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line 3: *name of organization (of Affiliation)*line 4: City, Country  
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# Introduction

# System design & implementation details

The Kaggle competition description suggested that the optimal solution would use Natural Language Processing (NLP) techniques. None of the authors of this paper had experience using these techniques before. To begin, we did a general survey of NLP libraries that we could use to implement a solution [1]. After some deeper exploration of the tools NLP has to offer, we settled on two main approaches: Named Entity Recognition (NER) and topic modeling.

## Named Entity Recognition (NER)

Named Entity Recognition is an information extraction technique in which key words or phrases pertaining to a particular pre-defined topic are identified within a body of text [2]. Common entities that are identified using this technique include people, organizations, times, locations, works of art, etc. The fundamental process itself is quite complex, but in summary it involves using “a deep neural network based on a Convolutional Neural Network (CNN) with a few tweaks” [3]. Readers interested in the detailed neural architecture underlying NER are requested to refer to [4]. The key to any successful NER model is a large, labeled set of training data so that the statistical underpinnings of the model can learn to identify the locations of entities within text. We were delighted to find out about this technique as it seemed particularly suited to the task at hand, namely, to identify the dataset label within a large research paper.

Traditional NER models use predefined entities that are already trained on an available corpus of texts. For this project, we required a way to define a custom entity peculiar to the task at hand. Thankfully, there are certain NER implementations that allow for such custom entity creation. One such library that offers this is the Python library SpaCy [5].

We chose the SpaCy library to implement NER on our data for custom dataset labels. The technology involved in terms of programming was surprisingly simple. We were asked to define a blank SpaCy model and then add an ‘ner’ pipe to the model. The main parameters we had to decide when training the model were a) the batch size for each iteration and b) the number of iterations to train the model and re-calculate losses. After each iteration, losses were calculated based on the difference between the predicted dataset labels and the actual dataset labels in the texts provided.

## Workflow

The workflow we followed for training our SpaCy model is shown in Fig 1. We first took the data from Kaggle and Diagram

Description automatically generatedFig 1. *Workflow Diagram for the SpaCy NER model*

preprocessed it appropriately (more details in the next section). Then, we fed a portion of the preprocessed data to our SpaCy NER model to train on. The other portion of the data was held aside for evaluation purposes. After training the SpaCy NER model on part of the entire dataset, we performed extensive internal evaluation to determine how well our model performed on unseen data. We then adjusted the model as necessary and retrained until we were satisfied with our model’s performance. Finally, we trained a SpaCy NER model on the entire training data available, made predictions on the test data, and submitted the results to Kaggle for evaluation.

Upon reaching the end of this workflow and submitting the results to Kaggle, we realized that Kaggle did not accept a csv file for submission. Rather, they required a notebook. We realized during training that this workflow was a lengthy process; therefore, we uploaded our trained model to Kaggle and created a notebook with the script we used to make entity predictions for test set papers.

# experiments & internal evaluation

## Dataset

The data used for this project was provided by the Kaggle competition. The training dataset consisted of over 14,000 publicly available scientific publications in JSON format. In addition to the papers, there was a csv file containing over 19,000 rows. Each row contained an ID corresponding to the JSON filename of a paper, the name of the paper, and the name of the dataset embedded within the paper (this is what we were trying to train our model to predict). The mismatch of ~19,000 rows in the csv file and only ~14,000 papers provided can be explained by the fact that some papers had multiple datasets within them. As such, these papers were split into multiple rows in the csv file, each corresponding to a single dataset mentioned within a particular paper.

The scientific publications were provided as JSON objects containing a particular paper divided into sections. Each section consisted of a title and the text in that section.

Kaggle provided us with data that contained no missing pieces. Indeed, dealing with raw data was not the challenge in this project.

The test data provided by Kaggle included four additional publications in JSON format, without dataset labels. There was an additional 8,000 publications in a hidden test set not available to competitors, 12% of which was used to determine the public leaderboard.

## SpaCy NER

#### Preprocessing: To be able to train a SpaCy NER model to locate a dataset label within a full text publication, we first had to preprocess the data to convert it to a format compatible with the SpaCy framework. The format required was an array of tuples [6]. Each tuple would have to contain a) a string of text and b) an “entities” dictionary containing the starting and ending index locations of the dataset labels (i.e. entities) within that that string. If a particular entity was located multiple times within the string, all locations would have to be provided in the “entities” dictionary for that particular string.

In terms of preprocessing, our initial approach was to feed our model all of the publication text available. We did not want to perform common NLP preprocessing techniques such as stopword removal or lemmatization because we thought that all this additional textual “noise” included in the scientific papers in our training set would also be present in the real-world test examples that our model would eventually have to face. Ignoring the “noise” and simultaneously extracting a very minute yet key phrase from a large body of text was the ultimate goal of our model. Thus, we felt that any cleaning of the text would defeat our purpose.

However, some preprocessing was required to convert the full publications into a the SpaCy-friendly format described above. To do this, a script was written to combine each publication into an exceedingly long, single string, and then to use a string search algorithm to find the location(s) of the dataset label within that publication. One can realize just how long these single strings for each publication were by imagining this entire paper to be one long string! Additionally, imagine finding the exact start and stop locations of the word “Kaggle” within this text! As one can see, this was a lengthy process, especially because we were running through this process for ~19,000 papers. Due to the length of this process, we decided to save our SpaCy-friendly preprocessed data to a text file to be read in for future use. That text file turned out to be over 1 GB size and contain over one billion characters!

After preprocessing the data in this way, we split the data into a training set (70%) and an evaluation/test set (30%) to get an idea of how our model performed on unseen data. We performed this split randomly. We decided not to implement cross-validation or multiple subsampling because the SpaCy NER model has a notoriously slow training time [7], even when we trained on computationally-rich systems. Furthermore, the holdout set method we were using is typically employed when the dataset is large [7].

We then proceeded to train the SpaCy NER model on this data. Keep in mind that we were using data in which each tuple contained a single string which contained an entire research paper. We ran into issues training the model on this shape of the data. The RAM being used was over what we had available and our program repeatedly crashed. Even after significantly increasing our RAM available, we still faced the same issue.

After struggling with this for some time, we decided to try an alternative strategy of preprocessing the data. Instead of fitting an entire publication into one string, we decided to break up each publication into a series of sentences. We created a dataset of tuples containing a sentence-long string and the dataset entities (if any) contained within that string. When we passed this reformatted data to the training phase of the SpaCy model, we found that our training was taking much more time than we had available. We realized we needed to further trim the data we were feeding to our model.

We decided that instead of including every sentence in each publication along with the entities in that sentence, we would include only three sentences from each publication. Two sentences would be ones containing no entities, and one would contain the dataset entity found in that paper. We decided to keep this ratio to more accurately reflect the actual ratio of sentences containing dataset labels and sentences not containing them, while at the same time limiting our data to a reasonable size so our model would be able to train in a reasonable amount of time. However, the ratio of two sentences without entities to one sentence with entities was far more biased towards finding sentences with entities than a real-world distribution would be. Nonetheless, we stuck with this ratio.

Upon splitting our publications into sentences and then passing it to our SpaCy NER model, we were encountering an error due to there being empty strings in the training data. Thus, we wrote a script to remove all blank strings from the training data.

After completing these preprocessing steps, we passed our SpaCy-friendly data to our model. We ran ten iterations with each iteration processing batches of 500 tuples at a time. Each iteration consisted of 67 such sized batches. The entire time required to run ten iterations on this data was approximately three hours. Due to this length of time required, we found a way to save our trained model locally so that we would not have to re-run this process every time.

## Analysis of Results

### SpaCy NER: A major limitation in the SpaCy NER training phase was the time it took to train the model. We had to adjust many preprocessing steps and limit the number of epochs to account for this factor. However, as we can see from the graph of model losses over training epochs that even with a limited epoch size of 10, we were able to achieve some type of convergence for the losses at a value of around 1,000. SpaCy does not explicity define the loss function it uses for NER [8], however they mention that a relatively high loss value does not necessarily indicate a poorly trained model due to the way in which they calculate the loss [9]. They suggest using other metrics such as an F-score to more accurately determine the performance of the model.

Our partially trained model achieved an average of 30 true positives (TP), 5 false positives (FP), and 16 false negatives (FN) when making entity predictions on 60 unseen papers. This indicates that about half of the entity predictions our model makes are correct. We feel we could improve this aspect of our model’s performance if we are able to access more computational power to be able to train on more sentences from each paper.

From these confusion matrix values, it follows that our partially trained model achieved a precision score of 0.840, a recall score of 0.655, and a F-score of 0.736. The high precision score indicates that our model does not often make erroneous predictions. When it predicts a dataset label to be present, it is usually present [10]. The lower recall value indicates that the major weakness of our model is that it sometimes misses dataset labels that actually exist in the papers analyzed. These values indicate that our model will predict dataset labels that most likely exist but might miss some that are there.

Based on the current Kaggle competition public leaderboard standings, our F-score of 0.736 would place us in the top 10. In reality, when we trained our model fully and submitted predictions on 12% of the hidden test data, we achieved an F-score of 0.399 on the public leaderboard. We are not sure what caused this huge difference between our internal evaluation results and the public leaderboard results. Public leaderboard results can often be misleading, so we will wait to see the score we receive on the private leaderboard and see if it tallies more with what we achieved in internal evaluation.

# Discussion and conclusions

## Decisions Made/Things That Worked

### SpaCy NER:The first major decision we had to make regarding NER is which library to use. There are a few NLP libraries capable of performing NER such as NLTK and Stanford NER. We ended up settling on SpaCy because it allowed us to define a custom entity to be extracted by the model, which is exactly what we needed in this project.

A major challenge we faced in training our SpaCy model was determining how to feed each publication into the model. After some trial and error with individual string sizes that were fed into the model, we finally settled on extracting exactly three sentences from each paper: two without a dataset entity and one containing such an entity. In retrospect, we believe this process worked in our favor. SpaCy NER seems to work well when processing smaller rather than larger strings. Furthermore, due to the way we extracted sentences from each paper, our “placebo” sentences (sentences containing no dataset labels) ended up being chosen close in proximity to the dataset-containing sentences (usually the sentences before or after). This, we believe, made our model more robust because it was seeing sentences semantically similar but learning to recognize specific labels from some sentences and not others.

Another aspect of our pipeline that worked magnificently was the SpaCy NER model itself. We found the ability of the model to learn to find “a needle in a haystack” (the dataset label withing a sentence) truly remarkable. The power of deep learning and CNNs were manifested in the power and simplicity experienced when using this model. Furthermore, making predictions on the test data turned out to be a relatively trivial programming exercise due to the well-designed architecture of this library.

We also feel we picked the correct epoch size for model training. At 10 epochs, our loss seemed to converge to a much lower number than it was initially.

We were very happy with the precision score we received in internal evaluation, which suggests that when our model predicts, it generally predicts correctly. Even the recall score we achieved was not totally abysmal. Additionally, we were very pleased the F-score we achieved in our evaluation. This was our first foray into NLP, not to mention NER, for all of us. To achieve an internal evaluation F-score that would place in the top-10 on the Kaggle public leaderboard is something we found truly remarkable.

## Difficulties Faced/Things That Didn’t Work Well

### SpaCy NER: The main difficulties we faced were related to lack of computational power, both in terms of processing speed and memory available. The SpaCy NER model is a state-of-the-art deep learning process. As such, it is reasonable to expect it to require massive amounts of processing power to execute optimally.

The first stumbling block we faced occurred in the preprocessing phase. As mentioned in Section II, we were required to convert the raw publications from JSON format to a SpaCy-friendly format, which was an array of tuples. We initially converted each publication into one large string. This resulted in our training phase causing our RAM to exceed capacity and our program to crash. Ideally, we would like our model to look at entire papers and extract entities from that large chunk of text, because this is the main purpose of this competition. However, we had to settle to breaking up each publication into sentences.

We initially wanted to use all the sentences in each paper. This is because our model would get an accurate idea of how sparse a dataset label is within a large publication. When we attempted to feed all the sentences from each paper to our training phase, the process of training ended up being extremely slow. It was not at all practical to continue in this fashion. As such, we had to further settle by extracting only three sentences from each publication. As mentioned in Section II, this was a heavily optimistically biased ratio of dataset labels to non-dataset labels in the training text.

While the SpaCy NER model was extremely powerful in predicting entities in unseen text, it was quite a time-consuming process to train it. Other users of this library online have noted that this model is notoriously slow in its training phase [11]. This speed limitation prevented us from doing extensive hyperparameter tuning and cross-validation. Doing so might have significantly increased the performance of our model.

Another difficulty we faced is the time required to use our trained model to predict on unseen, but labeled, “test” data. We kept aside approximately 6,000 publications to evaluate our model internally. This was approximately 30% of the entire training data available to us. However, when making predictions, we were required to break up the test publications into sentences and make entity predictions for each sentence, since this was the type of data our model was trained on. As you may recall, we were forced to only extract three sentences from each paper in the training phase due to the exorbitant amount of time the SpaCy NER model took to train. When conducting internal evaluation, we did not have the same luxury because we wanted to see how our model performed on real-world data. As it turned out, our model took too long to predict entities for 6,000 papers broken into sentences. Indeed, just predicting entities for 60 papers (1% of the test data) took approximately 10 minutes. We settled on using only a random 1% of the test data to evaluate our model’s performance. We sampled a random 1% (60 full publications) five times and then took the average over all samples to get our internal evaluation results.

Our Kaggle public leaderboard F-score did not reflect what we achieved in internal evaluation. We will wait and see whether the private leaderboard reflects a similar mismatch.

# Project Plan/Task Distribution

| Task Descriptions & Assignments | | |
| --- | --- | --- |
| Task Description | Assigned To | Completed By |
| Shared ideas with each other about our individual research in how to extract dataset labels from a publication using NLP. Akash proposed and researched SpaCy. Karanbir proposed and researched Topic Modeling. | All | All |
| Created GitHub repository and linked it to the Google Drive with data | Akash | Akash |
| explored using the NLP technique of topic modeling as a solution | Karanbir | Karanbir |
| Dataset exploration to find relevant anomalies and statistics | Karanbir | Karanbir |
| (Preprocessing for SpaCy) Wrote script to convert raw data to SpaCy friendly format and saved to text file | Akash | Akash |
| (Preprocessing for SpaCy) After encountering RAM issues due to data size, wrote a script to compress and data so that key sentences were extracted out of entire papers. Further preprocessed sentences by removing blanks. Confirmed that SpaCy was able to process this data | Akash | Akash |
| (SpaCy model) Added comments on preprocessing and SpaCy model training scripts | Akash | Akash |
| created a document matrix of the text and its content to run into the model | Karanbir | Karanbir |
| Trained SpaCy Named Entity Recognition (NER) model on 70% of the training data to identify dataset names in sentences containing datasets (also used sentences without datasets to balance the class distributions). Due to lengthy time of training the model, model was saved to our shared Google Drive folder | Akash | Akash |
| (SpaCy Internal Eval.) Used 70% trained NER model to predict dataset labels for test data | Sudanshu | Sudanshu |
| SpaCy Internal Evaluation Confusion Matrix Graph | Sudanshu | Sudanshu |
| SpaCy training losses per iteration graph | Sudanshu | Sudanshu |
| SpaCy Averages graph | Sudanshu | Sudanshu |
| (SpaCy Internal Eval.) Extracted a Jaccard-based FBeta (Beta = 0.5) confusion matrix of the SpaCy model’s predictions on unseen “test” set data. From this, got the final micro F0.5 score used for internal evaluation purposes (this is how we are evaluated on Kaggle) | Sudanshu | Sudanshu |
| Determined that the different topics were too vague and topic modeling was not a viable solution to the problem. | Karanbir | Karanbir |
| Restored data and started training a model on full training data, wrote scripts for outputting Kaggle-friendly csv submissions with the model’s predictions | Akash | Akash |
| Created Kaggle submission notebook and submitted partially trained model as first valid submission (0.399 micro F0.5 score, 549th out of 596 on Kaggle competition leaderboard based on 12% of overall test data) | Sudanshu | Sudanshu |
| Report Abstract | Sudanshu | Sudanshu |
| Report Introduction | Karanbir | Karanbir |
| Report: System Design and Implementation – SpaCy | Akash | Akash |
| Report: System Design and Implementation – Topic Modeling | Karanbir | Karanbir |
| Report Dataset description and Stats | Akash & Karanbir | Akash & Karanbir (Akash did overall description, Karanbir did exploration/stats) |
| Report Preprocessing Decisions | Akash & Karanbir | Akash (StaCy) and Karanbir (Topic Modeling) |
| Report: Evaluation Methodology | Sudanshu | Sudanshu |
| Report: Analysis of Results | Akash (SpaCy) & Karanbir (Topic Modeling) | Akash (SpaCy) & Karanbir (Topic Modeling) |
| Report: Things that worked/didn’t work | Akash (SpaCy) & Karanbir (Topic Modeling) | Akash (SpaCy) & Karanbir (Topic Modeling) |
| Report: Conclusions | Sudanshu | Sudanshu |

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