

Introduction to Computational Linguistics and Natural Language Processing

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Presentation

- Welcome to **Natural Language Processing Techniques**
- Two teachers from the *Department of Software and Computing Systems*:
 - ▶ **Miquel Esplà Gomis** (myself): first session
 - ▶ Juan Antonio Pérez Ortiz: rest of sessions
- All the information is on the subject website:
<https://mespla.github.io/tp1n2526/>
- Attending classes:
 - ▶ It is mandatory and we will take attendance
 - ▶ It is allowed to miss one session without a justification

Evaluation

- All the information is available on the official teaching guide:
<https://cvnet.cpd.ua.es/Guia-Docente/GuiaDocente/Index?wlengua=en&wcodasi=43505&scaca=2025-26>
- Three elements in evaluation:
 - ▶ Practical activities at class (that you may need to complete at home):
60%
 - ▶ Tests on the materials you prepare before class : 10%
 - ▶ Final test on January the 19th : 30%

- 1 Introduction
- 2 Text preprocessing
 - Removing Formatting
 - Tokenization
 - Text normalization
 - Stopwords
- 3 Morphological parsing
- 4 Syntactic parsing
- 5 Vector representations of text
- 6 Concluding remarks

Computational Linguistics (CL)

- An interdisciplinary field at the intersection of:
 - ▶ Linguistics
 - ▶ Computer Science
- Focuses on modeling human language using computational methods.
- Key objectives:
 - ▶ Analyze and understand natural language.
 - ▶ Develop linguistic theories supported by computational tools.
- Example topics:
 - ▶ Parsing syntactic structures.
 - ▶ Phonetics and phonology modeling.

Natural Language Processing (NLP)

- A subfield of Artificial Intelligence (AI) and Machine Learning (ML).
- Focuses on designing algorithms and systems to process natural language data.
- Key objectives:
 - ▶ Automate language-based tasks.
 - ▶ Enable machines to interact with humans through language.
- Example applications:
 - ▶ Machine Translation (e.g., Google Translate).
 - ▶ Sentiment Analysis.
 - ▶ Question Answering Systems.

Differences Between CL and NLP

- **Computational Linguistics (CL):**

- ▶ Emphasizes theoretical understanding of language.
- ▶ Grounded in linguistic principles.

- **Natural Language Processing (NLP):**

- ▶ Focuses on practical applications of language processing.
- ▶ Driven by engineering and computational efficiency.

Commonalities Between CL and NLP

- Both fields deal with natural language data.
- Share methods and tools, such as:
 - ▶ Syntax and semantics modeling.
 - ▶ Statistical and machine learning techniques.
- Work towards improving human-computer interaction through language.

What will we talk about during this session?

- **Text preprocessing:** preparing text for NLP applications
- **Morphological parsing:** how much information can we extract from words to better understanding text?
- **Syntactic parsing:** and what about the structure of the words in a sentence?
- **Vector representations of text:** how can we feed text in models that build on math?

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Text Preprocessing: An Essential Step

- Text preprocessing prepares raw text for effective processing by algorithms and models.
- Ensures consistency, reduces noise, and optimizes data for downstream tasks.
- Different tasks require different preprocessing steps.

Some frequent sub-tasks in Text Preprocessing

- **Format Cleaning:**

- ▶ Remove unwanted formatting, such as HTML tags or PDF metadata.

- **Text Tokenization:**

- ▶ Split text into smaller units like sentences, words, subwords, or characters.

- **Text Normalization:**

- ▶ Normalize punctuation and spaces.
- ▶ Convert text to lowercase for case-insensitive processing.

- **Dealing with Punctuation:**

- ▶ Remove or retain punctuation depending on the application.

- **Identifying Stopwords:**

- ▶ Remove commonly used words (e.g., *the*, *is*, *and*) to focus on meaningful content.

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Why do we need to clean format?

- Raw text often comes in formats unsuitable for NLP models:
 - ▶ HTML files with tags and scripts.
 - ▶ PDF documents with metadata and layout information.
 - ▶ Markdown files with format marks.
- In most cases data related to format adds noise to the text to be processed.

Removing Formatting: HTML and PDF

- **HTML:**

- ▶ Often contains tags (<div>, <script>, etc.) and styles.
- ▶ Content extraction involves ignoring these elements.

- **PDF:**

- ▶ May include page numbers, headers, and images.
- ▶ Text extraction tools can help retrieve only textual content.

Example: Removing HTML Tags

Raw Text:

```
<html>
  <head><title>Example</title></head>
  <body>
    <h1>Hello , World!</h1>
    <p>This is a sample text.</p>
  </body>
</html>
```

Cleaned Text:

```
Hello , World!
This is a sample text.
```


Techniques for Removing Formatting

- Regular Expressions (Regex):
 - ▶ Use patterns to identify and remove unwanted elements.
 - ▶ Example: Remove HTML tags using the pattern `<.*?>`.
- Libraries and Tools:
 - ▶ BeautifulSoup (Python): For parsing and cleaning HTML.
 - ▶ PyPDF2 (Python): For extracting text from PDFs.
- OCR Tools:
 - ▶ Use Optical Character Recognition for images or scanned text.

Common Challenges in Formatting Removal

- Handling noisy or incomplete data.
- Retaining meaningful structure (e.g., tables, paragraphs).
- Managing large or complex files efficiently.
- Language-specific formatting (e.g., RTL scripts or special characters).

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What is Tokenization?

- The process of breaking text into smaller units, called **tokens**.
- Tokens can represent:
 - ▶ Sentences (it is also usual to call this task *sentence splitting*)
 - ▶ Words
 - ▶ Characters
 - ▶ Sub-words
- Critical for transforming raw text into a format suitable for NLP algorithms.

Levels of Tokenization

- **Sentence Tokenization:**

- ▶ Splits text into sentences.
- ▶ Example: *"NLP is fascinating. Tokenization is essential."*
- ▶ Tokens: [*"NLP is fascinating."*, *"Tokenization is essential."*]

- **Word Tokenization:**

- ▶ Splits text into words.
- ▶ Example: *"NLP is fascinating"*
- ▶ Tokens: [*"NLP"*, *"is"*, *"fascinating"*]

- **Character Tokenization:**

- ▶ Splits text into individual characters.
- ▶ Example: *"NLP"*
- ▶ Tokens: [*"N"*, *"L"*, *"P"*]

- **Sub-word Tokenization:**

- ▶ Splits words into potentially meaningful sub-units.
- ▶ Example: *"unbelievable"*
- ▶ Tokens: [*"un"*, *"believ"*, *"able"*]

Sentence splitting

- For most languages, **punctuation** is used (split by colons, semicolons, etc.)
 - ▶ This is sometimes difficult: " *This is Dr. Smith. He is the author of the blog saludparatodos.net.*"
- Sometimes it is possible to use **format**; for example, some HTML tags delimit a text block, such as <p> or <h1>
- **Some languages do not use punctuation** (Thai, for example)

ประวัติ

ภาษาไทยจัดอยู่ในกลุ่มภาษาไท (Tai languages) ภาษาหนึ่ง ซึ่งเป็นสาขาย่อยของตระกูลภาษาขร้า-ไท ภาษาไทยมีความสัมพันธ์อย่างใกล้ชิดกับภาษาในกลุ่มภาษาไทตะวันตกเฉียงใต้ภาษาอื่น ๆ เช่น ภาษาลาว ภาษาผู้ไท ภาษาคำเมือง ภาษาไทใหญ่ เป็นต้น รวมถึงภาษาตระกูลไทอื่น ๆ เช่น ภาษากูย ภาษาเขม่านาน ภาษาบูอี ภาษาไทลื้อ ที่พูดโดยชนพื้นเมืองบริเวณไทหนาน กวางสี กวางตุ้ง กุ้ยโจว ตลอดจนยูนนาน ไปจนถึงเวียดนามตอนเหนือ ซึ่งสันนิษฐานว่าจุดกำเนิดของภาษาไทยน่าจะมาจากบริเวณดังกล่าว

Word Tokenization Strategies

- **Whitespace-Based Tokenization:**

- ▶ Fails with contractions or punctuation, for example.
- ▶ Words separated with a dash in English: *state-of-the-art*.
- ▶ What to do with languages that don't use spaces to separate words?

- **Using regular expressions:**

- ▶ Allows to identify some phenomena: some contractions in English, URLs, etc.

- **Language-Specific Tokenizers:** Tailored to account for language-specific features.

- ▶ Example: Tokenizing Japanese using MeCab or SudachiPy.
- ▶ There are tokenizers that build on knowledge (morphological dictionaries) and that build on statistical models (for example, HMM).

Why Sub-word Tokenization?

It has become very popular in neural-based NLP models:

- Addresses issues with **rare words** and **out-of-vocabulary** (OOV) words.
- Efficient for **morphologically rich languages**.
- Maintains a balance between word and character tokenization.

Approaches to Sub-word Tokenization

Task traditionally based on **morphological segmentation**.

Two popular strategies in the neural age:

- Byte Pair Encoding (BPE)
- Unigram Language Model

Byte Pair Encoding (BPE)

- Begins by splitting text in characters.
- Iteratively merges the most frequent pairs of characters or subwords.
- Example:
 - ▶ Initial tokens: ["l", "o", "w", "e", "r"]
 - ▶ Merge "l" and "o" \rightarrow ["lo", "w", "e", "r"]
 - ▶ Merge "lo" and "w" \rightarrow ["low", "e", "r"]
- Benefits:
 - ▶ Handles rare words by breaking them into sub-units.
 - ▶ Compact vocabulary size.

Unigram Language Model

- Steps:
 - ▶ Start with a large vocabulary of potential subwords (could be all the possible sub-words in the corpus).
 - ▶ Assign a probability to each of them according to their frequency observed in the corpus.
 - ▶ Use the vocabulary as an unigram model that allows to obtain the probability of a word.
 - ▶ Iteratively remove subwords that minimally impact the overall probability of the corpus.
- Benefits:
 - ▶ Allows for multiple segmentations with probabilities.
 - ▶ More flexible than deterministic methods like BPE.

Comparison: BPE vs. Unigram

- **BPE:**

- ▶ Deterministic.
- ▶ Fixed segmentation after training.

- **Unigram:**

- ▶ Probabilistic.
- ▶ Allows multiple valid segmentations with probabilities.

- **In common:**

- ▶ Both require pre-tokenization.
- ▶ Both allow to specify the size of the final vocabulary.

- It builds on Unigram or BPE
- Unigram and BPE assume that the corpus can be split in words by blank spaces.
- SentencePiece just omits this assumption:
 - ▶ Includes spaces in the initial vocabulary of BPE.
 - ▶ Includes sub-words containing spaces in the initial vocabulary of Unigram.
- Allows dealing with languages that do not use blank spaces.
- Allows using multi-word expressions as elements in the final vocabulary.

What is Text Normalization?

- The process of converting text into a standard form.
- Aims to reduce variability in the text while preserving meaning.
- Prepares text for consistent and effective processing in NLP tasks.

Examples:

- *"Hello,"* → *"hello"* (lowercasing).
- *"I've got 2 apples."* → *"i have two apples"* (normalizing contractions and numbers).

Challenges with Unicode Characters

- Modern text is usually encoded with **Unicode** that support a wide variety of scripts. Sometimes this leads to data sparsity at character level.
- **Visually Similar Characters:**
 - ▶ `\`a"` (U+00E1) vs. `\a`"` (U+0061 + U+0301).
 - ▶ Appear identical but have different underlying representations.
 - ▶ With punctuation it is even worse; have a look to UTF-8 punctuation at: <https://www.compart.com/en/unicode/category/Po>
- **Non-breaking Spaces and Invisible Characters:**
 - ▶ `\ "` (non-breaking space, U+00A0) vs. `\ "` (space, U+0020).
 - ▶ Introduce subtle errors in processing.

Task-Specific Normalization Needs

- Text normalization varies depending on the NLP task.
- **Examples:**
 - ▶ **Case-sensitive tasks:**
 - ★ Named Entity Recognition (NER): Retain original casing to identify entities like “Apple”.
 - ▶ **Removing Punctuation:**
 - ★ Useful for bag-of-words models.
 - ★ Not always suitable for tasks like sentiment analysis.
 - ▶ **Removing redundant text:**
 - ★ Removing duplicate or almost-duplicate sentences or paragraphs in a long corpus.
 - ★ Useful when we have a large corpus to training generative models.
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 - ★ Useful when we have a large corpus to training generative models.
- Normalization must strike a balance between generality and task-specific requirements.

Summary of Text Normalization

- Essential for standardizing text and reducing variability.
- Unicode introduces challenges like visually similar characters and non-breaking spaces.
- Techniques include lowercasing, punctuation removal, and whitespace normalization.
- Task-specific normalization must be tailored to the application.

Key Takeaway: Effective normalization improves downstream NLP performance.

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 - ▶ `\ "` (non-breaking space, U+00A0) vs. `\ "` (space, U+0020).
 - ▶ Introduce subtle errors in processing.
- **Normalization Standards:**
 - ▶ Use Unicode normalization forms (e.g., NFC, NFD) to standardize representations.

Common Text Normalization Techniques

- **Lowercasing:**

- ▶ Converts all text to lowercase.
- ▶ Example: *"NLP"* → *"nlp"*.

- **Removing Punctuation:**

- ▶ Removes special characters and punctuation marks.
- ▶ Example: *"Hello, world!"* → *"Hello world"*.

- **Whitespace Normalization:**

- ▶ Replaces multiple spaces or non-breaking spaces with a single space.
- ▶ Example: *"Hello world"* → *"Hello world"*.

- **Stemming or Lemmatization:**

- ▶ Reduces words to their base or root forms.
- ▶ Example: *"running"* → *"run"*.

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- Text normalization varies depending on the NLP task.
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 - ▶ **Removing Punctuation:**
 - ★ Useful for bag-of-words models.
 - ★ Not always suitable for tasks like sentiment analysis.
 - ▶ **Normalization of Numbers:**
 - ★ Convert digits to words for readability or analysis (e.g., *“3”* → *“three”*).
- Normalization must strike a balance between generality and task-specific requirements.

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What are Stopwords?

Stopwords are common words that are considered to contain low semantic value and are removed during text preprocessing for some NLP tasks.

- Examples: "the", "is", "in", "on", "at", "and", "for"
- Removing them can improve efficiency and focus on more important words
- They are more usual in languages with low morphological complexity.

How to Detect Stopwords

Stopwords can be detected in various ways:

- Predefined stopwords lists (e.g., NLTK, SpaCy)
- Frequency-based approaches:
 - ▶ Words appearing very frequently across many documents are potential stopwords
 - ▶ Commonly occurring words across corpora are candidates
- Part-of-speech tagging:
 - ▶ Function words (e.g., determiners, prepositions, conjunctions) are often stopwords

Vocabulary frequency distribution

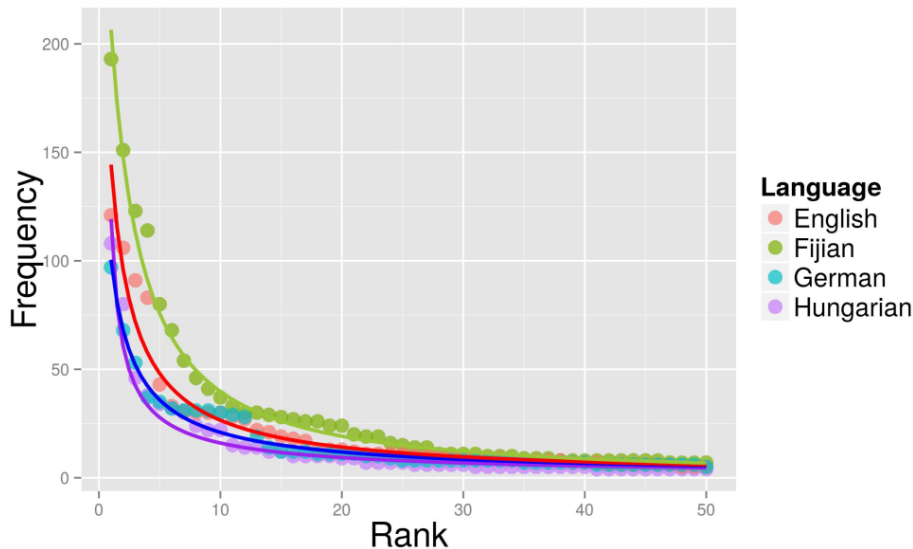


Figure 2 from: Bentz, C., Verkerk, A., Kiela, D., Hill, F., & Buttery, P. (2015).

Adaptive communication: Languages with more non-native speakers tend  

The zipfian distribution of vocabulary

- When the words in a corpus are ranked decreasingly they follow a zipfian distribution in which:

$$\text{freq}(r) \propto \frac{1}{r}$$

- In other words:
 - ▶ a few words in most languages have a very high frequency, and
 - ▶ most of the words in a language are in the so called "long tail".
- The most frequent words in a language are typically function words (stopwords)

Implications of Removing Stopwords in NLP

Removing stopwords has several effects:

- **Focuses on meaningful terms:** It can help to emphasize content-bearing words for tasks like classification or clustering
- **Risk of losing context:** Removing too many stopwords may change the sentence structure and meaning
- **Task-specific considerations:** Some tasks (e.g., sentiment analysis, language modeling, etc.) may benefit from retaining stopwords

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What is Morphological Parsing?

- **Morphology:** Study of the structure of words.
- **Morphological Parsing:** Breaking down words into:
 - ▶ **Lemmas:** Base forms of words.
 - ▶ **Morphemes:** Smallest units of meaning (roots, prefixes, suffixes).
- Essential for understanding word formation, meaning, and grammatical roles.

Why is Morphological Parsing Important?

① Handling Rich Morphology:

- ▶ Languages like Finnish, Turkish, or Arabic have complex word structures.

② Vocabulary Reduction:

- ▶ Groups inflected forms (e.g., *run*, *ran*, *running*) into a single base form.

③ Text Normalization:

- ▶ Preprocessing for tasks like sentiment analysis and information retrieval.

Most languages in Europe have rather simple morphology

We are used to **fusional languages**: few inflectional morphemes that add information to a stem.

A word in English

Computed

Comput ed
Stem suffix indicating past

How complex can morphology get? 1/

There are also **agglutinative languages**: combine many inflectional morphemes each of them adding new information.

A word in Finnish

Taloissammekin

talo	i	ssa	mme	kin
house	PLURAL	INNESIVE CASE	our	also

How complex can morphology get? 2/

And then, there are **polysynthetic languages**, that put many words together.

A word in Inuktitut

annulaksikkanninginnajualugasulauqsimagumanngittsiaqgaluaqtunga

annulaksi	kkanni	nginna	jualu	gasu	lauqsima	guma	nngit	...
imprison	again	really	a lot	try	ever	want	NEG	...

I would never ever even want to try to end up in jail ever again even for a bit. (Johns, 2007)

Why is important morphology in the age of neural technologies?

Two main uses:

- **In NLP:** mostly useful for low-resource languages
 - ▶ Simplifies text (helps to segment words).
 - ▶ Extracts information relevant to understand meaning.
 - ▶ Generation morphologically-correct text.
 - ▶ Support for language learners.
- **In CL:**
 - ▶ Automatic annotation of corpora.
 - ▶ Supports linguists in discovering linguistic phenomena.

Relevant resources for morphology in NLP 1/

- **Unimorph:** Datasets with exhaustive lists of words in 169 languages with tuples consisting of lemmas, surface words, word segmentation and lexical information (PoS, number, gender, case, etc.)
- **Universal Dependencies:** Corpora with (among other information) words are annotated with the lemma, the PoS and additional lexical information.

Provides type-level annotation, and is more exhaustive (is likelier to cover more words of a language).

lemma	surface form	lex. info
eat	eats	V;PRS;3;SG
eat	eating	V;V.PTCP;PRS
eat	ate	V;PST
eat	eaten	V;V.PTCP;PST
eat	eats	N;PL

Universal Dependencies

Provides **token-level annotation** with tokens in a context.

Form	Lemma	PoS	lex. info
He	he	PRON	PERS-P3SG-NOM Case=Nom...
ate	eat	VERB	PAST Mood=Ind—Tense=Past...
a	a	DET	IND-SG Definite=Ind...
mouthful	mouthful	NOUN	SG-NOM Number=Sing

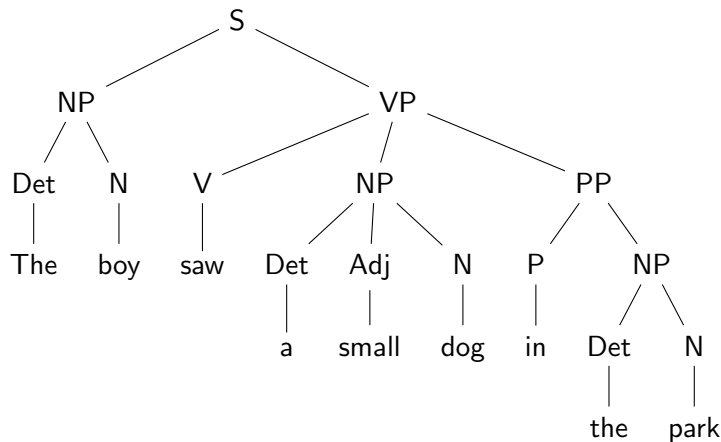
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What is Syntactic Parsing?

- Syntactic parsing is aimed at determining the structure of a sentence.
- It provides representations that help understand relationships between words.
- Two main strategies:
 - ▶ Phrase Structure (Constituency Grammar)
 - ▶ Dependency Structure (Dependency Grammar)

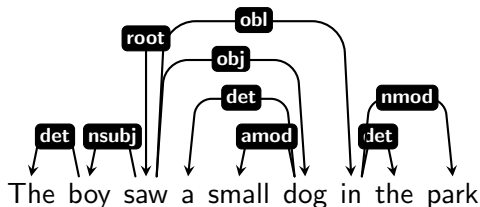
Phrase Structure

- Represents syntax as nested phrases.
- Commonly associated with constituency grammar.



Dependency Structure

- Represents syntax as directed relationships between words.
- Captures dependencies directly.



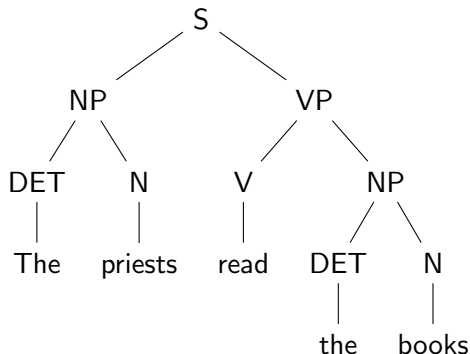
Why Dependency Structure is More Universal

- Dependency grammar focuses on word-to-word relations.
- Easier to apply to languages with different word orders (e.g., SVO, OVS, SOV, etc.).

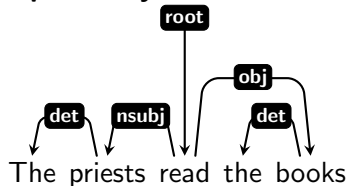
Example: Syntax Analysis in Two Languages 1/

English (SVO): The priests read the books.

Phrase Structure:



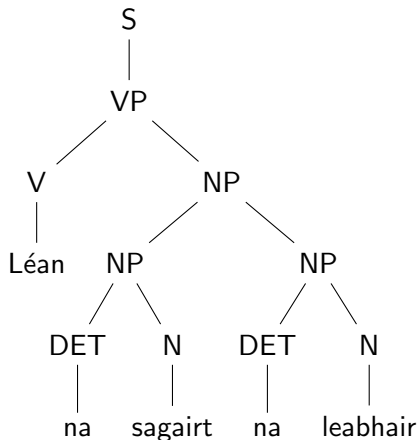
Dependency Structure:



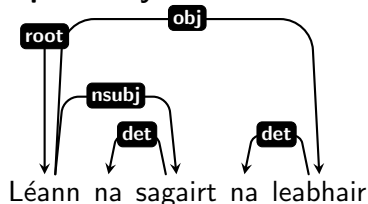
Example: Syntax Analysis in Two Languages 2/

Irish (VSO): Léann na sagairt na leabhair.

Phrase Structure:



Dependency Structure:



Why is important syntax in the age of neural technologies?

Two main uses:

- **In NLP:** mostly useful for low-resource languages
 - ▶ Split text into meaningful fragments
 - ▶ Disambiguate text
 - ▶ Knowledge-enhanced models (summarization, translation, etc.)
 - ▶ Helps identify named entities
- **In CL:**
 - ▶ Automatic annotation of corpora.
 - ▶ Search of specific syntactic structures in corpora.
 - ▶ Supports linguists in discovering linguistic phenomena.

Universal Dependencies

Annotation of both **morphological information** and **syntactic dependencies**

Form	Lemma	PoS	lex. info	Dep.	Dep. type
You	you	PRON	PERS-P2	3	nsubj
can	can	AUX	PRES-AUX VerbForm=Fin	3	aux
change	change	VERB	INF VerbForm=Inf	0	root
the	the	DET	DEF Definite=Def	6	det
security	security	NOUN	SG-NOM Number=Sing	6	compound
mode	mode	NOUN	SG-NOM Number=Sing	3	obj
...

What tools can be used for dependency parsing?

Many tools. Some of the most popular ones:

- **Stanza:**

- ▶ Graph-based parsing implemented as a neural network.
- ▶ Multilingual from its inception.
- ▶ More exhaustive, also slower.

- **ScyPy:**

- ▶ Statistical implementation of transition models.
- ▶ Initially focused on English, now it covers wide range of languages.
- ▶ More prone to make errors with long-range language phenomena, but faster.

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Words have meaning

Semantic compositionality principle

The meaning of a **complex expression** (a sentence) is determined by the **meanings of its constituent parts** (words) and **the way they are combined** (syntax).

- **Lexeme**: A unit of meaning in language, independent of inflectional forms.
 - ▶ Example: The lexeme *run* covers *runs*, *running*, *ran*.
- **Word Sense**: The specific meaning of a word in a given context.
 - ▶ Example: *bank* (financial institution) vs. *bank* (riverbank).

Words are related by their meaning

- **Synonymy**: words mean (almost) the same
- **Antonymy**: words are opposite
- **Similarity**: words share some aspects of their meaning
- **Relatedness**: words belong to the same *semantic field*
- **Connotation**: connotations independent of the meaning (for example, sentiment)

Words are related by their meaning

- **Synonymy**: words mean (almost) the same
 - ▶ *big* and *large*
 - ▶ yes, but: *my big sister* \neq *my large sister*
 - ▶ **Linguistic principle of contrast**: different form \rightarrow different meaning
- **Antonymy**: words are opposite
- **Similarity**: words share some aspects of their meaning
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- **Synonymy**: words mean (almost) the same
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 - ▶ *big* vs. *small*
 - ▶ *up* vs. *down*
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- **Similarity**: words share some aspects of their meaning
 - ▶ *cow, horse* → ruminants, size, etc.
 - ▶ *pen, pencil* → shape, purpose, etc.
- **Relatedness**: words belong to the same *semantic field*
- **Connotation**: connotations independent of the meaning (for example, sentiment)

Words are related by their meaning

- **Synonymy**: words mean (almost) the same
- **Antonymy**: words are opposite
- **Similarity**: words share some aspects of their meaning
- **Relatedness**: words belong to the same *semantic field*
 - ▶ *coffee, cup* → coffee is served in cups.
 - ▶ *car, wheel* → cars have four wheels.
- **Connotation**: connotations independent of the meaning (for example, sentiment)

Words are related by their meaning

- **Synonymy**: words mean (almost) the same
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- **Similarity**: words share some aspects of their meaning
- **Relatedness**: words belong to the same *semantic field*
- **Connotation**: connotations independent of the meaning (for example, sentiment)
 - ▶ *reproduce* vs. *plagiarize*
 - ▶ *mature* vs. *elderly*.

Introduction to Vector Semantics

- **Vector Semantics:** A method of representing word meanings using vectors in a high-dimensional space.
- Words are represented as points in this space, where:
 - ▶ The distance between vectors reflects the semantic similarity of words.
 - ▶ Words appearing in similar contexts are closer in the vector space.
- **Core Idea:** *"You shall know a word by the company it keeps"* (Firth, 1957).

Example: Words in the Same Context

Suppose you see these sentences:

- **Ong choi** is delicious **sautéed with garlic**.
- **Ong choi** is superb **over rice**.
- **Ong choi** **leaves** with **salty sauces**.

And you've also seen these:

- ... **spinach** sautéed with garlic over rice.
- **Chard** stems and leaves are delicious.
- **Collard greens** and other salty leafy greens.

Conclusion:

- **Ongchoi** is a leafy green like **spinach**, **chard**, or **collard greens**.
- We could conclude this based on words like "**leaves**" and "**delicious**" and "**sauteed**"

Introduction to Document Representation

- Representing text numerically is essential for machine learning models.
- **Bag-of-Words (BoW):**
 - ▶ Represents documents as a vector of word counts.
 - ▶ Ignores grammar, word order, and context.
- **TF-IDF (Term Frequency-Inverse Document Frequency):**
 - ▶ Weights words by their importance in the document and corpus.
 - ▶ Reduces the impact of frequent but uninformative words (e.g., "the").

Creating a Bag-of-Words (BoW) Vector

- Given a corpus:

Document 1: "The cat sat on the mat."

Document 2: "The dog lay on the rug."

- Vocabulary:

{cat, sat, mat, dog, lay, rug, on, the}

- Represent each document as a vector of word counts:

Document 1: [1, 1, 1, 0, 0, 0, 1, 2]

Document 2: [0, 0, 0, 1, 1, 1, 1, 2]

- Rows = documents, columns = word counts.

Creating a TF-IDF Vector

- **Step 1: Term Frequency (TF):**

$$TF = \frac{\text{Number of occurrences of the term in the document}}{\text{Total terms in the document}}$$

- **Step 2: Inverse Document Frequency (IDF):**

$$IDF = \log \frac{\text{Total number of documents}}{\text{Number of documents containing the term}}$$

- **Step 3: TF-IDF Score:**

$$TF\text{-}IDF = TF \times IDF$$

- **Example:**

- ▶ Word: "the" (appears in all documents).
- ▶ $IDF = \log \frac{100}{100} = 0$ (low importance).
- ▶ Word: "cat" (appears in one document).
- ▶ $IDF = \log \frac{100}{1} = \log 100 = 2$ (higher importance).

Limitations:

- BoW ignores context and word order.
- TF-IDF may give low scores to semantically important words.
- Both methods produce sparse vectors for large vocabularies (large vectors with large vocabulary)

Introduction to Embeddings

- **Embeddings:**

- ▶ Dense vector representations of text in a continuous vector space.
- ▶ Capture semantic and syntactic relationships between words.

- Unlike BoW or TF-IDF:

- ▶ Embeddings are **dense** (low-dimensional) rather than sparse.
- ▶ They are learned automatically from data rather than being based on simple counting or weighting.

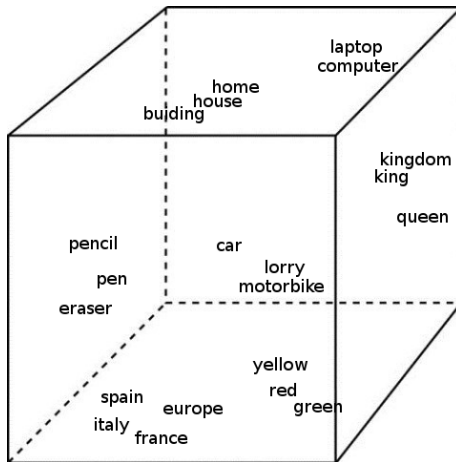
- Many existing strategies: Word2Vec, GloVe, Sent2Vec, BERT, etc.

Why Neural Networks for Embeddings?

- Neural networks are excellent for learning embeddings because:
 - ▶ They can learn complex, non-linear relationships from large amounts of data.
 - ▶ Representations are adjusted to optimize performance on downstream tasks (e.g., classification, translation).
- Key Idea:
Embeddings are learned during the process of training a neural network on a task.
- Example:
 - ▶ In a sentiment analysis task, embeddings capture semantic nuances relevant to predicting sentiment.

Visualization of Word Embeddings

- Semantically-related words (e.g., "pencil," "pen," "eraser") cluster together.
- Words with opposite meanings are farther apart.



Applications of Embeddings

- **Text-based applications:**

- ▶ Sentiment analysis, machine translation, question answering, etc.

- **Non-text applications:**

- ▶ Representing users (e.g., recommender systems).
- ▶ Representing products (e.g., in e-commerce search).

- **Advantages of embeddings:**

- ▶ Compact and efficient representations.
- ▶ Capture semantic relationships between words or entities.

Embeddings that represent sequences of words

- **General-purpose sentence embeddings:** USE, SBERT, SimCSE.
- **Multilingual tasks:** LASER, Multilingual USE, XLM-RoBERTa.
- **Lightweight options:** MiniLM, DistilBERT.
- **Paragraph embeddings:** Doc2Vec, GPT-based models, T5.

Distance Between Vector Representations

- To compare two vector representations (e.g., for sentences or documents), we compute their **distance** or **similarity**.
- Common measures:
 - ▶ **Euclidean Distance**: Measures the straight-line distance between vectors.
 - ▶ **Cosine Similarity**: Measures the cosine of the angle between vectors in the vector space.
- Why use cosine similarity?
 - ▶ Focuses on orientation, not magnitude.
 - ▶ Ideal for high-dimensional and sparse data (e.g., text embeddings).

Computing Cosine Similarity

- **Formula for Cosine Similarity:**

$$\text{cosine similarity} = \frac{\vec{u} \cdot \vec{v}}{\|\vec{u}\| \|\vec{v}\|}$$

Where:

- ▶ $\vec{u} \cdot \vec{v}$ = dot product of the two vectors.
- ▶ $\|\vec{u}\|$ and $\|\vec{v}\|$ = magnitudes (norms) of the vectors.

- **Steps:**

- ① Compute the dot product: $\vec{u} \cdot \vec{v} = \sum_{i=1}^n u_i v_i$
- ② Compute the magnitudes: $\|\vec{u}\| = \sqrt{\sum_{i=1}^n u_i^2}$, $\|\vec{v}\| = \sqrt{\sum_{i=1}^n v_i^2}$
- ③ Divide the dot product by the product of magnitudes.

- **Result:**

- ▶ Value ranges from -1 (opposite) to +1 (identical).
- ▶ A higher value means higher similarity.

- 1 Introduction
- 2 Text preprocessing
 - Removing Formatting
 - Tokenization
 - Text normalization
 - Stopwords
- 3 Morphological parsing
- 4 Syntactic parsing
- 5 Vector representations of text
- 6 Concluding remarks**

- Computational Linguistics (CL) and Natural Language Processing (NLP) are closely related, yet distinct fields.
- CL provides the theoretical foundation, while NLP focuses on practical implementation and real-world applications.
- Both fields are crucial for advancing our understanding of human language and improving human-computer interactions.
- Many of the tasks analyzed today are useful in these two disciplines.

Text preprocessing

- Crucial first step in NLP pipelines, ensuring data is clean, consistent, and ready for analysis.
- Key sub-tasks include removing formatting, tokenization, and normalization, each contributing to better model performance.
- Effective preprocessing requires tailored techniques for different tasks and languages.

Morphological parsing

- Very relevant in CL, as it allows word-level analysis of corpora, and helps to understand and identify linguistic phenomena.
- Especially relevant for low-resourced languages, for which it still plays a relevant role in NLP.
- Essential for handling rich morphology, reducing vocabulary size, and improving NLP models.
- Unimorph and Universal Dependencies are two of the most relevant multilingual resources for this task.

Syntactic parsing

- Aimed at understanding the structure and relationships between words in a sentence.
- Both phrase structure and dependency structure provide valuable insights, with dependency structure being more flexible across languages.
- Syntax remains important in NLP, especially for low-resource languages, aiding tasks like disambiguation, summarization, and named entity recognition.
- The use of universal dependencies and parsing tools like Stanza and ScyPy enhances syntactic analysis in a multilingual context.

Vector representations of text

- Words have complex relationships based on meaning: synonymy, antonymy, similarity, relatedness, etc.
- These relationships are fundamental to how we represent and understand language computationally.
- Vector semantics allow to represent word meanings as numeric vectors in high-dimensional spaces.
- Methods like **Bag-of-Words** and **TF-IDF** provide basic yet powerful representations for text; embeddings capture more nuanced semantic relationships.
- Comparing vector representations, such as through **cosine similarity**, enables efficient comparison of texts and supports a wide range of NLP applications.