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1 Problem: 1

1.1 Ring Reduce and Ring All Reduce

- These two parts have been implemented in the Python files- ring reduce and ring all reduce.

1.2 Describe how did I perform above two exercises. Compare the accuracy of the trained model and the training time.

- **Explanation of Part-a**

(i) Data Preprocessing: The MNIST dataset was used(as mentioned in the question), which consists of images of handwritten digits. For compatibility with the LeNet-5 architecture, images were padded. The dataset was converted into tensor format for normalization & PyTorch compatibility and was divided into training(100 images which are split into four equal subsets) and testing.

(ii) Model Architecture: The LeNet-5 model was implemented as a convolutional neural network (CNN) with the following layers:

- * First convolutional layer - 6 filters of size 5×5 , which uses a Tanh activation function.
- * An average pooling layer - A kernel size of 2×2 and a stride of 2 for feature maps.
- * Second convolutional layer - 16 filters of size 5×5 , which again uses a Tanh activation function.
- * Another average pooling layer - Same as before.
- * Third convolutional layer - 120 filters of size 5×5 , which again uses a Tanh activation function.
- * The output of the final convolutional layer - Flattened and passed through a fully connected (FC) layer with 84 neurons, using another Tanh activation function.
- * A second fully connected layer - 84 neurons to 10 output classes.

CrossEntropy loss function was used to train the model and Stochastic Gradient Descent (SGD) is optimizing it with a learning rate of 0.01.

(iii) Data Parallelism Implementation(all reduce): The training process is using PyTorch's Distributed Data Parallel (DDP) framework for parallel training. The steps are as follows:

- * Splitting jobs into equal four processes, each assigned to one of the four subsets.
- * Each process initialized a copy of model and loading its subset using PyTorch.
- * To enable distributed training in PyTorch, the environment variables `MASTER_ADDR` and `MASTER_PORT` are set to define the master node's address and communication port. These ensure proper coordination between multiple processes during training.
- * During training, each process was computing gradients independently which were synchronized across processes using `torch.distributed.all_reduce`.
- * Gradient synchronization is done after each process updates it's local parameters.
- * The distributed training follows a data parallelism approach which is managed using `torch.distributed` package of Pytorch (using 'gloo' backend for inter-process communication).

(iv) Performance Metrics Collection: The following metrics were recorded at each epoch while training:

- * Average training loss for each process.
- * Training accuracy.
- * The total training time per process.

- **Explanation of Part-b**

(i) Data Parallelism Implementation(ring all reduce):

- * The previous implementation used **all reduce** approach for gradient synchronization while this uses **ring all reduce**, where multiple processes work on different data subsets while maintaining synchronization using PyTorch. Steps for ring all reduce are as follows:
 1. Initialize the distributed process group.

2. Divide the gradients into chunks.
3. Perform the scatter-reduce operation using non-blocking send and receive operations.
4. Perform the all-gather operation to distribute the reduced gradients.
5. Average the gradients and update the model.

(ii) Changes in Data Loading Strategy:

- * Assigning subsets to processes using PyTorch's DistributedSampler to automatically partition the dataset among different processes.
- * This ensures equal workload distribution and prevents redundant data processing.

Rest of the settings are same as all reduce implementation.

• **Comparison of Part a and b**

(i) Accuracy Comparison

- * In Part (a), which is **all reduce**, the training accuracy starts at around 9% and gradually increases, reaching approximately 66% by the 100th epoch.
- * Whereas Part (b), which is **ring-all reduce**, has a much faster improvement in accuracy, and end up with final average accuracy of 91%.
- * The accuracies' trend of both the implementations show that **ring-all reduce** model is learning more effectively in early training stages than **all reduce**

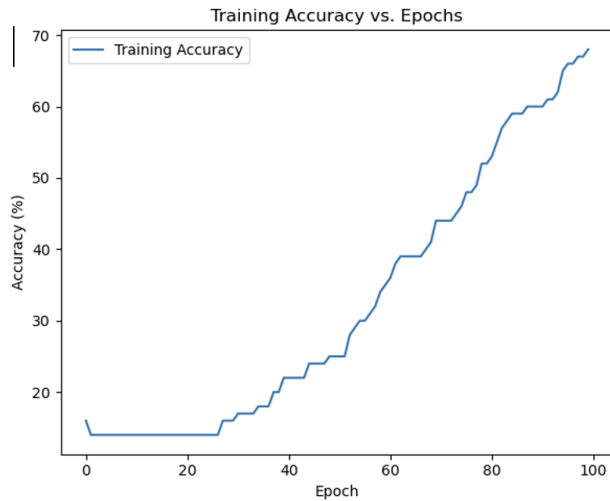


Fig.- All reduce

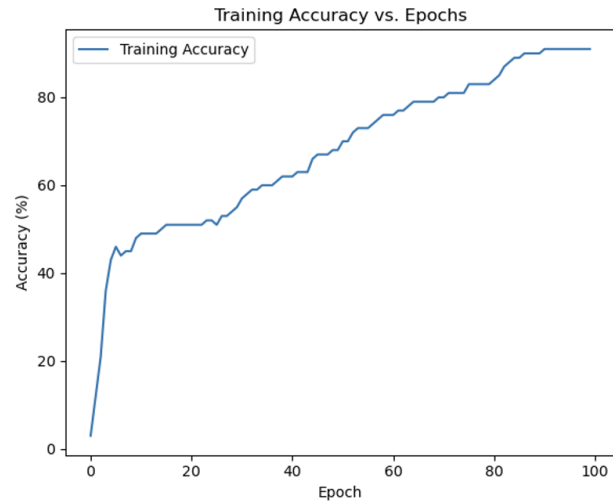


Fig.- Ring-all reduce

Figure 1: Accuracy vs Epochs

(ii) Training Loss and Convergence

- * Both the models are showing a decreasing trend in the loss but **ring-all reduce** demonstrates a considerably quicker reduction in loss compared **all reduce**.
- * In **all reduce**, the initial loss is approximately 2.3 and decreases to around 1.4 by the final epoch. This shows that the decline in loss is steady but not very sharp.
- * In **ring-all reduce**, the initial loss is slightly lower which is around 2.25 but it decreases more aggressively, reaching close to 0.6 by the 100th epoch.
- * The faster convergence of Part (b) indicates that it learns more efficiently and potentially due to improved architecture and better hyperparameters.

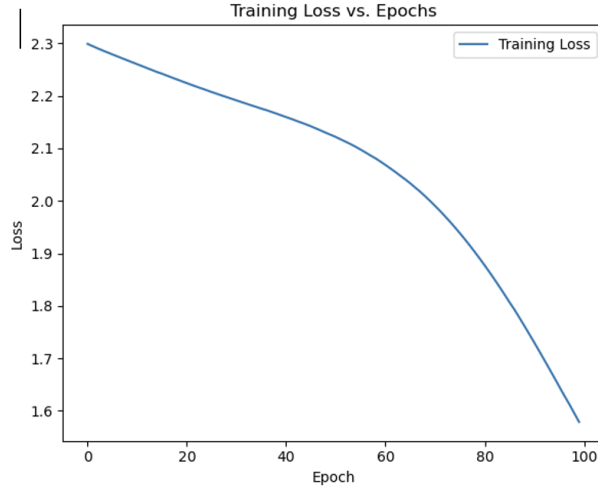


Fig.- All reduce

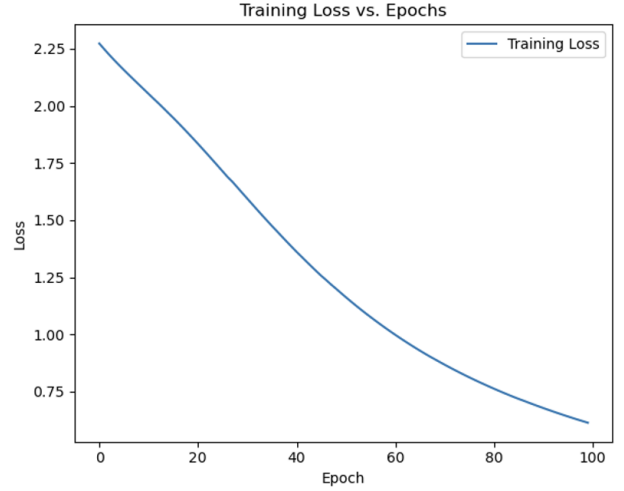


Fig.- Ring-all reduce

Figure 2: Loss vs Epochs

(iii) Training Time

- * The training time of both models for current run - **all reduce** is taking 3.03 seconds and **ring-all reduce** 2.80 seconds. This indicates that part (b) is performing better in aspects of training accuracy, training time and improvement over loss.
- * The dataset used in both cases can significantly influence the results, certain datasets may be easier to learn, leading to the faster accuracy improvement.

```

Rank 0, Epoch 98, Loss: 1.4445, Accuracy: 72.00%
Rank 2, Epoch 98, Loss: 1.5006, Accuracy: 72.00%
Rank 3, Epoch 98, Loss: 1.4609, Accuracy: 68.00%
Rank 1, Epoch 98, Loss: 1.4999, Accuracy: 52.00%
Rank 2, Epoch 99, Loss: 1.4825, Accuracy: 72.00%
Rank 0, Epoch 99, Loss: 1.4247, Accuracy: 72.00%
Rank 1, Epoch 99, Loss: 1.4820, Accuracy: 52.00%
Rank 3, Epoch 99, Loss: 1.4436, Accuracy: 68.00%
Rank 3, Epoch 100, Loss: 1.4265, Accuracy: 68.00%
Rank 2, Epoch 100, Loss: 1.4645, Accuracy: 72.00%
Rank 0, Epoch 100, Loss: 1.4052, Accuracy: 72.00%
Rank 1, Epoch 100, Loss: 1.4643, Accuracy: 52.00%
Rank 2, Training Time: 3.03 seconds
Rank 3, Training Time: 3.03 seconds
Rank 1, Training Time: 3.03 seconds
Rank 0, Training Time: 3.03 seconds
Averaged Train Losses: [2.3190438747406006, 2.3154043555259705, 2.311843991279602, 2.3083505630493164, 2.304912090301
5137, 2.3015183806419373, 2.2981602549552917, 2.2948291301727295, 2.2921221256256104, 2.288825750350952, 2.2855518460
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95606995, 2.219208240509033, 2.215293288230896, 2.2113178372383118, 2.207376778125763, 2.2032703161239624, 2.19909077
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1.750480741262436, 1.7327476143836975, 1.7147763073444366, 1.6968246698379517, 1.6784626841545105, 1.659952431917190
6, 1.6413249969482422, 1.6226114928722382, 1.603842705488205, 1.5850493609905243, 1.5664933919906616, 1.5477323830127
716, 1.5290318131446838, 1.5120707154273987, 1.494555652141571, 1.476458489894867, 1.4581830203533173, 1.440134137868
8812]
Averaged Train Accuracies: [9.0, 9.0, 9.0, 9.0, 10.0, 10.0, 9.0, 13.0, 15.0, 18.0, 17.0, 17.0, 17.0, 17.0, 16.0, 17.0
, 16.0, 16.0, 16.0, 18.0, 19.0, 20.0, 22.0, 23.0, 26.0, 27.0, 28.0, 29.0, 30.0, 30.0, 30.0, 29.0, 29.0, 32.0, 31.0, 3
1.0, 30.0, 30.0, 30.0, 30.0, 30.0, 29.0, 29.0, 29.0, 29.0, 31.0, 32.0, 32.0, 32.0, 33.0, 35.0, 35.0, 36.0, 36.0
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6.0, 59.0, 59.0, 60.0, 60.0, 61.0, 61.0, 61.0, 61.0, 62.0, 62.0, 63.0, 64.0, 64.0, 64.0, 64.0, 65.0, 65.0, 65.0, 65.0
, 65.0, 65.0, 66.0, 66.0, 66.0, 66.0]
Average Training Time: 3.03 seconds
Final Training Accuracy: 66.00%

```

Figure 3: Loss vs Epochs

```

Rank 3, Epoch 96, Loss: 0.6584, Accuracy: 92.00%
Rank 1, Epoch 96, Loss: 0.5721, Accuracy: 84.00%
Rank 1, Epoch 97, Loss: 0.5661, Accuracy: 84.00%
Rank 0, Epoch 97, Loss: 0.7493, Accuracy: 88.00%
Rank 2, Epoch 97, Loss: 0.5684, Accuracy: 100.00%
Rank 3, Epoch 97, Loss: 0.6510, Accuracy: 92.00%
Rank 1, Epoch 98, Loss: 0.5601, Accuracy: 84.00%
Rank 0, Epoch 98, Loss: 0.7419, Accuracy: 88.00%
Rank 3, Epoch 98, Loss: 0.6437, Accuracy: 92.00%
Rank 2, Epoch 98, Loss: 0.5614, Accuracy: 100.00%
Rank 2, Epoch 99, Loss: 0.5550, Accuracy: 100.00%
Rank 1, Epoch 99, Loss: 0.5545, Accuracy: 84.00%
Rank 3, Epoch 99, Loss: 0.6370, Accuracy: 92.00%
Rank 0, Epoch 99, Loss: 0.7346, Accuracy: 88.00%
Rank 3, Epoch 100, Loss: 0.6299, Accuracy: 92.00%
Rank 3, Training Time: 2.80 seconds
Rank 2, Epoch 100, Loss: 0.5483, Accuracy: 100.00%
Rank 2, Training Time: 2.80 seconds
Rank 1, Epoch 100, Loss: 0.5488, Accuracy: 84.00%
Rank 0, Epoch 100, Loss: 0.7275, Accuracy: 88.00%
Rank 1, Training Time: 2.80 seconds
Rank 0, Training Time: 2.80 seconds
Averaged Train Losses: [2.273197293281555, 2.2484784722328186, 2.224262773990631, 2.2011157274246216, 2.1787780523300
17, 2.157046675682068, 2.135757863521576, 2.1147748827934265, 2.093980133533478, 2.073269486427307, 2.052550971508026
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477668583393097, 0.6406504958868027, 0.6336628943681717, 0.6268003731966019, 0.6202735006809235, 0.613647073507309]
Averaged Train Accuracies: [3.0, 12.0, 21.0, 36.0, 43.0, 46.0, 44.0, 45.0, 45.0, 48.0, 49.0, 49.0, 49.0, 49.0, 50.0,
51.0, 51.0, 51.0, 51.0, 51.0, 51.0, 51.0, 51.0, 52.0, 52.0, 51.0, 53.0, 53.0, 54.0, 55.0, 57.0, 58.0, 59.0, 59.0, 60.
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91.0, 91.0, 91.0, 91.0, 91.0, 91.0]
Average Training Time: 2.80 seconds
Final Training Accuracy: 91.00%

```

Figure 4: Loss vs Epochs

References

- [1] M. Bosi et al., "Convolutional coding: An overview and new results," in *IEEE Transactions on Communications*, vol. 46, no. 9, pp. 1092-1103, Sept. 1998. [Online]. Available: