GRAMMARS

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CS159 – Spring 2023
some slides adapted from Ray Mooney

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Admin

Assignment 3 out today: due next Monday

Quiz

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Context free grammar

$S \rightarrow NP\ VP$

left hand side (single symbol)

right hand side (one or more symbols)

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Formally…

G = (NT, T, P, S)

NT: finite set of nonterminal symbols

T: finite set of terminal symbols, NT and T are disjoint

P: finite set of productions of the form
$A \rightarrow \alpha$, $A \in NT$ and $\alpha \in (T \cup NT)^*$

$S \in NT$: start symbol

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CFG: Example

Many possible CFGs for English, here is an example (fragment):

S → NP VP

VP → V NP

NP → DetP N | DetP AdjP N

AdjP → Adj | Adv AdjP

N → kid | dog

V → sees | likes

Adj → big | small

Adv → very

DetP → a | the

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Derivations in a CFG

S → NP VP
VP → V NP
NP → DetP N | DetP AdjP N
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S

What can we do?

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Derivations in a CFG

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NP VP

What can we do?

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NP VP

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DetP N VP

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the kid VP

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the kid likes NP

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Derivations in a CFG

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DetP → a | the

the kid likes a dog

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Derivations in a CFG; Order of Derivation Irrelevant

S → NP VP
VP → V NP
NP → DetP N | DetP AdjP N
AdjP → Adj | Adv AdjP
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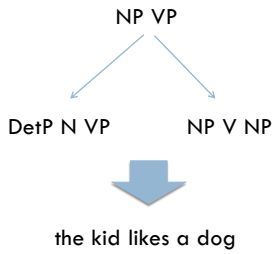
Adv → very
DetP → a | the



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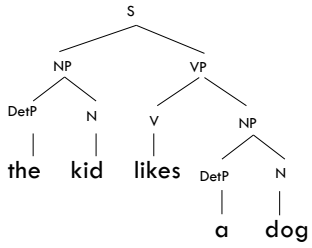
Derivations of CFGs

String rewriting system: we derive a string

Derivation history shows the constituent tree:

the kid likes a dog



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Parsing

Parsing is the field of NLP interested in automatically determining the syntactic structure of a sentence

Parsing can be thought of as determining what sentences are "valid" English sentences

As a byproduct, we often can get the structure

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Parsing

Given a CFG and a sentence, determine the possible parse tree(s)

I eat sushi with tuna

S -> NP VP
NP -> N
NP -> PRP
NP -> N PP
VP -> V NP
VP -> V NP PP
PP -> IN N
PRP -> I
V -> eat
N -> sushi
N -> tuna
IN -> with

What parse trees are possible for this sentence?

How did you do it?

What if the grammar is much larger?

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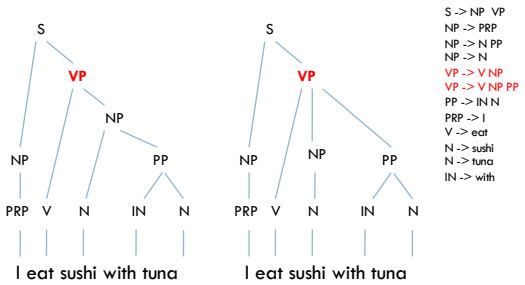
Parsing



What is the difference between these parses?

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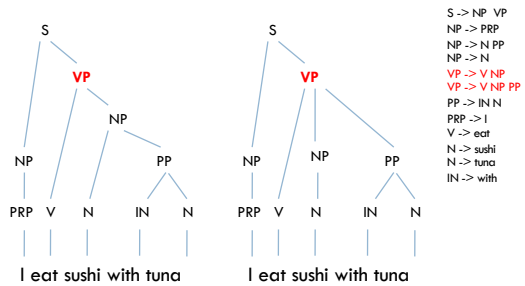
Parsing ambiguity



How can we decide between these?

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A Simple PCFG

Probabilities!

S	→	NP VP	1.0	NP	→	NP PP	0.4
VP	→	V NP	0.7	NP	→	*astronomers*	0.1
VP	→	VP PP	0.3	NP	→	*ears*	0.18
PP	→	P NP	1.0	NP	→	*saw*	0.04
P	→	*with*	1.0	NP	→	*stars*	0.18
V	→	*saw*	1.0	NP	→	*telescope*	0.1

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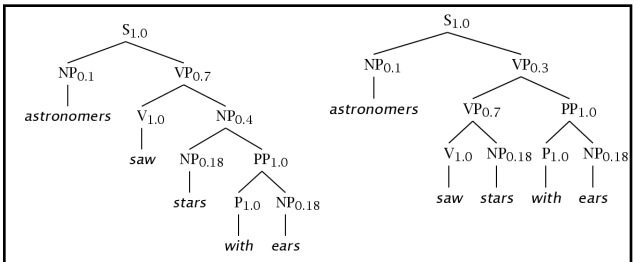

Just like *n*-gram language modeling, PCFGs break the sentence generation process into smaller steps/probabilities

The probability of a parse is the product of the PCFG rules

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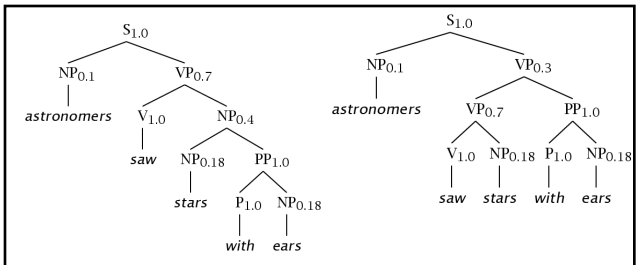

What are the different interpretations here?

Which do you think is more likely?

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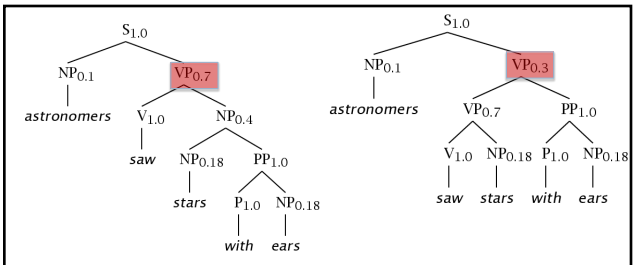

= 1.0 * 0.1 * 0.7 * 1.0 * 0.4 * 0.18
* 1.0 * 1.0 * 0.18
= 0.0009072

= 1.0 * 0.1 * 0.3 * 0.7 * 1.0 * 0.18
* 1.0 * 1.0 * 0.18
= 0.0006804

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Parsing problems

Pick a model
- e.g. CFG, PCFG, …

Train (or learn) a model
- What CFG/PCFG rules should I use?
- Parameters (e.g. PCFG probabilities)?
- What kind of data do we have?

Parsing
- Determine the parse tree(s) given a sentence

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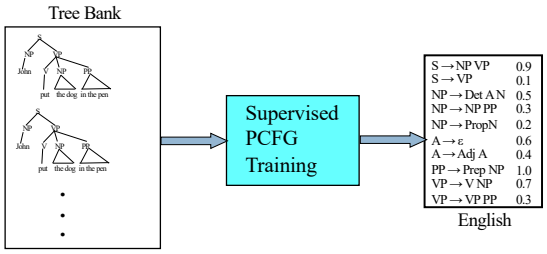
PCFG: Training

If we have example parsed sentences, how can we learn a set of PCFGs?



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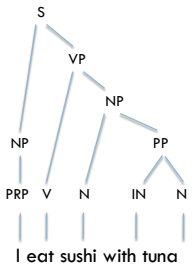
Extracting the rules



S → NP VP
NP → PRP
PRP → I
VP → V NP
V → eat
NP → N PP
N → sushi
PP → IN N
IN → with
N → tuna

What CFG rules occur in this tree?

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Estimating PCFG Probabilities

We can extract the rules from the trees

S → NP VP
NP → PRP
PRP → I
VP → V NP
V → eat
NP → N PP
N → sushi
…

S → NP VP 1.0
VP → V NP 0.7
VP → VP PP 0.3
PP → P NP 1.0
P → *with* 1.0
V → *saw* 1.0

How do we go from the extracted CFG rules to PCFG rules?

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Estimating PCFG Probabilities

Extract the rules from the trees

Calculate the probabilities using MLE

$$\alpha \rightarrow \beta \quad \Rightarrow \quad p(\alpha \rightarrow \beta \mid \alpha)$$

$$P(\alpha \rightarrow \beta \mid \alpha) = \frac{\text{count}(\alpha \rightarrow \beta)}{\sum_{\gamma} \text{count}(\alpha \rightarrow \gamma)} = \frac{\text{count}(\alpha \rightarrow \beta)}{\text{count}(\alpha)}$$

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Estimating PCFG Probabilities

		Occurrences
S	→ NP VP	10
S	→ V NP	3
S	→ VP PP	2
NP	→ N	7
NP	→ N PP	3
NP	→ DT N	6

P(S → V NP) = ?

P(S → V NP) = P(S → V NP | S) = $\frac{\text{count(S → V NP)}}{\text{count(S)}} = \frac{3}{15}$

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Grammar Equivalence

What does it mean for two grammars to be equal?

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Grammar Equivalence

Weak equivalence: grammars generate the same set of strings

- Grammar 1: NP → DetP N and DetP → a | the
- Grammar 2: NP → a N | the N

Strong equivalence: grammars have the same set of derivation trees

- With CFGs, possible only with useless rules
- Grammar 2: NP → a N | the N
- Grammar 3: NP → a N | the N, DetP → many

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Normal Forms

There are weakly equivalent normal forms (Chomsky Normal Form, Greibach Normal Form)

A CFG is in Chomsky Normal Form (CNF) if all productions are of one of two forms:

- A → B C with A, B, C nonterminals
- A → α, with A a nonterminal and α a terminal

Every CFG has a weakly equivalent CFG in CNF

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CNF Grammar

S -> VP
VP -> VB NP
VP -> VB NP PP
NP -> DT NN
NP -> NN
NP -> NP PP
PP -> IN NP
DT -> the
IN -> with
VB -> film
VB -> trust
NN -> man
NN -> film
NN -> trust

S -> VP
VP -> VB NP
VP -> VP2 PP
VP2 -> VB NP
NP -> DT NN
NP -> NN
NP -> NP PP
PP -> IN NP
DT -> the
IN -> with
VB -> film
VB -> trust
NN -> man
NN -> film
NN -> trust

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Probabilistic Grammar Conversion

Original Grammar		Chomsky Normal Form	
S → NP VP	0.8	S → NP VP	0.8
S → Aux NP VP	0.1	S → X1 VP	0.1
		X1 → Aux NP	1.0
S → VP	0.1	S → book | include | prefer	
		0.01 0.004 0.006	
		S → Verb NP	0.05
		S → VP PP	0.03
NP → Pronoun	0.2	NP → I | he | she | me	
		0.1 0.02 0.02 0.06	
NP → Proper-Noun	0.2	NP → Houston | NWA	
		0.16 .04	
NP → Det Nominal	0.6	NP → Det Nominal	0.6
Nominal → Noun	0.3	Nominal → book | flight | meal | money	
		0.03 0.15 0.06 0.06	
Nominal → Nominal Noun	0.2	Nominal → Nominal Noun	0.2
Nominal → Nominal PP	0.5	Nominal → Nominal PP	0.5
VP → Verb	0.2	VP → book | include | prefer	
		0.1 0.04 0.06	
VP → Verb NP	0.5	VP → Verb NP	0.5
VP → VP PP	0.3	VP → VP PP	0.3
PP → Prep NP	1.0	PP → Prep NP	1.0

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Grammar questions

Can we determine if a sentence is grammatical?

Given a sentence, can we determine the syntactic structure?

Can we determine how likely a sentence is to be grammatical? to be an English sentence?

Next time: parsing

Can we generate candidate, grammatical sentences?

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