



# Lecture 7: Part of Speech Tagging

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COMP-550

J&M Ch. 8.1–8.3 (1st ed); J&M Ch. 5.1–5.3 (2nd ed);  
J&M Ch. 8–8.4 (3rd ed)  
Eisenstein (Ch. 7 – 7.4; Ch. 8.1)

# Course So Far

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## Text classification

- Treat document as a bag of words or N-grams

## Language modelling

- Sequence models that assign a likelihood to a sequence

## Part of speech tagging [today]

- Make *a sequence of decisions* about the input text
- Will consider increasingly sophisticated models

# Outline

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Parts of speech in English

POS tagging as a sequence labelling problem

Markov chains revisited

Hidden Markov models

# Parts of Speech in English

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Nouns	<i>restaurant, me, dinner</i>
Verbs	<i>find, eat, is</i>
Adjectives	<i>good, vegetarian</i>
Prepositions	<i>in, of, up, above</i>
Adverbs	<i>quickly, well, very</i>
Determiners	<i>the, a, an</i>

# What is a Part of Speech?

A kind of syntactic category that tells you some of the grammatical properties of a word.

*The \_\_\_\_\_ was delicious.*

- Only a noun fits here.

*This hamburger is \_\_\_\_\_ than that one.*

- Only a comparative adjective fits.

*The cat ate.* (OK – **grammatical**)

*\*The cat enjoyed.* (**Ungrammatical**. Note the \*)

# Important Note

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You may have learned in grade school that nouns = things, verbs = actions. This is wrong!

Nouns that can be actions or events:

- *Examination, wedding, construction, opening*

Verbs that are not necessarily actions or events:

- *Be, have, want, enjoy, remember, realize*

# Penn Treebank Tagset

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CC	Coordinating conjunction	PRP\$	Possessive pronoun
CD	Cardinal number	RB	Adverb
DT	Determiner	RBR	Adverb, comparative
EX	Existential there	RBS	Adverb, superlative
FW	Foreign word	RP	Particle
IN	Preposition; subord. conjunct.	SYM	Symbol
JJ	Adjective	TO	to
JJR	Adjective, comparative	UH	Interjection
JJS	Adjective, superlative	VB	Verb, base form
LS	List item marker	VBD	Verb, past tense
MD	Modal	VBG	Verb, gerund or present part.
NN	Noun, singular or mass	VCN	Verb, past participle
NNS	Noun, plural	VBP	Verb, non-3rd pers. sing. pres.
NNP	Proper noun, singular	VBZ	Verb, 3rd pers. sing. pres.
NNPS	Proper noun, plural	WDT	Wh-determiner
PDT	Predeterminer	WP	Wh-pronoun
POS	Possessive ending	WP\$	Possessive wh-pronoun
PRP	Personal pronoun	WRB	Wh-adverb

# Other Parts of Speech

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## Modals and auxiliary verbs

- *The police can and will catch the fugitives.*
- *Did the chicken cross the road?*

In English, these play an important role in question formation, and in specifying tense, aspect and mood.

## Conjunctions

- *and, or, but, yet*

They connect and relate elements.

## Particles

- *look up, turn down*

Can be parts of particle verbs. May have other functions (depending on what you consider a particle.)



# Classifying Parts of Speech: Open Class

**Open classes** are parts of speech for which new words are readily added to the language (**neologisms**).

- Nouns                      *Twitter, Kleenex, turducken*
- Verbs                      *google, photoshop*
- Adjectives                *Pastafarian, sick*
- Adverbs                   *automagically*
- Interjections          *D'oh!*
- More at <http://neologisms.rice.edu/index.php>

Open class words usually convey most of the content. They tend to be **content words**.

# Closed Class

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Closed classes are parts of speech for which new words tend not to be added.

- Pronouns *I, he, she, them, their*
- Determiners *a, the*
- Quantifiers *some, all, every*
- Conjunctions *and, or, but*
- Modals and auxiliaries *might, should, ought*
- Prepositions *to, of, from*

Closed classes tend to convey grammatical information. They tend to be **function words**.

# Corpus Differences

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How fine-grained do you want your tags to be?

e.g., PTB tagset distinguishes singular from plural nouns

- NN                      *cat, water*
- NNS                     *cats*

e.g., PTB doesn't distinguish between **intransitive verbs** and **transitive verbs**

- VBD                     *listened* (intransitive)
- VBD                     *heard* (transitive)

Brown corpus (87 tags) vs. PTB (45)

# Language Differences

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Languages differ widely in which parts of speech they have, and in their specific functions and behaviours.

- In Japanese, there is no great distinction between nouns and pronouns. Pronouns are open class. OTOH, true verbs are a closed class.
  - I in Japanese: *watashi*, *watakushi*, *ore*, *boku*, *atashi*, ...
- In Wolof, verbs are not conjugated for person and tense. Instead, pronouns are.
  - *maa ngi* (1<sup>st</sup> person, singular, present continuous perfect)
  - *naa* (1<sup>st</sup> person, singular, past perfect)
- In Salishan languages (in the Pacific Northwest), there is no clear distinction between nouns and verbs in the lexicon (Kinkade, 1983).

# POS Tagging

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Assume we have a tagset and a corpus with words labelled with POS tags. What kind of problem is this?

Supervised or unsupervised?

Classification or regression?

Difference from classification that we saw last class—  
context matters!

*I saw the ...*

*The team won the match ...*

*Several cats ...*

# Sequence Labelling

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Predict labels for *an entire sequence of inputs*:

?      ?    ? ?    ?    ? ? ?    ?    ?    ?

Pierre Vinken , 61 years old , will join the board ...



NNP   NNP   , CD NNS   JJ   , MD VB   DT   NN

Pierre Vinken , 61 years old , will join the board ...

Must consider:

Current word

Previous context

# Markov Chains

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Our model will assume an underlying **Markov process** that generates the POS tags and words.

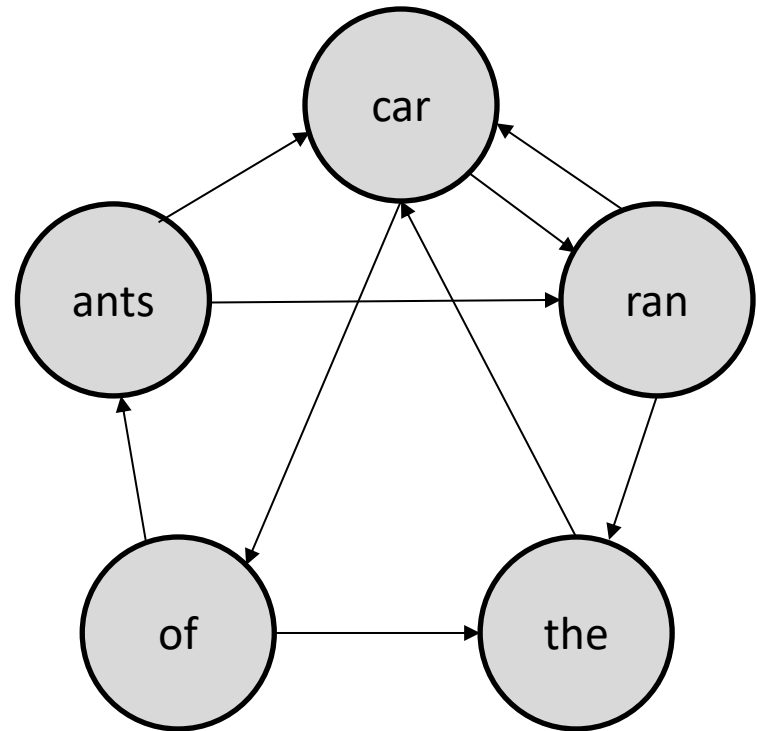
You've already seen Markov processes:

- Morphology: transitions between morphemes that make up a word
- N-gram models: transitions between words that make up a sentence

In other words, they are highly related to finite state automata

# Observable Markov Model

- N states that represent unique observations about the world.
- Transitions between states are weighted—weights of all outgoing edges from a state sum to 1.
- e.g., this is a bigram model
- What would a trigram model look like?

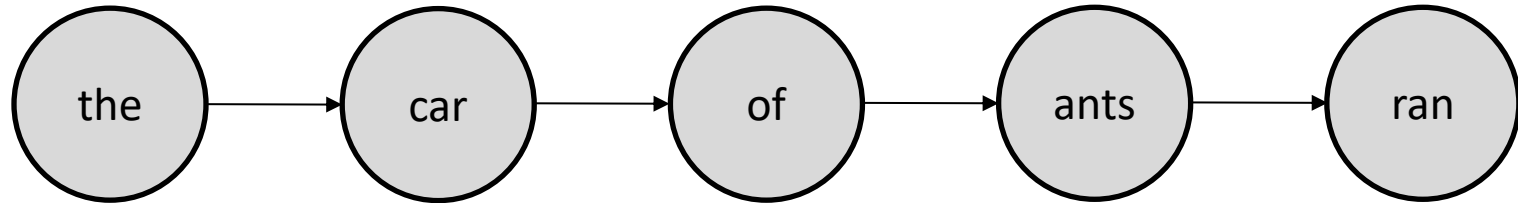




# Unrolling the Timesteps

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A walk along the states in the Markov chain generates the text that is observed:



The probability of the observation is the product of all the edge weights (i.e., transition probabilities).

# Hidden Variables

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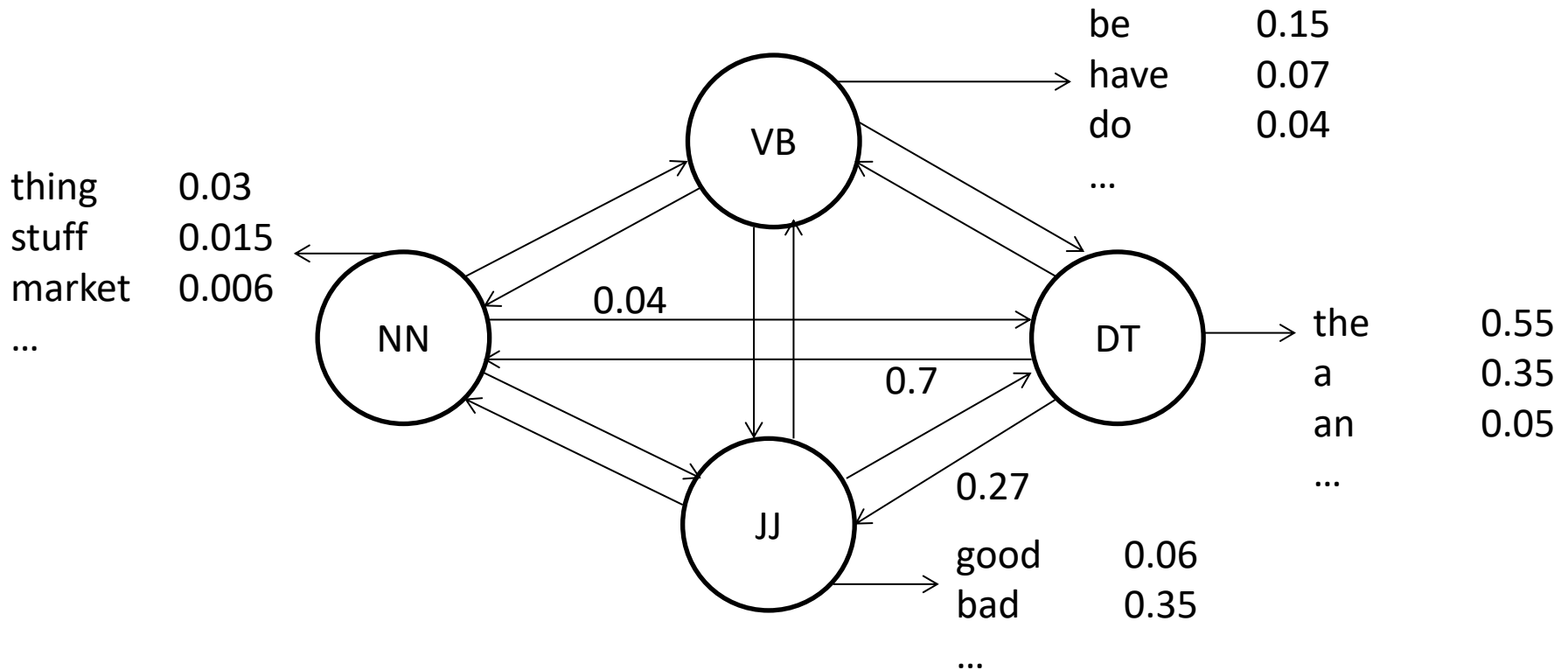
The POS tags to be predicted are **hidden variables**. We don't see them during test time (and sometimes not during training either).

It is very common to have hidden phenomena:

- Encrypted symbols are outputs of hidden messages
- Genes are outputs of functional relationships
- Weather is the output of hidden climate conditions
- Stock prices are the output of market conditions
- ...

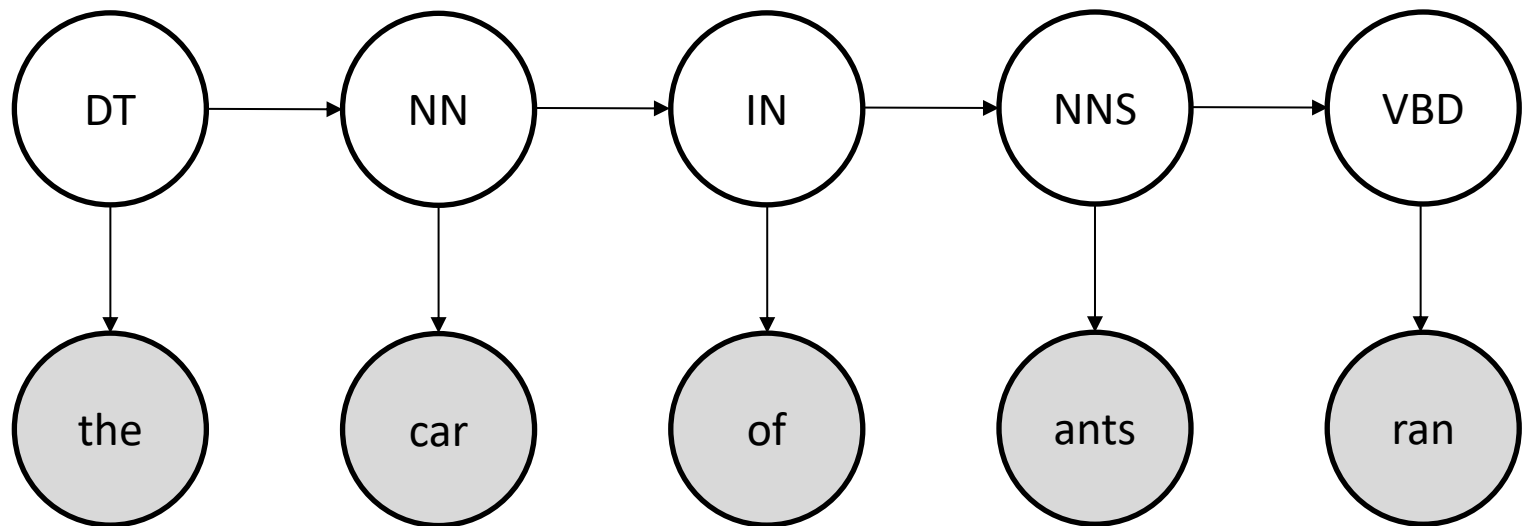
# Markov Process w/ Hidden Variables

Model transitions between *POS tags*, and outputs (“emits”) a word which is observed at each timestep.



# Unrolling the Timesteps

Now, the sample looks something like this:



# Probability of a Sequence

Suppose we know *both* the sequence of POS tags and words generated by them:

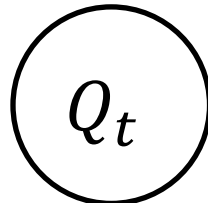
$$\begin{aligned} &P(\textit{The}/DT \textit{ car}/NN \textit{ of}/IN \textit{ ants}/NNS \textit{ ran}/VBD) \\ &= P(DT) \times P(DT \xrightarrow{\textit{emit}} \textit{The}) \\ &\quad \times P(DT \xrightarrow{\textit{trans}} NN) \times P(NN \xrightarrow{\textit{emit}} \textit{car}) \\ &\quad \times P(NN \xrightarrow{\textit{trans}} IN) \times P(IN \xrightarrow{\textit{emit}} \textit{of}) \\ &\quad \times P(IN \xrightarrow{\textit{trans}} NNS) \times P(NNS \xrightarrow{\textit{emit}} \textit{ants}) \\ &\quad \times P(NNS \xrightarrow{\textit{trans}} VBD) \times P(VBD \xrightarrow{\textit{emit}} \textit{ran}) \end{aligned}$$

- Product of hidden state *transitions* and observation *emissions*
- Note independence assumptions

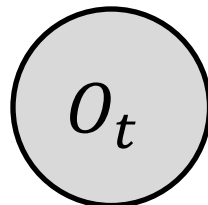
# Graphical Models

Since we now have many random variables, it helps to visualize them graphically. Graphical models precisely tell us:

- Latent or hidden random variables (clear)


$$Q_t \quad P(Q_t = VB) : \text{Probability that } t^{\text{th}} \text{ tag is VB}$$

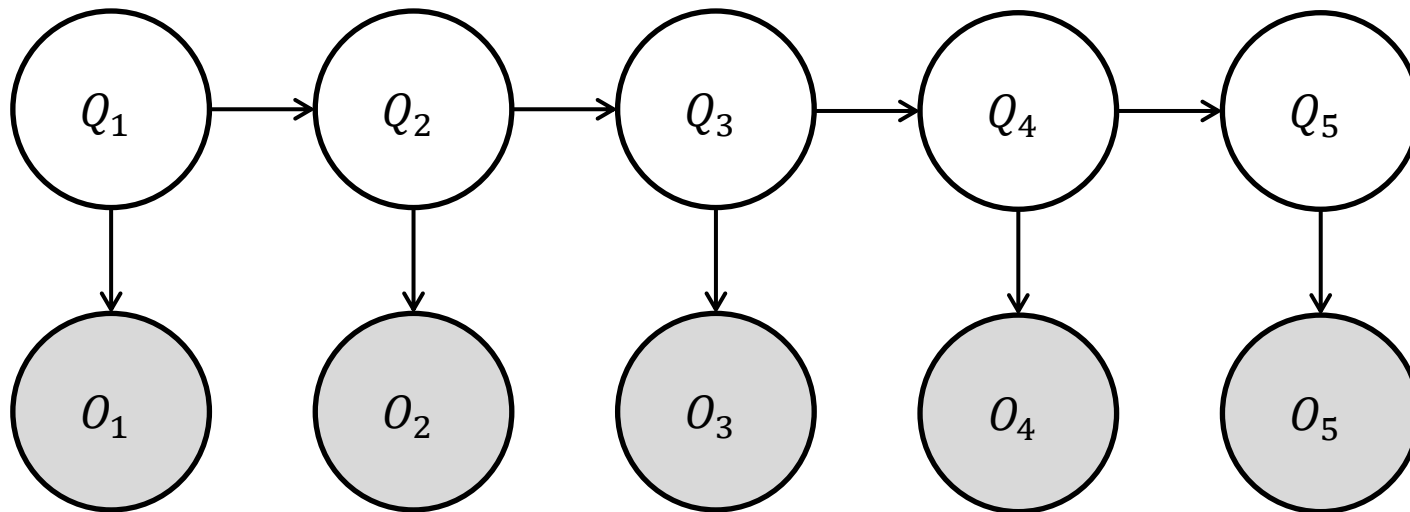
- Observed random variables (filled)


$$O_t \quad P(O_t = \textit{ants}) : \text{Probability that } t^{\text{th}} \text{ word is } \textit{ants}$$

- Conditional independence assumptions (the edges)

# Hidden Markov Models

Graphical representation

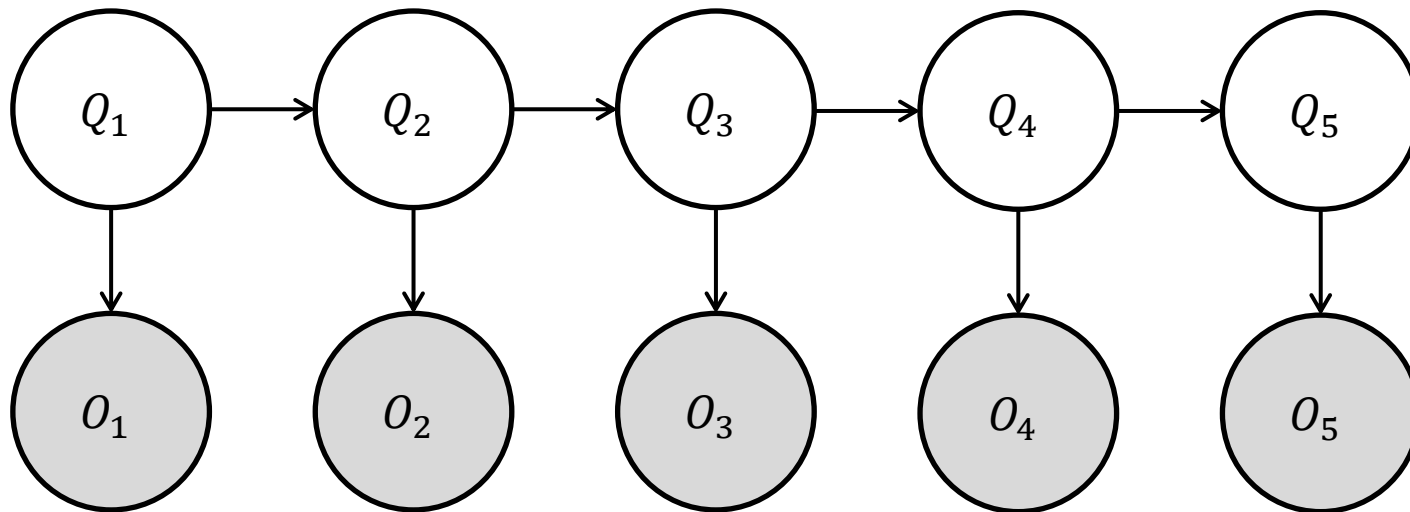


Denote entire sequence of tags as  $\mathbf{Q}$

Entire sequence of words as  $\mathbf{O}$

# Decomposing the Joint Probability

Graph specifies how joint probability decomposes



$$P(\mathbf{O}, \mathbf{Q}) = \underbrace{P(Q_1)}_{\text{Initial state probability}} \prod_{t=1}^{T-1} \underbrace{P(Q_{t+1}|Q_t)}_{\text{State transition probabilities}} \prod_{t=1}^T \underbrace{P(O_t|Q_t)}_{\text{Emission probabilities}}$$

Initial state probability

State transition probabilities

Emission probabilities



# Model Parameters

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Let there be  $N$  possible tags,  $W$  possible words

Parameters  $\theta$  has three components:

1. Initial probabilities for  $Q_1$ :

$$\Pi = \{\pi_1, \pi_2, \dots, \pi_N\} \quad (\text{categorical})$$

2. Transition probabilities for  $Q_t$  to  $Q_{t+1}$ :

$$A = \{a_{ij}\} \quad i, j \in [1, N] \quad (\text{categorical})$$

3. Emission probabilities for  $Q_t$  to  $O_t$ :

$$B = \{b_i(w_k)\} \quad i \in [1, N], k \in [1, W] \quad (\text{categorical})$$

How many distributions and values of each type are there?

# Training a HMM POS Tagger

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Suppose that we have a labelled corpus of words with their POS tags.

**Supervised training** possible using techniques that we learned for N-gram language models!

- *Initial probability distribution*: look at the POS tags in the first word of each sentence
- *Transition probability distributions*: look at transitions of POS tags that are seen in the training corpus
- *Emission probability distributions*: look at emissions of words from each POS tag in the training corpus

# Supervised Estimation of Parameters

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Recall categorical distributions' MLE:

$$P(\text{outcome } i) = \frac{\#(\text{outcome } i)}{\#(\text{all events})}$$

For our parameters:

$$\pi_i = P(Q_1 = i) = \frac{\#(Q_1 = i)}{\#(\text{sentences})}$$

$$a_{ij} = P(Q_{t+1} = j | Q_t = i) = \#(i, j) / \#(i)$$

$$b_{ik} = P(O_t = k | Q_t = i) = \#(\text{word } k, \text{tag } i) / \#(i)$$

Previous discussions about smoothing and OOV items also apply here.

# Exercise in Supervised Training

What are the MLE for the following training corpus?

- Give the initial probability distribution, and the transition and emission distributions from the DT and VBD tags.

DT NN VBD IN DT NN

*the cat sat on the mat*

DT NN VBD JJ

*the cat was sad*

RB VBD DT NN

*so was the mat*

DT JJ NN VBD IN DT JJ NN

*the sad cat was on the sad mat*

# Inference with HMMs

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Now that we have a model, how do we actually tag a new sentence?

- Suppose that for each word, we just found the most likely POS tag that emitted it. What is the problem with this?
- Need a way to find the **best** POS tag sequence (and we need to define what best means).

**Other questions:** What about unsupervised and semi-supervised learning?

# Questions for an HMM

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1. Compute likelihood of a sequence of observations,  
 $P(\mathbf{O}|\theta)$  Forward algorithm, backward algorithm
2. What state sequence best explains a sequence of observations?  
 $\operatorname{argmax}_Q P(\mathbf{Q}, \mathbf{O}|\theta)$  Viterbi algorithm
3. Given an observation sequence (without labels),  
what is the best model for it?  
Forward-backward algorithm  
Baum-Welch algorithm  
Expectation Maximization