

The Basics of NLP

Machine Learning for Natural Language Processing, ENSAE 2022

Lecture 1

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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

Course Logistics

- 6 sessions
- February 1st, 8th, 15th: 3h **lectures** (2x 1h30) with quizz (wooclap)
- March 1st, 8th, 15th: 3h **labs** (2x 1h30) ([google colab](#))
- Q&A on Discord

Material at nlp-ensae.github.io

Course Evaluation

- **Final Assignment [3/4 of the final grade]**
 - Solve a NLP problem and present your experiments synthetically
 - **Self-contained notebook uploaded to github and google colab**
 - **2 pages report**
- **Quizz [1/4 of the final grade]** happening during the lectures on wooclap

Lectures Outline

1. **The Basics of Natural Language Processing (February 1st)**
2. Representing Text with Vectors (February 1st)
3. Deep Learning Methods for NLP (February 8th)
4. Language Modeling (February 8th)
5. Sequence Labelling & Sequence Classification of Text (February 15th)
6. Sequence Generation Tasks (February 15th)

Labs Outline

1. Describe Statistically large scale corpora (March 1st)
2. Statistical Based and Word2vec Based Retriever (March 1st)
3. Task-Specific Modelling with Neural Networks (March 8th)
4. Task-Specific Modelling with Neural Networks (II) (March 8th)
5. Machine Translation (March 15th)
6. Project Follow-up (March 15h)

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?**

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%)

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


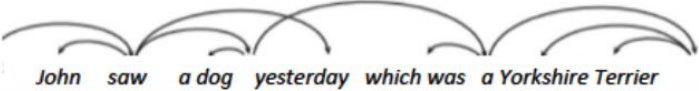
Why is Language Hard to Model?

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	Extra-linguistic context		Found him in the street inside a bag. I think he is happy with his new life <small>http://img.com/gag/serin/2007/Found-him-in-the-street-inside-a-bag-143bb-ha-0-happy-with-his-new-life</small>
	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		The landlord _{SPEAKER} has not yet REPLIED _{Communication_response} in writing _{MEDIUM} to the tenant _{ADDRESSEE} objecting the proposed alterations _{MESSAGE} . DNI _{TRIGGER}
Sentence-level analysis	Syntactic level		John saw a dog yesterday which was a Yorkshire Terrier
	Morphological level		brav+itude, bio+terror-isme/-iste, skype+(e)r mang-er-i-ons = MANGER+cond+1pl
	Phonological level	International Phonetic Alphabet	[aɪ p ^h i: eɪ]
	Graphemic level		enough, cough, draught, although, brought, through, thorough, hiccough

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

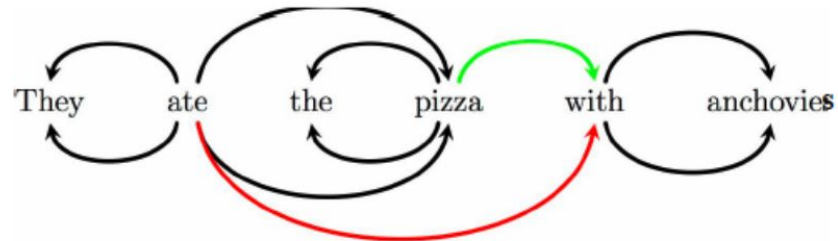
Most linguistic observations (speech, text) are open to **several interpretations**

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?

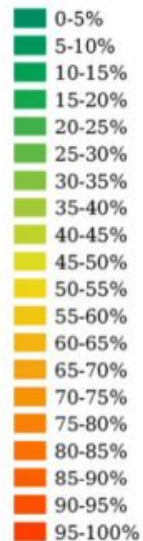
Variation

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 ?
> loool

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?
> loool

Variation Determiners

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

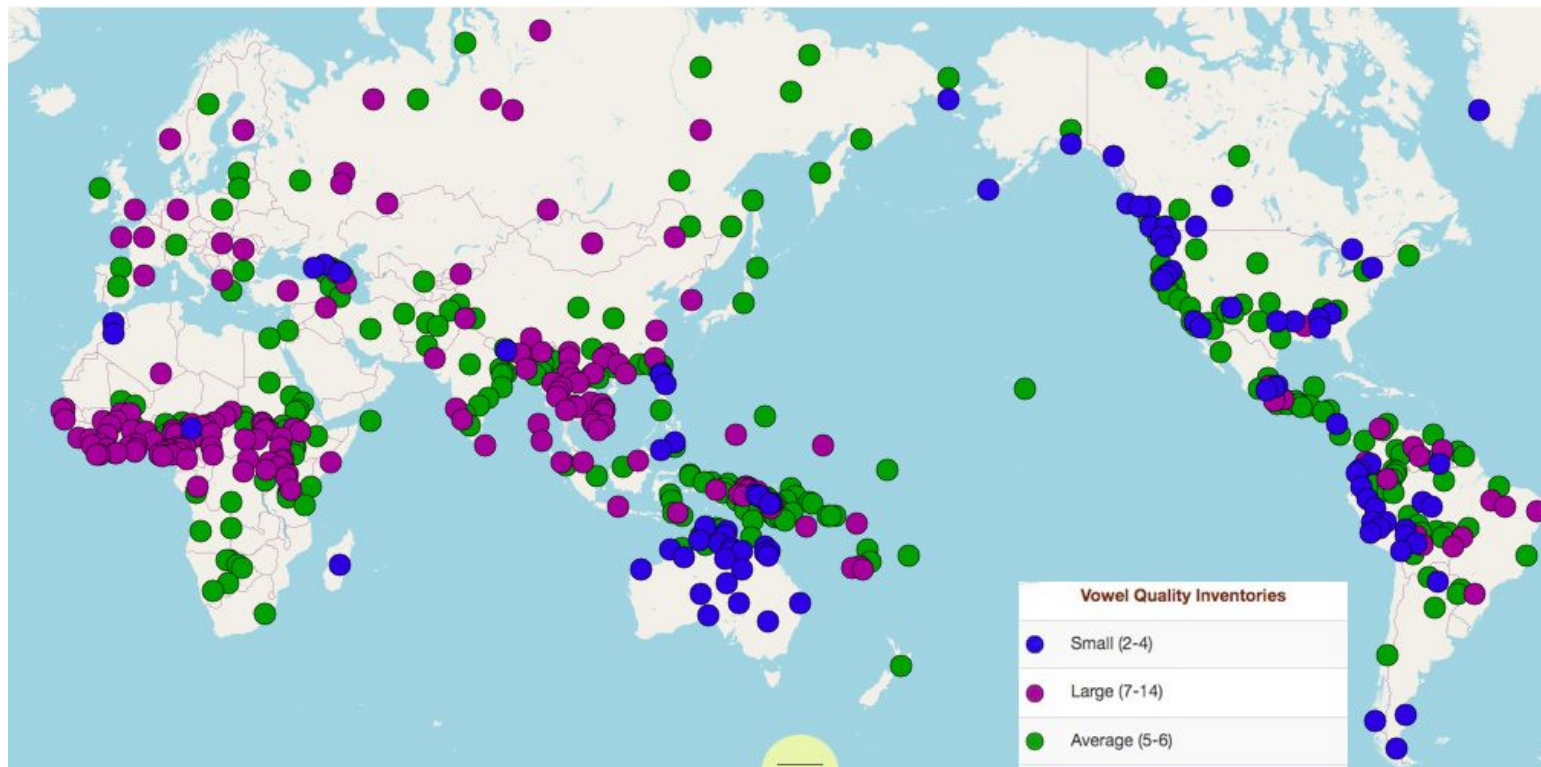
Essentially, the Variability of a language depends on:

- Social Context
- Geography
- Sociology
- Date
- Topic

Diversity

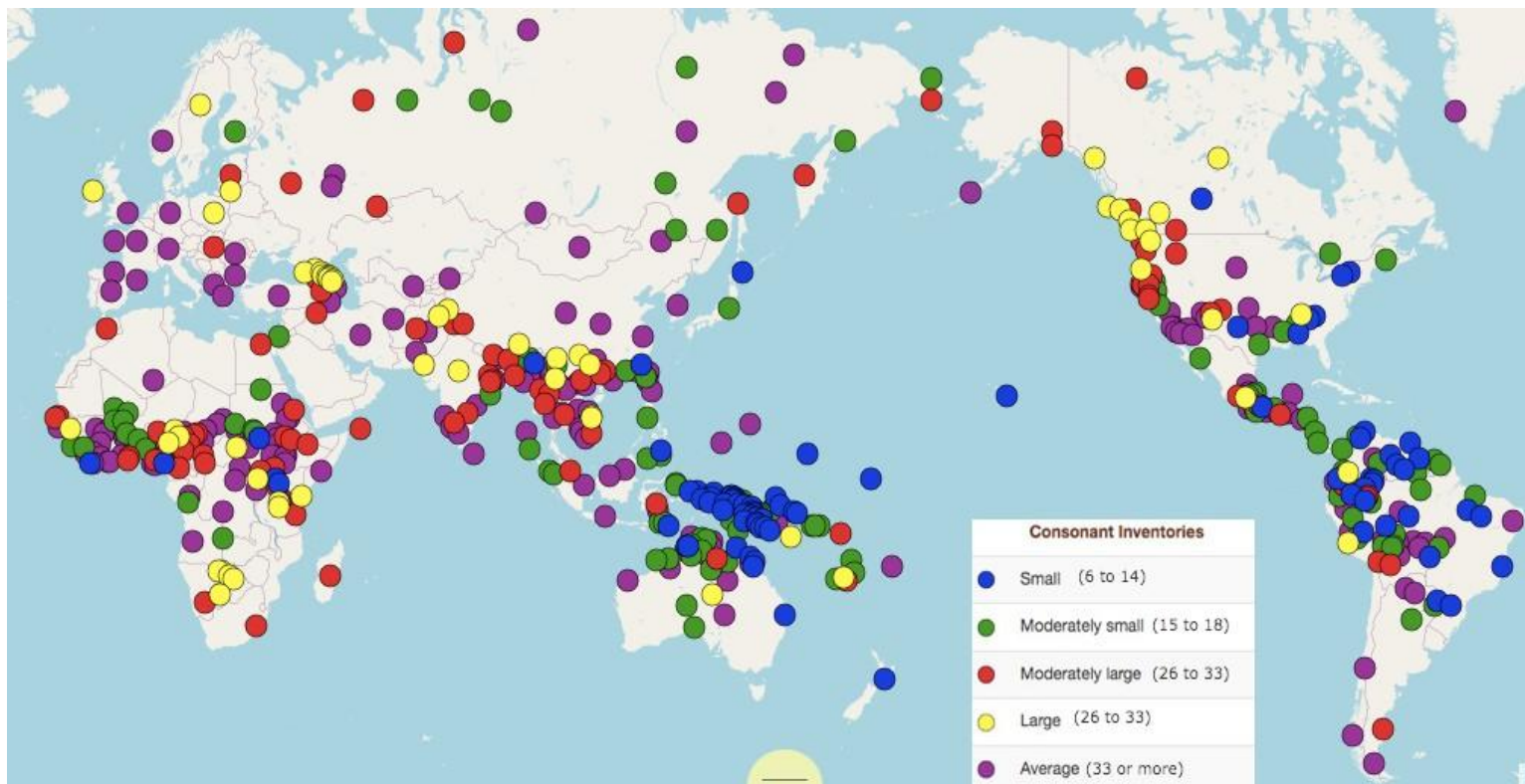
- About **7000 languages** spoken in the world
- About **60%** are found in the **written form** (cf. Omniglot)

Phonologic Diversity



(Dyer et. al 2013)

Phonologic Diversity



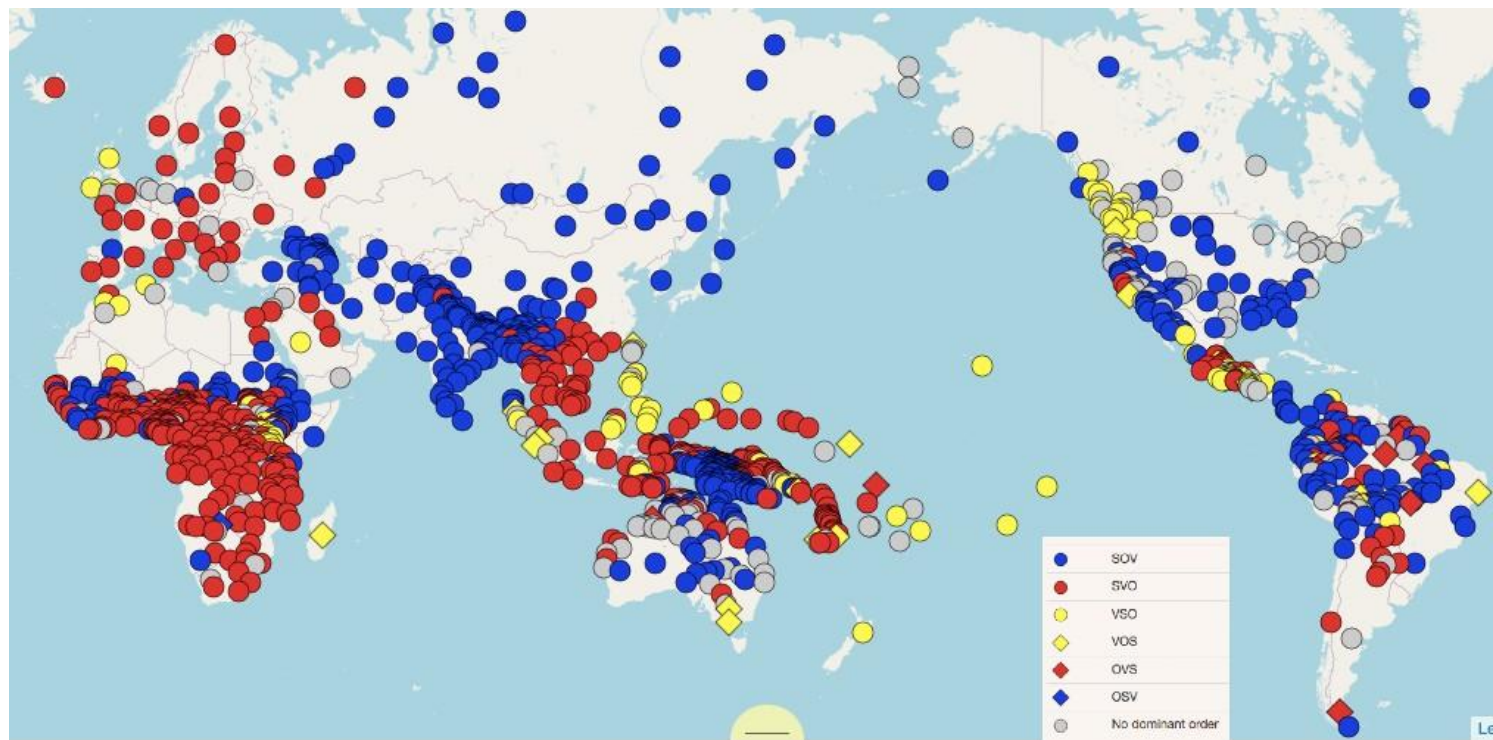
(Dyer et. al 2013)

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(О: -ей) *Кошки едят мышей* 

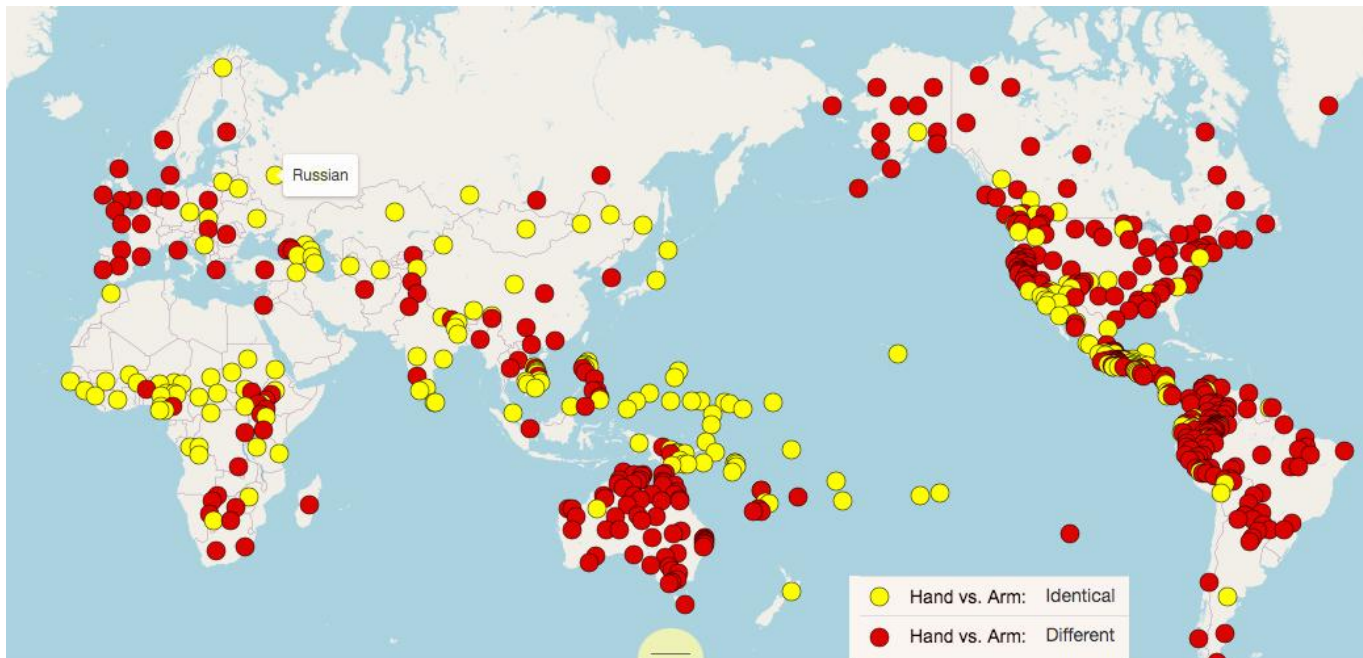
Мышей едят кошки 

Едят кошки мышей.

Едят мышей кошки.

Semantic Diversity

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



(Dyer et. al 2013)

Statistical Description of a Corpus

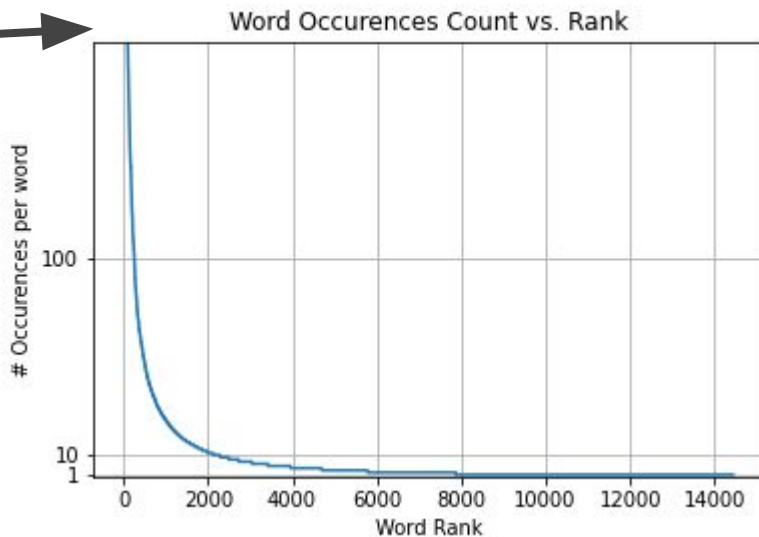
We describe statistically a corpus of 800 scientific articles

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

Statistical Description of a Corpus

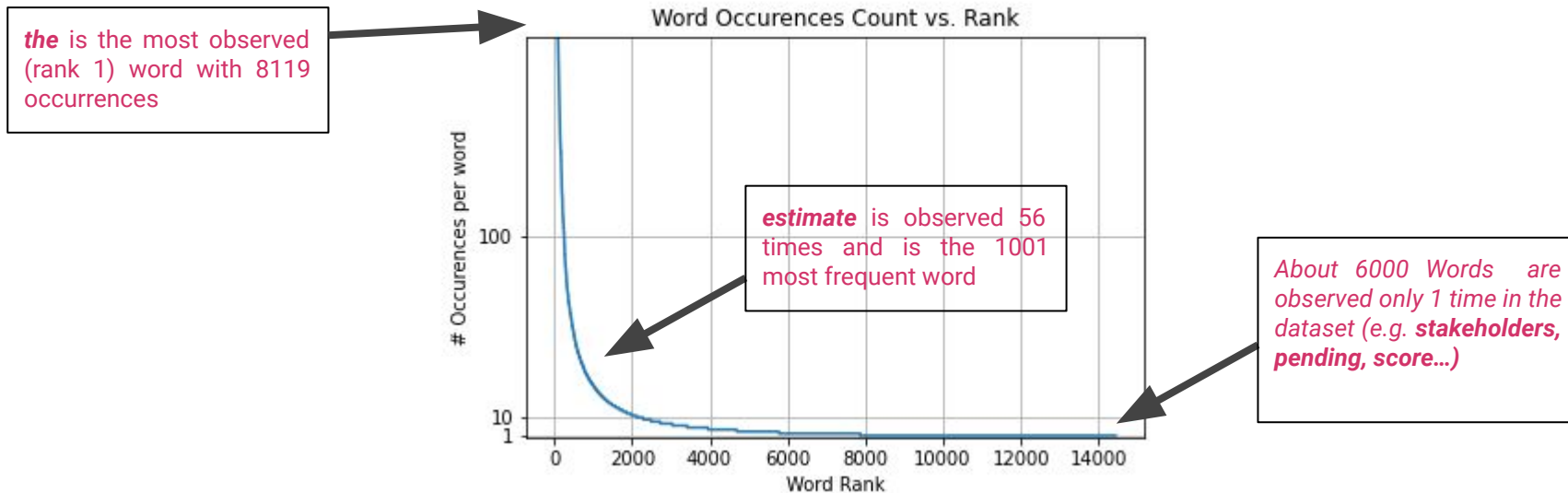
We describe statistically a corpus of 800 scientific articles

the is the most observed (rank 1) word with 8119 occurrences



Statistical Description of a Corpus

We describe statistically a corpus of 800 scientific articles



the is the most observed (rank 1) word with 8119 occurrences

estimate is observed 56 times and is the 1001 most frequent word

About 6000 Words are observed only 1 time in the dataset (e.g. *stakeholders, pending, score...*)

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 frequency of entity w

k frequency rank of entity w

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

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:**

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

- 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 $1, \dots, V$.
- A **document** is a sequence of N words denoted by $\mathbf{d} = (\mathbf{w}_1, \mathbf{w}_2, \dots, \mathbf{w}_N)$, 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:

NLP Tasks: Modeling Framework

Let (X, Y) a pair of random variable. X may characterize tokens or documents. Modeling an NLP task consists in estimating the conditional probability $Y|X$ in order to predict Y with X .

$$p(Y|X)$$

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

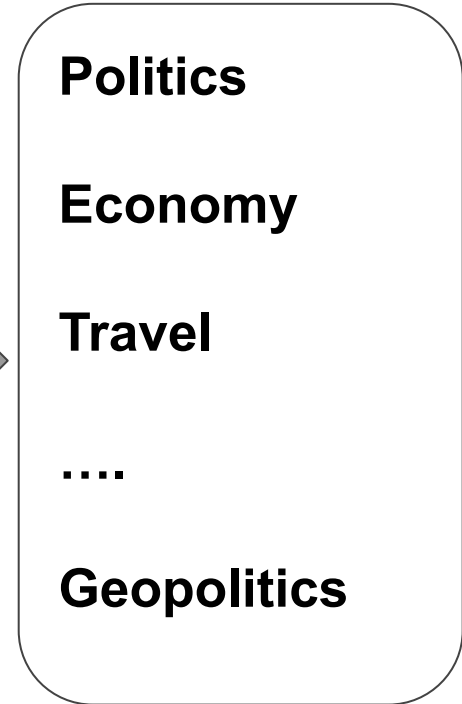
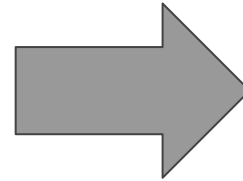
Document Classification

Europe

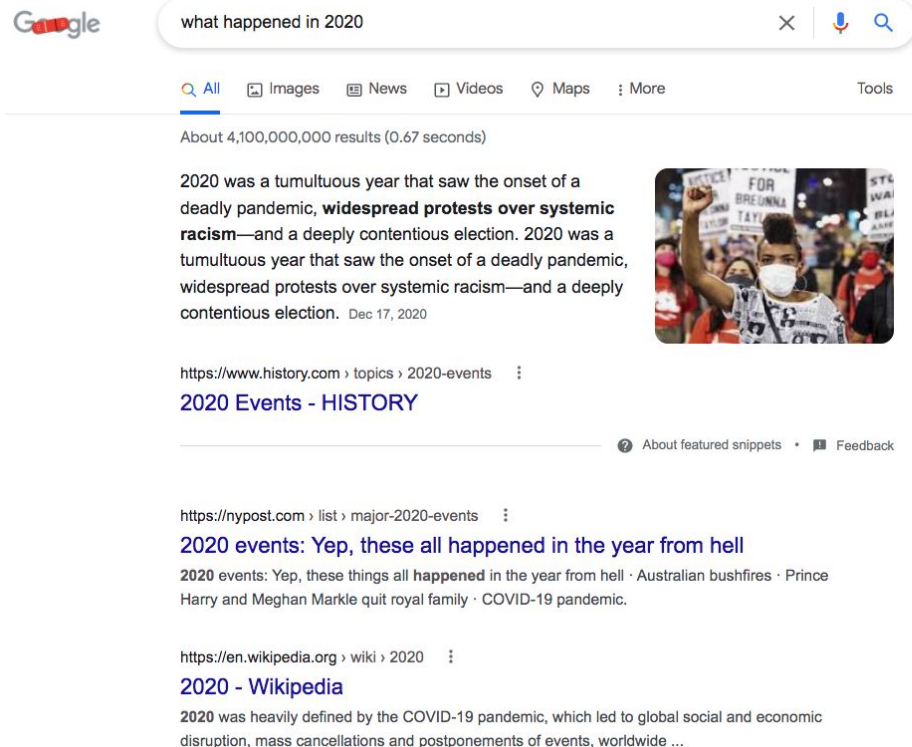
Germany's minimum wage hike will not cost jobs -labour minister

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.



Document Ranking (Retriever)



The image shows a Google search interface. The search bar contains the text "what happened in 2020". Below the search bar, there are navigation options: "All", "Images", "News", "Videos", "Maps", and "More". The search results show "About 4,100,000,000 results (0.67 seconds)". The first result is a snippet from history.com titled "2020 Events - HISTORY". The snippet text reads: "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". To the right of the text is a small image of a person wearing a white face mask and a black t-shirt, raising their right fist in a protest gesture. The background of the image shows other people and protest signs, including one that says "FOR BREXIT". Below the first result, there are links to "About featured snippets" and "Feedback". The second result is from nypost.com titled "2020 events: Yep, these all happened in the year from hell". The snippet text reads: "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." Below the second result, there is a link to "en.wikipedia.org" titled "2020 - Wikipedia". The snippet text reads: "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

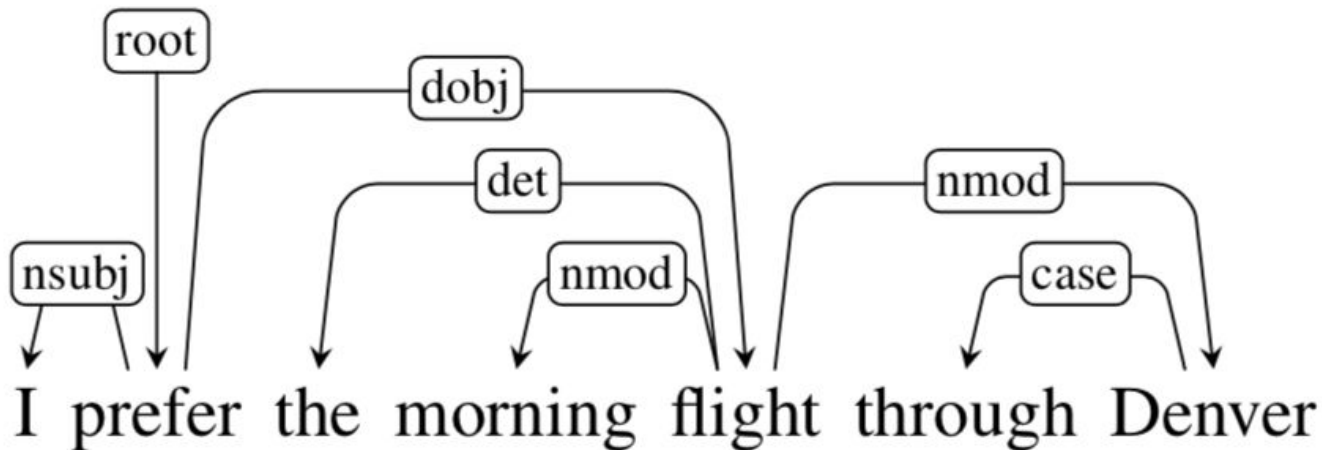
POS Tagging: Find the **grammatical category** of each word

[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

Brief History of NLP

Symbolic

1940-2000

Focus on rule-based systems, formal grammars

Development of linguistic resources (lexicon, ontologies, grammars...)

Statistical Learning

1990-2010

Statistical learning theory (SVM, Random Forest), Graphical Probabilistic Models (e.g. LDA, HMM)

Development of annotated datasets

Deep Learning

2010-Today

Deep Learning Architecture (Transformer)

Transfer Learning in NLP (word2vec, BERT, CamemBERT, GPT)

More compute, larger (raw) dataset, Open Source Deep Learning Libraries

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](#)]