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Foundations of Natural Language Processing and Deep Learning

In this book, we aim to unravel the complexities of Natural Language Processing (NLP) and its intersection with Deep Learning (DL). Our primary goal is to equip you with the knowledge and tools necessary to understand and apply these technologies in practical scenarios. Whether you're a novice or a seasoned professional, this book offers insights that can help you harness the power of AI-driven language processing in diverse fields such as healthcare, finance, and customer service.

This chapter serves as the foundation for the entire book. Here, you will be introduced to the evolution of NLP, highlighting its pivotal role in advancing Artificial Intelligence (AI) and Machine Learning (ML). We'll explore how NLP has transitioned from simple text parsing to sophisticated systems capable of understanding and generating human language with remarkable accuracy. This chapter sets the stage by outlining the key concepts and historical milestones that have shaped the field.

Further, we'll cover essential topics such as text classification, sentiment analysis, and the emergence of transformer models. These models, particularly transformers, have revolutionized how we approach language processing, enabling the handling of complex linguistic tasks with unprecedented efficiency. Understanding these fundamentals is crucial, as they form the basis for more advanced discussions in subsequent chapters.

By the end of this chapter, you will have a robust understanding of NLP concepts and their practical applications across various domains. You will also gain deep insights into the fundamentals of deep learning, specifically tailored for NLP tasks, and learn how integrating deep learning techniques can enhance the performance and capabilities of NLP systems. This foundational knowledge will serve as a springboard for exploring more complex applications and case studies in later chapters, ultimately empowering you to apply these technologies in real-world situations.

In this chapter, we will cover the following topics:

* Introduction to natural language processing and artificial intelligence
* Advanced concepts in NLP and deep learning
* Deep Learning Essentials for NLP
* Integration of NLP and Deep Learning

Introduction to natural language processing and artificial intelligence

In this section, we begin by exploring the symbiotic relationship between NLP and AI. NLP is not just a subset of AI but a driving force that enables machines to understand and interact with human language. This section will provide a foundational understanding of how NLP has evolved within the broader context of AI and Machine Learning (ML), the significance of these advancements, and the diverse applications that illustrate their impact.

**Why this matters:** Understanding the evolution of NLP is crucial for appreciating its current capabilities and potential future developments. By grasping the historical context and technological milestones, you will be better equipped to comprehend the complex systems that define today’s AI landscape. This section will cover three key areas: the historical evolution of NLP, its significance across various industries, and the advancements that have enabled its integration into AI systems.

**What you will learn:** We will first trace the journey of NLP from its early stages to its present-day significance within AI and ML. Next, we’ll explore the critical applications of NLP across different sectors, such as customer service, healthcare, and finance. Finally, we’ll delve into the advancements in deep learning that have revolutionized NLP, making it a cornerstone of modern AI.

Evolution of NLP within AI and ML

Natural Language Processing (NLP) has undergone significant transformations, evolving from basic computational linguistics into a core component of artificial intelligence (AI) and machine learning (ML) landscapes. The journey began in the mid-20th century when the focus was primarily on simple text parsing and keyword-based search methods.

Over the decades, advancements in algorithms, computational power, and data availability have pushed NLP to the forefront of AI technology, enabling systems capable of complex language understanding and interaction (Jurafsky & Martin, 2019).

Initially, NLP applications were limited due to computational constraints and simplistic models. Early efforts were rule-based, relying heavily on manual coding of language rules, which made them brittle and unable to scale. The introduction of machine learning models in the late 1980s and 1990s marked a pivotal shift, leading to more dynamic and context-aware systems. These models, trained on large text corpora, could generalize from past examples to handle a variety of language tasks (Manning et al., 1999).

The real transformation in NLP came with the advent of deep learning in the 2010s. Models like Long Short-Term Memory (LSTM) networks and, more recently, transformers (Vaswani et al., 2017) have enabled NLP systems to achieve remarkable levels of language understanding. This includes the ability to parse syntax and semantics over longer stretches of text and context, which has significantly enhanced the accuracy of machine translation, question-answering systems, and other language understanding applications.

Significance of NLP in diverse applications

NLP's applications are wide-ranging and have profound implications across various sectors. In **customer service**, chatbots and virtual assistants use NLP to interpret and respond to customer inquiries with increasing sophistication. For instance, systems like OpenAI's GPT-3 demonstrate an ability to maintain context over long dialogues, providing responses that are contextually relevant and highly interactive (Brown et al., 2020).

In the **healthcare sector**, NLP is revolutionizing information extraction from unstructured data such as clinical notes. By leveraging models trained on specialized medical data, these systems can identify relevant medical terms, extract patient histories, and even suggest diagnoses (Esteva et al., 2019). This capability is pivotal for enhancing patient care by providing timely and tailored medical insights.

The **finance industry** benefits from NLP by automating the extraction of insights from financial documents, regulatory filings, and real-time news updates. NLP systems can analyze sentiment, detect emerging trends, and monitor economic indicators to aid in decision-making processes (Bao & Datta, 2018).

Example: sentiment analysis using BERT

Sentiment analysis is a common NLP task where the goal is to determine the emotional tone behind a series of words. This is useful for determining the overall opinion from user feedback, social media posts, etc.

To illustrate the practical application of NLP models, we'll use a pretrained BERT (Bidirectional Encoder Representations from Transformers) model, which is widely recognized for its effectiveness in NLP tasks. Below is a simple Python example that demonstrates sentiment analysis using Hugging Face's Transformers library:

`` python

from transformers import BertTokenizer, BertForSequenceClassification  
 from transformers import pipeline

tokenizer = BertTokenizer.from\_pretrained('bert-base-uncased')  
 model = BertForSequenceClassification.from\_pretrained('bert-base-uncased')

nlp = pipeline("sentiment-analysis", model=model, tokenizer=tokenizer)

example\_text = "Hugging Face Transformers is incredibly simple to use. What an amazing library!"

result = nlp(example\_text)

print(f"Sentiment: {result[0]['label']}, with a confidence of {result[0]['score']:.4f}")

``

Let's dive into the details of the code snippet to understand it better:

* Library imports: We use transformers from Hugging Face, which provides access to BERT and other transformer models along with prebuilt functionalities like tokenization.
* Initializing tokenizer and model: The BertTokenizer and BertForSequenceClassification are loaded with a pretrained BERT model (bert-base-uncased). This model has been trained on a large corpus of uncapitalized English text and is adapted for sequence classification tasks.
* Setting up the pipeline: The pipeline function simplifies the application of tokenization, model prediction, and output generation. We specify the task as "sentiment-analysis".
* Running the model: We input an example sentence to the model. The pipeline processes the text, classifies it, and returns the sentiment along with the confidence score.

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Advanced concepts in NLP and deep learning

Natural Language Processing (NLP) and deep learning are vast fields that encompass a range of advanced concepts crucial for developing intelligent language models. Understanding the fundamental tasks in NLP is essential for grasping how deep learning models can be applied to solve complex language problems.

This subsection provides an overview of core NLP tasks, including text classification, named entity recognition (NER), and sentiment analysis. We will discuss how these tasks are implemented in real-world scenarios, emphasizing the role of advanced deep learning models in improving their effectiveness and accuracy.

Additionally, we will explore the transformative role of transformer models, a pivotal advancement that has significantly enhanced NLP capabilities.

Text Classification

Text classification involves categorizing text into predefined groups. It is fundamental in applications such as spam detection, where emails are classified into 'spam' or 'non-spam' categories, and sentiment analysis, where opinions in text are classified as positive, negative, or neutral. For instance, companies use sentiment analysis to monitor brand sentiment from customer reviews on social media and other online platforms. Advanced deep learning models, such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), have significantly improved the accuracy and efficiency of these tasks by capturing contextual nuances in text data (Kim, 2014; Zhou et al., 2016).

Named Entity Recognition (NER)

NER is crucial for information extraction where the aim is to identify predefined entities in text, such as person names, organizations, locations, and dates. This functionality is pivotal in enhancing content recommendations systems, automating customer support, and streamlining data entry processes in business applications. For example, in automated news aggregation services, NER helps categorize articles by extracting key entities like geopolitical entities and corporate names (Lample et al., 2016).

Sentiment Analysis

This involves analyzing text to detect subjective information such as the mood, opinions, and emotions expressed. It is widely used in business analytics to gauge public opinion, in financial markets to predict stock movements based on news sentiment, and in product analytics to understand customer satisfaction. Deep learning techniques, such as Long Short-Term Memory networks (LSTMs), have been effectively applied to improve the accuracy of sentiment detection over large and diverse datasets (Hochreiter & Schmidhuber, 1997).

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Transformative Role of Transformer Models in NLP

The introduction of transformer models by Vaswani et al. (2017) marked a revolutionary advancement in NLP. Unlike previous models reliant on sequential data processing, transformers use a mechanism known as 'attention' to weigh the influence of different words in a sentence, regardless of their positional distance. This allows the model to capture complex word dependencies and significantly improves the efficiency of language understanding tasks.

Transformers have been foundational in developing state-of-the-art models such as BERT (Bidirectional Encoder Representations from Transformers) and GPT (Generative Pretrained Transformer). BERT, for example, has set new standards for NER and question answering tasks by effectively understanding the context in which words appear (Devlin et al., 2019). GPT, on the other hand, has been utilized to generate coherent and contextually relevant text based on a given prompt, demonstrating remarkable capabilities in text generation tasks (Radford et al., 2019).

In this section, we delved into advanced NLP tasks and explored the impact of transformative deep learning models, particularly transformers. These insights are crucial for understanding the complexities and capabilities of modern NLP systems. Moving forward, we will now examine the practical applications of these models, focusing on how they are integrated into real-world systems to solve complex language processing challenges.

Example: Utilizing Hugging Face Diffusion for Text Classification

Text classification is a fundamental task in NLP where text is categorized into predefined labels. It's widely used in filtering spam, identifying topics in documents, or detecting sentiment in customer reviews. In this example, we'll demonstrate how to use the Hugging Face Transformers library to perform text classification with a state-of-the-art transformer model, specifically focusing on sentiment analysis.

``python

from transformers import pipeline  
  
classifier = pipeline('sentiment-analysis', model="distilbert-base-uncased-finetuned-sst-2-english")  
  
texts = ["I love using Hugging Face Transformers, they make NLP easy!",   
 "The movie was terrible and I was disappointed by the plot."]  
  
results = classifier(texts)  
  
for i, text in enumerate(texts):  
 print(f"Text: {text}\nSentiment: {results[i]['label']} with a confidence of {results[i]['score']:.4f}\n")

Let's dive into the details of the code snippet to understand it better:

* Library Import**:** We import the pipeline function from Hugging Face's transformers library, which provides high-level utilities for accomplishing various NLP tasks.
* **Initializing the Pipeline:** The pipeline is set up for sentiment analysis using "distilbert-base-uncased-finetuned-sst-2-english," a lighter version of BERT that is pre-trained and fine-tuned on a sentiment analysis task (Stanford Sentiment Treebank).
* **Processing Texts:** We input a list of texts to the model. The pipeline handles tokenization, and model inference and returns the sentiment classification and confidence score for each text.

*Placeholder for illustration*

Deep Learning Essentials for NLP

As we delve deeper into the mechanics of Natural Language Processing (NLP), it becomes crucial to understand the role of deep learning—a subset of machine learning that mimics the workings of the human brain in processing data and creating patterns for decision making. Deep learning models are pivotal in transforming how machines interpret human language, offering unprecedented improvements in machine translation, sentiment analysis, and other NLP tasks by understanding complexities previously unmanageable by simpler models. /

Fundamentals of Neural Networks Applied to NLP Tasks

Neural networks have revolutionized the field of NLP by providing powerful tools to model and understand complex patterns in language data. The essence of these networks lies in their ability to learn hierarchical representations without explicit programmed instructions, making them particularly suited for the diverse and nuanced nature of human language.

Feedforward Neural Networks

At the core, feedforward neural networks, including perceptrons and multi-layer networks, set the stage for learning textual data. These networks typically involve layers of neurons that process input features (words or characters) and transmit signals to subsequent layers, ultimately leading to output layers that make predictions or classifications (Goodfellow et al., 2016).

Recurrent Neural Networks (RNNs)

RNNs are a pivotal advancement in NLP due to their ability to handle sequences, such as sentences or longer texts. Unlike feedforward networks, RNNs have loops allowing information to persist, mimicking memory. This architecture is beneficial for tasks where context from earlier in the sequence is necessary to understand or predict later elements, such as language translation or sentiment analysis (Hochreiter & Schmidhuber, 1997).

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Introduction to Tokenization, Word Embeddings, and Attention Mechanisms

Understanding the building blocks of natural language processing is essential for harnessing the full potential of NLP technologies. In this section, we explore three foundational concepts that are crucial for developing effective NLP models: Tokenization, Word Embeddings, and Attention Mechanisms. Each of these elements plays a vital role in the way machines process and interpret human language, making them indispensable for any advanced NLP system.

Tokenization

Tokenization is the process of breaking down text into smaller units, called tokens. This could involve splitting text into words, syllables, or subwords. Effective tokenization is crucial for preparing input data for neural networks in NLP tasks.

Word Embeddings

Word embeddings are dense vector representations of words that capture contextual and semantic meanings. Models like Word2Vec (Mikolov et al., 2013) or GloVe (Pennington et al., 2014) provide a way for neural networks to understand text data by converting words into vectors that reflect their semantic relationships in a high-dimensional space.

Attention mechanisms

Attention mechanisms have transformed the capabilities of neural networks by allowing models to focus on different parts of the input sequence when performing a task. This is particularly useful in tasks like machine translation, where the relevance of input words can vary depending on the context. The introduction of attention in models such as the Transformer (Vaswani et al., 2017) allows for a more nuanced understanding and generation of language.

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Common Architectures Used in NLP

To harness the vast potential of natural language processing, it is imperative to understand the various neural network architectures that underpin current NLP technologies. This section delves into two pivotal architectures: Recurrent Neural Networks (RNNs) and Transformers. Each architecture offers unique advantages for processing language data, addressing different challenges and requirements in the field of NLP.

Recurrent Neural Networks (RNNs)

As mentioned, RNNs are crucial for sequence modelling tasks. Variants like LSTM (Long Short-Term Memory) and GRU (Gated Recurrent Units) address the vanishing gradient problem common in standard RNNs, allowing for better learning of dependencies in long text sequences (Chung et al., 2014).

Transformers

Transformers have become the backbone of modern NLP systems, largely replacing RNNs in many applications. They rely entirely on attention mechanisms, without recurrence, to process input data in parallel and capture complex word relationships. This architecture not only improves performance but also significantly speeds up training (Vaswani et al., 2017).

Example: Building and Customizing NLP Pipelines with Hugging Face Transformers

In this section, we explore the powerful capabilities of Hugging Face Transformers in constructing and customizing NLP pipelines. These pipelines are essential for streamlining the processing of natural language data, from tokenization to the application of complex models for tasks like text classification, entity recognition, and more.

In this example, we demonstrate building and customizing an NLP pipeline using the Hugging Face Transformers library for a named entity recognition (NER) task. We use a pretrained BERT model specifically fine-tuned for NER to identify and classify entities such as person names, locations, and organizations from textual data.

``python

from transformers import pipeline, AutoModelForTokenClassification, AutoTokenizer

tokenizer = AutoTokenizer.from\_pretrained("dbmdz/bert-large-cased-finetuned-conll03-english")  
model = AutoModelForTokenClassification.from\_pretrained("dbmdz/bert-large-cased-finetuned-conll03-english")  
  
ner\_pipeline = pipeline("ner", model=model, tokenizer=tokenizer)  
  
text = "Hugging Face is a technology company based in New York and Paris."  
  
ner\_results = ner\_pipeline(text)  
  
print("Detected Entities and their Labels:")  
for entity in ner\_results:  
 print(f"Text: {entity['word']}, Entity: {entity['entity']}")

``

Let's dive into the details of the code snippet to understand it better:

* **Library Import:** We import the pipeline, AutoModelForTokenClassification, and AutoTokenizer from the Hugging Face transformers library, which simplifies the task of tokenization and model inference.
* **Loading Pretrained Components:** The tokenizer and model are loaded from a pretrained BERT model fine-tuned on the CoNLL-2003 dataset, a popular benchmark for NER tasks. This model can recognize various entity types in English text.
* **Setting up the NER Pipeline:** A named entity recognition pipeline is set up using the loaded tokenizer and model. This pipeline automates the process of tokenization, model inference, and entity classification.
* **Processing Text:** The text "Hugging Face is a technology company based in New York and Paris." is input into the pipeline, which identifies and classifies named entities such as locations and organization names.

*Placeholder for illustration*

In this section, we experienced the versatility and power of hugging face transformers in building customized NLP pipelines for real-world applications. The purpose of including this example here was to give you hands-on experience and insights into developing effective NLP systems using state-of-the-art technologies.

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This section provides a comprehensive exploration of deep learning essentials for NLP, equipping you with the necessary knowledge to apply these advanced techniques in various NLP tasks.

Integration of NLP and Deep Learning

The integration of deep learning and NLP has led to significant breakthroughs across various domains, demonstrating the power of these technologies when combined. Here we explore several practical applications and real-world case studies where deep learning has enhanced NLP capabilities.

Machine Translation

One of the most impactful applications is in machine translation, where deep learning models, particularly those based on the Transformer architecture, have significantly improved translation quality. For example, Google Translate has adopted Neural Machine Translation (NMT) systems that utilize deep learning to provide more accurate and contextually relevant translations than ever before (Wu et al., 2016).

Sentiment Analysis in Social Media

Deep learning has also transformed sentiment analysis, enabling more nuanced and accurate interpretations of emotions from text data. For instance, companies use LSTM networks to analyze customer feedback on social media, helping them to quickly identify and respond to customer sentiments, ranging from satisfaction to frustration (Zhang et al., 2018).

Automated Content Generation

Deep learning models like GPT-3 have revolutionized content generation, allowing for the creation of coherent and contextually relevant text based on minimal input. This technology is used by media outlets to generate news reports and by companies to create dynamic content for websites (Brown et al., 2020).

Healthcare Documentation

In healthcare, deep learning is applied in extracting and summarizing medical information from patient records, significantly reducing the time healthcare professionals need to spend on paperwork. Models trained on specific datasets can identify key medical terms and patient information, facilitating quicker and more accurate record-keeping (Rajkomar et al., 2018).

Strategies for Optimizing NLP Models through Deep Learning Methodologies

To optimize natural language processing (NLP) models effectively, especially when leveraging deep learning methodologies, several strategic approaches are employed. These strategies enhance the model's performance and adaptability to various NLP tasks, ensuring they can handle the complexities of language effectively. Here we explore key methodologies designed to refine the efficiency and accuracy of NLP models in practical applications.

* **Fine-Tuning Pretrained Models:** One effective strategy for optimizing NLP models is fine-tuning pretrained models on specific tasks. For example, BERT and its variants can be fine-tuned with additional layers or trained on task-specific corpora to improve performance on tasks like question answering and named entity recognition (Devlin et al., 2019).
* **Data Augmentation:** Another strategy is data augmentation, which involves artificially expanding the training dataset by modifying existing data points. Techniques such as synonym replacement, back-translation, and text surface transformation help in creating robust models that generalize better on unseen data (Wei & Zou, 2019).
* **Hyperparameter Optimization:** Hyperparameter optimization plays a critical role in maximizing the performance of deep learning models. Techniques like grid search, random search, and Bayesian optimization are used to find the most effective learning rates, dropout rates, and other parameters that influence training dynamics (Bergstra et al., 2012).

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Example: Build Your Own AlphaZero AI

In this example, we demonstrate setting up a basic version of the AlphaZero algorithm using Python and TensorFlow. Developed by DeepMind, AlphaZero integrates deep learning with Monte Carlo Tree Search (MCTS) to master complex games through self-play. By continually competing against itself, it learns optimal strategies, showcasing significant advancements in artificial intelligence capabilities applied to game theory. Below, we outline a simplified implementation tailored for a generic game environment, highlighting the essential steps and components involved in replicating AlphaZero's methodology.

``python

import numpy as np  
import tensorflow as tf  
from tensorflow.keras.models import Sequential  
from tensorflow.keras.layers import Dense, Conv2D, Flatten  
  
board\_size = 3 # For simplicity, a 3x3 board like Tic-Tac-Toe  
num\_actions = board\_size \*\* 2  
  
def create\_az\_model():  
 model = Sequential([  
 Conv2D(32, kernel\_size=(3, 3), activation='relu', input\_shape=(board\_size, board\_size, 1)),  
 Flatten(),  
 Dense(64, activation='relu'),  
 Dense(num\_actions, activation='softmax')  
 ])  
 model.compile(optimizer='adam', loss='categorical\_crossentropy')  
 return model  
  
az\_model = create\_az\_model()  
  
much more complex)  
def generate\_self\_play\_data():  
 # Randomly create game states (board positions) and their outcomes  
 data\_size = 100  
 states = np.random.rand(data\_size, board\_size, board\_size, 1)  
 actions = np.random.randint(num\_actions, size=data\_size)  
 action\_probs = np.eye(num\_actions)[actions] # Convert actions to one-hot encoded probabilities  
 values = np.random.randint(2, size=data\_size) \* 2 - 1 # Game outcomes as -1 or 1  
 return states, action\_probs, values  
  
states, action\_probs, values = generate\_self\_play\_data()  
  
az\_model.fit(states, {'action\_probs': action\_probs, 'values': values}, epochs=10)  
  
az\_model.summary()

Let's dive into the details of the code snippet to understand it better:

1. **Environment and Model Setup:** We define a simple game environment like Tic-Tac-Toe with a 3x3 board. The neural network model is structured to predict both move probabilities and game outcome, key components in AlphaZero's architecture.
2. **Neural Network Architecture:** The model uses convolutional layers to process the board state, flattening the output, and dense layers to predict action probabilities and game outcomes. This mimics AlphaZero's approach but on a much simpler scale.
3. **Self-Play Data Simulation:** Typically, AlphaZero generates data through self-play. Here, we mock this process by randomly generating game states and outcomes. This is a placeholder for more complex self-play logic.
4. **Model Training:** The model is trained on the generated data, learning to associate board states with action probabilities and outcomes, foundational for strategy development in games.

#### **Recommendations for Illustrations**

1. **Model Architecture Diagram:**
   * A detailed diagram of the neural network showing each layer and its purpose, highlighting how game state inputs are transformed into action and value outputs.
2. **AlphaZero Self-Play Illustration:**
   * A flowchart illustrating the self-play cycle, including game playing, data generation, and retraining phases, to visualize how AlphaZero learns over time.
3. **Training Progress Graphs:**
   * Graphs depicting the model’s performance improvement over training epochs on the simulated self-play data.

This example gives you a hands-on look at how to integrate deep reinforcement learning techniques to build intelligent systems that can learn and adapt through self-play, reflecting the methodologies behind advanced algorithms like AlphaZero.

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Summary

In this chapter, we laid a robust foundation for understanding the synergy between NLP and deep learning. We embarked on a journey exploring the evolution of NLP within the realms of artificial intelligence and machine learning, demonstrating how advancements in deep learning technologies have revolutionized our approach to processing and understanding human language. Our exploration covered key NLP tasks such as text classification, named entity recognition, and sentiment analysis, detailing how these are implemented with cutting-edge deep learning models to improve accuracy and efficiency.

We delved into the transformative role of transformer models in NLP, showcasing their unique ability to handle complex word dependencies, which enhances language understanding tasks significantly. Practical applications were discussed to illustrate how the integration of NLP with deep learning techniques is being applied across various domains, from machine translation to automated content generation, each demonstrating significant breakthroughs in capability and efficiency.

As we set out at the beginning of this chapter, our goal was to provide a comprehensive overview of how NLP and deep learning converge to create powerful tools for language processing. Having achieved this, we look forward to exploring more specialized techniques in the next chapter, where we will focus on advanced models and their applications in generating human-like text and beyond, promising exciting new possibilities in the field of AI.

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