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Natural Language Processing and Large Language Models

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About the Course !

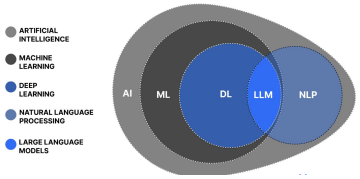
- Natural language processing (NLP) is the field of working with language to automatically perform a variety of tasks, instead of or in collaboration with people.
- Recently, large language models (LLMs) like ChatGPT have gotten the attention of the general public, but they have also greatly changed the landscape of modern NLP research.
- This course will show you **both old & new techniques** that are used today and will give you a basic understanding of why & how we do NLP.

Prerequisite

- Python
- Machine Learning
- Deep Learning
- Foundational understanding of PyTorch, or familiarity with other deep learning frameworks like TensorFlow, will be beneficial.

About the Course !

NLP vs LLMs



- **NLP** applies a combination of rule-based systems and machine learning to process text and speech efficiently.
- **LLMs**, rely on deep learning for language (knowledge) comprehension

About the Course !

NLP vs LLMs

Aspect	Natural Language Processing (NLP)	Large Language Models (LLMs)
Data Requirement	Structured, labeled data	Large-scale, unstructured datasets
Computational Power	Low to moderate; can run on local machines	High-performance GPUs and cloud-based processing
Primary Use Cases	Sentiment analysis, translation, speech recognition, text classification	Conversational AI, content creation, coding assistance, document summarization
Flexibility	Task-specific and specialized	Adaptable across domains and capable of handling diverse queries
Cost	Lower infrastructure demands; more cost-effective	High due to extensive computational and storage requirements
Scalability	Easily scalable for structured applications	Requires significant cloud-based resources to scale effectively

Learning Objective

By the end of the course, you will be able to…

1. **Foundations of NLP & LLMs:** Learn key concepts such as tokenization, embeddings, language modelling, and the core architecture and training mechanics behind transformer-based LLMs.
2. **Practical NLP Applications:** Apply models to tasks like text classification, machine translation, summarization, and zero-/few-shot prompting using real-world datasets.
3. **Hands-On Model Development:** Build NLP pipelines, evaluate multilingual performance (with focus on low-resource languages), and develop a simple language model from scratch.

Course Content

Week 1: Foundations of NLP & Classical Approaches
Core principles of NLP, including text preprocessing, tokenization, n-gram language models, word embeddings, and sequence-to-sequence modelling.

Week 2: Transformers, LLM, & Fine-Tuning

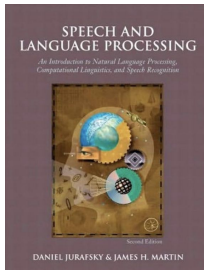
Transformer architecture, attention mechanisms, pre-training and transfer learning, supervised fine-tuning, prompting strategies, and evaluation of LLMs.

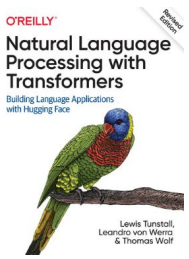
Week 3: Advanced Topics, & Ethical NLP
Advanced Topics, & Ethical NLP

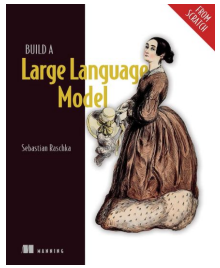
We will be discussing state-of-the-art papers about large language models.

Reference Books

- **Course page:** https://github.com/shmuhammadd/aims-nlp-course
- Assignment descriptions







Reference Books NLP

1. Speech and Language Processing, Dan Jurafsky and James H. Martin
   https://web.stanford.edu/~jurafsky/slp3/
2. Foundations of Statistical Natural Language Processing, Chris Manning and Hinrich Schütze
3. Build a Large Language Model (From Scratch): https://github.com/rasbt/LLMs-from-scratch
4. Hands-On Large Language Models: https://github.com/HandsOnLLM/Hands-On-Large-Language-Models

Other Sources

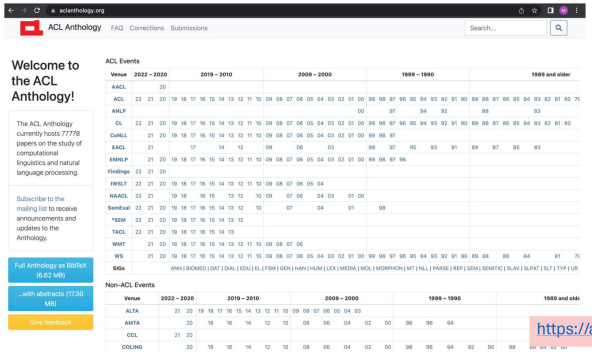
Journals

Computational Linguistics, Natural Language Engineering, TACL, JMLR, TMLR, etc

Conferences

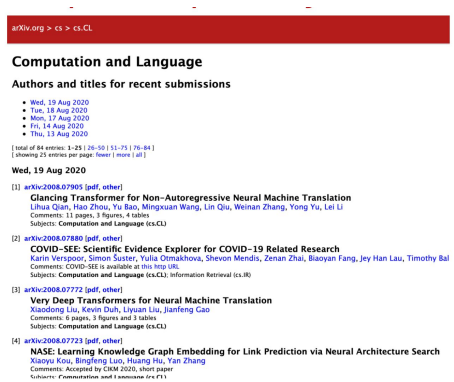
ACL, EMNLP, NAACL, COLING, AAAI, IJCNLP, ICML, NeurIPS, ICLR, WWW, KDD, SIGIR, etc

ACL Anthology



https://aclanthology.org/

ArXiv



https://arxiv.org/list/cs.CL/recent

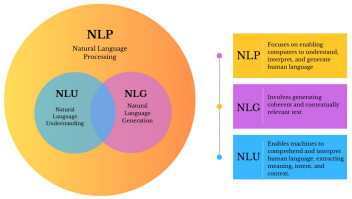
Acknowledgments

- Advanced NLP, Graham Neubig http://www.phontron.com/class/anlp2022/
- Advanced NLP, Mohit Iyyer https://people.cs.umass.edu/~miyyer/cs685/
- NLP with Deep Learning, Chris Manning, http://web.stanford.edu/class/cs224n/
- Understanding Large Language Models, Danqi Chen https://www.cs.princeton.edu/courses/archive/fall22/cos597G/
- Natural Language Processing, Greg Durrett https://www.cs.utexas.edu/~gdurrett/courses/online-course/materials.html
- Large Language Models: https://stanford-cs324.github.io/winter2022/
- Natural Language Processing at UMBC, https://laramartin.net/NLP-class/
- Computational Ethics in NLP, https://demo.clab.cs.cmu.edu/ethical_nlp/
- Self-supervised models, CS 601.471/671: Self-supervised Models (jhu.edu)
- WING.NUS Large Language Models, https://wing-nus.github.io/cs6101

What is Natural Language Processing (NLP)?

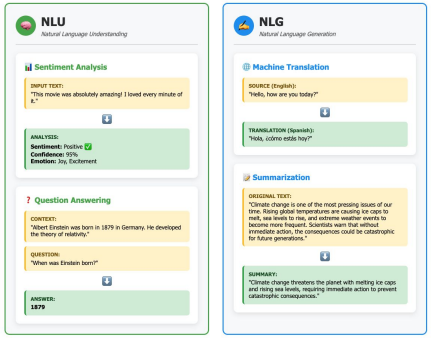
What is Natural Language Processing (NLP) ?

- **Natural Language Processing (NLP)** is a field of artificial intelligence focused on enabling machines to **understand**, **interpret**, and **generate** human language.
- **NLP** combines methods from linguistics, machine learning, and computer science to build systems that work with **text** and **speech** at scale.
- NLP includes two major subfields:
  - **NLU – Natural Language Understanding:** extracting meaning, intent, entities, and structure.
  - **NLG – Natural Language Generation:** producing coherent, context-appropriate text or speech.

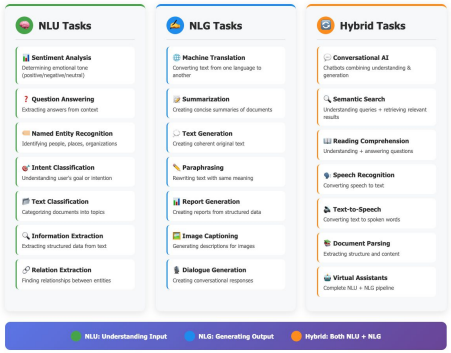


https://geekflare.com/blog/natural-language-understanding/

NLU vs NLG



NLU vs NLG



Natural Language Processing and Computational Linguistics

The computational study of language

Computational Linguistics

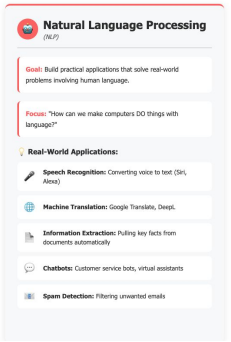
≈

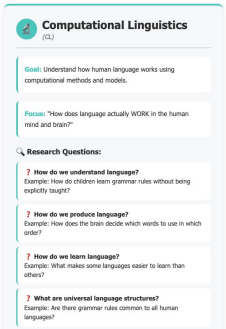
Natural Language Processing

The computational use of language

Association for Computational Linguistics

Both fields work with human language using computers, but they have different goals and perspectives!



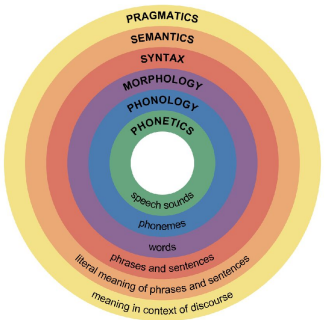


Natural Language Processing and Computational Linguistics

- Most of the conferences and journals that host natural language processing research bear the name "computational linguistics" (e.g., ACL, NACL).
- NLP and CL may be thought of as essentially synonymous.
- While there is substantial overlap, there is an important difference in focus
  - CL is essentially linguistics supported by computational methods (similar to computational biology, and computational astronomy)
  - NLP focuses on solving well-defined tasks involving human language (e.g., translation, query answering, holding conversations).

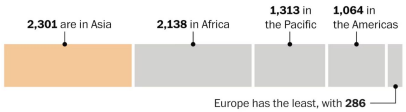
Linguistics

The study of language



Why is NLP interesting?

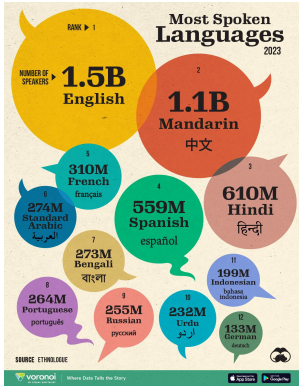
There are at least **7,102** living languages in the world.



NLP powers a broad range of applications:

Machine translation, information extraction, question answering, summarization, sentiment analysis, speech technologies, code generation, document retrieval, fact checking, etc.

The field is also rapidly evolving with the rise of large language models, offering new research challenges



Before Building NLP Systems…

- To build NLP systems, we need **large, high-quality text data**.
- But the world's **7,000+ languages** are not equally represented in digital form.
- This leads to major gaps: many languages have **little or no available corpus**, making them "**low-resource languages (e.g., African Languages)**."
- Before building models, we must understand **what a corpus is**, **how it is collected**, and **why it matters** for multilingual NLP.

Where does the data come from?

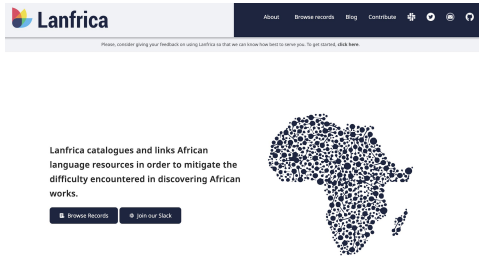
Corpus and Low-Resource Languages

- **Corpus** (plural: *corpora*): a structured collection of text used for training or evaluating NLP models.
- Languages with limited corpora are known as **low-resource languages**.

How Corpora Are Collected

- **Expert-curated data:** manually tagged and organized by linguists or annotators.
- **Open-web data:** collected from freely accessible sources (e.g., Wikipedia, blogs, forums).
- **Permission-based data:** obtained from closed platforms (e.g., messaging apps, social media) with explicit consent—less common but often higher quality.

Data creation in Africa



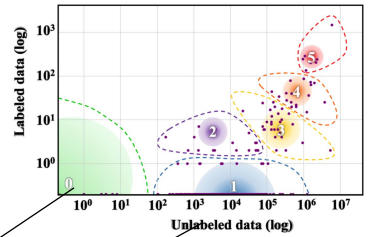
Under-resourced languages: Labelled+Unlabelled data

Six-class categorization of languages based on Joshi et al (2020)

- Unlabelled corpora
- Labelled corpora

categorization of languages based on the amount

of NLP resources available for each language



No unlabelled texts
80% of languages

Few texts

Six-class categorization

Highly Resourced (HRL)- Winners
- Languages with extensive NLP resources, including large-scale corpora, pre-trained models, and strong computational tools.
- Examples: English, Chinese, Spanish, French

Moderately Resourced (MRL) - Moderate
- Languages with reasonable NLP resources, but still lacking in some areas such as large-scale pre-trained models.
- Examples: Dutch, Russian, Korean

Somewhat Resourced (SRL) - Hopefuls
- Languages with limited but growing NLP resources, including some datasets and a few pre-trained models.
- Examples: Swahili, Finnish, Turkish

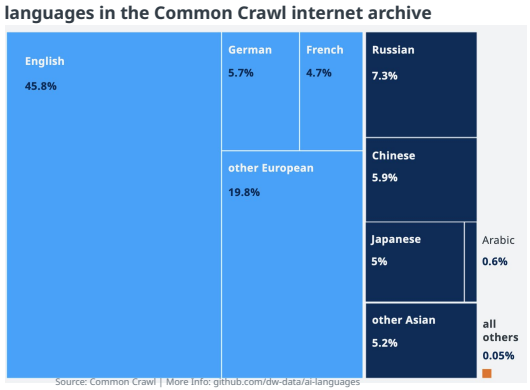
Six-class categorization

Low Resourced (LRL) - Scraping By
- Languages with very limited annotated data, small corpora, and minimal computational resources.
- Examples: Hausa, Tamil, Uzbek

Extremely Low Resourced (XLRL) - Left Behind
- Languages with almost no NLP resources, where some digitized text may exist, but annotated corpora and NLP tools are scarce.
- Examples: Wolof, Aymara, Tigrinya

Unsupervised (UL) - The Rest
- Languages with virtually no digital footprint, requiring unsupervised or few-shot learning techniques for any NLP progress.
- Examples: Many indigenous and endangered languages like Chadic languages, Amazonian languages

Lack of Publicly Available Dataset



30%

World languages are African (Ethnologue)

0.05%

Why is NLP hard?

Why is NLP hard?

Ambiguity

NLP is challenging due to the inherent complexities of human language.

Lexical Ambiguity

A single word can have multiple meanings, and the intended meaning depends on the context.

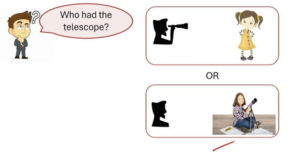
Example:

The bank is closed today. (Does "bank" refer to a financial institution or the side of a river?)

Syntactic Ambiguity

A sentence can have more than one valid structure, leading to different interpretations.

Example:



I saw a girl with the telescope.

Possible meanings:

- I used a telescope to see the girl.
- The girl is the one holding the telescope.

Ambiguity in Language

- I ate food with Spoon
  "with" = tool used to eat
- I ate rice with curd
  "with" = ingredient served together
-
- I ate rice with Muhammad
  "with" = person I ate together with

Semantic Ambiguity

A sentence can have more than one meaning because its interpretation depends on context.

Example:

"The chicken is ready to eat."

Possible interpretations:

- The chicken is **going to eat** something
- The chicken is **cooked and ready to be eaten**.

Pragmatic Ambiguity

Meaning depends on context, social norms, and the speaker's intention, not just the words themselves.

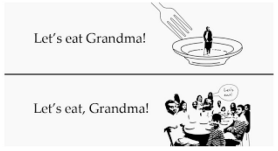
Example:

"Can you pass the salt?"

Two interpretations:

- **Literal:** "Are you able to pass the salt?" (asking about ability)
- **Pragmatic:** A polite way to say **"Please pass the salt."**

Ambiguity in Punctuation



A woman without her man is nothing.

A woman, without her man, is nothing.
A woman: without her, man is nothing.

Punctuation is powerful.

How NLP Overcomes Language Challenges

Human language is full of challenges: lexical, syntactic, semantic, and pragmatic ambiguities.

These difficulties vary across languages and are even more complex in **low-resource** contexts.

But despite these challenges:

- NLP provides tools to interpret meaning.
- resolve ambiguity using context and large datasets,
- and build systems that can understand and generate language with high accuracy.

In this course, we will explore how modern NLP, especially transformers and LLMs, addresses these challenges and how these methods can be applied to many languages, including those with limited resources.

Break

NLP Layers

- Understanding the semantics is a non-trivial task.
- Needs to performs a series of incremental tasks to achieve this.
- NLP happens in layers.

Pragmatics & Discourse	*Study of semantics in context.*
Semantics	*Meaning of the sentence.*
Parsing	*Syntactic structure of the sentence.*
Chunking	*Grouping of meaningful phrases.*
Part of speech tagging	*Grammatical classes.*
Morphology	*Study of word structure.*

Increasing Complexity Of Processing

Morphology

Morphology is the study of how words are formed and structured.

It looks at the smallest meaningful units (called **morphemes**) like prefixes, suffixes, and root words.

Different languages handle morphology differently -

some use very little word modification (morphologically poor), while others heavily modify words (morphologically rich).

Morphology helps computers understand how words are built and there two types/

Inflectional Morphology and Derivational Morphology

Inflectional Morphology

Changes the form of a word (tense, number, gender) without changing its core meaning.

Examples: walk → walked (past tense), cat → cats (plural)

Why this matters for NLP:

- **Tokenization & vocabulary size:** Inflected forms multiply the number of word types models must handle.
- **Lemmatization:** Systems need to group different forms into the same base word (*walk*).
- **POS tagging & parsing:** Inflections signal tense, plurality, agreement, etc.
- **Low-resource languages:** Richly inflected languages (e.g., Amharic, Arabic, Hausa) create data sparsity.

Derivational Morphology

Derivation creates **new words** with related meanings:

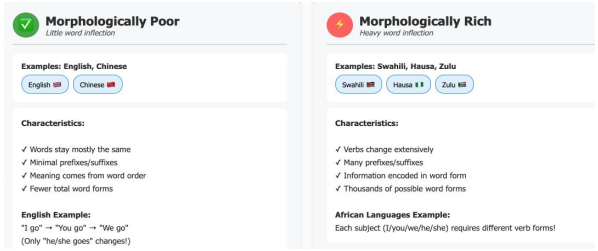
- *happy* → *unhappy*
- *teach* → *teacher*
- *kind* → *kindness*

Why this matters for NLP:

- **Word embeddings:** Models must learn that *teach* and *teacher* are related but not identical.
- **Sentiment analysis:** Prefixes like *un-* or *dis-* change polarity.
- **Text classification:** Derivational patterns signal topic or domain (*biology, biological, biologist*).

Morphology

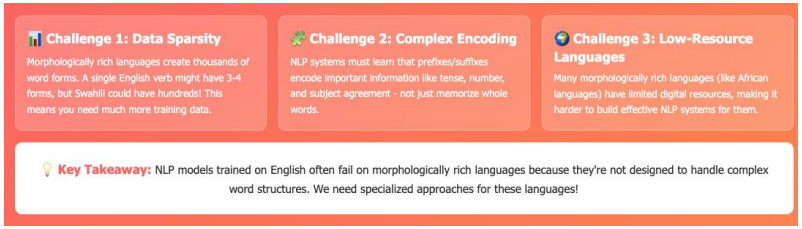
- English, Chinese, etc. are commonly referred as *morphologically-poor* language.
- Hindi, Turkish, Hungarian, etc. are termed as *morphologically-rich* language.



Comparison: "I/We/You/He/She will go"

English	Swahili	Hausa	Zulu	What Changes?
I will go	*Ni taenda*	*Zan tafi*	*Ngi zoya*	Verb changes based on **subject prefix**
We will go	*Tu taenda*	*Zamu tafi*	*Si zoya*	**Number agreement** (singular vs plural)
You will go	*U taenda*	*Za ka tafi*	*U zoya*	**Person agreement** (1st/2nd/3rd person)
He will go	*A taenda*	*Za shi tafi*	*U zoya*	**Gender/person marking** (in Hausa)
She will go	*A taenda*	*Za ta tafi*	*U zoya*	**Gender/person marking** (in Hausa)

Why Does This Matter for NLP?



Word and Token

- A **word** is the smallest meaningful unit of language that can stand alone.
- A **token** is a unit of text obtained after tokenization, which is the process of breaking a text into individual components (words, subwords, or even characters).
- A token may or may not correspond directly to a word.

Word and Token

Sentence: I love NLP research.

Words: I, love, NLP, research | **Tokens** (depending on tokenizer):

- **Word-level**: I, love, NLP, research
- **Subword-level (BPE)**: I, love, NL, P, research
- **Key idea:** Humans think in words. NLP models think in tokens, and these may not match human words exactly

Tokenization *is the process of breaking down text into smaller units, called* ***tokens****, which can be words, subwords, or characters.*

It is a fundamental preprocessing step in ***Natural Language Processing (NLP)*** *used for tasks such as machine translation, text classification, and language modeling.*

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Types of Tokenization

There are four main types of tokenization used in Natural Language Processing, each serving different purposes and use cases:

- **Word Tokenization**
- **Subword Tokenization**
- **Character Tokenization**
- **Sentence Tokenization**

Word Tokenization

The text is split into individual words based on **whitespace** and **punctuation**.

💡 **Example:**

Input:

I love NLP!

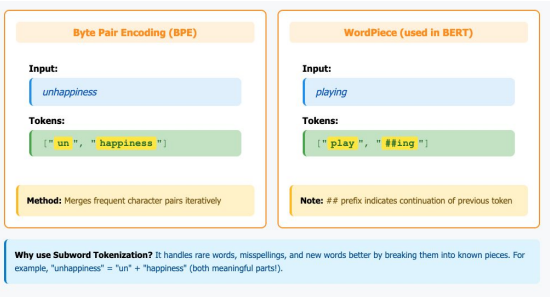
Tokens:

```
["I", "love", "NLP", "!"]
```

How it works: Splits text at spaces and separates punctuation marks. This is the simplest and most common tokenization method.

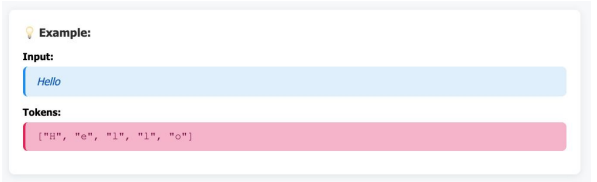
Subword Tokenization

Words are broken into smaller meaningful units, especially for handling **out-of-vocabulary (OOV)** words. Used in modern NLP models like **BERT**, **GPT**.



Character Tokenization

Each **character** is treated as a separate token. Useful for handling **unknown words** in languages with complex morphology (e.g., Chinese, Japanese, Korean).



Character Tokenization

Best Used For:

- ✓ Languages without clear word boundaries (Chinese: 你好世界)
- ✓ Handling misspellings and typos
- ✓ Working with very rare or unknown words
- ✓ Character-level language models

Trade-off: Creates very long sequences (more computation) but has smallest vocabulary size and zero out-of-vocabulary words!

Sentence Tokenization

The text is split into **sentences** instead of words. Useful in **summarization** or **translation** tasks where sentence boundaries matter.

Example:

Input:

I love NLP. It is exciting!

Tokens:

```
["I love NLP.", "It is exciting!"]
```

Sentence Tokenization

Best Used For:

- ✓ Text summarization (process sentence by sentence)
- ✓ Machine translation (translate complete sentences)
- ✓ Sentiment analysis per sentence
- ✓ Document segmentation and analysis

Challenge: Not all periods mean end of sentence! Need smart algorithms to handle abbreviations (Dr., Mr., U.S.A.), decimals (3.14), and ellipsis (...).

Part-of-Speech Tagging (POS)

- **Part of Speech (PoS)** refers to the grammatical category of words in a sentence based on their function and meaning.
- **PoS** tagging is essential in NLP for understanding sentence structure and meaning.

Grammatical class of the word.

He	ate	an	apple	.
PRP	VBD	DT	NN	.

PoS disambiguation:

- A word can belong to different grammatical classes.

He	went	to	the	*park*	in	a	car	.
PRP	VBD	TO	DT	*NN*	IN	DT	NN	.

They	went	to	*park*	the	car	in	the	shed	.
PRP	VBD	TO	*VB*	DT	NN	IN	DT	NN	.

Tags

PRP: Personal Pronoun
VBD: Verb, Past
DT: Determiner
NN: Noun, Singular, Mass
TO: *to*
IN: Preposition

- 45 tags in Penn Treebank tagset
- 146 tags in C7

Chunking

Chunking is the process of grouping words into meaningful phrases based on their Part of Speech (PoS) tags.

It helps in identifying syntactic structures like noun phrases (NP), verb phrases (VP), and prepositional phrases (PP).

Example of Chunking

Consider the sentence:

"The quick brown fox jumps over the lazy dog."

Chunking

Step 1: PoS Tagging

The (DT) quick (JJ) brown (JJ) fox (NN) jumps (VBZ) over (IN) the (DT) lazy (JJ) dog (NN)

Step 2: Chunking (Noun Phrases & Verb Phrases)

[NP The quick brown fox] [VP jumps] [PP over] [NP the lazy dog]

Here, the **Noun Phrases (NP)** and **Verb Phrases (VP)** are extracted.

Semantics

- **Semantics** is the study of meaning in language—how words, phrases, and sentences convey meaning.
- Semantic analysis helps NLP systems:
  - understand what a sentence means, not just what words it contains,
  - interpret words based on context (“bank” = money vs. riverbank),
  - capture relationships between words (who did what, to whom),
  - generate meaningful and coherent text.

Task we want to solve in NLP?

NLP Tasks

Understanding Tasks

Text Classification
Sentiment analysis, topic classification

Named Entity Recognition
Finding people, places, organizations

Part-of-Speech Tagging
Identifying grammatical roles

Dependency Parsing
Understanding sentence structure

Question Answering
Answering natural-language queries

Machine Reading Comprehension
Extracting meaning from text

Generation Tasks

Machine Translation
Converting text between languages

Summarization
Producing concise summaries

Text Generation
Writing coherent sentences or documents

Dialogue Systems / Chatbots
Human-like conversation

Paraphrasing
Rewriting text with same meaning

NLP Tasks

Speech & Multimodal Tasks

Speech Recognition
Speech → text conversion

Text-to-Speech
Text → speech conversion

Vision-Language Tasks
Image captioning, Visual Question Answering (VQA)

Low-Level / Core Tasks

Tokenization and Segmentation
Breaking text into words, sentences, or characters

Lemmatization and Stemming
Reducing words to their base form

Morphological Analysis
Analyzing word structure and inflections

Coreference Resolution
Determining who/what pronouns refer to

Basic NLP Tasks

Tokenization: Splitting text into words (word tokenization) or sentences (sentence tokenization). Example:

Input: "NLP is amazing!"
Output: ['NLP', 'is', 'amazing', '!']

Stopword Removal: Eliminating common words like "the," "is," "in," etc. Helps in reducing noise in text analysis.

Example:

Input: "This is a great NLP tutorial."
Output: ['great', 'NLP', 'tutorial']

Basic NLP Tasks

Stemming reduces words to their base or **stem form**, often by chopping off suffixes. However, it may not always result in a meaningful word.

Stemmed Words:

- **cats** → cat
- **were** → were (unchanged)
- **running** → run
- **gardens** → garden
- **happily** → happi (incorrect stem)
- **injured** → injur

- Some words (like *happily* → *happi*) lose meaning due to aggressive chopping.
- It does not consider the proper root word, just removes common suffixes.

Lemmatization

Lemmatization converts words into their **dictionary base form (lemma)**, using linguistic knowledge.

Lemmatized Words:

- **cats** → cat
- **were** → be (correct lemma)
- **running** → run
- **gardens** → garden
- **happily** → happy
- **injured** → injure

- More accurate and meaningful base forms.
- Proper grammatical transformations (e.g., *were* → *be*, *happily* → *happy*).
- Context-aware, ensuring the correct dictionary form.

Stemming vs Lemmatization?

Use Stemming when speed is important and minor errors are acceptable (e.g., search engines).

Use Lemmatization when **accuracy matters** (e.g., NLP applications like chatbots, text analysis).

IMPERIAL

Q and A