# Computational Linguistics

CSC 485/2501
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5A

## 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.

# 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 1

**Present tense**

| | Singular | | Plural | |
|---|---|---|---|---|
| **1** | *I* | *wash* | *we* | *wash* |
| **2** | *you* | *wash* | *you* | *wash* |
| **3** | *he/she/it* | *washes* | *they* | *wash* |

| | | | | |
|---|---|---|---|---|
| **1** | *I* | *am* | *we* | *are* |
| **2** | *you* | *are* | *you* | *are* |
| **3** | *he, she, it* | *is* | *they* | *are* |

# Subject–verb agreement 2

**Past tense**

| | Singular | Plural |
|---|---|---|
| **1** | *I washed* | *we washed* |
| **2** | *you washed* | *you washed* |
| **3** | *he, she, it washed* | *they washed* |

| | | |
|---|---|---|
| **1** | *I was* | *we were* |
| **2** | *you were* | *you were* |
| **3** | *he, she, it was* | *they were* |

# Agreement features 1

- 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 2

**Nominative Case** (Subject Case)

| Masculine | Feminine | Neuter | Plural |
|---|---|---|---|
| **der** | **die** | **das** | **die** |
| der neu**e** Wagen | die schön**e** Stadt | das alt**e** Auto | die neu**en** Bücher |
| the new car | the beautiful city | the old car | the new books |
| Masculine | Feminine | Neuter | Plural |
| **ein** | **eine** | **ein** | **keine** |
| ein neu**er** Wagen | eine schön**e** Stadt | ein alt**es** Auto | keine neu**en** Bücher |
| a new car | a beautiful city | an old car | no new books |

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

# Agreement features 2

**Accusative Case** (Direct Object)

| Masculine | Feminine | Neuter | Plural |
|---|---|---|---|
| **den** | **die** | **das** | **die** |
| den neu**en** Wagen | die schön**e** Stadt | das alt**e** Auto | die neu**en** Bücher |
| the new car | the beautiful city | the old car | the new books |
| Masculine | Feminine | Neuter | Plural |
| **einen** | **eine** | **ein** | **keine** |
| einen neu**en** Wagen | eine schön**e** Stadt | ein alt**es** Auto | keine neu**en** Bücher |
| a new car | a beautiful city | an old car | no new books |

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

# Agreement features 3

*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’

Zhang, Hong (2007). Numeral classifiers in Mandarin Chinese. *Journal of East Asian Linguistics*, 16(1), 43–59. Thanks also to Tong Wang, Vanessa Wei Feng, and Helena Hong Gao.

# Agreement features 1

- 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, diminuitives, 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 1

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

S $\rightarrow$ NP VP
NP $\rightarrow$ *you, dog, dogs, bear, bears,* …

VP $\rightarrow$ V NP
V $\rightarrow$ *washes, wash, washed, is, was,* …

S $\rightarrow$ $NP_{3s}$ $VP_{3s}$
S $\rightarrow$ $NP_{3p}$ $VP_{3p}$
S $\rightarrow$ $NP_{2}$ $VP_{2}$
S $\rightarrow$ $NP_{1s}$ $VP_{1s}$
S $\rightarrow$ $NP_{1p}$ $VP_{1p}$

$NP_{3s}$ $\rightarrow$ *dog*, *bear*, …
$NP_{3p}$ $\rightarrow$ *dogs*, *bears*

$NP_{2}$ $\rightarrow$ *you*
⋮
$VP_{3s}$ $\rightarrow$ $V_{3s}$ NP
⋮
$V_{3s}$ $\rightarrow$ *is, was, washes*, *washed*, …
$V_{3p}$ $\rightarrow$ *are, were, wash*, *washed*, …

$V_{1s}$ $\rightarrow$ *am, was, wash, washed, …*
⋮

# Rule proliferation 2

- *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.

# Feature structures 1

- *Solution:* Separate feature information from syntactic, structural, and lexical information.
- A **feature structure** is a list of pairs:
  [*feature-name 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 2

- *Drawback*: many equivalent notations.

$$\mathrm{N}\ \begin{bmatrix} \textbf{Num} & \mathrm{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{dog} \end{bmatrix} \qquad \textit{dog}\ \begin{bmatrix} \textbf{Cat} & \mathrm{N} \\ \textbf{Num} & \mathrm{s} \\ \textbf{Pers} & 3 \end{bmatrix} \qquad \mathrm{N}/\textit{dog}\ \begin{bmatrix} \textbf{Num} & \mathrm{s} \\ \textbf{Pers} & 3 \end{bmatrix}$$

$$\begin{bmatrix} \textbf{Cat} & \mathrm{N} \\ \textbf{Num} & \mathrm{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{dog} \end{bmatrix} \qquad \begin{bmatrix} \textbf{Cat} & \mathrm{N} \\ \textbf{Agr} & \begin{bmatrix} \textbf{Num} & \mathrm{s} \\ \textbf{Pers} & 3 \end{bmatrix} \\ \textbf{Lex} & \textit{dog} \end{bmatrix}$$

*Feature paths:* features of features; *e.g.,* (**Agr Pers** 3)

# Feature structures 3

$$\begin{bmatrix} \textbf{Cat} & \text{Det} \\ \textbf{Num} & \text{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{a} \end{bmatrix} \qquad \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Num} & \text{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{dog} \end{bmatrix} \Rightarrow \begin{bmatrix} \textbf{Cat} & \text{NP} \\ \textbf{Num} & \text{s} \\ \textbf{Det} & \begin{bmatrix} \textbf{Num} & \text{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{a} \end{bmatrix} \\ \textbf{N} & \begin{bmatrix} \textbf{Num} & \text{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{dog} \end{bmatrix} \end{bmatrix}$$

NP formed from Det and N.

Feature values in components become feature names in new constituent.

# Components of feature use

- **1. Lexical specification:**

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

*dog:* $\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Agr} & \text{3s} \end{bmatrix}$ *sleeps:* $\begin{bmatrix} \textbf{Cat} & \text{V} \\ \textbf{Agr} & \text{3s} \end{bmatrix}$

Or: ^3s

*dogs:* $\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Agr} & \text{3p} \end{bmatrix}$ *sleep:* $\begin{bmatrix} \textbf{Cat} & \text{V} \\ \textbf{Agr} & \{\text{1s,2s,1p,2p,3p}\} \end{bmatrix}$

Or: N → *dog*
(N **Agr**) = 3s
N → *dogs*
(N **Agr**) = 3p

V → *sleeps*
(V **Agr**) = 3s
V → *sleep*
(V **Agr**) = {1s,2s,1p,2p,3p}

# Components of feature use

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

NP → Det N

(Det **Num**) = (N **Num**)

S → NP VP

(NP **Agr**) = (VP **Agr**)

# Components of feature use

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

    VP → V ...

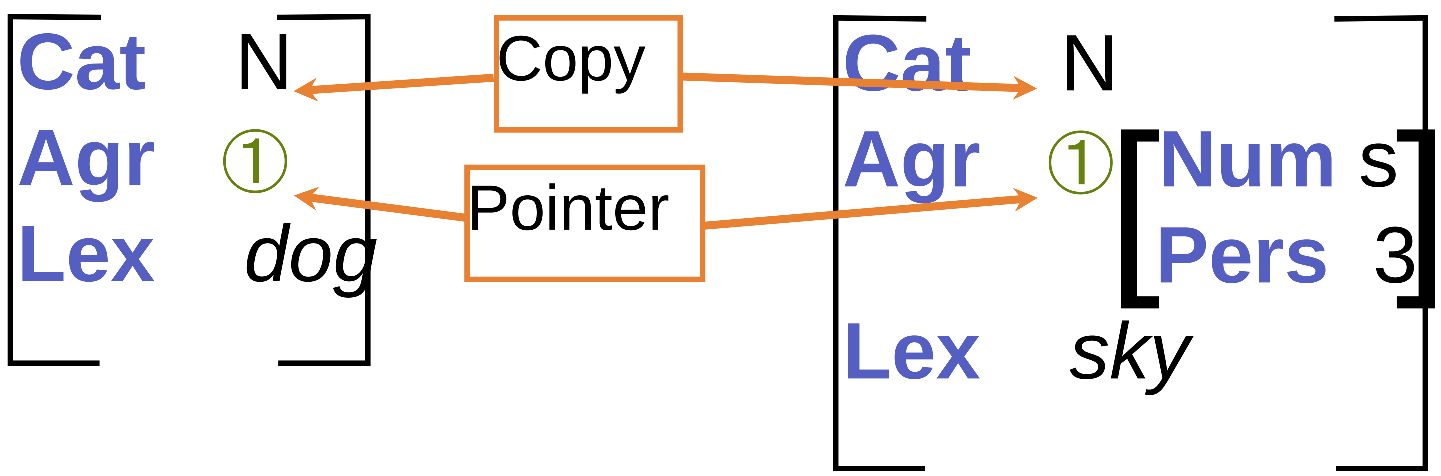
    (VP **Agr**) = (V **Agr**)

  - 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.)

# Constraints on feature values 1

- 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).



# Constraints on feature values 2

- But: It may be sufficient that two features are not equal, just *compatible* — that they can be *unified*.

  - *E.g.,* $\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \end{bmatrix}$ and $\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Gndr} & \text{F} \end{bmatrix}$

# Subsumption of feature structures 1

- 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.:
  - 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 2

- Examples:

$$\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \end{bmatrix} \sqsubseteq \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Gndr} & \text{F} \end{bmatrix} \quad \text{but} \quad \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \end{bmatrix} \not\sqsubseteq \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Gndr} & \text{F} \end{bmatrix}$$

$$\begin{bmatrix} \textbf{Cat} & \text{VP} \\ \textbf{Agr} & \textcircled{1} \\ \textbf{Subj} & \begin{bmatrix} \textbf{Agr} & \textcircled{1} \end{bmatrix} \end{bmatrix} \sqsubseteq \begin{bmatrix} \textbf{Cat} & \text{VP} \\ \textbf{Agr} & \textcircled{1} \\ \textbf{Subj} & \textbf{Agr} \ \textcircled{1} \begin{bmatrix} \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \end{bmatrix} \end{bmatrix}$$

Third example from Jurafsky & Martin, p. 496

# Unification 1

- 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

$$\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \end{bmatrix} \sqcup \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Gndr} & \text{F} \end{bmatrix} = \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \\ \textbf{Gndr} & \text{F} \end{bmatrix}$$

# 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 $\rightarrow$ 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*

[**Agr** 3s]

Det $\rightarrow$ *all*

[**Agr** 3p]

Det $\rightarrow$ *the*

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

N $\rightarrow$ *dog*

[**Agr** 3s]

N $\rightarrow$ *dogs*

[**Agr** 3p]

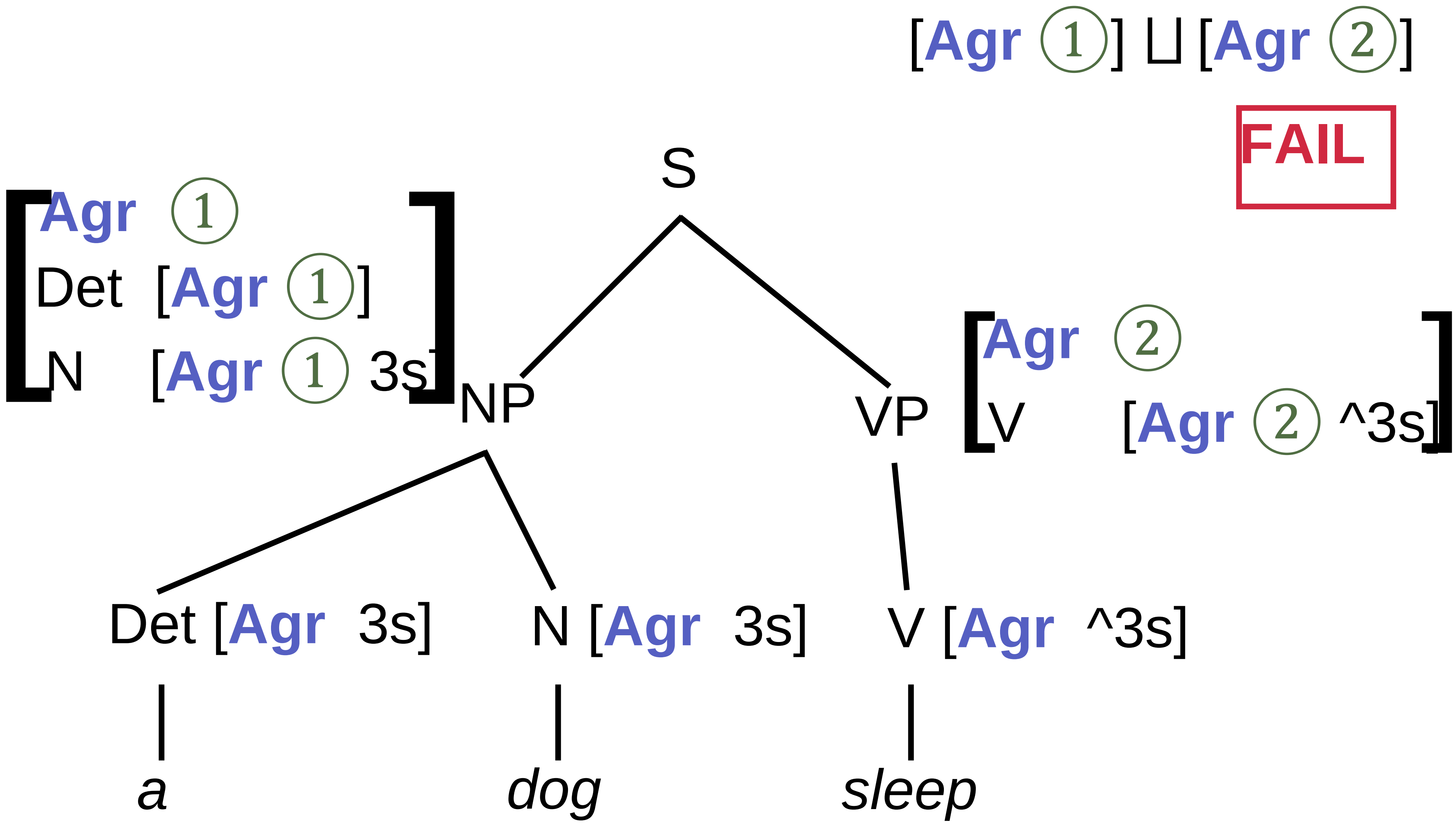
V $\rightarrow$ *sleep*

[**Agr** ^3s]

V $\rightarrow$ *sleeps*

[**Agr** 3s]

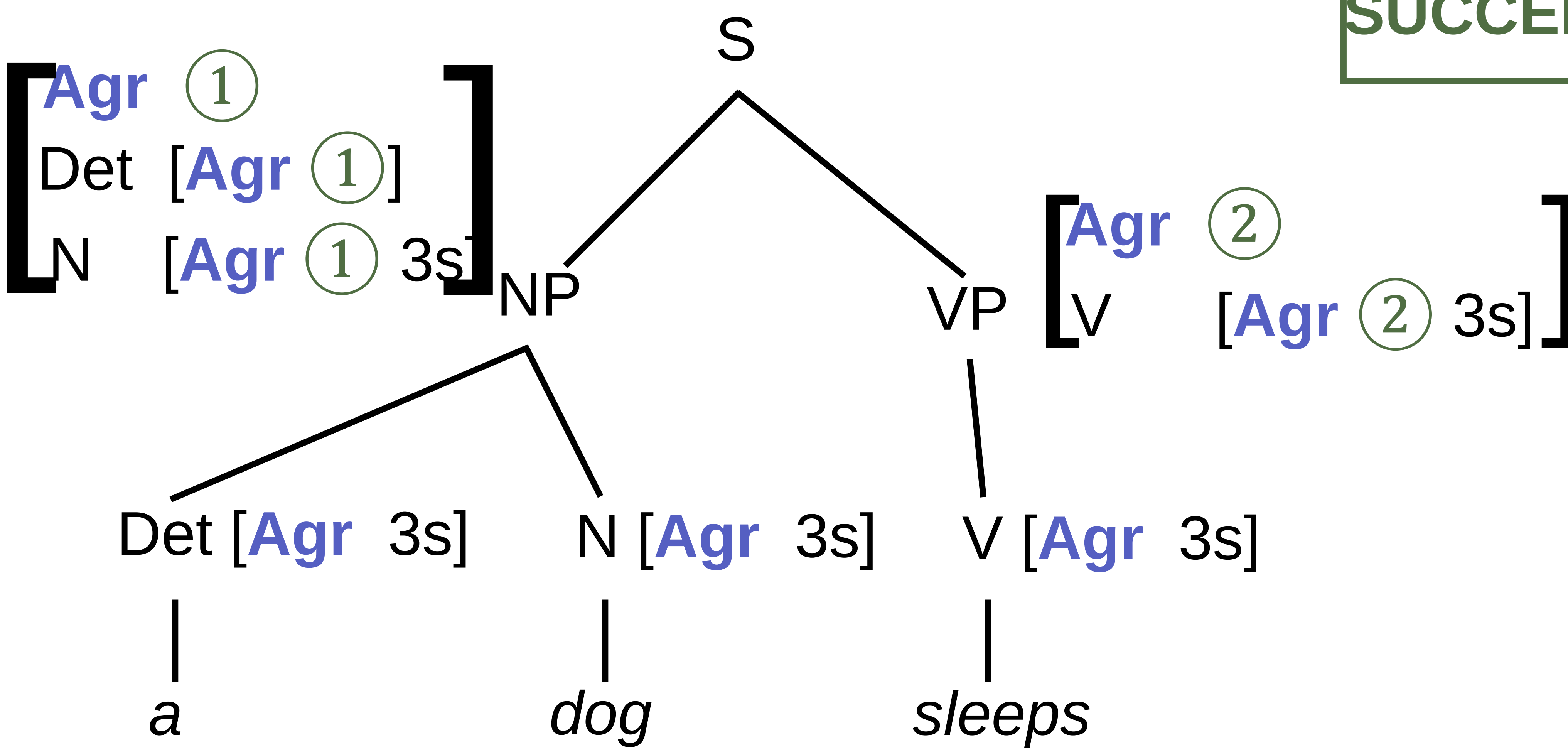
# Mismatched features fail



# Unifiable features succeed

[**Agr** ①] ⊔ [**Agr** ②]

**SUCCEED**



# Advantages of this approach

- Distinguishes structure from ”functional” info.
- Allows for economy of specification:
  - Equations in rules:
    S → NP VP
    (NP **Agr**) = (VP **Agr**)
    Must unify with
  - Sets of values in lexicon:
    N → *fish*
    (N **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* → *dog* [**Agr** 3p]
*dog* → *dog* [**Agr** 3s]
*berries* → *berry* [**Agr** 3p]
*buses* → *bus* [**Agr** 3p]

*eats* → *eat* [**Agr** 3s, **Tns** pres]
*ripped* → *rip* [**Tns** past]
*tarried* → *tarry* [**Tns** past]
*running* → *run* [**Tns** pp]

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

*children* → *child* [**Agr** 3p]   *sang* → *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:

$$\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Num} & \text{s} \\ \textbf{Pers} & 3 \\ \textbf{Lex} & \textit{dog} \\ \textbf{Sem} & \texttt{dog} \end{bmatrix}$$

Typewriter font
for semantic objects

- 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…

# Verb subcategorization 1

- **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 2

- 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 2

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

*Nadia …* Auxiliary verb

In progress

Complete

| | Simple | Progressive | Perfect |
|---|---|---|---|
| **Present** | *rides* | *is riding* | *has ridden* |
| **Past** | *rode* | *was riding* | *had ridden* |

*… the horse*

Present participle

Past participle

# Verb tense and aspect 3

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

Auxiliary verbs

*Nadia …*

| | Simple | Perfect progressive (continuous) |
|---|---|---|
| **Present** | *rides* | *has been riding* |
| **Past** | *rode* | *had been riding* |

*… 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):
  [MODAL] [HAVE] [BE] MAIN-VERB
- General pattern:

  VP $\rightarrow$ AUX VP

  AUX $\rightarrow$ MODAL | HAVE | BE

  - Use features to capture necessary agreements.

# Voice 1

*The goalie kicked the ball.* **ACTIVE**

Event: *kicked*

Role: Agent (doer)

Role: Theme (thing affected)

Thing: *the goalie* Thing: *the ball*

```
kick (agent=goalie, theme=ball)
```

# Voice 2

*The ball was kicked.*

**PASSIVE**

Event: *kicked*

Role: Theme
(thing affected)

Thing: *the ball*

```
kick (agent=?, theme=ball)
```

# Voice 3

*The ball was kicked by the goalie.* **PASSIVE**

Event: *kicked*

Role: Theme
(thing affected)

Role: Agent
(doer)

Thing: *the ball*

Thing: *the goalie*

```
kick (agent=goalie, theme=ball)
```

# Passive as *Diathetic alternation*

*the goalie* *kicked* *the ball*

# Passive as *Diathetic alternation*

From object position in VP
to subject position in S

*the ball was kicked by the goalie*

From subject position
in S to PP in VP

But the semantic representation doesn't change

# Voice 4

- **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:
  [Modal] [Have] [Be$_1$] [Be$_2$] 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:

$VP \rightarrow V\ \ NP\ X$
(V **Subcat**) = _$y$

ADD

$VP \rightarrow V\ X$
(V **Subcat**) = _$y$
(V **VForm**) = passive
(VP **VForm**) = passive

Metarule to ease grammar coding

- Augment Aux+VP rules:

$VP \rightarrow AUX\ \ VP$
(AUX **Root**) = Be2
(AUX **CompForm**) = ($VP_2$ **VForm**)
($VP_2$ **VForm**) = passive

# The GAP feature for passive voice

S $\rightarrow$ 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 $\rightarrow$ AUX VP
1 ($VP_1$ **Agr**) = (AUX **Agr**)
2 ($VP_1$ **VForm**) = ($VP_2$ **VForm**)
3 ($VP_1$ **Gap**) = ($VP_2$ **Gap**)
4 (AUX **Lex**) = be2
5 ($VP_2$ **VForm**) = passive

V $\rightarrow$ *kicked*
1 (V **VForm**) = {pastprt, passive}
2 (V **Subcat**) = _np
3 (V **Lex**) = *kick*
4 (V **Sem**) = `kick`

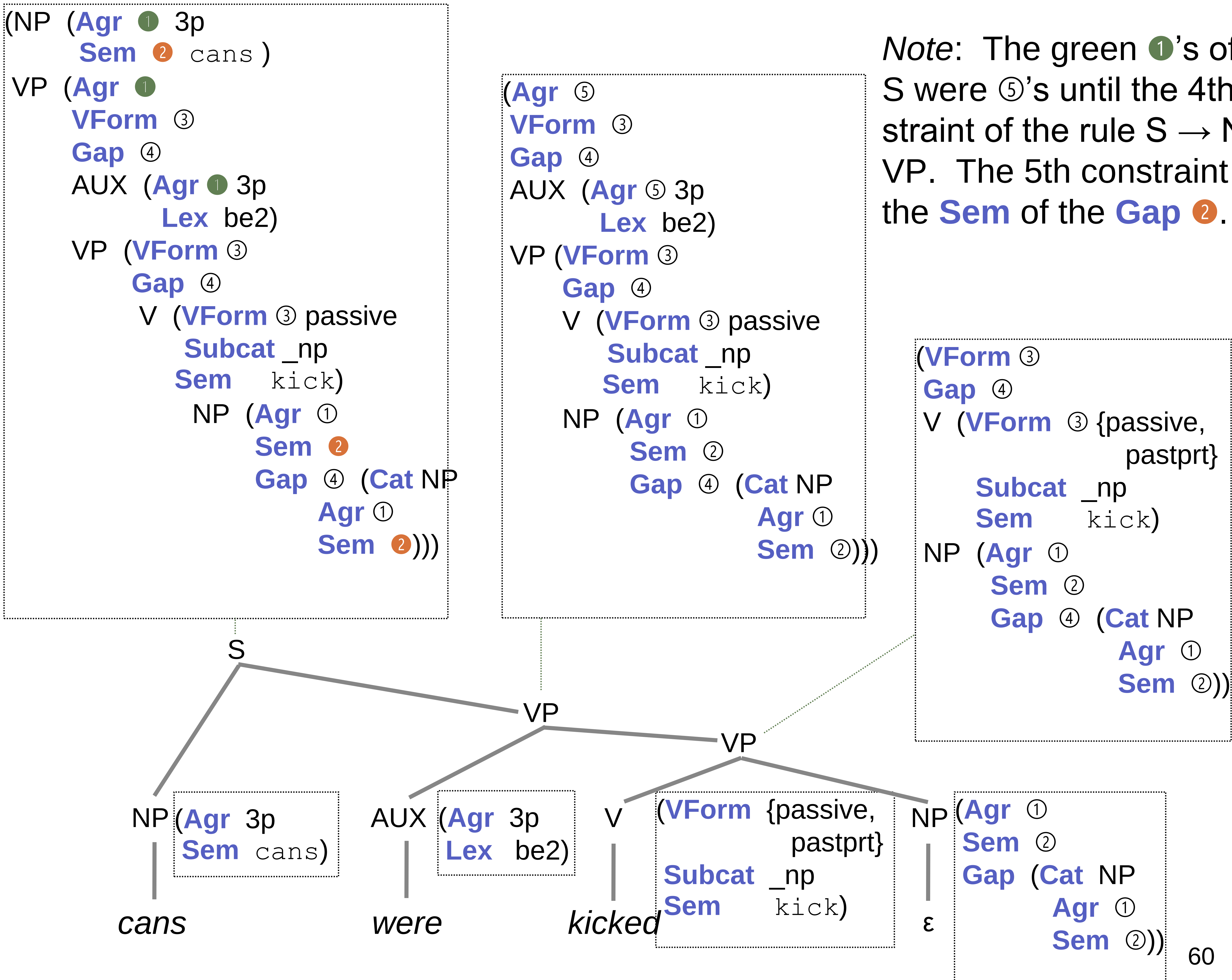
VP $\rightarrow$ V NP
1 (VP **VForm**) = (V **VForm**)
2 (VP **Gap**) = (NP **Gap**)
3 (V **Subcat**) = _np

Empty string

NP $\rightarrow$ ε
1 (NP **Gap Cat**) = NP
2 (NP **Gap Agr**) = (NP **Agr**)
3 (NP **Gap Sem**) = (NP **Sem**)

NP $\rightarrow$ *cans*
1 (NP **Agr**) = 3p
2 (NP **Lex**) = *can*
3 (NP **Sem**) = `cans`

AUX $\rightarrow$ *were*
1 (AUX **Agr**) = 3p
2 (AUX **Lex**) = be2




*Note*: The green ❶'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** ❷.

# 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.