Institute for Natural Language Processing

University of Stuttgart
Pfaffenwaldring 5B
D–70569 Stuttgart

Bachelorarbeit

Investigating Different Levels of Joining Entity and Relation Classification

Milan Milovanovic

Course of Study:	Informatik
Examiner:	Prof. Dr. Sebastian Padó, Dr. Roman Klinger
Supervisor:	Heike Adel
Commenced:	April 4, 2018
Completed:	September 27, 2018

Abstract

Named entities, such as persons or locations, are crucial bearers of information within an unstructured text. Recognition and classification of these (named) entities is an essential part of information extraction. Relation classification, the process of categorizing semantic relations between two entities within a text, is another task closely linked to named entities. Those two tasks – entity and relation classification – have been commonly treated as a pipeline of two separate models. While this separation simplifies the problem, it also disregards underlying dependencies and connections between the two subtasks. As a consequence, merging both subtasks into one joint model for entity and relation classification is the next logical step.

A thorough investigation and comparison of different levels of joining the two tasks is the goal of this thesis. This thesis will accomplish the objective by defining different levels of joint entity and relation classification and developing (implementing and evaluating) and analyzing machine learning models for each level. The levels which will be investigated are:

- (L1) a pipeline of independent models for entity classification and relation classification
- (L2) using the entity class predictions as features for relation classification
- (L3) global features for both entity and relation classification
- (L4) explicit utilization of a single joint model for entity and relation classification

The best results are achieved using the model for level 3 with an F_1 score of 0.830 for entity classification and an F_1 score of 0.52 for relation classification.

Kurzfassung

Entitäten, wie Personen oder Orte sind ausschlaggebende Informationsträger in unstrukturierten Texten. Das Erkennen und das Klassifizieren dieser Entitäten ist eine entscheidende Aufgabe in der Informationsextraktion. Das Klassifizieren von semantischen Relationen zwischen zwei Entitäten in einem Text ist eine weitere Aufgabe, die eng mit Entitäten verbunden ist. Diese zwei Aufgaben (Entitäts- und Relationsklassifikation) werden üblicherweise in einer Pipeline hintereinander mit zwei verschiedenen Modellen durchgeführt. Während die Aufteilung der beiden Probleme den Klassifizierungsprozess vereinfacht, ignoriert sie aber auch darunterliegende Abhängigkeiten und Zusammenhänge zwischen den beiden Aufgaben. Daher scheint es ratsam, ein gemeinsames Modell für beide Probleme zu entwickeln.
Eine umfassende Untersuchung von verschiedenen Stufen der Verknüpfung der beiden Aufgaben ist das Ziel dieser Bachelorarbeit. Dazu werden Modelle für die unterschiedlichen Stufen der Verknüpfung zwischen Entitäts- und Relationsklassifikation definiert und mittels maschinellen Lernens ausgewertet und evaluiert. Die verschiedenen Stufen die betrachtet werden, sind:

- (L1) Verwendung einer Pipeline zum sequentiellen und unabhängigen Ausführen beider Modelle
- (L2) Verwendung der Vorhersagen über die Entitätsklassen als Merkmale für die Relationsklassifikation
- (L3) Verwendung von globalen Merkmale für sowohl die Entitätsklassifikation als auch für die Relationsklassifikation
- (L4) Explizite Verwendung eines gemeinsamen Modells zur Entitäts- und Relationsklassifikation

Die besten Resultate wurden mit dem Modell für Level 3 erreicht. Das F_1-Maß der Entitätsklassifikation beträgt 0.830 und das F_1-Maß der Relationsklassifikation beträgt 0.52.

Contents

1 Introduction

Information Extraction (IE) describes the process of taking unstructured text as input and creating structured and unambiguous data as output. This usually requires a text processing task to identify and recognize necessary information, such as named entities and relations among them. Named entities include many different types of words such as locations, persons or organisations. Named entity recognition and classification is defined as the task of detecting and classifying named entities in an unstructured text. Several learning methods using diverse classifiers for supervised learning or more uncommon unsupervised learning are in use (McCallum and Li, 2003). The recognition and classification of named entities is a necessity to extract relations between two or more entities from a sentence. Relations typically include physical relations (located etc.) or social relations (family, employment etc.) among others (Wang et al., 2006). As the extraction of relations is based on the recognition and classification of entities, the two tasks have been commonly treated as a pipeline of two independent models (Miwa and Sasaki, 2014). While this separation simplifies the task, it also disregards underlying dependencies and connections between the two subtasks (Miwa and Sasaki, 2014). The model is prone to error propagation due to the pipeline approach as errors in entity recognition are propagated downwards to relation extraction. Furthermore, the model does not consider cross-task dependencies. Thus, a combination of both subtasks into one joint model seems like the next logical step (Li and Ji, 2014).

Figure 1 shows a visualization of a sentence with already annotated named entities and relations. A *Kill* relation requires two *People* entities and a *Live_In* relation requires *People* and *Loc* entities. The task of extracting relations is not possible without recognition and classification of the required named entities.

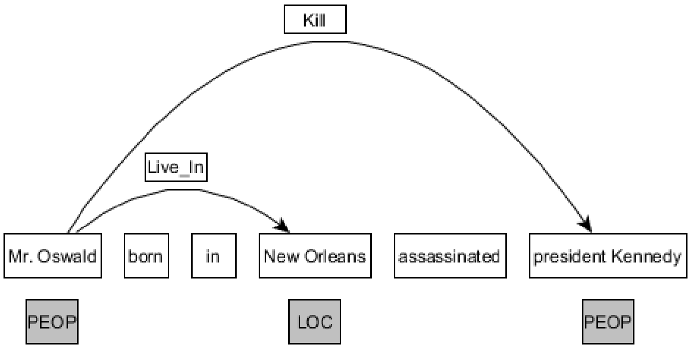


Figure 1: An example of entity and relation. Named entities persons (*Peop*) and locations (*Loc*) are connected by relations *Kill* and *Live_In* (Roth and Yih, 2004).

1.1 Goal of the Thesis

The purpose of this thesis is therefore to investigate different levels of joining entity and relation classification by examining the results for each level. The dataset used for this thesis is the "entity and relation recognition" (ERR) dataset from (Roth and Yih, 2004). The models for each level have a gradient increase of joining the two subtasks by using an incremental amount of cross-task features per level similar to (Li and Ji, 2014). Level one to three use a linear-chain conditional random field (CRF) as introduced by Lafferty et al. (2001) for entity classification while understanding the task of relation extraction as a multi-class classification problem (Zhou et al., 2005). The extraction of relations can be understood as the process of finding the necessary named entities and using a pair of entities as model input for relation classification. Given an entity pair $\{e1, e2\}$ the classification method has to decide what relation (if any) exists between the given pair (Roth and Yih, 2004; Zhou et al., 2005).

While level one uses the pipeline model of two independent subtasks, level two increases the level of joining entity and relation classification by using entity type information for relation extraction similar to Giuliano et al. (2007). Furthermore, level three uses relation type features for entity classification while keeping all other features. The model utilized for level four uses a single joint model for entity and relation classification similar to the one described by (Zheng et al., 2017).

The main research question investigated in this thesis is

- Which level or joining entity and relation classification performs the best?

This can be further divided into the following sub-questions:

- Which model performs the best?
- Which features are key to the performance?

Structure of the Thesis

This thesis is structured in the following manner:
Chapter 1 - Introduction: The topic and goals of the thesis are introduced.
Chapter 2 - Related Work: Related work is introduced.
Chapter 3 - Background: The fundamentals needed for named entity and relation classification are explained. This includes the principles of evaluation metrics and the definition of classification methods.
Chapter 4 - Data: This chapter focuses on the data and necessary preprocessing steps.
Chapter 5 - Models: The models, features and hyperparameters used for this thesis are introduced and specified.
Chapter 6 - Results and Analysis: The experiments and their results will be presented and analysed.
Chapter 7 - Conclusion and Future Work: The main findings are summarized and possible directions for future works are identified.

2 Related Work

The two tasks, entity and relation classification, have had multiple proposed models over the past years. A very popular model is the pipeline approach of treating the two tasks as a pipeline of two independent models. Other models use end-to-end methods to join entity and relation classification. A special focus will be put on works and studies using the same dataset as this thesis.

Traditional methods to handle this task is a pipeline manner, recognizing the entities first and then extracting their relations (Zheng et al., 2017). Most existing named entity recognition models use linear-chain conditional random fields (CRF) whose performances heavily rely on annotated features extracted by NLP tools (Wang et al., 2006; Lafferty et al., 2001; Yao et al., 2009). Florian et al. (2003) present a classifier-combination framework for named entity recognition using gazetteer information as features. The traditional models used for relation classification largely rely on feature representation (Kambhatla, 2004) or kernel design (Zelenko et al., 2003). Recently new models using neural networks have been proposed to both tasks with great success such as the combination of bidirectional LSTMs and conditional random fields by Lample et al. (2016) for named entity recognition and the introduction of dependency-based neural networks for relation classification by Liu et al. (2015).

Multiple studies and works use the ”entity and relation recognition” (ERR) dataset (Roth and Yih, 2004; 2007) although with different models. Roth and Yih (2004) use linear programming with constraints to normalize entity types and relations on a global scale. In contrast to the typically used pipeline framework, this model does not trust the results of classification and is therefore able to overcome mistakes made by classifiers with the usage of constraints (Roth and Yih, 2004). Kate and Mooney (2010) describe a novel method for joint entity and relation extracting by using a card-pyramid graph which encodes all possible entities and relations in a sentence, reducing the task of their joint extraction to jointly labeling its nodes. Giuliano et al. (2007) use entity type information for relation extraction without training both tasks in a joint model. Furthermore, Giuliano et al. (2007) use a combination of kernel functions to integrate two different information sources which include the whole sentence where the relation appears and the local contexts around the entities participating in the relation. The results of relation extraction show that the novel approach of using entity type information as features for relation extraction, significantly improves previous results achieved on the same dataset (Giuliano et al., 2007). Miwa and Sasaki (2014) propose a novel learning approach that jointly extracts entities and relations of a sentence by introducing a flexible table representation of entities and relations. The task of entity and relation classification is then mapped to a simple table-filling problem which outperforms the pipeline approach. Adel and Schütze (2017) note that previous works also use a variety of linguistic features, such as part-of-speech tags. Other works not using the ERR dataset include a single probabilistic graphical system for both tasks (Singh et al., 2013) and a model to incrementally join entity and relation extraction using structured perceptron with efficient beam-search (Li and Ji, 2014). Li and Ji (2014) assess that the results of entity recognition affect the performance of relation classification. Zheng et al. (2017) introduce a novel tagging scheme converting the task of joining entity and relation extraction to a tagging problem.

Similar to Roth and Yih (2004), Kate and Mooney (2010) and Giuliano et al. (2007) the models used for level one to three train separate models for entity and relation classification on the dataset while understanding the task of relation extraction as the task of identifying relations between named entity pairs. Thus, the query entities for relation extraction are only named entity pairs.

The features for the models used for named entity recognition and classification are similar to the features used by Florian et al. (2003) and Miwa and Sasaki (2014) and includes annotated features such as part-of-speech tags, word types and surrounding words. Some features are more general and the gazetteer information is excluded. Features for relation extraction include the usage of shortest dependency paths and their length similar to Xu et al. (2015) and context information such as the sentence the query entity pairs appear in. The model for level two also uses entity type information as features for relation extraction as introduced by Giuliano et al. (2007). The model for level three uses global features similar to Miwa and Sasaki (2014). The model for level four uses a similar tagging scheme as Zheng et al. (2017) with the inclusion of adjacency nodes in the dependency graph as features.

In contrast to most works, the goal of this thesis is the investigation of different levels of joining entity and relation classification. Miwa and Sasaki (2014) compare two different levels of joining both tasks while this thesis defines and investigates four different levels of joining entity and relation classification. Thus, the usage of features has to be constant across all levels with the incremental increase of cross-task features that help evaluating the process of finding out which level of joining the both tasks leads to the best result.

3 Background

3.1 Evaluation Metrics

The metric chosen for evaluation is very decisive. The selection of metrics influences how the performance of machine learning algorithms is measured and compared. The focus on different weights of characteristics is dependent on the choice of the evaluation metrics. Accuracy, Precision-Recall, F_1 score and confusion matrices are common options when deciding for a classification metric (Hossin and Sulaiman, 2015).

Precision and recall are classification metrics used to evaluate systems. Precision is the percentage of relevant answers in the result and recall is the percentage of relevant answers that have been predicted (Kent et al., 1955). In binary classification, a classifier labels documents as either positive or negative. This decision can be represented in a so called confusion matrix (or contingency table). The four categories of the table are the following: True positives (TP), false positives (FP), false negatives (FN) and true negatives (TN). True positives are positives which have been correctly labeled as positives. Likewise, true negatives are negatives which have been correctly labeled as negatives. False positives and false negatives however have an incorrect label. While false positives refer to negatives that have been wrongly labeled as positives, false negatives are positives that have been incorrectly labeled as negatives.

Table 1 shows the confusion matrix and the definitions of precision and recall where TP, FP and FN denote the number of true positives, false positives and false negatives, respectively.

		gold values		
		positive	**negative**	
predictions	**positive**	True Positive	False Positive	**Precision** $= \frac{TP}{TP+FP}$
	negative	False Negative	True Negative	
		Recall $= \frac{TP}{TP+FN}$		**Accuracy** $= \frac{TP+TN}{TP+FP+FN+TN}$

Table 1: Confusion matrix

The standard way to combine precision and recall into one single performance measure is through the F_1 **score**. The F_1 score is the harmonic average of precision and recall. It reaches its best value at 1 and its worst score at 0.

$$F_1 = \frac{2}{\dfrac{1}{\text{precision}} + \dfrac{1}{\text{recall}}} = \frac{2 \cdot \text{precision} \cdot \text{recall}}{\text{precision} + \text{recall}} = \frac{\text{TP}}{\text{TP} + \dfrac{\text{FP} + \text{FN}}{2}} \tag{1}$$

Two different methods are commonly used to determine the average; Micro- and macro average. Micro- and macro-averages are computed slightly differently and thus their interpretation differs. A macro-average computes the metric independently for each label and then takes the average. It treats all classes equally. Whereas a micro-average tries to aggregate the contributions of all classes to compute the average metric. The micro-average is affected less by performance on rare labels. Thus, it is preferable to use the micro-average in a multi-label classification problem (Lipton, Zachary Chase and Elkan, Charles and Narayanaswamy, Balakrishnan, 2014). The two methods can both be applied to both evaluation metrics, PR and F_1 score.

3.2 Part-of-Speech

Part-of-speech tagging is the assignment of words and punctuation characters of a text to their corresponding part-of-speech label. A part of speech is a category of lexical items with similar properties Brill (1992). A list of part-of-speech tags can be found in the appendix (Figure 11).

3.3 Training, Test and Validation Sets

One of the core concepts of machine learning is the notion of creating a model, capable of accurately making predictions on test data. Machine learning models need information to precisely make predictions. The training set is used to give the necessary information to the models (train) while the test set, like the name implies, is used for testing. The test set is untouched during training and only used in the end for testing and analysing the generalisability of the model. A third set needs to be prepared to estimate the prediction error for model selection, the validation set or development set (Guyon, 1997). While performing machine learning the following steps are advised: Initially the gold data is utilized to train the model by pairing the input with the expected output. Then in order to estimate how well the model has been trained and to adjust model properties (to find optimal numbers) a validation set is used (Hastie, Trevor and Tibshirani, Robert and Friedman, Jerome, 2001). Lastly a test set is utilized to assess the performance of a trained model and to ensure unbiased classification. Tuning the model after assessing the model on the test set is not advised as it leads to an underestimation of the true test error and is prone to biased decisions. Using cross-validation or a validation set may give an overall insight on how the model will predict a completely new dataset (Hastie, Trevor and Tibshirani, Robert and Friedman, Jerome, 2001).

As a general rule a typical split might be 50% for training, and 25% each for validation and testing (Hastie, Trevor and Tibshirani, Robert and Friedman, Jerome, 2001). Determining what fraction of the data set should be reserved as a validation set is a controversial topic as optimal performance depends on various factors (Guyon, 1997). This thesis uses a $60\% - 20\% - 20\%$ split of the training, validation and test set (see Section 4).

3.4 N-Gram

N-Grams are the results of partitioning a given text into fragments. An n-gram is a contiguous sequence of n characters or words of a given sample. An n-gram size of $n = 1$ is called unigram, size 2 is called bigram and an n-gram of size 3 is a trigram (Hastie, Trevor and Tibshirani, Robert and Friedman, Jerome, 2001). Sometimes the beginning and end of a text are explicity modeled to match beginning-of-word and ending-of-word situations (Cavnar, William B and Trenkle, John M and others, 1994) and a special character (e.g. ”_”) is used to represent blanks. Therefore the word ”Word” has the following character:

- unigrams: _, W, O, R, D, _
- bigrams: _W, WO, OR, RD, D_
- trigrams: _WO, WOR, ORD, RD_, D__

3.5 Vector Space Model and Bag-of-Words Model

Vector space model as introduced by Salton et al. (1975) is an algebraic model for representing a set of documents as vectors in a common vector space. As raw data (a sequence of characters) cannot be put into algorithms because they expect numerical features, the text documents have to undergo a vectorization process. In general this describes the process of turning a collection of text documents into numerical feature vectors (Ko, 2012). In the vector space model, a document is represented as a vector $d = (w_1, ..., w_{|V|})$, where $|V|$ is the size of the vocabulary. The value of the weight for each term w_1 represents how much the term w_1 contributes to the semantics of the document d (Ko, 2012). The term weight may be a binary value (with 1 indicating that the term occured in the document, and 0 indicating that it did not occur in the document) or a term frequency value $\mathrm{tf}_{t,d}$ (equal to the number of occurrences of term t in the document d) among others. The model of only counting the occurrences of each term but ignoring their relative position information in the document is called the bag-of-words model (Schütze et al., 2008). Thus, the documents d_1 = "John likes Mary" and d_2 = "Mary likes John" appear the same in this model. As term frequency is not necessarily the best representation for a text due to common words like "the" or "a" being almost always among the highest frequency terms in the text, the utilization of stop words is recommended (Tsz-Wai Lo et al., 2005).

3.6 Encoding with BILOU

The task of named entity recognition is commonly viewed as a prediction problem with the aim to assign the correct label for each token. There are many different ways of encoding information into a set of labels. This leads to many different representations of chunks. Two frequently used schemes are BILOU and BIO (Ratinov and Roth, 2009).

BIO stands for (B)eginning, (I)nside and (O)utside encoding of a text segment. Beginning signifies the beginning of a named entity. Inside signifies that the word is inside a named entity and outside signifies that the word is just a regular word outside of a named entity. Below is a sample sentence annotated in BIO:

- Tuvia Tzafir is from Israel
- B-Person I-Person O O B-Location

In BIO encoding labels can either be the beginning of an entity (B_X) or the continuation of an entity (I_X).

BILOU encodes the (B)eginning, the (I)nside and the (L)ast token of multi-token entities while (U)nit tokens are separated from other entities. (O)utside still signifies regular words not in a named entity. The same sentence is differently annotated in BILOU:

- Tuvia Tzafir is from Israel
- B-Person L-Person O O U-Location

In BILOU encoding, I_X can only follow B_X and L_X can either follow B_X or I_X. Ratinov and Roth (2009) have shown that for some datasets, BILOU outperforms BIO.

3.7 Classification

In text classification, a fixed set of classes $C = \{c_1, c_2, ..., c_n\}$ and an amount of inputs (which can be documents, sentences or words, depending on the task) $d \in X$ is given. Classes can also be called categories or labels. A prime example of classes are spam or non-spam emails. Furthermore a training set D of labeled inputs is given where each input $\langle d, c \rangle$, where $\langle d, c \rangle \in X \times C$ (e.g. $\langle d, c \rangle = \langle John\ F.\ Kennedy,\ Person\ \rangle$).
Using a learning method, we then wish to learn a classifier f that maps inputs to their label: $f : X \rightarrow C$ (Schütze et al., 2008). This is called supervised learning. Supervised learning can be seen as a function $y = f(x)$ where y needs to be predicted, x is the data while f is a function that needs to be learned. In short, supervised learning describes the process (given an already known training set of correctly labeled documents) of identifying to which set of categories a new document belongs to.

This process can be enhanced by using features. Features (or attributes) are representing characteristics of the input. Features for text classification may include the frequency of specific terms or the amount of punctuation characters. Features for named entity recognition usually include lexical features such as word types (lowercase, pos-tags etc.) or contextual features like surrounding words or variables indicating the position of the word in the sentence. Section 5.6 shows the features used for this thesis. Features also need to be turned into a vector model as classifiers need numerical features to represent a document.

In the following sections the classifiers used for this thesis will be presented.

3.7.1 Support Vector Machine

A Support Vector Machine (SVM) is a classifier defined by a separating max-margin hyperplane. Given already labeled training data, the algorithm tries to create an optimal hyperplane to categorize new examples. In two-dimensional space the hyperplane is a line and in three-dimensional space it is an ordinary plane. A vector w is defined as a weight vector which is perpendicular to the hyperplane and an intercept term b is defined. All points x on the hyperplane satisfy: $w^T x + b = 0$. Quadratic optimization can be used to find the plane. In a binary classification problem the two classes are $y_i = +1$ and $y_i = -1$. The linear classifier is then defined as $f(x) = sign(w^T x + b)$ where the sign indicates the class. As multiple hyperplanes exist the hyperplane with the highest margin should be selected as it guarantees the best generalisability (Schütze et al., 2008). Figure 2 shows the maximum-margin separating hyperplane in a simple two-dimensional binary classification problem. The margin is maximized for all points on the selected hyperplane. Non-optimal hyperplanes do not satisfy this requirement.

3.7.2 Perceptron

The perceptron is an algorithm used to classify binary data. The perceptron algorithm learns to separate data by changing weights w and bias b using

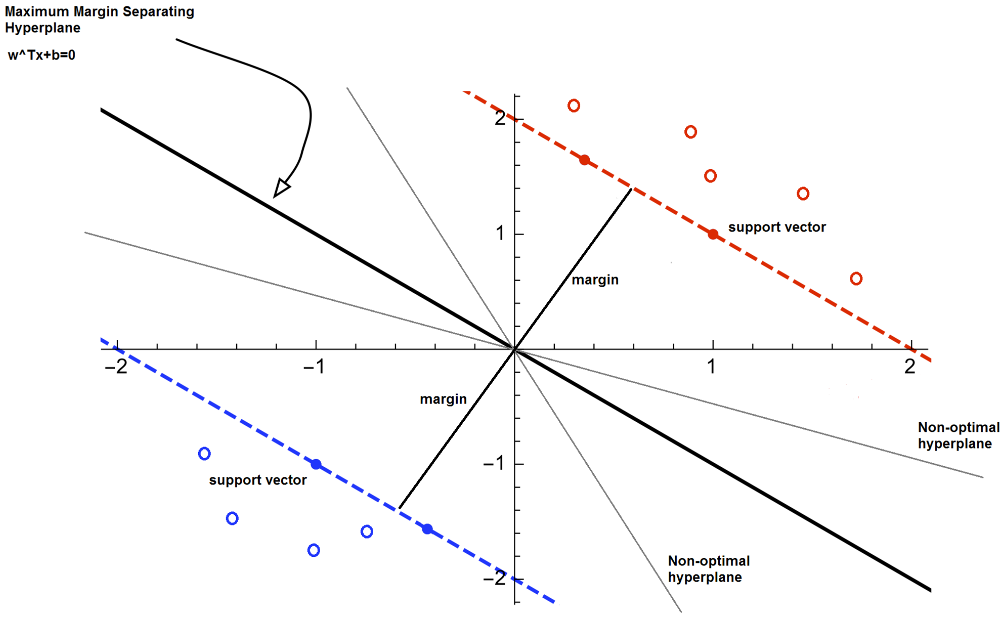


Figure 2: Example of a hyperplane.

iteration. A variable $0 < \alpha \leq 1$ is defined as the learning rate, which indicates how quickly the algorithm responds to changes. The function f is defined as:

$$f(x) = \begin{cases} 1 & \text{if } w^T x + b > 0 \\ 0 & \text{otherwise} \end{cases}$$

Perceptron follows an update rule:

1. Perform the following steps for all inputs x_i for each example i in the training set where f_i is the predicted output and d_i is the desired output. Two classes are defined as $d_i = 1$ if x_i belongs to that class and $d_i = 0$ otherwise.

2. Initializing the algorithm with $w(0), b(0), t = 0$

   2a. Calculate the output by computing the dot product:

$$f_i(t) = w_i(t) \cdot x_i + b$$

2b. Update the weights and bias accordingly for the next iteration:

$$
\begin{aligned}
w_i(t+1) &= w_i(t) + \alpha(d_i - f_i(t))x_i \\
b(t+1) &= b(t) + \alpha(d_i - f_i(t)) \\
t &= t+1
\end{aligned}
$$

The perceptron is guaranteed to converge if the training set is linearly separable (Collins, 2002). The perceptron can naturally be generalized to learn and classify multiclass classification problems. (Collins, 2002).

3.7.3 Decision Tree Classification

Decision Trees are a supervised learning method used for classification. The Decision Tree Classification uses decision trees to create a model that makes predictions by learning simple decision rules inferred from data features. In the context of named entity recognition, asked questions may include *"Is the word in lowercase?"* among others. The decision tree classifier asks questions with the highest information gain first aiming to reduce uncertainty.

3.7.4 Logistic Regression

Logistic regression, also known as Maximum Entropy (Manning and Klein, 2003), is a statistical model used to estimate probabilities. At the core of the method lies the logistic function $1/(1+e^X)$. Input values x_i are combined using weights (coefficients) w to predict a score:

$$score(x_i, k) = w_{0,k} + w_{1,k}x_{1,i} + ... + w_{N,k}x_{N,i} = w_k \cdot x_i$$

In machine learning, logistic regression is a widely used method with the goal to model the probability of a random variable y being 0 or 1:

$$p(y|x) = \begin{cases} h_\theta(x) & \text{if } y = 1 \\ 1 - h_\theta(x) & \text{if } y = 0 \end{cases} \tag{2}$$

where θ is the set of weights w (θ is the vector of weights) and $h_\theta(x) = \dfrac{1}{1+e^{-\theta^T X}} = Pr(Y=1|X;\theta)$

The probability function can be written as:

$$p(y|x) = (h_\theta(x))^y(1-h_\theta(x))^{1-y} \tag{3}$$

Using the maximum log-likelihood for N observation to estimate parameters:

$$l(\theta|x) = \log[\prod_{n=1}^{N}(h_\theta(x_n))^{y_n}(1-h_\theta(x_n))^{1-y_n}] \tag{4}$$

$$l(\theta|x) = \sum_{n=1}^{N}[y_n \log h_\theta(x_n) + (1-y_n)\log(1-h_\theta(x_n))] \tag{5}$$

While logistic regression is a probabilistic model for binomial cases, it can easily be extended for multinomial cases (multinomial logistic regression):

$$p(y|x) = \begin{cases} \dfrac{exp(\theta_1^T x)}{\sum_{i=1}^{N} exp(\theta_i^T x)} & \text{if } y=1 \\ \dfrac{exp(\theta_2^T x)}{\sum_{i=1}^{N} exp(\theta_i^T x)} & \text{if } y=2 \\ \dots \\ \dfrac{exp(\theta_N^T x)}{\sum_{i=1}^{N} exp(\theta_i^T x)} & \text{if } y=N \end{cases} \tag{6}$$

The following steps are omitted as they are corresponding to the binomial model. Unlike Naive Bayes Classifiers, Maximum Entropy does not assume statistical independence of features. In short, the logistic regression classifier computes the posterior class probability of an example by evaluating the normalized product of the active weights (Florian et al., 2003).

3.7.5 Conditional Random Field

A Conditional Random Field (CRF) is a method used for structured prediction. A Linear-Chain CRF is a special form of a CRF with linear structure (mainly used in natural language processing) used to predict sequences of labels for sequences of input samples. In a linear-chain CRF for text processing, each feature function f_i is a function that takes as input: The sentence s, the position i of a word in the sentence s, the label l_i of the current word and the label l_{i-1} of the previous word (Lafferty et al., 2001). Assigning a weight λ_j (finding the value of the weight by e.g. gradient descent) to each feature function f_j allows to score a labeling l of s by adding up the weighted features over all words in the sentence:

$$score(l|s) = \sum_{j=1}^{m} \sum_{i=1}^{n} \lambda_j f_j(s, i, l_i, l_{i-1}) \tag{7}$$

Where n is the amount of words in the sentence and m is the amount of sentences in the data. Transform the scores into probabilities $p(l|s)$ between 0 and 1:

$$p(l|s) = \frac{exp[score(l|s)]}{\sum_{l'} exp[score(l'|s)]} = \frac{exp[\sum_{j=1}^{m} \sum_{i=1}^{n} \lambda_j f_j(s, i, l_i, l_{i-1})]}{\sum_{l'} exp[\sum_{j=1}^{m} \sum_{i=1}^{n} \lambda_j f_j(s, i, l'_i, l'_{i-1})]} \tag{8}$$

The formula only includes features for the current and previous word's identity. Extending the linear-chain formula to include richer features such as prefixes and suffixes of the current word and the identities of surrounding words is fortunately very simple as the definition is quite extensible (Sutton et al., 2012).

Equation 8 is similar to the ones used in logistic regression as CRFs are basically the sequential version of logistic regression (Sutton et al., 2012). Figure 3 shows the relationship of naive bayes, logistic regression, hidden markov models (HMMs) and linear-chain CRFs. The also shown HMMs are another possible sequence model which is not used in this thesis.

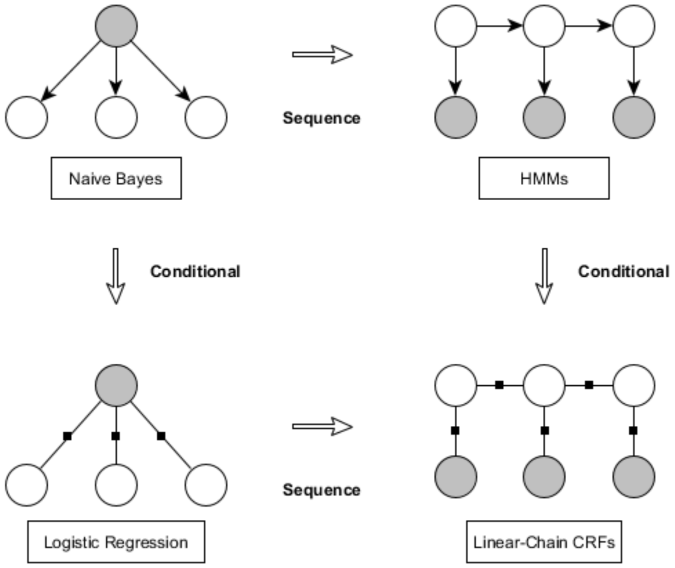


Figure 3: Relationships between Naive Bayes, Logistic Regression, HMMs and Linear-Chain CRFs (Sutton et al., 2012)

3.7.6 Stochastic Gradient Descent Classifier

Stochastic Gradient Descent (SGD) is a simple stochastic approximation of the gradient descent optimization method for minimizing a function. SGD tries to find minima (or maxima) by iteration. Hence, the SGD Classifier is a linear classifier that uses SGD for training by looking for the minima of the loss function using SGD. The loss function may be linear SVMs or logistic regression.

3.8 Dependency Grammar

In dependency grammars the syntactic structure of a sentence is described by the words in a sentence and an associated set of grammatical relations. Unlike phrase structure grammar, dependency grammar only focuses on how words relate to other words.

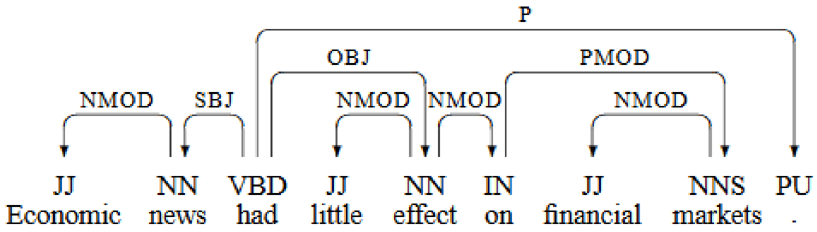


Figure 4: Dependency structure for an English sentence from the Penn Treebank (Kubler et al., 2009): Arrows point from heads to their dependents while labels indicate the grammatical function of the word as either subject or object.

4 Data

CoNLL (Conference Computational Natural Language Learning) is a conference organized by the SIGNLL (ACL's Special Interest Group on Natural Language Learning). The Text REtrieval Conference (TREC) is a series of conferences focusing on different information retrieval topics and research areas. The dataset which will be used for the experiments and analysis of this thesis is the "Entity and Relation Recognition" dataset[1]. It consists of 5516 sentences from the TREC corpus which have been manually annotated with four entity types and relations between them (Roth and Yih, 2004).

4.1 Structure of the Data

The data is split into a block for each sentence. Each block contains information about the entities and relations of one sentence. The format of each block is the following:

- the sentence and all the other columns in a table model
- empty line
- relation assignments (may be empty if no relations exist in the sentence)
- empty line

It is certainly possible for a sentence in the dataset to not contain any relations. When this is the case, the relation descriptors are omitted as they serve no purpose. It is also possible for a sentence to have more than one relation. The additional relations are simply added below.

In the block, each row represents an element (a single word, consecutive words or punctuation characters) of the sentence. The columns hold different amounts of expressiveness. The columns contain the following information:

[1] http://cogcomp.org/Data/ER/conll04.corp

- Column 1: SentenceID (sentence order number)
- Column 2: (Named) Entity class label
- Column 3: TokenID (The order of the elements in the sentence)
- Column 4: O
- Column 5: Part-of-speech tags
- Column 6: Tokens (words or punctuation characters)
- Column 7: O
- Column 8: O
- Column 9: O

As shown in the enumeration afore, the only columns to contain valuable information are columns one to three, five and six. All other columns can simply be ignored. Table 2 shows an exemplary sentence with relations in the dataset.

Four named entities are given in the CoNLL-2004 dataset: **Location**, **Organisation**, **People** and **Other**. Likewise, five relations are given in the CoNLL-2004 dataset: **Located_In**, **Work_For**, **OrgBased_In**, **Live_In** and **Kill**. The entity-relation dependencies are defined as shown in Table 3. There are no other possible relations other than those shown in the table. It is possible that a single named entity participates in more than one relation. It is however not possible that a single relation includes more (or less) than two named entities. Relations between eponymous entity types are reasonable except for the entity type Organisation. Relations are directed and are not reversible. Thus, a Person named Mike is able to live in Rome, Rome is not able to live in a Person named Mike.

SentenceID	NER	TokenID	O	POS	Token	O	O	O
28	Loc	0	O	NNP	Rome	O	O	O
28	O	1	O	VBZ	is	O	O	O
28	O	2	O	IN	in	O	O	O
28	Loc	3	O	NNP	Lazio	O	O	O
28	O	4	O	NN	province	O	O	O
28	O	5	O	CC	and	O	O	O
28	Loc	6	O	NNP	Naples	O	O	O
28	O	7	O	IN	in	O	O	O
28	Loc	8	O	NNP	Campania	O	O	O
28	O	9	O	.	.	O	O	O
0	3	Located_In						
6	8	Located_In						

Table 2: Example of a sentence with relations

4.2 Data Preprocessing

As the data is already annotated there is almost no need to revise it. It is however necessary to split multi-token entities (Table 4) into single tokens to get them into the BILOU encoding scheme (Table 5). Splitting multi-token entities is done by splitting on a special character. Most special characters such as brackets or parentheses are for instance replaced by -LRB- (Left Round Bracket) and -RRB- (Right Round Bracket). The special character ”\” still appears in the column token. In the data the backslash is used to separate multi-token entities. The words in those tokens share the same TokenID and NER tags while their POS tags could potentially be different. They are being grouped due to the fact that they only contribute to a relation if they are jointed. For example, New York City is a location in the United States but the word ”city” alone is neither a descriptive location nor a necessary

	Location	**Organisation**	**People**	**Other**
Location	Located_In			
Organisation	OrgBased_In			
People	Live_In	Work_For	Kill	
Other				

Table 3: Entity-Relation Dependencies

SentenceID	NER	TokenID	POS	Token
36	Org	13	NNP/IN/NNP	University/of/Virginia

Table 4: Example of a multi token entity

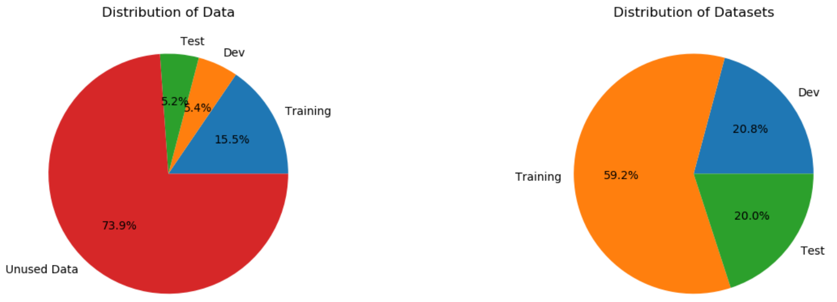
information carrier for this relation. For named entity recognition however it is quintessential to separate all multi-token entities (Vincze et al., 2011). The following algorithm creates a new DataFrame (see Section 5.7) splitting the old DataFrame on a given character.

```
DF_New =
pd.DataFrame([
    [sentenceID, NER, tokenID, O, p, t, O,O,O]
    for sentenceID, NER, tokenID, O, POS, token, O,O,O
     in DF.itertuples(index=False)
    for p, t in zip(POS.split('/'), token.split('/'))
        ], columns=DF.columns)
```

Splitting the data is a needed procedure to encode them into the aforementioned BILOU scheme. Encoding the tokens with their accurate BILOU tag is a process of iterating over the dataset and setting the proper tag according to the established rules. Multi-token entities cannot have tags other than

SentenceID	NER	TokenID	POS	Token
36	B-Org	13	NNP	University
36	I-Org	13	IN	of
36	L-Org	13	NNP	Virginia

Table 5: Example of a splitted multi-token entity with BILOU encoding



(a) percentage of unused sentences

(b) distribution of sets

Figure 5: Distribution of data

beginning, inside and last. The result of the encoding process can be found in Table 5.

The data needs to be split into a training, a test and a validation set. Following prior work (Gupta et al., 2016), only sentences with relations are used. Figure 5a shows the distribution of used and unused sentences. That implies that every sentence in each set possesses one or more relation. There are 1441 sentences with one or more relations. Splitting the sentences according to Gupta et al. (2016); Adel and Schütze (2017) into a training and a test set. The training set contains 1153 sentences and the test set contains 288 sentences. Additionally, the training set is randomly split ($74 - 26\%$) into a train

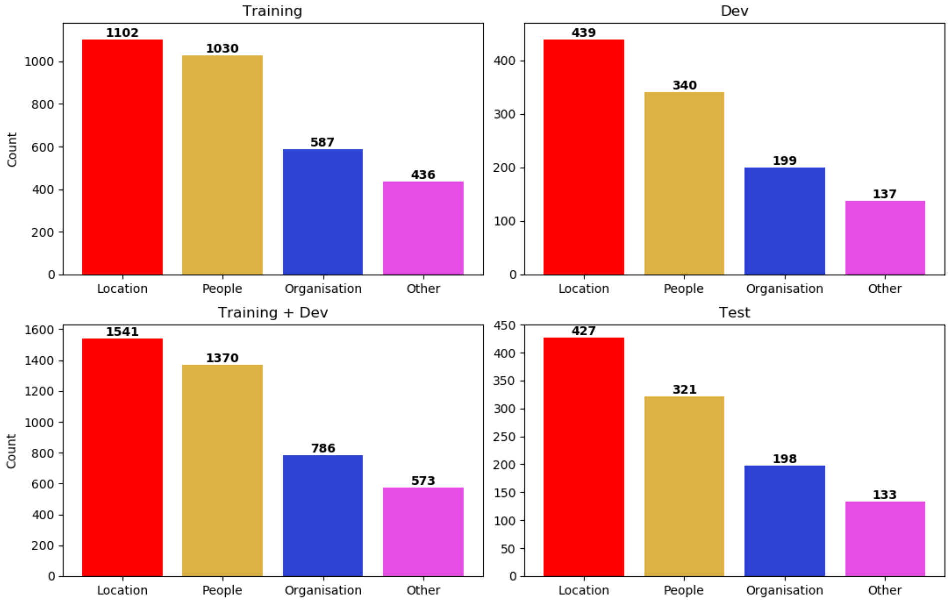


Figure 6: Named entity types

and a validation set (Figure 5b). The train-test split can be found online[2]. Indices within the respective set determine the belonging of the sentence.

4.3 Data Statistics

This section provides statistics of the dataset. The used sets for named entity recognition and classification (and relation classification) contain 1441 sentences and $33519 + 8337 = 41856$ tokens. The number of tokens without a named entity tag is 31912, meaning that $1 - \frac{31912}{41856} \approx 24.8\%$ of the tokens are named entities. The distribution of each type of named entity can be found in Figure 6.

The distribution of the named entity types is roughly the same across all different datasets. Location (1968) is the named entity type with the most

[2] https://github.com/pgcool/TF-MTRNN/tree/master/data/CoNLL04

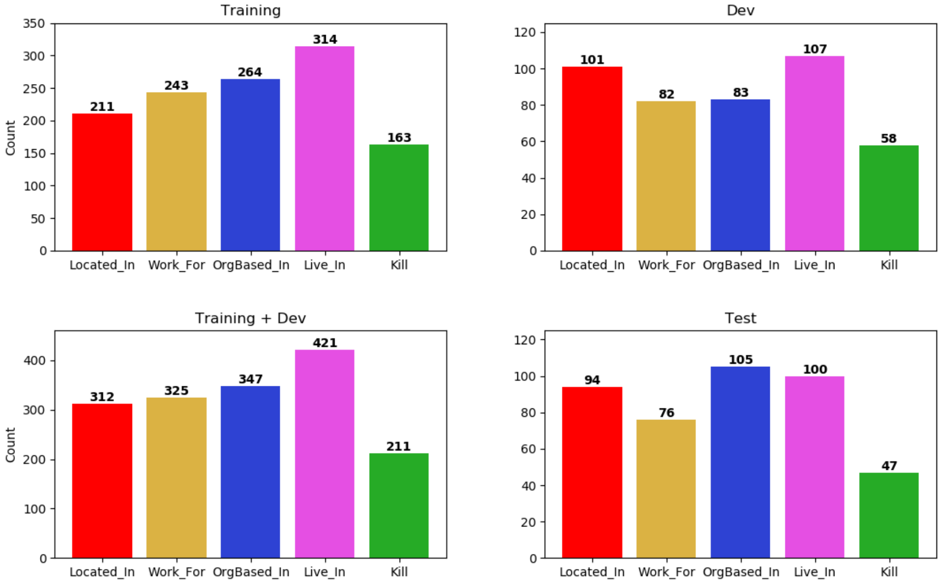


Figure 7: Relation types

appearances in the dataset with People (1691) following close behind while Organisation (984) and Other (706) occur about half as often.

All sentences contain at least one relation and two named entities are needed for a relation. Due to the distribution of the named entity types, certain relations occur much more frequently than others. The distribution of the relation types can be found in Figure 7. Unlike the distribution of the named entity types, the distribution of the relation types is not very similar across the different datasets. Live_In (521) is overall the relation type with the most appearances. OrgBased_In (452) is the second most common relation type. Located_In (406) and Work_For(401) are approximately equally represented in the dataset while Kill (258) has a noticeably low amount of occurrences. The distribution of relation types in each set however does not follow the same principle. The relation Live_In for example has the highest amount of appearances in the training and the dev set while having the second highest amount of occurrences in the actual test set. Located_In has a low number of occurrences in the training set while being close to the top in both dev and test. The relation Kill at least has the lowest amount of appearances across sets. The different distribution of the validation set might stem from its creation by random sampling.

5 Models

In this section the models used for named entity classification and relation classification for each level are defined. Entities and relations are extracted from a sentence. As described in Section 4 entities can span over multiple tokens and relations are directed. For extracting relations by multinomial classification, a new relation called ”N” is created. This relation type signifies there is no relation between two probed entities. The investigation distinguishes between four different levels of joining entity and relation classification. The data is usable after undergoing data preprocessing like described in Section 4. The predicted labels are compared with the expected labels at the end of each model returning a classification report, which includes precision, recall and F_1 score.

5.1 Level One

In Level one a pipeline of independent models for entity and relation classification is used. The model used for entity classification was first introduced by Lafferty et al. (2001). In the first step, a linear-chain CRF is used to recognize and classify entities by setting a sequence of tokens with corresponding features as the input and expecting a sequence of named entity types (labels) as output. A predicted label counts as correctly predicted if the entire label matches the entire named entity type with BILOU encoding. After predicting the entity labels, the predicted data is restructured to fit into the needed form to extract relations. In this process, all tokens with a predicted label that is not a named entity type are ignored. Thus, only tokens with a label of a named entity types will be left. All sequential entities with the same entity type are grouped into one entity with ”B-” and ”L-” being the start and the end of an entity boundary (likewise with ”U-”). Then all entities in a sentence are put against all other entities in the same sentence meaning there are $y = (n-1) \cdot n$ $(\forall n > 1)$ many possibilities of relation pairs for n extracted

SentenceID	Entity1	Entity2	Relation
10	Israel	Tuvia Tzafir	N
10	Tuvia Tzafir	Israel	Live_In

Table 6: Showing relation pairs of two entities. All other columns in this DataFrame are omitted as they would only cluster the table; Multi-token entities are treated as a single entity and any relations are mapped on the respective last token of the multi-token entity

entity pairs. The order of the relation is reflected by the order of the entities in the table: Entity1 ⇒ Entity2. An example table demonstrating this can be found in Table 6. Similar to Miwa and Sasaki (2014) relations on entities are mapped on the last words of the entities. In the last step the entity pair (Entity1, Entity2) in a vectorized form and a FeatureVector as described in Section 5.6 are used as input for the respective classifier.

5.2 Level Two

Level two utilizes the same aforementioned model although the model now includes entity type predictions as input for the classifiers as described by Giuliano et al. (2007). The best results have been achieved using only the named entity type prediction excluding the BILOU label.

5.3 Level Three

Level three uses global features to make more accurate predictions on the test set. The level three models still use local features as the level two models and global features in addition. In particular, the predictions of the entity classification are used for relation classification and afterwards the predictions of relation classification are used to predict better named entity tags. The predictions of linear support vector machines have been utilized as global features for entity-relation.

5.4 Level Four

Level four uses a model to join entity and relation classification. A linear-chain CRF is used to classify the data after being fitted on the train set. A sequence of tokens with corresponding features is the input and a sequence of the following format is the output:

- $Y - ARGX + Z$.
- X is the number of the argument. As relations are directed, the relation has a first and a second argument. X is the identifier of the relation argument.
- Y is a relation type such as *Live_In* or *Kill* of the token (or phrase)
- Z is the BILOU label of the token (or phrase)
- Examples: ”Live_In-ARG1+B” or ”Kill-ARG2+U”

If the token does not participate in any relations a simple ”N” will be given as the label. Table 7 shows already preprocessed data with the new label. As the input only expects a binary classification problem, the model has to be run multiple times with different relation types as labels with the same model type (CRF). Thus, one model is used for each relation type. The model cannot include entities with multi-labels (ARG1 and ARG2 for the same relation type). Therefore all tokens with multi-labels are modelled into tokens with one label. As this only happens in a miniscule amount of cases (around 1%) it should not affect the evaluation. Evaluating the predictions is not as

SentenceID	Token	NER	Relation	Label
10	Israel	U-Loc	Live_In	Live_In-ARG2+U
10	television	O	N	N
10	rejected	O	N	N
10	a	O	N	N
10	skit	O	N	N
10	by	O	N	N
10	comedian	O	N	N
10	Tuvia	B-Peop	Live_In	Live_In-ARG1+B
10	Tzafir	L-Peop	Live_In	Live_In-ARG1+L
. . .	. . .	. . .	. . .	. . .

Table 7: Result of restructuring the data of sentence 10 to fit the model used for level 4. In comparison to Table 6, all tokens have to be relabeled.

simple as it was for level one to three. First the tokens have to be converted into entities respective to their predicted label. As the order is already established there is no reason to determine the direction as seen in Table 6. Thus, only the predicted order is saved. A relation counts as correctly predicted if the entity boundaries are accurate and the order of the entity pair and the order of the arguments is correct. For entity classification the model chooses the predicted BILOU label and concatenates it with the appropriate named entity tag related to the position of the entity in the argument (see Table 3). Thus, only entities that participate in relations can be recognized. The entity type ”Other” cannot be predicted using this model since this entity type does not participate in any relation.

Figures 8 and 9 showcase the different models. Figure 8 shows the model of level one to three while Figure 9 shows the model of level four. All tokens that do not participate in relations have the label *N*.

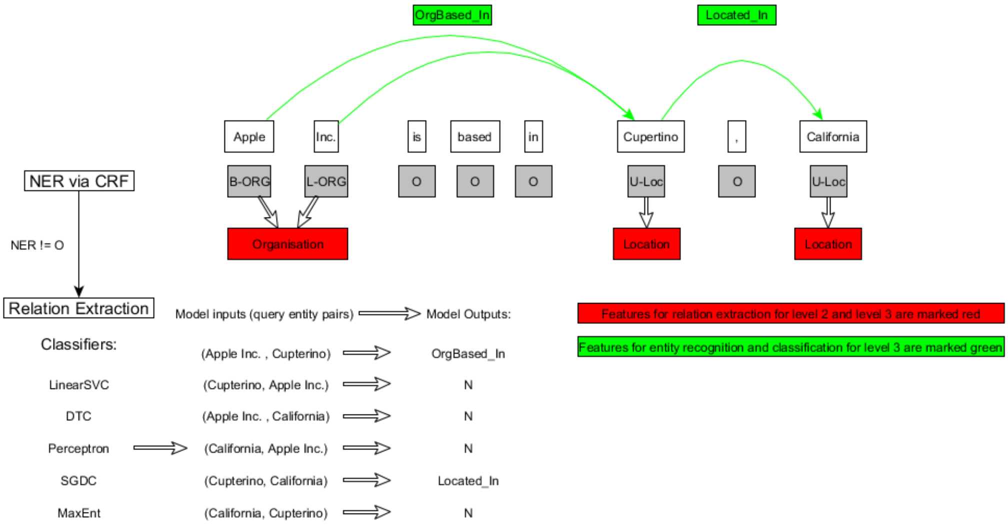


Figure 8: Model of level one to three of the sentence "Apple Inc. is based in Cupertino, California". The color red is used to mark features introduced by level two while the color green is used to mark features used for entity classification of level three.

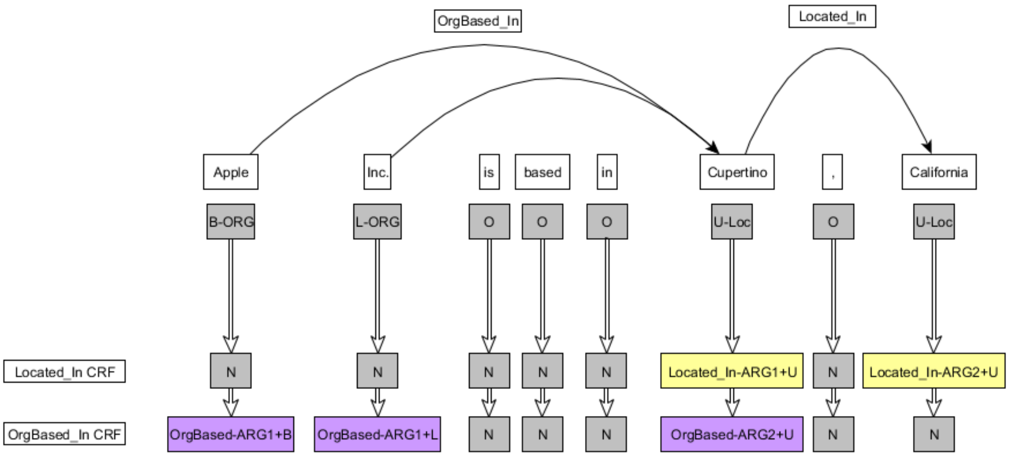


Figure 9: Model of level four of the sentence "Apple Inc. is based in Cupertino, California". Two different relations are found in the sentence indicating the usage of two different CRF models.

5.5 Hyperparameters

Hyperparameter optimization has been performed on named entity classification of levels one to three and on the joint model of level four. The optimization has been performed on regulation parameters ($c1, c2$) of the CRF classifier using randomized search and 3-fold cross-validation. The model was fitted $50 * 3 = 150$ times during the process. Hyperparameter optimization on the joint model of level four was done in a similar way for all relation types.

Optimizing the classifiers for relation classification has been done on a much smaller scale as hyperparameter optimization of five different classifiers per level is computationally expensive. Thus, only the parameter *class_weight* has been optimized for all classifiers. The LinearSVC classifier underwent an additional optimization process of finding the best value of C among multiple values. Parameters can be found in the appendix in Table 24.

5.6 Features

In this section the features are explained. The features for words (entities) are similar to the features used by Florian et al. (2003) and Miwa and Sasaki (2014). Some features are more general and the gazetteer information is excluded. For relations, a variety of different features is used. Cross-task features for entity recognition and classification are used in level three to represent dependencies between entity and relation. (Shortest) Dependency paths features are similar to Xu et al. (2015). The features used for each level can be found in the Table 8 to 11. The features marked with colour indicate features that are introduced in that respective level. Features marked with red are introduced in level two and features marked with green are introduced in level three. The colours are similar to the colours used in Figure 8.

Target	Category	Features
Entity	Lexical	Word (first 2/3 characters) Word types (word lower, initial-capitalized, all-digits, all-puncts, title) Part-Of-Speech Tags (+ pos bigrams)
	Contextual	Word (+ word bigrams within a context window of 3 words *(i-1,i,i+1)* Word types (as described) in a context window of 3 words *(i-1,i,i+1)* PoS-tags within a context window of 3 words*(i-1,i,i+1)* Begin of Sentence, End of Sentence
Relation	Entities	Entities in bag-of-words model
	Contextual	Sentences (bigrams of characters) in which the entities appear
	Shortest path	Shortest dependency path between two entities (entity1-dependency-entity2) The length of the paths

Table 8: Features for Level 1

Target	Category	Features
Entity	Lexical	Word (first 2/3 characters) Word types (word lower, initial-capitalized, all-digits, all-puncts, title) Part-Of-Speech Tags (+ pos bigrams)
	Contextual	Word (+ word bigrams within a context window of 3 words *(i-1,i,i+1)* Word types (as described) in a context window of 3 words *(i-1,i,i+1)* PoS-tags within a context window of 3 words*(i-1,i,i+1)* Begin of Sentence, End of Sentence
Relation	Entities	Entities in bag-of-words model
	Contextual	Sentences (bigrams of characters) in which the entities appear
	Shortest path	Shortest dependency path between two entities (entity1-dependency-entity2) The length of the paths
	Entity type	Predictions of entity label for each entity

Table 9: Features for Level 2. The features which are different to level 1 are highlighted in red.

Target	Category	Features
Entity	Lexical	Word (first 2/3 characters) Word types (word lower, initial-capitalized, all-digits, all-puncts, title) Part-Of-Speech Tags (+ pos bigrams)
	Contextual	Word (+ word bigrams within a context window of 3 words *(i-1,i,i+1)* Word types (as described) in a context window of 3 words *(i-1,i,i+1)* PoS-tags within a context window of 3 words*(i-1,i,i+1)* Begin of Sentence, End of Sentence
	Entity-relation	Relation label and the label of its participating entity
Relation	Entities	Entities in bag-of-words model
	Contextual	Sentences (bigrams of characters) in which the entities appear
	Shortest path	Shortest dependency path between two entities (entity1-dependency-entity2) The length of the paths
	Entity type	Predictions of entity label for each entity

Table 10: Features for Level 3. The features which are different to level 2 are highlighted in green.

Target	Category	Features
Entity and Relation	Lexical	Word (first 2/3 characters) Word types (word lower, initial-capitalized, all-digits, all-puncts, title) Part-Of-Speech Tags (+ pos bigrams)
	Contextual	Word (+ word bigrams within a context window of 3 words *(i-1,i,i+1)* Word types (as described) in a context window of 3 words *(i-1,i,i+1)* PoS-tags within a context window of 3 words*(i-1,i,i+1)* Begin of Sentence, End of Sentence
	Adjacency nodes	Adjacency nodes of all words from the dependency tree

Table 11: Features for Level 4

5.7 Implementation Methods

Python has been chosen as the programming language to implement the models as Python offers various libraries dedicated to natural language processing and machine learning.

Scikit-learn[3] offers simple and efficient tools for data mining and data analysis built on NumPy, SciPy and matplotlib. Scikit-learn is an open source library offering a wide range of state-of-the-art machine learning algorithms for supervised and unsupervised learning (Pedregosa et al., 2011). Used algorithms and methods for this thesis include CountVectorizer, a converter of text documents into matrices of token counts and the implementations of classifiers such as linear support vector machines.
Pandas[4] is an open source library providing data structures and data analysis tools for Python. Pandas.DataFrames are the primary data structure of pandas. DataFrames are two-dimensional tabular data structures with labeled axes, capable of allowing arithmetic operations on both row and column labels and mutable in size. In the context of this thesis, DataFrames are used to store all data in a flexible structure.
SpaCy[5] is a free open source library for NLP in Python. Alongside its wide area of NLP related tasks, it offers labelled dependency parsing. As our features include the dependency grammar, a combination of SpaCy and **NetworkX**[6] are used to create the graphs using trained tokenization models[7]. NetworkX algorithms are then applied to find the shortest path between two words in a graph and to calculate the length of the path. Furthermore, adjacent nodes within the graph are found and used as features for level four.

[3] http://scikit-learn.org/stable/
[4] https://pandas.pydata.org/
[5] https://spacy.io/
[6] https://networkx.github.io/
[7] https://spacy.io/usage/models

6 Results and Analysis

In this section, the experiments and their results will be presented and analyzed.

6.1 Experiments and Results

The models have been applied to the development set for validation and hyperparameter tuning and the test set for testing. The results of entity recognition and classification can be found in Table 12 and 13. Table 14 shows the results of each entity type with BILOU encoding for each level while Table 12 shows the results of each level for entity classification. All entity types (including Other) are included in the table. The results of level four are excluded as it uses a different model and therefore only includes named entities that participate in relations. Thus, the results are not comparable. The results of named entity recognition and classification for level four can be found in the appendix (see Figure 25 and Figure 26). Level one and level two use the same model for entity classification and hence their results are identical. The results show that level three has the best overall F_1 score with a value of 0.830. Level one and level two are equal with an F_1 score of 0.815. There is no noticeable discrepancy between precision and recall for level one and two. A slight discrepancy exists for level three as the score for recall is about 0.1 worse than the score for precision. Level four has a comparable precision score with 0.822. The accuracy score is comparable across all levels with level three having slightly better results than level one and two.

Table 13 shows the results of each level for entity classification with the exclusion of the entity type *Other* and an exclusion of the results of level four as aforementioned. The results for the remaining entity types *Person*, *Location* and *Organisation* are displayed in the table above. Level three has the overall best results for Person and Organisation, with 0.884 and 0.816 respectively while having the second best result of Location with an F_1 score of 0.811. The

Level	**All Entities**	Accuracy
Level 1	0.828 / 0.810 / 0.815	0.940
Level 2	0.828 / 0.810 / 0.815	0.940
Level 3	0.881 / 0.796 / 0.830	0.943

Table 12: Results of entity classification with all entity types (including *Other*) on the test set (precision / recall / F_1 score)

	Level 1 & 2	Level 3
Person	0.838 / 0.905 / 0.869	0.889 / 0.880 / 0.884
Location	0.880 / 0.806 / 0.838	0.914 / 0.744 / 0.811
Organisation	0.739 / 0.747 / 0.741	0.844 / 0.794 / 0.816
Average	**0.819 / 0.819 / 0.816**	**0.884 / 0.806 / 0.837**

Table 13: Results of entity classification with named entity types (excluding *Other*) on the test set (precision / recall / F_1 score)

model of level one and two offers slightly worse results. The precision scores of level four are nearly ideal for entity types Person and Location with 0.947 and 0.991 respectively. Table 14 is validating this observation. The entity type Location has the best precision scores with Person having the overall best recall scores and hence the best overall F_1 score. The label *U-Other* has low scores for both, precision and recall in all levels.

	Level 1	Level 2	Level 3	Level 4
B-Loc	0.91/0.76/0.83	0.91/0.76/0.83	0.98/0.66/0.79	1.00/0.37/0.54
I-Loc	0.95/0.69/0.80	0.95/0.69/0.80	0.97/0.58/0.73	1.00/0.52/0.68
L-Loc	0.88/0.74/0.80	0.88/0.74/0.80	0.98/0.66/0.79	1.00/0.37/0.54
U-Loc	0.85/0.89/0.87	0.85/0.89/0.87	0.83/0.87/0.85	0.98/0.34/0.51
B-Org	0.69/0.72/0.70	0.69/0.72/0.70	0.81/0.80/0.81	0.85/0.38/0.53
I-Org	0.69/0.77/0.73	0.69/0.77/0.73	0.89/0.87/0.88	0.76/0.38/0.50
L-Org	0.76/0.80/0.78	0.76/0.80/0.78	0.83/0.82/0.82	0.92/0.40/0.56
U-Org	0.86/0.67/0.76	0.86/0.67/0.76	0.85/0.62/0.72	1.00/0.28/0.43
B-Peop	0.82/0.88/0.84	0.82/0.88/0.84	0.89/0.89/0.89	0.92/0.55/0.69
I-Peop	0.82/0.95/0.88	0.82/0.95/0.88	0.94/0.91/0.92	0.98/0.68/0.80
L-Peop	0.87/0.94/0.91	0.87/0.94/0.91	0.89/0.89/0.89	0.94/0.56/0.70
U-Peop	0.83/0.81/0.82	0.83/0.81/0.82	0.80/0.78/0.79	1.00/0.29/0.45
B-Other	0.89/0.74/0.81	0.89/0.74/0.81	0.94/0.79/0.86	*
I-Other	0.84/0.70/0.76	0.84/0.70/0.76	0.91/0.76/0.83	*
L-Other	0.87/0.73/0.79	0.87/0.73/0.79	0.91/0.76/0.83	*
U-Other	0.58/0.45/0.51	0.58/0.45/0.51	0.54/0.39/0.45	*

Table 14: Results of entity classification visualized with all entity types in BILOU encoding (precision/recall/F_1 score). The * selected cells cannot be classified with the level four approach as explained in the model description.

Table 15 shows the results of each classifier used for relation extraction and classification for all levels. Five different classifiers have been used to extract and classify relations: Linear Support Vector Machine (LinearSVC), Decision Tree Classifier (DTC), Perceptron, Stochastic Gradient Descent Classifier (SGDC) and Maximum Entropy (MaxEnt). The arithmetic mean is added below the results for each level. Due to the different model of level four the relation extraction and classification of level four is done via linear-chain CRF with and without graph features. The used features can be found in Section 5.6.

The results for level one are mixed. DTC and SGDC have low F_1 scores with 0.32 and 0.36 respectively, whereas LinearSVC, Perceptron and MaxEnt have about 20% higher F_1 scores with around 0.44. The accuracy score is about equal for all classifiers with a value of approximately 0.89. There is, however a noticeable discrepancy between precision and recall for LinearSVC and DTC. Consequently, LinearSVC performs the best for level one and DTC performs the worst.

Level two sees distinguished improvements on all sides compared to level one. All classifiers have increased recall and F_1 scores with LinearSVC and Perceptron being the best classifiers with an F_1 score of 0.54. While precision went down for LinearSVC and SGDC, the increase of recall raised the F_1 score. Particularly the enhancement of the decision tree classifier is noticeable. With an increase of its recall score from 0.24 to 0.43, which is nearly an increase of 100% it augmented its F_1 score from a poor 0.32 to a solid 0.49. There are no huge differences when comparing the results of level two to the results of level three. SGD Classifier saw a small increase of 0.04 while the other classifiers stayed mostly the same. Thus, level three offers slightly better results than level two and given the results of the other levels, the best results of all levels with an average F_1 score of 0.52.

	Classifier	**All Relations**	Accuracy
Level 1	LinearSVC	0.66 / 0.36 / 0.46	0.912
	DTC	0.51 / 0.24 / 0.32	0.897
	Perceptron	0.52 / 0.41 / 0.44	0.881
	SGDC	0.45 / 0.36 / 0.36	0.876
	MaxEnt	0.50 / 0.42 / 0.44	0.888
	avg/total	**0.53 / 0.36 / 0.40**	**0.891**
Level 2	LinearSVC	0.62 / 0.49 / 0.54	0.914
	DTC	0.60 / 0.43 / 0.49	0.914
	Perceptron	0.55 / 0.55 / 0.54	0.897
	SGDC	0.40 / 0.59 / 0.46	0.857
	MaxEnt	0.50 / 0.56 / 0.52	0.892
	avg/total	**0.53 / 0.52 / 0.51**	**0.895**
Level 3	LinearSVC	0.58 / 0.49 / 0.53	0.915
	DTC	0.61 / 0.44 / 0.49	0.914
	Perceptron	0.53 / 0.55 / 0.53	0.894
	SGDC	0.47 / 0.55 / 0.50	0.878
	MaxEnt	0.49 / 0.58 / 0.53	0.892
	avg/total	**0.54 / 0.52 / 0.52**	**0.899**
Level 4	CRF_Graph	0.82 / 0.28 / 0.42	0.913
	CRF	0.86 / 0.31 / 0.43	0.915
	avg/total	**0.84 / 0.30 / 0.42**	**0.914**

Table 15: Results of relation extraction on the test set and using (precision / recall / F_1 score) and accuracy to evaluate

The results for level four show two linear-chain CRFs. One used graph features such as adjacency nodes while the other did not include graph features. Comparing the two models returns almost identical F_1 scores of 0.42 for a CRF with graph features and 0.43 for a CRF without graph features. The recall scores follow the same scheme, whereas the precision scores show slight differences with the CRF without graph features being marginally better than the CRF with graph features. Level four has slightly better accuracy scores compared to the other levels. However, accuracy as an evaluation metric is flawed when it comes to an unbalanced amount of positives and negatives. Thus, predicting N for all cases always results in high accuracy scores. Consequently, the F_1 score is the better alternative to compare results.

Table 16 and 17 show the results of each relation type for each classifier and level. Table 16 includes the relation types *Kill*, *Live_In* and *Located_In* whilst Table 17 shows the results of relation types *Work_For* and *OrgBased_In*. The first noticeable thing about the table is the fact that the relation type Kill has by far the best F_1 score of all relations with the DTC reaching 0.90 for level two and three. By way of contrast, the relation Located_In has by far the worst F_1 score reaching a value of 0.38 at best while using the perceptron classifier for level two and three. The results of OrgBased_In and Work_For are more or less equal while the results for Live_In are worse.

Moreover, Table 27 in the appendix shows the results of the used model for level four. Here, the F_1 scores for each argument of each relation are displayed. Additionally, each argument was split into all possible BILOU labels to provide further information. CRF_Dev describes the result on the validation set while CRF_Test and CRF_Test_Graph describe the results on the test set without graph features and with graph features. In short, the precision scores are very high while the recall scores are somewhere between very low and very good, as seen in all labels starting with Kill. Thus, performance of the model is not as stable as the performance of level two and three.

		Kill	Live_In	Located_In
Level 1	LinearSVC	0.84/0.79/0.81	0.64/0.27/0.38	0.43/0.21/0.29
	DTC	0.88/0.64/0.74	0.48/0.22/0.30	0.35/0.09/0.14
	Perceptron	0.68/0.81/0.74	0.44/0.31/0.36	0.22/0.38/0.28
	SGDC	0.45/0.89/0.60	0.46/0.19/0.27	0.30/0.17/0.22
	MaxEnt	0.68/0.85/0.75	0.46/0.28/0.35	0.32/0.32/0.32
Level 2	LinearSVC	0.79/0.79/0.79	0.50/0.55/0.53	0.49/0.21/0.30
	DTC	0.93/0.87/0.90	0.54/0.43/0.48	0.40/0.11/0.17
	Perceptron	0.75/0.83/0.79	0.39/0.58/0.47	0.35/0.41/0.38
	SGDC	0.66/0.89/0.72	0.39/0.58/0.47	0.42/0.26/0.32
	MaxEnt	0.66/0.87/0.75	0.40/0.59/0.48	0.34/0.38/0.36
Level 3	LinearSVC	0.79/0.79/0.79	0.49/0.51/0.50	0.45/0.24/0.32
	DTC	0.93/0.85/0.89	0.52/0.38/0.44	0.52/0.14/0.22
	Perceptron	0.76/0.81/0.78	0.39/0.53/0.45	0.32/0.45/0.38
	SGDC	0.51/0.91/0.65	0.43/0.54/0.48	0.27/0.44/0.33
	MaxEnt	0.67/0.85/0.75	0.41/0.55/0.47	0.34/0.41/0.37
Level 4	CRF_Graph	0.89/0.72/0.80	0.92/0.23/0.37	0.62/0.20/0.30
	CRF	0.87/0.72/0.79	0.95/0.19/0.32	0.72/0.20/0.30

Table 16: Results of relation extraction (i) on the data set using (precision / recall / F_1 score) to evaluate

		OrgBased_In	Work_For
Level 1	LinearSVC	0.82/0.43/0.56	0.64/0.30/0.41
	DTC	0.56/0.29/0.38	0.46/0.14/0.22
	Perceptron	0.80/0.34/0.48	0.51/0.45/0.48
	SGDC	0.69/0.34/0.46	0.30/0.49/0.37
	MaxEnt	0.72/0.39/0.51	0.37/0.49/0.42
Level 2	LinearSVC	0.70/0.54/0.61	0.69/0.50/0.58
	DTC	0.61/0.50/0.55	0.71/0.49/0.58
	Perceptron	0.75/0.51/0.61	0.63/0.55/0.59
	SGDC	0.29/0.70/0.41	0.44/0.67/0.53
	MaxEnt	0.58/0.56/0.57	0.59/0.55/0.57
Level 3	LinearSVC	0.67/0.55/0.61	0.62/0.49/0.53
	DTC	0.62/0.50/0.56	0.62/0.53/0.57
	Perceptron	0.71/0.51/0.60	0.59/0.58/0.58
	SGDC	0.62/0.46/0.53	0.52/0.63/0.57
	MaxEnt	0.58/0.58/0.58	0.56/0.64/0.60
Level 4	CRF_Graph	0.88/0.28/0.43	0.71/0.16/0.26
	CRF	0.92/0.31/0.47	0.77/0.17/0.28

Table 17: Results of relation extraction (ii) on the data set using (precision / recall / F_1 score) to evaluate

6.2 Analysis

The previous section introduced and presented the experiments the results. The goal of this section is a comprehensive analysis of the results for both, entity and relation classification starting from level one. The analysis of the results of entity and relation recognition and classification will be divided into two parts. First, the entity and relation classification for level one, two and level three will be analysed and evaluated and then the joint approach for level four will be examined.

	Level 1 & 2	Level 3
Top Likely	I-Org ⇒ L-Org 7.5	B-Org ⇒L-Org 6.5
	B-Org ⇒L-Org 7.1	B-Org ⇒ I-Org 6.4
	B-Loc ⇒L-Loc 7.0	I-Org ⇒ L-Org 6.2
	B-Org ⇒I-Org 6.6	I-Org ⇒ I-Org 6.0
	I-Org ⇒I-Org 6.6	B-Loc ⇒ L-Loc 6.0
	B-Loc ⇒I-Loc 6.6	B-Peop ⇒ L-Peop 5.9
	I-Peop ⇒L-Peop 6.2	I-Peop ⇒ L-Peop 5.6
Bot Likely	O ⇒ I-Org -4.2	O ⇒ L-Loc -2.1
	I-Other ⇒ O -4.1	B-Loc ⇒ O -2.1
	O ⇒ L-Loc -3.6	O ⇒ I-Peop -2.0
	O ⇒ I-Other -3.3	O ⇒ I-Org -2.0
	B-Other ⇒ O -3.3	B-Org ⇒ O -1.7
	B-Loc ⇒ O -3.2	O ⇒ L-Peop -1.5
	I-Loc ⇒ O -3.1	B-Peop ⇒ O -1.5

Table 18: Transitions of CRF labels

6.2.1 Entity Classification

Table 14 is an extensive spreadsheet showcasing the results for all possible labels. The first step in analyzing the CRF layer is the extraction of the most (and the least) likely transitions and the extraction of indicating words. Table 18 shows the seven most and least likely transitions while Table 19 displays the five top positive and negative words for level one to three. All correlations and transitions between entity types are accurate. It is very likely that the beginning of an organisation name is followed by a token inside the name (*I-Org*) or a token at the end of the name of the organisation. The same applies for the relation type People. Transitions from and to tokens with the label O are penalized. The *Organisation* labels have the most appearances in the table even though *Organisation* as an entity type has one of the worst F_1 scores (see Table 13). However when looking at Table 19 there are no appearances of *Org* labels in the rows for level one and two. The first appearance of an *Org* label is on position 12 with *"+1:word.lower():nomination"*. There is no appearance at all when looking at the top negatives. Thus even though *Organisation* as a label has the most likely transitions, it does not have many words indicating that the respective word does indeed belong to an *Organisation*. The tagging is however very good once the beginning token of a multi-token entity has been accurately labeled. Furthermore, the transition score may indicates a better performance for entity recognition and classification for level one and two than for level three but Table 19 weakens that particular sentiment as the top positives are dominated by all relation type features (global) with the prime example being "*relation:N*" with an outstanding score of 12. The other relation types are all having positive scores indicating that the inclusion of relation types as features is very helpful for entity recognition. Another perk of including relation types as features is the usage of context as for example the label *U-Peop* has the negative feature "*-1:word.lower():in*". This means that the word *in* before an entity implicitly denies the possibility of the entity being a person. Worth mentioning is the occurrence of an entity with two relation types which indicates a location.

	Label	Feature	Score
Level 1/2 Pos	U-Other	+1:word.lower():basque	7.12
	U-Other	word.lower():rice	6.6
	O	word[-2:]:94	5.2
	U-Loc	word.lower():beijing	5.0
	U-Loc	word.lower():france	4.6
Level 1/2 Neg	O	1:word.lower():18th	-4.0
	O	postag:NNP	-3.7
	O	+1:word.lower():side	-3.2
	L-Peop	+1:postag[:2]:NN	-2.6
	O	+1:word.lower():plant	-2.6
Level 3 Pos	O	relation:N	12.0
	U-Loc	relation: Located_In	4.3
	U-Peop	relation: Kill	4.1
	U-Org	relation: Work_For	3.7
	...	...	...
	U-Loc	relation: Located_In OrgBased_In	3.2
Level 3 Neg	U-Other	+1:postag[:2]:NN	-2.5
	L-Peop	+1:postag:NNP	-1.9
	U-Peop	-1:word.lower():in	-1.8

Table 19: Top positives and negatives CRF level 1&2 and level 3

In general, most of the top positives and negatives involve labels with the *BILOU label (U)nit*. Thus, entities with that particular label have some of the best F_1 scores, especially *U-Loc*. This is particularly important as relations are mapped on isolated entity tokens (Unit) and last tokens of multi-token entities. Furthermore, the occurences of various features revolving part-of-speech tags (see Figure 11) is encouraging as *"O, postag:NNP, -3.7"* indicates that words with a proper noun tag (NP) are often entities. The same applies for top positives or negatives like*"O, word[-2:]:94, +5.2"* that use word type features, in this case digits, to indicate that the word is most likely not an entity. Lafferty et al. (2001); Yao et al. (2009) described a close dependency between NLP processed features and CRF performance which can also be found in this model.

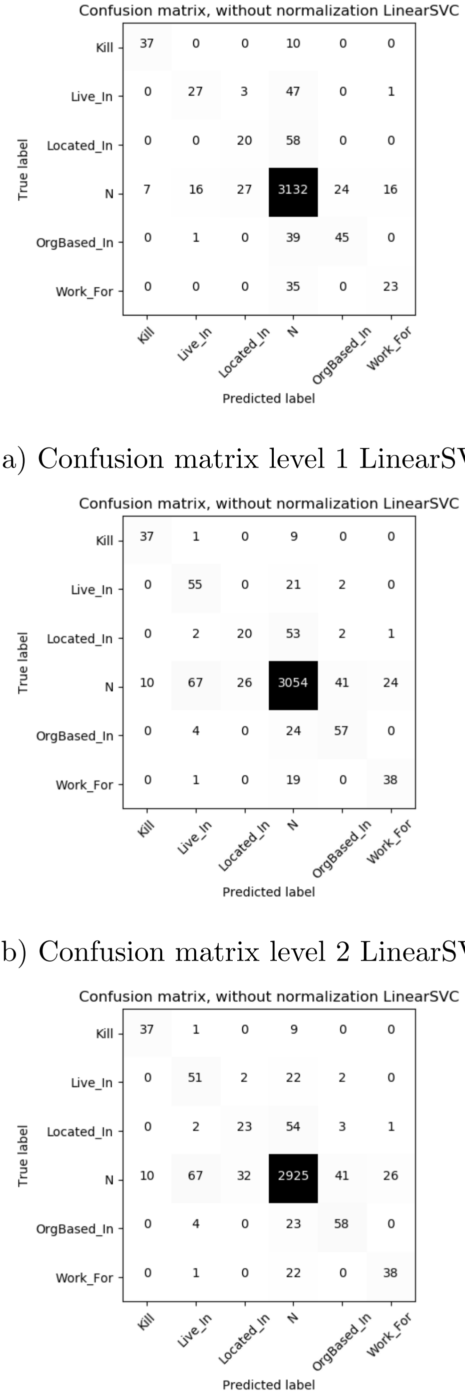
A rather worrisome point is the fact that the model seems to remember the names of some entities. This is the case for some of the positives across the three levels as locations such as France, Beijing or Moscow or even common words without relation affiliations like basque or rice appear in the top 15. This might be a case of overfitting which decreases the performance of the model on new data (Cawley and Talbot, 2010).

6.2.2 Relation Classification

The pipeline approach treats the process of entity recognition and classification as a necessary first step to extract relations. Relations are dependent on entities and cannot be extracted if the required entities are not recognized. Using cross-task features for both tasks improves the results of both tasks as described earlier. In this section, an analysis of the results of relation classification will be presented.

Table 16 and Table 17 on page 51 and 52 have shown the results of each classifier for each relation type. In this section, a special focus will be put on the linear support vector machine classifier as the classifier is considered state of the art (Lauer and Bloch, 2008; Tang, 2013). Figure 10 depicts the confusion matrix of level one, two and three. The graphic depicts the predictions of the classifier on the available data meaning that the best possible prediction is the correct prediction of all correctly recognized and classified named entities. The figure depicts the predicted labels on the x-axis and the actual labels on the y-axis. The colour visualises the count of elements although the sheer amount of accurate *N* predictions is dominating the figure. This result is expected because most entity pairs have no relation to each other. Regarding the *N-rows* there is a vast number of inaccurate predictions. Level one mostly predicts *N* when it should predict another label while level two and three predict another label when it should be *N*. This can be seen in the *N-column* of level one and the *N-row* on level two and three. There is a huge increase of predictions of the true label *Live_In* when comparing the values for level one and the other two. While this label is only 27 times predicted using level one, it is 55 times predicted using level two. A similar increase happens for the label *Work_For* and the label *OrgBased_In* while *Located_In* and *Kill* are barely affected. All those results can be seen in Table 16 and 17. The results for relation types *Located_In* and *Kill* for LinearSVC have only marginal changes across all levels, whereas the results for *Live_In*, *Work_For* and *OrgBased_In* have stark contrasts between level one and two.

Table 20 shows the percentage of correctly predicted labels for each level. The column *Count* lists the count of maximum possible relation types based on the predicted entities while the column *True Count* lists the true count of relation types. As expected, the percentage of correctly predicted relations is higher when only the maximum possible relations are considered. There is a steady increase of correctly predicted relation types across the three levels with the exception of *Live_In* which has better results for level two than level three. This can be explained by referencing Table 14 as *L-Loc* and *U-Loc* have better results for level two than level three and hence more existing relations can be discovered. There is also almost no improvement for *Located_In* as the



Confusion matrix, without normalization LinearSVC

True label

	Kill	Live_In	Located_In	N	OrgBased_In	Work_For
Kill	37	0	0	10	0	0
Live_In	0	27	3	47	0	1
Located_In	0	0	20	58	0	0
N	7	16	27	3132	24	16
OrgBased_In	0	1	0	39	45	0
Work_For	0	0	0	35	0	23

Predicted label

(a) Confusion matrix level 1 LinearSVC

Confusion matrix, without normalization LinearSVC

True label

	Kill	Live_In	Located_In	N	OrgBased_In	Work_For
Kill	37	1	0	9	0	0
Live_In	0	55	0	21	2	0
Located_In	0	2	20	53	2	1
N	10	67	26	3054	41	24
OrgBased_In	0	4	0	24	57	0
Work_For	0	1	0	19	0	38

Predicted label

(b) Confusion matrix level 2 LinearSVC

Confusion matrix, without normalization LinearSVC

True label

	Kill	Live_In	Located_In	N	OrgBased_In	Work_For
Kill	37	1	0	9	0	0
Live_In	0	51	2	22	2	0
Located_In	0	2	23	54	3	1
N	10	67	32	2925	41	26
OrgBased_In	0	4	0	23	58	0
Work_For	0	1	0	22	0	38

Predicted label

(c) Confusion matrix level 3 LinearSVC

Figure 10: Confusion matrices using the LinearSVC classifier

	Relation Type	Count	%	True Count	True %
Level 1	*Kill*	47	79	47	79
	Live_In	78	35	100	27
	Located_In	78	25	94	21
	OrgBased_In	85	53	105	43
	Work_For	58	40	76	30
Level 2	*Kill*	47	79	47	79
	Live_In	78	71	100	55
	Located_In	78	25	94	21
	OrgBased_In	85	67	105	54
	Work_For	59	64	76	50
Level 3	*Kill*	47	79	47	79
	Live_In	77	66	100	51
	Located_In	83	27	94	25
	OrgBased_In	85	69	105	55
	Work_For	61	64	76	50

Table 20: The percentage of correctly predicted relations for level one to three

results of relation classification of level one and two regarding relations with the entity type *Location* have the worst results. The small number of correctly predicted relations with the entity type *Location* as their first (or second) argument influences the results of level three by the fact that the linear-chain conditional random field precisely picks the already established location entities (marked with the relation type *Located_In*) without returning a broad amount of entities. This explains the low recall score of all location labels in Table 14 for level three. Due to the high precision score more actual relations with the entity type *Location* are discovered. The largest improvement in the Table 20 can be found for the relation type *Live_In*. The gradient jump from a low percentage of 35% of level one to a high percentage of 71% for level two is significant. As both models use the same entity classification method this increase can only be explained by the utilization of different features of the relation extraction. Level two uses entity type predictions as input for relation classification. The best results have been achieved without using BILOU encoding. The top positive features for level one and the relation type *Live_In* include common locations such as "england", "of york", "italy" or "mexico" or persons such as "robinson","george" or "elizabeth" while the top negative features include miscellaneous words like "comma came", "march", "replaced" or "president of". Furthermore, top negative features also include words like "ap" or "xinhua" which indicate organisations and the aforementioned words are indeed top positive features for the relation type *OrgBased_In*. In contrast, the top negative features for level two and the relation type *Live_In* is the predicted entity type *Other* among others. For the relation type N the top feature is also *Other* while various names or locations are included in the top negatives. Words with the entity type *Other* have no relations and therefore indicate the classifier that entities with the feature *Other* should not participate in any relation and hence the classifier predicts *N*. There is almost no difference between the top features for level two and the top features for level three. There is a noticeable change regarding the intercept values for level one and two. For level one the values are all negatives $[-0.8, -0.4]$ for the relation types without N which is around 0.08. Level two however has values between $[-1.0, -1.5]$ for the relation types and 0.7 for *N*. The classifier is therefore much more likely to predict N for an unknown entity pair for level one than for level two and three.

The increase of performance between level one and level two is the main difference between the levels. The increase of performance is due to the selection of entity types as additional features. This addition improves the classification process by a noticeable amount. The differences between level two and three can be explained by the better results of entity classification as there is no real difference regarding relation extraction between level two and three.

6.2.3 Analysis of the Joint Model

As the previous models treat the task of entity and relation classification as a pipeline of two separated tasks, the model may hurt the performance of both tasks. One of the most important arguments is the fact that named entity recognition and classification is the basis for relation classification. Thus, errors in the upstream component (NER) are propagated to the downstream component (RC) without any feedback (Zhou et al., 2017) as described in the sections before. Thus, it is impossible to properly extract relations if the corresponding entities were not even recognized. Furthermore, a separate model does not consider cross-task dependencies. As the results of level two and three show, using a more combined model including the consideration of cross-task dependencies such as relation type features as input for entity classification increases the performance for both tasks.

The model used for level four however, has worse results than the disjointed models as described in Section 6.1. The analysis of the joint model will explain the differences of performance. Table 21 shows a sentence of the dataset

SentenceID	NER	POS	Token	Model
2741	B-Loc	NNP	BUENOS	Located_In-ARG1-B
2741	L-Loc	NNP	AIRES	Located_In-ARG1-L
2741	O	,	COMMA	N
2741	U-Loc	NNP	Argentina	Located_In-ARG2-U
2741	O	-LRB-	-LRB	N
2741	U-Org	NNP	AP	N
2741	O	-RRB-	-RRB-	N
0	2	Located_In		

Table 21: Example of a sentence with the model for level four

using the format for level four. The labels have been adjusted to fit into the scheme. The sentence contains a relation of the relation type *Located_In* and the two corresponding entities *Buenos Aires* and *Argentina*. It also contains the entity *AP*. *AP* is an entity of the entity type *Organisation* that is very easy to classify (see Section 6.2.1) if the model could recognize it. Due to the method used however, the model is not able to recognize entities without relations as their label does not accurately represent them as named entities.

Label	True Count	Lvl 4 True	Lvl 4 Miss	Lvl 4 Pred
B-Loc	153	106	47	56
I-Loc	52	41	11	27
L-Loc	153	106	47	56
U-Loc	274	199	75	96
B-Org	122	92	30	54
I-Org	120	92	28	59
L-Org	122	92	30	53
U-Org	76	51	25	21
B-Peop	236	201	35	141
I-Peop	133	120	13	92
L-Peop	236	201	35	142
U-Peop	85	48	37	25
B-Other	84	0	84	0
I-Other	46	0	46	0
L-Other	84	0	84	0
U-Other	49	0	49	0
Sum	**2024**	**1349**	**675**	**822**

Table 22: Count of named entity types in the test set

Table 22 represents the amount of named entities in the test set using the model for level four. The column ”Lvl 4 True” displays the amount of named entity types in the test set for model four. As seen in the table, 675 named entities cannot be represented. This implies that $\frac{1}{3}$ of all named entities cannot be recognized and classified. Thus, using this model for named entity recognition and classification is not comparable to previous models as a third of all named entities cannot even be classified.

Table 27 in the appendix shows the complete results of the model for level four. Each argument is displayed for each *BILOU* label and relation type. All named entities participating in relations can be recognized and classified by the position they appear in. A relation is correctly extracted if the entire named entity boundary is accurate and the order of the named entities participating in the relation is accurate. That is to say, that in order for a relation to be correct, both arguments have to be accurate. If one of the two necessary arguments is wrong or simply inaccurate, the corresponding relation cannot be extracted. That implies that a multi-token entity has to be completely accurate for the relation to count as correct. The transition matrix of each CRF has learned correct transitions between arguments. Thus, it is likely for the CRF to correctly classify a multi-token entity if the entity was recognized. Recognition, however is a huge problem. This is mirrored in the results of each relation type. As the combination of two pertinent relation arguments proves to be difficult, the performance dwindles. A change of the evaluation method may thwart this assessment. Mapping relations to the last token of multi-token entities similar to the models for level one to three and only focus on the last token as entity boundary may increase performance of the model. An addition to the established tagging model may increase performance by adding new tags for entities that do not participate in relations. The tag could have a format of N-X+Z with N indicating that the token does not participate in a relation, X being the NER tag and Z being the *BILOU* label.

6.2.4 Comparison to State-of-the-Art Results

	Kate and Mooney (2010)	Roth and Yih (2004)
Person	0.921 / 0.942 / **0.932**	0.894 / 0.892 / 0.893
Location	0.908 / 0.942 / **0.924**	0.682 / 0.909 / 0.779
Organisation	0.905 / 0.887 / 0.895	0.869 / 0.914 / **0.891**
Kill	0.916 / 0.641 / 0.752	0.736 / 0.821 / 0.776
Live_In	0.664 / 0.601 / **0.629**	0.616 / 0.397 / 0.483
Located_In	0.675 / 0.567 / **0.583**	0.430 / 0.547 / 0.482
OrgBased_In	0.662 / 0.641 / **0.647**	0.849 / 0.361 / 0.506
Work_For	0.735 / 0.683 / **0.707**	0.516 / 0.421 / 0.464

	Level 3
Person	0.889 / 0.880 / 0.884
Location	0.914 / 0.744 / 0.811
Organisation	0.844 / 0.794 / 0.816
Kill	0.79 / 0.79 / **0.79**
Live_In	0.49 / 0.51 / 0.50
Located_In	0.45 / 0.24 / 0.32
OrgBased_In	0.67 / 0.55 / 0.61
Work_For	0.62 / 0.49 / 0.53

Table 23: Results of state-of-the-art methods and results of level three using linear support vector machines (precision / recall / F_1 score).

Table 23 shows a comparison of the results to standard state-of-the-art methods. As shown in the table, the model has comparable performances to the linear programming model utilized by Roth and Yih (2004) and to the card-pyramid model introdcued by Kate and Mooney (2010).

7 Conclusion and Future Work

Named entity classification and relation classification are two important tasks in Information Extraction that are heavily connected. The standard method of extracting entities and relations is defined as a pipeline model of two independent subtasks. With this separation, underlying dependencies and cross-task features are ignored. Incrementally joining entity and relation classification into one joint model is desirable not only due to possible utilization of cross-task dependencies but also to increase performance of the two tasks.

The goal of this thesis was the investigation of different levels of joining entity and relation classification. Four levels were hereto defined with an incremental increase of cross-task features per level. Level one uses the standard pipeline model of two sequential and independent subtasks. It achieved an F_1 score of 0.815 for entity classification and an F_1 score of 0.40 for relation classification across all classifiers. Level two includes the utilization of entity type information as features for relation extraction and increases the performance of relation extraction to an F_1 score of 0.51, whereas the entity classification uses the same model as level one. Level three uses relation type features as additional features for entity classification and increases the F_1 score of entity classification to 0.830. Relation classification uses the same model as level two and performs slight better with an F_1 score of 0.52 for relation classification across all classifiers.

Level four uses a completely joint model for both tasks. As the model only includes named entities that participate in relations, entity recognition and classification is not comparable to the other levels and is also not advised. Although good results for the prediction of relation arguments were achieved, the combination of two different arguments proved to be difficult resulting in a low F_1 score of 0.42, which while higher than level one, is still not on par with the models of level two and three. It could be proven however, that the enhancement of performance was indeed dependent on the usage of cross-task features. Thus, the model for level three saw better results than the model for level one.

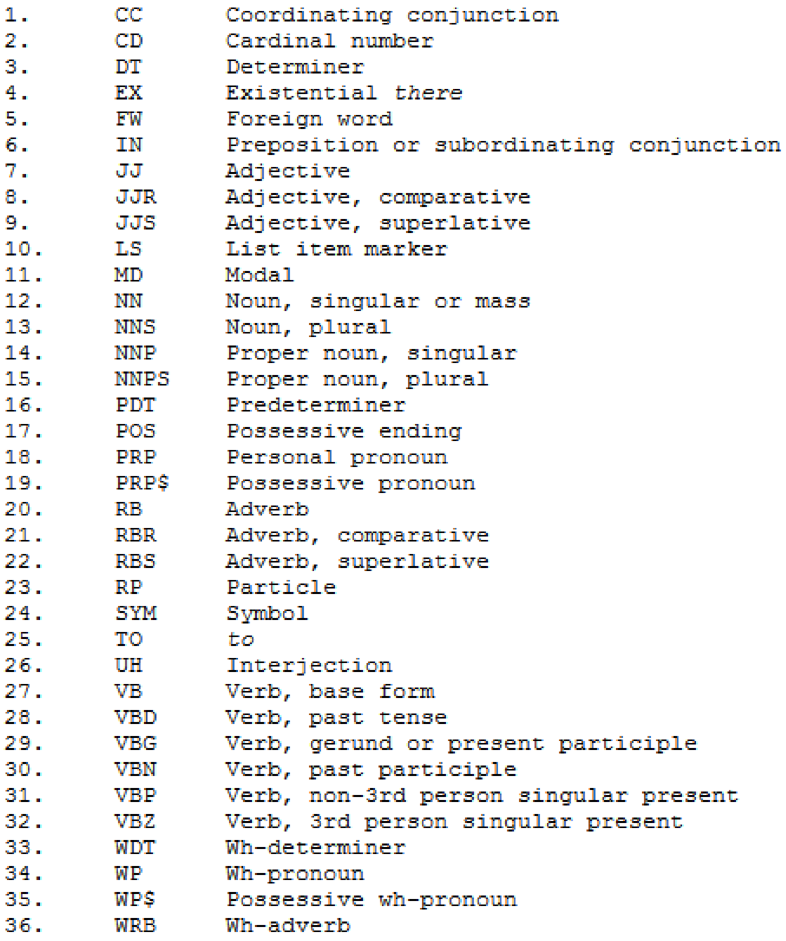
To sum up, the answer to the main research question of this thesis can be given as follows:

- Level three achieved the best results for both tasks.
- It used models which include cross-task features for both entity and relation classification.
- Those cross-task features were key to increase the performance.

7.1 Future Work

As for future work, improvements could be achieved by choosing additional features. Linear-chain CRFs rely heavily on features and thus, the correct choice of accurate features may improve the results of the model. Furthermore, the model for level four leaves much to be desired. The model should be capable of extracting named entities and relations more accurately and not exclude named entities from the data set by applying a more detailed tagging scheme as described earlier. Hyperparameter optimization should be done for all classifiers of each level as classifiers perform much better when optimized. Eventually, the models could be extended to apply deep learning methods as recent works using neural networks massively improve performance for relation extraction.

8 Appendix



1.	CC	Coordinating conjunction
2.	CD	Cardinal number
3.	DT	Determiner
4.	EX	Existential *there*
5.	FW	Foreign word
6.	IN	Preposition or subordinating conjunction
7.	JJ	Adjective
8.	JJR	Adjective, comparative
9.	JJS	Adjective, superlative
10.	LS	List item marker
11.	MD	Modal
12.	NN	Noun, singular or mass
13.	NNS	Noun, plural
14.	NNP	Proper noun, singular
15.	NNPS	Proper noun, plural
16.	PDT	Predeterminer
17.	POS	Possessive ending
18.	PRP	Personal pronoun
19.	PRP$	Possessive pronoun
20.	RB	Adverb
21.	RBR	Adverb, comparative
22.	RBS	Adverb, superlative
23.	RP	Particle
24.	SYM	Symbol
25.	TO	*to*
26.	UH	Interjection
27.	VB	Verb, base form
28.	VBD	Verb, past tense
29.	VBG	Verb, gerund or present participle
30.	VBN	Verb, past participle
31.	VBP	Verb, non-3rd person singular present
32.	VBZ	Verb, 3rd person singular present
33.	WDT	Wh-determiner
34.	WP	Wh-pronoun
35.	WP$	Possessive wh-pronoun
36.	WRB	Wh-adverb

Figure 11: List of part of speech tags Taylor et al. (2003)

	Classifier	Regulation	Class_Weight
Level 1-3	CRF	$c1 = 0.146$, $c2 = 0.046$	-
	LinearSVC	$C = 1$, penalty= $l2$	*None*
	DTC	-	*None*
	Perceptron	max_iter=50, alpha=0.0001	*None*
	SGDC	loss=hinge, penalty= $l2$	*Balanced*
	MaxEnt	$C = 1$, penalty= $l2$	*Balanced*
Level 4	CRF_Live_In	$c1 = 0.072$, $c2 = 0.023$	-
	CRF_Located_In	$c1 = 0.007$, $c2 = 0.081$	-
	CRF_Kill	$c1 = 0.070$, $c2 = 0.029$	-
	CRF_OrgBased_In	$c1 = 0.210$, $c2 = 0.039$	-
	CRF_Work_For	$c1 = 0.572$, $c2 = 0.009$	-

Table 24: Hyperparameter optimization results

Table 24 provides the results of hyperparameter optimization. All CRFs use gradient descent with the L-BFGS method and 100 iterations.

Level	**All Entities**	Accuracy
Level 4	0.822 / 0.382 / 0.513	0.849

Table 25: Results of entity classification with all entity types (including *Other*) on the test set (precision / recall / F_1 score) for level four

	Level 4
Person	0.947 / 0.548 / 0.451
Location	0.991 / 0.369 / 0.535
Organisation	0.873 / 0.367 / 0.513

Table 26: Results of entity classification with named entity types (excluding *Other*) on the test set (precision / recall / F_1 score) for level four

		CRF_Dev P/R/F1	CRF_Test P/R/F1	CRF_Test_Graph P/R/F1
Live_In	Live_InARG1+B	0.71/0.38/0.50	0.79/0.40/0.53	0.82/0.43/0.56
	Live_InARG1+I	0.80/0.24/0.36	0.85/0.46/0.59	1.00/0.50/0.67
	Live_InARG1+L	0.71/0.38/0.49	0.79/0.42/0.55	0.85/0.46/0.59
	Live_InARG1+U	0.00/0.00/0.00	1.00/0.05/0.10	1.00/0.05/0.10
	Live_InARG2+B	0.76/0.63/0.68	0.85/0.58/0.69	0.88/0.60/0.72
	Live_InARG2+I	0.87/0.79/0.83	0.92/0.88/0.90	0.92/0.88/0.90
	Live_InARG2+L	0.76/0.63/0.68	0.85/0.57/0.68	0.88/0.59/0.71
	Live_InARG2+U	0.48/0.18/0.26	0.33/0.11/0.17	0.31/0.09/0.14
	avg/total	**0.68/0.42/0.51**	**0.78/0.44/0.54**	**0.81/0.56/0.57**
Loc_In	Loc_In-ARG1+B	1.00/0.21/0.35	0.60/0.21/0.32	0.70/0.25/0.37
	Loc_In-ARG1+I	1.00/0.08/0.14	0.00/0.00/0.00	0.80/0.28/0.41
	Loc_In-ARG1+L	1.00/0.20/0.33	0.70/0.24/0.36	0.80/0.28/0.41
	Loc_In-ARG1+U	0.50/0.20/0.29	0.78/0.21/0.33	0.88/0.27/0.41
	Loc_In-ARG2+B	0.83/0.24/0.37	0.40/0.13/0.20	0.50/0.13/0.21
	Loc_In-ARG2+I	0.00/0.00/0.00	0.00/0.00/0.00	0.00/0.00/0.00
	Loc_In-ARG2+L	0.83/0.25/0.38	0.40/0.14/0.21	0.50/0.14/0.22
	Loc_In-ARG2+U	0.68/0.60/0.64	0.83/0.56/0.67	0.87/0.54/0.67
	avg/total	**0.78/0.30/0.39**	**0.66/0.29/0.39**	**0.78/0.32/0.44**
Work_For	Work_ForARG1+B	0.60/0.34/0.44	0.66/0.44/0.53	0.66/0.44/0.53
	Work_ForARG1+I	0.67/0.43/0.52	0.69/0.56/0.62	0.78/0.44/0.56
	Work_ForARG1+L	0.66/0.37/0.47	0.65/0.50/0.57	0.67/0.47/0.55
	Work_ForARG1+U	0.00/0.00/0.00	0.75/0.30/0.43	0.75/0.30/0.43
	Work_ForARG2+B	0.55/0.20/0.29	0.53/0.44/0.49	0.50/0.35/0.41
	Work_ForARG2+I	0.65/0.23/0.34	0.43/0.35/0.39	0.37/0.31/0.33
	Work_ForARG2+L	0.55/0.20/0.30	0.55/0.42/0.47	0.58/0.40/0.47
	Work_ForARG2+U	0.80/0.36/0.50	0.83/0.23/0.36	1.00/0.23/0.37
	avg/total	**0.59/0.27/0.37**	**0.59/0.42/0.48**	**0.60/0.38/0.46**
Org_In	Org_InARG1+B	0.86/0.36/0.51	0.73/0.38/0.50	0.83/0.40/0.54
	Org_InARG1+I	0.73/0.17/0.27	0.72/0.33/0.45	0.82/0.35/0.49
	Org_InARG1+L	0.86/0.35/0.49	0.85/0.44/0.58	0.88/0.40/0.55
	Org_InARG1+U	0.61/0.64/0.62	0.70/0.53/0.60	0.81/0.43/0.57
	Org_InARG2+B	1.00/0.27/0.42	1.00/0.46/0.63	1.00/0.42/0.59
	Org_InARG2+I	0.00/0.00/0.00	1.00/0.25/0.40	1.00/0.13/0.22
	Org_InARG2+L	1.00/0.31/0.47	1.00/0.45/0.63	1.00/0.46/0.63
	Org_InARG2+U	0.74/0.38/0.51	0.74/0.36/0.57	0.71/0.43/0.54
	avg/total	**0.80/0.34/0.46**	**0.80/0.43/0.55**	**0.84/0.40/0.54**
Kill	Kill-ARG1+B	0.97/0.88/0.92	0.94/0.82/0.88	0.91/0.82/0.86
	Kill-ARG1+I	0.96/0.86/0.91	1.00/0.81/0.89	0.96/0.84/0.90
	Kill-ARG1+L	0.97/0.88/0.92	0.94/0.82/0.88	0.91/0.82/0.86
	Kill-ARG1+U	1.00/0.64/0.78	1.00/0.86/0.92	0.88/1.00/0.93
	Kill-ARG2+B	1.00/0.72/0.84	0.86/0.76/0.81	0.89/0.73/0.80
	Kill-ARG2+I	1.00/0.93/0.96	0.94/0.90/0.92	0.96/0.86/0.90
	Kill-ARG2+L	1.00/0.72/0.84	0.86/0.76/0.81	0.89/0.73/0.80
	Kill-ARG2+U	1.00/0.76/0.86	0.92/0.86/0.89	0.92/0.79/0.85
	avg/total	**0.99/0.81/0.89**	**0.93/0.82/0.87**	**0.92/0.81/0.86**

Table 27: Results of relation arguments on the data set using the model for level four (precision / recall / F_1 score)

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All links were last followed on September 24, 2018.

Declaration

I hereby declare that the work presented in this thesis is entirely my own and that I did not use any other sources and references than the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

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