

In order to shift the input array, I reshaped it into a 28x28 matrix and then for each direction used vstack/hstack to add a row/col in the proper places after cutting off one of the rows/cols. For example, to shift it left one pixel, I sliced the first col off the matrix and then added an empty col of 0s to the last column of the matrix. To rotate it 15 degrees to the left and right, I used scipy.ndimage's rotate function with angle = 15, -15 and reshape=False to preserve the original matrix dimensions.

I implemented this in two ways in my code: the first was to jitter the training set only one time before the training process begins, and the results can be seen with the first console log output. Turns out my results were pretty similar to not jittering it at all (almost the same as no pre-jitter), which made me reconsider the approach, realizing that I should jitter *as the training process progresses*.

My second approach was to jitter the training set at *every epoch* to introduce this random variability, which resulted in 284 misclassifications in the training set and an astonishing **126** in the test set. This means I got 1.26% error, around 1.5% of improvement from the original network!

(wrong jitter)

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Epoch: 0  
Misclassified: 6590  
Epoch: 1  
Misclassified: 4546  
Epoch: 2  
Misclassified: 3327  
Epoch: 3  
Misclassified: 2528  
Epoch: 4  
Misclassified: 2195  
Epoch: 5  
Misclassified: 1901  
Epoch: 6  
Misclassified: 1612  
Epoch: 7  
Misclassified: 1419  
Epoch: 8  
Misclassified: 1256  
Epoch: 9  
Misclassified: 1135  
Epoch: 10  
Misclassified: 1055  
Epoch: 11  
Misclassified: 954  
Epoch: 12  
Misclassified: 877  
Epoch: 13  
Misclassified: 819  
Epoch: 14  
Misclassified: 780  
Epoch: 15  
Misclassified: 754  
Epoch: 16  
Misclassified: 715  
Epoch: 17  
Misclassified: 685  
Epoch: 18  
Misclassified: 651  
Epoch: 19  
Misclassified: 614  
Epoch: 20  
Misclassified: 595  
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Misclassified: 581  
Epoch: 22  
Misclassified: 562
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Epoch: 23
Misclassified: 545
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Misclassified: 406
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Misclassified: 403
Epoch: 49
Misclassified: 399
Epoch: 50
Misclassified: 396
Epoch: 51
Misclassified: 394
Epoch: 52
Misclassified: 1965
Epoch: 53
Misclassified: 1642
Epoch: 54
Misclassified: 1541
Epoch: 55
Misclassified: 1302
Epoch: 56
Misclassified: 1054
Epoch: 57
Misclassified: 917
Epoch: 58
Misclassified: 787
Epoch: 59
Misclassified: 791
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Misclassified: 715
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Misclassified: 652
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Misclassified: 586
Epoch: 63

Misclassified: 524
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Misclassified: 497
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Misclassified: 473
Epoch: 66
Misclassified: 463
Epoch: 67
Misclassified: 438
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Epoch: 96
Misclassified: 306
Epoch: 97
Misclassified: 302
Epoch: 98
Misclassified: 298
Epoch: 99
Misclassified: 297

Correct jitter:

Epoch: 0
Misclassified: 5637
Epoch: 1

Misclassified: 4536
Epoch: 2
Misclassified: 3368
Epoch: 3
Misclassified: 2763
Epoch: 4
Misclassified: 2589
Epoch: 5
Misclassified: 2228
Epoch: 6
Misclassified: 2149
Epoch: 7
Misclassified: 1986
Epoch: 8
Misclassified: 1795
Epoch: 9
Misclassified: 1797
Epoch: 10
Misclassified: 1612
Epoch: 11
Misclassified: 1532
Epoch: 12
Misclassified: 1613
Epoch: 13
Misclassified: 1497
Epoch: 14
Misclassified: 1368
Epoch: 15
Misclassified: 1374
Epoch: 16
Misclassified: 1384
Epoch: 17
Misclassified: 1222
Epoch: 18
Misclassified: 1195
Epoch: 19
Misclassified: 1192
Epoch: 20
Misclassified: 1010
Epoch: 21
Misclassified: 1128
Epoch: 22
Misclassified: 1019
Epoch: 23
Misclassified: 1061
Epoch: 24
Misclassified: 930
Epoch: 25
Misclassified: 1078
Epoch: 26
Misclassified: 899
Epoch: 27
Misclassified: 942
Epoch: 28
Misclassified: 921
Epoch: 29
Misclassified: 827
Epoch: 30
Misclassified: 832
Epoch: 31
Misclassified: 805
Epoch: 32
Misclassified: 834
Epoch: 33
Misclassified: 836
Epoch: 34
Misclassified: 769
Epoch: 35
Misclassified: 842
Epoch: 36
Misclassified: 712
Epoch: 37
Misclassified: 749
Epoch: 38
Misclassified: 816
Epoch: 39
Misclassified: 705
Epoch: 40
Misclassified: 653
Epoch: 41
Misclassified: 637

Epoch: 42
Misclassified: 715
Epoch: 43
Misclassified: 585
Epoch: 44
Misclassified: 660
Epoch: 45
Misclassified: 733
Epoch: 46
Misclassified: 578
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Misclassified: 594
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Misclassified: 611
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Misclassified: 411
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Misclassified: 482
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Misclassified: 422
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Misclassified: 303
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Misclassified: 337
Epoch: 98
Misclassified: 275
Epoch: 99
Misclassified: 284