Computational Linguistics

4

CSC 2501 / 485
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4. 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, 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 1

- **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
S → NP3p VP3p
S → NP2 VP2
S → NP1s VP1s
S → NP1p VP1p

NP3s → *dog*, *bear*, …
NP3p → *dogs*, *bears*

NP2 → *you*
⋮
VP3s → V3s NP
⋮
V3s → *is, was, washes*, *washed*, …
V3p → *are, were, wash*, *washed*, …

V1s → *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.

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

dog
$$\begin{bmatrix} \textbf{Cat} & N \\ \textbf{Num} & s \\ \textbf{Pers} & 3 \end{bmatrix}$$

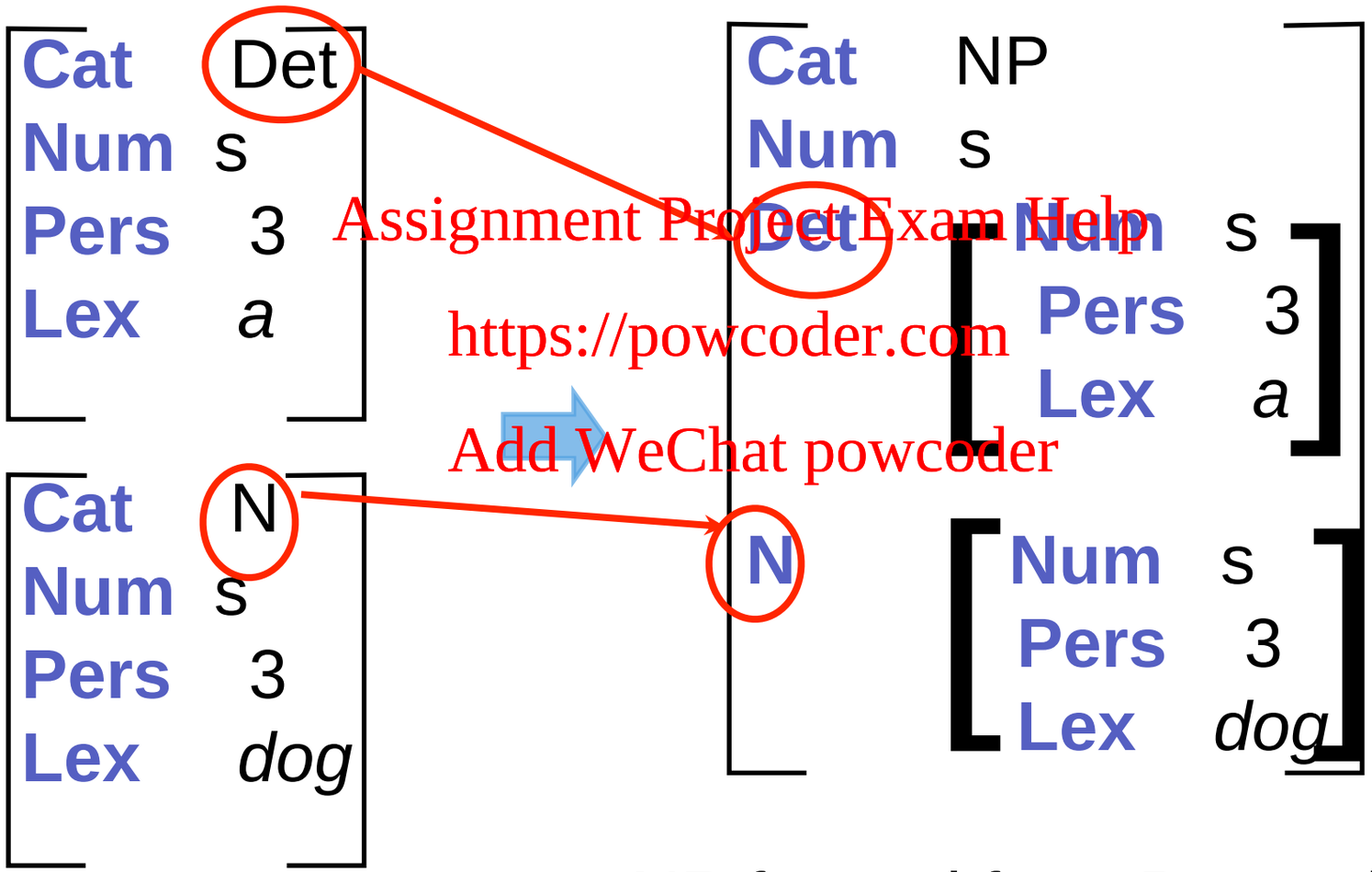
N/*dog*
$$\begin{bmatrix} \textbf{Num} & s \\ \textbf{Pers} & 3 \end{bmatrix}$$

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

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

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

Feature structures 3



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: [**Cat** N ; **Agr** 3s] *sleeps:* [**Cat** V ; **Agr** 3s]

dogs: [**Cat** N ; **Agr** 3p] *sleep:* [**Cat** V ; **Agr** {1s,2s,1p,2p,3p}]

Or: ^3s

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.

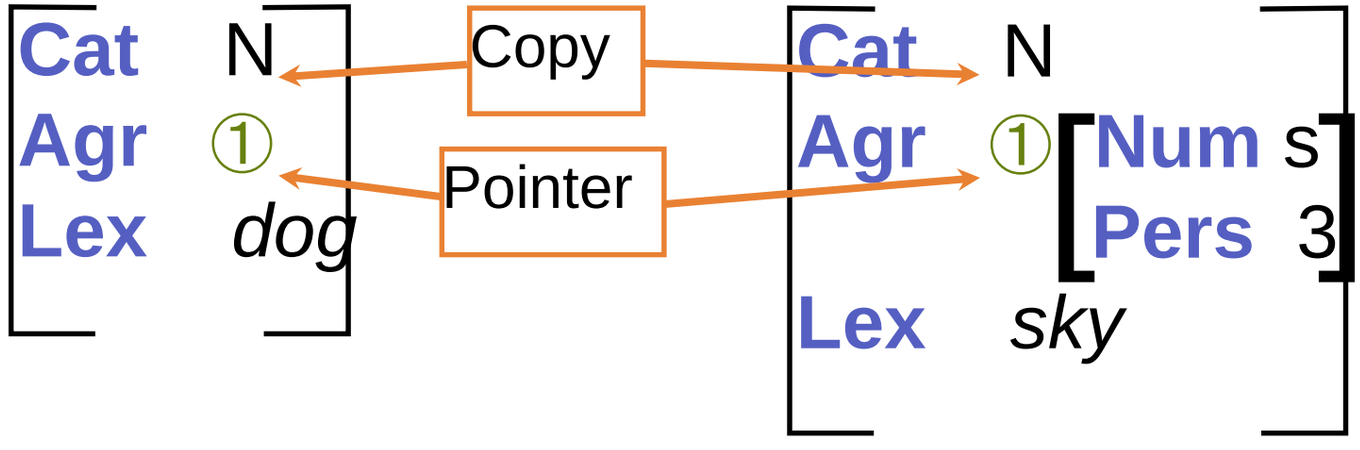
VP → V . . .

(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.,*

$$\begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Num} & \text{s} \end{bmatrix} \quad \textit{and} \quad \begin{bmatrix} \textbf{Cat} & \text{N} \\ \textbf{Pers} & 3 \\ \textbf{Gndr} & \text{F} \end{bmatrix}$$

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 ⊑ 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:

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

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

Third example from Jurafsky & Martin, p. 496

Unification 1

- The *unification* of X and Y (X ⊔ 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 → 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*

[**Agr** 3s]

Det → *all*

[**Agr** 3p]

Det → *the*

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

N → *dog*

[**Agr** 3s]

N → *dogs*

[**Agr** 3p]

V → *sleep*

[**Agr** ^3s]

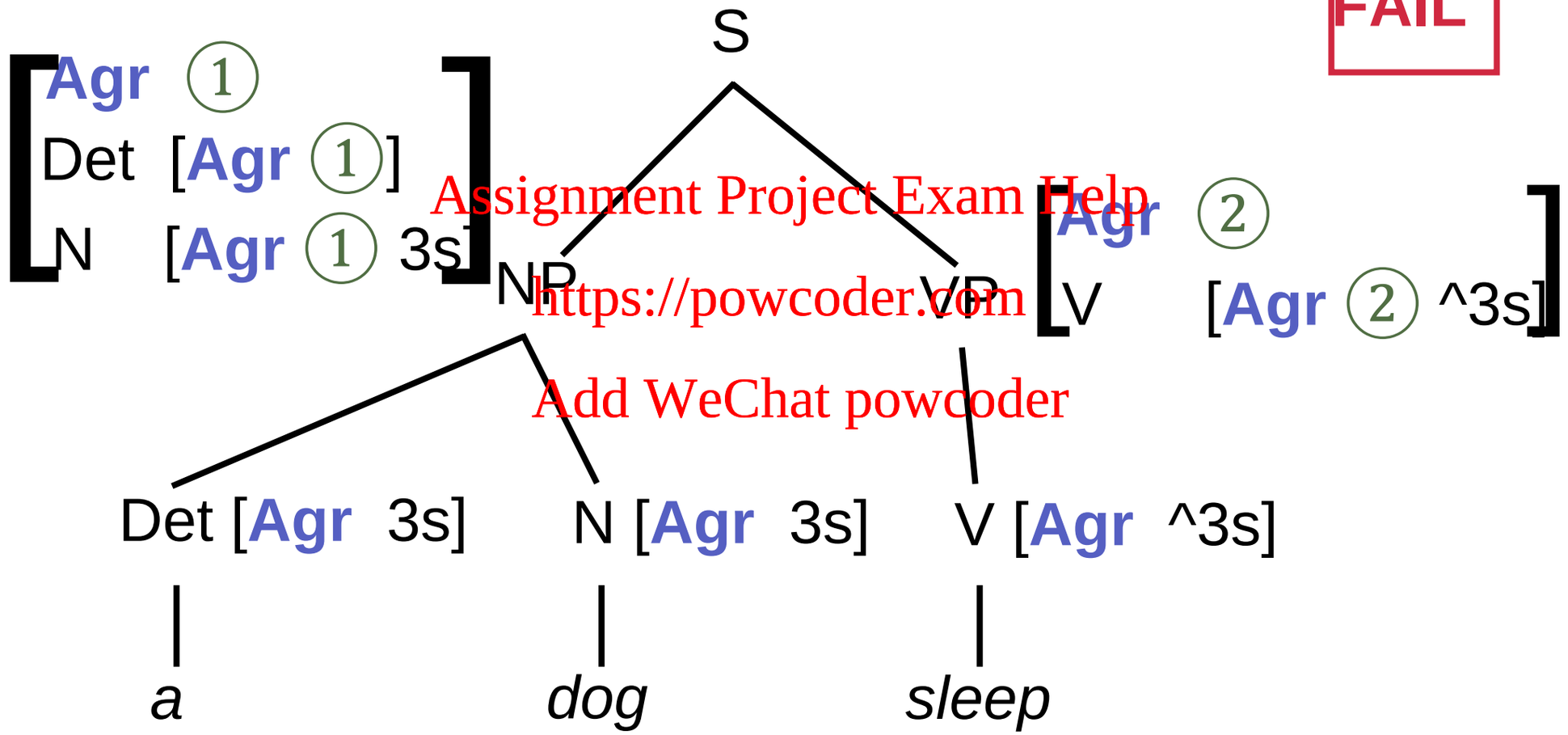
V → *sleeps*

[**Agr** 3s]

Mismatched features fail

[Agr ①] ⊔ [Agr ②]

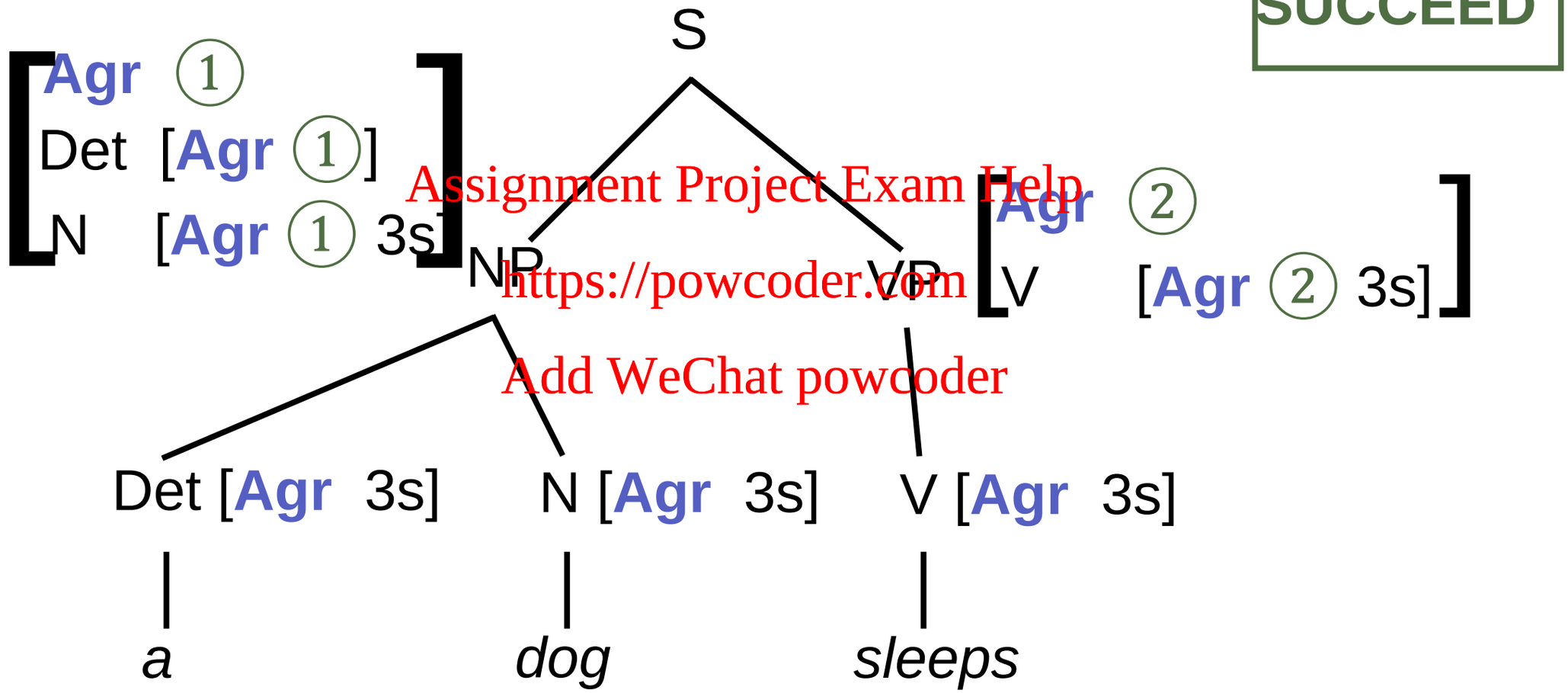
FAIL



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:

Cat	N
Num	s
Pers	3
Lex	*dog*
Sem	dog

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`.

Goal of parsing

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

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

  - Roles

} **Relations** between things and predicates.

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

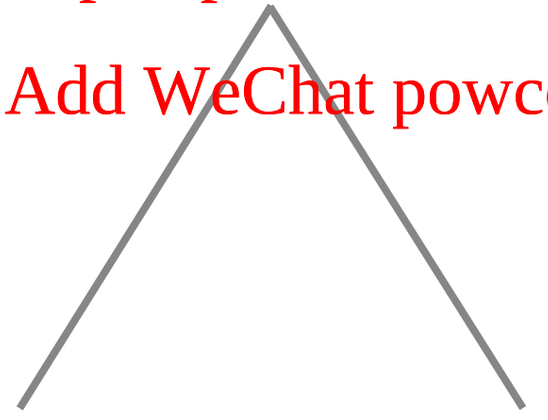
Example

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 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 … *the horse*

In progress

Complete

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

Present participle

Past participle

Verb tense and aspect 3

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

Nadia … Auxiliary verbs

	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, …*} *the horse.*

{*ride, be riding, have ridden, have been riding*}

English auxiliary system

- Structure (so far):
  [MODAL] [HAVE] [BE] MAIN-VERB
- General pattern:

VP → AUX VP

AUX → MODAL | HAVE | BE

- Use features to capture necessary agreements.

Voice 1

- **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

Voice 2

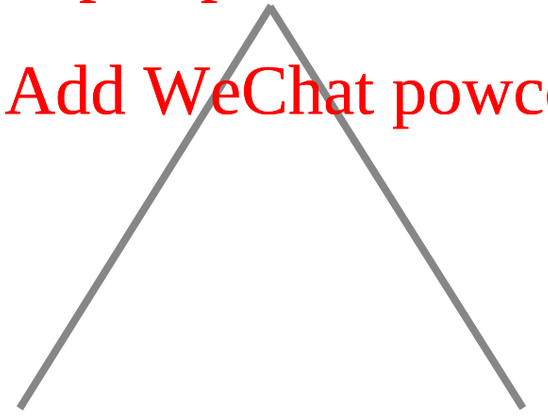
The goalie kicked the ball.

ACTIVE

Event: *kicked*

Role: Agent
(doer)

Role: Theme
(thing affected)



Thing: *the goalie*

Thing: *the ball*

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

Voice 3

The ball was kicked.

PASSIVE

Event: *kicked*

Role: Theme
(thing affected)

Thing: *the ball*

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

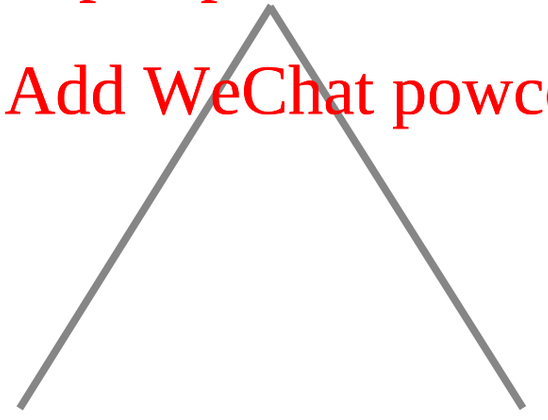
Voice 4

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

Event: *kicked*

Role: Theme
(thing affected)

Role: Agent
(doer)



Thing: *the ball*

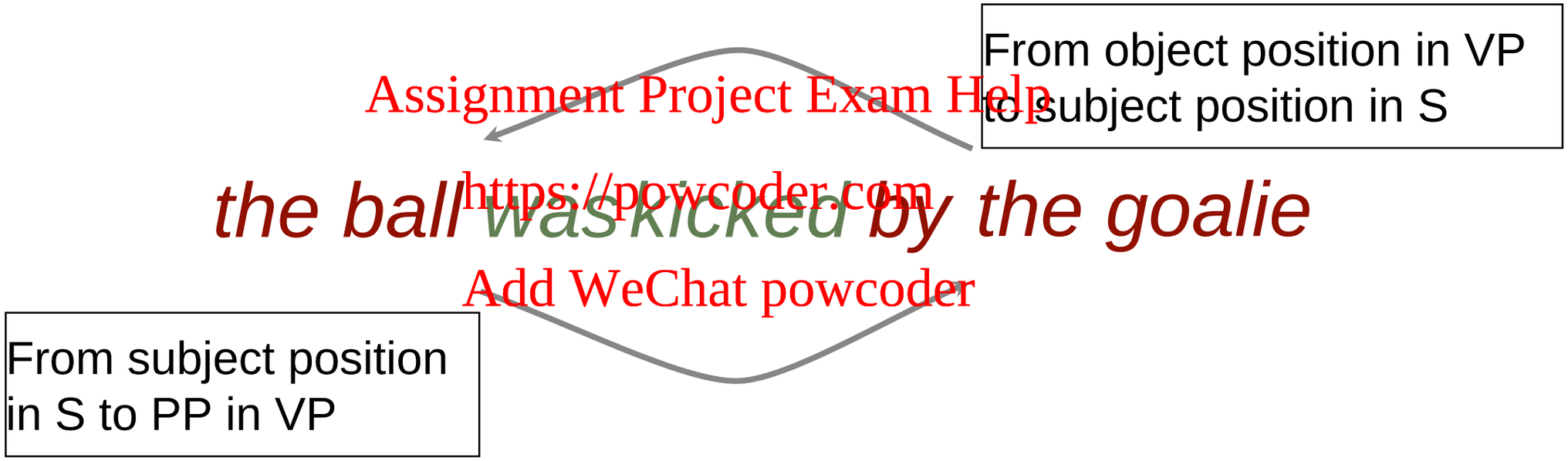
Thing: *the goalie*

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

Passive as *Diathetic alternation*

the goalie *kicked* *the ball*

Passive as *Diathetic alternation*



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:

VP → V NP *X*
(V **Subcat**) = *_y*

ADD

VP → V *X*
(V **Subcat**) = *_y*
(V **VForm**) = passive

Metarule to ease grammar coding

(VP **VForm**) = passive

- Augment Aux+VP rules:

VP → AUX VP
(AUX **Root**) = Be2
(AUX **CompForm**) = (VP_2 **VForm**)
(VP_2 **VForm**) = 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 (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 → *kicked*
1 (V **VForm**) = {pastprt, passive}
2 (V **Subcat**) = _np
3 (V **Lex**) = *kick*
4 (V **Sem**) = `kick`

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

Empty string

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`

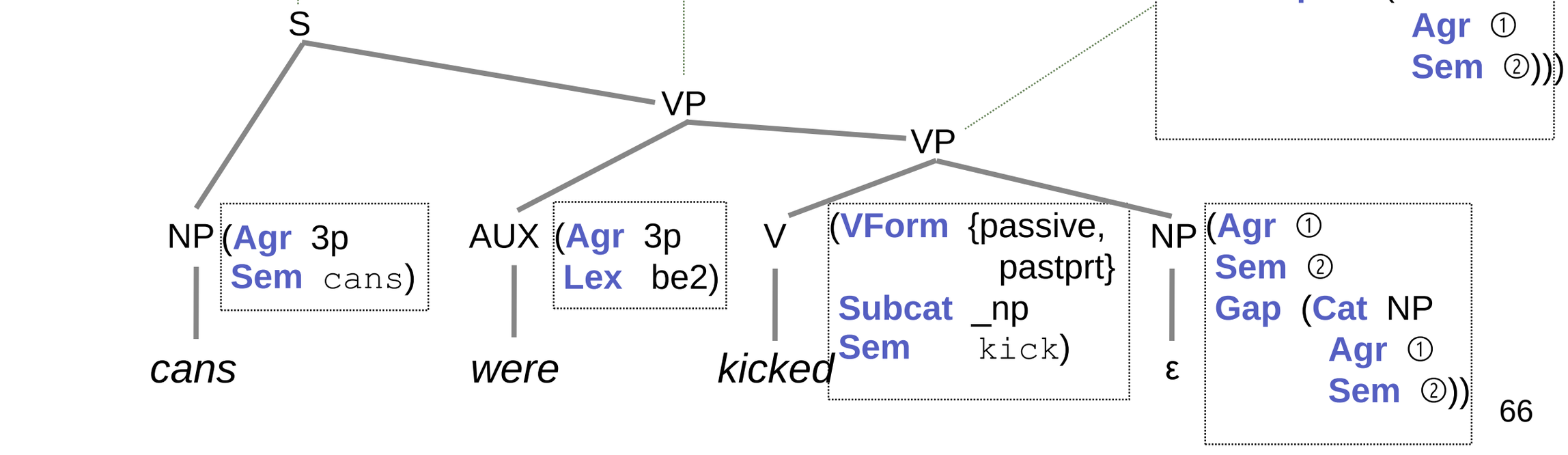
AUX → *were*
1 (AUX **Agr**) = 3p
2 (AUX **Lex**) = be2

(NP (**Agr** ❶ 3p
Sem ❷ cans)
VP (**Agr** ❶
VForm ③
Gap ④
AUX (**Agr** ❶ 3p
Lex be2)
VP (**VForm** ③
Gap ④
V (**VForm** ③ passive
Subcat _np
Sem kick)
NP (**Agr** ①
Sem ❷
Gap ④ (**Cat** NP
Agr ①
Sem ❷)))

(**Agr** ⑤
VForm ③
Gap ④
AUX (**Agr** ⑤ 3p
Lex be2)
VP (**VForm** ③
Gap ④
V (**VForm** ③ passive
Subcat _np
Sem kick)
NP (**Agr** ①
Sem ②
Gap ④ (**Cat** NP
Agr ①
Sem ②)))

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.

(**VForm** ③
Gap ④
V (**VForm** ③ {passive,
pastprt}
Subcat _np
Sem kick)
NP (**Agr** ①
Sem ②
Gap ④ (**Cat** NP
Agr ①
Sem 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.