

# 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

- Note on underflow: 
$$\log \prod_i P_i = \sum_i \log P_i$$

# Ambiguity of the Week



Adam Macqueen  
@adam\_macqueen



Personally feel not enough hospitals are named after sandwiches.



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# 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

- User: *What do I have on Thursday?*

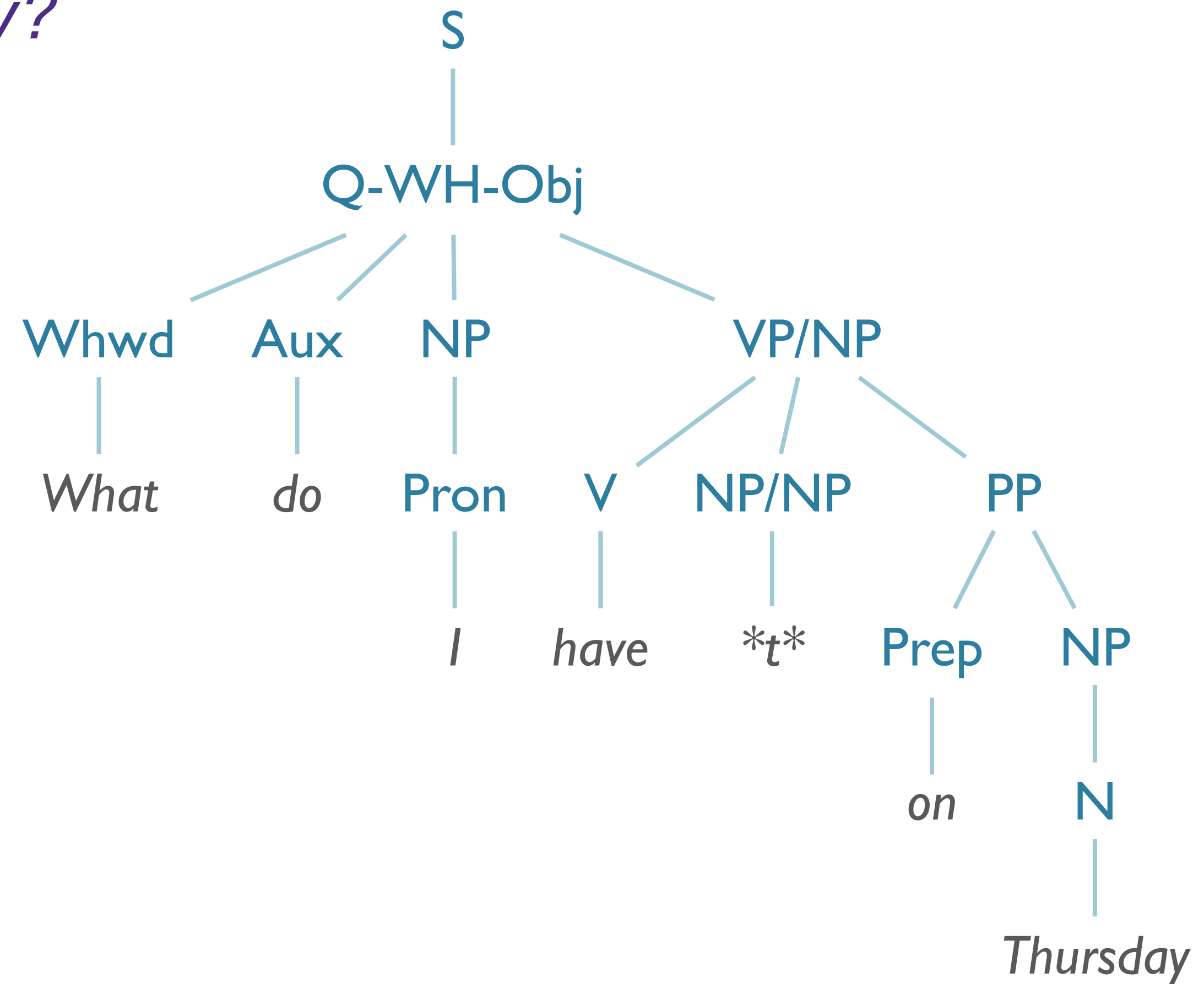


# Dialogue System

- User: *What do I have on Thursday?*
- Parser:
  - Yes! It's grammatical!

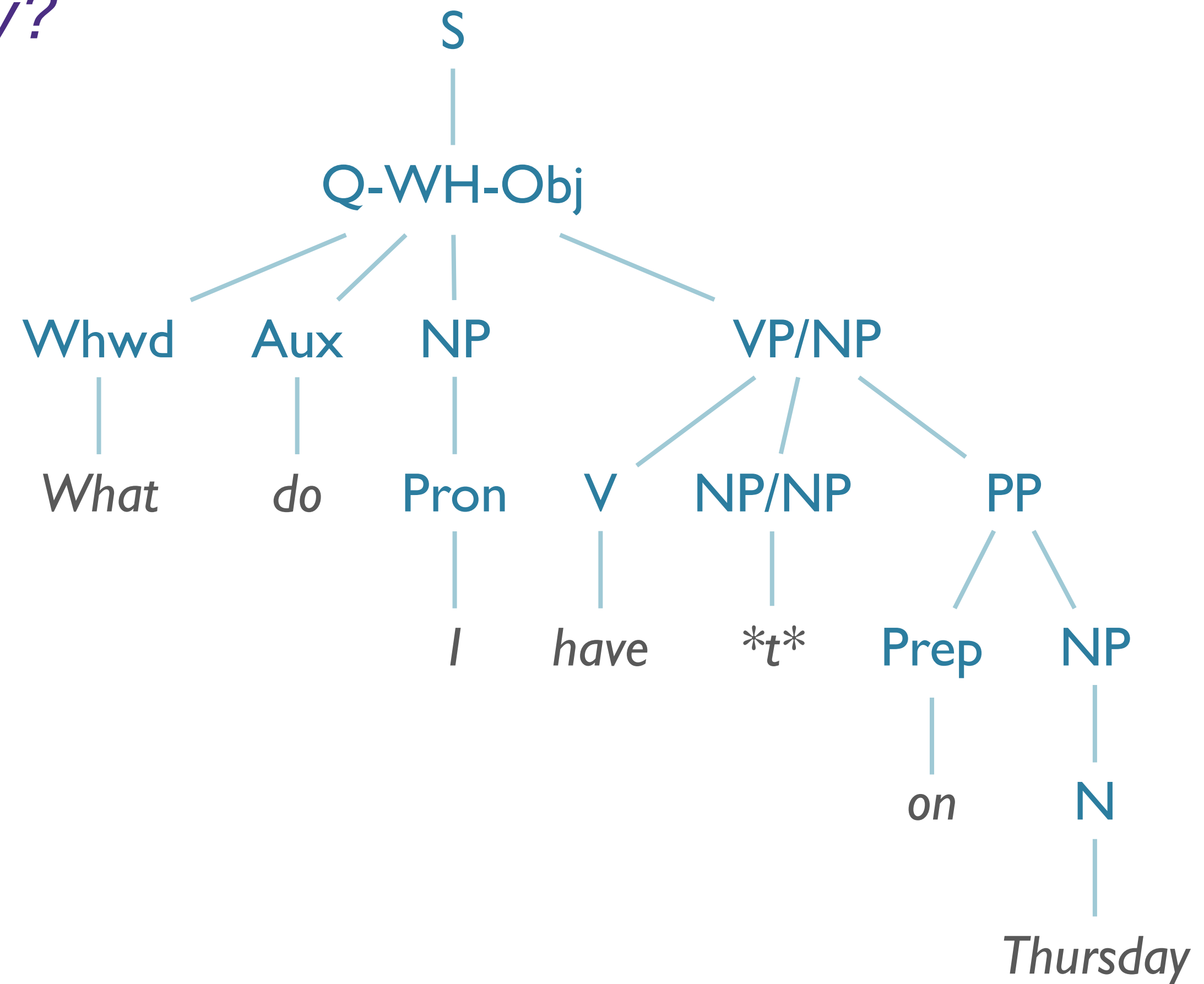
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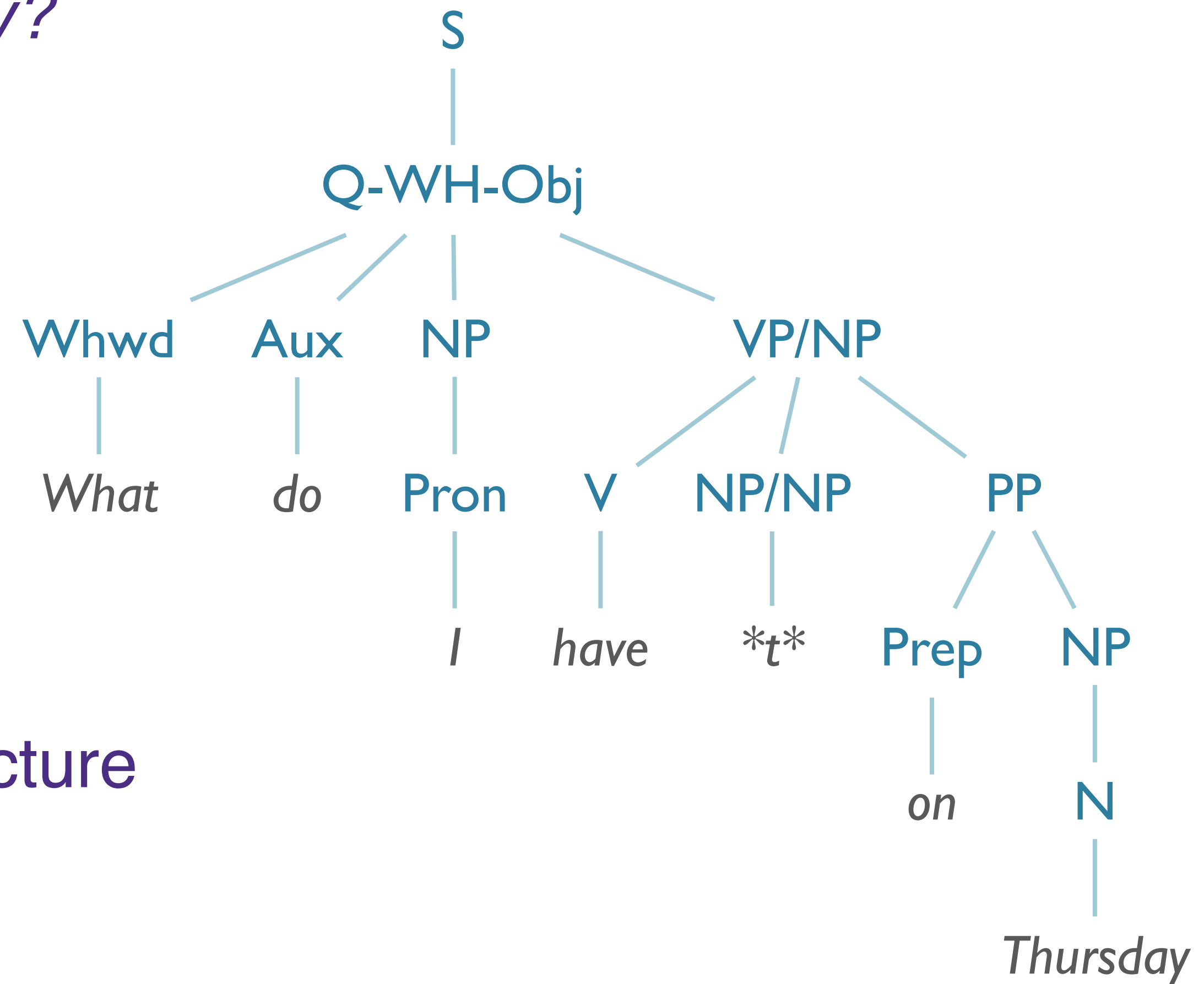
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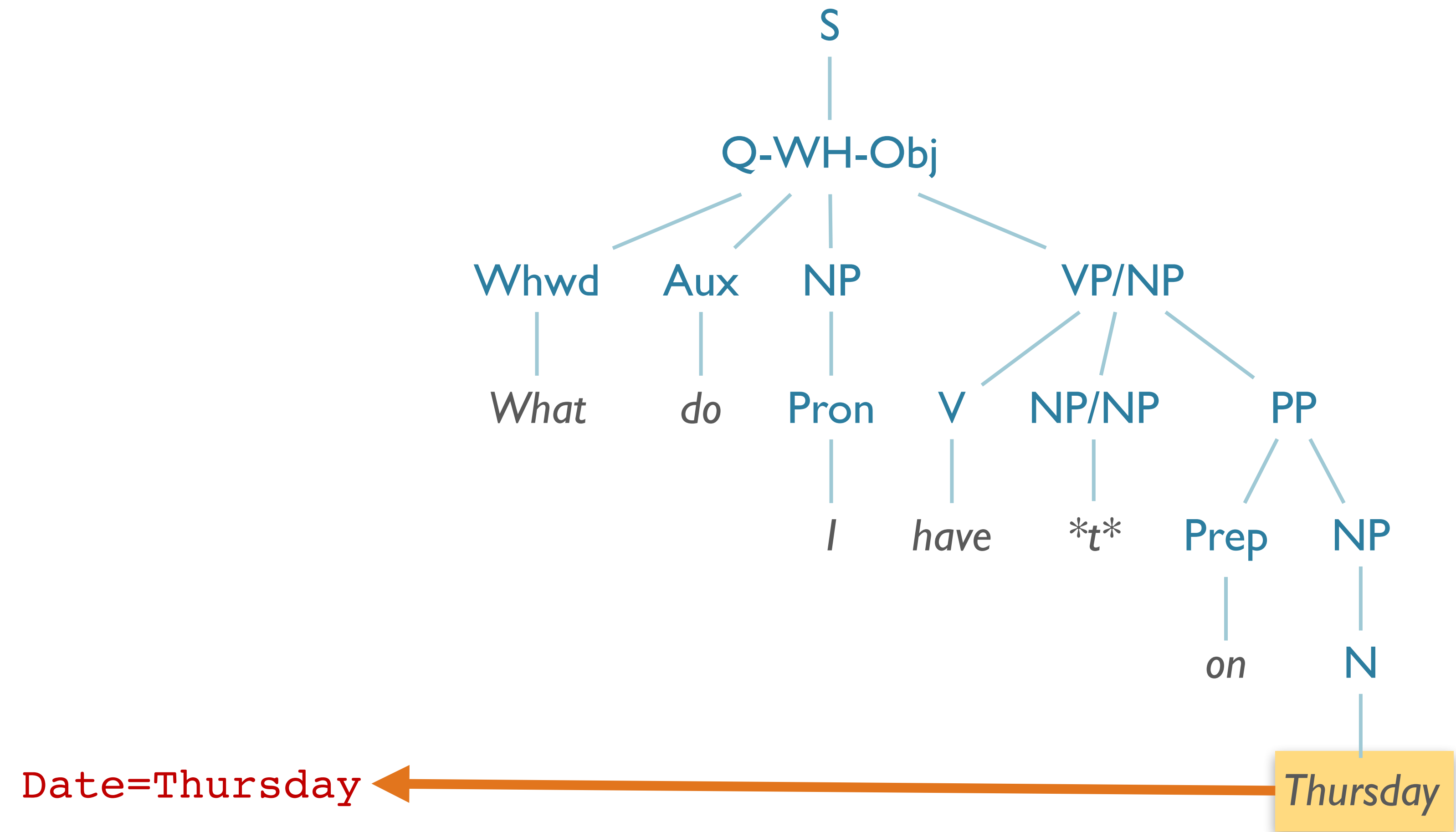


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- Need to associate meaning w/structure

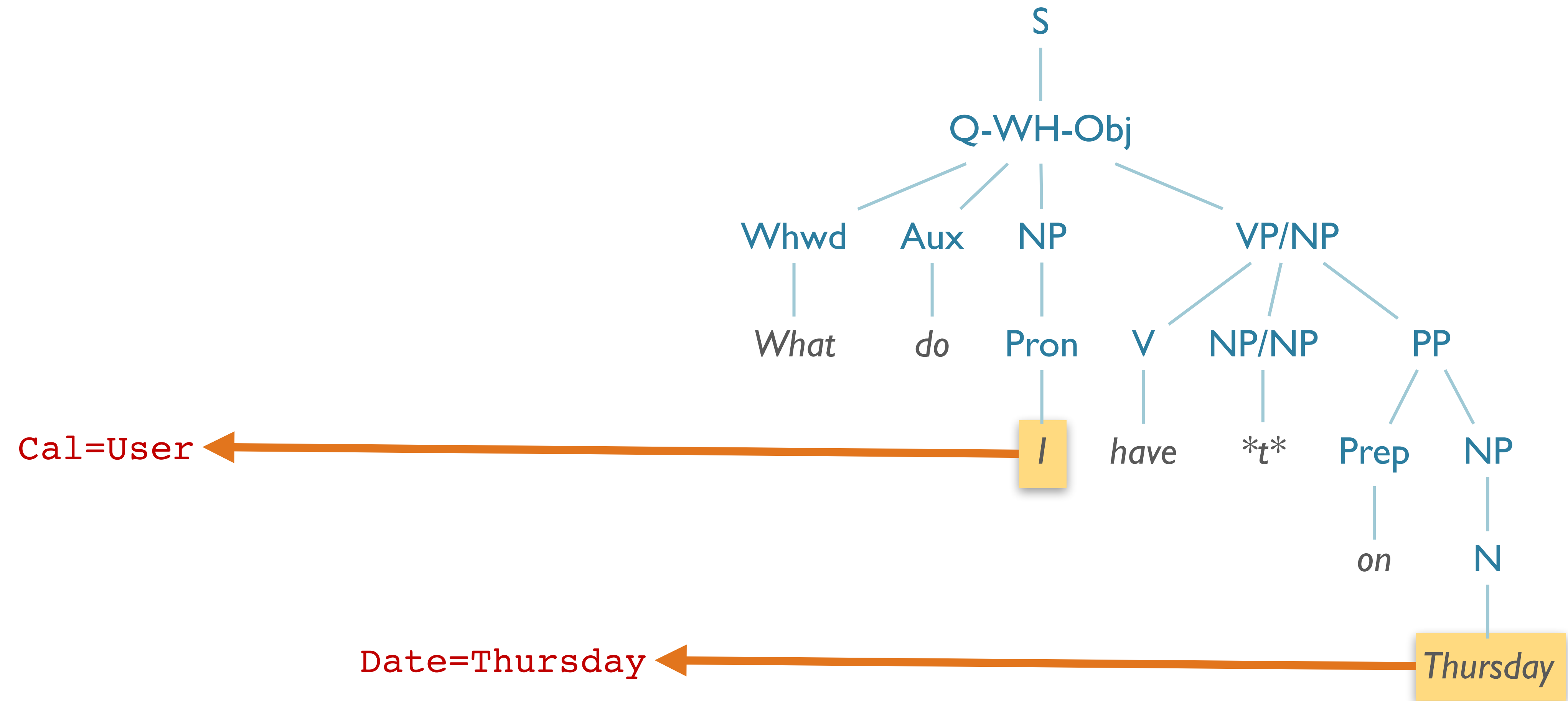


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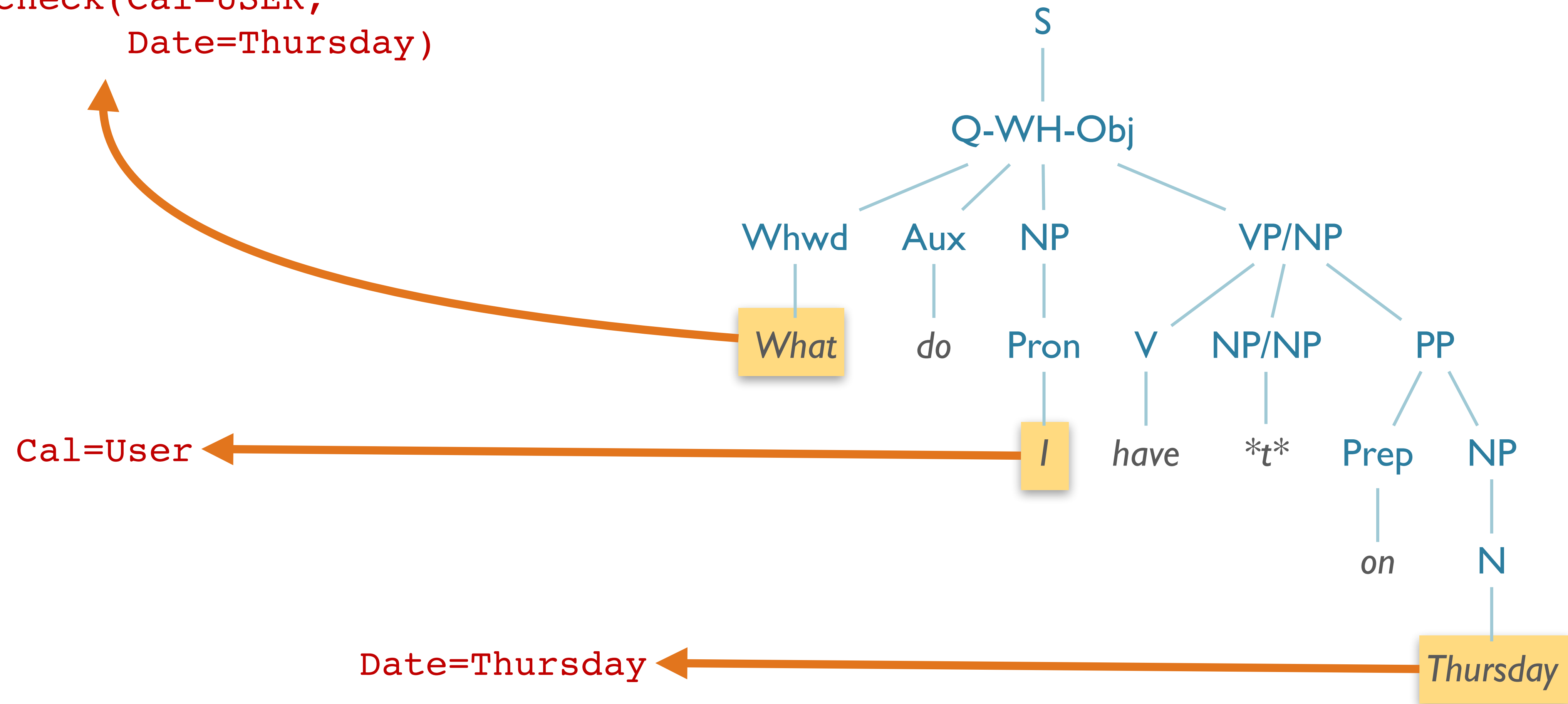
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Action:

check(Cal=USER,  
Date=Thursday)



# Syntax vs. Semantics

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

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

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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,<sup>1</sup> 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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$\exists x \text{ Sky}(x) \wedge \text{Blue}(x)$

**Logic**

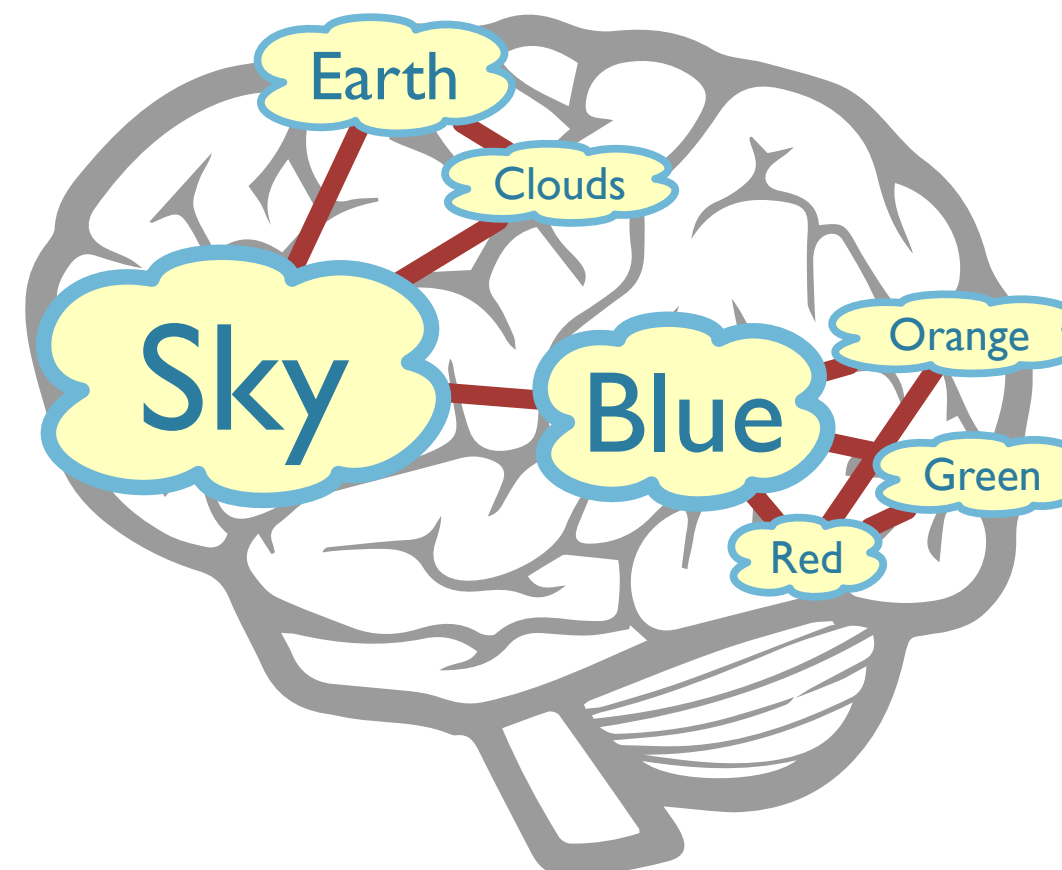


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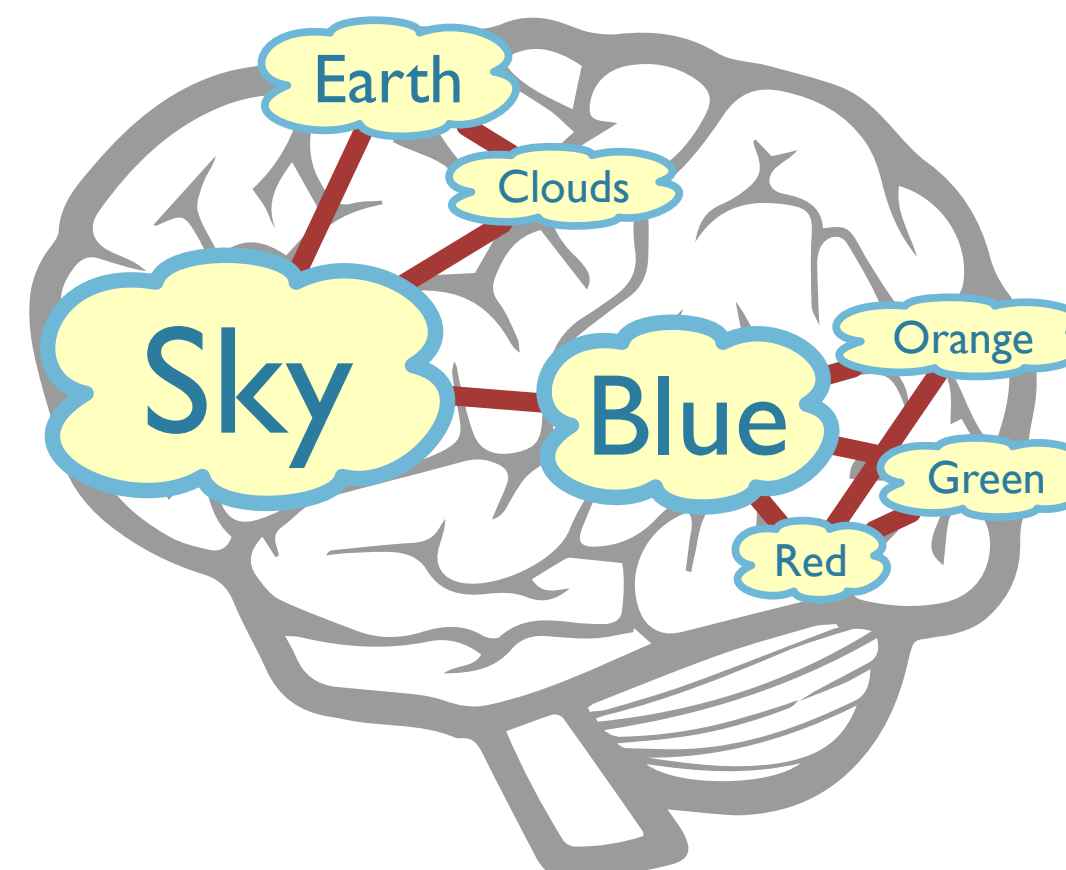
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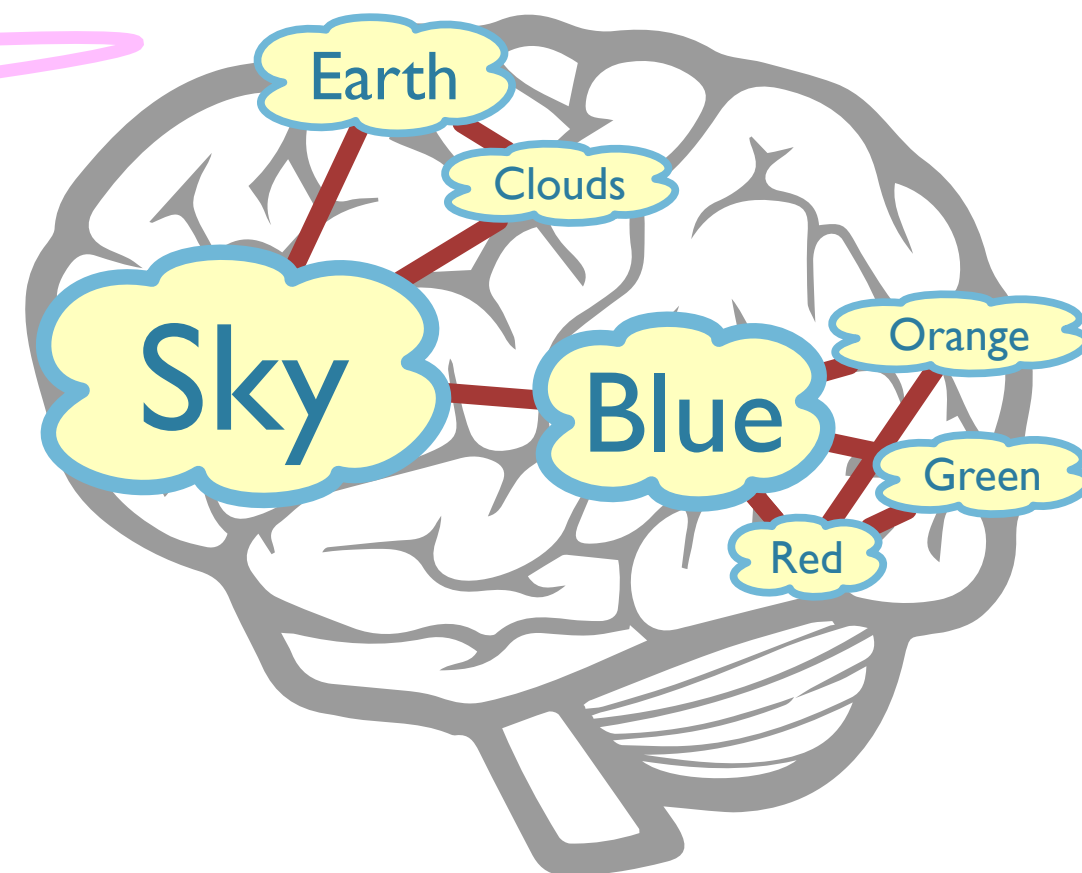
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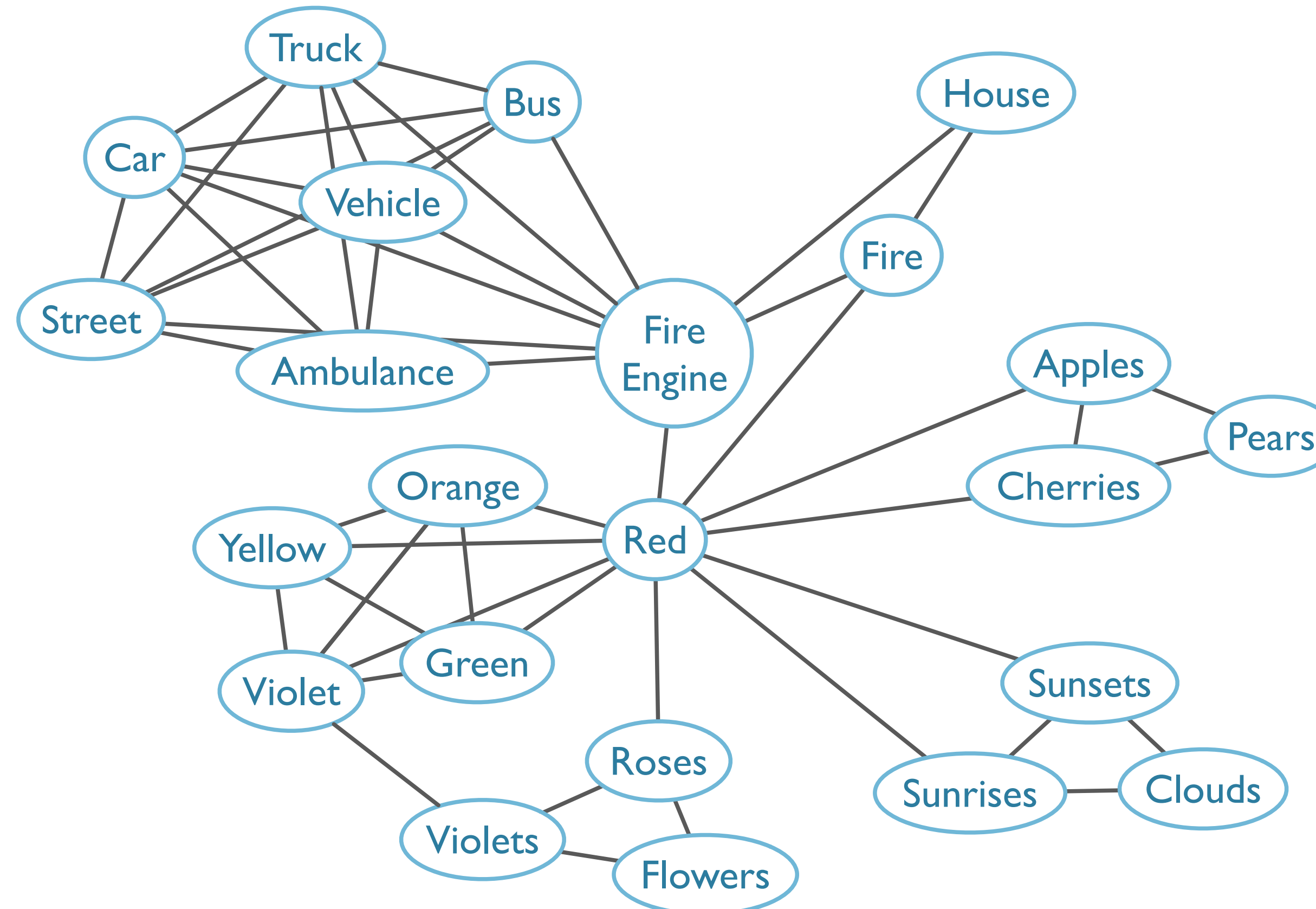
**Epistemology**

# 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
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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

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  - ...etc.

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- **Entailment:**

- What are all the conclusions that can be validly drawn from a sentence?
  - *Lincoln was assassinated*  $\models$  *Lincoln is dead*
  - $\models$  “semantically entails”: if former is true, the latter must be too



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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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  - ...convert strings from natural language to meaning representations
- 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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- **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.

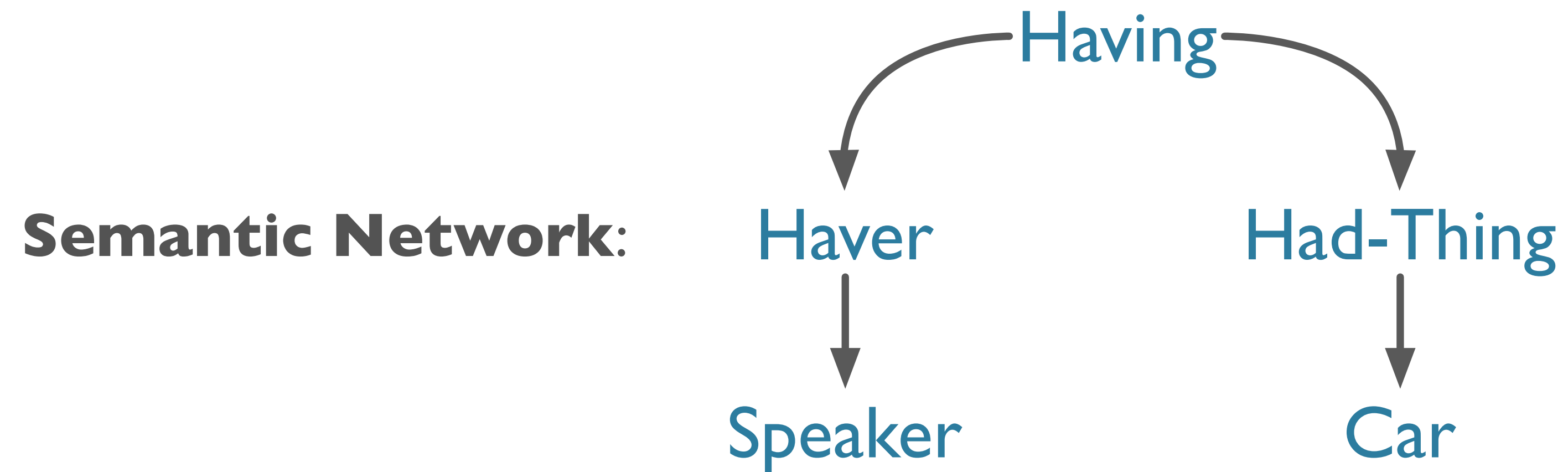
# Representing Meaning

# “I have a car”

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

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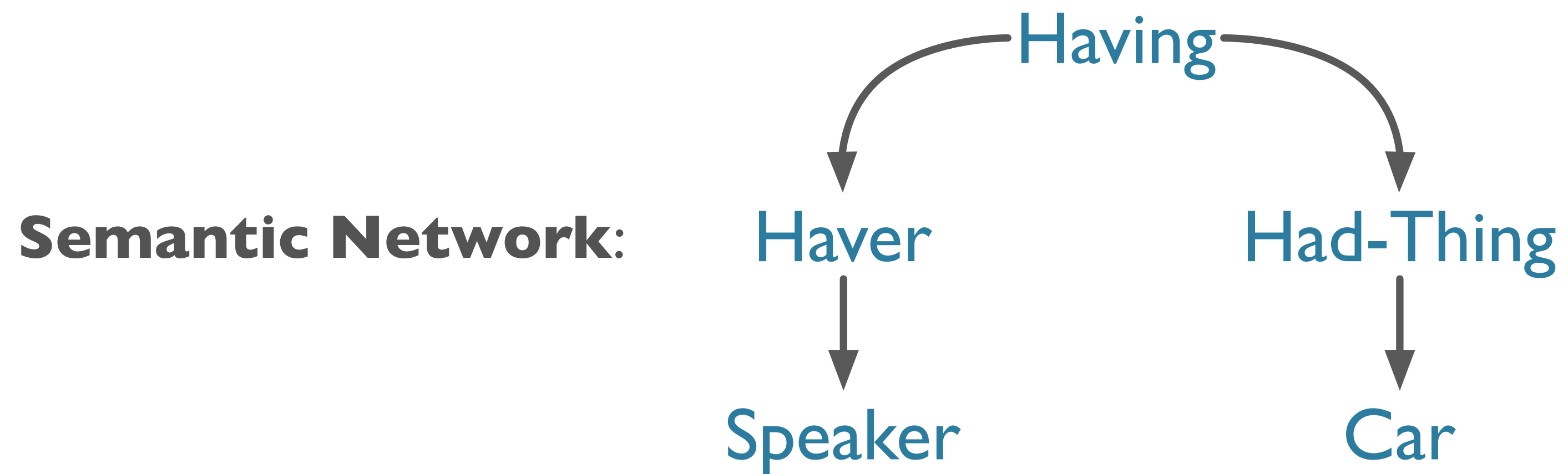
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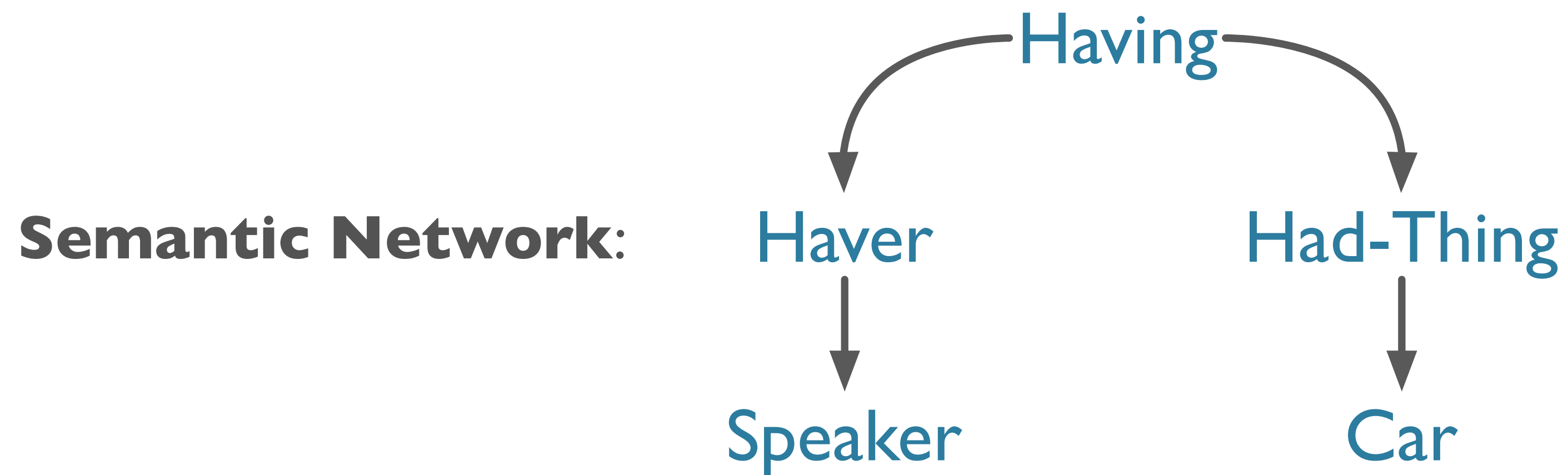


**Conceptual Dependency:**

```
graph TD; Car -- POSS-BY --> Speaker;
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**Conceptual Dependency:**

*Car*  
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**Frame-Based:**

<i>Having</i>
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- Here we focus on **literal** meaning (“what is said”)

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- Verifiability
- Unambiguous representations
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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

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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
    - *WASateGovernor* and *JayInslee*

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

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  - ‘*United serves Chicago*’
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- **Logical Connectives**

- $\{\wedge, \vee, \Rightarrow\} = \{\text{and, or, implies}\}$
- Allow for compositionality of meaning\* [\* many subtleties]
- ‘*Frontier serves Seattle and is cheap.*’
  - $Serves(Frontier, Seattle) \wedge Cheap(Frontier)$

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- **A non-stop flight** that **serves Pittsburgh**:  
 $\exists x \textit{Flight}(x) \wedge \textit{Serves}(x, \textit{Pittsburgh}) \wedge \textit{Non-stop}(x)$



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- **All flights include** beverages.

$$\forall x \text{ Flight}(x) \Rightarrow \text{Includes}(x, \text{beverages})$$

# FOL Syntax Summary

<i>Formula</i>	→	<i>AtomicFormula</i>	<i>Connective</i>	→	$\wedge \mid \vee \mid \Rightarrow$
		<i>Formula Connective Formula</i>	<i>Quantifier</i>	→	$\forall \mid \exists$
		<i>Quantifier Variable, ... Formula</i>	<i>Constant</i>	→	<i>VegetarianFood</i>   <i>Maharani</i>   ...
		$\neg$ <i>Formula</i>	<i>Variable</i>	→	$x \mid y \mid \dots$
		$(\textit{Formula})$	<i>Predicate</i>	→	<i>Serves</i>   <i>Near</i>   ...
<i>AtomicFormula</i>	→	<i>Predicate(Term,...)</i>	<i>Function</i>	→	<i>LocationOf</i>   <i>CuisineOf</i>   ...
<i>Term</i>	→	<i>Function(Term,...)</i>			
		<i>Constant</i>			
		<i>Variable</i>			

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

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

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- Lambda expressions!

# Lambda Expressions

- Lambda ( $\lambda$ ) notation ([Church, 1940](#))
  - Just like lambda in Python, Scheme, etc
  - Allows abstraction over FOL formulae
  - Supports compositionality
- Form: ( $\lambda$ ) + variable + FOL expression
  - $\lambda x.P(x)$       “Function taking  $x$  to  $P(x)$ ”
  - $\lambda x.P(x)(A) = P(A)$  [called beta-reduction]

# $\lambda$ -Reduction

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- Binds formal parameter to term

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$$P(A)$$

- Equivalent to function application

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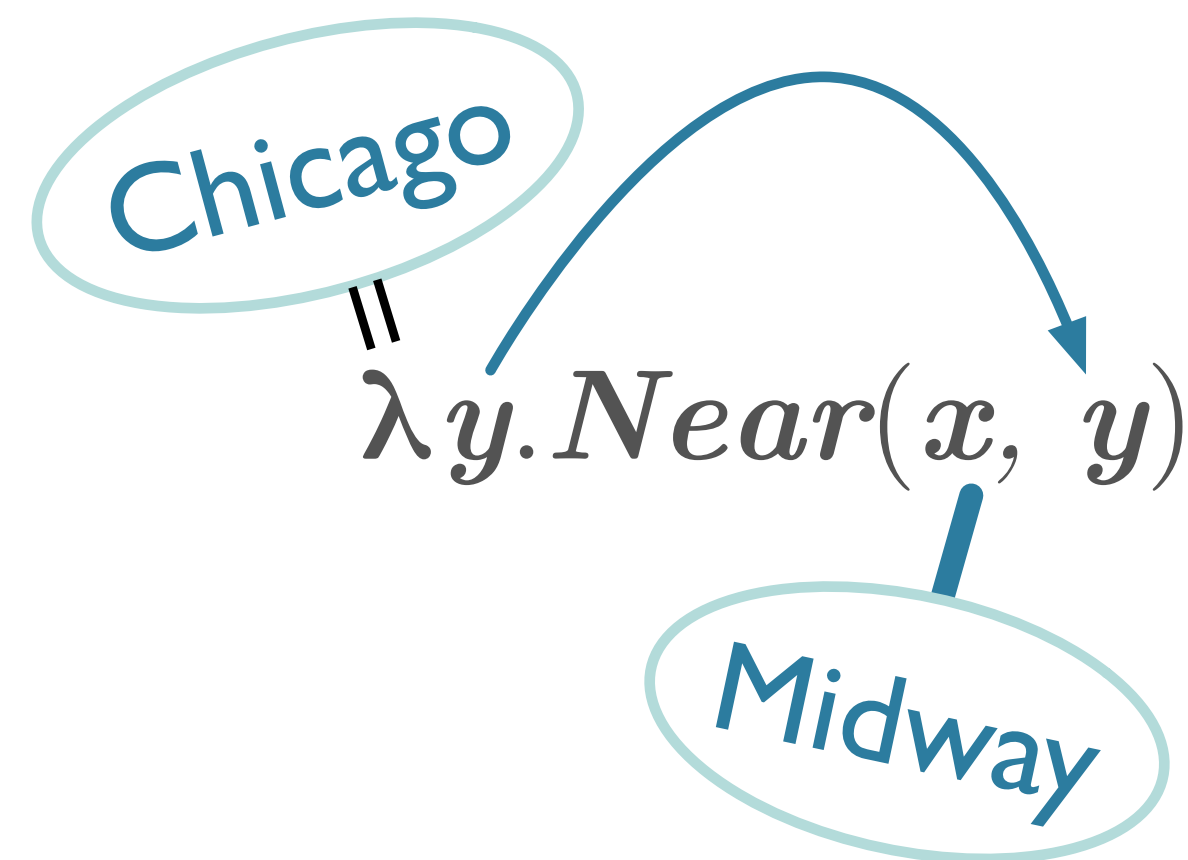
- If it helps, think of  $\lambda$ s as binding sites:





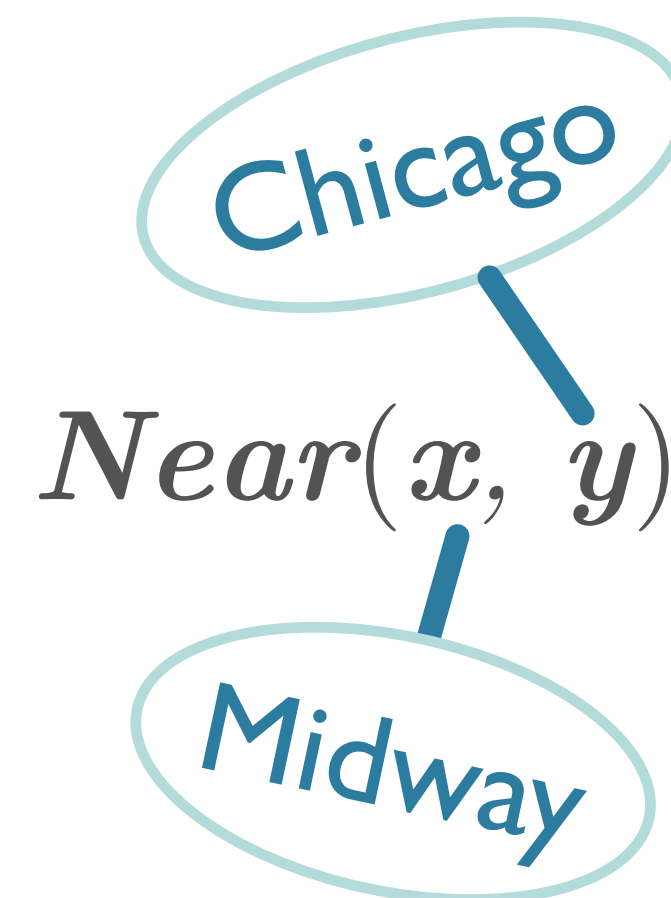
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  - Converting multi-argument predicates to sequence of single argument predicates
  - Why?
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  - Converting multi-argument predicates to sequence of single argument predicates
  - Why?
    - Incrementally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

# Logical Formulae

- FOL terms (objects): denote elements in a domain
  - Properties: sets of domain elements
  - Relations: sets of tuples of domain elements

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  - Properties: sets of domain elements
  - Relations: sets of tuples of domain elements
- Atomic formulae:  $P(x)$ ,  $R(x,y)$ , etc
- 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  $\underline{\vee}$  or  $\oplus$



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- $\vee$  is not exclusive:
  - *Your choice is pepperoni or sausage*
  - ...use  $\underline{\vee}$  or  $\oplus$
- $\Rightarrow$  is the logical form
  - Does not mean the same as natural language “if”, just that if LHS=T, then RHS=T

# Inference

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2.  $\alpha \Rightarrow \beta$

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2.  $\alpha \Rightarrow \beta$

3.  $\therefore \beta$

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1. *VegetarianRestaurant(Leaf)*

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  - 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

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- 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.*

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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):
    - $\exists e \text{ Arrival}(e, \text{Flight}, \text{Seattle}, \text{SFO}) \wedge \text{Time}(e, \text{Saturday})$
  - Neo-Davidsonian (Parsons 1990):
    - $\exists e \text{ Arrival}(e) \wedge \text{Arrived}(e, \text{Flight}) \wedge \text{Destination}(e, \text{Seattle}) \wedge \text{Origin}(e, \text{SFO}) \wedge \text{Time}(e, \text{Saturday})$

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  - 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
- $\lambda$ -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

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

$S \rightarrow NP\ VP$

$\langle NP\ AGREEMENT \rangle = \langle VP\ AGREEMENT \rangle$

$Det \rightarrow this$

$\langle Det\ AGREEMENT\ NUMBER \rangle = sg$

$S \rightarrow Aux\ NP\ VP$

$\langle Aux\ AGREEMENT \rangle = \langle NP\ AGREEMENT \rangle$

$Det \rightarrow these$

$\langle Det\ AGREEMENT\ NUMBER \rangle = pl$

$NP \rightarrow Det\ Nominal$

$\langle Det\ AGREEMENT \rangle = \langle Nominal\ AGREEMENT \rangle$

$\langle NP\ AGREEMENT \rangle = \langle Nominal\ AGREEMENT \rangle$

$Verb \rightarrow serve$

$\langle Verb\ AGREEMENT\ NUMBER \rangle = pl$

$Aux \rightarrow does$

$\langle AUX\ AGREEMENT\ NUMBER \rangle = sg$

$\langle AUX\ AGREEMENT\ PERSON \rangle = 3rd$

$Noun \rightarrow flight$

$\langle Noun\ AGREEMENT\ NUMBER \rangle = sg$

# 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

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

# NLTK Feature Syntax

- Basics
  - $X[\text{FEAT}_1=\text{VALUE}_1, \text{FEAT}_2=\text{VALUE}_2]$
- Variables
  - $X[\text{FEAT}=?f]$
- Binary Values
  - $X[-\text{FEAT}], Y[+\text{FEAT}]$

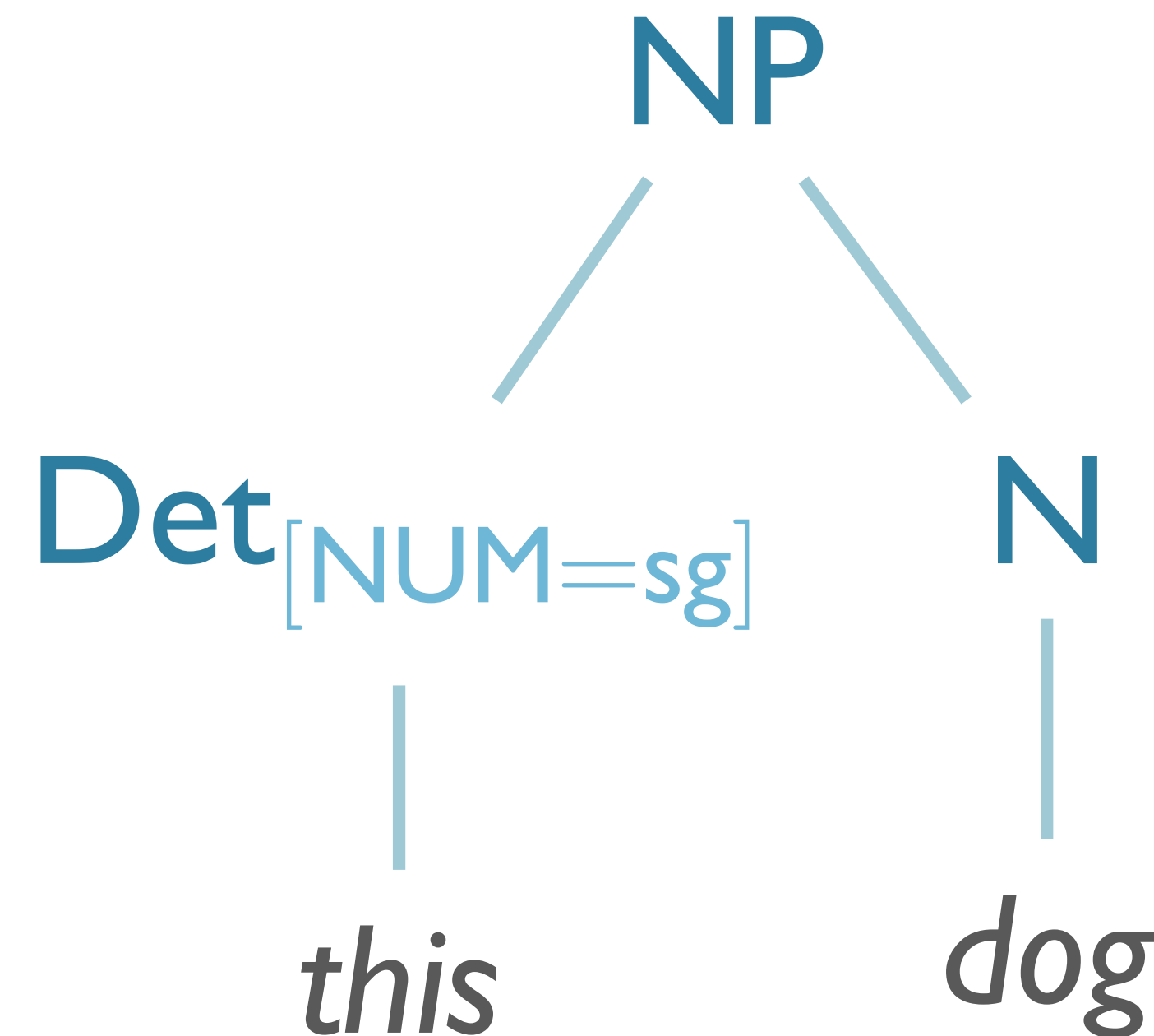
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`NP[NUM=?n] -> Det[NUM=?n] N[NUM=?n]`

`Det[NUM=sg] -> 'this' | 'that'`

`Det[NUM=pl] -> 'these' | 'those'`

`N[NUM=sg] -> 'dog' | 'cat'`



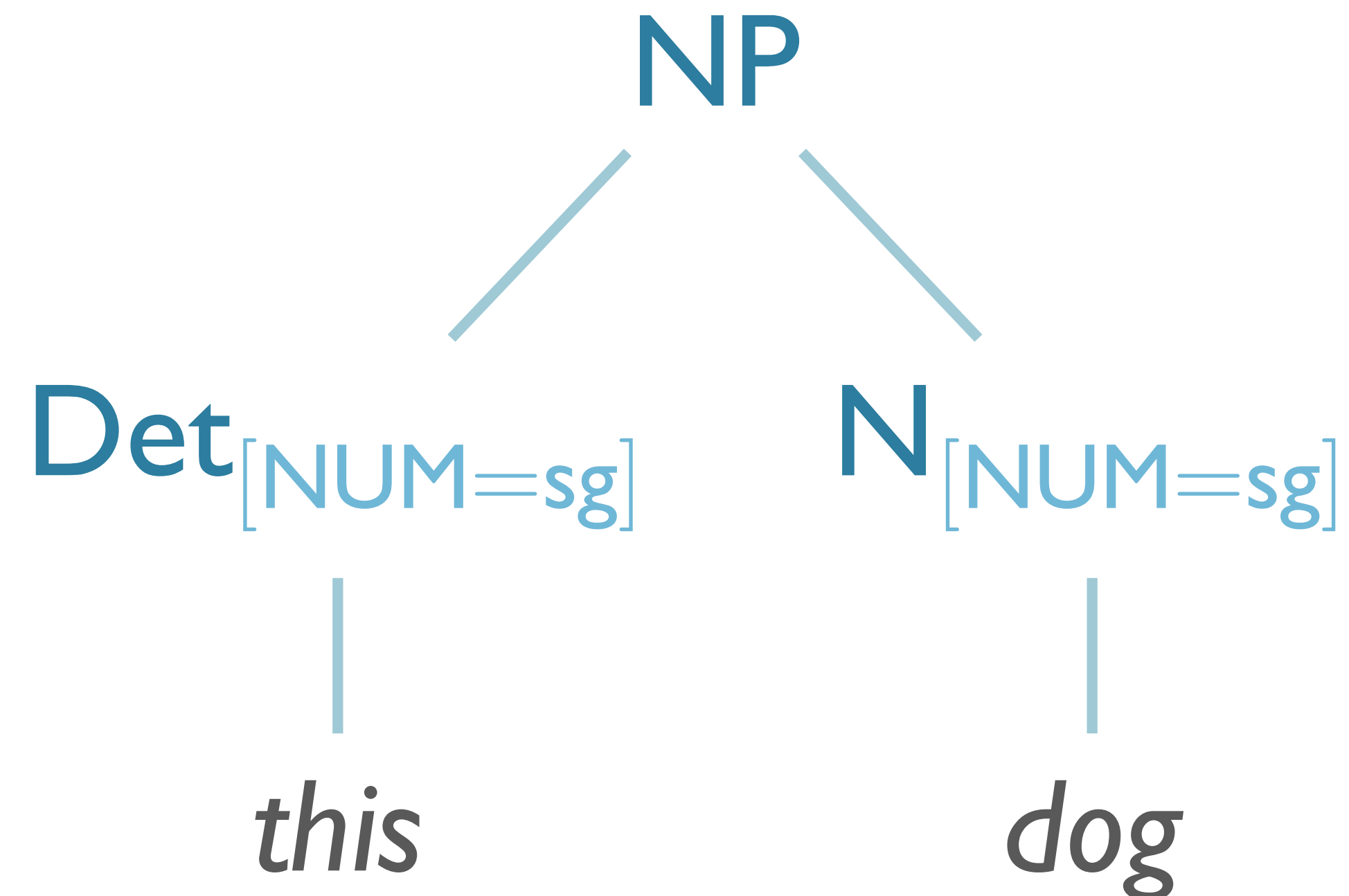
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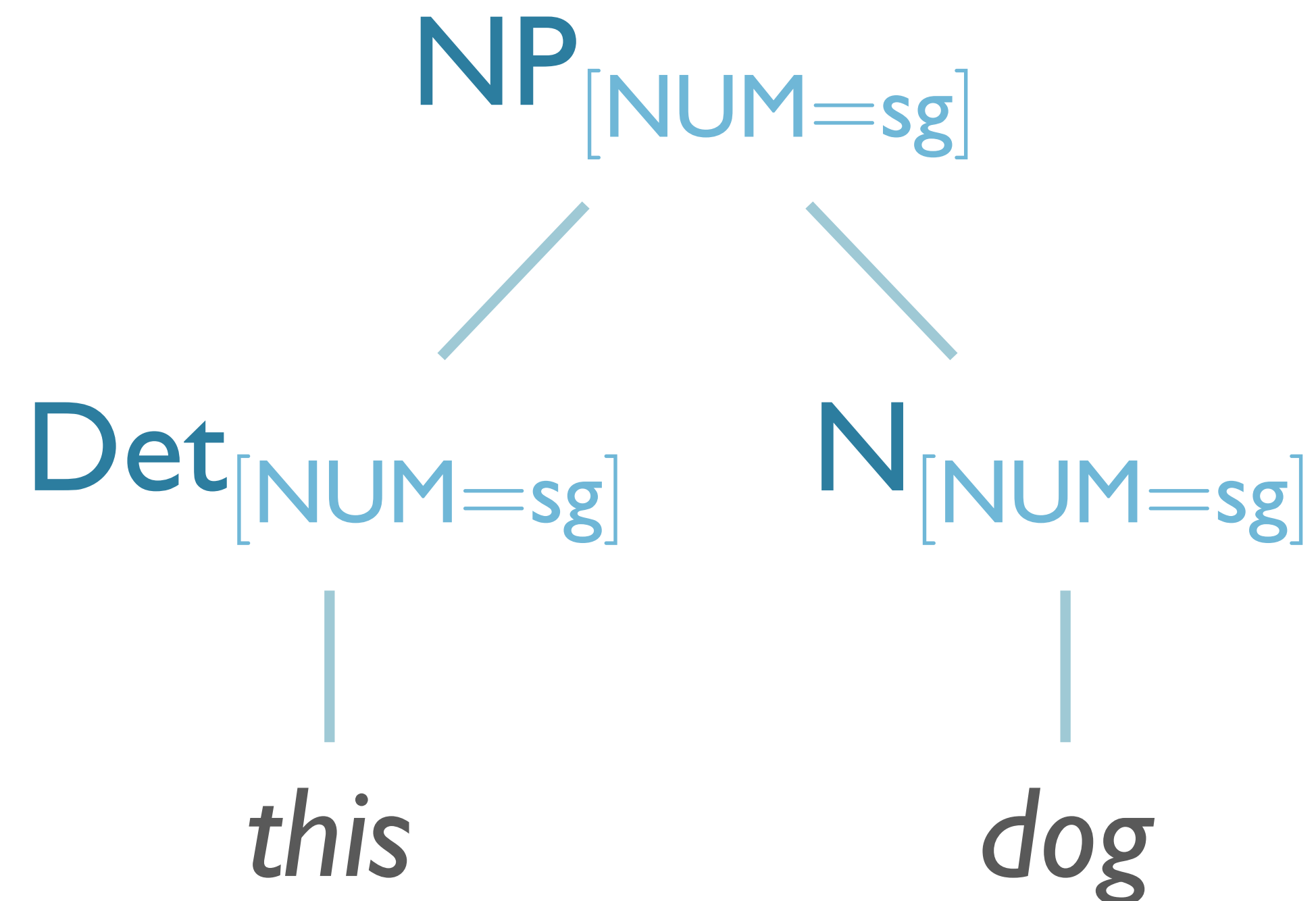
`Det[NUM=pl] -> 'these' | 'those'`

`N[NUM=sg] -> 'dog' | 'cat'`



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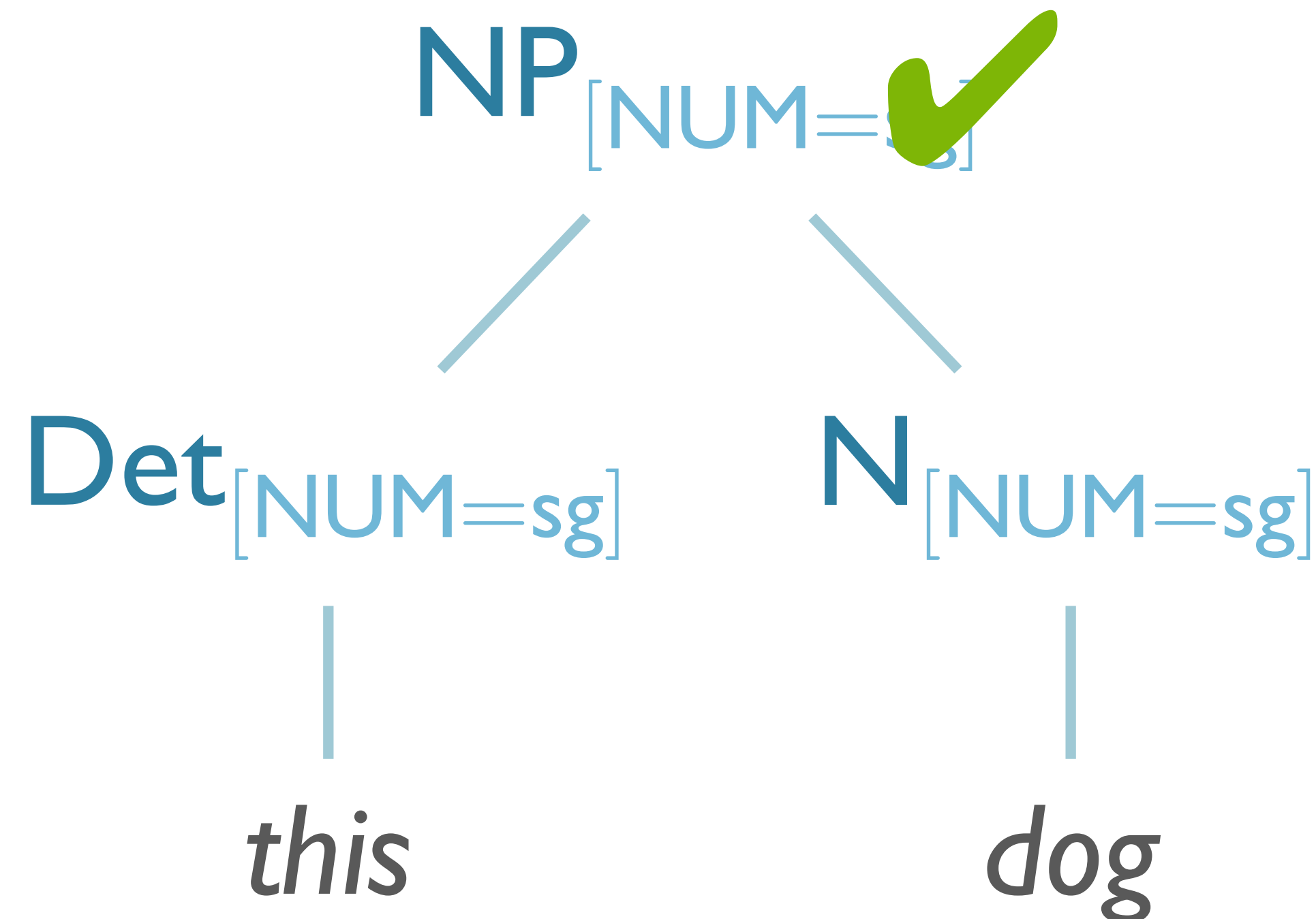
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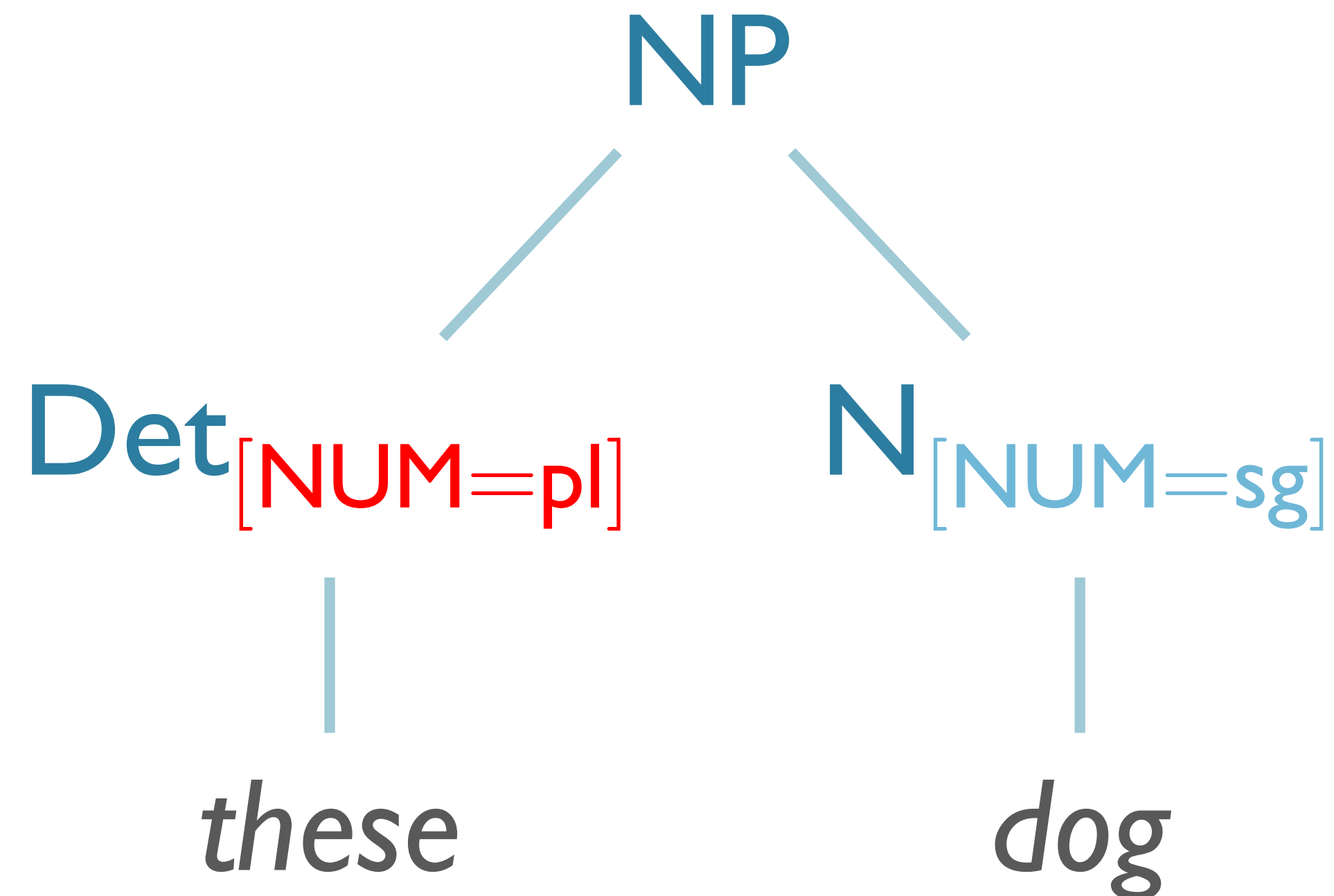
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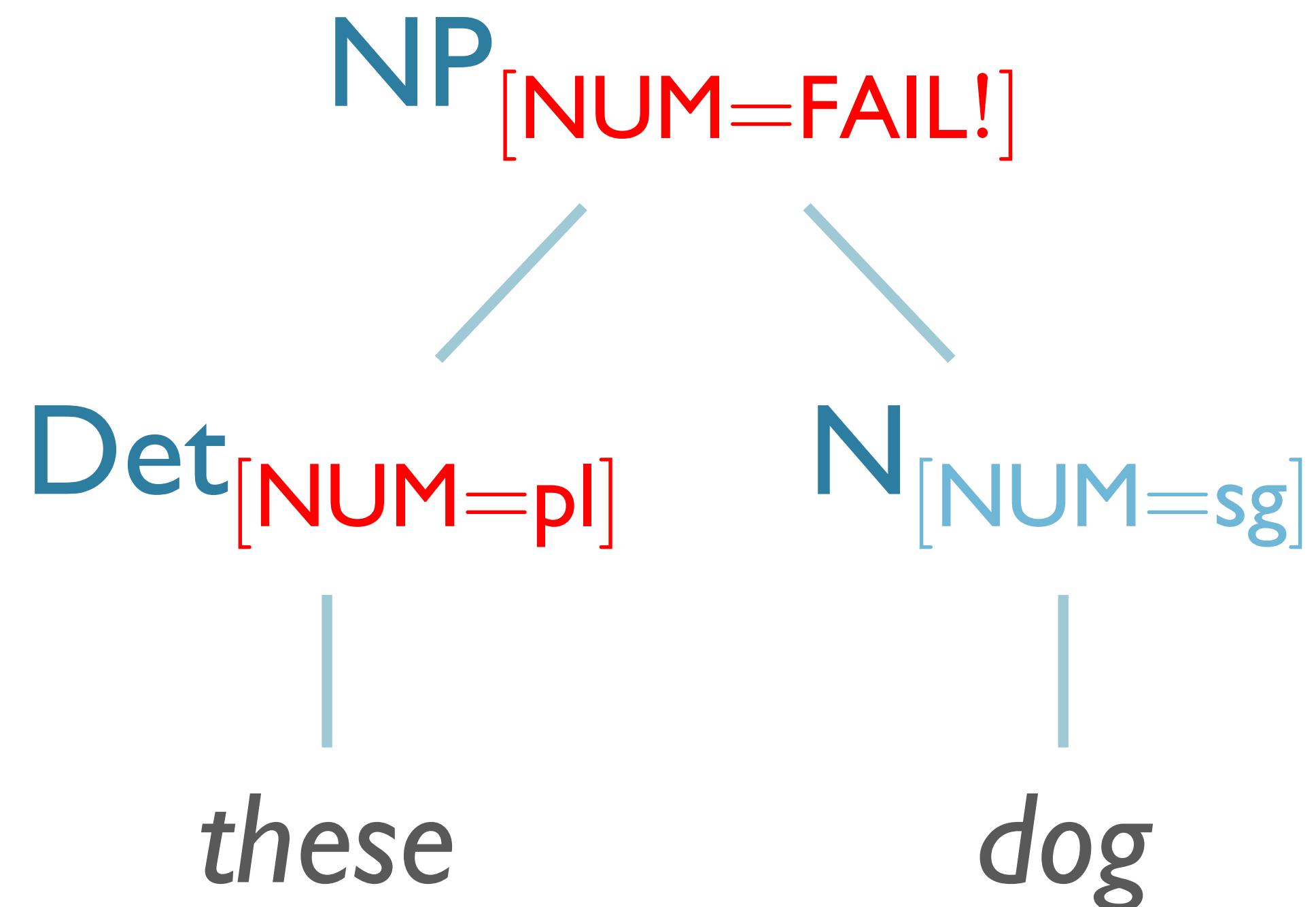
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NP[NUM=?n] -> Det[NUM=?n] N[NUM=?n]      Det[NUM=sg] -> 'this' | 'that'  
Det[NUM=pl] -> 'these' | 'those'  
N[NUM=sg] -> 'dog' | 'cat'



# 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: +/–

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

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- 
- 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`

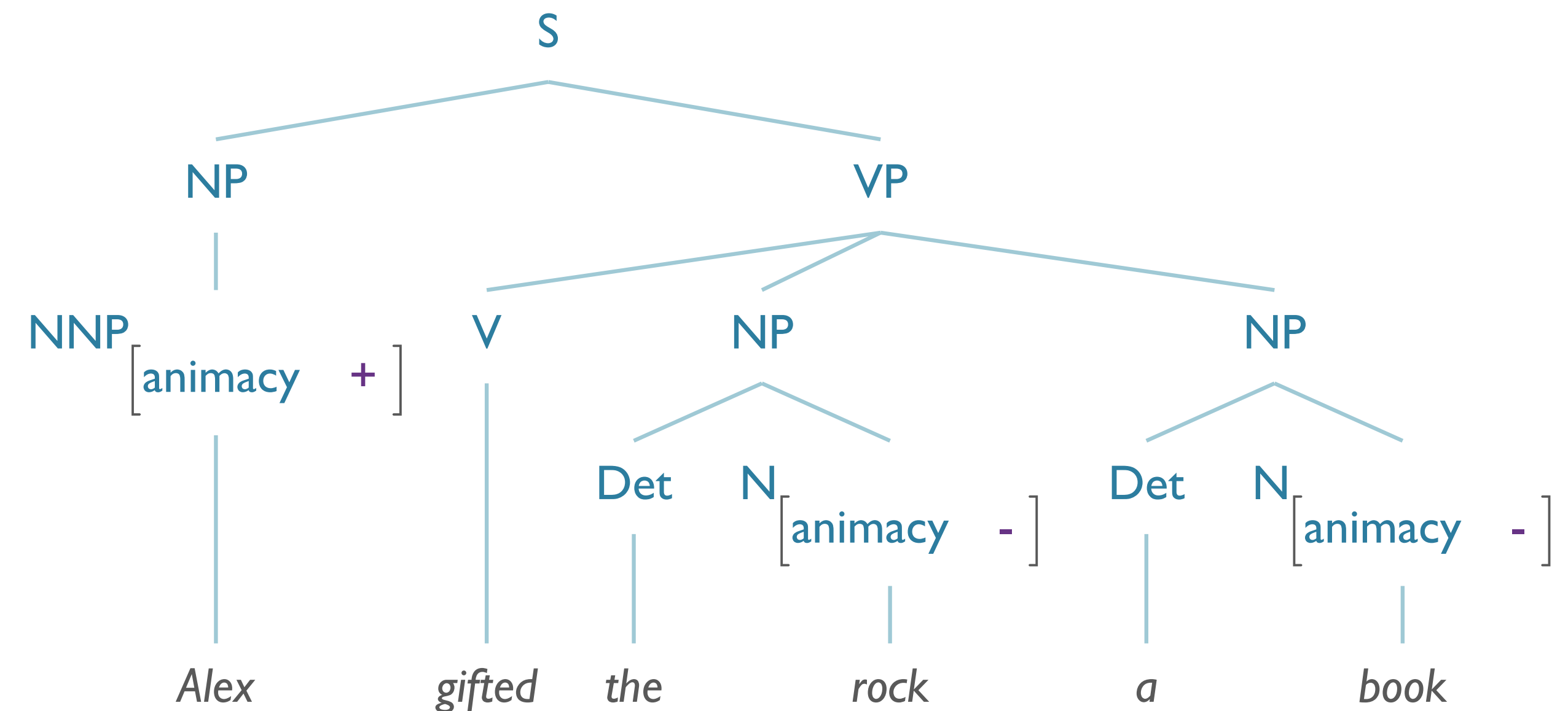
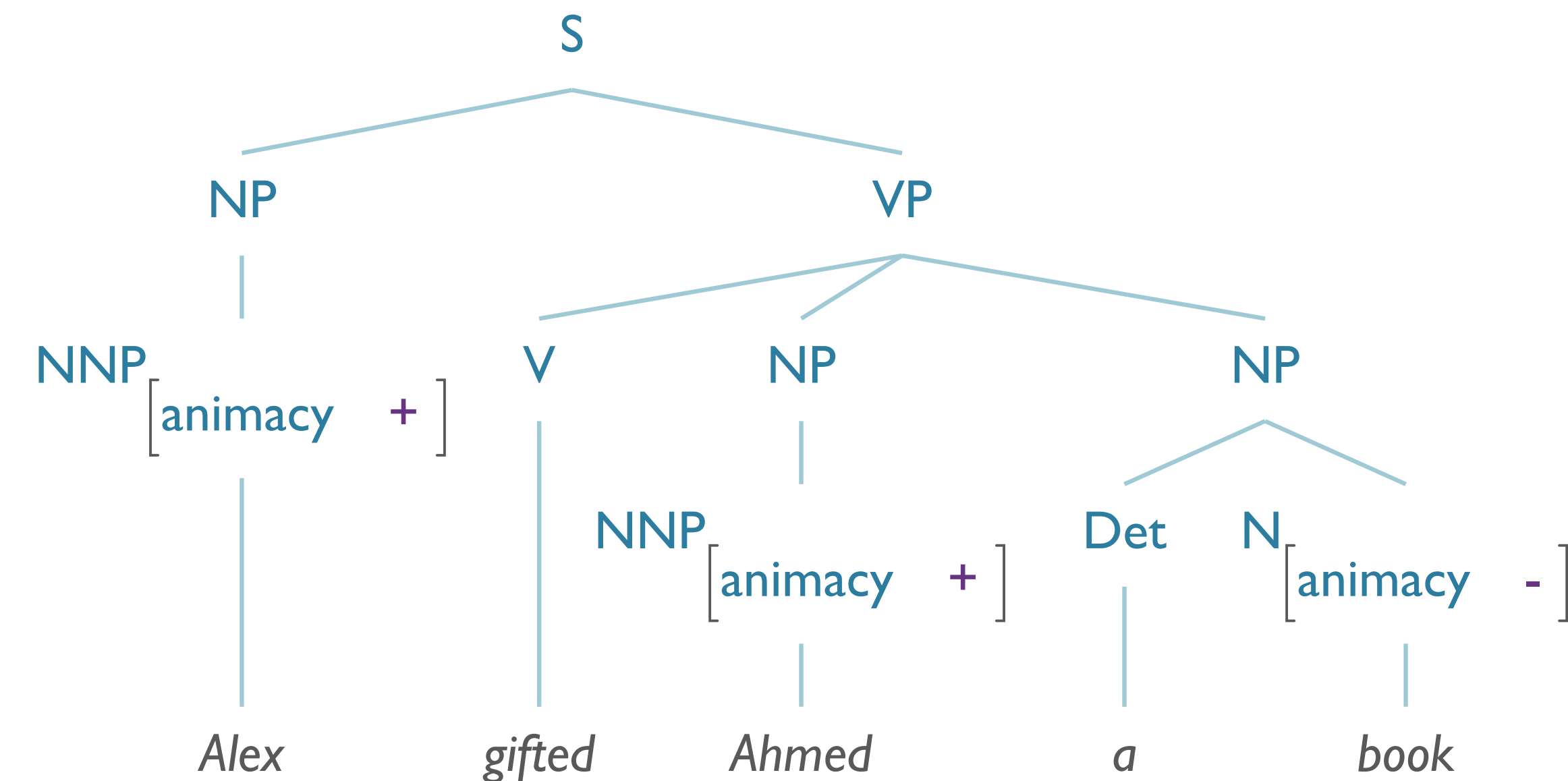
`NNP[animacy=True] -> 'Alex' | 'Ahmed'`

`V[subcat=ditrans] -> 'gifted'`

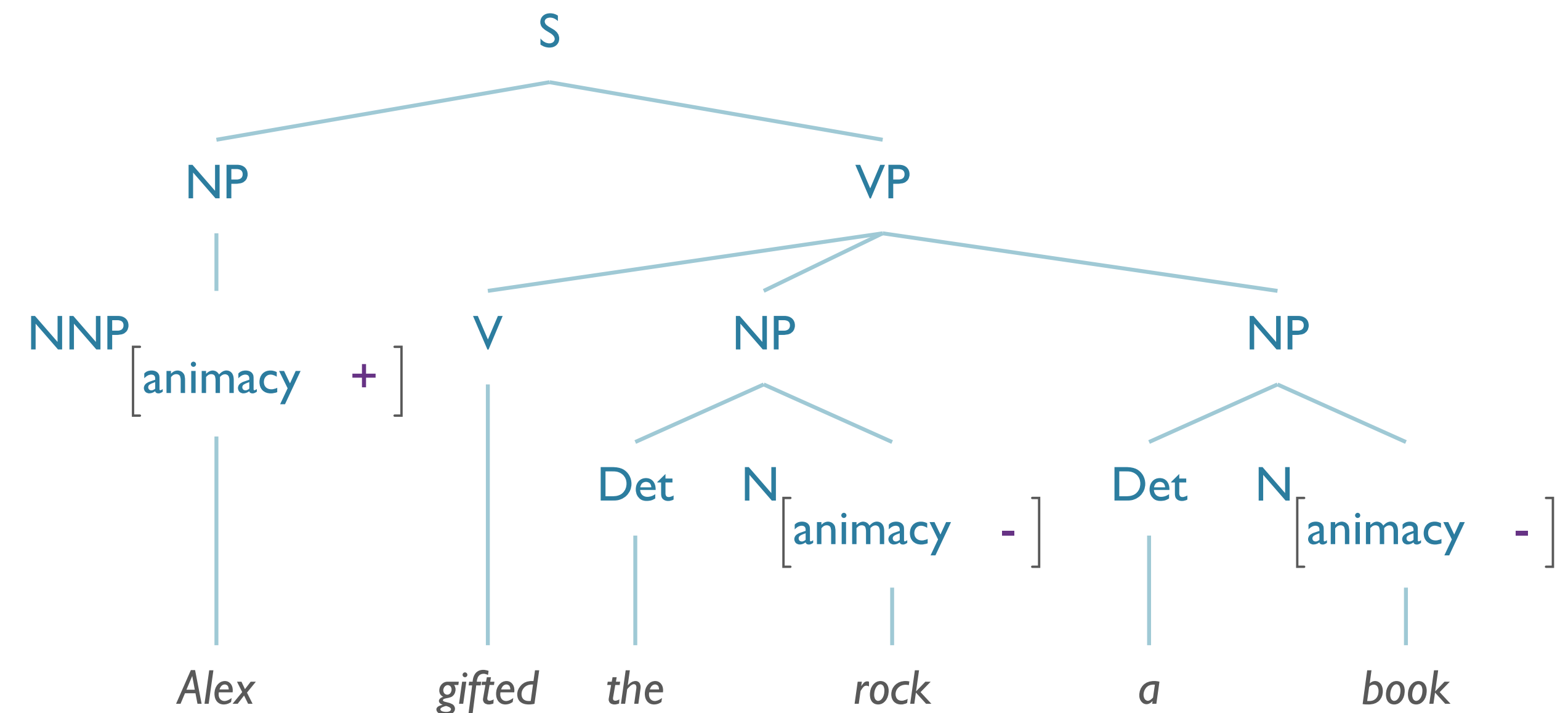
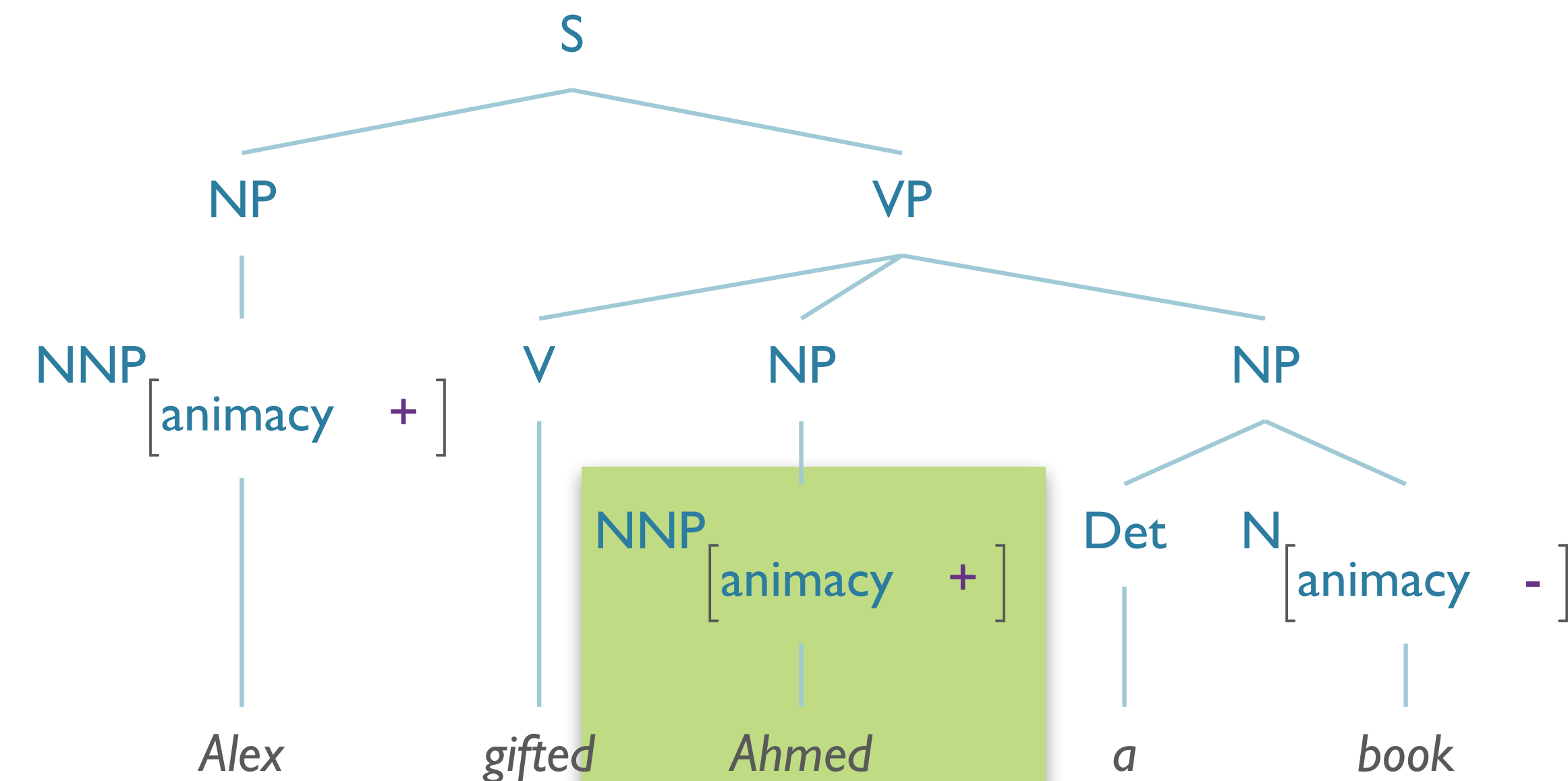
`Det -> 'a' | 'the'`

`N[animacy=False] -> 'book' | 'rock'`

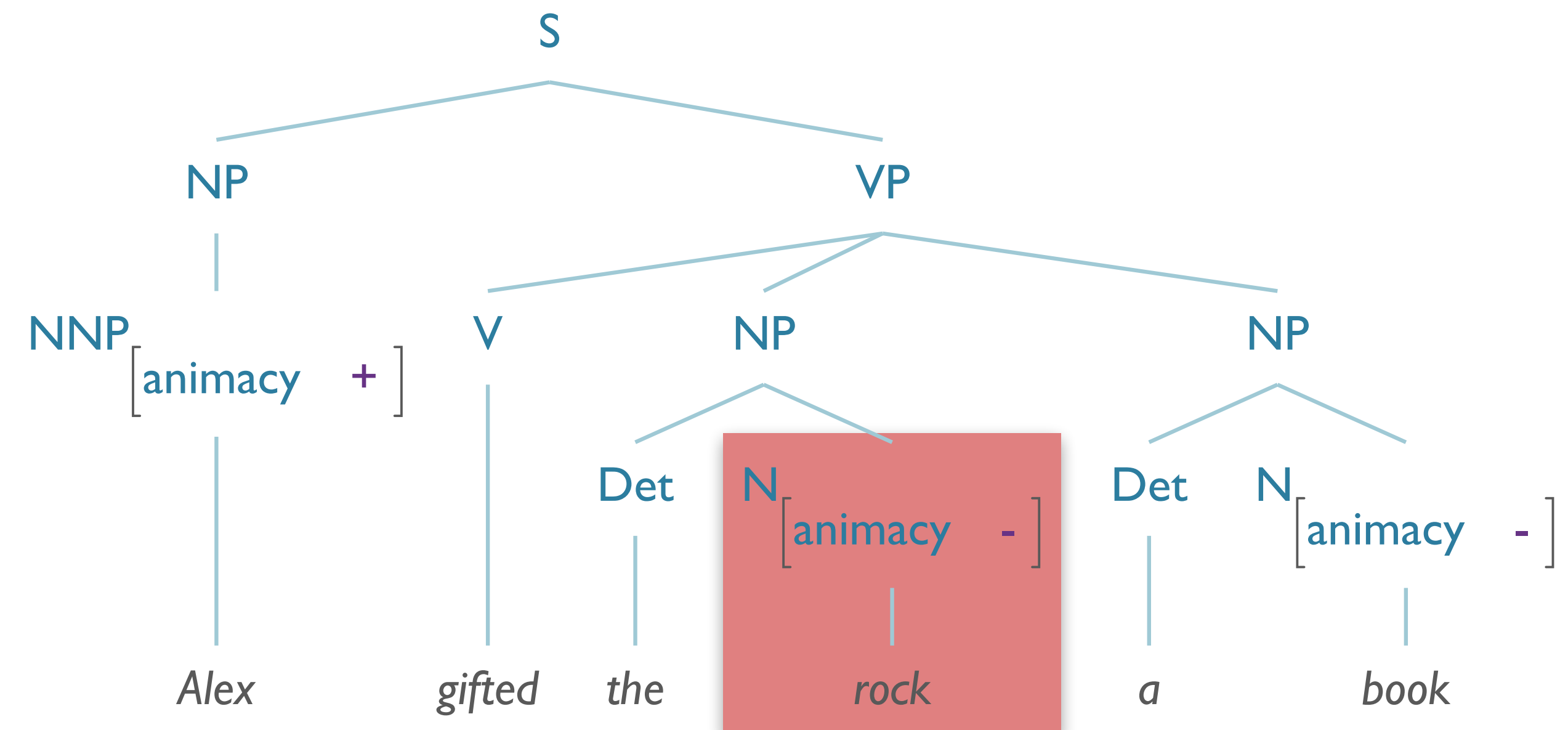
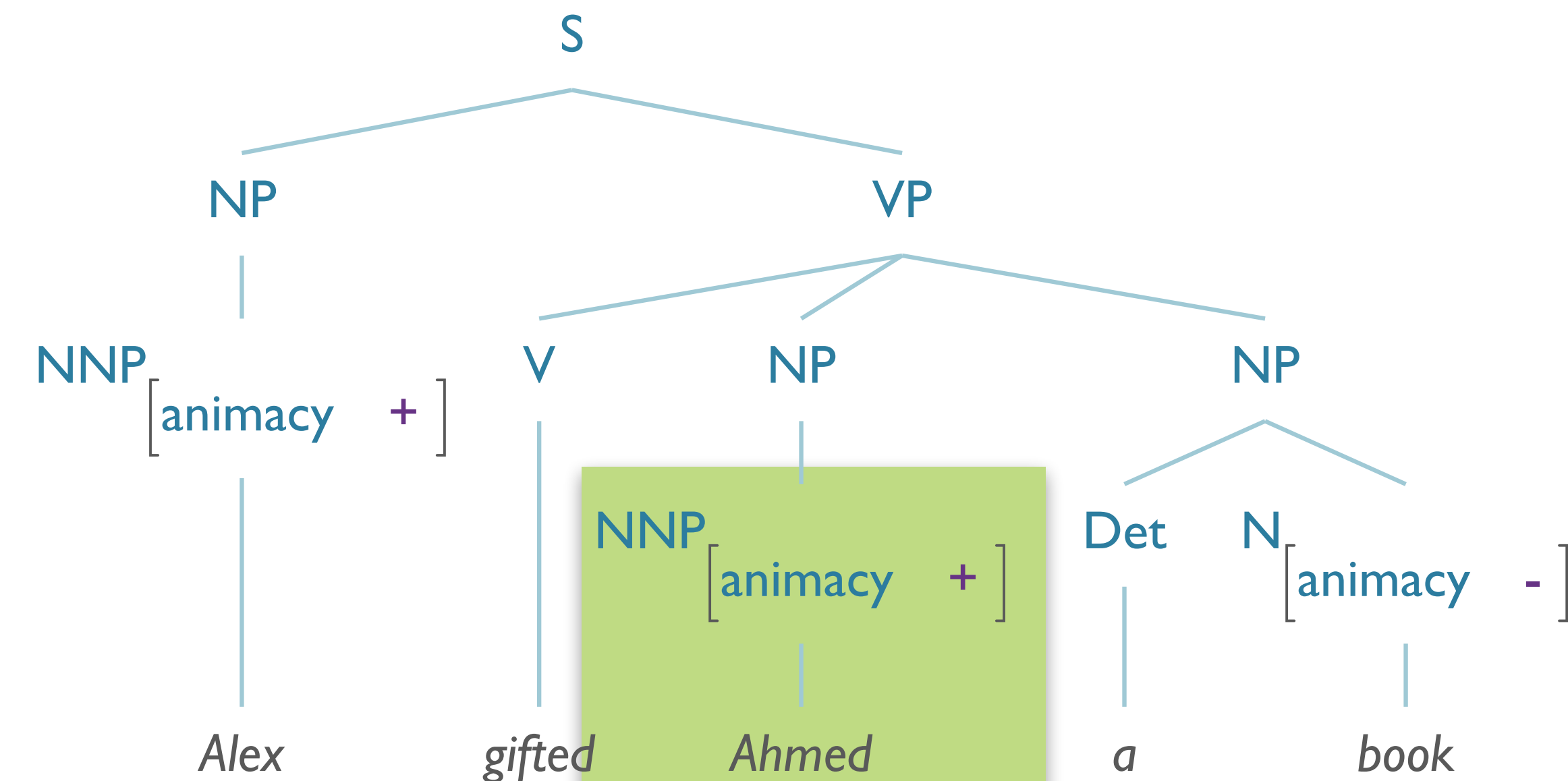
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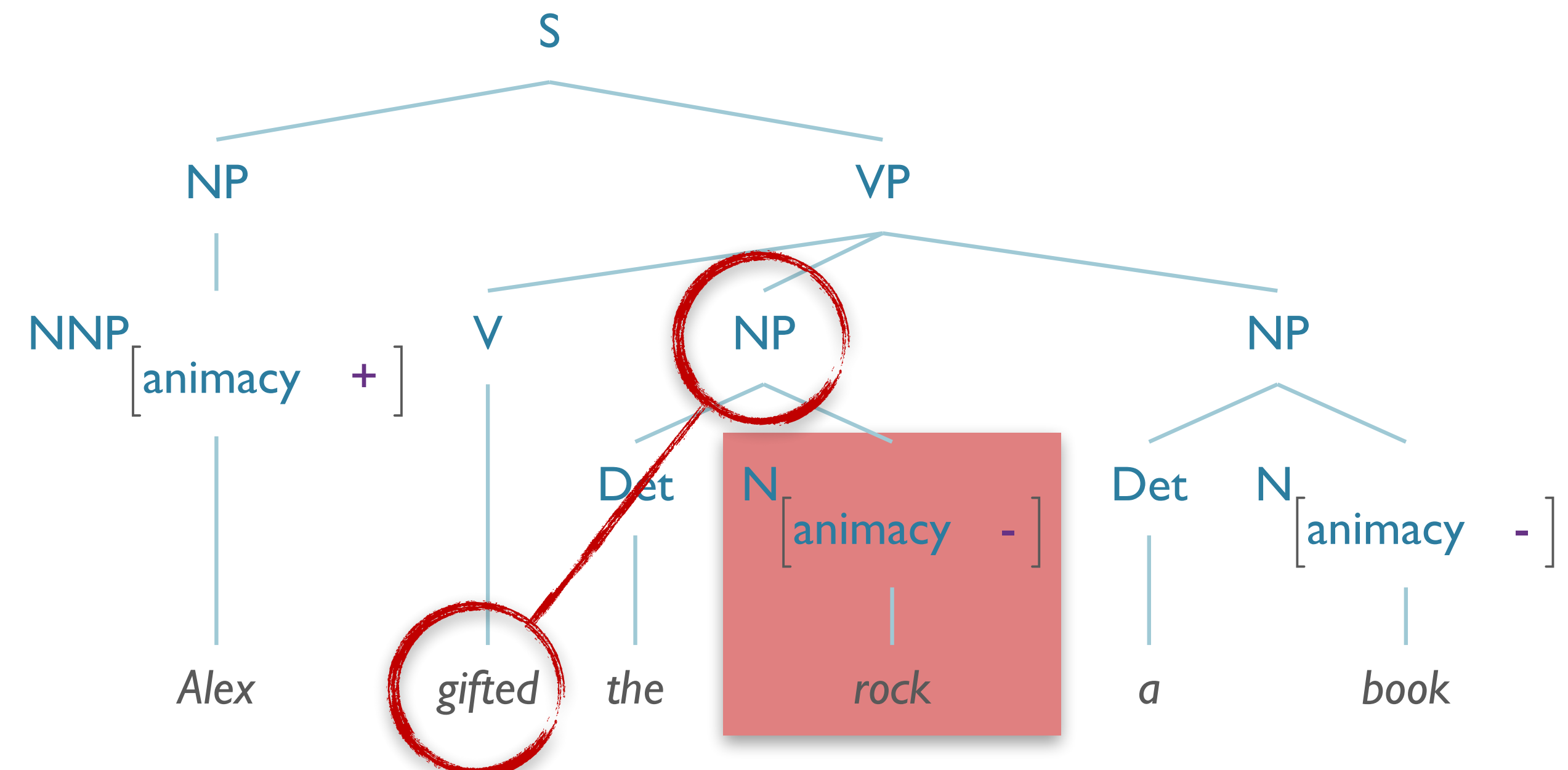
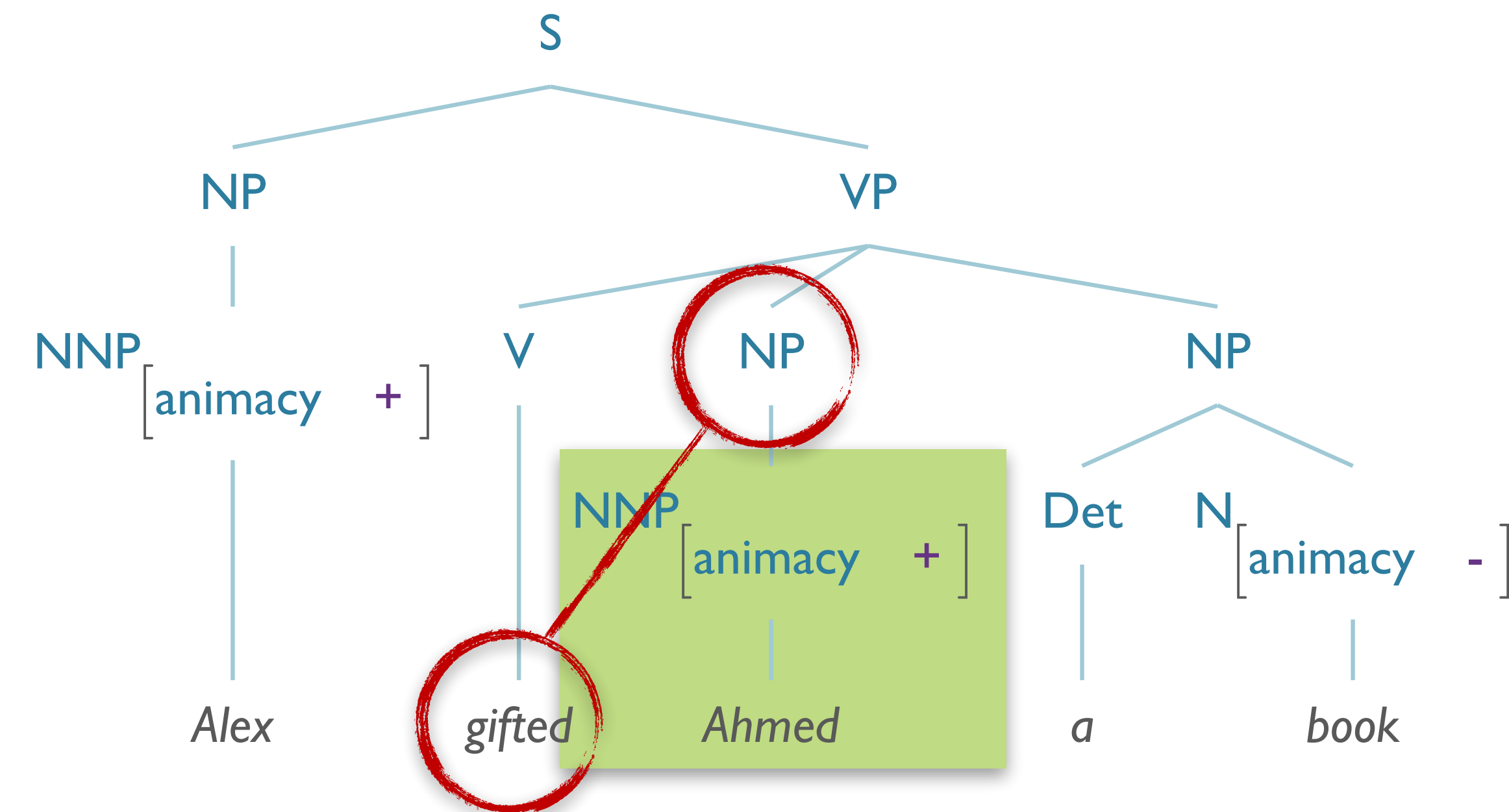


# Feature Grammar Practice





# 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