

A Survey on Recent Approaches for Natural Language Processing in Low-Resource Scenarios

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Abstract

Deep neural networks and huge language models are becoming omnipresent in natural language applications. As they are known for requiring large amounts of training data, there is a growing body of work to improve the performance in low-resource settings. Motivated by the recent fundamental changes towards neural models and the popular pre-train and fine-tune paradigm, we survey promising approaches for low-resource natural language processing. After a discussion about the different dimensions of data availability, we give a structured overview of methods that enable learning when training data is sparse. This includes mechanisms to create additional labeled data like data augmentation and distant supervision as well as transfer learning settings that reduce the need for target supervision. A goal of our survey is to explain how these methods differ in their requirements as understanding them is essential for choosing a technique suited for a specific low-resource setting. Further key aspects of this work are to highlight open issues and to outline promising directions for future research.

1 Introduction

Most of today’s research in natural language processing (NLP) is concerned with the processing of 10 to 20 high-resource languages with a special focus on English, and thus, ignores thousands of languages with billions of speakers (Bender, 2019). The rise of data-hungry deep learning systems increased the performance of NLP for high resource-languages, but the shortage of large-scale data in less-resourced languages makes their processing a challenging problem. Therefore, Ruder (2019) named NLP for low-resource scenarios one of the four biggest open problems in NLP nowadays.

The umbrella term low-resource covers a spectrum of scenarios with varying resource conditions.

It includes work on threatened languages, such as Yongning Na, a Sino-Tibetan language with 40k speakers and only 3k written, unlabeled sentences (Adams et al., 2017). Other languages are widely spoken but seldom addressed by NLP research. More than 310 languages exist with at least one million L1-speakers each (Eberhard et al., 2019). Similarly, Wikipedia exists for 300 languages.¹ Supporting technological developments for low-resource languages can help to increase participation of the speakers’ communities in a digital world. Note, however, that tackling low-resource settings is even crucial when dealing with popular NLP languages as low-resource settings do not only concern languages but also non-standard domains and tasks, for which – even in English – only little training data is available. Thus, the term “language” in this paper also includes domain-specific language.

This importance of low-resource scenarios and the significant changes in NLP in the last years have led to active research on resource-lean settings and a wide variety of techniques have been proposed. They all share the motivation of overcoming the lack of labeled data by leveraging further sources. However, these works differ greatly on the sources they rely on, e.g., unlabeled data, manual heuristics or cross-lingual alignments. Understanding the requirements of these methods is essential for choosing a technique suited for a specific low-resource setting. Thus, one key goal of this survey is to highlight the underlying assumptions these techniques take regarding the low-resource setup.

In this work, we (1) give a broad and structured overview of current efforts on low-resource NLP, (2) analyse the different aspects of low-resource settings, (3) highlight the necessary resources and data assumptions as guidance for practitioners and (4) discuss open issues and promising future direc-

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¹https://en.wikipedia.org/wiki/List_of_Wikipedias

Method	Requirements	Outcome	For low-resource	
			languages	domains
Data Augmentation (§ 4.1)	labeled data, heuristics*	additional labeled data	✓	✓
Distant Supervision (§ 4.2)	unlabeled data, heuristics*	additional labeled data	✓	✓
Cross-lingual projections (§ 4.3)	unlabeled data, high-resource labeled data, cross-lingual alignment	additional labeled data	✓	✗
Embeddings & Pre-trained LMs (§ 5.1)	unlabeled data	better language representation	✓	✓
LM domain adaptation (§ 5.2)	existing LM, unlabeled domain data	domain-specific language representation	✗	✓
Multilingual LMs (§ 5.3)	multilingual unlabeled data	multilingual feature representation	✓	✗
Adversarial Discriminator (§ 6)	additional datasets	independent representations	✓	✓
Meta-Learning (§ 6)	multiple auxiliary tasks	better target task performance	✓	✓

Table 1: Overview of low-resource methods surveyed in this paper. * Heuristics are typically gathered manually.

tions. Table 1 gives an overview of the surveyed techniques along with their requirements a practitioner needs to take into consideration.

2 Related Surveys

Recent surveys cover low-resource machine translation (Liu et al., 2019) and unsupervised domain adaptation (Ramponi and Plank, 2020). Thus, we do not investigate these topics further in this paper, but focus instead on general methods for low-resource, supervised natural language processing including data augmentation, distant supervision and transfer learning. This is also in contrast to the task-specific survey by Magueresse et al. (2020) who review highly influential work for several extraction tasks, but only provide little overview of recent approaches. In Table 2 in the appendix, we list past surveys that discuss a specific method or low-resource language family for those readers who seek a more specialized follow-up.

3 Aspects of “Low-Resource”

To visualize the variety of resource-lean scenarios, Figure 1 shows exemplarily which NLP tasks were addressed in six different languages from basic to higher-level tasks. While it is possible to build English NLP systems for many higher-level applications, low-resource languages lack the data foundation for this. Additionally, even if it is possible to create basic systems for tasks, such as tokenization and named entity recognition, for all tested low-resource languages, the training data is typical of lower quality compared to the English datasets,

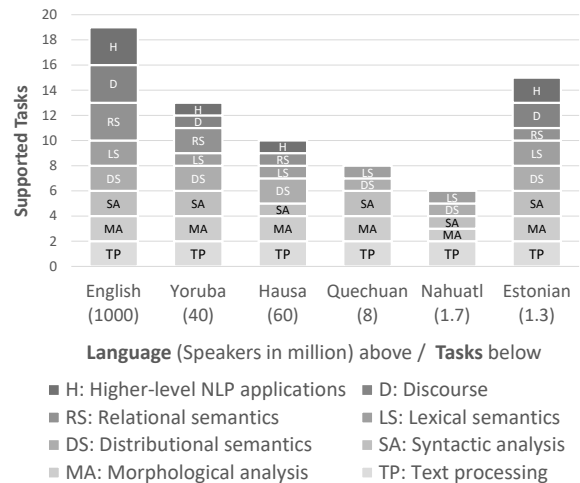


Figure 1: Supported NLP tasks in different languages. Note that the figure does not incorporate data quality or system performance. More details on the selection of tasks and languages are given in the appendix Section B.

or very limited in size. It also shows that the four American and African languages with between 1.5 and 60 million speakers have been addressed less than the Estonian language, with 1 million speakers. This indicates the unused potential to reach millions of speakers who currently have no access to higher-level NLP applications. Joshi et al. (2020) study further the availability of resources for languages around the world.

3.1 Dimensions of Resource Availability

Many techniques presented in the literature depend on certain assumptions about the low-resource sce-

nario. These have to be adequately defined to evaluate their applicability for a specific setting and to avoid confusion when comparing different approaches. We propose to categorize low-resource settings along the following three dimensions:

(i) The **availability of task-specific labels** in the target language (or target domain) is the most prominent dimension in the context of supervised learning. Labels are usually created through manual annotation, which can be both time- and cost-intensive. Not having access to adequate experts to perform the annotation can also be an issue for some languages and domains.

(ii) The **availability of unlabeled language- or domain-specific text** is another factor, especially as most modern NLP approaches are based on some form of input embeddings trained on unlabeled texts.

(iii) Most of the ideas surveyed in the next sections assume the **availability of auxiliary data** which can have many forms. Transfer learning might leverage task-specific labels in a different language or domain. Distant supervision utilizes external sources of information, such as knowledge bases or gazetteers. Some approaches require other NLP tools in the target language like machine translation to generate training data. It is essential to consider this as results from one low-resource scenario might not be transferable to another one if the assumptions on the auxiliary data are broken.

3.2 How Low is Low-Resource?

On the dimension of task-specific labels, different thresholds are used to define low-resource. For part-of-speech (POS) tagging, [Garrette and Baldrige \(2013\)](#) limit the time of the annotators to 2 hours resulting in up to 1-2k tokens. [Kann et al. \(2020\)](#) study languages that have less than 10k labeled tokens in the Universal Dependency project ([Nivre et al., 2020](#)) and [Loubser and Puttkammer \(2020\)](#) report that most available datasets for South African languages have 40-60k labeled tokens.

The threshold is also task-dependent and more complex tasks might also increase the resource requirements. For text generation, [Yang et al. \(2019\)](#) frame their work as low-resource with 350k labeled training instances. Similar to the task, the resource requirements can also depend on the language. [Plank et al. \(2016\)](#) find that task performance varies between language families given the same amount of limited training data.

Given the lack of a hard threshold for low-resource settings, we see it as a spectrum of resource availability. We, therefore, also argue that more work should evaluate low-resource techniques across different levels of data availability for better comparison between approaches. For instance, [Plank et al. \(2016\)](#) and [Melamud et al. \(2019\)](#) show that for very small datasets non-neural methods outperform more modern approaches while the latter obtain better performance in resource-lean scenarios once a few hundred labeled instances are available.

4 Generating Additional Labeled Data

Faced with the lack of task-specific labels, a variety of approaches have been developed to find alternative forms of labeled data as substitutes for gold-standard supervision. This is usually done through some form of expert insights in combination with automation. We group the ideas into two main categories: data augmentation which uses task-specific instances to create more of them (§ 4.1) and distant supervision which labels unlabeled data (§ 4.2) including cross-lingual projections (§ 4.3). Additional sections cover learning with noisy labels (§ 4.4) and involving non-experts (§ 4.5).

4.1 Data Augmentation

New instances can be obtained based on existing ones by modifying the features with transformations that do not change the label. In the computer vision community, this is a popular approach where, e.g., rotating an image is invariant to the classification of an image’s content. For text, on the token level, this can be done by replacing words with equivalents, such as synonyms ([Wei and Zou, 2019](#)), entities of the same type ([Raiman and Miller, 2017](#); [Dai and Adel, 2020](#)) or words that share the same morphology ([Gulordava et al., 2018](#); [Vania et al., 2019](#)). Such replacements can also be guided by a language model that takes context into consideration ([Fadaee et al., 2017](#); [Kobayashi, 2018](#)).

To go beyond the token level and add more diversity to the augmented sentences, data augmentation can also be performed on sentence parts. Operations that (depending on the task) do not change the label include manipulation of parts of the dependency tree ([Şahin and Steedman, 2018](#); [Vania et al., 2019](#); [Dehouck and Gómez-Rodríguez, 2020](#)), simplification of sentences by removal of sentence parts ([Şahin and Steedman, 2018](#)) and inversion

of the subject-object relation (Min et al., 2020). For whole sentences, paraphrasing through back-translation can be used. This is a popular approach in machine translation where target sentences are back-translated into source sentences (Bojar and Tamchyna, 2011; Hoang et al., 2018). An important aspect here is that errors in the source side/features do not seem to have a large negative effect on the generated target text the model needs to predict. It is therefore also used in other text generation tasks like abstract summarization (Parida and Motlicek, 2019) and table-to-text generation (Ma et al., 2019). Back-translation has also been leveraged for text classification (Xie et al., 2020; Hegde and Patil, 2020). This setting assumes, however, the availability of a translation system. Instead, a language model can also be used for augmenting text classification datasets (Kumar et al., 2020; Anaby-Tavor et al., 2020). It is trained conditioned on a label, i.e., on the subset of the task-specific data with this label. It then generates additional sentences that fit this label. Ding et al. (2020) extend this idea for token level tasks.

Adversarial methods are often used to find weaknesses in machine learning models (Jin et al., 2020; Garg and Ramakrishnan, 2020). They can, however, also be utilized to augment NLP datasets (Yasunaga et al., 2018; Morris et al., 2020). Instead of manually crafted transformation rules, these methods learn how to apply small perturbations to the input data that do not change the meaning of the text (according to a specific score). This approach is often applied on the level of vector representations. For instance, Grundkiewicz et al. (2019) reverse the augmentation setting by applying transformations that flip the (binary) label. In their case, they introduce errors in correct sentences to obtain new training data for a grammar correction task.

Open Issues: While data augmentation is ubiquitous in the computer vision community and while most of the above-presented approaches are task-independent, it has not found such widespread use in natural language processing. A reason might be that several of the approaches require an in-depth understanding of the language. There is not yet a unified framework that allows applying data augmentation across tasks and languages. Recently, Longpre et al. (2020) hypothesised that data augmentation provides the same benefits as pre-training in transformer models. However, we argue that data augmentation might be better suited to

leverage the insights of linguistic or domain experts in low-resource settings when unlabeled data or hardware resources are limited.

4.2 Distant & Weak Supervision

In contrast to data augmentation, distant or weak supervision uses unlabeled text and keeps it unmodified. The corresponding labels are obtained through a (semi-)automatic process from an external source of information. For named entity recognition (NER), a list of location names might be obtained from a dictionary and matches of tokens in the text with entities in the list are automatically labeled as locations. Distant supervision was introduced by Mintz et al. (2009) for relation extraction (RE) with extensions on multi-instance (Riedel et al., 2010) and multi-label learning (Surdanu et al., 2012). It is still a popular approach for information extraction tasks like NER and RE where the external information can be obtained from knowledge bases, gazetteers, dictionaries and other forms of structured knowledge sources (Luo et al., 2017; Hedderich and Klakow, 2018; Deng and Sun, 2019; Alt et al., 2019; Ye et al., 2019; Lange et al., 2019a; Nooralahzadeh et al., 2019; Le and Titov, 2019; Cao et al., 2019; Lison et al., 2020; Hedderich et al., 2021a). The automatic annotation ranges from simple string matching (Yang et al., 2018) to complex pipelines including classifiers and manual steps (Norman et al., 2019). This distant supervision using information from external knowledge sources can be seen as a subset of the more general approach of labeling rules. These encompass also other ideas like reg-ex rules or simple programming functions (Ratner et al., 2017; Zheng et al., 2019; Adelani et al., 2020; Hedderich et al., 2020; Lison et al., 2020; Ren et al., 2020; Karamanolakis et al., 2021).

While distant supervision is popular for information extraction tasks like NER and RE, it is less prevalent in other areas of NLP. Nevertheless, distant supervision has also been successfully employed for other tasks by proposing new ways for automatic annotation. Li et al. (2012) leverage a dictionary of POS tags for classifying unseen text with POS. For aspect classification, Karamanolakis et al. (2019) create a simple bag-of-words classifier on a list of seed words and train a deep neural network on its weak supervision. Wang et al. (2019) use context by transferring a document-level sentiment label to all its sentence-level in-

stances. [Mekala et al. \(2020\)](#) leverage meta-data for text classification and [Huber and Carenini \(2020\)](#) build a discourse-structure dataset using guidance from sentiment annotations. For topic classification, heuristics can be used in combination with inputs from other classifiers like NER ([Bach et al., 2019](#)) or from entity lists ([Hedderich et al., 2020](#)). For some classification tasks, the labels can be rephrased with simple rules into sentences. A pre-trained language model then judges the label sentence that most likely follows the unlabeled input ([Opitz, 2019](#); [Schick and Schütze, 2020](#); [Schick et al., 2020](#)). An unlabeled review, for instance, might be continued with "It was great/bad" for obtaining binary sentiment labels.

Open Issues: The popularity of distant supervision for NER and RE might be due to these tasks being particularly suited. There, auxiliary data like entity lists is readily available and distant supervision often achieves reasonable results with simple surface form rules. It is an open question whether a task needs to have specific properties to be suitable for this approach. The existing work on other tasks and the popularity in other fields like image classification ([Xiao et al., 2015](#); [Li et al., 2017](#); [Lee et al., 2018](#); [Mahajan et al., 2018](#); [Li et al., 2020](#)) suggests, however, that distant supervision could be leveraged for more NLP tasks in the future.

Distant supervision methods heavily rely on auxiliary data. In a low-resource setting, it might be difficult to obtain not only labeled data but also such auxiliary data. [Kann et al. \(2020\)](#) find a large gap between the performance on high-resource and low-resource languages for POS tagging pointing to the lack of high-coverage and error-free dictionaries for the weak supervision in low-resource languages. This emphasizes the need for evaluating such methods in a realistic setting and avoiding to just simulate restricted access to labeled data in a high-resource language.

While distant supervision allows obtaining labeled data more quickly than manually annotating every instance of a dataset, it still requires human interaction to create automatic annotation techniques or to provide labeling rules. This time and effort could also be spent on annotating more gold label data, either naively or through an active learning scheme. Unfortunately, distant supervision papers rarely provide information on how long the creation took, making it difficult to compare these approaches. Taking the human expert into the

focus connects this research direction with human-computer-interaction and human-in-the-loop setups ([Klie et al., 2018](#); [Qian et al., 2020](#)).

4.3 Cross-Lingual Annotation Projections

For cross-lingual projections, a task-specific classifier is trained in a high-resource language. Using parallel corpora, the unlabeled low-resource data is then aligned to its equivalent in the high-resource language where labels can be obtained using the aforementioned classifier. These labels (on the high-resource text) can then be projected back to the text in the low-resource language based on the alignment between tokens in the parallel texts ([Yarowsky et al., 2001](#)). This approach can, therefore, be seen as a form of distant supervision specific for obtaining labeled data for low-resource languages. Cross-lingual projections have been applied in low-resource settings for tasks, such as POS tagging and parsing ([Täckström et al., 2013](#); [Wisniewski et al., 2014](#); [Plank and Agić, 2018](#); [Eskander et al., 2020](#)). Sources for parallel text can be the OPUS project ([Tiedemann, 2012](#)), Bible corpora ([Mayer and Cysouw, 2014](#); [Christodoulopoulos and Steedman, 2015](#)) or the recent JW300 corpus ([Agić and Vulić, 2019](#)). Instead of using parallel corpora, existing high-resource labeled datasets can also be machine-translated into the low-resource language ([Khalil et al., 2019](#); [Zhang et al., 2019a](#); [Fei et al., 2020](#); [Amjad et al., 2020](#)). Cross-lingual projections have even been used with English as a target language for detecting linguistic phenomena like modal sense and telicity that are easier to identify in a different language ([Zhou et al., 2015](#); [Marasović et al., 2016](#); [Friedrich and Gateva, 2017](#)).

Open issues: Cross-lingual projections set high requirements on the auxiliary data needing both labels in a high-resource language and means to project them into a low-resource language. Especially the latter can be an issue as machine translation by itself might be problematic for a specific low-resource language. A limitation of the parallel corpora is their domains like political proceedings or religious texts. [Mayhew et al. \(2017\)](#), [Fang and Cohn \(2017\)](#) and [Karamanolakis et al. \(2020\)](#) propose systems with fewer requirements based on word translations, bilingual dictionaries and task-specific seed words, respectively.

4.4 Learning with Noisy Labels

The above-presented methods allow obtaining labeled data quicker and cheaper than manual annotations. These labels tend, however, to contain more errors. Even though more training data is available, training directly on this noisily-labeled data can actually hurt the performance. Therefore, many recent approaches for distant supervision use a noise handling method to diminish the negative effects of distant supervision. We categorize these into two ideas: noise filtering and noise modeling.

Noise filtering methods remove instances from the training data that have a high probability of being incorrectly labeled. This often includes training a classifier to make the filtering decision. The filtering can remove the instances completely from the training data, e.g., through a probability threshold (Jia et al., 2019), a binary classifier (Adel and Schütze, 2015; Onoe and Durrett, 2019; Huang and Du, 2019), or the use of a reinforcement-based agent (Yang et al., 2018; Nooralahzadeh et al., 2019). Alternatively, a soft filtering might be applied that re-weights instances according to their probability of being correctly labeled (Le and Titov, 2019) or an attention measure (Hu et al., 2019).

The noise in the labels can also be modeled. A common model is a confusion matrix estimating the relationship between clean and noisy labels (Fang and Cohn, 2016; Luo et al., 2017; Hedderich and Klakow, 2018; Paul et al., 2019; Lange et al., 2019a,c; Chen et al., 2019; Wang et al., 2019; Hedderich et al., 2021b). The classifier is no longer trained directly on the noisily-labeled data. Instead, a noise model is appended which shifts the noisy to the (unseen) clean label distribution. This can be interpreted as the original classifier being trained on a “cleaned” version of the noisy labels. In Ye et al. (2019), the prediction is shifted from the noisy to the clean distribution during testing. In Chen et al. (2020a), a group of reinforcement agents relabels noisy instances. Rehbein and Ruppenhofer (2017), Lison et al. (2020) and Ren et al. (2020) leverage several sources of distant supervision and learn how to combine them.

In NER, the noise in distantly supervised labels tends to be false negatives, i.e., mentions of entities that have been missed by the automatic method. Partial annotation learning (Yang et al., 2018; Nooralahzadeh et al., 2019; Cao et al., 2019) takes this into account explicitly. Related approaches learn latent variables (Jie et al., 2019), use

constrained binary learning (Mayhew et al., 2019) or construct a loss assuming that only unlabeled positive instances exist (Peng et al., 2019).

4.5 Non-Expert Support

As an alternative to an automatic annotation process, annotations might also be provided by non-experts. Similar to distant supervision, this results in a trade-off between label quality and availability. For instance, Garrette and Baldridge (2013) obtain labeled data from non-native-speakers and without a quality control on the manual annotations. This can be taken even further by employing annotators who do not speak the low-resource language (Mayhew and Roth, 2018; Mayhew et al., 2019; Tsygankova et al., 2020).

Nekoto et al. (2020) take the opposite direction, integrating speakers of low-resource languages without formal training into the model development process in an approach of participatory research. This is part of recent work on how to strengthen low-resource language communities and grassroots approaches (Alnajjar et al., 2020; Adelani et al., 2021).

5 Transfer Learning

While distant supervision and data augmentation generate and extend task-specific training data, transfer learning reduces the need for labeled target data by transferring learned representations and models. A strong focus in recent works on transfer learning in NLP lies in the use of pre-trained language representations that are trained on unlabeled data like BERT (Devlin et al., 2019). Thus, this section starts with an overview of these methods (§ 5.1) and then discusses how they can be utilized in low-resource scenarios, in particular, regarding the usage in domain-specific (§ 5.2) or multilingual low-resource settings (§ 5.3).

5.1 Pre-Trained Language Representations

Feature vectors are the core input component of many neural network-based models for NLP tasks. They are numerical representations of words or sentences, as neural architectures do not allow the processing of strings and characters as such. Collobert et al. (2011) showed that training these models for the task of language-modeling on a large-scale corpus results in high-quality word representations, which can be reused for other downstream tasks as well. Subword-based embeddings such as fastText

n-gram embeddings (Bojanowski et al., 2017) and byte-pair-encoding embeddings (Heinzerling and Strube, 2018) addressed out-of-vocabulary issues by splitting words into multiple subwords, which in combination represent the original word. Zhu et al. (2019) showed that these embeddings leveraging subword information are beneficial for low-resource sequence labeling tasks, such as named entity recognition and typing, and outperform word-level embeddings. Jungmaier et al. (2020) added smoothing to word2vec models to correct its bias towards rare words and achieved improvements in particular for low-resource settings. In addition, pre-trained embeddings were published for more than 270 languages for both embedding methods. This enabled the processing of texts in many languages, including multiple low-resource languages found in Wikipedia. More recently, a trend emerged of pre-training large embedding models using a language model objective to create context-aware word representations by predicting the next word or sentence. This includes pre-trained transformer models (Vaswani et al., 2017), such as BERT (Devlin et al., 2019) or RoBERTa (Liu et al., 2019b). These methods are particularly helpful for low-resource languages for which large amounts of unlabeled data are available, but task-specific labeled data is scarce (Cruz and Cheng, 2019).

Open Issues: While pre-trained language models achieve significant performance increases compared to standard word embeddings, it is still questionable if these methods are suited for real-world low-resource scenarios. For example, all of these models require large hardware requirements, in particular, considering that the transformer model size keeps increasing to boost performance (Raffel et al., 2020). Therefore, these large-scale methods might not be suited for low-resource scenarios where hardware is also low-resource.

Biljon et al. (2020) showed that low- to medium-depth transformer sizes perform better than larger models for low-resource languages and Schick and Schütze (2020) managed to train models with three orders of magnitude fewer parameters that perform on-par with large-scale models like GPT-3 on few-shot task by reformulating the training task and using ensembling. Melamud et al. (2019) showed that simple bag-of-words approaches are better when there are only a few dozen training instances or less for text classification, while more complex transformer models require more training

data. Bhattacharjee et al. (2020) found that cross-view training (Clark et al., 2018) leverages large amounts of unlabeled data better for task-specific applications in contrast to the general representations learned by BERT. Moreover, data quality for low-resource, even for unlabeled data, might not be comparable to data from high-resource languages. Alabi et al. (2020) found that word embeddings trained on larger amounts of unlabeled data from low-resource languages are not competitive to embeddings trained on smaller, but curated data sources.

5.2 Domain-Specific Pre-Training

The language of a specialized domain can differ tremendously from what is considered the standard language, thus, many text domains are often less-resourced as well. For example, scientific articles can contain formulas and technical terms, which are not observed in news articles. However, the majority of recent language models are pre-trained on general-domain data, such as texts from the news or web-domain, which can lead to a so-called “domain-gap” when applied to a different domain.

One solution to overcome this gap is the adaptation to the target domain by finetuning the language model. Gururangan et al. (2020) showed that continuing the training of a model with additional domain-adaptive and task-adaptive pre-training with unlabeled data leads to performance gains for both high- and low-resource settings for numerous English domains and tasks. This is also displayed in the number of domain-adapted language models (Alsentzer et al., 2019; Huang et al., 2019; Adhikari et al., 2019; Lee and Hsiang, 2020; Jain and Ganesamoorthy, 2020, (i.a.)), most notably BioBERT (Lee et al., 2020) that was pre-trained on biomedical PubMed articles and SciBERT (Beltagy et al., 2019) for scientific texts. For example, Friedrich et al. (2020) showed that a general-domain BERT model performs well in the materials science domain, but the domain-adapted SciBERT performs best. Xu et al. (2020) used in- and out-of-domain data to pre-train a domain-specific model and adapt it to low-resource domains. Aharoni and Goldberg (2020) found domain-specific clusters in pre-trained language models and showed how these could be exploited for data selection in domain-sensitive training.

Powerful representations can be achieved by combining high-resource embeddings from the gen-

eral domain with low-resource embeddings from the target domain (Akbik et al., 2018; Lange et al., 2019b). Kiela et al. (2018) showed that embeddings from different domains can be combined using attention-based meta-embeddings, which create a weighted sum of all embeddings. Lange et al. (2020b) further improved on this by aligning embeddings trained on diverse domains using an adversarial discriminator that distinguishes between the embedding spaces to generate domain-invariant representations.

5.3 Multilingual Language Models

Analogously to low-resource domains, low-resource languages can also benefit from labeled resources available in other high-resource languages. This usually requires the training of multilingual language representations by combining monolingual representations (Lange et al., 2020a) or training a single model for many languages, such as multilingual BERT (Devlin et al., 2019) or XLM-RoBERTa (Conneau et al., 2020). These models are trained using unlabeled, monolingual corpora from different languages and can be used in cross- and multilingual settings, due to many languages seen during pre-training.

In cross-lingual zero-shot learning, no task-specific labeled data is available in the low-resource target language. Instead, labeled data from a high-resource language is leveraged. A multilingual model can be trained on the target task in a high-resource language and afterwards, applied to the unseen target languages, such as for named entity recognition (Lin et al., 2019; Hvingelby et al., 2020), reading comprehension (Hsu et al., 2019), temporal expression extraction (Lange et al., 2020c), or POS tagging and dependency parsing (Müller et al., 2020). Hu et al. (2020) showed, however, that there is still a large gap between low and high-resource setting. Lauscher et al. (2020) and Hedderich et al. (2020) proposed adding a minimal amount of target-task and -language data (in the range of 10 to 100 labeled sentences) which resulted in a significant boost in performance for classification in low-resource languages.

The transfer between two languages can be improved by creating a common multilingual embedding space of multiple languages. This is useful for standard word embeddings (Ruder et al., 2019) as well as pre-trained language models. For example, by aligning the languages inside a single multilin-

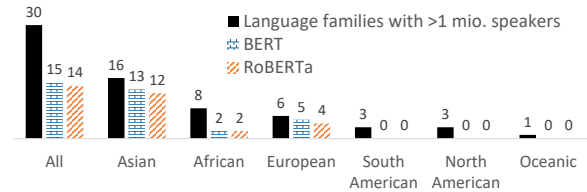


Figure 2: Language families with more than 1 million speakers covered by multilingual transformer models.

gual model, i.a., in cross-lingual (Schuster et al., 2019; Liu et al., 2019a) or multilingual settings (Cao et al., 2020).

This alignment is typically done by computing a mapping between two different embedding spaces, such that the words in both embeddings share similar feature vectors after the mapping (Mikolov et al., 2013; Joulin et al., 2018). This allows to use different embeddings inside the same model and helps when two languages do not share the same space inside a single model (Cao et al., 2020). For example, Zhang et al. (2019b) used bilingual representations by creating cross-lingual word embeddings using a small set of parallel sentences between the high-resource language English and three low-resource African languages, Swahili, Tagalog, and Somali, to improve document retrieval performance for the African languages.

Open Issues: While these multilingual models are a tremendous step towards enabling NLP in many languages, possible claims that these are universal language models do not hold. For example, mBERT covers 104 and XLM-R 100 languages, which is a third of all languages in Wikipedia as outlined earlier. Further, Wu and Dredze (2020) showed that, in particular, low-resource languages are not well-represented in mBERT. Figure 2 shows which language families with at least 1 million speakers are covered by mBERT and XLM-RoBERTa². In particular, African and American languages are not well-represented within the transformer models, even though millions of people speak these languages. This can be problematic, as languages from more distant language families are less suited for transfer learning, as Lauscher et al. (2020) showed.

²A language family is covered if at least one associated language is covered. Language families can belong to multiple regions, e.g., Indo-European belongs to Europe and Asia.

6 Ideas From Low-Resource Machine Learning in Non-NLP Communities

Training on a limited amount of data is not unique to natural language processing. Other areas, like general machine learning and computer vision, can be a useful source for insights and new ideas. We already presented data augmentation and pre-training. Another example is Meta-Learning (Finn et al., 2017), which is based on multi-task learning. Given a set of auxiliary high-resource tasks and a low-resource target task, meta-learning trains a model to decide how to use the auxiliary tasks in the most beneficial way for the target task. For NLP, this approach has been evaluated on tasks such as sentiment analysis (Yu et al., 2018), user intent classification (Yu et al., 2018; Chen et al., 2020b), natural language understanding (Dou et al., 2019), text classification (Bansal et al., 2020) and dialogue generation (Huang et al., 2020). Instead of having a set of tasks, Rahimi et al. (2019) built an ensemble of language-specific NER models which are then weighted depending on the zero- or few-shot target language.

Differences in the features between the pre-training and the target domain can be an issue in transfer learning, especially in neural approaches where it can be difficult to control which information the model takes into account. Adversarial discriminators (Goodfellow et al., 2014) can prevent the model from learning a feature-representation that is specific to a data source. Gui et al. (2017), Liu et al. (2017), Kasai et al. (2019), Griebhaber et al. (2020) and Zhou et al. (2019) learned domain-independent representations using adversarial training. Kim et al. (2017), Chen et al. (2018) and Lange et al. (2020c) worked with language-independent representations for cross-lingual transfer. These examples show the beneficial exchange of ideas between NLP and the machine learning community.

7 Discussion and Conclusion

In this survey, we gave a structured overview of recent work in the field of low-resource natural language processing. Beyond the method-specific open issues presented in the previous sections, we see the comparison between approaches as an important point of future work. Guidelines are necessary to support practitioners in choosing the right tool for their task. In this work, we highlighted that it is essential to analyze resource-lean scenarios across the different dimensions of data-availability.

This can reveal which techniques are expected to be applicable in a specific low-resource setting. More theoretic and experimental work is necessary to understand how approaches compare to each other and on which factors their effectiveness depends. Longpre et al. (2020), for instance, hypothesized that data augmentation and pre-trained language models yield similar kind of benefits. Often, however, new techniques are just compared to similar methods and not across the range of low-resource approaches. While a fair comparison is non-trivial given the different requirements on auxiliary data, we see this endeavour as essential to improve the field of low-resource learning in the future. This could also help to understand where the different approaches complement each other and how they can be combined effectively.

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A Existing Surveys on Low-Resource Topics and Languages

There is a growing body of task- and language-specific surveys concerning low-resource topics. We list these surveys in Table 2 as a starting point for a more in-depth reading regarding specific topics.

B Complexity of Tasks

While a large number of labeled resources for English are available for many popular NLP tasks, this is not the case for the majority of low-resource languages. To measure (and visualize as done in Figure 1 in the main paper) which applications are accessible to speakers of low-resource languages we examined resources for six different languages, ranging from high- to low-resource languages for a fixed set of tasks of varying complexity, ranging from basic tasks, such as tokenization, to higher-level tasks, such as question answering. For this short study, we have chosen the following languages. The number of speakers are the combined L1 and L2 speakers according to Eberhard et al. (2019).

- (1) English: The most high-resource language according to the common view and literature in the NLP community.
- (2) Yoruba: An African language, which is spoken by about 40 million speakers and contained in the EXTREME benchmark (Hu et al., 2020). Even with that many speakers, this language is often considered as a low-resource

language and it is still discussed whether this language is also endangered (Fabuni and Salawu, 2005).

- (3) Hausa: An African language with over 60 million speakers. It is not covered in EXTREME or the universal dependencies project (Nivre et al., 2020).
- (4) Quechua: A language family encompassing about 8 million speakers, mostly in Peru.
- (5) Nahuatl and (6) Estonian: Both have between 1 and 2 million speakers, but are spoken in very different regions (North America & Europe).

All speaker numbers according to Eberhard et al. (2019) reflecting the total number of users (L1 + L2). The tasks were chosen from a list of popular NLP tasks³. We selected two tasks for the lower-level groups and three tasks for the higher-level groups, which reflects the application diversity with increasing complexity. Table 3 shows which tasks were addressed for each language.

Word segmentation, lemmatization, part-of-speech tagging, sentence breaking and (semantic) parsing are covered for Yoruba and Estonian by treebanks from the universal dependencies project (Nivre et al., 2020). Cusco Quechua is listed as an upcoming language in the UD project, but no treebank is accessible at this moment. The WikiAnn corpus for named entity recognition (Pan et al., 2017) has resources and tools for NER and sentence breaking for all six languages. Lemmatization resources for Nahuatl were developed by Martínez-Gil et al. (2012) and Lozano et al. (2013) developed resources for part-of-speech tagging, tokenization and parsing of Quechuan. The CoNLL conference and SIGMORPHON organized two shared tasks for morphological reinflection which provided lemmatization resources for many languages, including Quechuan (Cotterell et al., 2018).

Basic resources for simple semantic role labeling and entity linking were developed during the LORELEI program for many low-resource languages (Strassel and Tracey, 2016; Tracey and Strassel, 2020), including resources for Yoruba and Hausa (even though the latter "fell short" according to the authors). Estonian coreference resolution is targeted by Kübler and Zhekova (2016), but

³https://en.wikipedia.org/wiki/Natural_language_processing#Common_NLP_Tasks

	Low-resource surveys	Cieri et al. (2016) , Magueresse et al. (2020)
<i>Method-specific</i>	Active learning	Olsson (2009), Settles (2009), Aggarwal et al. (2014)
	Distant supervision	Roth et al. (2013), Smirnova and Cudré-Mauroux (2018), Shi et al. (2019).
	Unsupervised domain adaptation	Wilson and Cook (2020), Ramponi and Plank (2020)
	Meta-Learning	Hospedales et al. (2020)
	Multilingual transfer	Steinberger (2012), Ruder et al. (2019)
	LM pre-training	Rogers et al. (2021), Qiu et al. (2020)
	Machine translation	Liu et al. (2019)
	Label noise handling	Frénay and Verleysen (2013), Algan and Ulusoy (2021)
	Transfer learning	Pan and Yang (2009), Weiss et al. (2016), Tan et al. (2018)
<i>Language-</i>	African languages	Grover et al. (2010), De Pauw et al. (2011)
	Arabic languages	Al-Ayyoub et al. (2018), Guellil et al. (2019), Younes et al. (2020)
	American languages	Mager et al. (2018)
	South-Asian languages	Daud et al. (2017), Banik et al. (2019), Harish and Rangan (2020)
	East-Asian languages	Yude (2011)

Table 2: Overview of existing surveys on low-resource topics.

the available resources are very limited. Estonian sentiment is done by Pajupuu et al. (2016). All languages are covered by the multilingual fasttext embeddings (Bojanowski et al., 2017) and byte-pair-encoding embeddings (Heinzerling and Strube, 2018). Yoruba, Hausa and Estonian are covered by mBERT or XLM-RoBERTa as well.

Text summarization is done for Estonian by Müürisep and Mutso (2005) and for Hausa by Bashir et al. (2017). The EXTREME benchmark (Hu et al., 2020) covers question answering and natural language inference tasks for Yoruba and Estonian (besides NER, POS tagging and more). Publicly available systems for optical character recognition support all six languages (Hakro et al., 2016). All these tasks are supported for the English language as well, and most often, the English datasets are many times larger and of much higher quality. Some of the previously mentioned datasets were automatically translated, as in the EXTREME benchmark for several languages. As outlined in the main paper, we do not claim that all tasks marked in the Table yield high-performance model, but we instead indicate if any resources or models can be found for a language.

Group	Task	Yoruba	Hausa	Quechuan	Nahuatl	Estonian
	Num-Speakers	40 mil.	60 mil.	8 mil.	1.7 mil.	1.3 mil.
Text processing	Word segmentation	✓	✓	✓	✓	✓
	Optical character recognition	Hakro et al. (2016)	Hakro et al. (2016)	Hakro et al. (2016)	Hakro et al. (2016)	Hakro et al. (2016)
Morphological analysis	Lemmatization / Stemming	Cotterell et al. (2018)	Cotterell et al. (2018)	Cotterell et al. (2018)	Martínez-Gil et al. (2012)	Cotterell et al. (2018)
	Part-of-Speech tagging	Nivre et al. (2020)	Tukur et al. (2019)	Lozano et al. (2013)	✓	Nivre et al. (2020)
Syntactic analysis	Sentence breaking	✓	✓	✓	✓	✓
	Parsing	Nivre et al. (2020)	✓	Nivre et al. (2020)	✓	Nivre et al. (2020)
Distributional semantics	Word embeddings	FT, BPEmb	FT, BPEmb	FT, BPEmb	FT, BPEmb	FT, BPEmb
	Transformer models	mBERT	XLN-R	✓	✓	mBERT, XLM-R
Lexical semantics	Named entity recognition	Adelani et al. (2020)	Adelani et al. (2020)	Pan et al. (2017)	Pan et al. (2017)	Tkachenko et al. (2013)
	Sentiment analysis	✓	✓	✓	✓	Pajupuu et al. (2016)
Relational semantics	Relationship extraction	✓	✓	✓	✓	✓
	Semantic Role Labelling	Tracey and Strassel (2020)	Tracey and Strassel (2020)	Tracey and Strassel (2020)	Tracey and Strassel (2020)	Tracey and Strassel (2020)
	Semantic Parsing	Nivre et al. (2020)	✓	✓	✓	Nivre et al. (2020)
Discourse	Coreference resolution	✓	✓	✓	✓	Kübler and Zhekova (2016)
	Discourse analysis	✓	✓	✓	✓	✓
	Textual entailment	Hu et al. (2020)	✓	✓	✓	Hu et al. (2020)
Higher-level NLP	Text summarization	✓	Bashir et al. (2017)	✓	✓	Müiriseip and Mutso (2005)
	Dialogue management	✓	✓	✓	✓	✓
	Question answering (QA)	Hu et al. (2020)	✓	✓	✓	Hu et al. (2020)
	SUM	13	10	8	6	15

Table 3: Overview of tasks covered by six different languages. Note that this list is non-exhaustive and due to space reasons we only give one reference per language and task.