Contents

1 Highly Scalable Deep Learning Training System with Mixed-Precision- Training ImageNet in Four Minutes

1.1 Challenge

Goals

Build a high-throughput distributed deep learning training system. 1. improve training throughout * need faster computation and more efficient bandwidth utilization 1. improve the scaling efficiency * need more collective communication primitives * can handle a system with thousands of GPUs

Challenge

1. Large mini-batch size leads to lower test accuracy due to the generalization gap problem.
2. When using large clusters, it is hard to achieve near-linear scalability as the number of machine increase.

1.2 Optimizations

1.2.1 1. Mixed-Precision Training with LARS

Mixed-precision training with LARS is one of the critical reasons that the proposed system could keep good scalability while increasing the mini-batch size to 64K.

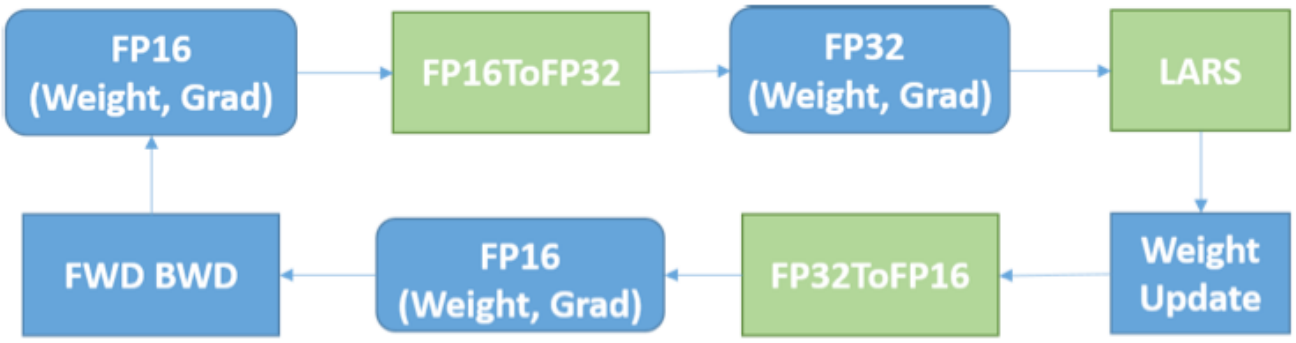
1. half-precision (FP16)
   - lower memory bandwidth pressure
   - increase arithmetic throughput
2. use LARS to enable large mini-batch training

Problems by a naive implementation

> using LARS directly on half-precision training will cause the computed learning rate to be out of the dynamic range of IEEE half-precision format (FP16), and thus cause the gradients to vanish and stall the training process.

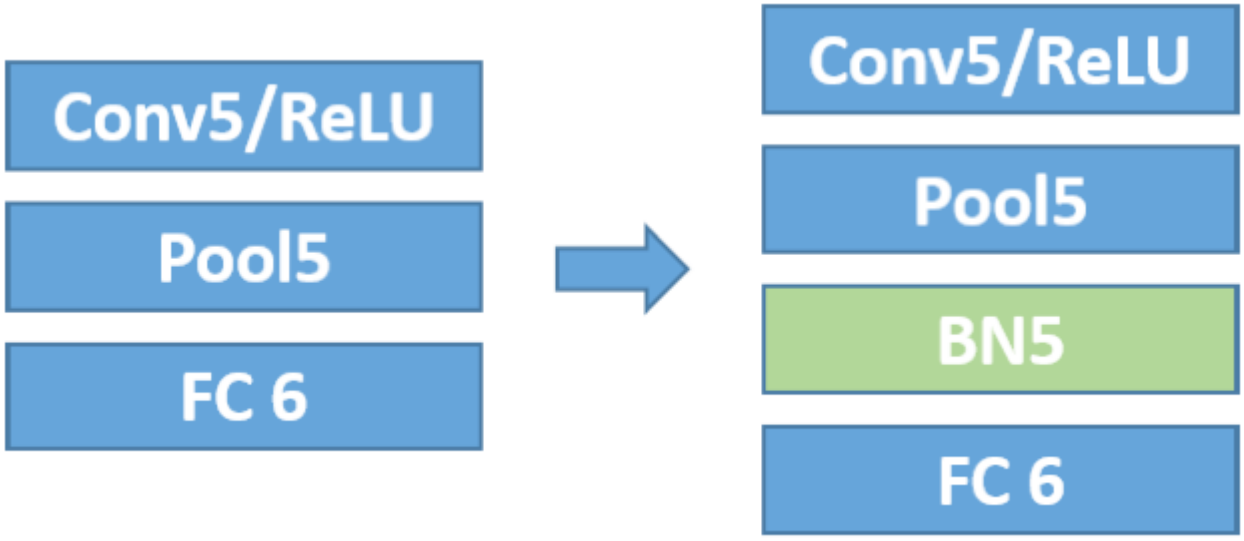
Solution

1. the operations in forward and backward propagation are performed in FP16.
2. weights and gradients are cast to single-precision (FP32) format before applying LARS
3. after applying LARS, weights and gradients are cast back to FP16.



1.2.2 2. Model Architecture Improvments

1. eliminate weight decay on the bias and batch normalization.
2. add proper batch normalization layers (after pool5) for AlexNet.



- In neural network training, it is a typical practice to penalize only the weights of the affine transformation at each layer and leaves the biases unregularized.

1.2.3 3. Communication Strategies

objective: maximize the throughput as well as reduce the latency.

- Tensor fusion
  - challenges
    1. when training deep neural networks with multiple layers, the sizes of gradient tensors to aggregate vary a lot for different types of layers.
    2. sending too many small tensors in the network will not only cause the bandwidth to be under-utilized but also increase the latency.
  - solution
    * pack multiple small size tensors together before all-reduce to better utilize the bandwidth of the network.
    * set a threshold in backward phase. only send fused tensor when the total size is larger than the threshold.
- Hybrid all-reduce

- challenges
    * tensor fusion increase the throughput but also increase latency.
    * hierarchical all-reduce instead of ring-base all-reduce perform better for small tensor communication.

1.3 Experimental Results

1. For ResNet-50 training, LARS could improve the top-1 accuracy from 60.6% to 71.9%, but cannot reach the baseline accuracy yet. Eliminating weight decay on bias and batch normalization meets the baseline test accuracy.
2. Using mixed-precision training can speedup single-node performance of ResNet-50 from 172 images/second to 218 images/second. (1.26)
3. scalability