NLP LINGUISTICS 101

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CS159 – Fall 2024

some slides adapted from Ray Mooney

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Admin

Assignment 2

Quiz #1
- Take-home anytime Thursday
- 45 minutes
- Open book/notes

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Quiz #1 material

T/F, short answer, pencil and paper work (no coding)

zipf's law
regular expressions

probability basics

language modeling
- MLE estimation/estimating from a corpus
- development set
- perplexity
- determining vocabulary
- smoothing techniques
  - add 1
  - add lambda
- interpolation
- backoff
  - absolute discounting

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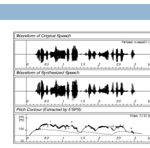
Simplified View of Linguistics

Phonology/Phonetics:  → /waddyasai/

Morphology: /waddyasai/ → what did you say

Syntax: what did you say → say (subj: you, obj: what)

Semantics: say (subj: you, obj: what) → P[λx. say(you, x)]

Discourse: what did you say → what did you say

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Morphology

What is morphology?

- study of the internal structure of words
  - morph-ology word-s jump-ing

Why might this be useful for NLP?

- generalization (runs, running, runner are related)
- additional information (it's plural, past tense, etc)
- allows us to handle words we've never seen before
  - smoothing?

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New words

AP newswire stories from Feb 1988 – Dec 30, 1988

- 300K unique words

New words seen on Dec 31

- compounds: prenatal-care, publicly-funded, channel-switching, …
- New words:
  - dumbbells, groveled, fuzzier, oxidized, ex-presidency, puppetry, boulderlike, over-emphasized, antiprejudice

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Morphology basics

Words are built up from morphemes

- stems (base/main part of the word)
- affixes
  - prefixes
    - precedes the stem
  - suffixes
    - follows the stem
  - infixes
    - inserted inside the stem
  - circumfixes
    - surrounds the stem
- Examples?

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Morpheme examples

prefix

- circum- (circumnavigate)
- dis- (dislike)
- mis- (misunderstood)
- com-, de-, dis-, in-, re-, post-, trans-, …

suffix

- -able (movable)
- -ance (resistance)
- -ly (quickly)
- -tion, -ness, -ate, -ful, …

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Morpheme examples

infix

- -fucking- (cinder-fucking-rella)
- more common in other languages

circumfix

- doesn't really happen in English
- a- -ing
  - a-running
  - a-jumping

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Agglutinative: Finnish

talo 'the-house'	kaup-pa 'the-shop'
talo-ni 'my house'	kaup-pa-ni 'my shop'
talo-ssa 'in the-house'	kaup-a-ssa 'in the-shop'
talo-ssa-ni 'in my house'	kaup-a-ssa-ni 'in my shop'
talo-i-ssa 'in the-houses'	kaup-o-i-ssa 'in the-shops'
talo-i-ssa-ni 'in my houses'	kaup-o-i-ssa-ni 'in my shops'

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Stemming (baby lemmatization)

Reduce a word to the main stem/morpheme

automate
automates
automatic
automation → *automat*

run
runs
running → *run*

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Stemming example

This is a poorly constructed example using the Porter stemmer.

This is a poorli construct example us the Porter stemmer.

https://text-processing.com/demo/stem/
(or you can download versions online)

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Porter's algorithm (1980)

Most common algorithm for stemming English
- Results suggest it is at least as good as other stemming options

Multiple sequential phases of reductions using rules, e.g.
- sses → ss
- ies → i
- ational → ate
- tional → tion

http://tartarus.org/~martin/PorterStemmer/

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What is Syntax?

Study of the structure of language

Examine the rules of how words interact and go together

Rules governing grammaticality

I will give you one perspective
- no single correct theory of syntax
- still an active field of research in linguistics
- we will often use it as a tool/stepping stone for other applications

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Structure in language

The man ____ all the way home.

what are some examples of words that can/can't go here?

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Structure in language

The man ____ all the way home.

why can't some words go here?

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Structure in language

The man flew all the way home.

Language is bound by a set of rules

It's not clear exactly the form of these rules, however, people can generally recognize them

This is syntax!

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Syntax != Semantics

Colorless green ideas sleep furiously.

Syntax is only concerned with how words interact from a grammatical standpoint, not semantically (i.e. meaning)

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Parts of speech

What are parts of speech (think 3rd grade)?

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Parts of speech

Parts of speech are constructed by grouping words that function similarly:
- with respect to the words that can occur nearby
- and by their morphological properties

The man ____ all the way home.

ran	integrated	washed
forgave	programmed	warned
ate	shot	walked
drove	shouted	spoke
drank	sat	succeeded
hid	slept	survived
learned	understood	read
hurt	voted	recorded

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Parts of speech

What are the English parts of speech?

- 8 parts of speech?
  - Noun (person, place or thing)
  - Verb (actions and processes)
  - Adjective (modify nouns)
  - Adverb (modify verbs)
  - Preposition (on, in, by, to, with)
  - Determiners (a, an, the, what, which, that)
  - Conjunctions (and, but, or)
  - Particles (off, up)

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English parts of speech

Brown corpus: 87 POS tags

Penn Treebank: ~45 POS tags
- Derived from the Brown tagset
- Most common in NLP
- Many of the examples we'll show use this one

British National Corpus (C5 tagset): 61 tags

C6 tagset: 148

C7 tagset: 146

C8 tagset: 171

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Tagsets

Brown tagset:

https://en.wikipedia.org/wiki/Brown_Corpus

C8 tagset:

http://ucrel.lancs.ac.uk/claws8tags.pdf

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English Parts of Speech

Noun (person, place or thing)
- Singular (NN): dog, fork
- Plural (NNS): dogs, forks
- Proper (NNP, NNPS): John, Springfields
- Personal pronoun (PRP): I, you, he, she, they, it
- Wh-pronoun (WP): who, what

Verb (actions and processes)
- Base, infinitive (VB): eat
- Past tense (VBD): ate
- Gerund (VBG): eating
- Past participle (VBN): eaten
- Non 3rd person singular present tense (VBP): eat
- 3rd person singular present tense: (VBZ): eats
- Modal (MD): should, can
- To (TO): to (to eat)

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English Parts of Speech (cont.)

Adjective (modify nouns)
- Basic (JJ): red, tall
- Comparative (JJR): redder, taller
- Superlative (JJS): reddest, tallest

Adverb (modify verbs)
- Basic (RB): quickly
- Comparative (RBR): quicker
- Superlative (RBS): quickest

Preposition (IN): on, in, by, to, with

Determiner:
- Basic (DT) a, an, the
- WH-determiner (WDT): which, that

Coordinating Conjunction (CC): and, but, or,

Particle (RP): off (took off), up (put up)

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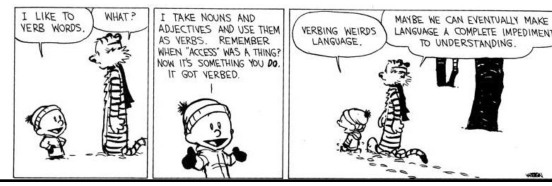
Closed vs. Open Class

Closed class categories are composed of a small, fixed set of grammatical function words for a given language.
- Pronouns, Prepositions, Auxiliary verbs, Determiners, Particles, Conjunctions

Open class categories have large number of words and new ones are easily invented.
- Nouns (Googler, futon, iPad), Verbs (Google, futoning), Adjectives (geeky), Abverb (chompingly)



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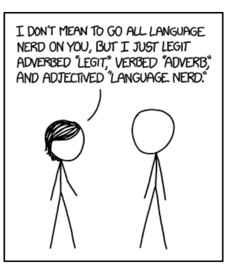

https://xkcd.com/1443/

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Part of speech tagging

Annotate each word in a sentence with a part-of-speech marker

Lowest level of syntactic analysis

John	saw	the	saw	and	decided	to	take	it	to	the	table.
NNP	VBD	DT	NN	CC	VBD	TO	VB	PRP	IN	DT	NN

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Ambiguity in POS Tagging

I like candy.
VBP
(verb, non-3rd person, singular, present)

Time flies like an arrow.
IN
(preposition)

Does "like" play the same role (POS) in these sentences?

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Ambiguity in POS Tagging

I bought it at the shop around the corner.
IN
(preposition)

I never got around to getting the car.
RP
(particle… on, off)

The cost of a new Prius is around $25K.
RB
(adverb)

Does "around" play the same role (POS) in these sentences?

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Ambiguity in POS Tagging

Like most language components, the challenge with POS tagging is ambiguity

Brown corpus analysis

- 11.5% of word types are ambiguous (this sounds promising!), but…
- 40% of word appearances are ambiguous
- Unfortunately, the ambiguous words tend to be the more frequently used words

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How hard is it?

If I told you had a POS tagger that achieved 90% accuracy would you be impressed?

- Shouldn't be… just picking the most frequent POS for a word gets you this

What about a POS tagger that achieves 93.7%?

- Still probably shouldn't be… only need to add a basic module for handling unknown words

What about a POS tagger that achieves 100%?

- Should be suspicious… humans only achieve ~97%
- Probably overfitting (or cheating!)

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POS Tagging Approaches

Rule-Based: Human crafted rules based on lexical and other linguistic knowledge

Learning-Based: Trained on human annotated corpora like the Penn Treebank
- **Statistical models**: Hidden Markov Model (HMM), Maximum Entropy Markov Model (MEMM), Conditional Random Field (CRF), log-linear models, support vector machines (SVMs), neural networks
- **Rule learning**: Transformation Based Learning (TBL)

The book discusses some of the more common approaches

Many publicly available:
- http://nlp.stanford.edu/links/statnlp.html (lists 15 different ones mostly publicly available!)
- http://www.coli.uni-saarland.de/~thorsten/tnt/

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Constituency

Parts of speech can be thought of as the lowest level of syntactic information

Groups *words* together into categories

________ likes to eat candy.

What can/can't go here?

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Constituency

________ likes to eat candy.

nouns	determiner nouns
Dave	The man
Prof Kauchak	The boy
Dr. Suess	The cat

pronouns	determiner nouns +
He	The man that I saw
She	The boy with the blue pants
They	The cat in the hat

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Constituency

Words in languages tend to form into functional groups (parts of speech)

Groups of words (aka phrases) can also be grouped into functional groups
- often some relation to parts of speech
- though, more complex interactions

These phrase groups are called constituents

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Common constituents

He likes to eat candy.

noun phrase — verb phrase

The man in the hat ran to the park.

noun phrase — verb phrase

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Common constituents

The man in the hat ran to the park.

noun phrase — prepositional phrase — prepositional phrase

noun phrase — verb phrase

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Common constituents

The man in the hat ran to the park.

noun phrase — prepositional phrase — noun phrase

noun phrase — prepositional phrase

verb phrase

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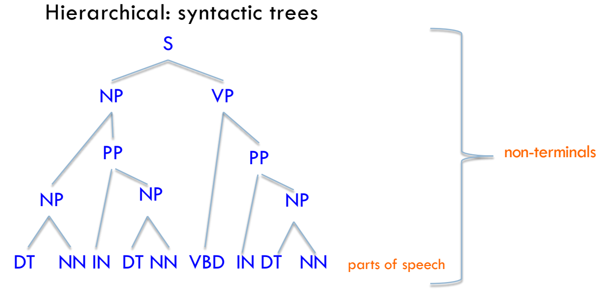
Syntactic structure

Hierarchical: syntactic trees



The man in the hat ran to the park.

terminals (words)

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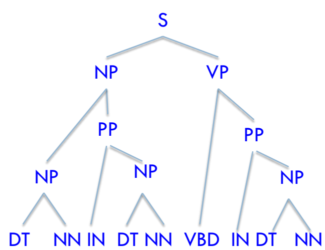
Syntactic structure

(S (NP (NP (DT the) (NN man)) (PP (IN in) (NP (DT the) (NN hat)))) (VP (VBD ran) (PP (TO to (NP (DT the) (NN park))))))



The man in the hat ran to the park.

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Syntactic structure

(S (NP (NP (DT the) (NN man)) (PP (IN in) (NP (DT the) (NN hat)))) (VP (VBD ran) (PP (TO to (NP (DT the) (NN park))))))

```
(S
  (NP
    (NP (DT the) (NN man))
    (PP (IN in)
      (NP (DT the) (NN hat))))
  (VP (VBD ran)
    (PP (TO to)
      (NP (DT the) (NN park))))))
```

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Syntactic structure

A number of related problems:

- Given a sentence, can we determine the syntactic structure?
- Can we determine if a sentence is grammatical?
- Can we determine how *likely* a sentence is to be grammatical? to be an English sentence?
- Can we generate candidate, grammatical sentences?

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Grammars

What is a grammar (3rd grade again…)?

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Grammars

Grammar is a set of structural rules that govern the composition of sentences, phrases and words

Lots of different kinds of grammars:

- regular
- context-free
- context-sensitive
- recursively enumerable
- transformation grammars

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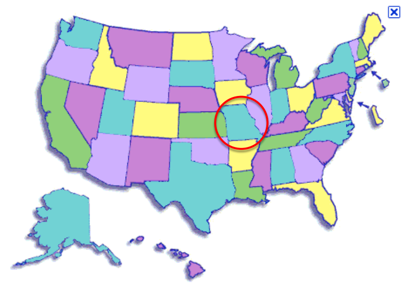
States



What is the capitol of this state? Jefferson City (Missouri)

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Context free grammar

How many people have heard of them?

Look like:

$S \rightarrow NP\ VP$

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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CFG: Example

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

S → NP VP

VP → V NP

NP → DetP N | DetP AdjP N

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N → kid | dog

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Adj → big | small

Adv → very

DetP → a | the

Formal grammar definition:

NT: {S, NP, VP, DetP, N, AdjP, Adj, Adv}

T: {kid, dog, sees, likes, big, small, very, a, the}

P:

S: S

Often just specify the production rules

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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?

Can we generate candidate, grammatical sentences?

Which of these can we answer with a CFG? How?

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Grammar questions

Can we determine if a sentence is grammatical?
- Is it accepted/recognized by the grammar
- Applying rules right to left, do we get the start symbol?

Given a sentence, can we determine the syntactic structure?
- Keep track of the rules applied…

Can we determine how likely a sentence is to be grammatical? to be an English sentence?
- Not yet… no notion of "likelihood" (probability)

Can we generate candidate, grammatical sentences?
- Start from the start symbol, randomly pick rules that apply (i.e. left hand side matches)

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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
AdjP → Adj | Adv AdjP
N → kid | dog
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the

S

What can we do?

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Derivations in a CFG

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

S

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Derivations in a CFG

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

NP VP

What can we do?

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Derivations in a CFG

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

NP VP

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Derivations in a CFG

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

DetP N VP

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Derivations in a CFG

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**

DetP N VP

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Derivations in a CFG

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

the kid VP

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Derivations in a CFG

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

the kid likes NP

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Derivations in a CFG

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

the kid likes a dog

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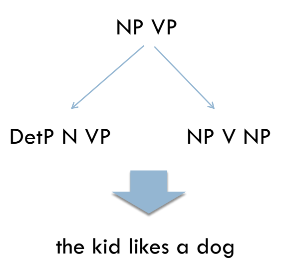
Derivations in a CFG; Order of Derivation Irrelevant

S → NP VP
VP → V NP
NP → DetP N | DetP AdjP N
AdjP → Adj | Adv AdjP
N → kid | dog
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the



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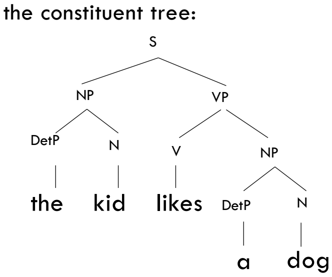
Derivations of CFGs

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)

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

I eat sushi with tuna

What parse trees are possible for this sentence?

How did you do it?

What if the grammar is much larger?

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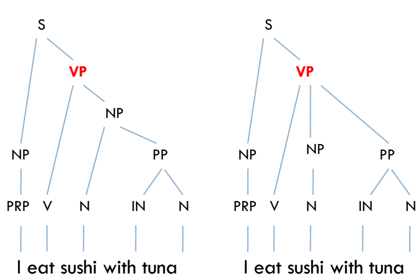
Parsing



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

What is the difference between these parses?

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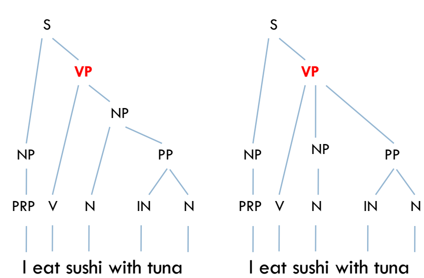
Parsing ambiguity



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

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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