Lexicalized and Probabilistic Parsing – Part 1

ICS 482 Natural Language Processing

Lecture 14: Lexicalized and Probabilistic Parsing – Part 1

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بسم الله الرحمن الرحيم

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NLP Credits and Acknowledgment

These slides were adapted from presentations of the Authors of the book

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SPEECH and LANGUAGE PROCESSING:

An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition

and some modifications from presentations found in the WEB by several scholars including the following

NLP Credits and Acknowledgment

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Jerry R. Hobbs
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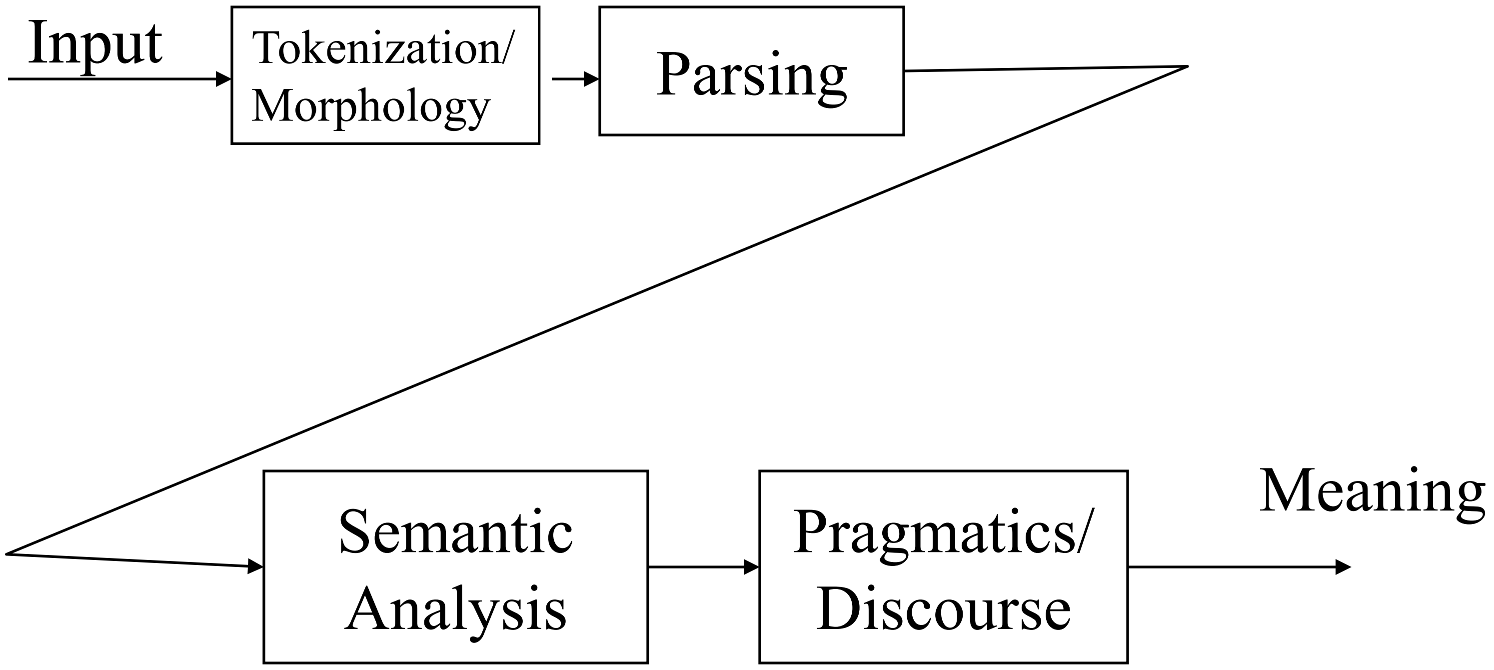
Previous Lectures

- Introduction and Phases of an NLP system
- NLP Applications - Chatting with Alice
- Finite State Automata, Regular Expressions &languages
- Morphology: Inflectional & Derivational
- Parsing and Finite State Transducers
- Stemming & Porter Stemmer
- Statistical NLP – Language Modeling
- N Grams, Smoothing : Add-one & Witten-Bell
- Parts of Speech - Arabic Parts of Speech
- Syntax: Context Free Grammar (CFG) & Parsing
- Parsing: Top-Down, Bottom-Up, Top-down parsing with bottom-up filtering
- Earley's Algorithm – Pop quiz on Earley's Algorithm

Today's Lecture

- Quiz 2 – 25 minutes
- Lexicalized and Probabilistic Parsing

Natural Language Understanding



Lexicalized and Probabilistic Parsing

- Resolving structural ambiguity: choose the most probable parse
- Use lexical dependency (relationship between words)

Probability Model (1)

- A derivation (tree) consists of the set of grammar rules that are in the tree

- The probability of a derivation (tree) is just the product of the probabilities of the rules in the derivation

Probability Model (1.1)

- The probability of a word sequence (sentence) is the probability of its tree in the unambiguous case
- It's the sum of the probabilities of the trees in the ambiguous case

Formal

$$P(T,S) = \prod_{n \in T} p(r(n))$$

$$P(T,S) = P(T)P(S \mid T)$$

Since $P(S \mid T) = 1, \;\; P(T,S) = P(T)$

T	Parse tree
r	rule
n	node in the pars tree
$p(r(n))$	probability of the rule expanded from node n

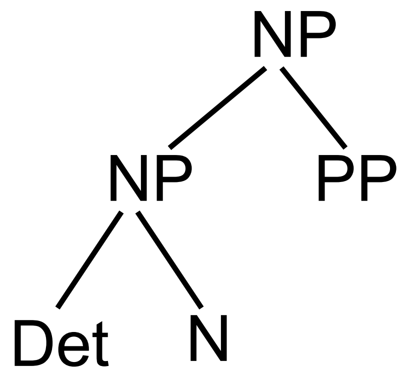
Probability Model

- Attach probabilities to grammar rules
- The expansions for a given non-terminal sum to 1

VP → Verb	.55
VP → Verb NP	.40
VP → Verb NP NP	.05

Probabilistic Context-Free Grammars

NP → Det N	:	0.4
NP → NPposs N	:	0.1
NP → Pronoun	:	0.2
NP → NP PP	:	0.1
NP → N	:	0.2



P(subtree above) = 0.1 x 0.4 = 0.04

Probabilistic Context-Free Grammars

- PCFG
- Also called Stochastic CFG (SCFG)
- $G = (N, \Sigma, P, S, D)$
  - A set of non-terminal symbols (or variables) N
  - A set of terminal symbols Σ $(N \cap \sum = \emptyset)$
  - A set of productions P, each of the form $A \rightarrow \alpha$, where $A \in N$ and $\alpha \in (\Sigma \cup N)^*$
    - $*$ denotes finite length of the infinite set of strings $(\Sigma \cup N)$
  - A designated start symbol $S \in N$
  - A function D that assigns a probability to each rule in P
- $P(A \rightarrow \alpha)$ or $P(A \rightarrow \alpha | A)$

Probabilistic Context-Free Grammars

$S \rightarrow NP\ VP$	[.80]	$Det \rightarrow that$ [.05] | the [.80] | a [.15]	
$S \rightarrow Aux\ NP\ VP$	[.15]	$Noun \rightarrow book$	[.10]
$S \rightarrow VP$	[.05]	$Noun \rightarrow flights$	[.50]
$NP \rightarrow Det\ Nom$	[.20]	$Noun \rightarrow meal$	[.40]
$NP \rightarrow Proper\text{-}Noun$	[.35]	$Verb \rightarrow book$	[.30]
$NP \rightarrow Nom$	[.05]	$Verb \rightarrow include$	[.30]
$NP \rightarrow Pronoun$	[.40]	$Verb \rightarrow want$	[.40]
$Nom \rightarrow Noun$	[.75]	$Aux \rightarrow can$	[.40]
$Nom \rightarrow Noun\ Nom$	[.20]	$Aux \rightarrow does$	[.30]
$Nom \rightarrow Proper\text{-}Noun\ Nom$	[.05]	$Aux \rightarrow do$	[.30]
$VP \rightarrow Verb$	[.55]	$Proper\text{-}Noun \rightarrow TWA$	[.40]
$VP \rightarrow Verb\ NP$	[.40]	$Proper\text{-}Noun \rightarrow Denver$	[~~.40~~].60
$VP \rightarrow Verb\ NP\ NP$	[.05]	$Pronoun \rightarrow you$ [.40] | I [.60]	

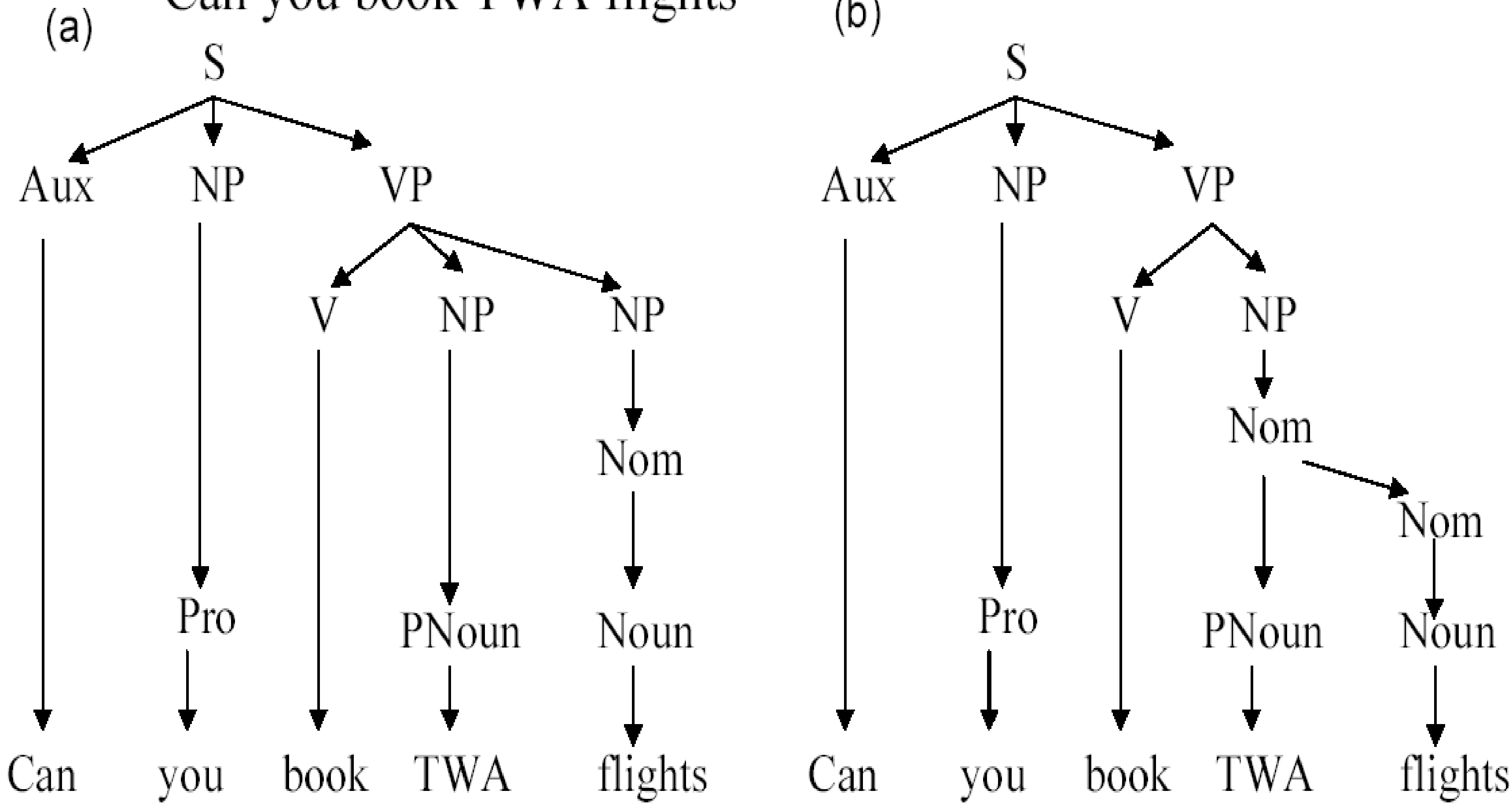
English practice

- What do you understand from the sentence:

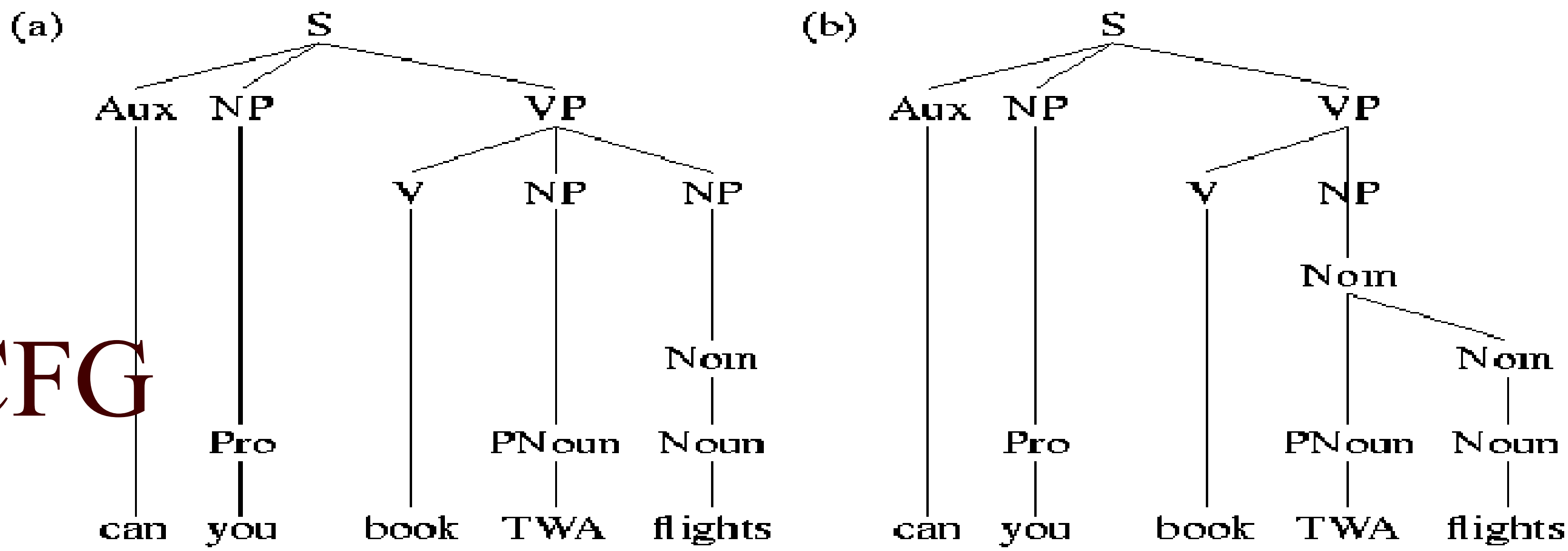
  “Can you book TWA flights?”

  - Can you book flights on behalf of TWA?
    - → [TWA] [flights]
  - Can you book flights run by TWA?
    - → [TWA flights]

Can you book TWA flights



PCFG



Rules			P
S	→	Aux NP VP	.15
NP	→	Pro	.40
VP	→	V NP NP	.05
NP	→	Nom	.05
NP	→	PNoun	.35
Nom	→	Noun	.75
Aux	→	Can	.40
~~NP~~	~~→~~	~~Pro~~	~~.40~~
Pro	→	you	.40
Verb	→	book	.30
PNoun	→	TWA	.40
Noun	→	flights	.50

Rules			P
S	→	Aux NP VP	.15
NP	→	Pro	.40
VP	→	V NP	.40
NP	→	Nom	.05
Nom	→	PNoun Nom	.05
Nom	→	Noun	.75
Aux	→	Can	.40
~~NP~~	~~→~~	~~Pro~~	~~.40~~
Pro	→	you	.40
Verb	→	book	.30
Pnoun	→	TWA	.40
Noun	→	flights	.50

PCFG

$$P(T,S) = \prod_{n \in T} p(r(n))$$

$$P(T,S) = P(T)P(S \mid T)$$

Since $P(S \mid T) = 1, \;\; P(T,S) = P(T)$

T	Parse tree
r	rule
n	node in the pars tree
$p(r(n))$	propability of the role expanded from node n

$$P(T_l) = .15 \times .40 \times .05 \times .05 \times .35 \times .75 \times .40 \times .40 \times .30 \times .40 \times .50 = 3.78 \times 10^{-7}$$

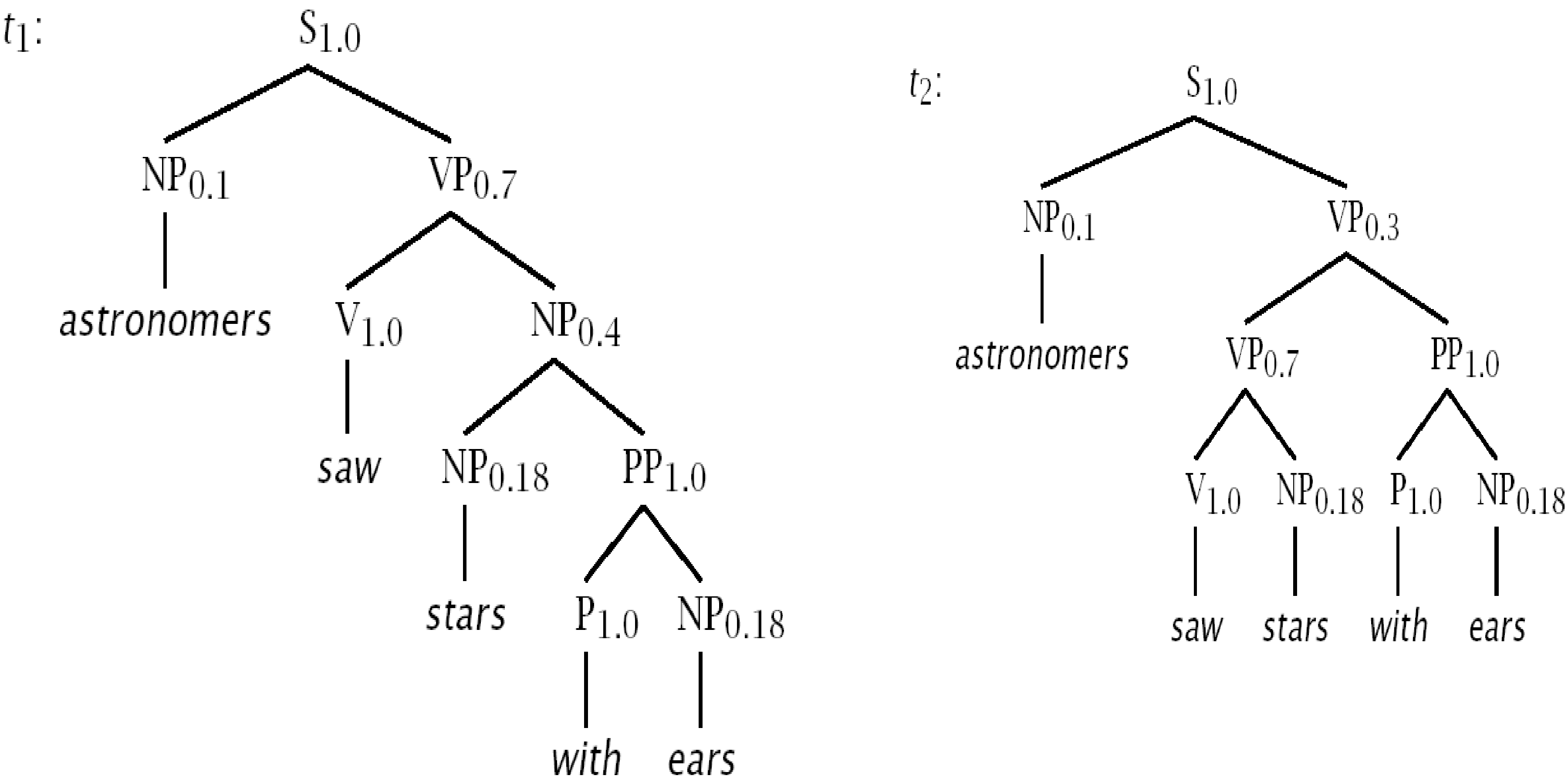
$$P(T_r) = .15 \times .40 \times .40 \times .05 \times .05 \times .75 \times .40 \times .40 \times .30 \times .40 \times .50 = 4.32 \times 10^{-7}$$

$$\hat{T}(S) = \arg\max_T P(T \mid S) = \arg\max_T \frac{P(T,S)}{P(S)} = \arg\max_T P(T,S) = \arg\max_T P(T)$$

A simple PCFG (in CNF)

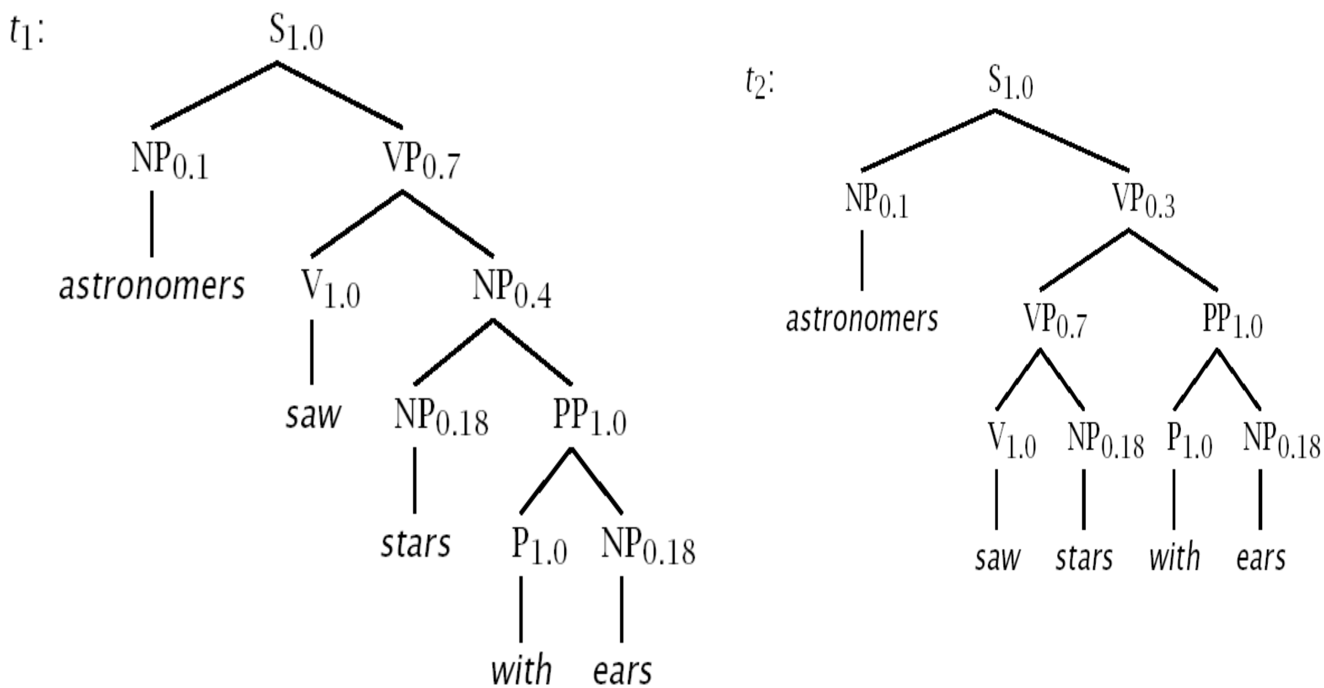
- $S \rightarrow NP\ VP\ 1.0$
- $PP \rightarrow P\ NP\ 1.0$
- $VP \rightarrow V\ NP\ 0.7$
- $VP \rightarrow VP\ PP\ 0.3$
- $P \rightarrow$ with 1.0
- $V \rightarrow$ saw 1.0
- $NP \rightarrow NP\ PP\ 0.4$
- $NP \rightarrow$ astronomers 0.1
- $NP \rightarrow$ ears 0.18
- $NP \rightarrow$ saw 0.04
- $NP \rightarrow$ stars 0.18
- $NP \rightarrow$ telescopes 0.1

Ex: Astronomers saw stars with ears



The two parse trees' probabilities & the sentence probability

- $P(t_1) = 1.0 \times 0.1 \times 0.7 \times 1.0 \times 0.4 \times 0.18 \times 1.0 \times 1.0 \times 0.18 = 0.0009072$
- $P(t_2) = 1.0 \times 0.1 \times 0.3 \times 0.7 \times 1.0 \times 0.18 \times 1.0 \times 1.0 \times 0.18 = 0.0006804$
- $P(w_{15}) = P(t_1) + P(t_2) = 0.0015876$



$S \rightarrow NP\ VP\ 1.0$
$PP \rightarrow P\ NP\ 1.0$
$VP \rightarrow V\ NP\ 0.7$
$VP \rightarrow VP\ PP\ 0.3$
$P \rightarrow$ with 1.0
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- $P(t_1) = 1.0 \times 0.1 \times 0.7 \times 1.0 \times 0.4 \times 0.18 \times 1.0 \times 1.0 \times 0.18 = 0.0009072$
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- $P(w_{15}) = P(t_1) + P(t_2) = 0.0015876$

Probabilistic CFGs

- The probabilistic model
  - Assigning probabilities to parse trees
- Getting the probabilities for the model
- Parsing with probabilities
  - Slight modification to dynamic programming approach
  - Task is to find the max probability tree for an input

Getting the Probabilities

- From an annotated database (a treebank)
- Learned from a corpus

Treebank

- Get a large collection of parsed sentences
- Collect counts for each non-terminal rule expansion in the collection
- Normalize
- Done

Learning

- What if you don’t have a treebank (and can’t get one)
- Take a large collection of text and parse it.
- In the case of syntactically ambiguous sentences collect all the possible parses
- Prorate the rule statistics gathered for rules in the ambiguous case by their probability
- Proceed as you did with a treebank.
- **Inside-Outside** algorithm

Assumptions

- We're assuming that there is a grammar to be used to parse with.
- We're assuming the existence of a large robust dictionary with parts of speech
- We're assuming the ability to parse (i.e. a parser)
- Given all that… we can parse probabilistically

Typical Approach

- Bottom-up dynamic programming approach
- Assign probabilities to constituents as they are completed and placed in the table
- Use the max probability for each constituent going up

Max probability

- Say we're talking about a final part of a parse
  - $S_0 \rightarrow NP_i VP_j$

The probability of the S is…

P(S → NP VP)*P(NP)*P(VP)

The green stuff is already known. We're doing bottom-up parsing

Max

- The P(NP) is known.
- What if there are multiple NPs for the span of text in question (*0* to *i*)?
- Take the max (Why?)
- Does not mean that other kinds of constituents for the same span are ignored (i.e. they might be in the solution)

Probabilistic Parsing

- Probabilistic CYK (Cocke-Younger-Kasami) algorithm for parsing PCFG
- Bottom-up dynamic programming algorithm
- Assume PCFG is in Chomsky Normal Form (production is either $A \rightarrow B\ C$ or $A \rightarrow a$)

Chomsky Normal Form (CNF)

All rules have form:

$$A \rightarrow BC \quad \text{and} \quad A \rightarrow a$$

Non-Terminal   Non-Terminal   terminal

Examples:

$$S \to AS$$
$$S \to a$$
$$A \to SA$$
$$A \to b$$

Chomsky Normal Form

$$S \to AS$$
$$S \to AAS$$
$$A \to SA$$
$$A \to aa$$

Not Chomsky Normal Form

Observations

- Chomsky normal forms are good for parsing and proving theorems
- It is possible to find the Chomsky normal form of any context-free grammar

Probabilistic CYK Parsing of PCFGs

- CYK Algorithm: bottom-up parser
- Input:
  - A Chomsky normal form PCFG, G= (N, Σ, P, S, D) Assume that the N non-terminals have indices 1, 2, …, |N|, and the start symbol S has index 1
  - n words $w_1, \ldots, w_n$
- Data Structure:
  - A dynamic programming array $\pi[i,j,a]$ holds the maximum probability for a constituent with non-terminal index a spanning words $i..j$.
- Output:
  - The maximum probability parse $\pi[1,n,1]$

Base Case

- CYK fills out $\pi[i,j,a]$ by induction
- Base case
  - Input strings with length = 1 (individual words w_i)
  - In CNF, the probability of a given non-terminal A expanding to a single word w_i must come only from the rule $A \rightarrow w_i$ i.e., $P(A \rightarrow w_i)$

Probabilistic CYK Algorithm [Corrected]

Function CYK(*words, grammar*)
  return the most probable parse and its probability
For i ←1 **to** *num_words*
  for $a \leftarrow 1$ **to** *num_nonterminals*
    If $(A \rightarrow w_i)$ is in grammar **then** $\pi[i, i, a] \leftarrow P(A \rightarrow w_i)$
For *span* ←2 **to** *num_words*
  For *begin* ←1 **to** *num_words* – *span* + 1
    end ←*begin* + *span* – 1
    For *m* ←*begin* **to** *end* – 1
     For *a* ←1 **to** *num_nonterminals*
      For *b* ←1 **to** *num_nonterminals*
       For *c* ←1 **to** *num_nonterminals*
        $prob \leftarrow \pi[begin, m, b] \times \pi[m+1, end, c] \times P(A \rightarrow BC)$
        If $(prob > \pi[begin, end, a])$ **then**
          $\pi[begin, end, a] = prob$
          $back[begin, end, a] = \{m, b, c\}$
Return *build_tree(back[1, num_words, 1]),* π*[1, num_words, 1]*

The CYK Membership Algorithm

Input:

- Grammar G in Chomsky Normal Form
- String w

Output:

find if $w \in L(G)$

The Algorithm

Input example:

- Grammar G:

$$S \to AB$$

$$A \to BB$$

$$A \to a$$

$$B \to AB$$

$$B \to b$$

- String : w $aabbb$

aabbb

All substrings of length 1	a	a	b	b	b
All substrings of length 2	aa	ab	bb	bb	
All substrings of length 3	aab	abb	bbb		
All substrings of length 4	aabb	abbb			
All substrings of length 5	aabbb				

$$S \rightarrow AB$$

$$A \rightarrow BB$$

$$A \rightarrow a$$

$$B \rightarrow AB$$

$$B \rightarrow b$$

a	a	b	b	b
A	A	B	B	B
aa	ab	bb	bb	
aab	abb	bbb		
aabb	abbb			
aabbb				

$$S \rightarrow AB$$

$$A \rightarrow BB$$

$$A \rightarrow a$$

$$B \rightarrow AB$$

$$B \rightarrow b$$

a	a	b	b	b
A	A	B	B	B
aa	ab	bb	bb	
	S,B	A	A	
aab	abb	bbb		
aabb	abbb			
aabbb				

$S \rightarrow AB$

$A \rightarrow BB$

$A \rightarrow a$

$B \rightarrow AB$

$B \rightarrow b$

a A	a A	b B	b B	b B
aa	ab S,B	bb A	bb A	
aab S,B	abb A	bbb S,B		
aabb A	abbb S,B			
aabbb S,B				

Therefore: $aabbb \in L(G)$

CYK Algorithm for Deciding Context Free Languages

IDEA: For each substring of a given input *x*, find all variables which can derive the substring. Once these have been found, telling which variables generate *x* becomes a simple matter of looking at the grammar, since it's in Chomsky normal form

Thank you

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