Syntactic Attributes

Morphology, heads, gaps, etc.

Note: The properties of nonterminal symbols are often called “features.” However, we will use the alternative name “attributes.”

(We’ll use “features” to refer only to the features that get weights in a machine learning model, e.g., a log-linear model.)
3 views of a context-free rule

- generation (production): \( S \rightarrow \text{NP VP} \)
- parsing (comprehension): \( S \leftarrow \text{NP VP} \)
- verification (checking): \( S = \text{NP VP} \)

- Today you should keep the third, declarative perspective in mind.

- Each phrase has
  - an interface (\( S \)) saying where it can go
  - an implementation (\( \text{NP VP} \)) saying what’s in it

- To let the parts of the tree coordinate more closely with one another, enrich the interfaces: \( S[\text{attributes...}] = \text{NP}[\text{attributes...}] \text{VP}[\text{attributes...}] \)
Examples

Verb → thrills
VP → Verb NP
S → NP VP

A roller coaster thrills every teenager

S
   NP
   VP
   Verb
   NP
3 Common Ways to Use Attributes

morphology of a single word:
Verb[head=thrill, tense=present, num=sing, person=3,...] → thrills

projection of attributes up to a bigger phrase
VP[head=α, tense=β, num=γ...] → V[head=α, tense=β, num=γ...] NP
provided α is in the set TRANSITIVE-VERBS

agreement between sister phrases:
S[head=α, tense=β] → NP[num=γ,...] VP[head=α, tense=β, num=γ...]
3 Common Ways to Use Attributes

Verb[head=thrill, tense=present, num=sing, person=3,...] \rightarrow \text{thrills}

VP[head=\alpha, tense=\beta, num=\gamma,...] \rightarrow V[head=\alpha, tense=\beta, num=\gamma,...] NP

S[head=\alpha, tense=\beta] \rightarrow NP[\text{num=\gamma},... \text{VP[head=\alpha, tense=\beta, num=\gamma},...]]

\text{(generation perspective)}

\begin{align*}
\text{S} & \quad \text{NP} & \quad \text{VP} \\
\text{num=sing} & \quad \text{num=sing} & \quad \text{num=sing} \\
\text{A roller coaster} \quad \text{thrills} & \quad \text{every teenager}
\end{align*}
3 Common Ways to Use Attributes

Verb[head=thrill, tense=present, num=sing, person=3,...] → thrills
VP[head=α, tense=β, num=γ,...] → V[head=α, tense=β, num=γ,...] NP
S[head=α, tense=β] → NP[num=γ,...] VP[head=α, tense=β, num=γ,...]

(comprehension perspective)

A roller coaster thrills every teenager
The plan to swallow Wanda has been thrilling Otto.
The plan to swallow Wanda has been thrilling Otto.
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The plan to swallow Wanda has been thrilling Otto.
The plan to swallow Wanda has been thrilling Otto.
Why use heads?

- **Morphology** (e.g., word endings)
  - $N[h=plan, n=1] \rightarrow plan$
  - $N[h=plan, n=2+] \rightarrow plans$
  - $N[h=thrill, tense=prog] \rightarrow thrilling$
  - $N[h=thrill, tense=past] \rightarrow thrilled$
  - $N[h=go, tense=past] \rightarrow went$

 NP $[h=\alpha] \rightarrow \text{Det}$ $N[h=\alpha]$
 NP $[h=\alpha] \rightarrow N[h=\alpha]$ VP
 $N[h=plan] \rightarrow \text{plan}$ $[\text{head}=\text{plan}]$
 $\text{Det}$ $\text{The}$ $\text{NP}$ $[\text{head}=\text{plan}]$
 $\text{VP}$ $\text{[head}=\text{swallow}]$
 $\text{NP}$ $\text{Otto}$
 $\text{V}$ centered
 $\text{been}$
 $\text{VP}$ $\text{[head}=\text{thril}]$
 $\text{V}$ centered
 $\text{to}$
 $\text{VP}$ $\text{[head}=\text{swallow}]$
 $\text{V}$ centered
 $\text{swallow}$
 $\text{NP}$ $\text{Wanda}$
 $\text{NP}$ $\text{[head}=\text{Wanda}]$
Why use heads?

- **Subcategorization** (i.e., transitive vs. intransitive)
  - When is VP → V NP ok?
    VP[\(h=\alpha\)] → V[\(h=\alpha\)] NP
    restrict to \(\alpha \in \text{TRANSITIVE VERBS}\)
  - When is N → N VP ok?
    N[\(h=\alpha\)] → N[\(h=\alpha\)] VP
    restrict to \(\alpha \in \{\text{plan, plot, hope,}...\}\)

- Why use heads?
**Why use heads?**

- Selectional restrictions
  - \( VP[h=\alpha] \rightarrow V[h=\alpha] \) \( NP \)
  - I.e., \( VP[h=\alpha] \rightarrow V[h=\alpha] \) \( NP[h=\beta] \)
  - Don’t fill template in all ways:
    - \( VP[h=\text{thrill}] \rightarrow V[h=\text{thrill}] \) \( NP[h=\text{Otto}] \)
    - \( *VP[h=\text{thrill}] \rightarrow V[h=\text{thrill}] \) \( NP[h=\text{plan}] \)
      - leave out, or low prob

\[ \begin{align*}
NP[h=\alpha] & \rightarrow \text{Det} \ N[h=\alpha] \\
N[h=\alpha] & \rightarrow N[h=\alpha] \ VP \\
N[h=\text{plan}] & \rightarrow \text{plan} \\
\end{align*} \]
Log-Linear Models of Rule Probabilities

- What is the probability of this rule?
  \[ S[\text{head=thrill, tense=pres, ...}] \rightarrow NP[\text{head=plan, num=1, animate=no...}] \]
  \[ \text{VP[head=thrill, tense=pres, num=1, ...]} \]

- We have many related rules.
- \[ p(NP[...] \text{ VP[...]} | S[...]) \]
  \[ = \frac{1}{Z} \exp \sum_k \theta_k \cdot f_k(S[...] \rightarrow NP[...] \text{ VP[...]})) \]
- We are choosing among all rules that expand \( S[...] \).
- If a rule has positively-weighted features, they raise its probability. Negatively-weighted features lower it.
- Which features fire will depend on the attributes!
Log-Linear Models of Rule Probabilities

$S[\text{head}=\text{thrill}, \text{tense}=\text{pres}, \ldots] \rightarrow$

$NP[\text{head}=\text{plan}, \text{num}=1, \text{animate}=\text{no}, \ldots]$

$VP[\text{head}=\text{thrill}, \text{tense}=\text{pres}, \text{num}=1, \ldots]$

- Some features that might fire on this ...
  - The raw rule without attributes is $S \rightarrow NP \ VP$.
    - Is that good? Does this feature have positive weight?
  - The NP and the VP agree in number. Is that good?
  - The head of the NP is “plan.” Is that good?
  - The verb “thrill” will get a subject.
  - The verb “thrill” will get an inanimate subject.
  - The verb “thrill” will get a subject headed by “plan.”
    - Is that good? Is “plan” a good subject for “thrill”?
Post-Processing

- You don’t have to handle everything with tons of attributes on the nonterminals
- Sometimes easier to compose your grammar with a post-processor:
  1. Use your CFG + randsent to generate some convenient internal version of the sentence.
  2. Run that sentence through a post-processor to clean it up for external presentation.
  3. The post-processor can even fix stuff up across constituent boundaries!

We’ll see a good family of postprocessors later: finite-state transducers.
We'll meet Smith, 59, the chief.

Simpler Grammar + Post-Processing

ROOT \rightarrow \text{CAPS S .}

NP_{\text{proper}} \rightarrow \text{CAPS smith}
Simpler Grammar + Post-Processing

Smith already met my children.

S

NP

Adverb

Verb

NP

NP

NP

CAPS CAPS smith

already

meet-ed

me ’s child -s.

Smith

already

met

my children.
What Do These Enhancements Give You? And What Do They Cost?

- In a sense, nothing and nothing!
  - Can automatically convert our new fancy CFG to an old plain CFG.
- This is reassuring ...
  - We haven’t gone off into cloud-cuckoo land where “ooh, look what languages I can invent.”
    - Even fancy CFGs can’t describe crazy non-human languages such as the language consisting only of prime numbers.
    - Because we already know that plain CFGs can’t do that.
  - We can still use our old algorithms, randsent and parse.
    - Just convert to a plain CFG and run the algorithms on that.
- But we do get a benefit!
  - Attributes and post-processing allow simpler grammars.
  - Same log-linear features are shared across many rules.
  - A language learner thus has fewer things to learn.
Analogy: What Does Dyna Give You?

- In a sense, nothing and nothing!
  - We can automatically convert our fancy Dyna program to plain old machine code.

- This is reassuring ...
  - A standard computer can still run Dyna. No special hardware or magic wands are required.

- But we do get a benefit!
  - High-level programming languages allow shorter programs that are easier to write, understand, and modify.
What Do These Enhancements Give You? And What Do They Cost?

- In a sense, nothing and nothing!
  - We can automatically convert our new fancy CFG to an old plain CFG.
- Nonterminals with attributes ➔ more nonterminals
  - \( S[\text{head}=\alpha, \text{tense}=\beta] \rightarrow \text{NP}[\text{num}=\gamma,...] \text{ VP}[\text{head}=\alpha, \text{tense}=\beta, \text{num}=\gamma...]\)
  - Can write out versions of this rule for all values of \(\alpha, \beta, \gamma\)
  - Now rename \(\text{NP}[\text{num}=1,...]\) to \(\text{NP}_{\text{num}}_1_...\)
  - So we just get a plain CFG with a ton of rules and nonterminals
- Post-processing ➔ more nonterminal attributes
  - Example: Post-processor changes “a” to “an” before a vowel
  - But we could handle this using a “starts with vowel” attribute instead
    - The determiner must “agree” with the vowel status of its Nbar
  - This kind of conversion can always be done! (automatically!)
  - At least for post-processors that are finite-state transducers
  - And then we can convert these attributes to nonterminals as above
### Part of the English Tense System

<table>
<thead>
<tr>
<th></th>
<th>Present</th>
<th>Past</th>
<th>Future</th>
<th>Infinitive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simple</strong></td>
<td>eats</td>
<td>ate</td>
<td>will eat</td>
<td>to eat</td>
</tr>
<tr>
<td><strong>Perfect</strong></td>
<td>has eaten</td>
<td>had eaten</td>
<td>will have eaten</td>
<td>to have eaten</td>
</tr>
<tr>
<td><strong>progressive</strong></td>
<td>is eating</td>
<td>was eating</td>
<td>will be eating</td>
<td>to be eating</td>
</tr>
<tr>
<td><strong>Perfect+ progressive</strong></td>
<td>has been eating</td>
<td>had been eating</td>
<td>will have been eating</td>
<td>to have been eating</td>
</tr>
</tbody>
</table>
**Tenses by Post-Processing: “Affix-hopping” (Chomsky)**

<table>
<thead>
<tr>
<th>Mary jumps</th>
<th>Mary [-s jump]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mary has jumped</td>
<td>Mary [-s have] [-en jump]</td>
</tr>
<tr>
<td>Mary is jumping</td>
<td>Mary [-s be] [-ing jump]</td>
</tr>
<tr>
<td>Mary has been jumping</td>
<td>Mary [-s have] [-en be] [-ing jump]</td>
</tr>
</tbody>
</table>

**Agreement, meaning**

where
- -s denotes “3rd person singular present tense” on following verb (by an -s suffix)
- -en denotes “past participle” (often uses -en or -ed suffix)
- -ing denotes “present participle”  Etc.

**Could we instead describe the patterns via attributes?**
Let’s distinguish the different kinds of VP by tense ...
The plan ... thrilled

Past
- Present tense
The plan ...

- Past tense
- Present tense
The plan … thrills

- Present tense (again)
The plan ... has thrilled Otto.

- Present perfect tense
The plan ... has thrilled Otto.

- Present **perfect** tense
The plan ...

- Present perfect tense
- The yellow material makes it a perfect tense – what effects?

The yellow material makes it a perfect tense – what effects?
The plan has thrilled Otto.

- Present perfect tense
The plan … 

- Present tense (again)
The plan...

- Present **progressive** tense
The plan … is thrilling.

Past

- Present progressive tense
The plan ...

- Present perfect tense (again)
The plan has been thrilling Otto.

- Present perfect progressive tense
The plan has been thrilling Otto.

- Present perfect progressive tense

[tense=pres,head=thrill]
[tense=pres,head=have]  [tense=perf,head=thrill]
[tense=perf,head=be]  [tense=prog,head=thrill]
[tense=prog,head=thril] [head=Otto]
The plan ... has been thrilling Otto.

Past
- Present perfect progressive tense
The plan … would have been thrilling.
So what pattern do all progressives follow?
So what pattern do all progressives follow?
Progressive: \(\text{VP}[\text{tense}=\alpha, \text{head}=\beta, \ldots] \rightarrow \text{V}[\text{tense}=\alpha, \text{head}=\text{be} \ldots]\)

\(\text{VP}[\text{tense}=\text{prog}, \text{head}=\beta \ldots]\)

Perfect: \(\text{VP}[\text{tense}=\alpha, \text{head}=\beta, \ldots] \rightarrow \text{V}[\text{tense}=\alpha, \text{head}=\text{have} \ldots]\)

\(\text{VP}[\text{tense}=\text{perf}, \text{head}=\beta \ldots]\)

Future or conditional:

\(\text{VP}[\text{tense}=\alpha, \text{head}=\beta, \ldots] \rightarrow \text{V}[\text{tense}=\alpha, \text{head}=\text{will} \ldots]\)

\(\text{VP}[\text{tense}=\text{stem}, \text{head}=\beta \ldots]\)

Infinitive:

\(\text{VP}[\text{tense}=\text{inf}, \text{head}=\beta, \ldots] \rightarrow \text{to}\)

\(\text{VP}[\text{tense}=\text{stem}, \text{head}=\beta \ldots]\)

Etc.

As well as the “ordinary” rules:

\(\text{VP}[\text{tense}=\alpha, \text{head}=\beta, \ldots] \rightarrow \text{V}[\text{tense}=\alpha, \text{head}=\beta, \ldots] \text{NP}\)

\(\text{V}[\text{tense}=\text{past}, \text{head}=\text{have} \ldots] \rightarrow \text{had}\)
Gaps ("deep" grammar!)

- Pretend "kiss" is a pure transitive verb.
- Is "the president kissed" grammatical?
  - If so, what type of phrase is it?
- the sandwich that
- I wonder what
- What else has

\[
\begin{align*}
\text{the president kissed } e \\
\text{Sally said the president kissed } e \\
\text{Sally consumed the pickle with } e \\
\text{Sally consumed } e \text{ with the pickle}
\end{align*}
\]
Gaps

- **Object gaps:**
  - the sandwich that
  - I wonder what
  - What else has

- **Subject gaps:**
  - the sandwich that
  - I wonder what
  - What else has

[how could you tell the difference?]
Gaps

- All gaps are really the same - a missing NP:
  - the sandwich that
  - I wonder what
  - What else has

Phrases with missing NP:

X[missing=NP]
or just X/NP for short
what else could go here?
he was kissing the sandwich that was \textit{kissing} the sandwich. What else could go there?
what he was wondering was that he was kissing the sandwich. What else could go here?
To indicate what fills a gap, people sometimes “coindex” the gap and its filler.

- Each phrase has a unique index such as “i”.
- In some theories, coindexation is used to help extract a meaning from the tree.
- In other theories, it is just an aid to help you follow the example.

The money I spend on the happiness I hope to buy which violin is this sonata easy to play on.
Lots of attributes (tense, number, person, gaps, vowels, commas, wh, etc...)

- Sorry, that's just how language is ...
- You know too much to write it down easily!

He has gone