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Teacher-Student Learning

Eric He

Who is this guy?

- My name is Eric He
- Third-year student at NYU
- Grew up in Bay Area, Evergreen Valley High School
- Wanted to do marketing, now studying mathematics and data science
- Strong interest in explanatory modeling

What is Teacher-Student Learning?

- An alternative method of training neural nets
- Normal loss functions penalize deviation of student model from the ground truth label
- Teacher-Student loss penalizes deviation of student model from the teacher's predictions, or **soft labels**

	Panther	Cat	Truck	Goose
Ground Truth	1	0	0	0
Soft Labels	0.7	0.28	0.015	0.005

Dark Knowledge: A panther is more like a cat than a truck or a goose

Image source: http://awesomejelly.com/panther-pinata/

Potential of Teacher-Student Learning

- Data flexibility
  - May not need to expend resources to label training data
  - Customers do not need to hand over proprietary data used to train models
- Model compression
  - train a smaller model for deployment
- Model diversity
  - Different architectures learn different features, which can all be transferred onto the student model

Infrastructure

Machine Learning

Caffe

python™

Hardware

NVIDIA®

ubuntu

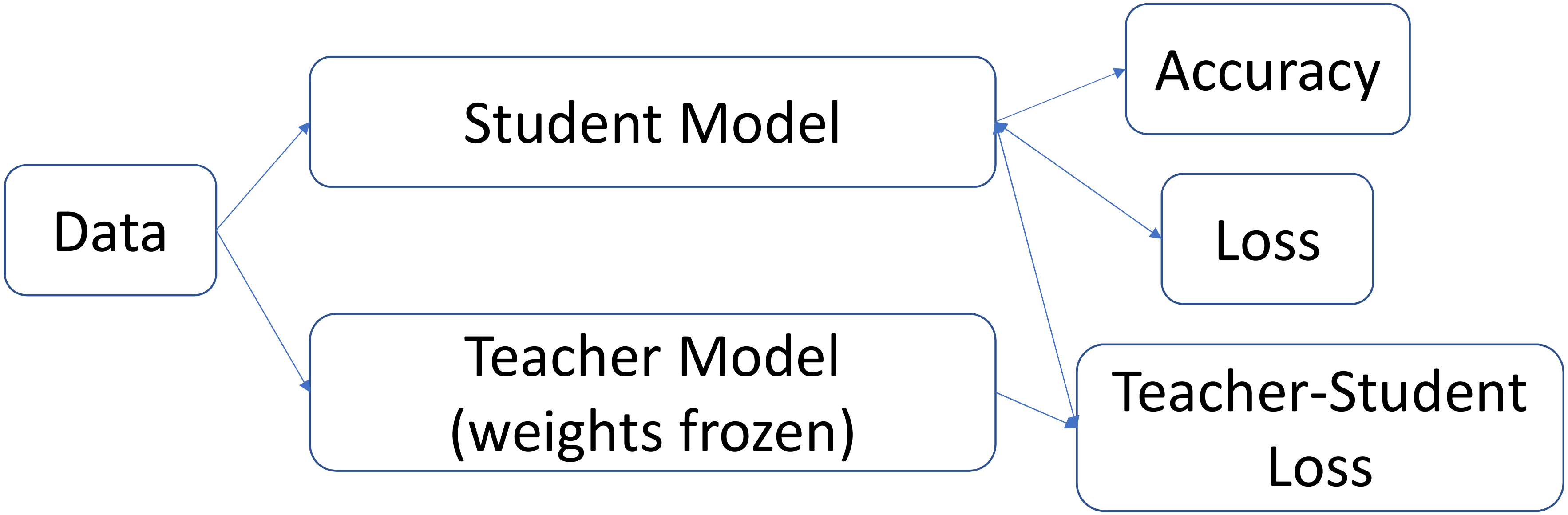
amazon web services™

Graphics

ggplot2

R

Setting up Teacher-Student Modeling



Method: Stack both teacher and student models into one .prototxt file

Problems: Highly memory intensive, both models require same data dimensions

- Batch size of 20 with AlexNet teacher and VGG16 student takes 12 GB of GPU memory

Three Performance Metrics

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Accuracy

Proportion of predicted top1 labels in concordance with the true labels

Loss

Sum of softmax cross-entropy scores between student-generated probability distributions and true labels

Teacher-Student Loss

Sum of softmax cross-entropy scores between student and teacher-generated probability distributions

Cross Entropy Loss

$$\mathcal{L}(y, \hat{y}) = -y \log \hat{y} - (1 - y) \log(1 - \hat{y})$$

For the purposes of visualization, Loss and Teacher-Student Loss are graphed as percentages of their maximum.

MNIST

- 60000 training images
- 20 x 20 x 1 (grayscale)
- 10 categories

0 1 2 3 4 5 6 7 8 9

CIFAR10

- 60000 training images
- 32 x 32 x 3 (color)
- 10 categories

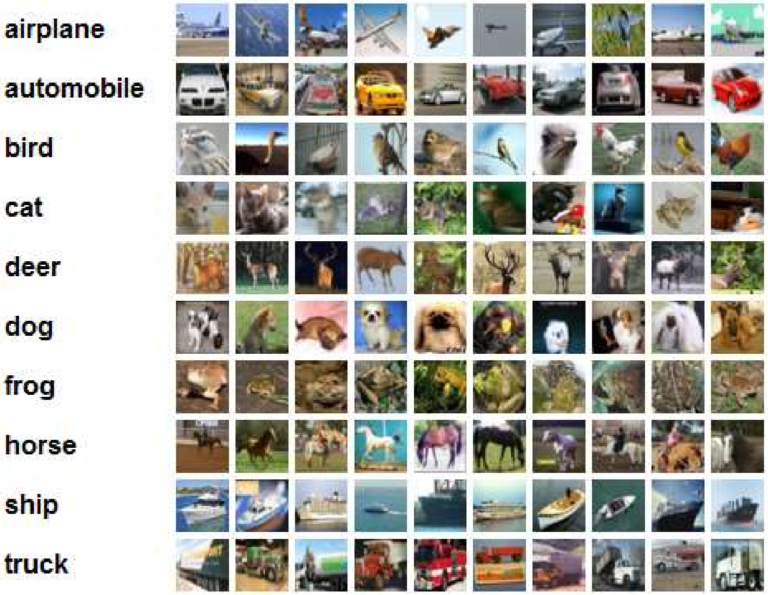


Image sources: https://github.com/cazala/mnist, http://karpathy.github.io/2011/04/27/manually-classifying-cifar10/

LeNet Structure

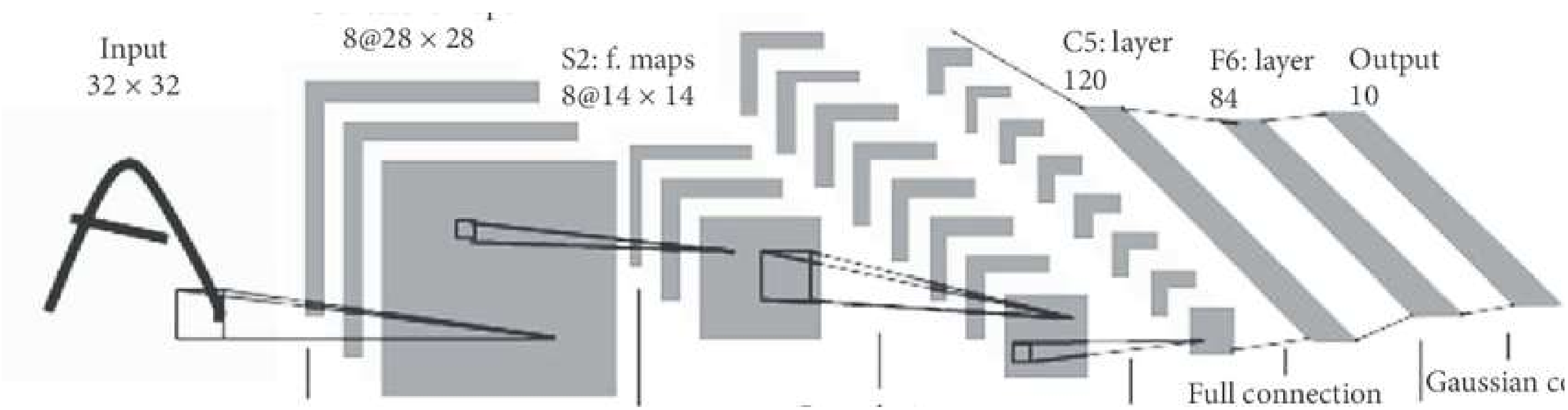
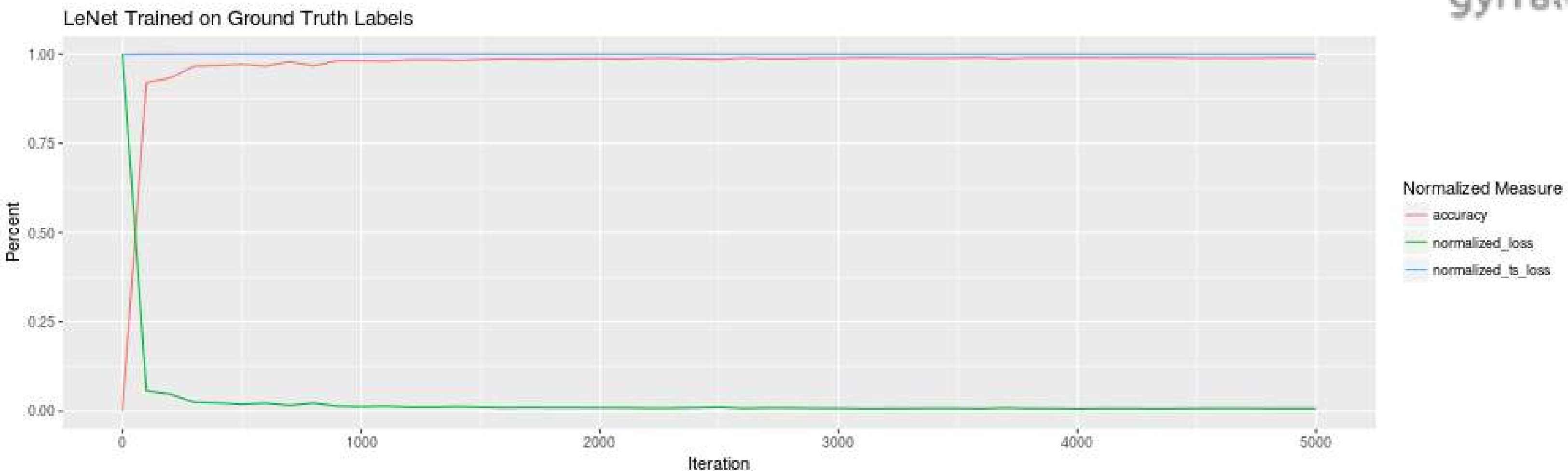
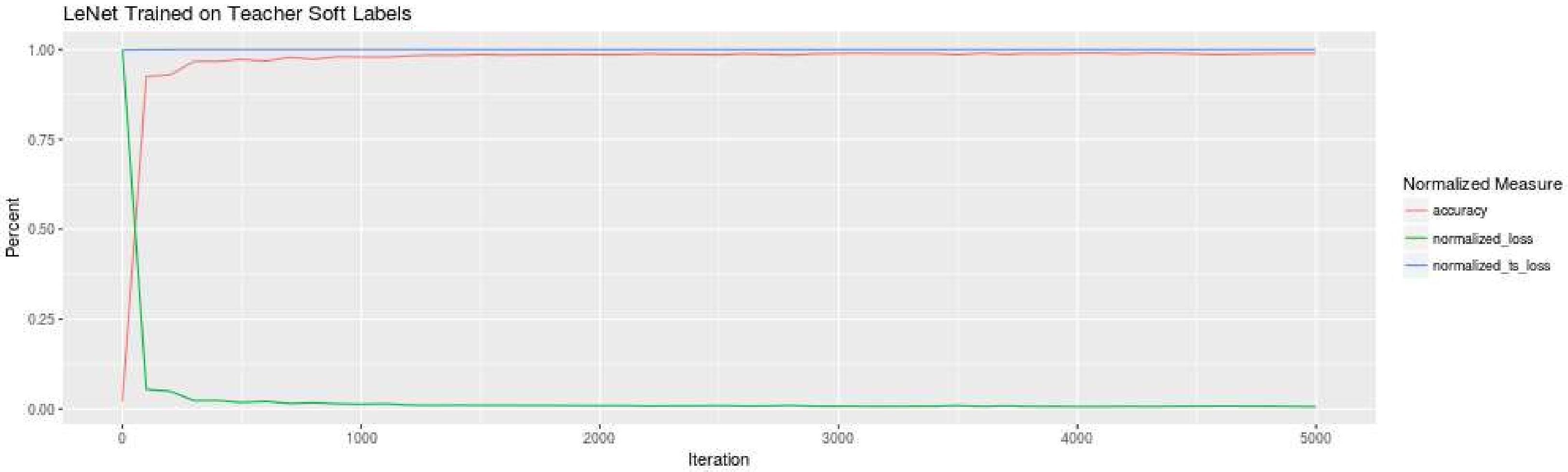


Image source: https://www.researchgate.net/figure/303857877_fig1_Figure-1-Architecture-of-CNN-by-LeCun-et-al-LeNet-5

No obvious differences between training regimes


LeNet Trained on Ground Truth Labels


LeNet Trained on Teacher Soft Labels

Soft labels slow training on MNIST!

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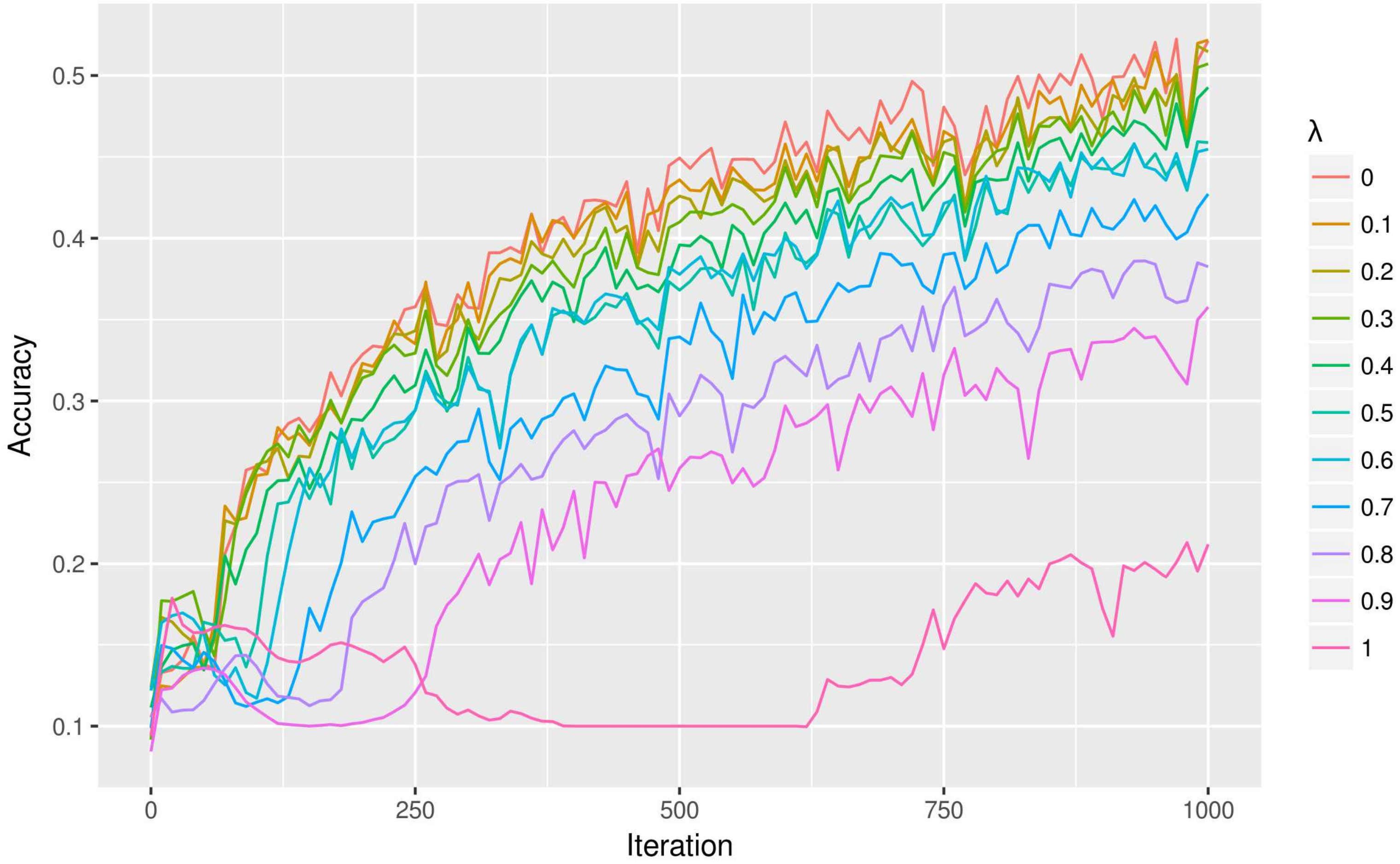

Combination Training works on CIFAR10 as well

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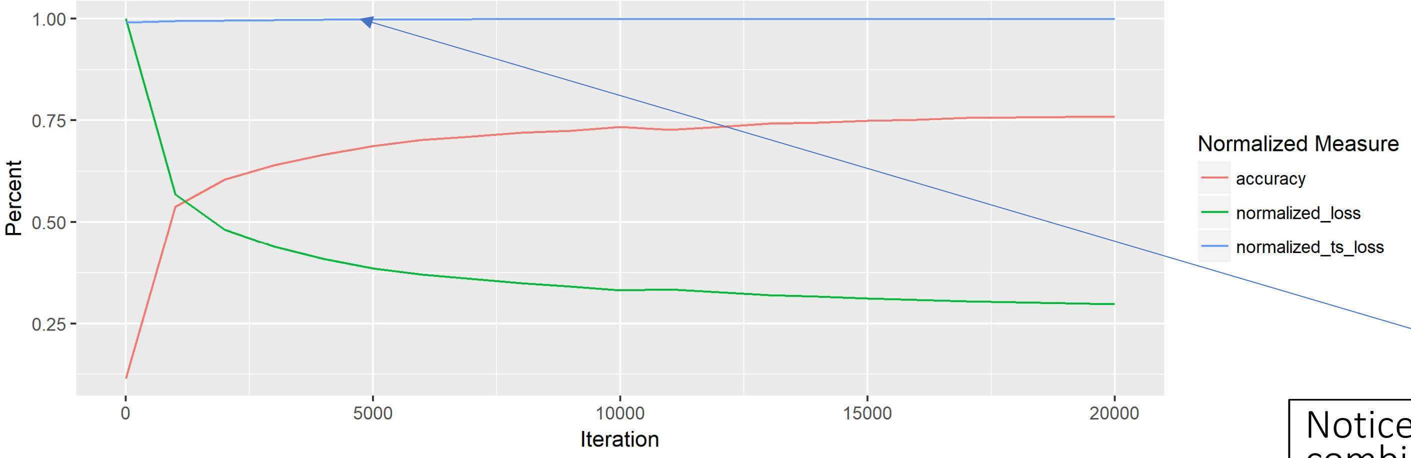
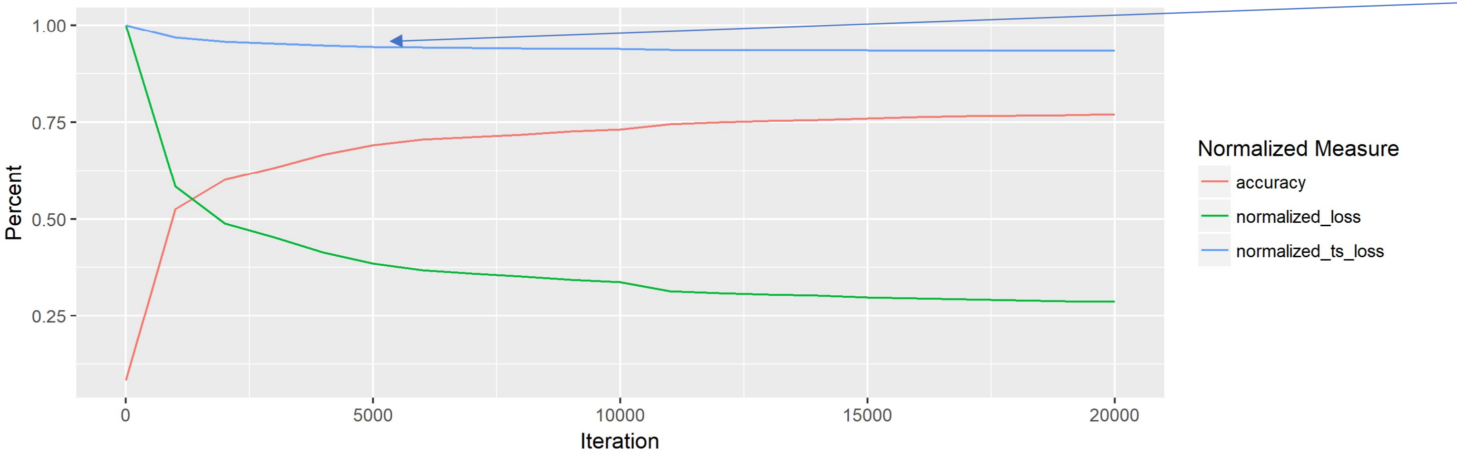
Cifar10 Trained on Ground Truth Labels

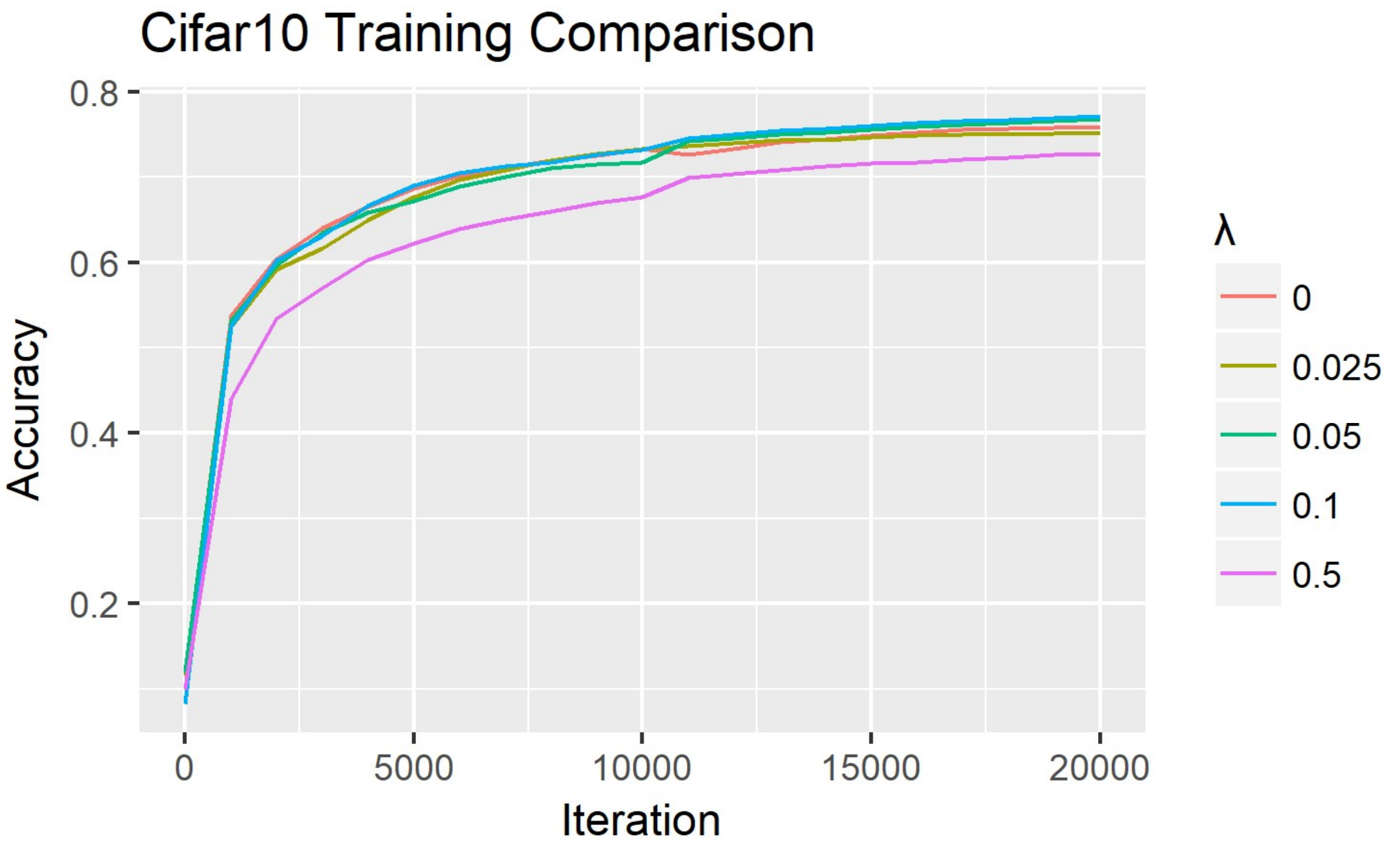


Notice small drop in TS cross-entropy in combination training

Cifar10 Teacher-Student Training with Lambda 0.1



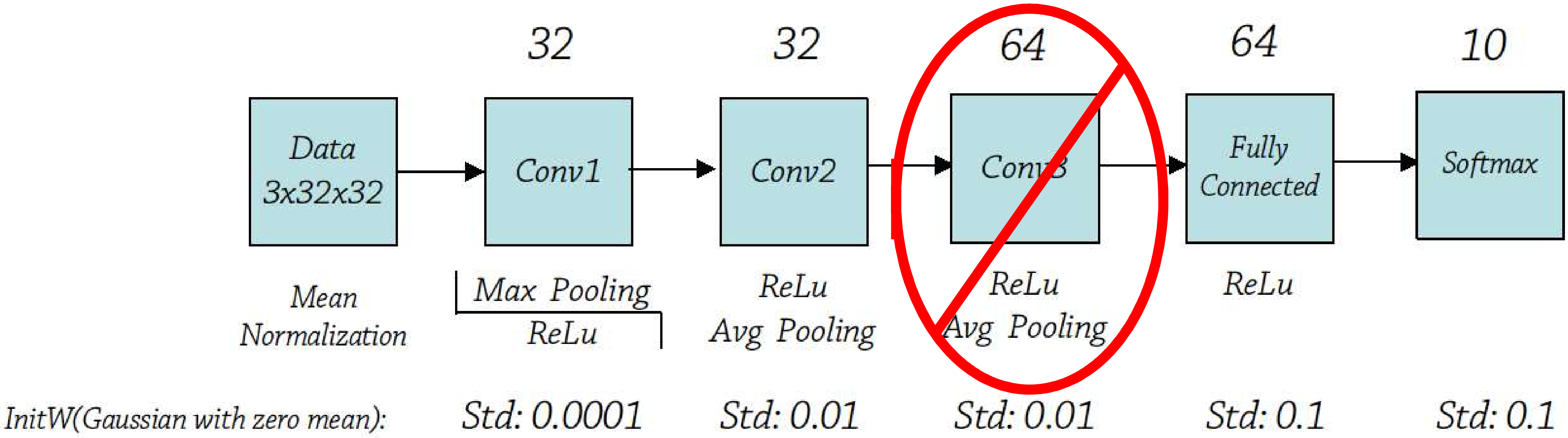
In fact, low-weighted soft labels are faster for early epochs



Position
3
4
1
2
5

What about a smaller student model?

Cifar-10 Fast Model(5 epochs with 25% Validation Error Rate)



Notes: All Convs Padding:2 Kernel:5 / All Poolings Overlapping(Kernel:3 Stride:2)

Image source: http://www.cnblogs.com/yymn/p/4589133.html

Training is faster for early epochs, but plateaus earlier

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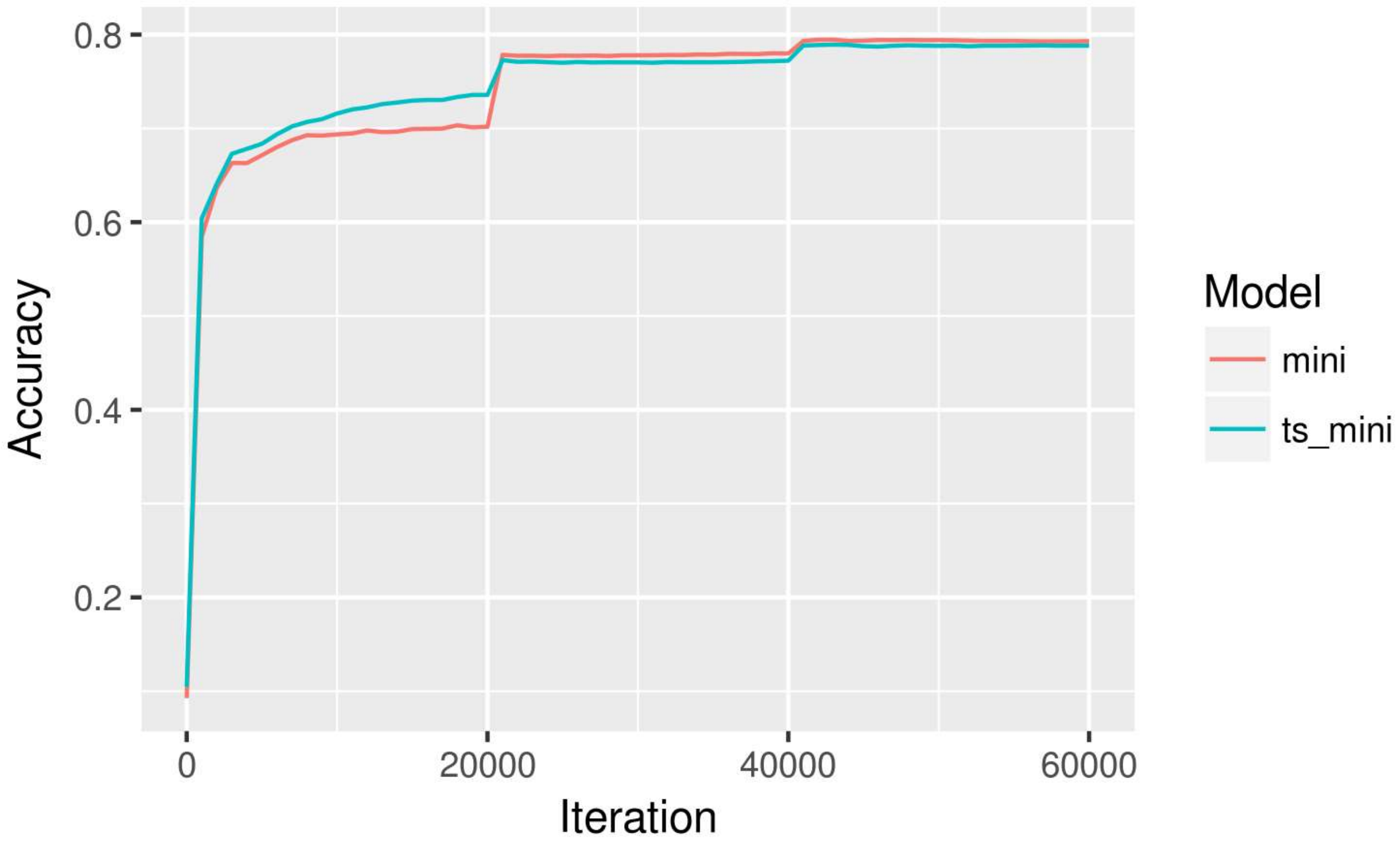

Conclusions

- Teacher-Student training IS possible, but performance is not great
- Soft labels appear to be best used as a supplement to hard labels during the middle of the training phase, while net is figuring out medium-level features
- Dark knowledge speed up training, but noisy labels means the student model plateaus earlier than when training on hard labels
- Student model is unable to make close approximation of teacher decision surface
  - Student-teacher cross-entropy remains large despite classification accuracies being about the same
  - Student and teacher models do not learn features the same way!

Looking forward

- Bigger datasets; ImageNet
  - Two of three months of the internship was spent trying and failing to make VGG16 model converge.
  - Teacher-Student training question remains unresolved for big datasets, where its potential is largest
- Best temperature for teacher soft labels?
  - A lower temperature raises the top1 probability of soft label towards 1 and decreases other class label probabilities towards 0
    - Makes teacher soft label more like hard label
  - A higher temperature makes all class probabilities closer to each other
    - Teacher models with low top1 accuracy but high top5 accuracy will be more informative
- Better loss function?
  - Cross-entropy is combination of entropy and KL-divergence
  - Entropy between student and teacher soft-labels may be extraneous
  - Paper-recommended loss function uses only KL-divergence for TS training

Questions?