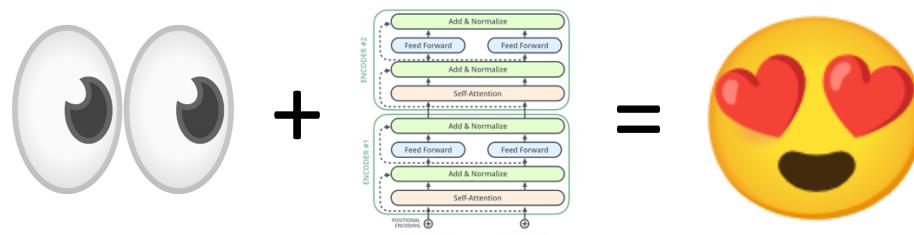




ACL 2025 Tutorial

Eye Tracking and NLP

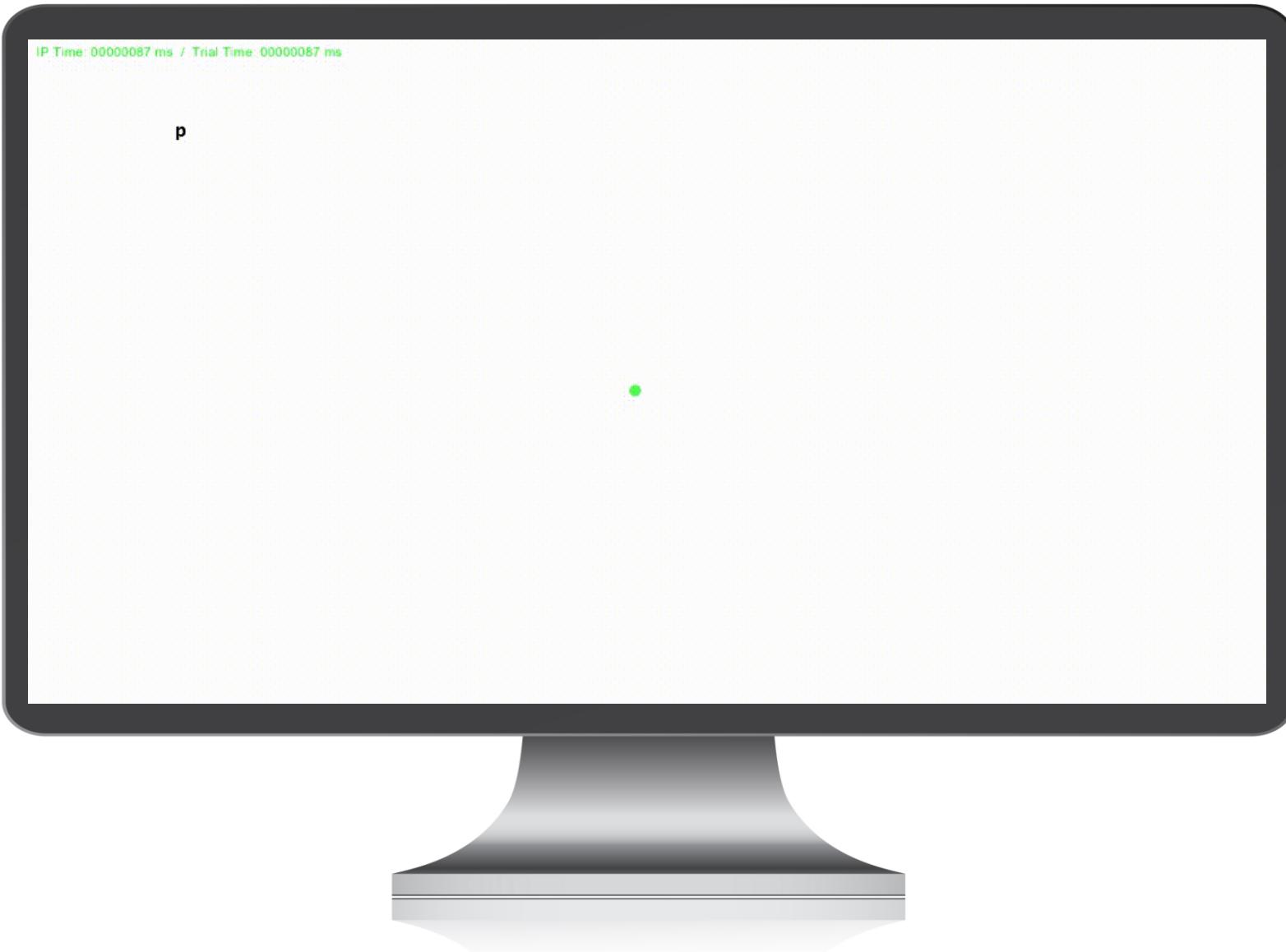


David Reich^{1,2}, Omer Shubi³, Lena Jäger¹ and Yevgeni Berzak³

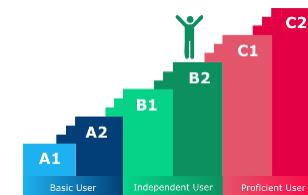
¹University of Zurich ²University of Potsdam ³Technion

Read the Following Paragraph

Over the next 30 years, the planet's human population will increase to nine billion. Already one billion people do not get enough food. The increase will mean more pressure on agricultural land, water, forests, fisheries and biodiversity resources, as well as nutrients and energy supplies. There is also the issue of methane excreted by cows. The livestock farming contribution, in terms of greenhouse gas emissions, is enormous – 35% of the planet's methane, 65% of its nitrous oxide and 9% of the carbon dioxide.



L1

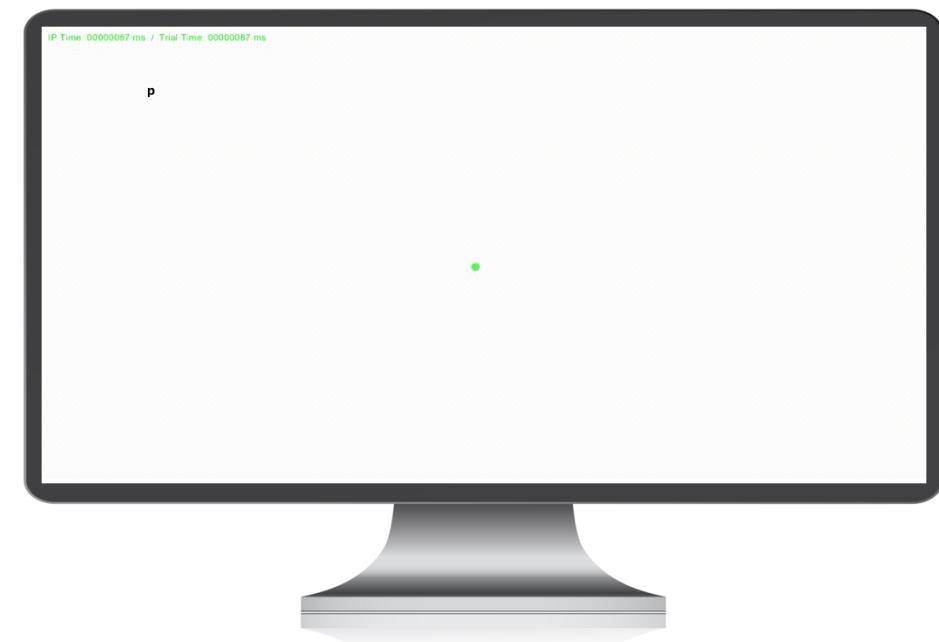


nsubj xcomp dobj
PRP VBZ TO aux
 VB PRP\$ NNS-POS poss
 NNS poss

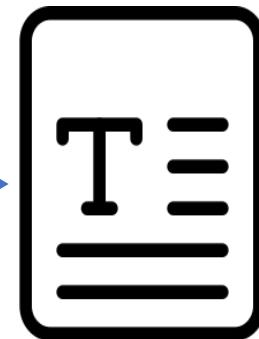
CNN wants to change its viewers' habits.



Eye Movements in Reading: Rich Information



Comprehension
Relevance
Goals
Prior exposure



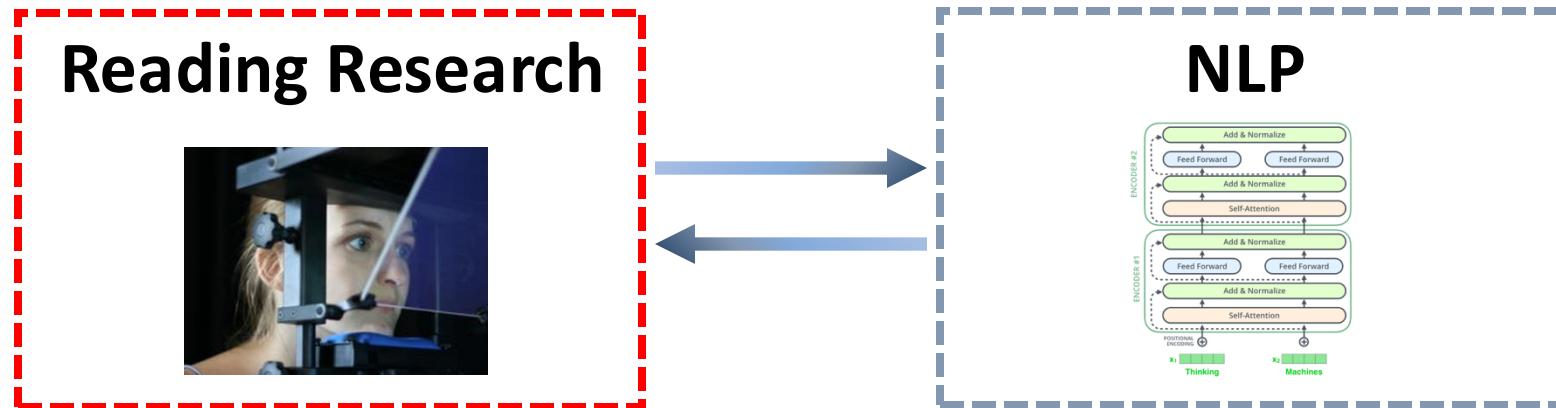
Ling. characteristics
Information structure
Difficulty level

Linguistic knowledge
Reading skill
Cognitive state

...

...

This Tutorial

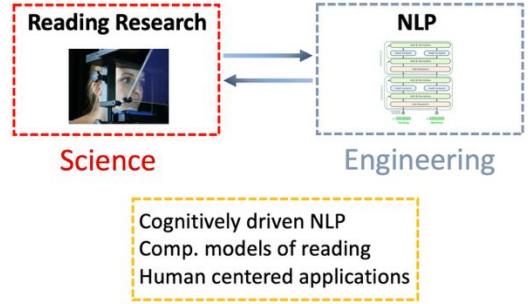


Science

Engineering

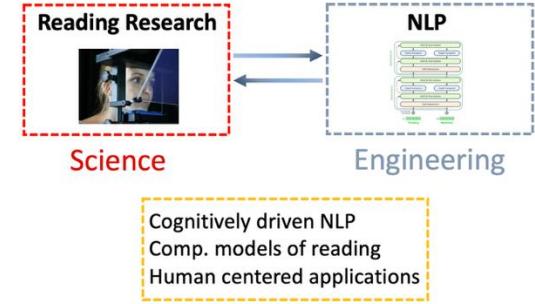
Cognitively driven NLP
Comp. models of reading
Human centered applications

Huge untapped potential for NLP research



- A unique multimodal modeling challenge
- Expanding the role of NLP in cognitive modeling and science
- Opportunities for innovative high-impact applications
 - Education
 - Language learning and assessment
 - Content personalization
 - Content accessibility
 - ...

The domain is ripe enough

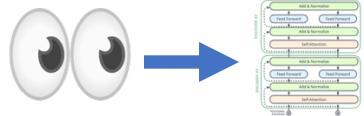


- Builds on a long tradition in the psychology of reading
- Amount and diversity of eye tracking data has reached a critical mass
- Recent NLP and ML modelling approaches demonstrate feasibility

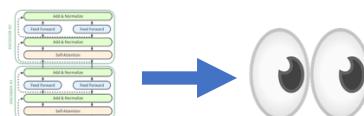
Tutorial Outline



1. Introduction to eye tracking



2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling



4. New human centered applications



5. Outlook and future directions

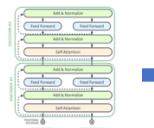
Tutorial Outline



1. Introduction to eye tracking



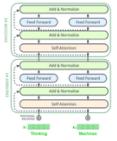
2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling



4. New human centered applications

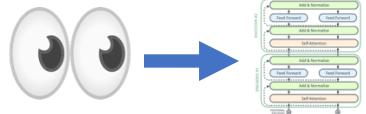


5. Outlook and future directions

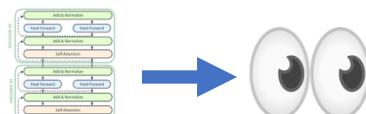
Tutorial Outline



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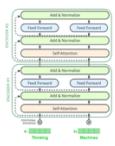


5. Outlook and future directions

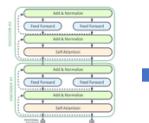
Tutorial Outline



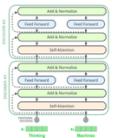
1. Introduction to eye tracking



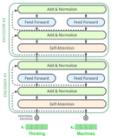
2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling



4. New human centered applications

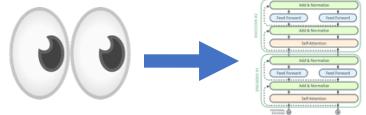


5. Outlook and future directions

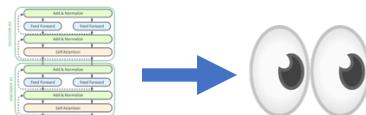
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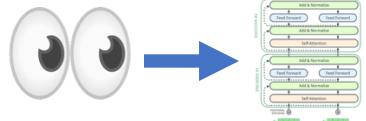


5. Outlook and future directions

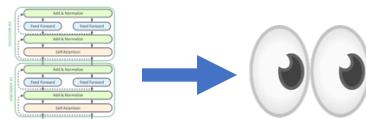
Tutorial Outline



1. Introduction to eye tracking



2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling



4. New human centered applications

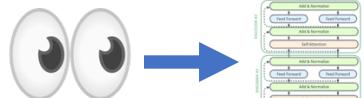


5. Outlook and future directions

Tutorial Outline

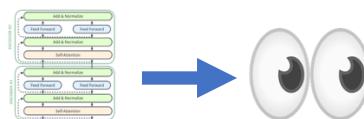


1. Introduction to eye tracking



2. Uses of eye tracking in NLP + QA

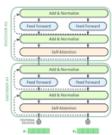
30 minutes break



3. NLP for eye movement and cognitive modeling

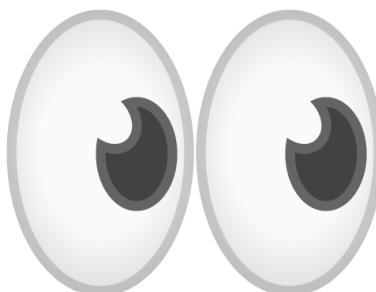


4. New human centered applications



5. Outlook and future directions + QA

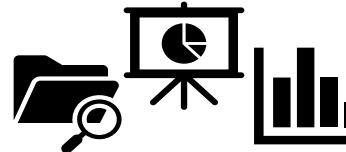
Introduction to Eye Movements in Reading and Eye Tracking



Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking

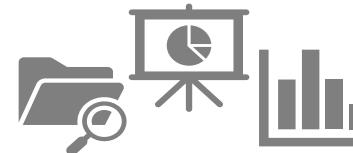


Datasets

Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking



Datasets

Read the Following Paragraph

Over the next 30 years, the planet's human population will increase to nine billion. Already one billion people do not get enough food. The increase will mean more pressure on agricultural land, water, forests, fisheries and biodiversity resources, as well as nutrients and energy supplies. There is also the issue of methane excreted by cows. The livestock farming contribution, in terms of greenhouse gas emissions, is enormous – 35% of the planet's methane, 65% of its nitrous oxide and 9% of the carbon dioxide.

How do people read?

IP Time: 00000087 ms / Trial Time: 00000087 ms

p



How do people read?

CNN wants to change its viewers' habits.

1 2 7 3 4 5 6 8

How do people read?

CNN wants to change its viewers' habits.

1 2 7 3 4 5 6 8

Fixations

How do people read?

CNN wants to change its viewers' habits.

1 2 7 3 4 5 6 8

Saccades

How do people read?

CNNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNN wants to change its  viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.

How do people read?

CNNN wants to change its viewers' habits.

How do people read?

CNN wants to change its viewers' habits.
225ms

How do people read?

CNN wants to change its viewers' habits.

225ms

How do people read?

CNN wants to change its viewers' habits.

225ms 30ms

How do people read?

CNN wants to change its viewers' habits.

What do you see during a **fixation**?

How do people read?

CNN wants to change its viewers' habits.



Perceptual
Span

What do you see during a **fixation**?

How do people read?

CNN wants to change its viewers' habits.

What do you see during a **saccade**?

How do people read?



What do you see during a **saccade**?

Nothing!

How do people read?

CNN wants to change its viewers' habits.

Forward
Saccade

How do people read?

CNN wants to change its  viewers' habits.

Forward
Saccade

How do people read?

CNN wants to change its viewers' habits.

Forward
Saccade

How do people read?

CNN wants to change its viewers' habits.

Backward
Saccade
(Regression)

How do people read?

CNN wants to change its viewers' habits.



The text 'CNN wants to change its viewers' habits.' is displayed in a serif font. Above the text, there are eight numbered red circles (1 through 8) positioned above the letters 'C', 'a', 'n', 't', 's', 'c', 'h', and 'e' respectively, likely indicating points of interest or analysis in the text.

1 2 7 3 4 5 6 8

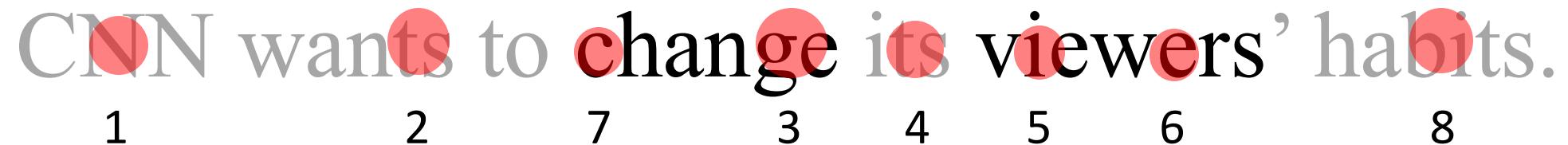
How do people read?

CNN wants to change its viewers' habits.

1 2 7 3 4 5 6 8

How do people read?

CNN wants to change its viewers' habits.



The text 'CNN wants to change its viewers' habits.' is displayed in a serif font. Above the text, there are eight small red circles, each containing a black number from 1 to 8. The numbers are positioned above the letters 'C', 'w', 'a', 'n', 't', 'c', 'v', and 'h' respectively, likely indicating the order of fixation or saccade landing points for that specific word.

1 2 7 3 4 5 6 8

How do people read?

CNN wants to change its viewers' habits.

1 2 7 3 4 5 6 8

How do people read?



Eye Mind Assumption: “*... there is no appreciable lag between what is fixated and what is processed.*” [Just & Carpenter, 1980](#)

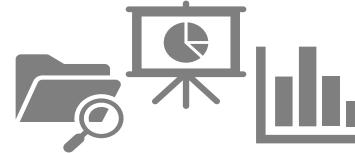
Tight correspondence between eye movements and linguistic processing

- Eye movements capture online processing difficulty:
e.g. longer, less frequent and less predictable words
→ shorter fixation times, skipping

Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking



Datasets

Reading Measures

CNN wants to change its viewers' habits.



- Skips (also skip rate / fixation probability)
- First fixation duration
- Gaze duration
- Regression rate
- Go-past duration
- Total fixation duration

Reading Measures

CNN wants to change its viewers' habits.

- Skips (also skip rate / fixation probability)
- First fixation duration
- Gaze duration
- Regression rate
- Go-past duration
- Total fixation duration

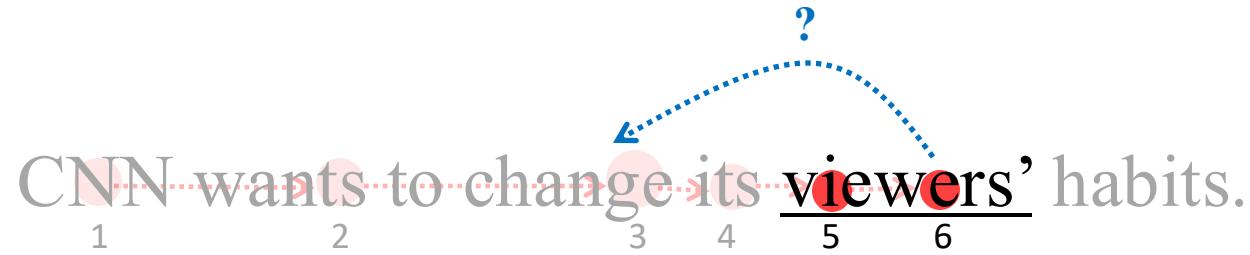
Reading Measures

CNN wants to change its viewers' habits.



- Skips (also skip rate / fixation probability)
- First fixation duration
- **Gaze duration**
- Regression rate
- Go-past duration
- Total fixation duration

Reading Measures



- Skips (also skip rate / fixation probability)
- First fixation duration
- Gaze duration
- **Regression rate**
- Go-past duration
- Total fixation duration

Reading Measures

CNN wants to change its viewers' habits.



A horizontal timeline with numbers 1 through 8. A red dot is placed above the number 7. A red arrow points from the word 'habits.' towards the number 8, indicating a progression or change.

- Skips (also skip rate / fixation probability)
- First fixation duration
- Gaze duration
- Regression rate
- Go-past duration
- Total fixation duration

Reading Measures

CNN wants to change its viewers' habits.

The text "CNN wants to change its" is in gray. The word "viewers'" is in red. The word "habits." is in gray. Red arrows point from left to right above the text, corresponding to the numbers 1 through 8 below it. A red bracket underlines the word "viewers'".

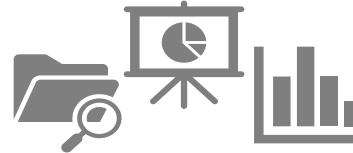
1 2 3 4 5 6 7 8

- Skips (also skip rate / fixation probability)
- First fixation duration
- Gaze duration
- Regression rate
- Go-past duration
- **Total fixation duration**

Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives

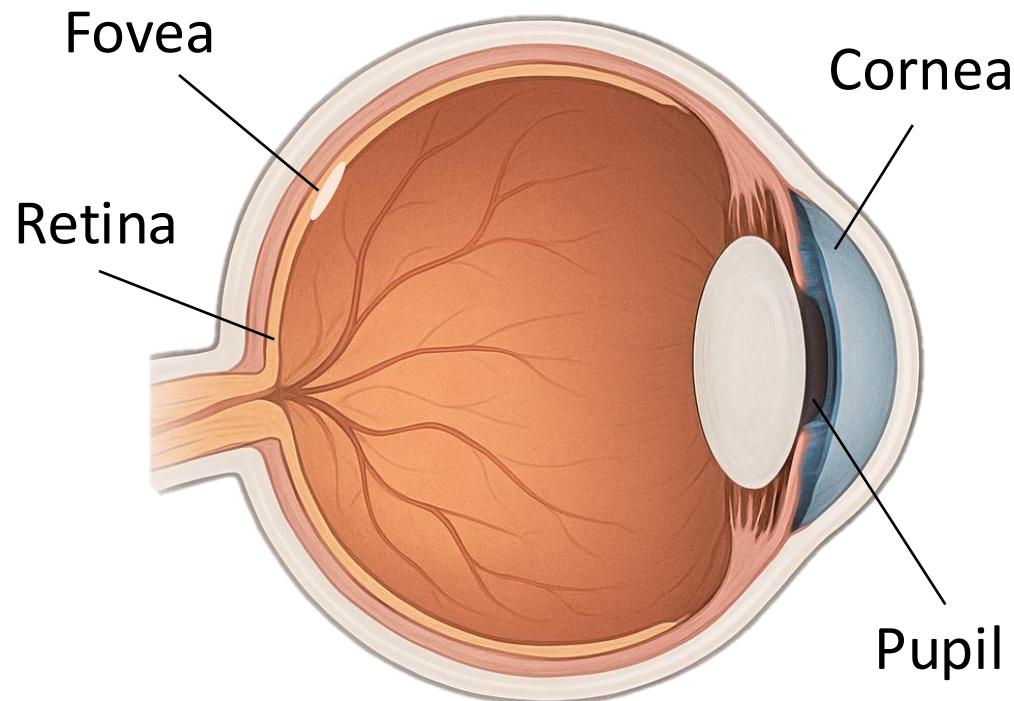


Eye Tracking



Datasets

Eye Physiology



Photoreceptor Cells on the Retina

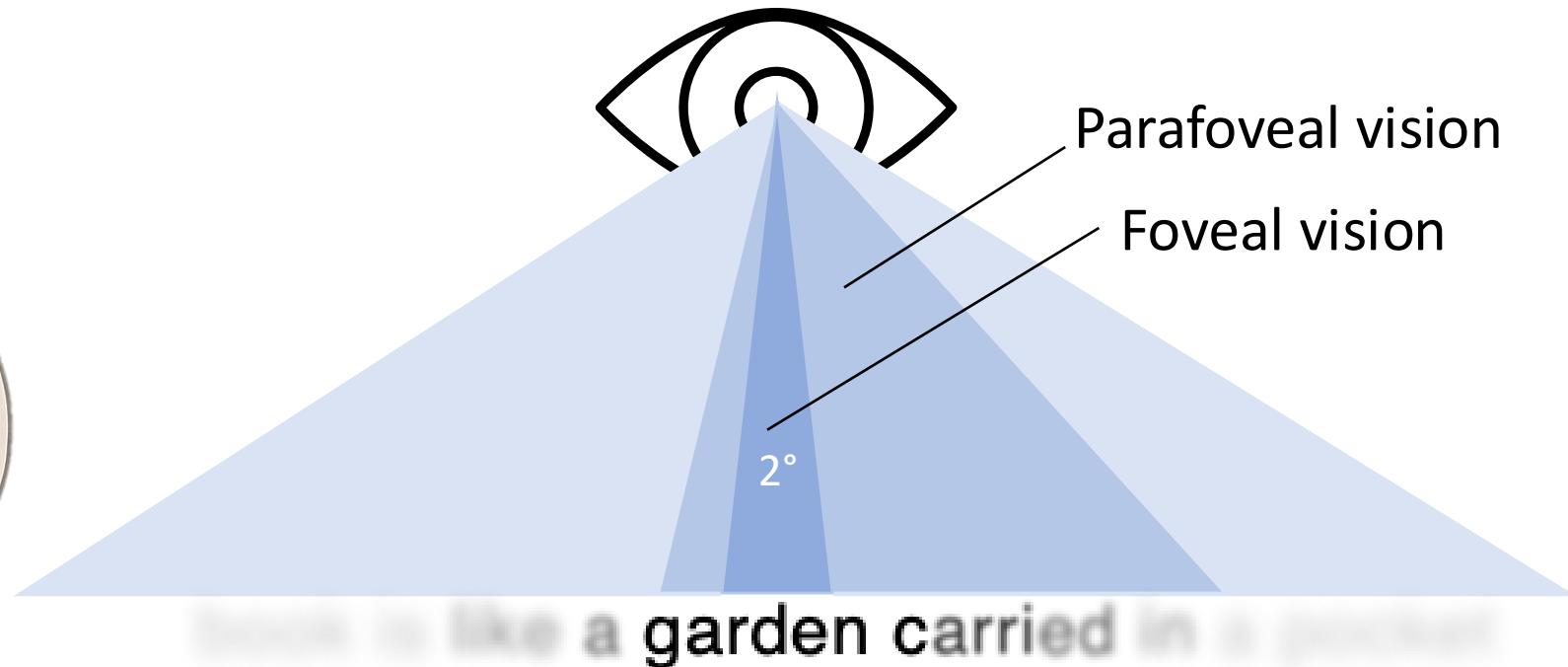
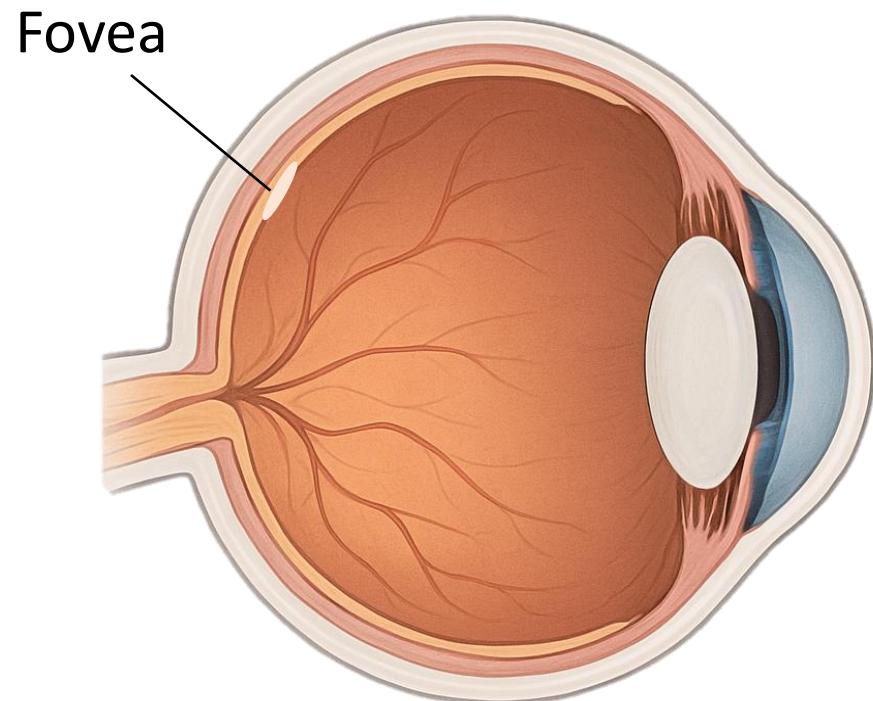
Cones

- Sensitive to “visual detail” (spatial frequency and color)
- High density in the fovea
- Low density in the periphery

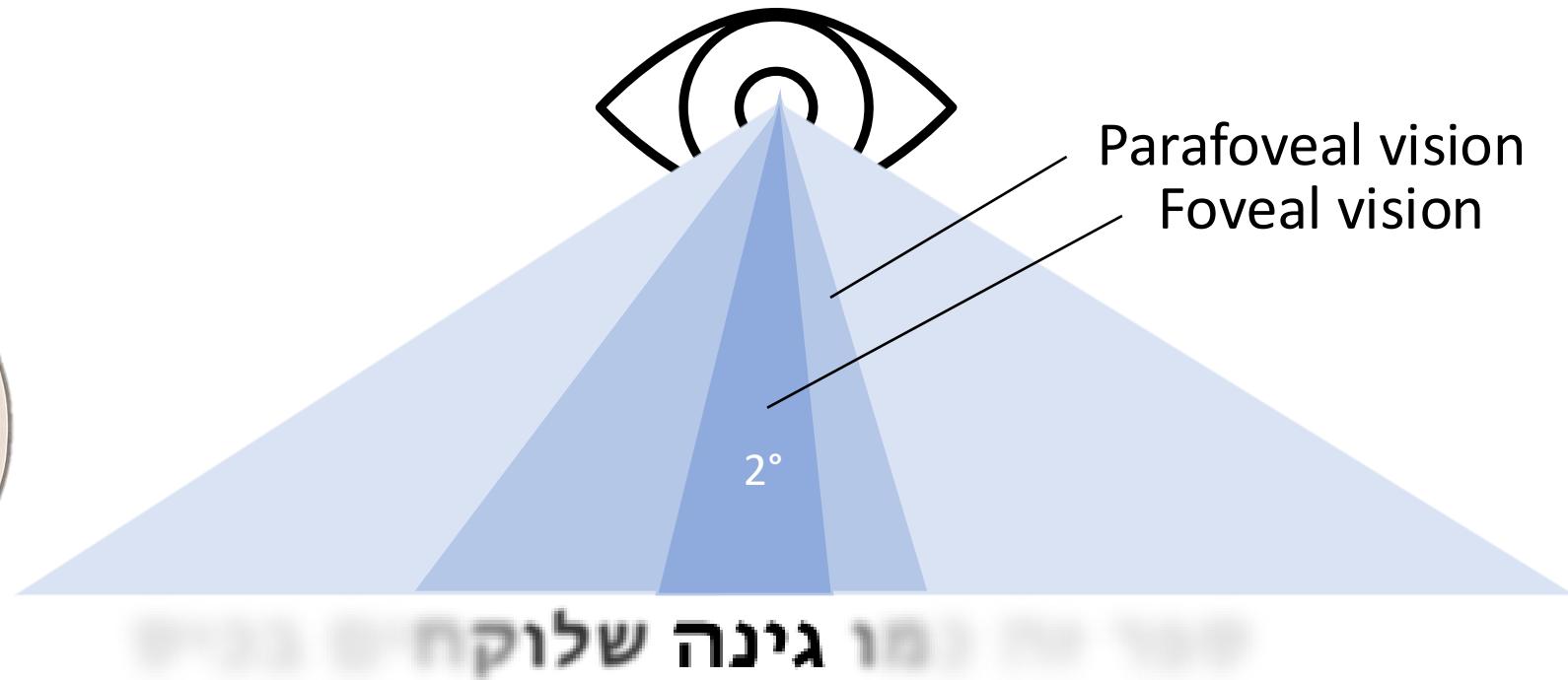
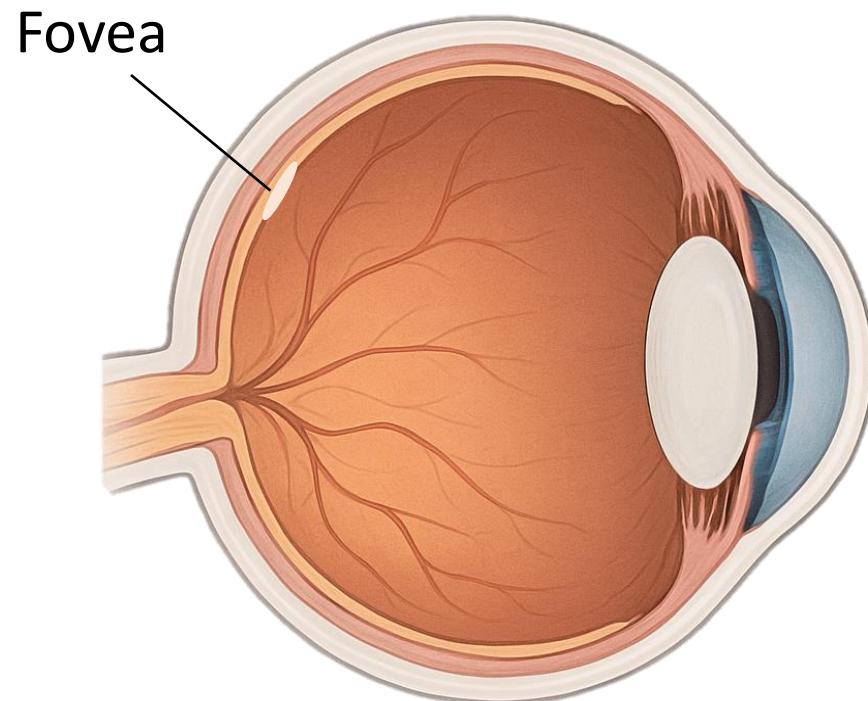
Rods

- Sensitive to light
- Low density in the fovea
- High density in the periphery

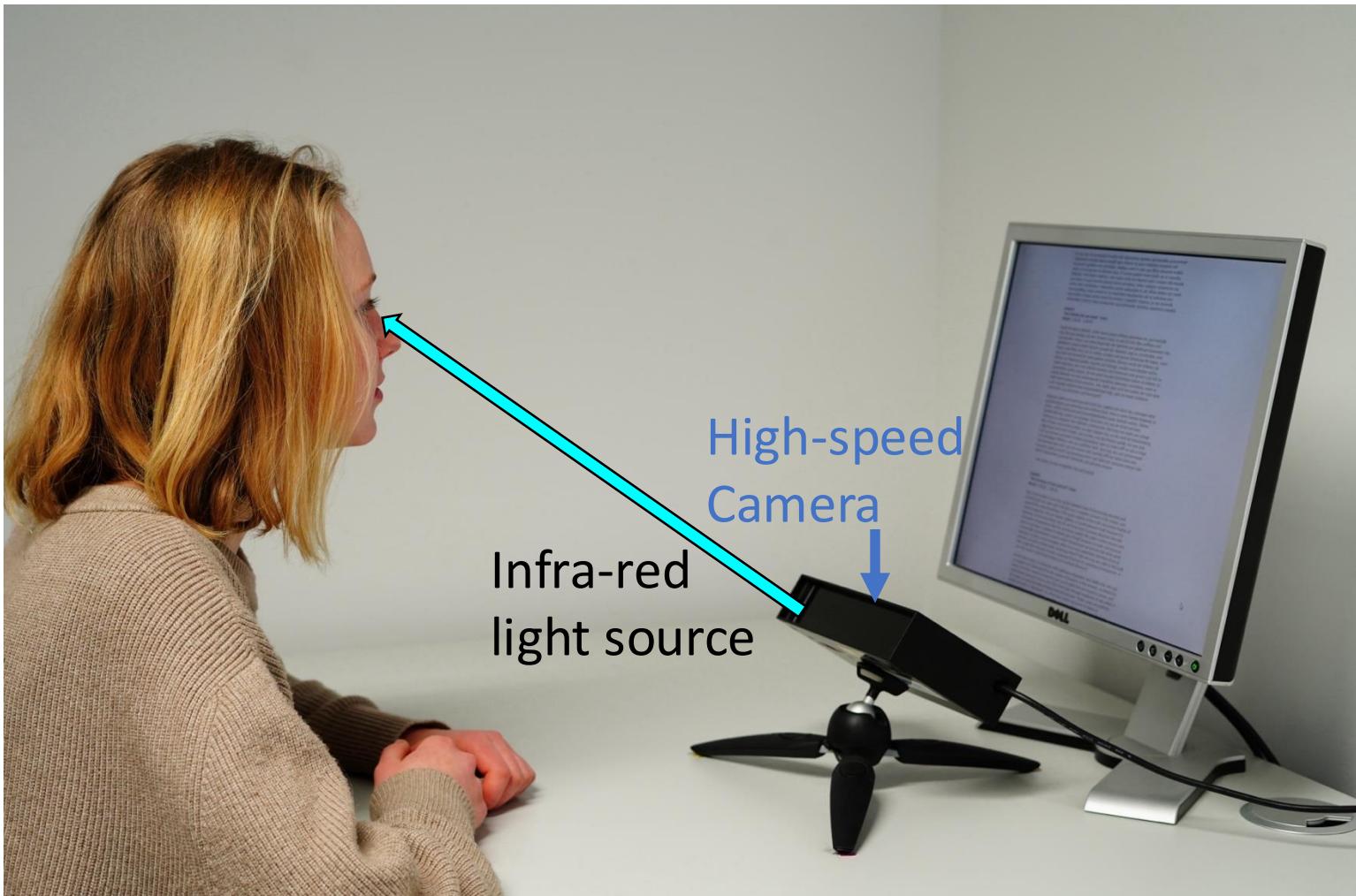
The Perceptual Span in Reading



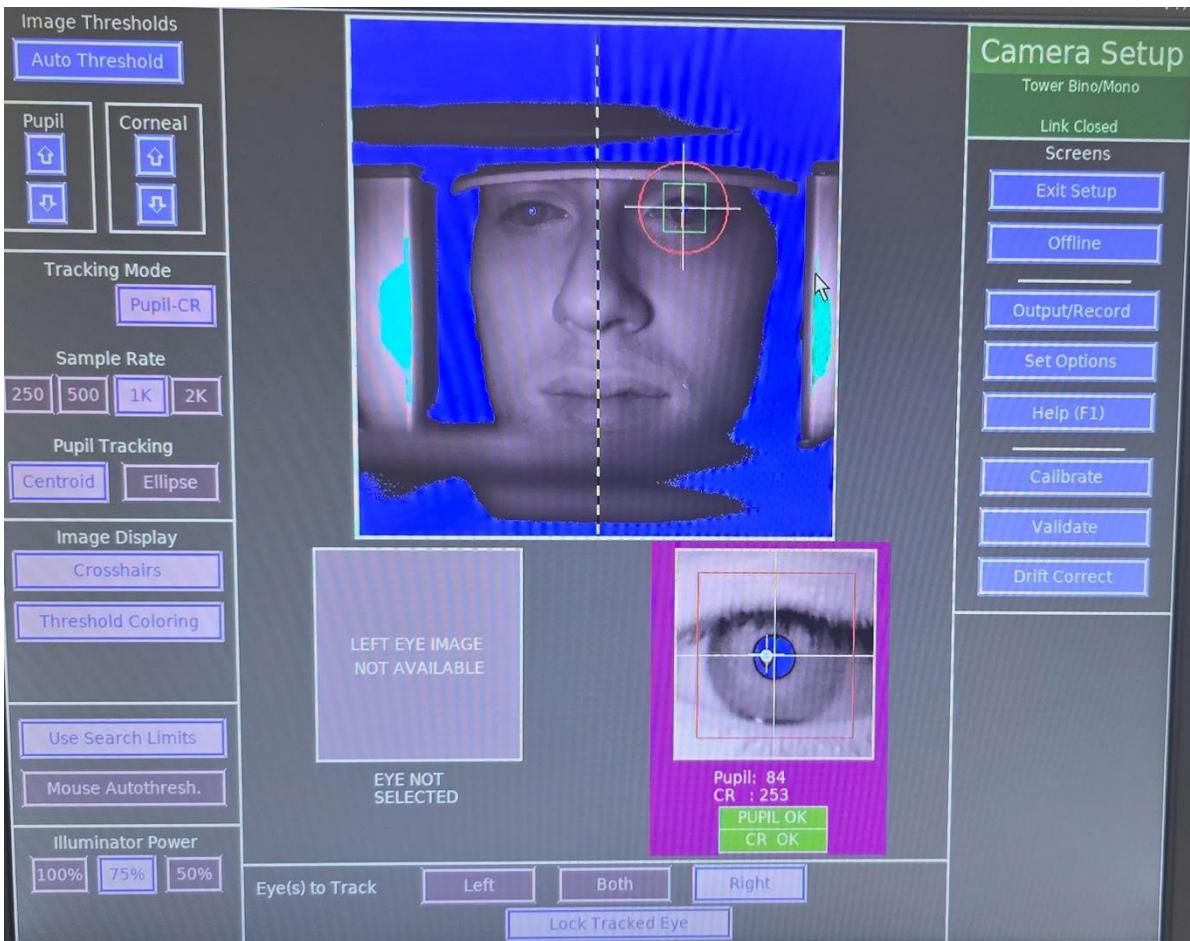
The Perceptual Span in Reading



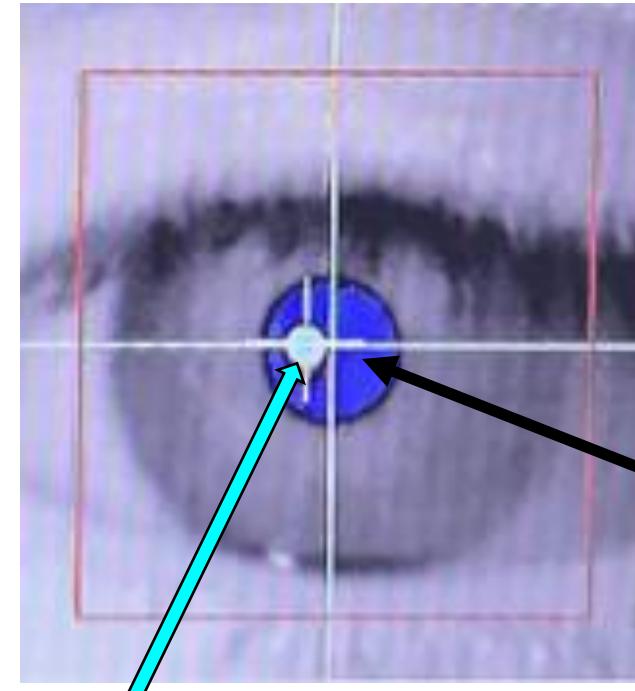
Video-Based Eye Tracking



Video-Based Eye Tracking



Two targets



Corneal Reflection
of the infra-red light

Video-Based Eye Tracking

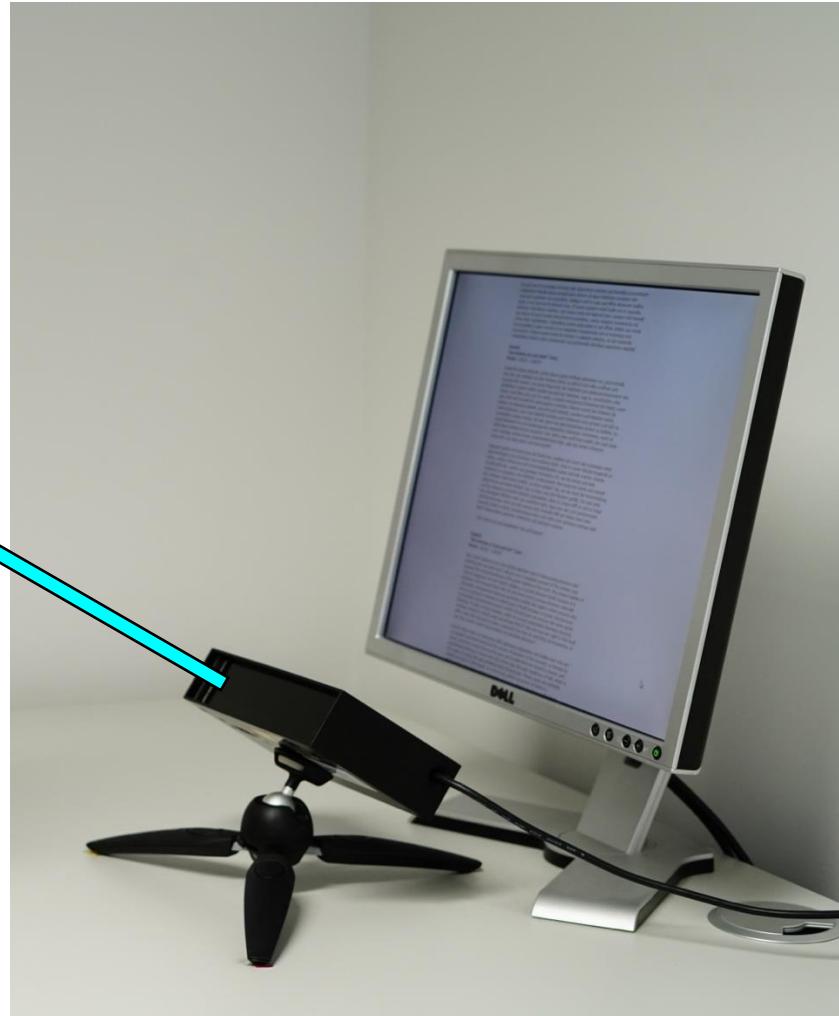
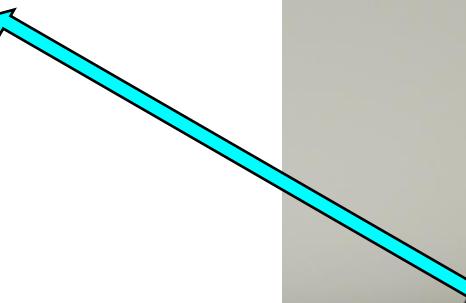
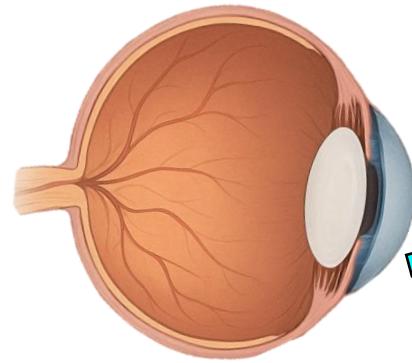
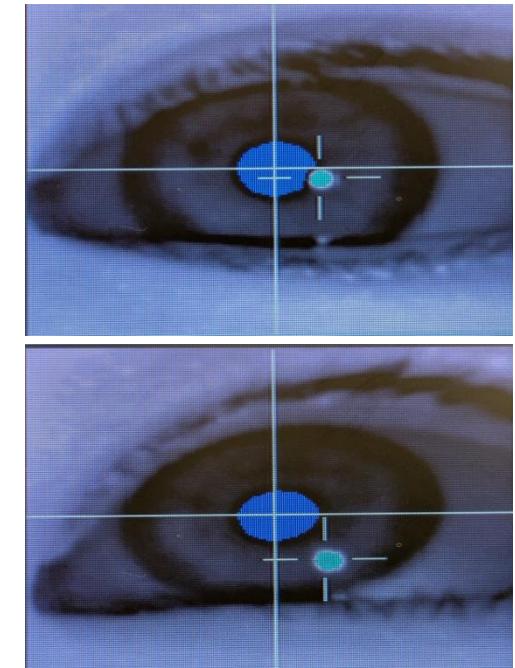


Image detection of the

- pupil
- corneal reflection (CR) of the IR light



Video-Based Eye Tracking

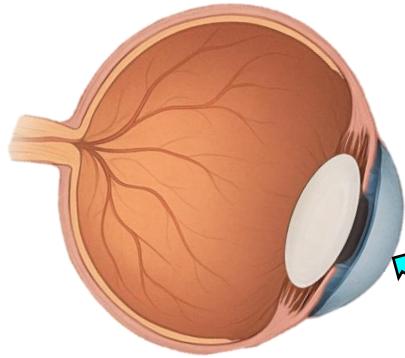
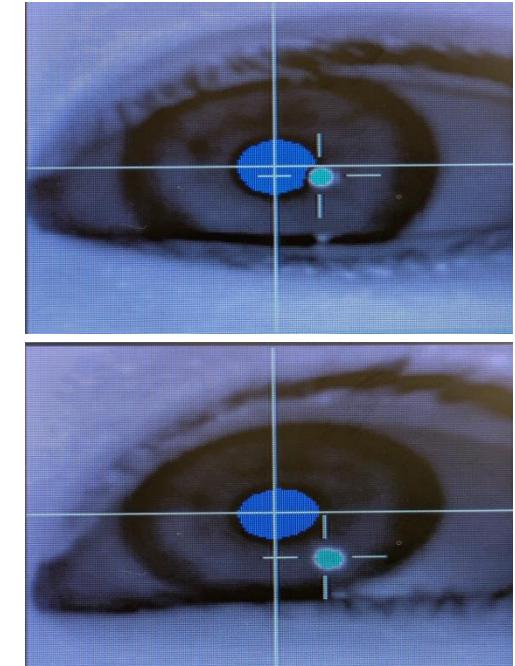


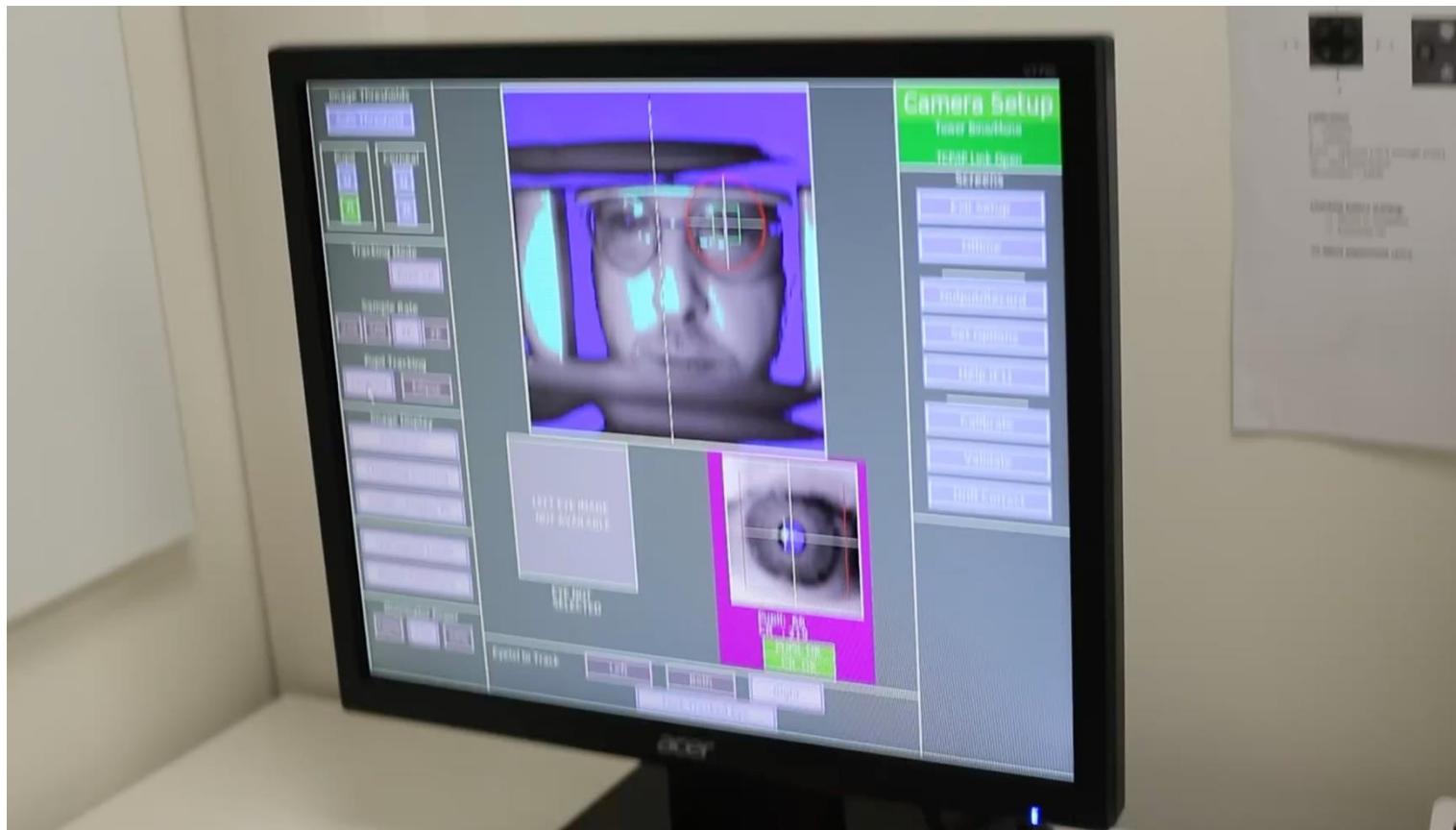
Image detection of the

- pupil
- corneal reflection (CR) of the IR light



Video-Based Eye Tracking

Calibration



[Calibration Video](#)

Very high calibration quality needed for reading research

Video-Based Eye Tracking Devices

Wearable



Portable



Stationary



Video-Based Eye Tracking Devices

For eye tracking-while-reading data sets we typically want

- character-level spatial resolution
 - very high accuracy (calibration quality) needed
 - head-stabilization (chin-rest) recommended
 - stationary or portable devices typically achieve better calibration than wearables
- precise fixation onset/offset times
 - sampling frequency of at least 200 Hz needed

Data Collection Considerations

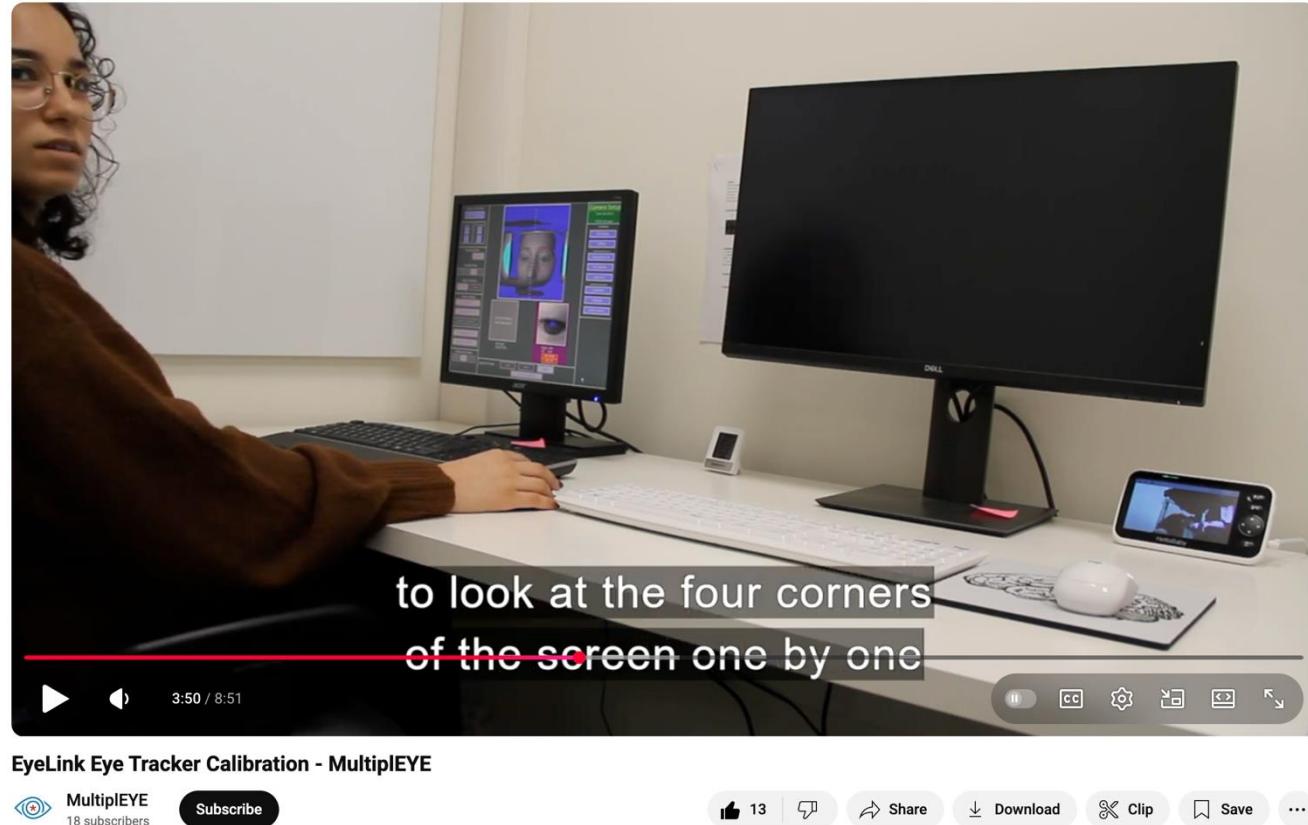
Many additional things to take care of

- Experimental design, counter balancing and randomization
- Attention checks / reading comprehension questions
- Monitoring drift and recalibration during the experiment
- Blocking accidental clickthrough's
- Text presentation:
 - Font (often monospace) and font size
 - Line spacing
- IRB (ethics approval, data protection etc.)
- ...

Data Collection Considerations

Data collection video tutorials (for EyeLink Eye Trackers)

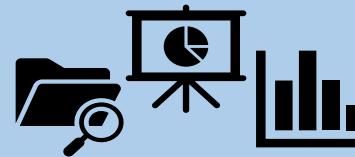
- Dominant eye test
- Calibration



Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking



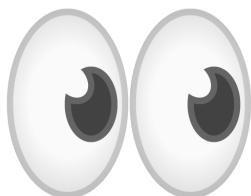
Datasets

Eye Tracking: Recorded data

CNN wants to change its viewers' habits.

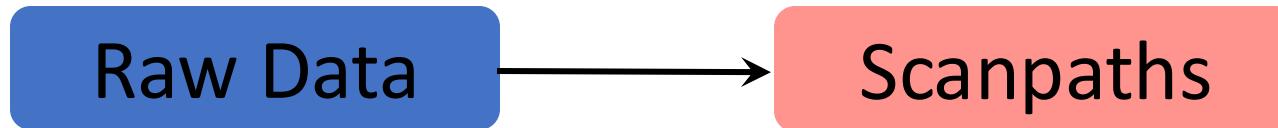
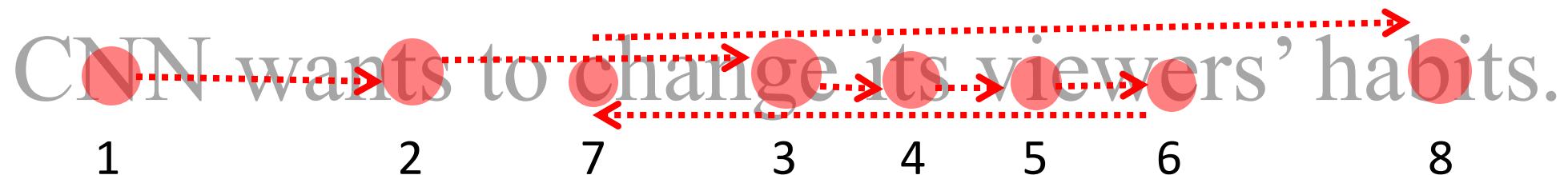
Raw Data

- Binocular or monocular



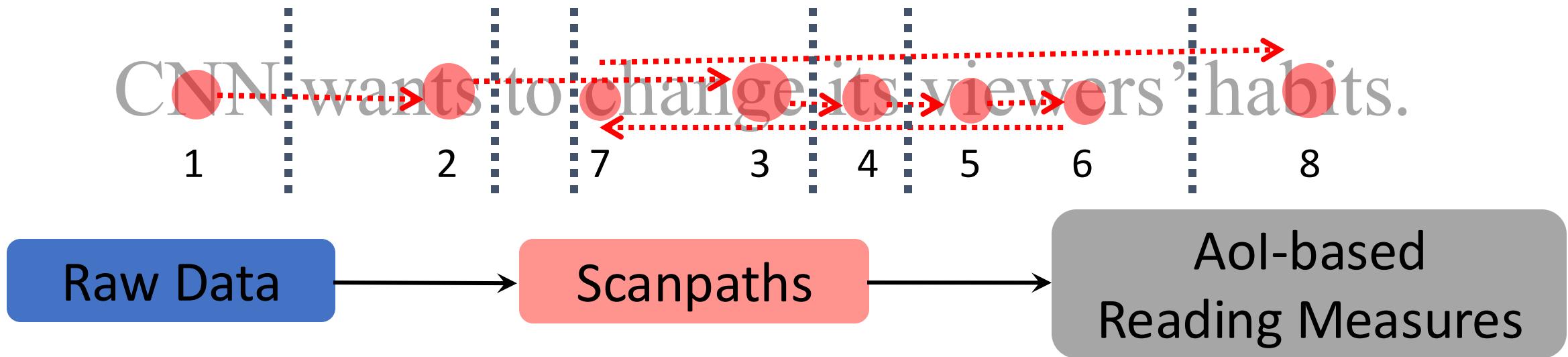
- Screen coordinates or visual angle

Eye Tracking: Preprocessing



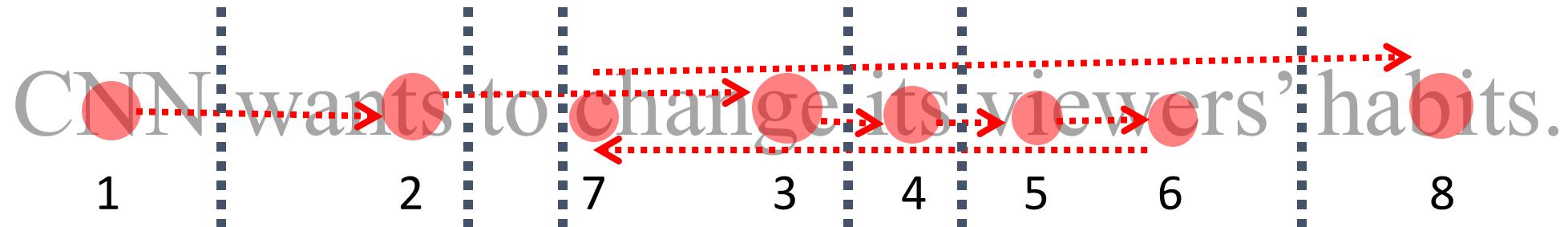
1. Extract fixations from raw samples

Eye Tracking: Preprocessing



1. Extract fixations from raw samples
2. Map fixations to *Areas of Interest*:
Pre-defined screen areas (in pixels)

Eye Tracking: Preprocessing



1. Extract fixations from raw samples
2. Map fixations to *Areas of Interest*:
Pre-defined screen areas (in pixels)



Python package
with preprocessing
algorithms

pymovements.readthedocs.io

Eye Tracking Data Structure

Raw Data

- Time series
- Each row contains one raw sample
- N depends on sampling frequency

Time (ms)	x (pixels)	y (pixels)
1	151	372
2	150	371
3	152	374
4	151	370
...

Scanpaths

- Discrete chronological sequence
- Each row contains one fixation

idx	x (mean, pixels)	y (mean, pixels)	word	aoi	dur
1	151	371	CNN	1	380
2	175	376	wants	2	180
3	198	378	change	4	224
4	227	370	viewers	6	299
5	251	369	habits	7	230
6	192	374	change	4	229
...

Aoi-based
Reading Measures

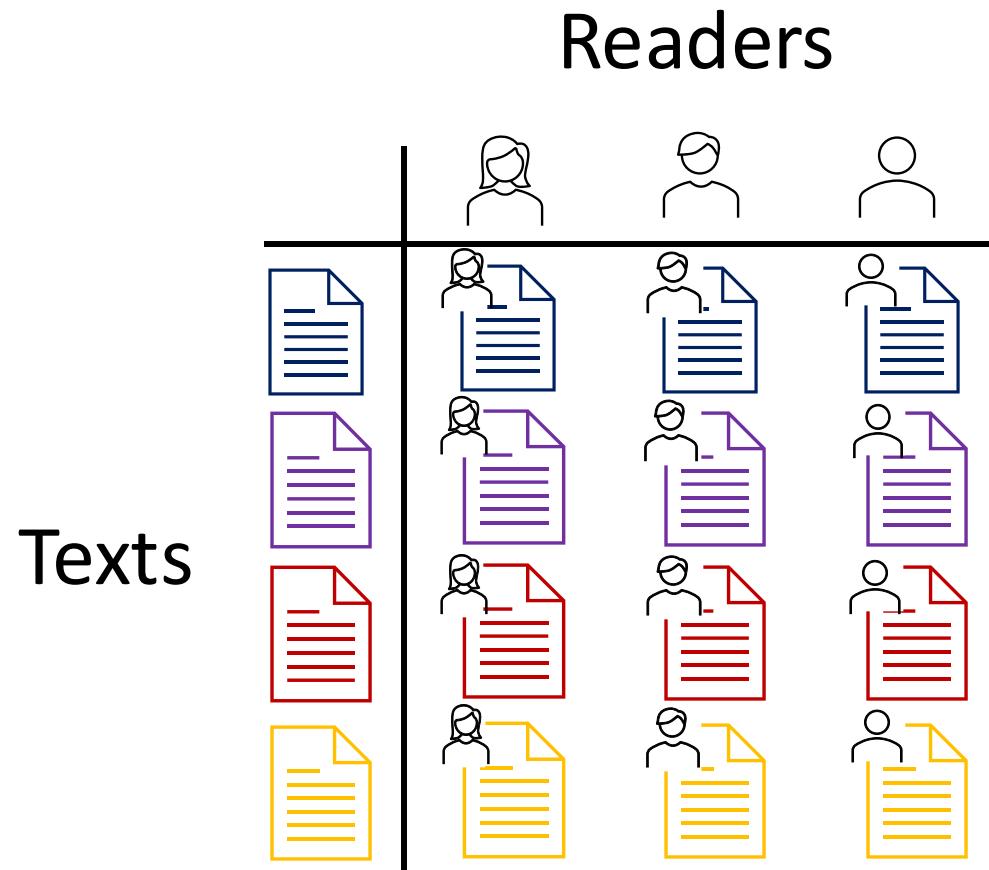
- Discrete sequence in aoi-order
- Each row contains RMs of one aoi read by one subj

subj	item	word	aoi	FFD
1	1	CNN	1	380
1	1	wants	2	180
1	1	to	3	NA
1	1	change	4	224
1	1	its	5	NA
1	1	viewers	6	299
1	1	habits	7	230
...

Data is not iid – it has structure

Implications for:

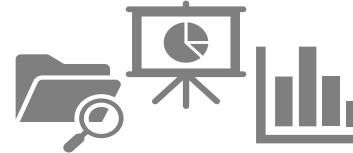
- Statistical modeling
- Training and evaluations
- Applications



Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking

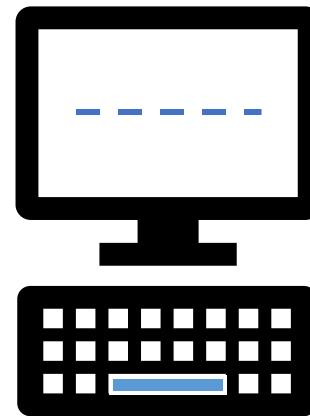


Datasets

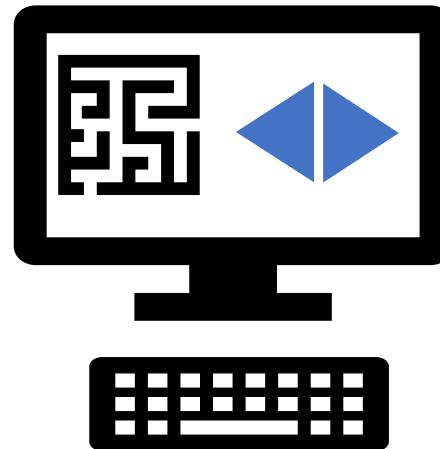
Eye Tracking vs Cheaper Low Tech Methods

Do we really need eye tracking?

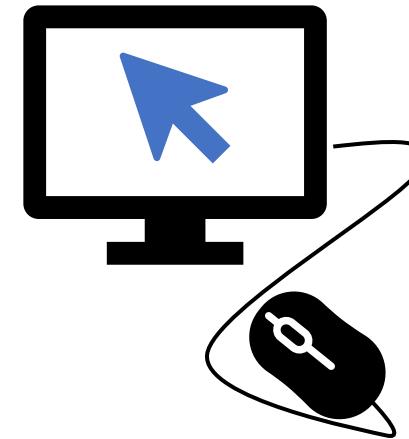
Popular alternatives in psycholinguistics:



Self-Paced Reading



Maze

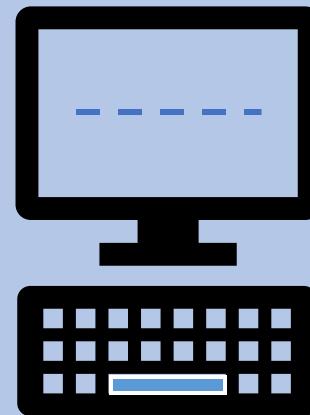


Mouse tracking

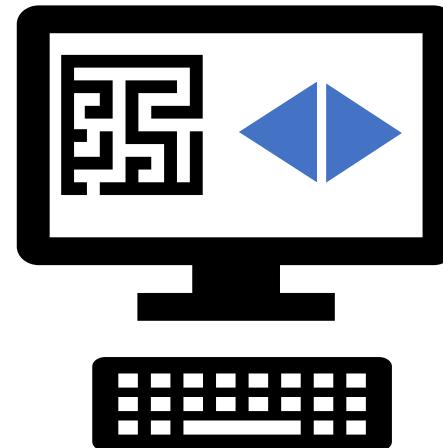
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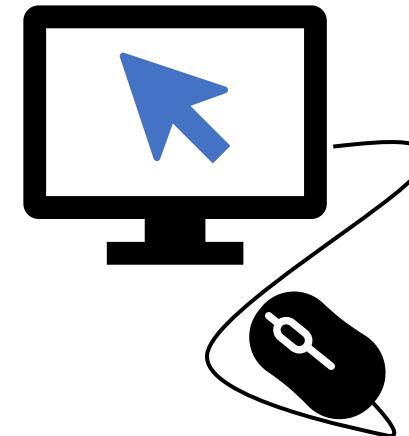
Popular alternatives in psycholinguistics:



Self-Paced Reading



Maze



Mouse tracking

Self Paced Reading (SPR)

- Reveal each consecutive word with a button press



Self Paced Reading (SPR)

- Reveal each consecutive word with a button press

Many-----

Self Paced Reading (SPR)

- Reveal each consecutive word with a button press

-----years-----

Self Paced Reading (SPR)

- Reveal each consecutive word with a button press

-----later-----

Self Paced Reading (SPR)

- Reveal each consecutive word with a button press

-----as-----

Self Paced Reading (SPR)

- Reveal each consecutive word with a button press

-----he-----

Self Paced Reading (SPR)

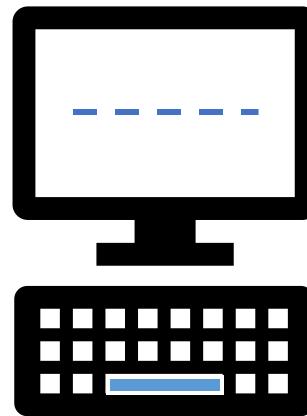
- Reveal each consecutive word with a button press
- Time between button presses as a proxy for incremental processing difficulty

-----faced-----

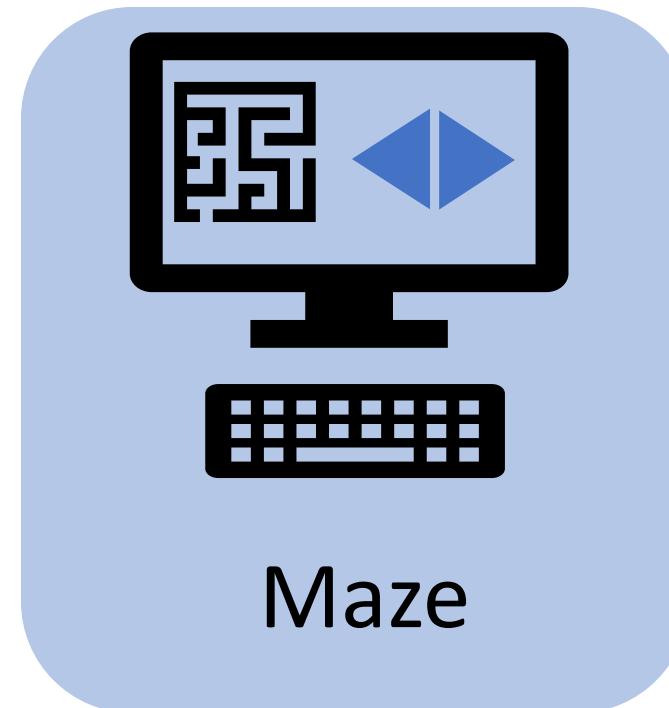
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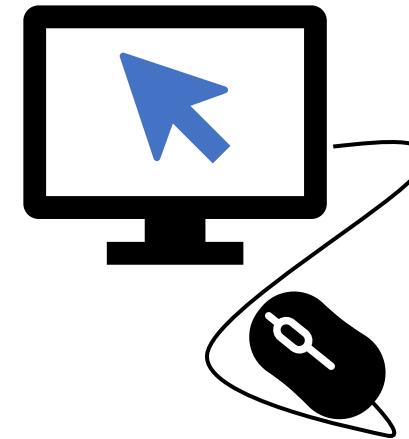
Popular alternatives in psycholinguistics:



Self Paced Reading



Maze



Mouse tracking

The Maze

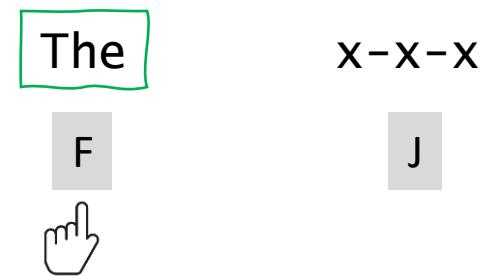
- Choose a word that fits given the preceding context

F

J

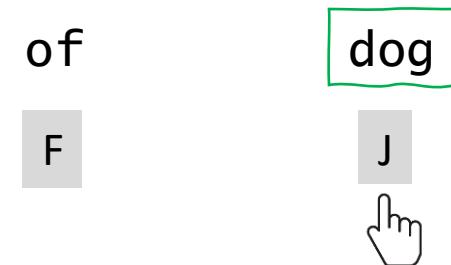
The Maze

- Choose a word that fits given the preceding context



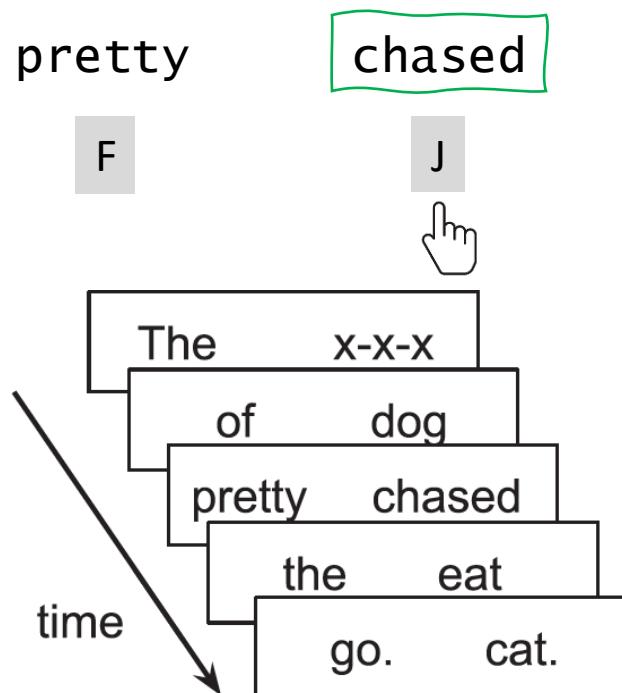
The Maze

- Choose a word that fits given the preceding context



The Maze

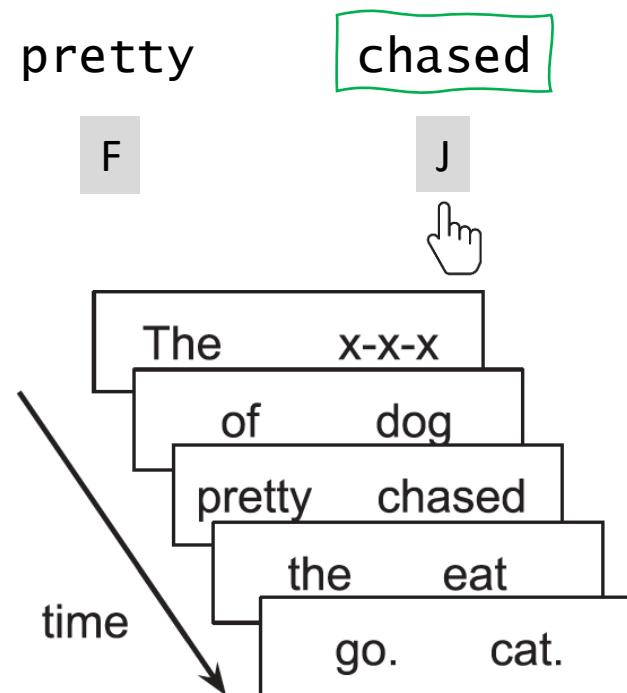
- Choose a word that fits given the preceding context



[Forster et al. \(2009\), Boyce et al. \(2020\)](#)

The Maze

- Choose a word that fits given the preceding context
- Time between button presses as a proxy for incremental processing difficulty

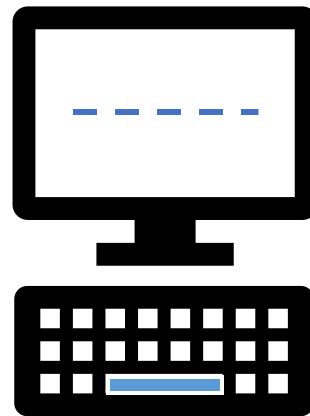


[Forster et al. \(2009\), Boyce et al. \(2020\)](#)

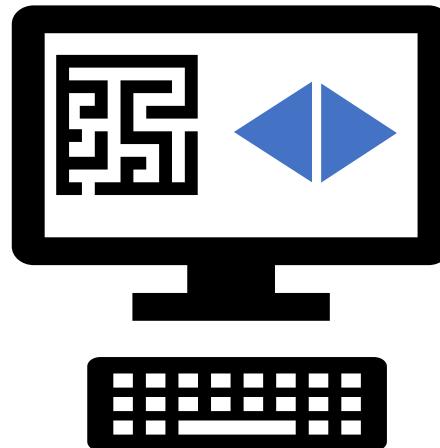
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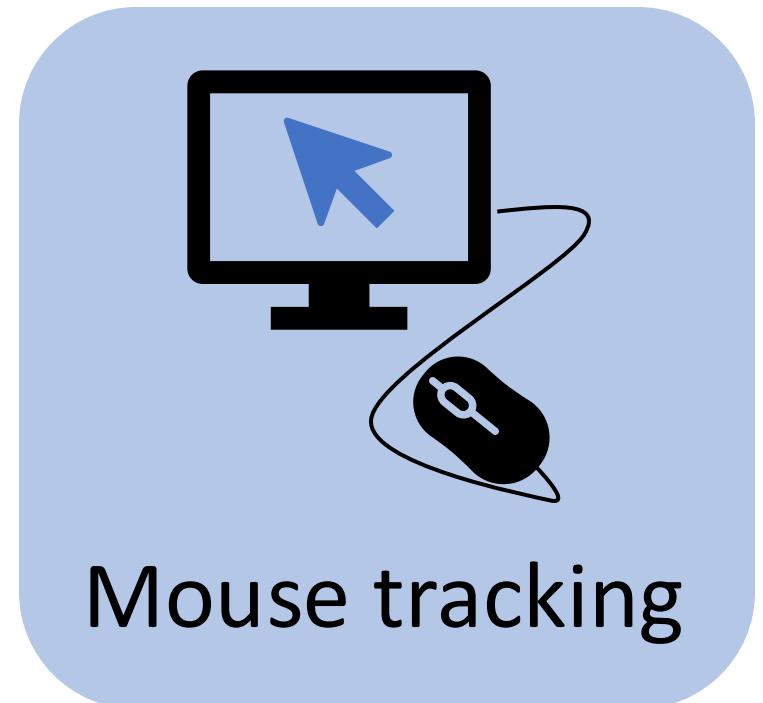
Popular alternatives in psycholinguistics:



Self Paced Reading

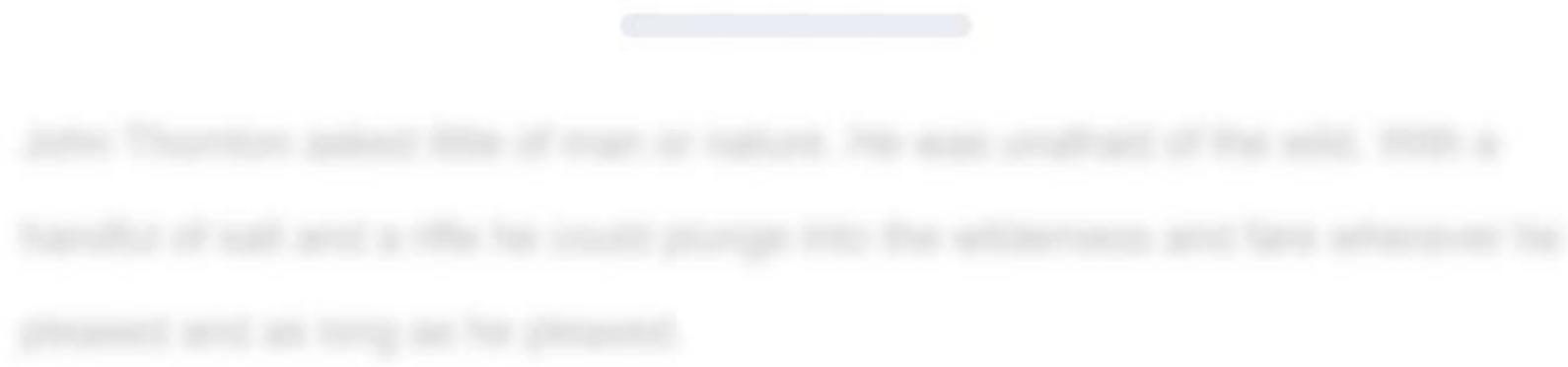


Maze

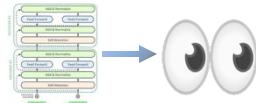


Mouse tracking

Mouse Tracking



Synthetic Eye Tracking Data



Over the next 30 years, the planet's human population will increase to nine billion. Already one billion people do not get enough food. The increase will mean more pressure on agricultural land, water, forests, fisheries and biodiversity resources, as well as nutrients and energy supplies. There is also the issue of methane excreted by cows. The livestock farming contribution, in terms of greenhouse gas emissions, is enormous – 35% of the planet's methane, 65% of its nitrous oxide and 9% of the carbon dioxide.



- 1. Cognitive models**
- 2. NLP / ML Models**

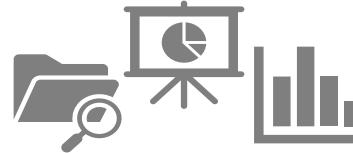
Eye Tracking vs Cheaper Methods

- More naturalistic
- More fine-grained information (multiple measures, not just RTs)
- Doesn't include time to execute button presses and mouse movements
- Higher quality than synthetic data
- Currently cannot be collected at scale (on the web)
- In most use cases, no eye tracking data is available at application time

Introduction to Eye Movements in Reading and Eye Tracking



How do People Read?



Data Representation



Reading Measures



Alternatives



Eye Tracking



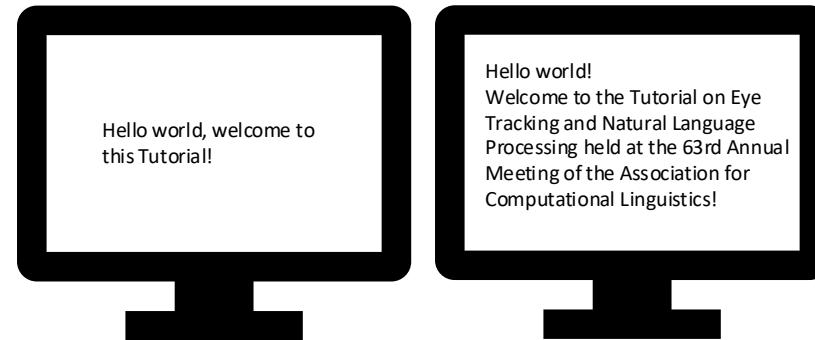
Datasets

Types of Reading Datasets

Minimal-pairs vs naturalistic reading

- 1a) *The horse raced past the barn fell.*
- 1b) *The horse **that was** raced past the barn fell.*

Single sentences vs parags/texts

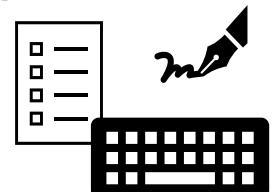


Eye tracking hardware quality



Reading task

- Natural reading
- Question answering
- Repeated reading
-



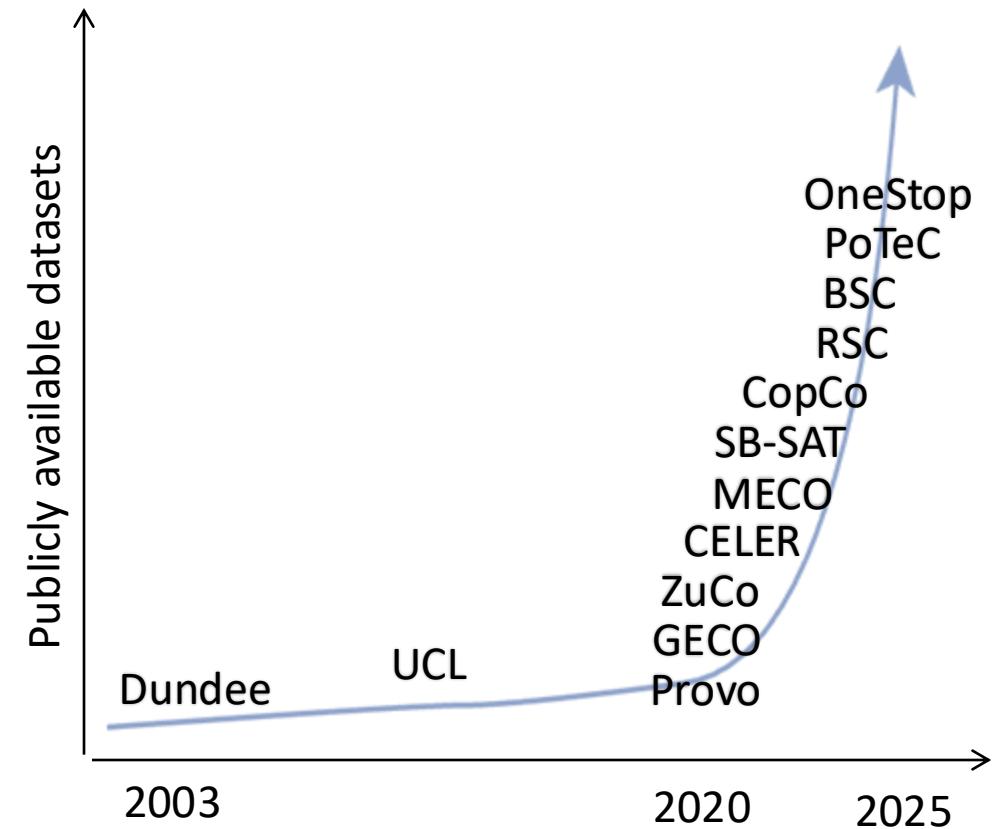
Additional Information Accompanying Eye Tracking Datasets

- Behavioral data
 - Response accuracies
 - Judgements/labels
- Psychometric test scores
- Demographic information
- Linguistic background



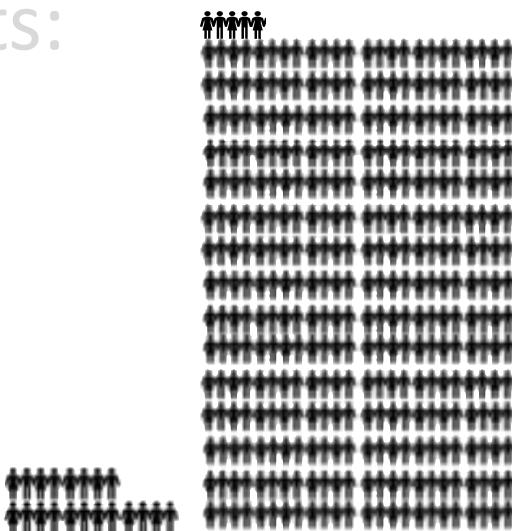
Current Datasets

- Increasing number of data sets
- Increasing number of participants
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets



Current Datasets

- Increasing number of data sets
- **Increasing number of participants**
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets



Dundee
(2003)
N = 20

CELER
(2022)
N = 365

MECO (2022–2025)
N=1,202

Current Datasets

- Increasing number of data sets
- Increasing number of participants
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets

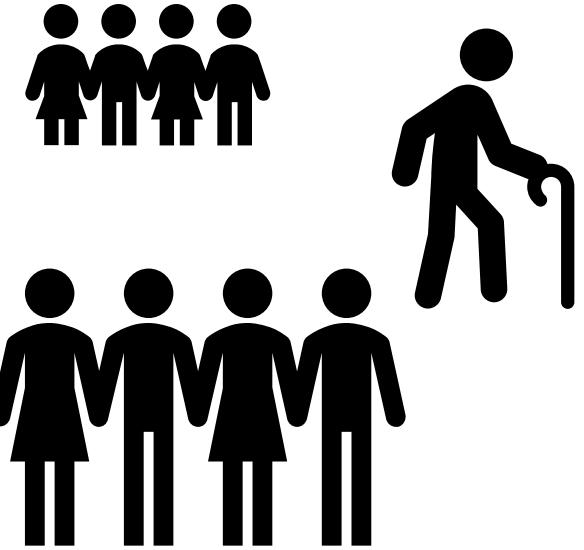


Chinese: BSC
Danish: CopCo
Dutch: GECO
German: PoTeC
Russian: RSC

...

Current Datasets

- Increasing number of data sets
- Increasing number of participants
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets



Dyslexia: CopCo
L2: GECO, MECO, CELER, ...
Wide age range: CELER
Domain-expertise: PoTeC

Current Datasets

- Increasing number of data sets
- Increasing number of participants
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets



Reading comprehension: SB-SAT, OneStop, Multipleye

Sentiment classification: ETSA

Relation extraction: ZuCo

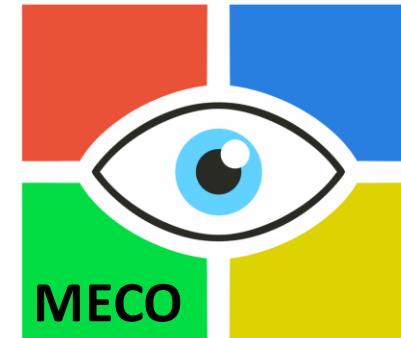
Repeated reading: OneStop

Information seeking: OneStop

...

Current Datasets

- Increasing number of data sets
- Increasing number of participants
- Increasing diversity of data sets:
 - Languages & Scripts
 - Populations
 - Tasks
- Multilingual data sets

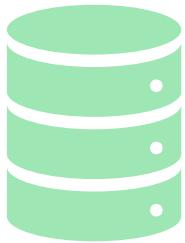


**Large-scale multi-lab multilingual
data collection initiatives**

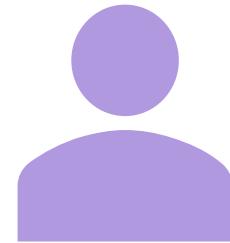
MECO: <https://meco-read.com>

MultiplEYE: <https://multipleye.eu>

Overview of Publicly Available Data Sets



60+
Datasets



4.5K+
Participants
Total



15K+
**Text
screens**



30+
languages

How to Access the Datasets?

pymovements



Python package to download 24+ datasets with 4.5K+ participants

pymovements.readthedocs.io

Or from:

- Open science repositories
- Direct links from papers
- From authors' websites

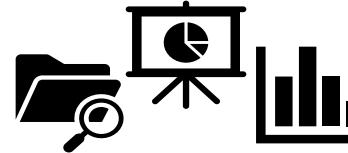


[Datasets References](#)

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Alternatives



Eye Tracking

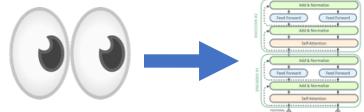


Datasets

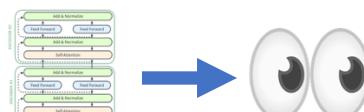
Tutorial Outline



1. Introduction to eye tracking



2. Uses of Eye Tracking in NLP



3. NLP for eye movement and cognitive modeling

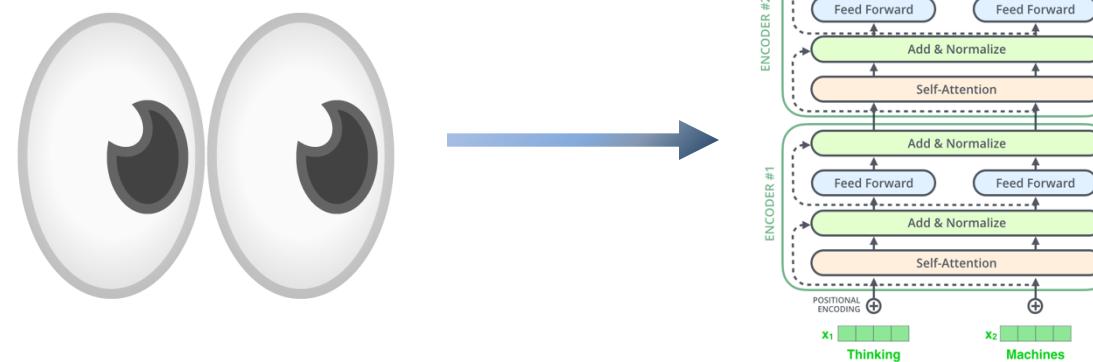


4. New human centered applications

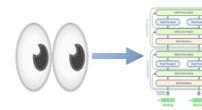


5. Outlook and future directions

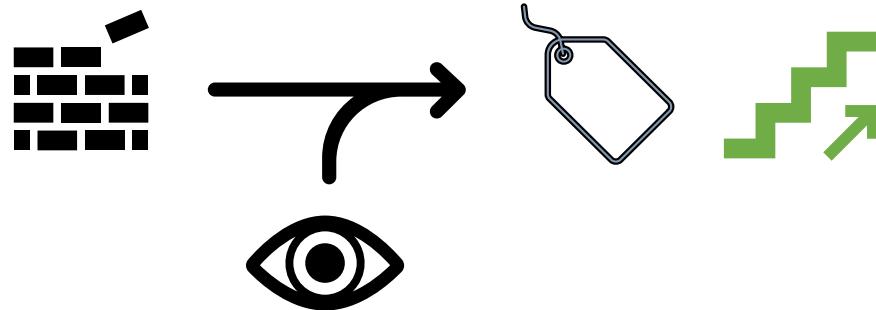
Uses of Eye Tracking in NLP



Uses of Eye Tracking in NLP

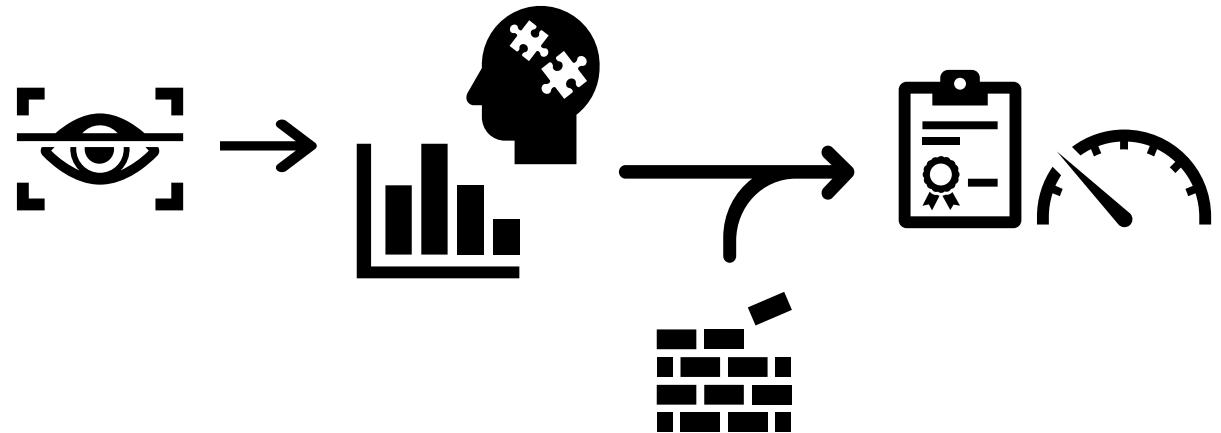


Modeling



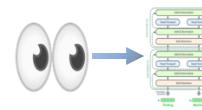
Eye movements can enhance the performance of NLP models

Evaluation

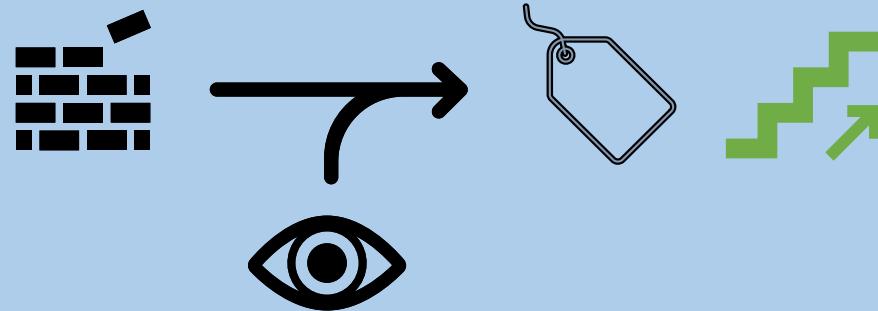


Eye movements as behavioral benchmarks for evaluating NLP models

Uses of Eye Tracking in NLP

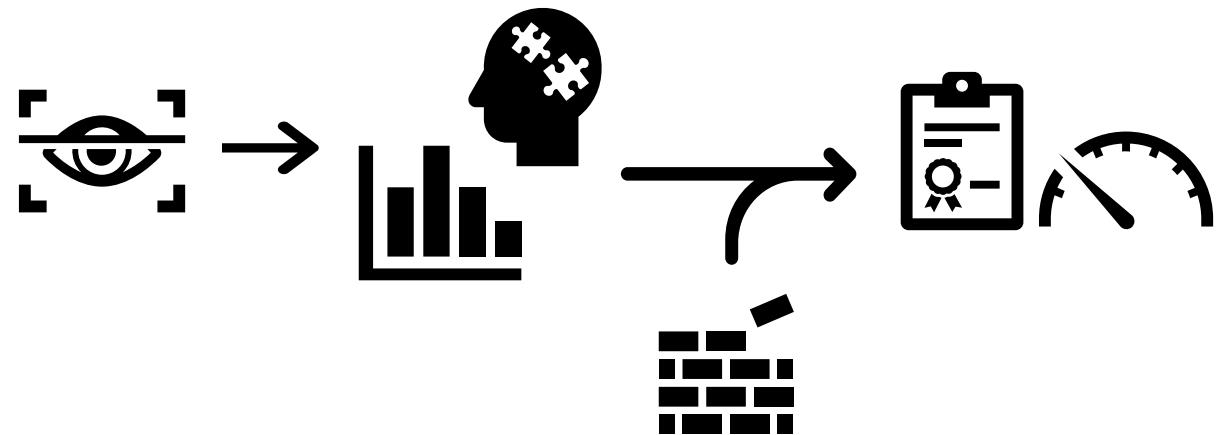


Modeling



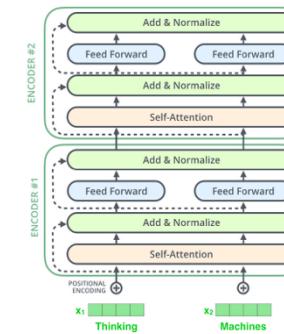
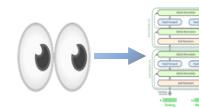
Eye movements can enhance the performance of NLP models

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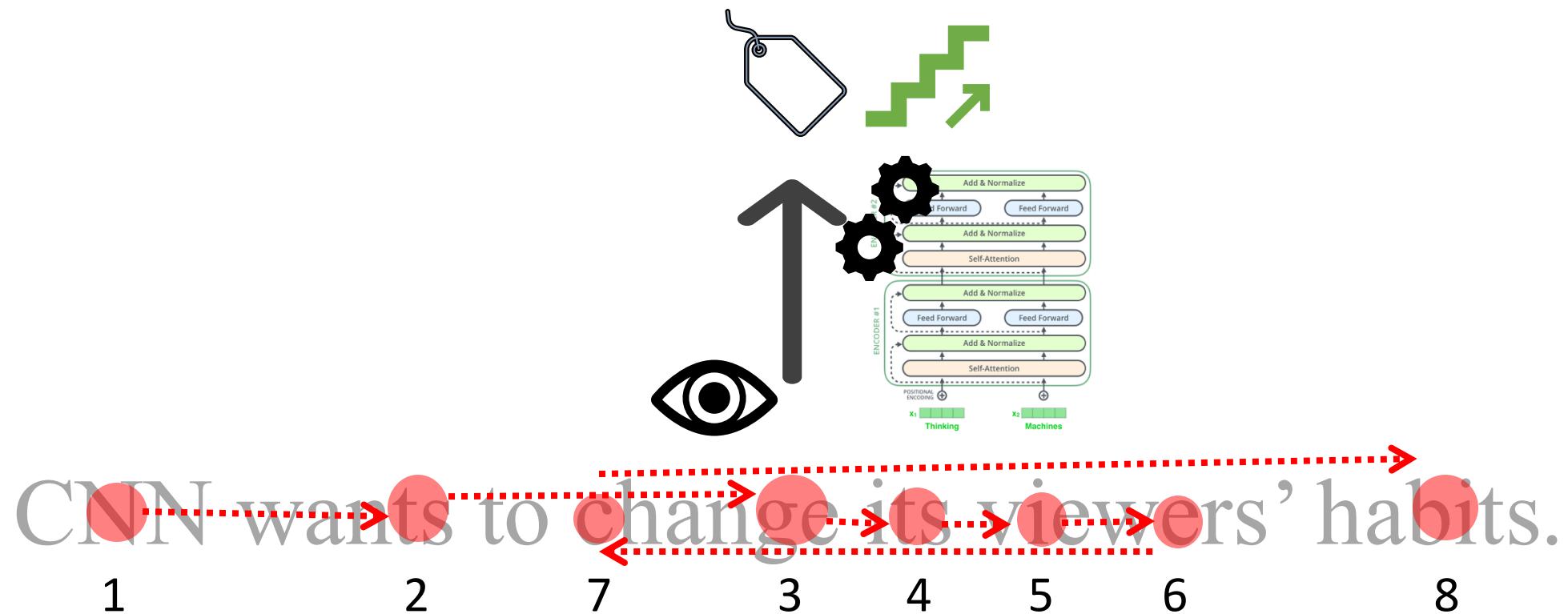
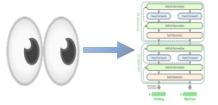
Eye movements as behavioral benchmarks for evaluating NLP models

Language modeling



CNN wants to change its viewers' habits.

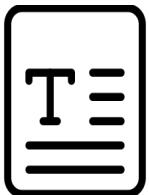
Language modeling and eye movements



Improving NLP with Gaze

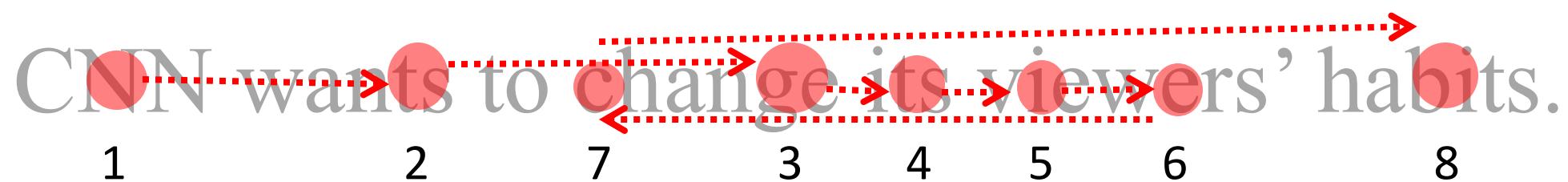
Tasks

- Sentiment analysis [Mishra et al. \(2016\)](#), [Barrett et al. \(2018\)](#),
[Yang and Hollenstein \(2023\)](#)
- NER [Hollenstein and Zhang \(2019\)](#)
- Paraphrase generation, sentence compression [Sood et al. \(2020\)](#),
[Klerke et al. \(2016\)](#)
- Relation extraction, sentiment analysis, NER [Ren and Xiong \(2021\)](#)
- GLUE [Deng et al. \(2023\)](#), [Deng et al. \(2024\)](#)
- Readability assessment [González-Garduño and Søgaard \(2017\)](#)
- Dependency parsing [Strzyz et al. \(2019\)](#)
- QA [Malmaud et al. \(2020\)](#)



Why eye movements?

- Eye movement in reading are influenced by
 - the **difficulty** of the text
 - the **individual**
 - **cognitive demands**
 - ...



How to combine eye movements and text?

- Static text

CNN wants to change its viewers' habits.

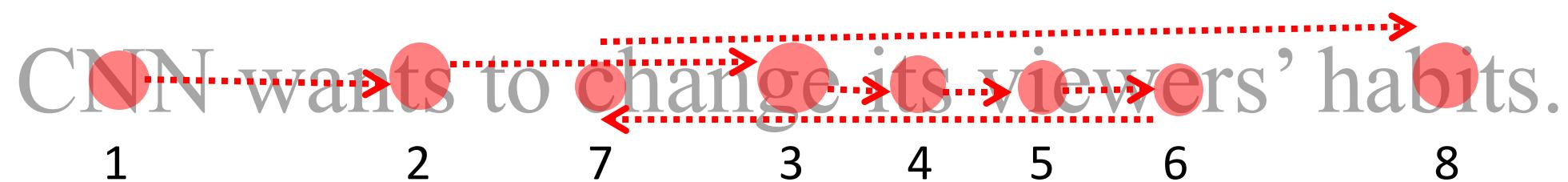
How to combine eye movements and text?

- Static text: linguistic axis

CNN wants to change its viewers' habits.

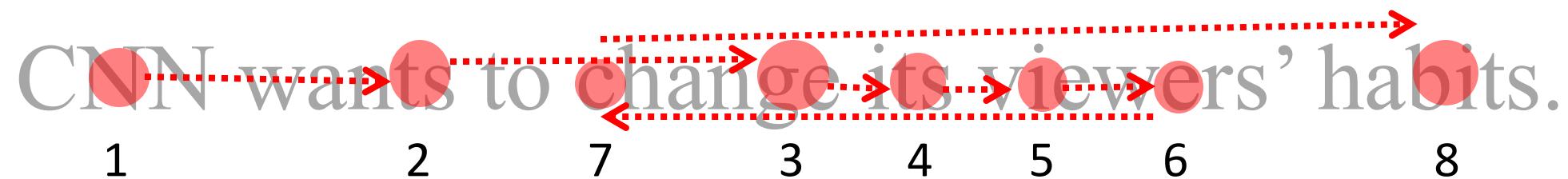
How to combine eye movements and text?

- Static text: linguistic axis
- Dynamic eye movements



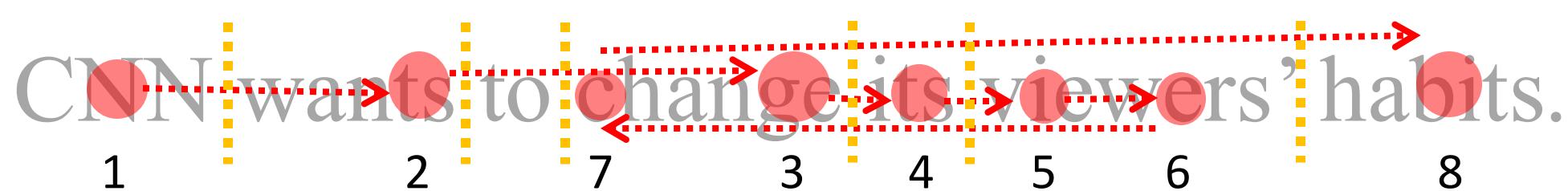
How to combine eye movements and text?

- Static text: linguistic axis
- Dynamic eye movements: temporal axis



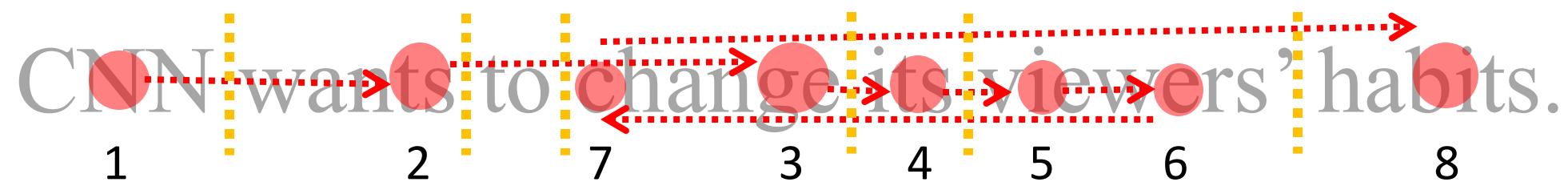
How to combine eye movements and text?

- Static text: linguistic axis
- Dynamic eye movements: temporal axis



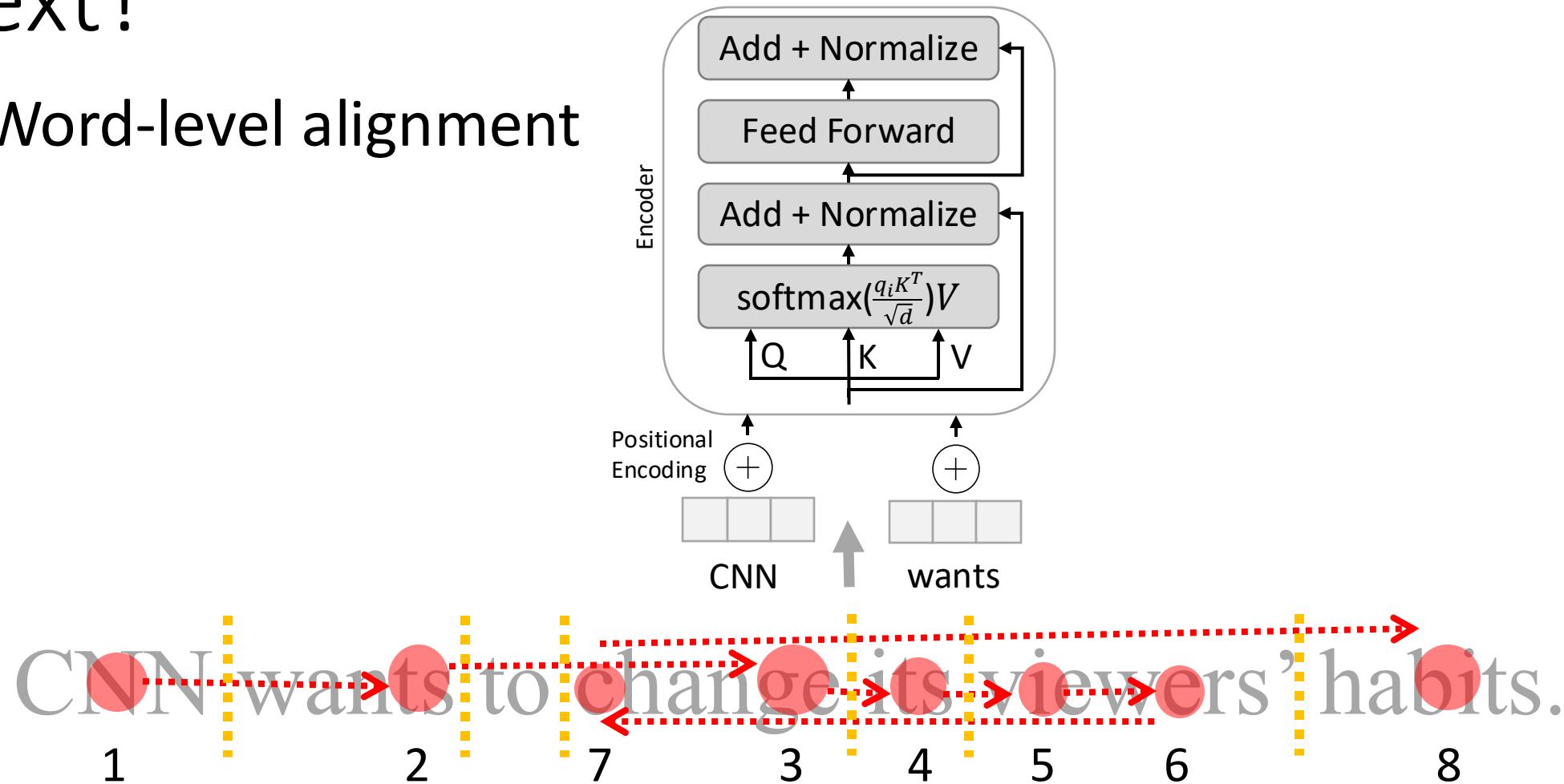
How to combine eye movements and text?

- Word-level alignment
 - E.g. total fixation duration



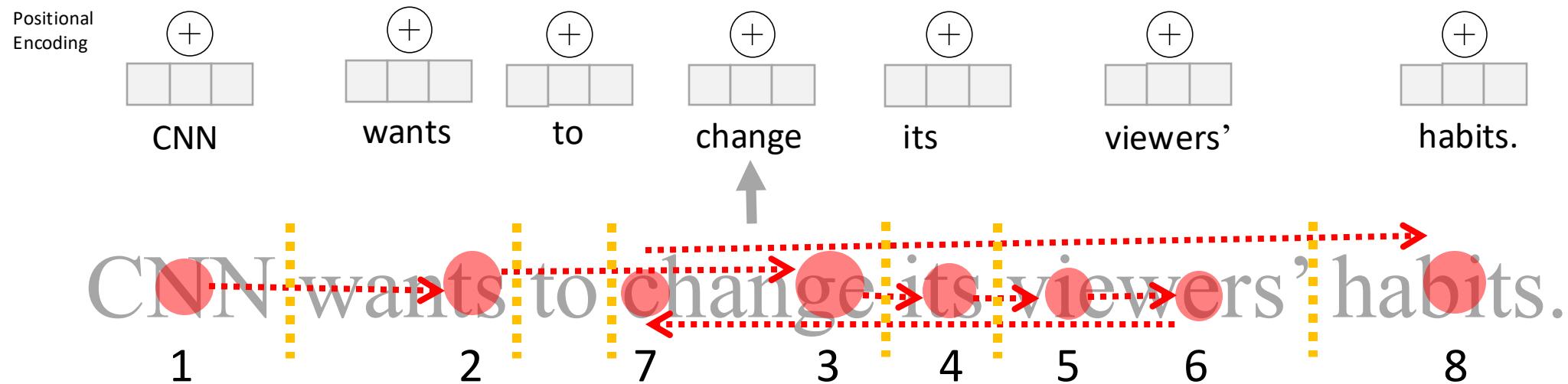
How to combine eye movements and text?

- Word-level alignment



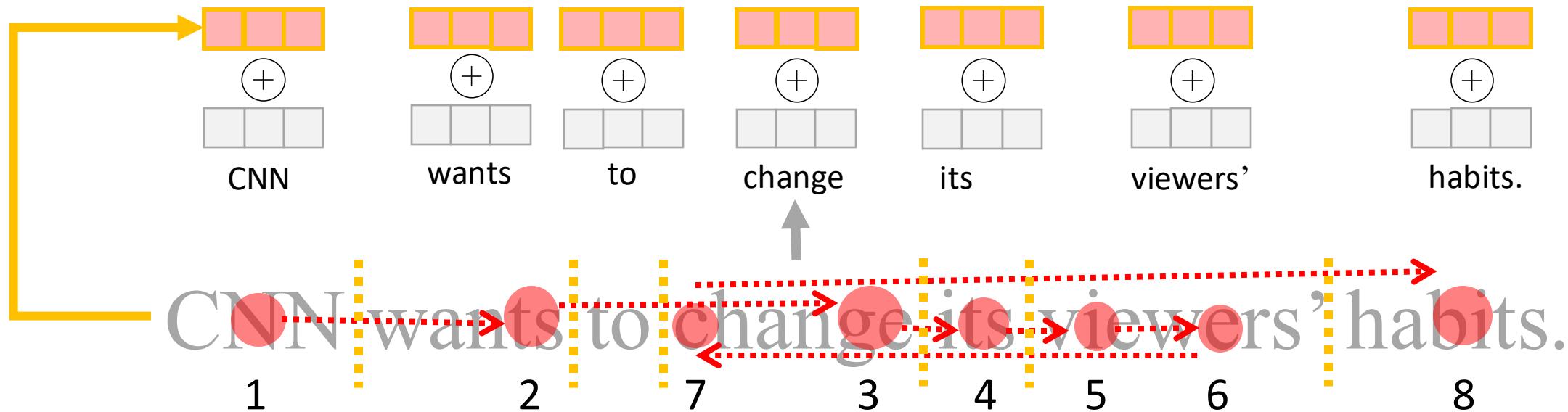
How to combine eye movements and text?

- Word-level alignment



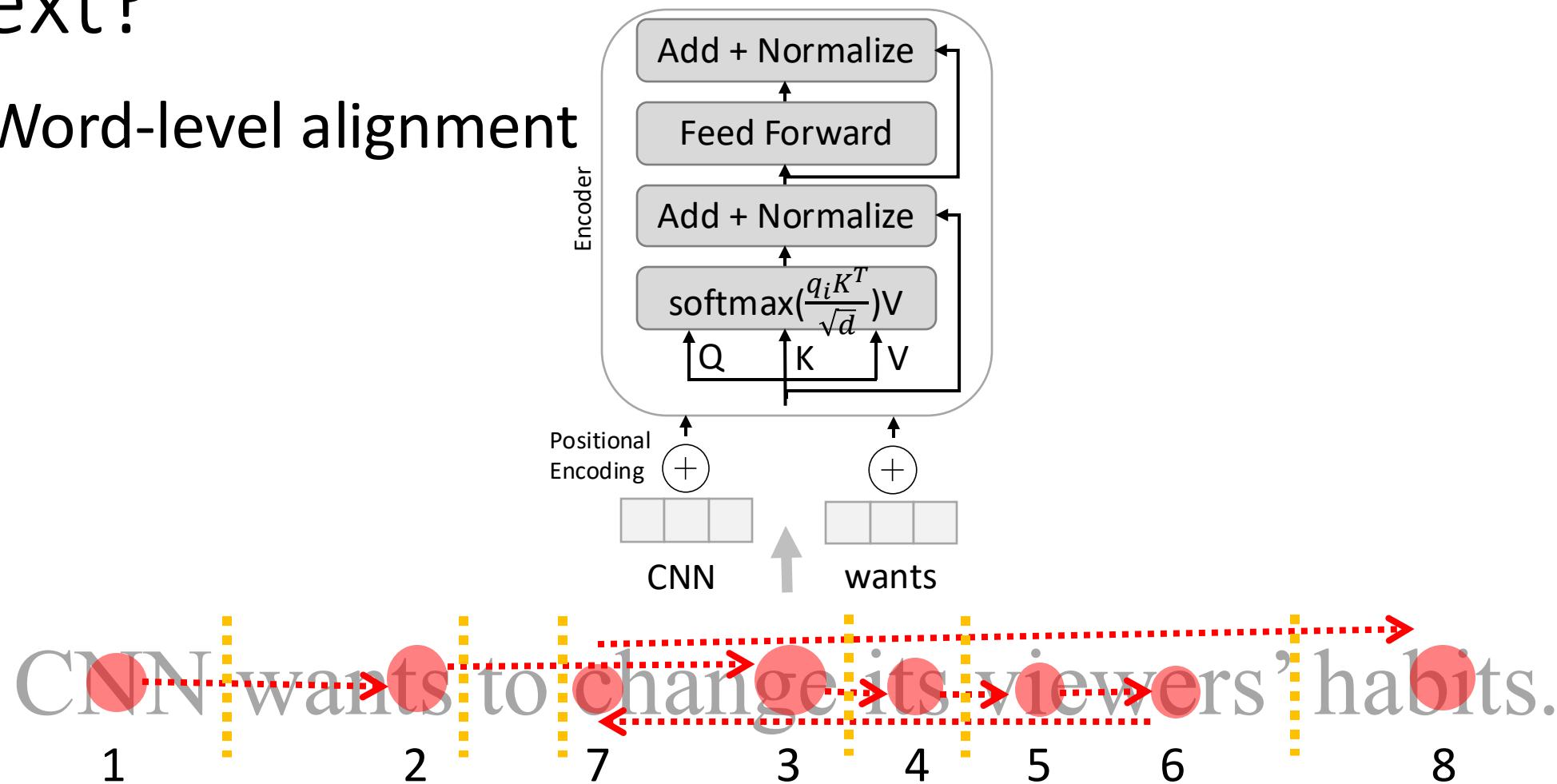
How to combine eye movements and text?

- Word-level eye movement embedding



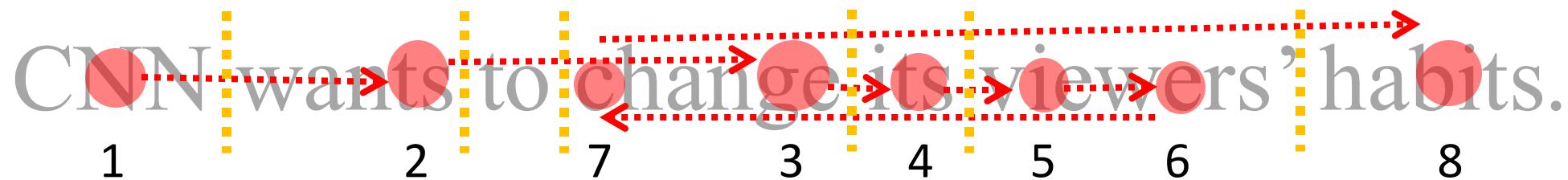
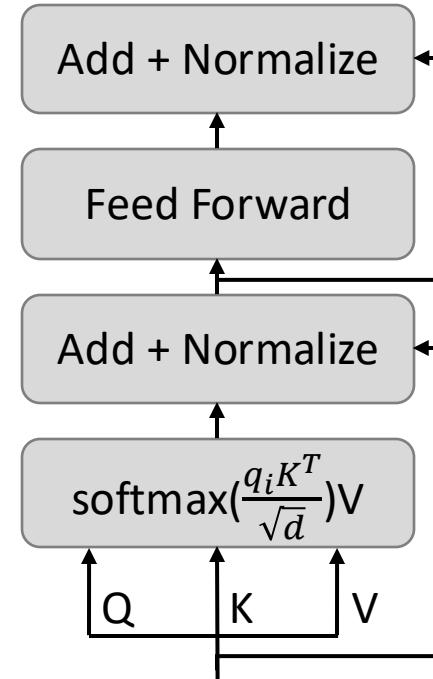
How to combine eye movements and text?

- Word-level alignment



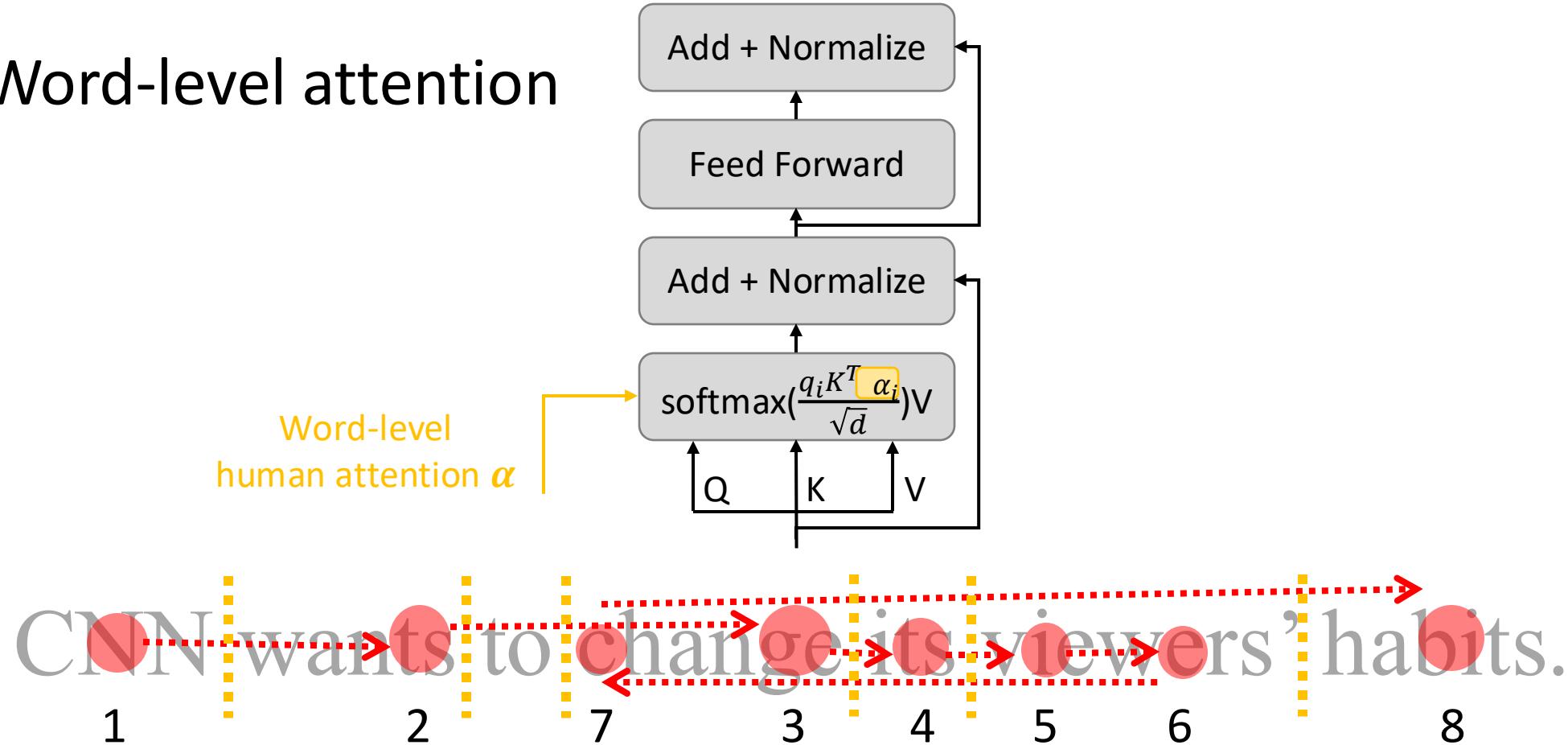
How to combine eye movements and text?

- Word-level alignment



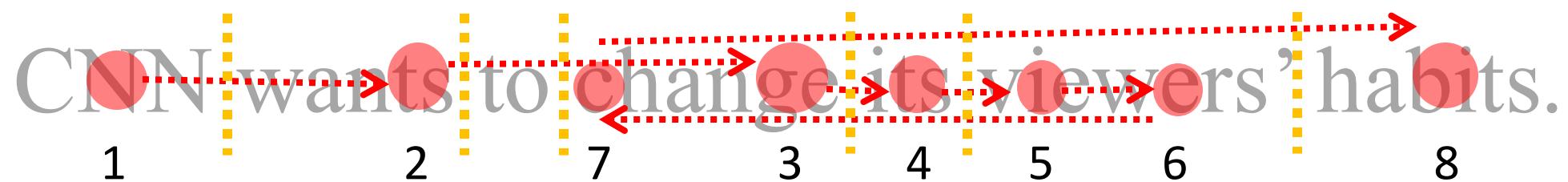
How to combine eye movements and text?

- Word-level attention



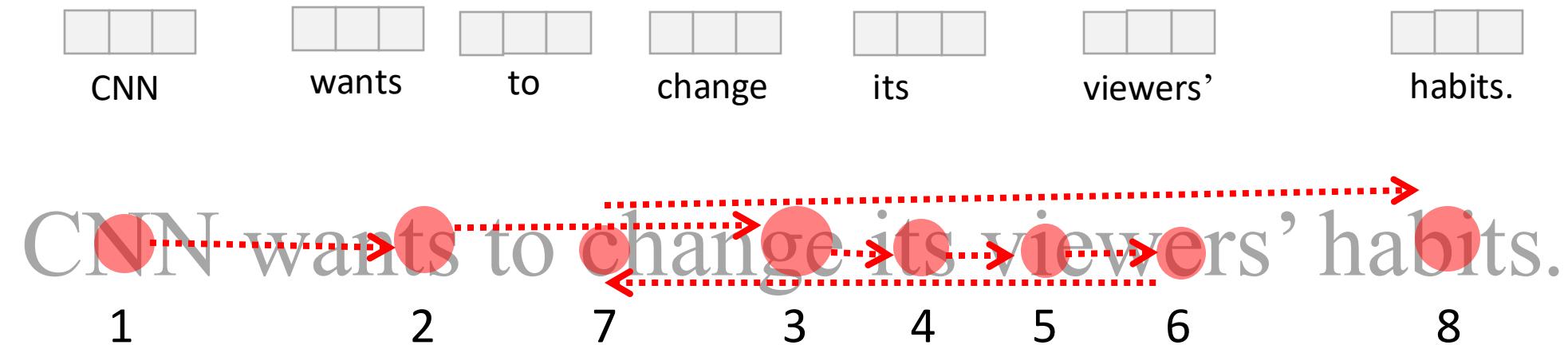
How to combine eye movements and text?

- Word-level alignment
 - E.g. total fixation duration



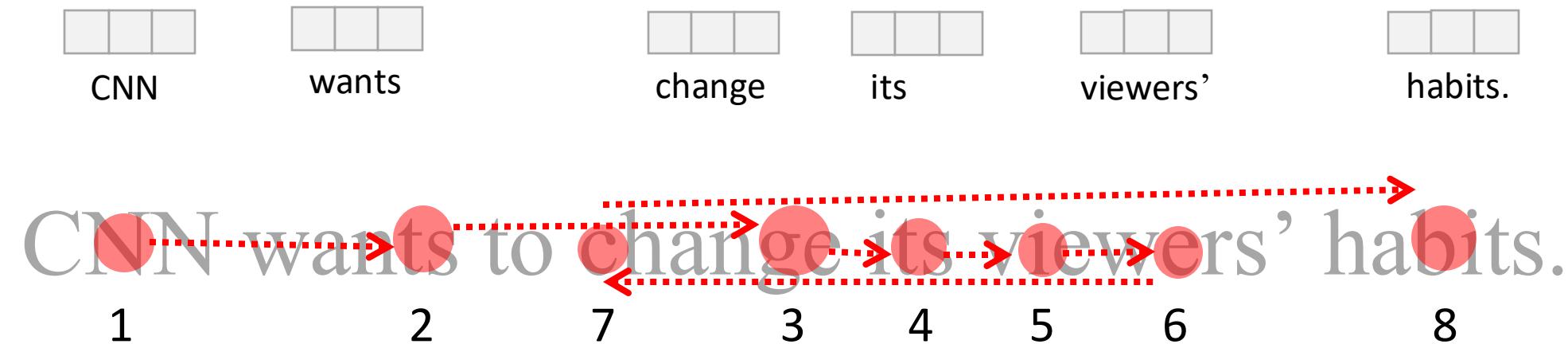
How to combine eye movements and text?

- Word reordering



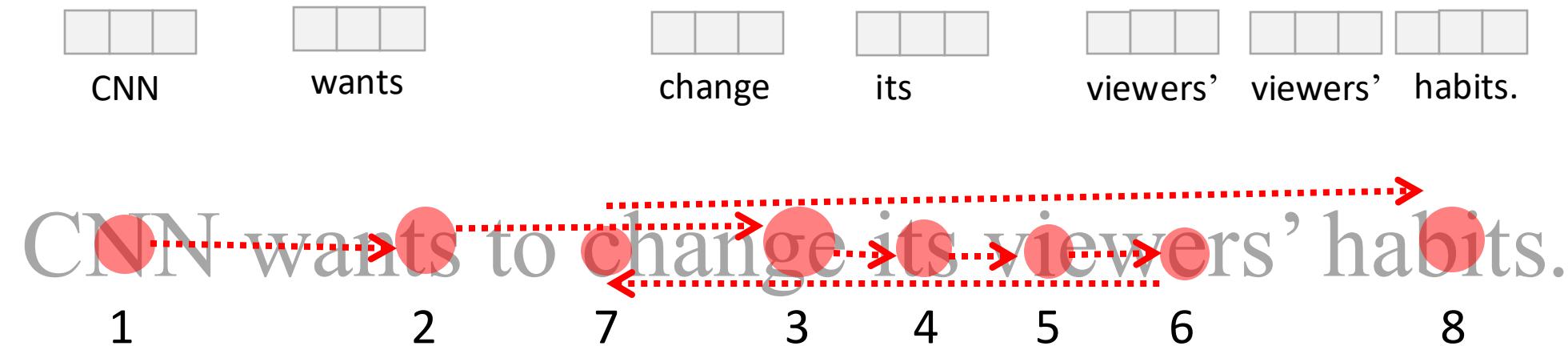
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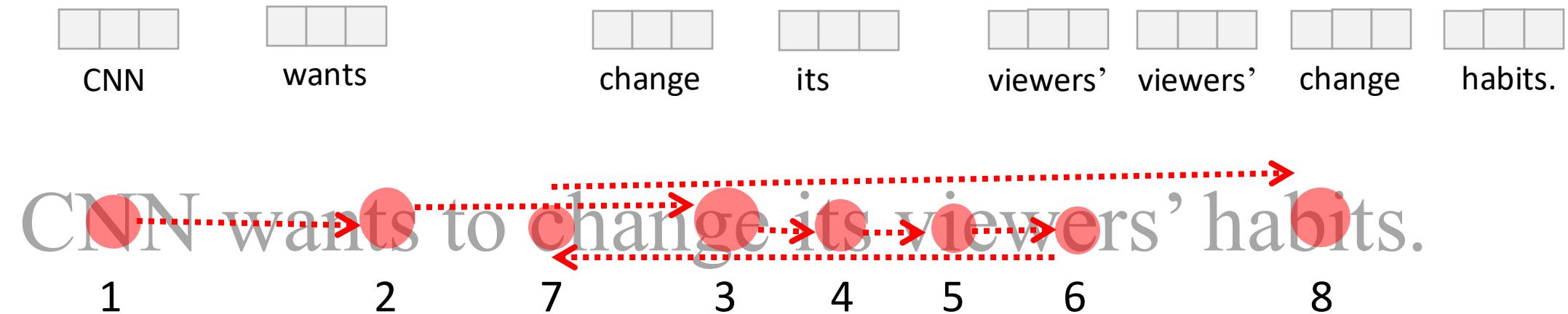
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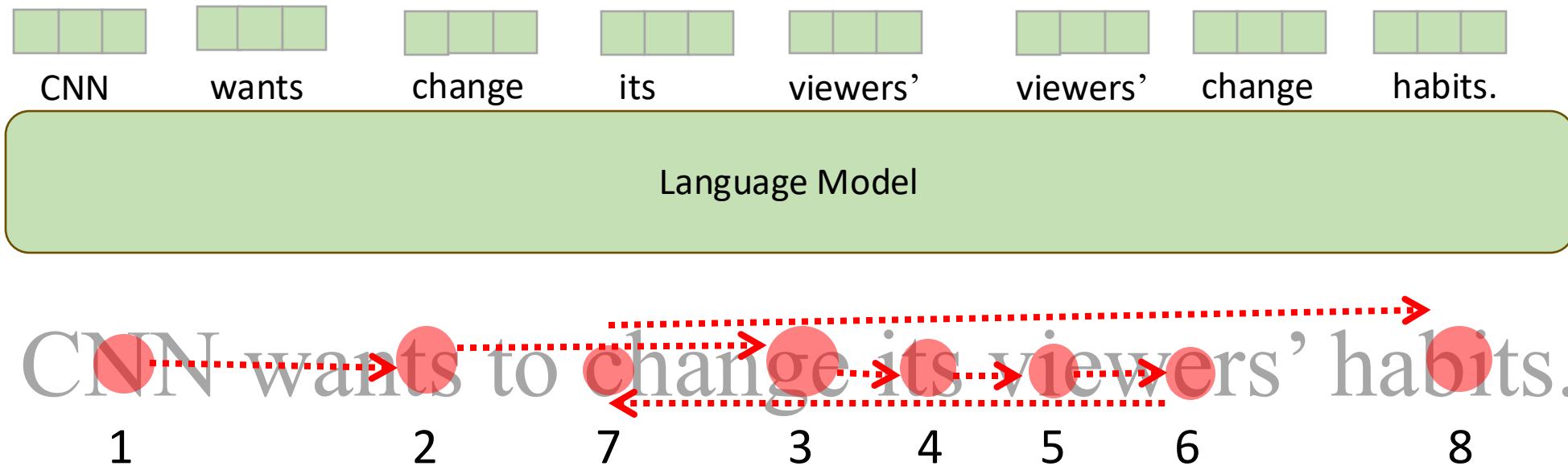
How to combine eye movements and text?

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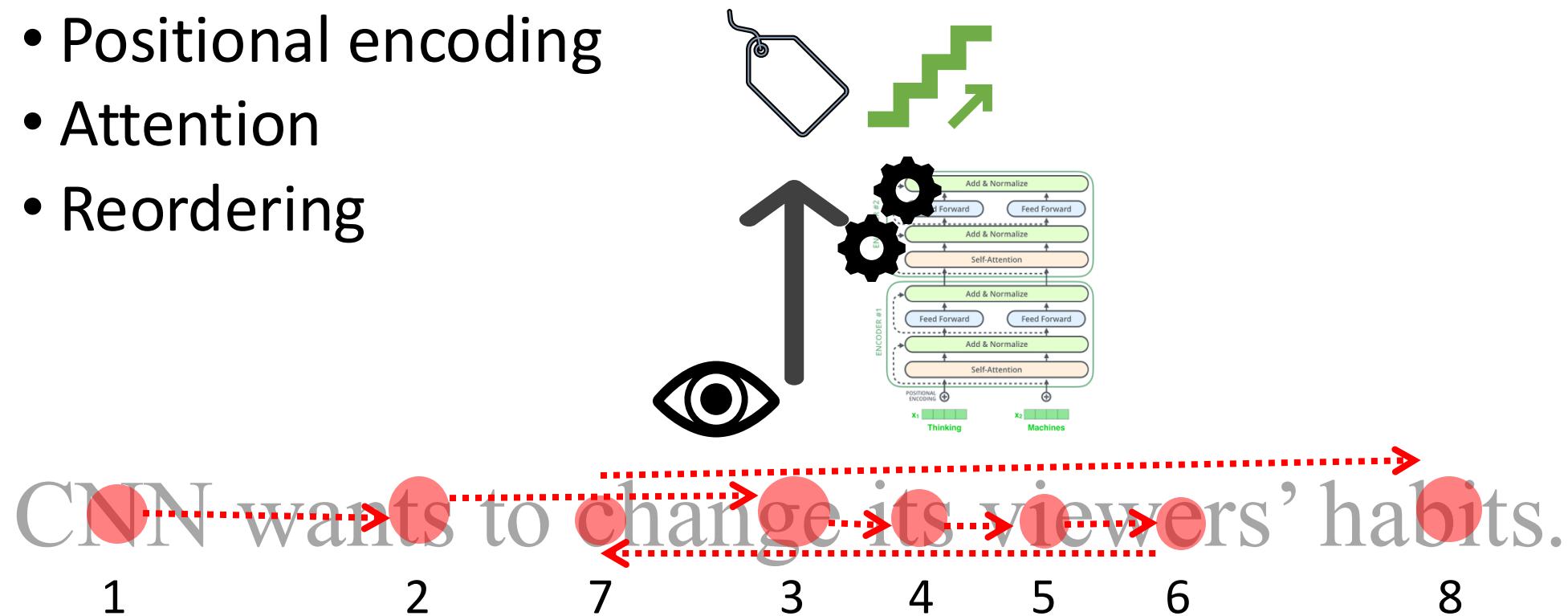
How to combine eye movements and text?

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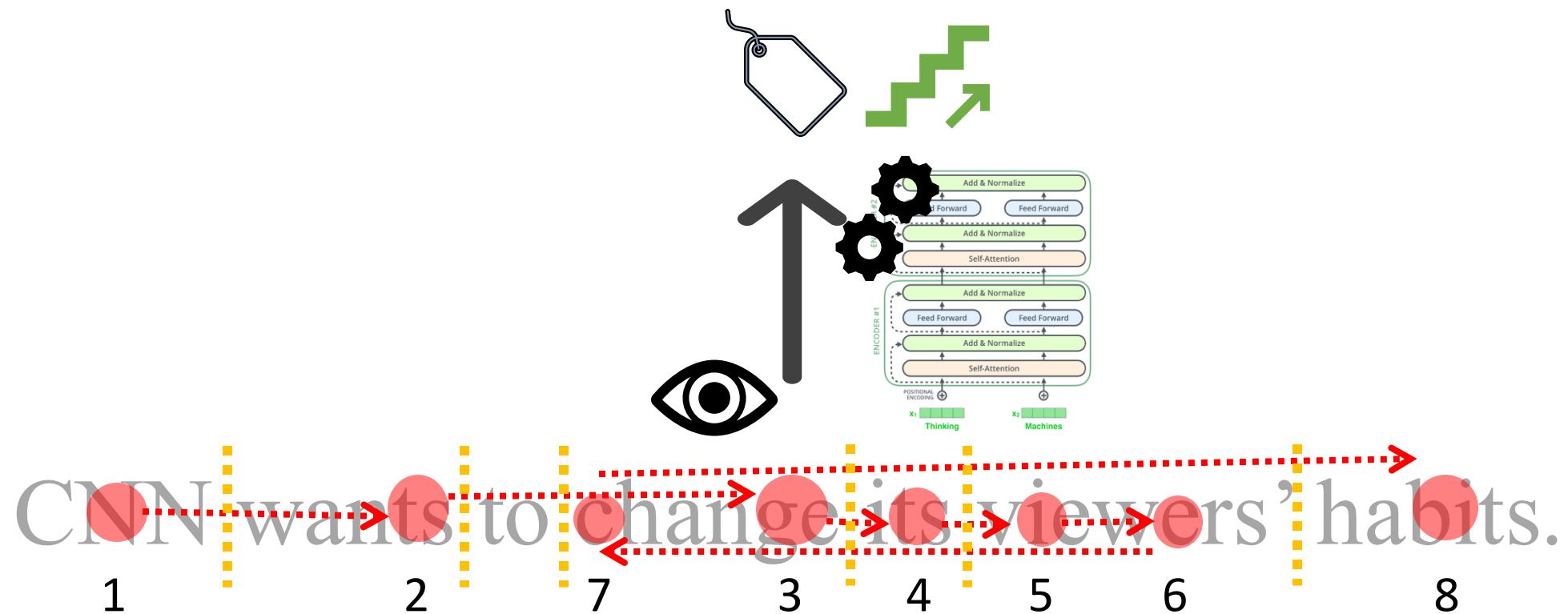


How to combine eye movements and text?

- Input:
 - Positional encoding
 - Attention
 - Reordering

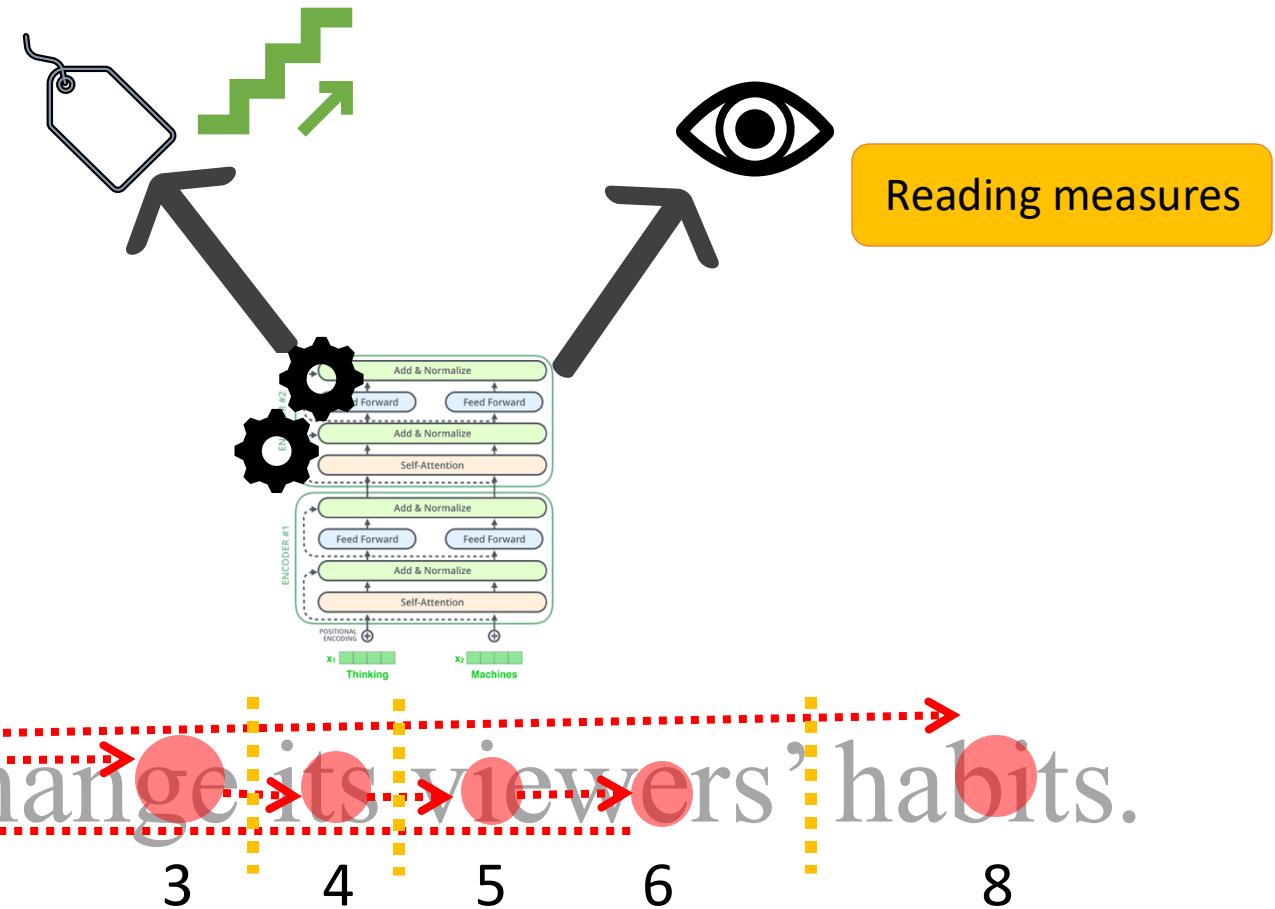


How to combine eye movements and text?



How to combine eye movements and text?

- Multi-task learning with ordinary reading data



[Klerke et al. \(2016\)](#), [González-Garduño and Søgaard \(2017\)](#),
[Barrett et al. \(2018\)](#), [Strzyz et al. \(2019\)](#)

How to combine eye movements and text?

- Multi-task learning with task specific (QA) data [Malmaud et al. \(2020\)](#)

Ordinary reading (no question preview)

In	the	next	30	years,	the	planet's	human	population	will
increase	to	nine	billion.	Already	one	billion	people	do	not
get	enough	food.	The	increase	will	put	more	pressure	on
agricultural	land,	water,	forests,	fisheries	and	resources,	and	also	food
and	energy	supplies.	The	cost	of	meat	is	increasing	-
it	costs	more	money	now,	but	also	people	have	to
destroy	a	lot	of	rainforest	to	make	fields	or	to
grow	food	for	cows.	Cows	also	make	methane.	The	farming
of	cows,	pigs	and	sheep	makes	very	large	amounts	of
greenhouse	gases	-	35%	of	the	planet's	methane,	65%	of
its	nitrous	oxide	and	9%	of	carbon	dioxide.		

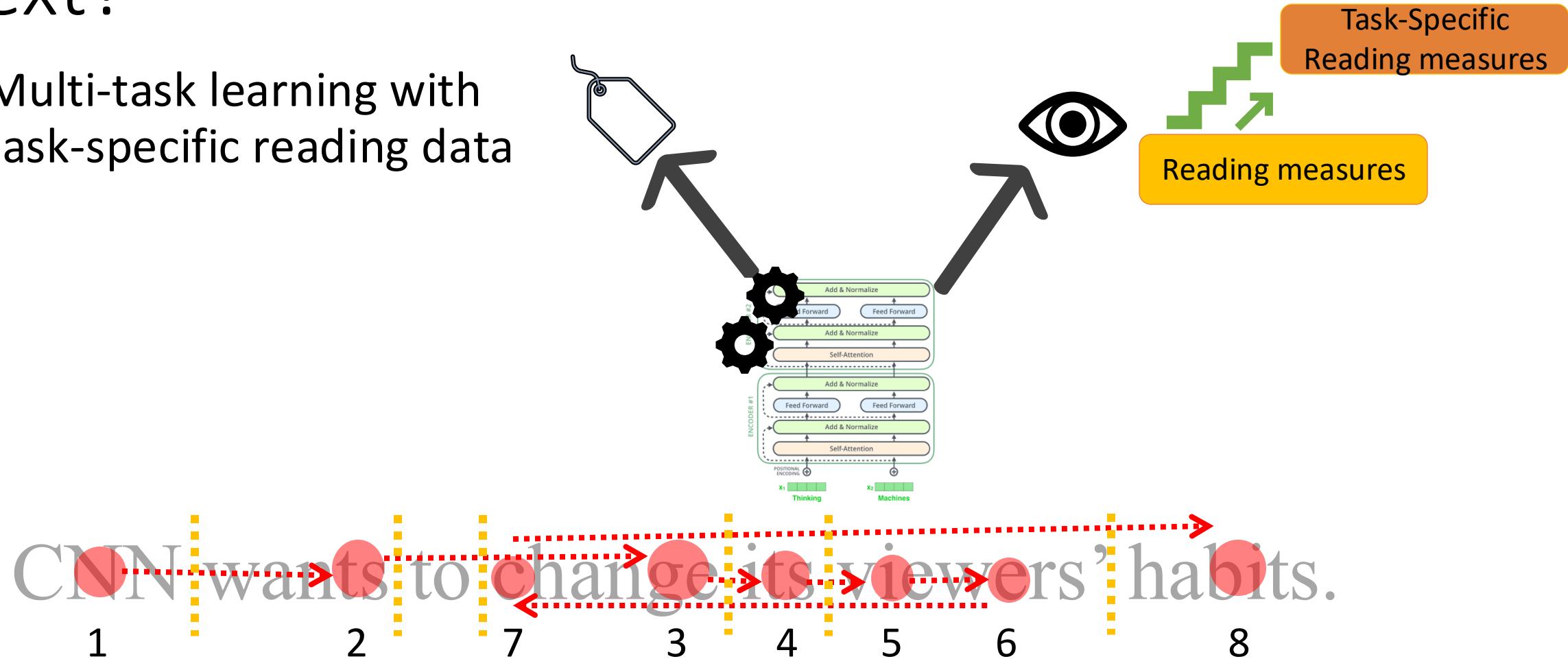
Information seeking (with question preview)

Q: What will result from an increase in human population in the future?

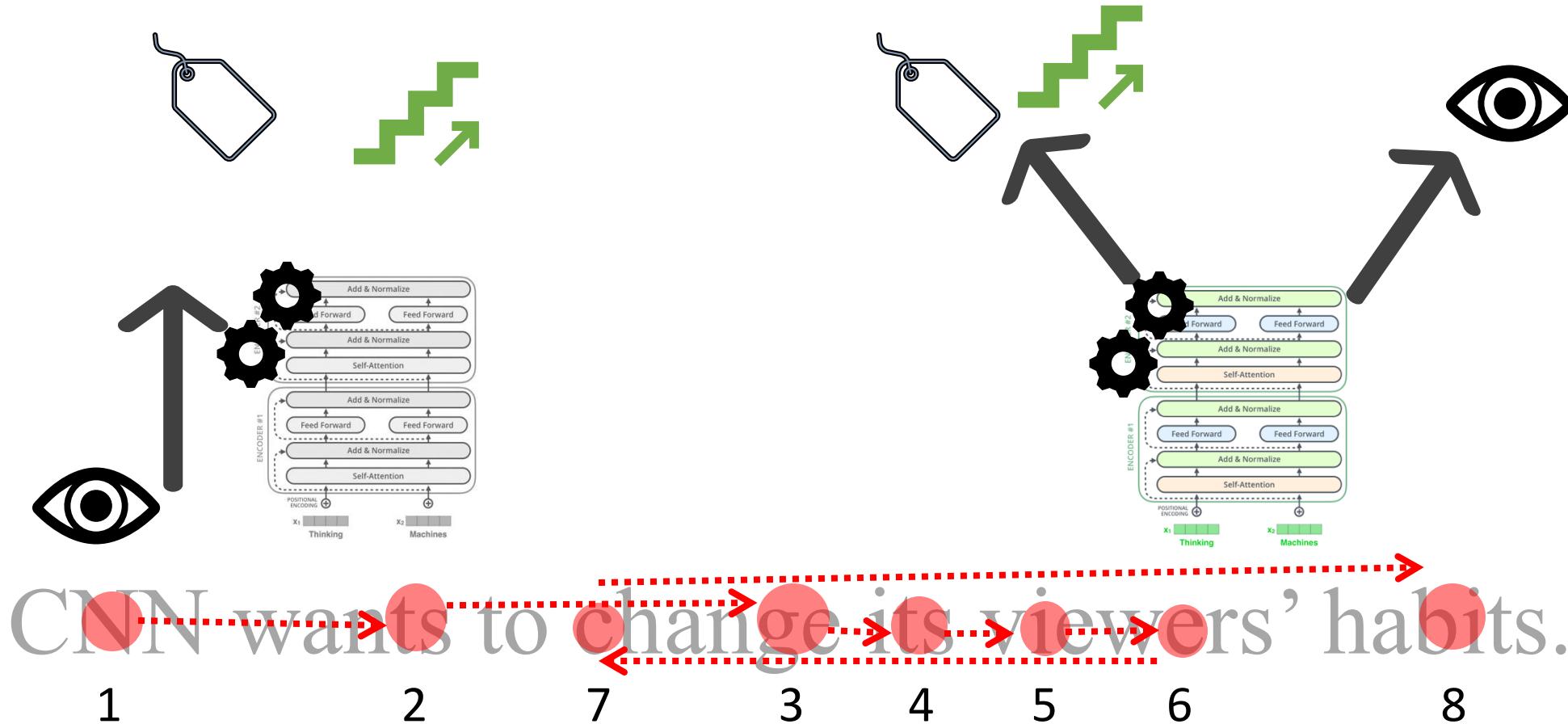
In	the	next	30	years,	the	planet's	human	population	will
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and	energy	supplies.	The	cost	of	meat	is	increasing	-
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of	cows,	pigs	and	sheep	makes	very	large	amounts	of
greenhouse	gases	-	35%	of	the	planet's	methane,	65%	of
its	nitrous	oxide	and	9%	of	the	carbon	dioxide.	

How to combine eye movements and text?

- Multi-task learning with task-specific reading data

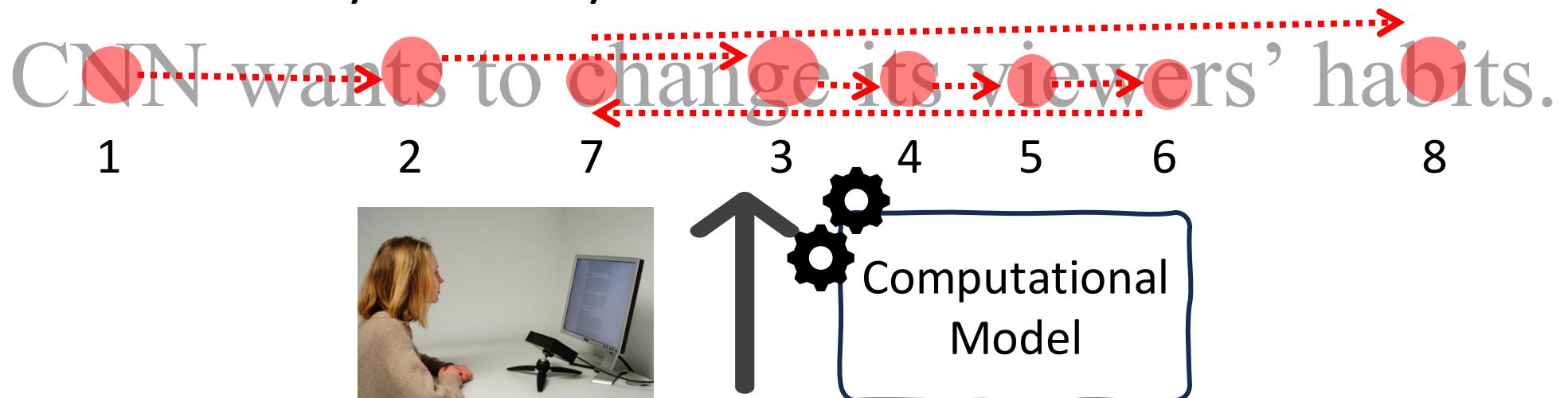


How to combine eye movements and text?



Additional challenges

- Human data is scarce
 - Scale with synthetic eye movements



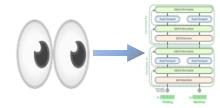
CNN wants to change its viewers' habits.

Additional challenges

- Human data is scarce
 - Scale with synthetic eye movements
- In reality, subwordtokens instead of words
 - Need to decide how to match representations

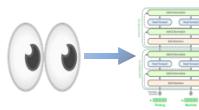
CNN|wants|to|change|its|viewers'|habits.

Discussion

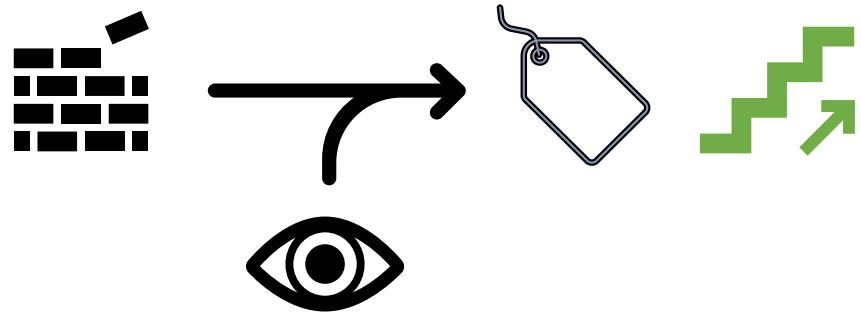


- Performance improvements are typically modest
- Hard to beat scale!
 - Currently no convincing example of large and robust improvements for a state-of-the-art LLM
- Possible directions forward
 - Better modeling
 - More human data
 - Higher quality synthetic eye movements
 - Low resource scenarios
 - Multilingual approaches

Uses of Eye Tracking in NLP

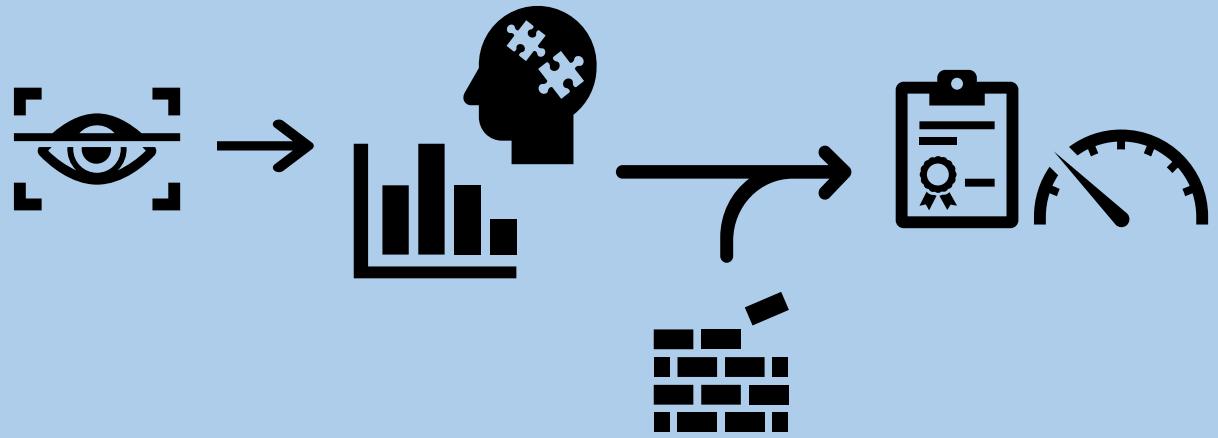


Modeling



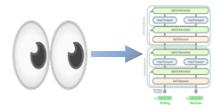
Eye movements can enhance the performance of NLP models

Evaluation



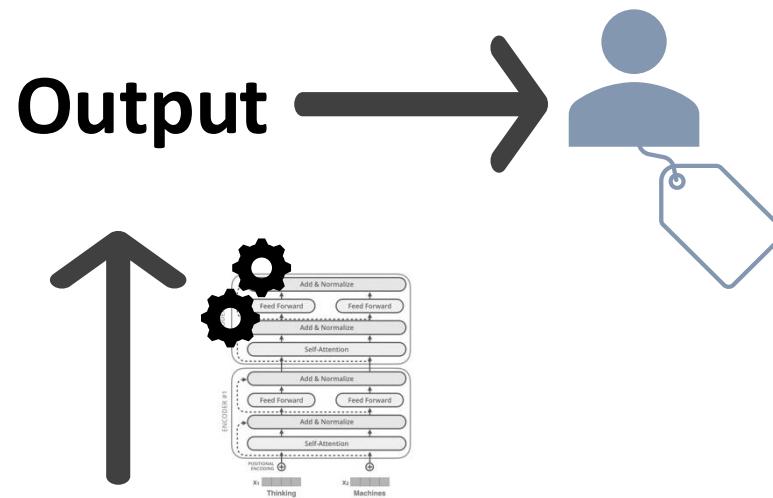
Eye movements for evaluating the performance of NLP models

Evaluating Task Performance

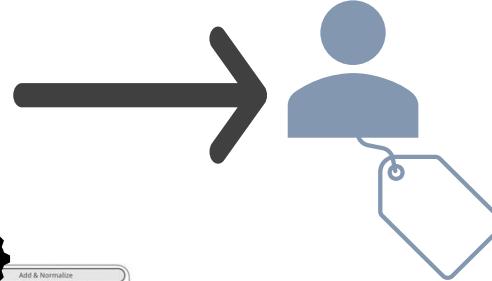


Offline Human Reference

Captures a behavioral
end product of
linguistic processing



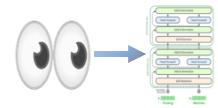
Output



Annotation
Summary
Translation
Preference
...

CNN wants to change its viewers' habits.

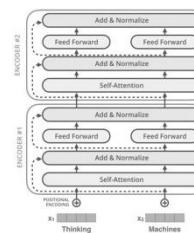
Evaluating Task Performance



Online Human Behavior

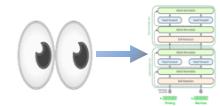
Captures language processing in **real time**

Output

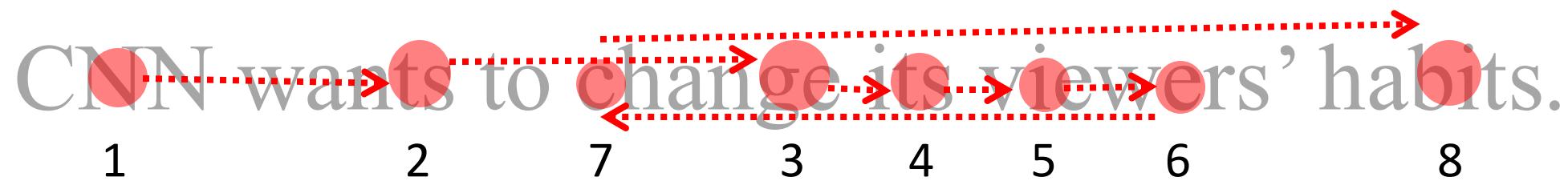


CNN wants to change its viewers' habits.

How do people read?

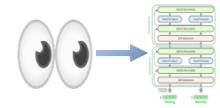


Eye Mind Assumption: “... *there is no appreciable lag between what is fixated and what is processed.*” [Just & Carpenter, 1980](#)



Tight correspondence between eye movements and linguistic processing

Evaluating Task Performance



Online Human Behavior

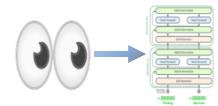
Captures language processing in real time

Machine translation [Doherty et al. \(2010\)](#)
[Sajjad et al. \(2016\)](#)

Summarization [Ikhwantri et al. \(2024\)](#)

Readability [Gruteke Klein et al. \(2025\)](#)

Example Task - ARA

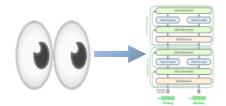


Automatic Readability Assessment (ARA):

Scoring the difficulty level of a text

- Popular task in NLP
- Over 100 years of research
- Hundreds of papers, dozens of measures and systems
- Many real-world applications

Automatic Readability Assessment

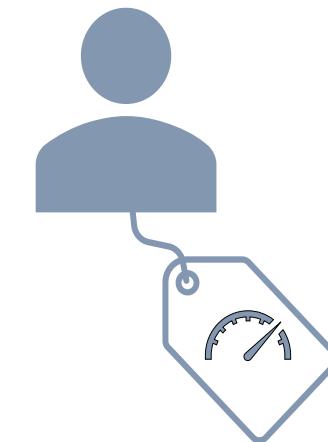


Standard evaluation methods:

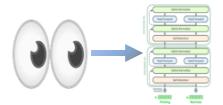
Reading Comprehension
Performance



Human Labeling



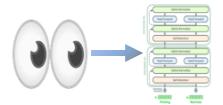
Automatic Readability Assessment



Reader's Comprehension

- Traditional readability measures fitted to reading comprehension data
- Harder to answer reading comprehension questions → the less readable the text.

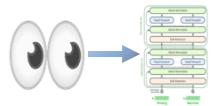
Automatic Readability Assessment



Reader's Comprehension ≠ Text's Readability

- Possible, but not necessary a byproduct of readability
- Depends on the difficulty of the questions
- Hard to estimate reliably

Automatic Readability Assessment



Human labeling → very challenging task

Text 1

A domain name is an identification string that defines a realm of administrative autonomy, authority or control within the Internet. Domain names are formed by the rules and procedures of the Domain Name System (DNS). Any name registered in the DNS is a domain name. Domain names are used in various networking contexts and application-specific naming and addressing purposes. In general, a domain name represents an Internet Protocol (IP) resource, such as a personal computer used to access the Internet, a server computer hosting a web site, or the web site itself or any other service communicated via the Internet. In 2015, 294 million domain names had been registered.

Domain names are organized in subordinate levels (subdomains) of the DNS root domain, which is nameless. The first-level set of domain names are the top-level domains (TLDs), including the generic top-level domains (gTLDs), such as the prominent domains com, info, net, edu, and org, and the country code top-level domains (ccTLDs).

Text 2

An organism is any living thing. It is easy to recognise a living thing, but not so easy to define it. Animals and plants are organisms, obviously. Organisms are a biotic, or living, part of the environment. Rocks and sunshine are parts of the non-living environment.

Organisms usually have five basic needs. They need air, water, nutrients (food), energy and a place to live. However, not all living things need all these at the same time. Many organisms do not need access to air at all.

A little thought is needed about viruses. There is no agreement as to whether they should be regarded as living. They are made of protein and nucleic acid, and they evolve, which is a really important fact. However, they exist in two quite different phases. One phase is dormant, not active. The other is inside a living cell of some other organism. Then the virus is very active reproducing itself.

(1) Read both texts. (2) Answer the questions. (3) Click "Rate Next Set."

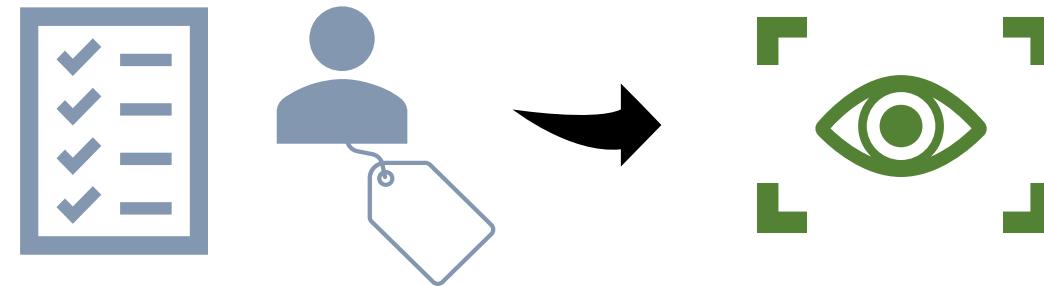
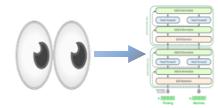
5/10 comparisons completed.

Text 1 mentions subdomains. True False

Text 2 mentions vaccines. True False

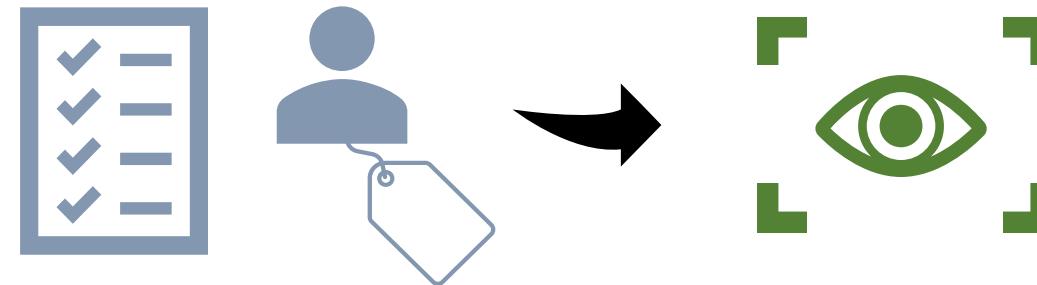
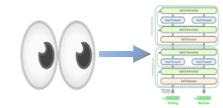
Which text is easier to understand? Text 1 Text 2

Automatic Readability Assessment



From reading **comprehension** performance and human
labeling of text difficulty to
cognitive evaluation of **reading ease** using eye tracking

Automatic Readability Assessment



Reading Speed



Skip Rate



Average Total Fixation Duration



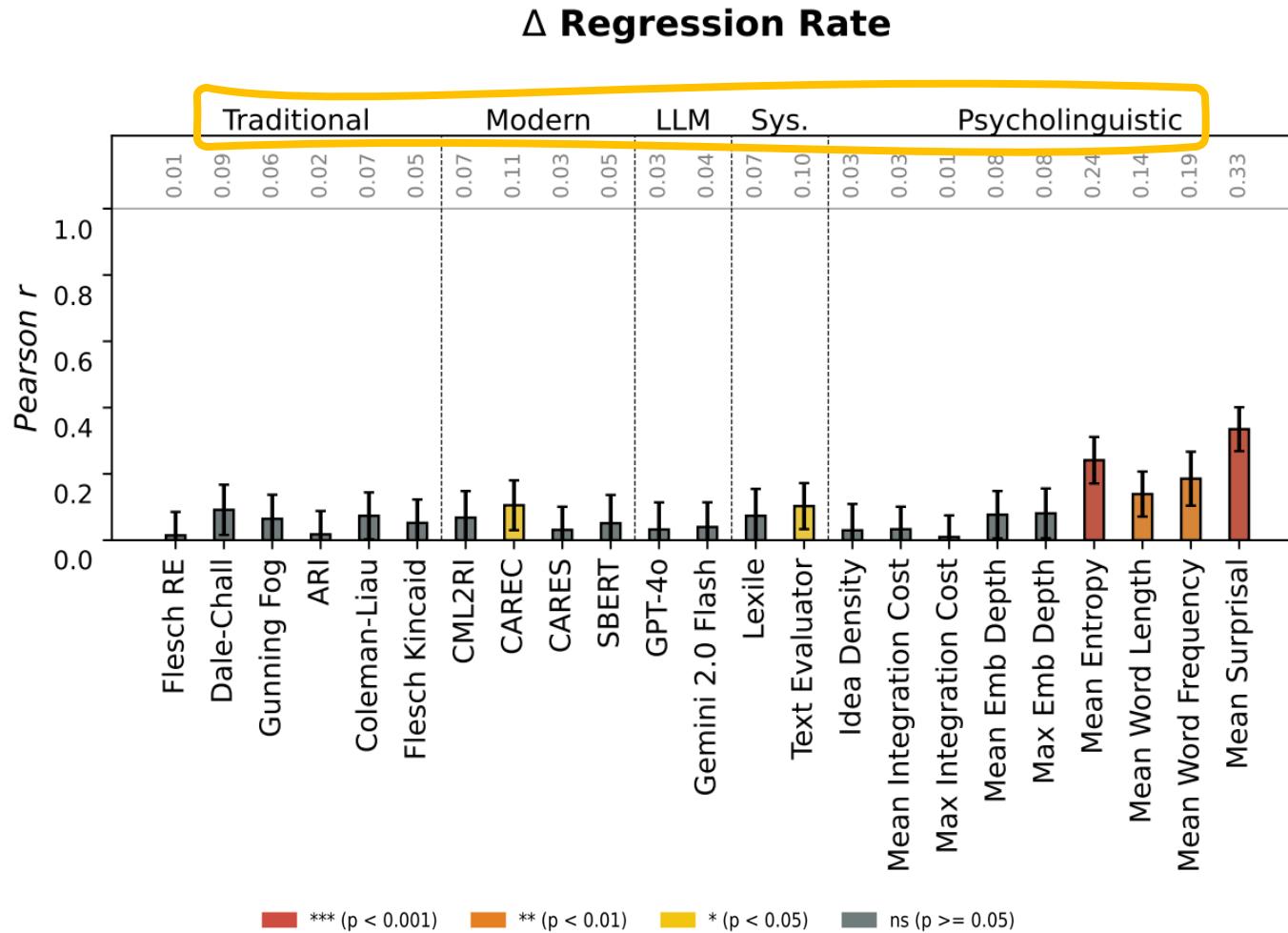
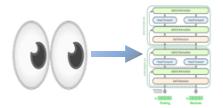
Regression Rate

Evaluation of readability measure M is the Pearson r of:

$$RT \sim Score_M$$

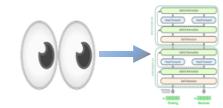
[Gruteke Klein et al. \(2025\)](#)

Automatic Readability Assessment



Low correlation between existing measures and reading ease

Evaluating Task Performance



Online Human Behavior

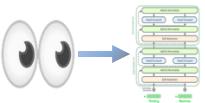
Captures language processing in real time

Machine translation [Doherty et al. \(2010\)](#)
[Sajjad et al. \(2016\)](#)

Summarization [Ikhwantri et al. \(2024\)](#)

Readability [Gruteke Klein et al. \(2025\)](#)

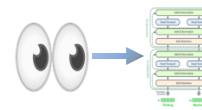
Discussion: Eye Movements for Evaluating NLP Models



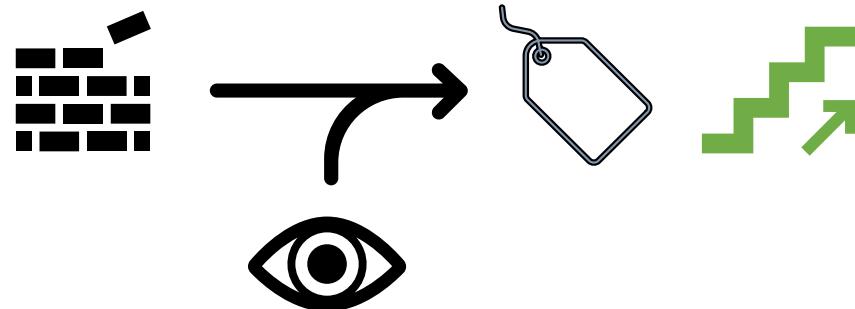
Current uses are limited

- Better use of existing eye tracking data
- Collect more eye tracking data for specific NLP tasks
- Large scale evaluations with synthetic eye movements

Uses of Eye Tracking in NLP

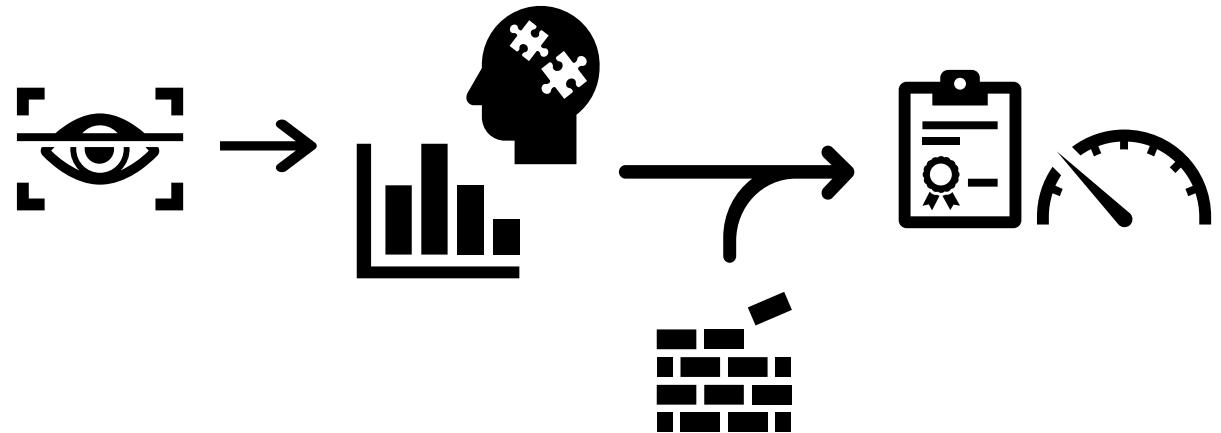


Modeling



Eye movements can enhance the performance of NLP models

Evaluation

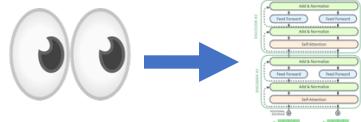


Eye movements for evaluating the performance of NLP models

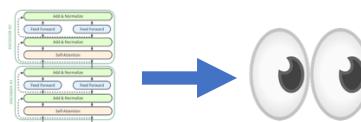
Tutorial Outline



1. Introduction to eye tracking



2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling

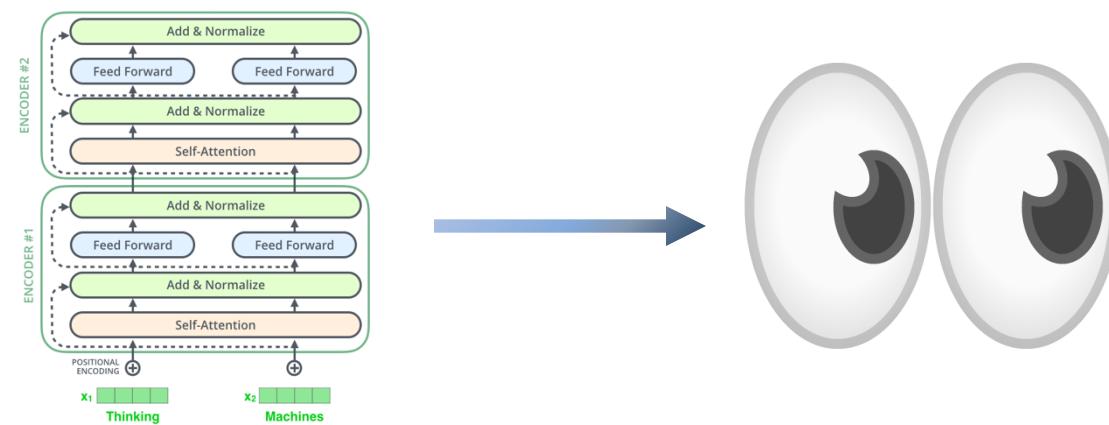


4. New human centered applications

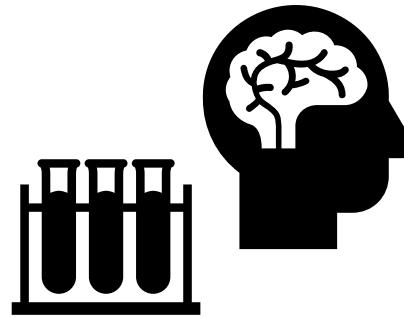
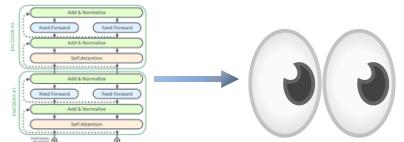


5. Outlook and future directions

Uses of NLP in Modeling Human Language Processing and Eye Movements



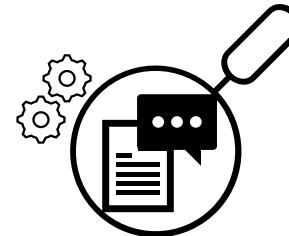
Uses of NLP in Modeling Eye Movements and Human Language Processing



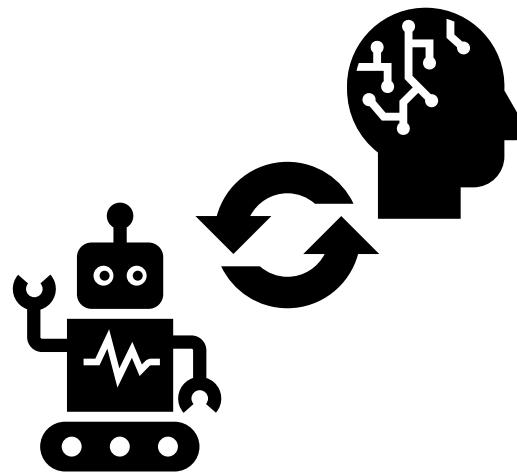
Testing Psycholinguistic Theories



Representations

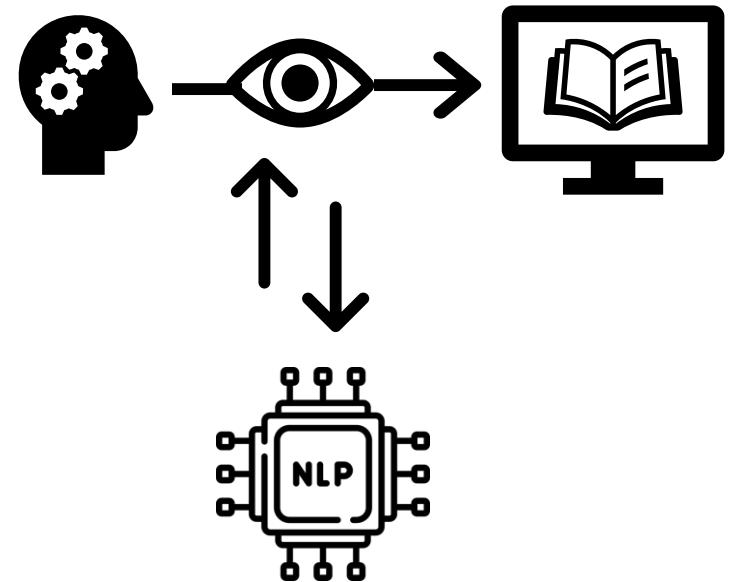


Linguistic quantities

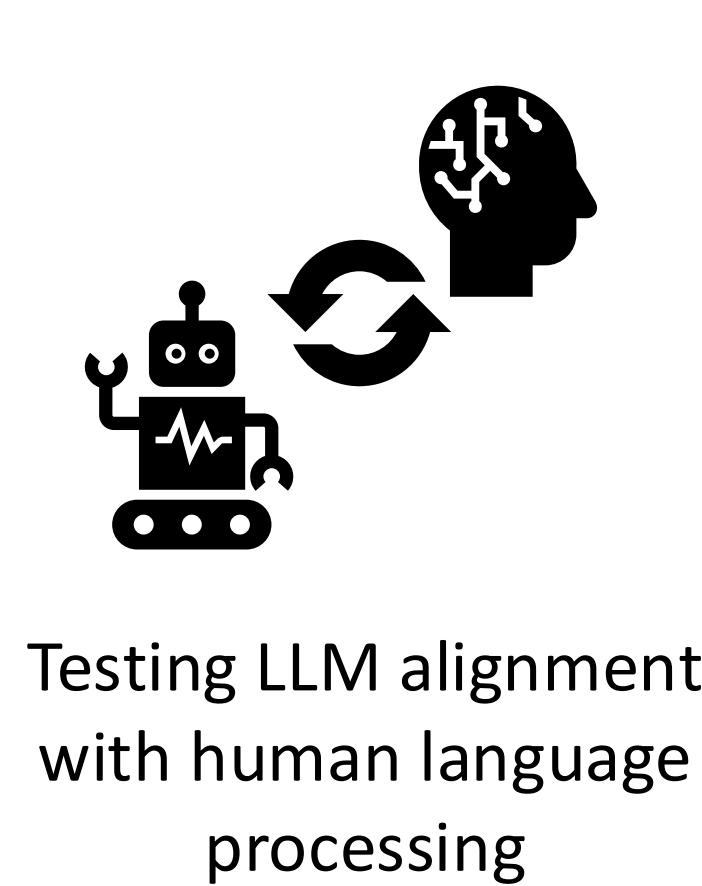
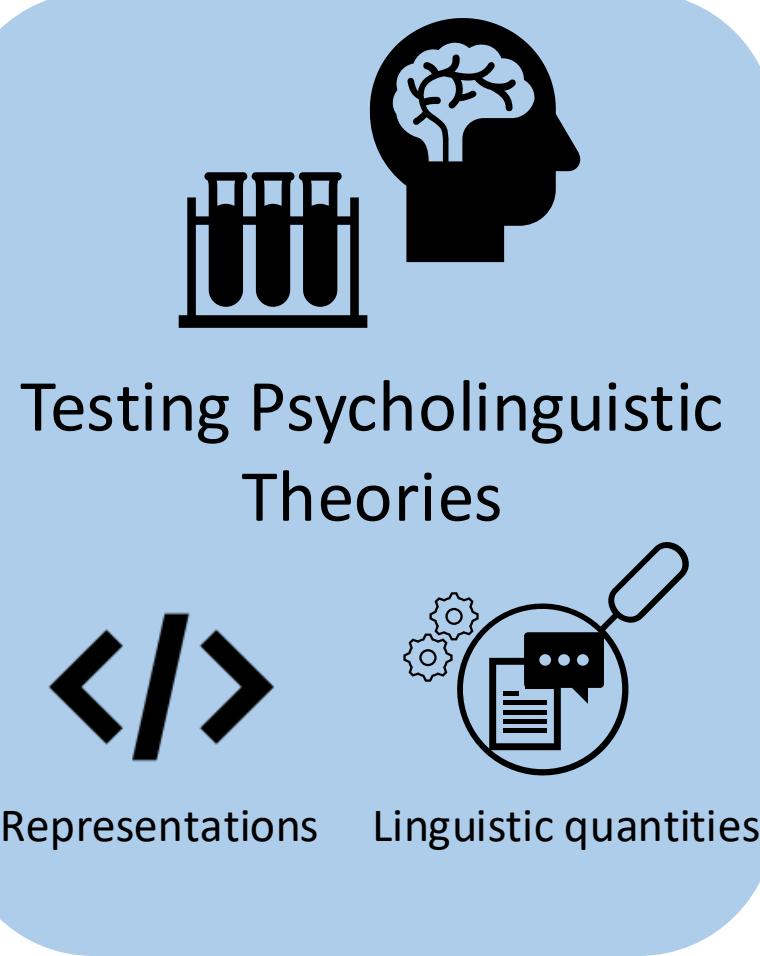
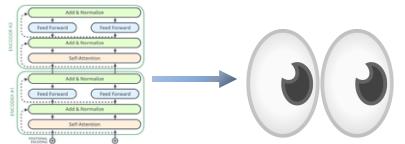


Testing LLM alignment with human language processing

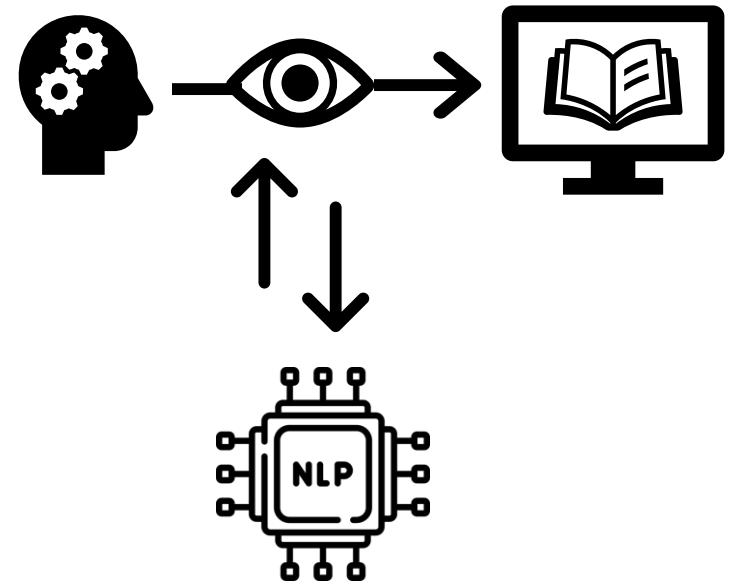
NLP for modeling eye movements in reading



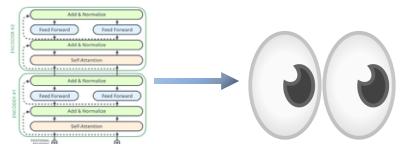
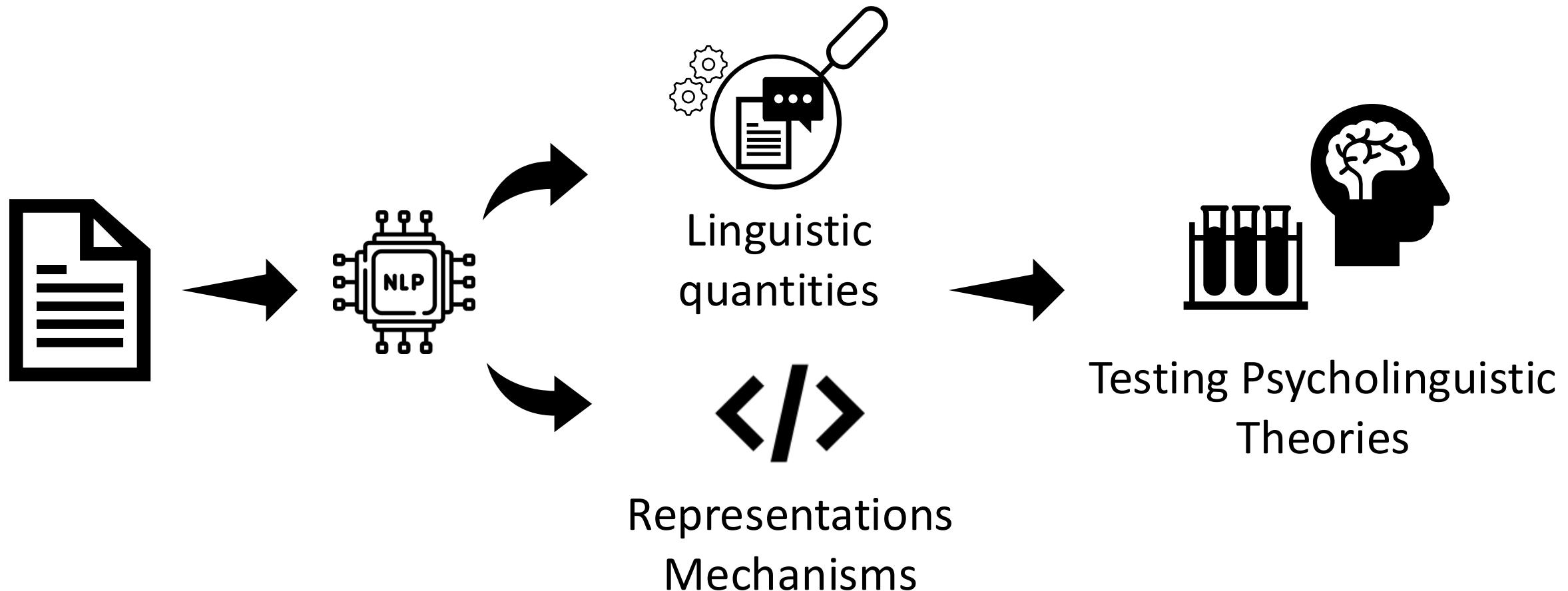
Uses of NLP in Modeling Eye Movements and Human Language Processing



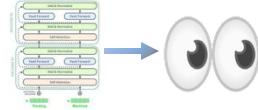
NLP for modeling eye movements in reading



NLP for Extracting Linguistic Quantities and Representations

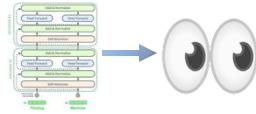


NLP for Extracting Linguistic Quantities and Representations



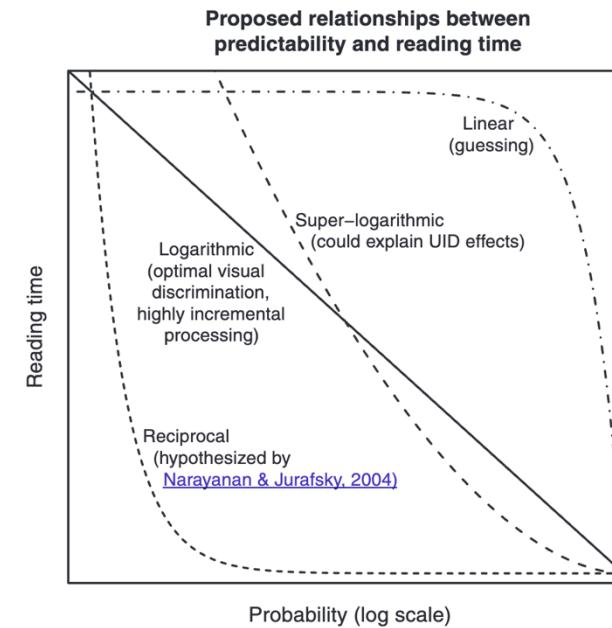
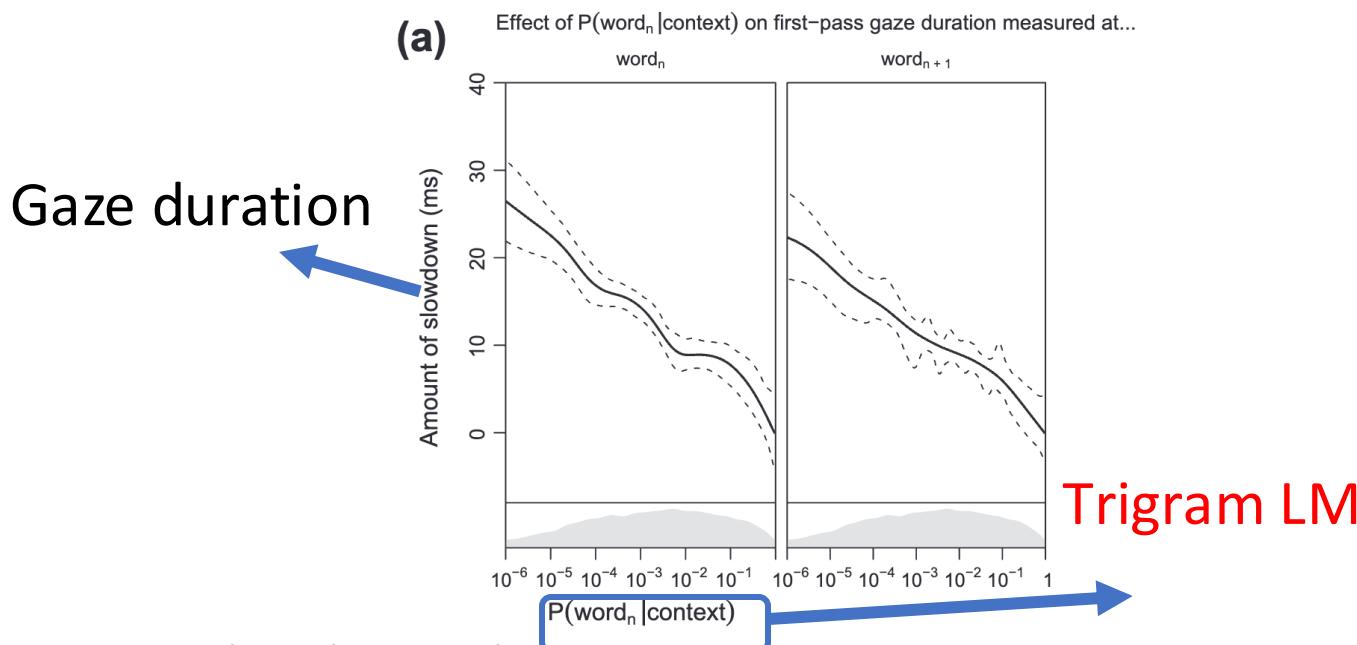
- NLP for broad coverage stimulus annotations
 - Surprisal, entropy
 - Syntactic structure
 - Semantic relations
 - Word embeddings
- Annotations (or derived quantities) are central for testing psycholinguistic theories of language processing
 - Surprisal theory [Hale \(2001\)](#), [Levy \(2008\)](#)
 - Dependency locality theory (DLT) [Gibson \(1998\)](#), [Gibson \(2000\)](#)
 - Uniform information density (UID) [Levy & Jaeger \(2007\)](#)
 - Cue-based retrieval (ACT-R) [Lewis & Vasishth \(2005\)](#), [Engelmann et al. \(2019\)](#)

NLP for Extracting Linguistic Quantities and Representations

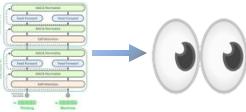


Smith and Levy (2013) testing predictions of Surprisal Theory

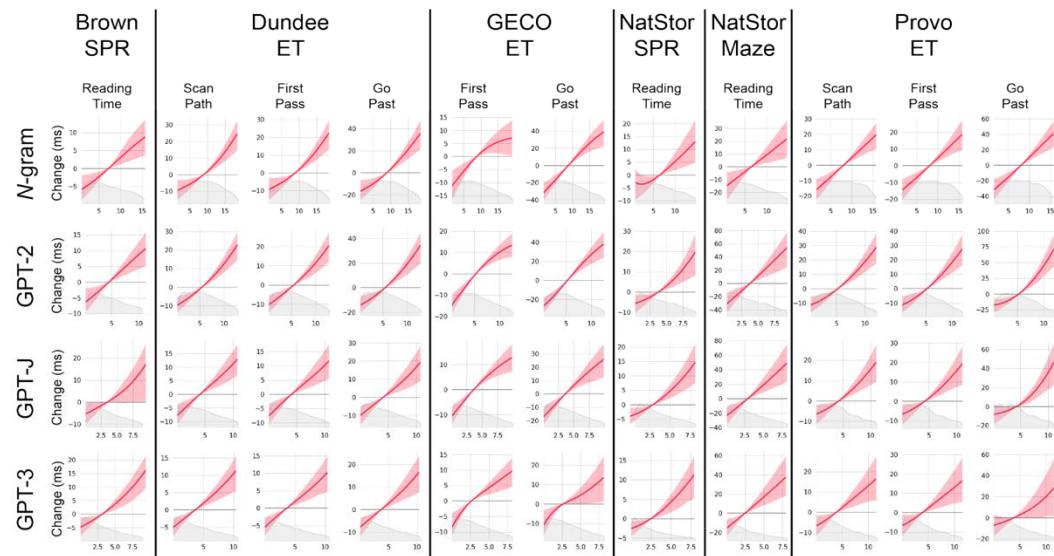
- Reading times (Dundee) as proxy for processing difficulty
- LM based surprisal as proxy for word predictability



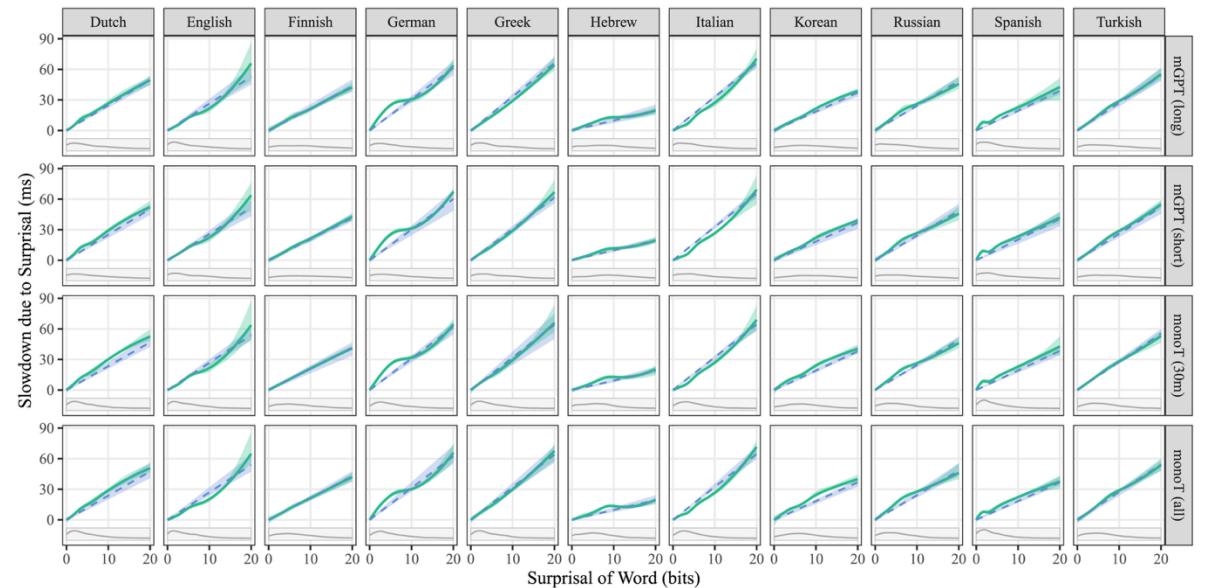
NLP for Extracting Linguistic Quantities and Representations



Linearity holds for different LLMs [Shain et al. \(2023\)](#) and across languages [Wilcox et al \(2023\)](#)

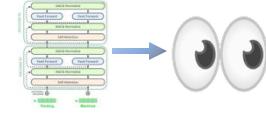


[Shain et al. \(2023\)](#)



MECO data, [Wilcox et al \(2023\)](#)

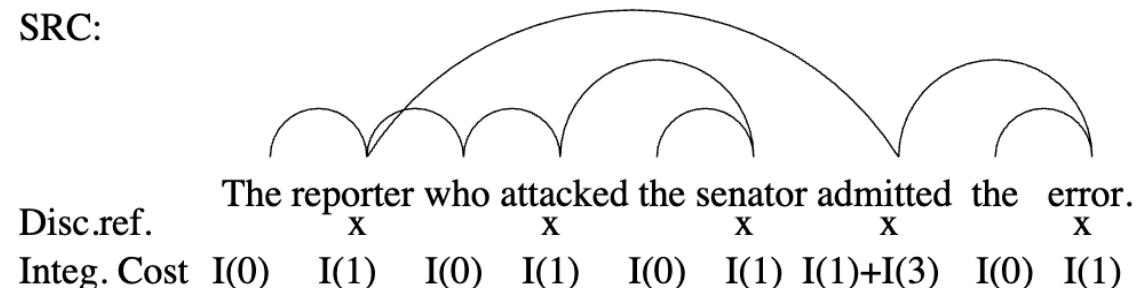
NLP for Extracting Linguistic Quantities and Representations



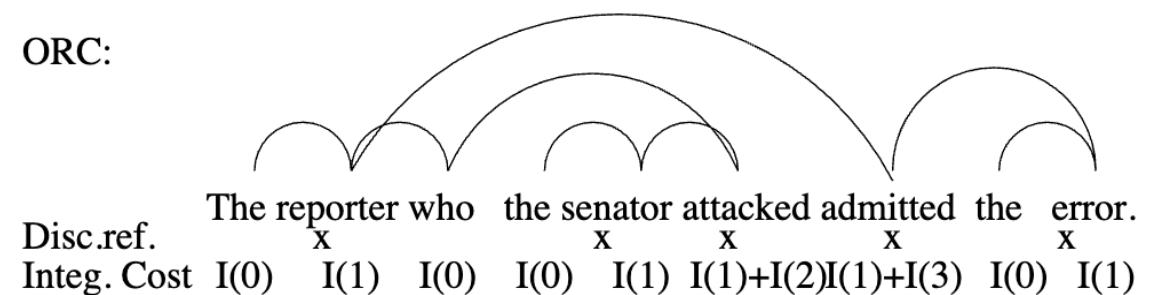
Testing predictions of DLT and Surprisal Theory [Demberg and Keller \(2008\)](#)

- Reading times (Dundee) as proxy for processing difficulty
- **LM based surprisal** as proxy for word predictability
- **Dependency parsing** for obtaining sentence structure

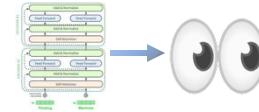
SRC:



ORC:

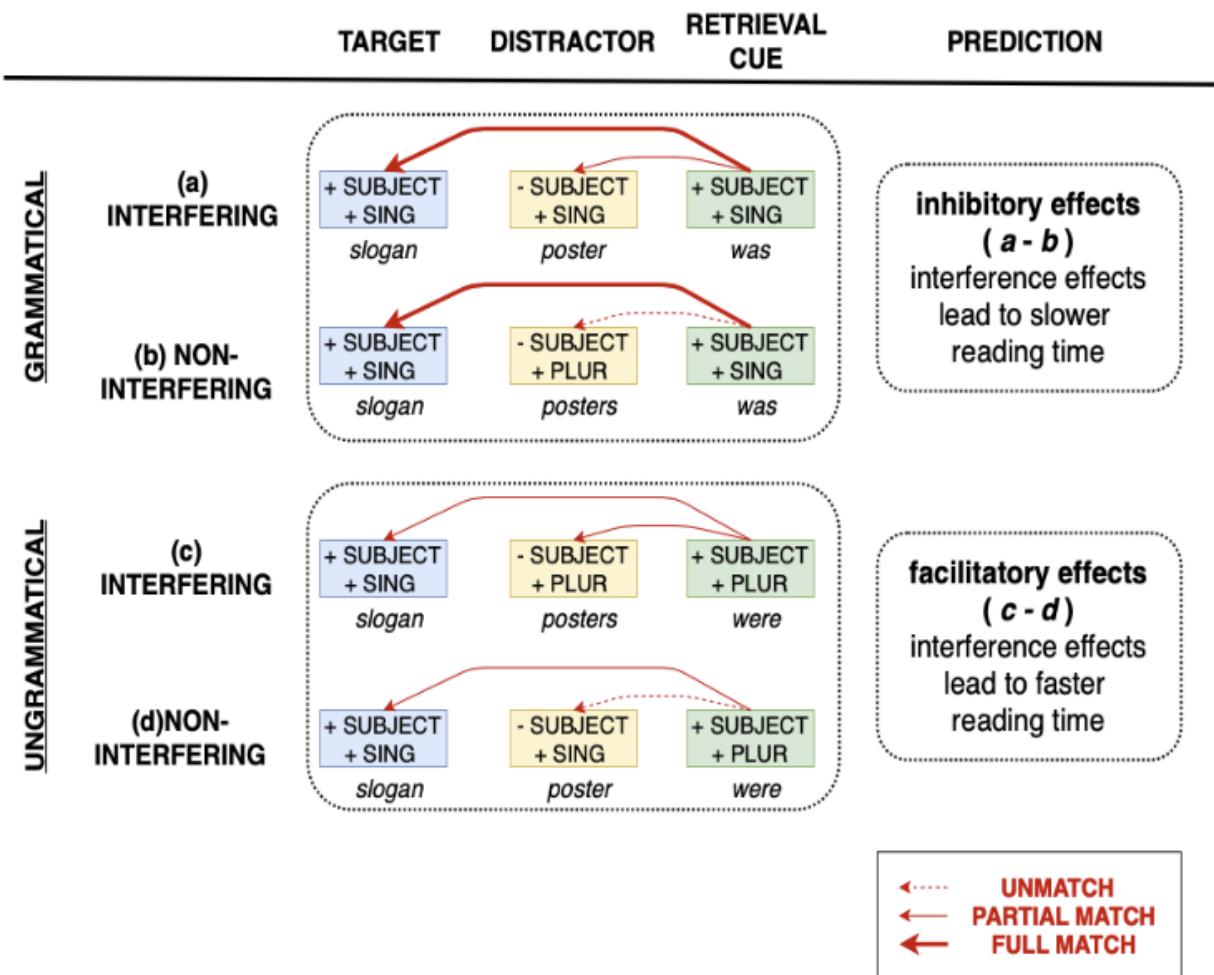


NLP for Extracting Linguistic Quantities and Representations



Controlled experiments with GPT2 surprisal for testing surprisal and interference based explanations to agreement phenomena

[Ryu and Lewis \(2021\)](#)

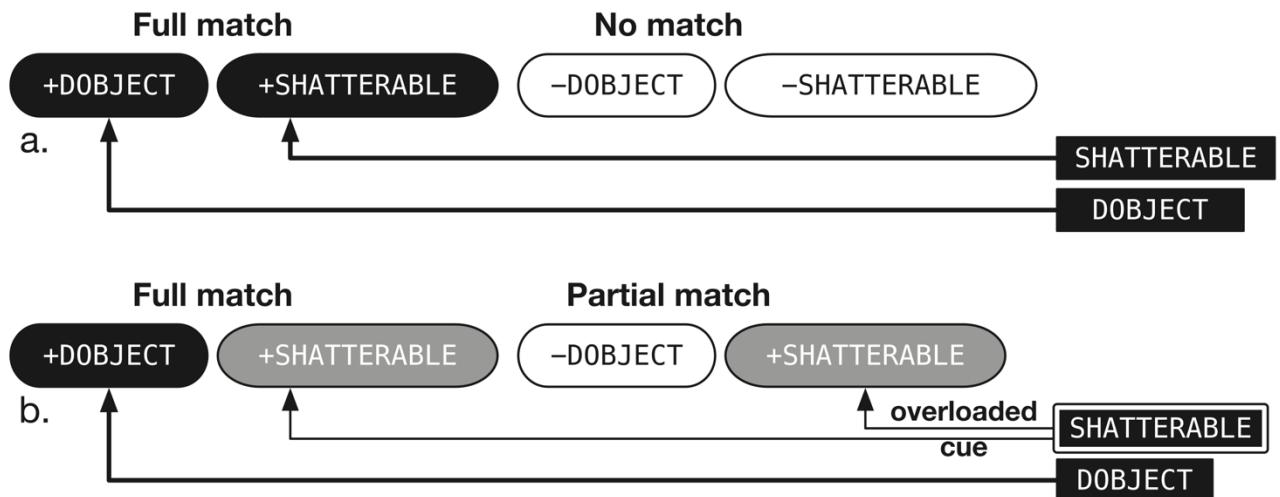


NLP for Extracting Linguistic Quantities and Representations

- a) ... the **plate** that the butler with the **tie** accidentally **shattered** ...
- b) ... the **plate** that the butler with the **cup** accidentally **shattered** ...

Cue-based Retrieval (ACT-R) assumes a content-addressable memory.

Dependency formation: Retrieval cues serve to access relevant chunks (e.g., words) from memory.

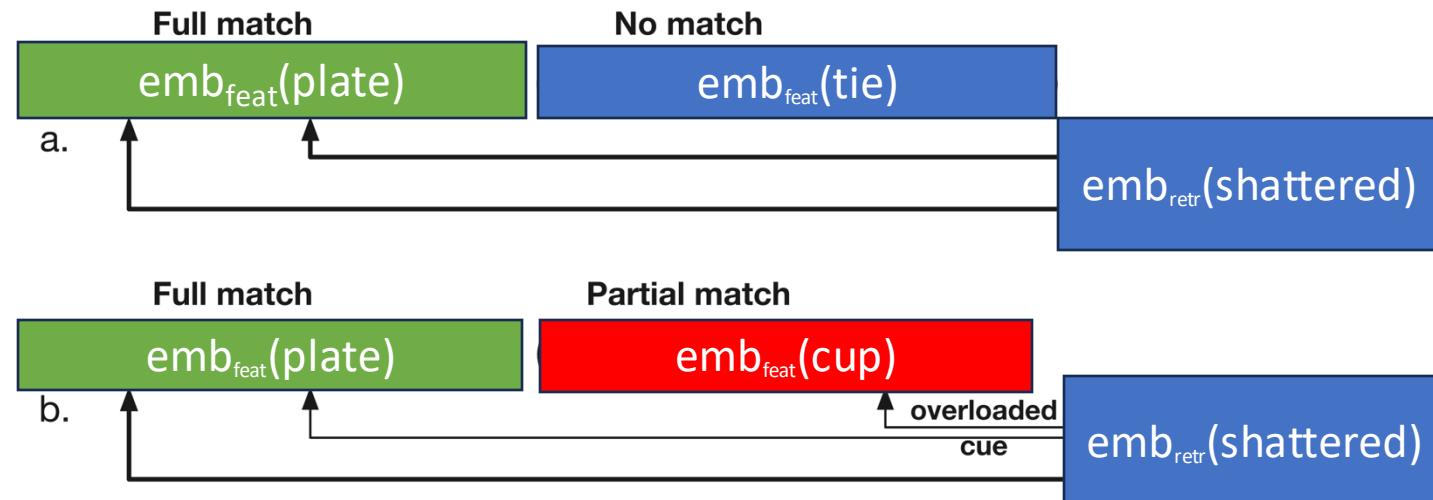


NLP for Extracting Linguistic Quantities and Representations

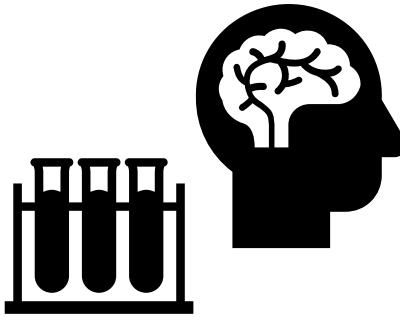
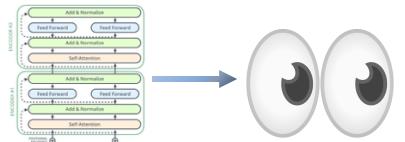
- a) ... the **plate** that the butler with the **tie** accidentally **shattered** ...
- b) ... the **plate** that the butler with the **cup** accidentally **shattered** ...

Replacing hand-crafted feature vectors with **word embeddings** as **cognitive representations** for **lexical items** in memory.

Smith and Vasishth (2020)



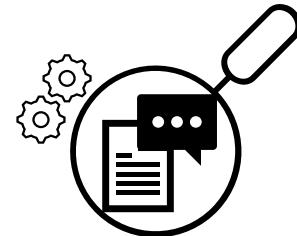
Uses of NLP in Modeling Eye Movements and Human Language Processing



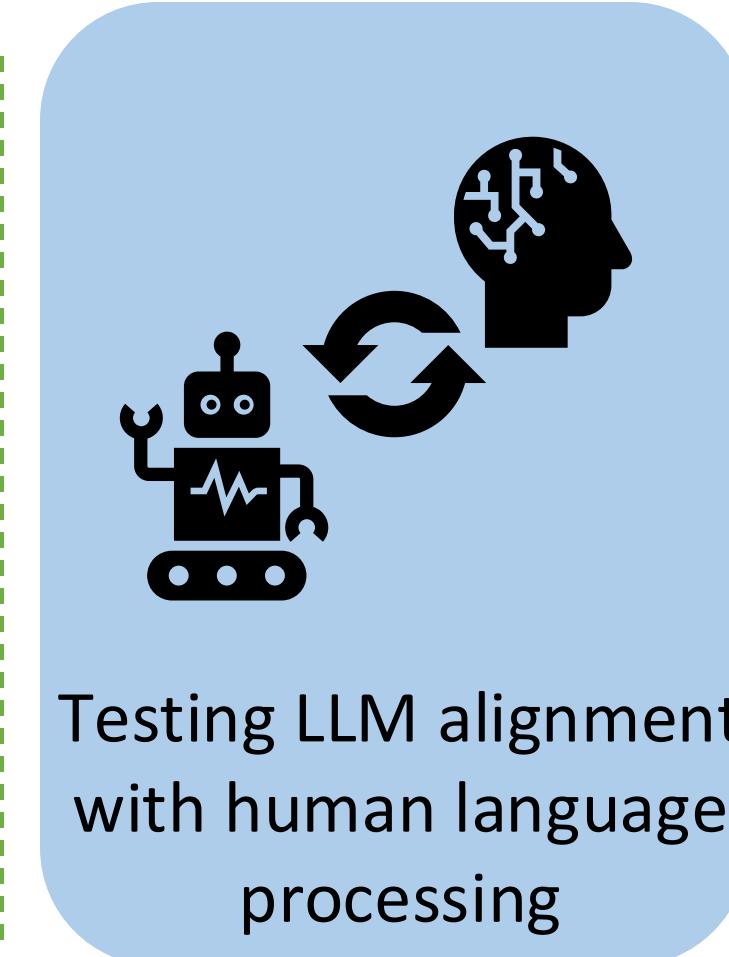
Testing Psycholinguistic Theories



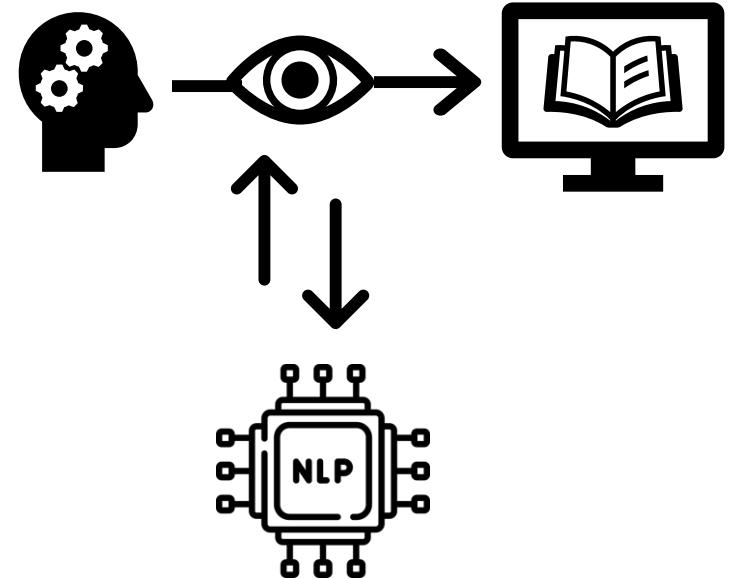
Representations



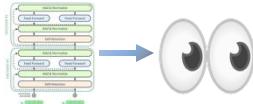
Linguistic quantities



NLP for modeling eye movements in reading



LLM Alignment with Human Reading



- Are LLMs good models of human linguistic processing?
If not, how can we make them relevant?
- Big and open area where eye tracking data could play a larger role
- Current directions:
 - Testing alignment of LLMs with reading data
 - Improving alignment with more cognitively plausible architectures

LLM Alignment with Human Reading

Predictive power of LLM-extracted **surprisal** (or other metrics) for human reading times (RTs)

Step 1:

Fit two regression models predicting reading times, **with** and **without surprisal as predictor**

Step 2:

Compute Log-Likelihood (LL) of each model

Step 3:

Predictive Power (PP) of surprisal is the ΔLL of the two models

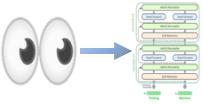
$$\mathcal{M}_{baseline}: RT \sim baseline_variables \longrightarrow LL(\mathcal{M}_{baseline})$$

$$PP(\text{surprisal})$$

$$\begin{aligned} \mathcal{M}_{surprisal}: RT \sim baseline_variables &\longrightarrow LL(\mathcal{M}_{surprisal}) \\ &\oplus \text{surprisal} \end{aligned}$$

$$:= \Delta LL(\mathcal{M}_{surprisal}, \mathcal{M}_{baseline})$$

$$:= LL(\mathcal{M}_{surprisal}) - LL(\mathcal{M}_{baseline})$$



LLM Alignment with Human Reading

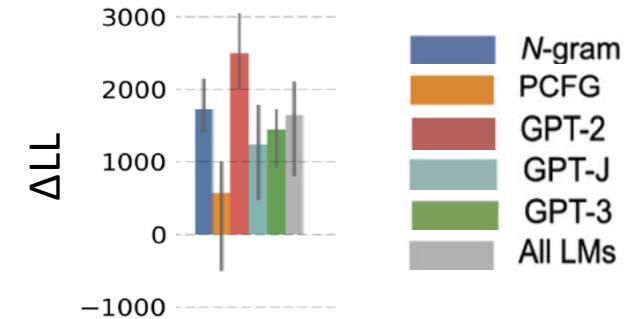
Older Models

Better LM --> surprisal predicts RTs better

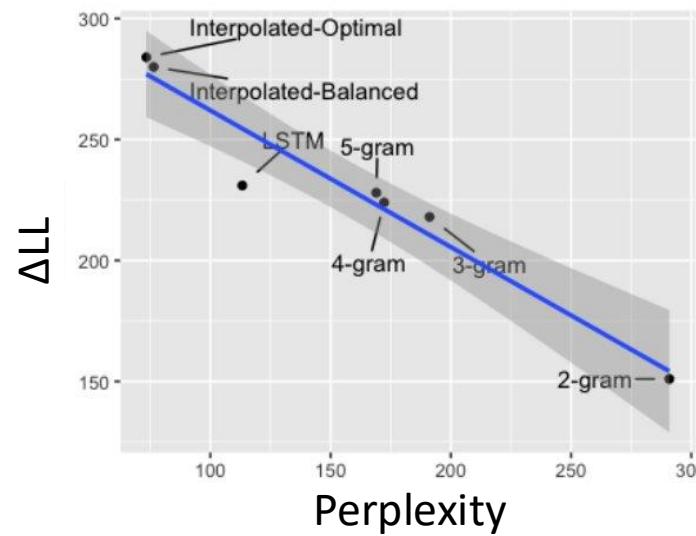
LLMs

Better LM --> surprisal predicts RTs worse

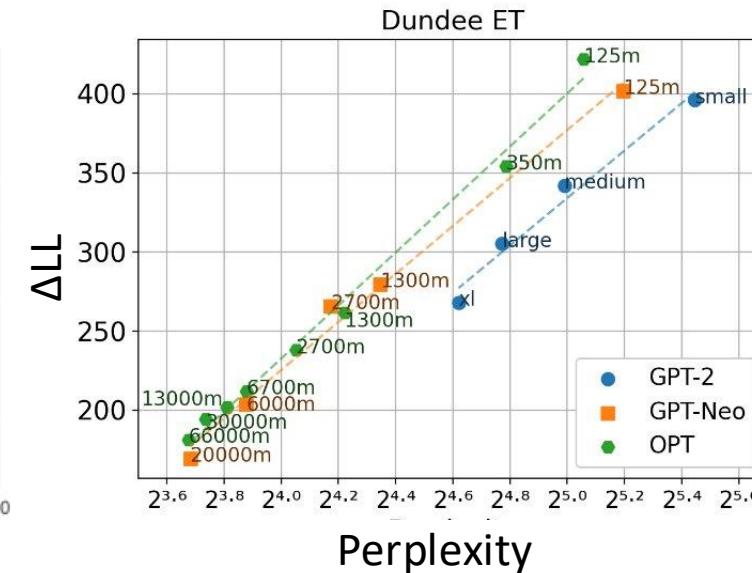
[Shain et al. \(2023\)](#)



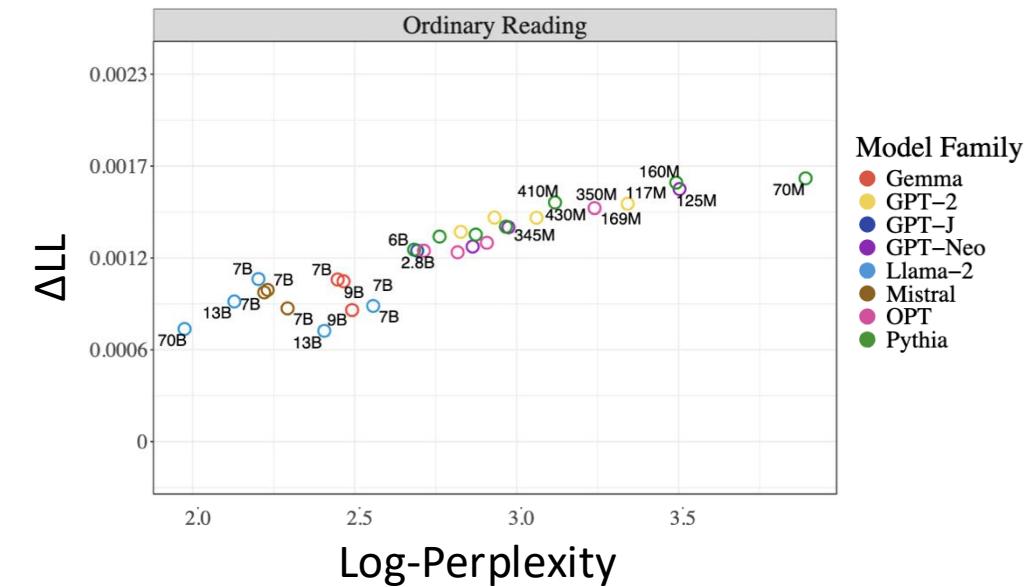
[Goodkind and Bicknell \(2018\)](#)

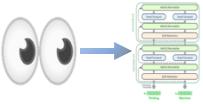


[Oh and Schuler \(2023\)](#)



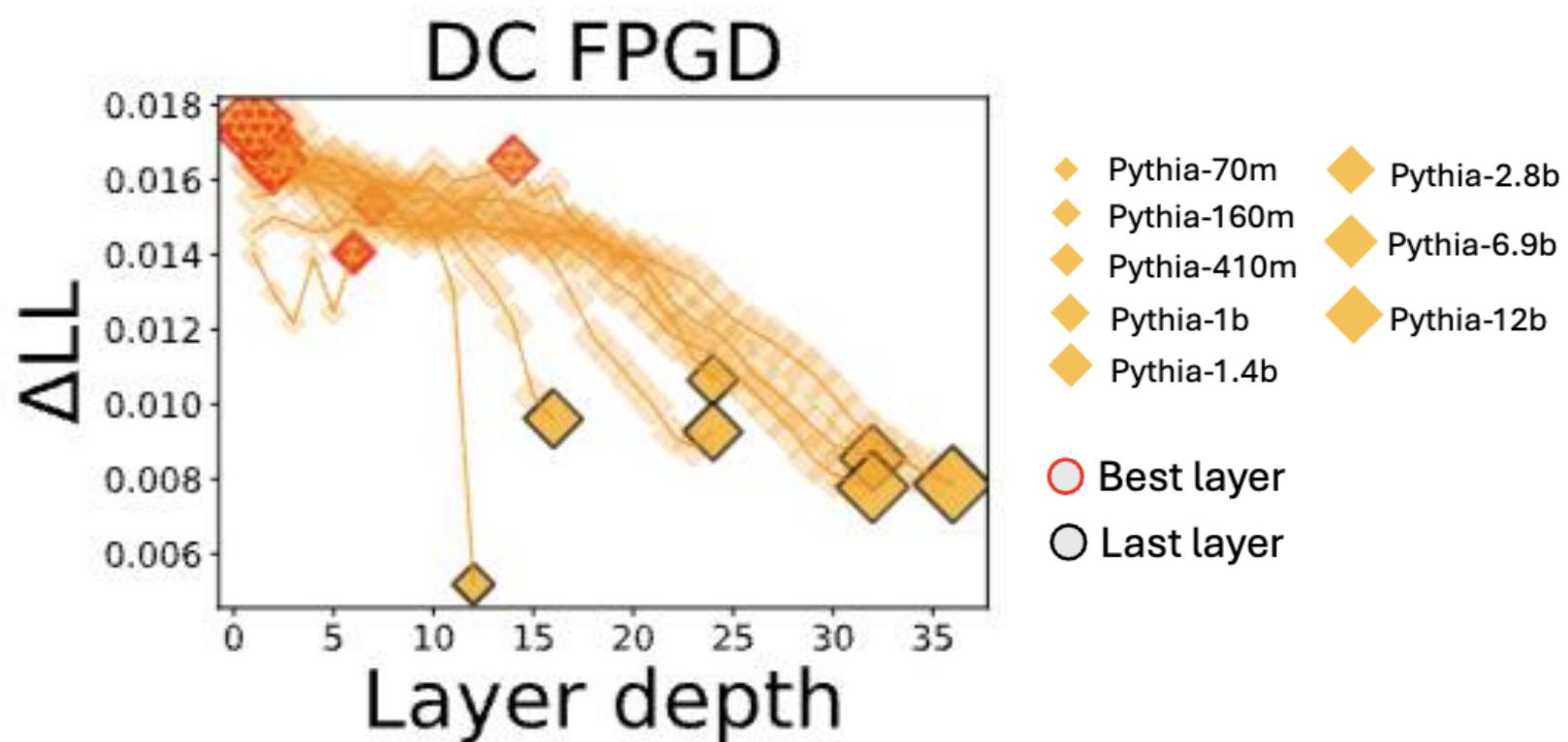
[Gruteke Klein et al. \(2024\)](#)



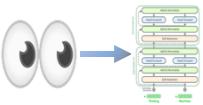


LLM Alignment with Human Reading

[Kurabayashi et al. \(2025\)](#) opposite conclusion for intermediate layers



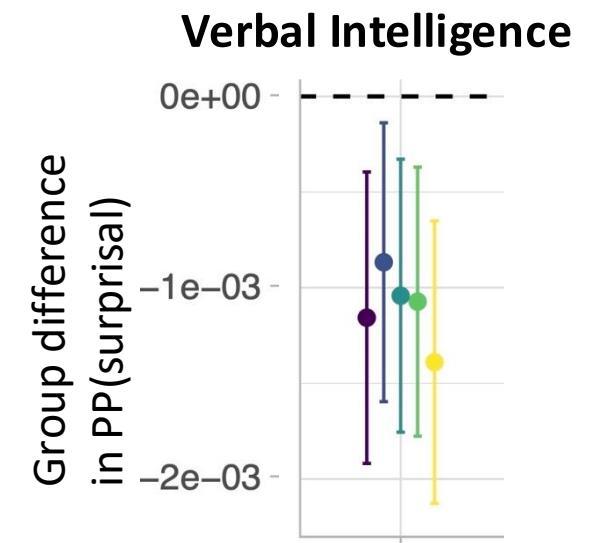
LLM Alignment with Human Reading



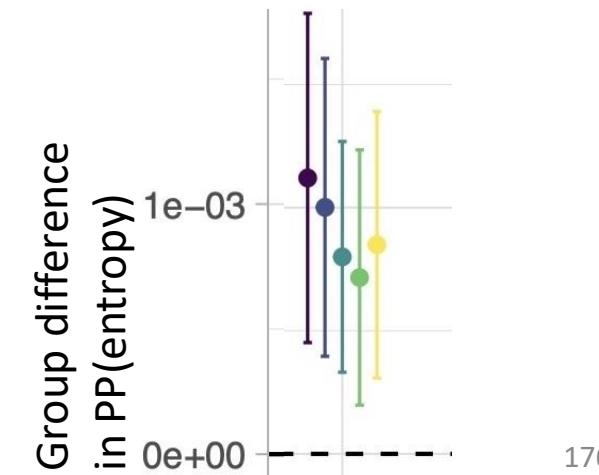
[Haller et al. \(2024\)](#) compare the PP on first-pass reading time of LM surprisal and LM entropy for **different cognitive groups of readers**.

- PP of surprisal is higher for readers with **lower verbal intelligence**.
- PP of entropy is higher for readers with **higher working memory capacity**.

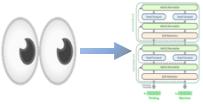
Model • GPT-2 base • GPT-2 large • Llama 7B • Llama 13B • Mixtral



Working Memory Capacity



LLM Alignment with Human Reading

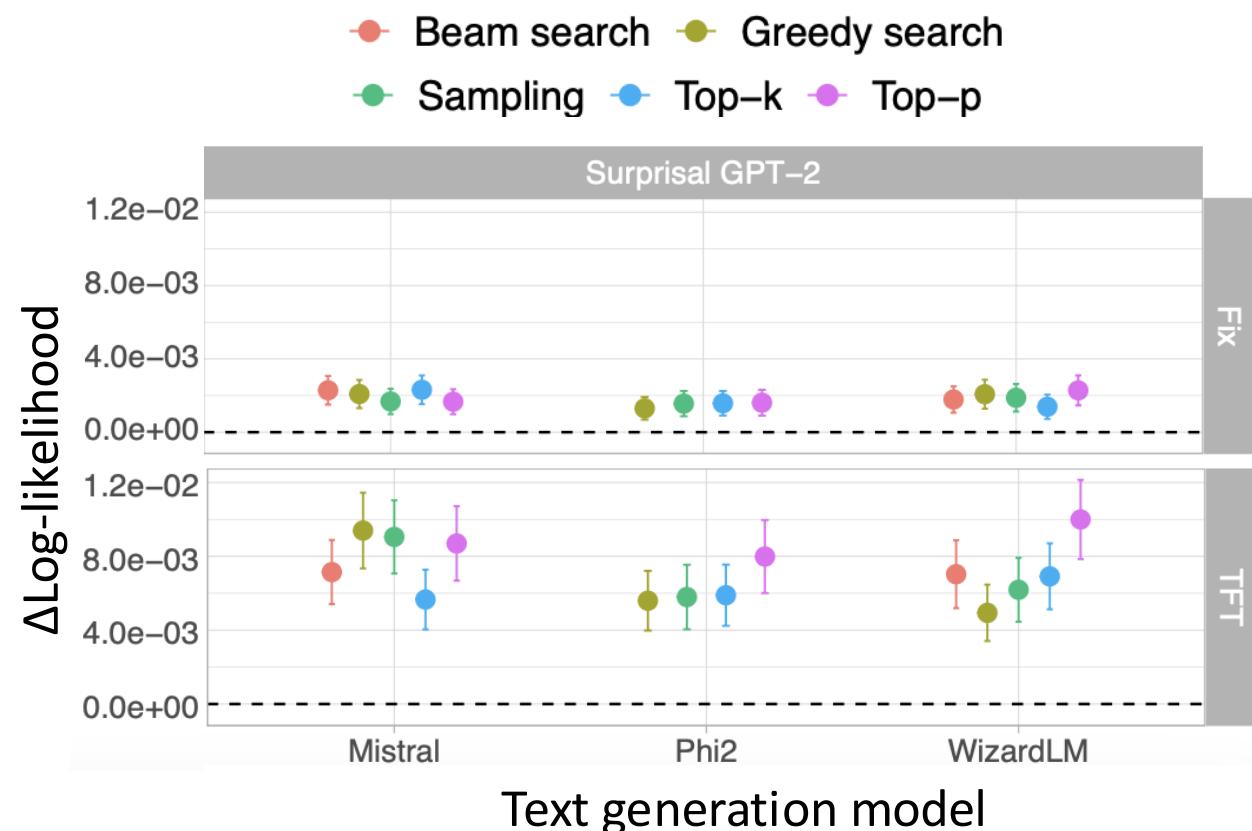


[Bolliger et al. \(2024\)](#) Predictive power for reading times varies between texts generated by different

- models
- decoding strategies

And across different

- **reading measures**

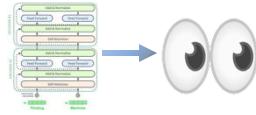


LLM Alignment with Human Reading

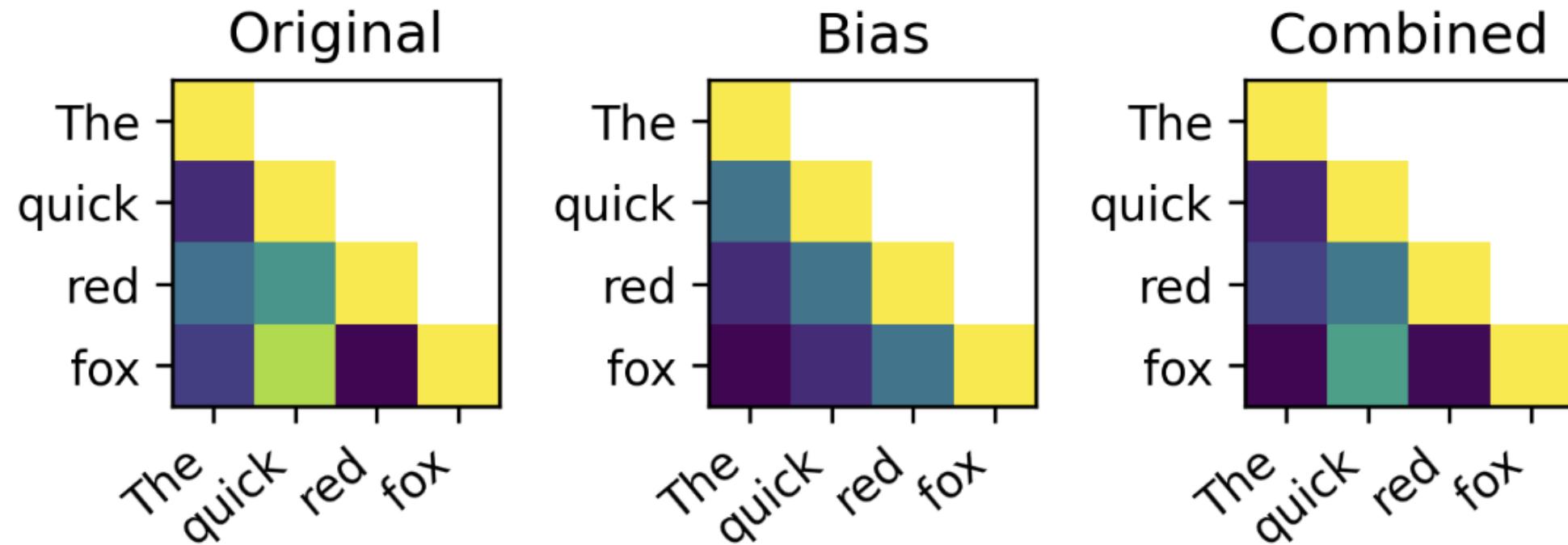


- Rich literature that focuses on
 - Models trained on human scale data
 - Controlled evaluations of targeted linguistic phenomena
- LLMs as a lower bound of what can be learned from the input without postulating innate linguistic knowledge ("poverty of the stimulus")
- Current online evals are primarily on SPR and Maze. E.g. [van Schijndel & Linzen \(2018\)](#), [Wilcox et al. \(2021\)](#)
- Open area for future work with eye tracking data!

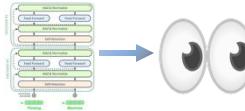
Improving Alignment: Adding Cognitive Constraints



- Recency bias for transformer attention [de Varda and Marelli \(2024\)](#), [Clark et al \(2025\)](#)

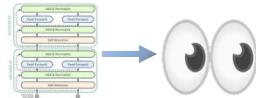


Discussion: Alignment



- Most studies focus on a single reading measure (e.g., Gaze Duration, Total Fixation Duration)
- No clear advantage of eye tracking over other methods
- Similar evaluations are done with cheaper methods that can be (and are) deployed on the web at scale (SPR, Maze)
- Possible directions forward
 - More fine-grained analyses of reading measures to reveal dynamics over time, scanpath prediction
 - Populations with different linguistic knowledge (e.g. L1 vs L2)

Addendum: Parsers as Cognitive Models

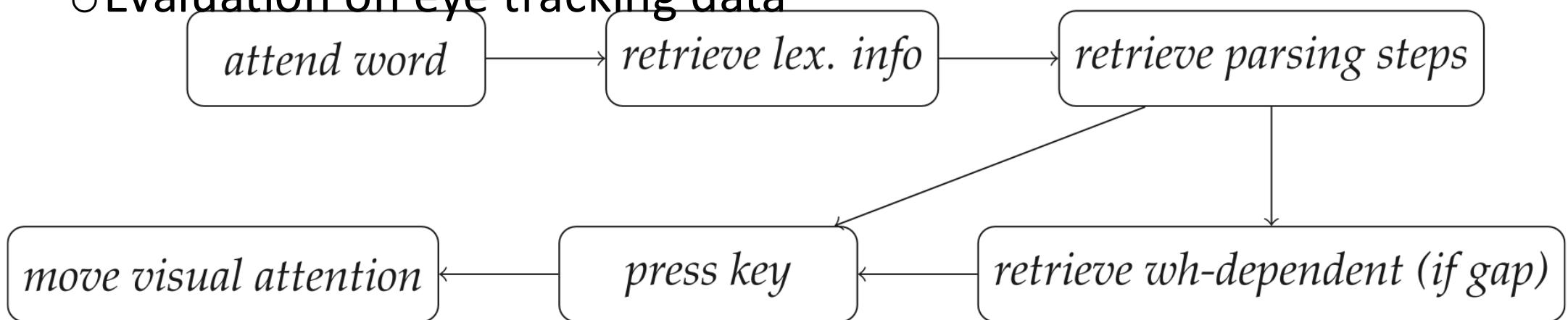


- Long Tradition in computational linguistics (e.g., [Jurafsky, 1996](#))

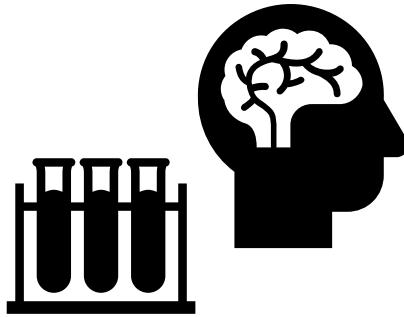
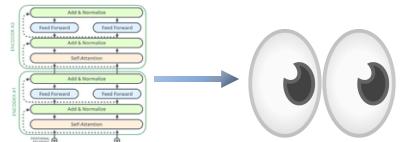
Example: [Dotlačil \(2021\)](#)

Transition based parser combined with cue-based retrieval (ACT-R)

- Evaluation on eye tracking data



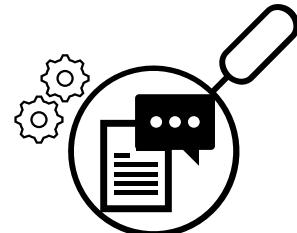
Uses of NLP in Modeling Eye Movements and Human Language Processing



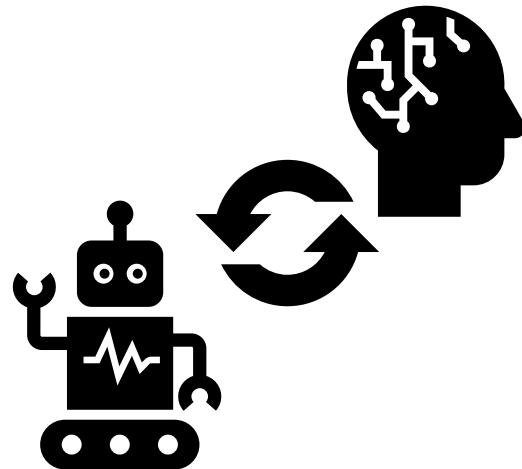
Testing Psycholinguistic Theories



Representations
Mechanisms

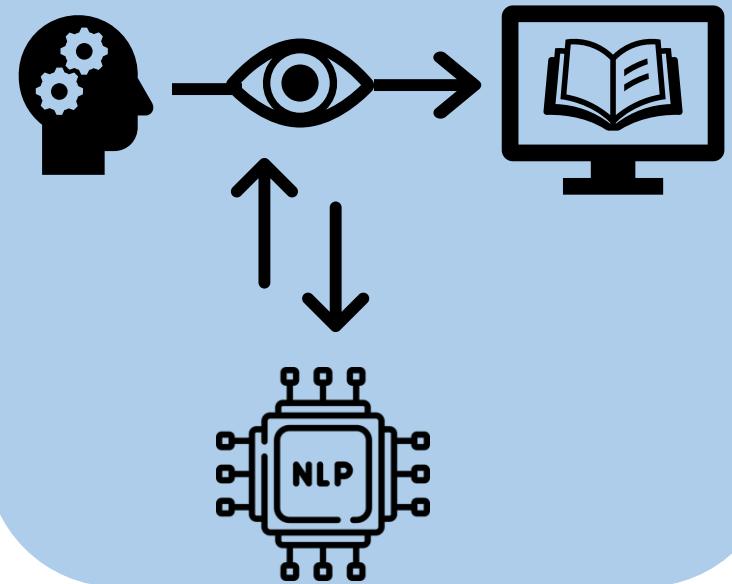


Linguistic quantities

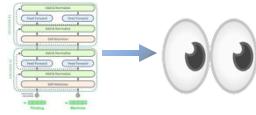


Testing LLM alignment
with human language
processing

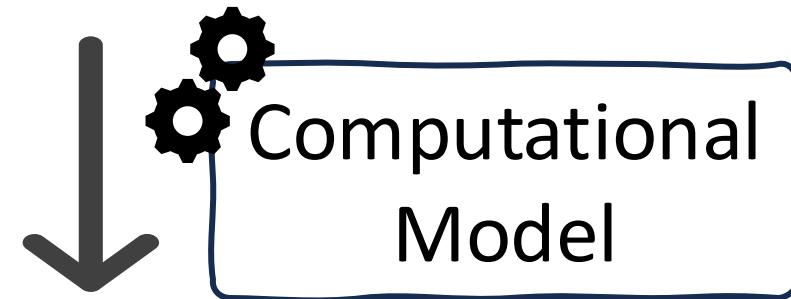
NLP for modeling eye movements in reading



NLP for Modeling Eye Movements in Reading



CNN wants to change its viewers' habits.

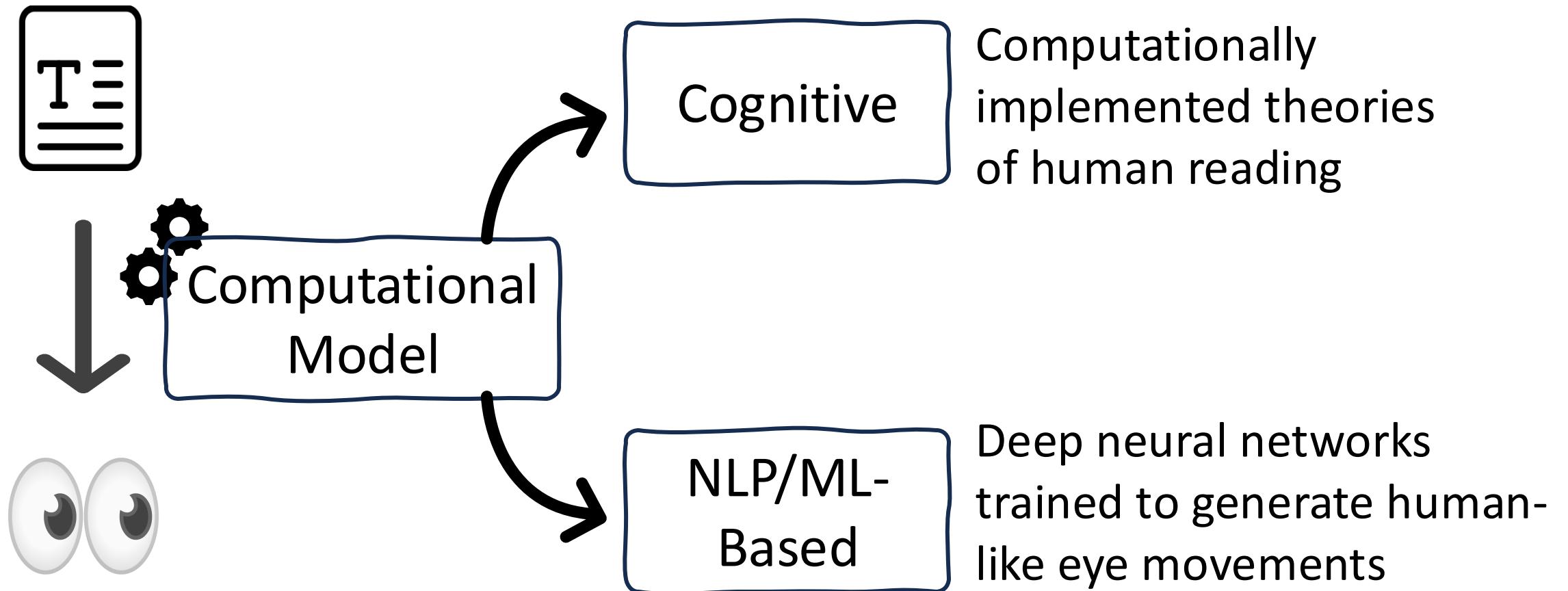
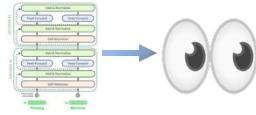


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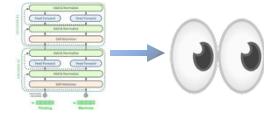
1 2 7 3 4 5 6 8

A horizontal dotted red line with arrows at both ends spans across the text. It has red circles at each of the numbered positions 1 through 8. Red arrows point from the first circle to the second, from the third to the fourth, and from the fifth to the sixth. There is also a red arrow pointing from the seventh circle back towards the first one.

NLP for Modeling Eye Movements in Reading

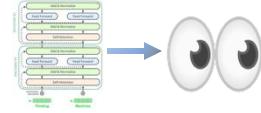


NLP for Modeling Eye Movements in Reading



		<u># Parameters</u>	<u>Interpretable?</u>
Cognitive	Computationally implemented theories of human reading	Few	Most parameters have direct cognitive interpretation
NLP/ML-Based	Deep neural networks trained to generate human-like eye movements	Many	Typically not interpretable

NLP for Modeling Eye Movements in Reading



Cognitive

Computationally implemented theories of human reading

NLP/ML-Based

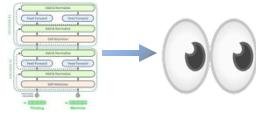
Deep neural networks trained to generate human-like eye movements

Examples

E-Z Reader [Reichle et al. \(1998, 2009\)](#)
SWIFT [Engbert et al. \(2005\)](#)
SEAM [Rabe et al. \(2024\)](#)
OB1-Reader [Snell et al. \(2018\)](#)

NEAT [Hahn and Keller \(2023\)](#)
Eyettention [Deng, Reich et al. \(2023\)](#)
ScanDL [Bolliger et al. \(2023, 2025\)](#)
SP-EyeGan [Prasse, Reich et al. \(2023\)](#)

NLP for Modeling Eye Movements in Reading



Cognitive

Examples

E-Z Reader [Reichle et al. \(1998, 2009\)](#)

SWIFT [Engbert et al. \(2005\)](#)

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NLP/ML-
Based

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Eyettention [Deng, Reich et al. \(2023\)](#)

ScanDL [Bolliger et al. \(2023, 2025\)](#)

SP-EyeGan [Prasse, Reich et al. \(2023\)](#)

Model

Serial attention

Parallel attention

Activation-coupled

Bayesian inference

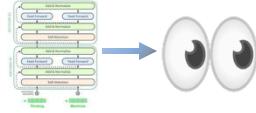
RNN

Cross-attention

Diffusion

GAN

NLP for Modeling Eye Movements in Reading



Cognitive

Examples

E-Z Reader [Reichle et al. \(1998, 2009\)](#)

SWIFT [Engbert et al. \(2005\)](#)

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ScanDL [Bolliger et al. \(2023, 2025\)](#)

SP-EyeGan [Prasse, Reich et al. \(2023\)](#)

Output

Fixation

Fixation, transition probability

Fixation, transition probability

Fixation, transition probability

Fixation

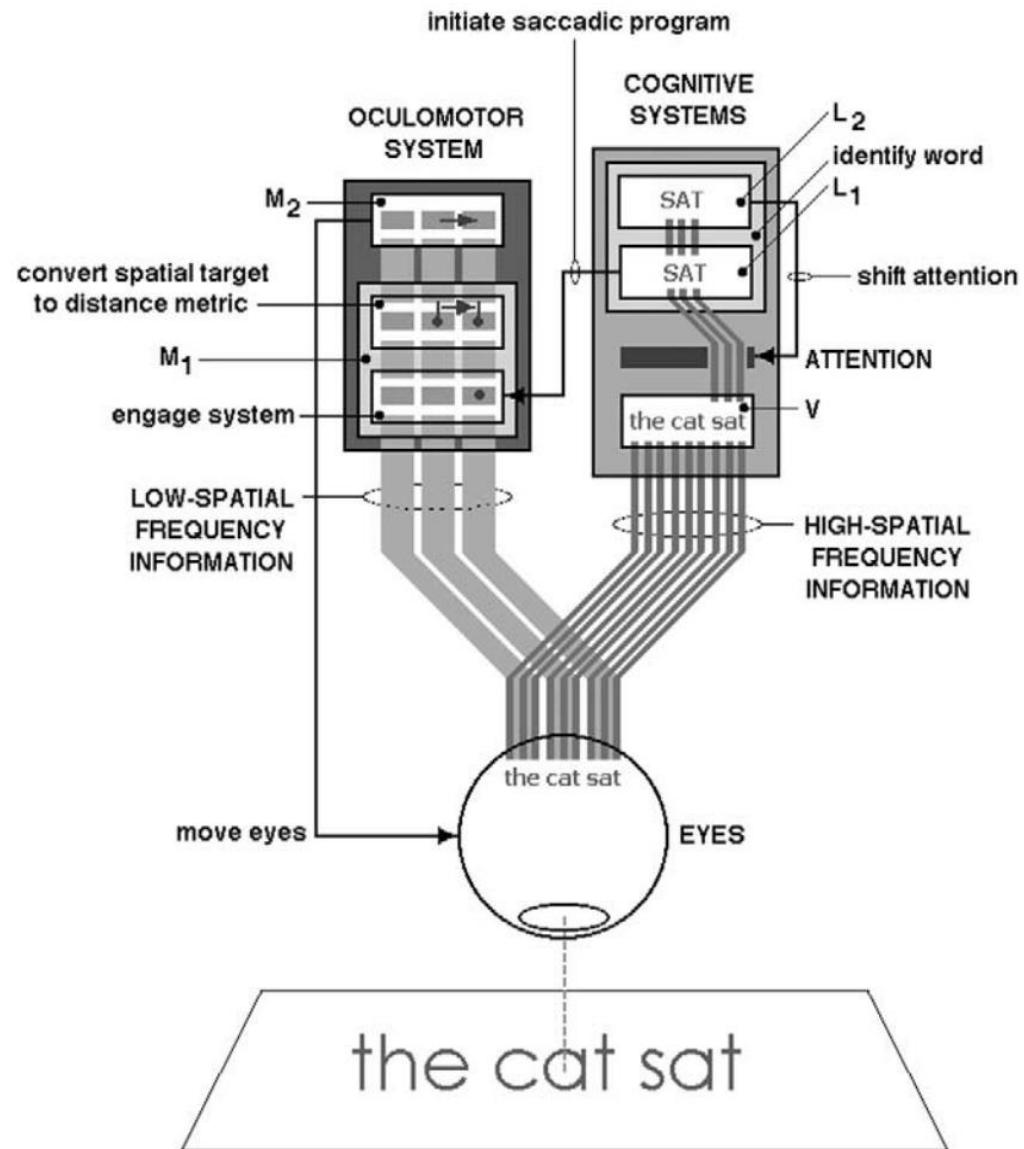
Transition probability

Fixation

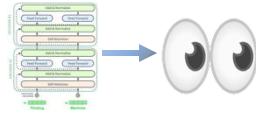
Raw samples

NLP for Modeling Eye Movements in Reading

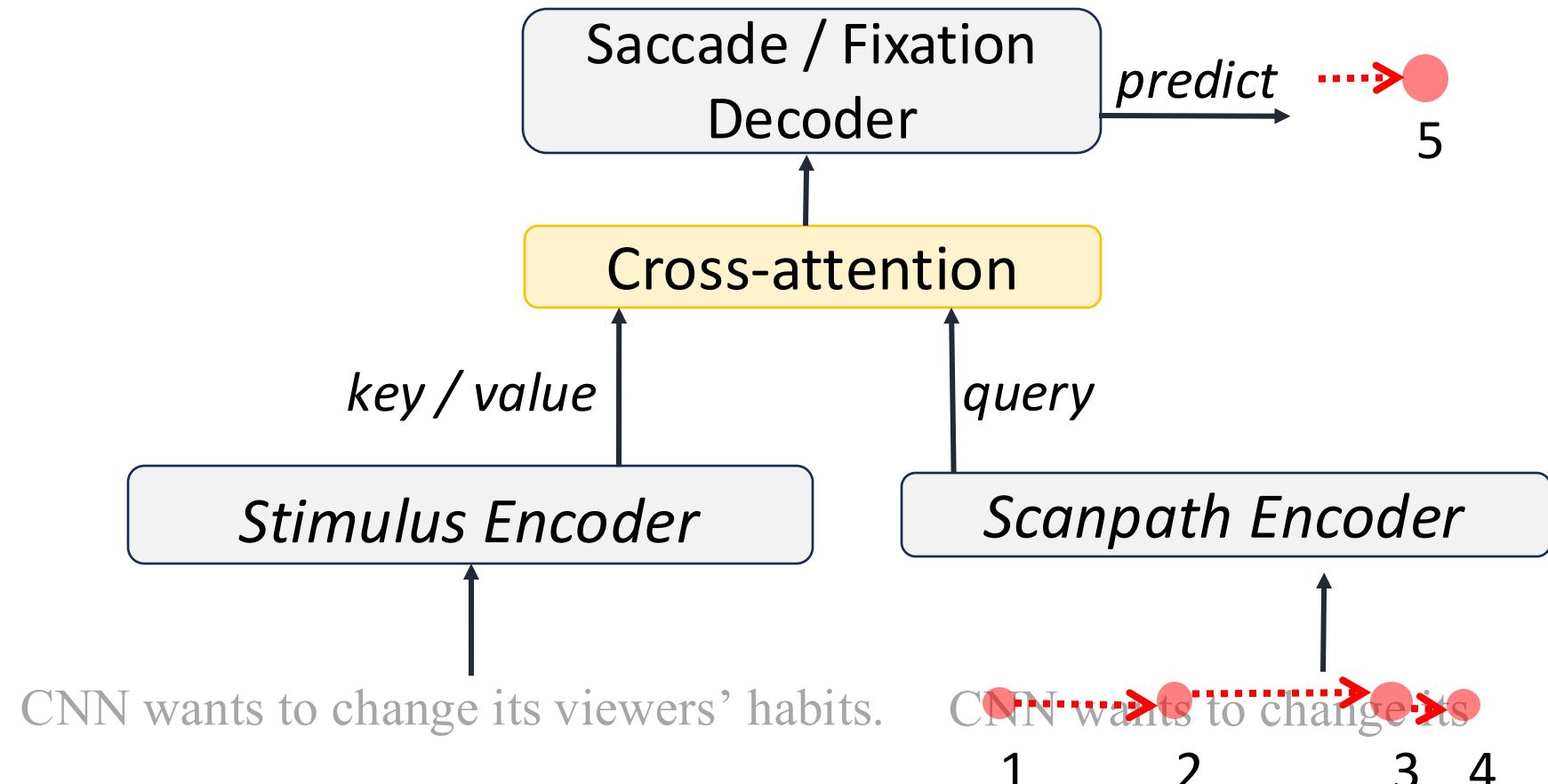
- E-Z Reader



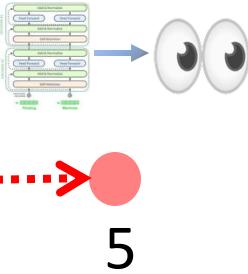
NLP for Modeling Eye Movements in Reading



Eyettention ([Deng et al., 2023](#))



NLP for Modeling Eye Movements in Reading



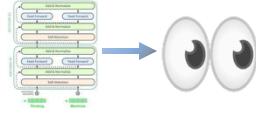
Eyettention ([Deng et al., 2023](#))

Extensions:
Reader- and population-specific models

CNN wants to change its viewers' habits.

1 2 3 4

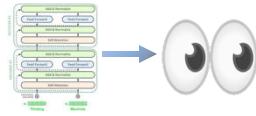
NLP for Modeling Eye Movements in Reading



ScanDL, ScanDL 2.0 ([Bolliger et al., 2023 ,2025](#))

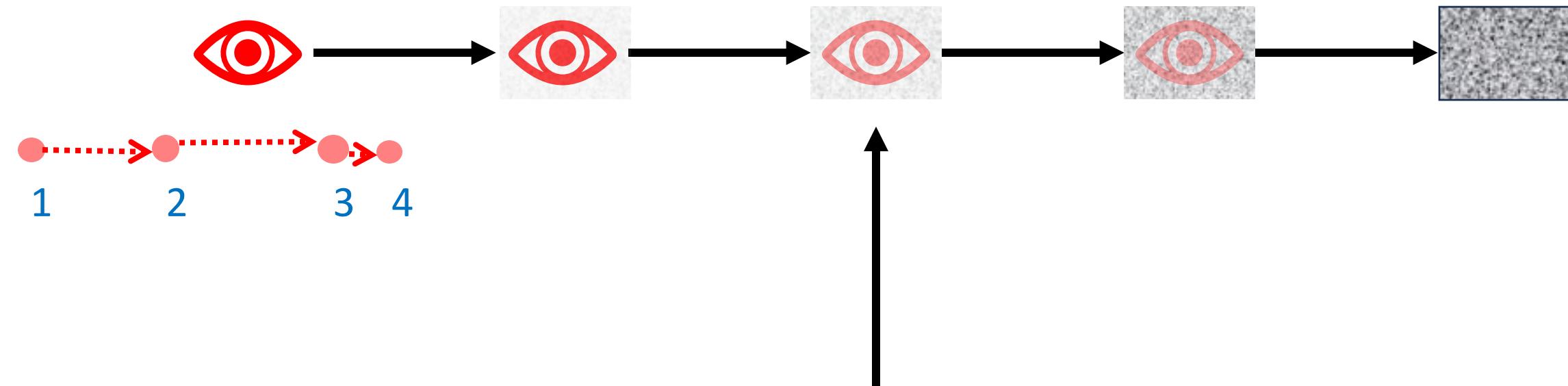


NLP for Modeling Eye Movements in Reading



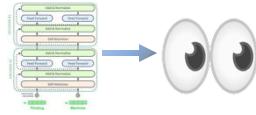
ScanDL, ScanDL 2.0 ([Bolliger et al., 2023 ,2025](#))

- How? Discrete input into continuous space



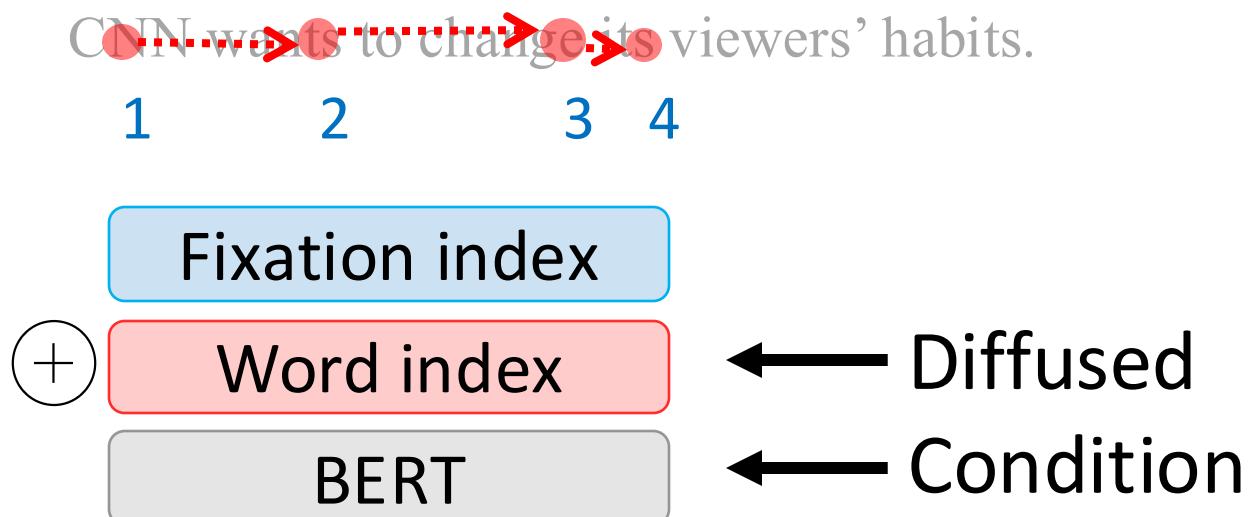
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NLP for Modeling Eye Movements in Reading

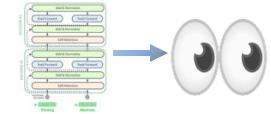


ScanDL, ScanDL 2.0 ([Bolliger et al., 2023 ,2025](#))

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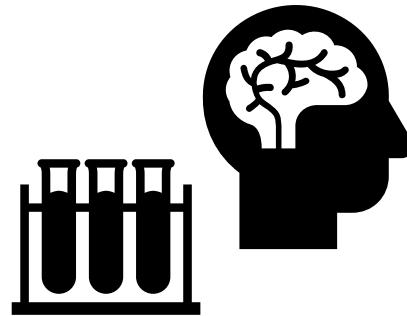
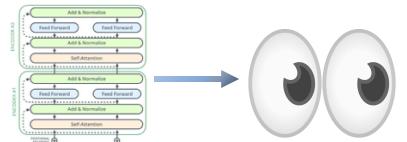


Discussion: NLP for Modeling Eye Movements in Reading



- NLP/ML based models outperform cognitive models
 - But metrics for scanpath generation – nontrivial!
- Making NLP/ML models more cognitively plausible and interpretable

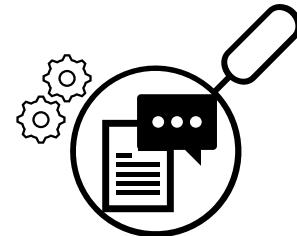
Uses of NLP in Modeling Eye Movements and Human Language Processing



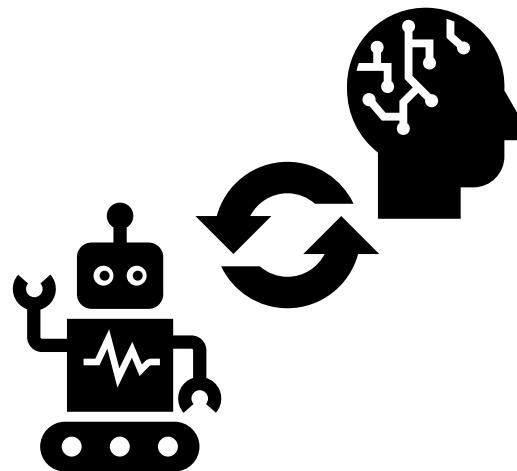
Testing Psycholinguistic Theories



Representations

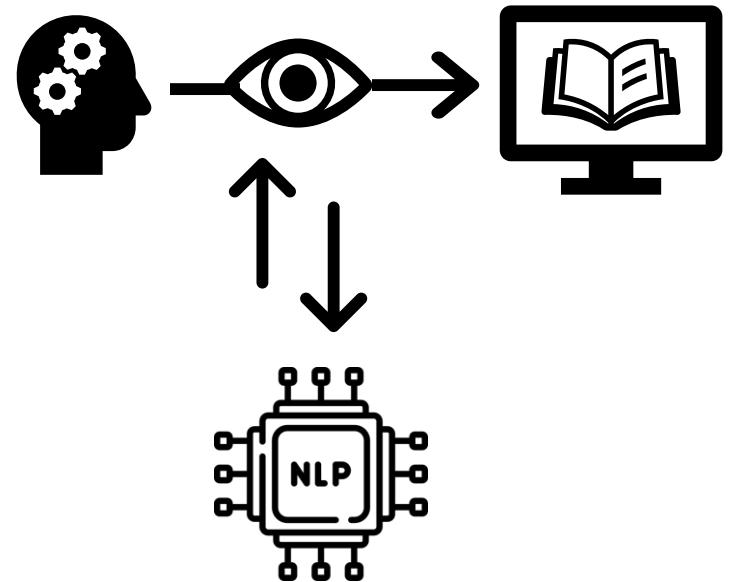


Linguistic quantities



Testing LLM alignment with human language processing

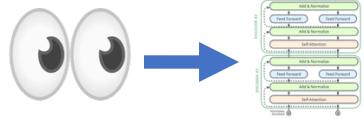
NLP for modeling eye movements in reading



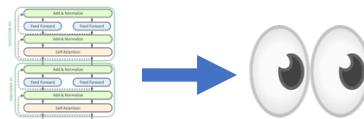
Tutorial Outline



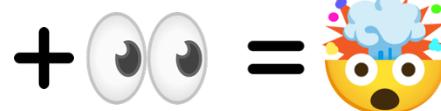
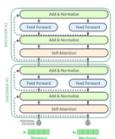
1. Introduction to eye tracking



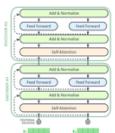
2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling



4. New human centered applications



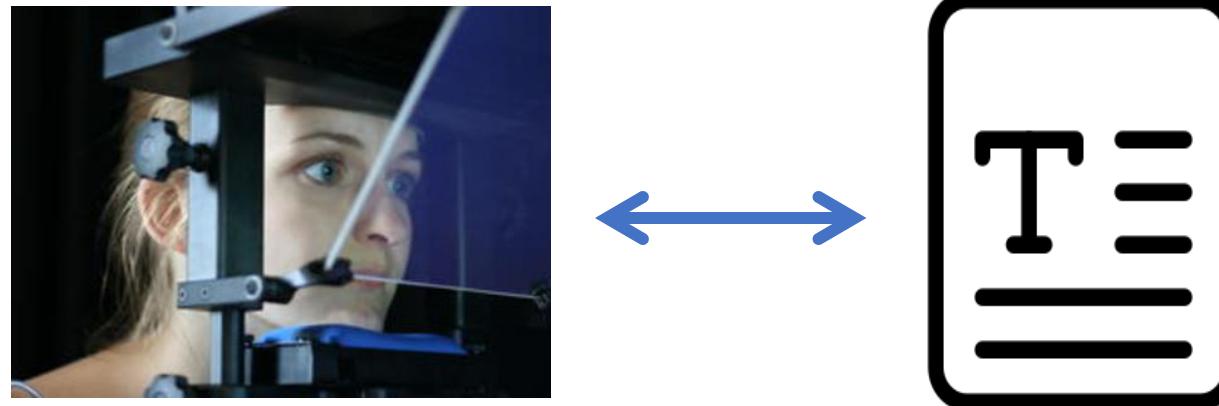
5. Outlook and future directions

New Human Centered Applications



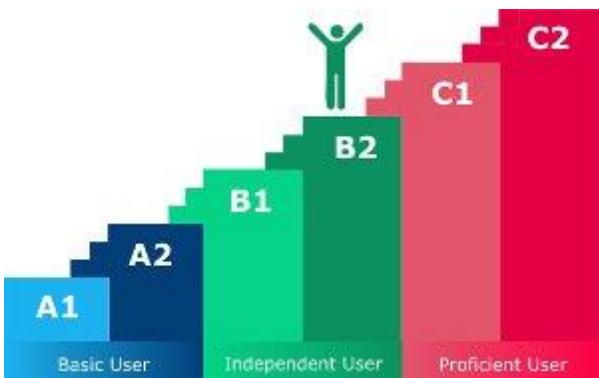
Human Centered NLP with Eye Movements

- Rethinking the future of NLP
- Enabling a wide range of new human centered tasks
- Real-time predictions about reader and their interactions with the text



Human Centered NLP with Eye Movements

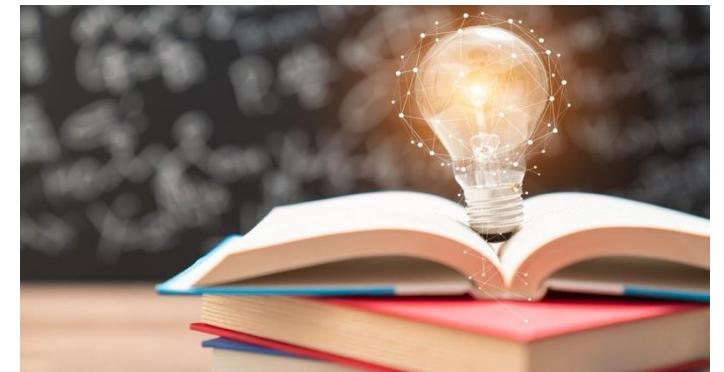
Language
assessment



Reading impairment
screening and monitoring

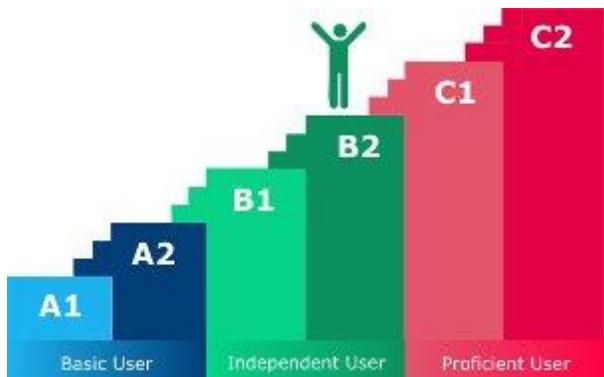


Assessment of Reading
Comprehension



Human Centered NLP with Eye Movements

Language assessment



Reading impairment screening and monitoring



Assessment of Reading Comprehension



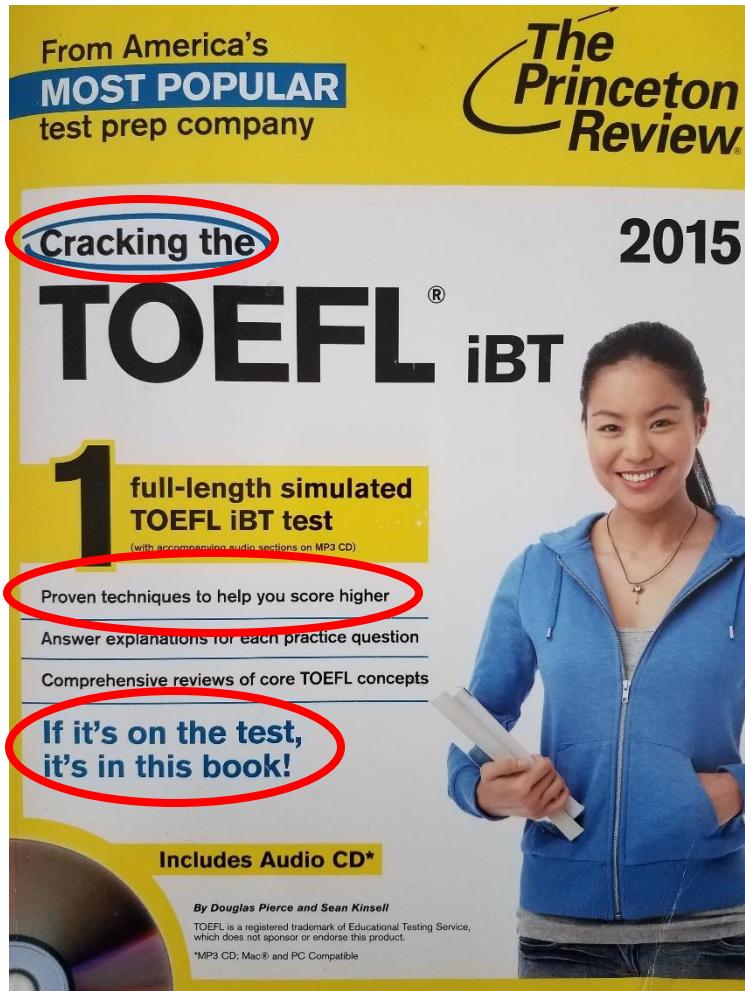
Language Proficiency Assessment



- Over 2 billion English learners worldwide
- Grammar & vocabulary quizzes
- Reading comprehension
- Listening comprehension
- Essay writing
- ...



Language Proficiency Assessment



Language Proficiency Assessment



- Expensive
- Require test specific preparation
- Cheating
- Manually crafted ad-hoc tasks
- No ability to track language processing online

Language Proficiency Assessment



- Eye movements are informative of L2 language proficiency

Assessing Language Proficiency from Eye Movements in Reading

Yevgeni Berzak
MIT BCS
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Boris Katz
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boris@mit.edu

Roger Levy
MIT BCS
rplevy@mit.edu

[Berzak et al. \(2018\)](#)

Journal of Optical Technology Vol. 89, Issue 8, pp. 484-489 (2022) • <https://doi.org/10.1364/JOT.89.000484>



Evaluation of level of foreign language proficiency based on eye movement data

V. A. Demareva, A. V. Golubinskaya, Yu. A. Edeleva, and R. V. Golubin

[Demareva et al. \(2022\)](#)

Inferring Search User Language Proficiency from Eye Gaze Data

Ben Steichen
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California State Polytechnic
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Christian Becerra
California State Polytechnic
University, Pomona
ceb@cpp.edu

[Steichen et al. \(2024\)](#)

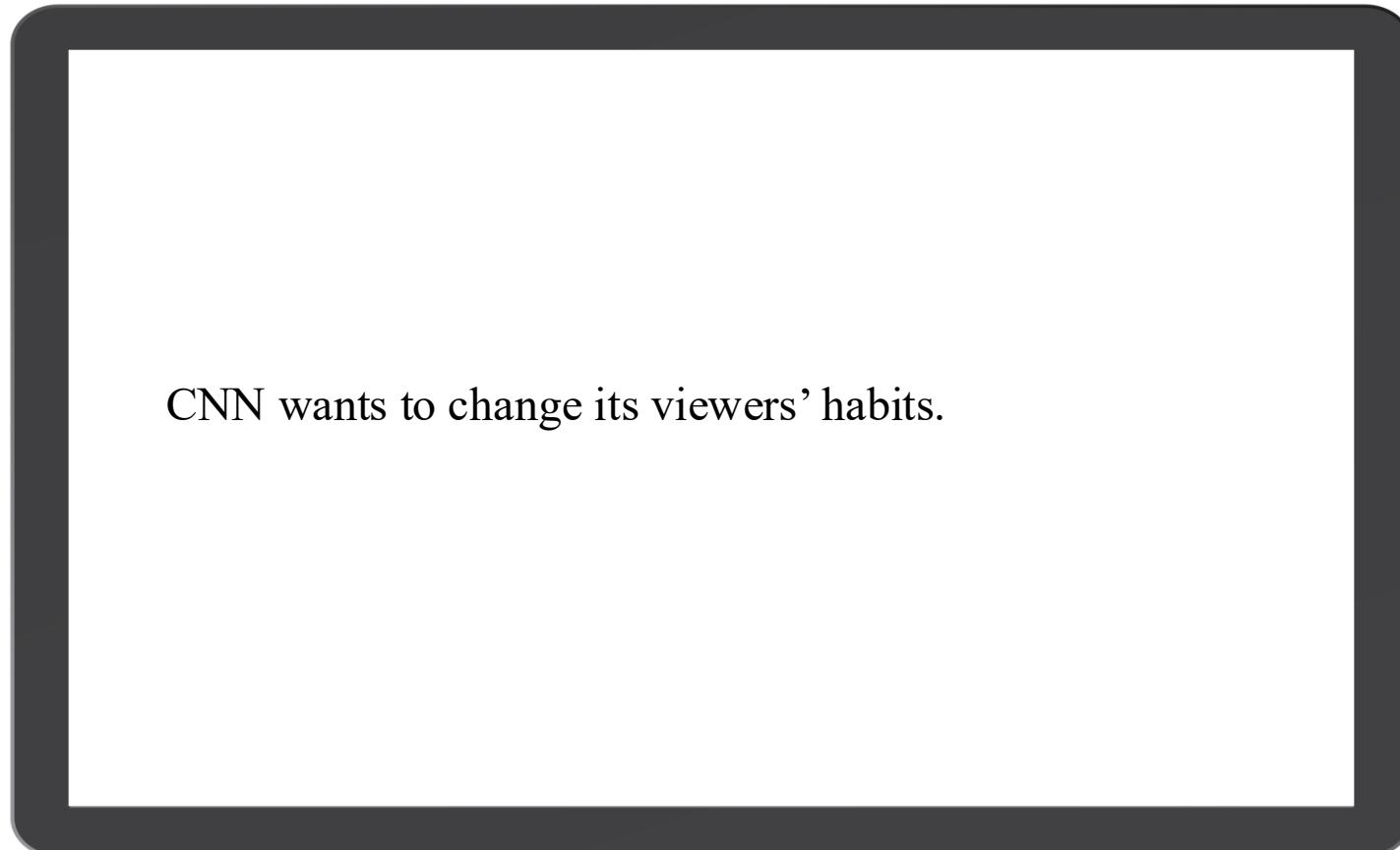
Predicting First-Language and Second-Language Proficiency Using Eye Fixation Data and Demographic Information: Assumptions, Data Representations, and Methods

Publisher: IEEE [Cite This](#) [PDF](#)

Soroosh Shalileh ; Matvey Kairov ; Ranga Baminiwatte ; Olga Parshina ; Olga Dragoy [All Authors](#)

[Shalileh et al. \(2024\)](#)

Our Test



Our Test

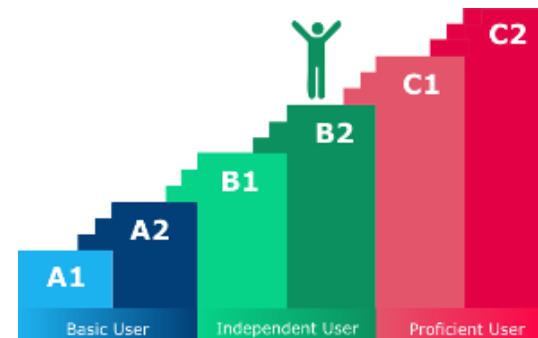
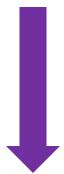


Our Test

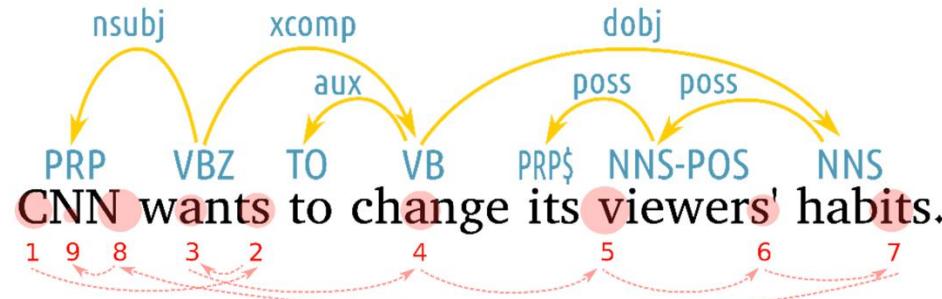


Our Test

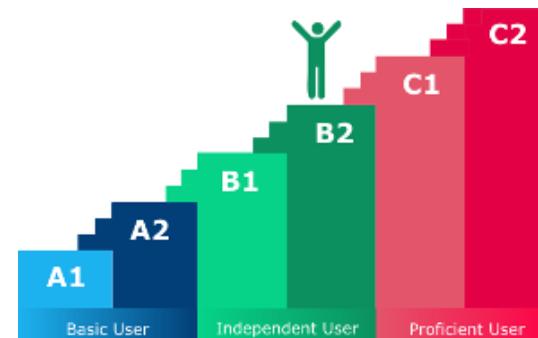
Ordinary Reading



Our Test

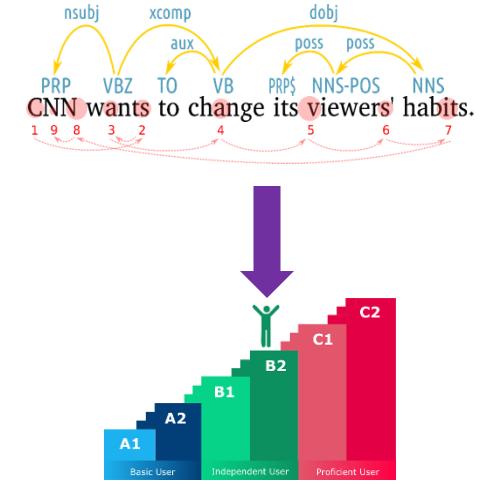


Linguistic Processing

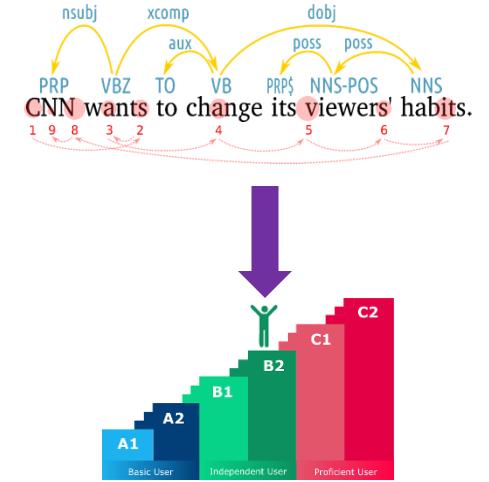


Our Test

- ~~Expensive~~
- ~~Require test specific preparation~~
- ~~Cheating~~
- ~~Manually crafted ad-hoc tasks~~
- Ability to track language processing online



Our Test

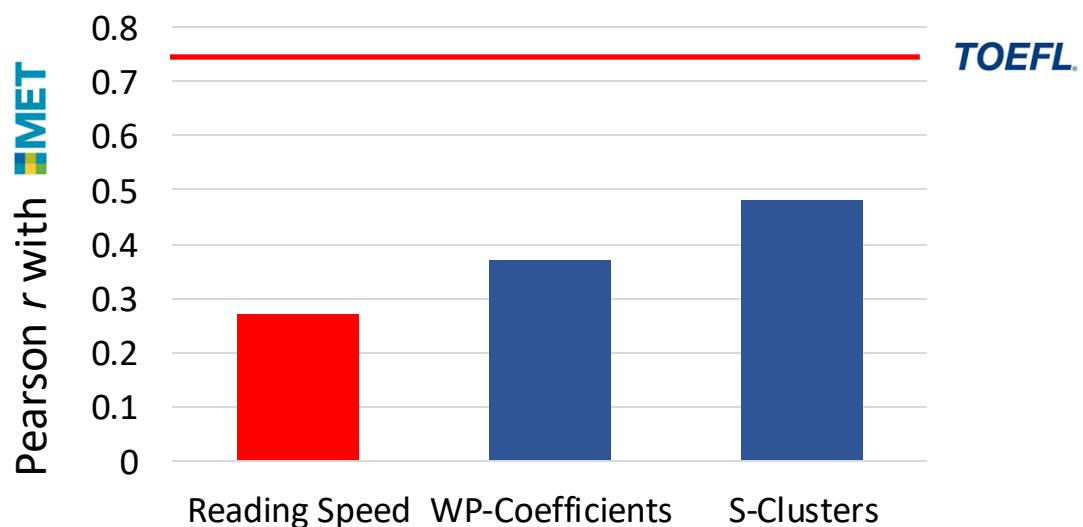
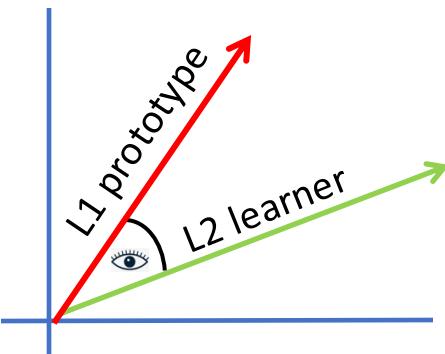


ESL proficiency \approx Similarity of reading
patterns to native
speakers of English

EyeScore

Berzak et al. (2018)

- Extract eye movement features for each participant
- Compute English L1 “prototype”
- **EyeScore** = cosine similarity to L1 prototype



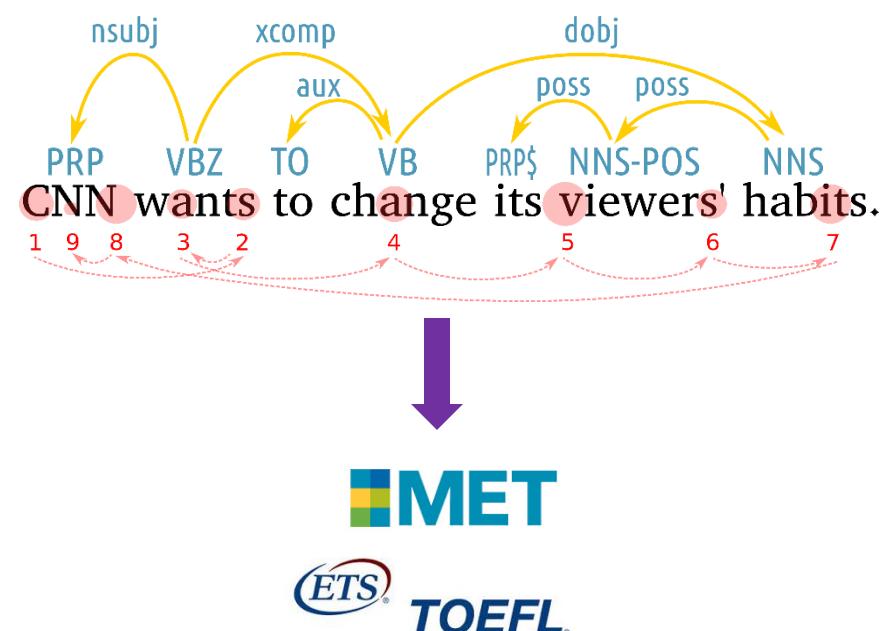
But



Predicting Scores on Standardized Tests

Berzak et al. (2018)

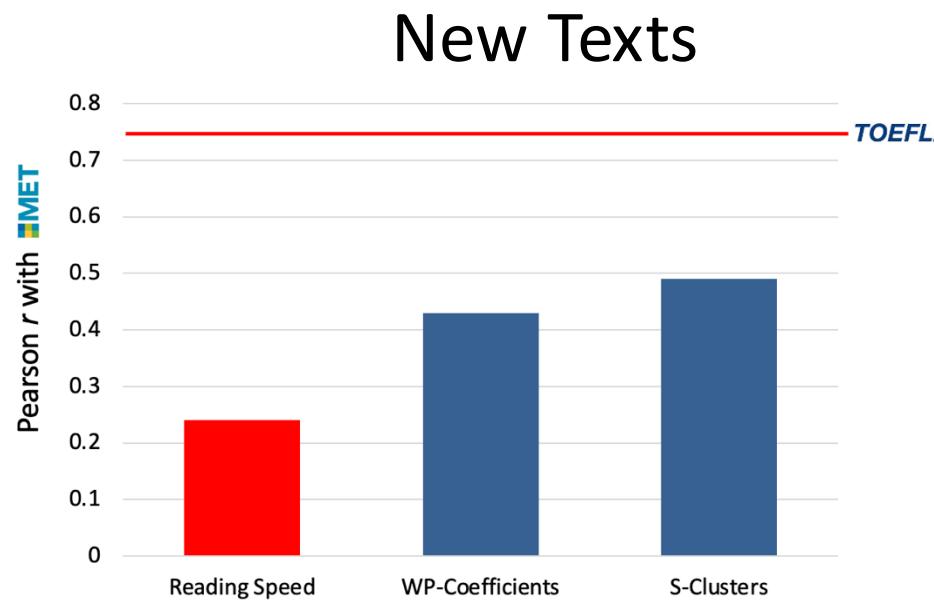
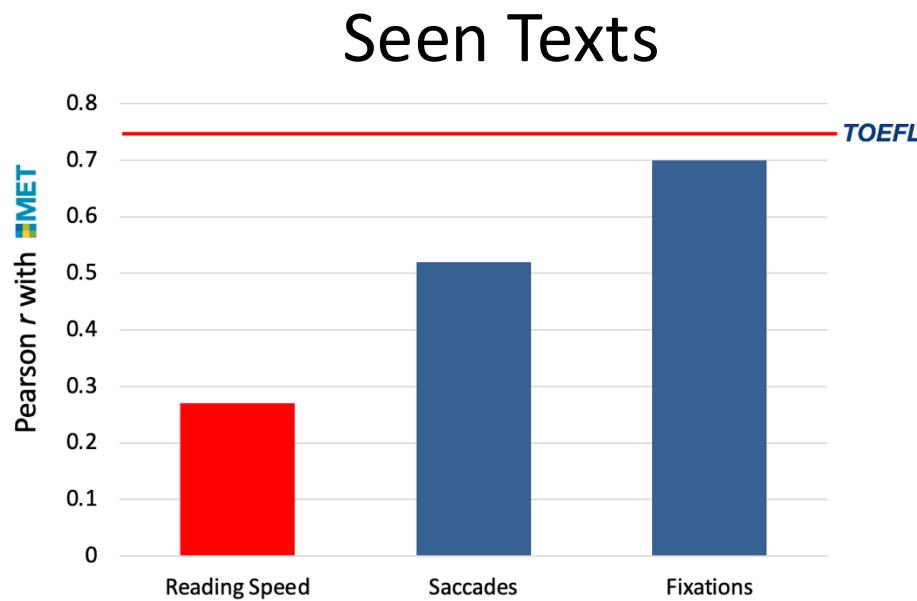
- Eye movement in reading can be used to predict scores of specific external proficiency tests



Predicting Scores on Standardized Tests

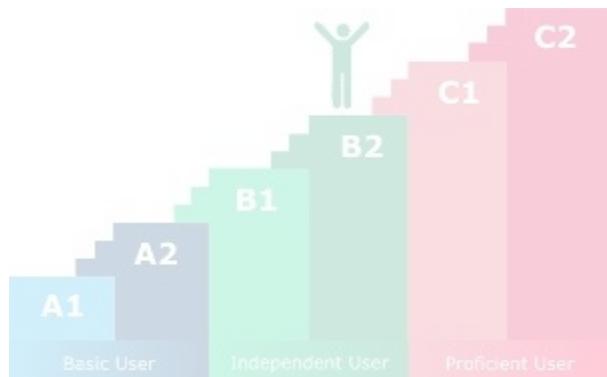
Berzak et al. (2018)

- Eye movement in reading can be used to predict scores of specific external proficiency tests



Human Centered NLP with Eye Movements

Language
assessment



Reading impairment
Screening and monitoring



Assessment of Reading
Comprehension



Reading Impairments

Developmental Dyslexia



"... impairment in reading [which] is characterised by significant and persistent difficulties in learning academic skills related to reading, ... [and] is not due to a disorder of intellectual development, sensory impairment (vision or hearing)," ([WHO, 2025](#))

- Affects approx. 7-10% of the population ([Catts et al., 2005](#), [Peterson & Pennington, 2012](#); [Moll et al., 2014](#))
- Early detection and intervention is key ([Snowling, 2012](#); [Torgesen, 2002](#))
- Existing testing batteries must be administered by a trained specialist.

Reading Impairments Developmental Dyslexia



Πηγαίνοντας με το λεωφορείο να σπάσει φτώ την αδερφή μου που είχε κάνει μια εγχείρηση πέρασα μπροστά από το τετράγωνο που βρισκόταν το εργοστασιο στο οποίο δούλευε η μητέρα μου. Το εργοστασιο και κατεύαζε πλυντήρια. Ήταν πολύ χρήσιμο να υπάρχει ένα μικροτέρο στο σπίτι.

Πηγαίνοντας με το λεωφορείο να σπάσει φτώ την αδερφή μου που είχε κάνει μια εγχείρηση πέρασα μπροστά από το τετράγωνο που βρισκόταν το εργοστασιο στο οποίο δούλευε η μητέρα μου. Το εργοστασιο και κατεύαζε πλυντήρια. Ήταν πολύ χρήσιμο να υπάρχει ένα μικροτέρο στο σπίτι.

Reading Impairments Developmental Dyslexia



Detecting Readers with Dyslexia Using Machine Learning with Eye Tracking Measures

Luz Rello
Human-Computer Interaction Institute
School of Computer Science
Carnegie Mellon University
luzrello@cs.cmu.edu

Miguel Ballesteros
Natural Language Processing Group
Universitat Pompeu Fabra
miguel.ballesteros@upf.edu

[Rello and Ballesteros \(2014\)](#)

Screening for Dyslexia Using Eye Tracking during Reading

Mattias Nilsson Benfatto , Gustaf Öqvist Seimyr, Jan Ygge, Tony Pansell, Agneta Rydberg, Christer Jacobson

Published: December 9, 2016 • <https://doi.org/10.1371/journal.pone.0165508>

[Nilsson Benfatto et al. \(2016\)](#)

Predictive Model for Dyslexia from Fixations and Saccadic Eye Movement Events

A Jothi Prabha , R Bhargavi

[Jothi Prabha and Bhargava \(2020\)](#)

Eye-tracking based classification of Mandarin Chinese readers with and without dyslexia using neural sequence models

Patrick Haller¹, Andreas Säuberli¹, Sarah E. Kiener¹
Jinger Pan³, Ming Yan⁴, Lena A. Jäger^{1,2}

[Haller et al. \(2022\)](#)

Dyslexia Prediction from Natural Reading of Danish Texts

Marina Björnsdóttir, Nora Hollenstein, Maria Barrett

[Björnsdóttir et al. \(2023\)](#)

Identifying dyslexia in school pupils from eye movement and demographic data using artificial intelligence

Soroosh Shalileh^{1,*}, Dmitry Ignatov², Anastasiya Lopukhina³, Olga Dragoy^{1,4}

[Shalileh et al. \(2023\)](#)

Automatic detection of dyslexia based on eye movements during reading in Russian

Anna Laurinavichyute

Anastasiya Lopukhina

David R. Reich

[Laurinavichyute et al. \(2025\)](#)

Reading Impairments Developmental Dyslexia Datasets



Björnsdóttir et al. (2023)

- 58 L1, L2 or adults with dyslexia reading paragraphs

Shalileh et al. (2023)

- 300+ children with or without dyslexia
- Two different assessments

Reading Impairments

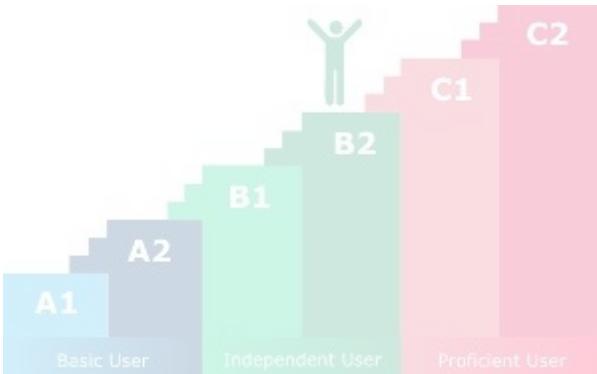
Developmental Dyslexia



- Scale with few eye trackers
 - Cheaper alternatives possible
 - Beyond screening

Human Centered NLP with Eye Movements

Language
assessment



Reading impairment
diagnostics and monitoring



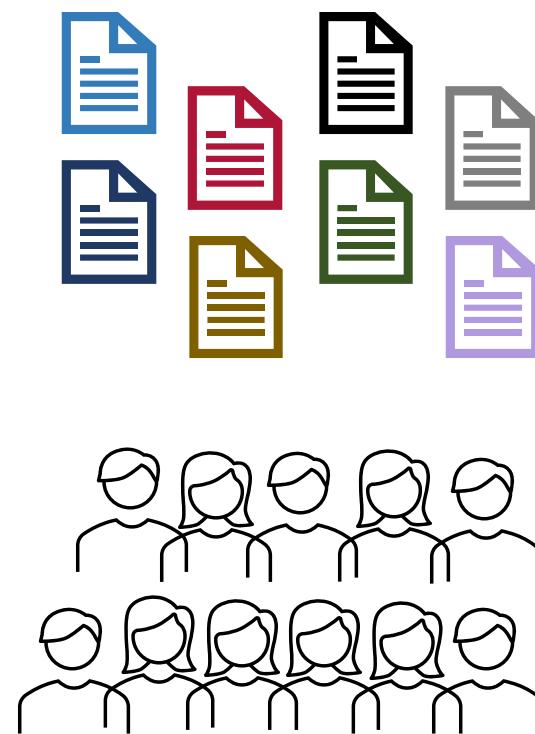
Assessment of Reading
Comprehension



Reading Comprehension



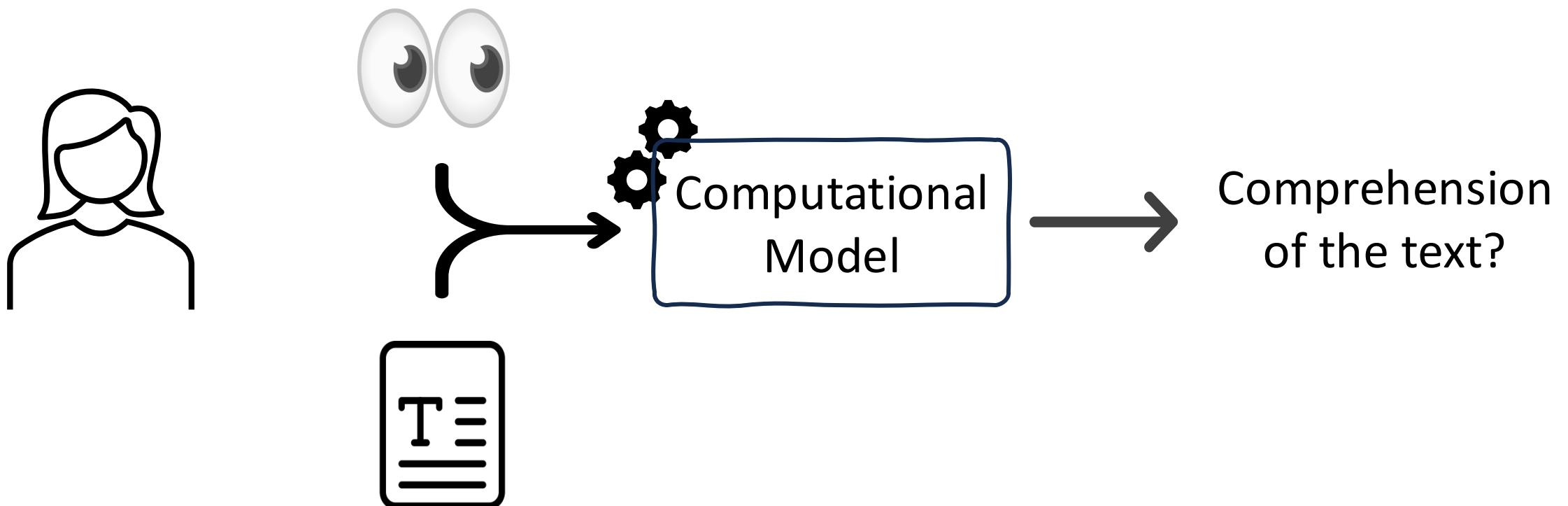
A Holy Grail in psycholinguistics



[Just and Carpenter \(1980\); Among others](#)



Reading Comprehension





Reading Comprehension

Towards Predicting Reading Comprehension From Gaze Behavior

Seoyoung Ahn
Stony Brook University
Stony Brook, New York

Aruna Balasubramanian
Stony Brook University
Stony Brook, New York

Conor Kelton
Stony Brook University
Stony Brook, New York

Gregory Zelinsky
Stony Brook University
Stony Brook, New York

[Ahn et al. \(2020\)](#)

Fine-Grained Prediction of Reading Comprehension from Eye Movements

Omer Shubi¹, Yoav Meiri¹, Cfir Avraham Hadar¹, Yevgeni Berzak^{1,2}

[Shubi et al. \(2024\)](#)

Above chance performance
but highly challenging task!

Inferring Native and Non-Native Human Reading Comprehension and Subjective Text Difficulty from Scanpaths in Reading

Authors: David Robert Reich, Paul Prasse, Chiara Tschirner, Patrick Haller, Frank Goldhammer,
Lena A. Jäger [Authors Info & Claims](#)

[Reich et al. \(2022\)](#)

Eye Movements as Images: A Multimodal Framework for Eye Movements Representation

Publisher: IEEE
[Cite This](#)

Dongsen Zhang; Peipei Li; Zekun Li; Yiwei Ru; Huijia Wu; Zhao Feng He [All Authors](#)

[Zhang et al. \(2025\)](#)

Human Centered NLP with Eye Movements

Open Frontiers



Information accessibility



Education and digital learning



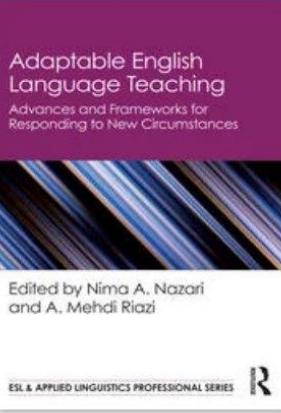
Human-machine communication

Interactive online systems



This is happening
now!

Eye tracking is starting to gain traction in education research!



Chapter

New Approaches to the Assessment of English as an Additional Language

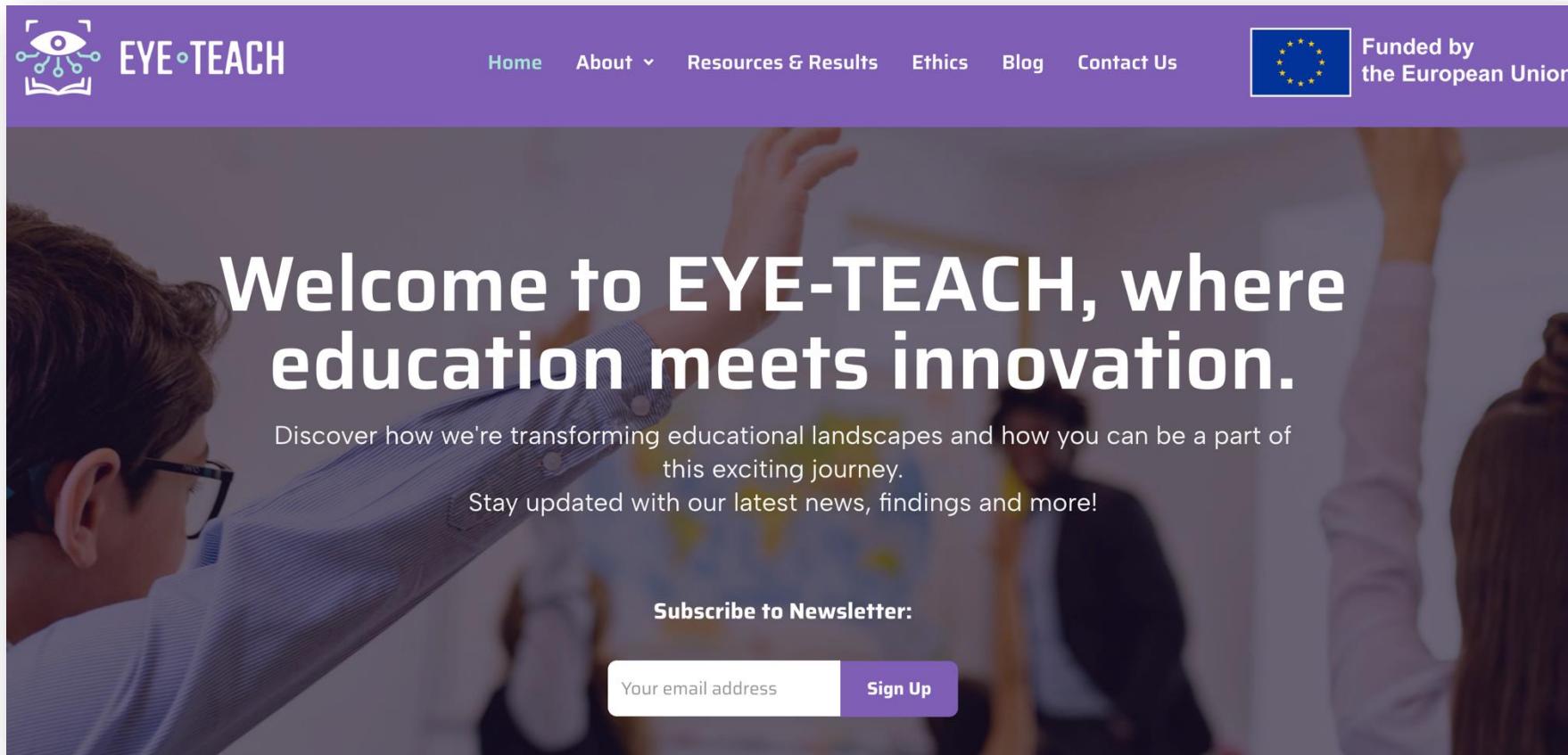
By [Graham Seed](#), [Angeliki Salamoura](#), [Nick Saville](#)

Book [Adaptable English Language Teaching](#)

Edition	1st Edition
First Published	2024
Imprint	Routledge
Pages	17
eBook ISBN	9781003361701

 Share

Eye tracking is starting to gain traction in education research!



The screenshot shows the EYE-TEACH website homepage. At the top, there is a purple navigation bar with the EYE-TEACH logo on the left, followed by menu items: Home, About, Resources & Results, Ethics, Blog, and Contact Us. On the right of the bar is a European Union flag icon with the text "Funded by the European Union". The main content area features a background image of a classroom setting. Overlaid on this image is the text "Welcome to EYE-TEACH, where education meets innovation." in large white letters. Below this, a smaller text block reads: "Discover how we're transforming educational landscapes and how you can be a part of this exciting journey. Stay updated with our latest news, findings and more!" At the bottom of the page, there is a newsletter sign-up form with fields for "Your email address" and a "Sign Up" button.

EYE-TEACH

Home About Resources & Results Ethics Blog Contact Us

Funded by
the European Union

Welcome to EYE-TEACH, where education meets innovation.

Discover how we're transforming educational landscapes and how you can be a part of this exciting journey.
Stay updated with our latest news, findings and more!

Subscribe to Newsletter:

Your email address

Eye tracking is starting to gain traction in education applications!

Reading XR

An AI-Powered Tool In the Fight to Improve Literacy

Reading XR is a tool for evaluating reading fluency, using eye movements to identify the underlying factors causing reading difficulties.

"25% of children have a significant vision problem that impacts their learning."
-American Optometric Association

[LEARN MORE](#)

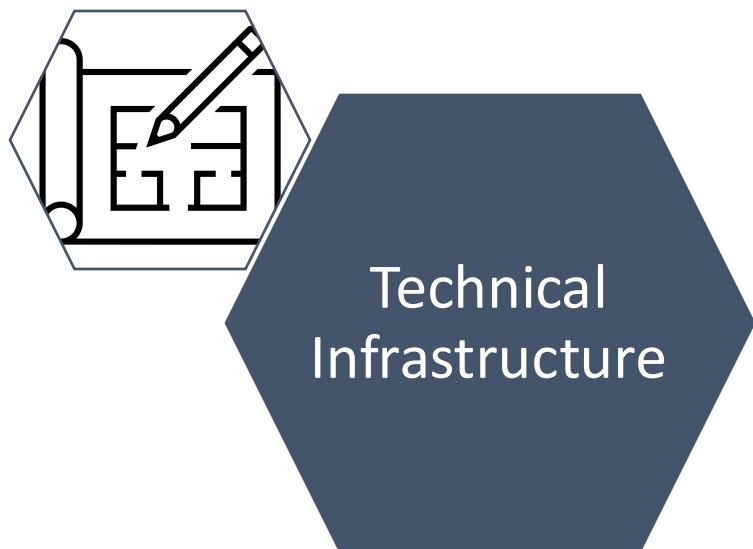


Lexplore

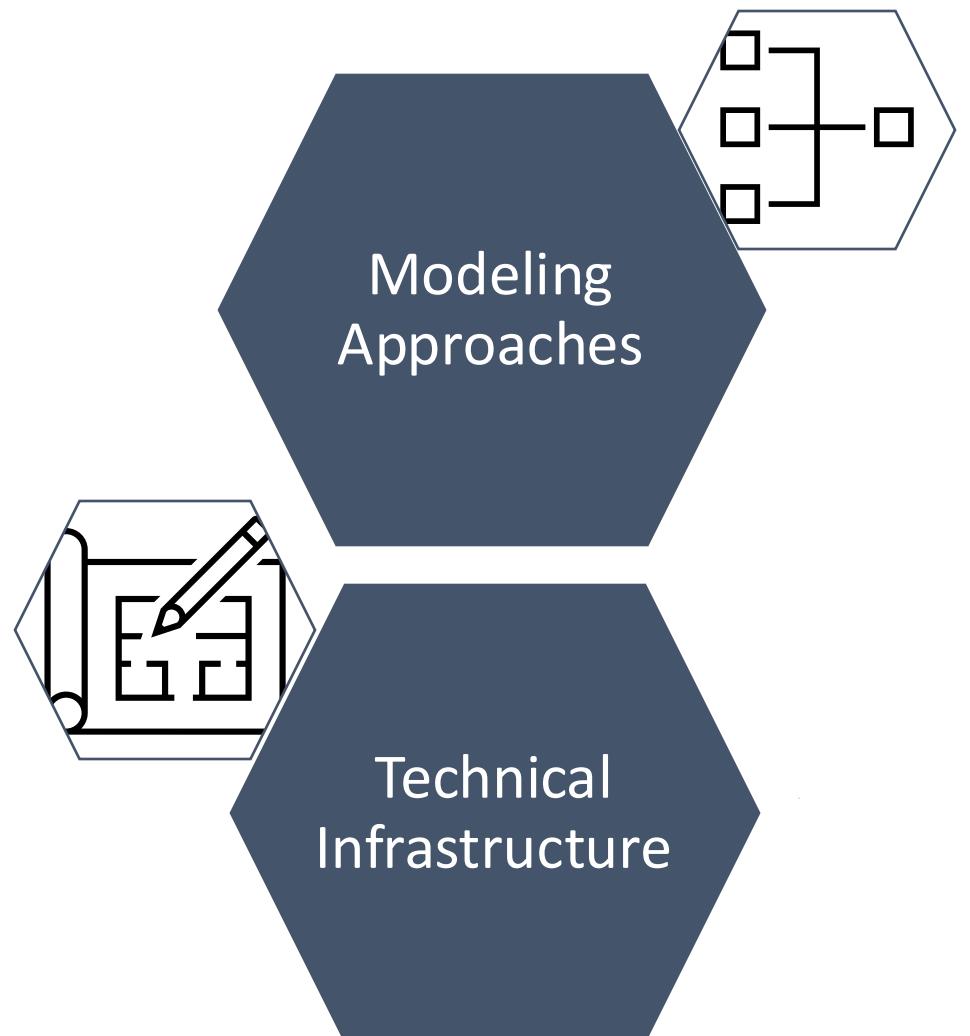
Our Service ▾ Resources ▾ Get in touch ▾

The all-in-one service for systematic reading development

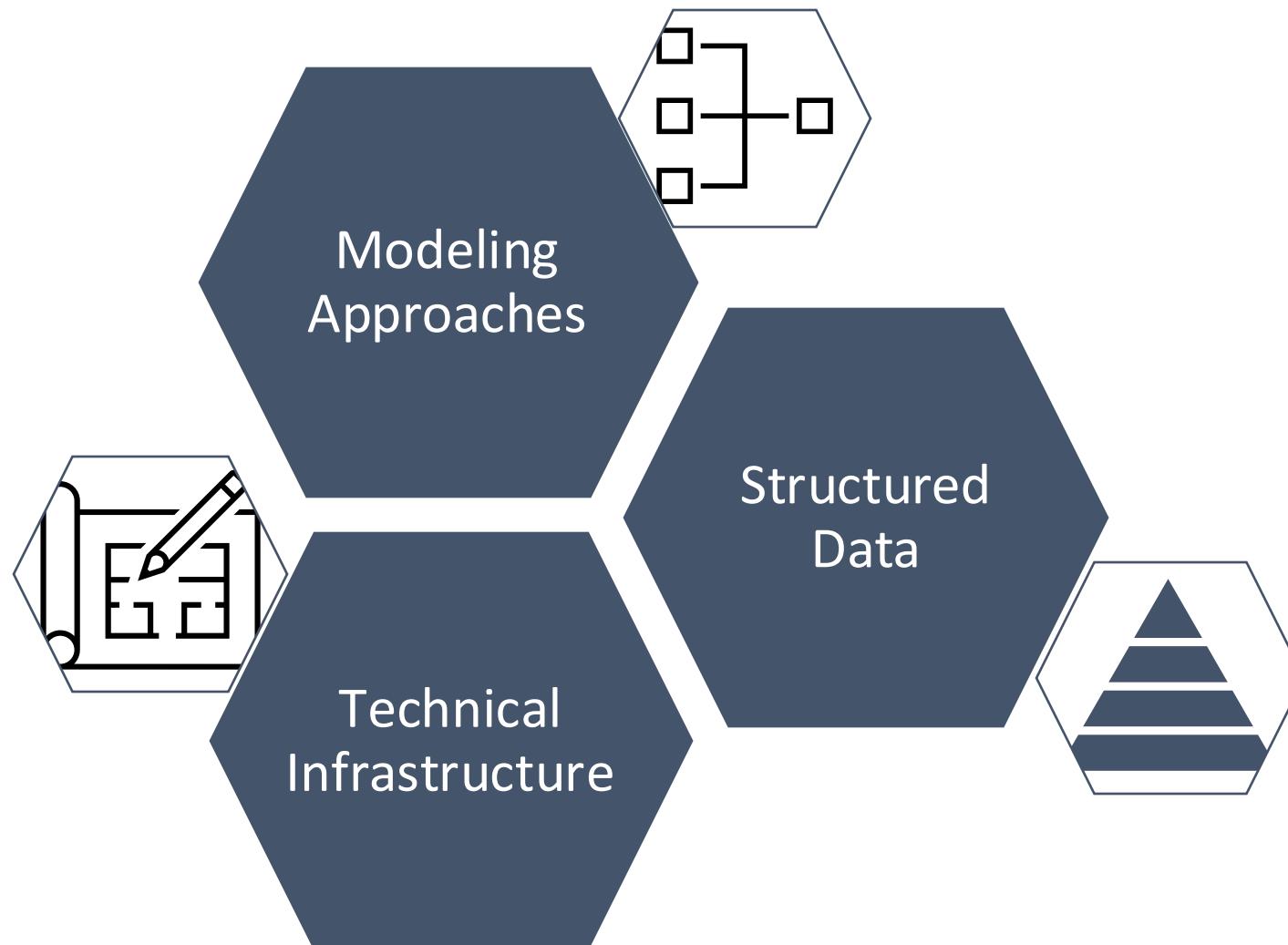
Human Centered NLP with Eye Movements



Human Centered NLP with Eye Movements



Human Centered NLP with Eye Movements

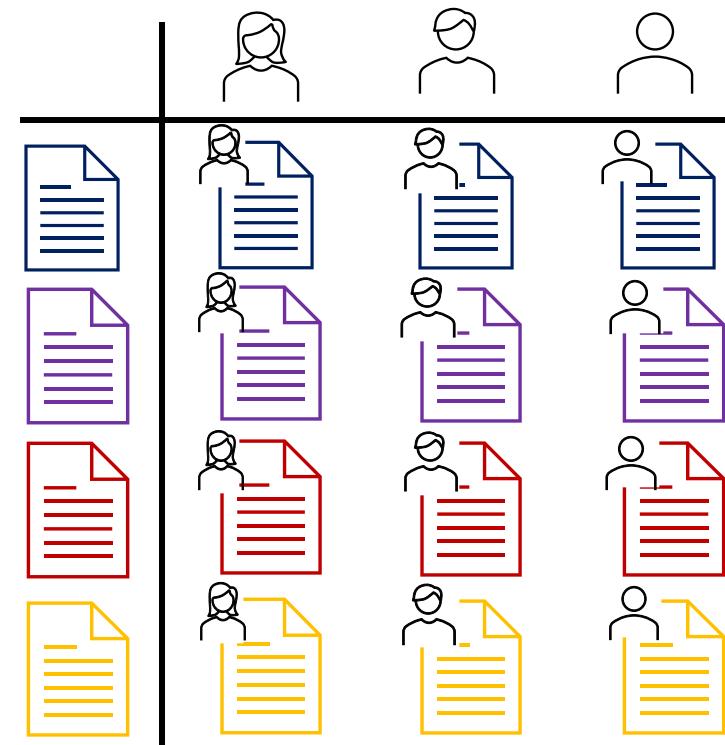


Relevant to any reader
/ reader-text task

Data is not iid – it is structured

Implications for:

- Statistical modeling
- Training and evaluations
- Applications

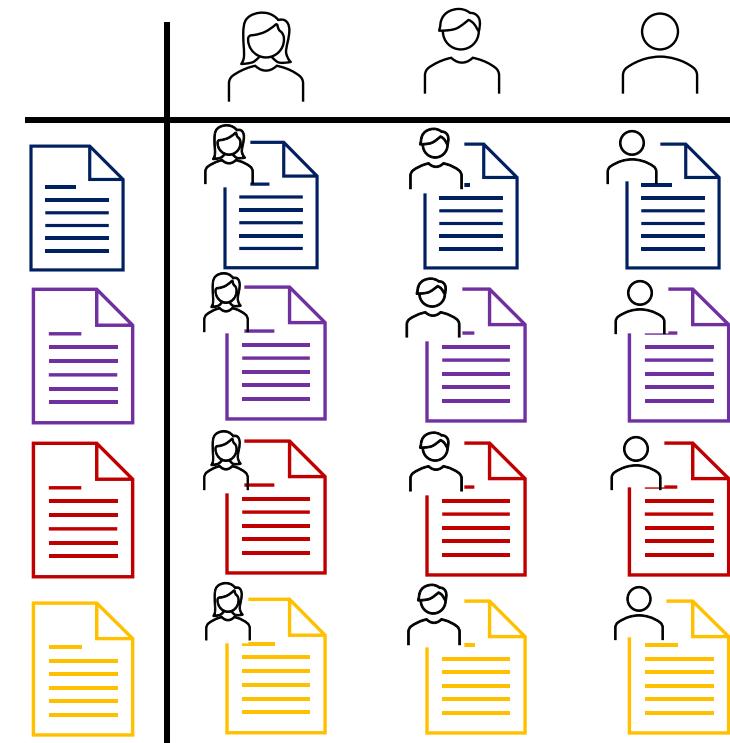


Data is not iid – it is structured

Implications for:

- **Statistical modeling**
- Training and Evaluations
- Applications

t-test → mixed effects models

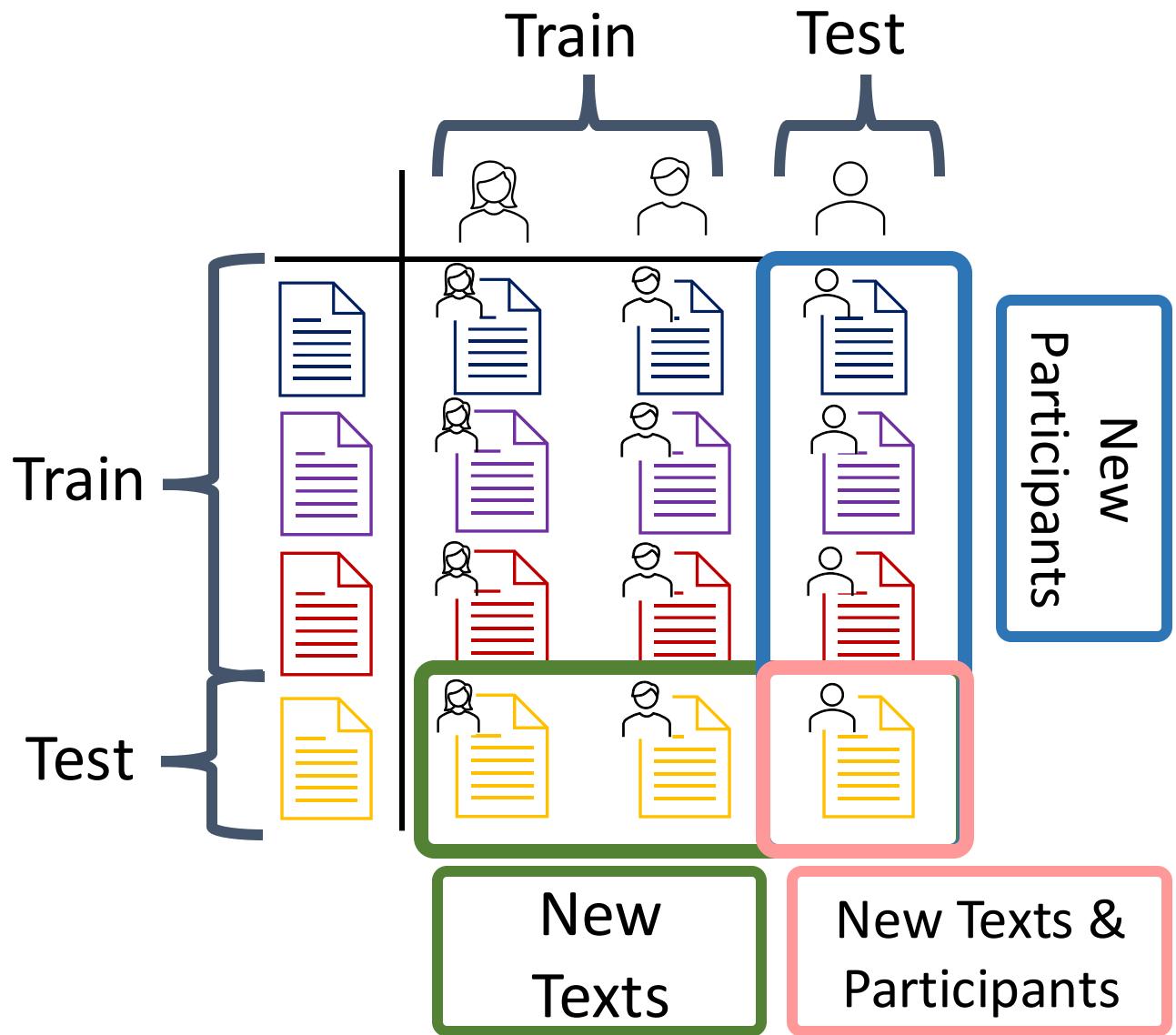


[Shravan Vasishth's Intro Stats course](#)

Data is not iid – it is structured

Implications for:

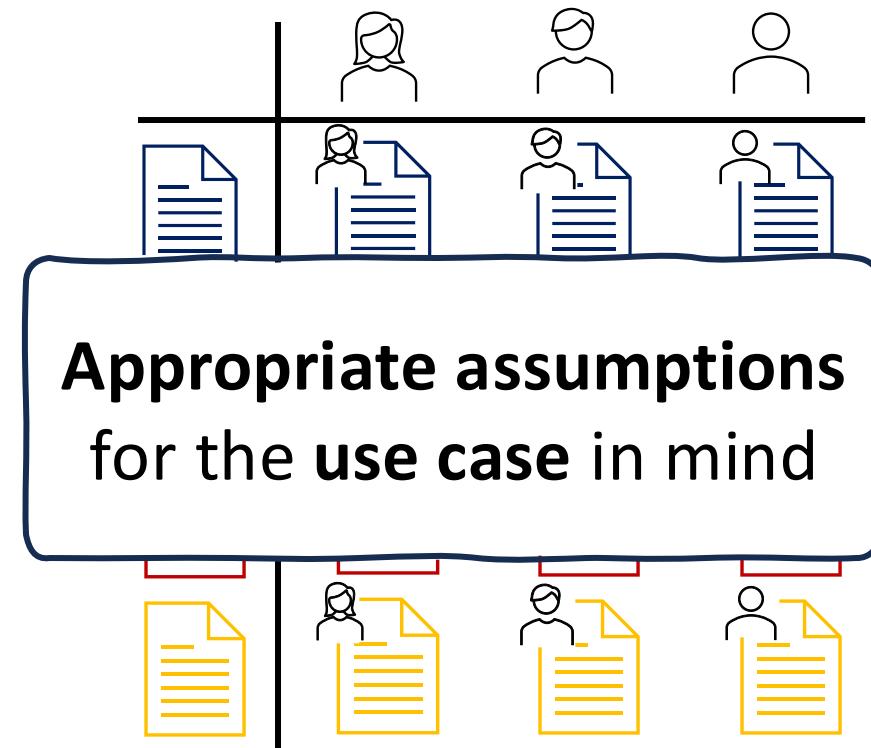
- Statistical modeling
- **Training and Evaluations**
- Applications



Data is not iid – it has structure

Implications for:

- Statistical modeling
- Training and Evaluations
- Applications



Human Centered NLP with Eye Movements

Open Frontiers



Information accessibility



Education and digital learning



Human-machine communication

Interactive online systems



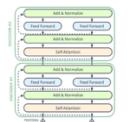
Tutorial Outline



1. Introduction to eye tracking



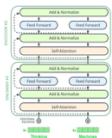
2. Uses of eye tracking in NLP



3. NLP for eye movement and cognitive modeling

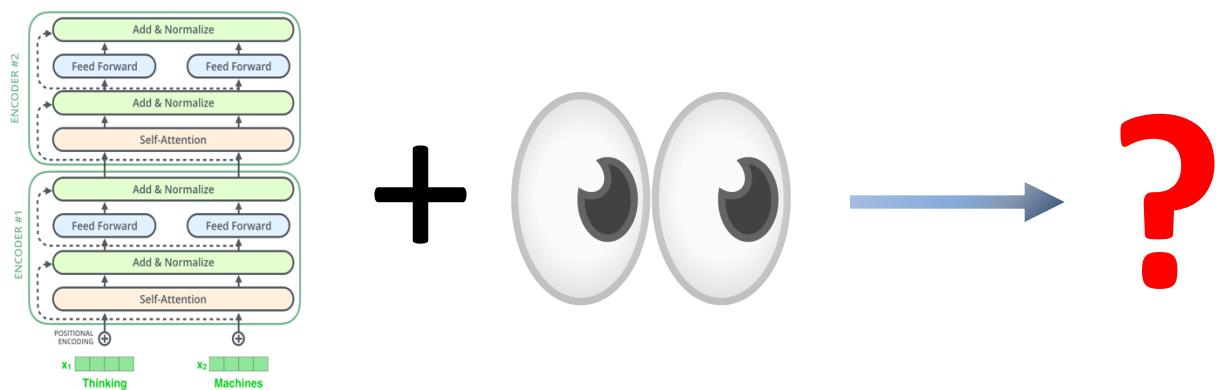


4. New human centered applications

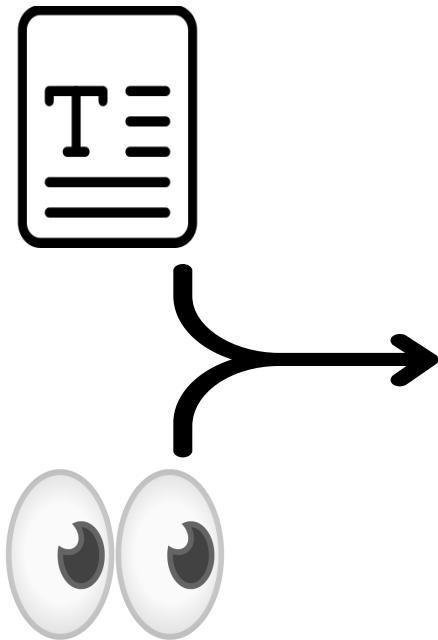


5. Outlook and future directions

Directions for Future Research



The Future: Text + Gaze Multimodal Models



Highly open and challenging problem

Eye movements representation
Alignment with text
Low resource settings
First-principles cognitive modeling

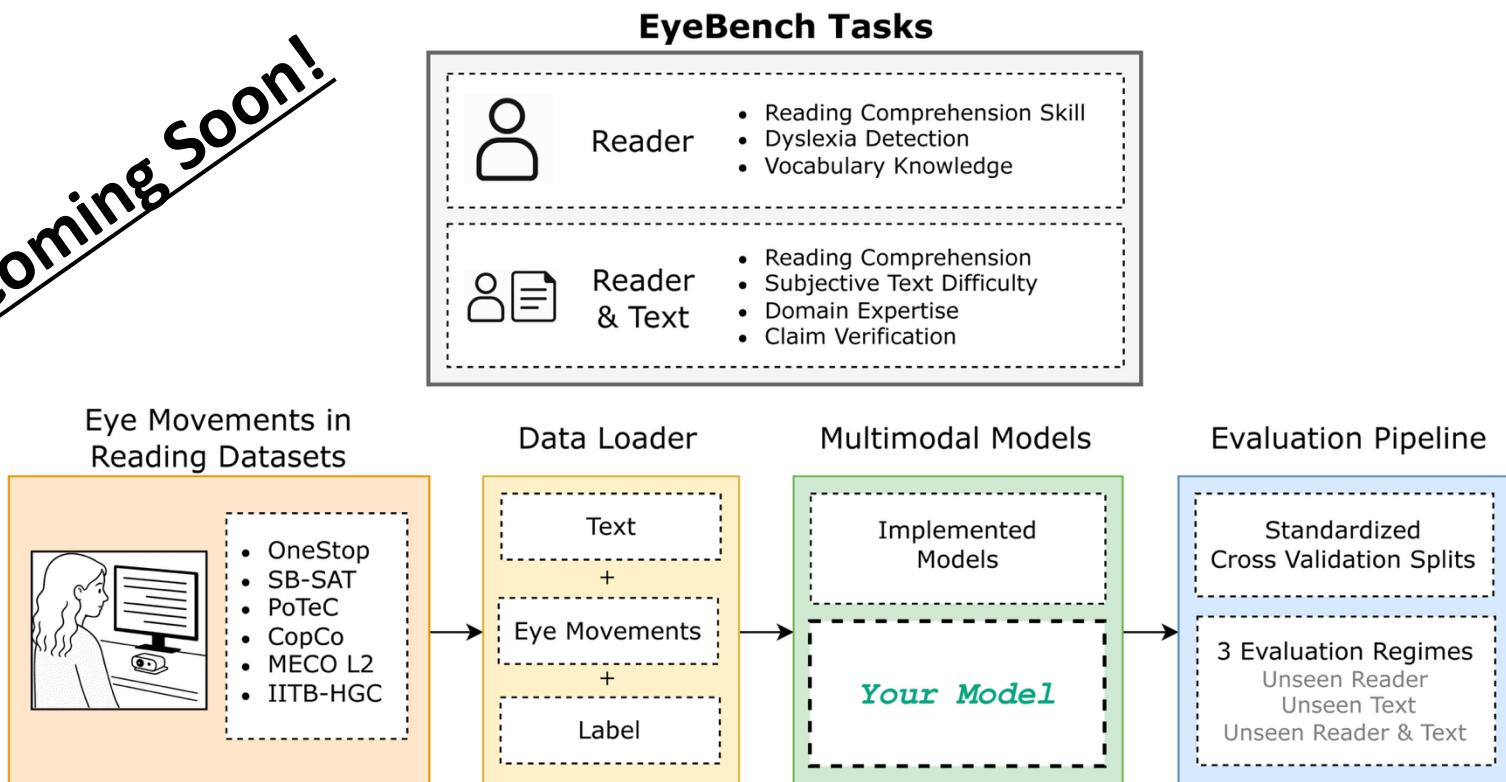
How to get involved? EyeBench!

[EyeBench](#): Predictive Modeling from Eye Movements in Reading

How to get involved? EyeBench!

EyeBench: Predictive Modeling from Eye Movements in Reading

Coming Soon!

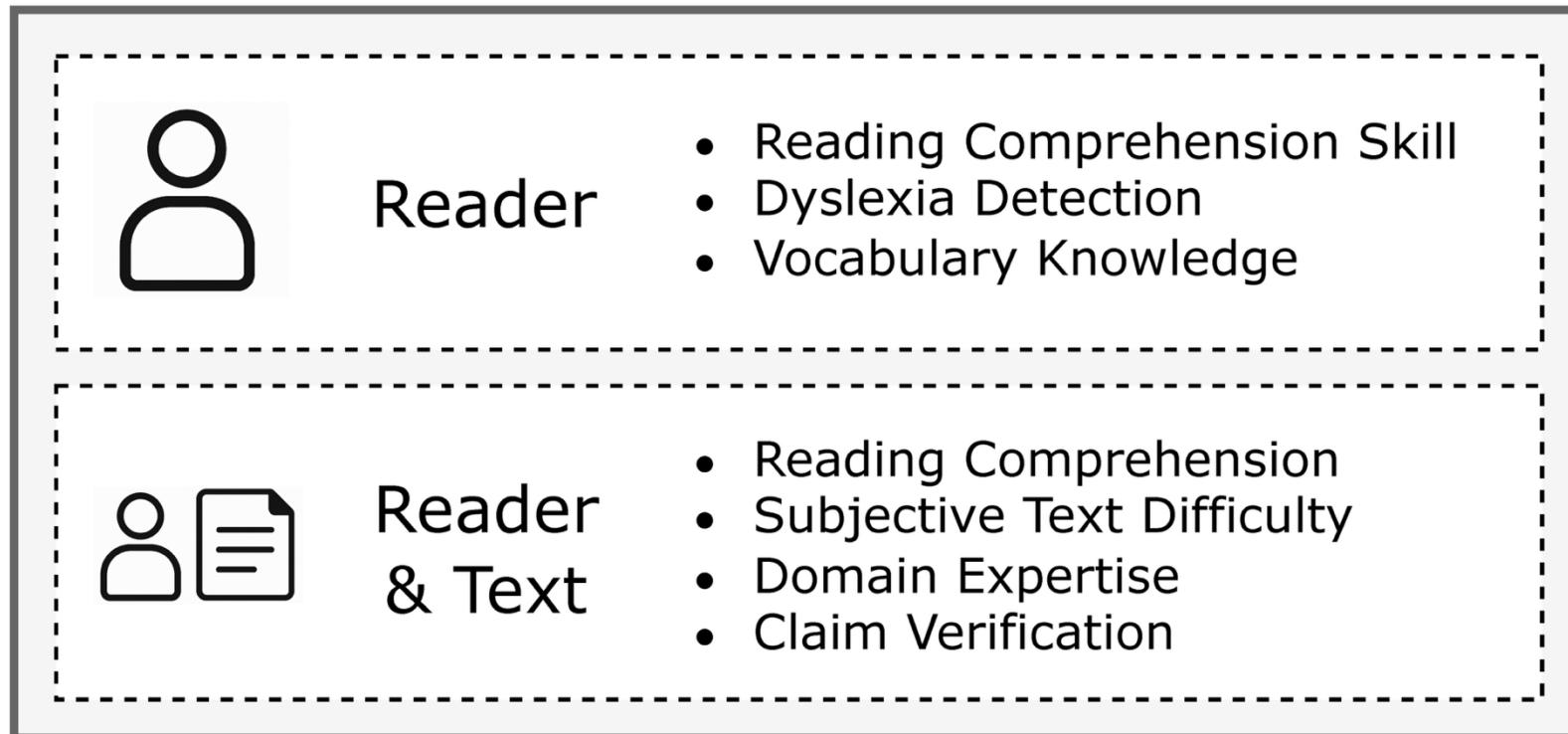


[github.com/
EyeBench](https://github.com/EyeBench)

Shubi, Reich et al. (in prep)

How to get involved? EyeBench!

[EyeBench](#): Predictive Modeling from Eye Movements in Reading

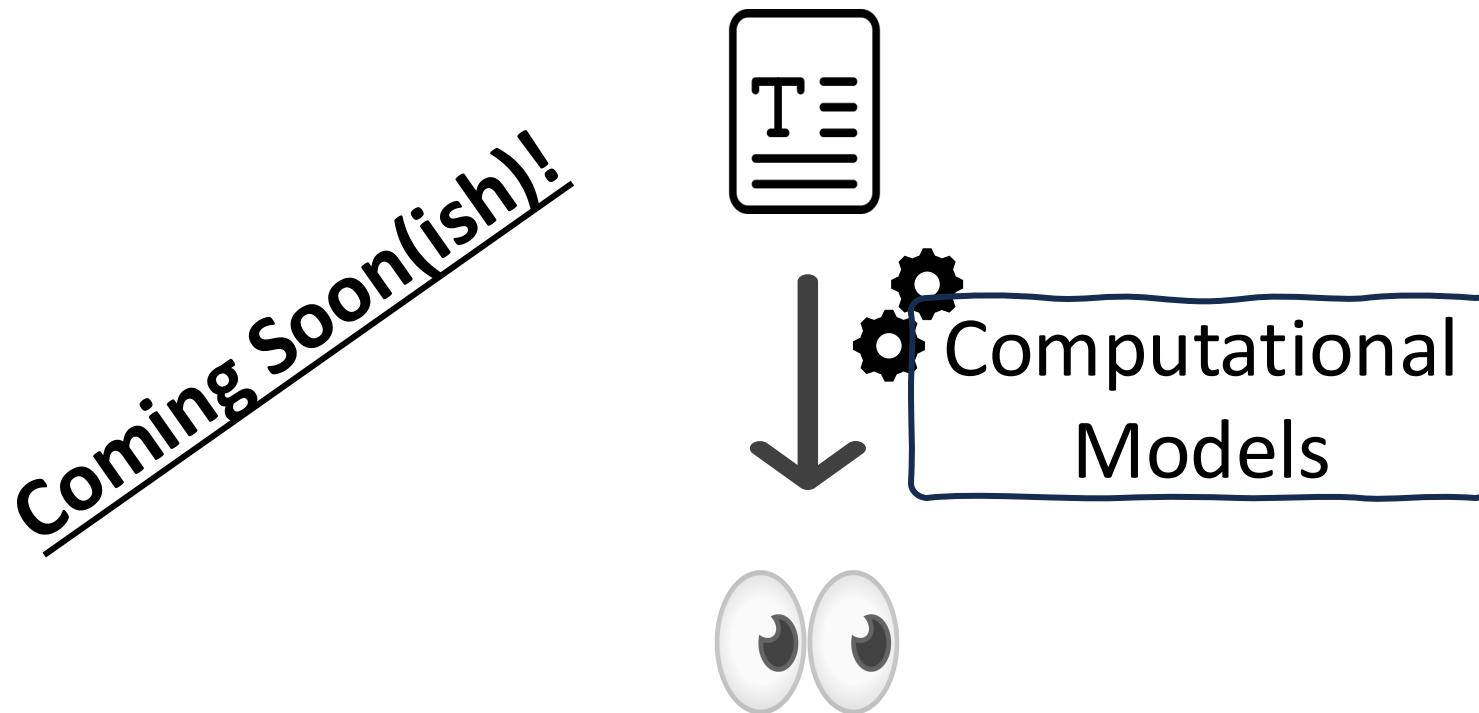


[github.com
/EyeBench](https://github.com/EyeBench)

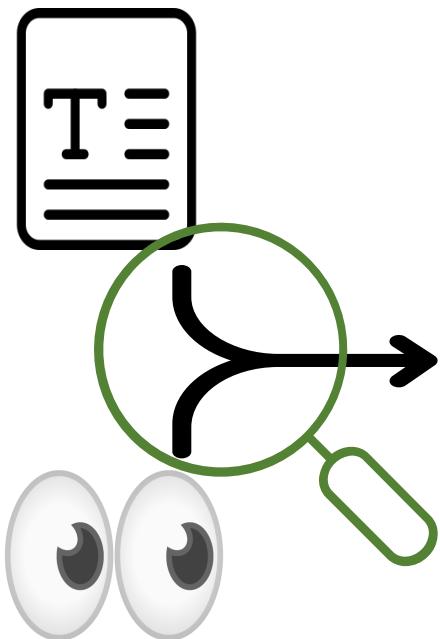
Shubi, Reich et al. (in prep)

Next Up – EyeGenBench!

EyeGenBench: An Evaluation Framework for Models of Eye Movements in Reading



The Future: Interpretability



LLM \longleftrightarrow Human Attention Analysis

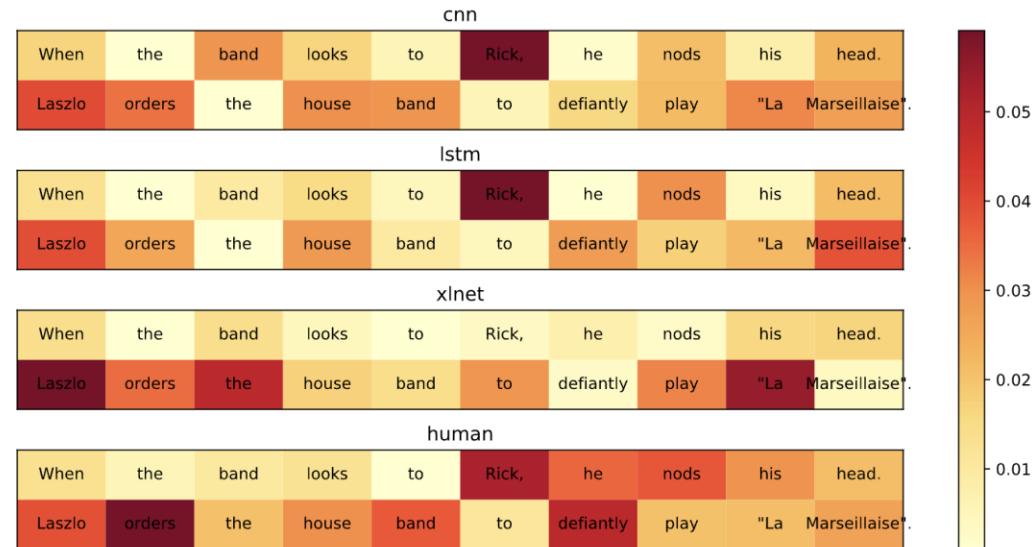
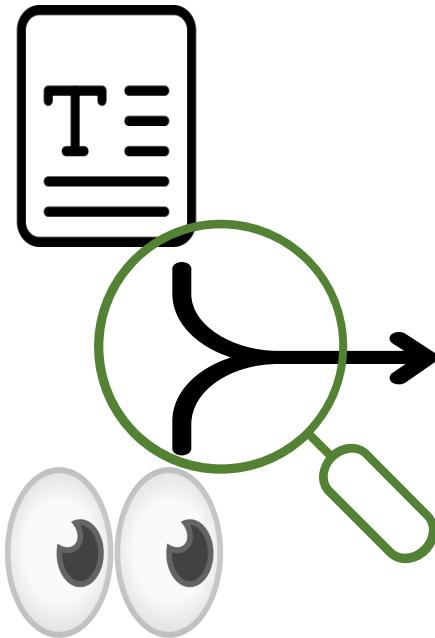


Figure 1: Example attention distributions of neural models (cnn, lstm, xlnet) and humans. [Sood et al. \(2020\)](#)

The Future: Interpretability



Explain and steer models

Identify reading strategies?

Do the models encode reader groups?

What properties are the models sensitive to?

Simulate diverse readers and experiments?

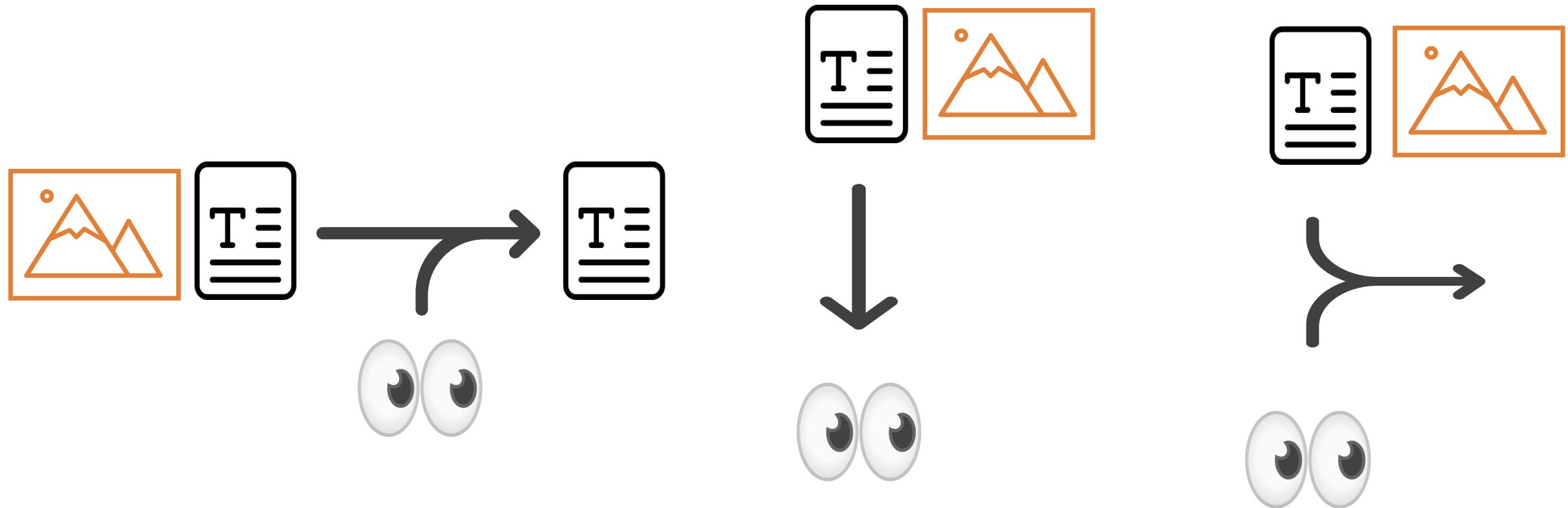
The Future: Cognitive Alignment



Using **eye movements** to make **language models** more **human-like**

- Increasing the relevance of LMs as models of human linguistic processing
- Alignment with different target groups
- Alignment with other cognitive signals (e.g. the brain)
- Practical gains for NLP (e.g. resource efficiency)

The Future: Eye Tracking, Language and Vision



The Future: Eye Tracking, Language and Vision

Building on foundational work on **visual saliency**

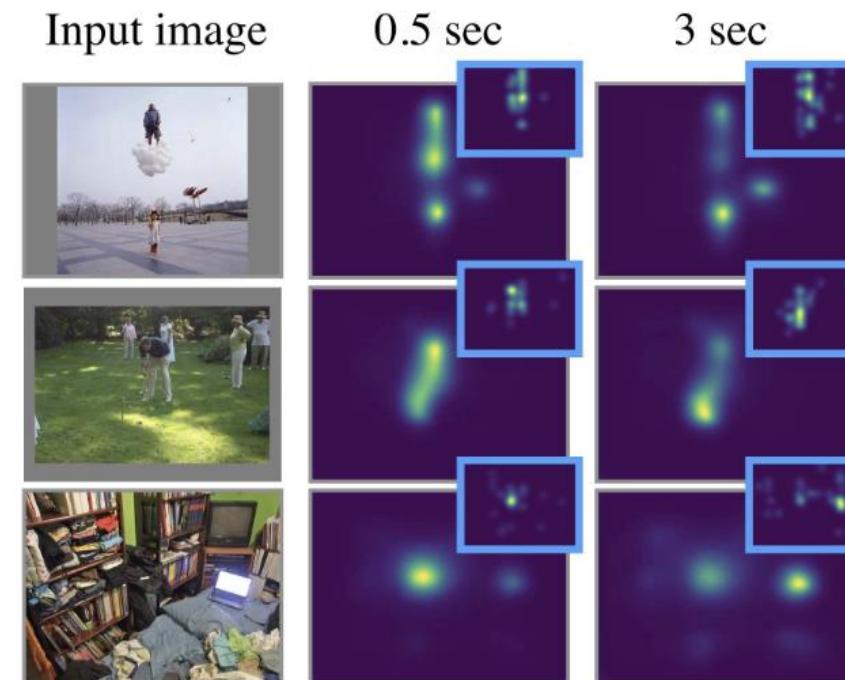
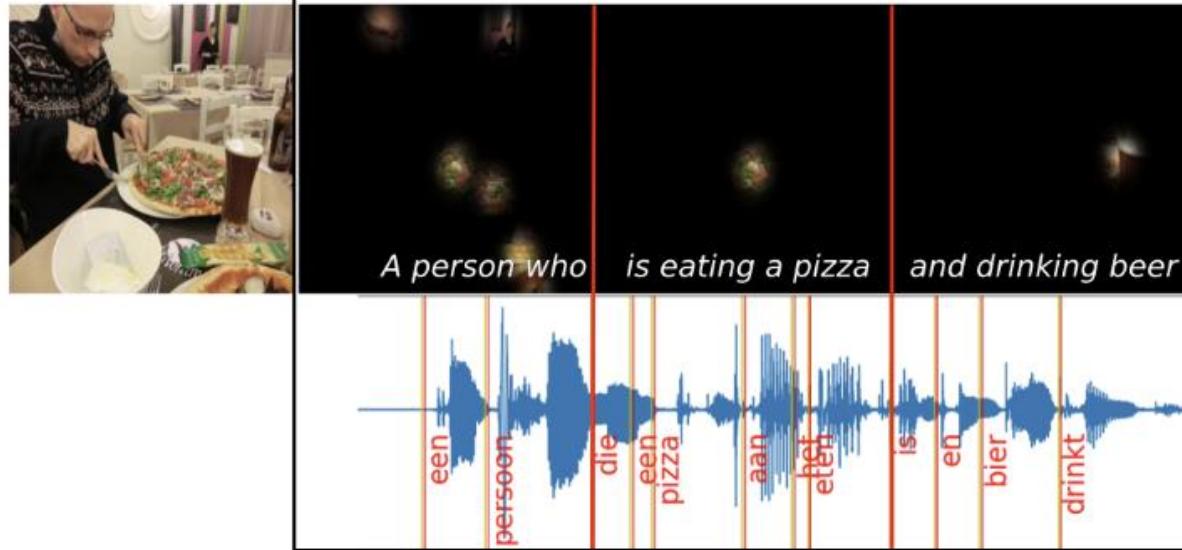


Image from [Fosco et al. \(2020\)](#)

The Future: Eye Tracking, Language and Vision

Image captioning

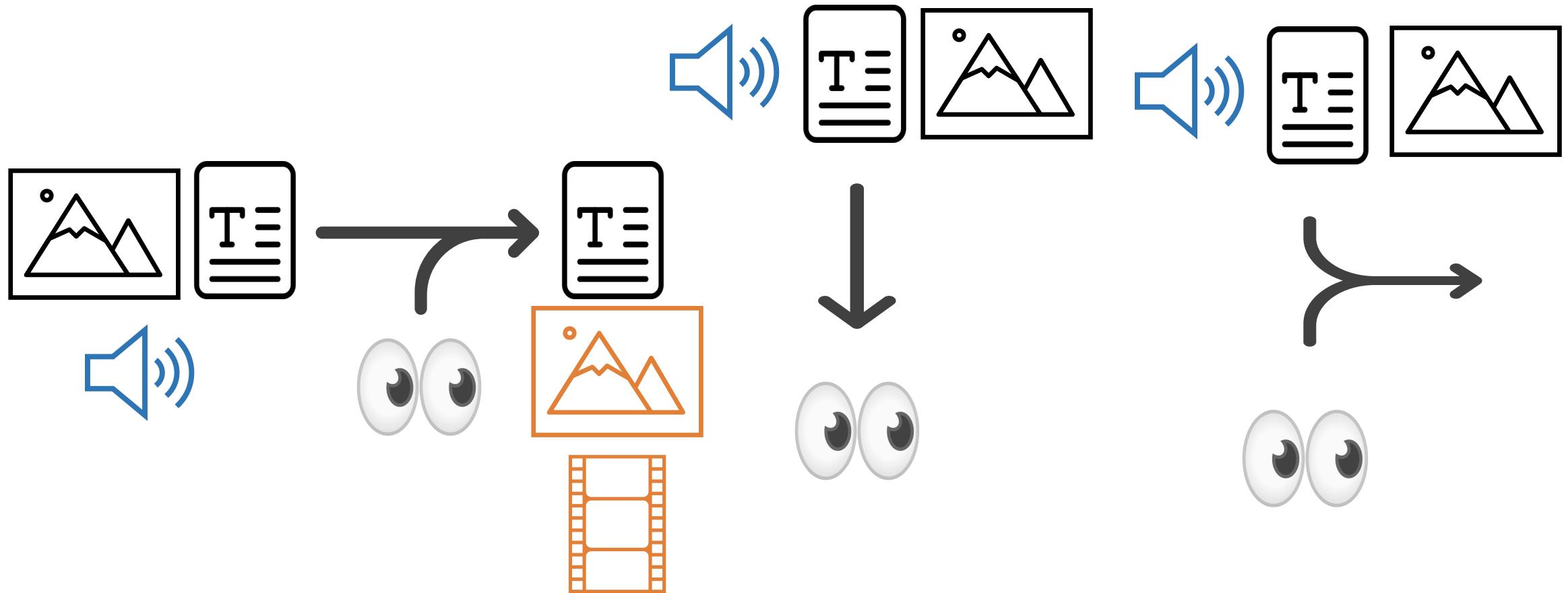
Takmaz et al. (2020)



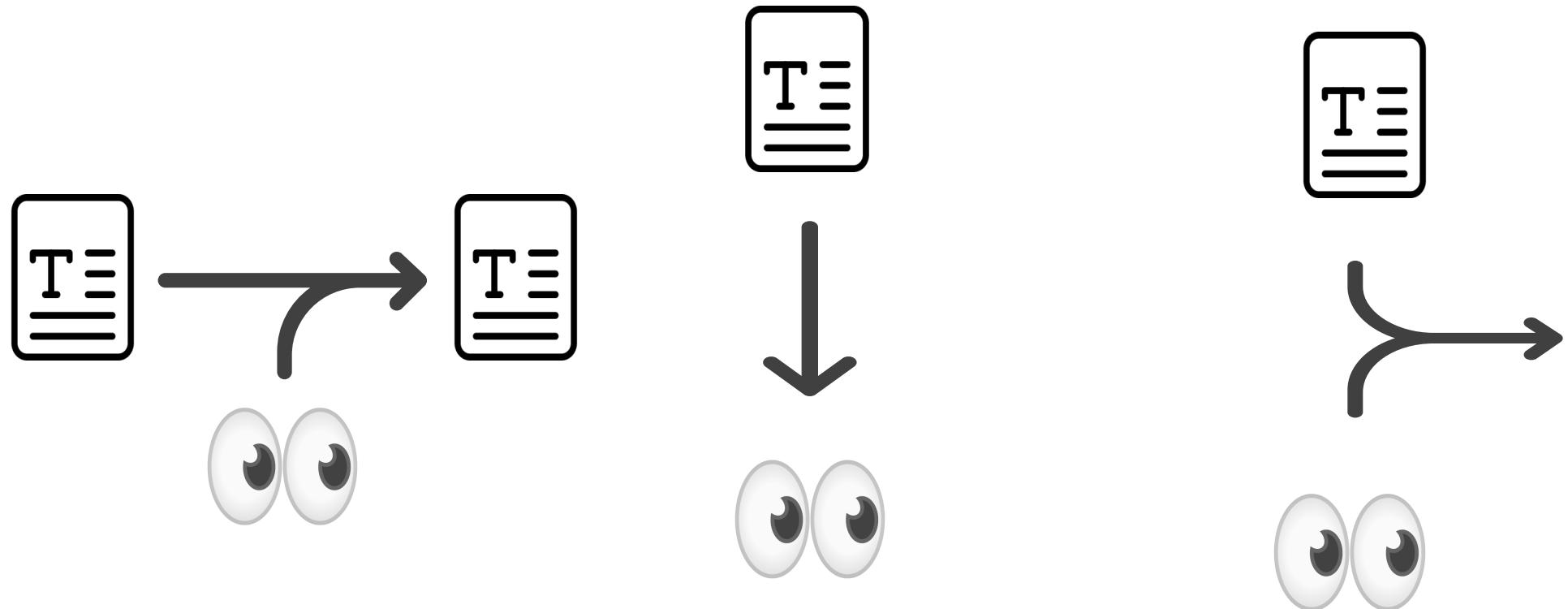
Visual question answering
Sood et al. (2023)



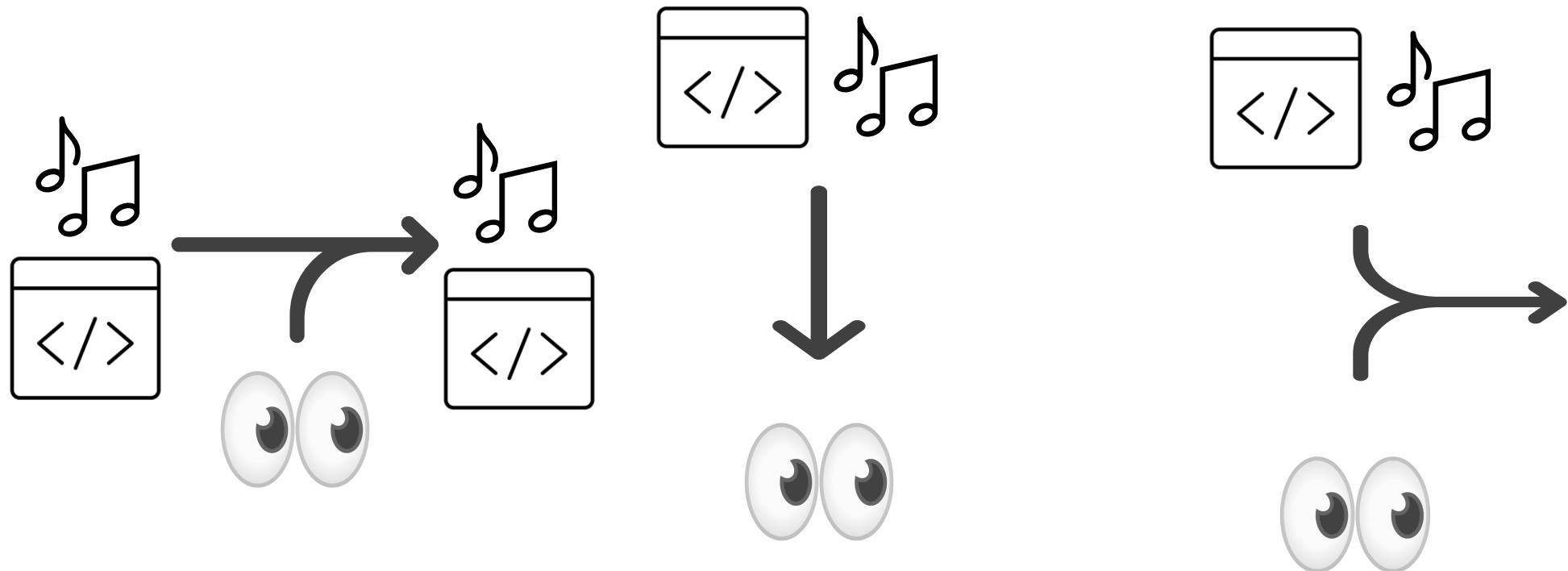
The Future: Eye Tracking, Language and Vision



The Future: Eye Tracking, Language and Vision

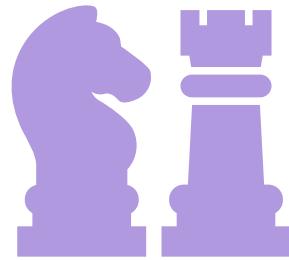


The Future: Eye Tracking, Language and Vision



The Future: Bias, Robustness and Fairness

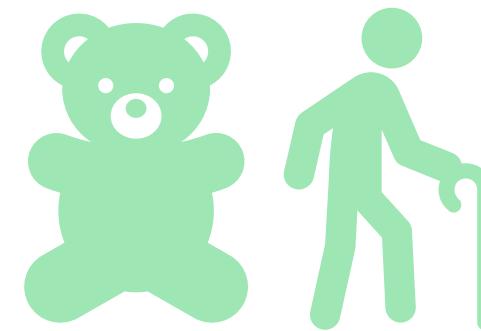
Evaluating and ensuring model performance across groups



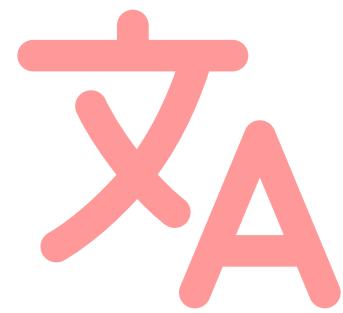
Reading
Strategies



Educational
Background



Age &
Gender



Native Language &
Language Skills

Human Centered NLP with Eye Movements

Open Frontiers



Information accessibility



Education and digital learning

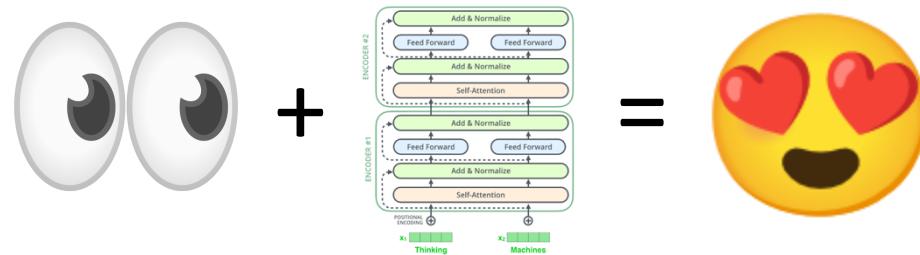


Human-machine communication

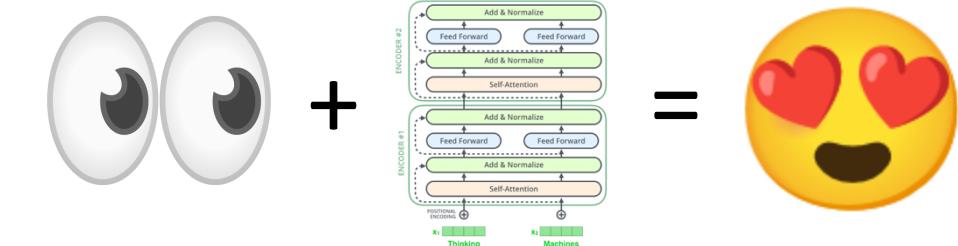
Interactive online systems



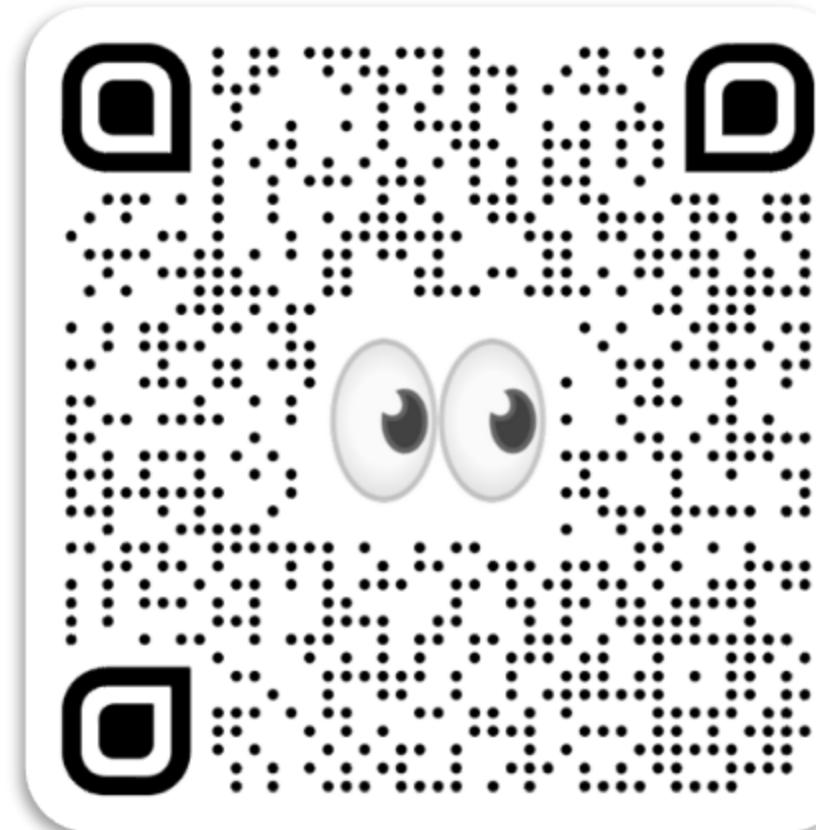
Integrate eye tracking data into YOUR research!



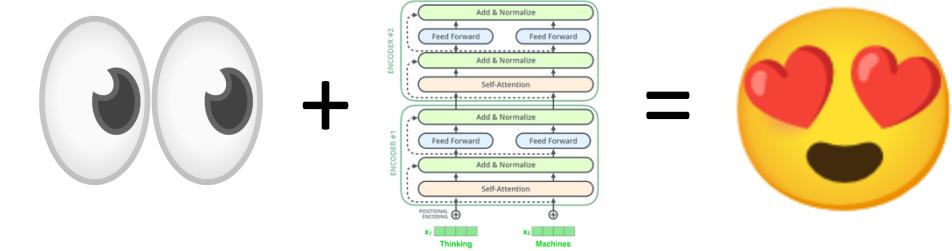
What Now?



Slides and links to additional resources will be available on the [tutorial website](#)



What Now?



Join a new [Discord channel](#) on Eye Tracking and NLP



Eye Tracking and NLP Papers at ACL 2025

Session Details	Title	
Monday, July 28 – 14:00-15:30 Room 1.61 – Session 3: IP-Orals	Déjà Vu? Decoding Repeated Reading from Eye Movements, Meiri et al.	
Monday, July 28 – 18:00-19:30 Hall 4/5 – Session 5: IP-Posters	Beyond the Average Reader: the Reader Embedding Approach, Scozzaro et al. CogSteer: Cognition-Inspired Selective Layer Intervention for Efficiently Steering Large Language Models, Wang et al.	 
Tuesday, July 29 – 10:30-12:00 Hall 4/5 – Session 7: IP-Posters	Exploring the Effect of Nominal Compound Structure in Scientific Texts on Reading Times of Experts and Novices, Landwehr et al.	
	Automatic detection of dyslexia based on eye movements during reading in Russian, Laurinavichyute et al.	
	Decoding Reading Goals from Eye Movements, Shubi et al.	
Wednesday, July 30 – 11:00-12:30 Hall 4/5 – Session 12: IP-Posters	From Human Reading to NLM Understanding: Evaluating the Role of Eye-Tracking Data in Encoder-Based Models, Dini et al.	
	ScanEZ: Integrating Cognitive Models with Self-Supervised Learning for Spatiotemporal Scanpath Prediction, Sood et al.	
	Fine-Grained Spatio-Temporal Modeling of Reading Behavior, Re et al.	

We thank Cui Ding, Jakub Dotlačil, Ece Takmaz and Shachar Frenkel for their support in preparing this tutorial!

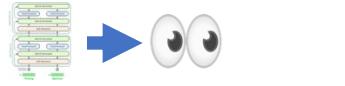
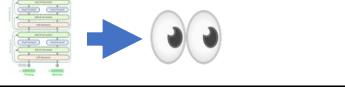
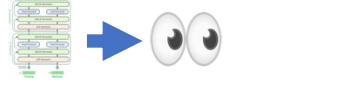
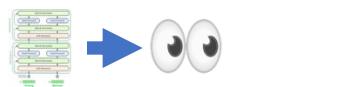


Department of Computational Linguistics



Universität
Zürich^{UZH}

Eye Tracking and NLP Papers at ACL 2025

Session Details	Title	
Monday, July 28 – 14:00-15:30 Room 1.61 – Session 3: IP-Orals	Déjà Vu? Decoding Repeated Reading from Eye Movements, Meiri et al.	
Monday, July 28 – 18:00-19:30 Hall 4/5 – Session 5: IP-Posters	Beyond the Average Reader: the Reader Embedding Approach, Scozzaro et al. CogSteer: Cognition-Inspired Selective Layer Intervention for Efficiently Steering Large Language Models, Wang et al.	 
Tuesday, July 29 – 10:30-12:00 Hall 4/5 – Session 7: IP-Posters	Exploring the Effect of Nominal Compound Structure in Scientific Texts on Reading Times of Experts and Novices, Landwehr et al.	
Wednesday, July 30 – 11:00-12:30 Hall 4/5 – Session 12: IP-Posters	Automatic detection of dyslexia based on eye movements during reading in Russian, Laurinavichyute et al.	
	Decoding Reading Goals from Eye Movements, Shubi and Hadar et al.	
	From Human Reading to NLM Understanding: Evaluating the Role of Eye-Tracking Data in Encoder-Based Models, Dini et al.	
	ScanEZ: Integrating Cognitive Models with Self-Supervised Learning for Spatiotemporal Scanpath Prediction, Sood et al.	
	Fine-Grained Spatio-Temporal Modeling of Reading Behavior, Re et al.	

Ethical Considerations

- **Informed Consent** – Collect data only with IRB approval and written participant consent.
- **Privacy Protection** – Keep data anonymized; avoid storing information enabling user identification.
- **Responsible Use** – Only with explicit consent.
- **Bias Awareness** – Validate models for fairness, especially for L2 learners, cognitive/visual impairments.
- **Transparency** – Clearly communicate risks, limitations, and intended uses of predictive systems.

The Future

