Context Sensitive Spelling Correction

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: a slow, graceful dance that was popular in the 17th and 18th centuries

: the music for a minuet

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Use a Language Model

P(about fifteen **minutes** from) > P(about fifteen **minuets** from)

Probablilistic Language Models: Applications

Speech Recognition

- P(I saw a van) $>>$ P(eyes awe of an)

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Machine Translation

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Other Applications

- Context Sensitive Spelling Correction
- Natural Language Generation
- ...

Completion Prediction

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  - Please turn off your cell ...
  - Your program does not ...

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  - Please turn off your cell ...
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- *Predictive text input* systems can guess what you are typing and give choices on how to complete it.

Probabilistic Language Modeling

- **Goal:** Compute the probability of a sentence or sequence of words:

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- A model that computes either of these is called a **language model**

Computing $P(W)$

How to compute the joint probability

P(about, fifteen, minutes, from)

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Basic Idea

Rely on the Chain Rule of Probability

The Chain Rule

Conditional Probabilities

$$P(B|A) = \frac{P(A,B)}{P(A)}$$

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More Variables

$$P(A,B,C,D) = P(A)P(B|A)P(C|A,B)P(D|A,B,C)$$

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The Chain Rule in General

$$P(x_1,x_2,\ldots,x_n) = P(x_1)P(x_2|x_1)P(x_3|x_1,x_2)\ldots P(x_n|x_1,\ldots,x_{n-1})$$

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

P("about fifteen minutes from") =

Probability of words in sentences

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

P("about fifteen minutes from") =

P(about) x P(fifteen | about) x P(minutes | about fifteen) x P(from | about fifteen minutes)

Estimating These Probability Values

Count and divide

$$P(\text{office} \mid \text{about fifteen minutes from}) = \frac{\textit{Count}\,(\text{about fifteen minutes from office})}{\textit{Count}\,(\text{about fifteen minutes from})}$$

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What is the problem

We may never see enough data for estimating these

Markov Assumption

Simplifying Assumption: Use only the previous word

P(office | about fifteen minutes from) $\approx$ P(office | from)

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Or the couple previous words

P(office | about fifteen minutes from) $\approx$ P(office | minutes from)

Markov Assumption

More Formally: kth order Markov Model

Chain Rule:

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Using Markov Assumption: only k previous words

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We approximate each component in the product

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

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Markov model and Language Model

An N-gram model is an $N-1$-order Markov Model

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- We can extend to trigrams, 4-grams, 5-grams
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  language has long-distance dependencies:
  "The computer which I had just put into the machine room on the fifth floor **crashed**."

N-Gram Models

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

Estimating N-grams probabilities

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Maximum Likelihood Estimate

Value that makes the observed data the "most probable"

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

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

An Example

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

<s>I am here </s>
<s>who am I </s>
<s>I would like to know </s>

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Estimating bigrams

P(I|<s>) =
P(</s>|here) =
P(would | I) =
P(here | am) =
P(know | like) =

An Example

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<s>I am here </s>
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Estimating bigrams

P(I|<s>) = 2/3
P(</s>|here) =1
P(would | I) = 1/3
P(here | am) = 1/2
P(know | like) = 0

Bigram counts from 9222 Restaurant 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

Computing bigram probabilities

Normlize by unigrams

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

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Bigram Probabilities

	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

Computing Sentence Probabilities

P(<s> I want english food </s>)

= P(I | <s>) x P(want | I) x P(english | want) x P(food | english) x P(</s> | food)

Computing Sentence Probabilities

P(<s> I want english food </s>)

= P(I | <s>) x P(want | I) x P(english | want) x P(food | english) x P(</s> | food)
= 0.000031

What knowledge does n-gram represent?

- P(english|want) = .0011
- P(chinese|want) = .0065
- P(to|want) = .66
- P(eat | to) = .28
- P(food | to) = 0
- P(want | spend) = 0
- P (i | <s>) = .25

Practical Issues

Everything in log space

- Avoids underflow

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Everything in log space

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$$log(p_1 \times p_2 \times p_3 \times p_4) = logp_1 + logp_2 + logp_3 + logp_4$$

Handling zeros

Use smoothing

Language Modeling Toolkit

SRILM

http://www.speech.sri.com/projects/srilm/

Google N-grams

Number of tokens: 1,024,908,267,229
Number of sentences: 95,119,665,584
Number of unigrams: 13,588,391
Number of bigrams: 314,843,401
Number of trigrams: 977,069,902
Number of fourgrams: 1,313,818,354
Number of fivegrams: 1,176,470,663
`http://googleresearch.blogspot.in/2006/08/all-our-n-gram-are-belong-to-you.html`

Example from the 4-gram data

serve as the inspector 66
serve as the inspiration 1390
serve as the installation 136
serve as the institute 187
serve as the institution 279
serve as the institutional 461

Google books Ngram Data