Computational Linguistics

CSC 485/2501
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2

2. Introduction to syntax and parsing

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Reading: Jurafsky & Martin: 5.0–1, 12.0–12.3.3, 12.3.7, *[13.1–2]*. Bird et al: 8.0–4.

Syntactic structure 1

- ***Syntax:***
  - The combinatorial structure of words.
  - How words can be linearly organized: ***left/right precedence,*** and ***contiguity***.
  - How words can be hierarchically organized into ***phrases*** and ***sentences***.

Syntactic structure 2

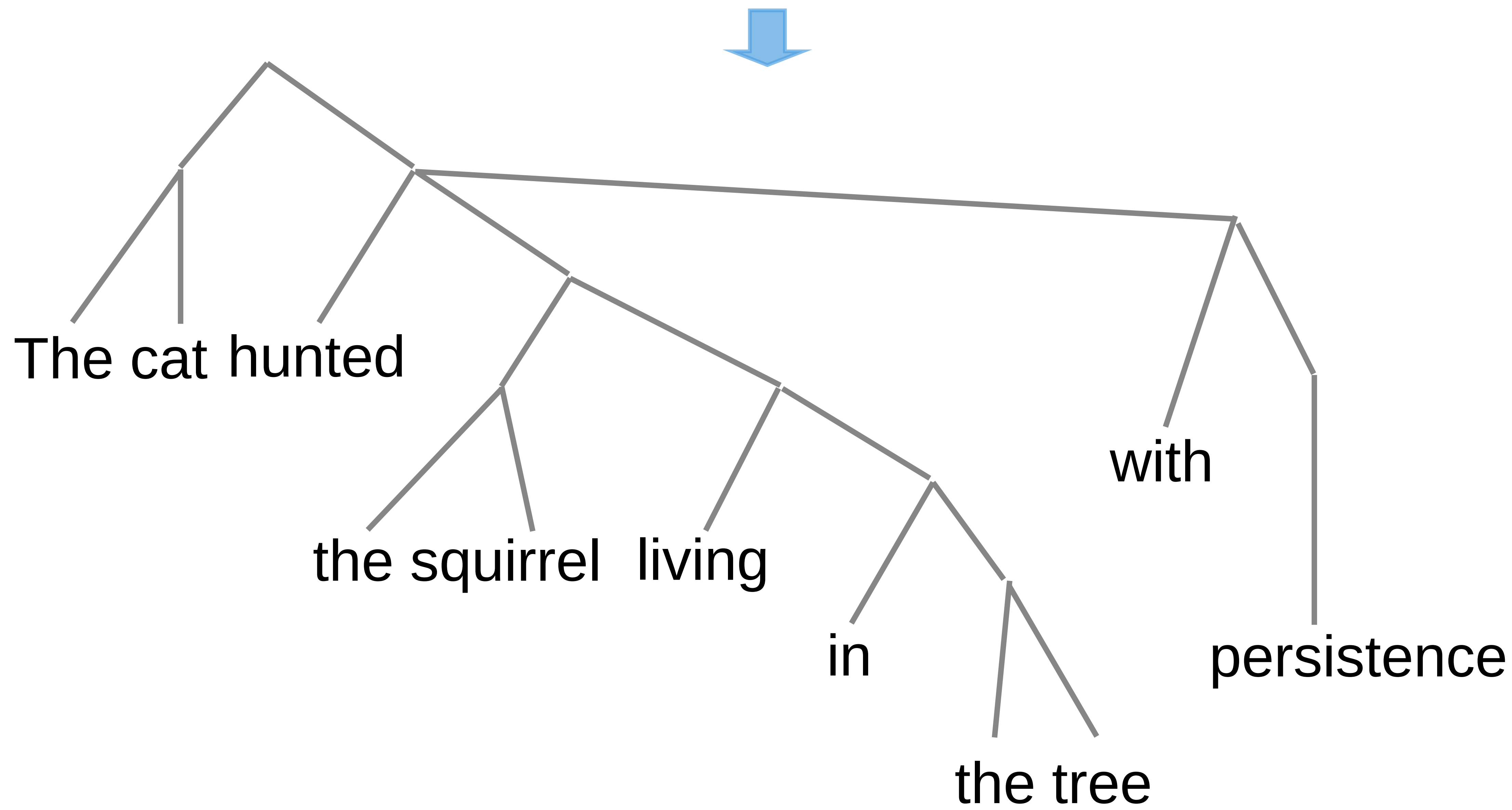
The cat hunted the squirrel living in the tree with persistence.

↓

[[The cat]
[hunted [the squirrel [living [in [the tree]]]]
[with [persistence]]]]

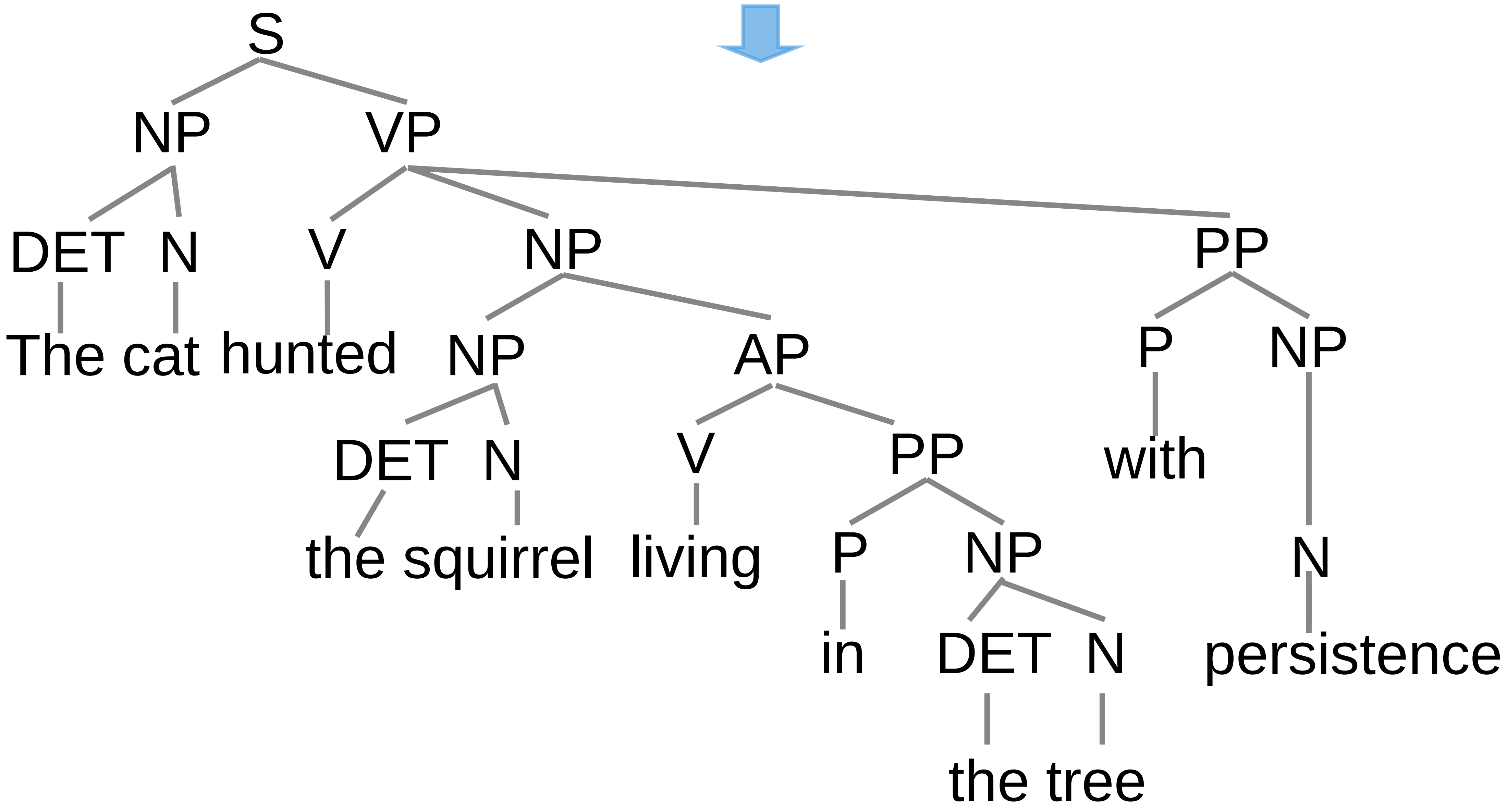
Syntactic structure 2

The cat hunted the squirrel living in the tree with persistence.



Syntactic structure 2

The cat hunted the squirrel living in the tree with persistence.



Syntactic structure 3

- ***Goal***: meaning, interpretation, semantics.
- So why do we care about syntax?

Grammars and parsing

- ***Grammar:***
  - **Formal specification** of allowable structures.
    - Knowledge
    - Representation
- ***Parsing:***
  - **Analysis** of string of words to determine the structure assigned by grammar.
    - Algorithm
    - Process

Using grammar to capture structure

- Main issues:
  - Which words are grouped together into phrases.
  - How words within a phrase project the properties of a single, common **word** (the **head** of the phrase).
  - How different phrases **relate** to each other.

- Grammar encodes these relations. Some grammars interpret these relations with respect to meaning.

Good and bad grammars

- There are many possible grammars for any natural language.
  - Some are better than others.
- Desiderata:
  - Faithfulness to (vastly divergent) details about language.
  - Economy of description.
  - Fidelity to some prevailing linguistic intuition.
  - Efficiency of parsing.

Elements of grammar

- **Primitives**: lexical categories or parts of speech.
  - Each ***word-type*** is a member of one or more.
  - Each ***word-token*** is an instance of exactly one.

  e.g. *The cat in the hat sat*.
- Categories are ***open*** or ***closed*** to new words.
- Eight main categories, many subcategories.

Nine Seven

Twenty-three

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  Nine Seven

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- The categories might possibly be language-specific as well.

Parts of speech 1

- ***Nouns:*** denote an object, a concept, a place, …
  - **Count nouns:** *dog, spleen, Band-Aid,* …
  - **Mass nouns:** *water, wheat, …*
  - **Proper nouns:** *Fred, New York City, …*
- ***Pronouns:*** *he, she, you, I, they, …*
- ***Adjectives:*** denote an attribute of the denotation of a noun.
  - **Intersective:** *pink, furry, …*
  - **Measure:** *big, …*
  - **Intensional:** *former, alleged, …*

Parts of speech 2

- ***Determiners, articles:*** specify certain attributes of the denotation of a noun that are grammatically relevant.
  - *the, a, some, …*
- ***Verbs:*** predicates, denote an action or a state. Numerous distinctions, e.g. transitivity:
  - **Intransitive:** *sleep, die, …*
  - **Transitive:** *eat, kiss, …*
  - **Ditransitive:** *give, sell, …*
  - **Copula:** *be, feel, become, …*

Parts of speech 3

- ***Adverbs:*** denote an attribute of the denotation of a predicate.
  - **Time and place:** *today, there, now, …*
  - **Manner:** *happily, furtively*, …
  - **Degree:** *much, very, …*
- ***Prepositions:*** relate two phrases with a location, direction, manner, etc.
  - *up, at, with, in front of, before, …*

Parts of speech 4

- ***Conjunctions:*** combine two clauses or phrases:
  - **Coordinating conjunctions:** *and, or, but*
  - **Subordinating conjunctions:** *because, while,…*
- ***Interjections:*** stand-alone emotive expressions:
  - *um, wow, oh dear, balderdash, crikey, …*

Elements of grammar

- Combinations:
  - **Phrase:** a hierarchical grouping of words and/or phrases.
  - **Clause:** a phrase consisting of a verb and (almost) all of its dependents.
  - **Sentence:** a clause that is syntactically independent of other clauses.
- Can be represented by tree (or a labelled bracketing).
- Terminology: A ***constituent*** is a well-formed phrase with overtones of semantic and/or psychological significance.

Types of phrase 1

- Noun phrase (NP):
  - *a mouse*
  - *mice*
  - *Mickey*
  - *the handsome marmot*
  - *the handsome marmot on the roof*
  - *the handsome marmot whom I adore*

- Verb phrase (VP):
  - *laughed loudly*
  - *quickly gave the book to Mary*

Types of phrase 2

- Adjective phrase (AP):
  - *green*
  - *proud of Kyle*
  - *very happy that you went*

- Prepositional phrase (PP):
  - *in the sink*
  - *without feathers*
  - *astride the donkey*

Clauses and sentences 1

- Clauses:
  - *Ross remarked upon Nadia's dexterity*
  - *to become a millionaire by the age of 30*
  - *that her mother had lent her for the banquet*

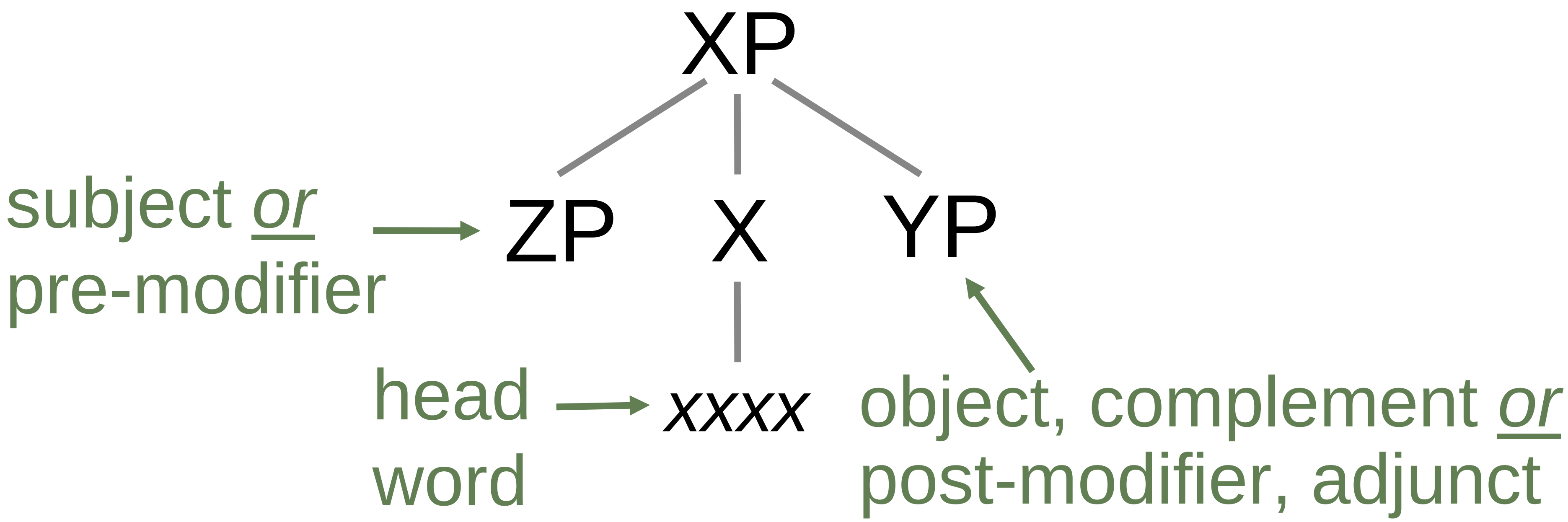
- Sentences:
  - *Ross remarked upon Nadia's dexterity.*
  - *Nathan wants to become a millionaire by the age of 30.*
  - *Nadia rode the donkey that her mother had lent her for the banquet.*
  - *The handsome marmot on the roof [in dialogue].*

Clauses and sentences 2

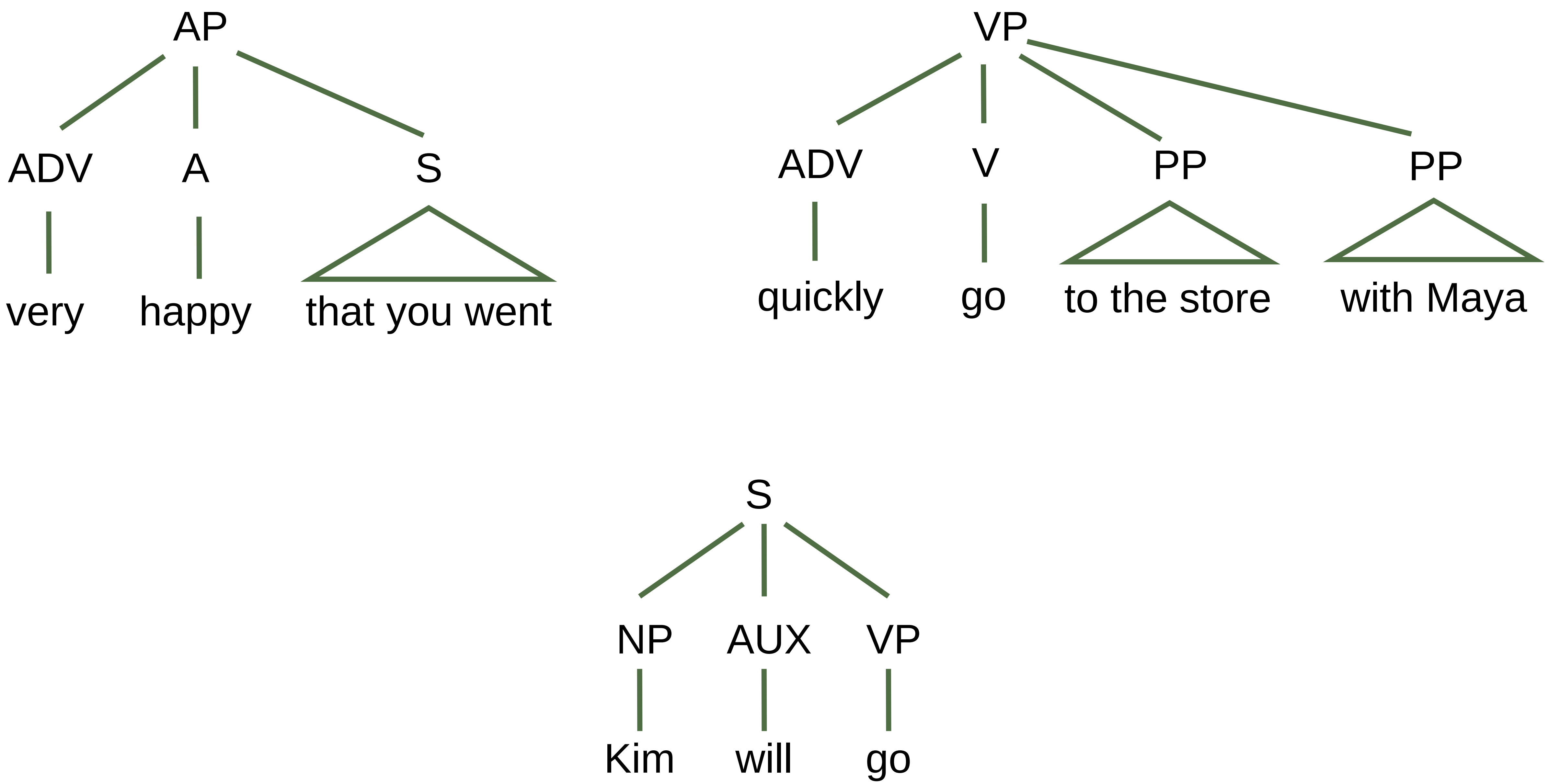
- Clauses may act as noun phrases:
  - *To become a millionaire by the age of 30 is what Ross wants.*
  - *Nadia riding her donkey is a spectacular sight.*
  - *Ross discovered that Nadia had been feeding his truffles to the donkey.*

The structure of an idealized phrase

XP → ZP X YP



Example phrases



Formal definition of a CFG

- A **context-free grammar** is a quadruple $G = (V_t, V_n, P, S)$, where
  - V_t is a finite set of **terminal** symbols.
  - V_n is a finite set of **non-terminal** symbols.
  - P is a finite set of **production rules** of the form

    $A \rightarrow \alpha$

    where $A \in V_n$ and α is a sequence of symbols in $(V_n \cup V_t)^*$.
  - $S \in V_n$ is the **start** symbol.

A very simple grammar

$\mathcal{S}$ = S,$\mathcal{P}$ = {

$$
\begin{aligned}
&\text{S} &&\rightarrow \text{NP VP} \\
&\text{NP} &&\rightarrow \text{Det N} \\
&\text{NP} &&\rightarrow \text{Det Adj N} \\
&\text{NP} &&\rightarrow \text{NP PP} \\
&\text{VP} &&\rightarrow \text{V} \\
&\text{VP} &&\rightarrow \text{V NP} \\
&\text{PP} &&\rightarrow \text{P NP} \\
&\text{Det} &&\rightarrow \textit{the} \mid \textit{a} \mid \textit{an} \\
&\text{Adj} &&\rightarrow \textit{old} \mid \textit{red} \mid \textit{happy} \mid \ldots \\
&\text{N} &&\rightarrow \textit{dog} \mid \textit{park} \mid \textit{statue} \mid \textit{contumely} \mid \textit{run} \mid \ldots \\
&\text{V} &&\rightarrow \textit{saw} \mid \textit{ate} \mid \textit{run} \mid \textit{disdained} \mid \ldots \\
&\text{P} &&\rightarrow \textit{in} \mid \textit{to} \mid \textit{on} \mid \textit{under} \mid \textit{with} \mid \ldots \quad \}
\end{aligned}
$$

V_t and V_n can be inferred from the production rules.

The lexicon:
In practice, a sep-arate data structure

Lexical categories:
NT's that rewrite as a single T.

Terminology

- **Non-terminal** (NT):

  A symbol that occurs on the left-hand side (LHS) of some rule.

- **Pre-terminal:** a kind of non-terminal located on the LHS of a lexical entry.
- **Terminal** (T):

  A symbol that never occurs on the LHS of a rule.

- **Start symbol:**

  A specially designated NT that must be the root of any tree derived from the grammar.

  In our grammars, it is usually S for sentence.

Parsing 1

- ***Parsing:*** Determining the structure of a sequence of words, given a grammar.
  - Which grammar rules should be used?
  - To which symbols (words / terminals and nodes / non-terminals) should each rule apply?

Parsing 2

- Input:
  - A context-free grammar.
  - A sequence of words
    Time flies like an arrow

  or, more precisely, of sets of parts of speech.

    {*noun,verb*} {*noun,verb*} {*verb,prep*} {*det*} {*noun*}
- Process:
  - (Working from left to right?,) ***guess*** how each word fits in.

Depth-first Parsing 3

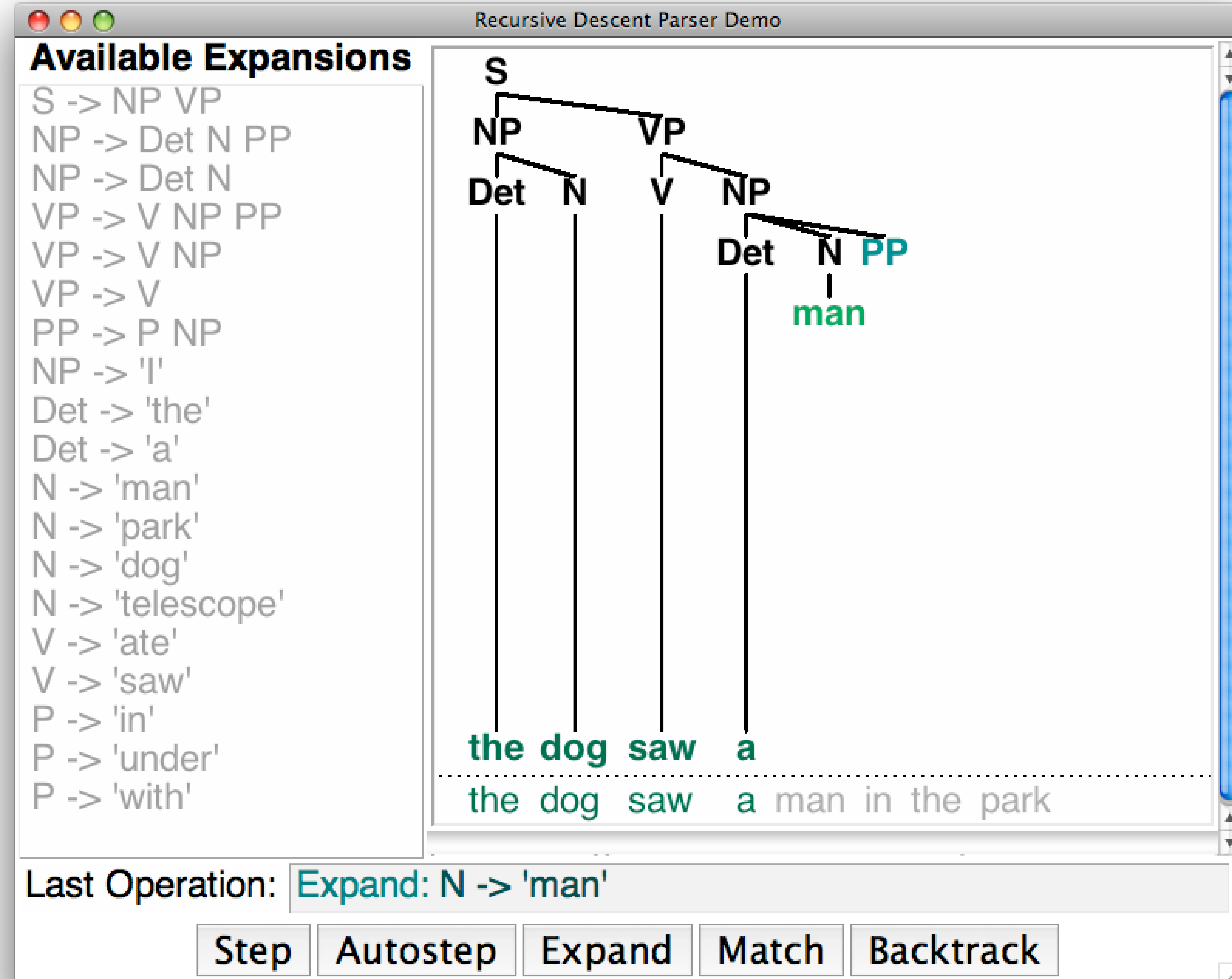
- If a guess leads to failure (parse is stymied), back up to a ***choice point*** and try a different guess.
  - Backtracking, non-determinism.
  - At each guess, must save state of parse on a stack.
  - (Or, explore in parallel.)
- Want to guess right:
  - Order of preference for rules.

Top-down parsing 1

- ***Top-down*** or ***rule-directed*** parsing:
  "Can I take these rules and match them to this input?"
  - Initial goal is an S.
  - Repeatedly look for rules that decompose /expand current goals and give new goals.
    E.g., goal of S may decompose to goals NP and VP.
  - Eventually get to goals that look at input.
    E.g., goal of NP may decompose to *det noun.*
  - Succeed iff entire input stream is accounted for as S.

Top-down parsing 2

- Example: A ***recursive descent parser***.
  ```
  >>> nltk.app.rdparser()
  ```
- Operations on ***leftmost frontier node***:
  - ***Expand*** it.
  - ***Match*** it to the next input word.


Recursive Descent Parser Demo
Available Expansions
S -> NP VP
NP -> Det N PP
NP -> Det N
VP -> V NP PP
VP -> V NP
VP -> V
PP -> P NP
NP -> 'I'
Det -> 'the'
Det -> 'a'
N -> 'man'
N -> 'park'
N -> 'dog'
N -> 'telescope'
V -> 'ate'
V -> 'saw'
P -> 'in'
P -> 'under'
P -> 'with'
S
NP
VP
Det
N
V
NP
Det
N
PP
man
the
dog
saw
a
the dog saw a man in the park
Last Operation:
Expand: N -> 'man'
Step
Autostep
Expand
Match
Backtrack

Top-down parsing 3

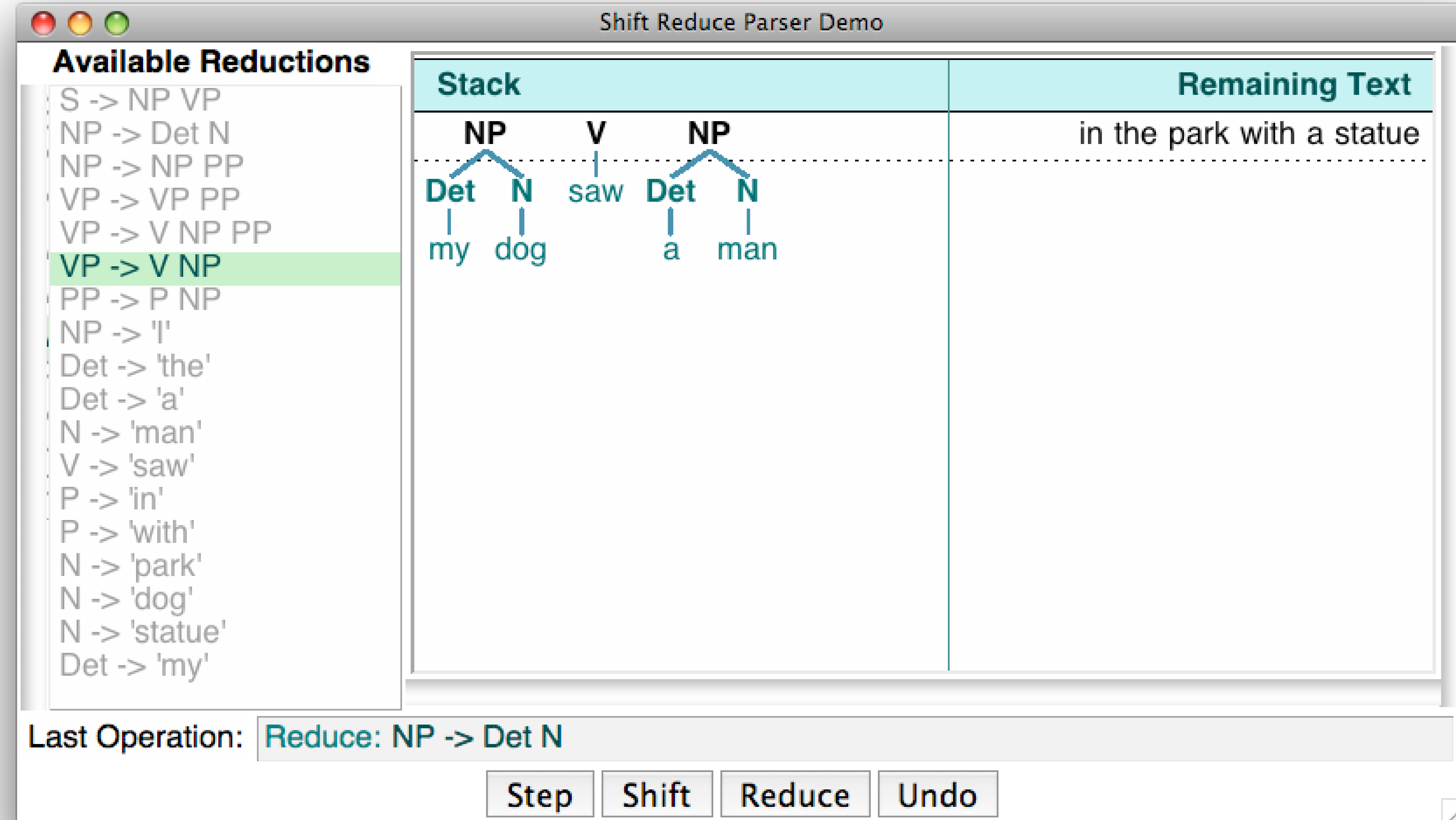
- Choice of next operation (in NLTK demo):
  - If it's a terminal, try matching it to input.
  - If it's a non-terminal, try expanding with first-listed untried rule for that non-terminal.

Bottom-up parsing 1

- ***Bottom-up*** or ***data-directed*** parsing:
  "Can I take this input and match it to these rules?"
  - Try to find rules that match a possible PoS of the input words …
  - … and then rules that match the constituents so formed.
  - Succeed iff the entire input is eventually matched to an S.

Bottom-up parsing 2

- Example: A ***shift–reduce parser***.
  `>>> nltk.app.srparser()`
- Operations:
  - ***Shift*** next input word onto stack.
  - Match the top *n* elements of stack to RHS of rule, ***reduce*** them to LHS.


Shift Reduce Parser Demo
Available Reductions
S -> NP VP
NP -> Det N
NP -> NP PP
VP -> VP PP
VP -> V NP PP
VP -> V NP
PP -> P NP
NP -> 'I'
Det -> 'the'
Det -> 'a'
N -> 'man'
V -> 'saw'
P -> 'in'
P -> 'with'
N -> 'park'
N -> 'dog'
N -> 'statue'
Det -> 'my'
Stack
Remaining Text
NP
V
NP
Det
N
saw
Det
N
my
dog
a
man
in the park with a statue
Last Operation:
Reduce: NP -> Det N
Step
Shift
Reduce
Undo

Bottom-up parsing 3

- Choice of next operation (in NLTK demo):
  - Always prefer reduction to shifting.
  - Choose the first-listed reduction that applies.
- Choice of next operation (in real life):
  - Always prefer reduction to shifting for words, but not necessarily for larger constituents.

Problems

- Neither top-down nor bottom-up search exploits useful idiosyncrasies that CFG rules, alone or together, often have.
- **Problems:**
  - Recomputation of constituents.
  - Recomputation of common prefixes.
- **Solution:** Keep track of:
  - Completed constituents.
  - Partial matches of rules.