Feature-based Parsing
+
Computational Semantics

LING 571 — Deep Processing for NLP
October 28, 2020
Shane Steinert-Threlkeld

Announcements

- HW4:
  - No improvements (e.g. upper/lower-case) in first 3 parts of assignment
    - Parser will miss some sentences :)
  - In shell script for part 5:
    - Hard code **full** paths to `evalb` and `parses.gold` in part 5 of assignment

Ambiguity of the Week

Adam Macqueen
@adam_macqueen

Personally feel not enough hospitals are named after sandwiches.


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    (VP (VBD dressed)
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http://nlp.stanford.edu:8080/parser/index.jsp

Roadmap

- Feature-based parsing
- Computational Semantics
  - Introduction
  - Semantics
  - Representing Meaning
    - First-Order Logic
    - Events
- HW#5
  - Feature grammars in NLTK
  - Practice with animacy

Computational Semantics

Dialogue System

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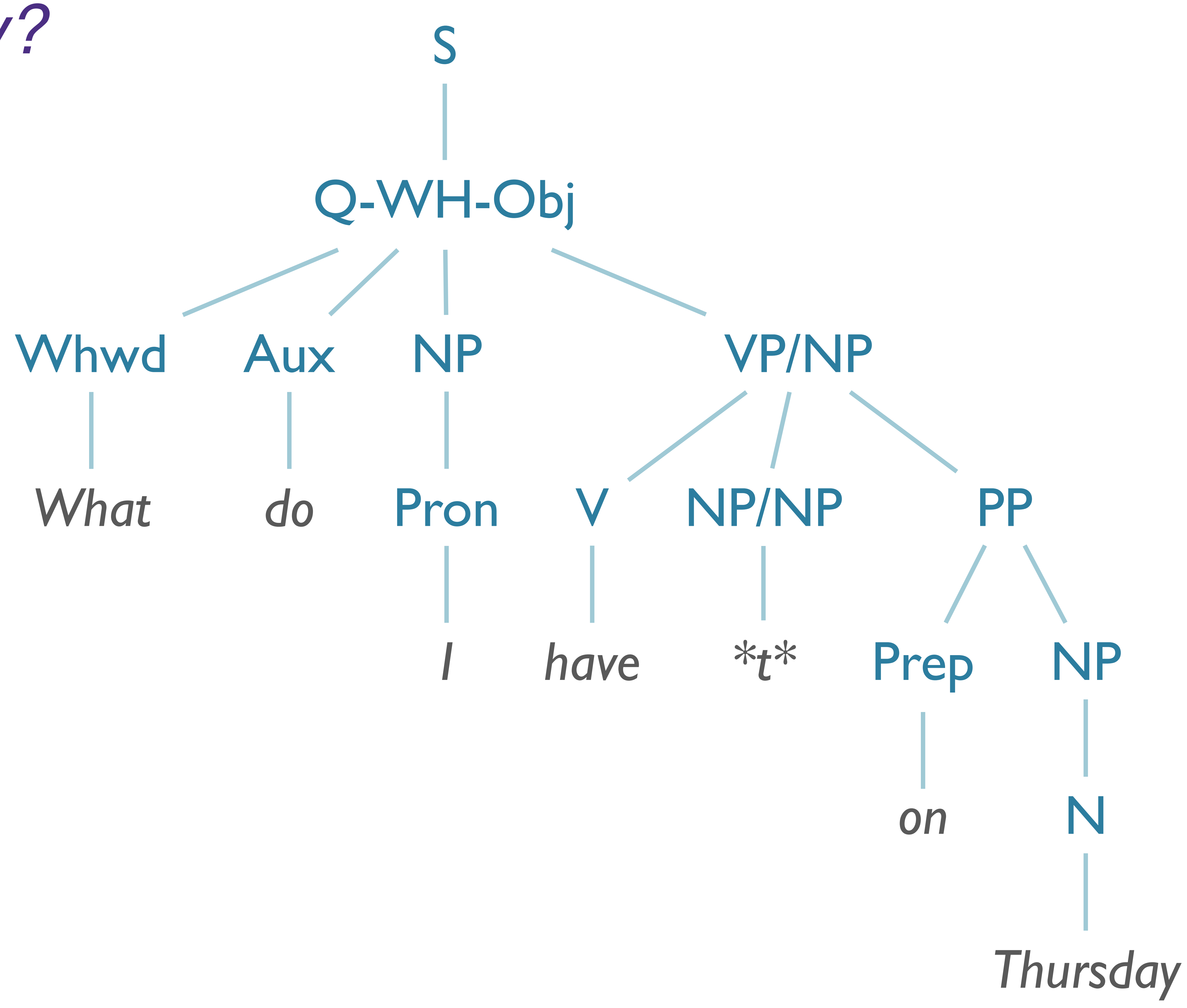

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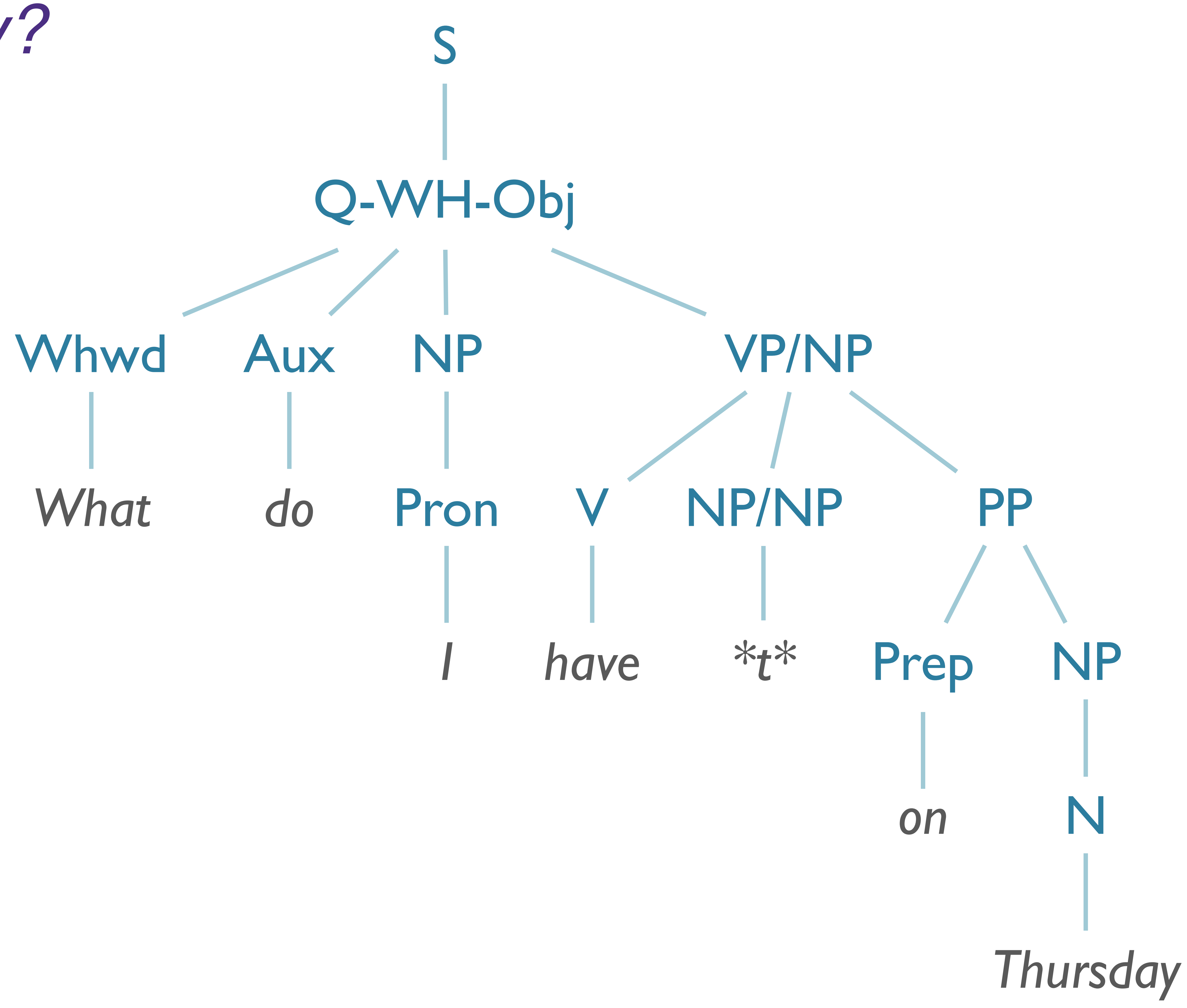

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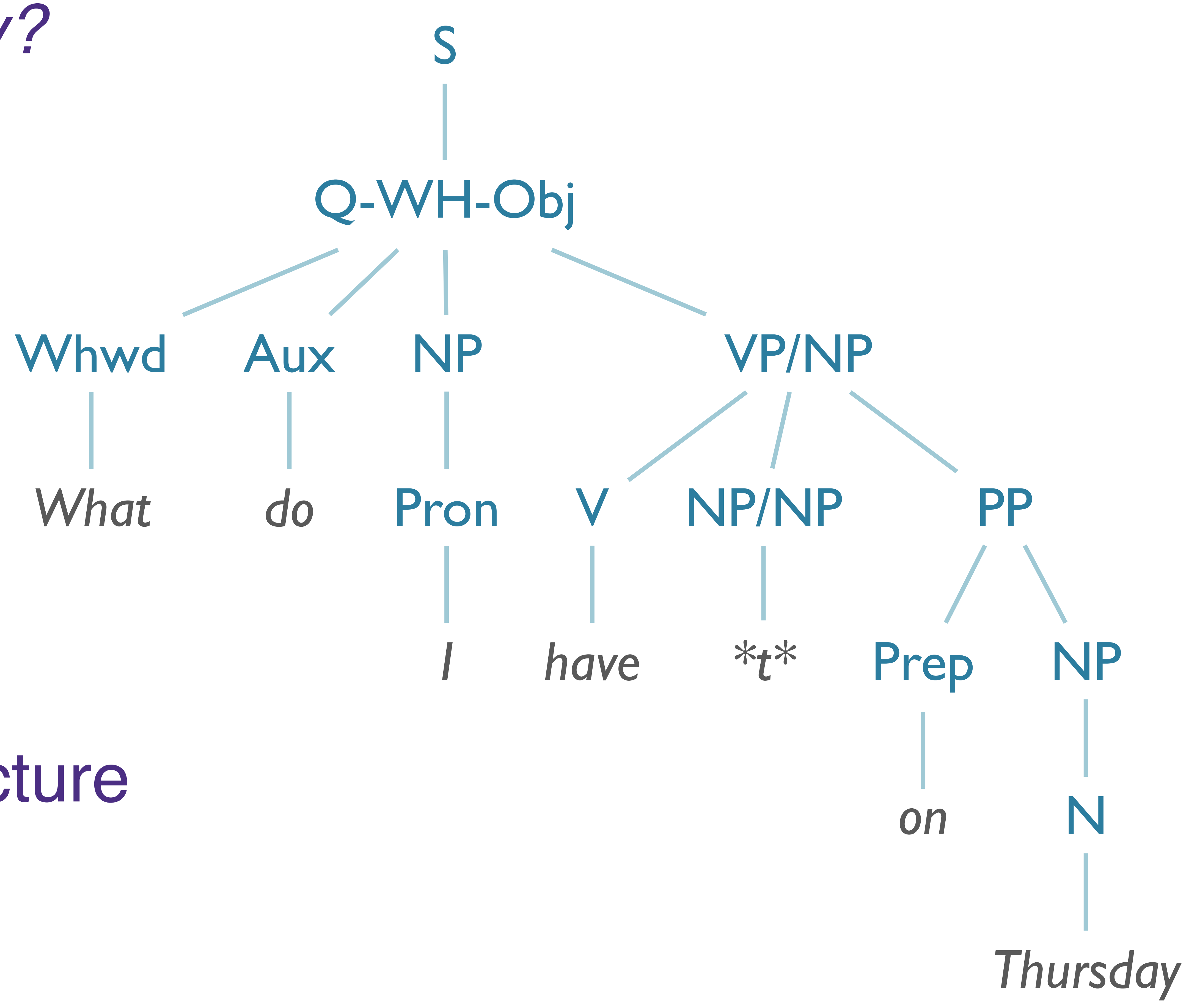
- Need to associate meaning w/structure



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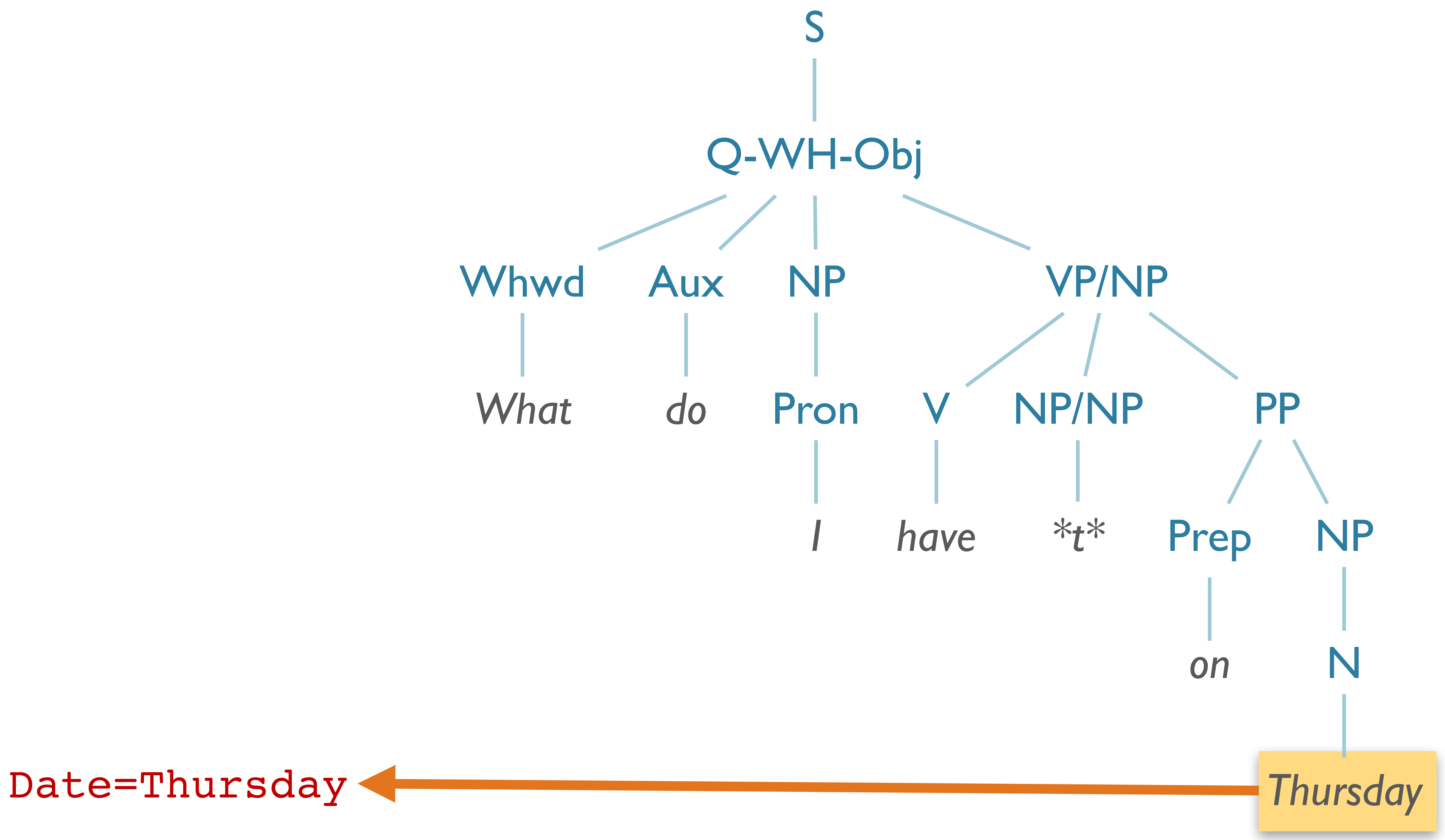

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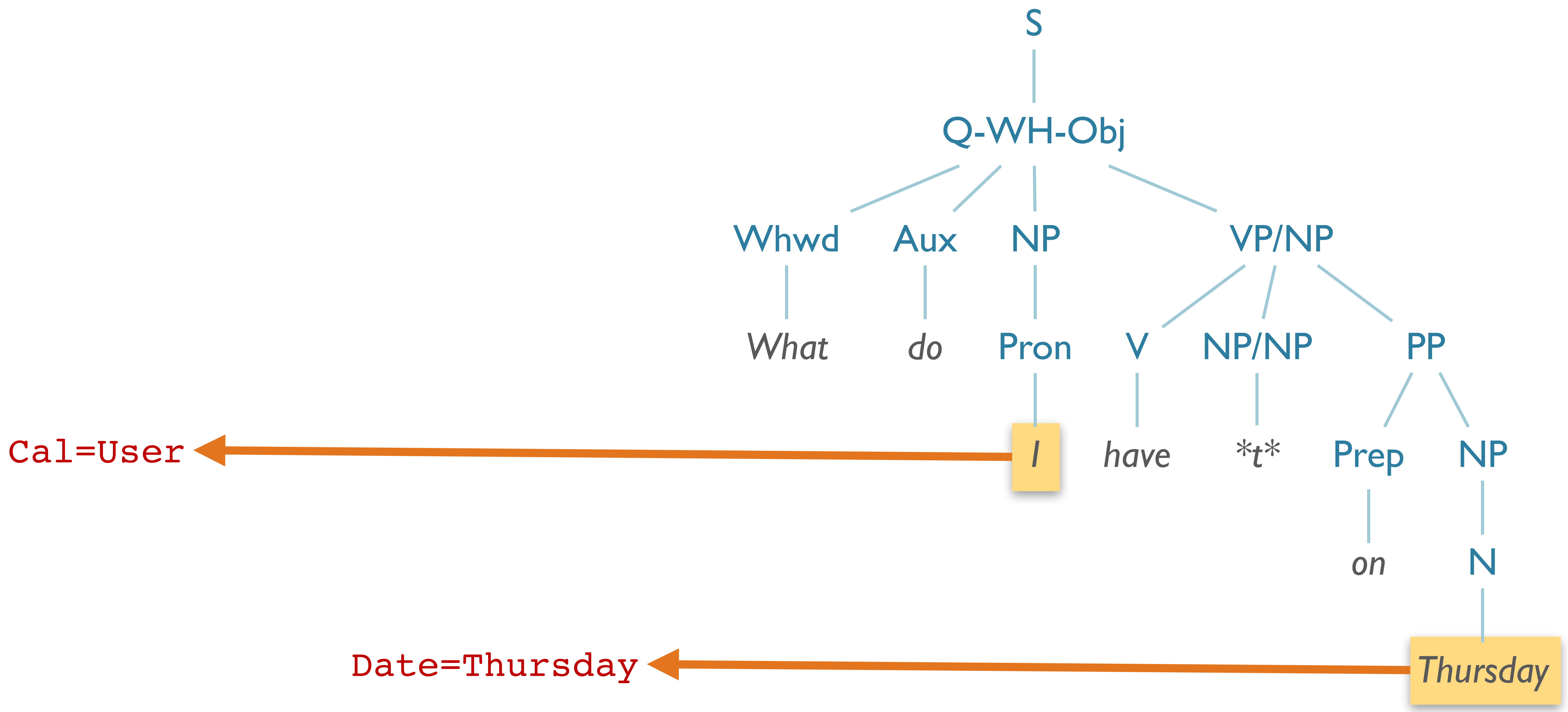

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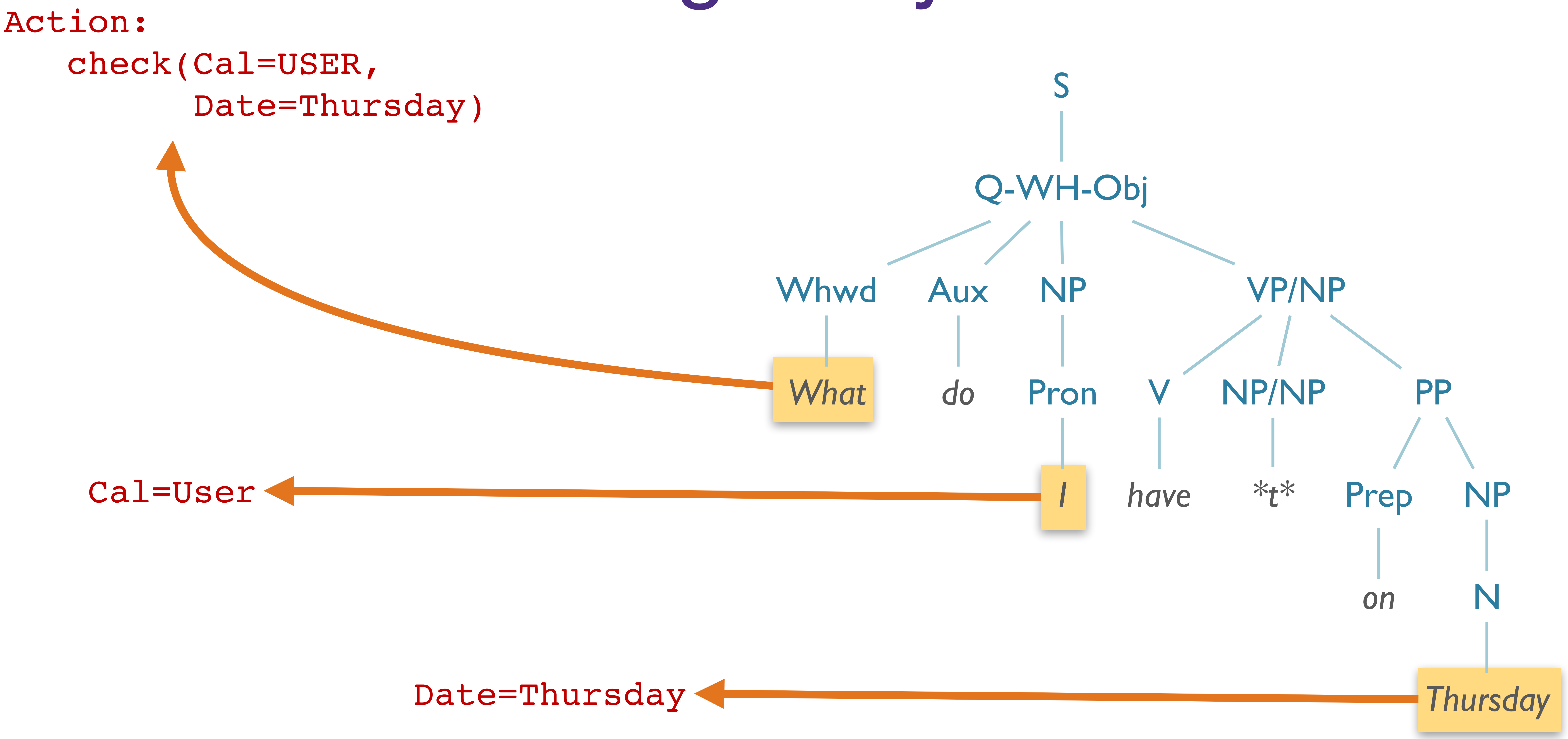

Syntax vs. Semantics

- Syntax:
  - Determine the ***structure*** of natural language input

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- Semantics:
  - Determine the ***meaning*** of natural language input

High-Level Overview

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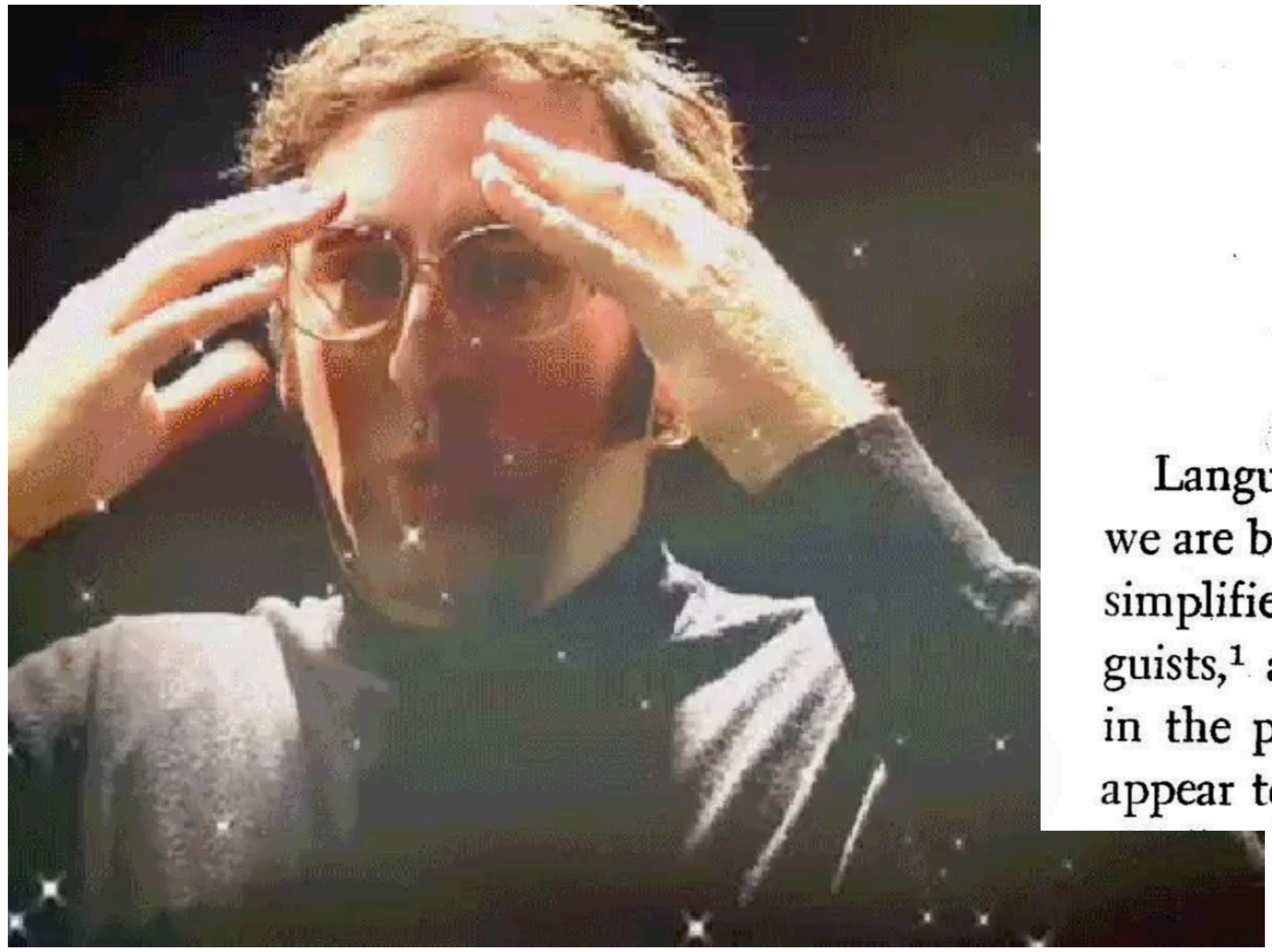

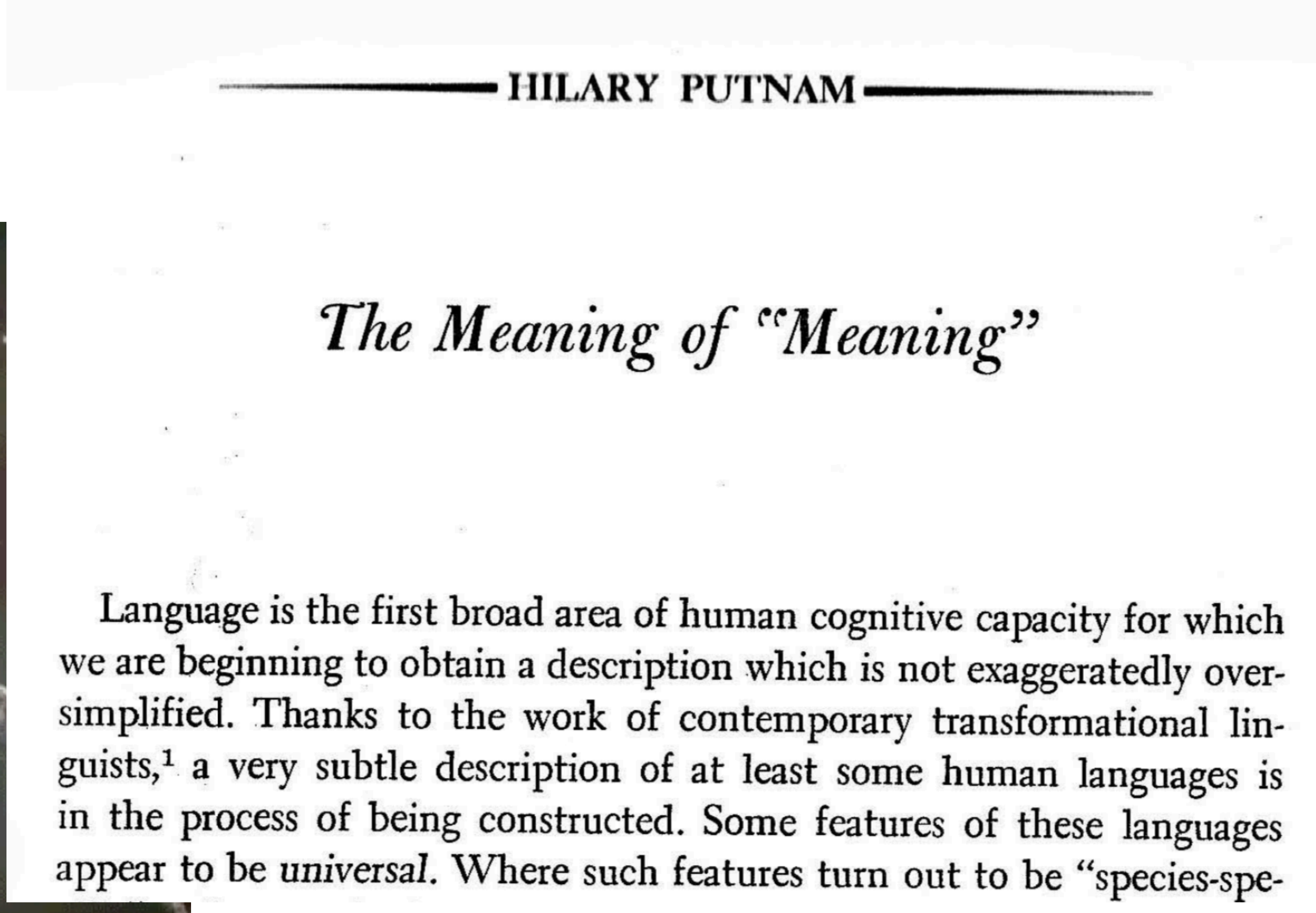

HILARY PUTNAM

The Meaning of “Meaning”

Language is the first broad area of human cognitive capacity for which we are beginning to obtain a description which is not exaggeratedly oversimplified. Thanks to the work of contemporary transformational linguists,[1] a very subtle description of at least some human languages is in the process of being constructed. Some features of these languages appear to be *universal*. Where such features turn out to be “species-spe-

“The sky is blue.”

Speech & Text

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Logic

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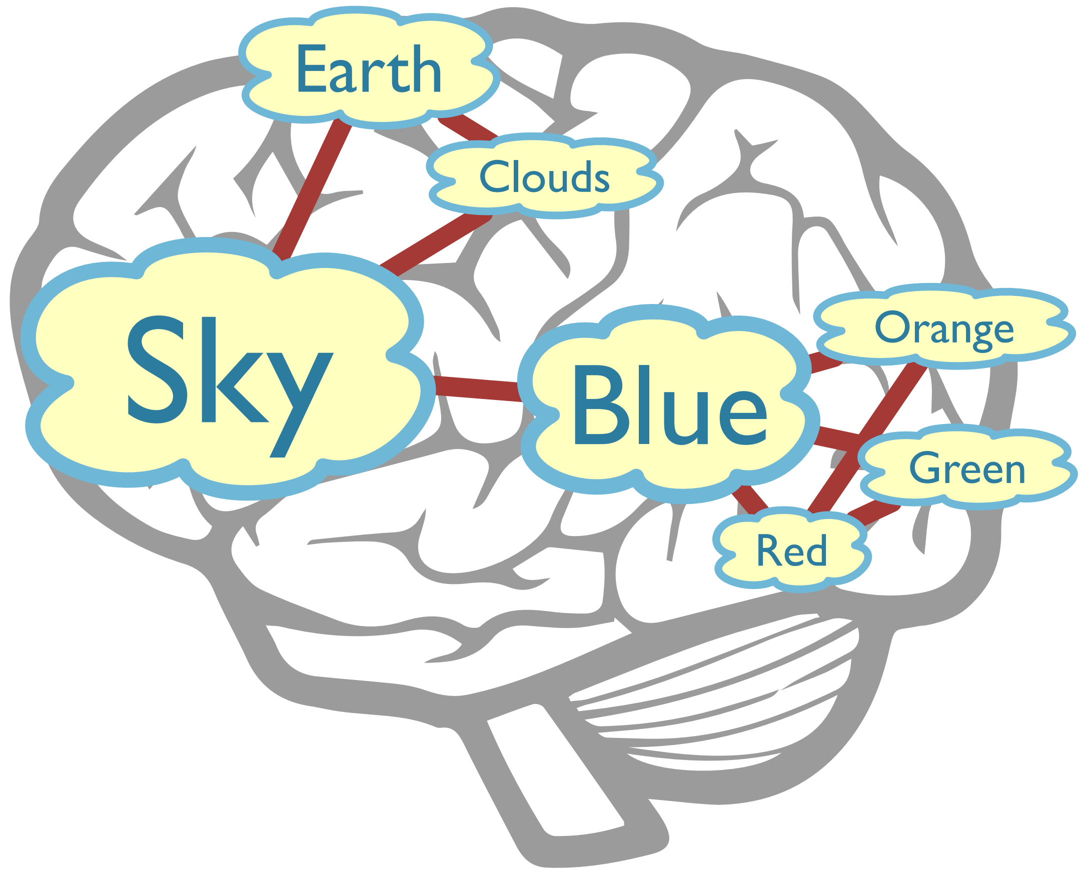

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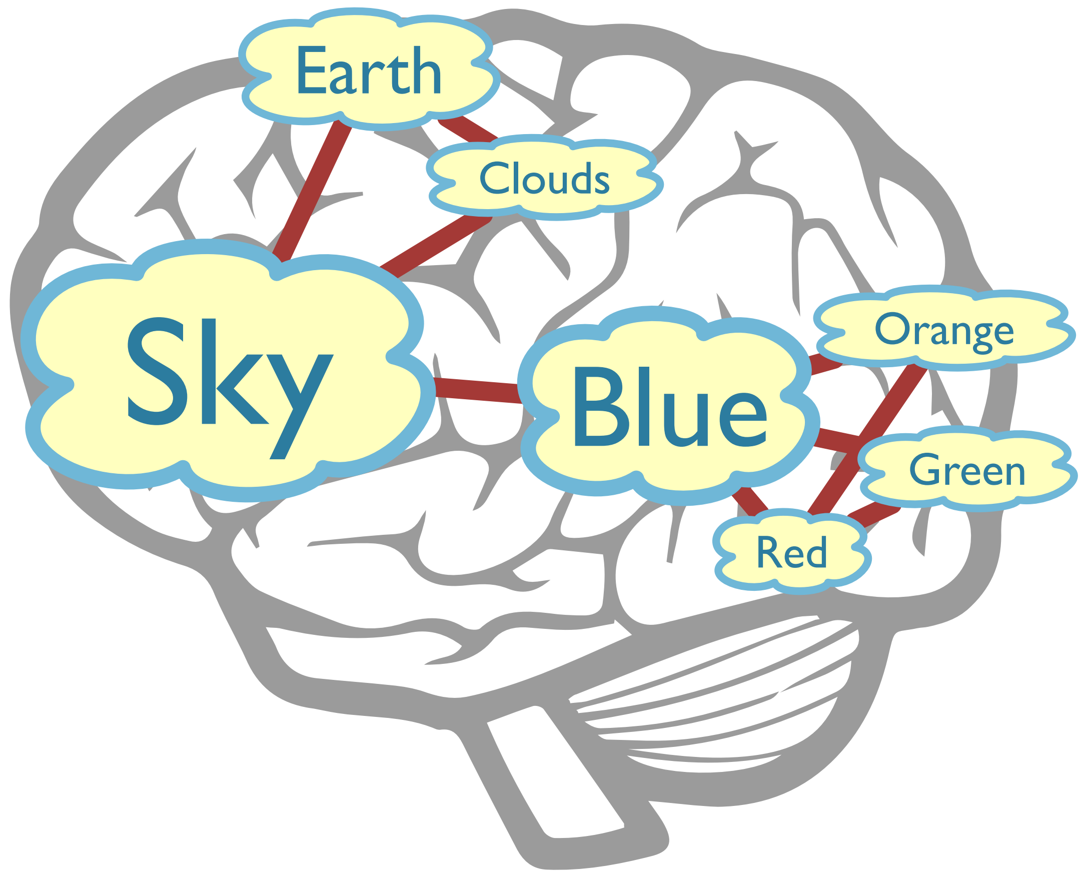

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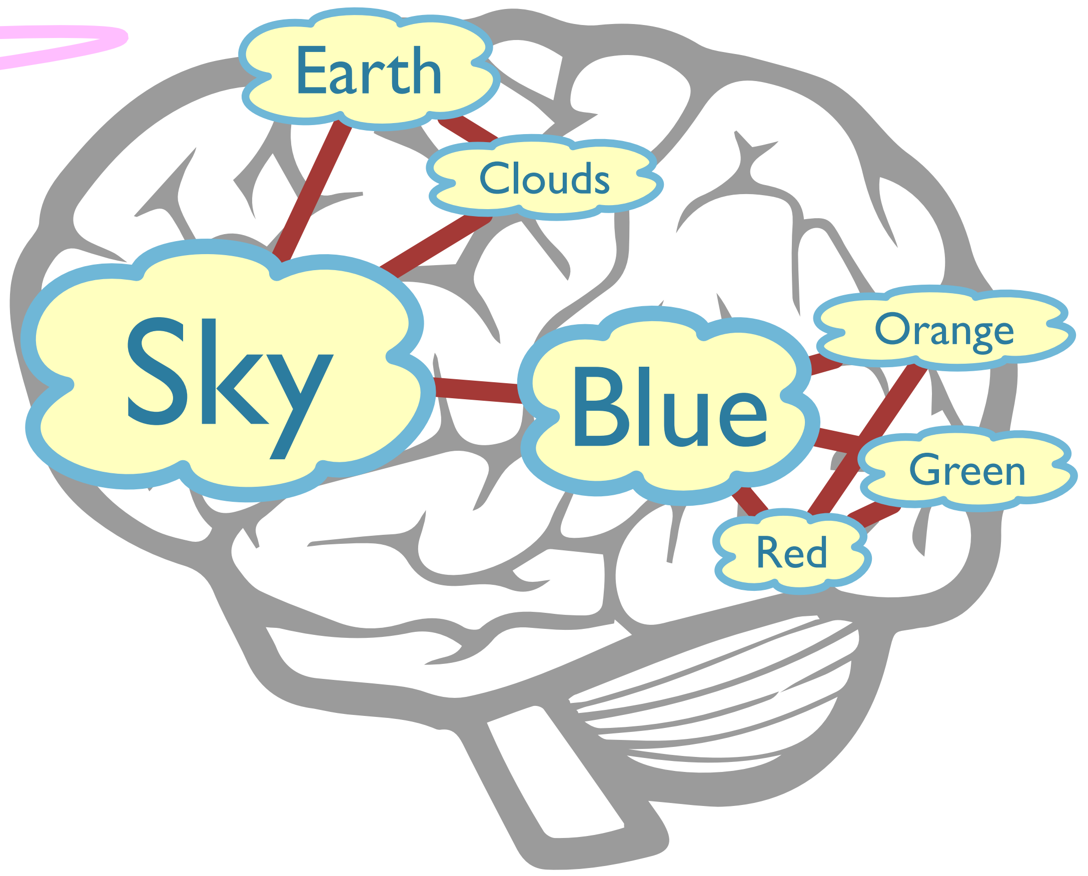


Psychology

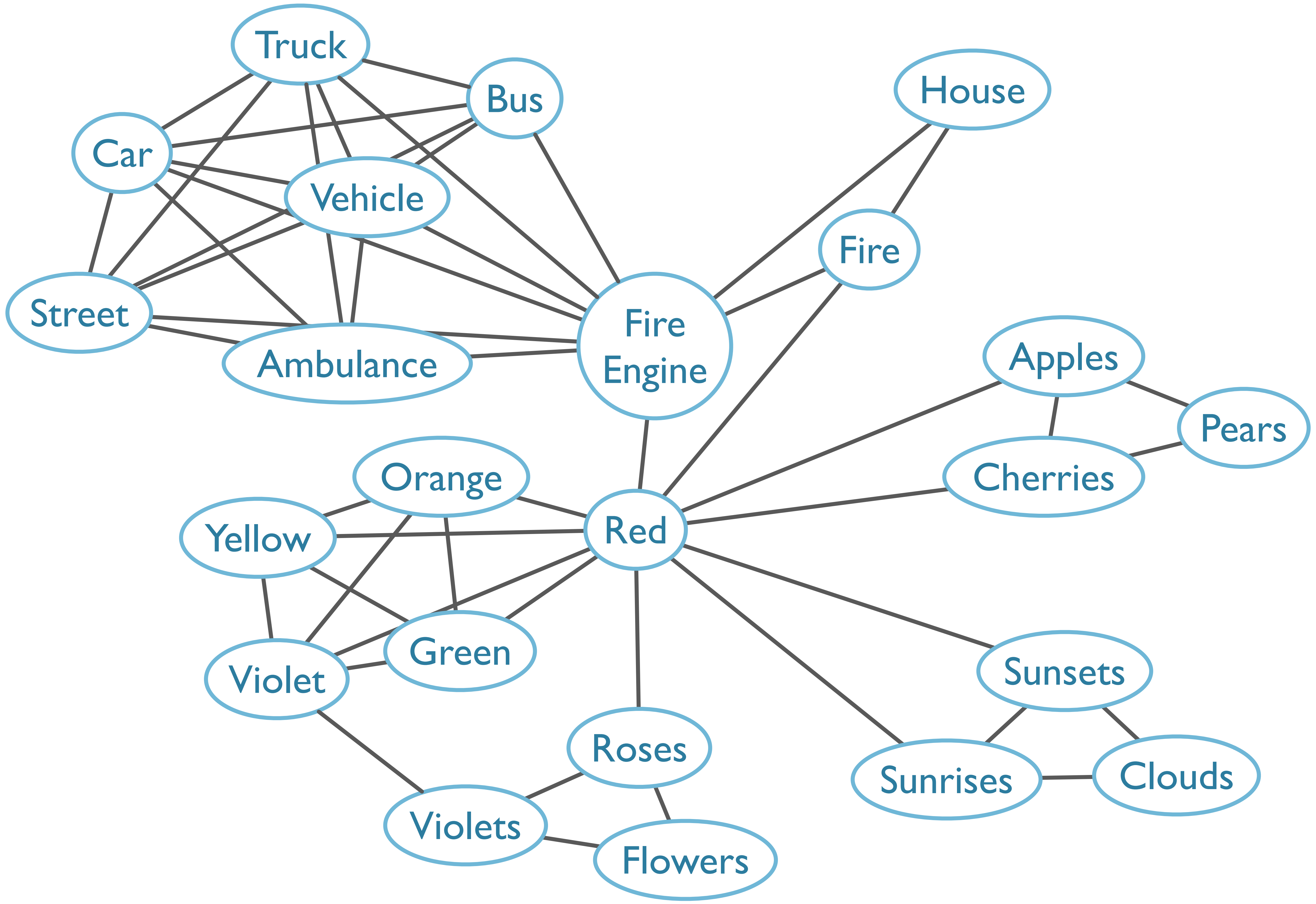
Epistemology

We Will Focus On:

- Concepts that we believe to be true about the world.
- How to connect strings and those concepts.

We ***Won't*** Focus On:

1. Building knowledge bases / semantic networks



Roadmap

- Computational Semantics
  - Overview
  - **Semantics**
  - Representing Meaning
    - First-Order Logic
    - Events
- HW#5
  - Feature grammars in NLTK
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Semantics: an Introduction

Uses for Semantics

- Semantic interpretation required for many tasks
  - Answering questions
  - Following instructions in a software manual
  - Following a recipe
- Requires more than phonology, morphology, syntax
- Must link linguistic elements to world knowledge

Semantics is Complex

- Sentences have many entailments, presuppositions, implicatures
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  - …etc.

Challenges in Semantics

- **Semantic Representation**:
  - What is the appropriate formal language to express propositions in linguistic input?
  - e.g.: predicate calculus: $\exists x \left(dog\left(x\right) \wedge disappear\left(x\right) \right)$

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- **Semantic Representation**:
  - What is the appropriate formal language to express propositions in linguistic input?
  - e.g.: predicate calculus: $\exists x \left(dog(x) \wedge disappear(x) \right)$
- **Entailment**:
  - What are all the conclusions that can be validly drawn from a sentence?
    - *Lincoln was assassinated* $\vDash$ *Lincoln is dead*
    - $\vDash$ "semantically entails": if former is true, the latter must be too

Challenges in Semantics

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  - How do linguistic expressions link to objects/concepts in the real world?
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- **Compositionality**
  - How can we derive the meaning of a unit from its parts?
  - How do syntactic structure and semantic composition relate?
  - ‘rubber duck’ vs. ‘rubber chicken’ vs. ‘rubber-neck’
  - *kick the bucket*

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- Develop methods for **reasoning** about these representations
  - …and performing inference

Tasks in Computational Semantics

- Semantic similarity (words, texts)
- Semantic role labeling
- Semantic analysis / semantic “parsing”
- Recognizing textual entailment (RTE) / natural language inference (NLI)
- Sentiment analysis

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- Knowledge of **the world**:
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- **Reasoning**
  - Given a representation and world, what new conclusions (bits of meaning) can we infer?

Complexity of Computational Semantics

- Effectively AI-complete
  - Needs representation, reasoning, world model, etc.

Representing Meaning

"I have a car"

First-Order Logic: $\exists e, y \left(Having\,(e) \wedge Haver\,(e, Speaker) \wedge HadThing\,(e, y) \wedge Car\,(y) \right)$

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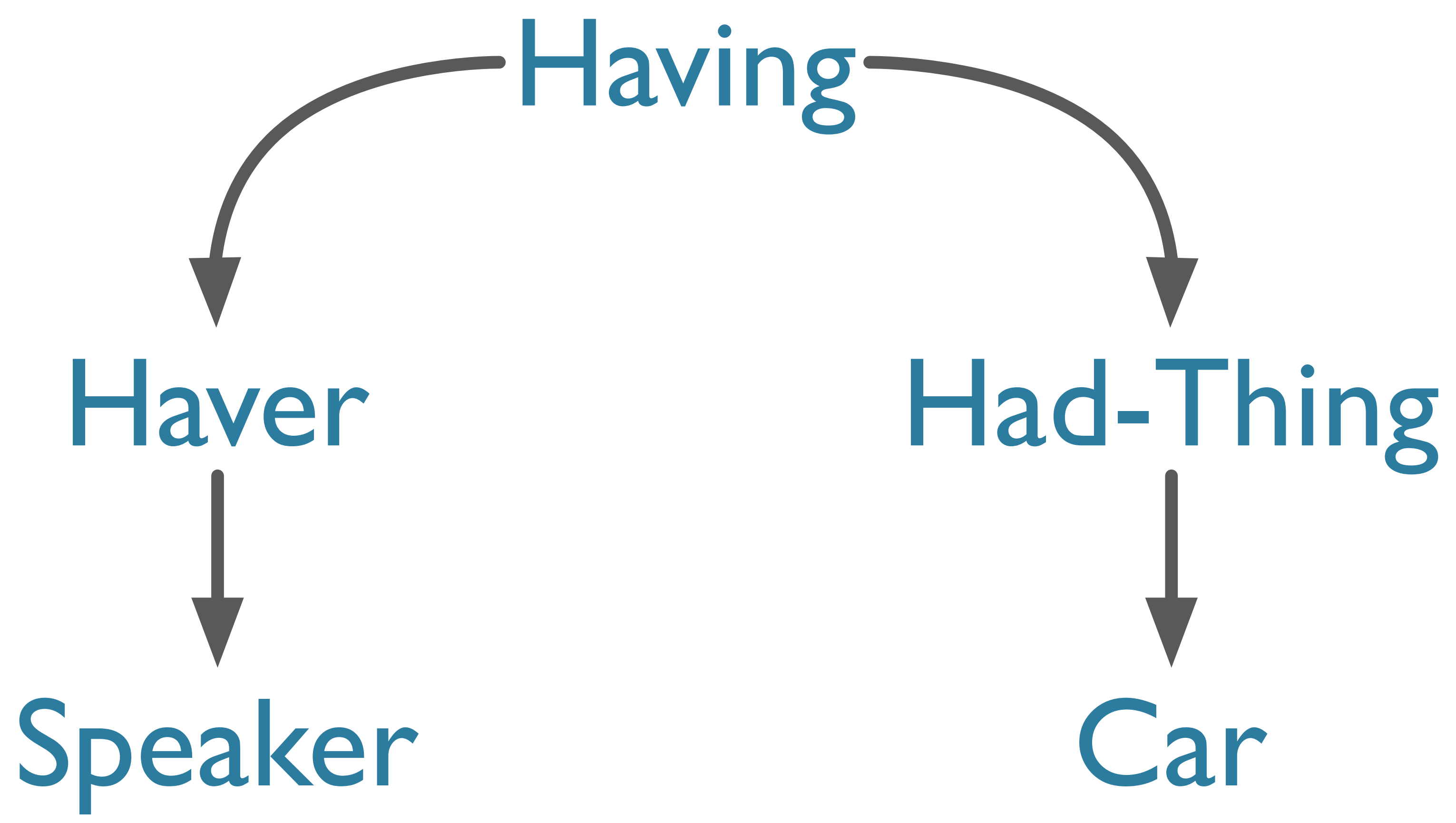

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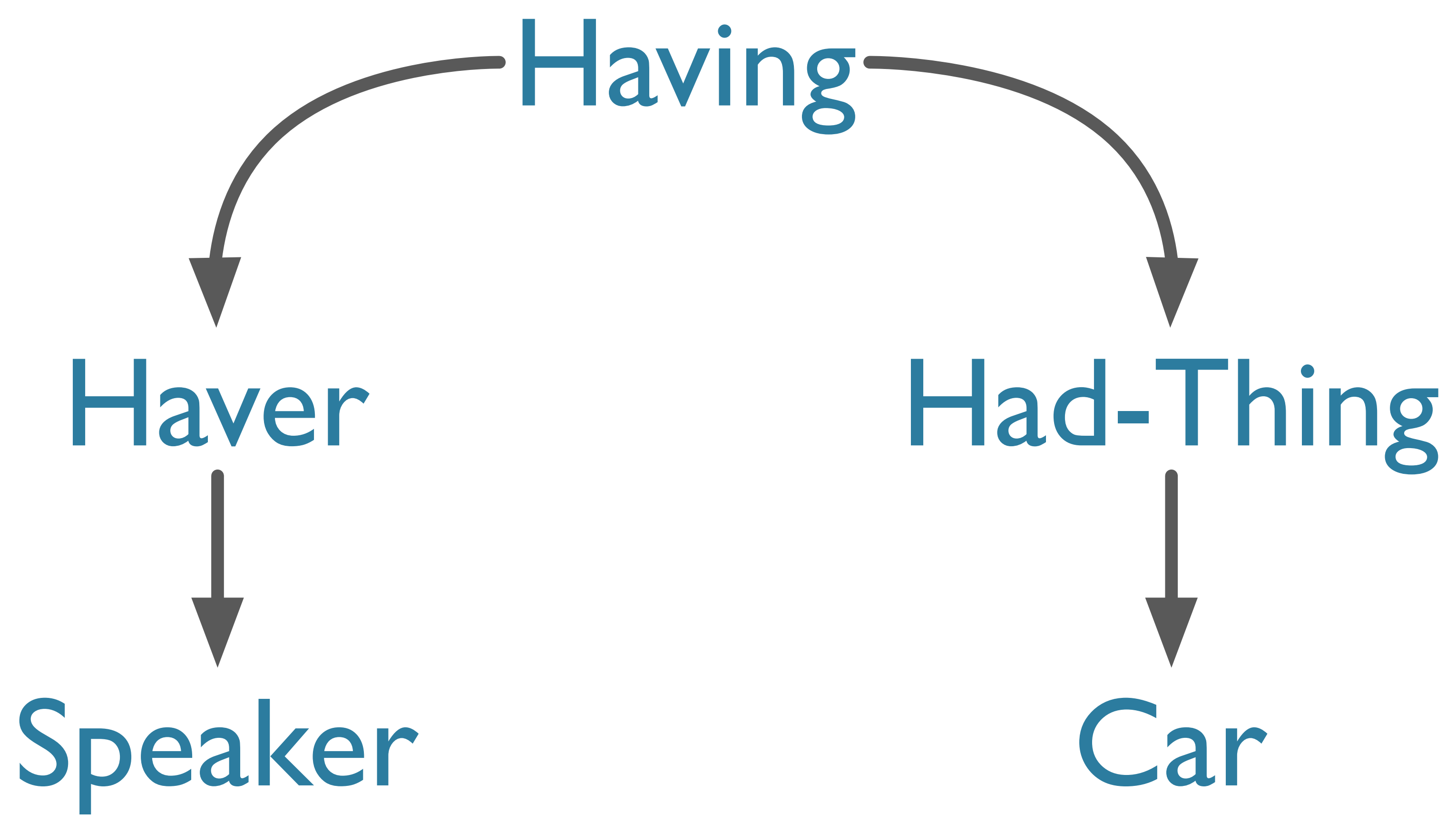

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\end{tikzcd}$$

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Frame-Based:

```
Having
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- Here we focus on **literal** meaning ("what is said")

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- Inference and Variables
  - Way to draw valid conclusions from semantics and KB
- Expressiveness
  - Represent any natural language utterance

Meaning Structure of Language

- Human Languages:
  - Display basic predicate-argument structure
  - Employ variables
  - Employ quantifiers
  - Exhibit a (partially) compositional semantics

Predicate-Argument Structure

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- Some words behave like arguments
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- Subcategorization frames indicate:
  - Number, Syntactic category, order of args, possibly other features of args

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- Supports inference
- Supports generalization through variables

First-Order Logic Terms

- **Constants**: specific objects in world;
  - $A,\ B,\ John$
  - Refer to exactly one object
  - Each object can have multiple constants refer to it
    - $WAStateGovernor$ and $JayInslee$

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- **Variables**:
  - $\boldsymbol{x}, \ \boldsymbol{e}$
  - Refer to any potential object in the world

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- **Predicates**
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  - *'United serves Chicago'*
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- **Predicates**
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- **Logical Connectives**
  - $\{\wedge, \vee, \Rightarrow\}$ = {and, or, implies}
  - Allow for compositionality of meaning* [* many subtleties]
  - *'Frontier serves Seattle and is cheap.'*
    - $Serves(Frontier, Seattle) \wedge Cheap(Frontier)$

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Quantifiers

- ∃: **existential** quantifier: *"there exists"*
- Indefinite NP
  - ≥**one** such object required for truth
- **A non-stop flight** that **serves Pittsburgh**:

$$\exists x\ Flight(x) \wedge Serves(x, Pittsburgh) \wedge Non\text{-}stop(x)$$

Quantifiers

- $\forall$: **universal** quantifier: *"for all"*
  - **All flights include beverages.**

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  - **All flights include beverages.**

    $\forall x \; Flight(x) \Rightarrow Includes(x, \; beverages)$

FOL Syntax Summary

$$
\begin{array}{lcc}
\textbf{\textit{Formula}} & \rightarrow & \textit{AtomicFormula} \\
 & | & \textit{Formula Connective Formula} \\
 & | & \textit{Quantifier Variable, ... Formula} \\
 & | & \neg\ \textit{Formula} \\
 & | & (\textit{Formula}) \\
\textbf{\textit{AtomicFormula}} & \rightarrow & \textit{Predicate}(\textit{Term},\ldots) \\
\textbf{\textit{Term}} & \rightarrow & \textit{Function}(\textit{Term},\ldots) \\
 & | & \textit{Constant} \\
 & | & \textit{Variable}
\end{array}
$$

$$
\begin{array}{lcc}
\textbf{\textit{Connective}} & \rightarrow & \wedge \mid \vee \mid \Rightarrow \\
\textbf{\textit{Quantifier}} & \rightarrow & \forall \mid \exists \\
\textbf{\textit{Constant}} & \rightarrow & \textit{VegetarianFood} \mid \textit{Maharani} \mid \ldots \\
\textbf{\textit{Variable}} & \rightarrow & x \mid y \mid \ldots \\
\textbf{\textit{Predicate}} & \rightarrow & \textit{Serves} \mid \textit{Near} \mid \ldots \\
\textbf{\textit{Function}} & \rightarrow & \textit{LocationOf} \mid \textit{CuisineOf} \mid \ldots
\end{array}
$$

J&M p. 556 (3rd ed. 16.3)

Compositionality

- The meaning of a complex expression is a function of the meaning of its parts, and the rules for their combination.

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- Formal languages **are** compositional.
- Natural language meaning is ***largely compositional,*** though not fully.

Compositionality

- …how can we derive:
  - $loves(John,\ Mary)$

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- from:
  - $John$
  - $loves(x,\ y)$
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- Lambda expressions!

Lambda Expressions

- Lambda (λ) notation (Church, 1940)
  - Just like lambda in Python, Scheme, etc
  - Allows abstraction over FOL formulae
  - Supports compositionality

- Form: (λ) + variable + FOL expression
  - $\lambda x.P(x)$ "Function taking x to $P(x)$"
  - $\lambda x.P(x)(A) = P(A)$ [called beta-reduction]

λ-Reduction

- λ-reduction: Apply λ-expression to logical term
  - Binds formal parameter to term

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$$\lambda x.P(x)$$
$$\lambda x.P(x)(A)$$

λ-Reduction

- λ-reduction: Apply λ-expression to logical term
  - Binds formal parameter to term

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- Equivalent to function application

Nested λ-Reduction

- Lambda expression as body of another

$$\lambda x.\lambda y.Near(x,\ y)$$

Nested λ-Reduction

- Lambda expression as body of another

$$\lambda x.\lambda y.Near(x,\ y)$$
$$\lambda x.\lambda y.Near(x,\ y)(Midway)$$

Nested λ-Reduction

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- Lambda expression as body of another

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$$\lambda x.\lambda y.Near(x,\ y)$$
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Nested λ-Reduction

- Lambda expression as body of another

$$\lambda x.\lambda y.Near(x,\ y)$$
$$\lambda x.\lambda y.Near(x,\ y)(Midway)$$
$$\lambda y.Near(Midway,\ y)$$
$$\lambda y.Near(Midway,\ y)(Chicago)$$
$$Near(Midway,\ Chicago)$$

Nested λ-Reduction

- If it helps, think of λs as binding sites:

Nested λ-Reduction

- If it helps, think of λs as binding sites:

Chicago

$$\lambda y.Near(x,\ y)$$

Midway

Nested λ-Reduction

- If it helps, think of λs as binding sites:

Chicago

$$\boldsymbol{Near}(\boldsymbol{x},\ \boldsymbol{y})$$

Midway

Lambda Expressions

- ***Currying***
  - Converting multi-argument predicates to sequence of single argument predicates
  - Why?
    - Incrementally accumulates multiple arguments spread over different parts of parse tree

Lambda Expressions

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  - Converting multi-argument predicates to sequence of single argument predicates
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- …or *Schönkfinkelization*

Logical Formulae

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- Atomic formulae are:
  - If properties, sets of domain elements
  - If relations, sets of tuples of elements
- Formulae based on logical operators:

P	Q	$\neg P$	$P \wedge Q$	$P \vee Q$	$P \Rightarrow Q$
F	F	T	F	F	T
F	T	T	F	T	T
T	F	F	F	T	F
T	T	F	T	T	T

Logical Formulae: Finer Points

- $\vee$ is not exclusive:
  - *Your choice is pepperoni or sausage*
  - …use $\veebar$ or $\oplus$

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- $\Rightarrow$ is the logical form
  - Does not mean the same as natural language "if", just that if LHS=T, then RHS=T

Inference

1. α

Inference

1. α
2. $\alpha \Rightarrow \beta$

Inference

1. α
2. $\alpha \Rightarrow \beta$
3. $\therefore \beta$

Inference

1. $VegetarianRestaurant(Leaf)$

Inference

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2. $\forall x \; VegetarianRestaurant(x) \Rightarrow Serves(x, VegetarianFood)$

Inference

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2. $\forall x \; VegetarianRestaurant(x) \Rightarrow Serves(x, VegetarianFood)$

3. $\therefore Serves(Leaf, \; VegetarianFood)$

Inference

- Standard AI-type logical inference procedures
  - Modus Ponens
  - Forward-chaining, Backward Chaining
  - Abduction
  - Resolution
  - Etc…

Inference

- Standard AI-type logical inference procedures
  - Modus Ponens
  - Forward-chaining, Backward Chaining
  - Abduction
  - Resolution
  - Etc…
- We'll assume we have a theorem prover.

Roadmap

- Computational Semantics
  - Introduction
  - Semantics
  - Representing Meaning
    - First-Order Logic
    - **Events**
- HW#5
  - Feature grammars in NLTK
  - Practice with animacy

Events

Representing Events

- Initially, single predicate with some arguments
  - $Serves(United,\ Houston)$
  - Assume # of args = # of elements in subcategorization frame

Representing Events

- Initially, single predicate with some arguments
  - $Serves(United, Houston)$
  - Assume # of args = # of elements in subcategorization frame
- Example:
  - *The flight arrived*
  - *The flight arrived in Seattle*
  - *The flight arrived in Seattle on Saturday.*
  - *The flight arrived on Saturday.*
  - *The flight arrived in Seattle from SFO.*
  - *The flight arrived in Seattle from SFO on Saturday.*

Representing Events

- ***Arity***:
  - How do we deal with different numbers of arguments?

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Representing Events

- ***Arity***:
  - How do we deal with different numbers of arguments?

- *The flight arrived in Seattle from SFO on Saturday.*
  - Davidsonian (Davidson 1967):
    - $\exists \boldsymbol{e}\ Arrival(\boldsymbol{e}, Flight, Seattle, SFO) \wedge Time(\boldsymbol{e}, Saturday)$
  - Neo-Davidsonian (Parsons 1990):
    - $\exists \boldsymbol{e}\ Arrival(\boldsymbol{e}) \wedge Arrived(\boldsymbol{e}, Flight) \wedge Destination(\boldsymbol{e}, Seattle) \wedge Origin(\boldsymbol{e}, SFO) \wedge Time(\boldsymbol{e}, Saturday)$

Neo-Davidsonian Events

- Neo-Davidsonian representation:
  - Distill event to single argument for event itself
  - Everything else is additional predication

Neo-Davidsonian Events

- Neo-Davidsonian representation:
  - Distill event to single argument for event itself
  - Everything else is additional predication
- Pros
  - No fixed argument structure
  - Dynamically add predicates as necessary
  - No unused roles
  - Logical connections can be derived

Meaning Representation for Computational Semantics

- Requirements
  - Verifiability
  - Unambiguous representation
  - Canonical Form
  - Inference
  - Variables
  - Expressiveness
- Solution:
  - First-Order Logic
    - Structure
    - Semantics
    - Event Representation

Summary

- FOL can be used as a meaning representation language for natural language
- Principle of compositionality:
  - The meaning of a complex expression is a function of the meaning of its parts
- λ-expressions can be used to compute meaning representations from syntactic trees based on the principle of compositionality
- In next classes, we will look at syntax-driven approach to semantic analysis in more detail

HW #5: Feature-based Parsing

Agreement with Heads and Features

- $\beta \rightarrow \beta_1 \ldots \beta_n$
  $\{set\ of\ constraints\}$ $\quad \langle \beta_i\ feature\ path \rangle = Atomic\ value \mid \langle \beta_j\ feature\ path \rangle$

$$\boldsymbol{S} \rightarrow \boldsymbol{NP}\ \boldsymbol{VP}$$
$$\langle \boldsymbol{NP}\ \textsc{Agreement} \rangle = \langle \boldsymbol{VP}\ \textsc{Agreement} \rangle$$

$$\boldsymbol{S} \rightarrow \boldsymbol{Aux}\ \boldsymbol{NP}\ \boldsymbol{VP}$$
$$\langle \boldsymbol{Aux}\ \textsc{Agreement} \rangle = \langle \boldsymbol{NP}\ \textsc{Agreement} \rangle$$

$$\boldsymbol{NP} \rightarrow \boldsymbol{Det}\ \boldsymbol{Nominal}$$
$$\langle \boldsymbol{Det}\ \textsc{Agreement} \rangle = \langle \boldsymbol{Nominal}\ \textsc{Agreement} \rangle$$
$$\langle \boldsymbol{NP}\ \textsc{Agreement} \rangle = \langle \boldsymbol{Nominal}\ \textsc{Agreement} \rangle$$

$$\boldsymbol{Aux} \rightarrow does$$
$$\langle \boldsymbol{Aux}\ \textsc{Agreement Number} \rangle = \boldsymbol{sg}$$
$$\langle \boldsymbol{Aux}\ \textsc{Agreement Person} \rangle = \boldsymbol{3rd}$$

$$\boldsymbol{Det} \rightarrow this$$
$$\langle \boldsymbol{Det}\ \textsc{Agreement Number} \rangle = \boldsymbol{sg}$$

$$\boldsymbol{Det} \rightarrow these$$
$$\langle \boldsymbol{Det}\ \textsc{Agreement Number} \rangle = \boldsymbol{pl}$$

$$\boldsymbol{Verb} \rightarrow serve$$
$$\langle \boldsymbol{Verb}\ \textsc{Agreement Number} \rangle = \boldsymbol{pl}$$

$$\boldsymbol{Noun} \rightarrow flight$$
$$\langle \boldsymbol{Noun}\ \textsc{Agreement Number} \rangle = \boldsymbol{sg}$$

Goals

- Explore the role of features in implementing linguistic constraints.
- Identify some of the challenges in building compact constraints to define a precise grammar.
- Apply feature-based grammars to perform grammar checking.

Tasks

- Build a Feature-Based Grammar
  - We will focus on the building of the grammar itself — you may use NLTK's `nltk.parse.FeatureEarleyChartParser` or similar.
- Use the grammar to parse a small set of sentences we provide.

Simple Feature Grammars

- `S -> NP[NUM=?n] VP[NUM=?n]`
- `NP[NUM=?n] -> N[NUM=?n]`
- `NP[NUM=?n] -> PropN[NUM=?n]`
- `NP[NUM=?n] -> Det[NUM=?n] N[NUM=?n]`
- `Det[NUM=sg] -> 'this' | 'every'`
- `Det[NUM=pl] -> 'these' | 'all'`
- `N[NUM=sg] -> 'dog' | 'girl' | 'car' | 'child'`
- `N[NUM=pl] -> 'dogs' | 'girls' | 'cars' | 'children'`

NLTK Feature Syntax

- Basics
  - `X[FEAT₁=VALUE₁, FEAT₂=VALUE₂]`

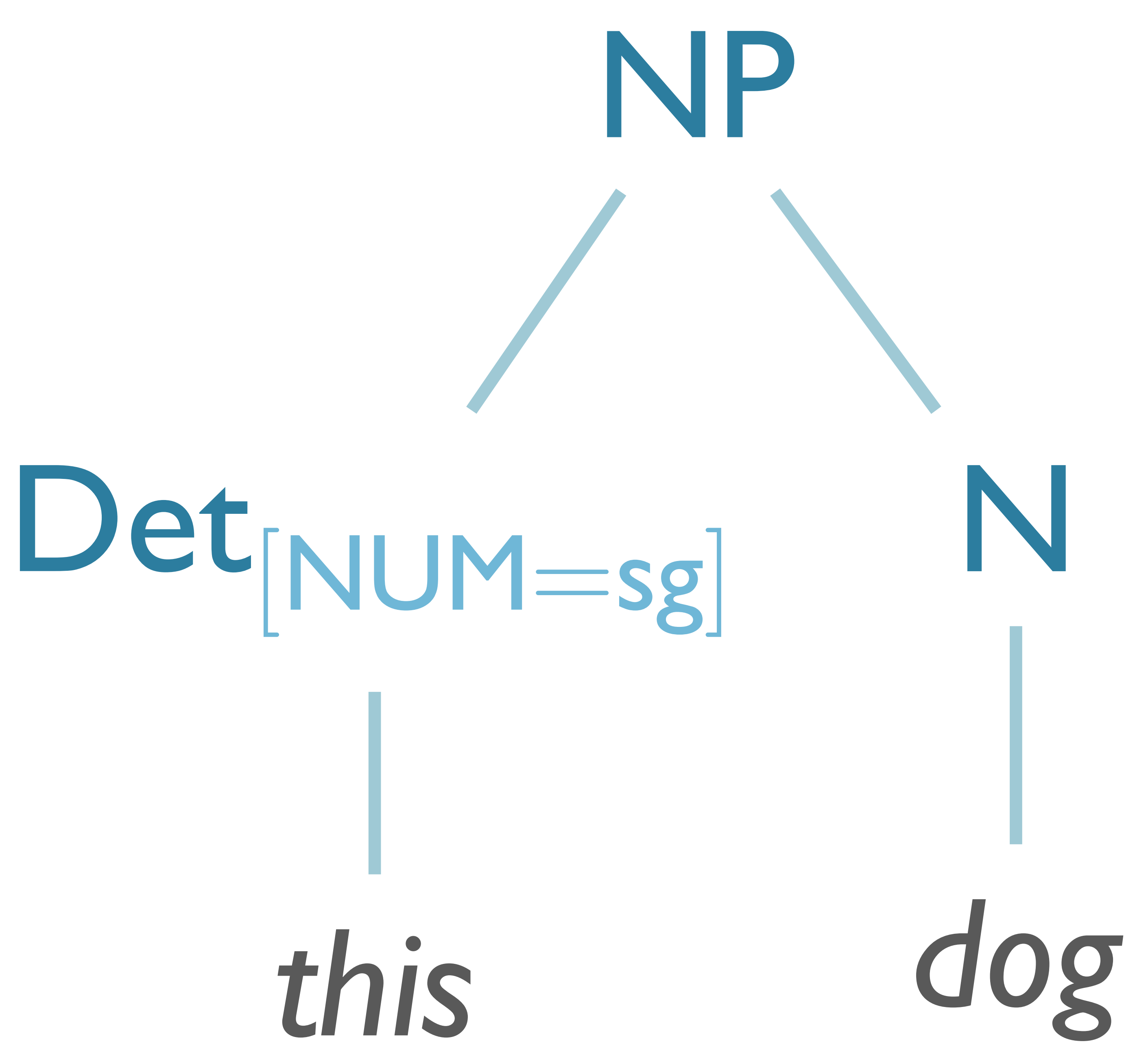
- Variables
  - `X[FEAT=?f]`

- Binary Values
  - `X[-FEAT], Y[+FEAT]`

HW #5: NLTK Feature Syntax

```
NP[NUM=?n] -> Det[NUM=?n] N[NUM=?n]
```

```
Det[NUM=sg] -> 'this' | 'that'
Det[NUM=pl] -> 'these' | 'those'
N[NUM=sg] -> 'dog' | 'cat'
```



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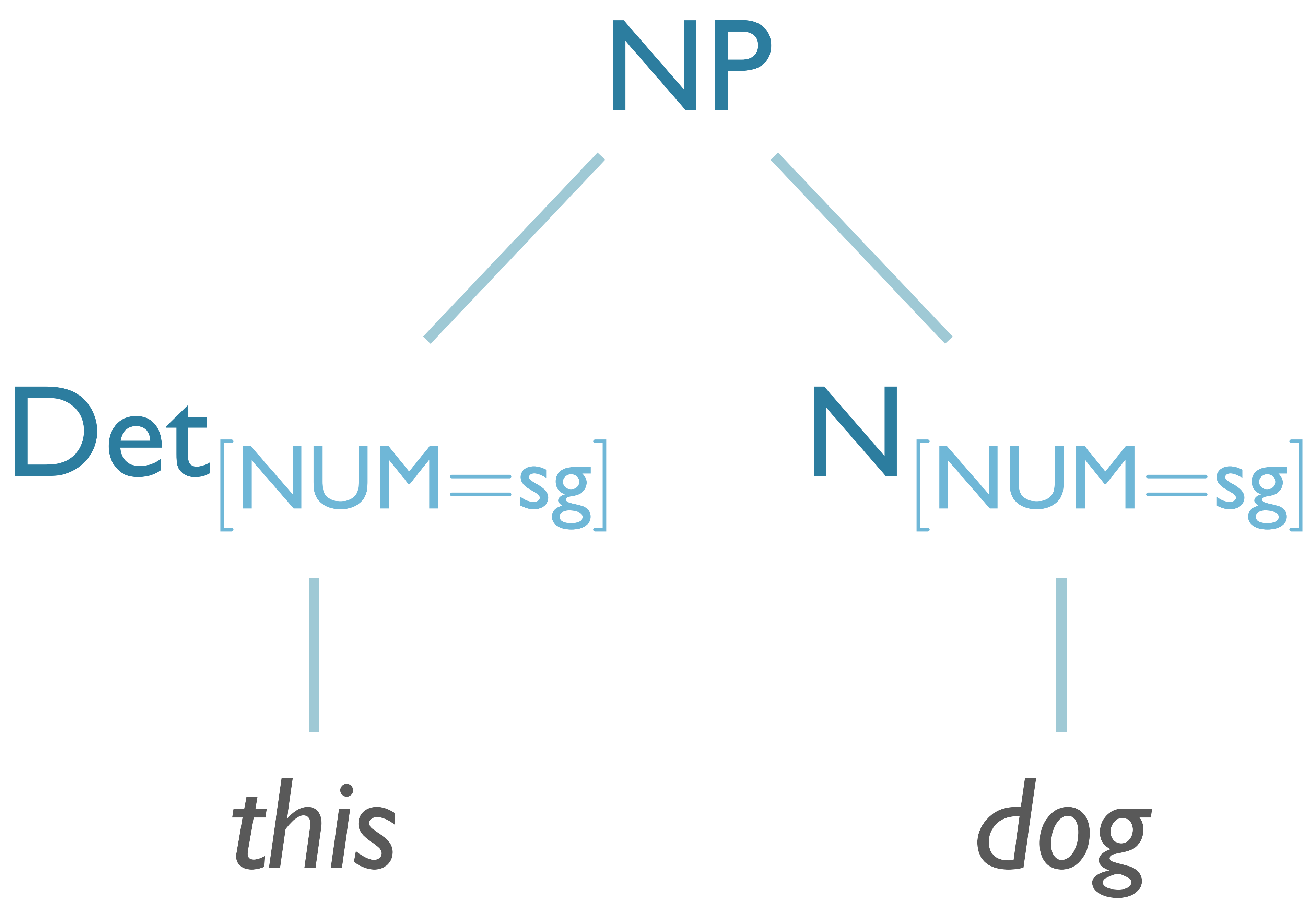

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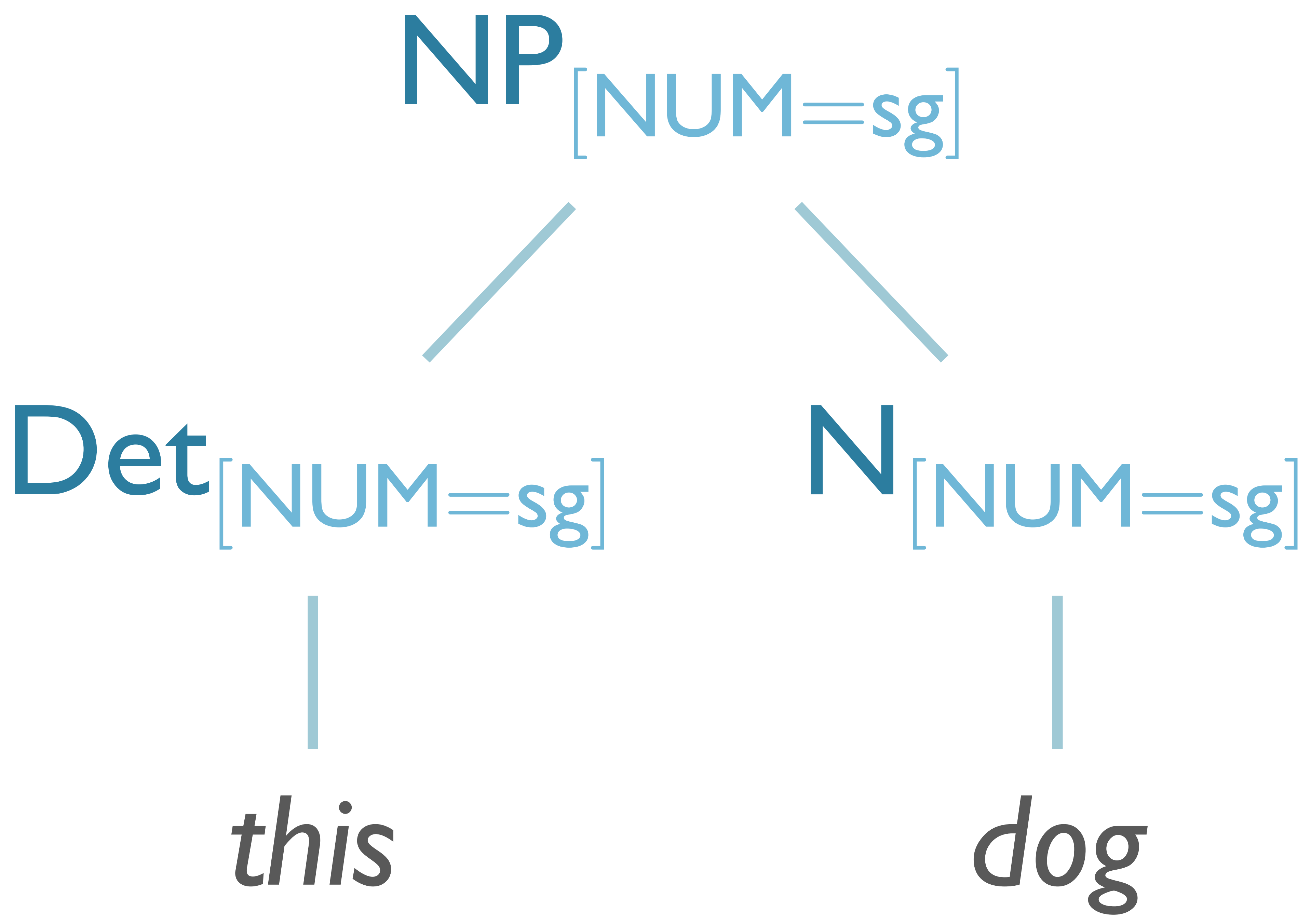

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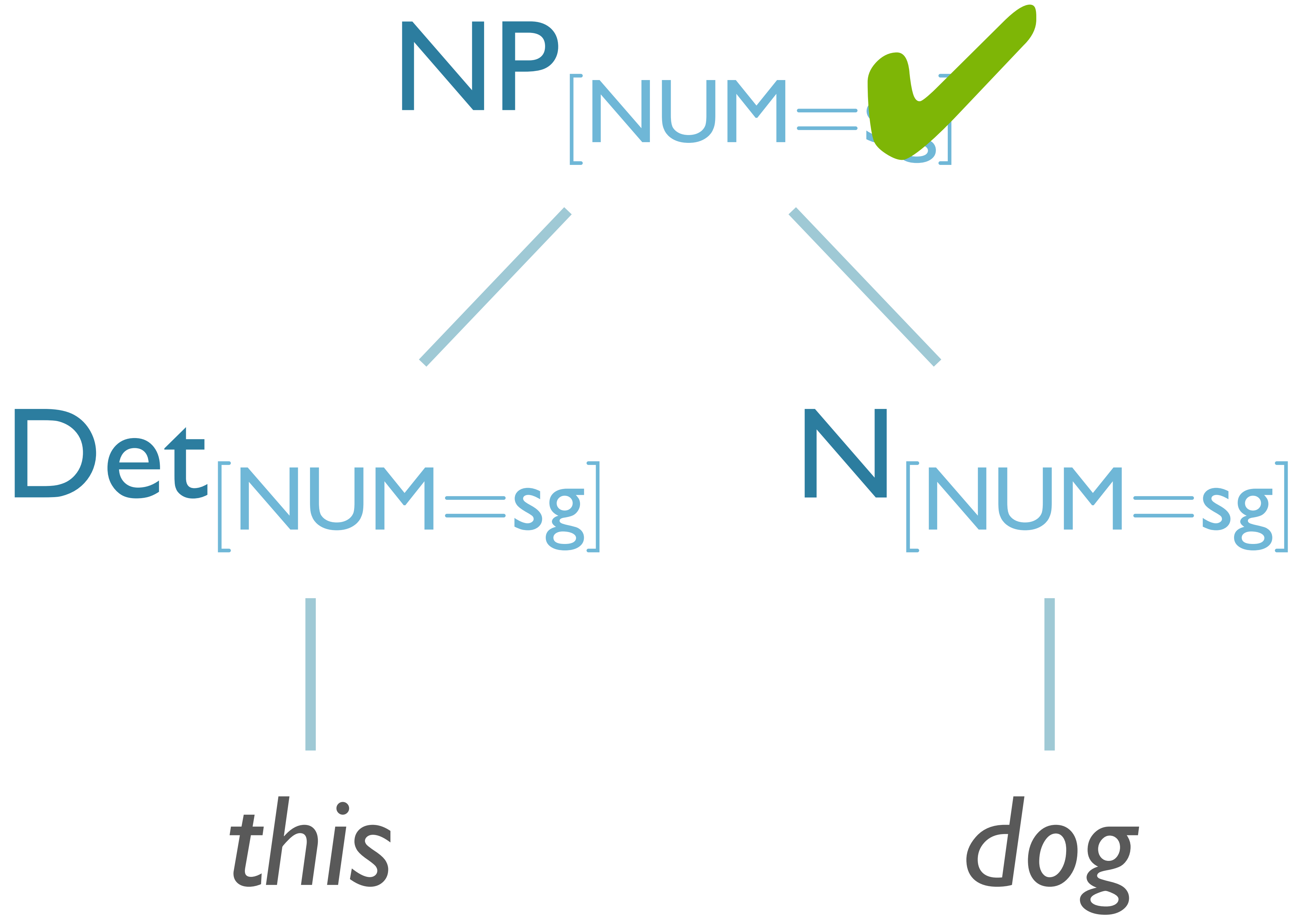

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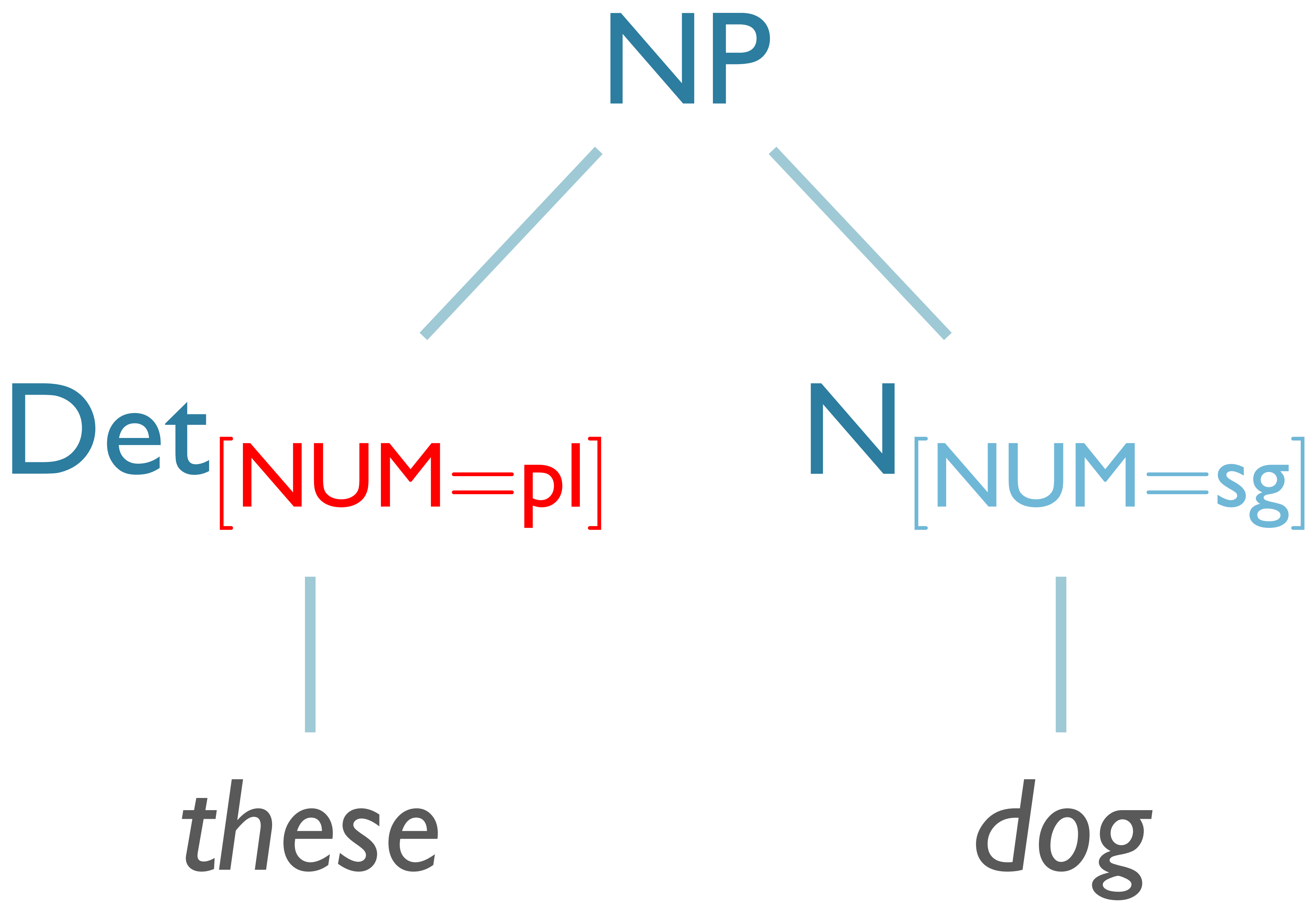

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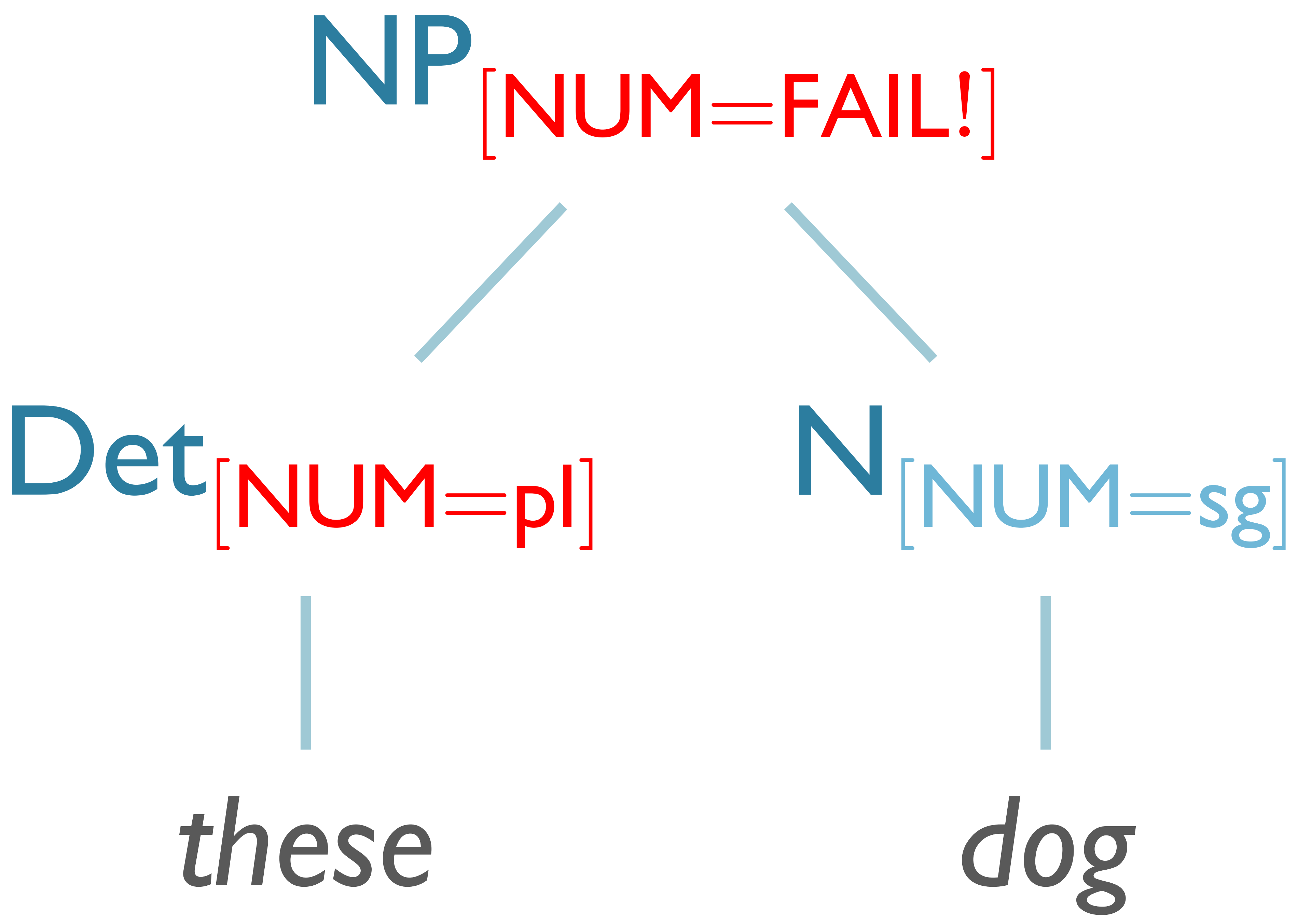

HW #5: Grammars

- It’s possible to get the grammar to work with completely arbitrary rules, BUT…
- We would prefer them to be linguistically motivated!
  - instead of `[IT_OK=yes]` or `[PRON_AGR=it]`
  - `[GENDER=neut, PERSON=3rd, NUMBER=sg]`

Parsing with Features

```
>>> cp = load_parser('grammars/book_grammars/
feat0.fcfg')
>>> for tree in cp.parse(tokens):
...     print(tree)

(S[] (NP[NUM='sg']
  (PropN[NUM='sg'] Kim))
    (VP[NUM='sg', TENSE='pres']
      (TV[NUM='sg', TENSE='pres'] likes)
      (NP[NUM='pl'] (N[NUM='pl'] children))))
```

Feature Applications

- Subcategorization
  - Verb-Argument constraints
    - Number, type, characteristics of args
      - e.g. is the subject *animate*?
      - Also adjectives, nouns
- Long-distance dependencies
  - e.g. filler–gap relations in wh-questions

Morphosyntactic Features

- Grammtical feature that influences morphological or syntactic behavior
  - English:
    - Number:
      - Dog, dogs
    - Person:
      - am; are; is
    - Case (more prominent in other languages):
      - I / me; he / him; etc.

Semantic Features

- Grammatical features that influence semantic (meaning) behavior of associated units
- E.g.:
  - *?The rocks slept.*
- Many proposed:
  - `Animacy: +/-`
  - `Gender: masculine, feminine, neuter`
  - `Human: +/-`
  - `Adult: +/-`
  - `Liquid: +/-`

Aspect (J&M 17.4.2)

- *The climber [hiked] [for six hours].*

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- *The climber [hiked] [for six hours].*
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Aspect (J&M 17.4.2)

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- *The climber [hiked] [on Saturday].*
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- **The climber [reached the summit] [for six hours].*

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- *The climber [hiked] [on Saturday].*
- *The climber [reached the summit] [on Saturday].*
- **The climber [reached the summit] [for six hours].*

- Contrast:
  - *Achievement* (in an instant) vs *activity* (for a time)

Feature Grammar Practice: Animacy

Feature Grammar Practice

- **Initial Grammar:**

```
S -> NP VP
VP[subcat=ditrans] -> V NP NP
NP -> NNP
NP -> Det N
NNP[animacy=True] -> 'Alex' | 'Ahmed'
V[subcat=ditrans] -> 'gifted'
Det -> 'a' | 'the'
N[animacy=False] -> 'book' | 'rock'
```

Feature Grammar Practice

Feature Grammar Practice

Feature Grammar Practice

Feature Grammar Practice

Practice Task

- Modify the initial grammar to incorporate animacy in such a way that you get the right results:
  - Alex gifted Ahmed a book
  - * Alex gifted the rock a book