Statistical NLP
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Lecture 7: POS / NER Tagging

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Feature-Rich Sequence Models

- Problem: HMMs make it hard to work with arbitrary features of a sentence

- Example: name entity recognition (NER)

PER PER O O O O O O ORG O O O O O LOC LOC O

Tim Boon has signed a contract extension with Leicestershire which will keep him at Grace Road .

Local Context

	Prev	Cur	Next
State	Other	???	???
Word	at	Grace	Road
Tag	IN	NNP	NNP
Sig	x	Xx	Xx

MEMM Taggers

- Idea: left-to-right local decisions, condition on previous tags and also entire input

$$P(\mathbf{t}|\mathbf{w}) = \prod_i P_{\text{ME}}(t_i|\mathbf{w}, t_{i-1}, t_{i-2})$$

  - Train up $P(t_i|w,t_{i-1},t_{i-2})$ as a normal maxent model, then use to score sequences
  - This is referred to as an MEMM tagger [Ratnaparkhi 96]
  - Beam search effective! (Why?)
  - What about beam size 1?

Decoding

- Decoding MEMM taggers:
  - Just like decoding HMMs, different local scores
  - Viterbi, beam search, posterior decoding
- Viterbi algorithm (HMMs):

$$\delta_i(s) = \arg\max_{s'} P(s|s')P(w_{i-1}|s')\delta_{i-1}(s')$$

- Viterbi algorithm (MEMMs):

$$\delta_i(s) = \arg\max_{s'} P(s|s', \mathbf{w})\delta_{i-1}(s')$$

- General:

$$\delta_i(s) = \arg\max_{s'} \phi_i(s', s)\delta_{i-1}(s')$$

Maximum Entropy II

- Remember: maximum entropy objective

$$L(\mathbf{w}) = \sum_i \left(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y}^i) - \log \sum_{\mathbf{y}} \exp(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y})) \right)$$

- Problem: lots of features allow perfect fit to training set
- Regularization (compare to smoothing)

$$\max_{\mathbf{w}} \sum_i \left(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y}^i) - \log \sum_{\mathbf{y}} \exp(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y})) \right) - k||\mathbf{w}||^2$$

Derivative for Maximum Entropy

$$L(\mathbf{w}) = -k||\mathbf{w}||^2 + \sum_i \left(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y}^i) - \log \sum_{\mathbf{y}} \exp(\mathbf{w}^\top \mathbf{f}_i(\mathbf{y})) \right)$$

$$\frac{\partial L(\mathbf{w})}{\partial \mathbf{w}_n} = -2k\mathbf{w}_n + \sum_i \left(\mathbf{f}_i(\mathbf{y}^i)_n - \sum_{\mathbf{y}} P(\mathbf{y}|\mathbf{x}_i)\mathbf{f}_i(\mathbf{y})_n \right)$$

Big weights are bad

Expected count of feature n in predicted candidates

Total count of feature n in correct candidates

Example: NER Regularization

Because of regularization term, the more common prefixes have larger weights even though entire-word features are more specific.

Local Context

	Prev	Cur	Next
State	Other	???	???
Word	at	Grace	Road
Tag	IN	NNP	NNP
Sig	x	Xx	Xx

Feature Weights

Feature Type	Feature	PERS	LOC
Previous word	*at*	-0.73	0.94
Current word	*Grace*	0.03	0.00
Beginning bigram	*<G*	0.45	-0.04
Current POS tag	NNP	0.47	0.45
Prev and cur tags	IN NNP	-0.10	0.14
Previous state	Other	-0.70	-0.92
Current signature	Xx	0.80	0.46
Prev state, cur sig	O-Xx	0.68	0.37
Prev-cur-next sig	x-Xx-Xx	-0.69	0.37
P. state - p-cur sig	O-x-Xx	-0.20	0.82
…			
Total:		**-0.58**	**2.68**

Perceptron Taggers

[Collins 01]

- Linear models:

$$\text{score}(\mathbf{t}|\mathbf{w}) = \lambda^\top f(\mathbf{t}, \mathbf{w})$$

- … that decompose along the sequence

$$= \lambda^\top \sum_i f(t_i, t_{i-1}, \mathbf{w}, i)$$

- … allow us to predict with the Viterbi algorithm

$$\mathbf{t}^* = \arg\max_{\mathbf{t}} \ \text{score}(\mathbf{t}|\mathbf{w})$$

- … which means we can train with the perceptron algorithm (or related updates, like MIRA)

Conditional Random Fields

- Make a maxent model over entire taggings
  - MEMM

$$P(\mathbf{t}|\mathbf{w}) = \prod_i \frac{1}{Z(i)} \exp\left(\lambda^\top f(t_i, t_{i-1}, \mathbf{w}, i)\right)$$

  - CRF

$$\begin{aligned} P(\mathbf{t}|\mathbf{w}) &= \frac{1}{Z(\mathbf{w})} \exp\left(\lambda^\top f(\mathbf{t}, \mathbf{w})\right) \\ &= \frac{1}{Z(\mathbf{w})} \exp\left(\lambda^\top \sum_i f(t_i, t_{i-1}, \mathbf{w}, i)\right) \\ &= \frac{1}{Z(\mathbf{w})} \prod_i \phi_i(t_i, t_{i-1}) \end{aligned}$$

CRFs

- Like any maxent model, derivative is:

$$\frac{\partial L(\lambda)}{\partial \lambda} = \sum_k \left(\mathbf{f}_k(\mathbf{t}^k) - \sum_{\mathbf{t}} P(\mathbf{t}|\mathbf{w}_k)\mathbf{f}_k(\mathbf{t}) \right)$$

- So all we need is to be able to compute the expectation of each feature (for example the number of times the label pair *DT-NN* occurs, or the number of times *NN-interest* occurs)

- Critical quantity: counts of posterior marginals:

$$\text{count}(w, s) = \sum_{i: w_i = w} P(t_i = s|\mathbf{w})$$

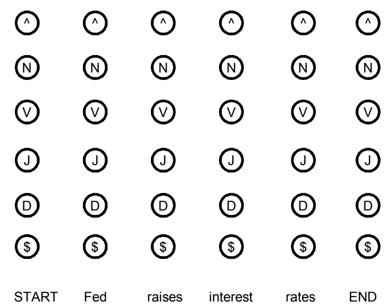
$$\text{count}(s \rightarrow s') = \sum_i P(t_{i-1} = s, t_i = s'|\mathbf{w})$$

Computing Posterior Marginals

- How many (expected) times is word w tagged with s?

$$\text{count}(w, s) = \sum_{i: w_i = w} P(t_i = s|\mathbf{w})$$

- How to compute that marginal?



$$\alpha_i(s) = \sum_{s'} \phi_i(s', s)\alpha_{i-1}(s')$$
$$\beta_i(s) = \sum_{s'} \phi_{i+1}(s, s')\beta_{i+1}(s')$$

$$P(t_i = s|\mathbf{w}) = \frac{\alpha_i(s)\beta_i(s)}{\alpha_N(\text{END})}$$

TBL Tagger

- [Brill 95] presents a *transformation-based* tagger
  - Label the training set with most frequent tags

    DT MD VBD VBD .
    The can was rusted .

  - Add transformation rules which reduce training mistakes
    - MD → NN : DT __
    - VBD → VBN : VBD __ .
  - Stop when no transformations do sufficient good
  - Does this remind anyone of anything?
- Probably the most widely used tagger (esp. outside NLP)
- … but definitely not the most accurate: 96.6% / 82.0 %

TBL Tagger II

- What gets learned? [from Brill 95]

#	Change Tag From	Change Tag To	Condition
1	NN	VB	Previous tag is *TO*
2	VBP	VB	One of the previous three tags is *MD*
3	NN	VB	One of the previous two tags is *MD*
4	VB	NN	One of the previous two tags is *DT*
5	VBD	VBN	One of the previous three tags is *VBZ*
6	VBN	VBD	Previous tag is *PRP*
7	VBN	VBD	Previous tag is *NNP*
8	VBD	VBN	Previous tag is *VBD*
9	VBP	VB	Previous tag is *TO*
10	POS	VBZ	Previous tag is *PRP*
11	VB	VBP	Previous tag is *NNS*
12	VBD	VBN	One of previous three tags is *VBP*
13	IN	WDT	One of next two tags is *VB*
14	VBD	VBN	One of previous two tags is *VB*
15	VB	VBP	Previous tag is *PRP*
16	IN	WDT	Next tag is *VBZ*
17	IN	DT	Next tag is *NN*
18	JJ	NNP	Next tag is *NNP*
19	IN	WDT	Next tag is *VBD*
20	JJR	RBR	Next tag is *JJ*

#	Change Tag From	Change Tag To	Condition
1	NN	NNS	Has suffix **-s**
2	NN	CD	Has character **.**
3	NN	JJ	Has character **-**
4	NN	VBN	Has suffix **-ed**
5	NN	VBG	Has suffix **-ing**
6	??	RB	Has suffix **-ly**
7	??	JJ	Adding suffix **-ly** results in a word.
8	NN	CD	The word **$** can appear to the left.
9	NN	JJ	Has suffix **-al**
10	NN	VB	The word **would** can appear to the left.
11	NN	CD	Has character **0**
12	NN	JJ	The word **be** can appear to the left.
13	NNS	JJ	Has suffix **-us**
14	NNS	VBZ	The word **it** can appear to the left.
15	NN	JJ	Has suffix **-ble**
16	NN	JJ	Has suffix **-ic**
17	NN	CD	Has character **1**
18	NNS	NN	Has suffix **-ss**
19	??	JJ	Deleting the prefix **un-** results in a word
20	NN	JJ	Has suffix **-ive**

EngCG Tagger

- English constraint grammar tagger
  - [Tapanainen and Voutilainen 94]
  - Something else you should know about
  - Hand-written and knowledge driven
  - "Don't guess if you know" (general point about modeling more structure!)
  - Tag set doesn't make all of the hard distinctions as the standard tag set (e.g. JJ/NN)
  - They get stellar accuracies: 99% on *their* tag set
  - Linguistic representation matters…
  - … but it's easier to win when you make up the rules

```
walk
   walk <SV> <SVO> V SUBJUNCTIVE VFIN
   walk <SV> <SVO> V IMP VFIN
   walk <SV> <SVO> V INF
   walk <SV> <SVO> V PRES -SG3 VFIN
   walk N NOM SG
```

```
walk V-SUBJUNCTIVE V-IMP V-INF
     V-PRES-BASE N-NOM-SG
```

Domain Effects

- Accuracies degrade outside of domain
  - Up to triple error rate
  - Usually make the most errors on the things you care about in the domain (e.g. protein names)
- Open questions
  - How to effectively exploit unlabeled data from a new domain (what could we gain?)
  - How to best incorporate domain lexica in a principled way (e.g. UMLS specialist lexicon, ontologies)

Unsupervised Tagging?

- AKA part-of-speech induction
- Task:
  - Raw sentences in
  - Tagged sentences out
- Obvious thing to do:
  - Start with a (mostly) uniform HMM
  - Run EM
  - Inspect results

EM for HMMs: Process

- Alternate between recomputing distributions over hidden variables (the tags) and reestimating parameters
- Crucial step: we want to tally up how many (fractional) counts of each kind of transition and emission we have under current params:

$$\text{count}(w, s) = \sum_{i:w_i=w} P(t_i = s|\mathbf{w})$$

$$\text{count}(s \to s') = \sum_i P(t_{i-1} = s, t_i = s'|\mathbf{w})$$

- Same quantities we needed to train a CRF!

EM for HMMs: Quantities

- Total path values (correspond to probabilities here):

$$\begin{aligned} \alpha_i(s) &= P(w_0 \dots w_i, s_i) \\ &= \sum_{s_{i-1}} P(s_i|s_{i-1}) P(w_i|s_i) \alpha_{i-1}(s_{i-1}) \end{aligned}$$

$$\begin{aligned} \beta_i(s) &= P(w_i + 1 \dots w_n|s_i) \\ &= \sum_{s_{i+1}} P(s_{i+1}|s_i) P(w_{i+1}|s_{i+1}) \beta_{i+1}(s_{i+1}) \end{aligned}$$

EM for HMMs: Process

- From these quantities, can compute expected transitions:

$$\text{count}(s \to s') = \frac{\sum_i \alpha_i(s) P(s'|s) P(w_i|s) \beta_{i+1}(s')}{P(\mathbf{w})}$$

- And emissions:

$$\text{count}(w, s) = \frac{\sum_{i:w_i=w} \alpha_i(s) \beta_{i+1}(s)}{P(\mathbf{w})}$$

Merialdo: Setup

- Some (discouraging) experiments [Merialdo 94]
- Setup:
  - You know the set of allowable tags for each word
  - Fix k training examples to their true labels
    - Learn P(w|t) on these examples
    - Learn $P(t|t_{-1},t_{-2})$ on these examples
  - On n examples, re-estimate with EM
- Note: we know allowed tags but not frequencies

Merialdo: Results

	Number of tagged sentences used for the initial model						
	0	100	2000	5000	10000	20000	all
Iter	Correct tags (% words) after ML on 1M words						
0	77.0	90.0	95.4	96.2	96.6	96.9	97.0
1	80.5	92.6	95.8	96.3	96.6	96.7	96.8
2	81.8	93.0	95.7	96.1	96.3	96.4	96.4
3	83.0	93.1	95.4	95.8	96.1	96.2	96.2
4	84.0	93.0	95.2	95.5	95.8	96.0	96.0
5	84.8	92.9	95.1	95.4	95.6	95.8	95.8
6	85.3	92.8	94.9	95.2	95.5	95.6	95.7
7	85.8	92.8	94.7	95.1	95.3	95.5	95.5
8	86.1	92.7	94.6	95.0	95.2	95.4	95.4
9	86.3	92.6	94.5	94.9	95.1	95.3	95.3
10	86.6	92.6	94.4	94.8	95.0	95.2	95.2

Distributional Clustering

♦ *the president said that the downturn was over* ♦

president	*the __ of*
president	*the __ said*
governor	*the __ of*
governor	*the __ appointed*
said	*sources __ ♦*
said	*president __ that*
reported	*sources __ ♦*

president governor

the a

said reported

[Finch and Chater 92, Shuetze 93, many others]

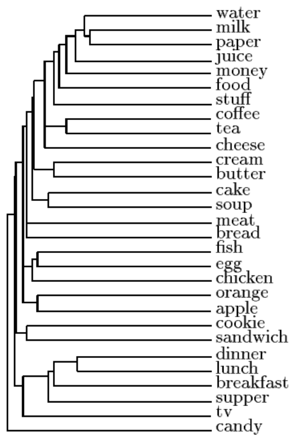
Distributional Clustering

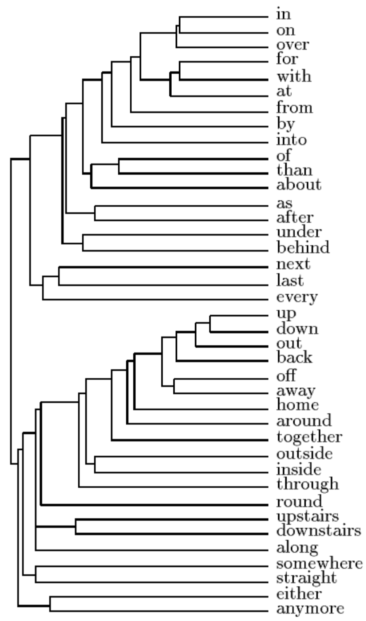
- Three main variants on the same idea:
  - Pairwise similarities and heuristic clustering
    - E.g. [Finch and Chater 92]
    - Produces dendrograms
  - Vector space methods
    - E.g. [Shuetze 93]
    - Models of ambiguity
  - Probabilistic methods
    - Various formulations, e.g. [Lee and Pereira 99]

Nearest Neighbors

word	nearest neighbors
accompanied	submitted banned financed developed authorized headed canceled awarded barred
almost	virtually merely formally fully quite officially just nearly only less
causing	reflecting forcing providing creating producing becoming carrying particularly
classes	elections courses payments losses computers performances violations levels pictures
directors	professionals investigations materials competitors agreements papers transactions
goal	mood roof eye image tool song pool scene gap voice
japanese	chinese iraqi american western arab foreign european federal soviet indian
represent	reveal attend deliver reflect choose contain impose manage establish retain
think	believe wish know realize wonder assume feel say mean bet
york	angeles francisco sox rouge kong diego zone vegas inning layer
on	through in at over into with from for by across
must	might would could cannot will should can may does helps
they	we you i he she nobody who it everybody there

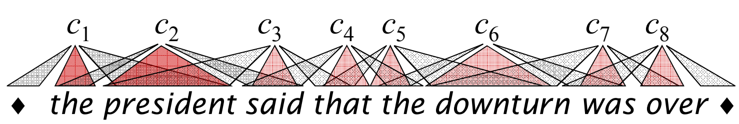
Dendrograms

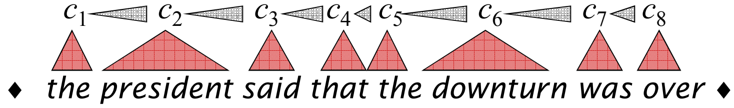




A Probabilistic Version?

$$P(S,C) = \prod_i P(c_i)P(w_i \mid c_i)P(w_{i-1}, w_{i+1} \mid c_i)$$





What Else?

- Various newer ideas:
  - Context distributional clustering [Clark 00]
  - Morphology-driven models [Clark 03]
  - Contrastive estimation [Smith and Eisner 05]
  - Feature-rich induction [Haghighi and Klein 06]

- Also:
  - What about ambiguous words?
  - Using wider context signatures has been used for learning synonyms (what's wrong with this approach?)
  - Can extend these ideas for grammar induction (later)