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DSE-512

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Assignment 4

Pytorch and Data Parallelism

# Method

Per the Instructions in the assignment, I “created” a new python script to run the PyTorch analysis on the MNIST data. I wrote very little new code, as I was able to use the code that Jacob produced and make small modifications to complete the assignment. Here is a short summary of the process I followed:

1. Copied Jacob’s python code (train\_mnist.py) and the job script (train\_mnist.pbs) into my directory.
2. I updated both the python file and the job script for my specific application,
   1. Updated references in scripts to my directory.
   2. Increased the number of epochs from 9 to 30.
3. I copied the MNIST data set into my directory.
4. After running the file, I ran into an issue, and modified the code to reduce the memory allocation.
5. After the code ran successfully, I created new git repository for the code and the job logs.
6. I create a remote repository on GitHub, and pushed all code to “master” branch on GitHub (main would not work).
7. I ran the job four times, with the number of processes as required (8, 4, 2, and 1).
   1. Note: for 1 process, the job was killed because it hit the wall time of 10 minutes, so I updated to 15 minutes in the job script.
8. I added all of the output files to the GitHub repository.
9. I tried to come up with a way to view and visualize the results using Python. However, at the time I was creating this code, I thought that Pandas was not in Jacob’s environment. So, I manually copied the data from the output files on GitHub, and pasted into Word (see attachement below).
10. I reformatted the data in Word into tables, then copied into Excel.
11. It this stage, I found some weird data in the 8 processes version… the error rate spiked at the 18th epoch. So, I reran the 8process version and imported new data. These results were more smooth, so I used them in the visualizations.
12. I build graphs in Excel, and copied back into this document.
13. Uploaded Word and Excel filed back to GitHub repository.

# Problem 1

Having run all of the analyses in problem 1, the The python code and job script can be found in GitHub here:

<https://github.com/RSitton5/MNIST/tree/master>

The output files are here:

* 8 processes: <https://github.com/RSitton5/MNIST/blob/master/logs/train_mnist_dse512.4752728.apollo-acf.o>
* 4 processes: <https://github.com/RSitton5/MNIST/blob/master/logs/train_mnist_dse512.4750354.apollo-acf.o>
* 2 processes: <https://github.com/RSitton5/MNIST/blob/master/logs/train_mnist_dse512.4750418.apollo-acf.o>
* 1 process: <https://github.com/RSitton5/MNIST/blob/master/logs/train_mnist_dse512.4750421.apollo-acf.o>

# Problem 2

This first figure shows the plot of accuracy, by epoch, for each of the four runs with different number of processes:

This second figure shows the cumulative runtime per epoch for each of the four runs.

Using these graphs, I have answered the questions from Problem 2:

*What is the effect of training time as we increase the number of processes available?*

The training time dropped by 46% (758 to 408) just by doubling the processes from one to two. However, quadrupling from 2 to 8 processes decreased process time by 40%.

*How does this line up with your expectations of the scalability laws that we discussed?*

It matches exactly what we would expect, as there are diminished returns for adding more processes as that can only accelerate certain portions of the code.

*Which scalability law is most applicable in this case?*

It appears that Amdahl’s law is a good fit, as only the proportion of the process that benefits from multiple processes or parallel computing can be improved, leaving the other portion static.

*How is our model accuracy affected by the increase in the number of processes running?*

This was interesting. It appears that 1, 2, and 4 processes returned accuracy levels with negligible differences, while 8 processes nearly doubled the error. More importantly, the second epoch in these three runs was already MORE accurate the final (30th) in the 8 processes mode. This seemed off to me, so I reran the models again but got very similar results. In all, it seems like running less epochs with four processors would give the optimal balance of accuracy and process time.

# Attachment 1: Data from Process Runs

World size: 8

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| epoch | 0 | num\_iters | 938 | loss | 1.5038832475000352 | elapsed | time | (s) | 7.955124003812671 |
| epoch | 1 | num\_iters | 938 | loss | 1.0781107082454635 | elapsed | time | (s) | 15.755681922659278 |
| epoch | 2 | num\_iters | 938 | loss | 1.019053194632154 | elapsed | time | (s) | 23.64816310070455 |
| epoch | 3 | num\_iters | 938 | loss | 0.9692533455058329 | elapsed | time | (s) | 31.5563433971256 |
| epoch | 4 | num\_iters | 938 | loss | 0.9212365294379721 | elapsed | time | (s) | 39.40355081111193 |
| epoch | 5 | num\_iters | 938 | loss | 0.8805021964537818 | elapsed | time | (s) | 47.314601516351104 |
| epoch | 6 | num\_iters | 938 | loss | 0.8452073125117051 | elapsed | time | (s) | 55.24326091632247 |
| epoch | 7 | num\_iters | 938 | loss | 0.8367114403068638 | elapsed | time | (s) | 63.114288890734315 |
| epoch | 8 | num\_iters | 938 | loss | 0.8340746721685696 | elapsed | time | (s) | 70.92010896652937 |
| epoch | 9 | num\_iters | 938 | loss | 0.819843235050342 | elapsed | time | (s) | 78.8709452599287 |
| epoch | 10 | num\_iters | 938 | loss | 0.8502099138261603 | elapsed | time | (s) | 86.7944817841053 |
| epoch | 11 | num\_iters | 938 | loss | 0.8753516107702306 | elapsed | time | (s) | 94.65805634856224 |
| epoch | 12 | num\_iters | 938 | loss | 0.8660824317643955 | elapsed | time | (s) | 102.53759880922735 |
| epoch | 13 | num\_iters | 938 | loss | 0.8635727943959774 | elapsed | time | (s) | 110.41179802827537 |
| epoch | 14 | num\_iters | 938 | loss | 0.8627216543303307 | elapsed | time | (s) | 118.27258248254657 |
| epoch | 15 | num\_iters | 938 | loss | 0.8615895017965643 | elapsed | time | (s) | 126.11480985209346 |
| epoch | 16 | num\_iters | 938 | loss | 0.8486550578088966 | elapsed | time | (s) | 133.98393361270428 |
| epoch | 17 | num\_iters | 938 | loss | 0.8428262354873581 | elapsed | time | (s) | 141.813233692199 |
| epoch | 18 | num\_iters | 938 | loss | 1.560874952019246 | elapsed | time | (s) | 149.65333004668355 |
| epoch | 19 | num\_iters | 938 | loss | 1.6673342630680181 | elapsed | time | (s) | 157.518295455724 |
| epoch | 20 | num\_iters | 938 | loss | 1.4370029151185488 | elapsed | time | (s) | 165.45724843256176 |
| epoch | 21 | num\_iters | 938 | loss | 1.3068060973115059 | elapsed | time | (s) | 173.26895354688168 |
| epoch | 22 | num\_iters | 938 | loss | 1.301669618023484 | elapsed | time | (s) | 181.14741431176662 |
| epoch | 23 | num\_iters | 938 | loss | 1.3022061073576718 | elapsed | time | (s) | 188.9991903770715 |
| epoch | 24 | num\_iters | 938 | loss | 1.5268936127042974 | elapsed | time | (s) | 196.9120307881385 |
| epoch | 25 | num\_iters | 938 | loss | 1.4128080169592838 | elapsed | time | (s) | 204.73405710235238 |
| epoch | 26 | num\_iters | 938 | loss | 1.2973941098779505 | elapsed | time | (s) | 212.6422277893871 |
| epoch | 27 | num\_iters | 938 | loss | 1.4030189171973577 | elapsed | time | (s) | 220.4405029118061 |
| epoch | 28 | num\_iters | 938 | loss | 1.3215302521867285 | elapsed | time | (s) | 228.28450262919068 |
| epoch | 29 | num\_iters | 938 | loss | 1.3152558081693995 | elapsed | time | (s) | 236.0316519998014 |

World size: 4

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| epoch | 0 | num\_iters | 1875 | loss | 1.4016163437247275 | elapsed | time | (s) | 23.91768017783761 |
| epoch | 1 | num\_iters | 1875 | loss | 0.8831258048097292 | elapsed | time | (s) | 36.615055510774255 |
| epoch | 2 | num\_iters | 1875 | loss | 0.7977700795153777 | elapsed | time | (s) | 48.29730539396405 |
| epoch | 3 | num\_iters | 1875 | loss | 0.7768476130803426 | elapsed | time | (s) | 59.92796378582716 |
| epoch | 4 | num\_iters | 1875 | loss | 0.7546378274877866 | elapsed | time | (s) | 71.55229785107076 |
| epoch | 5 | num\_iters | 1875 | loss | 0.7367842477281888 | elapsed | time | (s) | 83.09637979790568 |
| epoch | 6 | num\_iters | 1875 | loss | 0.7298891852120558 | elapsed | time | (s) | 94.72171778976917 |
| epoch | 7 | num\_iters | 1875 | loss | 0.7197745033860207 | elapsed | time | (s) | 106.23887034319341 |
| epoch | 8 | num\_iters | 1875 | loss | 0.7180521093825499 | elapsed | time | (s) | 118.00372955016792 |
| epoch | 9 | num\_iters | 1875 | loss | 0.7073814815580844 | elapsed | time | (s) | 129.6716748829931 |
| epoch | 10 | num\_iters | 1875 | loss | 0.7037361914992333 | elapsed | time | (s) | 141.25971302576363 |
| epoch | 11 | num\_iters | 1875 | loss | 0.6954606826364994 | elapsed | time | (s) | 152.83163310587406 |
| epoch | 12 | num\_iters | 1875 | loss | 0.6944564990341663 | elapsed | time | (s) | 164.49329742603004 |
| epoch | 13 | num\_iters | 1875 | loss | 0.6922580709377925 | elapsed | time | (s) | 176.0971654485911 |
| epoch | 14 | num\_iters | 1875 | loss | 0.6938745220253865 | elapsed | time | (s) | 187.82416746206582 |
| epoch | 15 | num\_iters | 1875 | loss | 0.692571501694123 | elapsed | time | (s) | 199.36661630310118 |
| epoch | 16 | num\_iters | 1875 | loss | 0.6878758243183295 | elapsed | time | (s) | 211.15474666655064 |
| epoch | 17 | num\_iters | 1875 | loss | 0.6791301957825819 | elapsed | time | (s) | 222.73505369201303 |
| epoch | 18 | num\_iters | 1875 | loss | 0.6713603915284078 | elapsed | time | (s) | 234.2594595104456 |
| epoch | 19 | num\_iters | 1875 | loss | 0.6636076401496926 | elapsed | time | (s) | 246.026539420709 |
| epoch | 20 | num\_iters | 1875 | loss | 0.663578285112977 | elapsed | time | (s) | 257.6048142109066 |
| epoch | 21 | num\_iters | 1875 | loss | 0.6570761951540908 | elapsed | time | (s) | 269.2340896129608 |
| epoch | 22 | num\_iters | 1875 | loss | 0.6462544375543793 | elapsed | time | (s) | 280.8132284190506 |
| epoch | 23 | num\_iters | 1875 | loss | 0.6423028499364853 | elapsed | time | (s) | 292.40422883816063 |
| epoch | 24 | num\_iters | 1875 | loss | 0.6346187157322963 | elapsed | time | (s) | 303.76311441510916 |
| epoch | 25 | num\_iters | 1875 | loss | 0.6379635095919172 | elapsed | time | (s) | 315.36307405494153 |
| epoch | 26 | num\_iters | 1875 | loss | 0.631137453875939 | elapsed | time | (s) | 326.89104809984565 |
| epoch | 27 | num\_iters | 1875 | loss | 0.6359451394339403 | elapsed | time | (s) | 338.4405088108033 |
| epoch | 28 | num\_iters | 1875 | loss | 0.6278932487666606 | elapsed | time | (s) | 350.0821542777121 |
| epoch | 29 | num\_iters | 1875 | loss | 0.6266932828893265 | elapsed | time | (s) | 361.7179539836943 |

World size: 2

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| epoch | 0 | num\_iters | 3750 | loss | 1.3364088261087737 | elapsed | time | (s) | 13.743825105950236 |
| epoch | 1 | num\_iters | 3750 | loss | 0.9061606536388397 | elapsed | time | (s) | 27.416982110589743 |
| epoch | 2 | num\_iters | 3750 | loss | 0.8600543038104971 | elapsed | time | (s) | 41.07328854687512 |
| epoch | 3 | num\_iters | 3750 | loss | 0.8329696714470783 | elapsed | time | (s) | 54.77358531020582 |
| epoch | 4 | num\_iters | 3750 | loss | 0.8143351763705412 | elapsed | time | (s) | 68.4543466027826 |
| epoch | 5 | num\_iters | 3750 | loss | 0.8037662349998951 | elapsed | time | (s) | 82.12351648323238 |
| epoch | 6 | num\_iters | 3750 | loss | 0.7874507247616848 | elapsed | time | (s) | 95.79377811774611 |
| epoch | 7 | num\_iters | 3750 | loss | 0.7804718572278817 | elapsed | time | (s) | 109.52852516807616 |
| epoch | 8 | num\_iters | 3750 | loss | 0.7748097022657593 | elapsed | time | (s) | 123.24903102591634 |
| epoch | 9 | num\_iters | 3750 | loss | 0.7641960932294528 | elapsed | time | (s) | 136.86633173003793 |
| epoch | 10 | num\_iters | 3750 | loss | 0.7669501769870519 | elapsed | time | (s) | 150.5726538989693 |
| epoch | 11 | num\_iters | 3750 | loss | 0.7632104112972816 | elapsed | time | (s) | 164.27030355483294 |
| epoch | 12 | num\_iters | 3750 | loss | 0.754665650014331 | elapsed | time | (s) | 177.93934039585292 |
| epoch | 13 | num\_iters | 3750 | loss | 0.7489972292688986 | elapsed | time | (s) | 191.86927416920662 |
| epoch | 14 | num\_iters | 3750 | loss | 0.7379082160385947 | elapsed | time | (s) | 205.49890453368425 |
| epoch | 15 | num\_iters | 3750 | loss | 0.7354376407019794 | elapsed | time | (s) | 219.16657983884215 |
| epoch | 16 | num\_iters | 3750 | loss | 0.7294986390608053 | elapsed | time | (s) | 232.8219153061509 |
| epoch | 17 | num\_iters | 3750 | loss | 0.729912659239769 | elapsed | time | (s) | 246.4898934904486 |
| epoch | 18 | num\_iters | 3750 | loss | 0.7271614386706302 | elapsed | time | (s) | 259.9684435222298 |
| epoch | 19 | num\_iters | 3750 | loss | 0.7250049218090872 | elapsed | time | (s) | 273.6127353142947 |
| epoch | 20 | num\_iters | 3750 | loss | 0.7254406115729362 | elapsed | time | (s) | 287.11683629080653 |
| epoch | 21 | num\_iters | 3750 | loss | 0.7240289052569617 | elapsed | time | (s) | 300.6922943741083 |
| epoch | 22 | num\_iters | 3750 | loss | 0.7256641292432944 | elapsed | time | (s) | 314.160487966612 |
| epoch | 23 | num\_iters | 3750 | loss | 0.7268318121922512 | elapsed | time | (s) | 327.75352119095623 |
| epoch | 24 | num\_iters | 3750 | loss | 0.72061435230275 | elapsed | time | (s) | 341.2718033324927 |
| epoch | 25 | num\_iters | 3750 | loss | 0.7225163818739354 | elapsed | time | (s) | 354.8312651887536 |
| epoch | 26 | num\_iters | 3750 | loss | 0.7232617566920817 | elapsed | time | (s) | 368.36963439919055 |
| epoch | 27 | num\_iters | 3750 | loss | 0.7244465883261214 | elapsed | time | (s) | 381.91522592678666 |
| epoch | 28 | num\_iters | 3750 | loss | 0.723437401642402 | elapsed | time | (s) | 395.45783356390893 |
| epoch | 29 | num\_iters | 3750 | loss | 0.7199253097220013 | elapsed | time | (s) | 408.98062906228006 |

World size: 1

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| epoch | 0 | num\_iters | 7500 | loss | 1.408808980297049 | elapsed | time | (s) | 25.481847988441586 |
| epoch | 1 | num\_iters | 7500 | loss | 0.9241771430358291 | elapsed | time | (s) | 50.86394836008549 |
| epoch | 2 | num\_iters | 7500 | loss | 0.885114690061162 | elapsed | time | (s) | 76.2778228521347 |
| epoch | 3 | num\_iters | 7500 | loss | 0.8668278944591681 | elapsed | time | (s) | 101.539445258677 |
| epoch | 4 | num\_iters | 7500 | loss | 0.8511852825269103 | elapsed | time | (s) | 126.82256385870278 |
| epoch | 5 | num\_iters | 7500 | loss | 0.8426025497734546 | elapsed | time | (s) | 152.1041457671672 |
| epoch | 6 | num\_iters | 7500 | loss | 0.8321729748224219 | elapsed | time | (s) | 177.36364407278597 |
| epoch | 7 | num\_iters | 7500 | loss | 0.8209679949519535 | elapsed | time | (s) | 202.6351113114506 |
| epoch | 8 | num\_iters | 7500 | loss | 0.7282759850951532 | elapsed | time | (s) | 227.90818507038057 |
| epoch | 9 | num\_iters | 7500 | loss | 0.6954213170257707 | elapsed | time | (s) | 253.17104200460017 |
| epoch | 10 | num\_iters | 7500 | loss | 0.6866004127405584 | elapsed | time | (s) | 278.44525928609073 |
| epoch | 11 | num\_iters | 7500 | loss | 0.679588438162456 | elapsed | time | (s) | 303.72757324390113 |
| epoch | 12 | num\_iters | 7500 | loss | 0.6740954894776146 | elapsed | time | (s) | 328.979630721733 |
| epoch | 13 | num\_iters | 7500 | loss | 0.6699691162221134 | elapsed | time | (s) | 354.2500544600189 |
| epoch | 14 | num\_iters | 7500 | loss | 0.6666144658274948 | elapsed | time | (s) | 379.5095054861158 |
| epoch | 15 | num\_iters | 7500 | loss | 0.6667030269215505 | elapsed | time | (s) | 404.75567151606083 |
| epoch | 16 | num\_iters | 7500 | loss | 0.6650587707978983 | elapsed | time | (s) | 430.0152416136116 |
| epoch | 17 | num\_iters | 7500 | loss | 0.6641278739112119 | elapsed | time | (s) | 455.2740191128105 |
| epoch | 18 | num\_iters | 7500 | loss | 0.6623788794529935 | elapsed | time | (s) | 480.5173242352903 |
| epoch | 19 | num\_iters | 7500 | loss | 0.6607611530768375 | elapsed | time | (s) | 505.74672109261155 |
| epoch | 20 | num\_iters | 7500 | loss | 0.6612294003941118 | elapsed | time | (s) | 530.9691086988896 |
| epoch | 21 | num\_iters | 7500 | loss | 0.659925247754405 | elapsed | time | (s) | 556.4736792054027 |
| epoch | 22 | num\_iters | 7500 | loss | 0.660291858488818 | elapsed | time | (s) | 581.705624602735 |
| epoch | 23 | num\_iters | 7500 | loss | 0.658619474982967 | elapsed | time | (s) | 606.9472286067903 |
| epoch | 24 | num\_iters | 7500 | loss | 0.658675862827897 | elapsed | time | (s) | 632.2417401578277 |
| epoch | 25 | num\_iters | 7500 | loss | 0.6567718361154199 | elapsed | time | (s) | 657.4533856473863 |
| epoch | 26 | num\_iters | 7500 | loss | 0.6569147356331348 | elapsed | time | (s) | 682.6946793869138 |
| epoch | 27 | num\_iters | 7500 | loss | 0.6569961424623927 | elapsed | time | (s) | 707.9264640118927 |
| epoch | 28 | num\_iters | 7500 | loss | 0.6569108194820583 | elapsed | time | (s) | 733.1788316685706 |
| epoch | 29 | num\_iters | 7500 | loss | 0.6559347781245907 | elapsed | time | (s) | 758.42965881899 |

World size: 8 (second time)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| epoch | 0 | num\_iters | 938 | loss | 1.9896268836979165 | elapsed | time | (s) | 13.059057489037514 |
| epoch | 1 | num\_iters | 938 | loss | 1.7488661272439368 | elapsed | time | (s) | 23.351448636502028 |
| epoch | 2 | num\_iters | 938 | loss | 1.5897917029445867 | elapsed | time | (s) | 31.227160580456257 |
| epoch | 3 | num\_iters | 938 | loss | 1.4904235731691187 | elapsed | time | (s) | 39.05406421236694 |
| epoch | 4 | num\_iters | 938 | loss | 1.369374118443491 | elapsed | time | (s) | 46.96820507198572 |
| epoch | 5 | num\_iters | 938 | loss | 1.2935517851128253 | elapsed | time | (s) | 54.874655056744814 |
| epoch | 6 | num\_iters | 938 | loss | 1.282037411258419 | elapsed | time | (s) | 62.80311529710889 |
| epoch | 7 | num\_iters | 938 | loss | 1.253916783691215 | elapsed | time | (s) | 70.69099847227335 |
| epoch | 8 | num\_iters | 938 | loss | 1.2420919865115618 | elapsed | time | (s) | 78.57685207761824 |
| epoch | 9 | num\_iters | 938 | loss | 1.2333692799626128 | elapsed | time | (s) | 86.53026358783245 |
| epoch | 10 | num\_iters | 938 | loss | 1.2300965854131591 | elapsed | time | (s) | 94.38385902903974 |
| epoch | 11 | num\_iters | 938 | loss | 1.2203091170424338 | elapsed | time | (s) | 102.24661912024021 |
| epoch | 12 | num\_iters | 938 | loss | 1.2180210678879895 | elapsed | time | (s) | 110.15697582811117 |
| epoch | 13 | num\_iters | 938 | loss | 1.2082220865433404 | elapsed | time | (s) | 118.00332870334387 |
| epoch | 14 | num\_iters | 938 | loss | 1.2005257925816946 | elapsed | time | (s) | 125.7451044972986 |
| epoch | 15 | num\_iters | 938 | loss | 1.2014175686500728 | elapsed | time | (s) | 133.60027042031288 |
| epoch | 16 | num\_iters | 938 | loss | 1.2077930235722933 | elapsed | time | (s) | 141.52178036421537 |
| epoch | 17 | num\_iters | 938 | loss | 1.2057731550480766 | elapsed | time | (s) | 149.37432579696178 |
| epoch | 18 | num\_iters | 938 | loss | 1.2082014342805725 | elapsed | time | (s) | 157.21307760849595 |
| epoch | 19 | num\_iters | 938 | loss | 1.2104942251814963 | elapsed | time | (s) | 165.06730214878917 |
| epoch | 20 | num\_iters | 938 | loss | 1.224225234502414 | elapsed | time | (s) | 172.9672757908702 |
| epoch | 21 | num\_iters | 938 | loss | 1.2069276197394456 | elapsed | time | (s) | 180.8313062917441 |
| epoch | 22 | num\_iters | 938 | loss | 1.2108732744384167 | elapsed | time | (s) | 188.73819484375417 |
| epoch | 23 | num\_iters | 938 | loss | 1.2028843168574355 | elapsed | time | (s) | 196.57521494105458 |
| epoch | 24 | num\_iters | 938 | loss | 1.217848061911587 | elapsed | time | (s) | 204.64623886533082 |
| epoch | 25 | num\_iters | 938 | loss | 1.2005671225091032 | elapsed | time | (s) | 212.6001928281039 |
| epoch | 26 | num\_iters | 938 | loss | 1.208778620989465 | elapsed | time | (s) | 220.50500585138798 |
| epoch | 27 | num\_iters | 938 | loss | 1.1905928246819897 | elapsed | time | (s) | 228.35418251343071 |
| epoch | 28 | num\_iters | 938 | loss | 1.1851418829326437 | elapsed | time | (s) | 236.25980744883418 |
| epoch | 29 | num\_iters | 938 | loss | 1.1937037852368375 | elapsed | time | (s) | 244.2496366426348 |