

The Basics of NLP

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Advanced Natural Language Processing



https://github.com/PierreColombo/NLP_CS_2025_2026

Who Am I?



Occupation

Chief Scientist Officer - Co-founder - Equall, *NYC - Paris - Lisbon*

Maitre de Conférence - CentraleSupélec, Paris Saclay, *France*

PhD in Computer Science, Institut Polytechnique de Paris, *France*

MSc in Computer Science, EPFL, *Switzerland*

MSc CentraleSupélec, *France*

Past

Invited Researcher, ILLS - MILA - McGill - ETS - CNRS, Canada

Disney Research, USA

IBM Research, Switzerland

Procter and Gamble Research Center, Germany

Research 30+ papers, NeurIPS, ICML, ACL, TMLR, AAAI, EMNLP, NAACL

Awards Best Paper Award AAAI 2022: For evaluation of Generative AI.

Course Objective

Goal: Provide a toolkit of **concepts and methods** to **describe** and **tackle** NLP problems in real-life.

- Introduce **core ideas** at the basis of modern NLP algorithms
- Focus on **Machine Learning & Deep Learning applied to NLP**
- Focus on **empirical considerations** (accuracy, memory, speed) as opposed to theoretical guarantees

Lectures Outline

This class will consist of both theory & **practice**:

1. Intro to Natural Language Processing
2. Learning text representation with Vectors
3. Training Large Language Models
4. Building NLP applications (RAG, VLLM)
5. (OPEN)

Course Evaluation

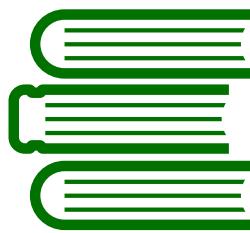
Paper Presentation (100% of the grade):

1. You have one research paper to present
2. You need to register today by group of 5
3. Details are available at [Link](#)

Today Lecture Outline

- **Why Natural Language Processing?**
- **What is Natural Language Processing?**
 - Modelling Framework
 - Tokenization as a first-step task
 - Overview of NLP Tasks
- **A Brief History of NLP**
- **How to tackle any NLP problem?**

NLP is Everywhere.



Education



Culture



Healthcare



Legal

Why Natural Language Processing?

What do we use language for?

- We **communicate** using language
- We **think** (partly) with language
- We **tell stories** in language
- We build **Scientific Theories** with language
- We make friends/build **relationships**

Why NLP ?

- **Access Knowledge** (search engine, recommender system...)
- **Communicate** (e.g. Translation)
- **Linguistics** and **Cognitive Sciences** (Analyse Languages themselves)

Why Natural Language Processing?

Amount of online textual data...

- 70 billion web-pages online (1.9 billion websites)
- 55 million Wikipedia articles

...Growing at a fast pace

- 9000 tweets/second
- 3 million mail / second (60% spam)

Why Natural Language Processing?

Potential Users of Natural Language Processing

- 7.9 billion people use some sort of language (January 2022)
- 4.7 billion internet users (January 2021) (~59%)
- 4.2 billion social media users (January 2021) (~54%)

NLP is reshaping the World

Time To Acquire 1M User

Netflix ~ 3.5 years

Spotify ~ 5 months

Instagram ~ 2.5 months

Chat GPT ~ 5 day

Airbnb ~ 2.5 years

Facebook ~ 10 months

iPhone ~ 74 day



Why Natural Language Processing?

What Products ?

- Search: +2 billion Google users, 700 millions Baidu users
- Social Media: +3 billion users of Social media (Facebook, Instagram, WeChat, Twitter...)
- Voice assistant: +100 million users (Alexa, Siri, Google Assistant)
- Machine Translation: 500M users for google translate

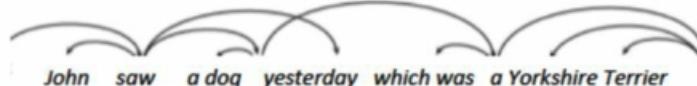
Why is Language Hard to Model?

A Definition of Language

Definition 1: *Language is a means to communicate, it is a semiotic system.*
*By that we simply mean that it is a **set of signs** . A sign is a pair consisting in [...] **a signifier and a signified** .*

Definition 2: *A sign consists in a phonological structure, a morphological structure, a syntactic structure and a semantic structure*

The Six Levels of Linguistics Analysis

Analysis in context Sentence-level analysis	Extra-linguistic context	 <i>Found him in the street inside a bag. I think he is happy with his new life</i> http://tagq.com/tag/1182/found-him-in-the-street-inside-a-bag-i-think-he-is-happy-with-his-new-life
	Linguistic context	<ul style="list-style-type: none">— You know what? John gave Peter a Christmas present yesterday— Wow, was he surprised? What was it like?— Surprisingly good. He spent quite a bit on it.
	Semantic level	<p>The landlord <small>SPEAKER</small> has not yet REPLIED <small>Communication_response</small> in writing <small>MEDIUM</small> to the tenant <small>ADRESSEE</small> objecting the proposed alterations <small>DNI</small>. <small>MESSAGE</small> <small>TRIGGER</small></p>
	Syntactic level	
	Morphological level	<i>brav+itude, bio+terror-isme/-iste, skype+(e)r</i> <i>mang-er-i-ons = MANGER+cond+1pl</i>
	Phonological level	International Phonetic Alphabet [aɪ pʰi: eɪ]
	Graphemic level	<i>enough, cough, draught, although, brought, through, thorough, hiccough</i>

The 5 Challenges of NLP

1. Productivity
2. Ambiguous
3. Variability
4. Diversity
5. Sparsity

Productivity

Definition

“property of the language-system which enables native speakers to construct and understand an indefinitely large number of utterances, including utterances that they have never previously encountered.” (Lyons, 1977)

→ New words, senses, structure are introduced in languages all the time

Examples: *staycation* and *social distance* were added to the Oxford Dictionary in 2021

Ambiguous

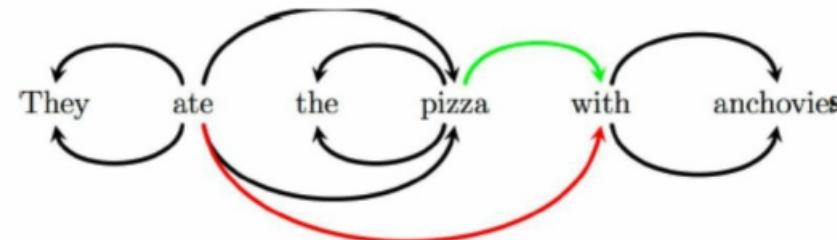
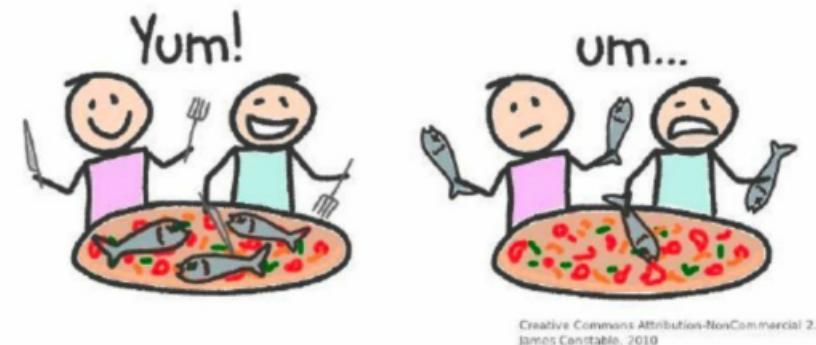
Most linguistic observations (speech, text) are open to **several interpretations**

We (Humans) disambiguate - i.e. **find the correct interpretation** - using all kind of signals (linguistic and extra linguistic)

Ambiguity can appear at all levels (phonology, graphemics, morphology, syntax, semantics)

Ambiguous

Syntactic Ambiguity



Ambiguous

Semantic Ambiguity

- Polysemy : e.g. **set**, **arm**, **head**

Head of New-Zealand is a woman

- Name Entity : e.g. **Michael Jordan**

Michael Jordan is a professor at Berkeley

- Object/Color : e.g. **cherry**

Your cherry coat

Ambiguous

Pragmatic Ambiguity

Two Soviet ships collide, one dies

Dealers will hear car talk at noon

Ambiguous

Disambiguating can requires Discourse Knowledge

Where can I find **a vegetarian restaurant** in Paris

Here is a list of restaurant in Paris:

Give me the top ranked ones, in the 14th arrondissement

Here are the top ranked restaurant in the 14th arrondissement in Paris

How far is **the closest one** from my current location?

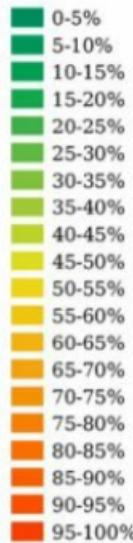
Variation

Language Varies at all levels

- Phonetic (accent)
- Morphological, Lexical (spelling)
- Syntactic
- Semantic

Phonetic Variation

Do you pronounce the
“r” in “arm” ?



Spelling and Syntactic Variation



T'as vu il l'a bien cherché wsh #AperoChezRicard

> +10000, shah!

> tabuz, lavé rien fé

> ki ca ? le mec ou son chien ?

> Wtf is wrong with him ? #PETA4EVER

> ki ca ? le chien ?

> loooool

BING translation:

You saw coming it #AperoChezRicard wsh

> +10000, shah!

> tabuz, washed anything fe

> Ki ca? the guy or his dog?

> WTF is wrong with him?

#PETA4EVER

> Ki ca? the dog?

> loooool

Variation Determiners

- Who is talking?
- To Whom?
- Where? *Work, Home, Restaurant*
- When? *19th century, 2008, 2022...*
- About what? *Specialised domain, the Weather,...*

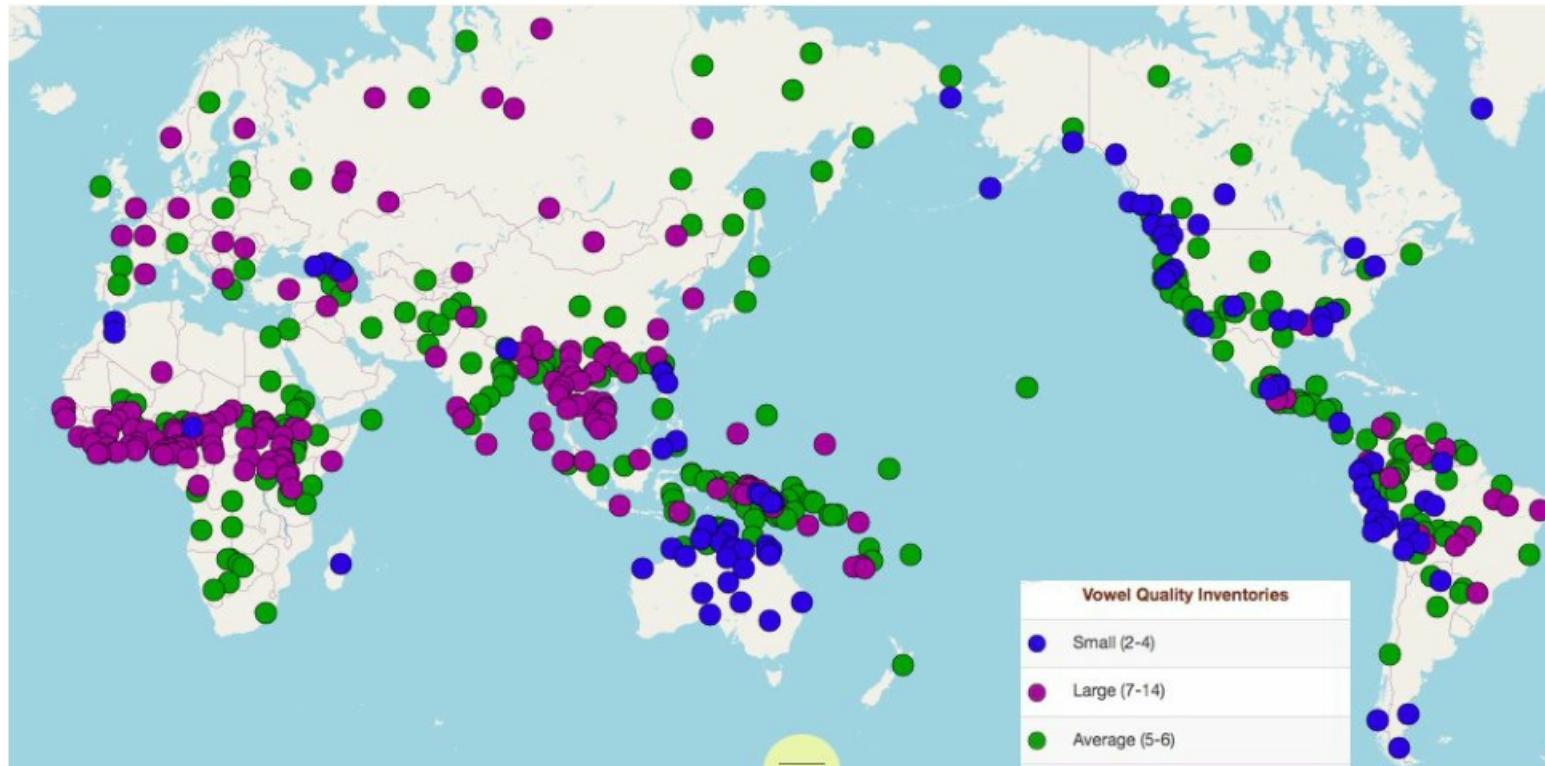
Essentially, the Variability of a language depends on:

- Social Context
- Geography
- Sociology
- Date
- Topic

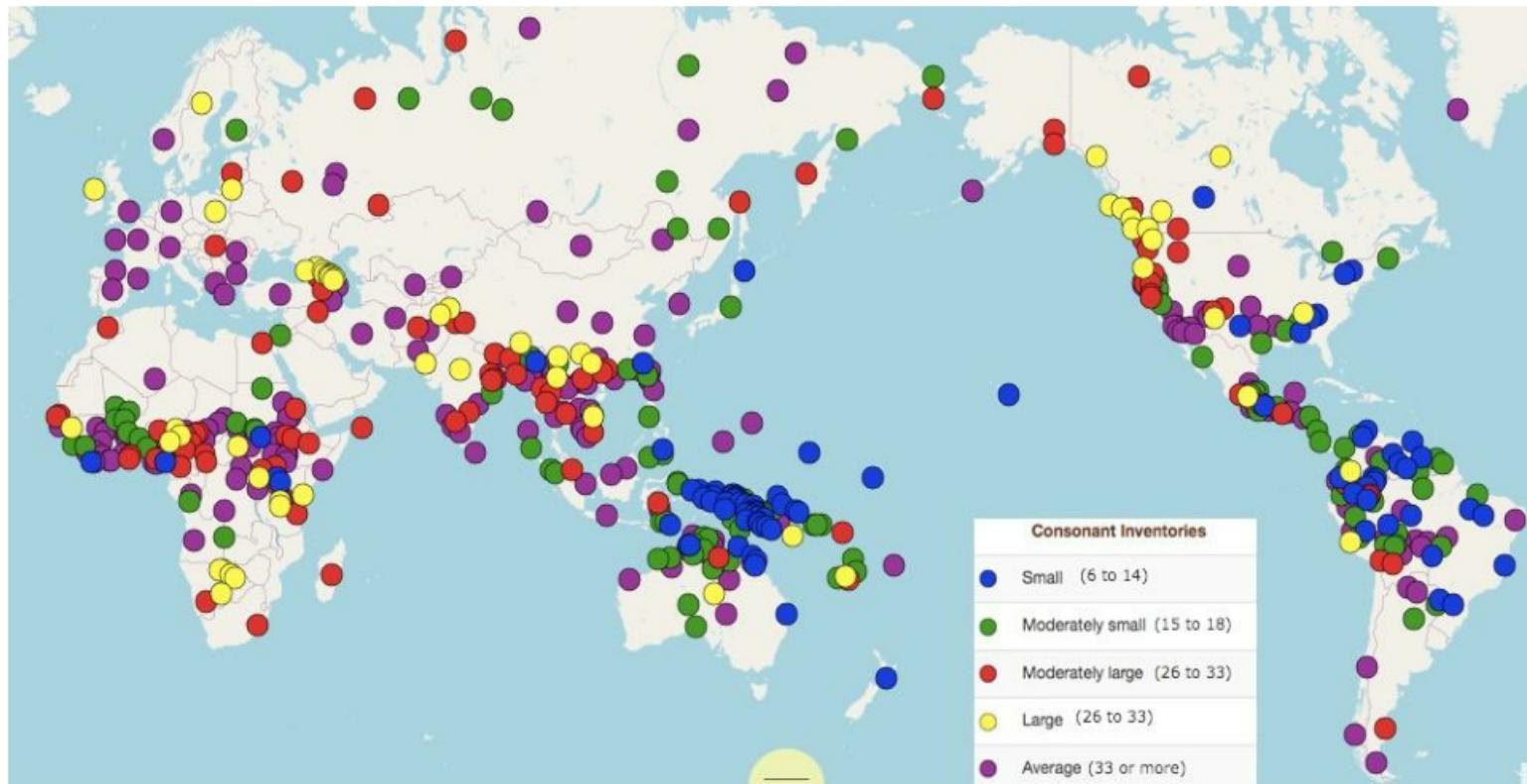
Diversity

- About **7000 languages** spoken in the world
- About **60%** are found in the **written form** (cf. Omniglot)

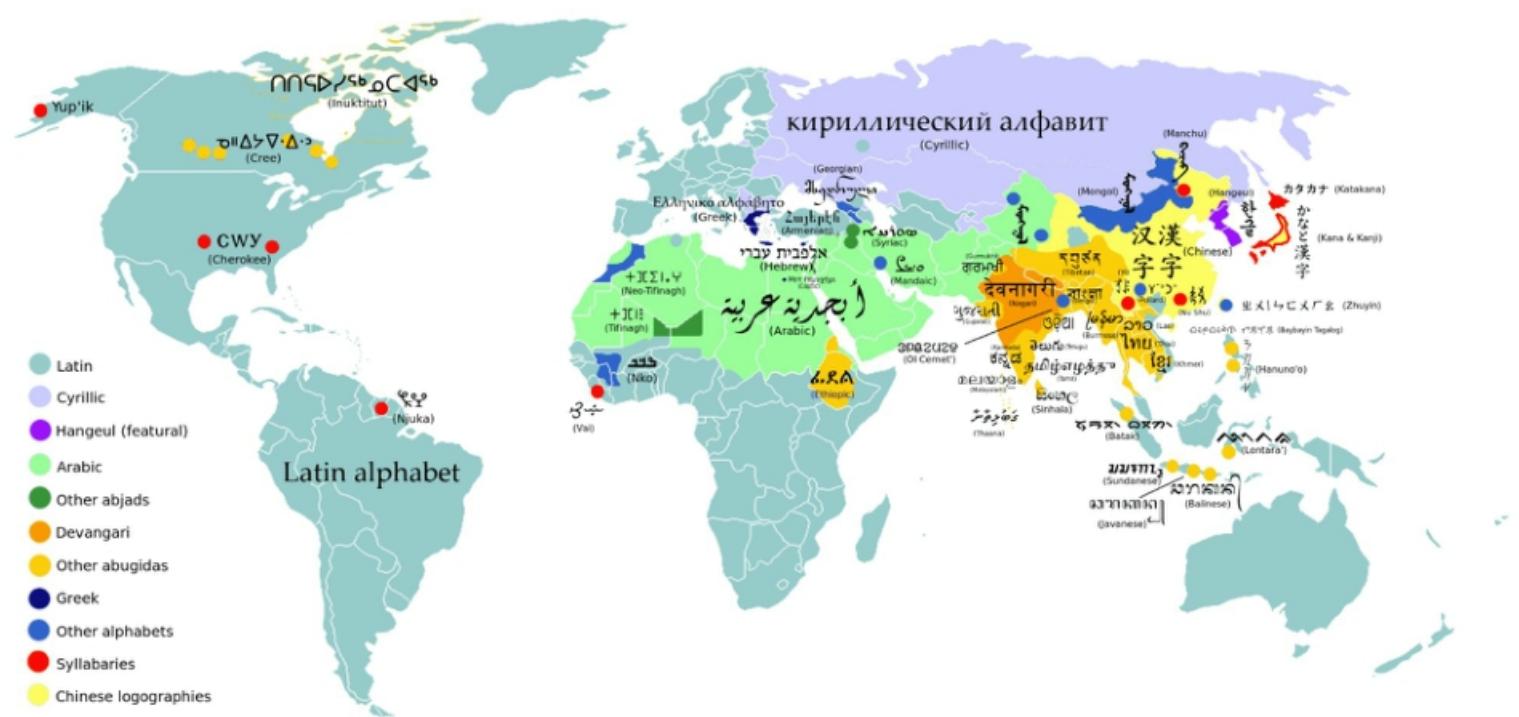
Phonologic Diversity



Phonologic Diversity



Graphemic Diversity



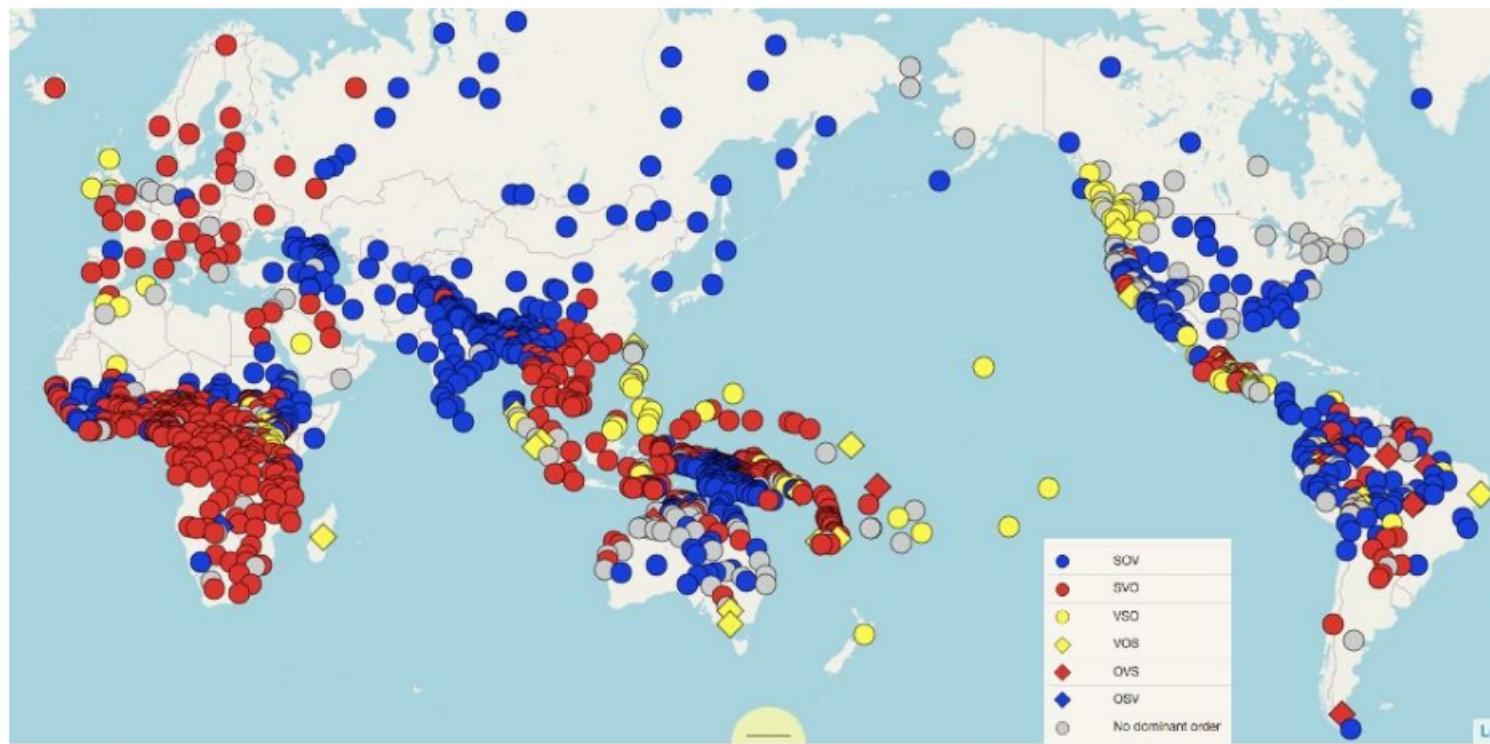
wikipedia

Syntactic Diversity

A key characteristics of the syntax of a given language is **the word order**

- **Word order differs** across languages
- Word order **degree of freedom** also differs across languages
- We characterize word orders with: **Subject (S) Verb (V) Object (O) order**

Syntactic Diversity



(Dyer et. al 2013)

Word Order Freedom And Morphology

- Word orders freedom and morphology are usually related
- **The more freedom in word orders**
 - the less information is conveyed by word positions
 - the more information is carried by each word
 - **the richer the morphology**

English *cats eat mice*

Russian (O: -ей) *Кошки едят мышей*
Мышей едят кошки
Едят кошки мышей.
Едят мышей кошки.

Semantic Diversity

- Words partition the semantic space
- This partition is very diverse across language



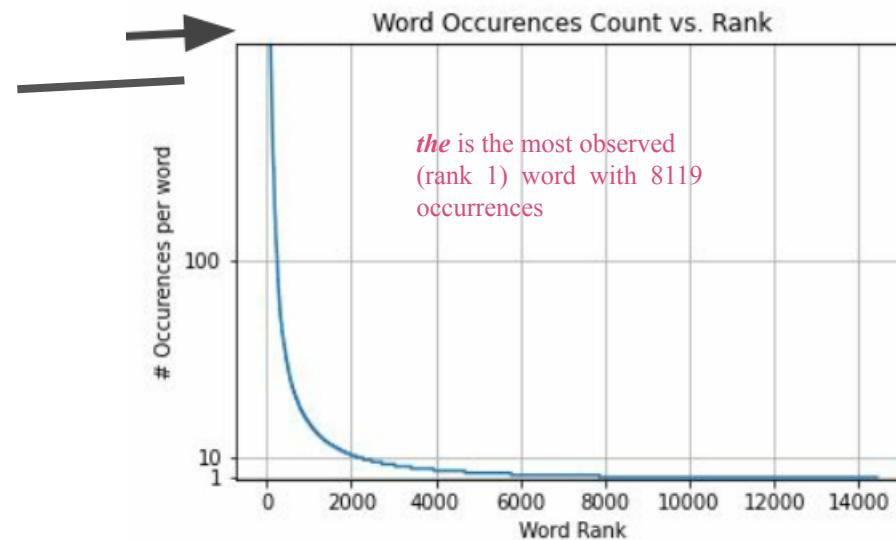
Statistical Description of a Corpus

We describe statistically a corpus of 800 scientific articles

Question: If we plot the number of occurrences of each word vs. the rank, what will we observe?

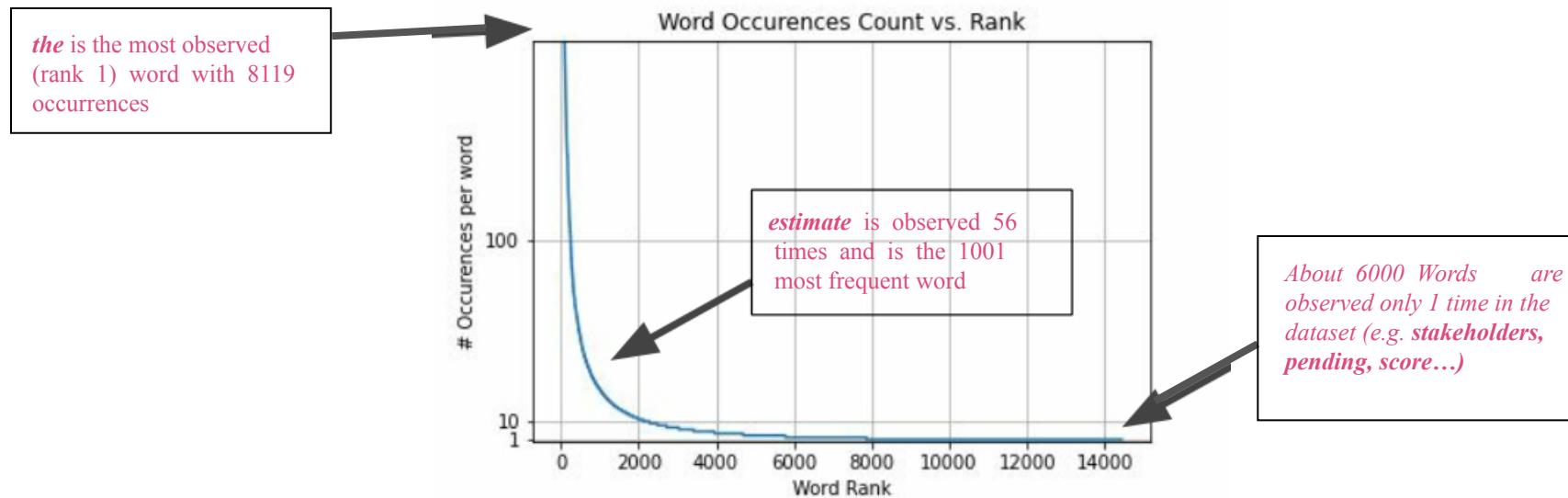
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Statistical Description of a Corpus

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- In a large enough corpus, word distributions follows *a Zipf Law ie:*

f_w **frequency of entity w**

k **frequency rank of w**

$$f_w(k) \propto \frac{1}{k^\alpha}$$

Statistical Description of a Corpus

We describe statistically a corpus of 800 scientific articles

- In a large enough corpus, word distributions follows *a Zipf Law ie:*

$$f_w \quad \text{frequency of entity w} \qquad f_w(k) \propto \frac{1}{k^\alpha}$$
$$k \quad \text{frequency rank of w}$$

- Zipf law is a Power relation between the rank and frequency
The most frequent entities are much more frequent than the less frequent ones
- Under a Zipf law, $\log(f_w)$ and $\log(k)$ are linearly related

Statistical Description of Language

Zipf Distributions are observed not only for words but with many other units of language (sounds, syntactic structure, name entities...)

Consequence

- A large number of units are observed in language with very low frequency i.e. **Sparsity**
- Very challenging for NLP

What is Natural Language Processing?

In a nutshell, NLP consists in handling the complexities of natural languages "to do something"

- Raw Text / Speech → Structured Information
- Raw Text / Speech → (Controlled) Text/Speech

In this course we will focus on **textual data**

Framework

We assume:

- A **token** is the basic unit of discrete data, defined to be an item from a vocabulary indexed by 1, ..., V.
- A **document** is a sequence of N words denoted by $d = (w_1, w_2, \dots, w_N)$, where w_n is the N-th word in the sequence.
- A **corpus** is a collection of M documents denoted by $D = (d_1, d_2, \dots, d_M)$

Example: *Wikipedia, All the articles of the NYT in 2021 ...*

Token

With regard to our end task, a token can be:

- A word
- A sub-word: *e.g. a sequence of 3 characters*
- A character
- An sequence of characters (sometimes a word, sometimes several words, sometimes a sub-word...)

Document

A Document can be:

- A Sentence
- A Paragraph
- A sequence of characters

Text Segmentation

Definition: Text Segmentation is the process of splitting raw text
(i.e. list of characters) into **units of interest**.

Two level of segmentation (usually) required :

- Split raw text into **modeling units** (ex: sentence, paragraph, 1000 characters, web-page...)
- Split modeling units into sequence of **basic units** (referred as tokens)
(e.g: words, word-pieces, characters, ...)

Two distinct approaches:

- **Linguistically informed** e.g. word, sentence segmentation...
- **Statistically informed** e.g. frequent sub-words (word pieces, sentence pieces...)

Tokenization

Definition: Tokenization consists in *segmenting* raw textual data into tokens:

Tokenization

Definition: Tokenization consists in *segmenting* raw textual data into tokens:

Can be framed as a character level task

input: *une industrie métallurgique existait.*

output: IIIIEIIIIIIIIIIIEIIIIIIIIIIIIIIIEIIIIIIIIIE

- **Easy task** for most languages and domains
- Can be **very complex in some cases** (Chinese, Social Media...)

NLP Tasks: Modeling Framework

Let (X, Y) a pair of r.v. X may characterize tokens, sentences or documents.

Modeling an NLP task consists in estimating the conditional probability $X | Y$ to predict Y with X .

Tasks Taxonomy

- If Y is a single label and X a sequence of tokens (e.g. a sentence):
Sequence Classification
- If we have one label per token: **Sequence Labelling**
- If Y is a sequence of tokens: **Sequence Prediction**
- If Y is a graph, a tree or a complex structured output:
Structure Prediction

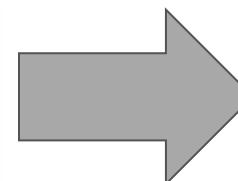
Document Classification

Europe

Germany's minimum wage hike will not cost jobs -labour minister

BERLIN, Jan 21 (Reuters) - Germany's planned minimum wage hike to 12 euros (\$13.61) per hour from October means a pay rise for over 6 million people across the country and should not cost jobs contrary to critics, Labour Minister Hubertus Heil said on Friday.

Increasing the German minimum wage, currently 9.82 euros per hour and will increase to 10.45 euros per hour from July, to 12 euros per hour was one of the key election promises of Chancellor Olaf Scholz and his Social Democrats.



Politics

Economy

Travel

....

Geopolitics

Document Ranking (Retriever)

Google search results for "what happened in 2020".

Search bar: what happened in 2020

Results:

- 2020 was a tumultuous year that saw the onset of a deadly pandemic, widespread protests over systemic racism—and a deeply contentious election.** 2020 was a tumultuous year that saw the onset of a deadly pandemic, widespread protests over systemic racism—and a deeply contentious election. Dec 17, 2020
- 
- <https://www.history.com> › topics › 2020-events
- 2020 Events - HISTORY**
- <https://nypost.com> › list › major-2020-events
- 2020 events: Yep, these all happened in the year from hell**
- 2020 events: Yep, these things all happened in the year from hell · Australian bushfires · Prince Harry and Meghan Markle quit royal family · COVID-19 pandemic.
- <https://en.wikipedia.org> › wiki › 2020
- 2020 - Wikipedia**
- 2020 was heavily defined by the COVID-19 pandemic, which led to global social and economic disruption, mass cancellations and postponements of events, worldwide ...

NLP Tasks: Part-of-Speech Tagging

POS Tagging: Find the **grammatical category** of each word

[*My* , *name* , *is* , *Bob* , *and* , *I* , *live* , *in* , *NY* , !]

NLP Tasks: Part-of-Speech Tagging

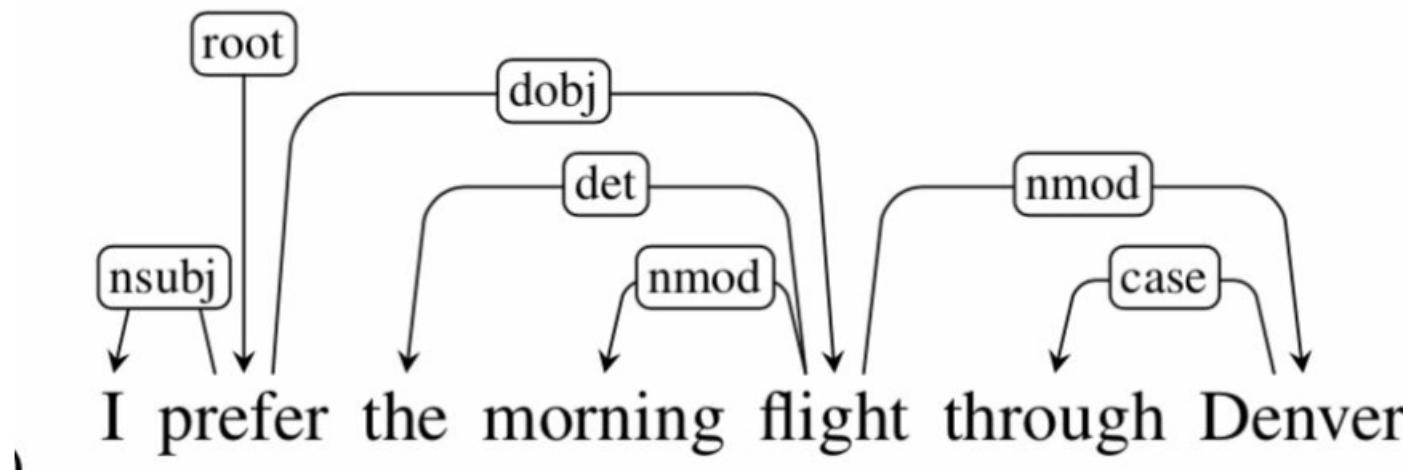
POS Tagging: Find the **grammatical category** of each word

[*My* , *name* , *is* , *Bob* , *and* , *I* , *live* , *in* , *NY* , !]

[**PRON** , **NOUN** , **VERB** , **NOUN** , **CC** , **PRON** , **VERB** , **PREP** , **NOUN** , **PUNCT**]

Syntactic Parsing

Syntactic Parsing consists in **extracting the syntactic structure** of a sentence. For instance, **Dependency Parsing** (here) predicts an acyclic directed graph (a **tree**)



Slot-Filling / Intent Detection

Intent Detection is a sequence classification task that consists in **classifying the intent of a user** in a pre-defined category.

Slot-Filling is a sequence labelling task that consists in identifying **specific parameters in a user request** .

Can you please play Hello from Adele ?

Intent: *play_music*

Slots: [*Can, you, please, play, Hello, from, Adele, ?*]
[*O , O , O , O , SONG , O , ARTIST , O*]

Semantic Role Labelling (SLR)

SRL is the task of finding the **semantic role** of each predicate in a sentence.

Given a sentence, SRL predicts: *who did what to whom, when, where, why, how*

NLP Tasks: Name Entity Recognition

NER: Find the **Name-Entities** in a sentence

[*My* , *name* , *is* , *Bob* , *and* , *I* , *live* , *in* , *NY* , !]

[*O* , *O* , *O* , **PERSON** , *O* , *O* , *O* , *O* , **LOCATION** , *O*]

Machine Translation

INPUT: *My name is Bob and I live in NY !*

OUTPUT: *Je m'appelle Bob et je vis à New-York!*

Question Answering

INPUT: *How many episodes in season 2 breaking bad?*

OUTPUT: **13**

How do we solve an NLP Problem?

Each NLP Problem is unique

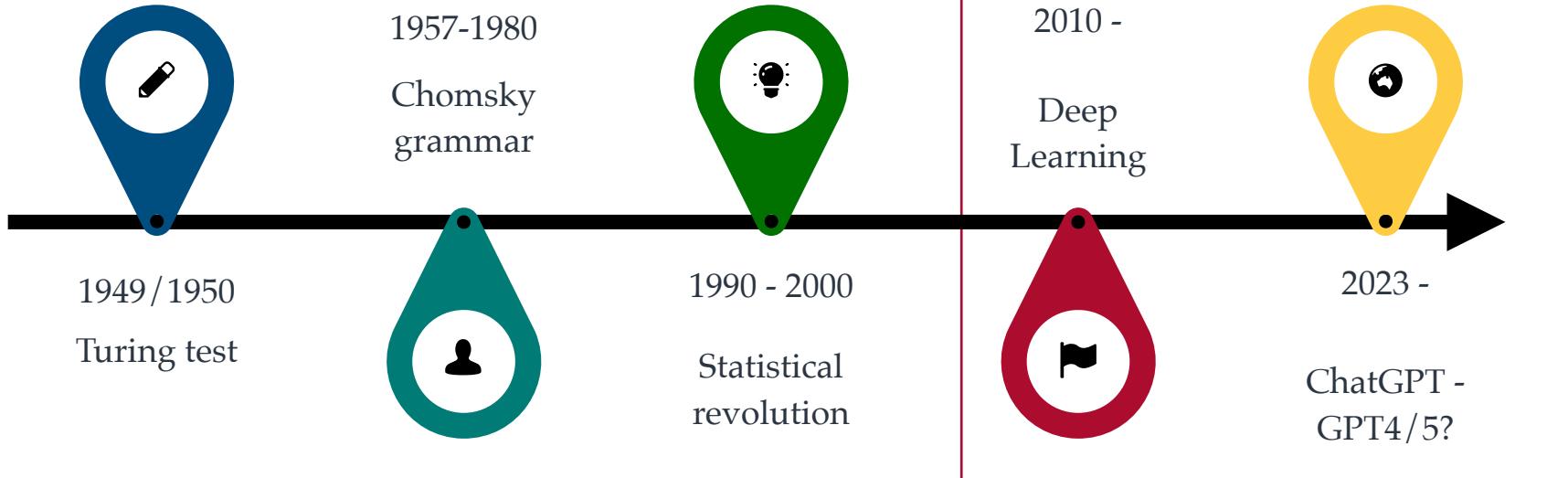
- **No Universal Method to solve them all**
- Have a toolkit in mind of methods (symbolic, statistics and deep learning based)

NLP Engineering: Find **what works best** for your given method based on what has been done already in the literature, by colleagues...

NLP Research : Find a **better** way to do (more accurate, cheaper, faster...)

Brief History of NLP

The Rise of the Generative Paradigm



1949: First Machine Translation “Model”

1949 *Memorandum on Translation*, Warren Weaver

First to propose the idea of using “*electronic computers*” to do translation

- Using Shannon’s information theory to frame Machine Translation as a *cryptographic* problem
- **Modeling context** to disambiguate between word senses
- “*Going down*” from each language to *universal language* in order to translate

1964: ELIZA First Conversational Bot

Men are all alike.

IN WHAT WAY

They're always bugging us about something or other.

CAN YOU THINK OF A SPECIFIC EXAMPLE

Well, my boyfriend made me come here.

YOUR BOYFRIEND MADE YOU COME HERE

He says I'm depressed much of the time.

I AM SORRY TO HEAR YOU ARE DEPRESSED

It's true. I am unhappy.

DO YOU THINK COMING HERE WILL HELP YOU NOT TO
BE UNHAPPY

I need some help, that much seems certain.

WHAT WOULD IT MEAN TO YOU IF YOU GOT SOME HELP

Perhaps I could learn to get along with my mother.

TELL ME MORE ABOUT YOUR FAMILY

My mother takes care of me.

WHO ELSE IN YOUR FAMILY TAKES CARE OF YOU

My father.

YOUR FATHER

You are like my father in some ways.

WHAT RESEMBLANCE DO YOU SEE

Natural Language Processing WorkFlow

Assume we have a **Research, Engineering, Product Problem**

1. Define a **NLP System** to solve it
Split into **modules**, each one performing a **task**
2. Define **Evaluation Metric(s)** for your system and submodules
3. **Collect Data** to build/train your models
4. Build **Baseline Models** (i.e. most simple model you can think of that have a non trivial performance metric)
5. Build **Better Models** using symbolic/statistical/DL methods

Session Summary

- The **6 Levels of analysis in linguistics**
- The **5 Challenges** of Natural Language Processing
- The NLP Modelling Framework
- **A Brief History** of Natural Language Processing: **the 3 Era of NLP**

Bibliography and Acknowledgment

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- ❖ [Warren Weaver, 1949] Memorandum on Translation
- ❖ [Weizenbaum, 1966] Eliza
- ❖ [Dryer, Matthew S. & Haspelmath, Martin (eds.) The [WALS](#)]

All these class have been taken from <https://nlp-ensae.github.io/materials/> and is taken from Benjamin Muller