Homework 2 MNIST with Python - Analysis

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Introduction

Up until this point we have been creating our own neural networks. This is an important step in learning the actual operations in a neural network. We have also been designing our networks to sequentially handle test cases. In this homework, we used a batch-training neural network that would be trained to recognize handwritten digits (MNIST). In my analysis I compared the results of training using 5 different learning rates {0.01, 0.5, 0.75, 0.9, and 3.0}, with 3 trials for each learning rate. I compiled two diagrams that showed the results of that training. The first diagram shows the maximum accuracy of the network (rounded to one decimal place). The second diagram shows the epoch when the network first achieved its convergence value (truncated to a whole percentile). These two diagrams not only show how accurate the network became at recognizing the digits, but also how quickly it arrived at that point.

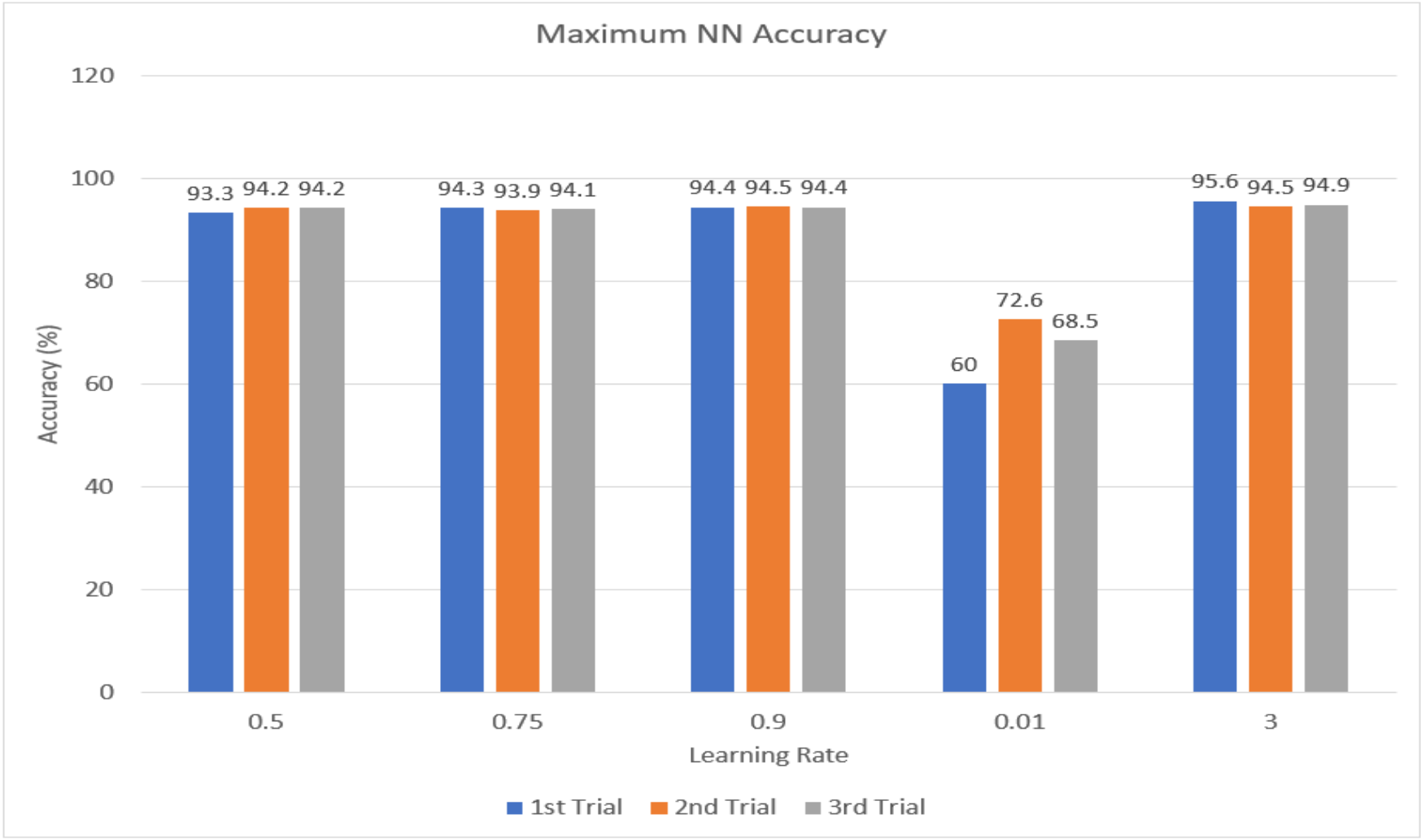

Figure 1: Final Values at Epoch 30

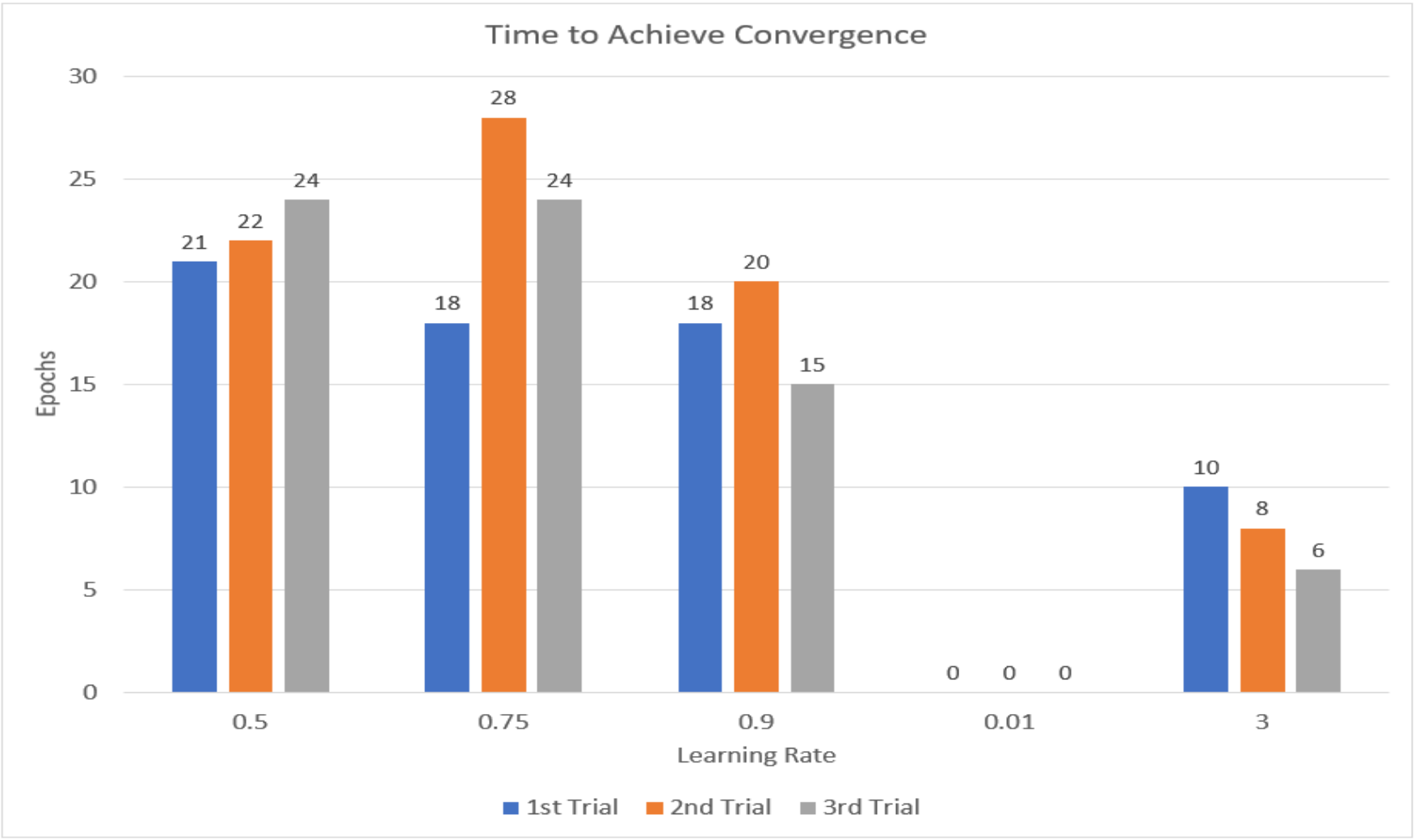

Figure 2: Epoch when the trial first achieved its (closest whole) converged percentile

Analysis

What we would consider "mid to high" level learning rates all managed to converge. And they all managed to converge at roughly the same value. The differences between the mid to high learning rates and their trials really don't constitute a significant difference. Someone unfamiliar with neural networks might think that because not all the samples were classified correctly that this trial failed. I know it's simply because the network is rudimentary and unless we implement more layers or pre-process the image better we won't get better convergence. That's why the convergence values are all so similar. At roughly 94-95% accuracy we achieve the limits of what this network can do. **The low learning rate (0.01) does not converge for a trial of 30 epochs.** This is because the learning rate is simply too small to make it there in 30 epochs. And that's just the convergence values. **Figure 2** shows us that the higher the learning rate, the faster we tend to converge (I believe 28 for 0.75 was just an anomaly with the RNG weight generator). The learning rate of 0.01 never converged so its values were all 0 for the time it reached convergence.

Conclusions

The learning rate is an important part of a neural network. Depending on the problem, there needs to be tweaks and changes based on the results of your network. This could be an important part to get right early, especially if your network takes a significant amount of time to run. In this example we didn't see the network accuracy get affected by the learning rate but it can happen. The learning rate could be potentially too high and we could miss the lowest point of error in the cost function. The short version of all this, is the learning rate needs to be selected carefully, and correctly.

1 Appendix A. Raw Data

```
0.5 First iteration
Epoch 0: 7492 / 10000
Epoch 1: 8624 / 10000
Epoch 2: 8835 / 10000
Epoch 3: 8969 / 10000
Epoch 4: 9034 / 10000
Epoch 5: 9096 / 10000
Epoch 6: 9111 / 10000
Epoch 7: 9143 / 10000
Epoch 8: 9174 / 10000
Epoch 9: 9180 / 10000
Epoch 10: 9199 / 10000
Epoch 11: 9212 / 10000
Epoch 12: 9246 / 10000
Epoch 13: 9247 / 10000
Epoch 14: 9262 / 10000
Epoch 15: 9279 / 10000
Epoch 16: 9281 / 10000
Epoch 17: 9280 / 10000
Epoch 18: 9289 / 10000
Epoch 19: 9297 / 10000
Epoch 20: 9299 / 10000
Epoch 21: 9312 / 10000
Epoch 22: 9309 / 10000
Epoch 23: 9311 / 10000
Epoch 24: 9331 / 10000
Epoch 25: 9319 / 10000
Epoch 26: 9313 / 10000
Epoch 27: 9327 / 10000
Epoch 28: 9326 / 10000
Epoch 29: 9329 / 10000

0.5 Second Iteration

Epoch 0: 7443 / 10000
```

```
Epoch 1: 8832 / 10000
Epoch 2: 8985 / 10000
Epoch 3: 9073 / 10000
Epoch 4: 9148 / 10000
Epoch 5: 9175 / 10000
Epoch 6: 9213 / 10000
Epoch 7: 9240 / 10000
Epoch 8: 9266 / 10000
Epoch 9: 9280 / 10000
Epoch 10: 9282 / 10000
Epoch 11: 9312 / 10000
Epoch 12: 9326 / 10000
Epoch 13: 9346 / 10000
Epoch 14: 9331 / 10000
Epoch 15: 9355 / 10000
Epoch 16: 9371 / 10000
Epoch 17: 9376 / 10000
Epoch 18: 9381 / 10000
Epoch 19: 9389 / 10000
Epoch 20: 9388 / 10000
Epoch 21: 9393 / 10000
Epoch 22: 9401 / 10000
Epoch 23: 9409 / 10000
Epoch 24: 9412 / 10000
Epoch 25: 9422 / 10000
Epoch 26: 9409 / 10000
Epoch 27: 9431 / 10000
Epoch 28: 9426 / 10000
Epoch 29: 9422 / 10000

0.5 Third Iteration

Epoch 0: 7644 / 10000
Epoch 1: 8620 / 10000
Epoch 2: 8865 / 10000
Epoch 3: 8983 / 10000
Epoch 4: 9073 / 10000
Epoch 5: 9121 / 10000
```

```
Epoch 6: 9171 / 10000
Epoch 7: 9189 / 10000
Epoch 8: 9239 / 10000
Epoch 9: 9273 / 10000
Epoch 10: 9276 / 10000
Epoch 11: 9290 / 10000
Epoch 12: 9305 / 10000
Epoch 13: 9314 / 10000
Epoch 14: 9330 / 10000
Epoch 15: 9341 / 10000
Epoch 16: 9347 / 10000
Epoch 17: 9337 / 10000
Epoch 18: 9353 / 10000
Epoch 19: 9382 / 10000
Epoch 20: 9370 / 10000
Epoch 21: 9378 / 10000
Epoch 22: 9386 / 10000
Epoch 23: 9391 / 10000
Epoch 24: 9408 / 10000
Epoch 25: 9402 / 10000
Epoch 26: 9401 / 10000
Epoch 27: 9406 / 10000
Epoch 28: 9415 / 10000
Epoch 29: 9415 / 10000
```

.75 First Iteration

```
Epoch 0: 8636 / 10000
Epoch 1: 8973 / 10000
Epoch 2: 9119 / 10000
Epoch 3: 9147 / 10000
Epoch 4: 9209 / 10000
Epoch 5: 9256 / 10000
Epoch 6: 9266 / 10000
Epoch 7: 9301 / 10000
Epoch 8: 9312 / 10000
Epoch 9: 9331 / 10000
Epoch 10: 9335 / 10000
```

```
Epoch 11: 9356 / 10000
Epoch 12: 9366 / 10000
Epoch 13: 9390 / 10000
Epoch 14: 9370 / 10000
Epoch 15: 9396 / 10000
Epoch 16: 9405 / 10000
Epoch 17: 9381 / 10000
Epoch 18: 9411 / 10000
Epoch 19: 9400 / 10000
Epoch 20: 9401 / 10000
Epoch 21: 9406 / 10000
Epoch 22: 9408 / 10000
Epoch 23: 9425 / 10000
Epoch 24: 9424 / 10000
Epoch 25: 9422 / 10000
Epoch 26: 9420 / 10000
Epoch 27: 9435 / 10000
Epoch 28: 9426 / 10000
Epoch 29: 9425 / 10000
```

.75 Second Iteration

```
Epoch 0: 7765 / 10000
Epoch 1: 8057 / 10000
Epoch 2: 8157 / 10000
Epoch 3: 8253 / 10000
Epoch 4: 8262 / 10000
Epoch 5: 8323 / 10000
Epoch 6: 8338 / 10000
Epoch 7: 8379 / 10000
Epoch 8: 8389 / 10000
Epoch 9: 8395 / 10000
Epoch 10: 8404 / 10000
Epoch 11: 8440 / 10000
Epoch 12: 8444 / 10000
Epoch 13: 8439 / 10000
Epoch 14: 8452 / 10000
Epoch 15: 8457 / 10000
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```
Epoch 16: 8472 / 10000
Epoch 17: 8458 / 10000
Epoch 18: 8478 / 10000
Epoch 19: 8476 / 10000
Epoch 20: 8477 / 10000
Epoch 21: 8472 / 10000
Epoch 22: 8483 / 10000
Epoch 23: 8475 / 10000
Epoch 24: 8492 / 10000
Epoch 25: 8485 / 10000
Epoch 26: 8503 / 10000
Epoch 27: 8505 / 10000
Epoch 28: 9406 / 10000
Epoch 29: 9389 / 10000

.75 Third Iteration

Epoch 0: 8538 / 10000
Epoch 1: 8883 / 10000
Epoch 2: 9055 / 10000
Epoch 3: 9146 / 10000
Epoch 4: 9203 / 10000
Epoch 5: 9248 / 10000
Epoch 6: 9256 / 10000
Epoch 7: 9267 / 10000
Epoch 8: 9294 / 10000
Epoch 9: 9313 / 10000
Epoch 10: 9313 / 10000
Epoch 11: 9310 / 10000
Epoch 12: 9343 / 10000
Epoch 13: 9356 / 10000
Epoch 14: 9360 / 10000
Epoch 15: 9367 / 10000
Epoch 16: 9363 / 10000
Epoch 17: 9365 / 10000
Epoch 18: 9387 / 10000
Epoch 19: 9396 / 10000
Epoch 20: 9395 / 10000
```

```
Epoch 21: 9391 / 10000
Epoch 22: 9382 / 10000
Epoch 23: 9397 / 10000
Epoch 24: 9404 / 10000
Epoch 25: 9415 / 10000
Epoch 26: 9408 / 10000
Epoch 27: 9427 / 10000
Epoch 28: 9416 / 10000
Epoch 29: 9414 / 10000
```

.9 First Iteration

```
Epoch 0: 8780 / 10000
Epoch 1: 9029 / 10000
Epoch 2: 9141 / 10000
Epoch 3: 9211 / 10000
Epoch 4: 9244 / 10000
Epoch 5: 9252 / 10000
Epoch 6: 9296 / 10000
Epoch 7: 9312 / 10000
Epoch 8: 9331 / 10000
Epoch 9: 9339 / 10000
Epoch 10: 9350 / 10000
Epoch 11: 9355 / 10000
Epoch 12: 9392 / 10000
Epoch 13: 9384 / 10000
Epoch 14: 9381 / 10000
Epoch 15: 9389 / 10000
Epoch 16: 9395 / 10000
Epoch 17: 9399 / 10000
Epoch 18: 9400 / 10000
Epoch 19: 9395 / 10000
Epoch 20: 9399 / 10000
Epoch 21: 9405 / 10000
Epoch 22: 9407 / 10000
Epoch 23: 9410 / 10000
Epoch 24: 9425 / 10000
Epoch 25: 9416 / 10000
```

```
Epoch 26: 9414 / 10000
Epoch 27: 9426 / 10000
Epoch 28: 9424 / 10000
Epoch 29: 9439 / 10000

.9 Second Iteration

Epoch 0: 8792 / 10000
Epoch 1: 9045 / 10000
Epoch 2: 9124 / 10000
Epoch 3: 9162 / 10000
Epoch 4: 9217 / 10000
Epoch 5: 9251 / 10000
Epoch 6: 9283 / 10000
Epoch 7: 9302 / 10000
Epoch 8: 9320 / 10000
Epoch 9: 9313 / 10000
Epoch 10: 9347 / 10000
Epoch 11: 9352 / 10000
Epoch 12: 9376 / 10000
Epoch 13: 9391 / 10000
Epoch 14: 9384 / 10000
Epoch 15: 9401 / 10000
Epoch 16: 9405 / 10000
Epoch 17: 9408 / 10000
Epoch 18: 9381 / 10000
Epoch 19: 9398 / 10000
Epoch 20: 9426 / 10000
Epoch 21: 9426 / 10000
Epoch 22: 9408 / 10000
Epoch 23: 9429 / 10000
Epoch 24: 9433 / 10000
Epoch 25: 9427 / 10000
Epoch 26: 9426 / 10000
Epoch 27: 9431 / 10000
Epoch 28: 9433 / 10000
Epoch 29: 9445 / 10000
```

```
.9 Third Iteration

Epoch 0: 7023 / 10000
Epoch 1: 7781 / 10000
Epoch 2: 9089 / 10000
Epoch 3: 9182 / 10000
Epoch 4: 9218 / 10000
Epoch 5: 9256 / 10000
Epoch 6: 9285 / 10000
Epoch 7: 9299 / 10000
Epoch 8: 9310 / 10000
Epoch 9: 9333 / 10000
Epoch 10: 9356 / 10000
Epoch 11: 9372 / 10000
Epoch 12: 9372 / 10000
Epoch 13: 9392 / 10000
Epoch 14: 9399 / 10000
Epoch 15: 9418 / 10000
Epoch 16: 9423 / 10000
Epoch 17: 9429 / 10000
Epoch 18: 9421 / 10000
Epoch 19: 9425 / 10000
Epoch 20: 9434 / 10000
Epoch 21: 9425 / 10000
Epoch 22: 9430 / 10000
Epoch 23: 9432 / 10000
Epoch 24: 9437 / 10000
Epoch 25: 9433 / 10000
Epoch 26: 9423 / 10000
Epoch 27: 9446 / 10000
Epoch 28: 9431 / 10000
Epoch 29: 9444 / 10000

.01 First Iteration

Epoch 0: 1982 / 10000
Epoch 1: 2634 / 10000
Epoch 2: 3169 / 10000
```

```
Epoch 3: 3475 / 10000
Epoch 4: 3686 / 10000
Epoch 5: 3831 / 10000
Epoch 6: 3948 / 10000
Epoch 7: 4059 / 10000
Epoch 8: 4190 / 10000
Epoch 9: 4284 / 10000
Epoch 10: 4390 / 10000
Epoch 11: 4509 / 10000
Epoch 12: 4633 / 10000
Epoch 13: 4779 / 10000
Epoch 14: 4950 / 10000
Epoch 15: 5145 / 10000
Epoch 16: 5286 / 10000
Epoch 17: 5410 / 10000
Epoch 18: 5504 / 10000
Epoch 19: 5594 / 10000
Epoch 20: 5663 / 10000
Epoch 21: 5715 / 10000
Epoch 22: 5772 / 10000
Epoch 23: 5811 / 10000
Epoch 24: 5863 / 10000
Epoch 25: 5896 / 10000
Epoch 26: 5927 / 10000
Epoch 27: 5947 / 10000
Epoch 28: 5975 / 10000
Epoch 29: 6000 / 10000

.01 Second Iteration

Epoch 0: 1716 / 10000
Epoch 1: 2360 / 10000
Epoch 2: 2946 / 10000
Epoch 3: 3363 / 10000
Epoch 4: 3677 / 10000
Epoch 5: 3934 / 10000
Epoch 6: 4182 / 10000
Epoch 7: 4368 / 10000
```

```
Epoch 8: 4610 / 10000
Epoch 9: 4829 / 10000
Epoch 10: 5065 / 10000
Epoch 11: 5290 / 10000
Epoch 12: 5501 / 10000
Epoch 13: 5726 / 10000
Epoch 14: 5925 / 10000
Epoch 15: 6052 / 10000
Epoch 16: 6167 / 10000
Epoch 17: 6259 / 10000
Epoch 18: 6331 / 10000
Epoch 19: 6411 / 10000
Epoch 20: 6485 / 10000
Epoch 21: 6547 / 10000
Epoch 22: 6617 / 10000
Epoch 23: 6725 / 10000
Epoch 24: 6836 / 10000
Epoch 25: 6944 / 10000
Epoch 26: 7047 / 10000
Epoch 27: 7153 / 10000
Epoch 28: 7225 / 10000
Epoch 29: 7261 / 10000
```

.01 Third Iteration

```
Epoch 0: 1538 / 10000
Epoch 1: 2076 / 10000
Epoch 2: 2641 / 10000
Epoch 3: 3036 / 10000
Epoch 4: 3371 / 10000
Epoch 5: 3651 / 10000
Epoch 6: 3928 / 10000
Epoch 7: 4198 / 10000
Epoch 8: 4472 / 10000
Epoch 9: 4856 / 10000
Epoch 10: 5097 / 10000
Epoch 11: 5279 / 10000
Epoch 12: 5430 / 10000
```

```
Epoch 13: 5572 / 10000
Epoch 14: 5676 / 10000
Epoch 15: 5749 / 10000
Epoch 16: 5820 / 10000
Epoch 17: 5866 / 10000
Epoch 18: 5943 / 10000
Epoch 19: 6019 / 10000
Epoch 20: 6108 / 10000
Epoch 21: 6210 / 10000
Epoch 22: 6301 / 10000
Epoch 23: 6394 / 10000
Epoch 24: 6492 / 10000
Epoch 25: 6580 / 10000
Epoch 26: 6659 / 10000
Epoch 27: 6725 / 10000
Epoch 28: 6784 / 10000
Epoch 29: 6849 / 10000

3.0 First Iteration

Epoch 0: 9134 / 10000
Epoch 1: 9214 / 10000
Epoch 2: 9340 / 10000
Epoch 3: 9387 / 10000
Epoch 4: 9430 / 10000
Epoch 5: 9429 / 10000
Epoch 6: 9439 / 10000
Epoch 7: 9492 / 10000
Epoch 8: 9444 / 10000
Epoch 9: 9496 / 10000
Epoch 10: 9501 / 10000
Epoch 11: 9499 / 10000
Epoch 12: 9501 / 10000
Epoch 13: 9512 / 10000
Epoch 14: 9524 / 10000
Epoch 15: 9531 / 10000
Epoch 16: 9535 / 10000
Epoch 17: 9523 / 10000
```

```
Epoch 18: 9536 / 10000
Epoch 19: 9534 / 10000
Epoch 20: 9540 / 10000
Epoch 21: 9524 / 10000
Epoch 22: 9543 / 10000
Epoch 23: 9548 / 10000
Epoch 24: 9538 / 10000
Epoch 25: 9540 / 10000
Epoch 26: 9530 / 10000
Epoch 27: 9518 / 10000
Epoch 28: 9550 / 10000
Epoch 29: 9556 / 10000

3.0 Second Iteration

Epoch 0: 9004 / 10000
Epoch 1: 9244 / 10000
Epoch 2: 9264 / 10000
Epoch 3: 9301 / 10000
Epoch 4: 9368 / 10000
Epoch 5: 9357 / 10000
Epoch 6: 9403 / 10000
Epoch 7: 9388 / 10000
Epoch 8: 9449 / 10000
Epoch 9: 9422 / 10000
Epoch 10: 9448 / 10000
Epoch 11: 9443 / 10000
Epoch 12: 9454 / 10000
Epoch 13: 9448 / 10000
Epoch 14: 9474 / 10000
Epoch 15: 9477 / 10000
Epoch 16: 9443 / 10000
Epoch 17: 9457 / 10000
Epoch 18: 9434 / 10000
Epoch 19: 9446 / 10000
Epoch 20: 9451 / 10000
Epoch 21: 9439 / 10000
Epoch 22: 9440 / 10000
```

```
Epoch 23: 9459 / 10000
Epoch 24: 9433 / 10000
Epoch 25: 9463 / 10000
Epoch 26: 9468 / 10000
Epoch 27: 9469 / 10000
Epoch 28: 9479 / 10000
Epoch 29: 9453 / 10000

3.0 Third Iteration

Epoch 0: 9040 / 10000
Epoch 1: 9242 / 10000
Epoch 2: 9295 / 10000
Epoch 3: 9345 / 10000
Epoch 4: 9364 / 10000
Epoch 5: 9399 / 10000
Epoch 6: 9408 / 10000
Epoch 7: 9452 / 10000
Epoch 8: 9447 / 10000
Epoch 9: 9454 / 10000
Epoch 10: 9454 / 10000
Epoch 11: 9465 / 10000
Epoch 12: 9465 / 10000
Epoch 13: 9443 / 10000
Epoch 14: 9471 / 10000
Epoch 15: 9482 / 10000
Epoch 16: 9485 / 10000
Epoch 17: 9474 / 10000
Epoch 18: 9482 / 10000
Epoch 19: 9487 / 10000
Epoch 20: 9483 / 10000
Epoch 21: 9464 / 10000
Epoch 22: 9484 / 10000
Epoch 23: 9450 / 10000
Epoch 24: 9467 / 10000
Epoch 25: 9486 / 10000
Epoch 26: 9487 / 10000
Epoch 27: 9482 / 10000
```

```
Epoch 28: 9472 / 10000
Epoch 29: 9490 / 10000
```