Sequence Models for Information Extraction, POS tagging, Word Segmentation, Chunking, …

CS224N

2007

(Including some slides from Andrew McCallum and William Cohen)

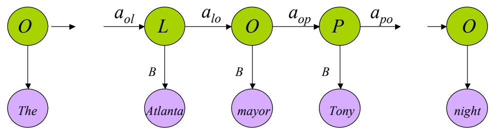
Statistical sequence models for Information Extraction

- There are several techniques for information extraction (template/wrapper learning, hand-coded rules) …
- But statistical sequence models (Hidden Markov Models, MaxEnt markov models, CRFs) are good methods for sequence-based information extraction
- Pros:
  - Well-understood underlying statistical model
  - Can do some form of optimal inference along sequence
  - Portable, broad coverage, robust, good recall
- Cons:
  - Not necessarily as good for complex or multi-slot patterns
  - Only doing the entity mention labeling task (in general)

Applying HMMs to IE

(Leek 1997, Freitag and McCallum 2000)

- **Multinomial HMMs** are sequential version of naïve Bayes/LM.
- **Document** ⇒ generated by a stochastic process
- **Observation** ⇒ word
- **State** ⇒ "reason/explanation" for a given token
  - '*Background'* state emits tokens like '*the*', '*said*', …
  - '*Money*' state emits tokens like '*million*', '*euro*', …
  - '*Person*' state emits tokens like '*Tony*', '*Prithi*', …
- **Extraction**: via the Viterbi (max likelihood parse) algorithm

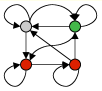


IE with Hidden Markov Models

Given a sequence of observations:

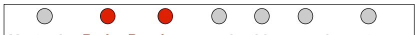
Yesterday Pedro Domingos spoke this example sentence.

and a trained HMM:



🟥	person name
🟩	location name
▨	background

Find the most likely state sequence: (Viterbi)



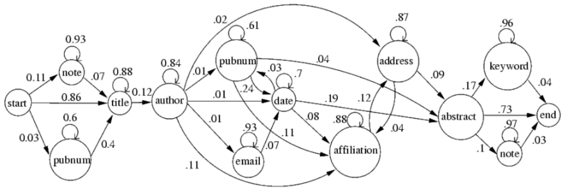
Yesterday Pedro Domingos spoke this example sentence.

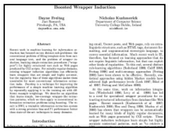
Any words said to be generated by the designated "person name" state extract as a person name:

Person name: Pedro Domingos

HMM for research papers: transitions A

[Seymore *et al.*, 99]





Boosted Wrapper Induction

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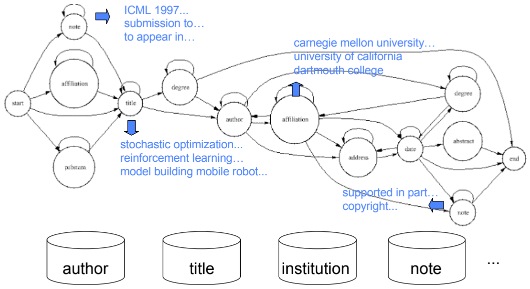
Abstract

HMM for research papers: emissions B

[Seymore *et al.*, 99]



ICML 1997...
submission to…
to appear in…

carnegie mellon university…
university of california
dartmouth college

stochastic optimization...
reinforcement learning…
model building mobile robot...

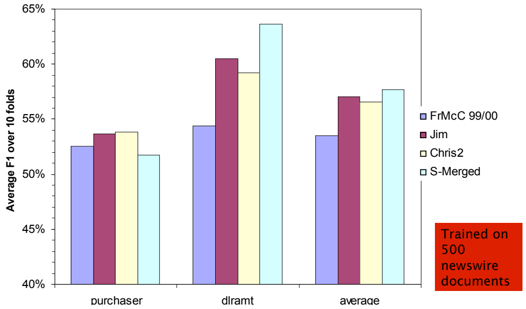
supported in part…
copyright...

Trained on 2 million words of BibTeX data from the Web

Freitag and McCallum (2000) IE with HMMs details

- Partly fixed structure, partly hidden (constrained EM using remote supervision)
  - Class HMM (also used in comp. bio.)
- Parameter tying and shrinkage smoothing techniques
  - Better just to use a good unknown model?
- Structure learning of transition structure
  - Why not just plain EM?
- Results great on semi-structured data!
  - 92.9% token accuracy on paper/citations data
- Still rather modest on free form text

HMM IE results (F_1) on Freitag and McCallum Acquisitions data



Trained on 500 newswire documents

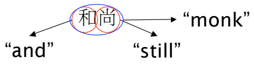
Other Sequence Modeling Tasks: Chinese Word Segmentation

(also: Japanese, Thai, Ancient Greek, …)

- Basic units in written text are “characters”.
- A sentence is a sequence of “characters”, without explicit boundaries.

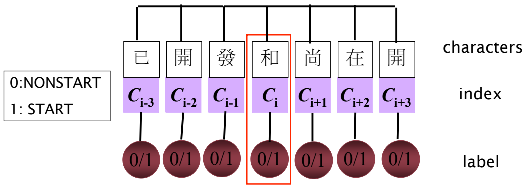
  已開發和尚在開發的資源

- Meaningful units in written texts are “words”
- Word meaning can differ greatly from characters



- But definition of “words” is debatable
  - Different segmentation standards defined by linguists
  - It’s like whether you segment compounds (cf. German)

Sequence Model Chinese Word Segmenter



Other sequence modeling tasks

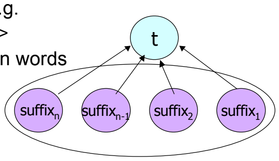
- Base noun phrase chunking
  - Small noun phrases are a useful unit for many applications of terminology extraction, web search
  - Mitsubishi has just announced a new 21.3-inch flat panel monitor for the Japanese market, and even though it offers two DVI ports and a UXGA resolution of 1,600 x 1,200, we're not sure how many folks will be willing to part with close to 200,000 yen
  - Sequence model marks segment start, end

Other sequence modeling tasks

- Topic/FAQ segmentation (question, answer)
- Part-of-speech tagging
- Musical sequences
- DNA sequences
- …

HMM Tagging Models - Brants 2000

- Highly competitive with other state-of-the art models
- Trigram HMM with smoothed transition probabilities
- Capitalization feature becomes part of the state – each tag state is split into two e.g.
  NN → <NN,cap>,<NN,not cap>
- Suffix features for unknown words



$$P(w \mid tag) = P(suffix \mid tag)(w \mid suffix)$$
$$\approx \hat{P}(suffix)\tilde{P}(tag \mid suffix) / \hat{P}(tag)$$

$$\tilde{P}(tag \mid suffix_n) = \lambda_1 \hat{P}(tag \mid suffix_n) + \lambda_2 \hat{P}(tag \mid suffix_{n-1}) + \ldots + \lambda_n \hat{P}(tag)$$

Named Entity Extraction

- The task: find and classify names in text, for example:

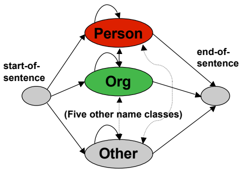
```
The European Commission [ORG] said on Thursday it disagreed
with German [MISC] advice.

Only France [LOC] and Britain [LOC] backed Fischler [PER]
's proposal .

"What we have to be extremely careful of is how other
countries are going to take Germany 's lead", Welsh
National Farmers ' Union [ORG] ( NFU [ORG] ) chairman John
Lloyd Jones [PER] said on BBC [ORG] radio .
```

- The purpose:
  - … a lot of information is really associations between named entities.
  - … for question answering, answers are usually named entities.
  - … the same techniques apply to other slot-filling classifications.

HMM Example: "Nymble"

[Bikel, et al 1998], [BBN "IdentiFinder"]

Task: Named Entity Extraction



<u>**Transition probabilities**</u>	<u>**Observation probabilities**</u>
$P(s_t \mid s_{t-1}, o_{t-1})$	$P(o_t \mid s_t, s_{t-1})$ or $P(o_t \mid s_t, o_{t-1})$
<u>**Back-off to:**</u>	<u>**Back-off to:**</u>
$P(s_t \mid s_{t-1})$	$P(o_t \mid s_t)$
$P(s_t)$	$P(o_t)$

Train on ~500k words of news wire text.

Results:

Case	Language	F1 .
Mixed	English	93%
Upper	English	91%
Mixed	Spanish	90%

•Since 1997, probabilistic sequence approaches (BBN, NYU, then everyone) achieves state-of-the-art performance

Other examples of shrinkage for HMMs in IE: *[Freitag and McCallum '99]*

What is a symbol?

Bikel *et al* mix symbols from **two** abstraction levels

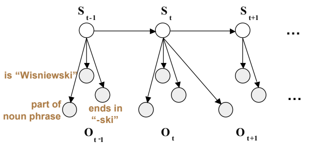
- A word token (for known words, seen more than *k* times

Word Feature	Example Text	Intuition
`twoDigitNum`	90	Two-digit year
`fourDigitNum`	1990	Four digit year
`containsDigitAndAlpha`	A8956-67	Product code
`containsDigitAndDash`	09-96	Date
`containsDigitAndSlash`	11/9/89	Date
`containsDigitAndComma`	23,000.00	Monetary amount
`containsDigitAndPeriod`	1.00	Monetary amount, percentage
`otherNum`	456789	Other number
`allCaps`	BBN	Organization
`capPeriod`	M.	Person name initial
`firstWord`	*first word of sentence*	No useful capitalization information
`initCap`	Sally	Capitalized word
`lowerCase`	can	Uncapitalized word
`other`	,	Punctuation marks, all other words

What is a symbol?

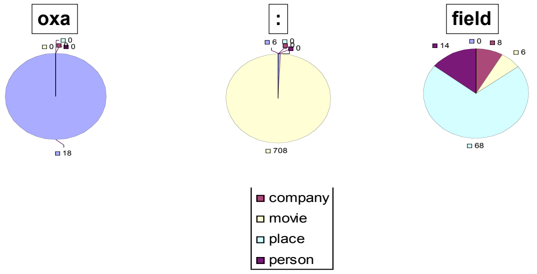
Ideally we would like to use many, arbitrary, overlapping features of words. Useful, but this is hard with HMMs

identity of word
ends in "-ski"
is capitalized
is part of a noun phrase
is in a list of city names
is under node X in WordNet
is in bold font
is indented
is in hyperlink anchor
…



Lots of learning systems are **not** confounded by multiple, non-independent features: decision trees, maxent models, neural nets, SVMs, …

What's in a Name?



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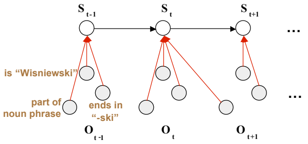

Idea: replace **generative** model in HMM with a **maxent** model, where **state** depends on **observations**

$$\Pr(s_t \mid x_t) = \ldots$$

What is a symbol?

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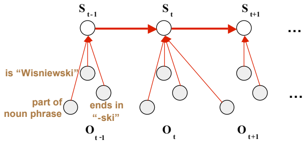
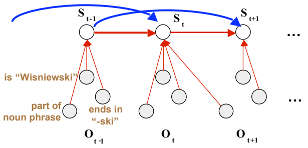


Idea: replace **generative** model in HMM with a **maxent** model, where **state** depends on **observations** and **previous state**

$$\Pr(s_t \mid x_t, s_{t-1,}) = \ldots$$

What is a symbol?

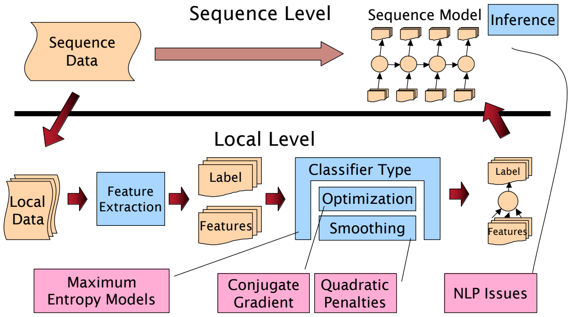
identity of word
ends in “-ski”
is capitalized
is part of a noun phrase
is in a list of city names
is under node X in WordNet
is in bold font
is indented
is in hyperlink anchor
…



Idea: replace **generative** model in HMM with a **maxent** model, where **state** depends on **observations** and **previous state** history

$$\Pr(s_t \mid x_t, s_{t-1,} s_{t-2,} \ldots) = \ldots$$

Inference in Systems



Sequence Level

Sequence Data

Sequence Model

Inference

Local Level

Local Data

Feature Extraction

Label

Features

Classifier Type

Optimization

Smoothing

Label

Features

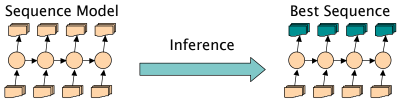
Maximum Entropy Models

Conjugate Gradient

Quadratic Penalties

NLP Issues

Beam Inference



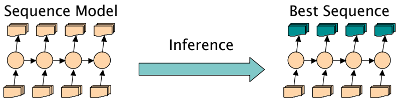
Sequence Model

Inference

Best Sequence

- Beam inference:
  - At each position keep the top k complete sequences.
  - Extend each sequence in each local way.
  - The extensions compete for the k slots at the next position.
- Advantages:
  - Fast; and beam sizes of 3–5 are as good or almost as good as exact inference in many cases.
  - Easy to implement (no dynamic programming required).
- Disadvantage:
  - Inexact: the globally best sequence can fall off the beam.

Viterbi Inference



Sequence Model

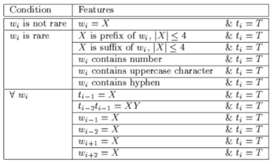
Inference

Best Sequence

- Viterbi inference:
  - Dynamic programming or memoization.
  - Requires small window of state influence (e.g., past two states are relevant).
- Advantage:
  - Exact: the global best sequence is returned.
- Disadvantage:
  - Harder to implement long-distance state-state interactions (but beam inference tends not to allow long-distance resurrection of sequences anyway).

POS tagging: Ratnaparkhi's MXPOST

- Sequential learning problem: predict POS tags of words.
- Uses MaxEnt model described above.
- Rich feature set.
- To smooth, discard features occurring < 10 times.



Condition	Features	
w_i is not rare	$w_i = X$	& $t_i = T$
w_i is rare	X is prefix of w_i, $\|X\| \le 4$	& $t_i = T$
	X is suffix of w_i, $\|X\| \le 4$	& $t_i = T$
	w_i contains number	& $t_i = T$
	w_i contains uppercase character	& $t_i = T$
	w_i contains hyphen	& $t_i = T$
$\forall\ w_i$	$t_{i-1} = X$	& $t_i = T$
	$t_{i-2}t_{i-1} = XY$	& $t_i = T$
	$w_{i-1} = X$	& $t_i = T$
	$w_{i-2} = X$	& $t_i = T$
	$w_{i+1} = X$	& $t_i = T$
	$w_{i+2} = X$	& $t_i = T$

Table 1: Features on the current history h_i

CMM Tagging Models -II

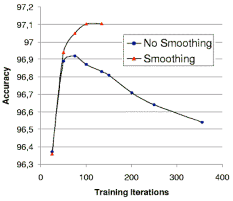
- Ratnaparkhi (1996): local distributions are estimated using maximum entropy models
  - Previous two tags, current word, previous two words, next two words, suffix, prefix, hyphenation, and capitalization features for unknown words
- Toutanova et al. (2003)
  - Richer features, bidirectional inference, better smoothing, better unknown word handling

Model	Overall Accuracy	Unknown Words
HMM (Brants 2000)	96.7	85.5
CMM (Ratn. 1996)	96.63	85.56
CMM (T. et al 2003)	97.24	89.04

Smoothing: POS Tagging

- From (Toutanova et al., 2003):

	Overall Accuracy	Unknown Word Acc
Without Smoothing	96.54	85.20
With Smoothing	97.10	88.20



- Smoothing helps:
  - Softens distributions.
  - Pushes weight onto more explanatory features.
  - Allows many features to be dumped (fairly) safely into the mix.
  - Speeds up convergence (if both are allowed to converge)!

Summary of POS Tagging

For tagging, the change from generative to discriminative model **does not by itself** result in great improvement

One profits from discriminative models for specifying dependence on **overlapping features of the observation** such as spelling, suffix analysis,etc

A CMM allows integration of rich features of the observations, but suffers strongly from assuming independence from following observations; this effect can be relieved by adding dependence on following words

This additional power (of the CMM ,CRF, Perceptron models) has been shown to result in improvements in accuracy

The **higher accuracy** of discriminative models comes at the price of **much slower training**

CoNLL (2003) Named Entity Recognition task

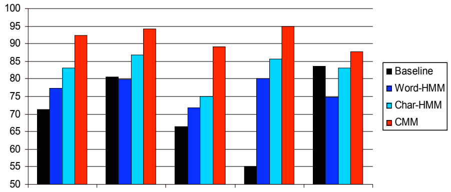
Task: Predict semantic label of each word in text

Foreign	NNP	I-NP	ORG
Ministry	NNP	I-NP	ORG
spokesman	NN	I-NP	O
Shen	NNP	I-NP	PER
Guofang	NNP	I-NP	PER
told	VBD	I-VP	O
Reuters	NNP	I-NP	ORG
:	:	:	:

Standard evaluation is per entity, *not* per token

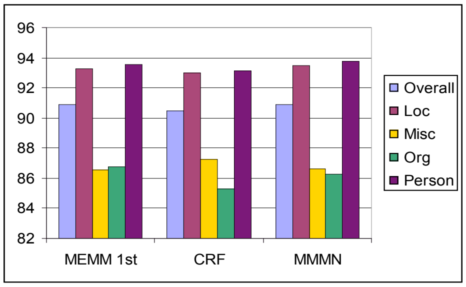
NER Results: Discriminative Model

- Increases from better features, a better classification model.

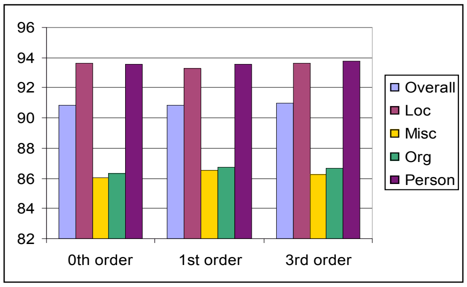


CoNLL 2003 Shared Task: English NER; entity precision/recall F1

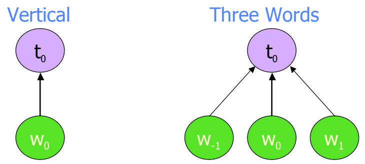
Sequence models? CoNLL 2003 NER shared task Results on English Devset



CoNLL NER Results: CMM Order



Sequence Tagging Without Sequence Information: POS tagging

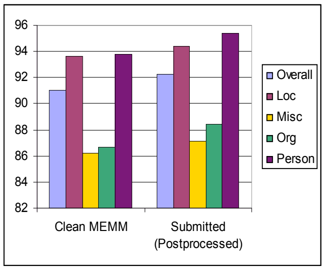


Model	Features	Token	Unknown	Sentence
Vertical	56,805	**93.69%**	82.61%	26.74%
3Words	239,767	**96.57%**	86.78%	48.27%

Using 3 words only works significantly better than using the previous two or three tags instead! (Toutanova et al. 2003)

CoNLL NER: A real difference

- A difference of about 0.7% gives significance among good CoNLL results
- Here we get one!
- It was done with some Perl regular expressions


Clean MEMM
Submitted (Postprocessed)
Overall
Loc
Misc
Org
Person