

LMs continued

CS 490A, Fall 2021 - Sept. 14

https://people.cs.umass.edu/~brenocon/cs490a_f21/

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[slides from Mohit Iyyer and SLP3]

- HW0 grading is done
- HW1 is released! **Start early!!**
- Come to office hours!
 - Computer setup help?
 - Questions on probability or anything
- Unix tutorial: this Friday (see Piazza)

goal: assign probability to a piece of text

- why would we ever want to do this?
- translation:
 - $P(i \text{ flew to the movies}) \lllll P(i \text{ went to the movies})$
- speech recognition:
 - $P(i \text{ saw a van}) \ggggg P(\text{eyes awe of an})$
- text classification (next week):
 - $P(i \text{ am so mad!!} \mid [author \text{ is happy}]) < P(i \text{ am so mad!!} \mid [author \text{ is not happy}])$

Probabilistic Language Modeling

- Goal: compute the probability of a sentence or sequence of words:

$$P(W) = P(w_1, w_2, w_3, w_4, w_5 \dots w_n)$$

- Related task: probability of an upcoming word:

$$P(w_5 | w_1, w_2, w_3, w_4)$$

- A model that computes either of these:

$P(W)$ or $P(w_n | w_1, w_2 \dots w_{n-1})$ is called a **language model** or **LM**

How to compute $P(W)$

- How to compute this joint probability:
 - $P(\text{its, water, is, so, transparent, that})$
- Intuition: let's rely on the Chain Rule of Probability

The Chain Rule applied to compute joint probability of words in sentence

$$P(w_1 w_2 \dots w_n) = \prod_i P(w_i | w_1 w_2 \dots w_{i-1})$$

$$\begin{aligned} P(\text{“its water is so transparent”}) = & \\ & P(\text{its}) \times P(\text{water} | \text{its}) \times P(\text{is} | \text{its water}) \\ & \times P(\text{so} | \text{its water is}) \times P(\text{transparent} | \text{its water is so}) \end{aligned}$$

How to estimate these probabilities

- Could we just count and divide?

$$P(\text{the } | \text{ its water is so transparent that}) = \frac{\textit{Count}(\text{its water is so transparent that the})}{\textit{Count}(\text{its water is so transparent that})}$$

How to estimate these probabilities

- Could we just count and divide?

$$P(\text{the} \mid \text{its water is so transparent that}) = \frac{\textit{Count}(\text{its water is so transparent that the})}{\textit{Count}(\text{its water is so transparent that})}$$

- No! Too many possible sentences!
- We'll never see enough data for estimating these

Markov Assumption

- Simplifying assumption:



Andrei Markov (1856~1922)

$P(\text{the } | \text{ its water is so transparent that}) \approx P(\text{the } | \text{ that})$

- Or maybe

$P(\text{the } | \text{ its water is so transparent that}) \approx P(\text{the } | \text{ transparent that})$

Markov Assumption

$$P(w_1 w_2 \dots w_n) \approx \prod_i P(w_i | w_{i-k} \dots w_{i-1})$$

- In other words, we approximate each component in the product

$$P(w_i | w_1 w_2 \dots w_{i-1}) \approx P(w_i | w_{i-k} \dots w_{i-1})$$

Simplest case: Unigram model

$$P(w_1 w_2 \dots w_n) \approx \prod_i P(w_i)$$

Some automatically generated sentences from a unigram model:

fifth, an, of, futures, the, an, incorporated, a, a,
the, inflation, most, dollars, quarter, in, is, mass

thrift, did, eighty, said, hard, 'm, july, bullish

that, or, limited, the

Approximating Shakespeare

1
gram

–To him swallowed confess hear both. Which. Of save on trail for are ay device and rote life have

–Hill he late speaks; or! a more to leg less first you enter

2
gram

–Why dost stand forth thy canopy, forsooth; he is this palpable hit the King Henry. Live king. Follow.

–What means, sir. I confess she? then all sorts, he is trim, captain.

3
gram

–Fly, and will rid me these news of price. Therefore the sadness of parting, as they say, 'tis done.

–This shall forbid it should be branded, if renown made it empty.

4
gram

–King Henry. What! I will go seek the traitor Gloucester. Exeunt some of the watch. A great banquet serv'd in;

–It cannot be but so.

N-gram models

- We can extend to trigrams, 4-grams, 5-grams
- In general this is an insufficient model of language
 - because language has **long-distance dependencies**:
“The computer which I had just put into the machine room on the fifth floor crashed.”
- But we can often get away with N-gram models

we're doing longer-distance language modeling near the end of this course

Estimating bigram probabilities

- The Maximum Likelihood Estimate (MLE)
 - relative frequency based on the empirical counts on a training set

$$P(w_i | w_{i-1}) = \frac{\mathit{count}(w_{i-1}, w_i)}{\mathit{count}(w_{i-1})}$$

$$P(w_i | w_{i-1}) = \frac{c(w_{i-1}, w_i)}{c(w_{i-1})}$$

c – count

An example

$$P(w_i | w_{i-1}) \stackrel{\text{MLE}}{=} \frac{c(w_{i-1}, w_i)}{c(w_{i-1})}$$

<s> I am Sam </s>
<s> Sam I am </s>
<s> I do not like green eggs and ham </s>

$$P(\text{I} | \text{<s>}) = \frac{2}{3} = .67$$

$$P(\text{Sam} | \text{<s>}) = ???$$

$$P(\text{</s>} | \text{Sam}) = \frac{1}{2} = 0.5$$

$$P(\text{Sam} | \text{am}) = ???$$

An example

$$P(w_i | w_{i-1}) \stackrel{\text{MLE}}{=} \frac{c(w_{i-1}, w_i)}{c(w_{i-1})}$$

<s> I am Sam </s>
<s> Sam I am </s>
<s> I do not like green eggs and ham </s>

$$P(\mathbf{I} | \langle \mathbf{s} \rangle) = \frac{2}{3} = .67$$

$$P(\text{Sam} | \langle \mathbf{s} \rangle) = \frac{1}{3} = .33$$

$$P(\text{am} | \mathbf{I}) = \frac{2}{3} = .67$$

$$P(\langle \mathbf{s} \rangle | \text{Sam}) = \frac{1}{2} = 0.5$$

$$P(\text{Sam} | \text{am}) = \frac{1}{2} = .5$$

$$P(\text{do} | \mathbf{I}) = \frac{1}{3} = .33$$

A bigger example:

Berkeley Restaurant Project sentences

- can you tell me about any good cantonese restaurants close by
- mid priced thai food is what i'm looking for
- tell me about chez panisse
- can you give me a listing of the kinds of food that are available
- i'm looking for a good place to eat breakfast
- when is caffe venezia open during the day

Raw bigram counts

- Out of 9222 sentences

	i	want	to	eat	chinese	food	lunch	spend
i	5	827	0	9	0	0	0	2
want	2	0	608	1	6	6	5	1
to	2	0	4	686	2	0	6	211
eat	0	0	2	0	16	2	42	0
chinese	1	0	0	0	0	82	1	0
food	15	0	15	0	1	4	0	0
lunch	2	0	0	0	0	1	0	0
spend	1	0	1	0	0	0	0	0

Raw bigram probabilities

$$P(w_i | w_{i-1}) \stackrel{\text{MLE}}{=} \frac{c(w_{i-1}, w_i)}{c(w_{i-1})}$$

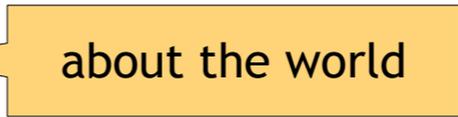
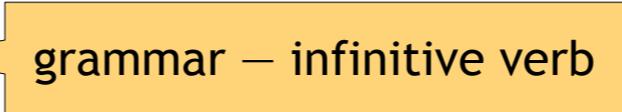
- Normalize by unigrams:

i	want	to	eat	chinese	food	lunch	spend
2533	927	2417	746	158	1093	341	278

- Result:

	i	want	to	eat	chinese	food	lunch	spend
i	0.002	0.33	0	0.0036	0	0	0	0.00079
want	0.0022	0	0.66	0.0011	0.0065	0.0065	0.0054	0.0011
to	0.00083	0	0.0017	0.28	0.00083	0	0.0025	0.087
eat	0	0	0.0027	0	0.021	0.0027	0.056	0
chinese	0.0063	0	0	0	0	0.52	0.0063	0
food	0.014	0	0.014	0	0.00092	0.0037	0	0
lunch	0.0059	0	0	0	0	0.0029	0	0
spend	0.0036	0	0.0036	0	0	0	0	0

What kinds of knowledge?

- $P(\text{english} | \text{want}) = .0011$ 
- $P(\text{chinese} | \text{want}) = .0065$
- $P(\text{to} | \text{want}) = .66$ 
- $P(\text{eat} | \text{to}) = .28$
- $P(\text{food} | \text{to}) = 0$ 
- $P(\text{want} | \text{spend}) = 0$ 
- $P(i | \langle s \rangle) = .25$

Evaluation: How good is our model?

- Does our language model prefer good sentences to bad ones?
 - Assign higher probability to “real” or “frequently observed” sentences
 - Than “ungrammatical” or “rarely observed” sentences?
- We train parameters of our model on a **training set**.
- We test the model’s performance on data we haven’t seen.
 - A **test set** is an unseen dataset that is different from our training set, totally unused.
 - An **evaluation metric** tells us how well our model does on the test set.

Evaluation: How good is our model?

- The goal isn't to pound out fake sentences!
 - Obviously, generated sentences get “better” as we increase the model order
 - More precisely: using maximum likelihood estimators, higher order is always better likelihood on **training set**, but not **test set**

N-grams are sparse

- $N=884,647$ tokens, $V=29,066$
- Shakespeare produced 300,000 bigram types out of $V^2= 844$ million possible bigrams.
 - So 99.96% of the possible bigrams were never seen (have zero entries in the table)
- Quadrigrams worse: What's coming out looks like Shakespeare because it *is* Shakespeare

N-grams are sparse

Training set:

... denied the allegations
... denied the reports
... denied the claims
... denied the request

- Test set
 - ... denied the offer
 - ... denied the loan

$$P(\text{"offer"} \mid \text{denied the}) = 0$$

What issues does this cause?

The intuition of smoothing (from Dan Klein)

- When we have sparse statistics:

$P(w \mid \text{denied the})$

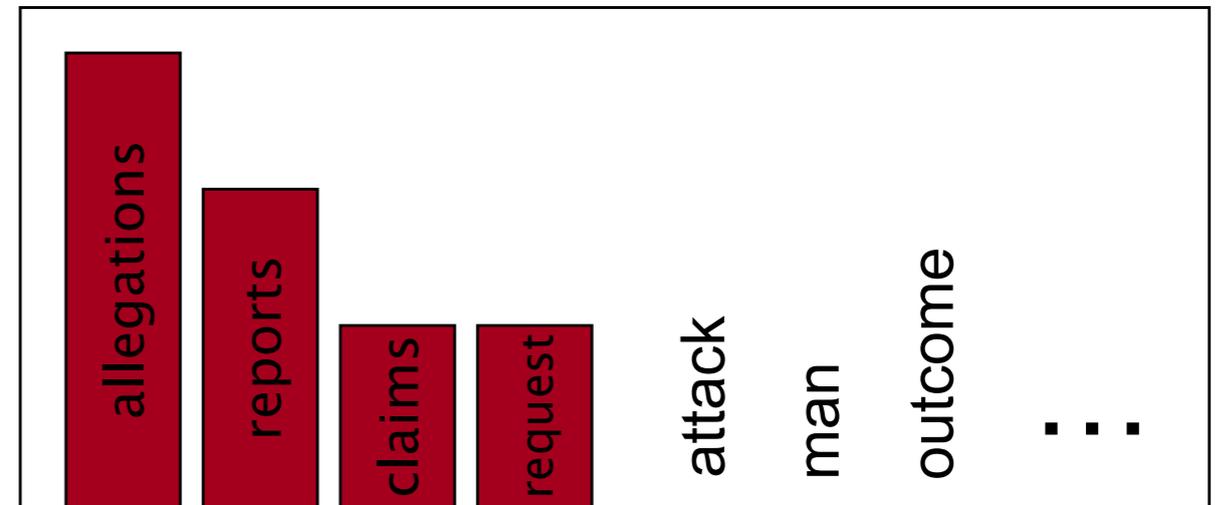
3 allegations

2 reports

1 claims

1 request

7 total



- Steal probability mass to generalize better

$P(w \mid \text{denied the})$

2.5 allegations

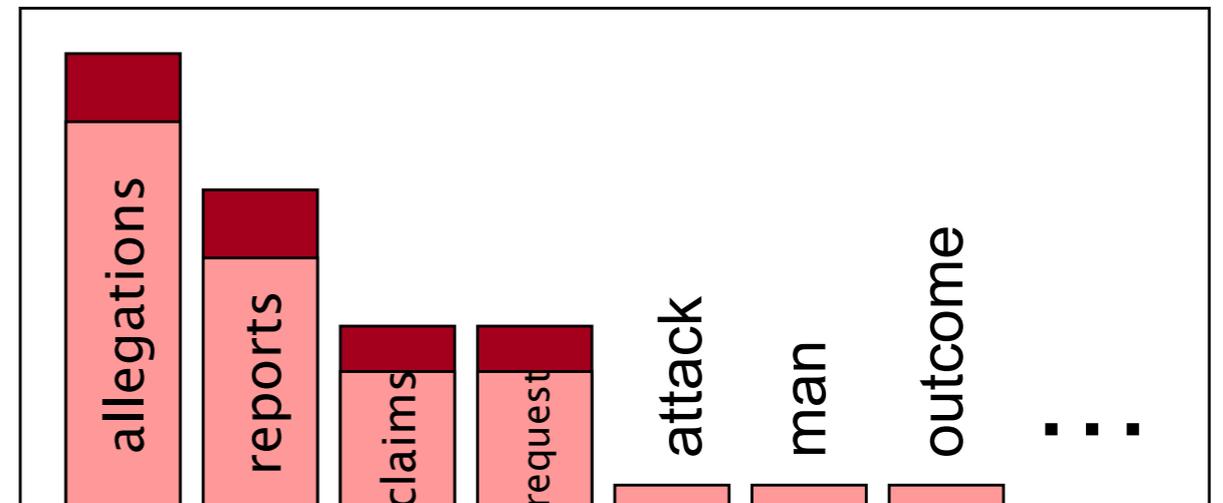
1.5 reports

0.5 claims

0.5 request

2 other

7 total



Add-one estimation (again!)

- Also called Laplace smoothing
- Pretend we saw each word one more time than we did
- Just add one to all the counts!

$$P_{MLE}(w_i | w_{i-1}) = \frac{c(w_{i-1}, w_i)}{c(w_{i-1})}$$

- MLE estimate:

$$P_{Add-1}(w_i | w_{i-1}) = \frac{c(w_{i-1}, w_i) + 1}{c(w_{i-1}) + V}$$

- Add-1 estimate:

More generally: **Add-alpha**
(can interpret as Dirichlet Bayesian prior)

Berkeley Restaurant Corpus: Laplace smoothed bigram counts

	i	want	to	eat	chinese	food	lunch	spend
i	6	828	1	10	1	1	1	3
want	3	1	609	2	7	7	6	2
to	3	1	5	687	3	1	7	212
eat	1	1	3	1	17	3	43	1
chinese	2	1	1	1	1	83	2	1
food	16	1	16	1	2	5	1	1
lunch	3	1	1	1	1	2	1	1
spend	2	1	2	1	1	1	1	1

Laplace-smoothed bigrams

$$P^*(w_n|w_{n-1}) = \frac{C(w_{n-1}w_n) + 1}{C(w_{n-1}) + V}$$

	i	want	to	eat	chinese	food	lunch	spend
i	0.0015	0.21	0.00025	0.0025	0.00025	0.00025	0.00025	0.00075
want	0.0013	0.00042	0.26	0.00084	0.0029	0.0029	0.0025	0.00084
to	0.00078	0.00026	0.0013	0.18	0.00078	0.00026	0.0018	0.055
eat	0.00046	0.00046	0.0014	0.00046	0.0078	0.0014	0.02	0.00046
chinese	0.0012	0.00062	0.00062	0.00062	0.00062	0.052	0.0012	0.00062
food	0.0063	0.00039	0.0063	0.00039	0.00079	0.002	0.00039	0.00039
lunch	0.0017	0.00056	0.00056	0.00056	0.00056	0.0011	0.00056	0.00056
spend	0.0012	0.00058	0.0012	0.00058	0.00058	0.00058	0.00058	0.00058

Add-1 estimation is a blunt instrument

- So add-1 isn't used for N-grams:
 - We'll see better methods
- But add-1 is used to smooth other NLP models
 - For text classification
 - In domains where the number of zeros isn't so huge.

Reconstituted counts

$$c^*(w_{n-1}w_n) = \frac{[C(w_{n-1}w_n) + 1] \times C(w_{n-1})}{C(w_{n-1}) + V}$$

	i	want	to	eat	chinese	food	lunch	spend
i	3.8	527	0.64	6.4	0.64	0.64	0.64	1.9
want	1.2	0.39	238	0.78	2.7	2.7	2.3	0.78
to	1.9	0.63	3.1	430	1.9	0.63	4.4	133
eat	0.34	0.34	1	0.34	5.8	1	15	0.34
chinese	0.2	0.098	0.098	0.098	0.098	8.2	0.2	0.098
food	6.9	0.43	6.9	0.43	0.86	2.2	0.43	0.43
lunch	0.57	0.19	0.19	0.19	0.19	0.38	0.19	0.19
spend	0.32	0.16	0.32	0.16	0.16	0.16	0.16	0.16

Compare with raw bigram counts

	i	want	to	eat	chinese	food	lunch	spend
i	5	827	0	9	0	0	0	2
want	2	0	608	1	6	6	5	1
to	2	0	4	686	2	0	6	211
eat	0	0	2	0	16	2	42	0
chinese	1	0	0	0	0	82	1	0
food	15	0	15	0	1	4	0	0
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eat	0.34	0.34	1	0.34	5.8	1	15	0.34
chinese	0.2	0.098	0.098	0.098	0.098	8.2	0.2	0.098
food	6.9	0.43	6.9	0.43	0.86	2.2	0.43	0.43
lunch	0.57	0.19	0.19	0.19	0.19	0.38	0.19	0.19
spend	0.32	0.16	0.32	0.16	0.16	0.16	0.16	0.16

