4. Extending grammars with features

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Reading: Jurafsky & Martin: 12.3.4–6, 15.0–3;
Agreement and inflection

• 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>1</td>
<td><em>I</em> wash</td>
<td><em>we</em> wash</td>
</tr>
<tr>
<td>2</td>
<td><em>you</em> wash</td>
<td><em>you</em> wash</td>
</tr>
<tr>
<td>3</td>
<td><em>he/she/it</em> washes</td>
<td><em>they</em> wash</td>
</tr>
<tr>
<td>1</td>
<td><em>I</em> am</td>
<td><em>we</em> are</td>
</tr>
<tr>
<td>2</td>
<td><em>you</em> are</td>
<td><em>you</em> are</td>
</tr>
<tr>
<td>3</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><strong>Singular</strong></th>
<th></th>
<th><strong>Plural</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>I washed</td>
<td>we</td>
<td>washed</td>
<td></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>you washed</td>
<td>you</td>
<td>washed</td>
<td></td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>he, she, it</td>
<td>they</td>
<td>washed</td>
<td></td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>I was</td>
<td>we</td>
<td>were</td>
<td></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>you were</td>
<td>you</td>
<td>were</td>
<td></td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>he, she, it</td>
<td>they</td>
<td>were</td>
<td></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:
### Nominative Case (Subject Case)

<table>
<thead>
<tr>
<th>Masculine</th>
<th>Feminine</th>
<th>Neuter</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>der</em></td>
<td><em>die</em></td>
<td><em>das</em></td>
<td><em>die</em></td>
</tr>
<tr>
<td>der neue Wagen</td>
<td>die schöne Stadt</td>
<td>das alte Auto</td>
<td>die neuen Bücher</td>
</tr>
<tr>
<td>the new car</td>
<td>the beautiful city</td>
<td>the old car</td>
<td>the new books</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Masculine</th>
<th>Feminine</th>
<th>Neuter</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>ein</em></td>
<td><em>eine</em></td>
<td><em>ein</em></td>
<td><em>keine</em></td>
</tr>
<tr>
<td>ein neuer Wagen</td>
<td>eine schöne Stadt</td>
<td>ein altes Auto</td>
<td>keine neuen Bücher</td>
</tr>
<tr>
<td>a new car</td>
<td>a beautiful city</td>
<td>an old car</td>
<td>no new books</td>
</tr>
</tbody>
</table>
### 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>den</td>
<td>die</td>
<td>das</td>
<td>die</td>
</tr>
<tr>
<td>den neuenen Wagen</td>
<td>die schöne Stadt</td>
<td>das alte Auto</td>
<td>die neuenen Bücher</td>
</tr>
<tr>
<td>the new car</td>
<td>the beautiful city</td>
<td>the old car</td>
<td>the new books</td>
</tr>
<tr>
<td>einen</td>
<td>eine</td>
<td>ein</td>
<td>keine</td>
</tr>
<tr>
<td>einen neuenen Wagen</td>
<td>eine schöne Stadt</td>
<td>ein altes Auto</td>
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<td>no new books</td>
</tr>
</tbody>
</table>
Agreement features

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.
• **Problem:** How to account for this in grammar.

• **Possible solution:** Replace all NPs, Vs, and VPs throughout the grammar.

\[
\begin{align*}
S & \rightarrow \text{NP VP} & & & & V & \rightarrow \text{washes, wash, washed, is, was, ...} \\
\text{NP} & \rightarrow \text{you, dog, dogs, bear, bears, ...} & & & & \text{VP} & \rightarrow \text{V NP} \\
S & \rightarrow \text{NP}_3^s \text{ VP}_3^s & & & & V_{1s} & \rightarrow \text{am, was, wash, washed, ...} \\
S & \rightarrow \text{NP}_3^p \text{ VP}_3^p & & & & \text{VP}_3^s & \rightarrow \text{V}_3^s \text{ NP} \\
\text{NP}_2 & \rightarrow \text{you} & & & & \vdots & \\
S & \rightarrow \text{NP}_2 \text{ VP}_2 & & & & \text{V}_1^s & \rightarrow \text{am, was, wash, washed, ...} \\
S & \rightarrow \text{NP}_1^s \text{ VP}_1^s & & & & \vdots & \\
S & \rightarrow \text{NP}_1^p \text{ VP}_1^p & & & & V_{3s} & \rightarrow \text{is, was, washes, washed, ...} \\
\text{NP}_3^s & \rightarrow \text{dog, bear, ...} & & & & \text{V}_3^p & \rightarrow \text{are, were,} \\
\text{NP}_3^p & \rightarrow \text{dogs, bears} & & & & \text{wash, washed, ...} \\
\end{align*}
\]
• **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.
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, ...

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

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

Or: \( N \rightarrow \text{dog} \) 
   \( (N \ Agr) = 3s \)

Or: \( N \rightarrow \text{dogs} \) 
   \( (N \ Agr) = 3p \)

Or: \( V \rightarrow \text{sleeps} \) 
   \( (V \ Agr) = 3s \)

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

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

\[
\begin{align*}
\text{NP} &\rightarrow \text{Det N} \\
&D\text{et \ Num} = (N \text{ Num}) \\
\text{S} &\rightarrow \text{NP VP} \\
&\text{NP Agr} = (\text{VP Agr})
\end{align*}
\]
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.,

```
+---+---+---+
| Cat | N  | 3  |
| Pers|     |     |
| Num | s   |     |
+---+---+---+
```

and

```
+---+---+---+
| Cat | N  | 3  |
| Pers|     |     |
| Gndr|     | F   |
+---+---+---+
```
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 ⊑ Y) iff there is a simulation of X inside Y, i.e., a function s.t.:
- 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 sim simulates X.f inside Y.f.
Subsumption of feature structures

• Examples:

\[
\begin{array}{c}
\text{Cat} \quad \text{N} \\
\text{Pers} \quad 3 \\
\text{Gndr} \quad \text{F}
\end{array}
\] \equiv
\begin{array}{c}
\text{Cat} \quad \text{N} \\
\text{Pers} \quad 3 \\
\text{Gndr} \quad \text{F}
\end{array}
\quad \text{but}
\begin{array}{c}
\text{Cat} \quad \text{N} \\
\text{Pers} \quad 3 \\
\text{Gndr} \quad \text{F}
\end{array}
\not\equiv
\begin{array}{c}
\text{Cat} \quad \text{N} \\
\text{Pers} \quad 3 \\
\text{Gndr} \quad \text{F}
\end{array}
\]

\[
\begin{array}{c}
\text{Cat} \quad \text{VP} \\
\text{Agr} \quad 1 \\
\text{Subj} \quad [\text{Agr} \quad 1]
\end{array}
\] \equiv
\begin{array}{c}
\text{Cat} \quad \text{VP} \\
\text{Agr} \quad 1 \\
\text{Subj} \quad \text{Agr} \quad [\text{Pers} \quad 3 \quad \text{Num} \quad \text{s}]
\end{array}
\]

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

\[
\begin{array}{c}
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Num} & s \\
\hline
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Gndr} & F \\
\hline
\text{Cat} & N \\
\text{Pers} & 3 \\
\text{Num} & s \\
\text{Gndr} & F
\end{array}
\]
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

\[ S \rightarrow NP \ VP \]
\[ (NP \ Agr) = (VP \ Agr) \]
\[ NP \rightarrow Det \ N \]
\[ (NP \ Agr) = (N \ Agr) \]
\[ (Det \ Agr) = (N \ Agr) \]
\[ VP \rightarrow V \]
\[ (VP \ Agr) = (V \ Agr) \]
\[ Det \rightarrow a \]
\[ Det \rightarrow all \]
\[ Det \rightarrow the \]
\[ N \rightarrow dog \]
\[ N \rightarrow dogs \]
\[ V \rightarrow sleep \]
\[ V \rightarrow sleeps \]
Mismatched features fail

```
NP [Agr 1] 
  Det [Agr 1]  N [Agr 3s]
    a

VP [Agr 2]
  V [Agr ^3s]
    sleep

S [Agr 1] ∪ [Agr 2] 
```

FAIL
Unifiable features succeed
Advantages of this approach

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

  dogs $\rightarrow$ dog [Agr 3p]  
  dog $\rightarrow$ dog [Agr 3s]  
  berries $\rightarrow$ berry [Agr 3p]  
  buses $\rightarrow$ bus [Agr 3p]  
  eats $\rightarrow$ eat [Agr 3s, Tns pres]  
  ripped $\rightarrow$ rip [Tns past]  
  tarried $\rightarrow$ tarry [Tns past]  
  running $\rightarrow$ run [Tns pp]  

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

  children $\rightarrow$ child [Agr 3p]  
  sang $\rightarrow$ sing [Tns past]
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>N</td>
<td>s</td>
<td>3</td>
</tr>
<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.
Goal of parsing

- A representation of properties relevant to meaning and interpretation:
  - Things
  - Predicates (events)
  - Roles

\{ Entities (e.g., in a knowledge base) \}

\{ Relations between things and predicates. \}

- Syntactic structure helps in:
  - Determining **things** and **predicates**.
  - Determining mapping of **things** to **roles** of **predicates**.
Example

The goalie *kicked* the ball.

Event: *kicked*

Role: **Agent** (doer)

Role: **Theme** (thing affected)

Thing: *The goalie*  

Thing: *the ball*

kick (agent=goalie, theme=ball)
Syntax ↔ interpretation

- Mapping from structure to objects of interpretation
  - Things: NPs, Ss
  - Predicates: verbs, preps, APs
  - Roles: ??

- What are the roles in these examples?

  Sara left.
  Joan found the treasure in the garage.
  Ken put the ball in the garage.
  Tim cut the wire with a pair of scissors.
  Melissa visited Ottawa with Nadia.
  Andrew felt like a failure.
Syntax ↔ interpretation

- Mapping from structure to objects of interpretation
  - Things: NPs, Ss
  - Predicates: verbs, preps, APs
  - Roles: ?? (thematic roles)

- What are the roles in these examples?
  
  Sara left.
  Joan found the treasure in the garage.
  Ken put the ball in the garage.
  Tim cut the wire with a pair of scissors.
  Melissa visited Ottawa with Nadia.
  Andrew felt like a failure.
Grammatical function vs. thematic roles

- Mapping is more or less regular:
  Subject ≈ Agent / Experiencer
  Object ≈ Theme
  Object of preposition ≈ Goal/Location/
      Recipient / Instrument

- This mapping is used to determine appropriate semantic representation.
Verb subcategorization

**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:
    - 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, …

Write this way to distinguish from constituents.
Verb tense and aspect 1

- **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

<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>

Nadia … the horse

Auxiliary verb

In progress

Complete

Present participle

Past participle
Verb tense and aspect

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

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

Nadia … *Auxiliary verbs* … 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:
  \[\text{VP} \rightarrow \text{AUX} \ \text{VP}\]
  \[\text{AUX} \rightarrow \text{MODAL} \mid \text{HAVE} \mid \text{BE}\]

  - Use features to capture necessary agreements.
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 had been kissed.*
  - *Nadia could be kissed.*

  - *Nadia was being kissed.*
  - *Nadia had been being kissed.*
  - *Nadia could have been being kissed.*

- **Structure:**
  
  \[
  \text{[MODAL]} \ [\text{HAVE}] \ [\text{BE}_1] \ [\text{BE}_2] \ \text{MAIN-VERB}
  \]
The goalie kicked the ball.

Event: *kicked*

Role: **Agent** (doer)

Role: **Theme** (thing affected)

Thing: *the goalie*  

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. [PASSIVE]

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

But the semantic representation doesn’t change
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:

\[ \text{VP} \rightarrow \text{V} \ \text{NP} \ \text{X} \ \text{ADD} \ \text{VP} \rightarrow \text{V} \ \text{X} \]

\[(\text{V Subcat}) = \_y\]

\[(\text{VP VForm}) = \text{passive}\]

Metarule to ease grammar coding

- Augment Aux+VP rules:

\[\text{VP} \rightarrow \text{AUX} \ \text{VP}\]

\[(\text{AUX Root}) = \text{Be2}\]

\[(\text{AUX CompForm}) = (\text{VP}_2 \ \text{VForm})\]

\[(\text{VP}_2 \ \text{VForm}) = \text{passive}\]
The GAP feature for passive voice

S → NP VP
1 (NP Agr) = (VP Agr)
2 (VP VForm) = passive
3 (VP Gap Cat) = NP
4 (VP Gap Agr) = (NP Agr)
5 (VP Gap Sem) = (NP Sem)

VP → AUX VP
1 (VP₁ Agr) = (AUX Agr)
2 (VP₁ VForm) = (VP₂ VForm)
3 (VP₁ Gap) = (VP₂ Gap)
4 (AUX Lex) = be2
5 (VP₂ VForm) = passive

VP → V NP
1 (VP VForm) = (V VForm)
2 (VP Gap) = (NP Gap)
3 (V Subcat) = _np

NP → ε
1 (NP Gap Cat) = NP
2 (NP Gap Agr) = (NP Agr)
3 (NP Gap Sem) = (NP Sem)

NP → cans
1 (NP Agr) = 3p
2 (NP Lex) = can
3 (NP Sem) = cans

AUX → were
1 (AUX Agr) = 3p
2 (AUX Lex) = be2
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.