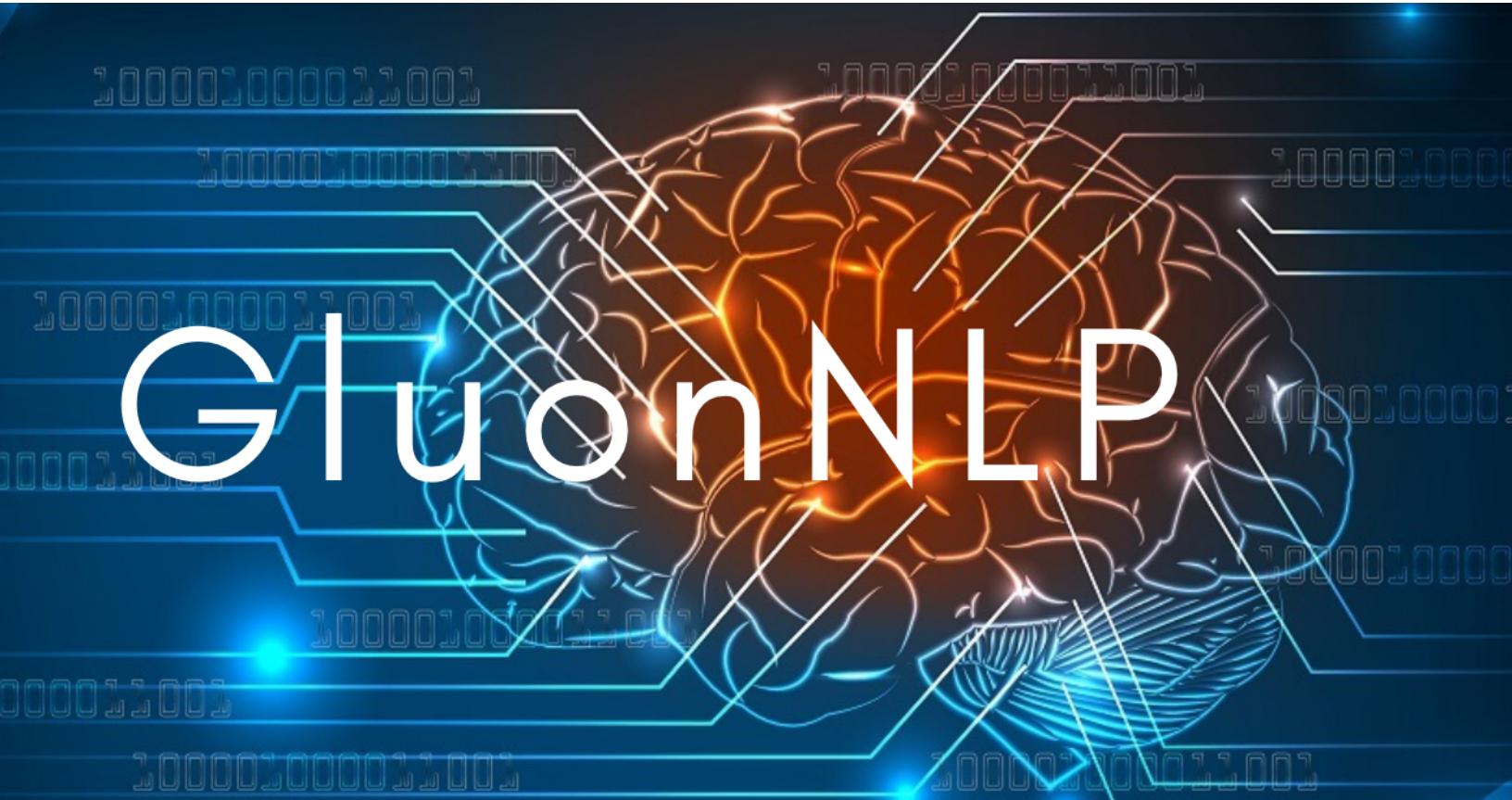


CS 410 Final Project

Gluon NLP with MXNet on AWS Sagemaker

Training for Yelp Sentiment Analysis



Text Information Systems

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Yelp Sentiment Analysis

Motivation

State-of-the-art deep learning models in natural language processing (NLP) are fascinating to read about and try to understand for a graduate-level computer science student. It is also possible for a hobbyist or student to obtain pre-trained models from these research breakthroughs and perform inference using the meager hardware at their disposal while working and studying from home (i.e. no access to lab clusters at an institution).

Perhaps a deeper and more satisfying approach for investigating this multi-layered architecture with broad areas of application is to train a dataset by ones self, much like raising your own puppy. However, time and compute resources can be an intimidating constraint in these compute-intensive algorithms.

For this project, I aimed to find a relatively cutting edge approach in NLP where the training can be replicated by a hobbyist developer. The Gluon Project aims to meet this need. According to this blog post:

- ✗ Symptom: Natural language processing papers are difficult to reproduce. The quality of open source implementations available on Github varies a lot, and maintainers can stop supporting the projects.
- ✓ GluonNLP prescription: Reproduction of latest research results. Frequent updates of the reproduction code, which comes with training scripts, hyper-parameters, runtime logs etc.¹

A broad description from the [GluonNLP website](#) is as follows:

¹ <https://medium.com/apache-mxnet/gluonnlp-deep-learning-toolkit-for-natural-language-processing-98e684131c8a>

GluonNLP provides implementations of the state-of-the-art (SOTA) deep learning models in NLP, and build blocks for text data pipelines and models. It is designed for engineers, researchers, and students to fast prototype research ideas and products based on these models.²

From their model zoo, we selected the Text Classification example, which trains the FastText classification model on the Yelp review dataset. This is a binary classification dataset (positive vs. negative sentiment), and we aim to replicate their validation accuracy score of 94% in a reasonable time frame and cost.

For optimum training times, we turned to NVIDIA Tesla V100 GPUs available on Amazon Web Services (or AWS) Sagemaker instances. These are available on-demand and can be powered up just for training times to keep costs at a minimum. We investigate adapting the FastText scripts provided by the Gluon project to the AWS environment, such as loading required Jupyter kernels and dependent libraries for this algorithm, reading and writing data from S3 buckets, and of course keeping compute regions and permissions (or roles) in good order.



² <https://nlp.gluon.ai/#about-gluonnlp>

Fast-text Word N-gram

This model is a slight variation of the one published by the Facebook AI Research team in 2016 in a paper called “Bag of tricks for efficient text classification” by Armand Joulin, Edouard Grave, Piotr Bojanowski, and Tomas Mikolov. The aim of this approach, which they call fastText or a “library for efficient text classification and representation learning,” is also to increase training speed over the dominant deep learning algorithms of the day. The abstract states:

Our experiments show that our fast text classifier fastText is often on par with deep learning classifiers in terms of accuracy, and many orders of magnitude faster for training and evaluation. We can train fastText on more than one billion words in less than ten minutes using a standard multicore CPU, and classify half a million sentences among $\sim 312K$ classes in less than a minute.³

The Gluon-provided code used in this project, found at text_classification/fasttext_word_ngram.py in the repo, does not reference any code from the fastText project. It uses only gluonnlp and mxnet python libraries, so it appears to be a complete rewrite of the approach. It is modified here to meet the requirements of running on AWS infrastructure, which we cover in the next section, and becomes text_classification/fasttext_word_ngram_aws.py in the Github repo.

Apache MXNet is an open-source deep learning framework that is well supported on AWS and is rivaled by TensorFlow and PyTorch in popularity and performance on NLP. The advantage of MXNet (short for mix net) is the broad language support of Python, R, C++, Julia, and Scala. It also scales well:

“Another advantage is that the models built using MXNet are portable such that they can fit in small amounts of memory. So, once your model is trained and tested, it can be easily deployed to mobile devices or connected systems. MXNets are scalable to be

³ <https://arxiv.org/abs/1607.01759>

used on multiple machines and GPU simultaneously. This is why Amazon has chosen this framework for its deep learning web services.”⁴

In this code, the Gluon authors create two classes:

- a MeanPoolingLayer — a block for mean pooling of encoder features — which takes a gluon.HybridBlock as a parameter.
- a FastTextClassificationModel—the trained embeddings layer—which takes a HybridBlock as a parameter.

The rest of the logic centers around argument parsing to the main function, the creation of n-grams (defaults to 1 and recommended ≤ 2 for large datasets), data loading, preprocessing, labeling, and evaluating accuracy of the training against a test dataset.

Scripts to fetch the the training and test datasets from Google Drive are hosted at [fastText’s Github repo](#)⁵, but these proved problematic given the response time of the downloads. I manually fetched the Yelp Review Polarity set only, then modified the code to normalize the text. This modified bash script is at `text_classification/data_fetch.sh` in the project repo, and the CSV files are placed in the `data/` subdirectory.

Once this was prepared, we can start running the python script locally with the recommended parameters as follows:

```
python fasttext_word_ngram.py --input data/yelp_review_polarity.train \
                            --output data/yelp_review_polarity.gluon \
                            --validation data/yelp_review_polarity.test \
                            --ngrams 1 --epochs 10 --lr 0.1 --emsize 100
```

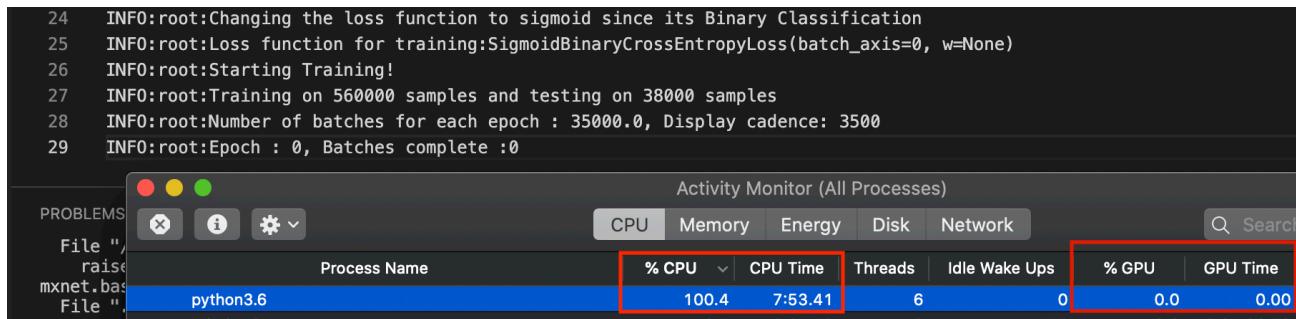
This set of parameters is notably missing the ‘—gpu=0’ flag for the local run only. This is because my laptop, a 2019 MacBook Pro with a 6-Core Intel i7 CPU, has a AMD Radeon Pro 5300M graphics card that does not implement CUDA architecture. This job will run on the CPU instead, and while threading does not appear to be implemented, according to MXNet documentation:

⁴ <https://analyticsindiamag.com/mxnet-tutorial-complete-guide-with-hands-on-implementation-of-deep-learning-framework/>

⁵ <https://github.com/facebookresearch/fastText/blob/master/classification-example.sh>

“For a CPU, MXNet will allocate data on main memory, and try to use all CPU cores as possible, even if there is more than one CPU socket.”⁶

The Activity Monitor on the laptop shows the CPU being pegged at 100% and no use of the GPU:



A screenshot of the macOS Activity Monitor application. The window title is "Activity Monitor (All Processes)". The tab bar has "CPU" selected, followed by Memory, Energy, Disk, and Network. A search bar is on the right. Below the tabs is a table with columns: Process Name, % CPU, CPU Time, Threads, Idle Wake Ups, % GPU, and GPU Time. The first row shows system logs. The second row, for "python3.6", has its "% CPU" and "CPU Time" columns highlighted with a red box. The "python3.6" row also has a blue highlight underneath it.

Process Name	% CPU	CPU Time	Threads	Idle Wake Ups	% GPU	GPU Time
python3.6	100.4	7:53.41	6	0	0.0	0.00

With 35000 batches configured to run on 464402 vocabulary words and 560000 sentences, the first attempt never even completed a single epoch. I quit the job after 8 hours of processing time and only 17000 batches completed. So now we move this workload to the GPUs hosted on the cloud!

AWS Sagemaker and NVIDIA Tesla V100 GPUs

I implement this training job using high-end P3 AWS Sagemaker instances.⁷ According to the table of instance sizes listed at the bottom of the above linked page, the cheapest instance offered - p3.2xlarge - provides one Tesla V100 GPU with 16GB of GPU memory for \$3.07/hr on demand. A helpful reference were these published benchmarks of NVIDIA GPUs provided in TensorFLOPs, which are units of floating-point arithmetic performance aimed at NVIDIA GPU hardware called Tensor Cores:

“A new, specialized Tensor Core unit was introduced with “Volta” generation GPUs. It combines a multiply of two FP16 units (into a full precision product) with a FP32 accumulate operation—the exact operations used in Deep Learning Training

⁶ https://mxnet.apache.org/versions/1.7.0/api/python/docs/tutorials/getting-started/crash-course/6-use_gpus.html

⁷ <https://aws.amazon.com/ec2/instance-types/p3/>

computation. NVIDIA is now measuring GPUs with Tensor Cores by a new deep learning performance metric: a new unit called TensorTFLOPS.”⁸

According to that metric, the Tesla V100 GPU rates around 112-125 TensorTFLOPS (exact figure depending on the use of PCI-Express or SXM2 SKU interfaces). For comparison, the maximum known deep learning performance at any precision of the Tesla K80 is 5.6 TFLOPS for FP32. This GPU is provided on the P2 Sagemaker instances, and for 1 GPU on the p2.xlarge instance size, the cost is \$0.90/hr. If we can attain a 20x performance increase on our training job for approx. 4x compute resource cost, that seems like a great win! The clock time used by the p3.2xlarge instance and costs incurred for several training runs is discussed in the Results sub-section below.

Data Workflow

The first step on AWS Services is to select a region for all our work, in this case US East (Ohio) or **us-east-2**. This is important for several reasons: one, the data transferred between Amazon S3 buckets and Amazon EC2 instances in the same Region and account is relatively straightforward and free, and our training data sizes are significant (where I live in a remote area, it took 30 minutes to upload due to low bandwidth). Two, the cost of the P3 instances (also significant) are determined by region, and we want to accurately estimate our costs for this workload to avoid a surprise bill. Furthermore, I had to request access to these highly specialized machines on my account via a support ticket, and their staff response time was not immediate. On the first attempt, they enabled a different region than I had uploaded the training data, so I had to sync it across to another S3 bucket, now called **sagemaker-cs410-finalproj** and pictured here:

Sagemaker has an S3 Uploader library available for outputting the model parameters (a local file save is first required first) and returning the training results —**net.params**— to the S3 bucket under a **yelp_sentiment_polarity.gluon** directory, as pictured above. These parameters will be needed for later inference use cases outside this JupyterNotebook instance, so they must be offloaded for access.

⁸ <https://www.microway.com/knowledge-center-articles/comparison-of-nvidia-geforce-gpus-and-nvidia-tesla-gpus/>

Bucket overview

Region	Amazon resource name (ARN)	Creation date	Access
US East (Ohio) us-east-2	arn:aws:s3:::sagemaker-cs410-finalproj	December 11, 2020, 15:23 (UTC-08:00)	Bucket and objects not public

Objects (4)

Drag and drop files and folders you want to upload here, or choose Upload.

<input type="checkbox"/>	Name	Type	Last modified	Size	Storage class
<input type="checkbox"/>	test/	Folder	-	-	-
<input type="checkbox"/>	yelp_review_polarity.gluon/	Folder	-	-	-
<input type="checkbox"/>	yelp_review_polarity.test	test	December 11, 2020, 22:28 (UTC-08:00)	27.5 MB	Standard
<input type="checkbox"/>	yelp_review_polarity.train	train	December 11, 2020, 22:28 (UTC-08:00)	406.6 MB	Standard

```
def save_model(net, output_file):
    file_name = "net.params" # local version
    net.save_parameters(file_name)
    S3Uploader.upload(file_name, output_file)
```

Since we established this bucket in the same region, the S3 Uploader utility only requires the bucket name to perform this work. That variable was configured in the first JupyterNotebook cell, with:

```
bucket = 'sagemaker-cs410-finalproj'
```

Although you can also use a default bucket for the session, which is initialized like this:

```
bucket = Session().default_bucket()
```

For streaming lines from the data in S3 to the data parsing method, we used a library called **smart_open**⁹ which simulates reading in data from a local file in an iterable function such as a for-in loop, like:

```
for line in open(filename):
    tokens = line.split(',', 1)
    labels.append(tokens[0].strip())
    data.append(tokens[1].strip())
return labels, data
```

This proved very effective and the data was parsed quickly into labels and normalized text data for the training run.

⁹ <https://pypi.org/project/smarter-open/>

Training Results

The one Tesla V100 GPU performing text classification on our p3.2xlarge instance exceeded expectations and churned out training and test results for 10 Epochs in under 20 mins. Furthermore, the same accuracy of 94% was achieved as mentioned on the Gluon page where we sourced this code. SGD performed slightly better than Adam as an optimizer, and this is discussed in the **Further Work** section below.

Jupyter notebook run 1 with `adam` as optimizer, 10 Epochs

- Highest Test Accuracy: 0.9401578947368421 (Epoch 8)
 - Final Test Accuracy: 0.939921052631579, Test Loss: 0.17803387705344548 (Epoch 10)

Jupyter notebook run 2 with `sgd` as optimizer, 10 Epochs

- Highest Test Accuracy: 0.9403157894736842 (Epoch 8)
 - Final Test Accuracy: 0.9400526315789474, Test Loss: 0.17815197125596924 (Epoch 10)

Jupyter notebook run 3 with `sgd` as optimizer, 25 Epochs

- Highest Test Accuracy: 0.9403157894736842 (Epoch 8)
 - Final Test Accuracy: 0.9397105263157894, Test Loss: 0.17758843273002864 (Epoch 25)
 - Note, the accuracy above was reached at Epoch 18 and remained stable.

The screenshot shows a JupyterLab interface running on an AWS Sagemaker ml.p3.xlarge instance. The left pane displays the code for `fasttext_word_ngram.py`, which performs text classification using FastText. The right pane shows the execution environment and the output of the script's execution.

Code:

```
fasttext_word_ngram.py --CodeProject
text_classification
    layer is applied on top of it.
    ...
def __init__(self, vocab_size, embedding_dim, num_classes, **kwargs):
    super(FastTextClassificationModel, self).__init__(**kwargs)
    with self.name_scope():
        self.vocab_size = vocab_size
        self.embedding_dim = embedding_dim
        self.embedding = nn.Embedding(
            self.vocab_size,
            self.embedding_dim,
            weight_initializer=mx.init.Xavier(),
            name='embedding')
        num_output_units = num_classes
        if num_classes == 2:
            num_output_units = 1
        logging.info('Number of output units in the last layer :%s',
                    num_output_units)
        self.agg_layer = MeanPoolingLayer()

```

Execution Environment: AWS Sagemaker ml.p3.xlarge instance

Output Log:

```
JupyterLab x + tebook.us-east-1.sagemaker.aws/lab Settings Help
fasttext_word_ngram.py x
z3be0w0Trz24cc0eeT
Successfully built smart-open
Installing collected packages: smart-open
Successfully installed smart-open-4.0.1
WARNING: You are using pip version 20.0.2; however, version 20.3.1 is available.
You should consider upgrading via the '/home/ec2-user/anaconda3/envs/mxnet_p36/bin/python -m pip
install --upgrade pip' command.

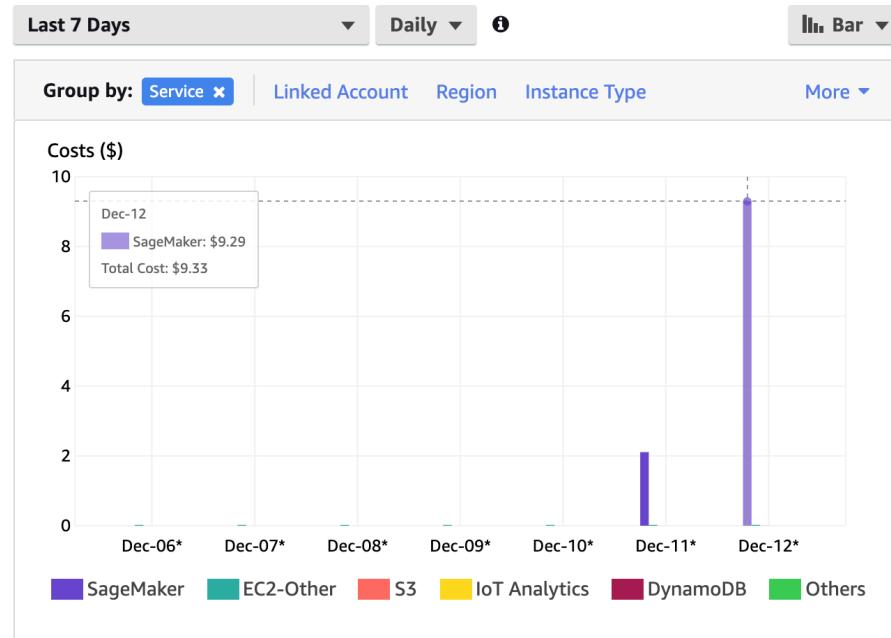
+1: ! python fasttext_word_ngram.py --input $train_data_location \
--output $output_data_location \
--validation $test_data_location \
--ngrams 1 --epoch 10 --lr 0.1 --emsize 100 --gpu=0

INFO:root:Ngrams range for the training run : 1
INFO:root:Loading training data
INFO:root:Opening file s3://sagemaker-gluon-data/yelp_review_polarity.train for reading input
INFO:root:Loading Test data
INFO:root:Opening file s3://sagemaker-gluon-data/yelp_review_polarity.test for reading input
INFO:root:Vocabulary size: 464402
INFO:root:Converting data converting to sequences...
INFO:root:Done! Sequence conversion Time=45.24s, #Sentences=560000
INFO:root:Done! Sentence conversion Time=45.24s, #Sentences=560000
INFO:root:Done! Sequence conversion Time=8.00s, #Sentences=38000
INFO:root:Encoding labels
INFO:root:Label mapping:{'_label_1': 0, '_label_2': 1}
INFO:root:Done! Preprocessing Time=18.16s, #Sentences=560000
INFO:root:Done! Preprocessing Time=1.00s, #Sentences=38000
INFO:root:Number of Labels: 2
INFO:root:Initializing network
INFO:root:Running on GPU:0
INFO:root:Embedding Matrix length:464402
INFO:root:Number of output units in the last layer :1
INFO:root:Network initialized
INFO:root:Changing the loss function to sigmoid since its Binary Classification
INFO:root:Loss Function for training: SigmoidBinaryCrossEntropyLoss(batch_axis=0, w=None)
INFO:root:Starting Training!
INFO:root:Training on 560000 samples and testing on 38000 samples
INFO:root:Epoch : 0, Batches complete :0
INFO:root:Epoch : 0, Batches complete :3500
INFO:root:Epoch : 0, Batches complete :7000
INFO:root:Epoch : 0, Batches complete :10500
INFO:root:Epoch : 0, Batches complete :14000
INFO:root:Epoch : 0, Batches complete :17500
INFO:root:Epoch : 0, Batches complete :21000
INFO:root:Epoch complete :0, Computing Accuracy
```

AWS Sagemaker
ml.p3.xlarge instance
1 Epoch = 2 mins!

To reiterate, my MacBook Pro CPU (`ctx=cpu(0)`) never completed a single epoch after 8 hours of run time, and the V100 GPU (`ctx=gpu(0)`) finished one epoch in less than 2 minutes! The entire job run of 10 epochs required only 17 minutes total, which is very satisfying.

The costs incurred for several hours of experimenting with the AWS SageMaker JupyterNotebook environment, plus the three training runs above (and a few failed ones when parameter output to file was not configured correctly) remained under \$10. So we were able to capture reliable and conclusive training work at the expected cost of around \$3/hr! The Cost Explorer returns this data analysis by service typically the next day.



Importantly, I shut off my P3 EC2 instance whenever I was not using it, and I deleted other experimental instances, such as P2, when I moved onto another solution. Not performing this cleanup task is a painful way to discover an exorbitant bill from AWS at the end of the month!

Further Work

- 1) The Gluon team notes that they simplified the model somewhat for training speed as follows:

“We have added dropout to the final layer, and the optimizer is changed from ‘sgd’ to ‘adam’ These are made for demo purposes and we can get very good numbers with

original settings too, but a complete async sgd with batch size = 1, might be very slow for training using a GPU.”¹⁰

I was able to pass ‘sgd’ (or Stochastic Gradient Descent) as an optimizer parameter and get slightly better testing accuracy over ‘adam’ (0.94032 vs. .94016) with no noticeable decrease in training speed. I did not remove the dropout nor change the batch size, so these could be restored to the original fastText algorithm for more benchmarking on this particular GPU instance.

2) Rather than firing up JupyterLab in our P3 instance and copy/pasting in the custom algorithm for our training job, Amazon SageMaker can interact with a Docker container based on a pre-built image. This would be a better practice for continued use of this approach, since it can easily be deployed into different regions and scaled up or down on different EC2 instances for more or less GPU power.¹¹

This workflow is covered in more detail here, which was also an early inspiration for this project (although they use GluonCV):

Deploying custom models built with Gluon and Apache MXNet on Amazon SageMaker

“When you build models with the Apache MXNet deep learning framework, you can take advantage of the expansive model zoo provided by GluonCV to quickly train state-of-the-art computer vision algorithms for image and video processing. A typical development environment for training consists of a Jupyter notebook hosted on a compute instance configured by the operating data scientist. To make sure this environment is replicated during use in production, the environment is wrapped inside a Docker container, which is launched and scaled according to the expected load.”¹²

I felt great enjoyment in this project and learned a lot about NLP using AWS Sagemaker GPUs, and look forward to experimenting more with Gluon/MXNet.

¹⁰ https://nlp.gluon.ai/model_zoo/text_classification/index.html

¹¹ <https://docs.aws.amazon.com/sagemaker/latest/dg/your-algorithms-training-algo.html>

¹² <https://aws.amazon.com/blogs/machine-learning/deploying-custom-models-built-with-gluon-and-apache-mxnet-on-amazon-sagemaker/>