

# Convolutional Neural Networks (CNNs)

ML Laboratory 04

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# 1 Objective

Students should understand and be able use some basic pretrained CNN models available in Matlab

## 2 CNN networks

CNNs are multilayer networks adapted for image processing, which use the **convolution** operation extensively.

### 2.1 Starting points

1. The layers in a normal multilayer perceptron network (MLP) are **fully-connected**: each output value is a combination of all inputs
2. Each full-connected layer is a **full (dense) matrix**

Problems:

1. Images are large: 1 Mexapixel color image = 3 million values
2. Fully-connected layers have **huge** size (the number of parameters in fully-connected layers is huge).

**Example:** Consider a layer with input size = 300 x 300 color pixels, and output size equivalent to 150 x 150 color pixels. How many parameters does this layer have?

### 2.2 Convolution

DSP deja-vu vibes:

$$y[n] = \sum_k x[n-k]h[k]$$

- Some videos here: a **kernel** with fixed coefficients  $h[k]$  is slid over the input  $x[n]$  and computes the output as a linear combination of the surrounding input samples

Key points:

- Convolution has been used since forever in signal and image processing for **extracting features** (edges, frequency bands, etc)
- Convolution is a kind of matrix multiplication, with an almost sparse matrix of a special form (“circulant” or “Toeplitz”)
- Each output value depends only on the surrounding pixels

## 2.3 Convolutional Neural Networks

- The basic unit is now **a layer**
- The data is viewed as **tensors**: 3D cubes of data (like a three-dimensional matrix)
- Each layer takes as input an  $M_1 \times N_1 \times C_1$  tensor and produces an output  $M_2 \times N_2 \times C_2$  tensor
- We don't think of individual neurons anymore. Each neuron in a convolutional layer does exactly the same operation as the others, with the same weights, but “sees” just one small part of the input image

## 2.4 Architecture of a CNN

AlexNet:

[1] Krizhevsky, Alex; Sutskever, Ilya; Hinton, Geoffrey E. (2017-05-24). “ImageNet classification with deep convolutional neural networks” (PDF). Communications of the ACM. 60 (6): 84–90. doi:10.1145/3065386. ISSN 0001-0782.

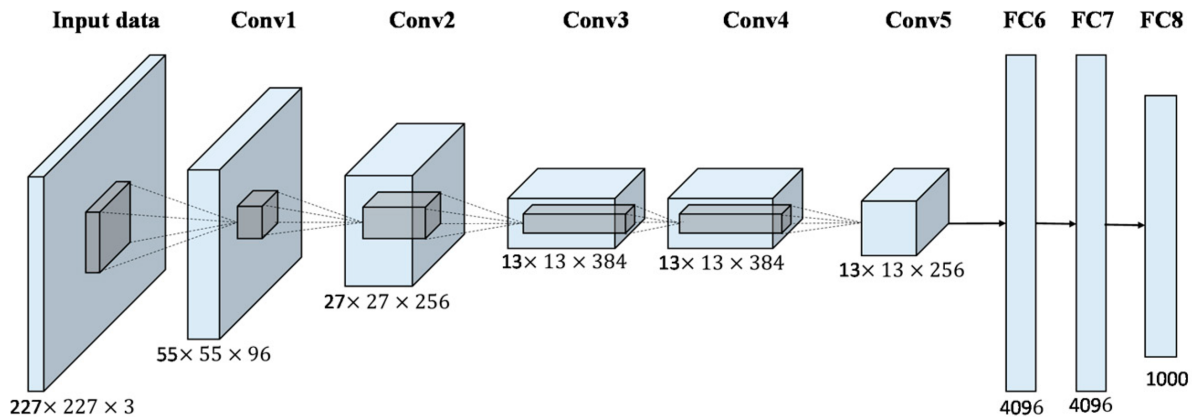


Figure 1: AlexNet architecture (image from <https://www.mdpi.com/2072-4292/9/8/848/htm>)

## 2.5 Layer types

Open the AlexNet model in Matlab and look at the architecture directly.

```
net = alexnet('Weights','imagenet')
analyzeNetwork(net) % or double-click `net` in the Workspace
```

Layer types:

- Convolutional
- Activation
- Pooling (MaxPooling)
- Fully connected (e.g. like in multilayer perceptron)
- Softmax activation to get probability-like scores (like in multilayer perceptron)
- Other optional stuff: normalization, dropout, batch normalization etc

A CNN can be viewed as a feature extractor + classifier:

- The output layers are very similar to multilayer perceptron: fully-connected layers + softmax
- The first part, with the convolution layers, is a kind of **feature extractor**

## 2.6 The model

A CNN has a fixed architecture composed of several layers. For typical networks, the architecture is described in the accompanying papers.

**Inputs:**

- a color image represented as a tensor  $X$  of size  $L_1 \times L_2 \times 3$

**Outputs** (assuming one-hot encoding):

- a vector  $\hat{y}$  which should be understood as scores/probability of belonging in each class
- the **location of the maximum** value gives the predicted class

## 2.7 The model parameters

The model parameters are the parameters of the layers:

- the filter coefficients in the convolutional layers
- the weights in the fully-connected layers

The number of parameters of the convolutional layers is **much smaller** than for fully-connected layers.

## 2.8 The cost function

For classification, the **cross-entropy** is typically used. This is exactly the same loss function used in MLP networks.

For a single input:

$$L(y, \hat{y}) = -y_1 \log \hat{y}_1 - \dots - y_n \log \hat{y}_n = -\log y_{\hat{class}},$$

where  $y_{\hat{class}}$  is the model's predicted probability for the true class of the input.

For multiple inputs: do the average of all

$$J = \frac{1}{N} \sum_i L(y^i, \hat{y}^i)$$

## 2.9 Training

Training is done with **backpropagation** and gradient descent (or some variant of it).

**Backpropagation** = the technique to compute the derivatives of  $J$  with respect to all parameters in the network.

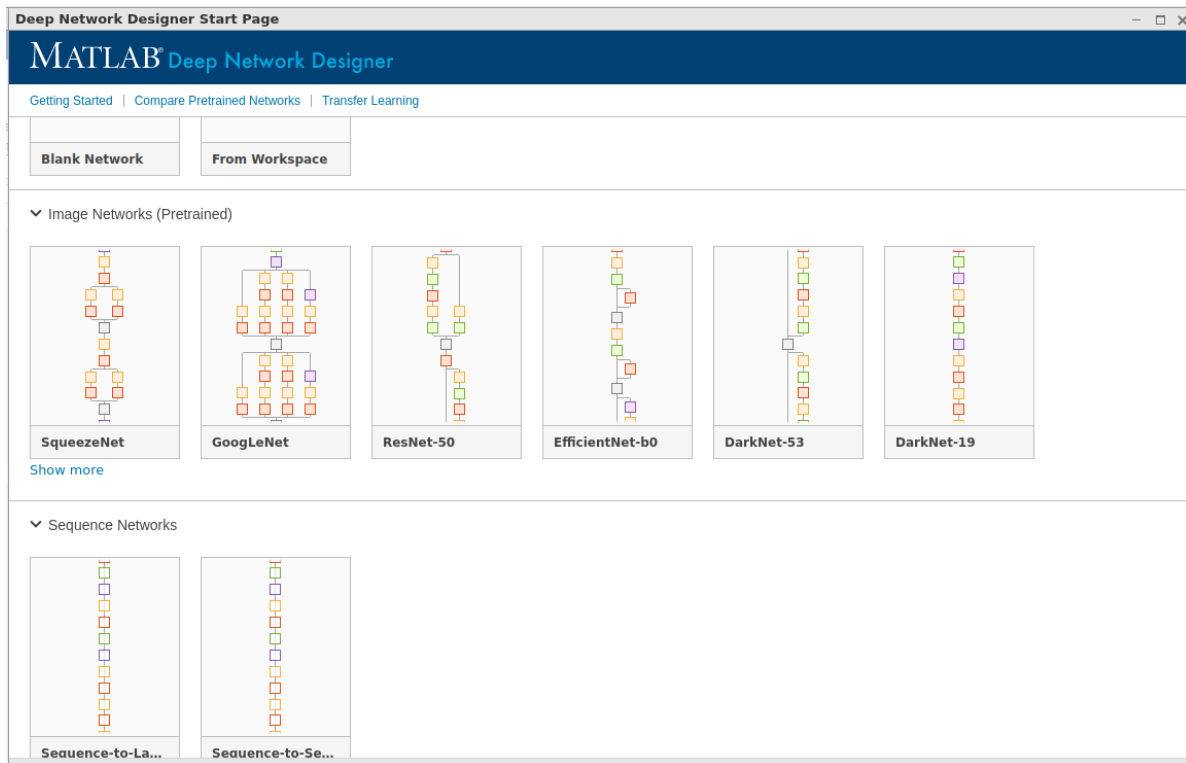
This is the same approach used in multilayer perceptron (MLP) networks

## 3 Matlab tools and functions for working with CNNs

There are lots of new functions and tools in Matlab for using Deep Neural Networks, introduced in the last 2-3 years. There are also Matlab courses and tutorials on how to use them.

But anyone who is serious on this topic should use the Python frameworks (Pytorch, Tensorflow/Keras).

## 3.1 Deep Network Designer



## 3.2 Other frameworks besides Matlab

The most used deep learning frameworks are written in Python:

- Tensorflow + Keras
- Pytorch
- ...

## 4 Walkthroughs

We go step by step through the following Matlab examples:

1. [Classify Image Using GoogLeNet](#)
2. [Transfer Learning with Deep Network Designer](#)
  - alternative: [Transfer Learning Using AlexNet](#)
3. [Create Simple Deep Learning Network for Classification](#)

Additional links:

- DeepLearning OnRamp: <https://matlabacademy.mathworks.com/details/deep-learning-onramp/deeplearning>

## 5 Practical work

### 5.1 Exercise 1 - Play with pretrained networks

1. Load the AlexNet model with pretrained weights on the ImageNet database. Open the model and examine the architecture.
  - How many parameters does the first convolutional layer have?
  - How many parameters does each trainable layer have? (trainable = convolutional or fully-connected)
  - What is the share of the fully-connected layers in the total number of parameters?
2. Compare other networks (GoogLeNet, Resnet-18, Mobile-net v2) with AlexNet:
  - which has more/less layers?
  - which has bigger/smaller fully-connected layers at the end?

3. Play with GoogLeNet and AlexNet. Download an image of a dog from the Internet and classify it. Does it work?

*Note:* The networks were pretrained on the ImageNet dataset, with 1000 image categories, each category having 1000 images. The ImageNet class names can be found [here](#)

- What is the second highest predicted score?
4. Using AlexNet with the image above, visualize the internal activations of the layers 'conv1', 'conv2', 'fc7' and 'prob' inside the network.
    - What are their shapes?

Use the following code sample:

```
% `net` is the model
% `im` is the input image
% 'conv1' is the layer name
act1 = activations(net,im,'conv1');

% Nice plotting
sz = size(act1);
```

```
act1 = reshape(act1,[sz(1) sz(2) 1 sz(3)]);  
I = imtile(mat2gray(act1),'GridSize',[8 8]);  
imshow(I)
```

The sample code is taken from here: <https://www.mathworks.com/help/deeplearning/ug/visualize-activations-of-a-convolutional-neural-network.html>

## 5.2 Exercise 2 - Transfer Learning to classify Cola vs Pepsi

Use transfer learning to train AlexNet (or GoogLeNet) to classify images of Pepsi vs CocaCola beverages.

The dataset is in the file `Data_PepsiCola.zip`, downloaded from here: <https://www.kaggle.com/datasets/die9origephit/pepsi-and-cocacola-images>

1. Download and unzip images, look through them
2. Use the training data to train the network
3. Test the results with some of the images from the dataset.

## 5.3 Exercise 3 - Add a new layer and retrain

1. In DeepNetworkDesigner, and remove one convolutional layer (+ the pooling layer after it) from the middle part of AlexNet. Retrain the whole network on the Pepsi/Cola dataset (it may take some time).
2. Add one extra convolutional layer (+ pooling) in the middle part of AlexNet. Retrain the whole network on the Pepsi/Cola dataset (it may take some time).

## 6 Final questions

TBD