(Advanced) Natural Language Processing

Jacob Andreas / MIT 6.806-6.864 / Spring 2020

An alien broadcast

f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z

chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz

o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42

kj8l4z38h42jehze5zj78iz1h8j8i7z8d3kijh80bz2ed6bec4h0j4z05ehcze5z0i14ijeized24zki

43zjezc0a4za4djz2860h4jj4z58bj4hiz70iz20ki43z0z7867f4h24dj064ze5z20d24hz340j7iz0

ced6z0z6hekfze5zmeha4hiz4nfei43zjez8jzceh4zj70dztqo40hiz06ezh4i40h274hizh4fehj43

zj74z0i14ijeiz5814hz2he283eb8j4z8izkdkik0bboh4i8b84djzed24z8jz4dj4hizj74zbkd6izm

8j7z4l4dz1h845z4nfeikh4izjez8jz20ki8d6iocfjecizj70jzi7emzkfz342034izb0j4hzh4i40h

Predictability

```
f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z
chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz
o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42
```

$$p(X_t \mid X_{1:t-1})$$

Can I guess what character is coming next?

Predictability

```
f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z
chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz
o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42
```

$$p(8 \mid 63b3z)$$

Can I guess what character is coming next?

Predictability

```
f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z
chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz
o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42
```

$$p(8 \mid \cancel{63b3}z) = \frac{\#(z\ 8)}{\#(z)}$$

e.g. by counting frequencies?

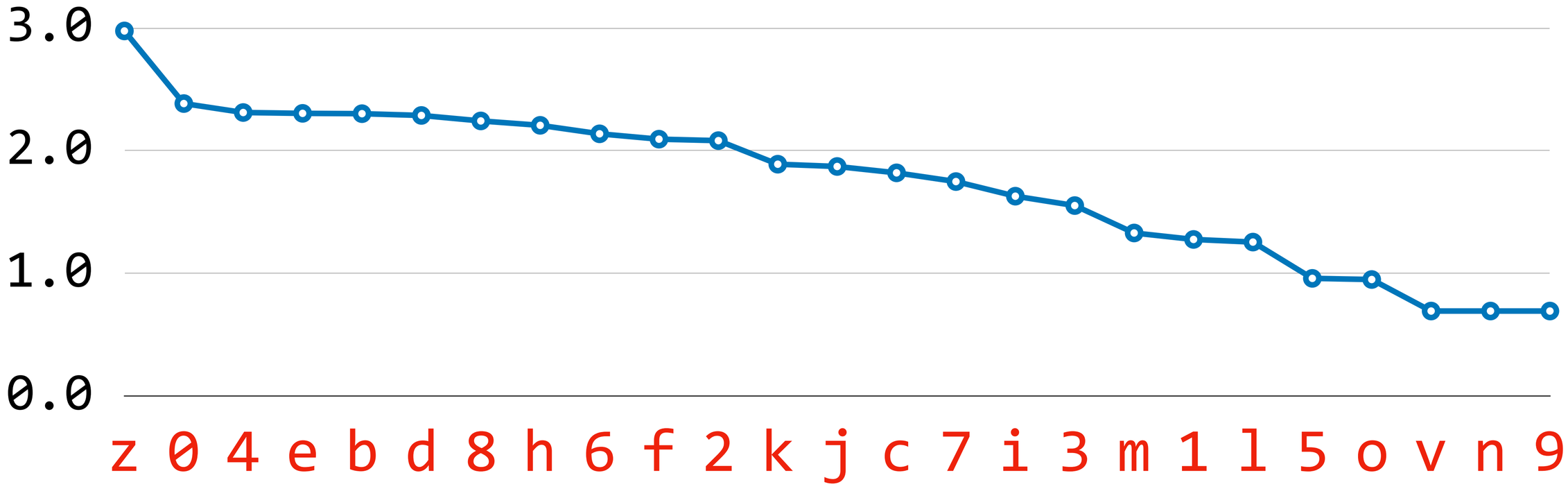
Predictability

```
f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z
chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz
o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42
```

$$H(X_t \mid \mathtt{z}) = -\sum_{x} p(x_t \mid \mathtt{z}) \log p(x_t \mid \mathtt{z})$$

How much uncertainty do I have about the next character, given that the last one was a z?

Predictability



$$H(X_t \mid x_{t-1})$$

Predictability

f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z

chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz

o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42

Hypothesis: “islands of local predictability”

Discrete structure?

f84hh4-l8da4d-wr-o40hi-eb3-m8bb-9e8d-j74-1e0h3-0i-0-ded4n42kj8l4-38h42jeh-dels9-

ch-l8da4d-8i-2708hc0d-e5-4bi4l84h-dl-j74-3kj27-fk1b8i78d6-6hekfhk3ebf7-06d4m-vv-

o40hi-eb3-0d3-5ehc4h-2708hc0d-e5-2edieb830j43-6eb3-584b3i-fb2m0i-d0c43-0-ded4n42

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f84hh4-l8da4d-wr-o40hi-eb3-m8bb-9e8d-j74-1e0h3-0i-0-ded4n42kj8l4-38h42jeh-dels9-ch-l8da4d-8i-2708hc0d-e5-4bi4l84h-dl-j74-3kj27-fk1b8i78d6-6hekfhk3ebf7-06d4m-vv-o40hi-eb3-0d3-5ehc4h-2708hc0d-e5-2edieb830j43-6eb3-584b3i-fb2m0i-d0c43-0-ded4n42

This segmentation reveals lots of repeated units!

Ordering rules?

1o-j74-kic1-5hec-r9xv-j7hek67-r9yx-j74-0dc2-74b3-0-i4h84i-e5-m4bb-0jj4d343-0ddk0b-2ed54h4d24i-ik1i4gk4djbo-0-i4h84i-e5-d0j8ed0b-c4jh82-2ed54h4d24i-9e8djbo-ifedieh43-1o-j74-0dc2-j74-ki-c4jh82-0iie280j8ed-kic0-j74-34f0hjc4dj-e5-2ecc4h24-0d3-j74-d0j8ed0b-8dij8jkj4-e5-ij0d30h3i-0d3-j427debe6o-d8ij-m4h4-74b3-5hec-r9yx-j7hek67-r99t

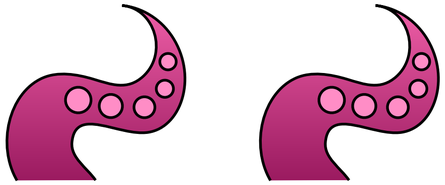
Some units seem to occur in similar contexts.

Alien e-commerce

f84hh4-l8da4d-wr-o40hi-r99t

m8bb-9e8d-j74-1e0h3-0i-0-de

d4n42kj8l4-38h42jeh-dels9-x

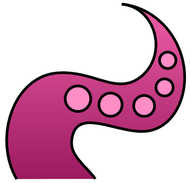


o40hi-eb3-0d3-5ehc4h-2708hc

0d-e5-2edieb830j43-6eb3-584

b3i-fb2m0i-d0c43-0-ded4n42-

kj8l4-38h42jeh-e5-r99t-1h8j

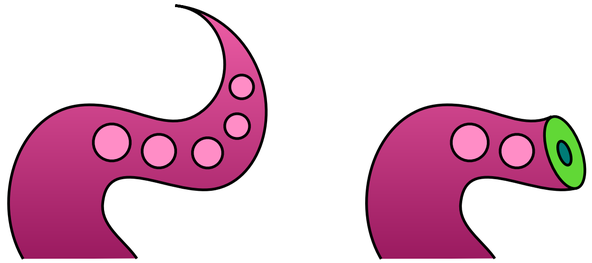


These units co-occur with features of the world described by the messages

Photos: KTS Design/ Science Photo Library/Getty Images, Amazon

Predicting grounded meanings

f84hh4-l8da4d-wr-o40hi-eb3-m8bb-r9yx-j74-1e0h3-0i-0-ded4n42kj8l4-38h42jeh-dels9-ch-l8da4d-8i-2708hc0d-e5-4bi4l84h-dl-j74-3kj27-fk1b8i78d6-6hekfhk3ebf7-06d4m-vv-o40hi-eb3-0d3-5ehc4h-2708hc0d-e5-2edieb830j43-6eb3-584b3i-fb2m0i-d0c43-0-ded4n42

$p($  $| X_{1:t})$

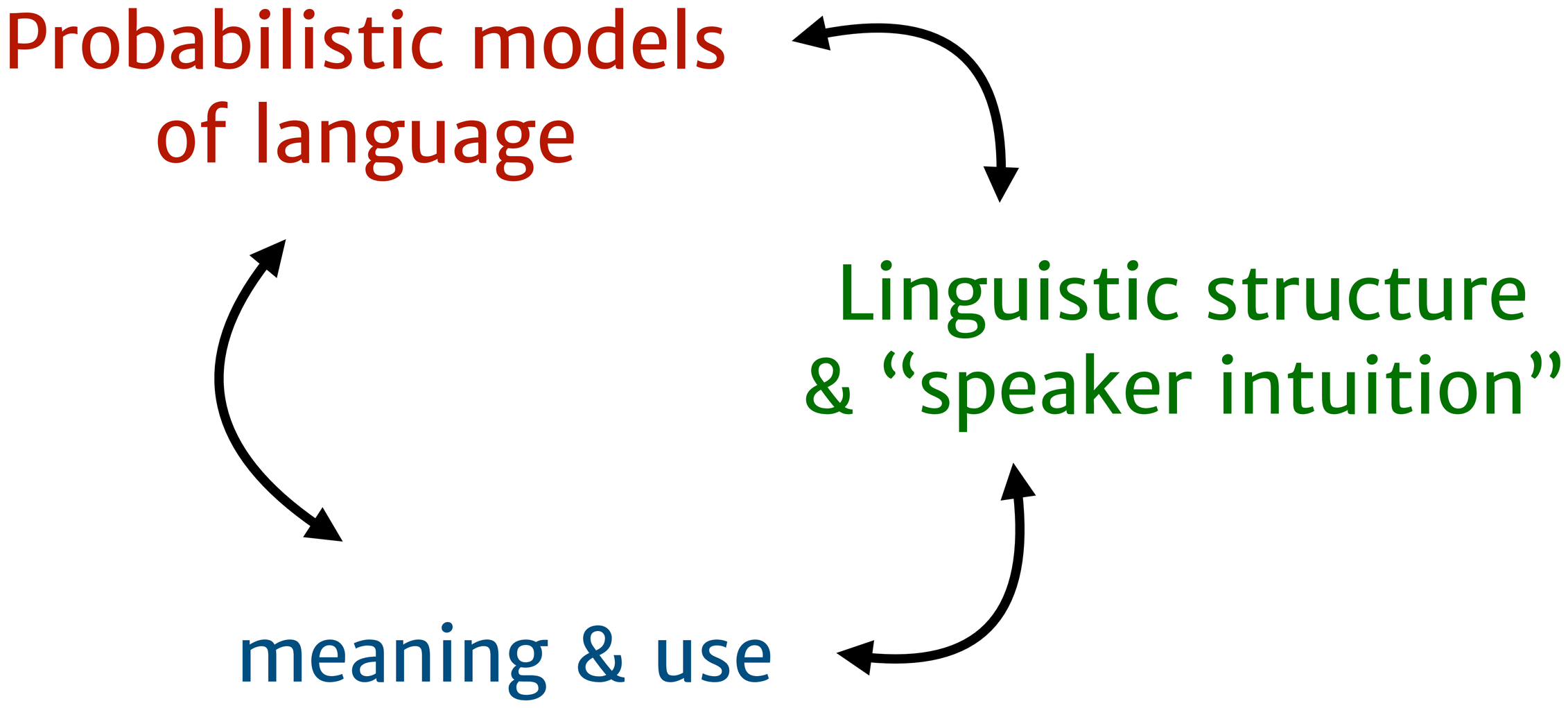
$| \texttt{r9yx})$

and help us accurately predict the context (and meaning?) of new messages

Questions: controlled generation

$$p(\texttt{qxx} - \texttt{93ar} \mid \textbf{take me to your leader})$$

or even to generate new messages based on meanings we want to communicate.


Probabilistic models of language
Linguistic structure & “speaker intuition”
meaning & use

f84hh4zl8da4dzwrzo40hizeb3zm8bbz9e8dzj74z1e0h3z0iz0zded4n42kj8l4z38h42jehzdels9z

chzl8da4dz8iz2708hc0dze5z4bi4l84hzdlzj74z3kj27zfk1b8i78d6z6hekfhk3ebf7z06d4mzvvz

o40hizeb3z0d3z5ehc4hz2708hc0dze5z2edieb830j43z6eb3z584b3izfb2m0izd0c43z0zded4n42

kj8l4z38h42jehze5zj78iz1h8j8i7z8d3kijh80bz2ed6bec4h0j4z05ehcze5z0i14ijeized24zki

43zjezc0a4za4djz2860h4jj4z58bj4hiz70iz20ki43z0z7867f4h24dj064ze5z20d24hz340j7iz0

ced6z0z6hekfze5zmeha4hiz4nfei43zjez8jzceh4zj70dztqo40hiz06ezh4i40h274hizh4fehj43

zj74z0i14ijeiz5814hz2he283eb8j4z8izkdkik0bboh4i8b84djzed24z8jz4dj4hizj74zbkd6izm

8j7z4l4dz1h845z4nfeikh4izjez8jz20ki8d6iocfjecizj70jzi7emzkfz342034izb0j4hzh4i40h

This is what all datasets look like to NLP models

((Human (language)) (processing))

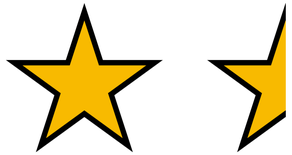
Language as input

Text classification

(input)

This film will ruin your childhood.

(output)



Language as input

Machine translation

(input)

Le programme a été mis en application.

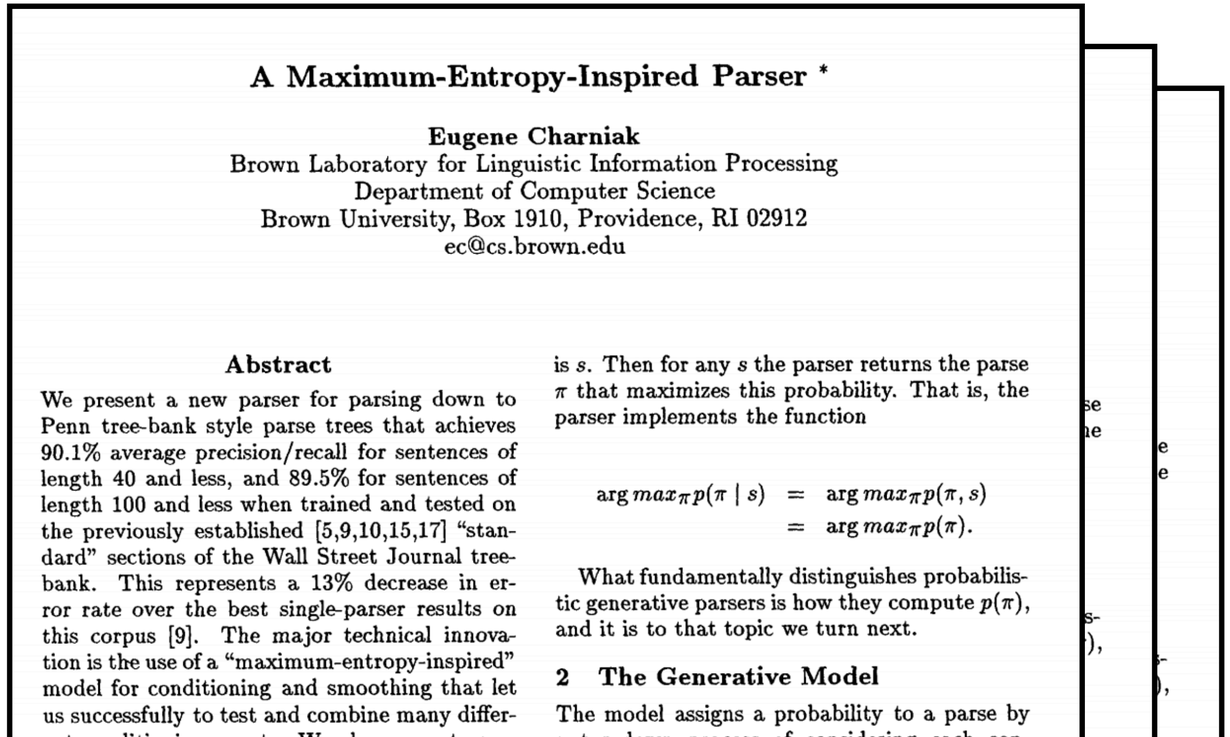
(output)

The program was implemented.

Language as input

Automatic summarization

(input)



A Maximum-Entropy-Inspired Parser *

Eugene Charniak
Brown Laboratory for Linguistic Information Processing
Department of Computer Science
Brown University, Box 1910, Providence, RI 02912
ec@cs.brown.edu

Abstract

We present a new parser for parsing down to Penn tree-bank style parse trees that achieves 90.1% average precision/recall for sentences of length 40 and less, and 89.5% for sentences of length 100 and less when trained and tested on the previously established [5,9,10,15,17] "standard" sections of the Wall Street Journal tree-bank. This represents a 13% decrease in error rate over the best single-parser results on this corpus [9]. The major technical innovation is the use of a "maximum-entropy-inspired" model for conditioning and smoothing that let us successfully to test and combine many differ-

is s. Then for any s the parser returns the parse π that maximizes this probability. That is, the parser implements the function

$$\begin{aligned} \arg max_{\pi} p(\pi \mid s) &= \arg max_{\pi} p(\pi, s) \\ &= \arg max_{\pi} p(\pi). \end{aligned}$$

What fundamentally distinguishes probabilistic generative parsers is how they compute $p(\pi)$, and it is to that topic we turn next.

2 The Generative Model

The model assigns a probability to a parse by

(output)

We present a new parser for the Penn Treebank. The parser achieves 90% accuracy using a "maximum-entropy-inspired" model for conditioning and smoothing that let us combine many different conditioning events.

Language as output

Generation from structured data

(input)

Frederick Parker-Rhodes	
Born	21 November 1914 Newington, Yorkshire
Died	2 March 1987 (aged 72)
Residence	UK
Nationality	British
Fields	Mycology, Plant Pathology, Mathematics, Linguistics, Computer Science
Known for	Contributions to computational linguistics, combinatorial physics, bit-string physics, plant pathology, and mycology

(output)

Frederick Parker-Rhodes (21 March 1914 – 21 November 1987) was an English linguist, plant pathologist, computer scientist, mathematician, mystic, and mycologist.

[Lebret et al. 2016]

Language as interface

Task-oriented dialog

What do I have today?

```
You have five events scheduled. The
first is a one-on-one with Anjali.
```

Can you reschedule that for tomorrow at the same time?

```
Sure, I've sent an email to let her
know.
```

Can you add a cram session with Nick and his manager? We'll need a room on the 10th floor.

[Microsoft / Semantic Machines]

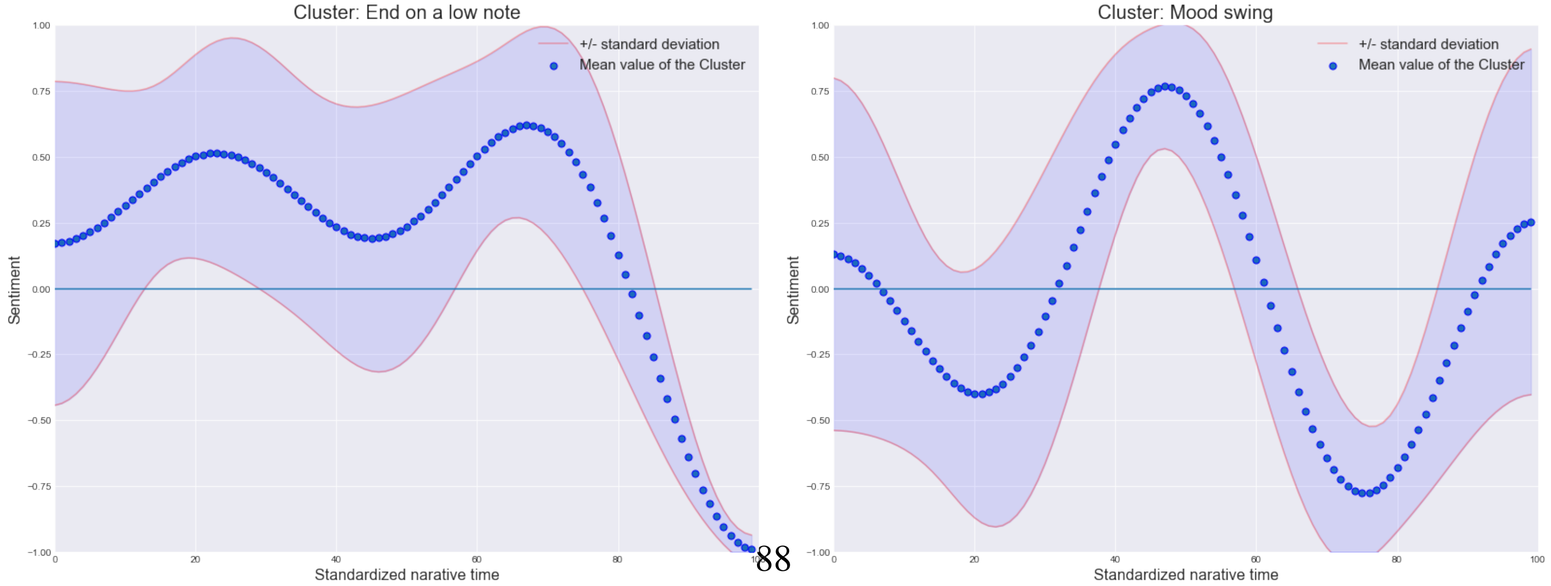
Instruction following

[Tellex et al., 2011]

Language as data

Computational social science

sentiment trajectories in Youtube videos



predictiveness of political stance

	Political leaning	
Cluster	Left	Right
Rags to riches	-0.96	0.96
Riches to rags	1.09	-1.09
Downhill from here	-3.25*	3.25*
End on a high note	1.28	-1.28
Uphill from here	2.74*	-2.74*
End on a low note	-2.44	2.44
Mood swing	1.13	-1.13

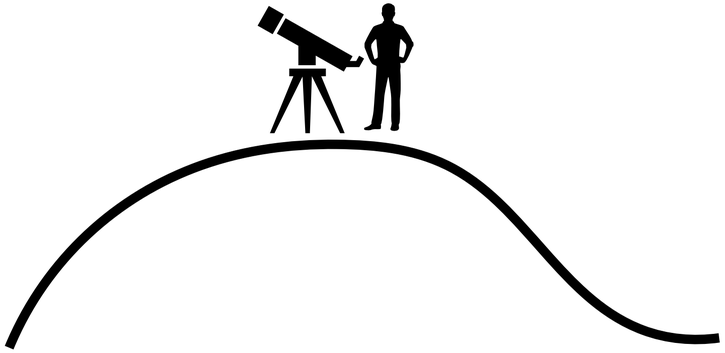
[Soldner et al., 2019]

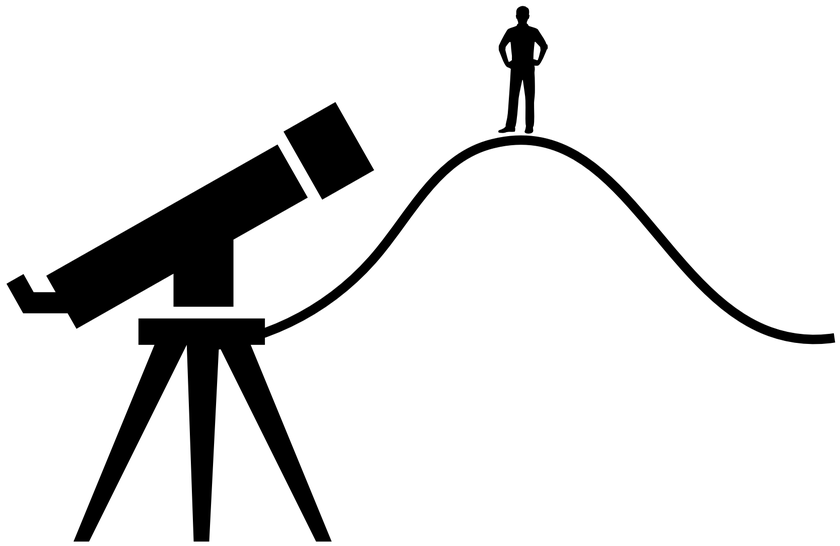
Our toolbox

Probabilistic modeling

I saw the man on the hill with the telescope.

Probabilistic modeling



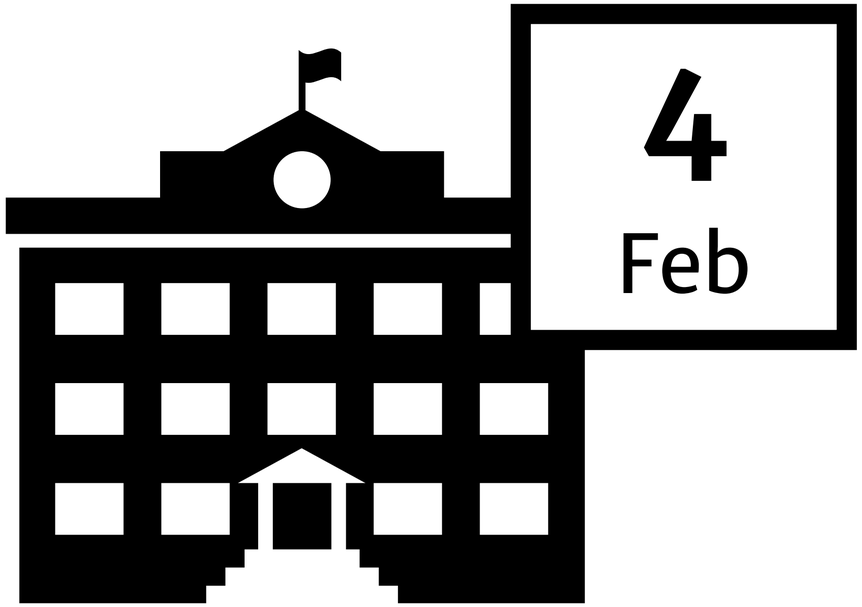


I saw the man on the hill with the telescope.

Probabilistic modeling

I went to the restaurant on February 4th.

Probabilistic modeling



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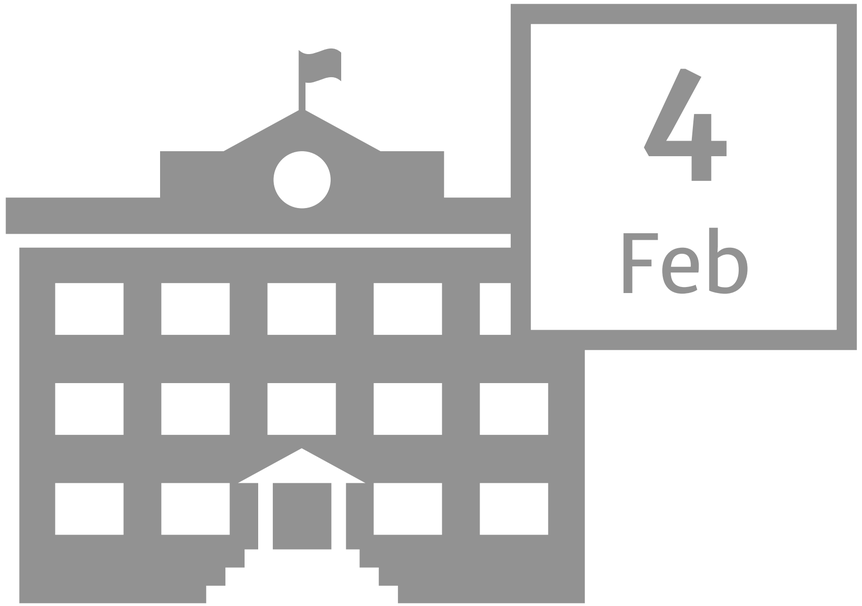
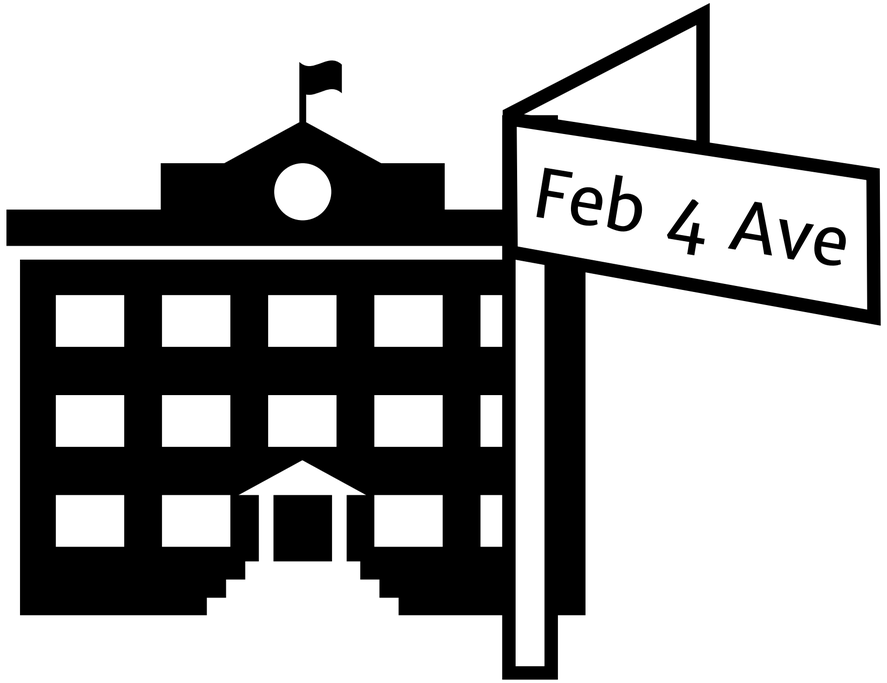
Probabilistic modeling





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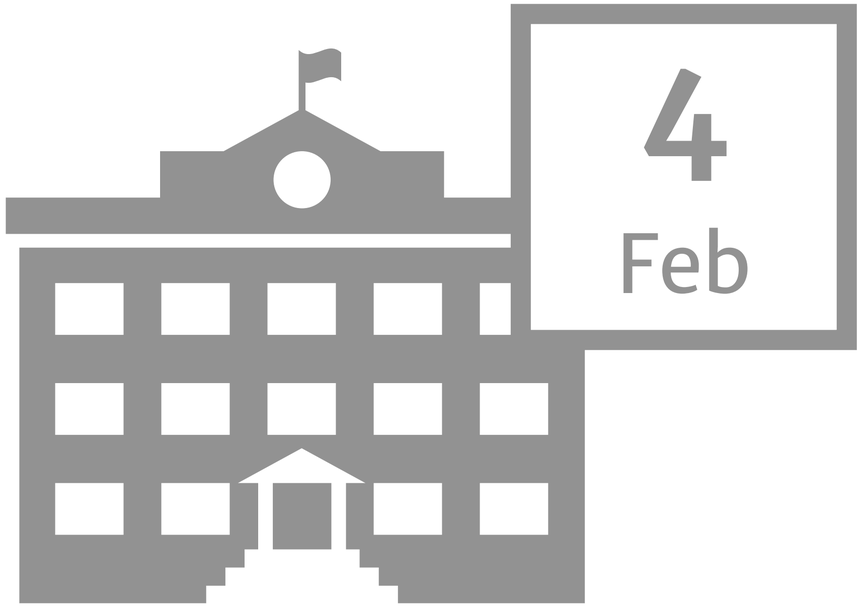
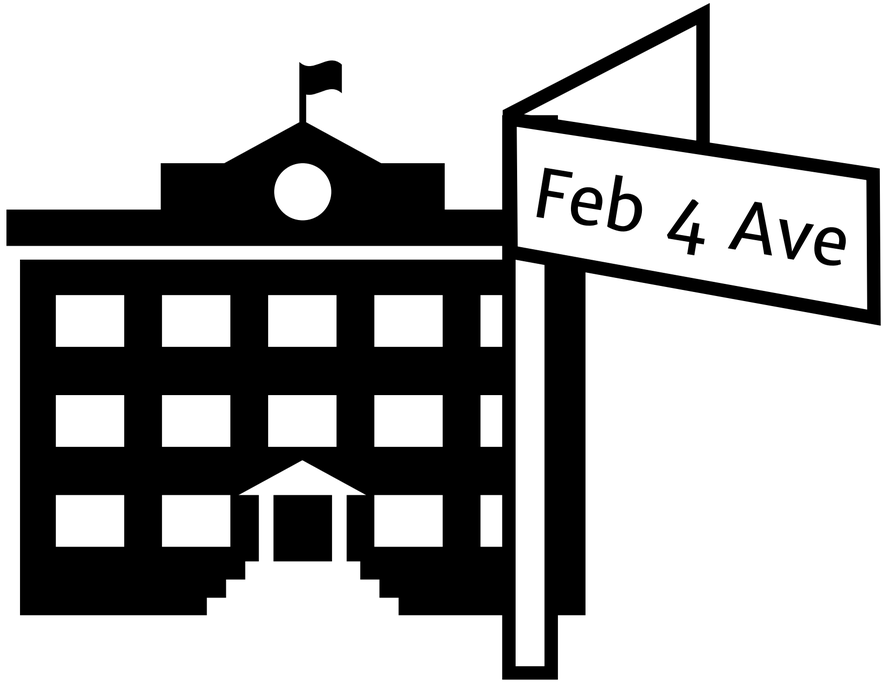
Probabilistic modeling

Probabilistic modeling





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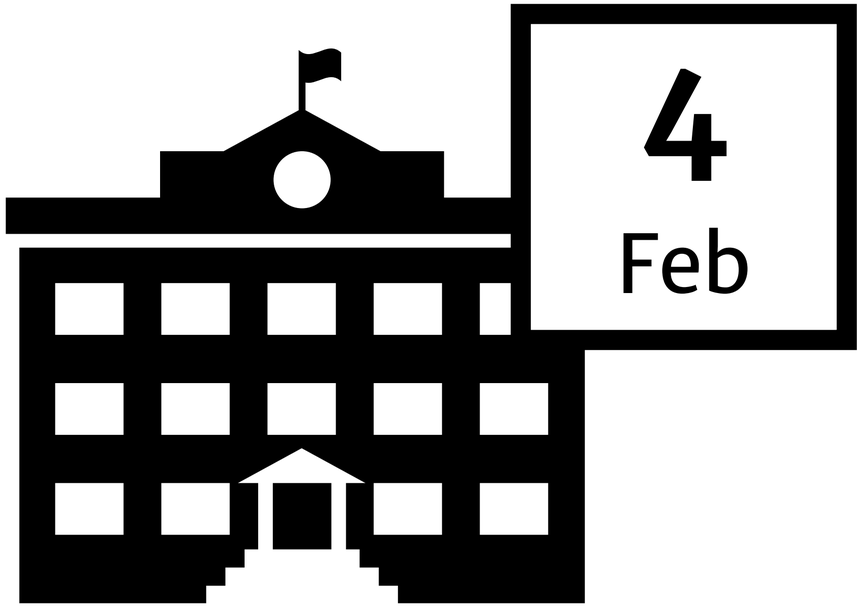
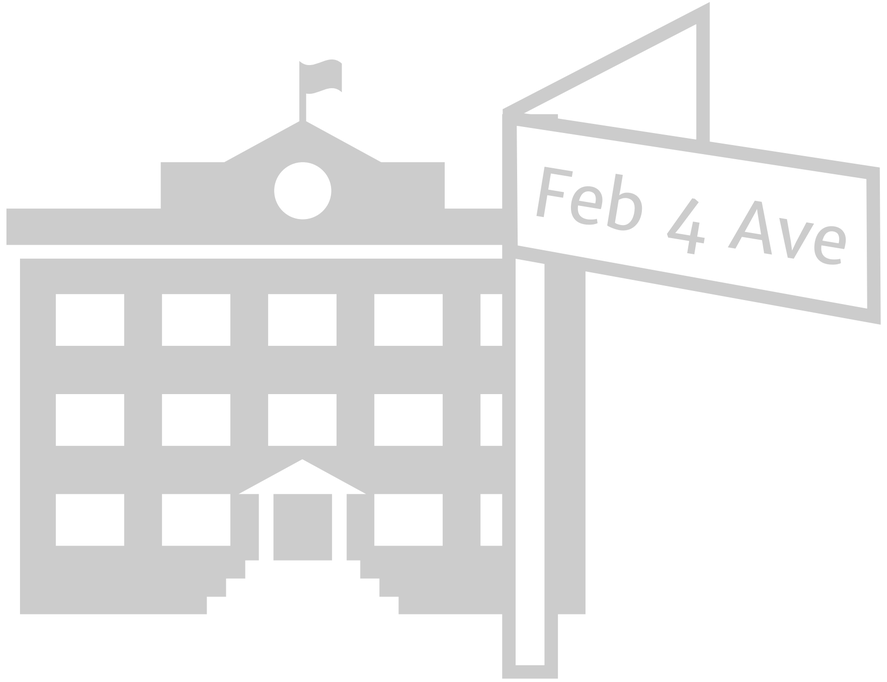
Probabilistic modeling





I went to the restaurant on February 4th.

Probabilistic modeling

$p(\text{a quick brown fox} \mid \text{jumps over the lazy dog})$

$p(\text{jumps over the lazy dog} \mid \text{a quick brown fox})$

$p(\text{a quick brown fox})$ $p(\text{jumps over the lazy dog})$

We need to predict which interpretations are **allowed**, and which are **most likely**.

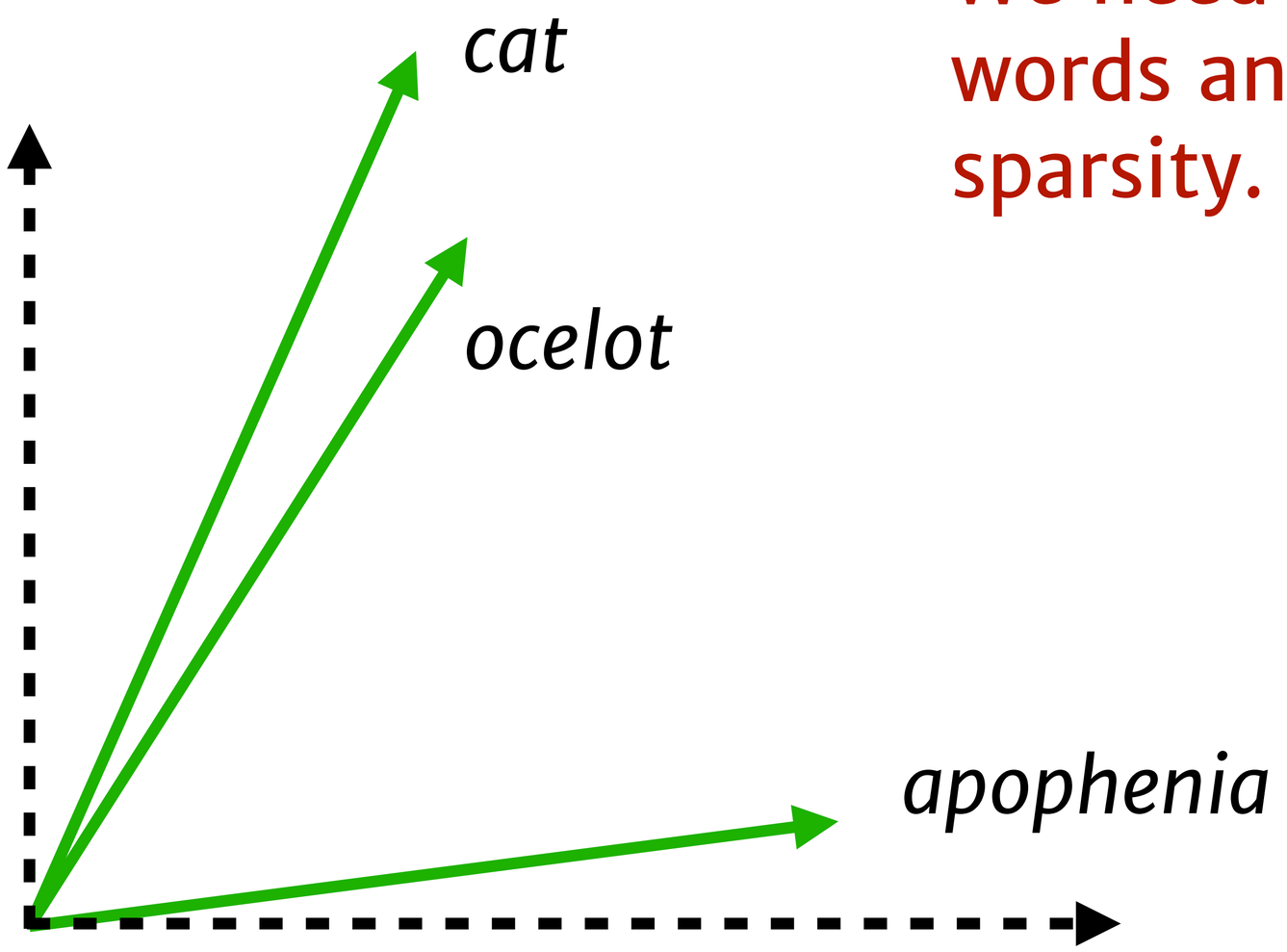
Machine learning

$$p_\theta(\text{a quick brown fox}) \propto \exp\{\theta^\top(f(\text{a}) + f(\text{quick}) + \cdots)\}$$

$$\theta^* = \text{argmin}_\theta \sum_{\text{sentence}} -\log(p_\theta(\text{sentence}))$$

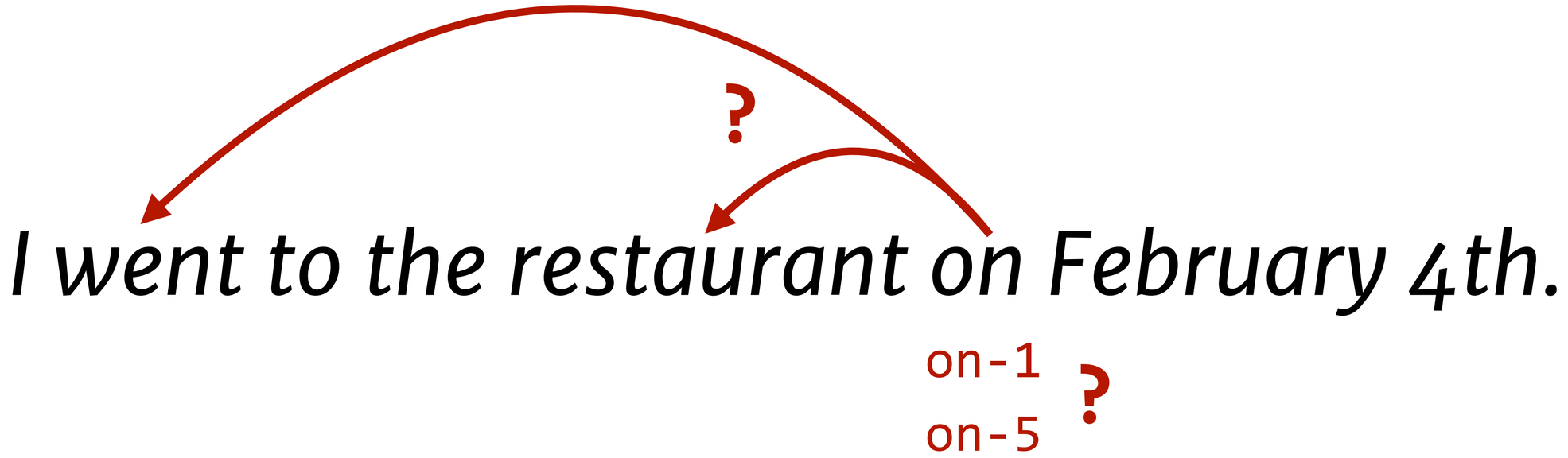
We need to estimate these probability distributions **from corpus data.**

Representation learning



We need to share information across words and tasks to handle with data sparsity.

Linguistics



We need to constrain the space of **interesting prediction problems** (and relevant features ?) and **form hypotheses about model behavior**.

Admin

Prereq: probability

$p(\text{a quick brown fox} \mid \text{jumps over the lazy dog})$

$p(\text{jumps over the lazy dog} \mid \text{a quick brown fox})$

$p(\text{a quick brown fox})$

$p(\text{jumps over the lazy dog})$

Prereq: intro ML

$$p_\theta(\text{a quick brown fox}) \propto \exp\{\theta^\top(f(\text{a}) + f(\text{quick}) + \cdots)\}$$

$$\theta^* = \text{argmin}_\theta \sum_{\text{sentence}} -\log(p_\theta(\text{sentence}))$$

Prereq: algorithms & discrete math

a	*quick*	*brown*	*fox* w_i
a	*bright*	*purple* w_{i-1}	*fox*
the	*florescent*	*indigo*	*badger*

$$f(w_i) = \sum_{w_{i-1}} f(w_{i-1}) \cdot g(w_{i-1}, w_i)$$

Course staff

Instructors:

Jacob Andreas

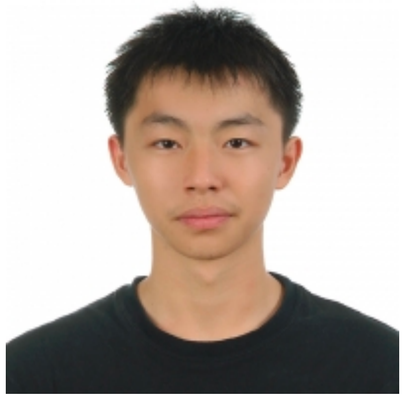
Jim Glass

TAs:

Tianxing He

Hongyin Luo

Faraaz Nadeem



Yu-An Chung

Zihao Xu

Course outline

Feb 4 – Mar 5: sequence models

Mar 10 – Mar 31: syntax & semantics

Apr 2 – Apr 28: guest lectures

Apr 30 – May 7: project presentations

Structure of the course

- Three homework assignments
- Midterm exam
- (6.806 only) Extra homework
  (6.864 only) Final group project

Homework assignments

- 1/2 paper, 1/2 coding
- coding: we'll provide **pytorch** notebooks in Google colab, but you're free to submit whatever you want to eval server

Homework assignments

Collaboration policy:

We encourage you to work together, but final writeup and code must be your own!

Midterm exam

March 19 in class

(Makeup session date TBD)

Late work policy

- Due dates will be posted on Stellar
- Due at midnight
- 10% off for every day late
- Late final projects will not be accepted!

(talk to S^3 / us if you need specific accommodations)

Final projects (6.864)

- Implement a {previously published, new} model for a {standard benchmark, new task}
- Groups of ~3 people
- 3 submissions: proposal, update, final report
- Dates & details TBD (after spring break)

Recitations

2x on Fridays

Date & location TBD

Course website

https://stellar.mit.edu/S/course/6/sp20/6.864

Detailed syllabus, assignments, slides, recordings.

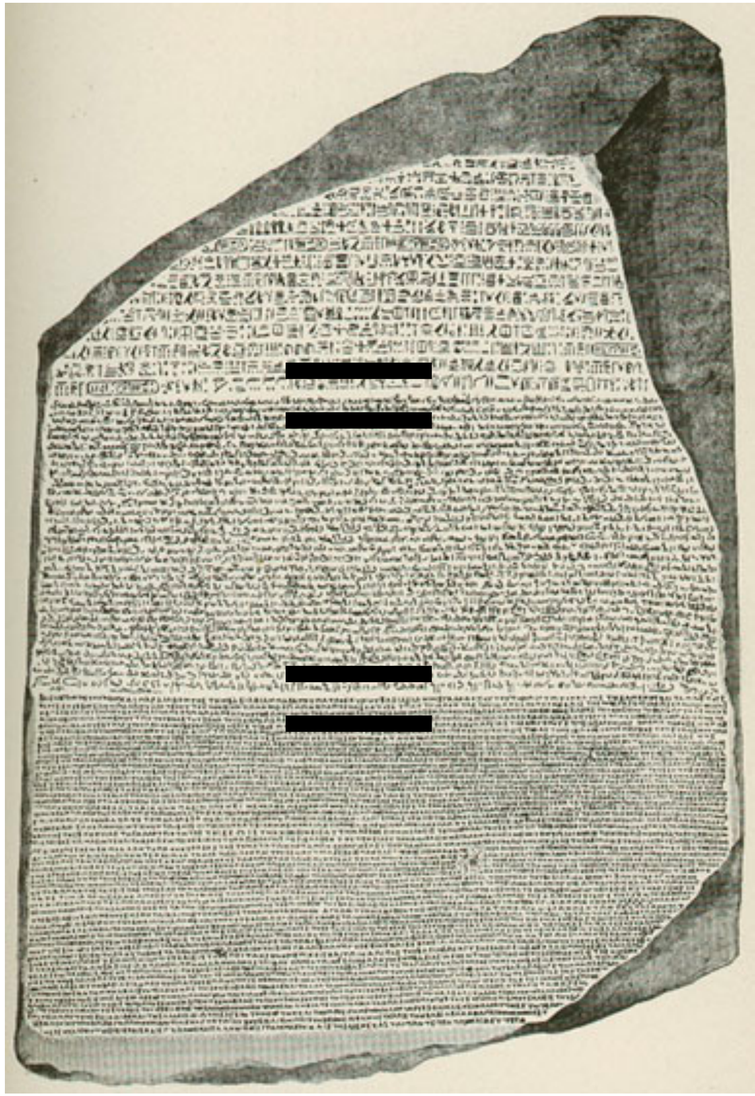
Piazza

piazza.com/mit/spring2020/68066864

Discussions for homework, class content.

Preview

Unsupervised translatioin



Two households, both alike in dignity, In fair Verona, where we lay our scene, From ancient grudge break to new mutiny, Where civil blood makes civil hands unclean. From forth the fatal loins of these two foes A pair of star-cross'd lovers take their life; whose misadv

$\neq$

Desocupado lector: sin juramento me podrás creer que quisiera que este libro, como hijo del entendimiento, fuera el más hermoso, el más gallardo y más discreto que pudiera imaginarse. Pero no he podido yo contravenir al orden de naturaleza, que en ella cada cos

Learning word representations

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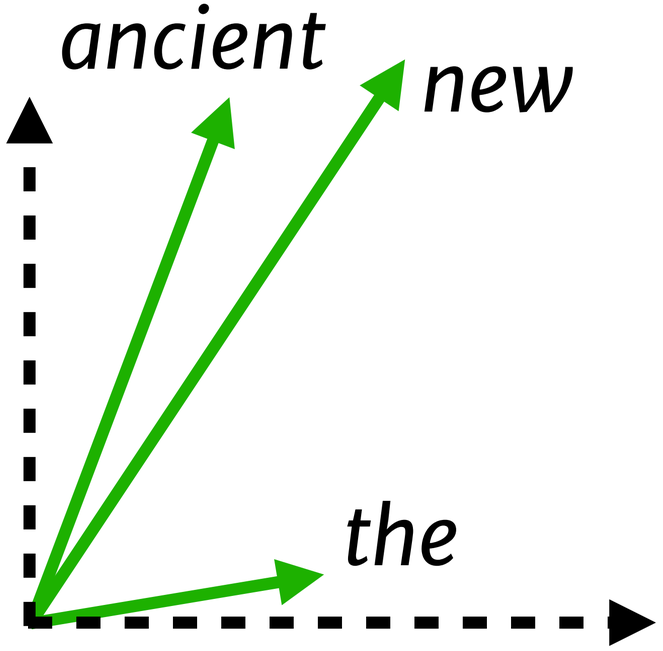
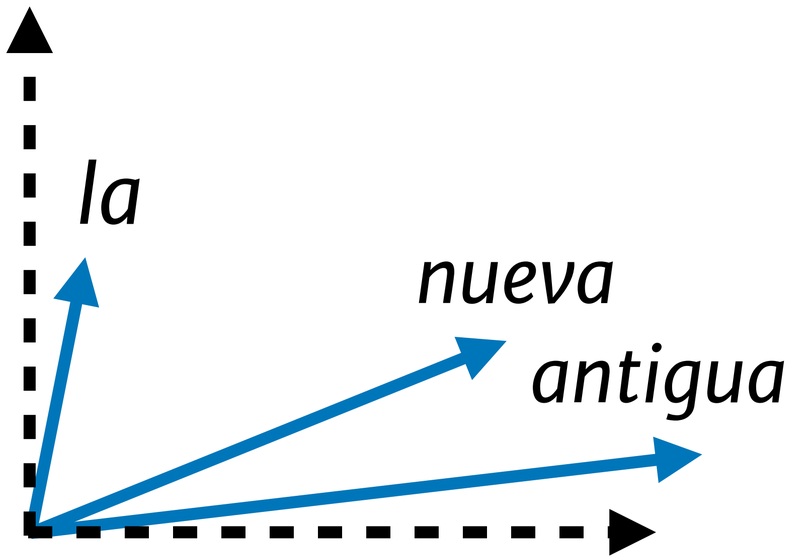
Desocupado lector: sin jura quisiera que este libro, cor fuera el más hermoso, el m que pudiera imaginarse. contravenir al orden de natu





Learning word representations

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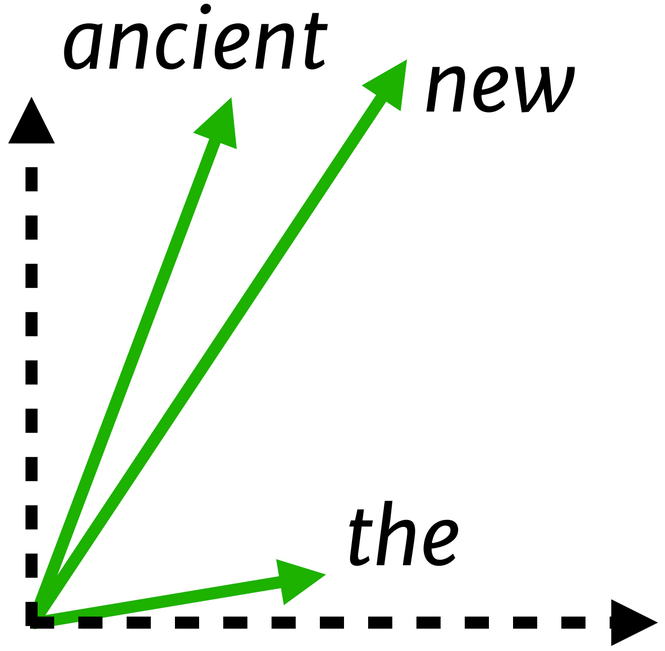

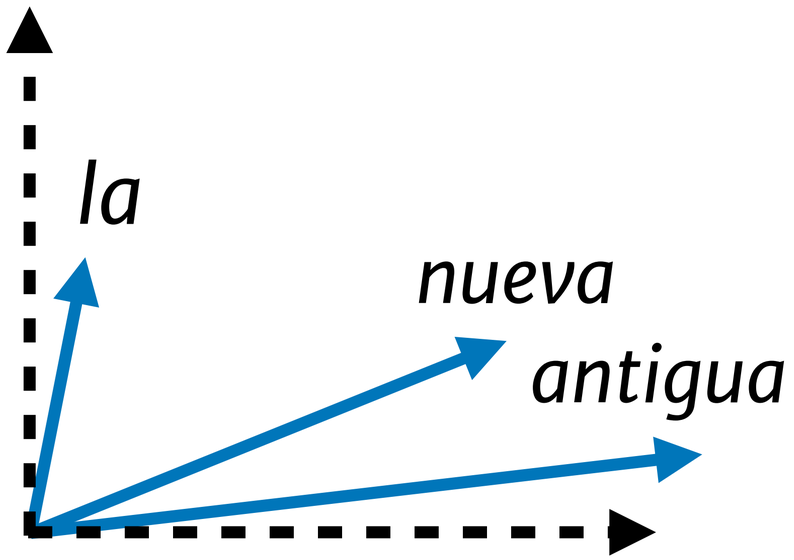

Learning word representations

Two **households**, both alike in dignity, In fair Verona, where we lay our scene, From ancient grudge break to new mutiny, Where civil blood makes civil hands unclean. From forth the fatal loins of these **two** **foes** A pair of star-cross'd lovers take their life; whose misadv

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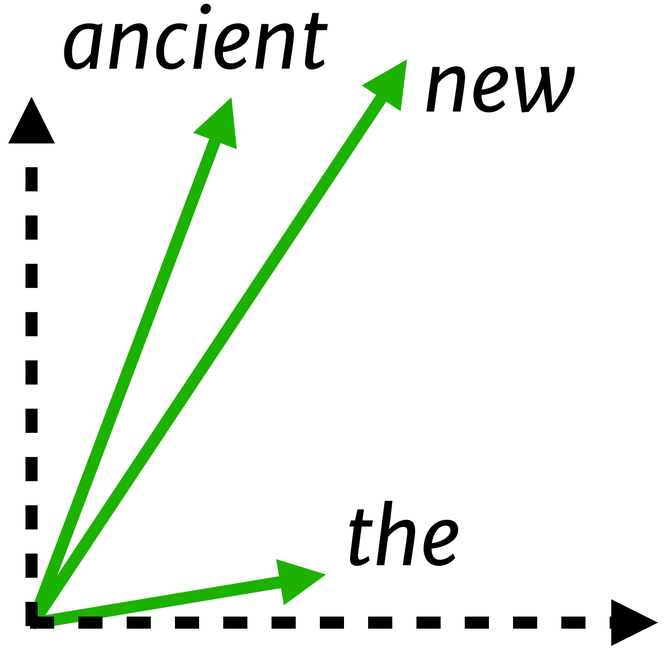
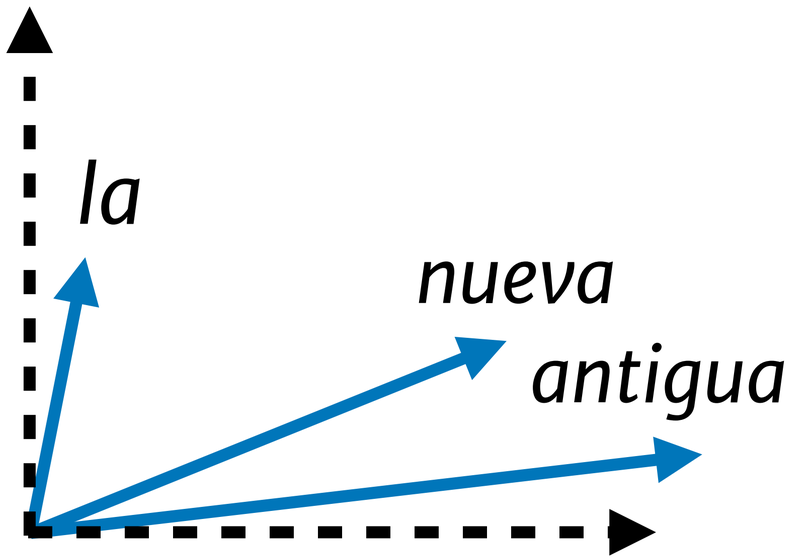
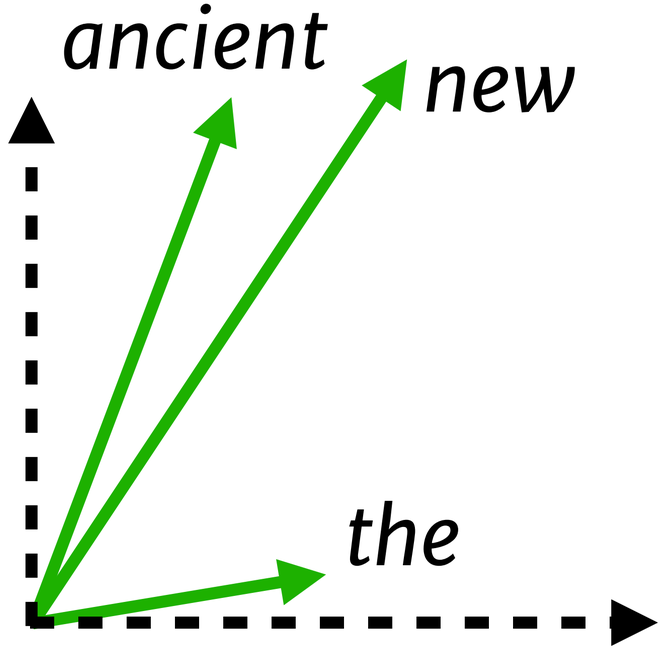
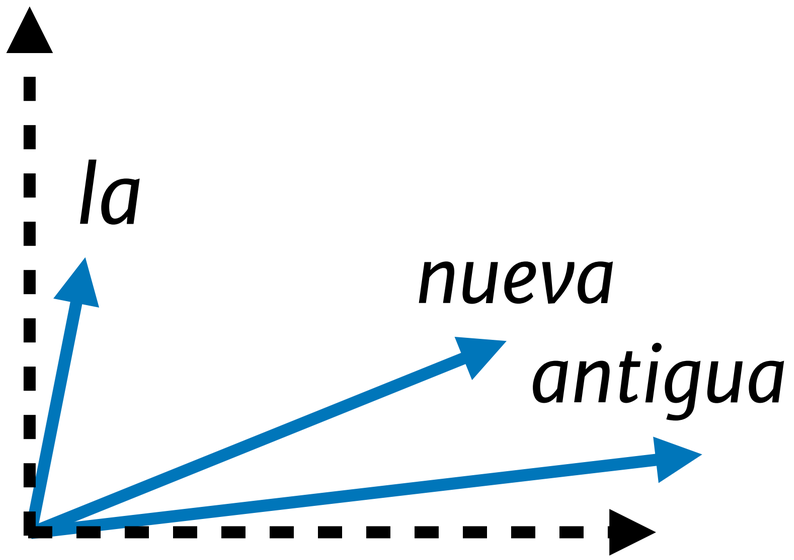


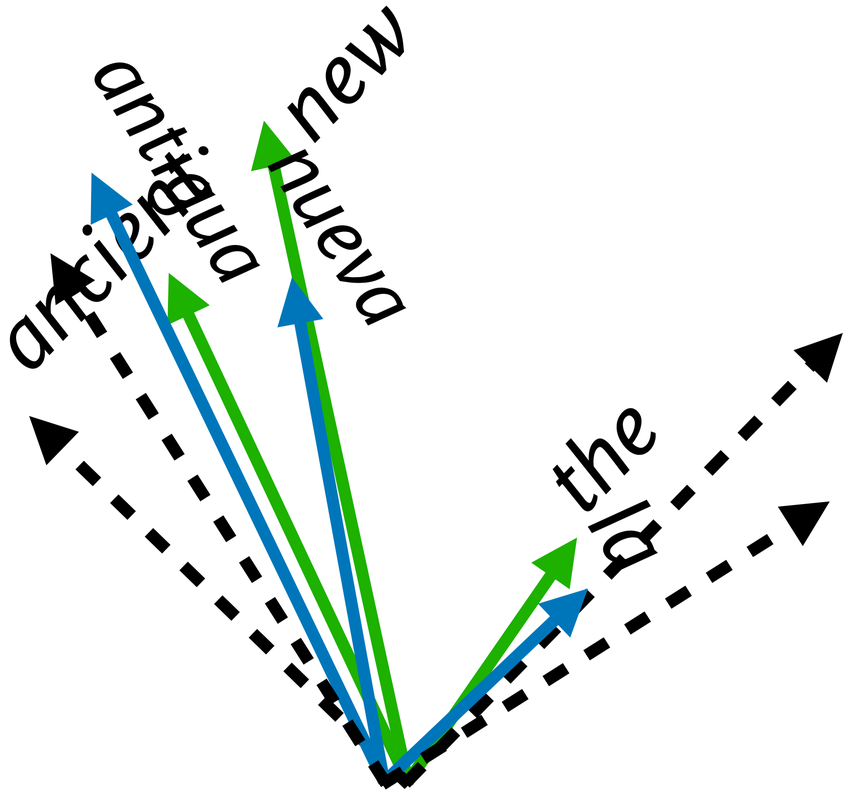


Aligning representations across languages

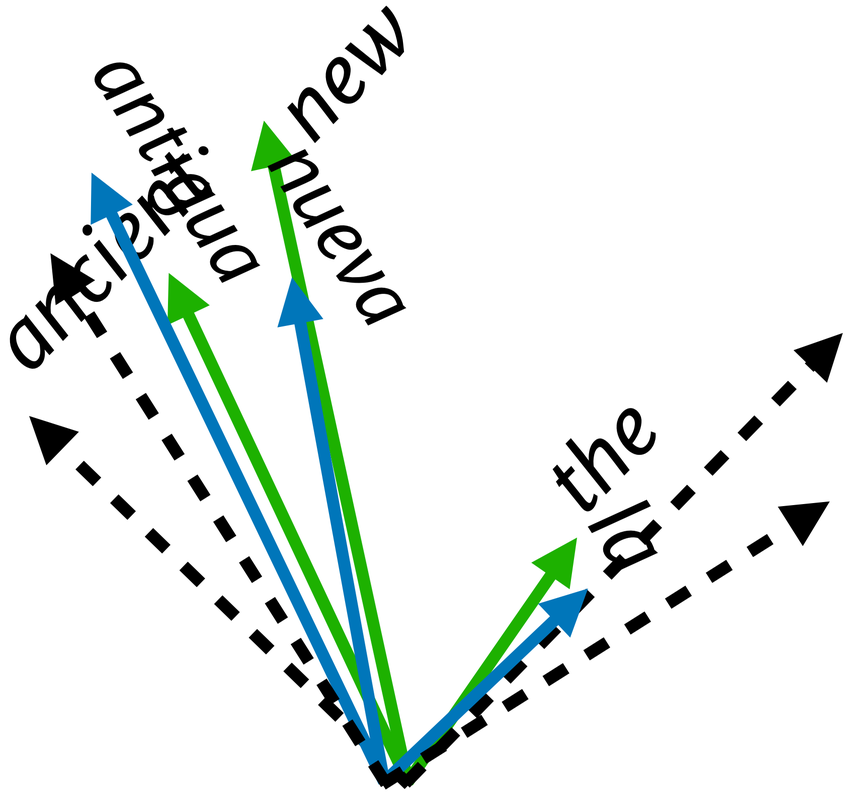




Aligning representations across languages



Aligning representations across languages



Aligning representations across languages

new
nueva
antigua
ancient
the
la

Translating words

Desocupado lector: sin juramento me podrás creer que

idle reader without oath me able believe that

Denoising

Two households, both alike in dignity, In fair Verona, where we lay our scene, From ancient grudge break to new mutiny, Where civil blood makes civil hands uncl

↓

households Two, both alike dignity, fair In Verona, where lay our scene, From ancient grudge vacation to new mutiny, Where blood civil five makes civil hands

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↓

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p(original sentence | corrupted sentence)

Translating sentences

Desocupado lector: sin juramento me podrás creer que

idle reader: without oath me able believe that

idle reader, doubtless you can believe me that

[Lample et al. 2018]

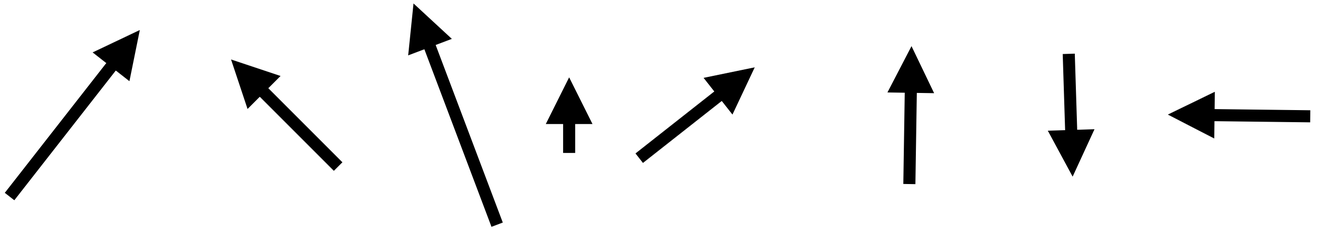
Language to code

Language to code

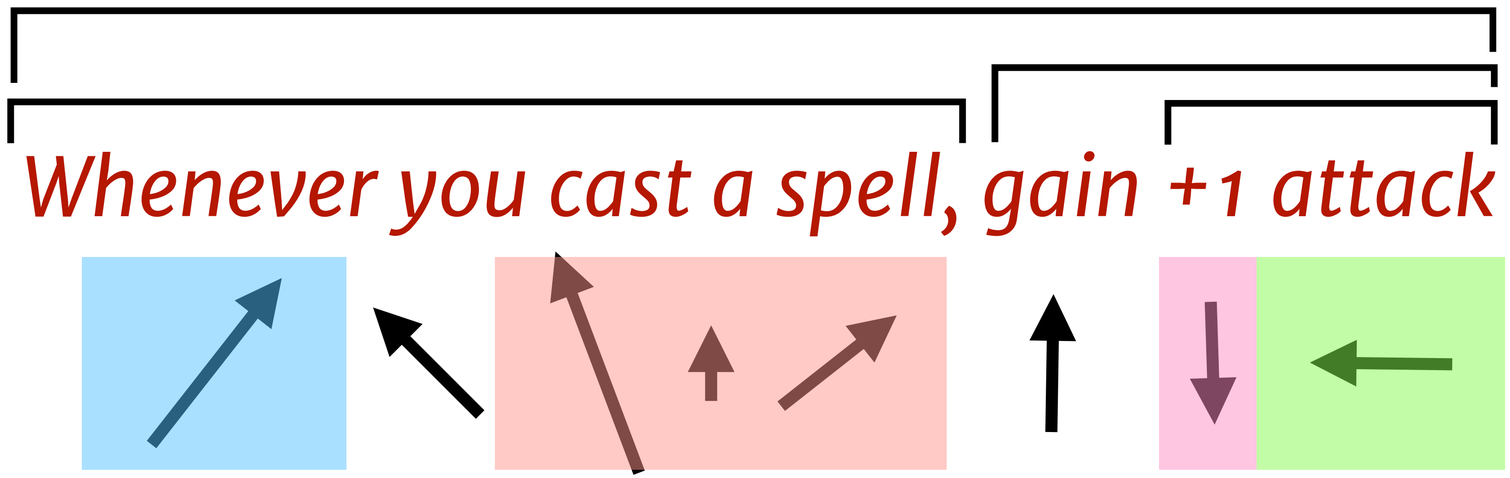

```
return Minion(
  1, 3, effects=[
    Effect(
      SpellCast(),
      ActionTag(
        Give(ChangeAttack(1)),
            SelfSelector()))
  ])
```

Learning sentence representations

Whenever you cast a spell, gain +1 attack



Predicting structured outputs

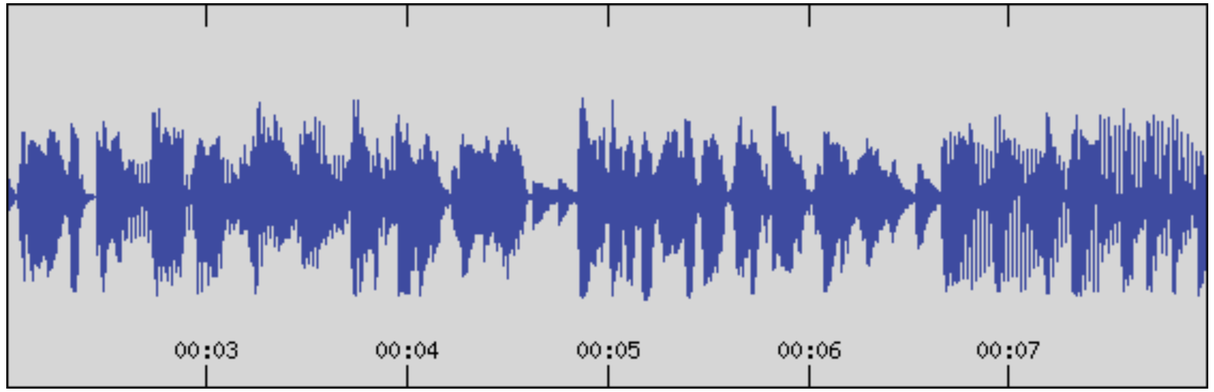



```
return Minion(
  1, 3, effects=[
    Effect(
      SpellCast(),
      ActionTag(
        Give(ChangeAttack( ...
```

[Rabinovich et al. 2017]

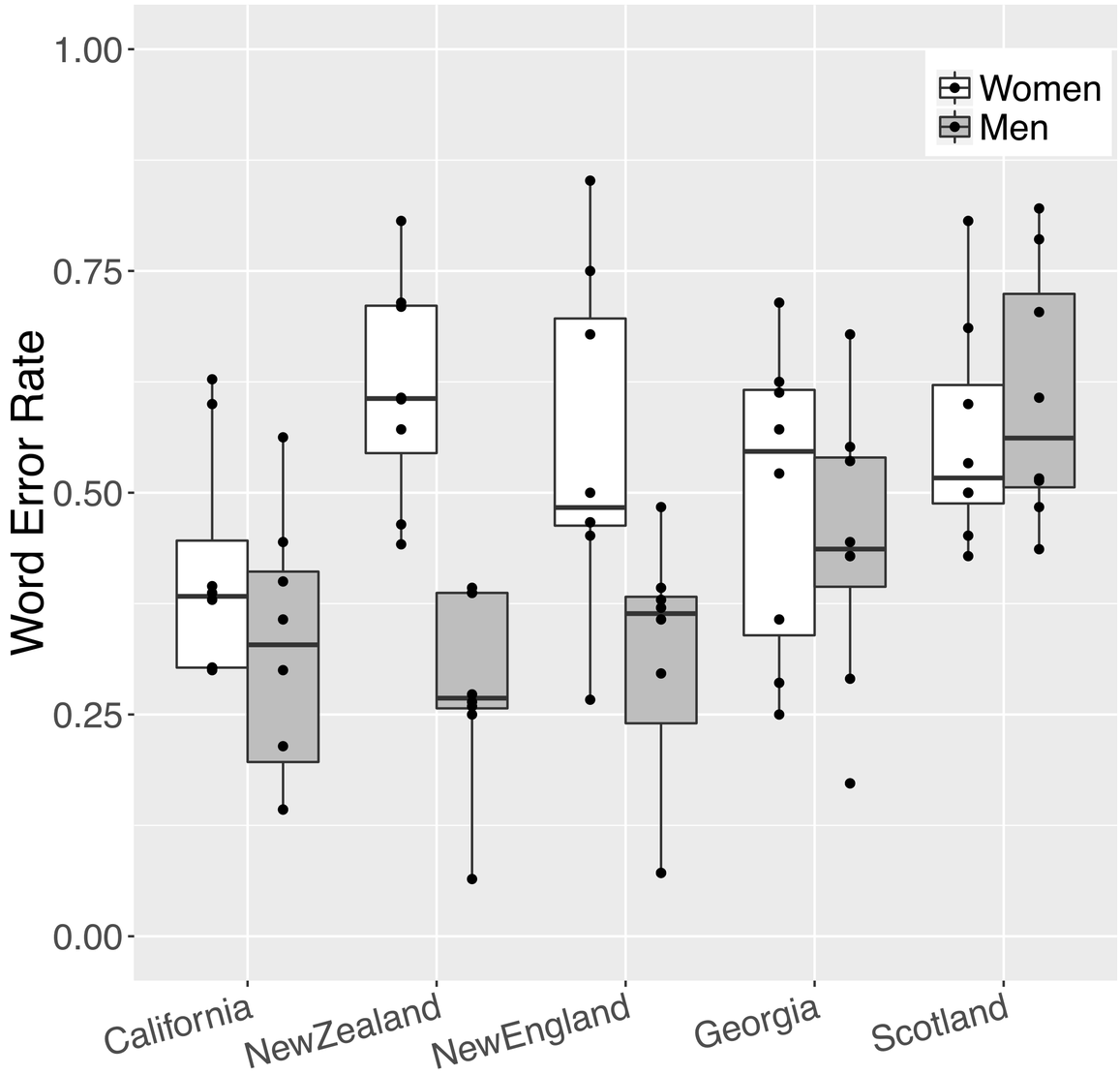
Disparate model accuracy

Speech recognition:



→ *It's hard to wreck a nice beach.*

Disparate model accuracy



[Tatman et al. 2017]

Building fair datasets & models

Modeling

Inductive bias favoring particular groups

Genuine difficulty of underlying prediction problem

Data collection

Bias from researchers

Bias from annotators

This semester:

Machine learning approaches to **interpreting**, **generating** and **analyzing** human languages.

Next class: text classification