5a. Extending grammars with features

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Reading: Jurafsky & Martin: 12.3.4–6, 15.0–3; [Allen: 4.1–5]; Bird et al: 9.
Problem: **Agreement** phenomena.

*Nadia* {washes/*wash} the dog.

*The boys* {*washes/wash*} the dog.

*You* {*washes/wash*} the dog.

**Morphological inflection** of verb must match subject noun in person and number.
## Subject–verb agreement

### Present tense

<table>
<thead>
<tr>
<th></th>
<th>Singular</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td><em>I</em> wash</td>
<td><em>we</em> wash</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td><em>you</em> wash</td>
<td><em>you</em> wash</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><em>he/she/it</em> washes</td>
<td><em>they</em> wash</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th><strong>1</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td><em>I</em> am</td>
<td><em>we</em> are</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td><em>you</em> are</td>
<td><em>you</em> are</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><em>he, she, it</em> is</td>
<td><em>they</em> are</td>
</tr>
</tbody>
</table>
### Subject–verb agreement

#### Past tense

<table>
<thead>
<tr>
<th></th>
<th>Singular</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>I</em> washed</td>
<td><em>we</em> washed</td>
</tr>
<tr>
<td>2</td>
<td><em>you</em> washed</td>
<td><em>you</em> washed</td>
</tr>
<tr>
<td>3</td>
<td><em>he, she, it</em> was</td>
<td><em>they</em> washed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Singular</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>I</em> was</td>
<td><em>we</em> were</td>
</tr>
<tr>
<td>2</td>
<td><em>you</em> were</td>
<td><em>you</em> were</td>
</tr>
<tr>
<td>3</td>
<td><em>he, she, it</em> was</td>
<td><em>they</em> were</td>
</tr>
</tbody>
</table>
Agreement features

• English agreement rules are fairly simple.
  • Subject : verb w.r.t. person and number.
  • No agreement required between verb and object.
• Many languages have other agreements.
  • E.g., German: Article and adjective ending depends on noun gender and case:
## Agreement features

<table>
<thead>
<tr>
<th>Nominative Case (Subject Case)</th>
<th>Masculine</th>
<th>Feminine</th>
<th>Neuter</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Masculine</strong></td>
<td>der</td>
<td>die</td>
<td>das</td>
<td>die</td>
</tr>
<tr>
<td>der neue Wagen</td>
<td>die schöne Stadt</td>
<td>das alte Auto</td>
<td>die neuen Bücher</td>
<td></td>
</tr>
<tr>
<td>the new car</td>
<td>the beautiful city</td>
<td>the old car</td>
<td>the new books</td>
<td></td>
</tr>
<tr>
<td><strong>Feminine</strong></td>
<td>eine</td>
<td>ein</td>
<td></td>
<td>keine</td>
</tr>
<tr>
<td>ein neuer Wagen</td>
<td>eine schöne Stadt</td>
<td>ein altes Auto</td>
<td>keine neuen Bücher</td>
<td></td>
</tr>
<tr>
<td>a new car</td>
<td>a beautiful city</td>
<td>an old car</td>
<td>no new books</td>
<td></td>
</tr>
</tbody>
</table>

Ask about.com: German language: Adjective endings I and II.  
http://german.about.com/library/weekly/aa030298.htm  
and  
http://german.about.com/library/weekly/aa033098.htm
## Agreement features

### Accusative Case (Direct Object)

<table>
<thead>
<tr>
<th>Masculine</th>
<th>Feminine</th>
<th>Neuter</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>den</strong></td>
<td><strong>die</strong></td>
<td><strong>das</strong></td>
<td><strong>die</strong></td>
</tr>
<tr>
<td>den <strong>neu/en</strong> Wagen</td>
<td>die schöne Stadt</td>
<td>das alte Auto</td>
<td>die neuen <strong>Bücher</strong></td>
</tr>
<tr>
<td>the new car</td>
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<tr>
<td><strong>einen</strong></td>
<td><strong>eine</strong></td>
<td><strong>ein</strong></td>
<td><strong>keine</strong></td>
</tr>
<tr>
<td>einen <strong>neu/en</strong> Wagen</td>
<td>eine schöne Stadt</td>
<td>ein altes Auto</td>
<td>keine neuen <strong>Bücher</strong></td>
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and  
http://german.about.com/library/weekly/aa033098.htm
E.g., Chinese: Numeral classifiers, often based on shape, aggregation, …:

两条鱼  liang tiao yu ‘two CLASSIF-LONG-ROPELIKE fish’
两条河  liang tiao he ‘two CLASSIF-LONG-ROPELIKE rivers’
两条腿  liang tiao tui ‘two CLASSIF-LONG-ROPELIKE legs’
两条裤子 liang tiao kuzi ‘two CLASSIF-LONG-ROPELIKE pants’
两只胳膊 liang zhi gebo ‘two CLASSIF-GENERAL arms’
两件上衣 liang jian shangyi ‘two CLASSIF-CLOTHES-ABOVE-WAIST tops’
两套西装 liang tao xizhuang ‘two CLASSIF-SET suits’

Agreement features

• English agreement rules are fairly simple.
• Many languages have other agreements.
• Some languages have multiple grammatical genders.
  • E.g. Chichewa has genders for men, women, bridges, houses, diminutives, men inside houses, etc. Between 12-18 in total.
• Some languages overtly realize many of these distinctions.
  • E.g. some Hungarian verbs have as many as 4096 inflected forms.
Inflectional morphology

- Word may be inflected …
  - … to indicate paradigmatic properties, e.g. singular / plural, past / present, …
  - … to indicate some (other) semantic properties
  - … to agree with inflection of other words.
- Each (open-class) word-type has a base form / stem / lemma.
- Each occurrence of a word includes inflection by a (possibly null) morphological change.
Rule proliferation

- **Problem:** How to account for this in grammar.
- **Possible solution:** Replace all NPs, Vs, and VPs throughout the grammar.

S → NP VP
NP → you, dog, dogs, bear, bears, ...
VP → V NP
V → washes, wash, washed, is, was, ...

S → NP₃s VP₃s
NP₂ → you
VP₃s → V₃s NP
V₃s → is, was, washes, washed, ...

S → NP₃p VP₃p
S → NP₂ VP₂
S → NP₁s VP₁s
S → NP₁p VP₁p
NP₃s → dog, bear, ...
NP₃p → dogs, bears

V₁s → am, was, wash, washed, ...
V₃p → are, were,
• **Drawback 1:** the result is big … really big.

• **Drawback 2:** Losing the generalization:
  • All these Ss, NPs, VPs have the same structure.
  • Doesn’t depend on particular verb, noun, and number.

• CF rules collapse together structural and featural information.

• All information must be completely and directly specified.
  • *E.g.,* can’t just say that values must be equal for some feature without saying exactly what values.
• **Solution**: Separate feature information from syntactic, structural, and lexical information.

• A **feature structure** is a list of pairs:
  \[
  [\text{feature-name} \text{ feature-value}]
  \]

• Feature-values may be atoms or feature structures.

• Can consider syntactic category or word to be bundle of features too.

• Can represent syntactic structure.
Feature structures

- **Drawback**: many equivalent notations.

Feature paths: features of features; e.g., \((\text{Agr Pers 3})\)
NP formed from Det and N.
Feature values in components become feature names in new constituent.
• 1. Lexical specification:

Description of properties of a word: morphological, syntactic, semantic, …

\[
\begin{align*}
dog: & \quad \text{[Cat N] Agr 3s} \\
dogs: & \quad \text{[Cat N] Agr 3p}
\end{align*}
\]

\[
\begin{align*}
sleeps: & \quad \text{[Cat V] Agr 3s} \\
sleep: & \quad \text{[Cat V] Agr \{1s,2s,1p,2p,3p\}}
\end{align*}
\]

Or: \quad N \rightarrow dog \\
\quad (N Agr) = 3s

V \rightarrow sleeps \\
\quad (V Agr) = 3s

N \rightarrow dogs \\
\quad (N Agr) = 3p

V \rightarrow sleep \\
\quad (V Agr) = \{1s,2s,1p,2p,3p\}
2. Agreement:

- **Constraints** on co-occurrence in a rule — within or across phrases.
- Typically are equational constraints.

\[
\begin{align*}
\text{NP} & \rightarrow \text{Det} \ N \\
(\text{Det Num}) &= (N \text{ Num}) \\
\text{S} & \rightarrow \text{NP} \ \text{VP} \\
(\text{NP Agr}) &= (\text{VP Agr})
\end{align*}
\]
Components of feature use

3. Projection:
   - **Sharing of features** between the head of a phrase and the phrase itself.

   \[
   \text{VP} \rightarrow \text{V} \ldots \\
   (\text{VP Agr}) = (\text{V Agr})
   \]

   - Head features:
     - **Agr** is typical, but so is the head-word itself as a feature.
       (Common enough that there’s usually a mechanism for “declaring” head features and omitting them from rules.)
What does it mean for two features to be “equal”?

A *copy* of the value or feature structure, *or* a *pointer* to the same value or feature structure (re-entrancy, shared feature paths).
But: It may be sufficient that two features are not equal, just *compatible* — that they can be *unified*.

E.g.,

\[
\begin{array}{c|c|c}
\text{Cat} & N & 3 \\
\text{Pers} & & \\
\text{Num} & s & \\
\end{array}
\quad \text{and} \quad
\begin{array}{c|c|c}
\text{Cat} & N & 3 \\
\text{Pers} & & \\
\text{Gndr} & F & \\
\end{array}
\]
• Feature structure $X$ *subsumes* feature structure $Y$ if $Y$ is consistent with, and at least as specific as $X$.
  • Also say that $Y$ *extends* $X$.
    $Y$ can add (non-contradictory) features to those in $X$.

**Definition:** $X$ *subsumes* $Y$ ($X \sqsubseteq Y$) iff there is a *simulation* of $X$ inside $Y$, i.e., a function s.t.:
  • $\text{sim}(X) = Y$
  • If $X$ is atomic, so is $Y$ and $X = Y$
  • Otherwise, for all feature values $X.f$: $Y.f$ is defined, and $\text{sim}$ simulates $X.f$ inside $Y.f$. 
Subsumption of feature structures

- Examples:

\[
\begin{align*}
\text{Cat} & \ N & \equiv & \text{Cat} & \ N \\
\text{Pers} & \ 3 & & \text{Pers} & \ 3 \\
\text{Gndr} & & & \ F & \\
\end{align*}
\]

but

\[
\begin{align*}
\text{Cat} & \ N & \not\equiv & \text{Cat} & \ N \\
\text{Pers} & \ 3 & & \text{Pers} & \ 3 \\
\text{Num} & & & \ s & \\
\text{Gndr} & & & \ F & \\
\end{align*}
\]

Third example from Jurafsky & Martin, p. 496
The *unification* of X and Y ($X \sqcup Y$) is the most general feature structure Z that is subsumed by both X and Y.

- Z is the smallest feature structure that extends both X and Y.
- Unification is a constructive operation.
  - If any feature values in X and Y are incompatible, it fails.
  - Else it produces a feature structure that includes all the features in X and all the features in Y.
Unification 2

\[
\begin{array}{c}
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Num} & s \\
\hline
\end{array}
\cup
\begin{array}{c}
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Gndr} & F \\
\end{array}
= \begin{array}{c}
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Num} & s \\
\text{Gndr} & F \\
\end{array}
\]
Features in chart parsing

• Each constituent has an associated feature structure.
  • Constituents with children have a feature structure for each child.

• Arc addition:
  • The feature structure of the new arc is initialized with all known constraints.

• Arc extension:
  • The feature structure of the predicted constituent must unify with that of the completed constituent extending the arc.
Sample grammar fragment

S → NP VP

(NP Agr) = (VP Agr)

NP → Det N
(NP Agr) = (N Agr)
(Det Agr) = (N Agr)

VP → V

(VP Agr) = (V Agr)

Det → a
Det → all
Det → the

[ Agr 3s]
[ Agr 3p]
[ Agr \{3s,3p\}]

N → dog
N → dogs

[ Agr 3s]
[ Agr 3p]

V → sleep
V → sleeps

[ Agr ^3s]
[ Agr 3s]
Mismatched features fail
Unifiable features succeed
Advantages of this approach

• Distinguishes structure from "functional" info.

• Allows for economy of specification:
  • Equations in rules:
    \[ S \rightarrow NP \ VP \]
    \[ (NP \ Agr) = (VP \ Agr) \]
  • Sets of values in lexicon:
    \[ N \rightarrow fish \]
    \[ (N \ Agr \{3s, 3p\}) \]
  • Allows for indirect specification and transfer of information, e.g., head features.

Must unify with
Features and the lexicon

- Lexicon may contain each inflected form.
  - Feature values and base form listed.
- Lexicon may contain only base forms.
  - Process of morphological analysis maps inflected form to base form plus feature values.
  - Time–space trade-off, varies by language.
- Lexicon may contain semantics for each form.
Morphological analysis

- Morphological analysis is simple in English.
- Reverse the rules for inflections, including spelling changes.

\[
\begin{align*}
dogs & \rightarrow \text{dog} \quad \text{[Agr 3p]} & \text{eats} & \rightarrow \text{eat} \quad \text{[Agr 3s, Tns pres]} \\
dog & \rightarrow \text{dog} \quad \text{[Agr 3s]} & \text{rippled} & \rightarrow \text{rip} \quad \text{[Tns past]} \\
berries & \rightarrow \text{berry} \quad \text{[Agr 3p]} & \text{tarried} & \rightarrow \text{tarry} \quad \text{[Tns past]} \\
buses & \rightarrow \text{bus} \quad \text{[Agr 3p]} & \text{running} & \rightarrow \text{run} \quad \text{[Tns pp]} \\
\end{align*}
\]

- Irregular forms will always have to be explicitly listed in lexicon.

\[
\begin{align*}
\text{children} & \rightarrow \text{child} \quad \text{[Agr 3p]} & \text{sang} & \rightarrow \text{sing} \quad \text{[Tns past]} \\
\end{align*}
\]
Morphology in other languages

- Rules may be more complex in other (even European) languages.
- Languages with compounding (e.g., German) or agglutination (e.g., Finnish) require more sophisticated methods.
  - E.g., *Verdauungsspaziergang*, a stroll that one takes after a meal to assist in digestion.
Semantics as a lexical feature

- Add a **Sem** feature:

<table>
<thead>
<tr>
<th>Cat</th>
<th>Num</th>
<th>Pers</th>
<th>Lex</th>
<th>Sem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>dog</td>
<td>dog</td>
</tr>
</tbody>
</table>

- The meaning of *dog* is *dog*. The meaning of *chien* and *Hund* are both *dog*. The meaning of *dog* is G52790. Not uncommon, but pretty unimpressive…
**Problem:** Constraints on verbs and their complements.

*Nadia told / instructed / *said / *informed Ross to sit down.*
*Nadia *told / *instructed / said / *informed to sit down.*
*Nadia told / *instructed / *said / informed Ross of the requirement to sit down.*

*Nadia gave / donated her painting to the museum.*
*Nadia gave / *donated the museum her painting.*

*Nadia put / ate the cake in the kitchen.*
*Nadia *put / ate the cake.*
Verb subcategorization

- VPs are much more complex than just V with optional NP and/or PP.
  - Can include more than one NP.
  - Can include clauses of various types: 
    \[\text{that Ross fed the marmoset to pay him the money}\]
- **Subcat**: A feature on a verb indicating the kinds of verb phrase it allows: 
  \[\_np, \_np\_np, \_inf, \_np\_inf, \ldots\]
Verb tense and aspect

- **Tense** and **aspect** markings on verb:
  - Locate the event in time (relative to another time).
  - Mark the event as complete/finished or in progress.

*Nadia rides the horse.* — In progress now.

*Nadia rode the horse.* — Completed before now.

*Nadia had ridden the horse.* — Completed before before now.

*Nadia was riding the horse.* — In progress before now.
Verb tense and aspect

- Tense: past or present
- Aspect: simple, progressive, or perfect

### Nadia ...

<table>
<thead>
<tr>
<th></th>
<th>Simple</th>
<th>Progressive</th>
<th>Perfect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>rides</td>
<td>is riding</td>
<td>has ridden</td>
</tr>
<tr>
<td>Past</td>
<td>rode</td>
<td>was riding</td>
<td>had ridden</td>
</tr>
</tbody>
</table>

Auxiliary verb

**Present participle**: rides

**Past participle**: ridden

... the horse

In progress

Complete
Verb tense and aspect

- Tense: past or present
- Aspect: simple, progressive, or perfect

<table>
<thead>
<tr>
<th>Tense</th>
<th>Simple</th>
<th>Perfect progressive (continuous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>rides</td>
<td>has been riding</td>
</tr>
<tr>
<td>Past</td>
<td>rode</td>
<td>had been riding</td>
</tr>
</tbody>
</table>

Nadia ... the horse
Modal verbs

- **Modal verbs**: Auxiliary verbs that express degrees of certainty, obligation, possibility, prediction, etc.

  Nadia
  
  \{could, should, must, ought to, might, will, …\}
  
  \{ride, be riding, have ridden, have been riding\}
  
  the horse.
English auxiliary system

- Structure (so far):
  \[ \text{[MODAL]} \ [\text{HAVE}] \ [\text{BE}] \ \text{MAIN-VERB} \]

- General pattern:
  \[ \text{VP} \rightarrow \text{AUX \ VP} \]
  \[ \text{AUX} \rightarrow \text{MODAL | HAVE | BE} \]
  
  - Use features to capture necessary agreements.
The goalie kicked the ball.

Event: *kicked*

Role: **Agent** (doer)

Thing: *the goalie*

Role: **Theme** (thing affected)

Thing: *the ball*

kick (agent=goalie, theme=ball)
The ball was kicked.

Event: kicked

Role: Theme (thing affected)

Thing: the ball

kick (agent=?, theme=ball)
The ball was kicked by the goalie.

Event: kicked

Role: Theme (thing affected)

Thing: the ball

Role: Agent (doer)

Thing: the goalie

kick (agent=goalie, theme=ball)
Passive as *Diathetic alternation*

*the goalie* kicked *the ball*
Passive as *Diathetic alternation*

The ball *was kicked by* the goalie

- From object position in VP to subject position in S
- From subject position in S to PP in VP

But the semantic representation doesn’t change
Voice

• **Voice**: System of assigning thematic roles to syntactic positions.
  • English has **active** and **passive** voices.

• Passive expressed with *be*+past participle. Other auxiliaries may also apply, including progressive *be*.

  • Nadia was kissed. Nadia was being kissed.
  • Nadia had been kissed. Nadia had been being kissed.
  • Nadia could be kissed. Nadia could have been being kissed.

• Structure:
  \[\text{[MODAL]} \ [\text{HAVE}] \ [\text{BE}_1] \ [\text{BE}_2] \ \text{MAIN-VERB}\]
Some useful features

- **VForm**: The tense/aspect form of a verb: passive, pastprt, ...
- **CompForm**: The tense/aspect form of the complement of an auxiliary.
Augmenting rules for passive voice

- For all rules of the form:

  \[ VP \rightarrow V \ NP \ X \quad \text{ADD} \quad VP \rightarrow V \ X \]
  
  \[(V \ \text{Subcat}) = \_y \quad \rightarrow \quad (V \ \text{Subcat}) = \_y \]
  
  \[(V \ \text{VForm}) = \text{passive} \quad \rightarrow \quad (V \ \text{VForm}) = \text{passive} \]

- Augment Aux+VP rules:

  \[ VP \rightarrow \text{AUX} \ VP \]
  
  \[(\text{AUX} \ \text{Root}) = \text{Be2} \]
  
  \[(\text{AUX} \ \text{CompForm}) = (VP_2 \ \text{VForm}) \]
  
  \[(VP_2 \ \text{VForm}) = \text{passive} \]
The GAP feature for passive voice

\[
\begin{align*}
S & \rightarrow \text{NP } \text{VP} \\
1 \text{ (NP Agr)} & = \text{(VP Agr)} \\
2 \text{ (VP VForm)} & = \text{passive} \\
3 \text{ (VP Gap Cat)} & = \text{NP} \\
4 \text{ (VP Gap Agr)} & = \text{(NP Agr)} \\
5 \text{ (VP Gap Sem)} & = \text{(NP Sem)} \\
\text{VP} & \rightarrow \text{V } \text{NP} \\
1 \text{ (VP VForm)} & = \text{(V VForm)} \\
2 \text{ (VP Gap)} & = \text{(NP Gap)} \\
3 \text{ (V Subcat)} & = \_\text{np} \\
\text{NP} & \rightarrow \_\text{\varepsilon} \\
1 \text{ (NP Gap Cat)} & = \text{NP} \\
2 \text{ (NP Gap Agr)} & = \text{(NP Agr)} \\
3 \text{ (NP Gap Sem)} & = \text{(NP Sem)} \\
\text{V} & \rightarrow \text{kicked} \\
1 \text{ (V VForm)} & = \{\text{pastprt, passive}\} \\
2 \text{ (V Subcat)} & = \_\text{np} \\
3 \text{ (V Lex)} & = \text{kick} \\
4 \text{ (V Sem)} & = \text{kick} \\
\text{AUX} & \rightarrow \text{were} \\
1 \text{ (AUX Agr)} & = \text{3p} \\
2 \text{ (AUX Lex)} & = \text{be2} \\
\end{align*}
\]
Note: The green 1’s of the S were 5’s until the 4th constraint of the rule S → NP VP. The 5th constraint fills in the Sem of the Gap 2.
Other cases of *gap percolation*

- Other constructions involve NPs in syntactic configurations where they would not get the right thematic roles using linear order alone.

  Nadia seems to like Ross.
  Nadia seems to be liked.
  Nadia is easy to like.
  Who did Nadia like?
  I fed the dog that Nadia likes to walk.

- Can use grammar rules with gap features to ensure correct structure/interpretation of these as well.
Summary

- Features help capture syntactic constructions in a general and elegant grammar.
- Features can encode the compositional semantics of a sentence as you parse it.
- Features can accomplish mapping functions between syntax and semantics that simplify the interpretation process.