University of Glasgow

Convolutional Neural Networks for image classification
- application to autofocusing in microscopy

Carol Webster

Neural Networks (Deep learning)

University of Glasgow

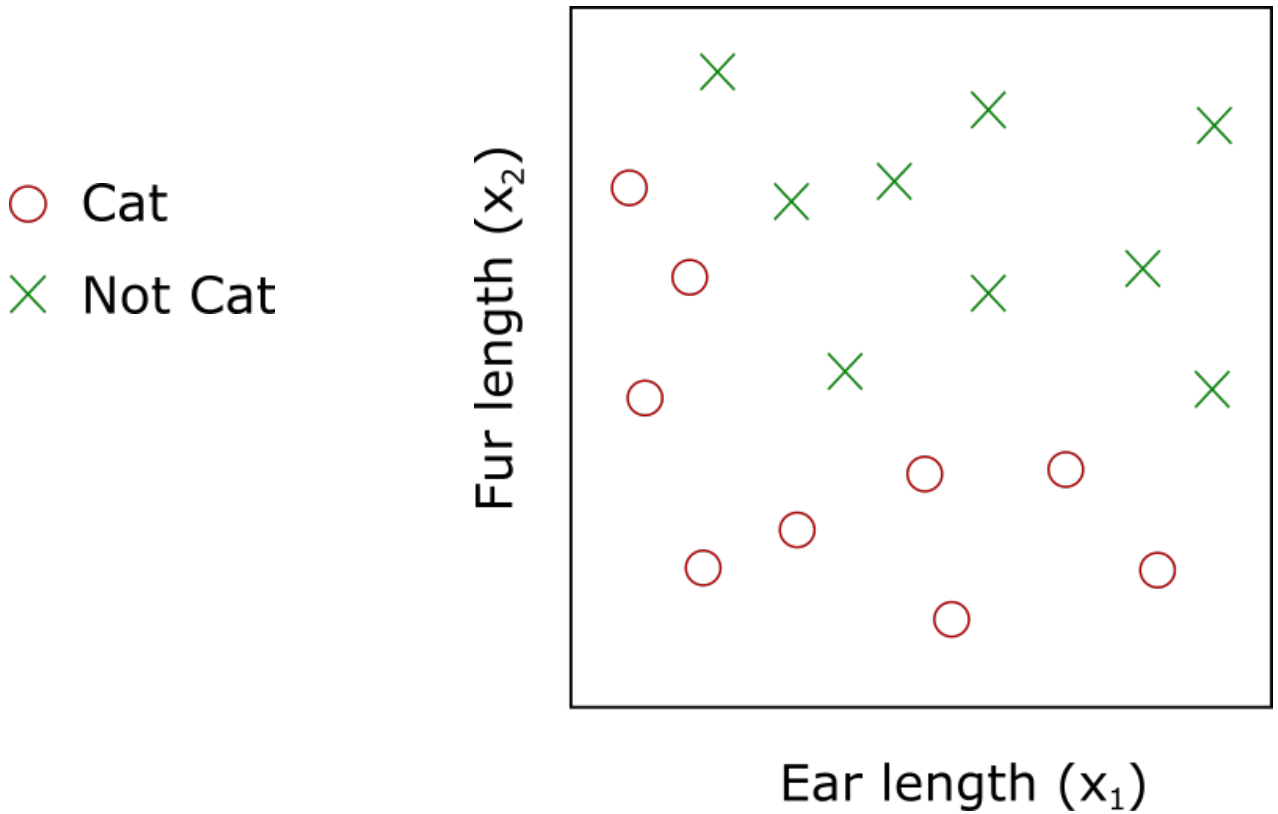
- Tutorial on convolutional neural networks (CNNs).
- Overview of some applications in microscopy.

Neural Networks for classification (Deep learning)

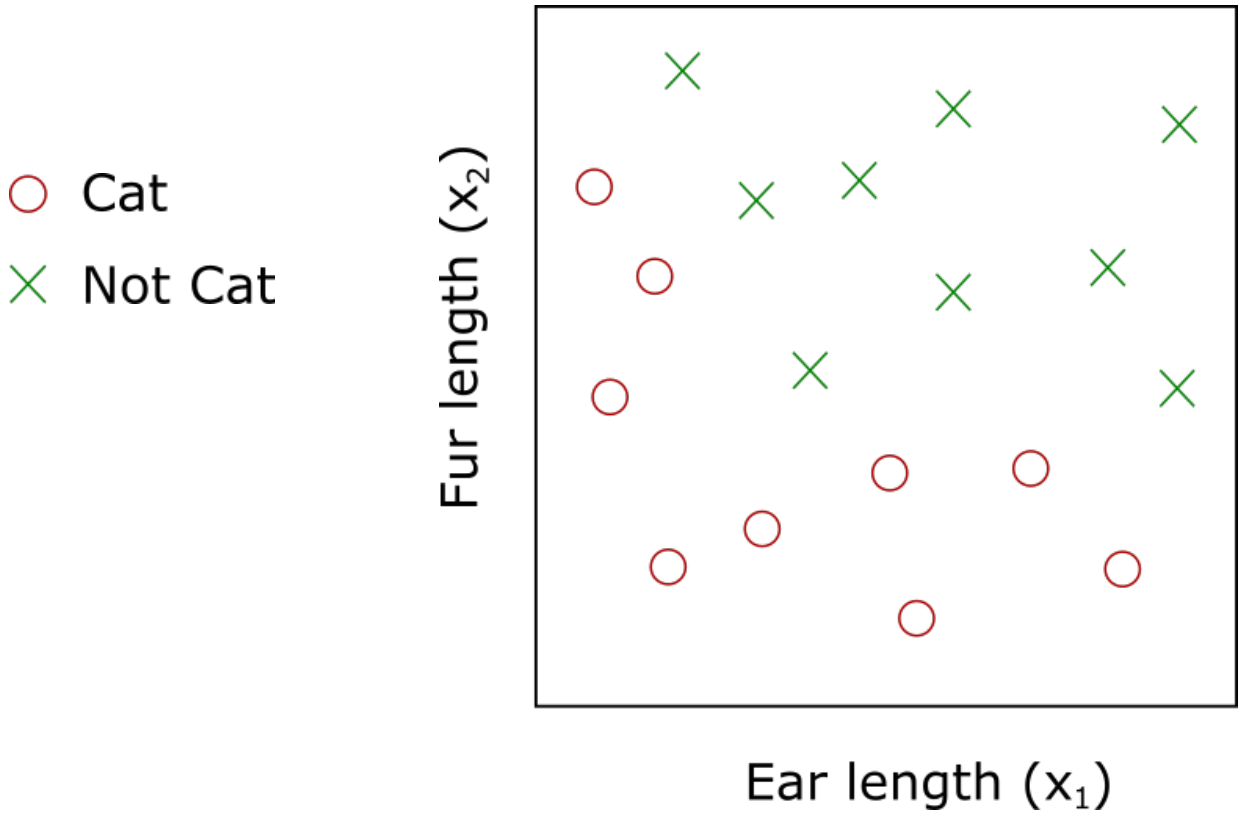
Cat (1)

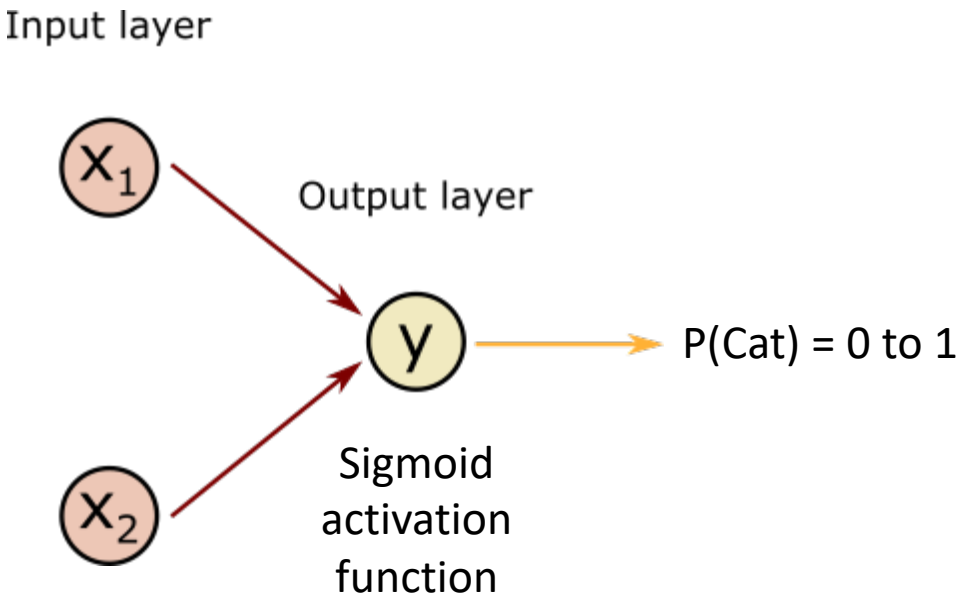
Not Cat (0)

Neural Networks for classification



Logistic regression for classification





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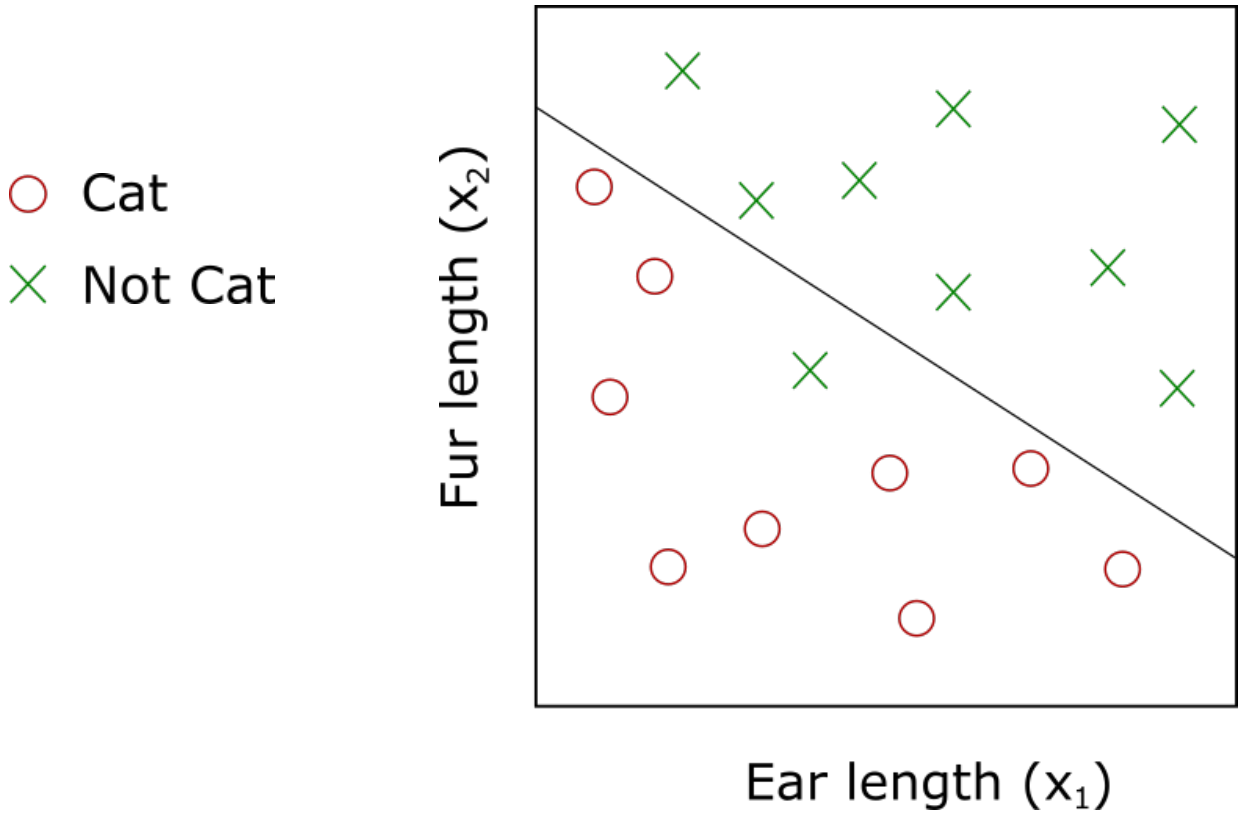

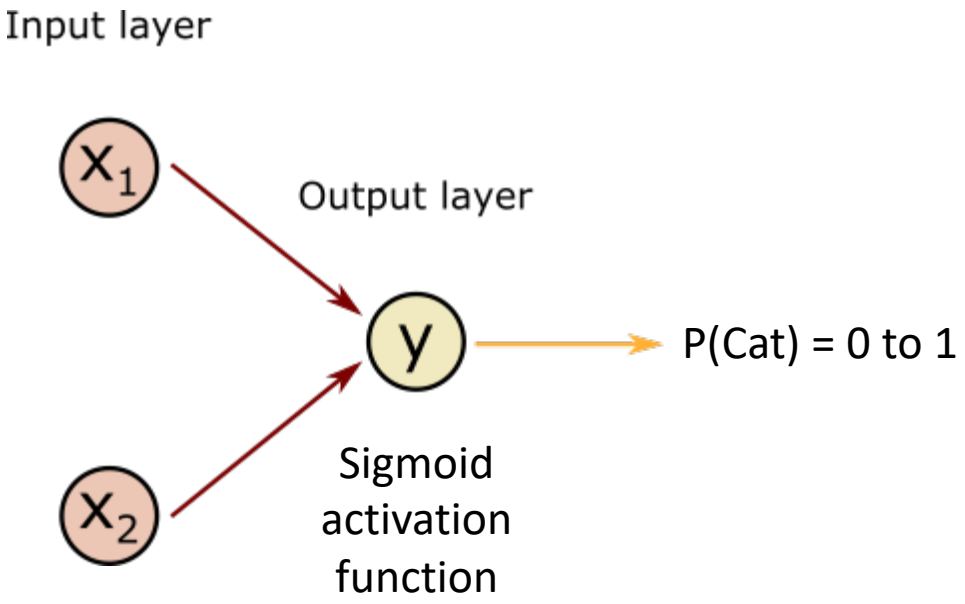

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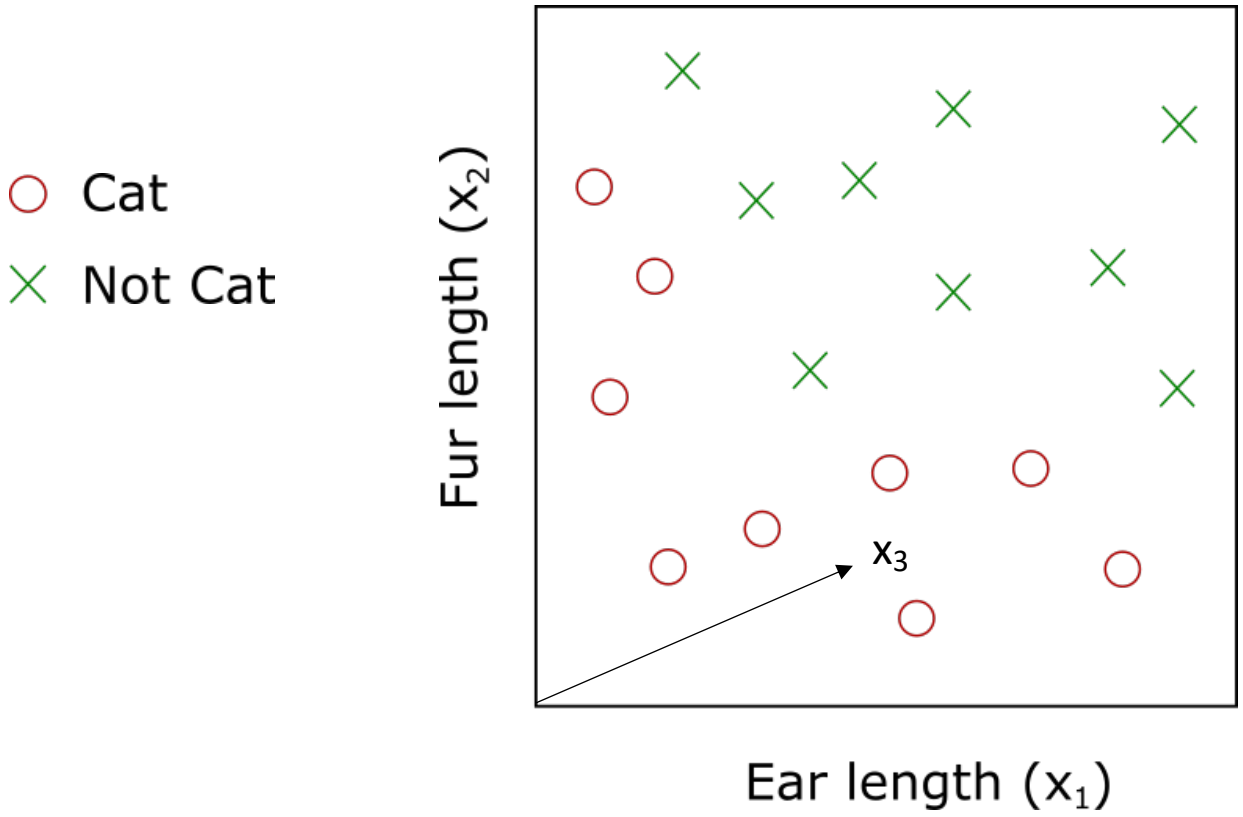

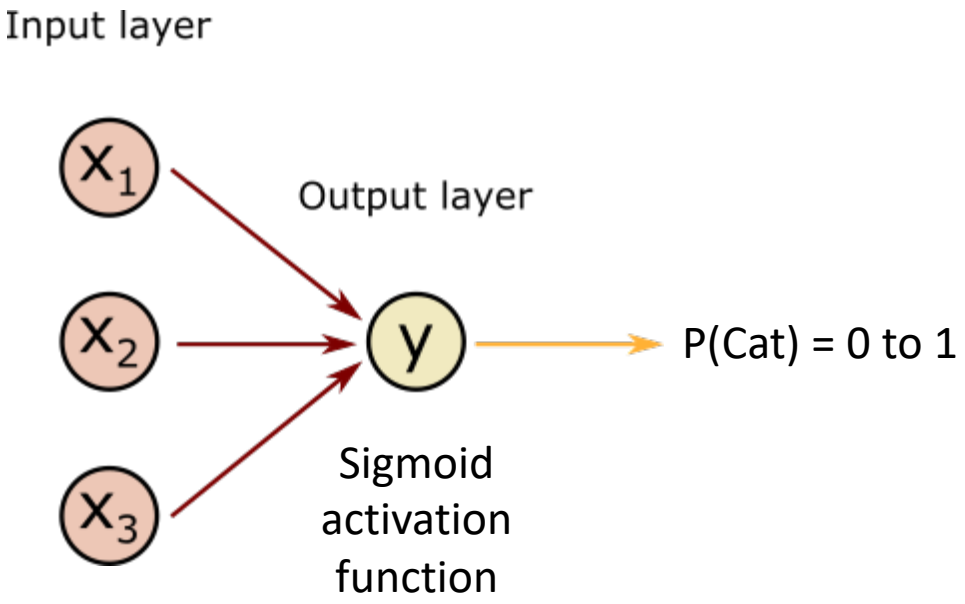

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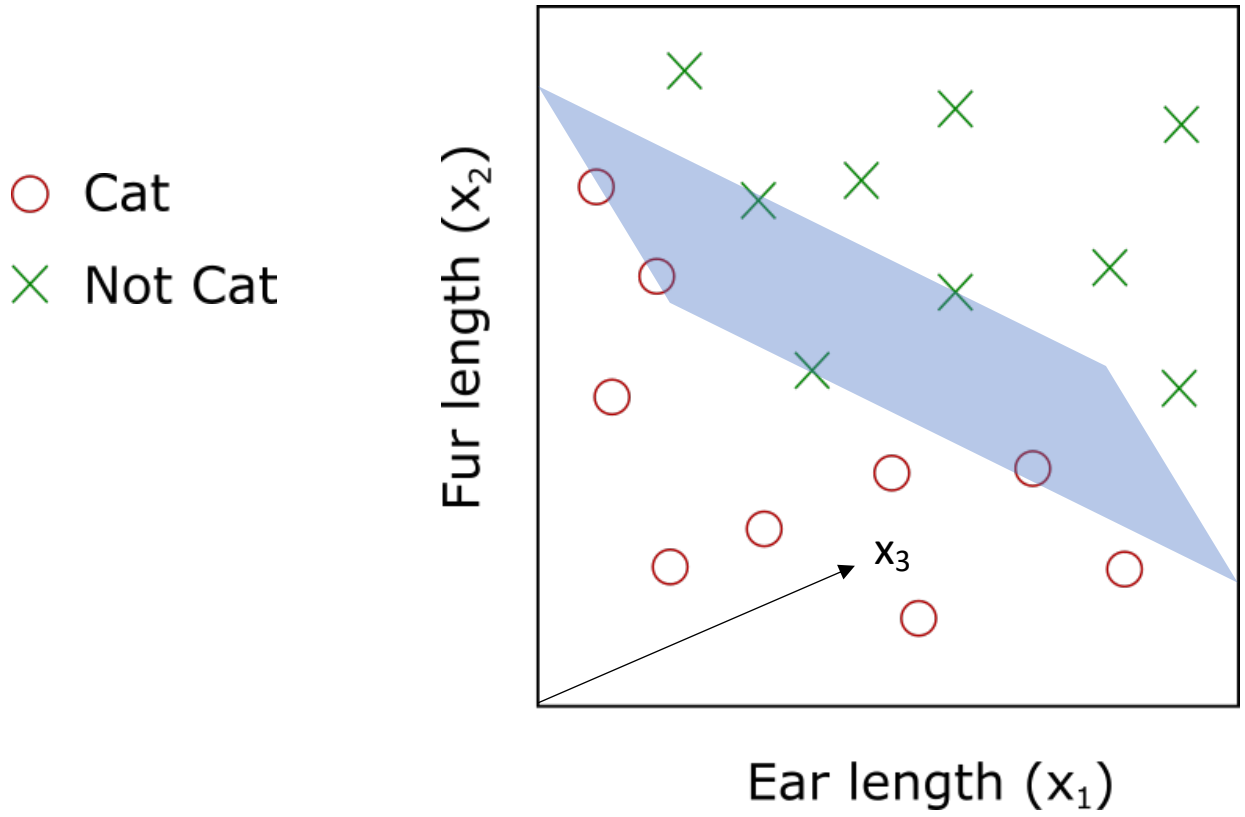

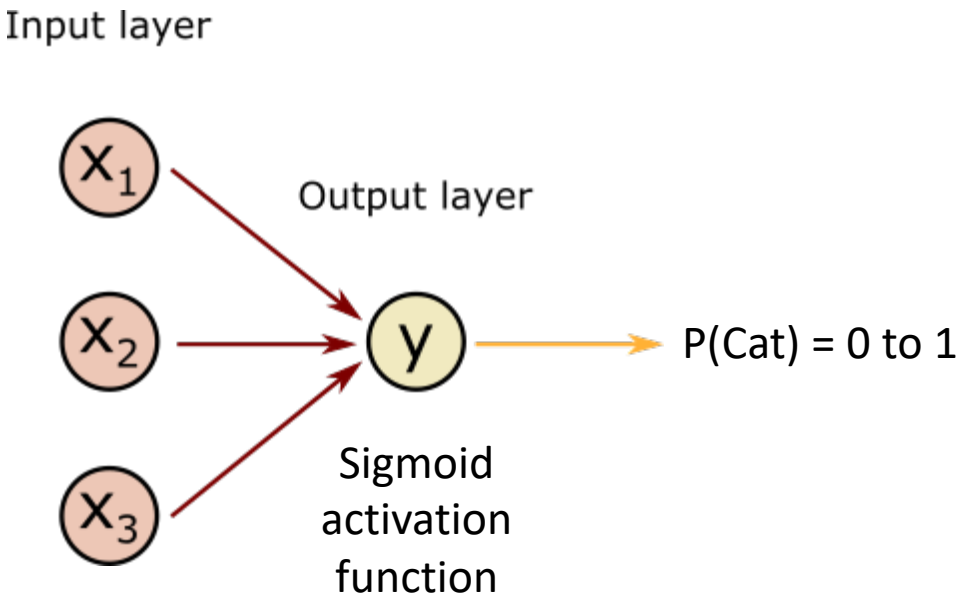

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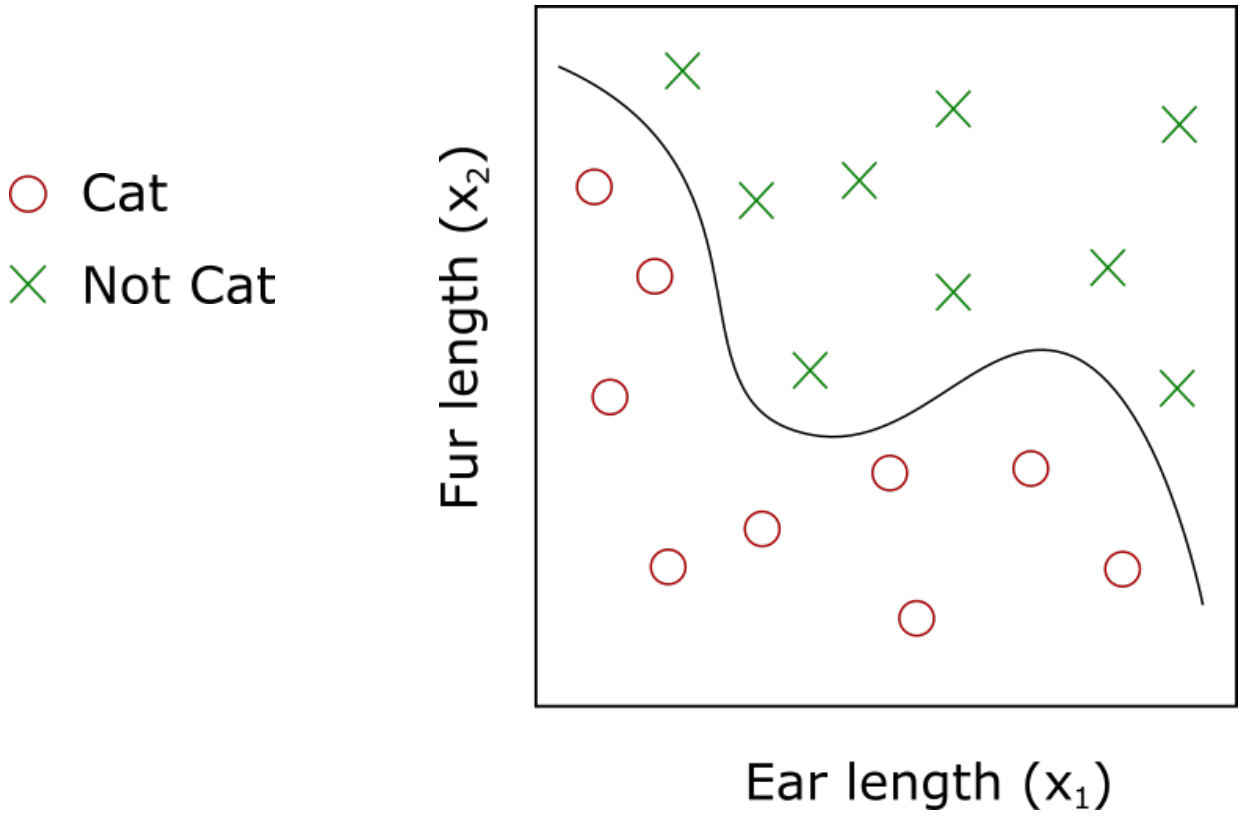

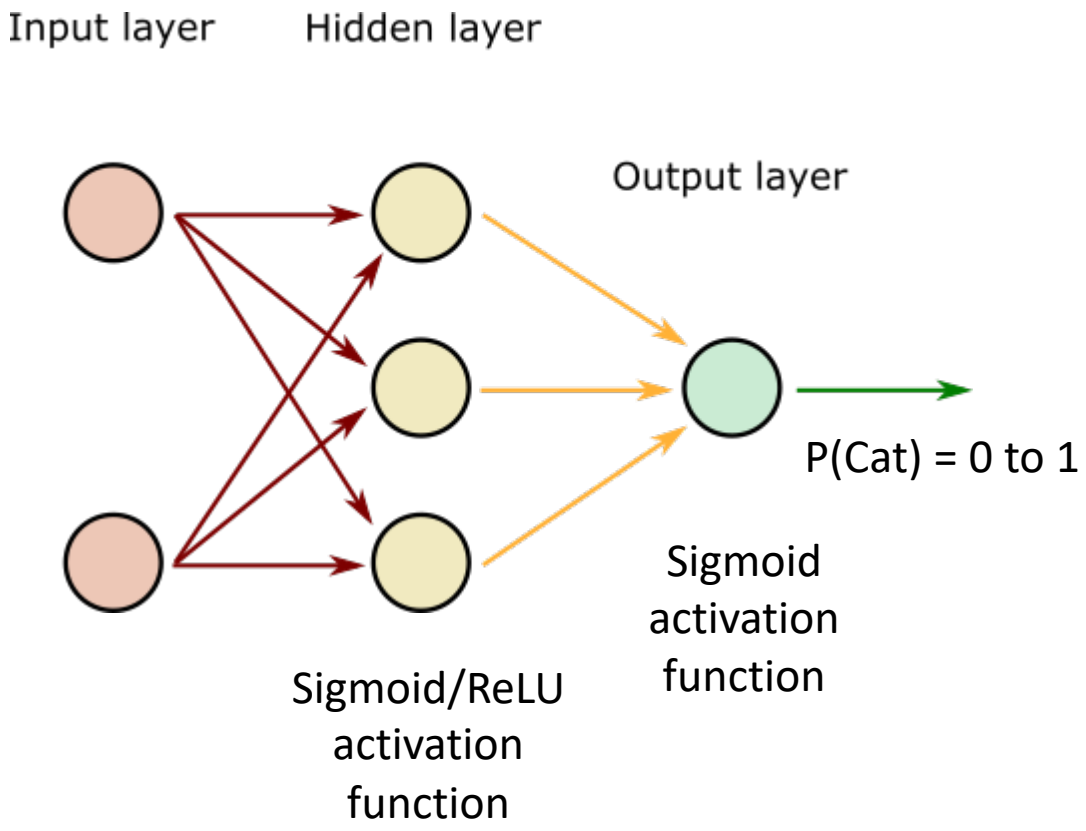

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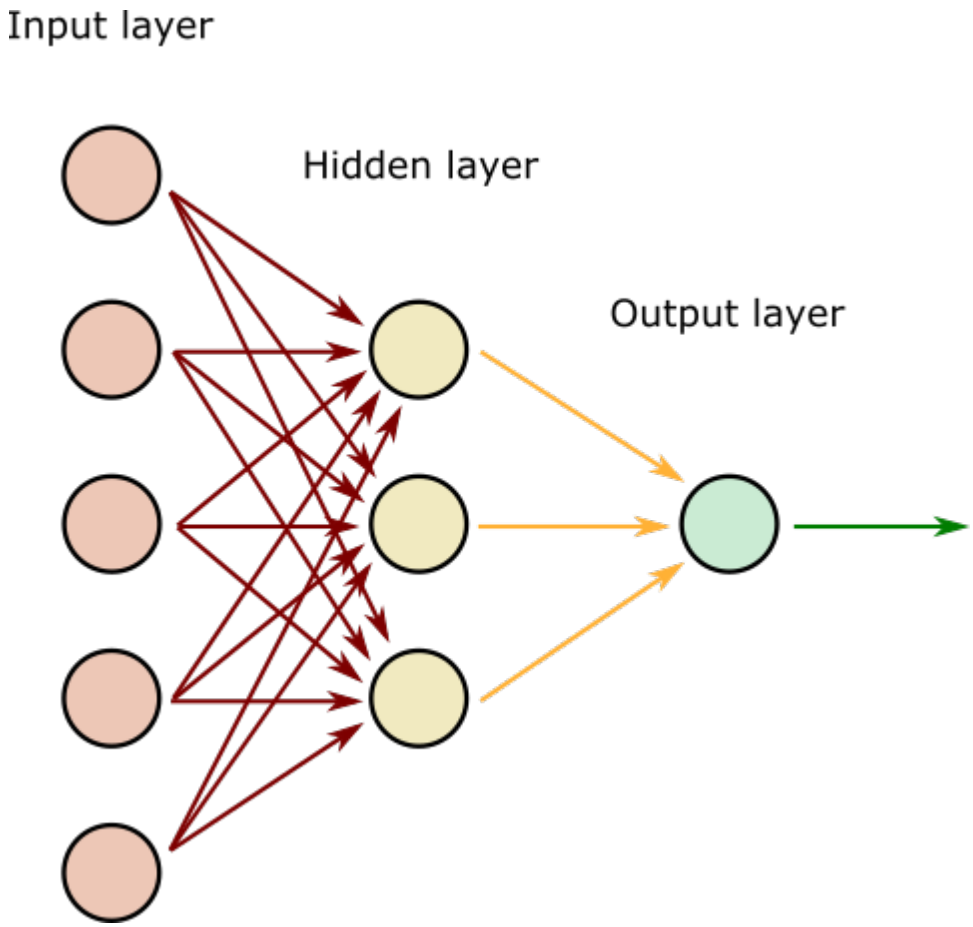

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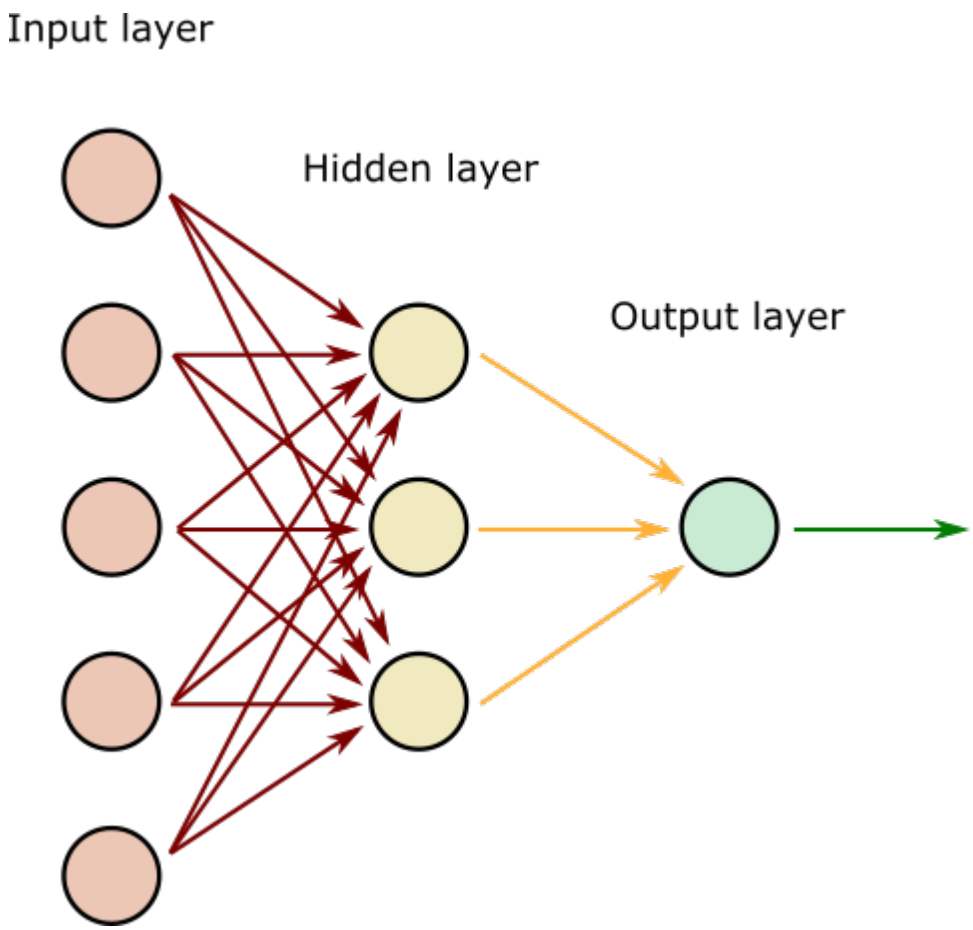

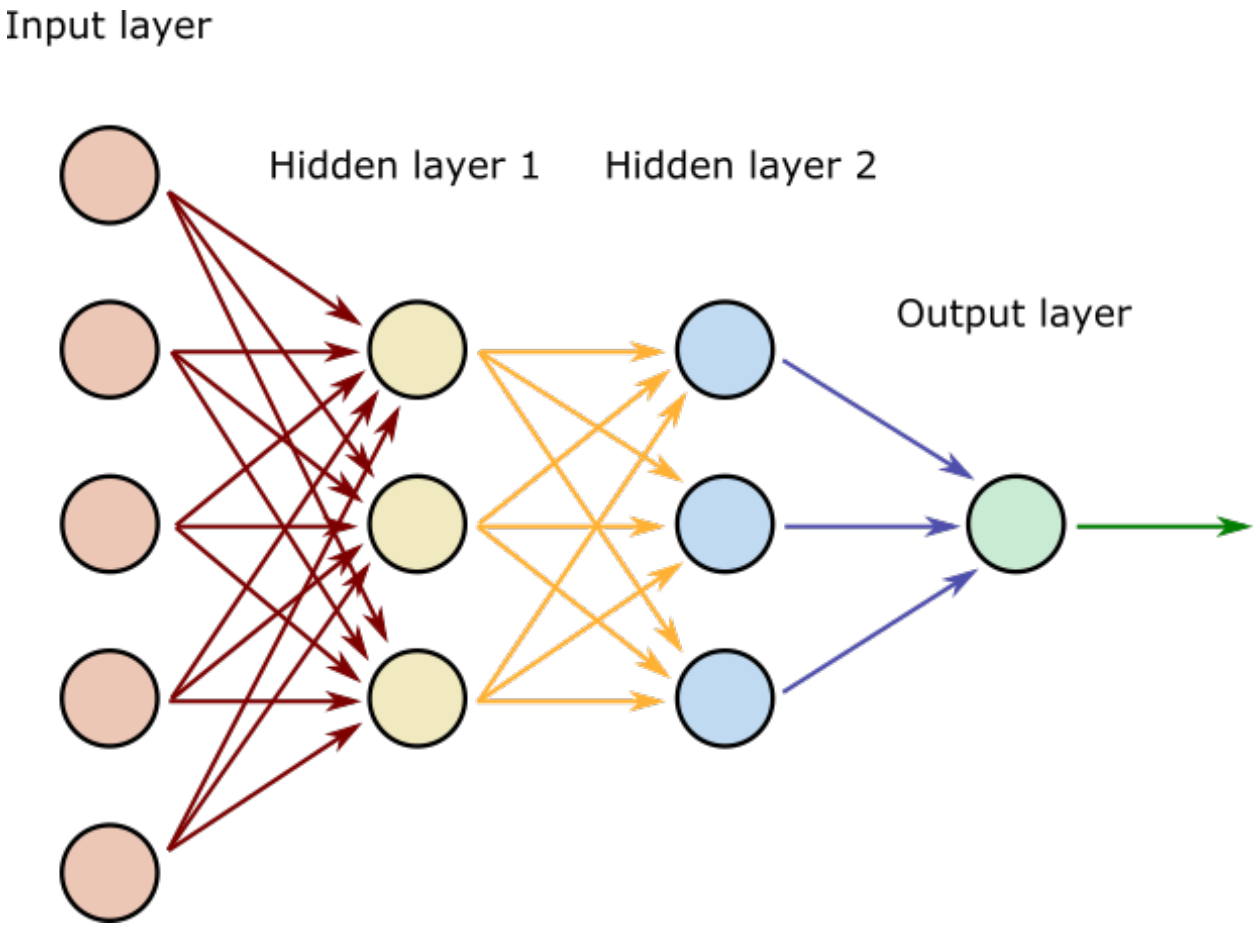

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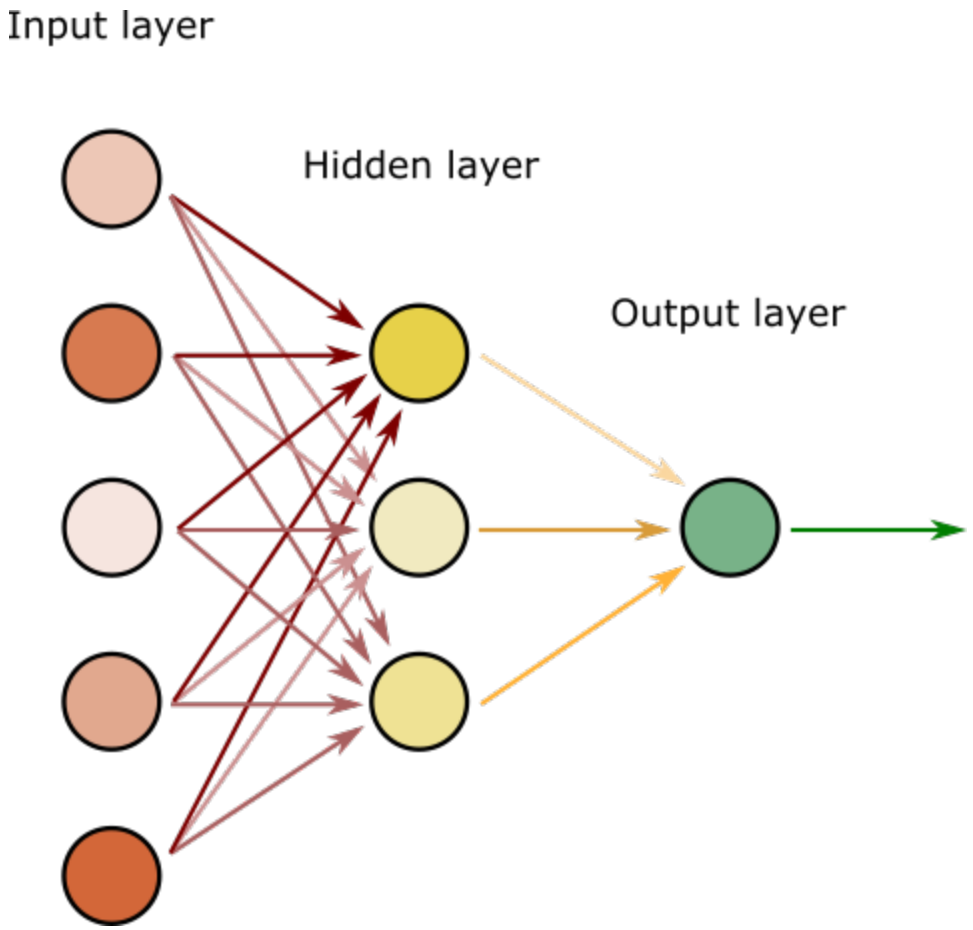
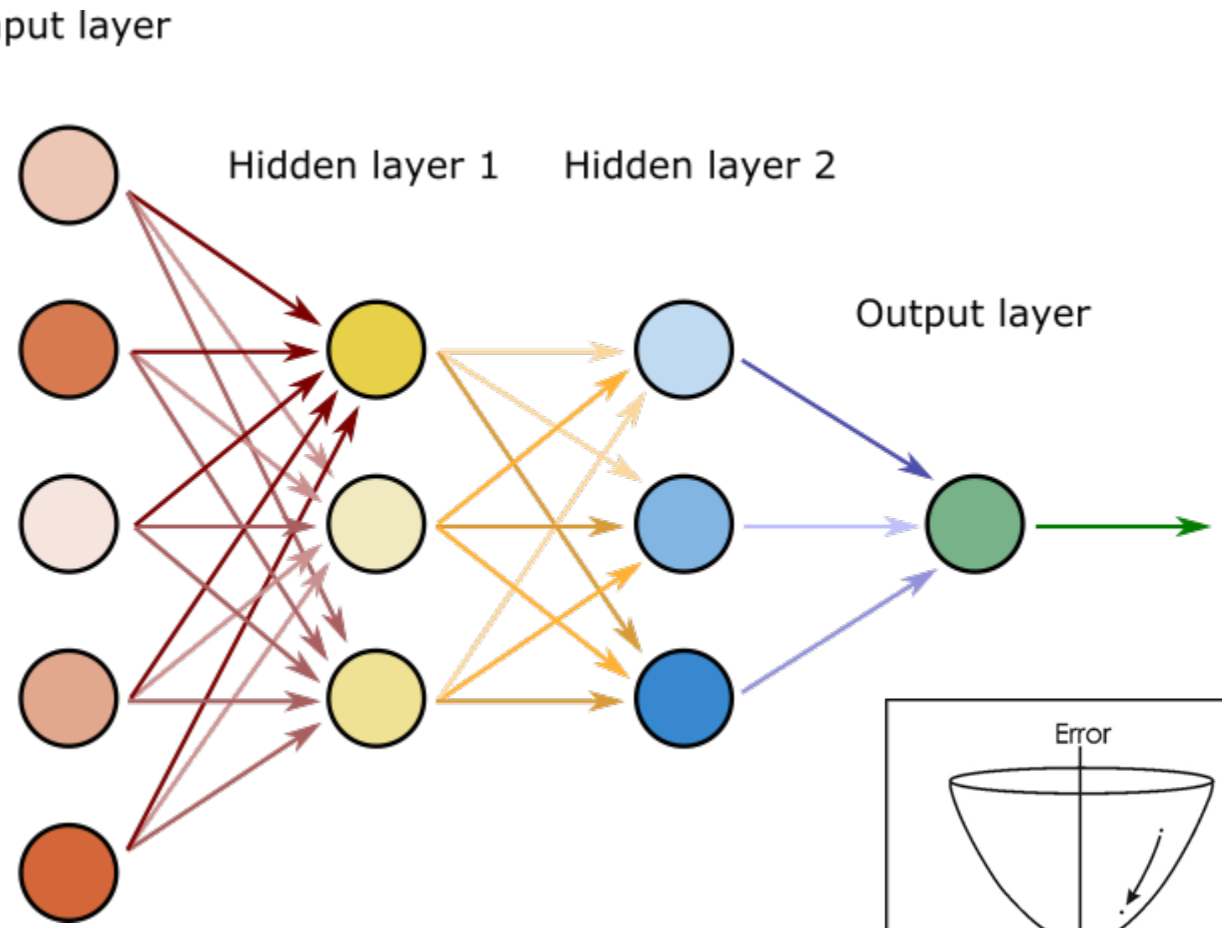
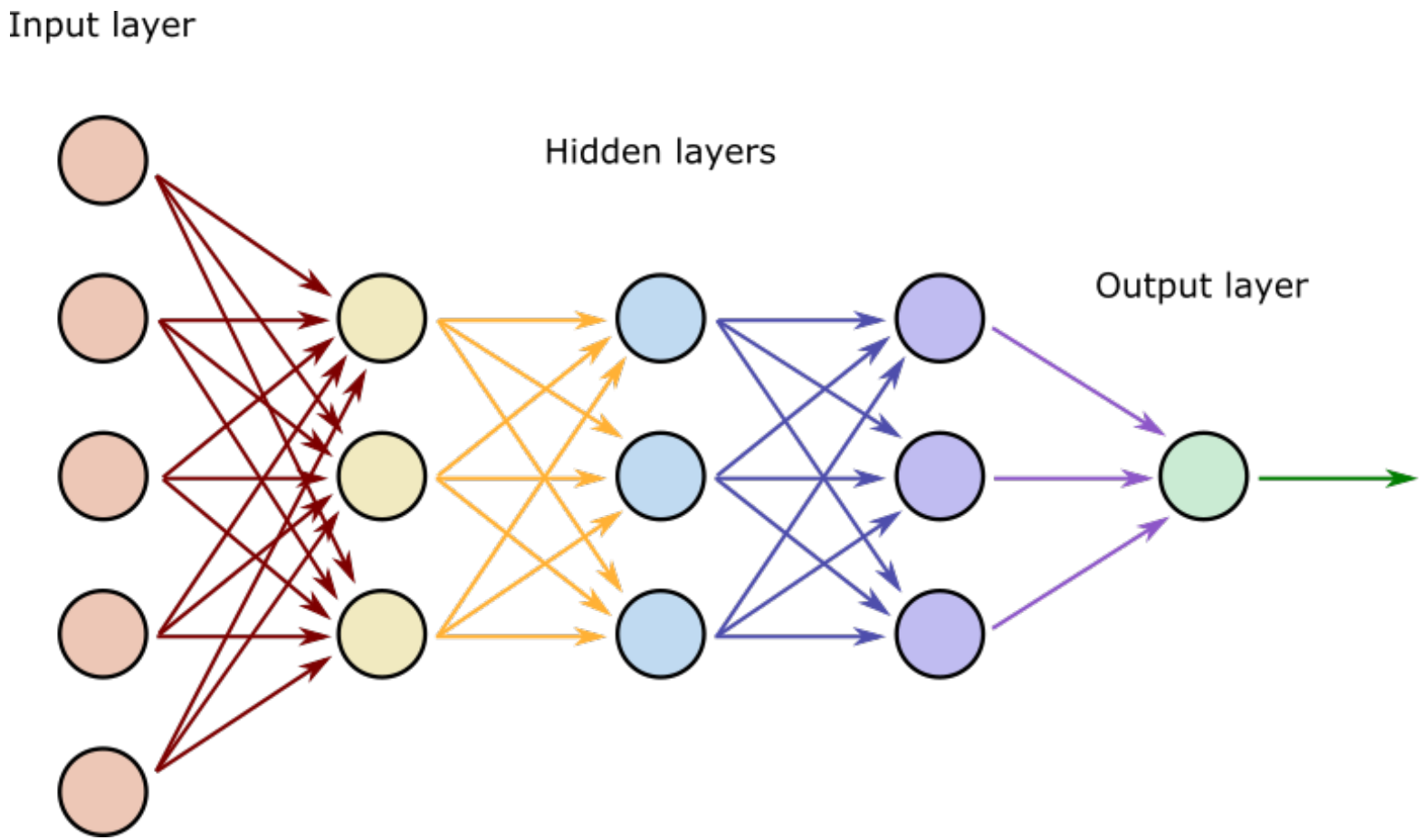




Classifying images: Deep learning



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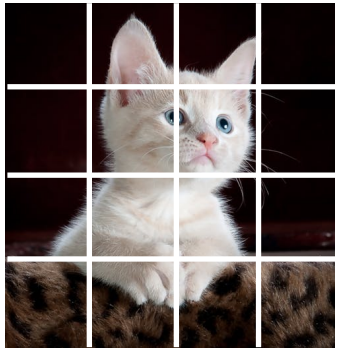
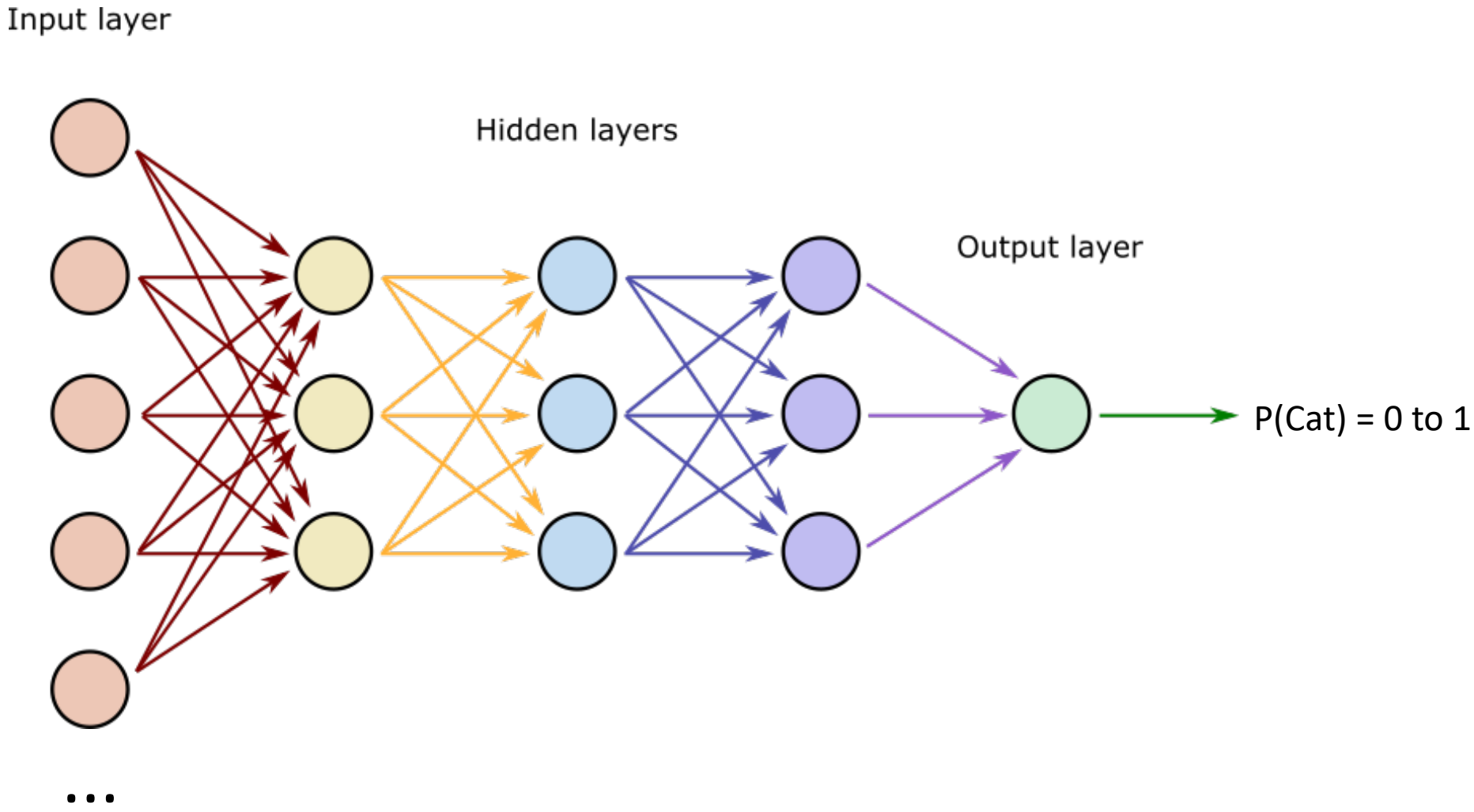
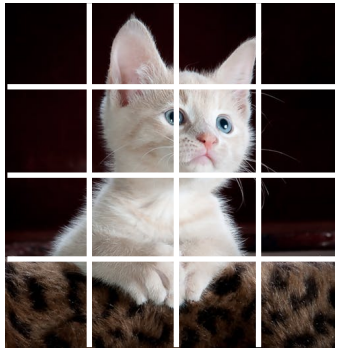


Thousands of pixels



Classifying images: Convolutional Neural Networks



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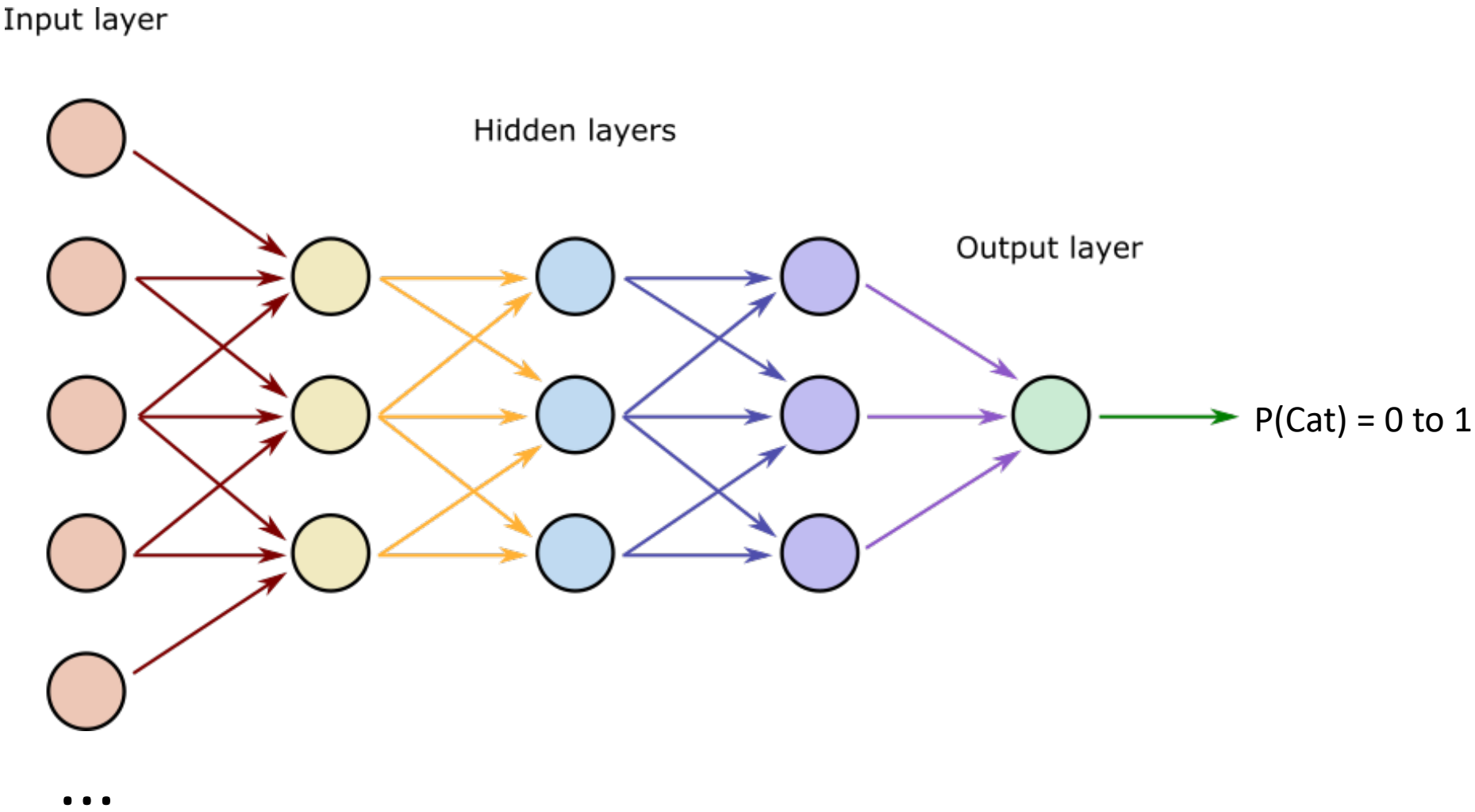
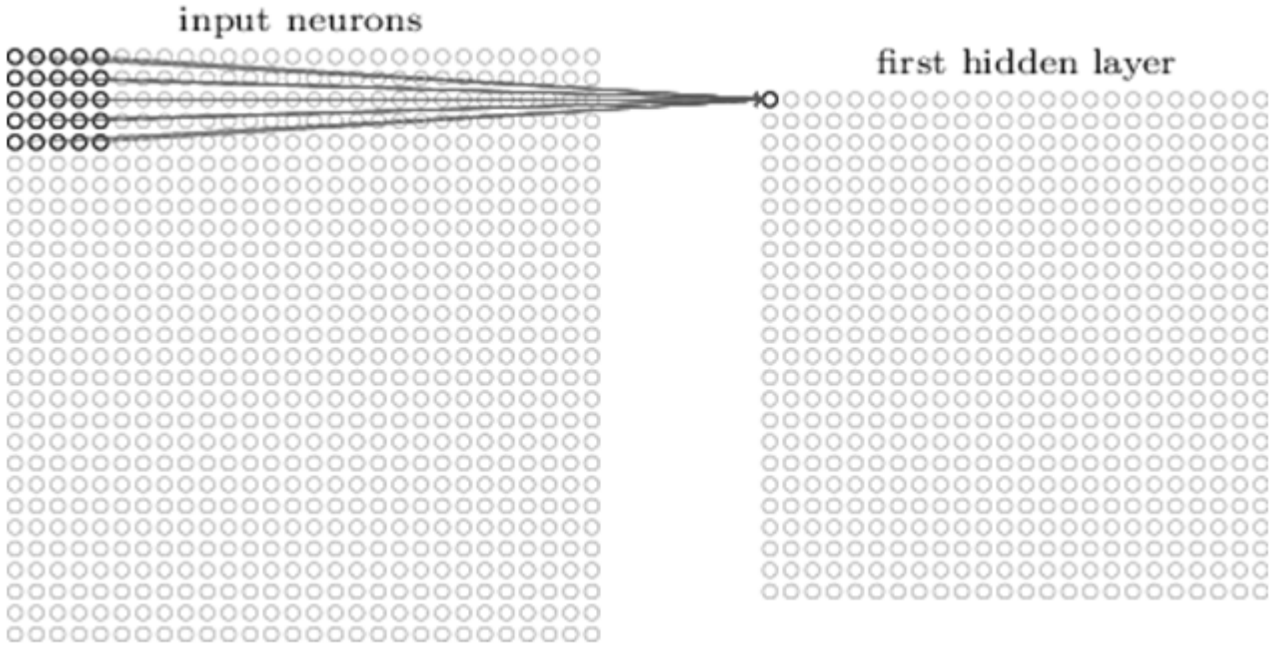


Classifying images: Convolutional Neural Networks

Convolution (cross-correlation):

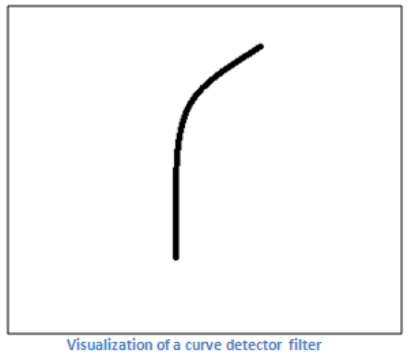
- Slide filter (kernel) across image and compute dot product of filter pixels with image pixels (i.e. multiply each pair of pixels and add them all up).
- Resulting value goes into a pixel in the next layer.
- Use many filters. The resulting hidden layer is an image with as many channels as there are filters.
- CNN learns the pixels values of the filters (these are the parameters of the model).



Visualization of 5 x 5 filter convolving around an input volume and producing an activation map

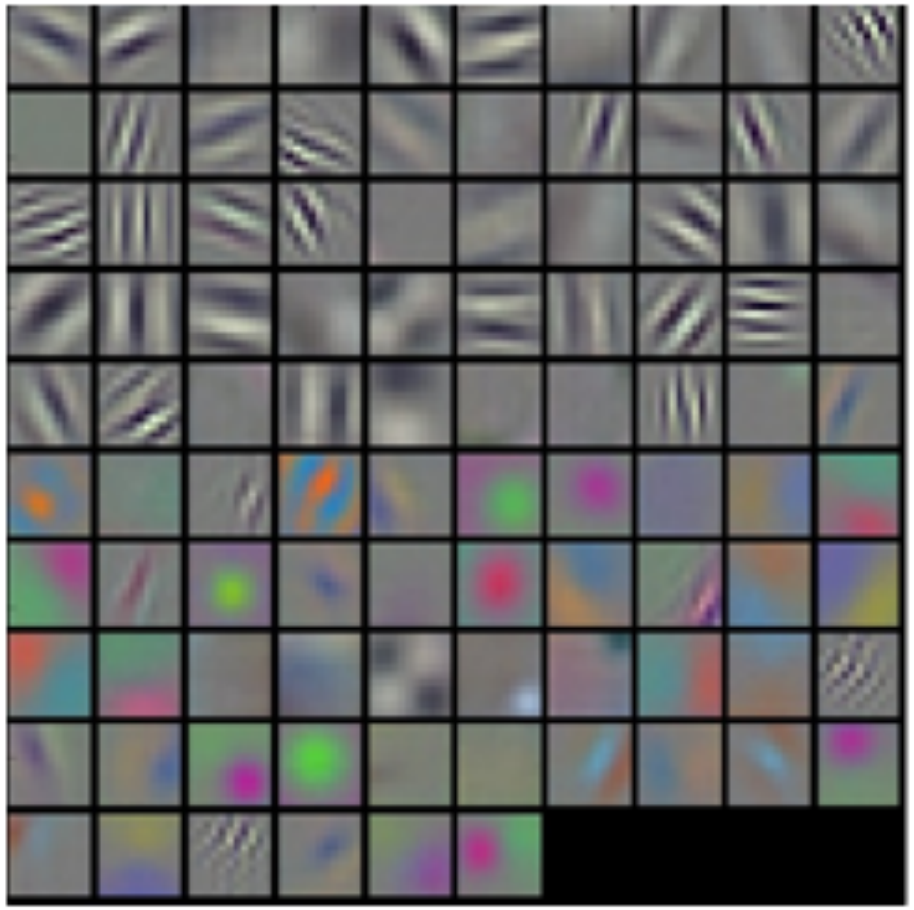
0	0	0	0	0	30	0
0	0	0	0	30	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	0	0	0	0

Pixel representation of filter


Visualization of a curve detector filter

Neural Networks and Deep Learning, by Michael Nielsen
http://neuralnetworksanddeeplearning.com/

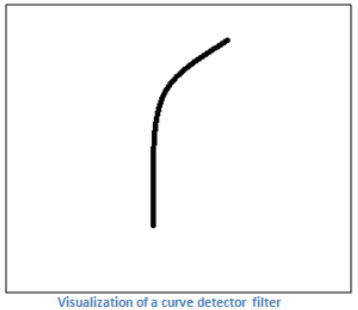
Classifying images: Convolutional Neural Networks



Visualizations of filters

0	0	0	0	0	30	0
0	0	0	0	30	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	30	0	0	0
0	0	0	0	0	0	0

Pixel representation of filter



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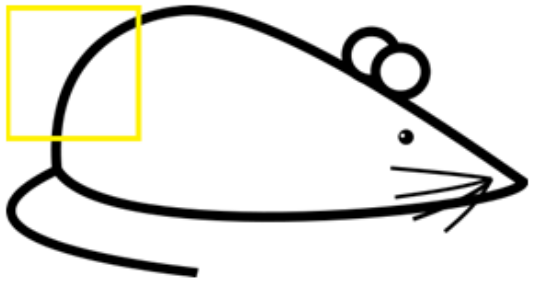

Visualization of the filter on the image

Visualization of the filter on the image

Danger: filters may pick out features of the background that we didn't intend to use for classification!

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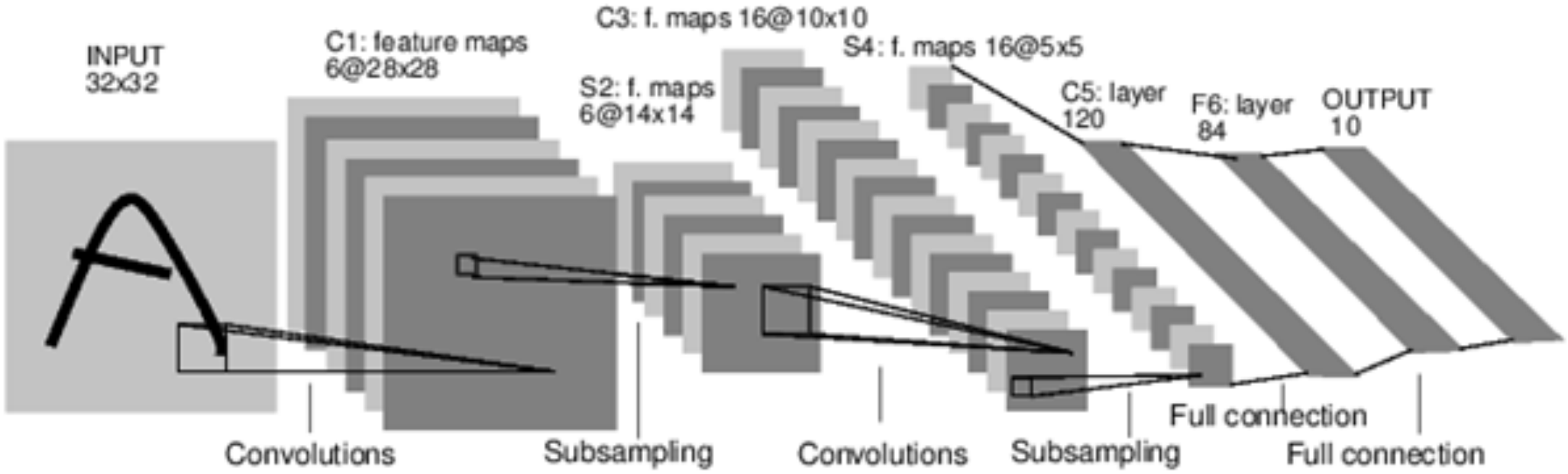

A Full Convolutional Neural Network (LeNet)

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General points about deep learning

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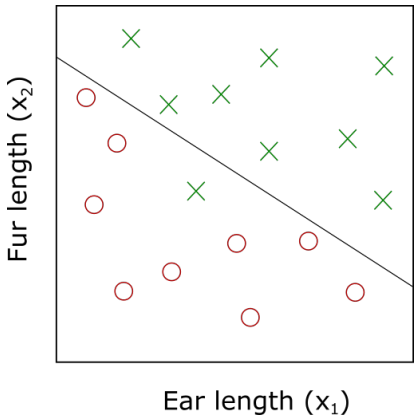

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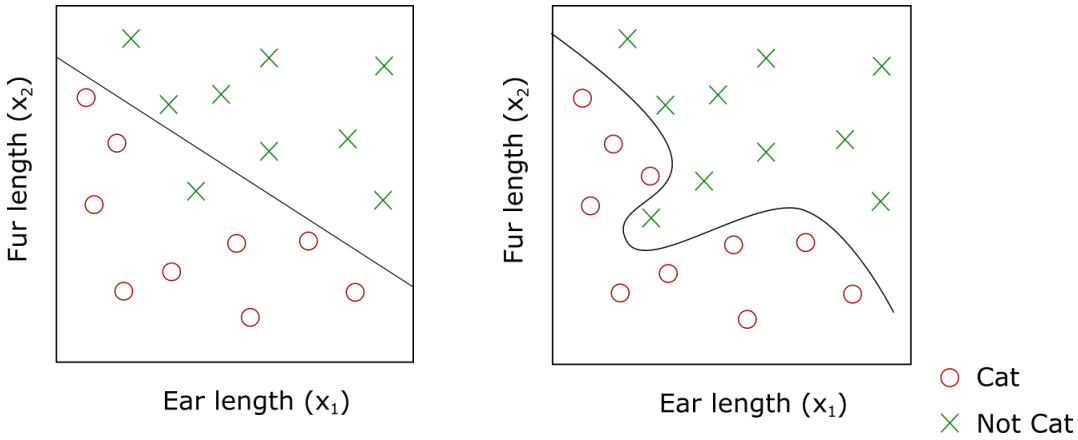

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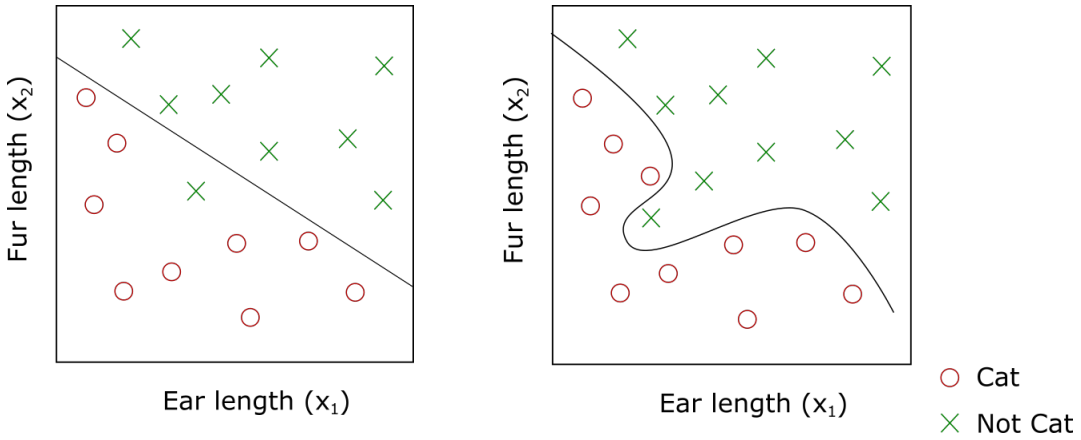

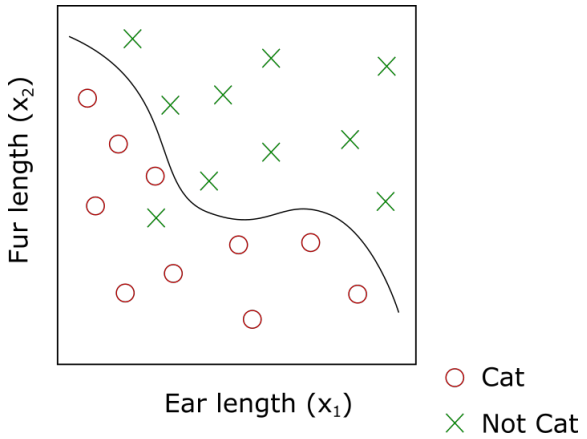

- Regularisation can reduce overfitting.

Frameworks for deep learning

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- Keras/Tensorflow
- https://keras.io/

- PyTorch
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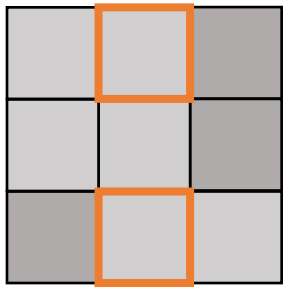
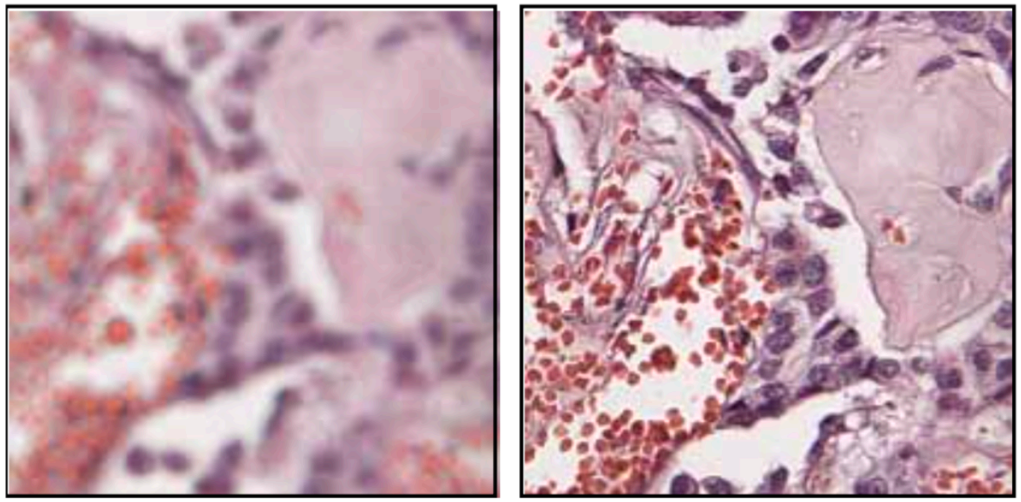
- Keras vs PyTorch
- https://deepsense.ai/keras-or-pytorch/

Autofocus based on image contrast

- Expect high contrast when image is sharp
- Read image into a 2D array of pixel intensities and compute Brenner gradient:

$$B = \sum_i \sum_j \left[g(i,j) - g(i+2,j) \right]^2$$





J. F. Brenner et al., J. Histochem. Cytochem. **24**, 100-111 (1976)

S. Yazdanfar, Optics Express **16**, 8670-8677 (2008)

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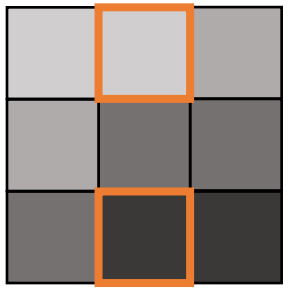

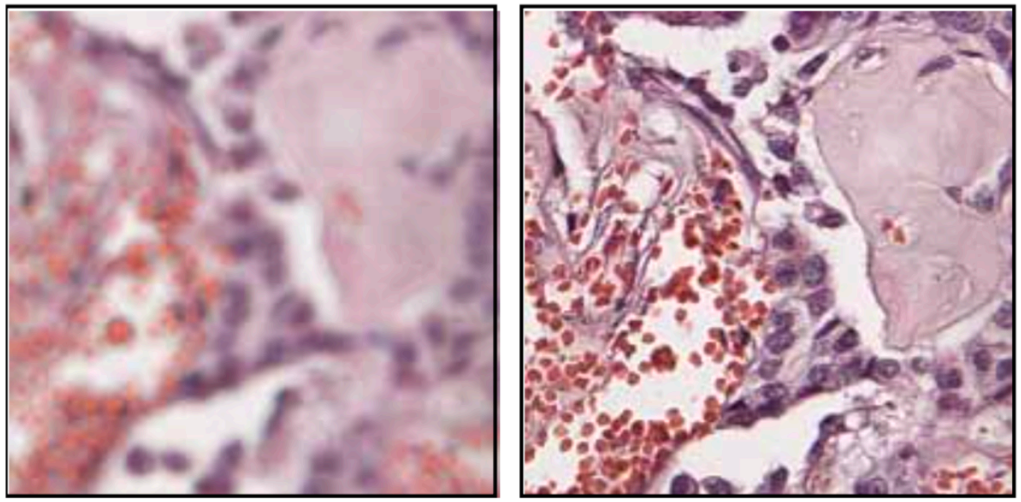

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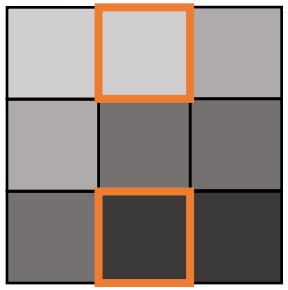

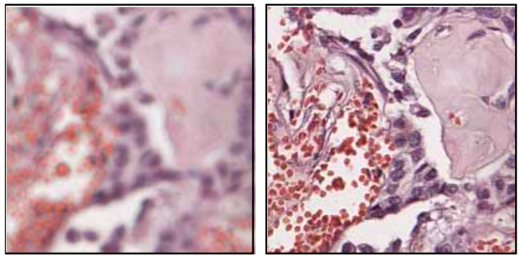

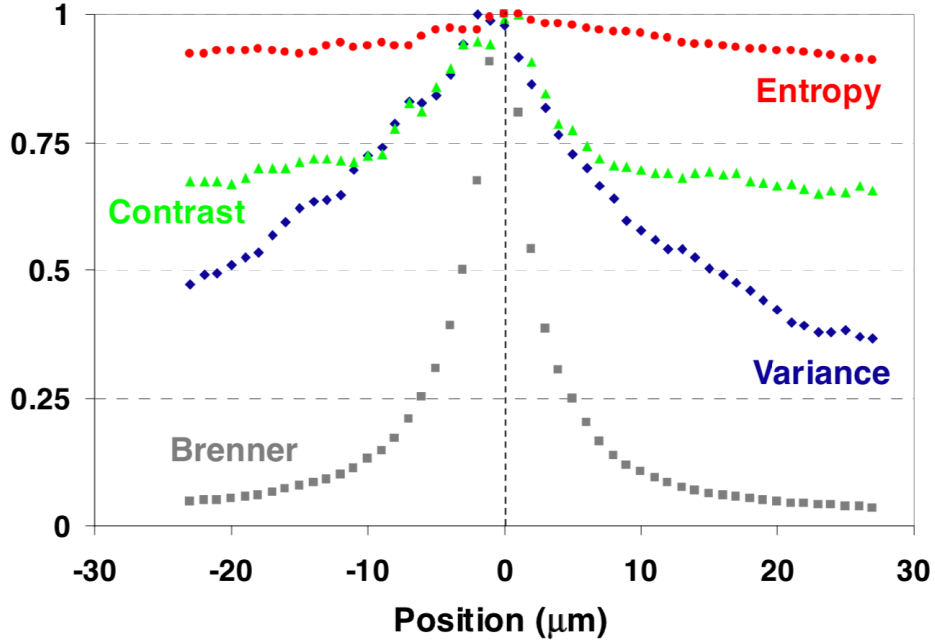

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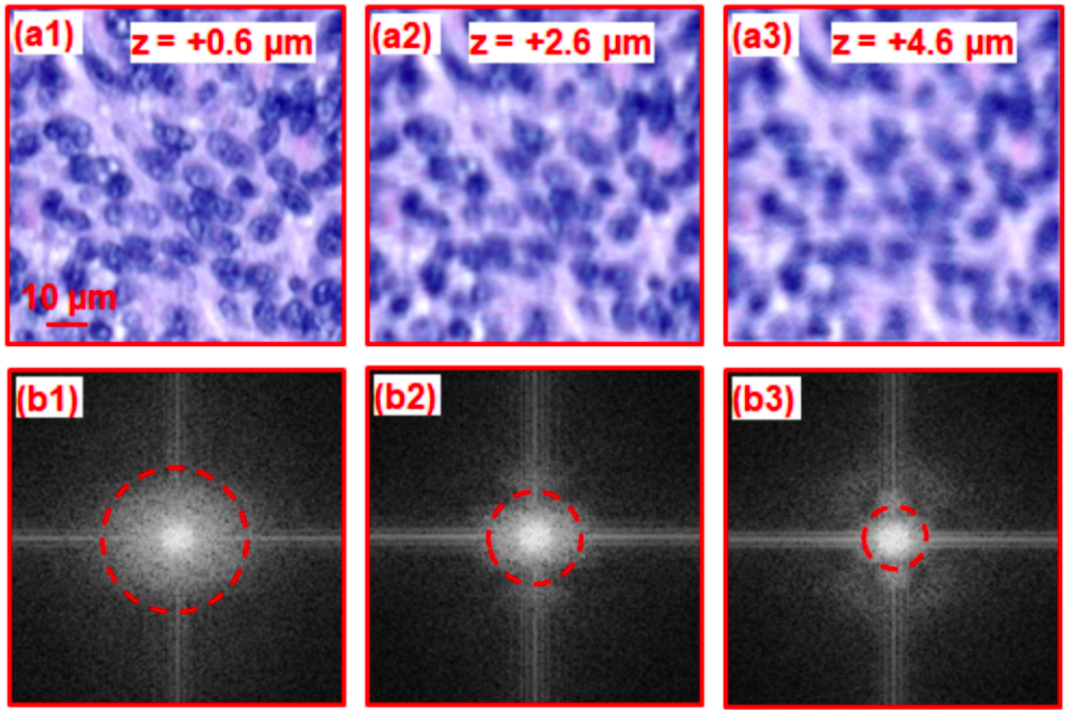
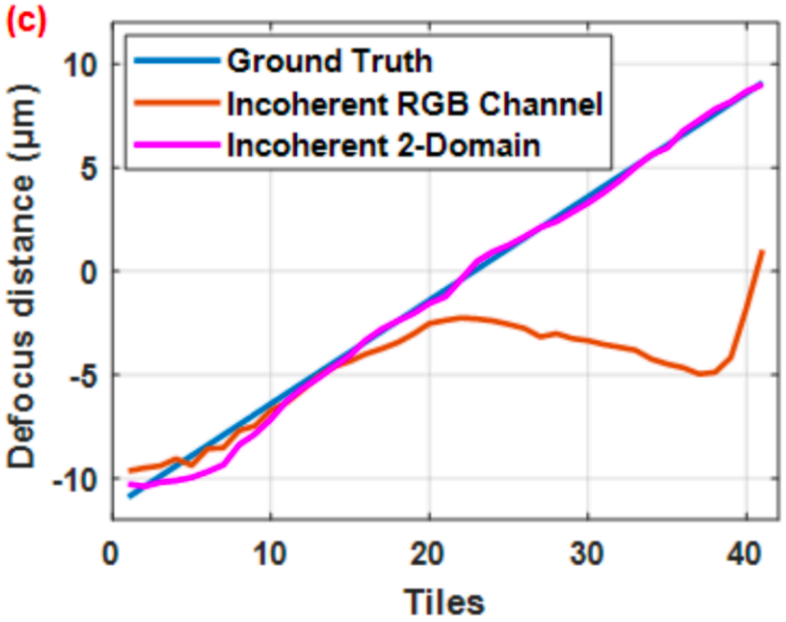
S. Yazdanfar, Optics Express **16**, 8670-8677 (2008)

Convolutional Neural Network can predict distance from optimal focus

- Determine optimal focus using Brenner gradient.
- Use CNN to predict distance from optimal focus (regression model).
- Requires semi-coherent illumination of the sample using an off-axis LED.
- Model can be improved by including 2D FFT of image as an additional input.

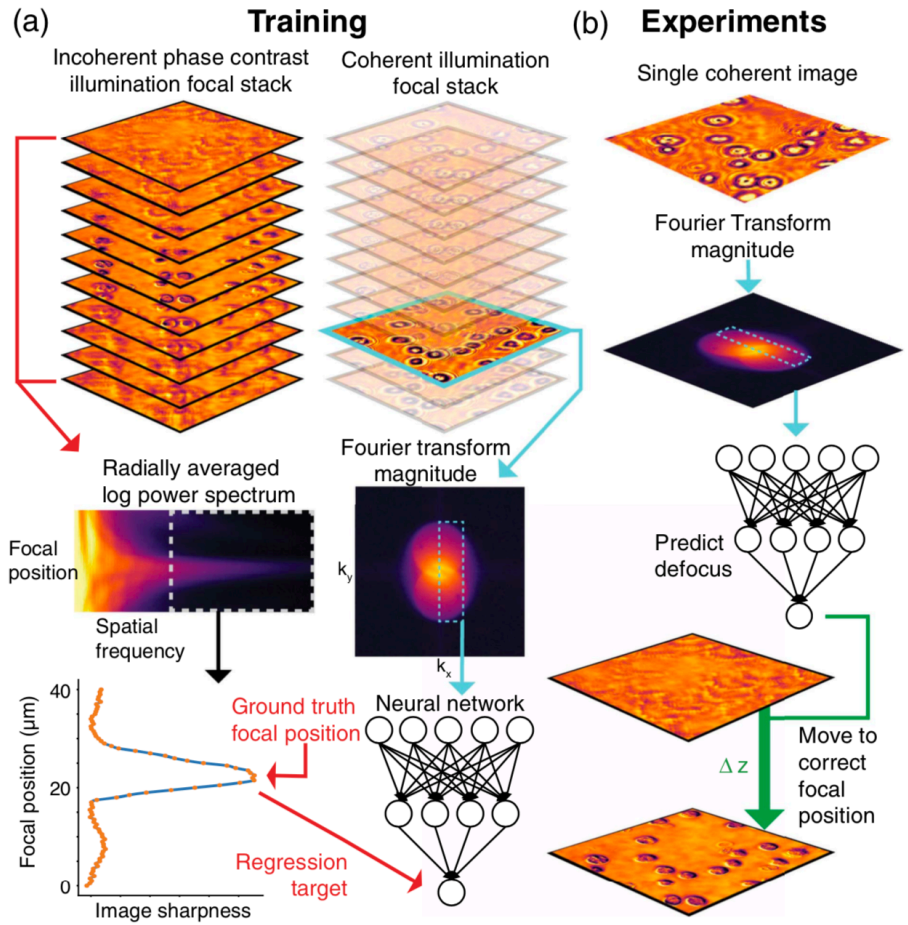


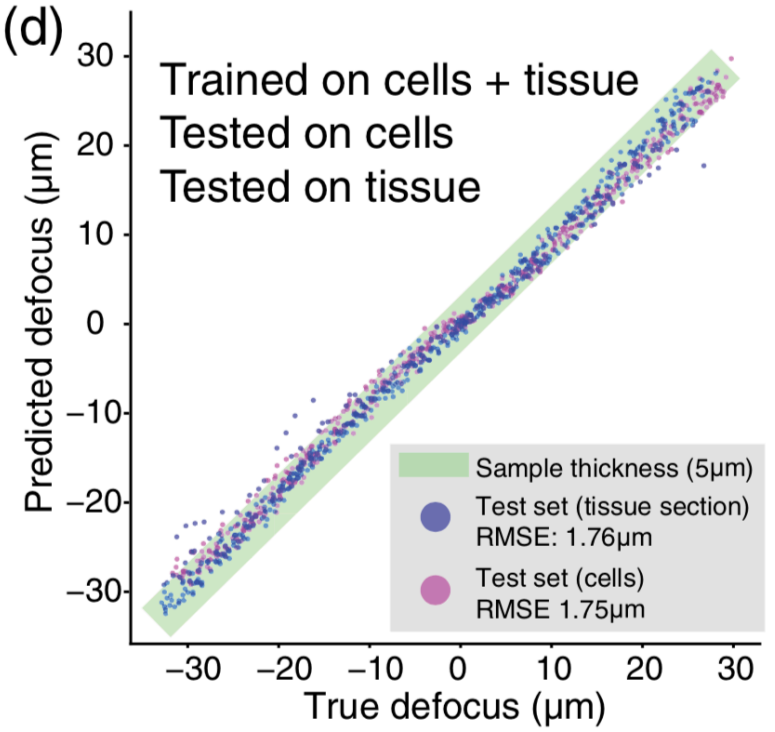


S. Jiang et al., Biomedical Optics Express **9**, 1601–1612 (2018)

Convolutional Neural Network can predict distance from optimal focus

- Can also get good results using the FFT alone as input to a standard fully-connected deep neural network.





H. Pinkard et al., Optica **6**, 794–797 (2019)

Where to find more information

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- https://www.coursera.org/learn/machine-learning
- https://www.coursera.org/specializations/deep-learning

} Online courses

- http://neuralnetworksanddeeplearning.com/
- https://www.deeplearningbook.org/

} Books on theory

- https://pytorch.org/deep-learning-with-pytorch
- https://www.amazon.co.uk/Hands-Machine-Learning-Scikit-Learn-TensorFlow/dp/1492032646

} Books on frameworks