Department of Computer Science
UNIVERSITY OF COLORADO **BOULDER**

Why Language is Hard: Structure and Predictions

Advanced Machine Learning for NLP
Jordan Boyd-Graber
SLIDES ADAPTED FROM LIANG HUANG

POS Tagging: Task Definition

- Annotate each word in a sentence with a part-of-speech marker.
- Lowest level of syntactic analysis.

John	saw	the	saw	and	decided	to	take	it	to	the	table
NNP	VBD	DT	NN	CC	VBD	TO	VB	PRP	IN	DT	NN

Features (ϕ)

Assume K parts of speech, a lexicon size of V, a series of observations $\{x_1, \dots, x_N\}$, and a series of unobserved states $\{z_1, \dots, z_N\}$.

- π Start state scores (vector of length K): π_i
- θ Transition matrix (matrix of size K by K): $\theta_{i,j}$
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$$f(x, z) \equiv \sum_i w_i \phi_i(x, z) \tag{1}$$

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Total score of hypothesis z given input x

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Feature weight

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Feature present (binary)

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Viterbi Algorithm

- Given an unobserved sequence of length L, $\{x_1, \dots, x_L\}$, we want to find a sequence $\{z_1 \dots z_L\}$ with the highest score.

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- It's impossible to compute K^L possibilities.
- So, we use dynamic programming to compute most likely tags for each token subsequence from 0 to t that ends in state k.
- Memoization: fill a table of solutions of sub-problems
- Solve larger problems by composing sub-solutions
- Base case:

$$f_1(k) = \pi_k + \beta_{k,x_i} \tag{2}$$

- Recursion:

$$f_n(k) = \max_j \left(f_{n-1}(j) + \theta_{j,k} \right) + \beta_{k,x_n} \tag{3}$$

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- The complexity of this is now $K^2 L$.
- In class: example that shows why you need all $O(KL)$ table cells (garden pathing)
- But just computing the max isn't enough. We also have to remember where we came from. (Breadcrumbs from best previous state.)

$$\Psi_n = \text{argmax}_j f_{n-1}(j)\theta_{j,k} \tag{4}$$

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- Let's do that for the sentence "come and get it"

POS	π_k	β_{k,x_1}	$f_1(k)$
MOD	$\log 0.234$	$\log 0.024$	-5.18
DET	$\log 0.234$	$\log 0.032$	-4.89
CONJ	$\log 0.234$	$\log 0.024$	-5.18
N	$\log 0.021$	$\log 0.016$	-7.99
PREP	$\log 0.021$	$\log 0.024$	-7.59
PRO	$\log 0.021$	$\log 0.016$	-7.99
V	$\log 0.234$	$\log 0.121$	-3.56

come and get it (with HMM probabilities)

Why logarithms?

1. More interpretable than a float with lots of zeros.
2. Underflow is less of an issue
3. Generalizes to linear models (next!)
4. Addition is cheaper than multiplication

$$log(ab) = log(a) + log(b) \tag{5}$$

POS	$f_1(j)$		$f_2(\text{CONJ})$
MOD	-5.18		
DET	-4.89		
CONJ	-5.18		
N	-7.99		
PREP	-7.59		
PRO	-7.99		
V	-3.56		

come **and** get it

POS	$f_1(j)$		$f_2(\text{CONJ})$
MOD	-5.18		
DET	-4.89		
CONJ	-5.18		???
N	-7.99		
PREP	-7.59		
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V	-3.56		

come **and** get it

POS	$f_1(j)$	$f_1(j) + \theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18		
DET	-4.89		
CONJ	-5.18		???
N	-7.99		
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come **and** get it

$$f_0(\text{V}) + \theta_{\text{V, CONJ}} = f_0(k) + \theta_{\text{V, CONJ}} = -3.56 + -1.65$$

POS	$f_1(j)$	$f_1(j) + \theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18		
DET	-4.89		
CONJ	-5.18		???
N	-7.99		
PREP	-7.59		
PRO	-7.99		
V	-3.56	-5.21	

come **and** get it

POS	$f_1(j)$	$f_1(j)+\theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18		
DET	-4.89		
CONJ	-5.18		???
N	-7.99	≤ -7.99	
PREP	-7.59	≤ -7.59	
PRO	-7.99	≤ -7.99	
V	-3.56	-5.21	

come **and** get it

POS	$f_1(j)$	$f_1(j) + \theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18	-8.48	
DET	-4.89	-7.72	
CONJ	-5.18	-8.47	???
N	-7.99	≤ -7.99	
PREP	-7.59	≤ -7.59	
PRO	-7.99	≤ -7.99	
V	-3.56	-5.21	

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POS	$f_1(j)$	$f_1(j) + \theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
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MOD	-5.18	-8.48	
DET	-4.89	-7.72	
CONJ	-5.18	-8.47	
N	-7.99	≤ -7.99	
PREP	-7.59	≤ -7.59	
PRO	-7.99	≤ -7.99	
V	-3.56	-5.21	

come **and** get it

$$\log f_1(k) = -5.21 + \beta_{\text{CONJ, and}} =$$

POS	$f_1(j)$	$f_1(j)+\theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18	-8.48	
DET	-4.89	-7.72	
CONJ	-5.18	-8.47	
N	-7.99	≤ -7.99	
PREP	-7.59	≤ -7.59	
PRO	-7.99	≤ -7.99	
V	-3.56	-5.21	

come **and** get it

$$\log f_1(k) = -5.21 + \beta_{\text{CONJ, and}} = -5.21 - 0.64$$

POS	$f_1(j)$	$f_1(j) + \theta_{j,\text{CONJ}}$	$f_2(\text{CONJ})$
MOD	-5.18	-8.48	
DET	-4.89	-7.72	
CONJ	-5.18	-8.47	-6.02
N	-7.99	≤ -7.99	
PREP	-7.59	≤ -7.59	
PRO	-7.99	≤ -7.99	
V	-3.56	-5.21	

come **and** get it

POS	$f_1(k)$	$f_2(k)$	b_2	$f_3(k)$	b_3	$f_4(k)$	b_4
MOD	-5.18						
DET	-4.89						
CONJ	-5.18	-6.02	V				
N	-7.99						
PREP	-7.59						
PRO	-7.99						
V	-3.56						
WORD	come	and		get		it	

POS	$f_1(k)$	$f_2(k)$	b_2	$f_3(k)$	b_3	$f_4(k)$	b_4
MOD	-5.18	-0.00	X				
DET	-4.89	-0.00	X				
CONJ	-5.18	-6.02	V				
N	-7.99	-0.00	X				
PREP	-7.59	-0.00	X				
PRO	-7.99	-0.00	X				
V	-3.56	-0.00	X				
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POS	$f_1(k)$	$f_2(k)$	b_2	$f_3(k)$	b_3	$f_4(k)$	b_4
MOD	-5.18	-0.00	X	-0.00	X		
DET	-4.89	-0.00	X	-0.00	X		
CONJ	-5.18	-6.02	V	-0.00	X		
N	-7.99	-0.00	X	-0.00	X		
PREP	-7.59	-0.00	X	-0.00	X		
PRO	-7.99	-0.00	X	-0.00	X		
V	-3.56	-0.00	X	-9.03	CONJ		
WORD	come	and		get		it	

POS	$f_1(k)$	$f_2(k)$	b_2	$f_3(k)$	b_3	$f_4(k)$	b_4
MOD	-5.18	-0.00	X	-0.00	X	-0.00	X
DET	-4.89	-0.00	X	-0.00	X	-0.00	X
CONJ	-5.18	-6.02	V	-0.00	X	-0.00	X
N	-7.99	-0.00	X	-0.00	X	-0.00	X
PREP	-7.59	-0.00	X	-0.00	X	-0.00	X
PRO	-7.99	-0.00	X	-0.00	X	-14.6	V
V	-3.56	-0.00	X	-9.03	CONJ	-0.00	X
WORD	come	and		get		it	