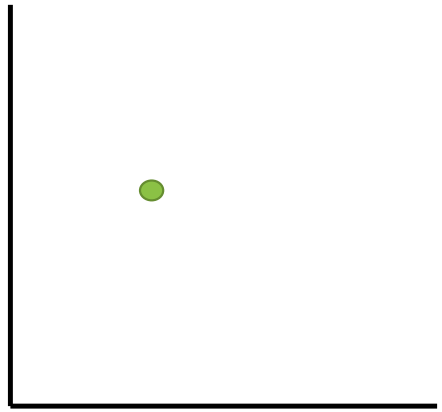
# Image clustering

**Output:**
Grouped data

# Dimensionality reduction



High-dimensional data



Low-dimensional data

**Output:**
Low dimensional data

https://en.wikipedia.org/wiki/Hyperspectral_imaging#/media/File:HyperspectralCube.jpg

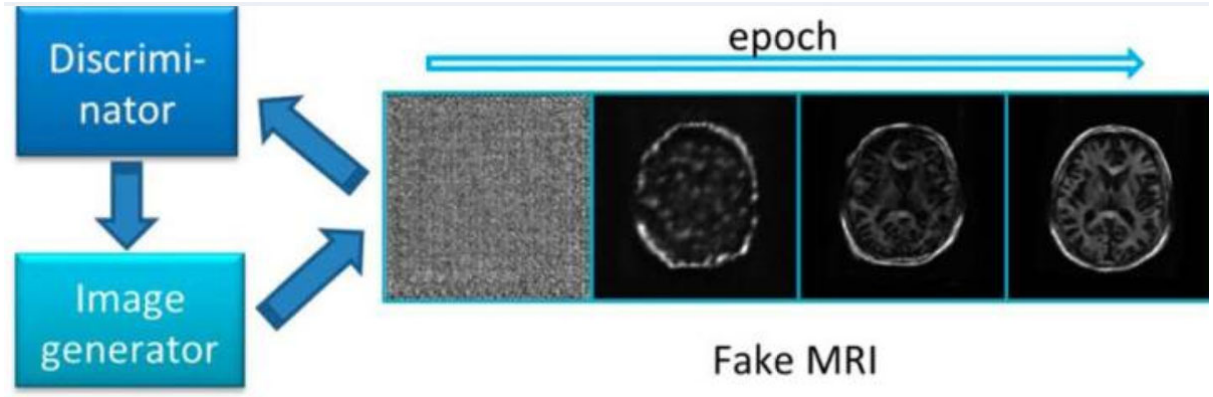
# Image generation

https://thispersondoesnotexist.com/

Tomography. 2018 Dec;4(4):159-163. doi: 10.18383/j.tom.2018.00042.

**Generative Adversarial Networks for the Creation of Realistic Artificial Brain Magnetic Resonance Images.**

Kazuhiro K[1], Werner RA[2,3,4], Toriumi F[5], Javadi MS[2], Pomper MG[2,6,7], Solnes LB[2], Verde F[7], Higuchi T[1,3,4], Rowe SP[2,6,7].



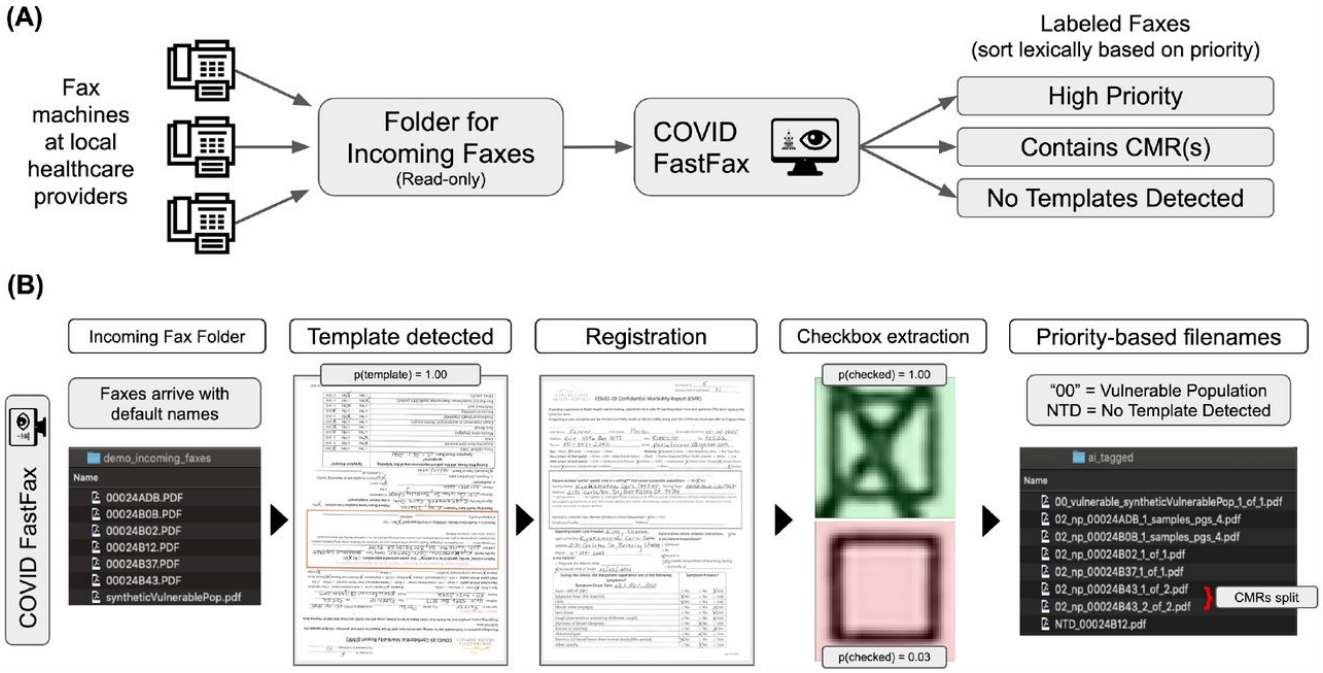
# Autonomous robotic surgery

https://youtu.be/XeYeAzsQ1-U?feature=shared

# Computer vision-driven assistant devices


https://youtu.be/vAGybwLb3kg?feature=shared

# Assisting hospital logistics: COVID FastFax




Lavertu 2020, medRxiv https://www.medrxiv.org/content/10.1101/2020.12.15.20248256v1

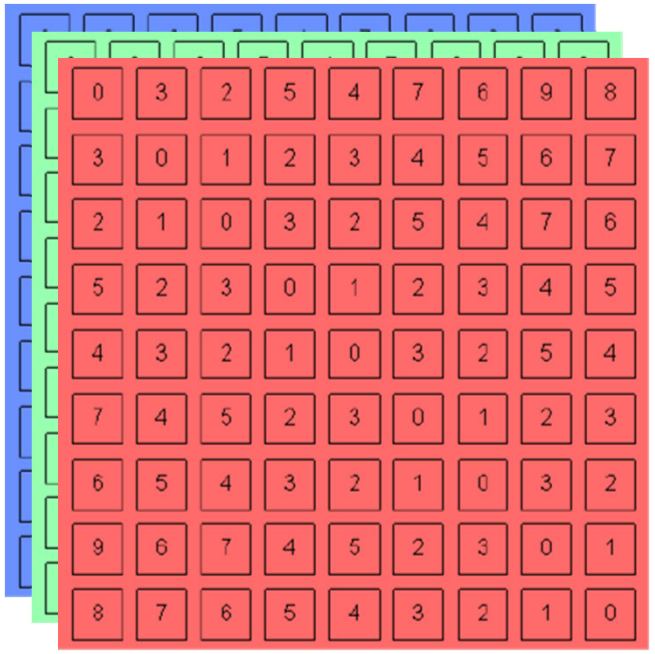
# The technical side…

# How do computers perceive images and videos?

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 3 | 2 | 5 | 4 | 7 | 6 | 9 | 8 |
| 3 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | 1 | 0 | 3 | 2 | 5 | 4 | 7 | 6 |
| 5 | 2 | 3 | 0 | 1 | 2 | 3 | 4 | 5 |
| 4 | 3 | 2 | 1 | 0 | 3 | 2 | 5 | 4 |
| 7 | 4 | 5 | 2 | 3 | 0 | 1 | 2 | 3 |
| 6 | 5 | 4 | 3 | 2 | 1 | 0 | 3 | 2 |
| 9 | 6 | 7 | 4 | 5 | 2 | 3 | 0 | 1 |
| 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

**Pixel intensities:**
8-bit greyscale: 0 – 255 ($2^8$)
16-bit greyscale: 0 - 65 535 ($2^{16}$)

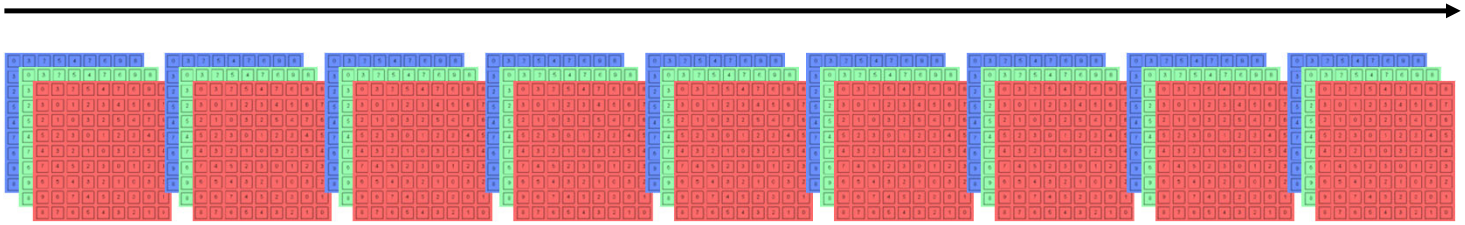
# How do computers perceive images and videos?



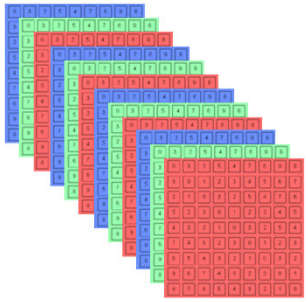

**RGB**

# How do computers perceive images and videos?

**Video**

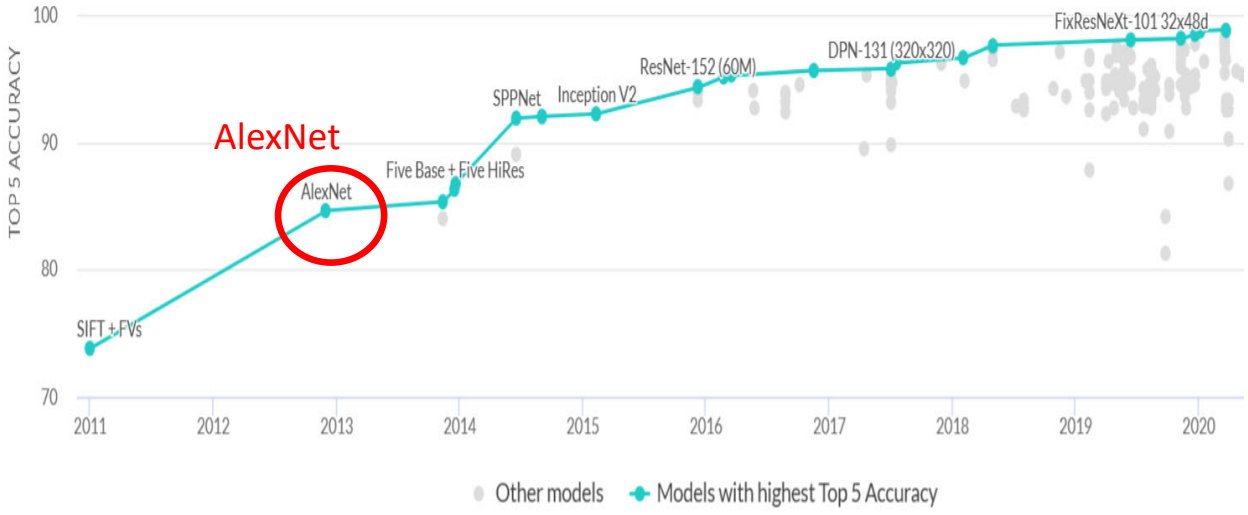


**3D**



# AlexNet: the breakthrough of GPU-driven deep learning for computer vision

ImageNet Large Scale Visual Recognition Challenge (ILSVRC)




https://paperswithcode.com/sota/image-classification-on-imagenet?metric=Top%205%20Accuracy
https://cs.stanford.edu/people/karpathy/cnnembed/

# Convolutional neural networks (CNNs)

- Network type most used for computer vision
- Characterized by convolutional layers
- Neurons arranged in 3D: width, height, depth
- Neurons connected to small area of previous layer

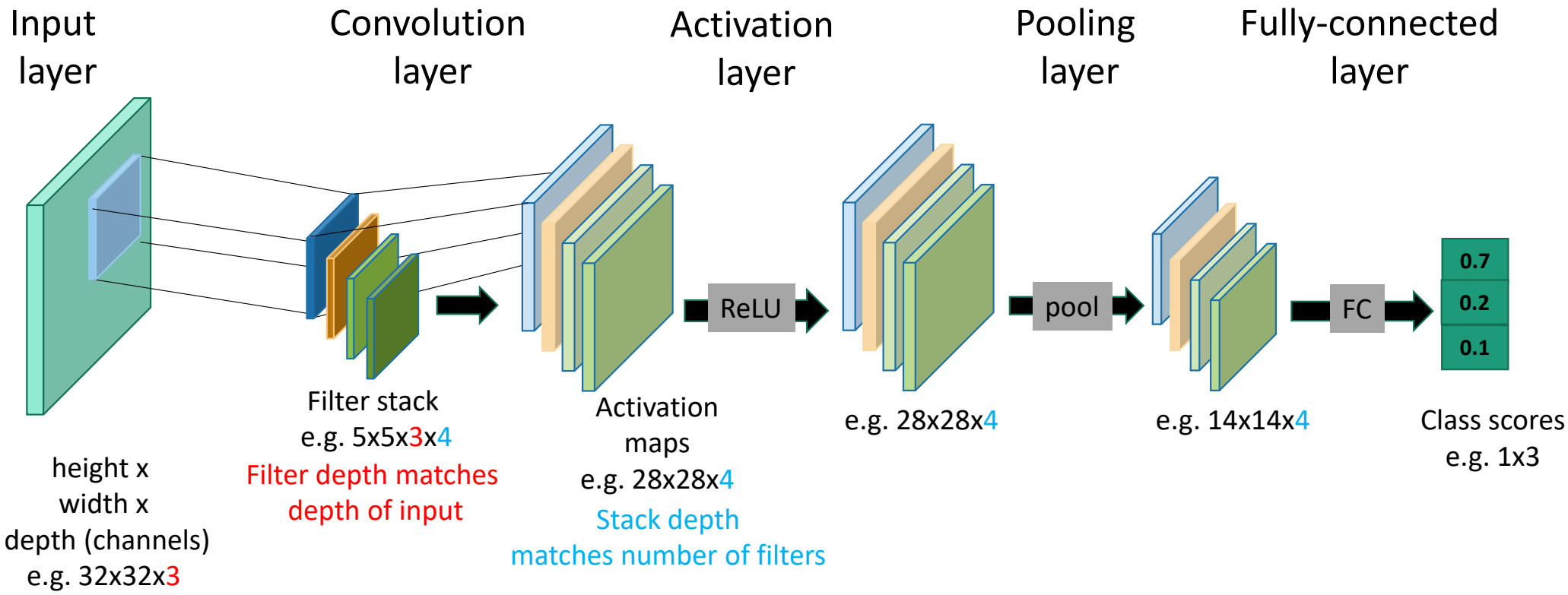
  $\leftrightarrow$ Fully connected network

# CNN components

- Input layer: holds pixel values of image/video
- Convolutional layer: slides filters over input computing dot product
- Pooling layer: reduces width and height by pooling (downsampling)
- Fully connected layer: every output neuron connected to all input neurons → can recombine all input

- Activation layer: applies activation function (element-wise)
- Normalization layer: normalizes its input
- Dropout layer: randomly sets input units to 0 → prevents overfitting

# Simple CNN


Input layer
Convolution layer
Activation layer
Pooling layer
Fully-connected layer
ReLU
pool
FC
0.7
0.2
0.1
height x width x depth (channels)
e.g. 32x32x3
Filter stack
e.g. 5x5x3x4
Filter depth matches depth of input
Activation maps
e.g. 28x28x4
Stack depth matches number of filters
e.g. 28x28x4
e.g. 14x14x4
Class scores
e.g. 1x3

# Mini quiz: Supervised or unsupervised?

- Predicting whether patient has COVID-19 from a CT scan of the lung
- Determining the severity grade of a tumor from histology images
- Clustering cells of similar shape from microscopy images
- Tracking bird flightpaths in a video
- Outlining areas of deforestation on satellite images
- Flagging blurry MRI images
- Finding unknown types of image corruption in a large dataset

## Supervised learning

Labeled data (x,y)

Defined target

Aim: mapping function x -> y

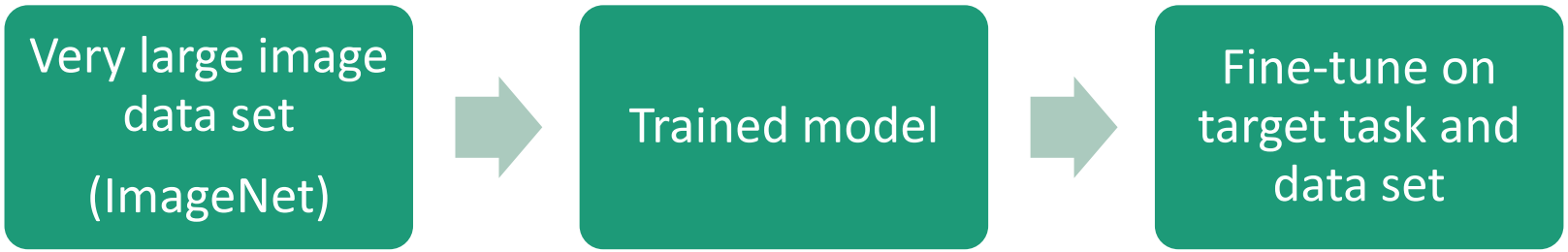
## Unsupervised learning

Unlabeled data

No defined target

Aim: Learn structure of the data

# Training computer vision models often uses transfer learning



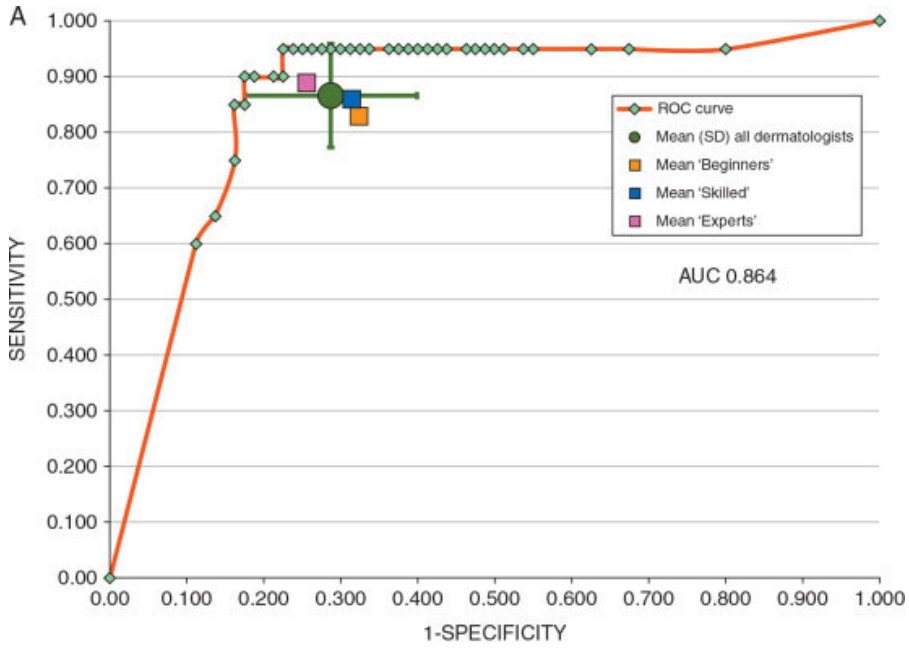
# Data augmentation

- Flip
- Rotate
- Zoom in
- Add noise
- Split images
- Illumination variation
- Blur

# AI surpasses human performance in many individual studies

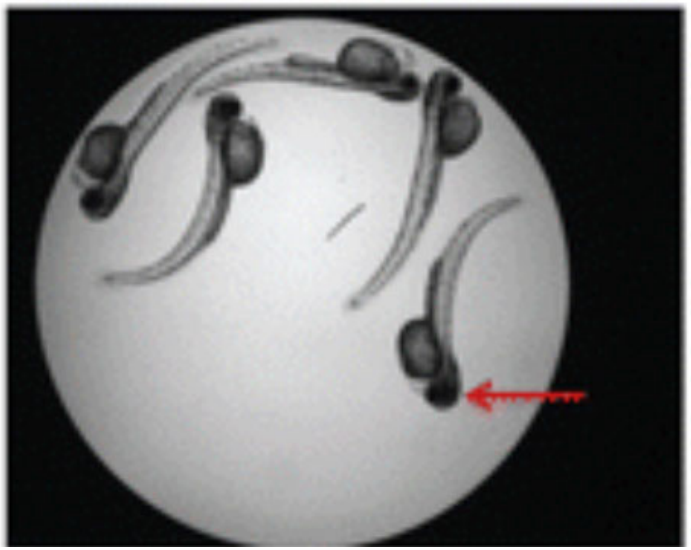
Observational Study > Ann Oncol. 2018 Aug 1;29(8):1836-1842. doi: 10.1093/annonc/mdy166.

**Man against machine: diagnostic performance of a deep learning convolutional neural network for dermoscopic melanoma recognition in comparison to 58 dermatologists**

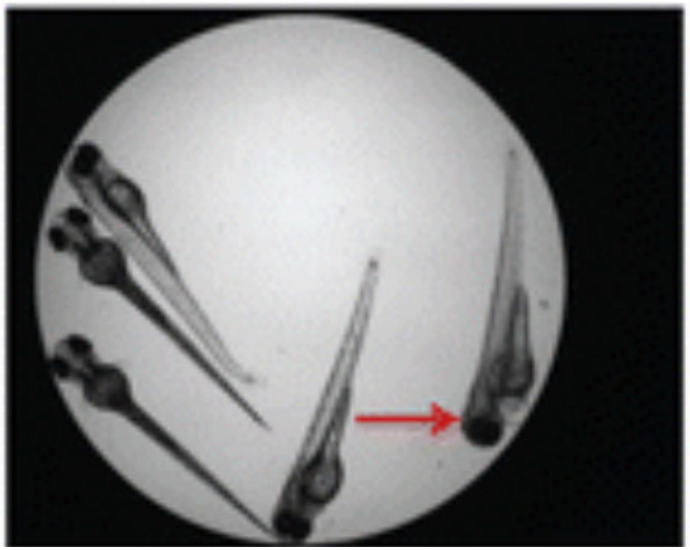


# Neural networks “see” things humans cannot perceive…

Unhealthy zebrafish

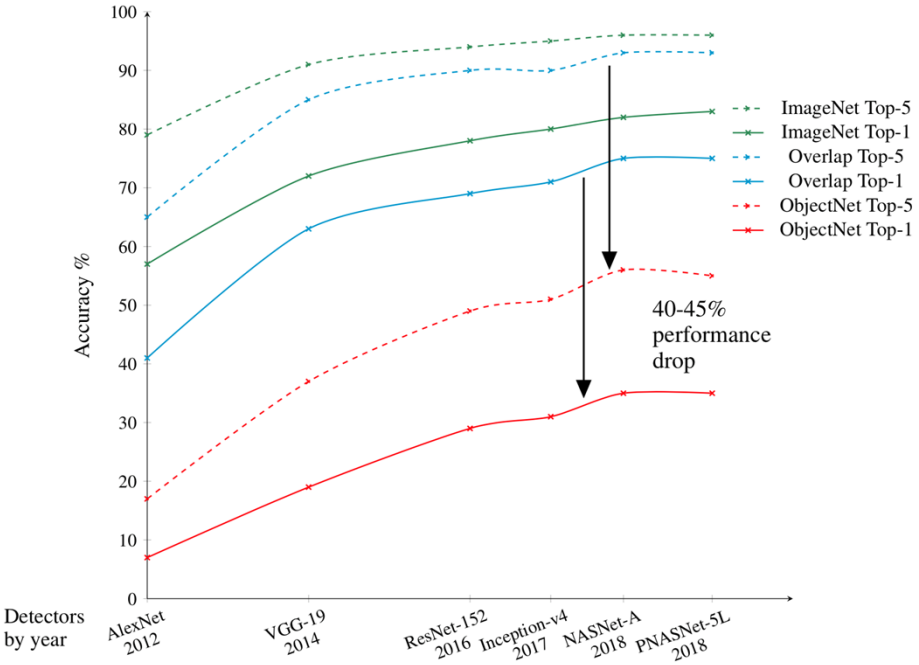


Healthy zebrafish



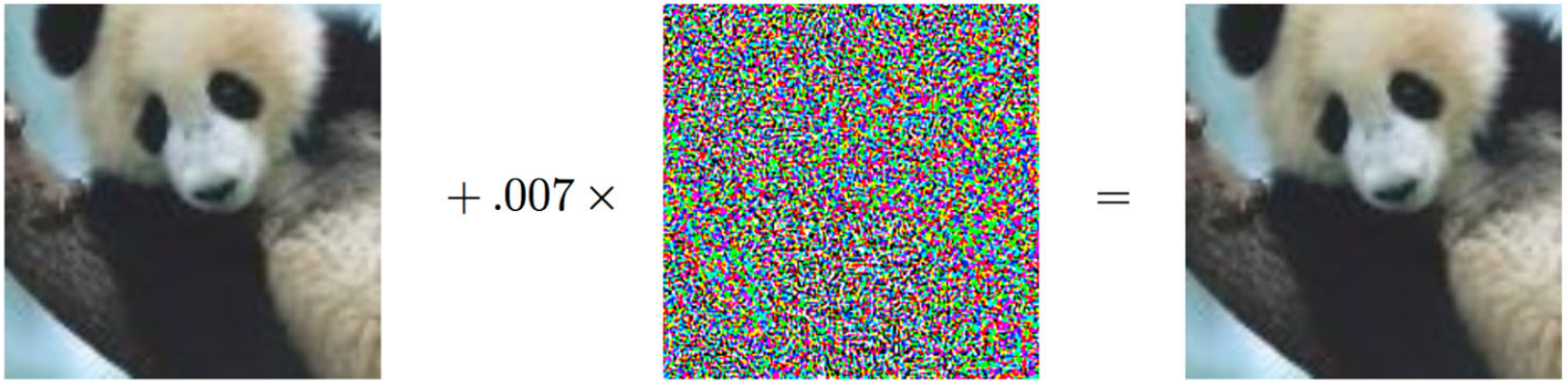
Ishaq, Sadanandan, Wählby. 2017 22(1):102-107. doi: 10.1177/1087057116667894

# …but can struggle with problems that are easy for humans


Barbu et al. Advances in Neural Information Processing Systems 32, pages 9448–9458. 2019.

# …but can struggle with problems that are easy for humans




"panda"

57.7% confidence

noise

"gibbon"

99.3% confidence

*Goodfellow et al, ICLR 2015*


From Karen Zack
@teenybiscuit

# Computer vision is challenging

- Variable viewpoints
- Noise
- “Accidental” similarities
- Variable scale
- Deformable and/or moving objects
- Occlusion
- Variable illumination
- Intra-class variation
- Variable background

# AI-based software for bioimage analysis

**DeepImageJ: A user-friendly plugin to run deep learning models in ImageJ**

Comm

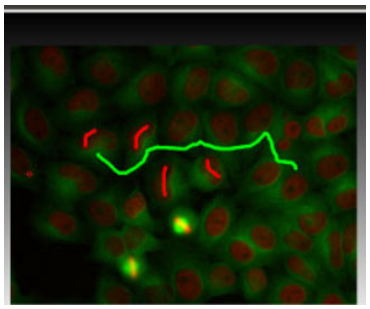
Estibaliz Gómez-de-Mariscal, Carlos García-López-de-Haro, Laurène Donati, Michael Unser, Arrate Muñoz-Barrutia, Daniel Sage

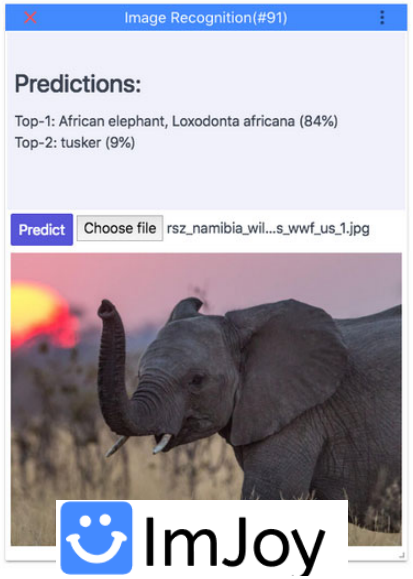
**doi:** https://doi.org/10.1101/799270

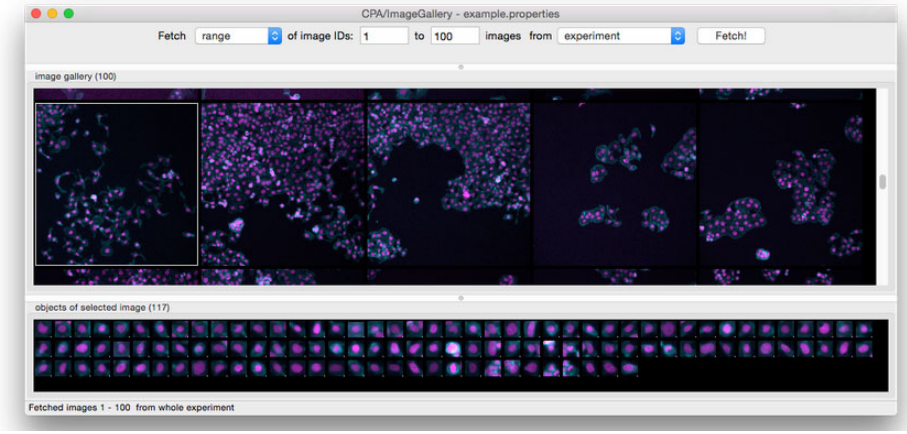
CellProfiler Analyst

Interactive data exploration, analysis, and classification of large biological image sets

ilastik





# Summary: common computer vision tasks

- Classification
- Regression
- Object detection
- Object tracking
- Semantic segmentation
- Instance segmentation
- Pose estimation
- Image registration
- Image restoration
- Super-resolution
- Image captioning
- Image clustering
- Dimensionality reduction
- Image generation

# Summary: CNNs and Transfer learning

- Convolutional layers are the defining characteristic of computer vision models (“convolutional neural networks”)
- Increases in network depth and complexity increase performance
- Transfer learning with networks pre-trained on ImageNet is default choice