Context-Free Grammars for English

From: Chapter 12 of *An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition,* by Daniel Jurafsky and James H. Martin

Overview

- **Syntax:** the way words are arranged together
- Main ideas of syntax:
  - **Constituency**
    - Groups of words may behave as a single unit or phrase, called **constituent**, e.g., NP
    - CFG, a formalism allowing us to model the constituency facts
  - **Grammatical relations**
    - A formalization of ideas from traditional grammar about SUBJECT, OBJECT and other such relations
  - **Subcategorization and dependencies**
    - Referring to certain kind of relations between words and phrases, e.g., the verb *want* can be followed by an infinitival phrase, as in *I want to fly to Detroit*.

Background

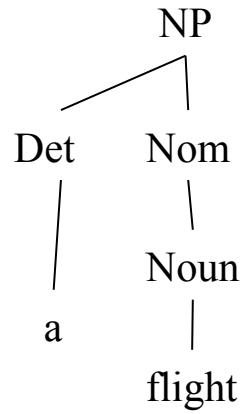
- All of the kinds of syntactic knowledge can be modeled by various kinds of CFG-based grammars.
- CFGs are thus backbone of many models of the syntax of NL.
- They are powerful enough to express sophisticated relations among the words in a sentence, yet computationally tractable enough that efficient algorithms exists for parsing sentences with them.
- Also probability version of CFG are available
- Example sentences from the Air Traffic Information System (ATIS) domain

Constituency

- **NP:**
  - A sequence of words surrounding at least one noun, e.g.,
    - three parties from Brooklyn *arrive …*
    - a high-class spot such as Mindy's *attracts* …
    - They *sit*
    - Harry the Horse
    - the reason he comes into the Hot Box
- Evidences of constituency
  - The above NPs can all appear in similar syntactic environment, e.g., before, a verb.
  - **Preposed** or **postposed** constructions, e.g., the PP, *on September seventeenth*, can be placed in a number of different locations
    - On September seventeenth, I'd like to fly from Atlanta to Denver.
    - I'd like to fly on September seventeenth from Atlanta to Denver.
    - I'd like to fly from Atlanta to Denver On September seventeenth.

Context-Free Rules and Trees

- **CFG (or Phrase-Structure Grammar):**
  - The most commonly used mathematical system for modeling constituent structure in English and other NLs
  - Terminals and non-terminals
  - Derivation
  - Parse tree
  - Start symbol

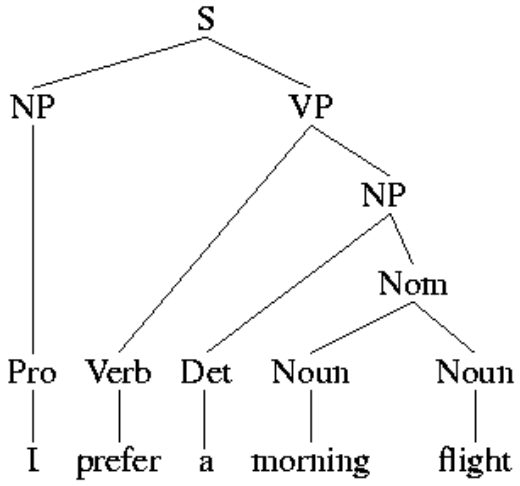


Context-Free Rules and Trees

Noun → *flight* | *breeze* | *trip* | *morning* | ...
Verb → *is* | *prefer* | *like* | *need* | *want* | *fly* ...
Adjective → *cheapest* | *non-stop* | *first* | *latest* | *other* | *direct* | ...
Pronoun → *me* | *I* | *you* | *it* | ...
Proper-Noun → *Alaska* | *Baltimore* | *Los Angeles* | *Chicago* | *United* | *American* | ...
Determiner → *the* | *a* | *an* | *this* | *these* | *that* | ...
Preposition → *from* | *to* | *on* | *near* | ...
Conjunction → *and* | *or* | *but* | ...

The lexicon for L_0

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



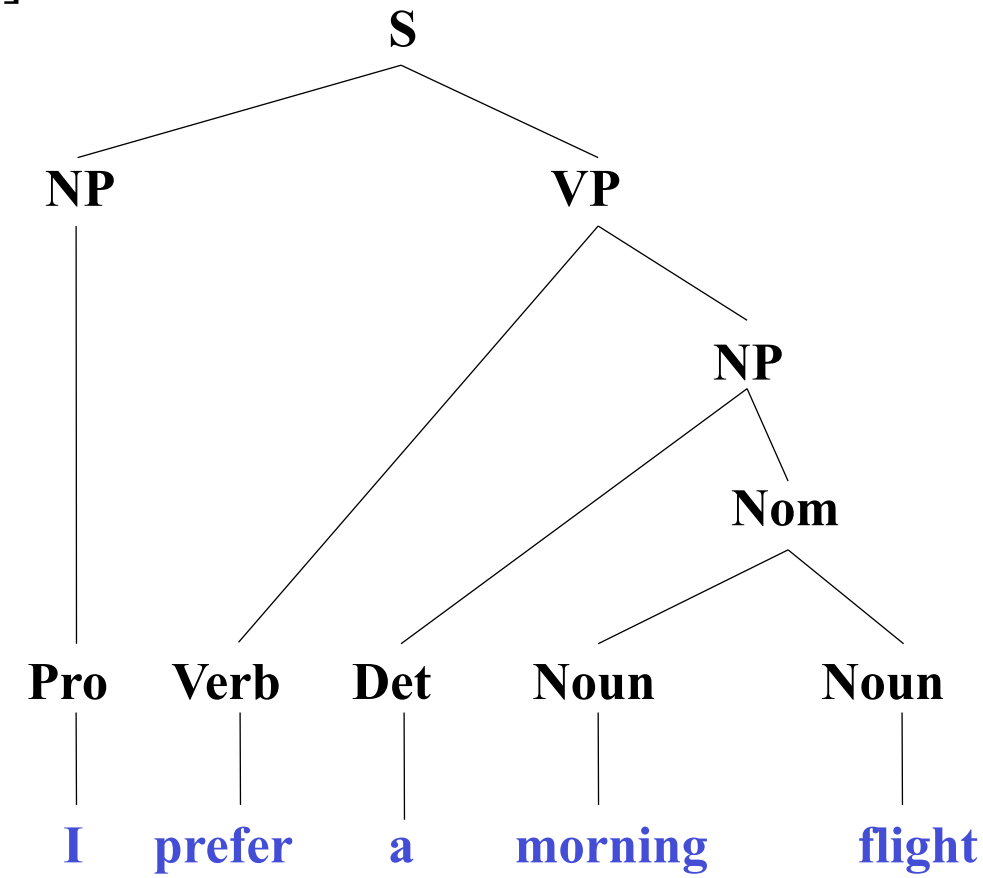
The grammar for L_0

Context-Free Rules and Trees

- **Bracket notation** of parse tree (see next page)
- Grammatical vs. ungrammatical sentences
- The use of formal languages to model NLs is called **generative grammar**, since the language is defined by the set of possible sentences "generated" by the grammar.
- The formal definition of a CFG is a 4-tuple: (A set of non-terminal symbols, a set of terminal symbols, a set of rules, a start symbol).

Bracketed Notation

[$_S$ [$_{NP}$ [$_{PRO}$ I]] [$_{VP}$ [$_V$ prefer] [$_{NP}$ [$_{Det}$ a] [$_{Nom}$ [$_N$ morning] [$_N$ flight]]]]]



Sentence-Level Constructions

- There are a great number of possible overall sentence structures, but four are particularly common and important:
  - *Declarative structure, imperative structure, interrogative structure (yes-n-no-question structure,* and *wh-question structure).*
- Sentences with **declarative** structure
  - A subject NP followed by a VP
    - *The flight should be eleven a.m. tomorrow.*
    - *I need a flight to Seattle leaving from Baltimore making a stop in Minneapolis.*
    - *The return flight should leave at around seven p.m.*
    - *I would like to find out the flight number for the United flight that arrives in San Jose around ten p.m.*
    - *I'd like to fly the coach discount class.*
    - *I want a flight from Ontario to Chicago.*
    - *I plan to leave on July first around six thirty in the evening.*
  - *S → NP VP*

Sentence-Level Constructions

- Sentence with **imperative** structure
  - Begin with a VP and have no subject.
  - Always used for commands and suggestions
    - *Show the lowest fare.*
    - *Show me the cheapest fare that has lunch.*
    - *Give me Sunday's flight arriving in Las Vegas from Memphis and New York City.*
    - *List all flights between five and seven p.m.*
    - *List all flights from Burbank to Denver.*
    - *Show me all flights that depart before ten a.m. and have first class fares.*
    - *Show me all the flights leaving Baltimore.*
    - *Show me flights arriving within thirty minutes of each other.*
    - *Please list the flights from Charlotte to Long Beach arriving after lunch time.*
    - *Show me the last flight to leave.*
  - $S \rightarrow VP$

Sentence-Level Constructions

- Sentences with **yes-no-question** structure
  - Begin with auxiliary, followed by a subject *NP*, followed by a *VP*.
    - *Do any of these flights have stops?*
    - *Does American's flight eighteen twenty five serve dinner?*
    - *Can you give me the same information for United?*
  - *S* → *Aux NP VP*

Sentence-Level Constructions

- The **wh-subject-question** structure
  - Identical to the declarative structure, except that the first NP contains some wh-word.
    - *What airlines fly from Burbank to Denver?*
    - *Which flights depart Burbank after noon and arrive in Denver by six p.m.?*
    - *Which flights serve breakfast?*
    - *Which of these flights have the longest layover Nashville?*
  - *S* → *Wh-NP VP*
- The **wh-non-subject-question** structure
    - *What flights do you have from Burbank to Tacoma Washington?*
  - *S* → *Wh-NP Aux NP VP*

The Noun Phrase

- View the NP as revolving around a **head**, the central noun in the NP.
  - The syntax of English allows for both pre-nominal (pre-head) modifiers and post-nominal (post-head) modifiers.

The Noun Phrase
Before the Head Noun

- NPs can begin with a determiner,
  - *a stop, the flights, that fare, this flight, those flights, any flights, some flights (*can be complex: *some but not all* flights)
- Determiners can be optional,
  - *Show me **flights** from San Francisco to Denver on weekdays.*
- **Mass nouns** don't require determiners.
  - Substances, like *water* and *snow*
  - Abstract nouns, *music, homework*,
  - In the ATIS domain, *breakfast, lunch, dinner*
    - *Does this flight server **dinner**?*

The Noun Phrase
Before the Head Noun

- **Predeterminers:**
  - Word classes appearing in the NP before the determiner
    - ***all*** *the flights,* ***all*** *flights*
- **Postdeterminers:**
  - Word classes appearing in the NP between the determiner and the head noun
    - **Cardinal numbers:** *two friends, one stop*
    - **Ordinal numbers:** *the first one, the next day, the second leg, the last flight, the other American flight, and other fares*
    - **Quantifiers:** *many fares*
      - The quantifiers, *much* and *a little* occur only with noncount nouns.

The Noun Phrase
Before the Head Noun

- Adjectives occur after quantifiers but before nouns.
  - *a **first-class** fare, a **nonstop** flight, the **longest** layover, the **earliest** lunch flight*
- Adjectives can be grouped into a phrase called an **adjective phrase** or **AP.**
  - AP can have an adverb before the adjective
    - *the **least** expensive fare*
- *NP* → (*Det*) (*Card*) (*Ord*) (*Quant*) (*AP*) *Nominal*
  - *The first few non-stop flights*
  - *The two first non-stop flights*

The Noun Phrase
After the Head Noun

- A head noun can be followed by **postmodifiers.**
  - Prepositional phrases
    - *All flights from Cleveland*
  - Non-finite clauses
    - *Any flights arriving after eleven a.m.*
  - Relative clauses
    - *A flight that serves breakfast*

The Noun Phrase
After the Head Noun

- PP postmodifiers
  - *any stopovers [for Delta seven fifty one]*
  - *all flight [from Cleveland] [to Newark]*
  - *arrival [in San Jose] [before seven a.m.]*
  - *a reservation [on flight six oh six] [from Tampa] [to Montreal]*
  - *Nominal → Nominal PP (PP) (PP)*

The Noun Phrase
After the Head Noun

- The three most common kinds of **non-finite** postmodifiers are the gerundive (-*ing*), -*ed,* and infinitive form.
  - A gerundive consists of a VP beginning with the gerundive (-*ing*)
    - *any of those [leaving on Thursday]*
    - *any flights [arriving after eleven a.m.]*
    - *flights [arriving within thirty minutes of each other]*

Nominal → Nominal GerundVP
GerundVP → GerundV NP | GerundV PP | GerundV | GerundV NP PP
GerundV → being | preferring | ariving | leaving | ...

  - Examples of two other common kinds
    - *the last flight **to arrive** in Boston*
    - *I need to have dinner **served***
    - *Which is the aircraft **used by this flight?***

The Noun Phrase
After the Head Noun

- A postnominal relative clause
  - is a clause that often begins with a **relative pronoun** (*that* and *who* are the most common).
  - The relative pronoun functions as the subject of the embedded verb,
    - *a flight that serves breakfast*
    - *flights that leave in the morning*
    - *the United flight that arrives in San Jose around ten p.m.*
    - *the one that leaves at ten thirty five*

Nominal → Nominal RelClause
RelClause → (who | that) VP

The Noun Phrase

After the Head Noun

- Various postnominal modifiers can be combined,
  - *a flight [from Phoenix to Detroit] [leaving Monday evening]*
  - *I need a flight [to Seattle] [leaving from Baltimore] [making a stop in Minneapolis]*
  - *evening flights [from Nashville to Houston] [that serve dinner]*
  - *a friend [living in Denver] [that would like to visit me here in Washington DC]*

Coordination

- NPs and other units can be **conjoined** with **coordinations** like *and, or,* and *but.*
  - *Please repeat* $[_{NP}$ $[_{NP}$ *the flight] and* $[_{NP}$ *the departure time]]*
  - *I need to know* $[_{NP}$ $[_{NP}$ *the aircraft] and* $[_{NP}$ *flight number]]*
  - *I would like to fly from Denver stopping in* $[_{NP}$ $[_{NP}$ *Pittsburgh] and* $[_{NP}$ *Atlanta]]*
  - *NP* $\rightarrow$ *NP and NP*
  - *VP* $\rightarrow$ *VP and VP*
  - *S* $\rightarrow$ *S and S*

Agreement

- Most verbs in English can appear in two forms in the present tense:
  - 3sg, or non-3sg

Do [$_{NP}$ any flights] stop in Chicago?
Do [$_{NP}$ all of these flights] offer first class service?
Do [$_{NP}$ I] get dinner on this flight?
Do [$_{NP}$ you] have a flight from Boston to Forth Worth?
Does [$_{NP}$ this flight] stop in Dallas?
Does [$_{NP}$ that flight] serve dinner?
Does [$_{NP}$ Delta] fly from Atlanta to San Francisco?

What flight *leave* in the morning?
What flight *leaves* from Pittsburgh?

*[What flight] *leave* in the morning?
*Does [$_{NP}$ you] have a flight from Boston to Fort Worth?
*Do [$_{NP}$ this flight] stop in Dallas?

S → Aux NP VP

S → 3sgAux 3sgNP VP
S → Non3sgAux Non3sgNP VP
3sgAux → does | has | can | ...
Non3sgAux → do | have | can | ...
3sgNP → (Det) (Card) (Ord) (Quant) (AP) SgNominal
Non3sgNP → (Det) (Card) (Ord) (Quant) (AP) PlNominal
SgNominal → SgNoun | SgNoun SgNoun
PlNominal → PlNoun | SgNoun PlNoun
SgNoun → flight | fare | dollar | reservation | ...
PlNoun → flights | fares | dollars | reservation | ...

Agreement

- Problem for dealing with number agreement:
  - it doubles the size of the grammar.
- The rule proliferation also happens for the noun's **case:**
  - For example, English pronouns have **nominative** (*I, she, he, they*) and **accusative** (*me, her, him, them*) versions.
- A more significant problem occurs in languages like German or French
  - Not only N-V agreement, but also **gender agreement.**
- In Sanskrit, there are three numbers: single, dual and plural, that require agreement.
- A way to deal with these agreement problems without exploding the size of the grammar:
  - By effectively **parameterizing** each non-terminal of the grammar with **feature-structures.**

The Verb Phrase and Subcategorization

- The VP consists of the verb and a number of other constituents.

VP → Verb	disappear
VP → Verb NP	prefer a morning flight
VP → Verb NP PP	leave Boston in the morning
VP → Verb PP	leaving on Thursday

- An entire embedded sentence, called **sentential complement**, can follow the verb.

You [$_{VP}$ [$_{V}$ said [$_{S}$ there were two flights that were the cheapest]]]
You [$_{VP}$ [$_{V}$ said [$_{S}$ you had a two hundred sixty six dollar fare]]]
[$_{VP}$ [$_{V}$ Tell] [$_{NP}$ me] [$_{S}$ how to get from the airport in Philadelphia to downtown]]
I [$_{VP}$ [$_{V}$ think [$_{S}$ I would like to take the nine thirty flight]]

VP → Verb S

The Verb Phrase and Subcategorization

- Another potential constituent of the VP is another VP
  - Often the case for verbs like *want, would like, try, intent, need*

I want [$_{VP}$ to fly from Milwaukee to Orlando]
Hi, I want [$_{VP}$ to arrange three flights]
Hello, I'm trying [$_{VP}$ to find a flight that goes from Pittsburgh to Denver after two p.m.]

- Recall that verbs can also be followed by *particles*, word that resemble a preposition but that combine with the verb to form a *phrasal verb*, like *take off*.
  - These particles are generally considered to be an integral part of the verb in a way that other post-verbal elements are not;
  - Phrasal verbs are treated as individual verbs composed of two words.

The Verb Phrase and Subcategorization

- A VP can have many possible kinds of constituents, not every verb is compatible with every VP.
  - *I want a flight ...*
  - *I want to fly to ...*
  - **I found to fly to Dallas.*
- The idea that verbs are compatible with different kinds of complements
  - Traditional grammar **subcategorize** verbs into two categories (transitive and intransitive).
  - Modern grammars distinguish as many as 100 subcategories

Frame	**Verb**	**Example**
ϕ	eat, sleep	I want to eat
NP	prefer, **find** leave	Find [$_{NP}$ the flight from Pittsburgh to Boston]
NP NP	show, give, **find**	Show [$_{NP}$ me] [$_{NP}$ airlines with flights from Pittsburgh]
PP_{from} PP_{to}	fly, travel	I would like to fly [$_{PP}$ from Boston] [$_{PP}$ to Philadelphia]
NP_{PPwith}	help, load	Can you help [$_{NP}$ me] [$_{PP}$ with a flight]
Vpto	prefer, want, need	I would prefer [$_{VPto}$ to go by United airlines]
S	mean	Does this mean [$_{S}$ AA has a hub in Boston?]

The Verb Phrase and Subcategorization

Verb-with-NP-complement → *find* | *leave* | *repeat* | ...
Verb-with-S-complement → *think* | *believe* | *say* | ...
Verb-with-Inf-VP-complement → *want* | *try* | *need* | ...

VP → *Verb-with-no-complement*	disappear
VP → *Verb-with-NP-complement NP*	prefer a morning flight
VP → *Verb-with-S-complement S*	said there were two flights

Auxiliaries

- **Auxiliaries** or **helping verbs**
  - A subclass of verbs
  - Having particular syntactic constraints which can be viewed as a kind of subcategorization
  - Including the **modal** verb, *can, could many, might, must, will, would, shall,* and *should*
  - The **perfect** auxiliary *have*,
  - The **progressive** auxiliary *be,* and
  - The **passive** auxiliary *be*.

Auxiliaries

- Modal verbs subcategorize for a *VP* whose head verb is a bare stem.
  - *can go in the morning, will try to find a flight*
- The perfect verb *have* subcategorizes for a *VP* whose head verb is the past participle form:
  - *have booked 3 flights*
- The progressive verb *be* subcategorizes for a *VP* whose head verb is the gerundive participle:
  - *am going from Atlanta*
- The passive verb *be* subcategorizes for a *VP* who head verb is the past participle:
  - *was delayed by inclement weather*

Auxiliaries

- A sentence may have multiple auxiliary verbs, but they must occur in a particular order.
  - modal < perfect < progressive < passive

modal perfect	could have been a contender
modal passive	will be married
perfect progressive	have been feasting
modal perfect passive	might have been prevented