Feature-based Parsing
+
Computational Semantics

LING 571 — Deep Processing for NLP

October 26, 2022

Shane Steinert-Threlkeld

Announcements

- Thanks for the mid-term feedback!
  - We appreciate the kind words, and
  - Will work on incorporating a few of the themes that came up a couple of times.
  - (Small note on Markdown / .md)
- Parent annotation and evaluation:
  - Splitting non-terminals = introducing new ones, may not be in gold/eval data
  - For this assignment, need to “de-parent” your parses at the end

Ambiguity of the Week

Adam Macqueen
@adam_macqueen

Personally feel not enough hospitals are named after sandwiches.

https://www.theguardian.com/environment/video/2019/oct/18/extinction-rebellion-protester-dressed-as-boris-johnson-scales-big-ben-video

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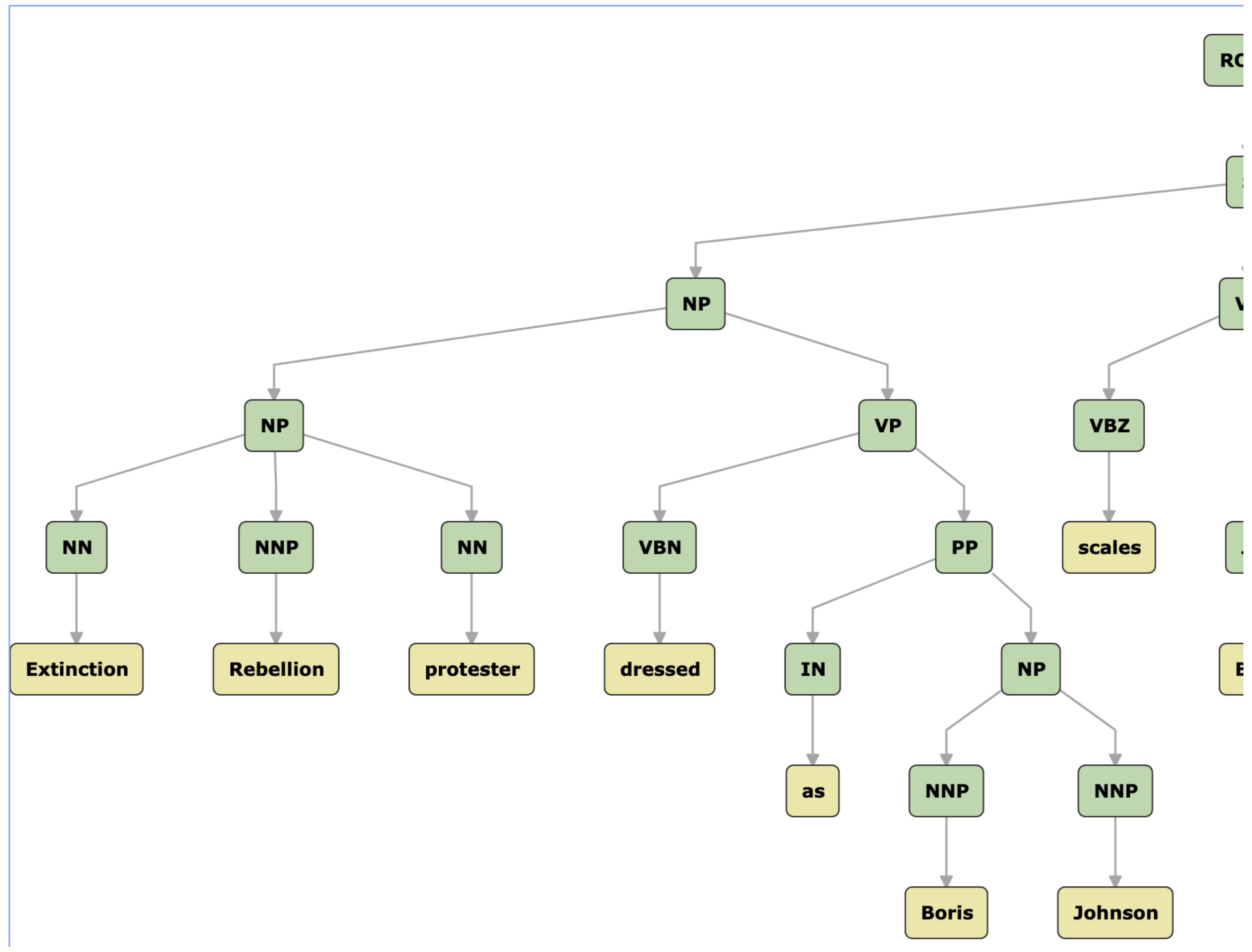

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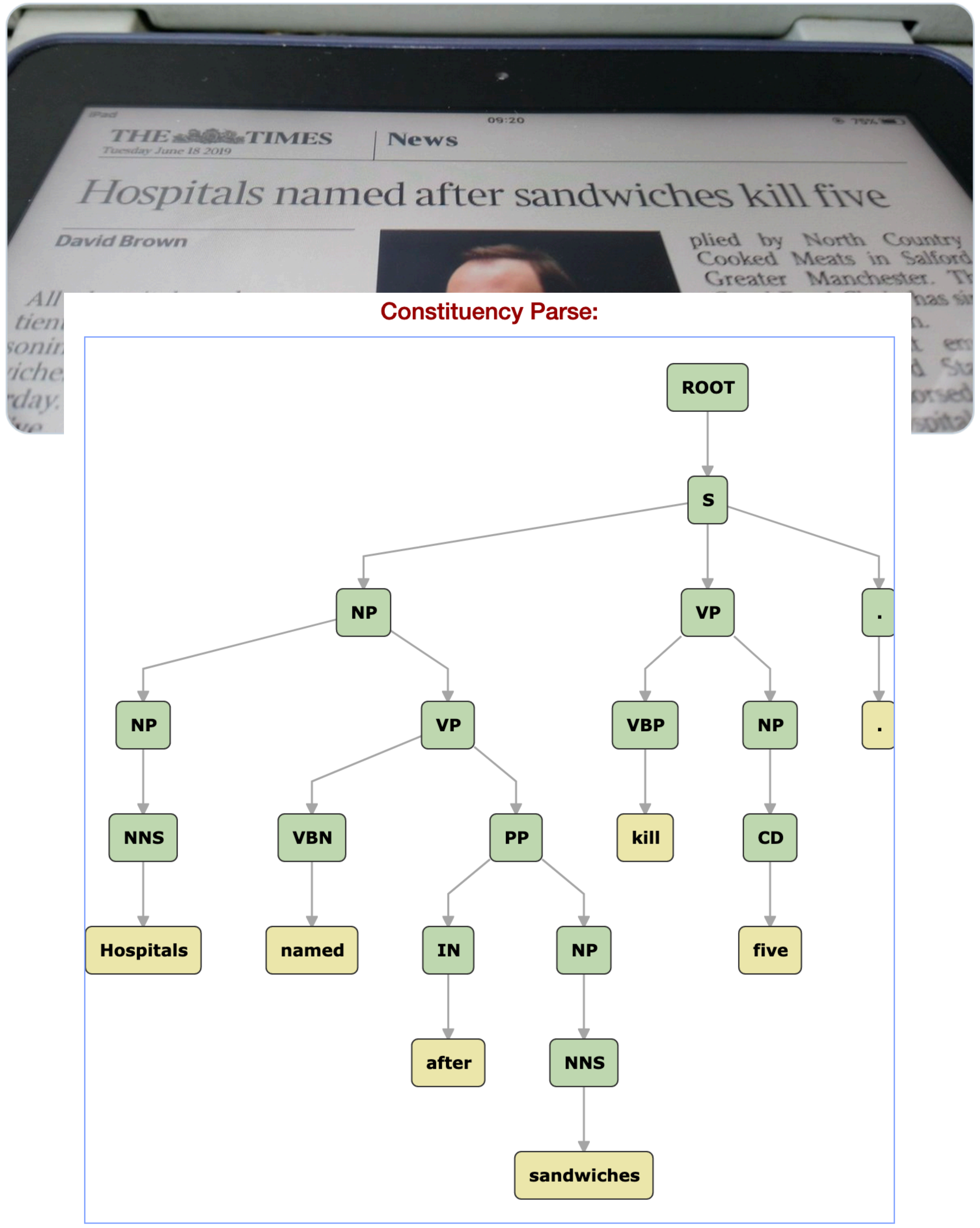

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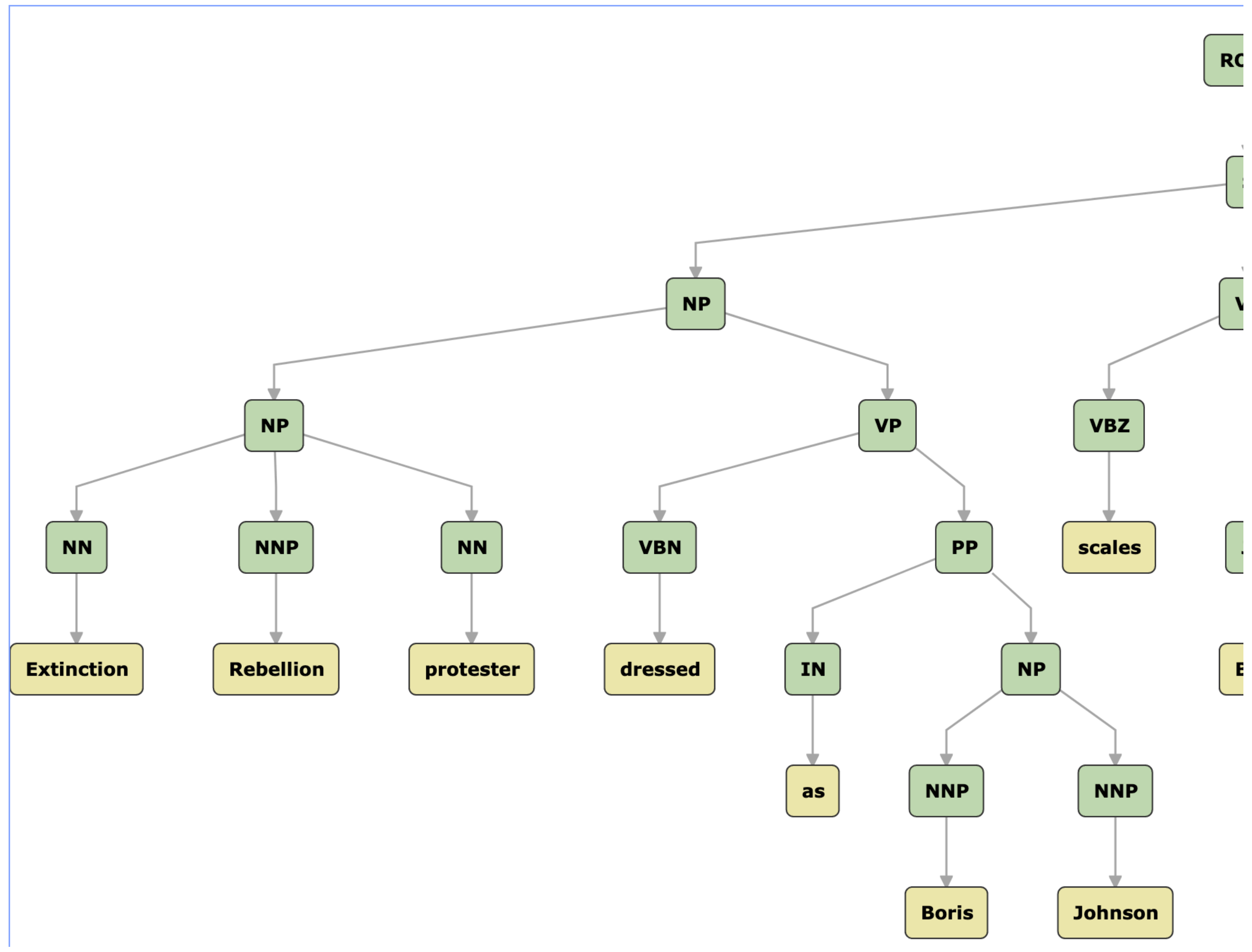

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If you could replace the grating alarm bell in Thomson Hall with any other sound, what would it be?

Total Results: 0

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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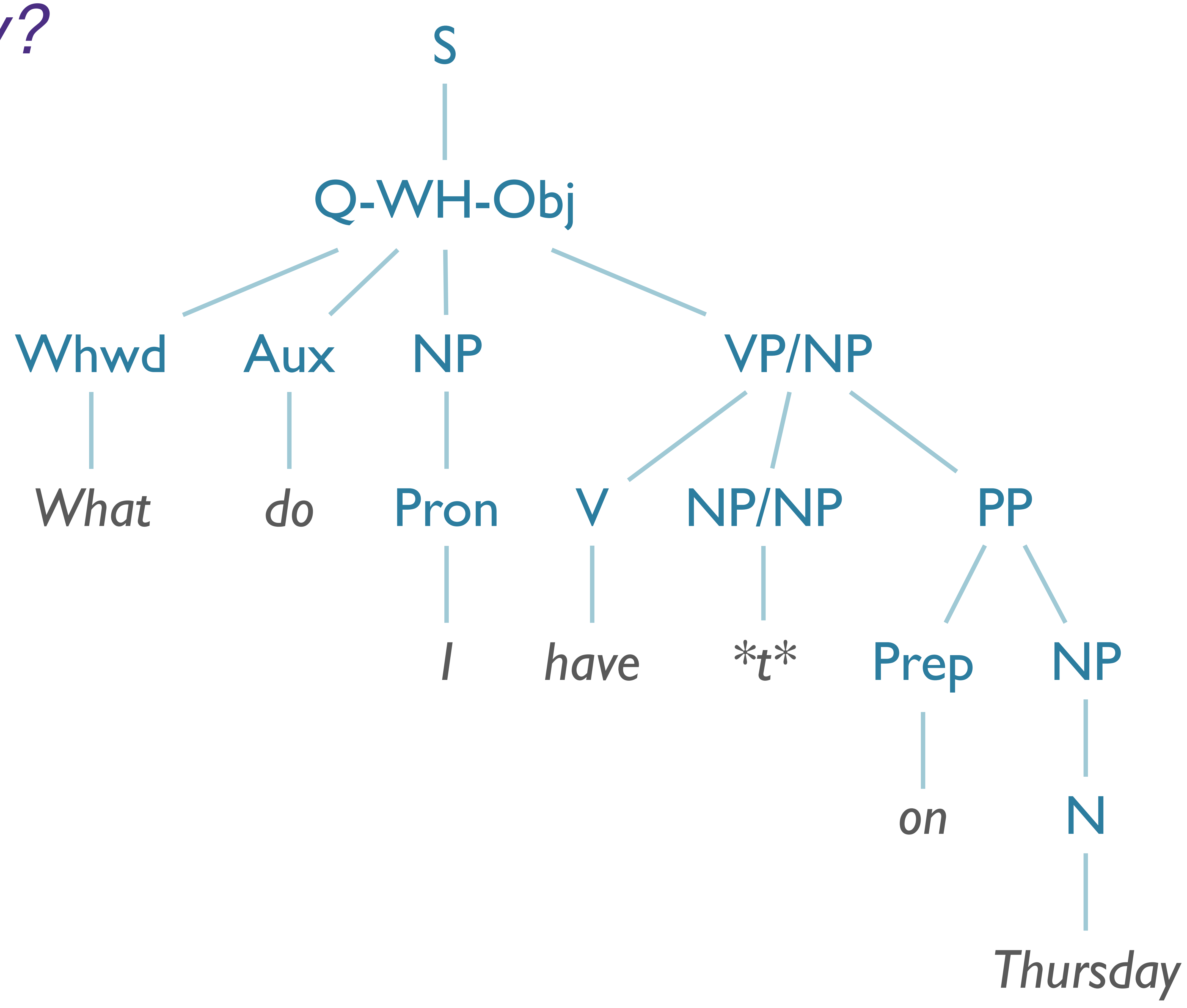

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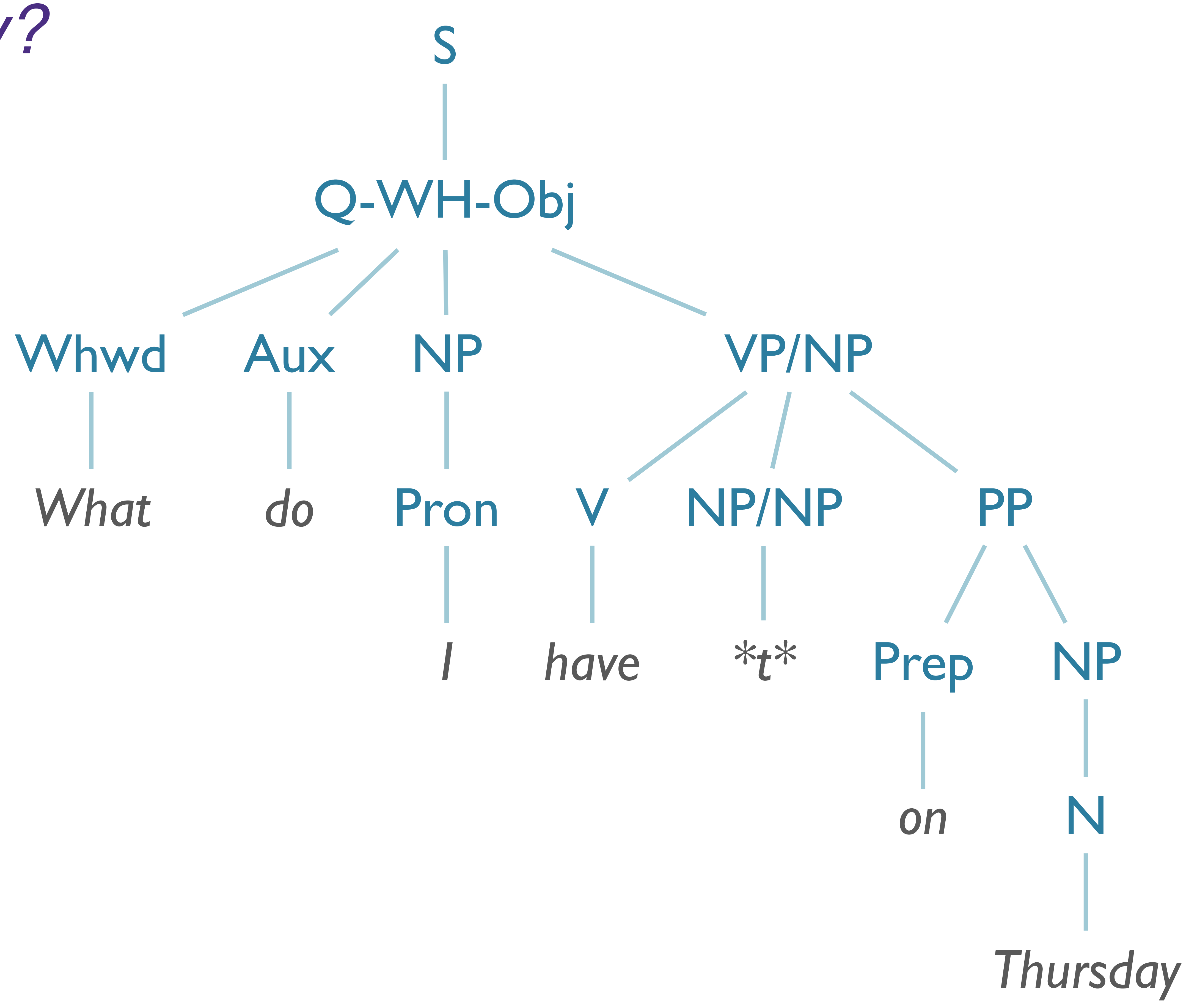

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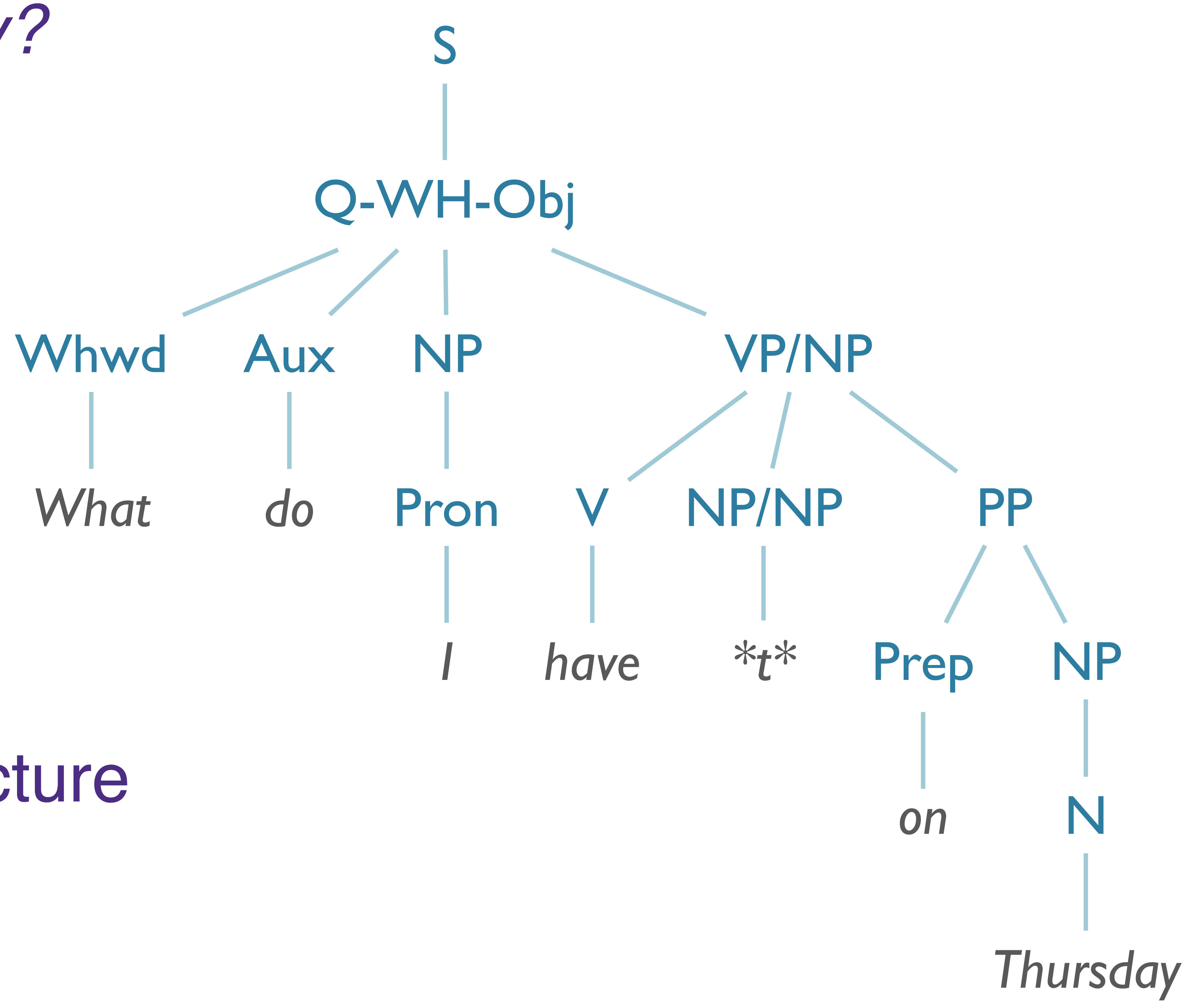
- Need to associate meaning w/structure



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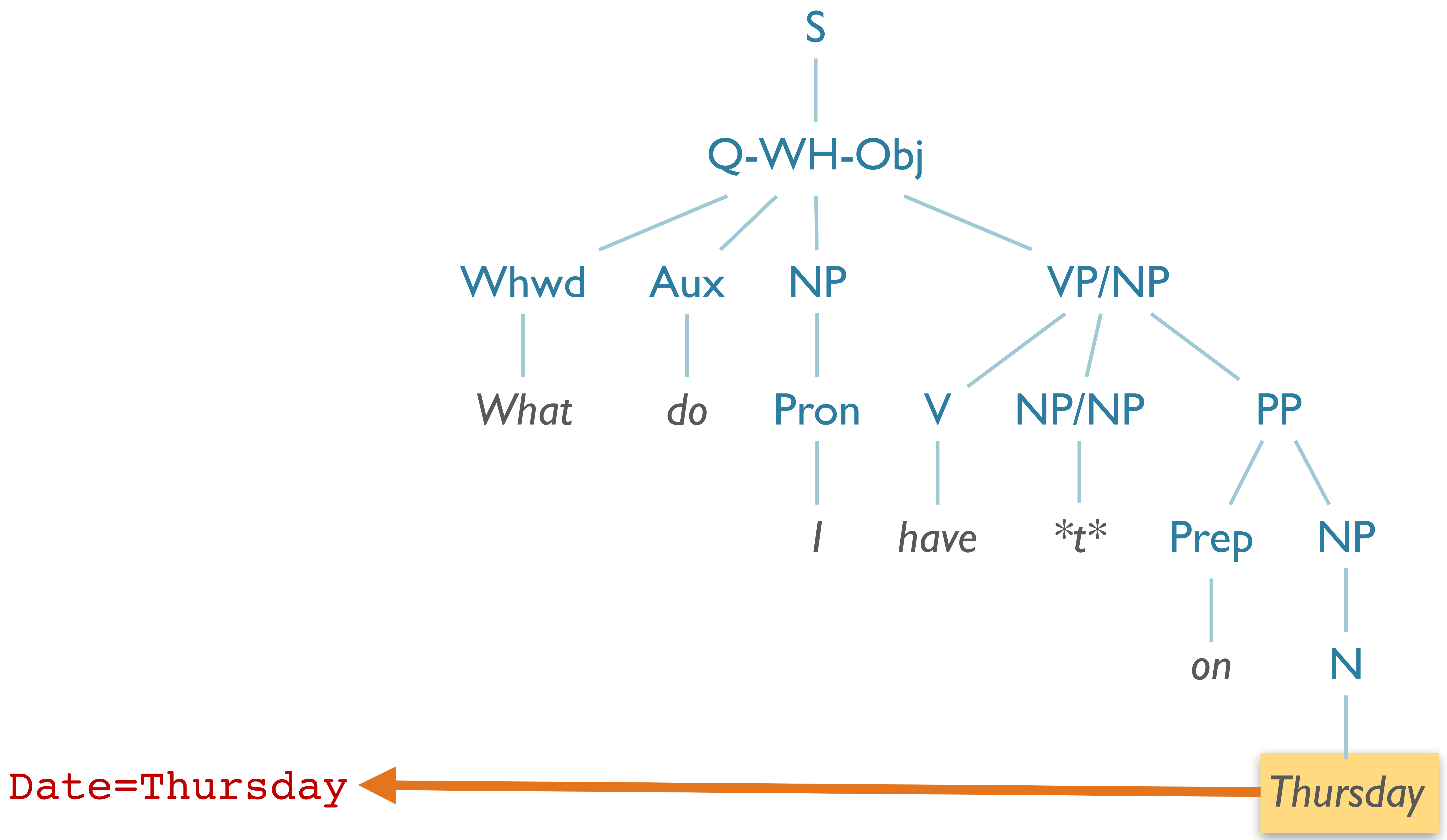

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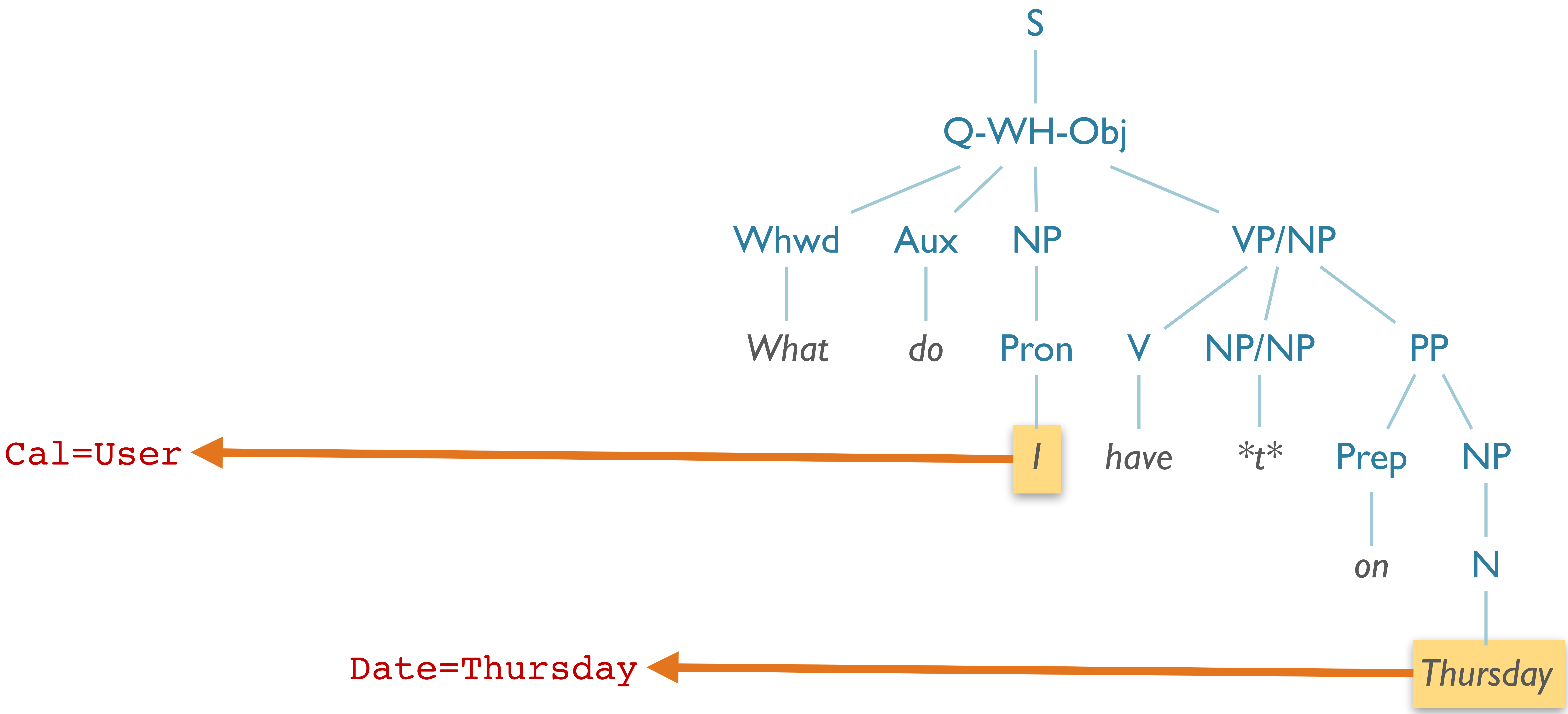

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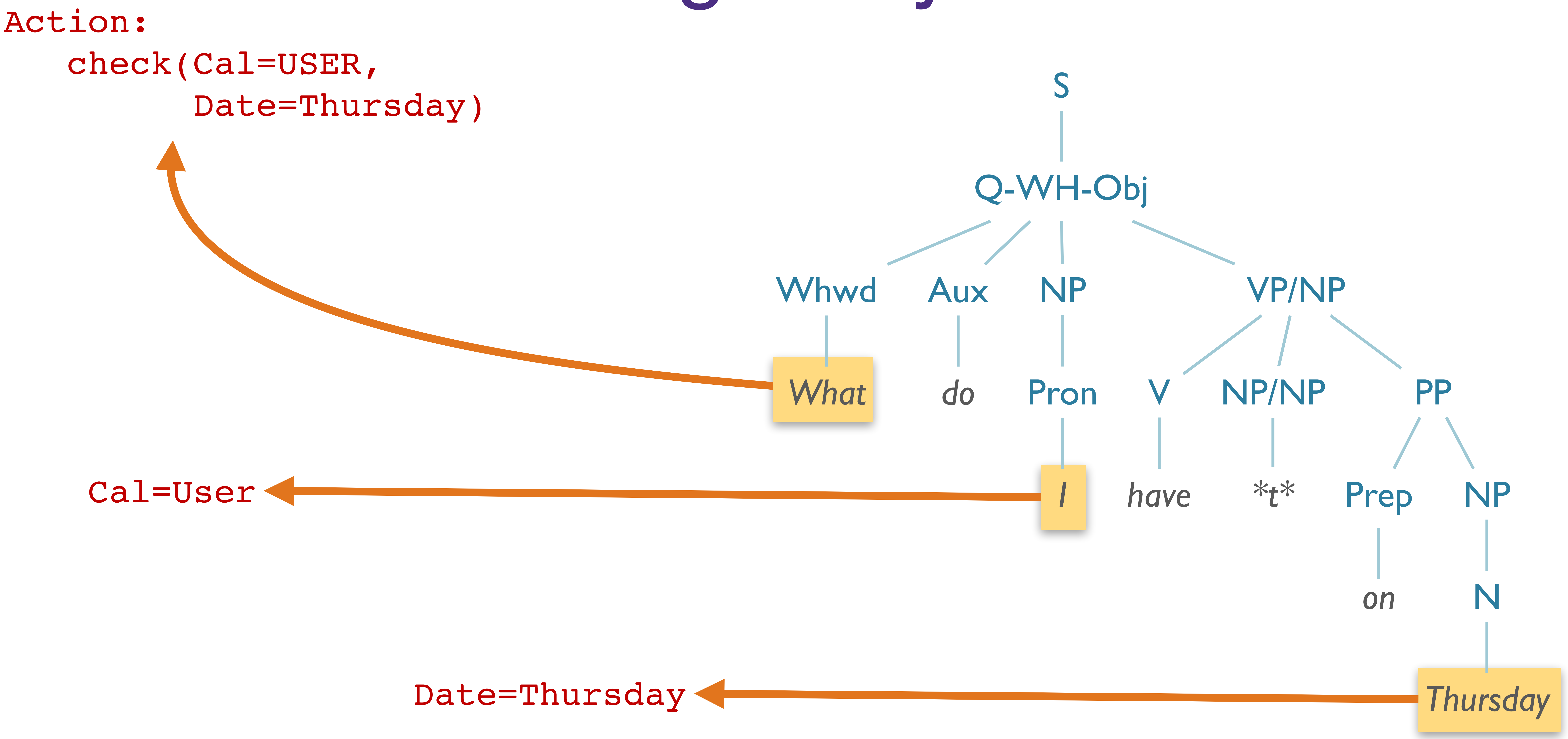

Syntax vs. Semantics

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

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

High-Level Overview

- Semantics = meaning

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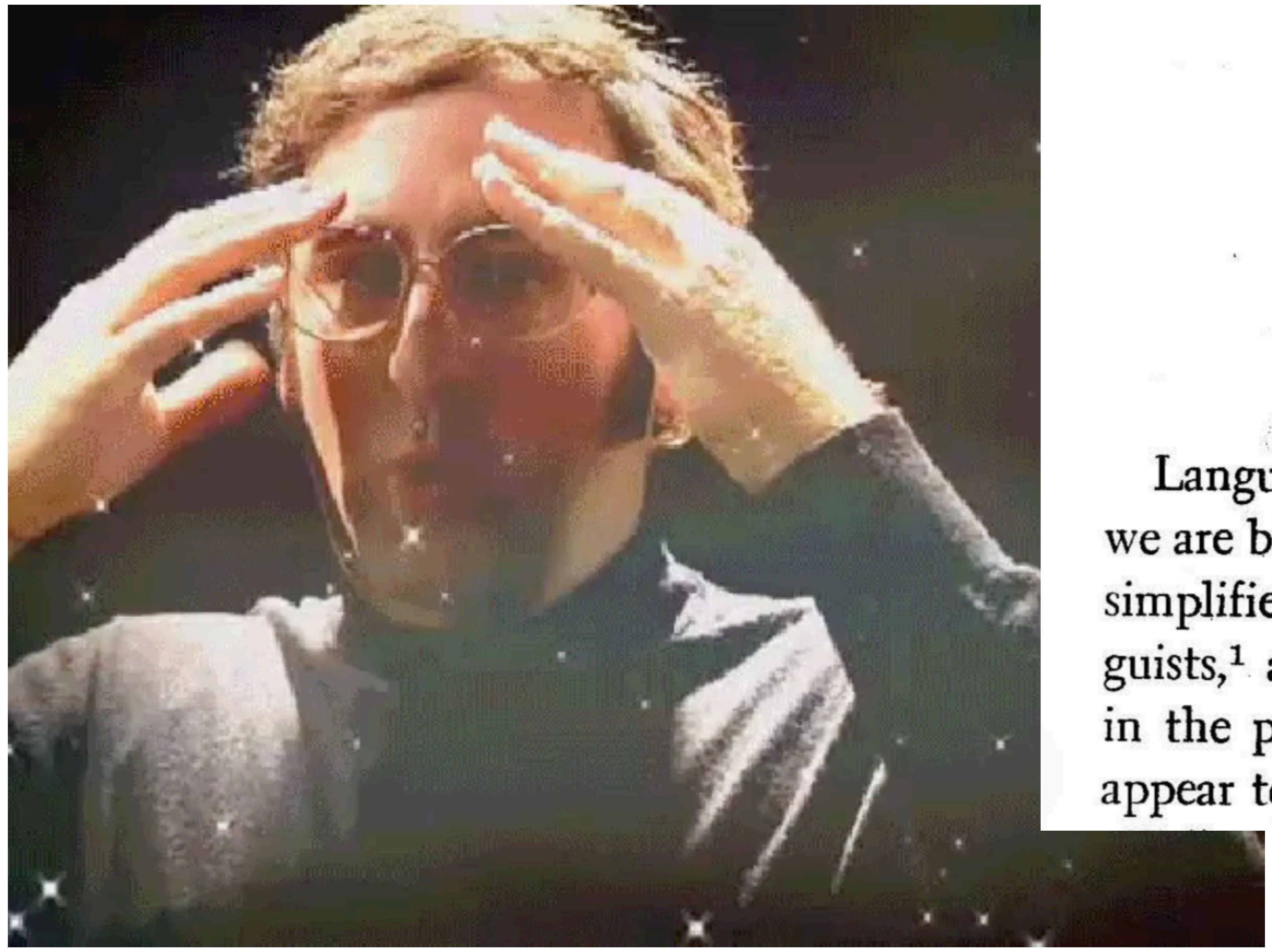

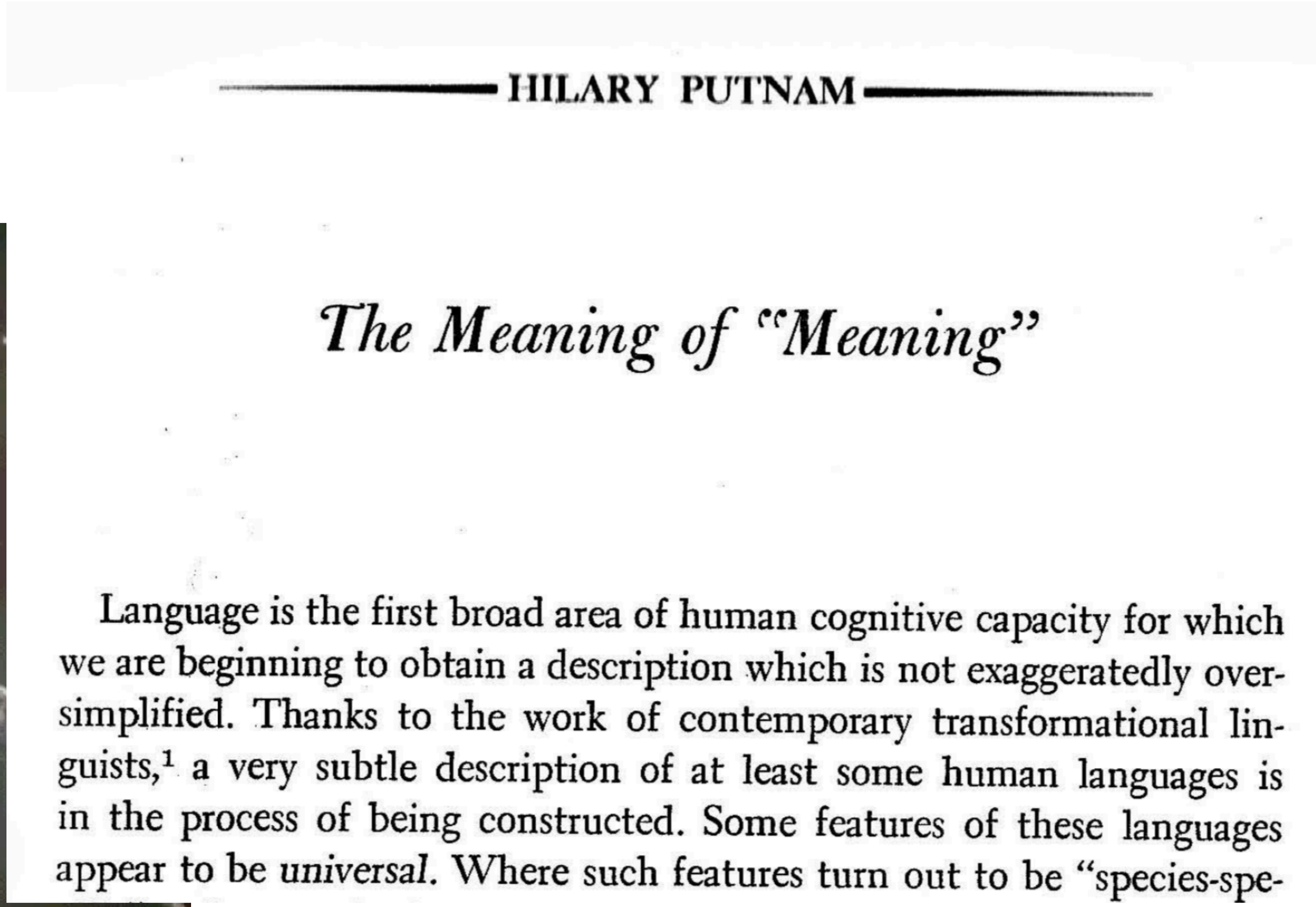

HILARY PUTNAM

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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Speech & Text

$$\exists x \; Sky(x) \wedge Blue(x)$$

Logic

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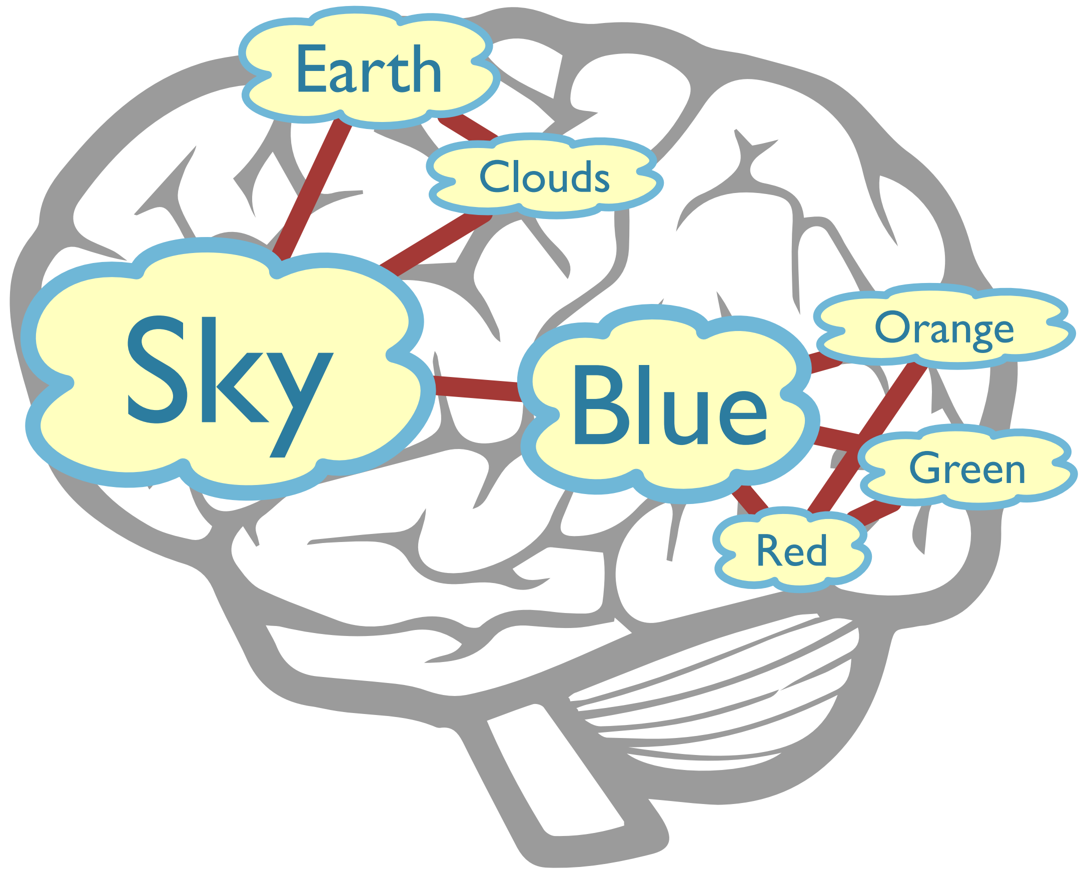

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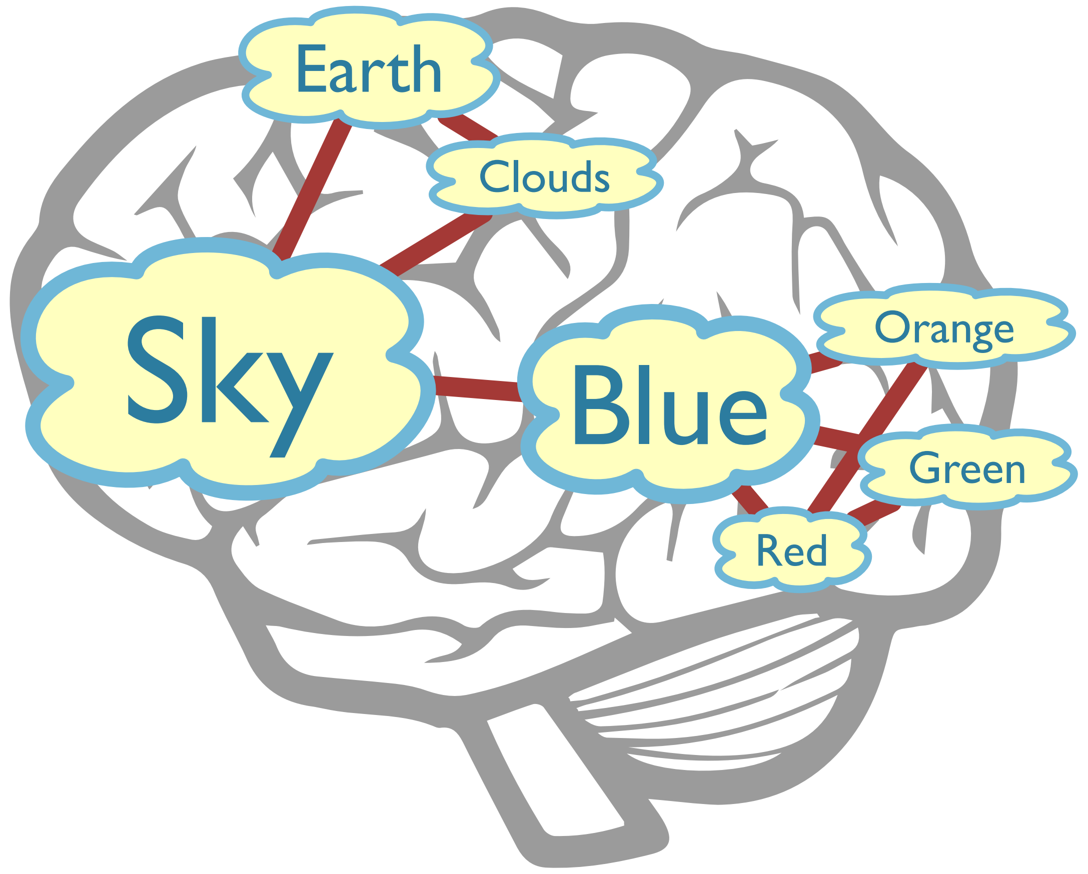

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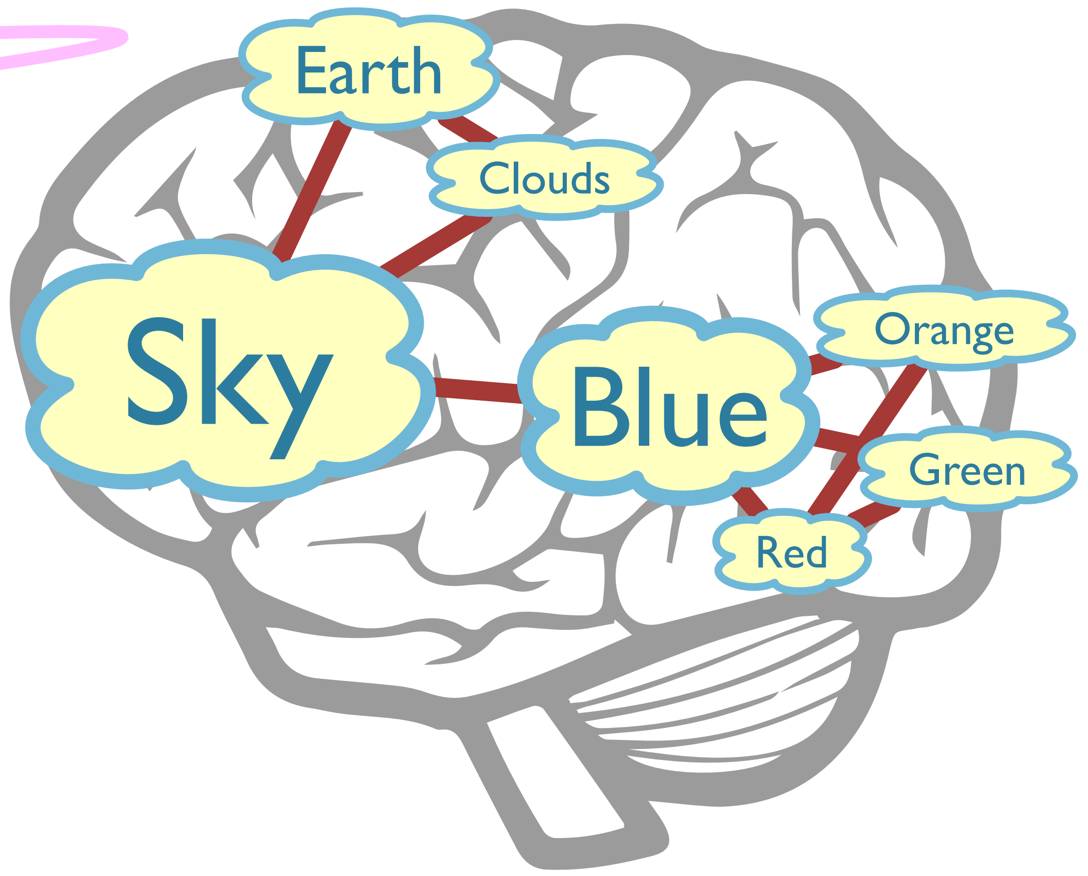


Psychology

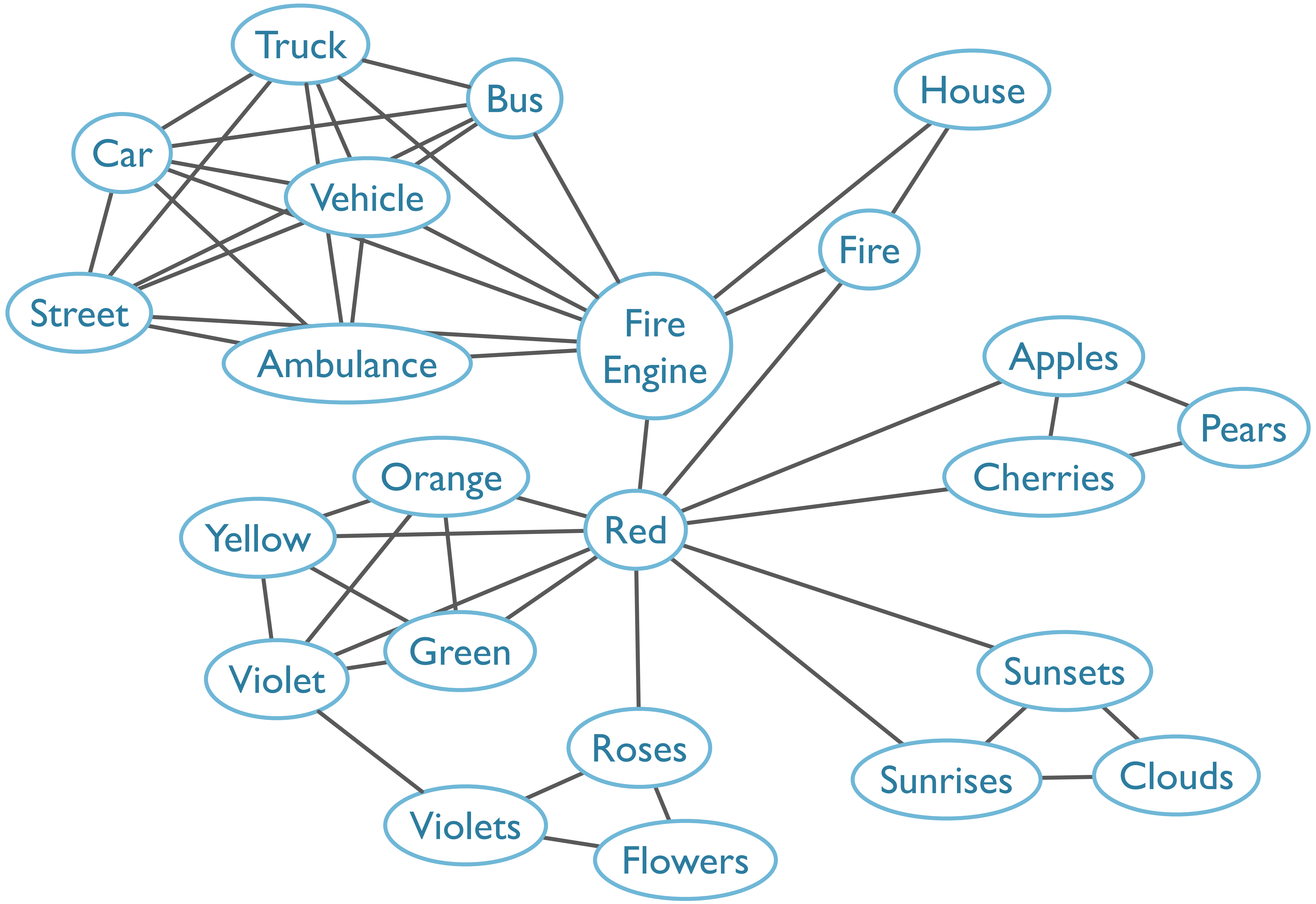
Epistemology

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

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  - Overview
  - **Semantics**
  - Representing Meaning
    - First-Order Logic
    - Events
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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: $\exists x \left(dog(x) \wedge disappear(x) \right)$

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  - What is the appropriate formal language to express propositions in linguistic input?
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- **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

- **Reference**
  - How do linguistic expressions link to objects/concepts in the real world?
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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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- **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: $\exists e, y \left(Having\,(e) \wedge Haver\left(e, Speaker\right) \wedge HadThing\left(e, y\right) \wedge Car\left(y\right) \right)$

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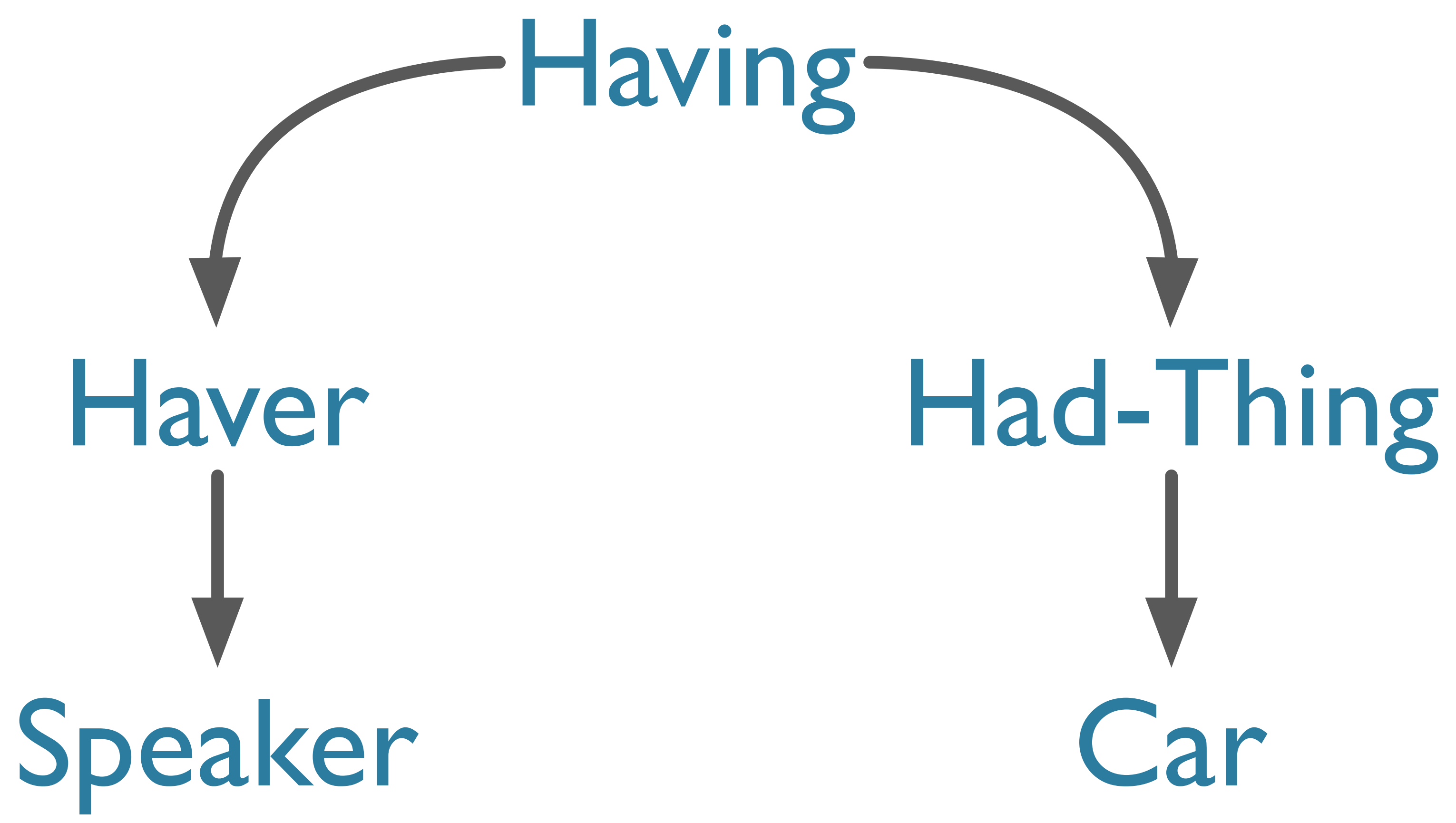

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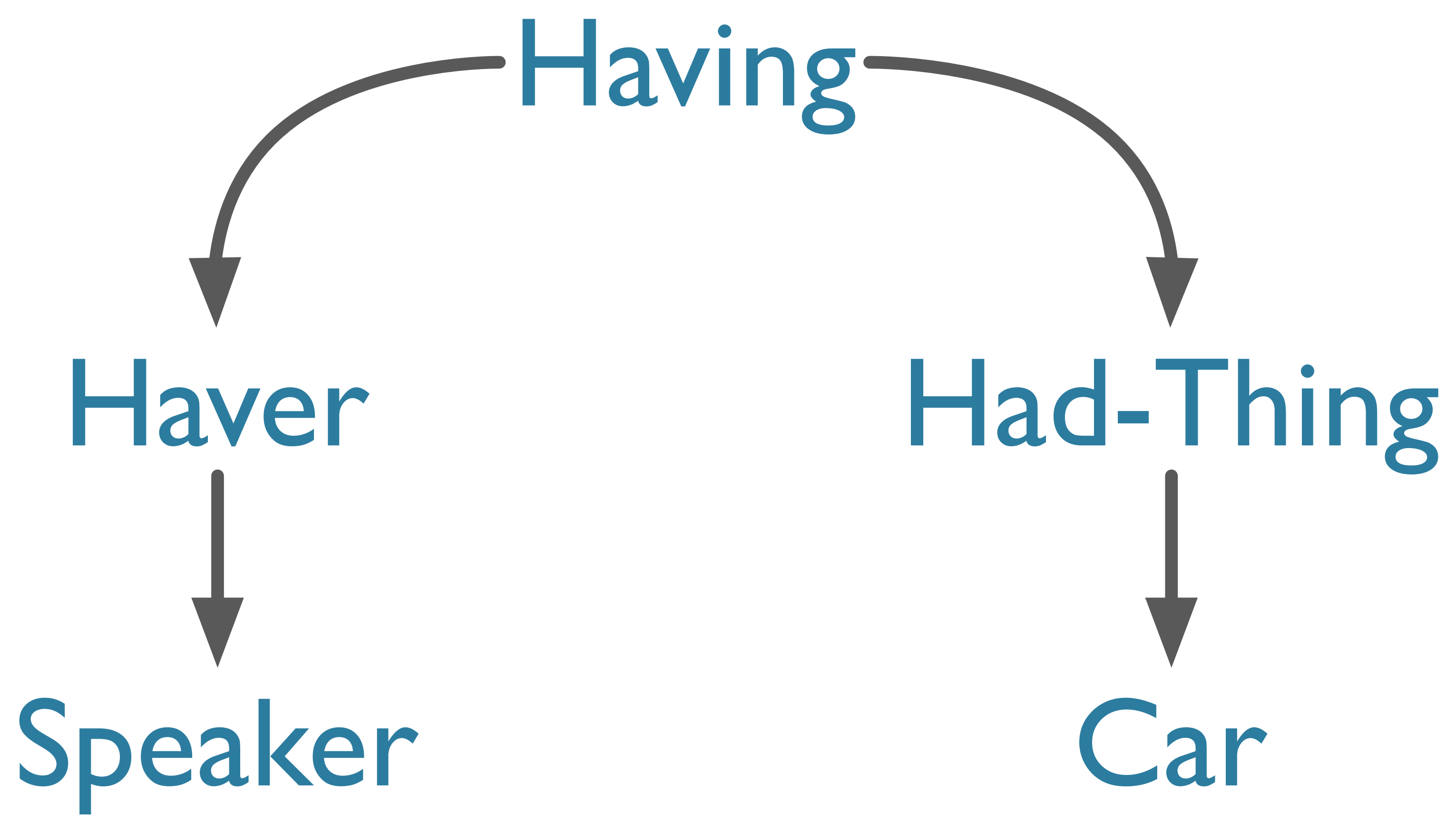

Conceptual Dependency:

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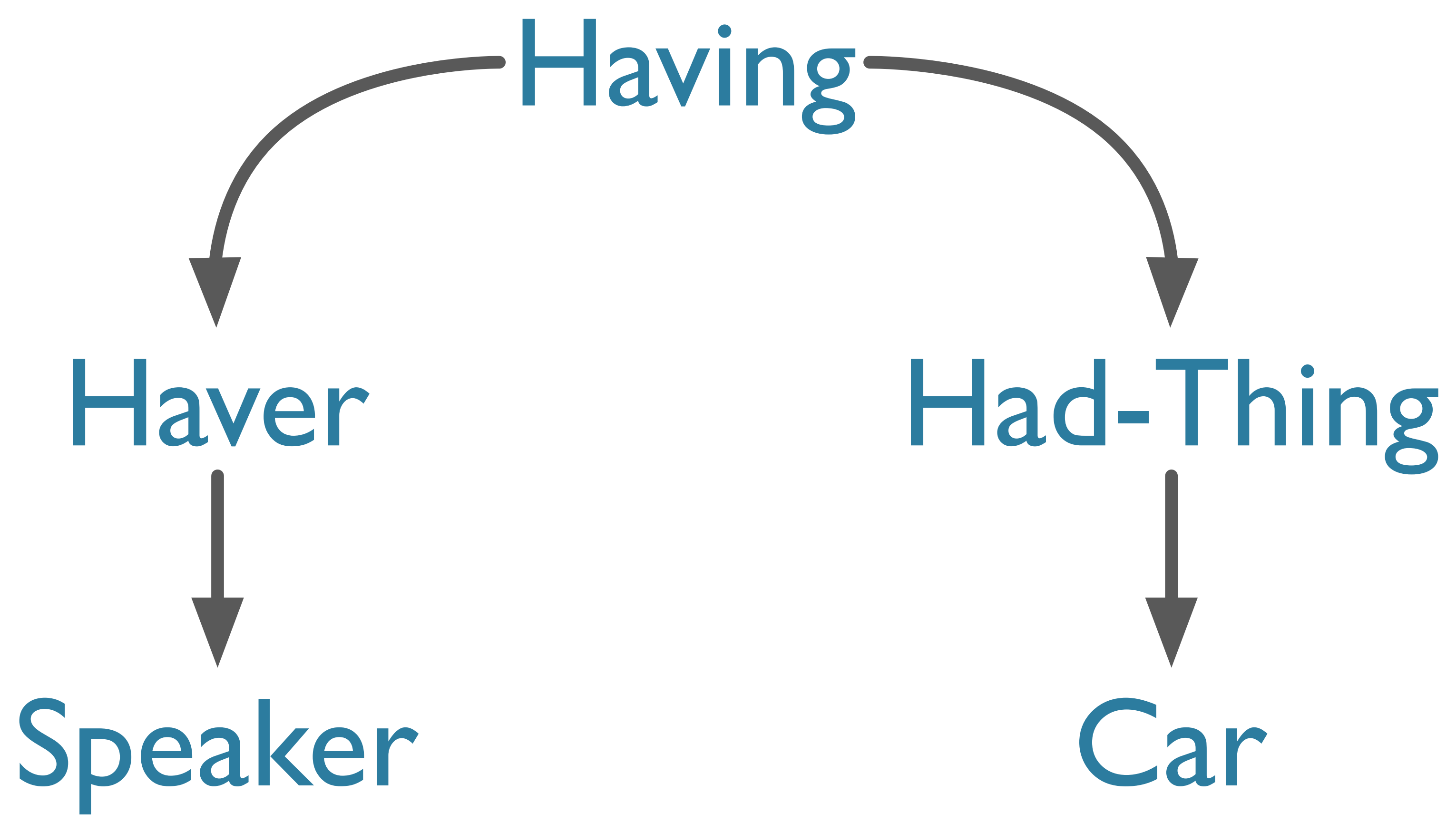

Conceptual Dependency:

Frame-Based:

```
Having
    Haver: Speaker
    HadThing: Car
```

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- Here we focus on **literal** meaning (“what is said”)

Representational Requirements

- Verifiability
- Unambiguous representations
- Canonical Form
- Inference and Variables
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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

- Represent concepts and relationships

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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**
  - Relate ***objects*** to other ***objects***
  - *‘United serves Chicago’*
    - $Serves(United,\ Chicago)$

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  - *'United serves Chicago'*
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- **Logical Connectives**
  - {∧, ∨, ⇒} = {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**:

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

Quantifiers

- ∀: **universal** quantifier: *"for all"*
  - **All flights include beverages.**

Quantifiers

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

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

FOL Syntax Summary

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

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

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

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

Compositionality

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

Compositionality

- …how can we derive:
  - $loves(John,\ Mary)$
- from:
  - $John$
  - $loves(x,\ y)$
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  - $Mary$
- 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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- Equivalent to function application

Nested λ-Reduction

- Lambda expression as body of another

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Nested λ-Reduction

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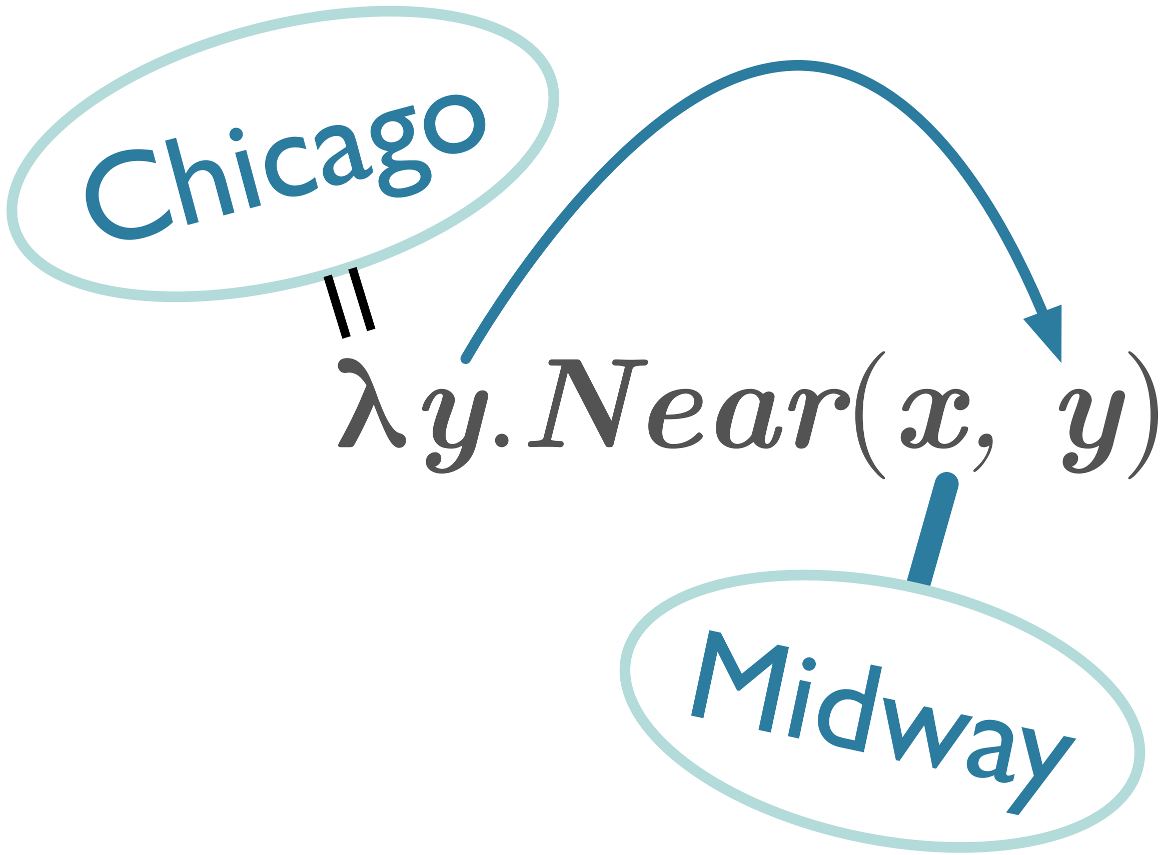

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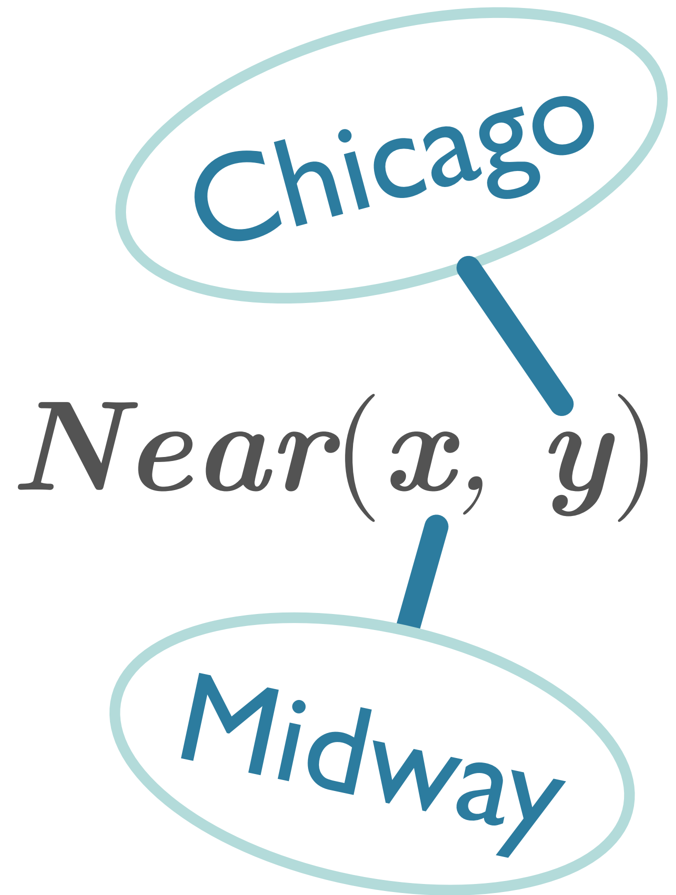

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- ***Currying***
  - Converting multi-argument predicates to sequence of single argument predicates
  - Why?
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- …or *Schönkfinkelization*

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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- 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*
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Logical Formulae: Finer Points

- $\vee$ is not exclusive:
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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

1. $\forall x\ \alpha(x)$

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Inference

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

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- Standard AI-type logical inference procedures
  - Modus Ponens
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  - 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

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

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- Variable number of arguments; many entailment relations here.

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Representing Events

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

Why events?

- “Adverbial modification is thus seen to be logically on a par with adjectival modification: what adverbial clauses modify is not verbs but the events that certain verbs introduce.” —Davidson

Neo-Davidsonian Events

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- Neo-Davidsonian representation:
  - Distill event to single argument for main predicate
  - 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