

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)

```
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
Epoch: 21
Misclassified: 581
Epoch: 22
Misclassified: 562
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Epoch: 23  
Misclassified: 545  
Epoch: 24  
Misclassified: 534  
Epoch: 25  
Misclassified: 527  
Epoch: 26  
Misclassified: 515  
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Misclassified: 507  
Epoch: 28  
Misclassified: 499  
Epoch: 29  
Misclassified: 490  
Epoch: 30  
Misclassified: 476  
Epoch: 31  
Misclassified: 472  
Epoch: 32  
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Epoch: 33  
Misclassified: 459  
Epoch: 34  
Misclassified: 453  
Epoch: 35  
Misclassified: 450  
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Misclassified: 446  
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Epoch: 48  
Misclassified: 403  
Epoch: 49  
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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  
Epoch: 60  
Misclassified: 715  
Epoch: 61  
Misclassified: 652  
Epoch: 62  
Misclassified: 586  
Epoch: 63

Misclassified: 524  
Epoch: 64  
Misclassified: 497  
Epoch: 65  
Misclassified: 473  
Epoch: 66  
Misclassified: 463  
Epoch: 67  
Misclassified: 438  
Epoch: 68  
Misclassified: 422  
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Epoch: 94  
Misclassified: 308  
Epoch: 95  
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Epoch: 96  
Misclassified: 306  
Epoch: 97  
Misclassified: 302  
Epoch: 98  
Misclassified: 298  
Epoch: 99  
Misclassified: 297

## Correct jitter:

Epoch: 0  
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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  
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Misclassified: 1222  
Epoch: 18  
Misclassified: 1195  
Epoch: 19  
Misclassified: 1192  
Epoch: 20  
Misclassified: 1010  
Epoch: 21  
Misclassified: 1128  
Epoch: 22  
Misclassified: 1019  
Epoch: 23  
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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  
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Misclassified: 769  
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Misclassified: 842  
Epoch: 36  
Misclassified: 712  
Epoch: 37  
Misclassified: 749  
Epoch: 38  
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Epoch: 39  
Misclassified: 705  
Epoch: 40  
Misclassified: 653  
Epoch: 41  
Misclassified: 637

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Misclassified: 275  
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Misclassified: 284