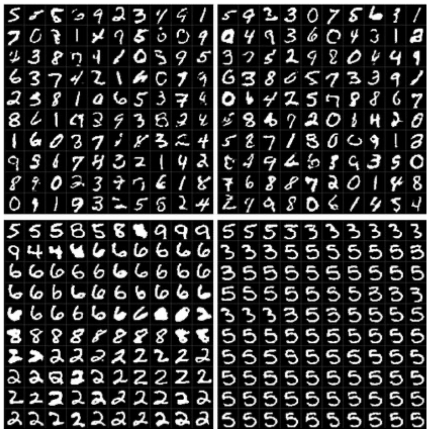
277B: Machine Learning Algorithms
Homework assignment #7: Convolutional and Residual Neural Networks
Assigned March 12 and Due March 22



1. Convolutional Neural Networks applied to classification. We will again use the MNIST data set to train, validation, and test but this time using a CNN. As described in lecture, 2D convolutional neural nets are specified by various hyperparameters: a receptive field (filter size, DxWxH), number of filters K, stride S, amount of zero padding P, and type of pooling. We will represent our input data, as well as the hidden layers, as 3D-arrays. Since MNIST images are black-and-white and thus have scalar-valued pixels, the depth of the input image is 1.

(a) (4.5pt) Calculate the dimensionality of the output for the following convolutions **sequentially** applied to a black and white MNIST input:
(i). Convolution Filter size of 2x2, number of filters 33, stride of 2, padding of 0
(ii). Convolution Filter size of 3x3, number of filters 55, stride of 1, padding of 1
(iii). Convolution Filter size of 3x3, number of filters 77, stride of 1, padding of 1. Followed by a Max Pooling with filter size of 2x2 and stride 2.

(b) (4.5pt) The MNIST data set was, in fact, in color (RGB). This means the depth of the input image would be 3. Calculate the dimensionality of the output for the following convolutions **sequentially** applied to a RGB MNIST input:
(i). Convolution Filter size of 2x2, number of filters 33, stride of 2, padding of 0
(ii). Convolution Filter size of 3x3, number of filters 55, stride of 1, padding of 1. Followed by a max pooling layer of kernel size 3x3, stride of 1, padding of 0
(iii). Convolution Filter size of 3x3, number of filters 77, stride of 1, padding of 1. Followed by a Max Pooling with filter size of 2x2 and stride 2.

(c) (5pt) Next, implement a CNN to see if we can extract additional features from the MNIST data. For this start with one convolutional layer with a 5x5 kernel, with stride of 1, zero-padding of size 2, and 3 output channels. Flatten the resulting feature maps and add a second layer of fully connected (FC) layer to the 10-neuron output layer. Use ReLU as your activation function. Use the ADAM optimizer with learning rate of 1e-3, batchsize of 128, and 30 epochs (you can also train for longer if time permits). Use mini-batches of data and converge your training to where the loss function is minimal, and choose some regularization techniques. Using 3-fold cross-validation and report your average test accuracy.

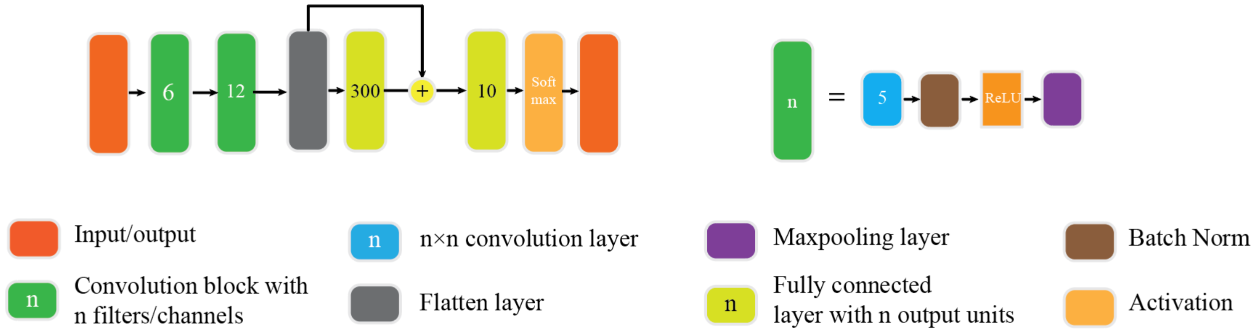
(d) (6pt) Now build a deeper (more layers) architecture with two layers each composed of one convolution and one pooling layer. Flatten the resulting feature maps and use two fully connected (FC) layers. Use conv/pooling layers that with kernel, stride and padding size of your choice. Use ReLU as your activation function. Again, use the ADAM optimizer with learning rate of 1e-3, batchsize of 128, and 30 epochs (you can also train for longer if time permits). Use mini-batches of data and converge your training to where the loss function is minimal, and choose some regularization techniques. Using 3-fold cross-validation report and your average test accuracy. You should aim for getting test accuracy above 98.5%.

2. Residual Neural Networks applied to classification. (20 pt) We will again use the MNIST data set to train, validation, and test but this time using a ResNN. As described in lecture, we are going to formulate a skip connection in order to improve gradient flow.

Using the CNN developed above, adapt your architecture to the one shown in the figure below (architecture with two layers each composed of one convolution and one pooling layer.) Use ReLU as your activation function. Use conv/pooling layers that with kernel, stride and padding size that lead to output size of 12x5x5 before flattening. Flatten the resulting feature maps and use two fully connected (FC) layers of output size

(300,10). Add an additive skip connection from flattened layer to the second fully connected layer. Again, use the ADAM optimizer with learning rate of 1e-3, batchsize of 128, and 30 epochs (you can also train for longer if time permits). Split the MNIST training set into 2/3 for training and 1/3 for validation, you don't need to do KFold this time. Use batch normalization of data, choose some regularization techniques and converge your training to where the loss function is minimal.

- **(a)** (10 pt) Run the model with and without batch normalization. Which give you better test accuracy?
- **(b)** (10 pt) Run the model with and without the skip connection at learning rate of 5e-3 for 10 epochs. Do you see faster training and/or better test accuracy with the skip connection?


6
12
300
+
10
Soft max
n
=
5
ReLU
Input/output
n
n×n convolution layer
Maxpooling layer
Batch Norm
n
Convolution block with n filters/channels
Flatten layer
n
Fully connected layer with n output units
Activation