# Introduction to Natural Language Processing

Chapter 9



## Today's Outline

Homework 2

Midterm October 22

Rebecca Hwa on Monday

Review

Syntax

Context Free Grammars

Derivations and Trees

Formal Language View

Grammar Development

Some Difficulties



## Review

Parts of Speech and Tagging

- parts of speech represent classes of words based on morphological and distributional similarities
- accurate part of speech tagging is pretty much a solved problem (at least for English) by any one of a number of statistical or rule-based approaches
- for situations where there is *no* tagged training data one can fall back on unsupervised approaches



## Syntax

Representing knowledge of the structure of phrases and sentences

Word order is significant

- may have no effect on meaning
  - *Jack Horner stuck in his thumb*
  - *Jack Horner stuck his thumb in*
- may change meaning
  - *Salome danced for Herod*
  - *Herod danced for Salome*
- may make a sentence ungrammatical
  - **for danced Herod Salome*

## Grammaticality

Doesn't depend on

- having heard the sentence before
- the sentence being true
  - *I saw a unicorn yesterday*
- the sentence being meaningful
  - *Colorless green ideas sleep furiously*
  - **Furiously sleep ideas green colorless*

Grammaticality is a formal property that we can investigate and describe



## Syntax

By syntax, we mean various aspects of how words are strung together to form components of sentences and how those components are strung together to form sentences.

New concept: Constituency

- groups of words may behave as a single unit or constituent
- e.g., noun phrases
- evidence
  - the *whole* group appears in similar syntactic environments
  - e.g., before a verb
  - preposed/postposed constructions

Again, note that notions of meaning play no role in what we're talking about (at least not yet).



## Tests for Syntactic Constituency

Ability to stand alone

- *What do many students do?*
- *Eat at Atwood restaurants*
- **Students eat at*

Substitution by a pro-form

- *Many students do*

Movement

- *At Atwood restaurants, many students eat*
- **Restaurants, many students eat at Atwood*



## Constituency (continued)

Constituency is decided relative to the sentence in question.

- *Pat and Leslie* raised llamas.
- Robin raised *Pat and Leslie* adopted Chris.

Constituency is hierarchical.

- no overlapping of constituents

Tree diagrams and phrase structure rules.

## Who Cares?

Grammar checkers

Information extraction

Generation



## Context Free Grammars

Captures constituency and ordering.

We'll need something else for other aspects of syntax.

Modern linguistic theories of grammar are only vaguely based on context-free grammars.



## Context Free Grammars (CFGs)

Consist of

- sets of terminals (either lexical items or parts of speech)
- sets of non-terminals (the constituents of the language)
- sets of *rules* (*productions*) of the form $A \rightarrow \alpha$
  - $\alpha$ is a string of one or more terminals and non-terminals
  - A is a non-terminal (POS for the lexicon entries)

They are exactly equivalent to Backus-Naur Form (BNF).

Also called Phrase-Structure Grammar.



## Examples

S $\rightarrow$ NP VP

NP $\rightarrow$ Det Nominal

Nominal $\rightarrow$ Noun

VP $\rightarrow$ V

Det $\rightarrow$ the

Det $\rightarrow$ a

Noun $\rightarrow$ flight

V $\rightarrow$ left

## Generativity

Just as we did with FSAs, you can view these rules as either structure imposing devices or generative devices.

The grammar can be viewed as a formal device that specifies the strings in and not in a language.

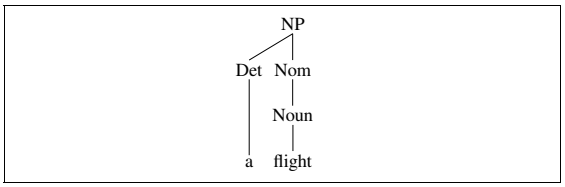


## Derivations and Trees

A derivation of a word string is just a sequence of rule applications.

- e.g., the string $a$ *flight* can be derived from the non-terminal NP

Derivations can be visualized as parse trees.




There is also a bracketed notation.

The formal language defined by a CFG is the set of strings that are derivable from the $start\ symbol$, e.g., from S, the set of sentences in English.



## As opposed to what?

Regular expressions (too weak).

Context sensitive grammars (too strong).

Turing machines (way too strong).

Approaches that are too strong have the power to predict/describe/capture syntactic structures that don't exist in human languages.

And the computational processes associated with them are not as efficient as those associated with weaker methods.



## A More Formal View

A CFG is a 4-tuple, and defines a formal language (a set of strings)

- a set of non-terminal symbols $N$
- a set of terminal symbols $\Sigma$
- a set of productions $P$
  - $A \rightarrow \alpha$
  - $A$ is a non-terminal
  - $\alpha$ is a string of symbols from the infinite set of strings $(\Sigma \cup N)\star$
- a designated start symbol $S$

## A More Formal View (cont.)

A language is defined via Derivation.

Sentences that can be derived by a grammar are in the formal language defined by the grammar, and are called Grammatical Sentences.

Those sentences that cannot be derived are Ungrammatical Sentences.

The language $L_G$ generated by a grammar G is the set of strings composed of terminal symbols which can be derived from the start symbol.

- $L_G$ = W | w is in $\Sigma\star$ and S derives w

Parsing is mapping from a word string to its parse tree.

- see Chapter 10



## Outline

Paper Discussion

Homework 2 questions?

Formal Language View

Grammar Development

Some Difficulties



## Equivalence and Normal Form

Strong Equivalence

- two grammars generate the same set of strings and assign the same phrase structures

Weak Equivalence

- two grammars generate the same set of strings but do $not$ assign the same phrase structures

Chomsky Normal Form (CNF)

- productions of the form $A \rightarrow BC$ or $A \rightarrow a$
- upper case indicates non-terminals, lowercase indicates terminals

Original

- A $\rightarrow$ B C D

CNF

- A $\rightarrow$ B X
- X $\rightarrow$ C D

What type of equivalence?



## Note!

All the use of the term context-free really means is that the non-terminal on the left-hand side of the rule is sitting over there all by itself.

A $\rightarrow$ B C

In other words, I can rewrite A as BC, regardless of the context in which I find the A.

## Developing Grammars

An awful lot goes into the development of grammars for human languages. We'll only scratch the surface.

The primary thing we'll consider is what constitutes a constituent. A consistent, recurring, syntactic substructure.



## A Tiny Lexicon

$$
\begin{aligned}
\textit{Noun} &\rightarrow \textit{flights} \mid \textit{breeze} \mid \textit{trip} \mid \textit{morning} \mid \ldots \\
\textit{Verb} &\rightarrow \textit{is} \mid \textit{prefer} \mid \textit{like} \mid \textit{need} \mid \textit{want} \mid \textit{fly} \\
\textit{Adjective} &\rightarrow \textit{cheapest} \mid \textit{non-stop} \mid \textit{first} \mid \textit{latest} \\
&\quad \mid \textit{other} \mid \textit{direct} \mid \ldots \\
\textit{Pronoun} &\rightarrow \textit{me} \mid \textit{I} \mid \textit{you} \mid \textit{it} \mid \ldots \\
\textit{Proper-Noun} &\rightarrow \textit{Alaska} \mid \textit{Baltimore} \mid \textit{Los Angeles} \\
&\quad \mid \textit{Chicago} \mid \textit{United} \mid \textit{American} \mid \ldots \\
\textit{Determiner} &\rightarrow \textit{the} \mid \textit{a} \mid \textit{an} \mid \textit{this} \mid \textit{these} \mid \textit{that} \mid \ldots \\
\textit{Preposition} &\rightarrow \textit{from} \mid \textit{to} \mid \textit{on} \mid \textit{near} \mid \ldots \\
\textit{Conjunction} &\rightarrow \textit{and} \mid \textit{or} \mid \textit{but} \mid \ldots
\end{aligned}
$$



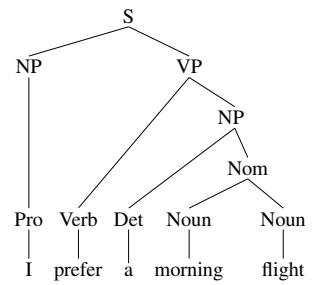
## A Tiny Grammar (and examples)

| | | | |
|---|---|---|---|
| $S$ | $\rightarrow$ | *NP VP* | I + want a morning flight |
| *NP* | $\rightarrow$ | *Pronoun* | I |
| | \| | *Proper-Noun* | Los Angeles |
| | \| | *Det Nominal* | a + flight |
| Nominal | $\rightarrow$ | *Noun Nominal* | morning + flight |
| | \| | *Noun* | flights |
| *VP* | $\rightarrow$ | *Verb* | do |
| | \| | *Verb NP* | want + a flight |
| | \| | *Verb NP PP* | leave + Boston + in the morning |
| | \| | *Verb PP* | leaving + on Thursday |
| *PP* | $\rightarrow$ | *Preposition NP* | from + Los Angeles |

- "or" symbol indicates alternate expansions for a non-terminal



## A Parse Tree



## Key Constituents

Sentences

Noun phrases

Verb phrases

Prepositional phrases



## Common Sentence Structures

Declaratives

- John left.
- S $\rightarrow$ NP VP

Imperatives

- Leave!
- S $\rightarrow$ VP

Yes-No Questions

- Did John leave?
- S $\rightarrow$ Aux NP VP

WH Questions (who, where, what, which, why, how)

- When did John leave?
- S $\rightarrow$ Wh-NP Aux NP VP
- S $\rightarrow$ Wh-NP VP



## Other Sentence Structures

The previous simple sentence structures had a single verb group.

Coordinate Sentences

- Mary bought a new coat, *but* she didn't wear it often.

Complex Sentences

- Sue said *Danny fell.*



## Noun Phrases (simplified)

Revolves around a Head (the central noun)

Prenominal modifiers come *before* the head noun

- NP $\rightarrow$ (Det) (Card) (Ord) (Quant) (AP) Nominal

Determiners (Det)

- *a* flight
- optional (plurals: *the* flights, $\star$*a* flights; mass nouns...)

Cardinal Numbers (Card)

- *one* stop

Ordinal Numbers (Ord)

- the *first* stop

Quantifiers (Quant)

- *many* fares

Adjective Phrases (AP)

- a *nonstop* flight

## Noun Phrases (continued)

Postnominal modifiers come *after* the head noun

- Nominal → Nominal PP (PP) (PP)
- Nominal → Nominal GerundVP
- Nominal → Nominal RelClause

Prepositional Phrase (PP)

- the flights *from Pittsburgh* to Denver

Non-finite clauses

- Gerundive (GerundVP): flights *leaving on Thursday*
- infinitive: the last flight *to arrive*
- -ed form: the aircraft *used*

Relative Clauses (RelClause)

- RelClause → (RelPronoun) VP
- flights *that serve lunch*

Postnominal modifiers can be combined

- a flights *from Pittsburgh* **leaving Monday**



## Recursive Structures

One of the more interesting patterns we'll have to deal with involves recursive rules - rules where the non-terminal on the left-hand side also appears on the right-hand side.

Direct recursion:

- NP → NP PP (the flight to Boston)
- VP → VP PP (departed Miami at noon)

In general, recursion cannot be handled using FSAs, which is why we need the more powerful CFG representation.

However, there are FSA *approximations* of English syntax.



## Recursive Structures (continued)

Note this is what allows us to do the following:

- Flights to Miami
- Flights to Miami from Boston
- Flights to Miami from Boston in April
- Flights to Miami from Boston in April on Friday
- Flights to Miami from Boston in April on Friday with lunch.



## Conjunctions

S → S and S

NP → NP and NP

VP → VP and VP

In fact, any phrasal constituent can be *conjoined* with a constituent of the same type to form a new constituent of that type. In other words, English really has the following rule:

X → X and X

## Some Difficulties

Agreement

Subcategorization



## Agreement

Examples

- This dog
- Those dogs
- *Those dog
- *This dogs
- What flight leaves in the morning
- *What flight leave in the morning

Could expand our grammar with multiple sets of rules, but doubles the size.

Chapter 11 will present a better approach.



## Subcategorization

Verbs have preferences for the kinds of constituents they co-occur with.

Examples:

- I found the cat
- *I disappeared the cat

A traditional subcategorization of verbs:

- transitive (takes a direct object NP)
- intransitive

Today, there are often a hundred subcategories for the *complements* of a verb.

- e.g., *find* subcategorizes for an NP (can take an NP complement)

The possible sets of complements are called the *Subcategorization Frame* for the verb.

Like with agreement, the obvious CFG solution yields rule explosion. Again, Chapter 11 will introduce a better approach.



## Subcategorization (continued)

See Table on Page 343 in Jurafsky and Martin.

# Grammars for Spoken Language

Spoken language is both similar, yet different, from written language.

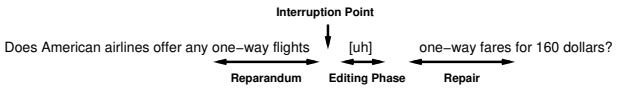
| |
|---|
| the . [exhale] . . . [inhale] . . [uh] does American airlines . offer any . one way flights . [uh] one way fares, for one hundred and sixty one dollars |
| [mm] i'd like to leave i guess between [um] . [smack] . five o'clock no, five o'clock and [uh], seven o'clock . P M |
| around, four, P M |
| all right, [throat_clear] . . i'd like to know the . give me the flight . times . in the morning . for September twentieth . nineteen ninety one |
| [uh] one way |
| [uh] seven fifteen, please |
| on United airlines . . give me, the . . time . . from New York . [smack] . to Boise-, to . I'm sorry . on United airlines . [uh] give me the flight, numbers, the flight times from . [uh] Boston . to Dallas |

Differences include...

- lexical statistics (e.g., spoken language has more pronouns)
- disfluencies (e.g., *uh*, *um*, word repetitions, false starts)
- fragments



# Disfluencies in Spoken Language




- false start
- *uh*



# For Next Time

Read Chapter 10