Artificial intelligence and machine learning in microscopy

by Dominic Waithe UKRI Innovation Fellow.

18th November 2020

Micron Advanced Microscopy Course 2020

TODAYS TALK:

- Introduction to Machine Learning and Artificial Intelligence
- Conventional Machine Learning
- Deep Learning
- Machine Learning in Microscopy Safari

MRC Weatherall Institute of Molecular Medicine

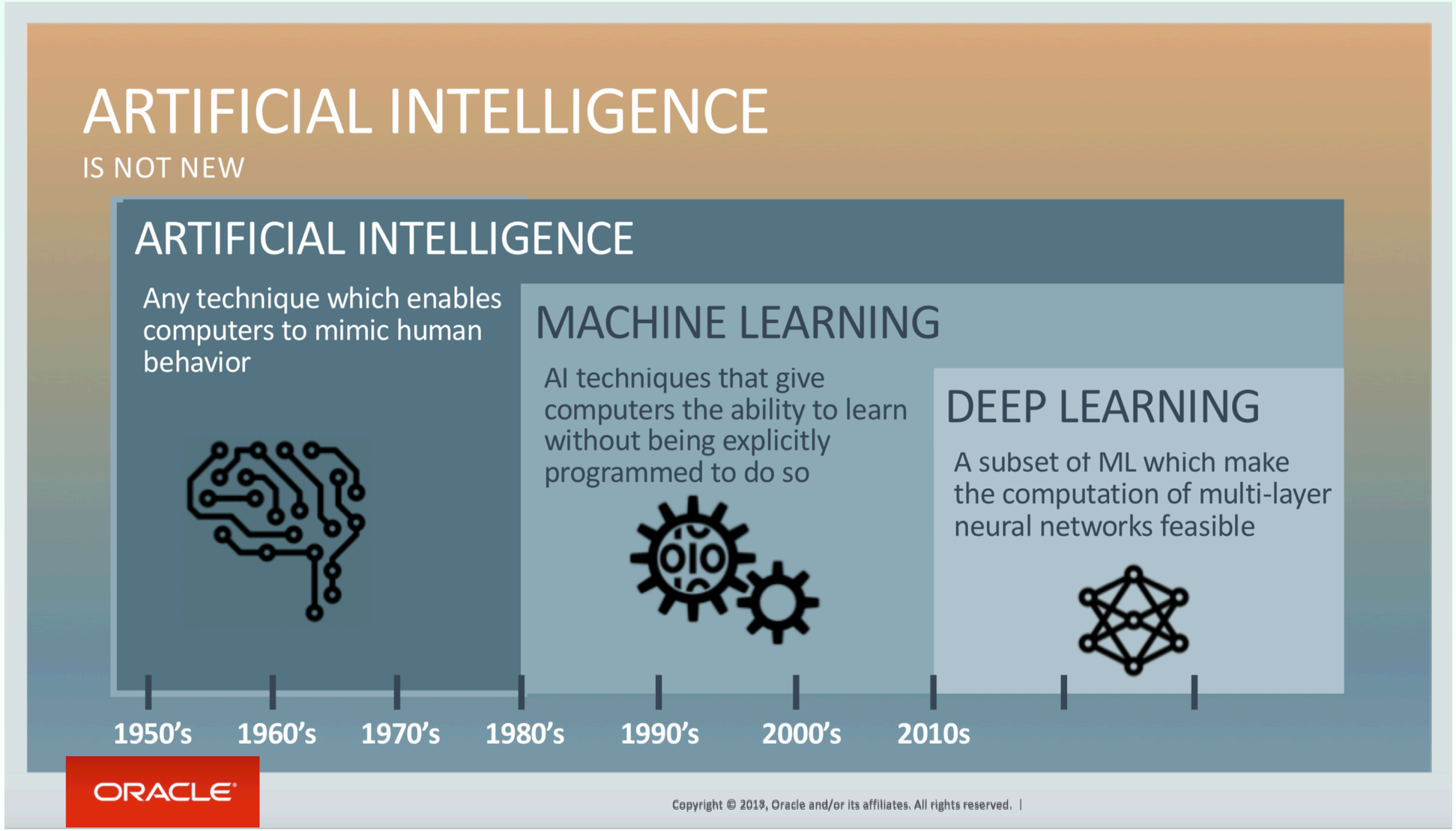
MRC Medical Research Council

UNIVERSITY OF OXFORD

UK Research and Innovation

Introduction to Machine Learning and Artificial Intelligence

AI, Machine learning and Deep Learning.



Source: https://blogs.oracle.com/bigdata/difference-ai-machine-learning-deep-learning

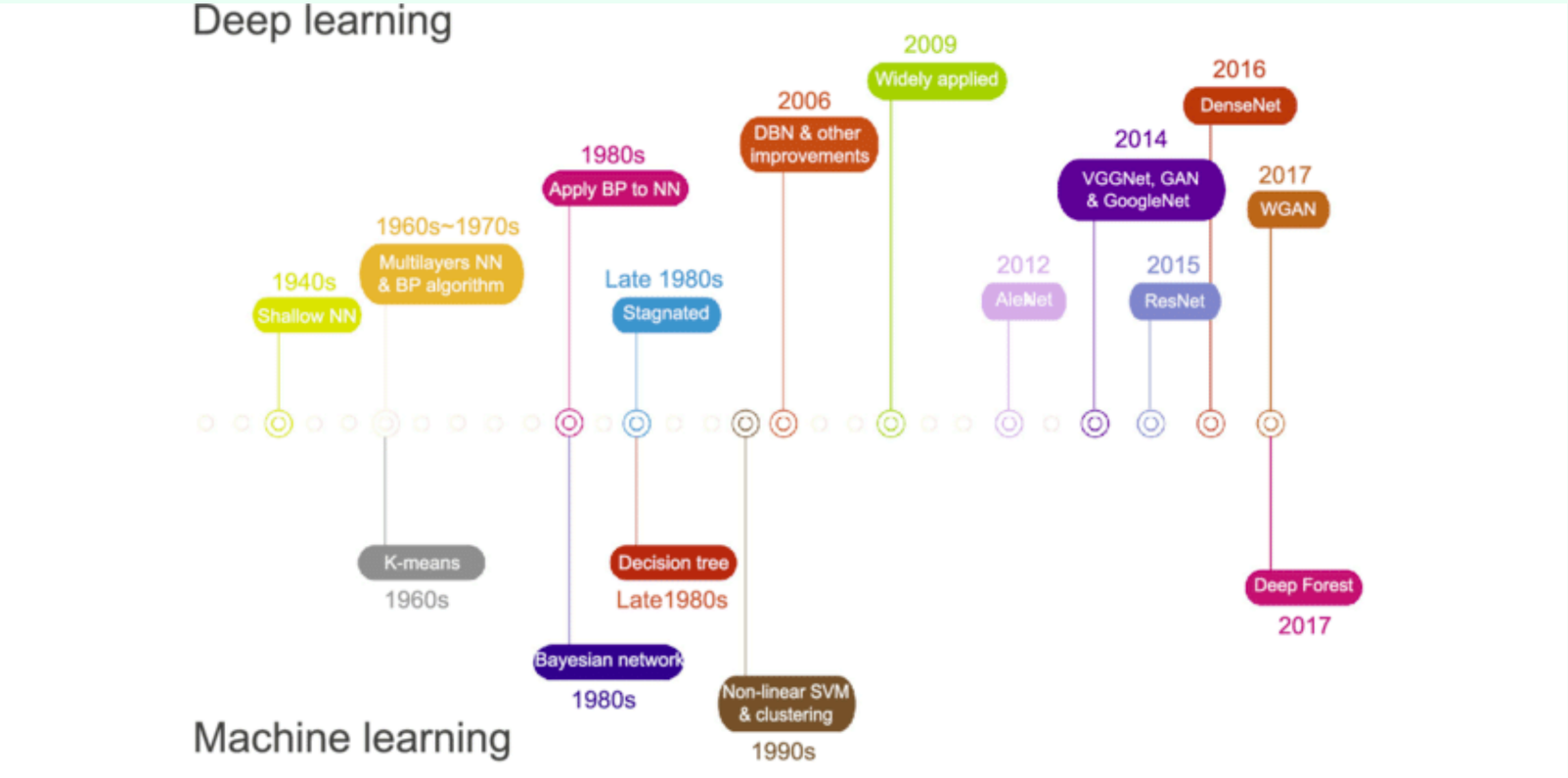
Machine learning

Machine learning is a scientific discipline that deals with the construction and study of algorithms that can learn from data.

Machine learning and **Statistics** are highly related, with algorithms and models appearing in both.

Source: http://en.wikipedia.org/wiki/Machine_learning

TimeLine

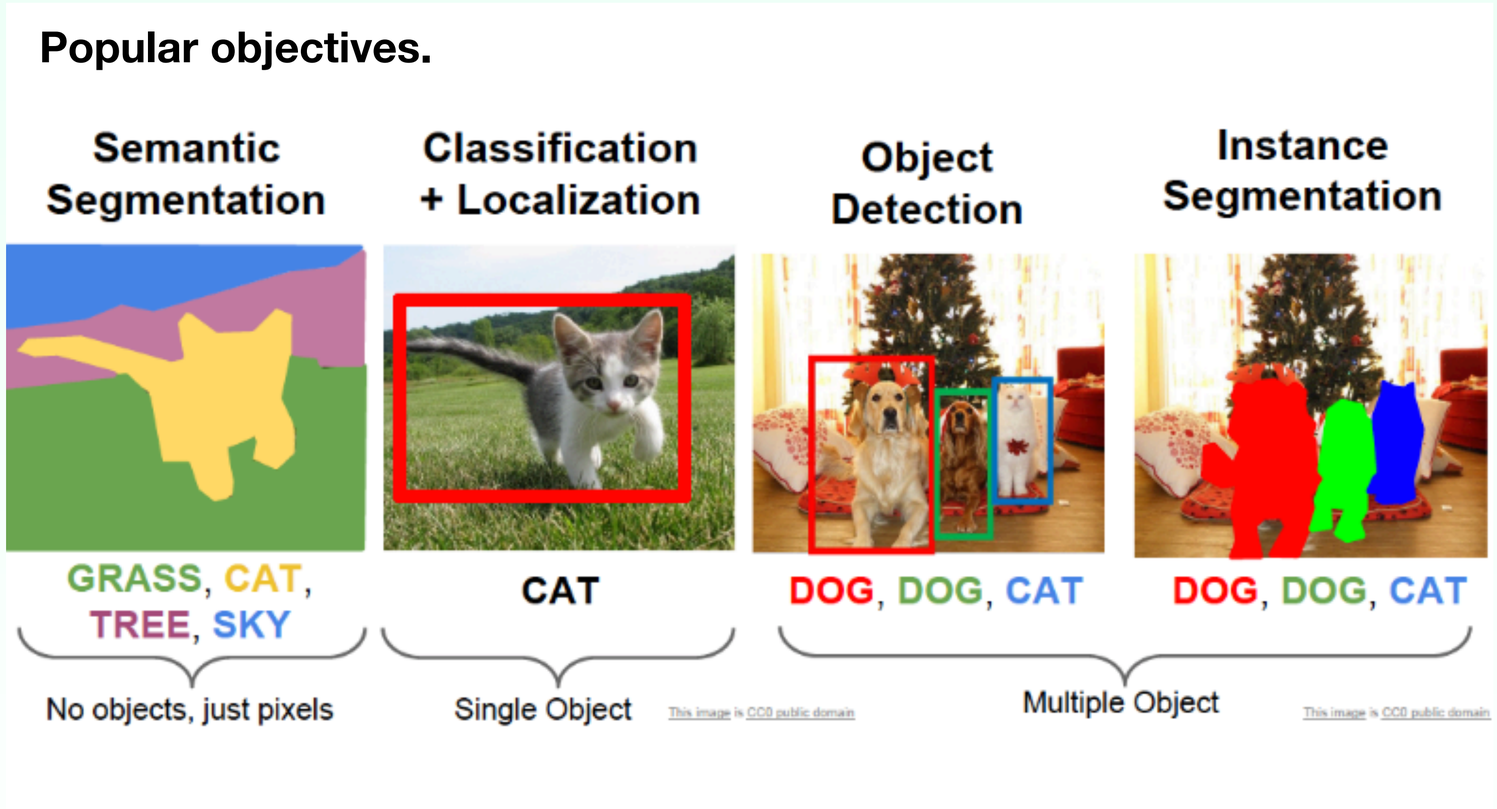


From around 2012, deep learning has really taken off, but has been around a long time.

Source: Cao, Chensi & Liu, Feng & Tan, Hai & Song, Deshou & Shu, Wenjie & Li, Weizhong & Zhou, Yiming & Bo, Xiaochen & Xie, Zhi. (2018). Deep Learning and Its Applications in Biomedicine. Genomics, Proteomics & Bioinformatics. 16. 10.1016/j.gpb.2017.07.003.

Computer Vision

Machine learning has been applied successfully in many domains of image analysis. **Computer Vision**, a domain where computers are taught to understand and interpret the visual world has seen great advances.



Source: Advanced Image Segmentation using ImageJ/Fiji (Ignacio Arganda-Carreras)

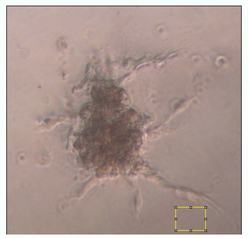
Supervised machine learning.

In supervised learning we use labelled training data as input and desired output.

Matched training data $\mathbf{D} = \{(\boldsymbol{x}_1, y_1), \ldots, (\boldsymbol{x}_n, y_n)\}$

$$g : X \Rightarrow Y$$

For example we learn to classify pixels as either organoid or not organoid:

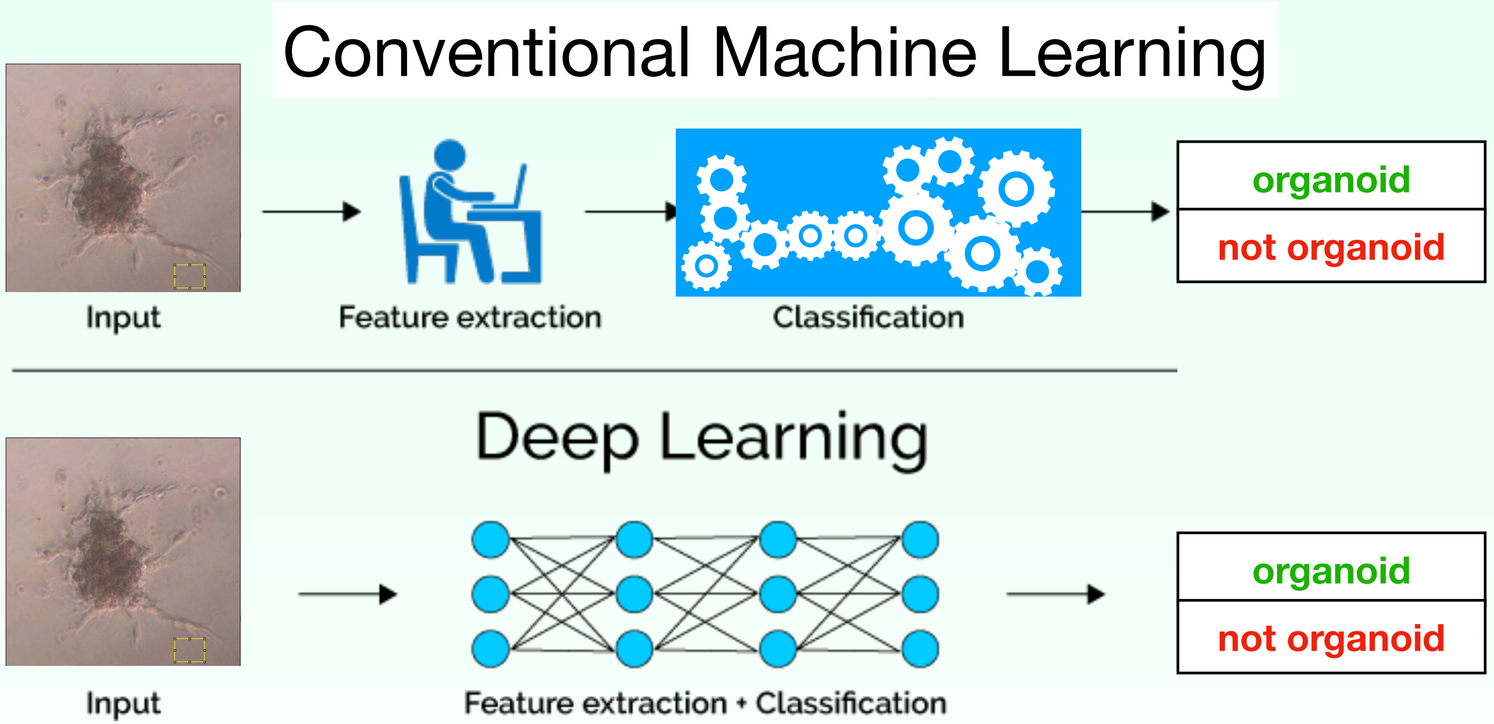
$g :$  $\Rightarrow$ 

organoid

not organoid

Source:

Supervised approaches, Machine Learning Vs Deep Learning

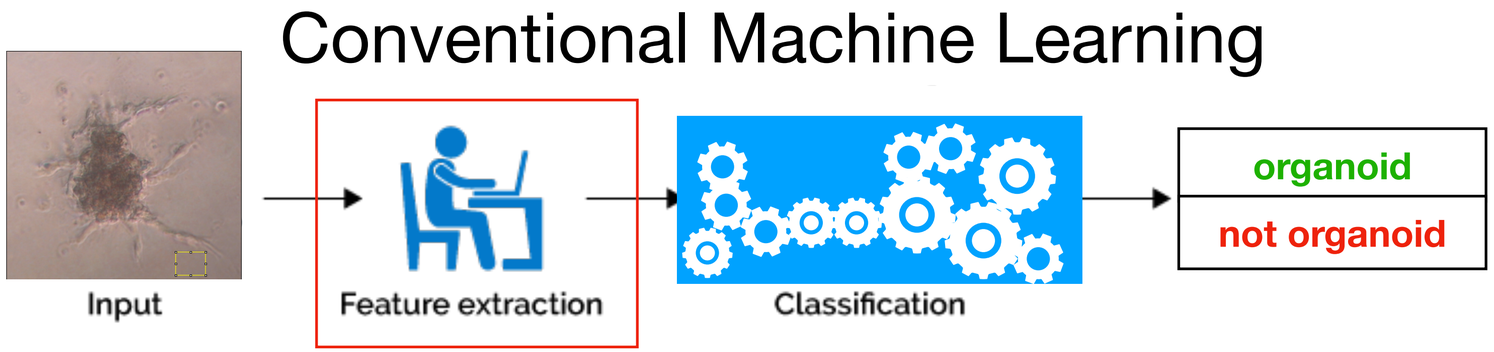


In conventional machine learning we design/choose our own features, and apply a classifier

In Deep learning, we let the network do everything, feature creation and classification.

Source: https://towardsdatascience.com/cnn-application-on-structured-data-automated-feature-extraction-8f2cd28d9a7e

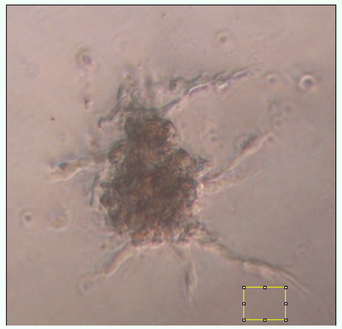
Feature Extraction for conventional Machine Learning



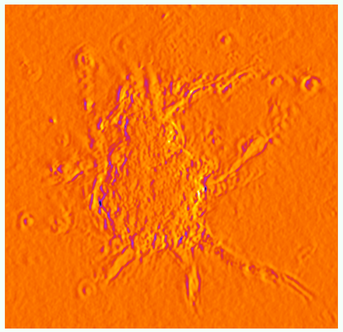
Feature extraction

Feature extraction starts from an initial set of input data and builds derived values (**features**) which are intended to be informative and non-redundant.

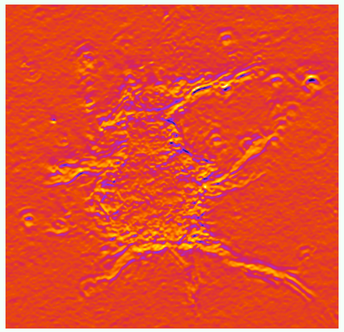
input



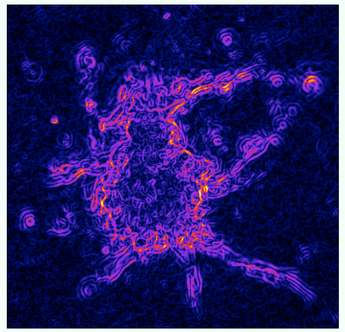
derivative-X



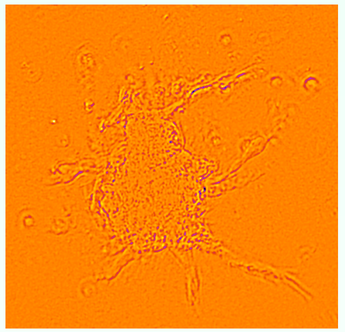
derivative-Y



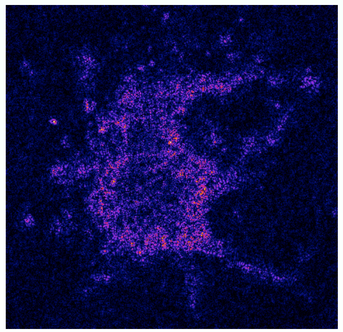
Edge mag.



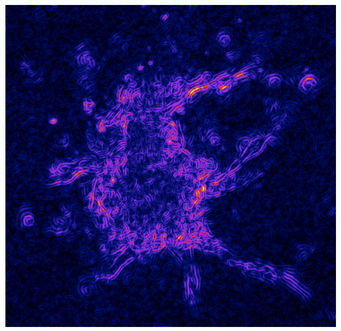
Laplacian



Hessian min

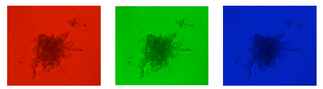


Hessian max



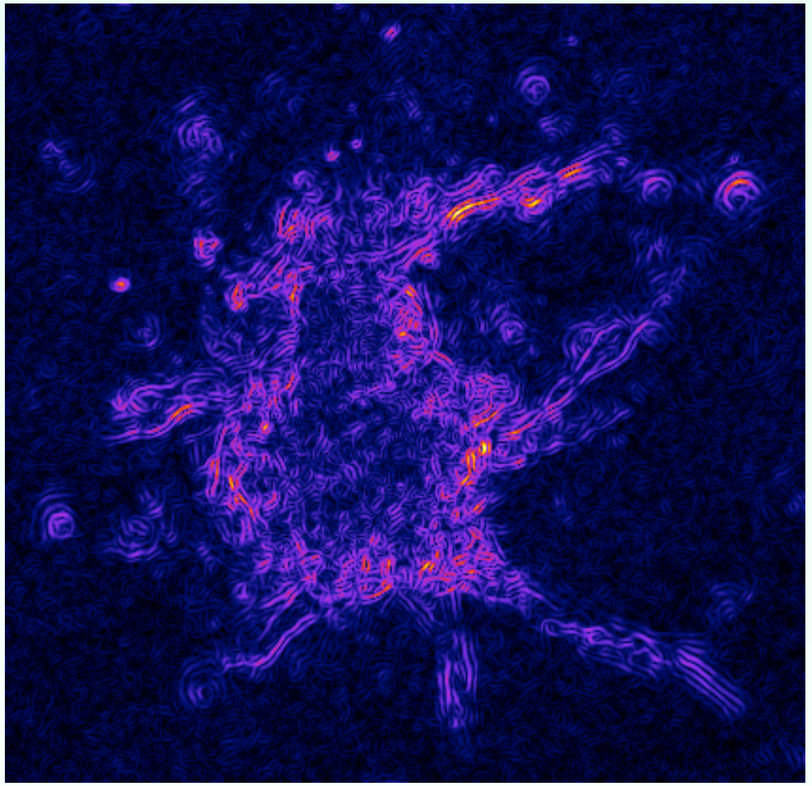
Each pixel in each colour has a value for each one of these image interpretations

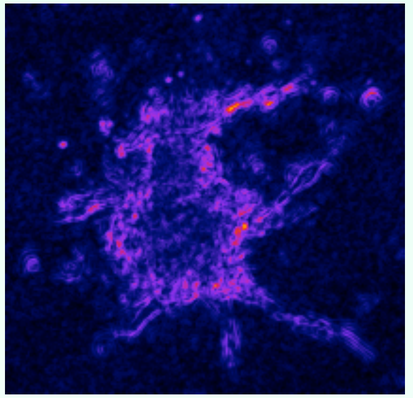
e.g. 3 x 6

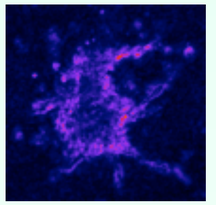


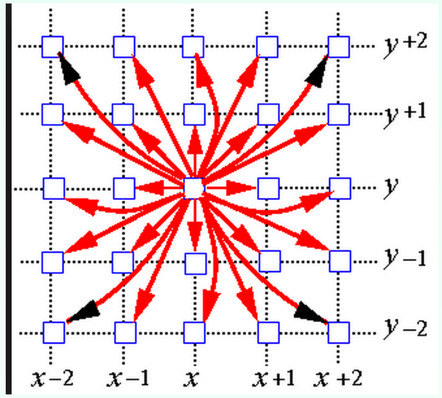
Source:

Feature Extraction different scales



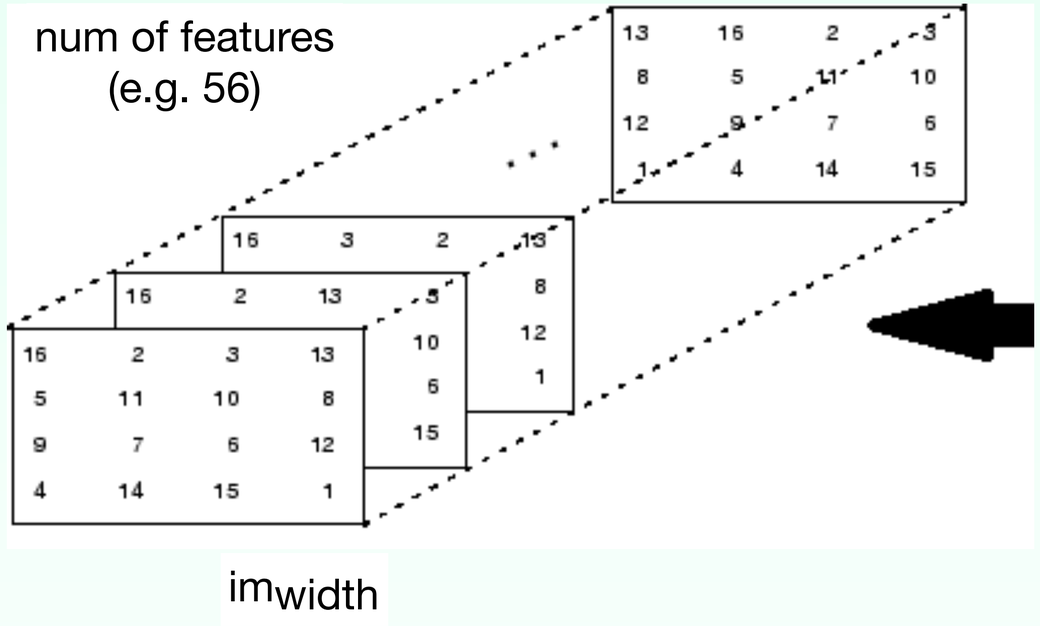


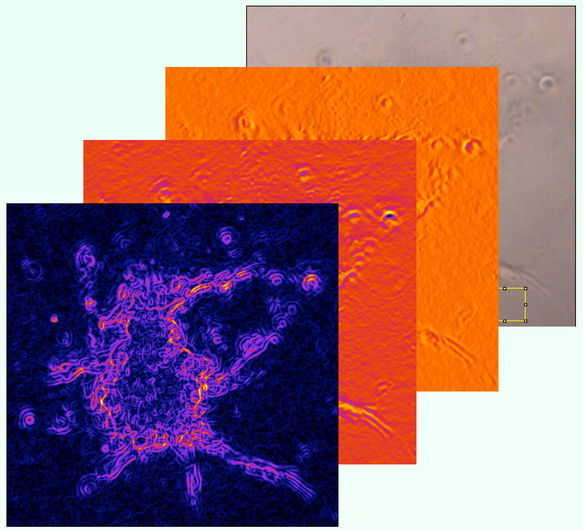




Not only are different Geometric filters used, but at different scales. By blurring the image and applying the different filters you get a sense of the greater

Extracted features:- A matrix of values.



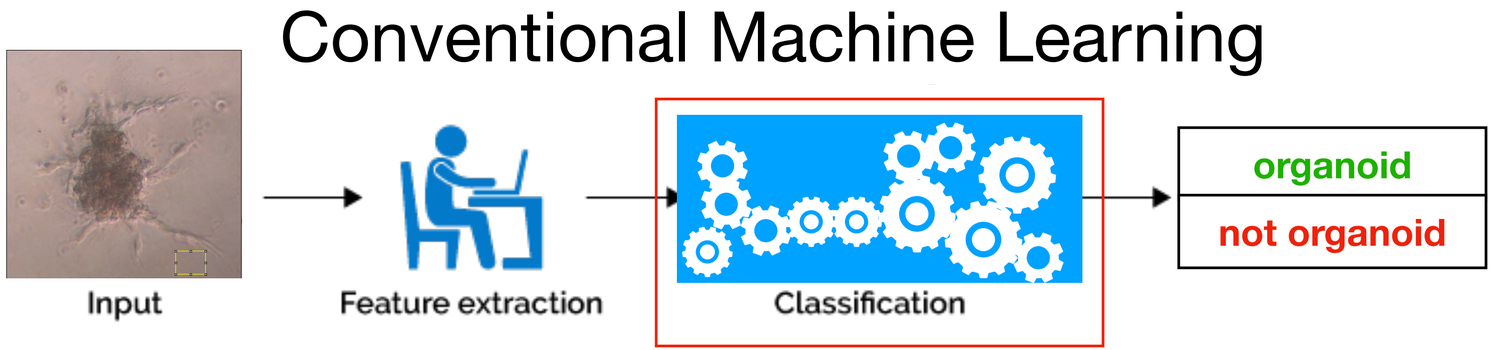


The result is a matrix which has 3-dimensions. and is equivalent in size to im_{height} x im_{width} x 56 (no. of features). For each image.

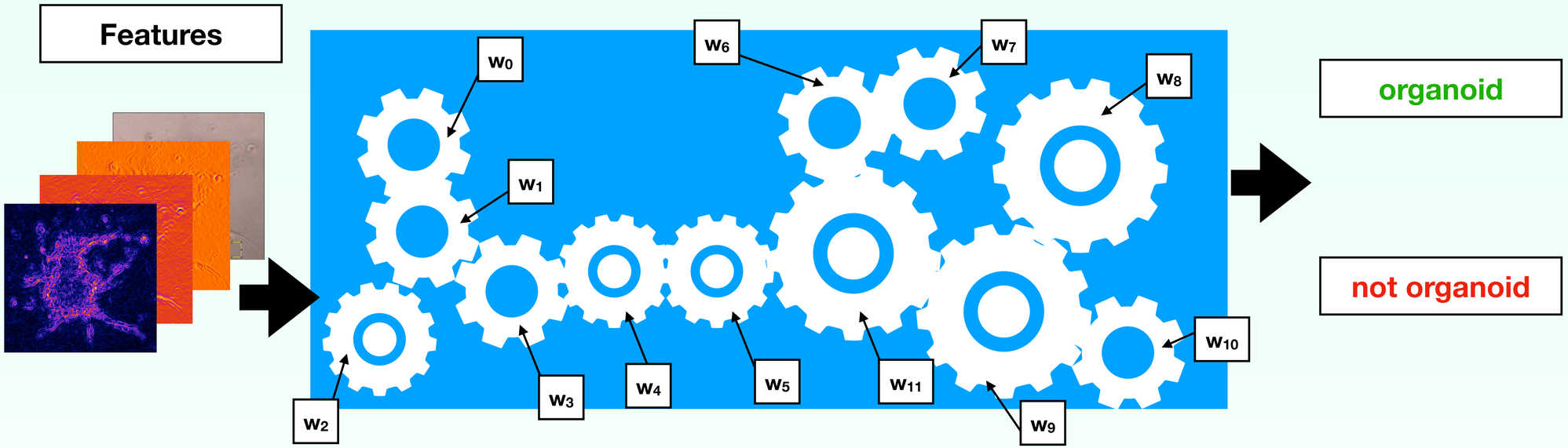
For each pixel, there is a feature vector.

Source:

Shallow Methods for Classification
(i.e. machine learning classification methods)



Machine learning - classification

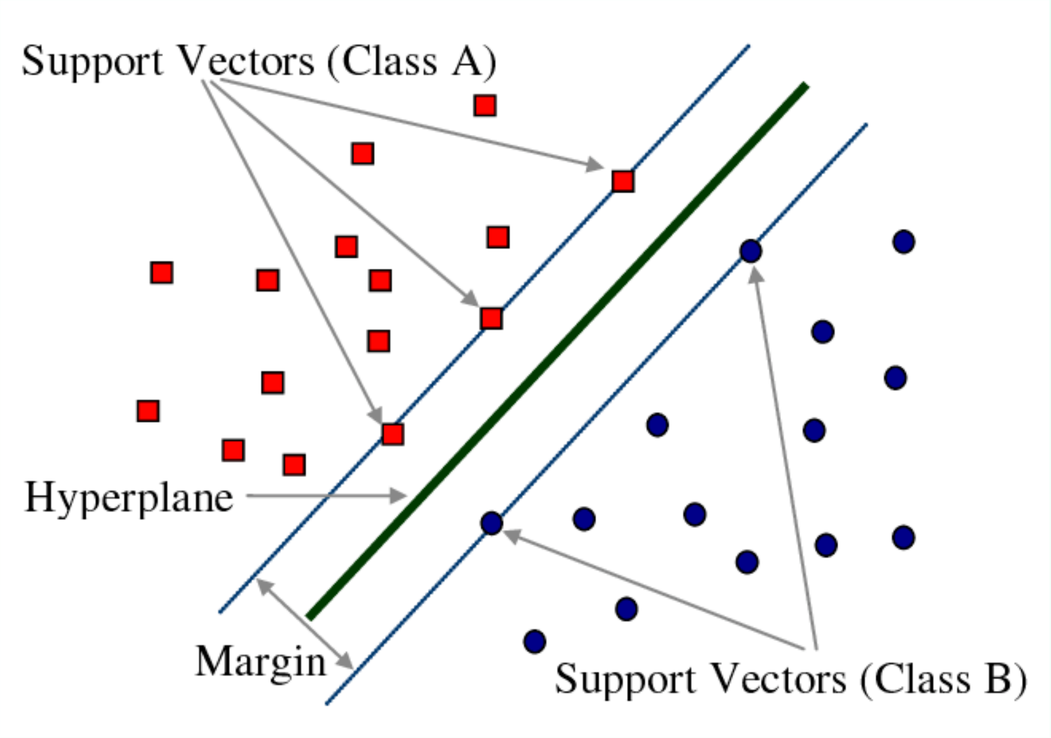


All machine learning algorithms have parameters (weights) that must be learnt from some kind of training procedure.

The more complicated the model, the more powerful it will likely be, but the more parameters you will need to train. Generally speaking, the more parameters you need to learn the more training material is required.

Source: https://en.wikipedia.org/wiki/Random_forest

Supervised - Support Vector Machines (SVMs)

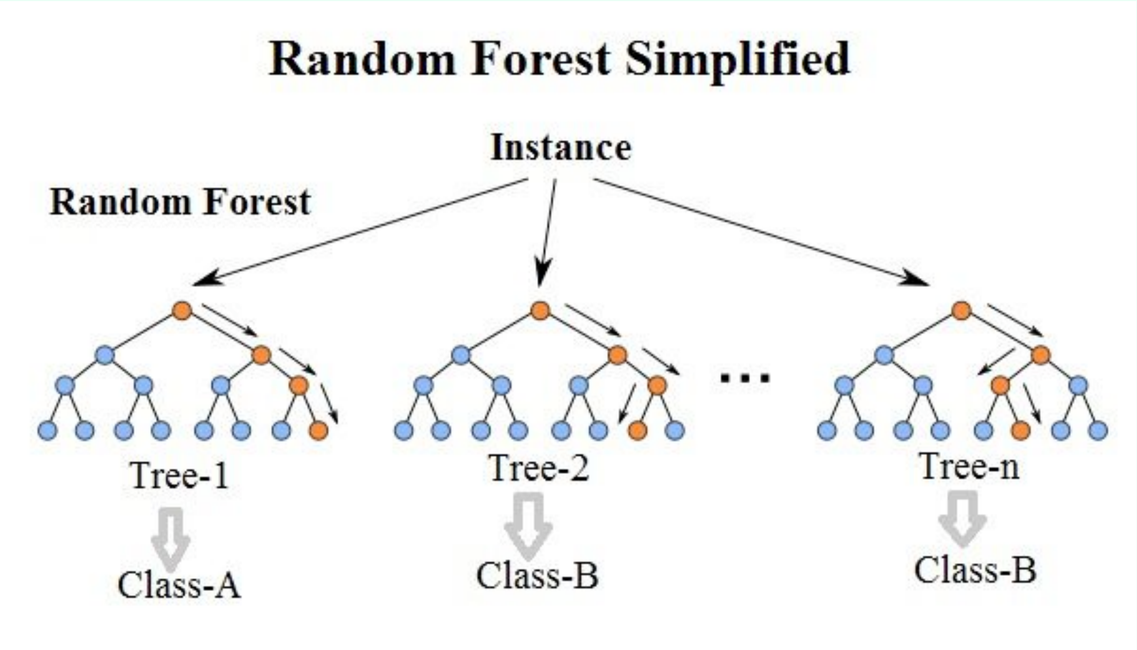


Works well on high dimensional features.
Mostly for binary class problems.
Can handle sparse data well.

A Support Vector Machine (SVM) is a discriminative classifier formally defined by a separating hyperplane. In other words, given labeled training data (supervised learning), the algorithm outputs an optimal hyperplane which categorizes new examples.

Source: https://images.app.goo.gl/GnkzCHMGLdwt2Qj19 An Incremental Learning Algorithm for Supervised Neural Network with Contour Preserving Classification https://en.wikipedia.org/wiki/

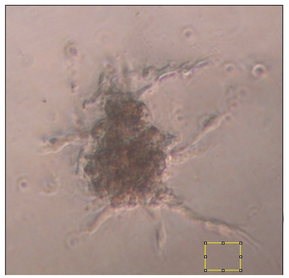
Supervised - Random Forests



Fast to train, can do multi-class problems with ease.
Handles large number of features less well

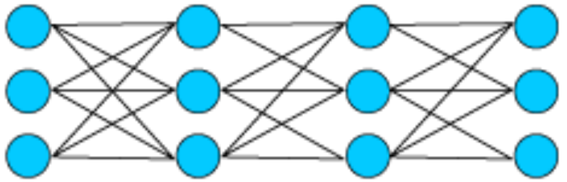
Random forests or random decision forests are an ensemble learning method for classification, regression and other tasks that operates by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes or mean prediction of the individual trees.

Source: https://en.wikipedia.org/wiki/Random_forest



Input

Deep Learning

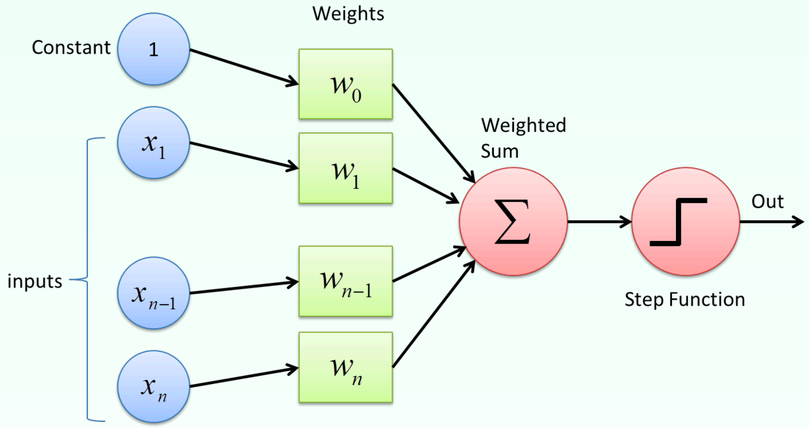


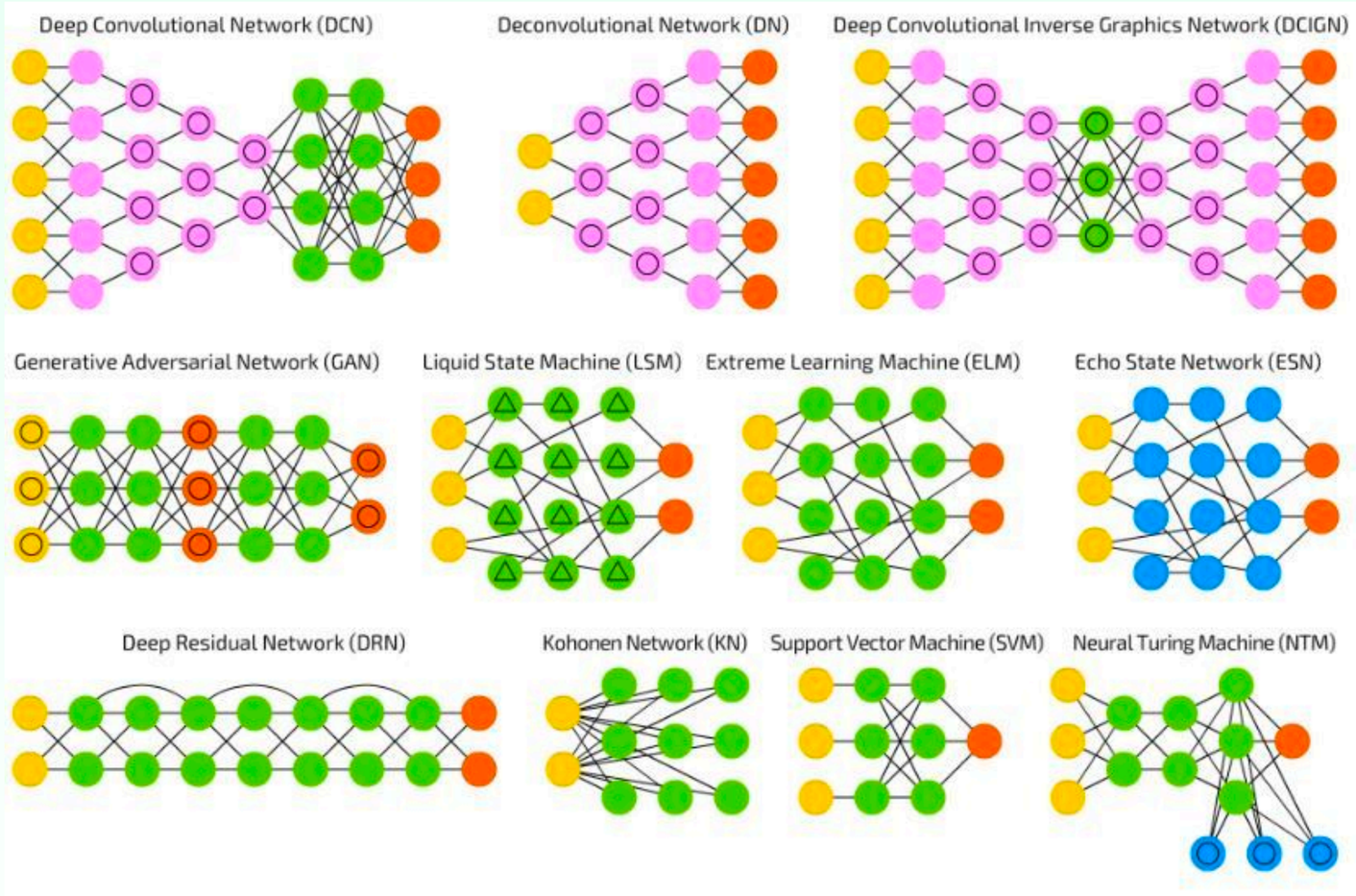
Feature extraction + Classification

organoid
not organoid

Deep Neural Networks.

A single perceptron, the archetypal building block of a neural network





Deep learning models come in many forms, however most typically features and classification parameters are learnt directly from data and the network is comprised of small repeating units.

Source: https://i.pinimg.com/originals/04/f6/54/04f6541018b0dd297deea926a1543c71.jpg, https://images.deepai.org/glossary-terms/perceptron-6168423.jpg

Machine Learning in Microscopy Safari

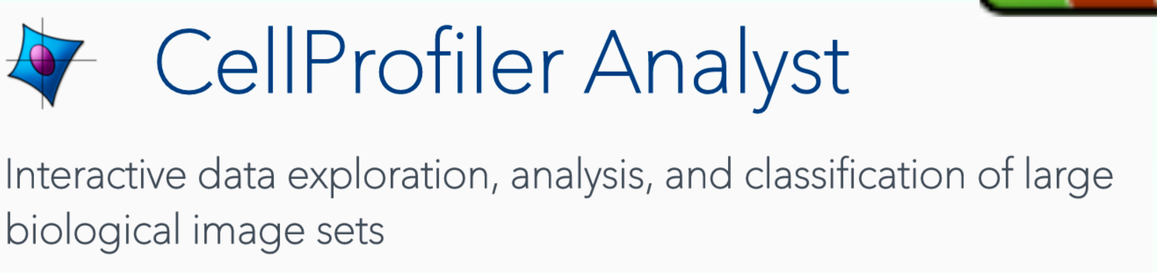
Machine Learning Software

WEKA (In Java standalone or in ImageJ/Fiji)

ilastik

Orbit

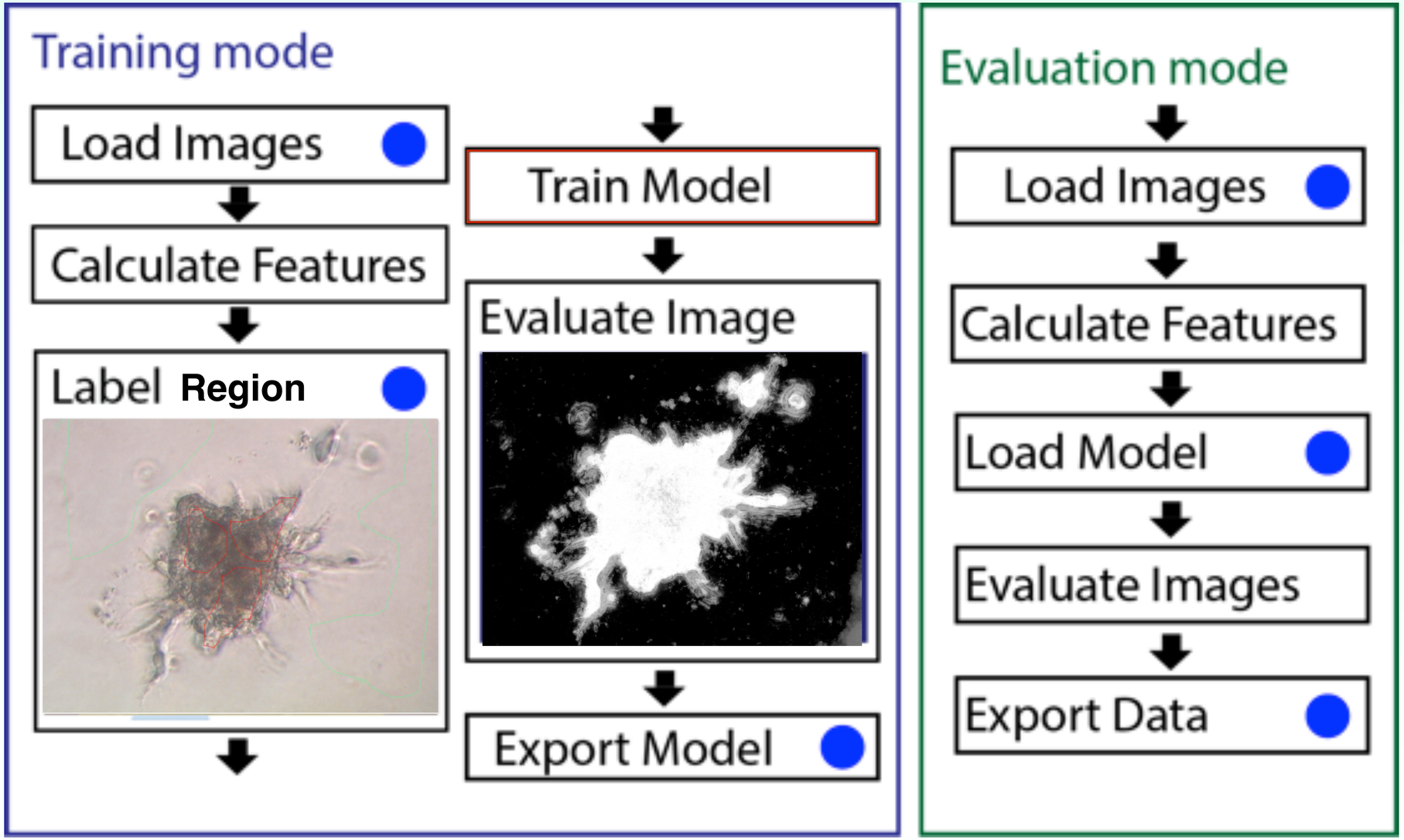
Cell profiler Analyst



Zeiss Machine Learning (Intellesis)

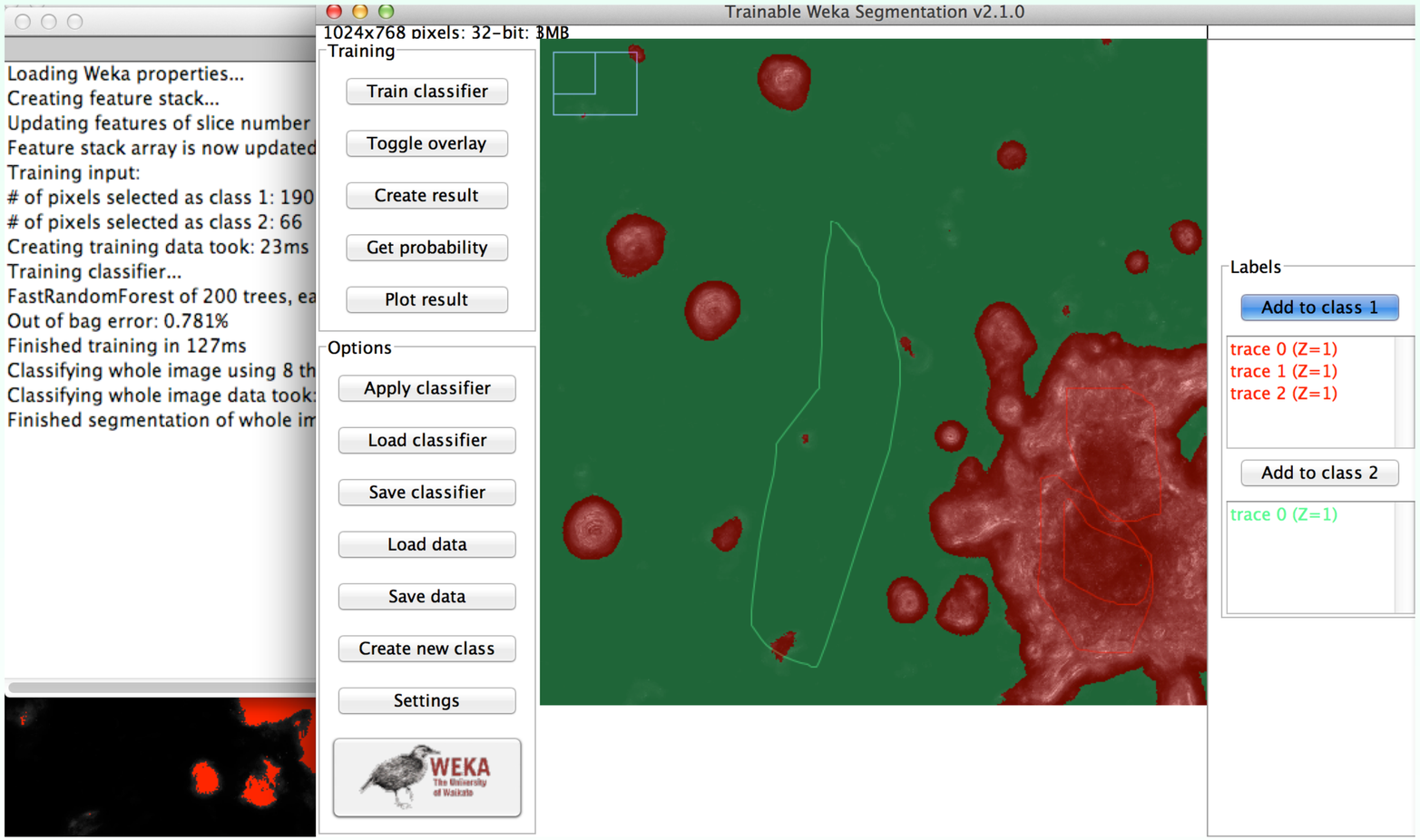
Olympus

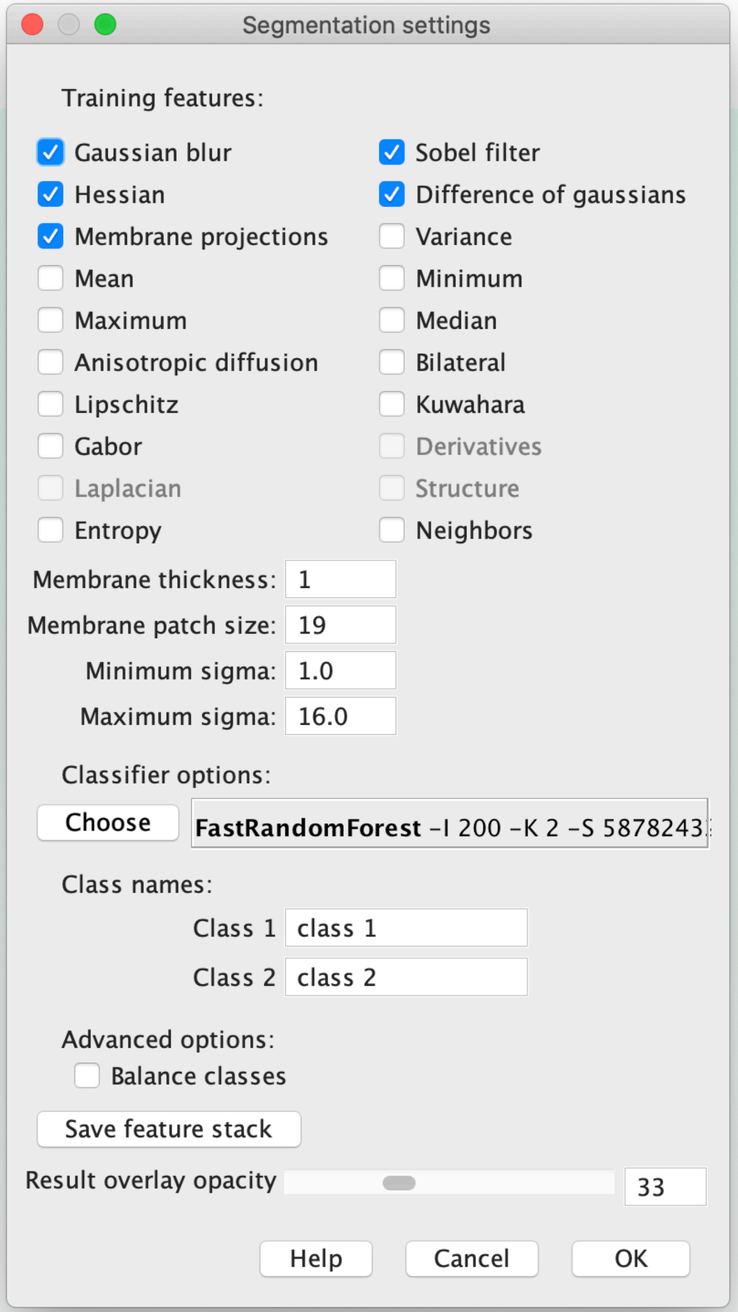
Typical work-flow for supervised learning



Source:

Weka in FIJI/IJ. Good Entry Level.

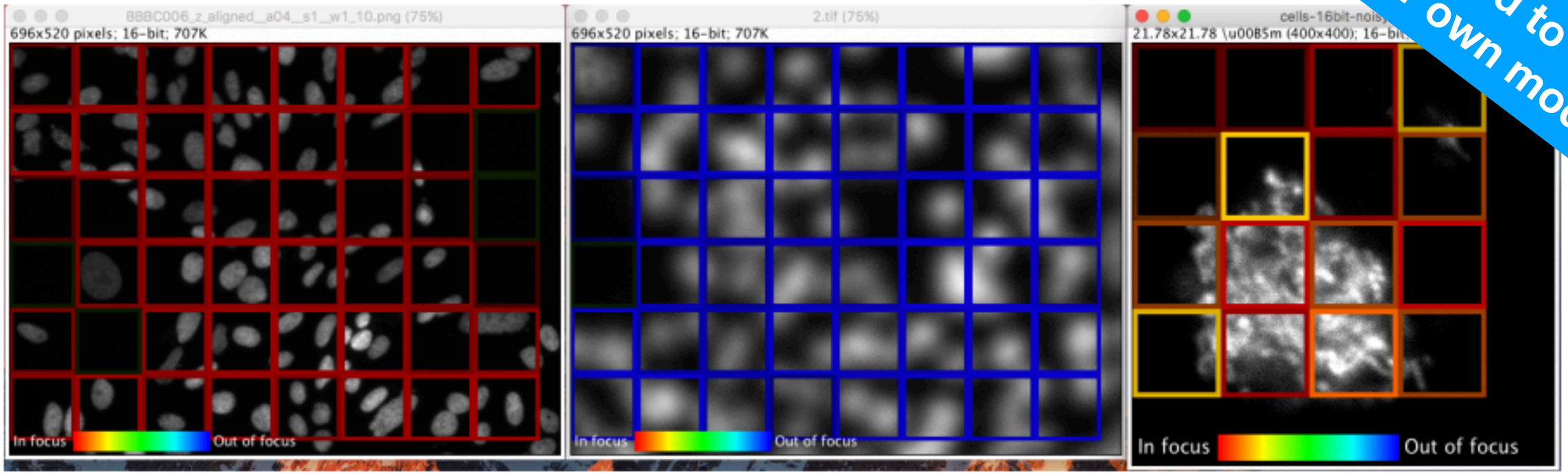




Source:

Microscope Focus Quality Plugin for ImageJ/Fiji

No Need to train your own model.



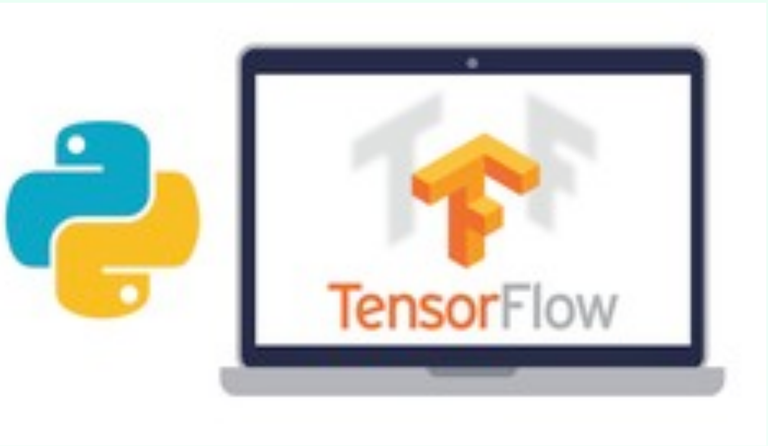
https://imagej.net/Microscope_Focus_Quality

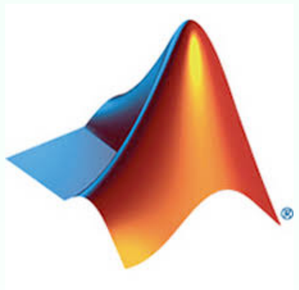
Very Easy Installation:

Enable the TensorFlow update site.

The command is in Plugins › Classification › Microscope Image Focus Quality.

Most deep learning is written in Python





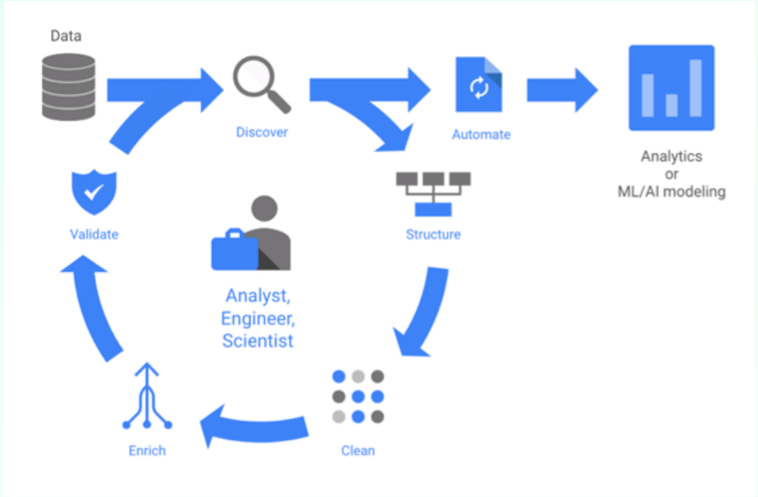
Matlab is also and option.

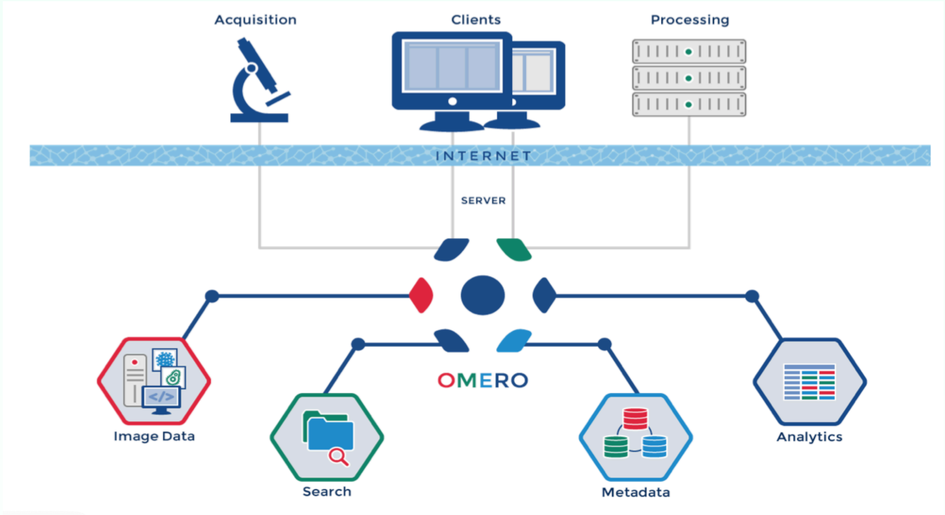
These libraries are also available in other languages including Java, but so far there is not much usage in Fiji/ImageJ. This makes its much more challenging to use them without knowledge of Python.

Big companies like Google and Facebook will pump money into specific frameworks.

Source: Udemy, Tensorflow, Nvidia, pyTorch.

Big gap between routine usage of machine learning and best practise.





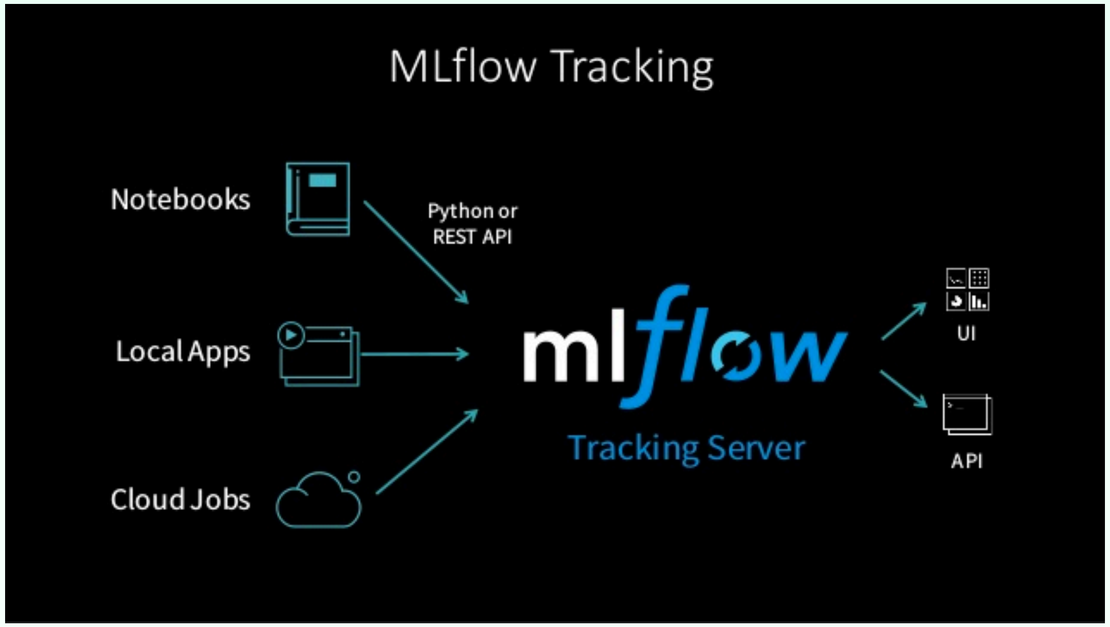


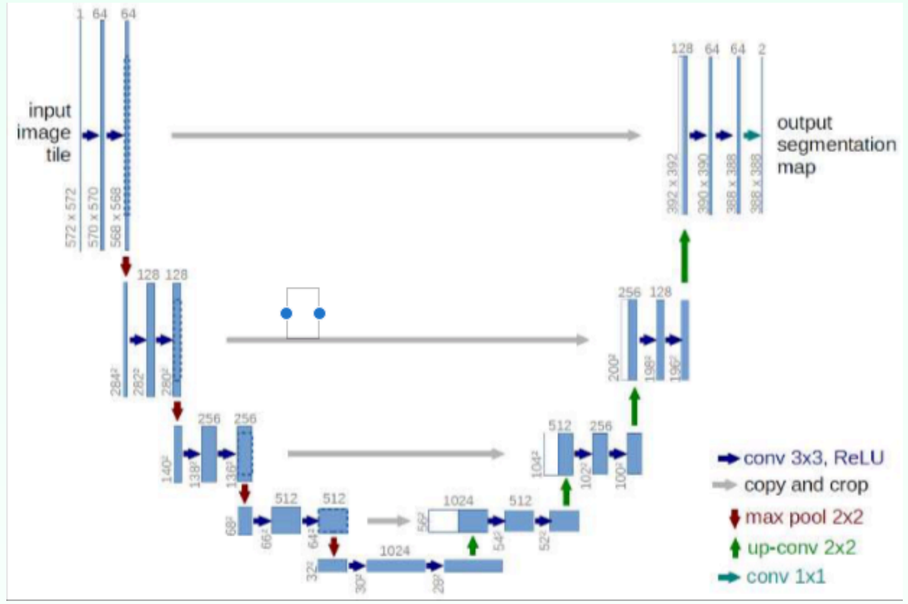
Image Analysis facilities with local or external cloud support.

Analysis workflows.

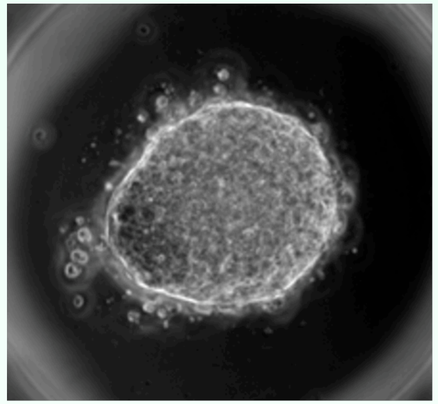
Source: http://www.netdesignarena.com/index.php/2019/01/21/machine-learning-on-google-cloud-platform-simplified/

Medical Imaging- semantic segmentation

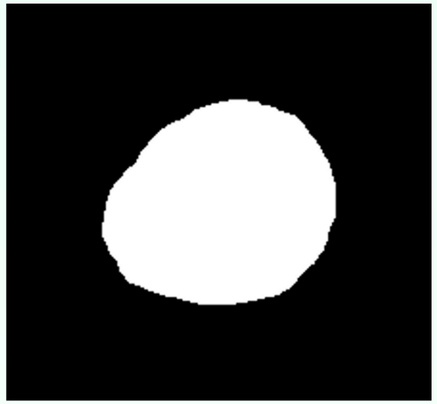
Biomedical imaging, another domain of image analysis, has also seen



Produces semantic segmentation



Input Image

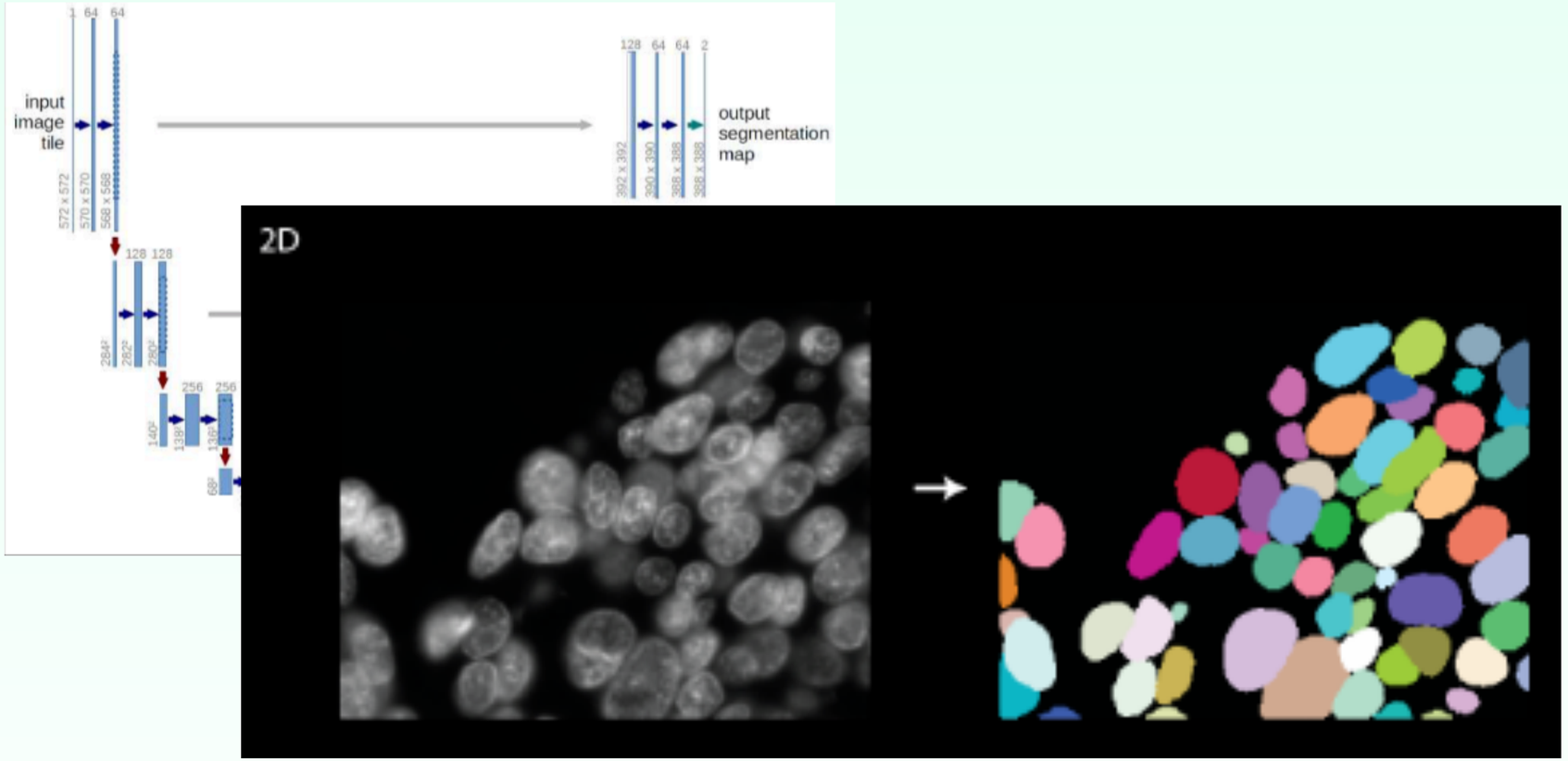


Output Mask

O. Ronneberger, et al., U-Net: Convolutional Networks for Biomedical Image Segmentation, MICCAI 2015

Source: Advanced Image Segmentation using ImageJ/Fiji (Ignacio Arganda-Carreras) O. Ronneberger, et al., U-Net: Convolutional Networks for Biomedical Image Segmentation, MICCAI 2015. https://mathematica.stackexchange.com/questions/172481/how-can-image-segmentation-from-unet-be-improved

Stardist - Star convex polygon detection

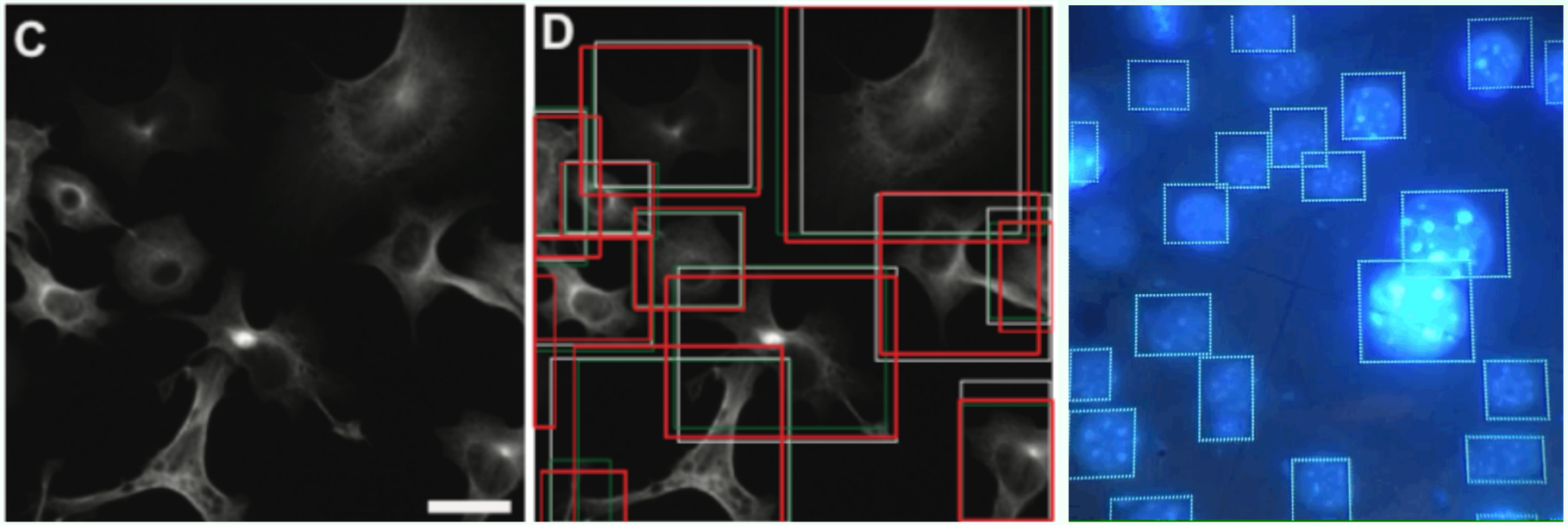


Powerful segmentation algorithm which avoids pixel livel (instance-level) segmentation.

Instead learns parameterised output more akin to what gets analysed.

Source:https://github.com/mpicbg-csbd/stardist

My own work: Object detection networks



Used for drawing bounding boxes around objects in images. I compare some of the state-of-the-art detectors, and apply them in augmented reality system.

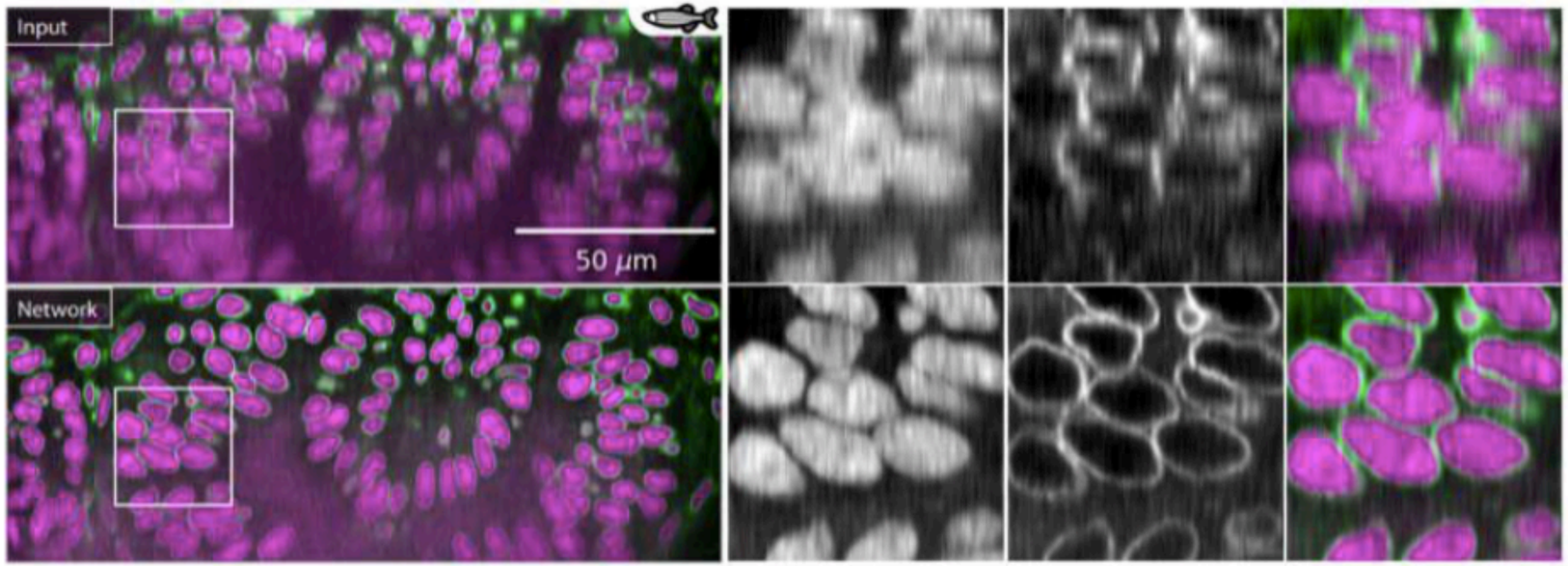
- Extremely fast-can work inline with microscope to influence control.
- Very accurate

Source: JCB: Object Detection Networks and Augmented Reality for Cellular Detection in Fluorescence Microscopy. Waithe D,, Brown JM, Reglinski K, Diez-Sevilla I, Roberts D, Christian Eggeling1,4,6,7,

Bioimage Analysis specific applications

Content-Aware image restoration

Zebrafish retina (nuclei and the nuclear envelope) in the anisotropic raw data (top row) and the isotropic restoration with deep learning.

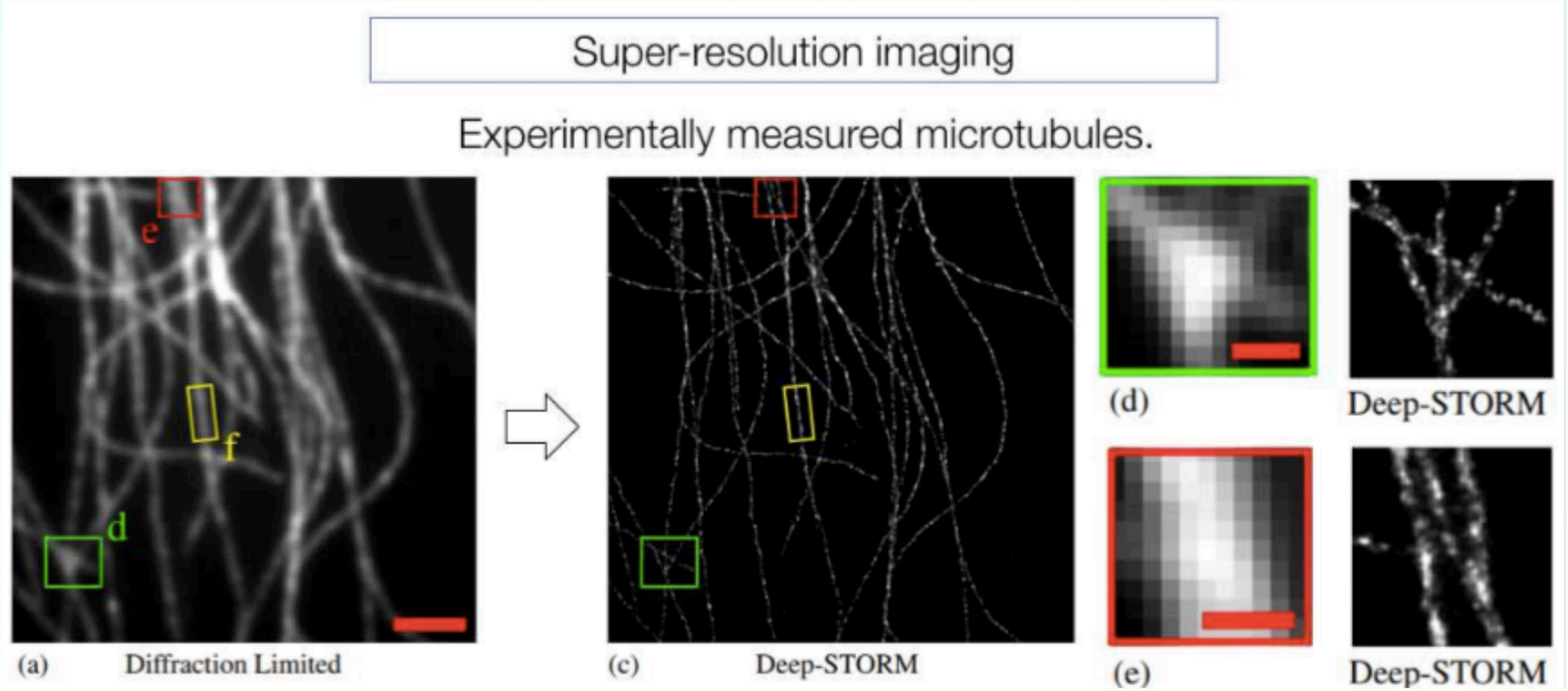


Weigert, M., 2018 **Content-aware image restoration: pushing the limits of fluorescence microscopy**. Nature Methods 15.

Source: Advanced Image Segmentation using ImageJ/Fiji (Ignacio Arganda-Carreras)

Bioimage Analysis specific applications

Can be used to improve reconstructions of super-resolution data, by pattern-recognition.



Deep-STORM reference here

Source: Advanced Image Segmentation using ImageJ/Fiji (Ignacio Arganda-Carreras)

Clustering of data from neural network features

The features of neural networks can be used to describe and cluster images by appearance. Allowing phenotypes to be distinguished.

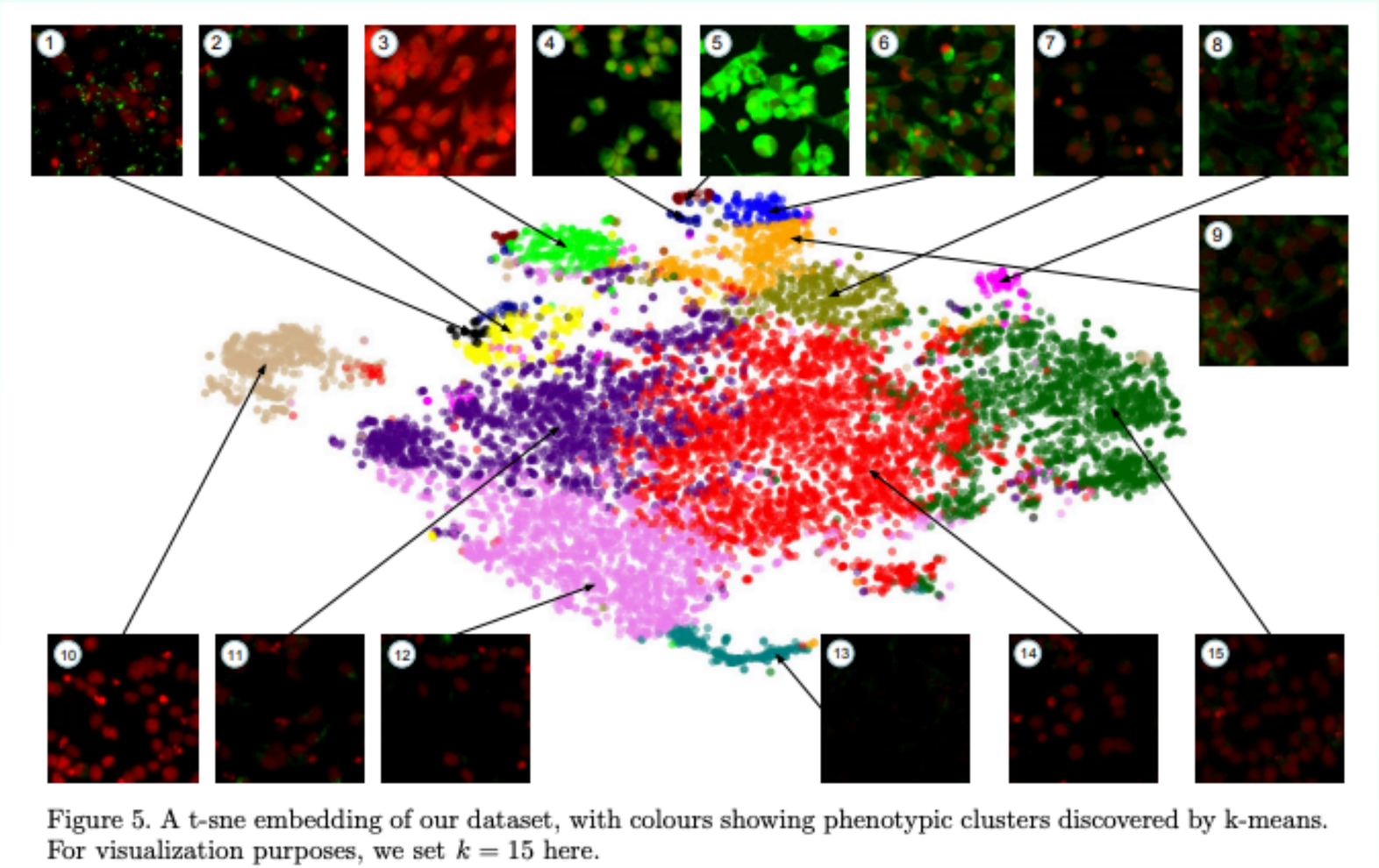


Figure 5. A t-sne embedding of our dataset, with colours showing phenotypic clusters discovered by k-means. For visualization purposes, we set $k = 15$ here.

Phenotypic Profiling of High Throughput Imaging Screens with Generic Deep

Conclusion

Machine learning, pattern recognition and image processing intermingle.

Becoming more and more important in the imaging sciences.

Used when simple techniques are not sufficient. Where multiple aspects of the image are useful for completing the task.

Many different approaches, most supervised machine learning follow the same paradigm. Image loading, feature calculation, training, evaluation.

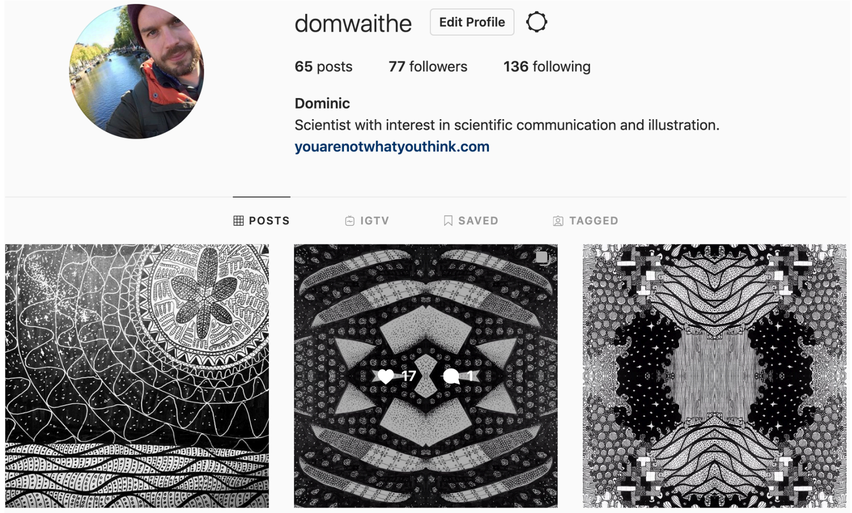
If you want to master advanced techniques you must learn to code a language such as Python and invest time in understanding how each algorithm works.

Thank you for time

https://twitter.com/dwaithe

https://github.com/dwaithe

https://instagram.com/domwaithe



dominic.waithe@imm.ox.ac.uk

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