KU LEUVEN

Natural Language Processing: Introduction

H02B1A

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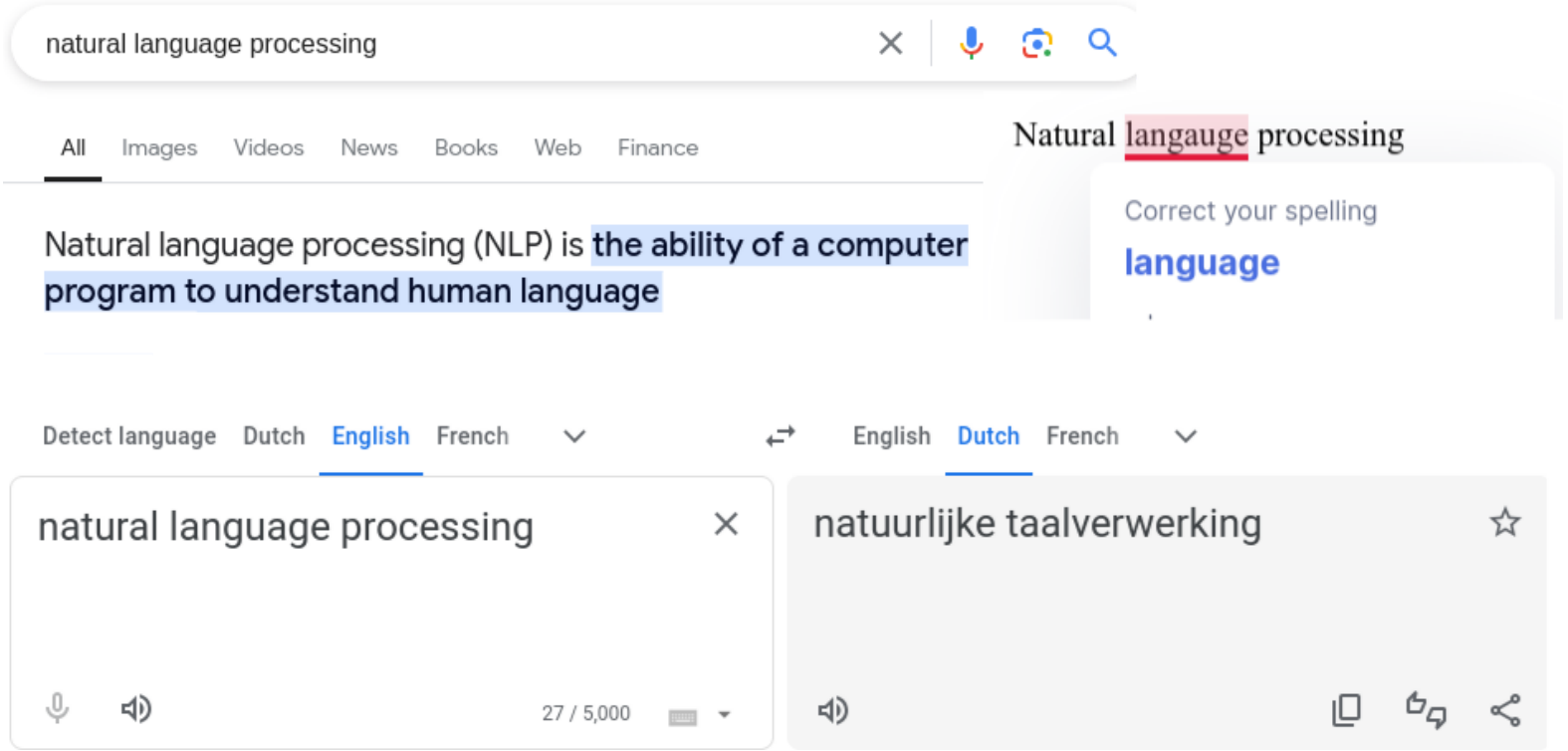
Natural language processing



Natural language processing: definition

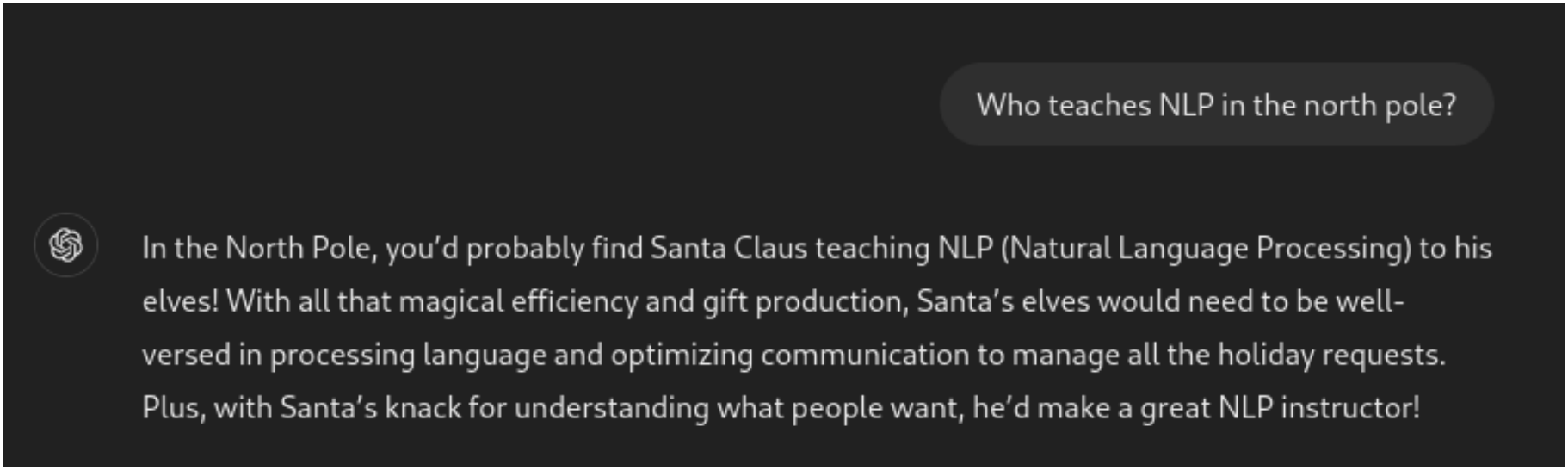
> Natural language processing is a field of science and engineering focused on the development and study of automatic systems that understand and generate natural (that is, human,) languages.

StanfordNLP (2024)

Natural language processing: all-in-one

Retrieved 19/08/2024

Natural language processing: all-in-one



Retrieved 19/08/2024

This course

Foundations

- Building blocks of state-of-the-art NLP systems
- What challenges have been overcome?
- What challenges are still open?

Tasks and applications

- Tasks that cover all levels of linguistic processing (morphology, syntax, semantics)
- Example applications (e.g. machine translation and conversational agents)

This course

Learning goals

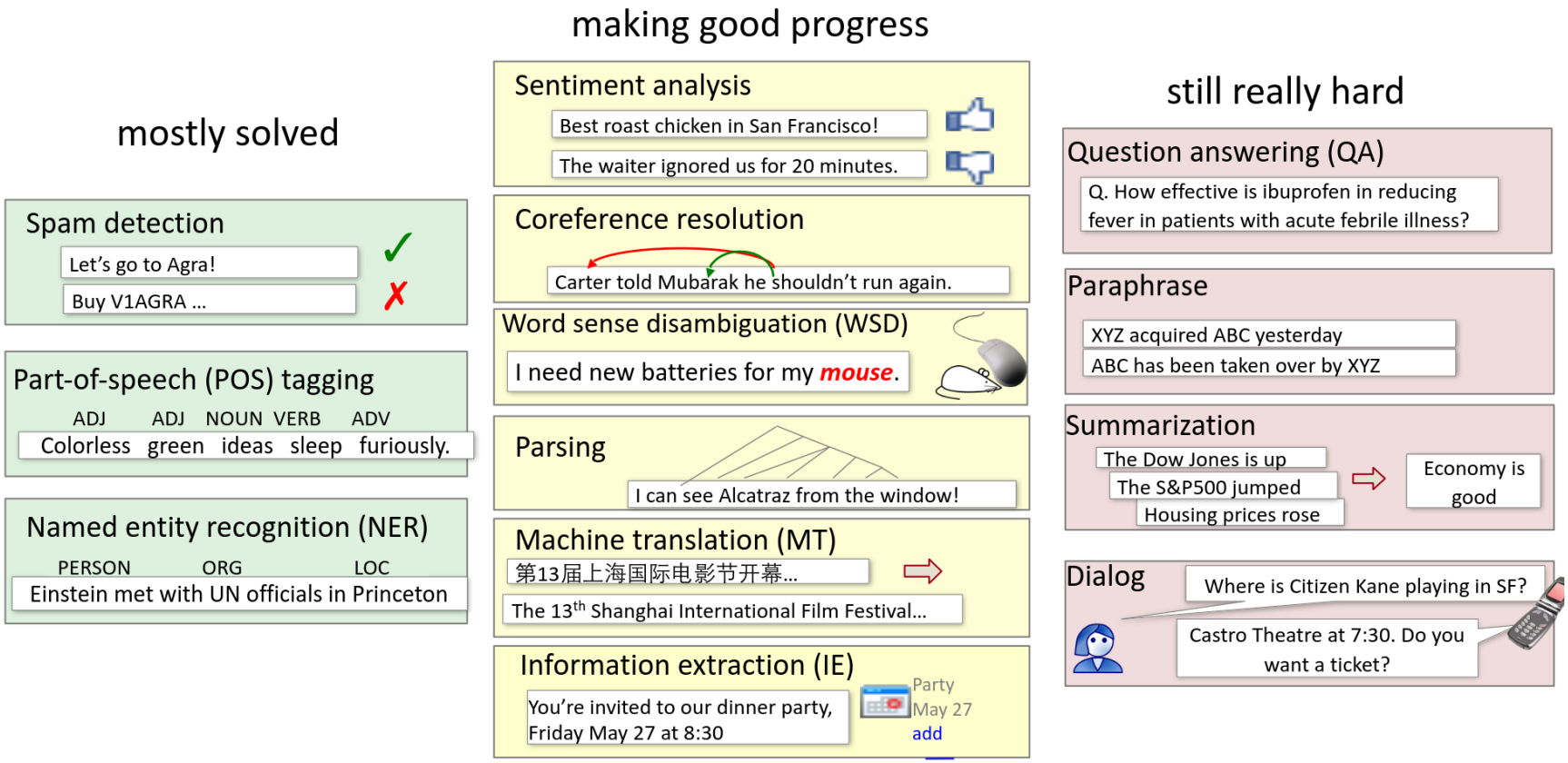
At the end of the course, you should be able to

- describe fundamental concepts and algorithms seen in class
- implement and apply these algorithms
- describe and use state-of-the-art NLP models

This lecture

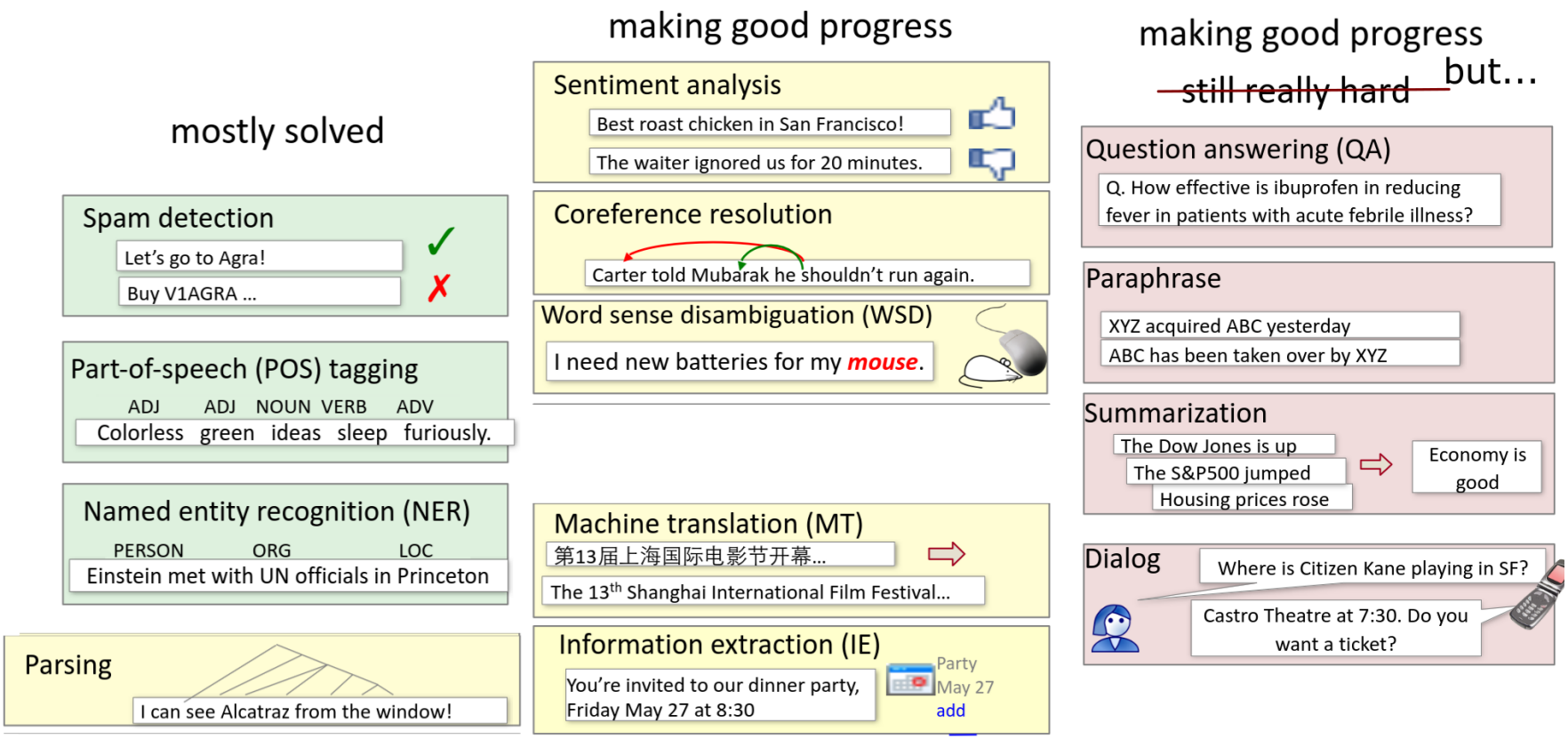
- Current state of NLP
- General challenges
- Representing words and sentences
- Practical aspects of the course

State of NLP



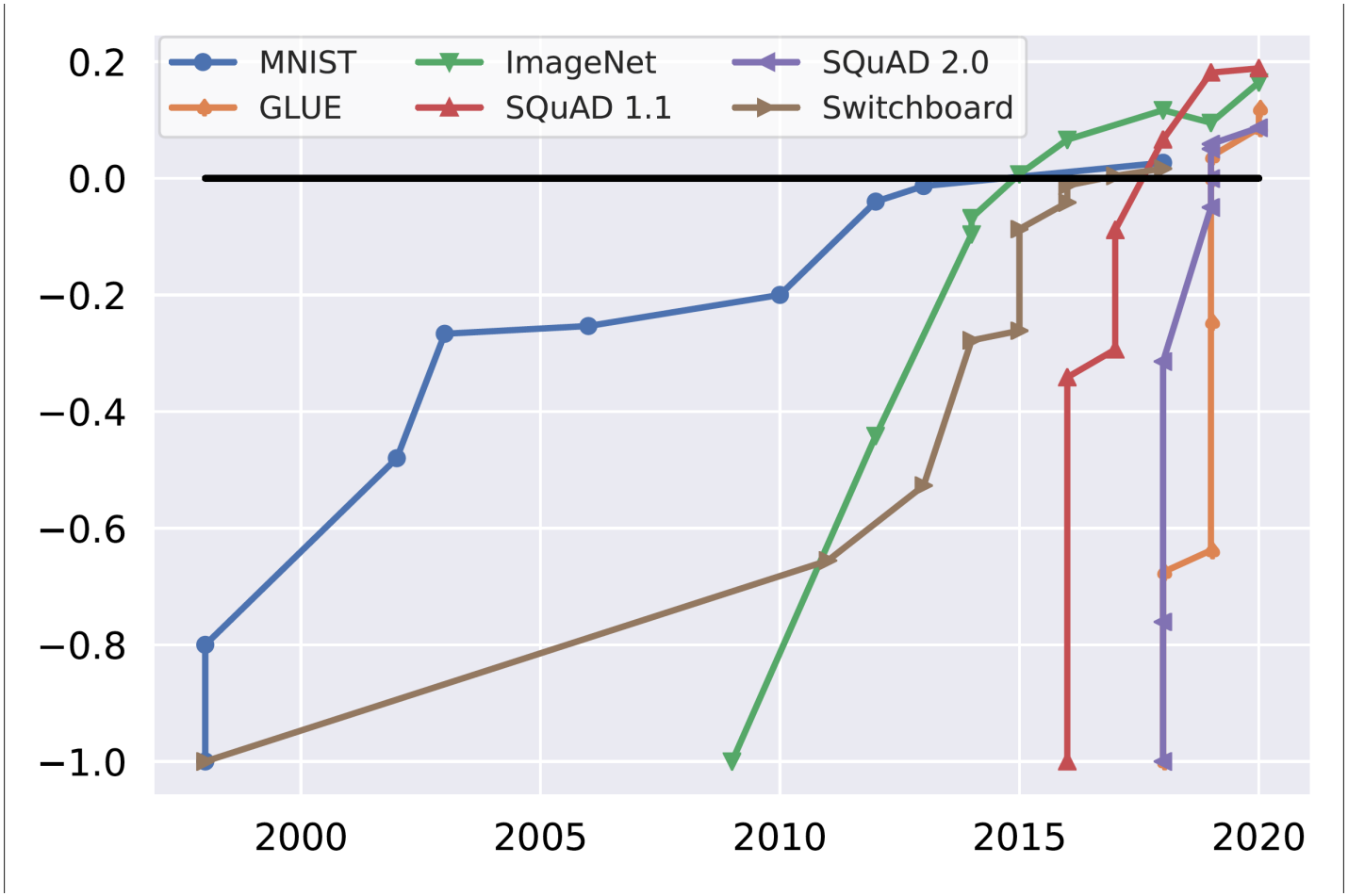
NLP progress in 2012 by Dan Jurafsky

State of NLP



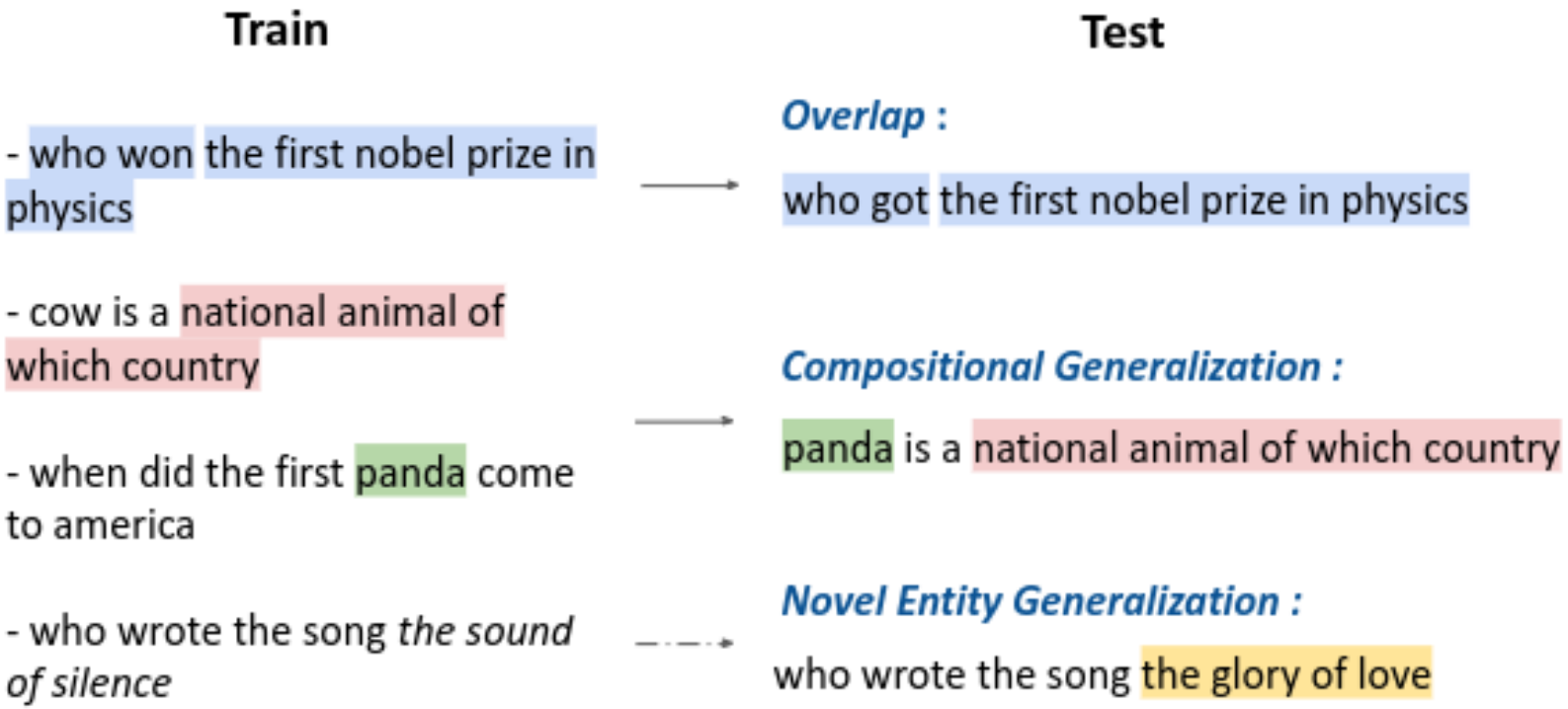
NLP progress in 2024, adapted from Dan Jurafsky

State of NLP



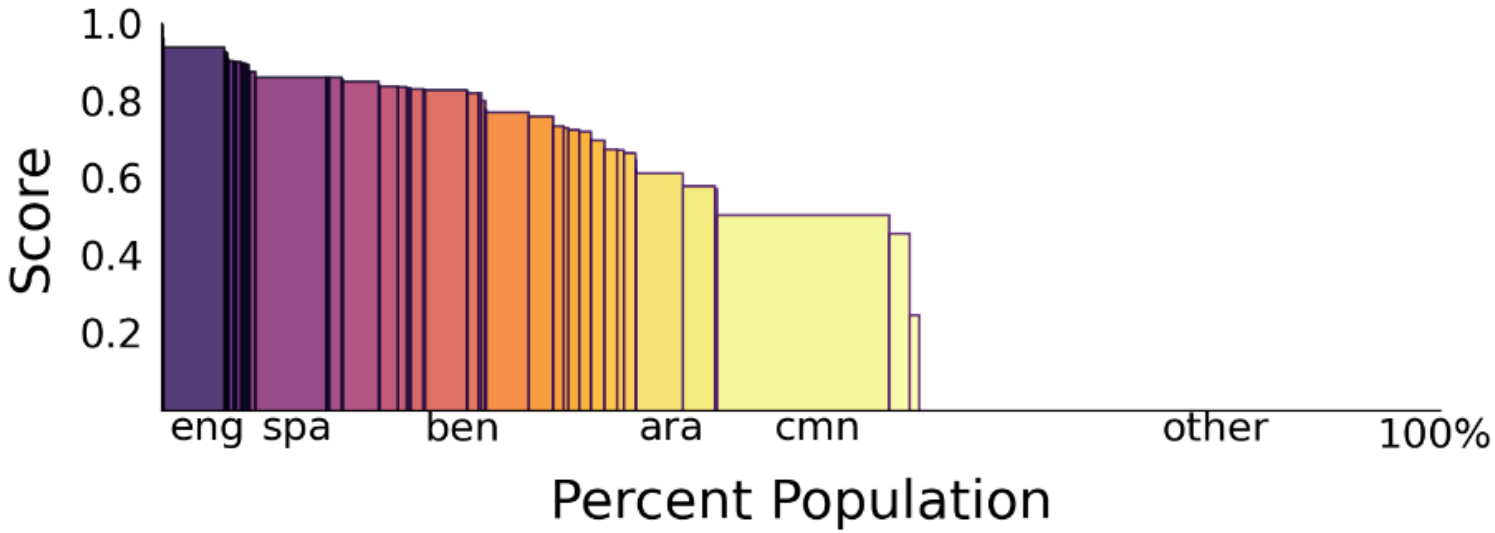
Benchmark progress in NLP and CV. -1=initial performance, 0=human performance. Kiela et al. (2021).

State of NLP



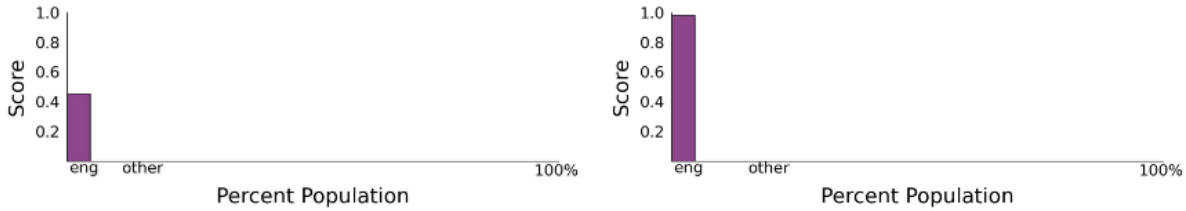
Challenges of open-domain QA (Liu et al., 2022).

State of NLP



Performance disparity of NER systems considering languages and their number of speakers (Song et al., 2023).

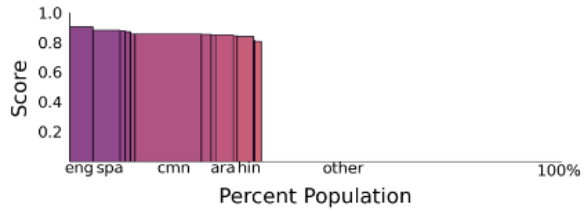
State of NLP



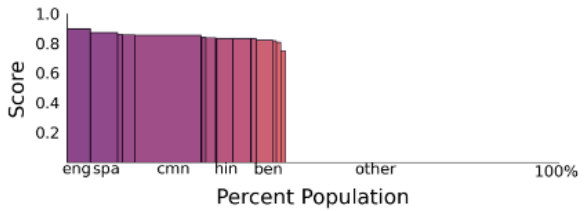
(a) KG Link Tail Prediction

(b) Text Classification

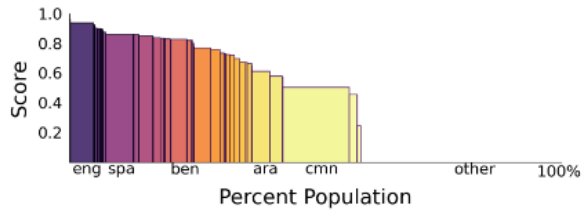
(c) Machine Translation



(d) Text Pair Classification



(e) Extractive QA



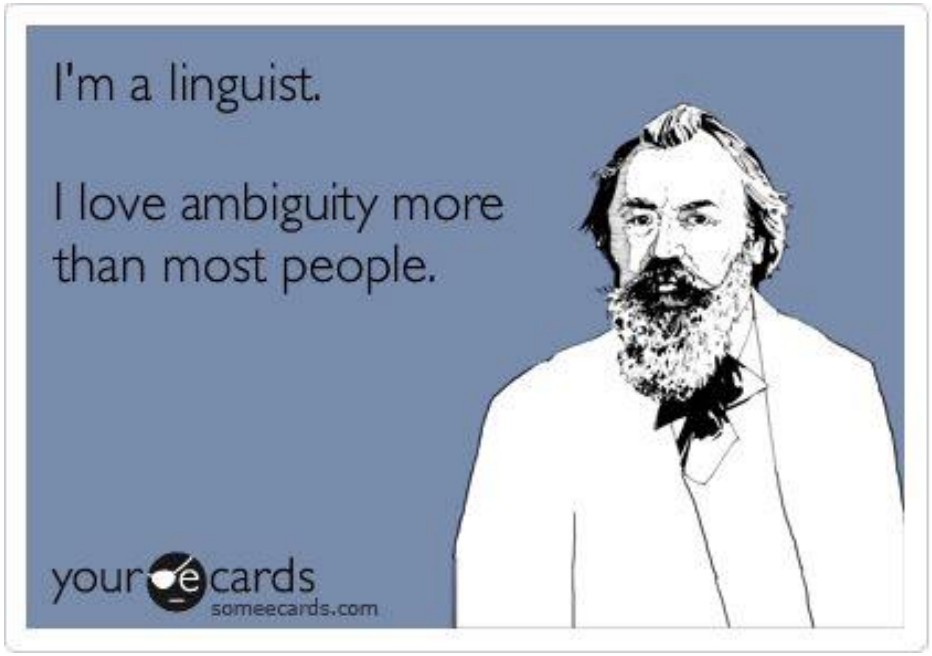
(f) Named Entity Recognition

Performance disparity of systems considering languages and their number of speakers for 6 tasks. (Song et al., 2023).

What makes NLP challenging?

- Ambiguity
- Non-standard language
- Neologisms
- Need for external knowledge
- Long tail of rare words/pheonomena

Ambiguity



- I love ambiguity more than most people love ambiguity.
- I love ambiguity more than I love most people.

Ambiguity

I made her duck

- I cooked duck for her
- I cooked a duck which belonged to her
- I created the duck which belongs to her
- I caused her to lower her head
- I turned her into a duck

Need context to disambiguate.

Ambiguity

Types of ambiguity

- Lexical: *I saw a bat*

  saw = past tense of *see* or present tense of *saw*
  bat = flying mammal or wooden club

- Structural: *I saw a man with a telescope*

  I have a telescope or *the man* does

- Semantic: *John and Mary are married*

  to each other or to other people

- Anaphoric: *Margaret invited Susan, and she gave her a sandwich.*

  she = Margaret or Susan

Exercise: find all the ambiguities in this sentence

The old men and women gathered by the bank, and they were surprised to see it collapse.

Exercise: find all the ambiguities in this sentence

1. Lexical ambiguity: *bank*

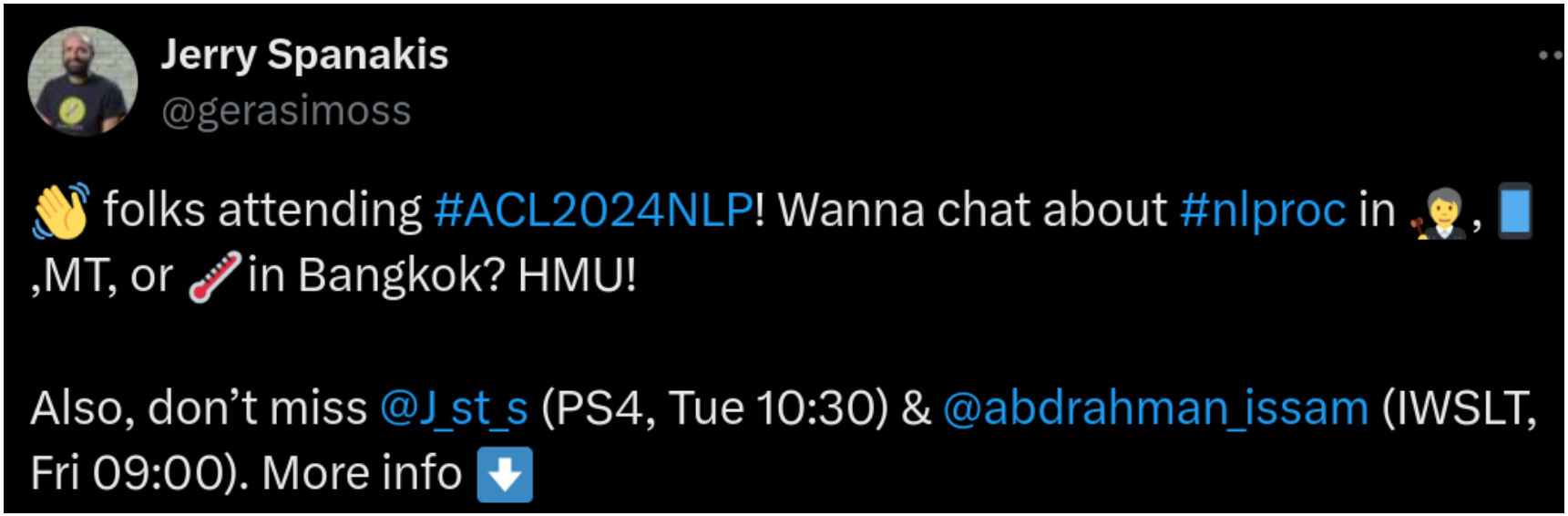
   financial institution or edge of a river

2. Structural ambiguity: *The old men and women*
   - Both the men and the women are old.
   - Only the men are old, but the women are not.
3. Semantic ambiguity: *collapse*

   financial collapse or physical collapse

4. Anaphoric ambiguity: *they*
   - The old men and women.
   - Just the men, or just the women

Non-standard language



Example tweet including emoji, hashtags, slang (*wanna*), abbreviations (*MT*, *HMU*)

Neologisms

Recent neologisms

- Deepfake
- Prompt engineer
- Situationship
- Enshittification

Neologisms

NYT first said twitter bot 🔗

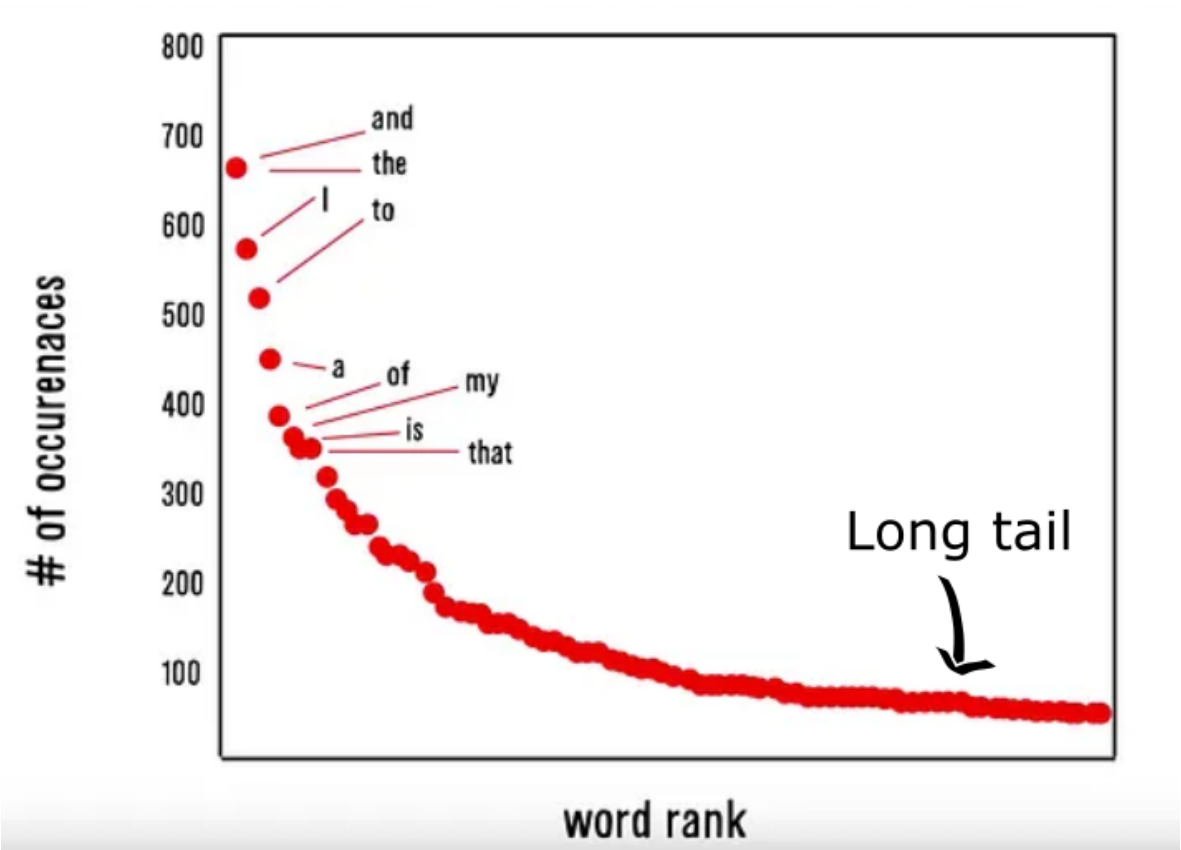
Need for external knowledge

> *Jack needed some money, so he went and shook his piggy bank. He was disappointed when it made no sound.*
>
> Why was he disappointed?
>
> Minsky (2000)

Types of external knowledge

- Commonsense knowledge of the physical and social world
- Domain knowledge
- Knowledge of the broader context

Law of Zipf



Frequency of words per rank in Romeo and Juliet 🔗

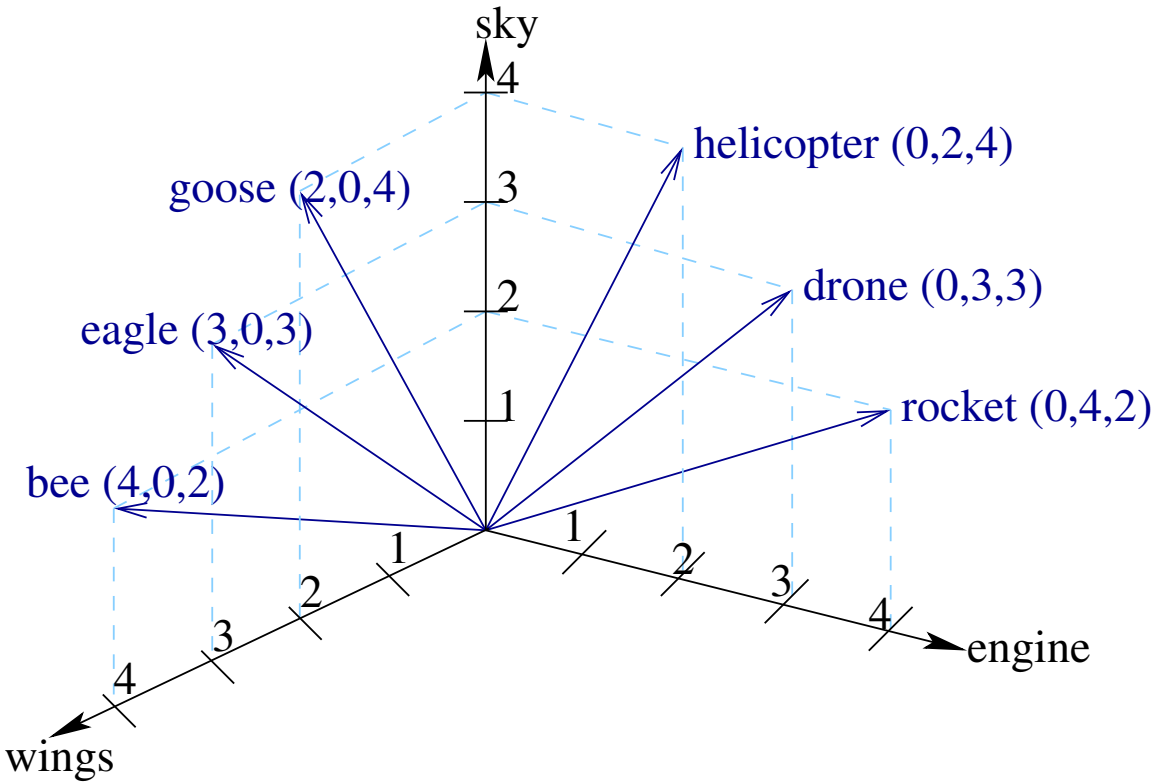
Representing words

Vocabulary: {sky, wings, engine, helicopter, drone, rocket, goose, eagle, bee}

The goose is in the sky.
The eagle in the sky has wings.
The bee in the sky has wings.
The goose with wings in the sky.
The eagle with wings in the sky.
The bee with wings in the sky.
The goose and the eagle with wings are in the sky.
The goose flies in the sky.
The wings of the bee are good wings.
The helicopter, the drone and the rocket are in the sky.
The helicopter in the sky is a useful engine.
The drone in the sky is an engine that takes pictures.
A rocket is an engine.
The helicopter is an engine.
A drone is an engine that takes pictures.
A rocket is a useful engine among sky engines.
A helicopter is flying in the sky.
The sky is full of helicopters and drones.
The engine here is a drone, the one there is a rocket.

Toy corpus

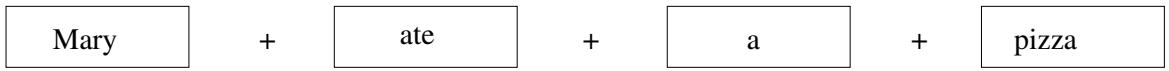
Representing words



Vector space of word co-occurrences with 3 dimensions

Representing phrases/sentences

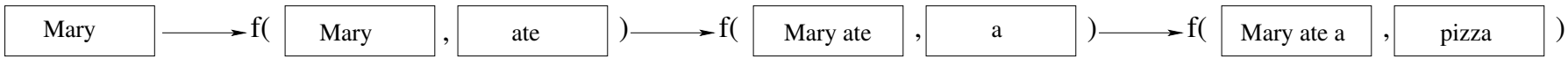
Bag of words



Mary ate a pizza

Representing phrases/sentences

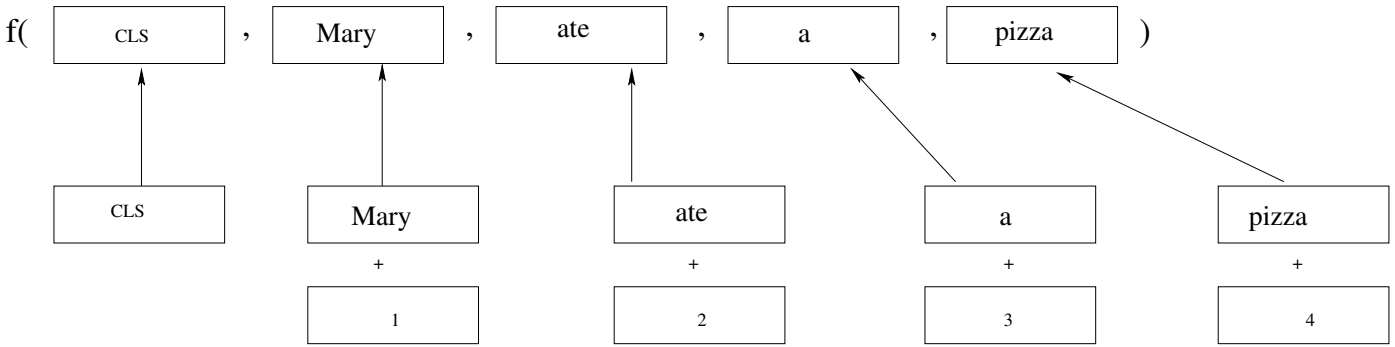
Recurrent Neural Network



Mary ate a pizza

Representing phrases/sentences

Transformer



Mary ate a pizza

Representing phrases/sentences

The reality is not so simple

- Word vectors are learned/updated by the neural network
- $f()$ is complex for RNNs (see lecture 4)
- $f()$ is even more complex for transformers (see lecture 4)
- Neural networks are deep and consist of multiple layers.
- The input units of transformers are not words but subwords (see lecture 2)

Fundamentals

1. Introduction
2. Segmentation and tokenization
3. Language modelling
4. Neural language modelling

Levels of linguistic processing

5. POS tagging
6. Morphological analysis
7. Syntactic parsing
8. Semantics
9. Discourse

Applications

10. Neural Machine Translation
11. Question Answering
12. *(Q&A session)*
13. Conversational agents (guest lecture by Thomas Winters)

2. Tokenization

Sample Data:

"This is tokenizing."

Character Level

[T] [h] [i] [s] [i] [s] [t] [o] [k] [e] [n] [i] [z] [i] [n] [g] [.]

Word Level

[This] [is] [tokenizing] [.]

Subword Level

[This] [is] [token] [izing] [.]

- What units to even use?
- How to split text into these units?
- Sentence segmentation

3. Language modelling

Before

P(I saw a cat on a mat) =

P(I)
· P(saw | I)
· P(a | I saw)
· P(cat | I saw a)
· P(on | I saw a cat)
· P(a | I saw a cat on)
· P(mat | I saw a cat on a)

After (3-gram)

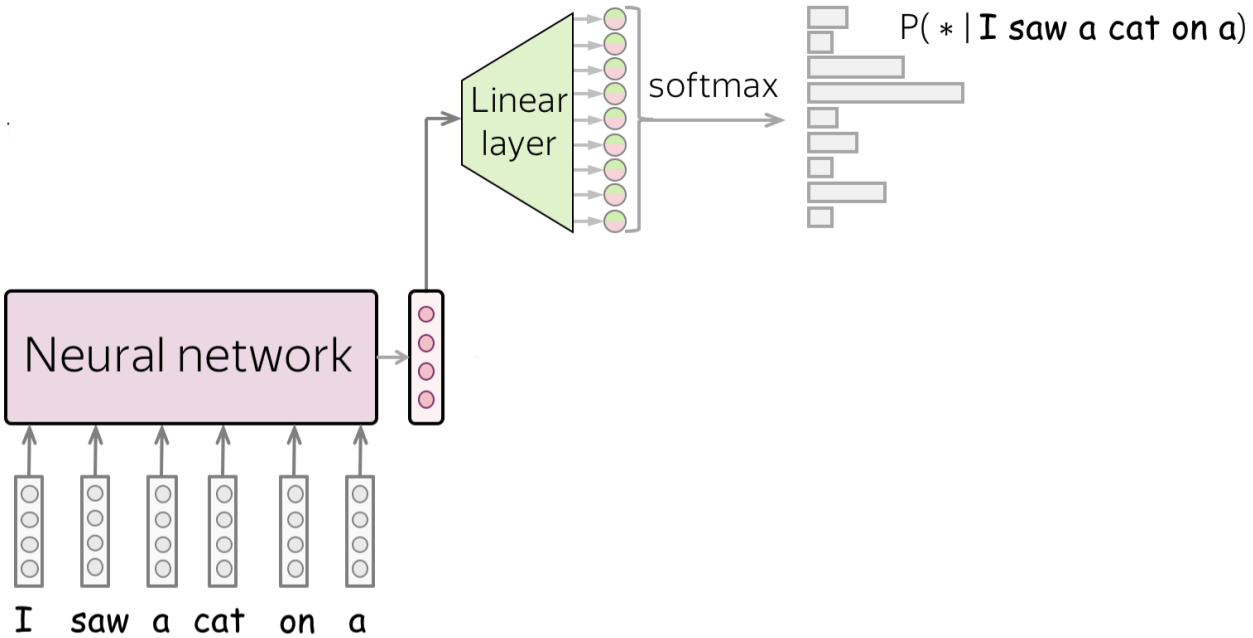
P(I saw a cat on a mat) =

P(I) → P(I)
· P(saw | I) → · P(saw | I)
· P(a | I saw) → · P(a | I saw)
· P(cat | ~~I~~ saw a) → · P(cat | saw a)
· P(on | ~~I saw~~ a cat) → · P(on | a cat)
· P(a | ~~I saw a~~ cat on) → · P(a | cat on)
· P(mat | ~~I saw a cat~~ on a) → · P(mat | on a)

ignore use

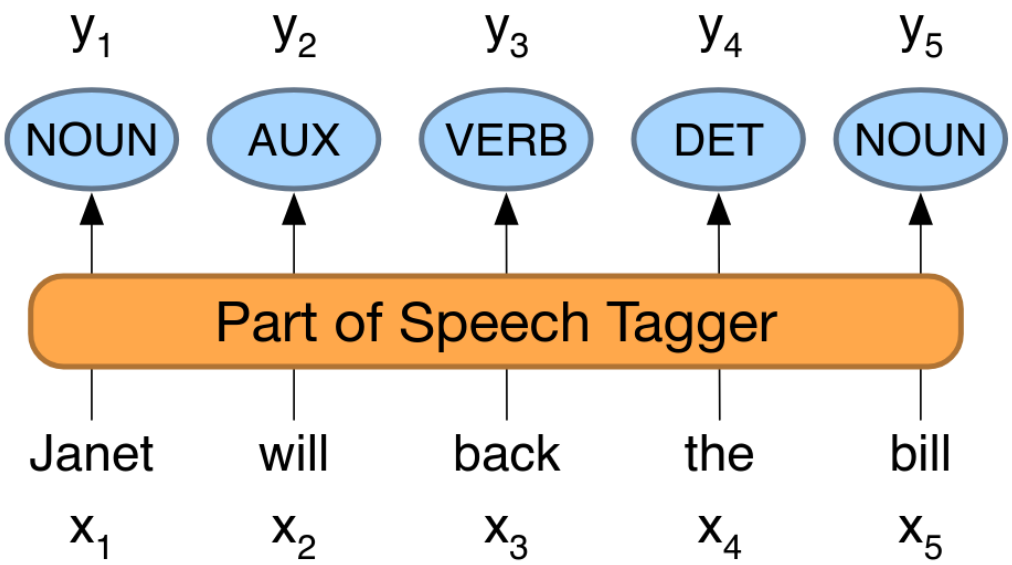
Probabilistic foundations of language modelling

4. Neural Language modelling



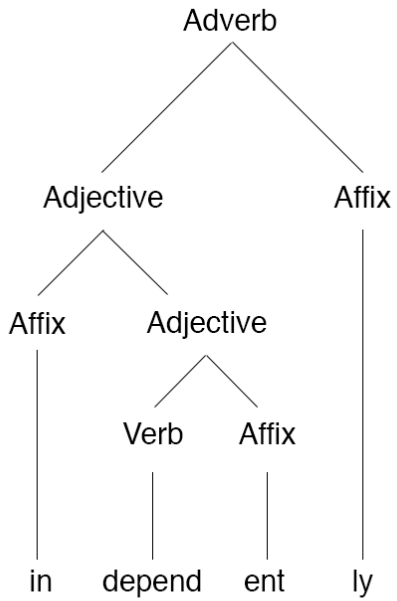
- Language modelling with RNNs
- Language modelling with transformers

5. POS tagging



POS tagging: mapping from input words $x_1, x_2, ..., x_n$ to output POS tags $y_1, y_2, ..., y_n$ (Jurafsky and Martin, 2024).

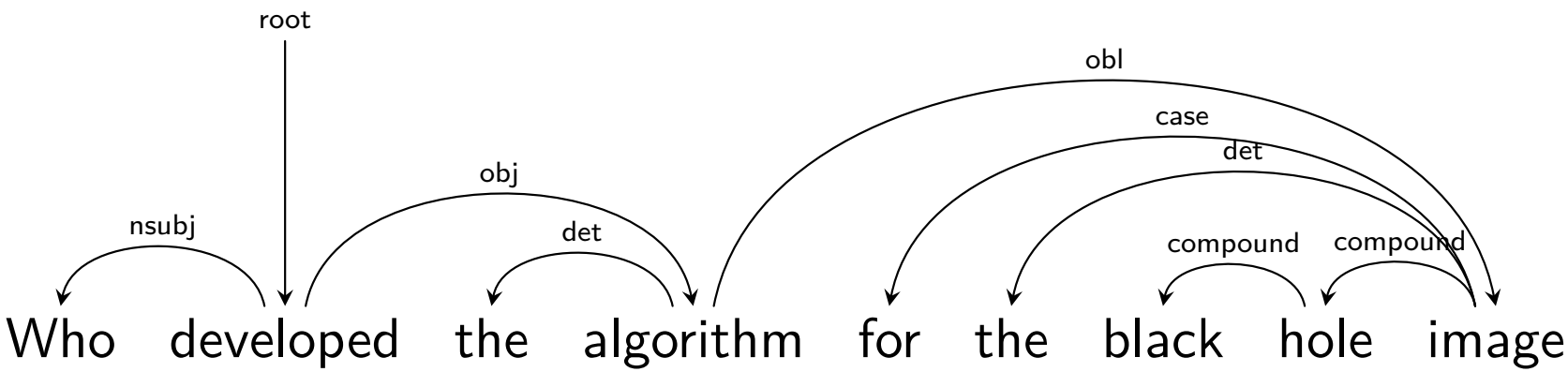
6. Morphological analysis



Morphological analysis of the word *independently* 🔗

Analysing the internal structure of words

7. Syntactic parsing

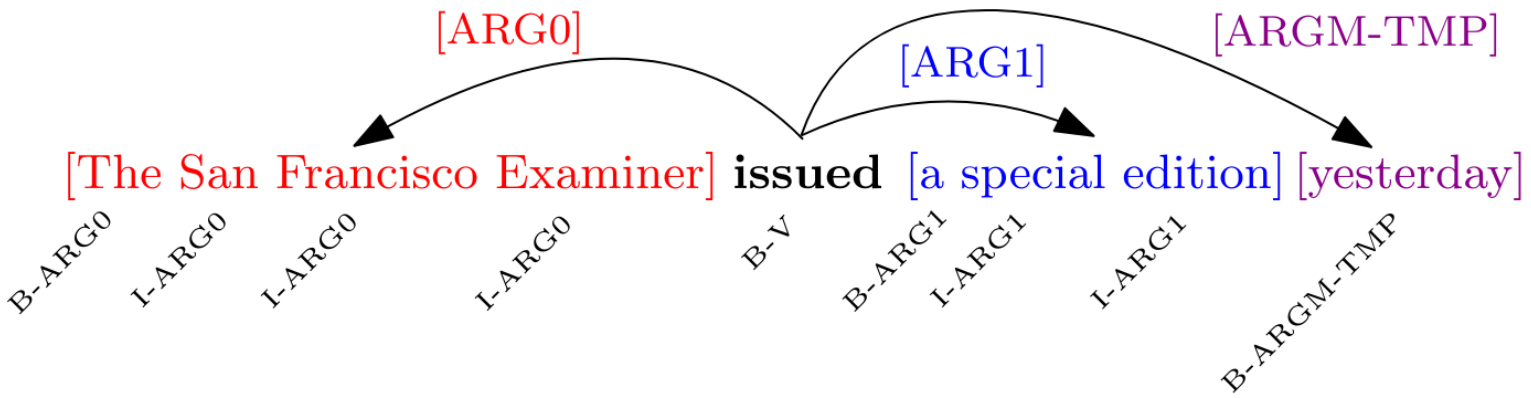


Analysing the structure of sentences

8. Semantics

Word sense disambiguation🔗

8. Semantics

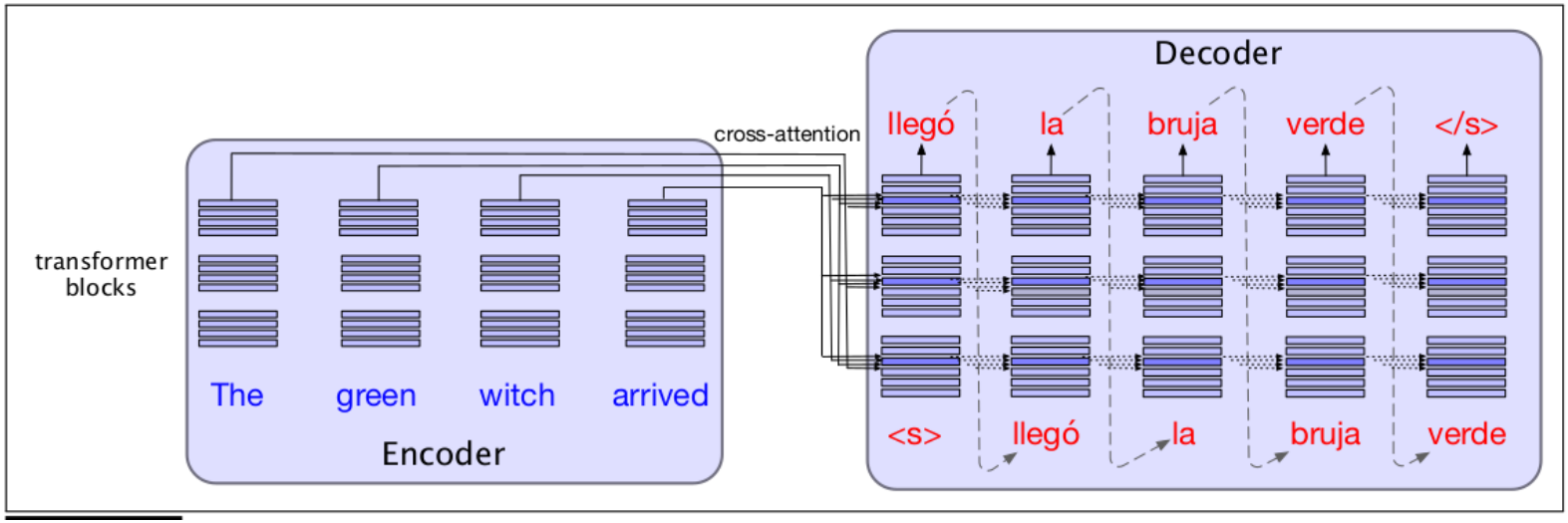


Semantic role labelling: who did what to whom, when (Jindal et al., 2020)

9. Discourse

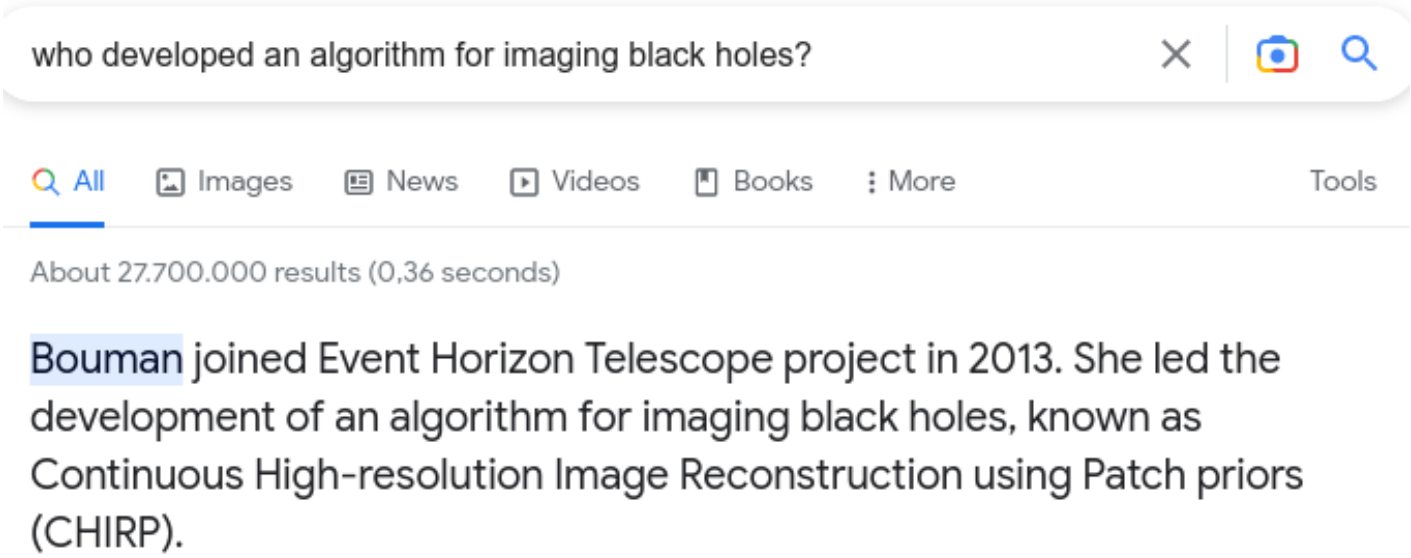
Coreference resolution 🔗

10. Neural Machine Translation



The encoder-decoder transformer architecture for machine translation (Jurafsky and Martin, 2024).

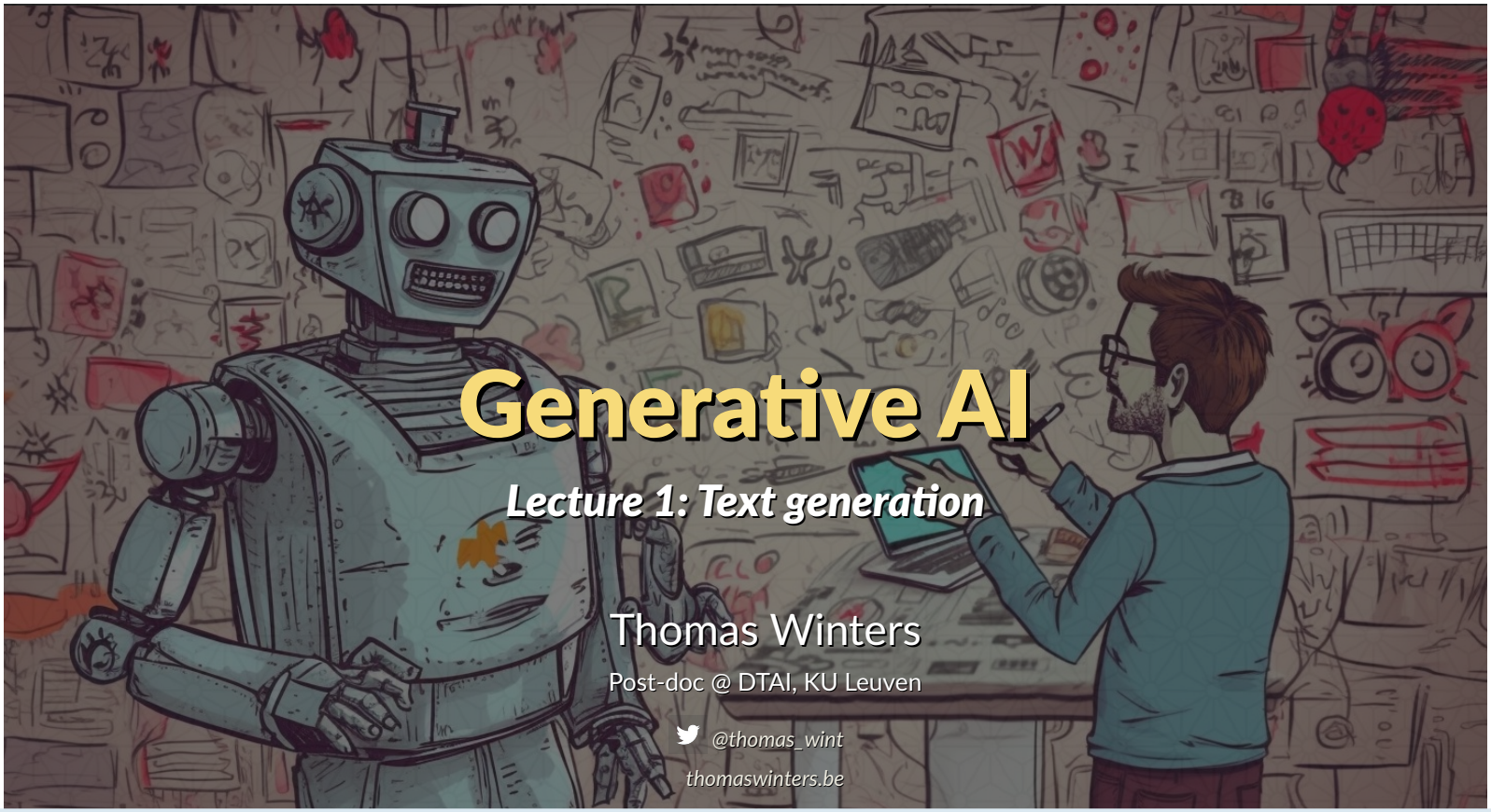
11. Question Answering



12. Q&A session

Opportunity to ask any question about any of the lectures or the reading material. We can go through some exercises together.

13. Conversational agents



Not part of the course material but fun and informative lecture about LLM-based conversational agents.

Views on teaching

Views

- Traditional lectures are bad - you learn best by activating your brain 🧠⛹️.
- Interaction with teacher and peers boosts learning - you should feel encouraged to come to class.
- You should not feel obliged to come (stay home if you are sick!) I aim to make the course accessible.

Format

- Online: **all content material** (pre-recorded videos of lectures, slides and required readings).
- In-person lectures: interactive and with short exercises. Opportunity to ask for clarifications, get and give feedback.

Classes

- 13 lectures: Tuesdays 16h00 to 18h00
- 6 exercises sessions of 2 hours, 2 groups.
  - Mix of implementation and paper exercises (algorithms application).
  - No additional material but direct preparation for the exam.

Relation to other courses this academic year

It is complementary to the *Linguistics and AI* course taught by Tim Van de Cruys (not a requirement).

Linguistics and AI

Stronger focus on the linguistic formalisms and high-level intuitions of models.

NLP

We go deeper in mathematical modelling and see the different algorithms in more detail.

We are collaborating to make the courses as compatible as possible. Redundancy may still happen. We welcome feedback!

Relation to other courses in the past

- Direct replacement of the NLP course formerly taught by Sien Moens.
- Meant to be more accessible to non-engineering backgrounds.

$\Rightarrow$ Thorough revision of the course material.

- Work in progress, feedback welcome!

Course material

Course slides, video recordings and required readings can be downloaded from the Toledo platform.

Evaluation

- Written, open book theoretical part of the exam (50%):

  Broad overview questions, comparison of technologies.
- Written, open book exercise part of the exam (50%):

  Apply or implement (pseudo-code) algorithms or evaluation metrics and analyse the results.

Teaching team

Course coordinator and lecturer

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Dpt of Computer Science
Celestijnlaan 200A, room 4.50
email: miryam.delhoneux@kuleuven.be

Please include [H02B1A] in the subject line

TAs

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References

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