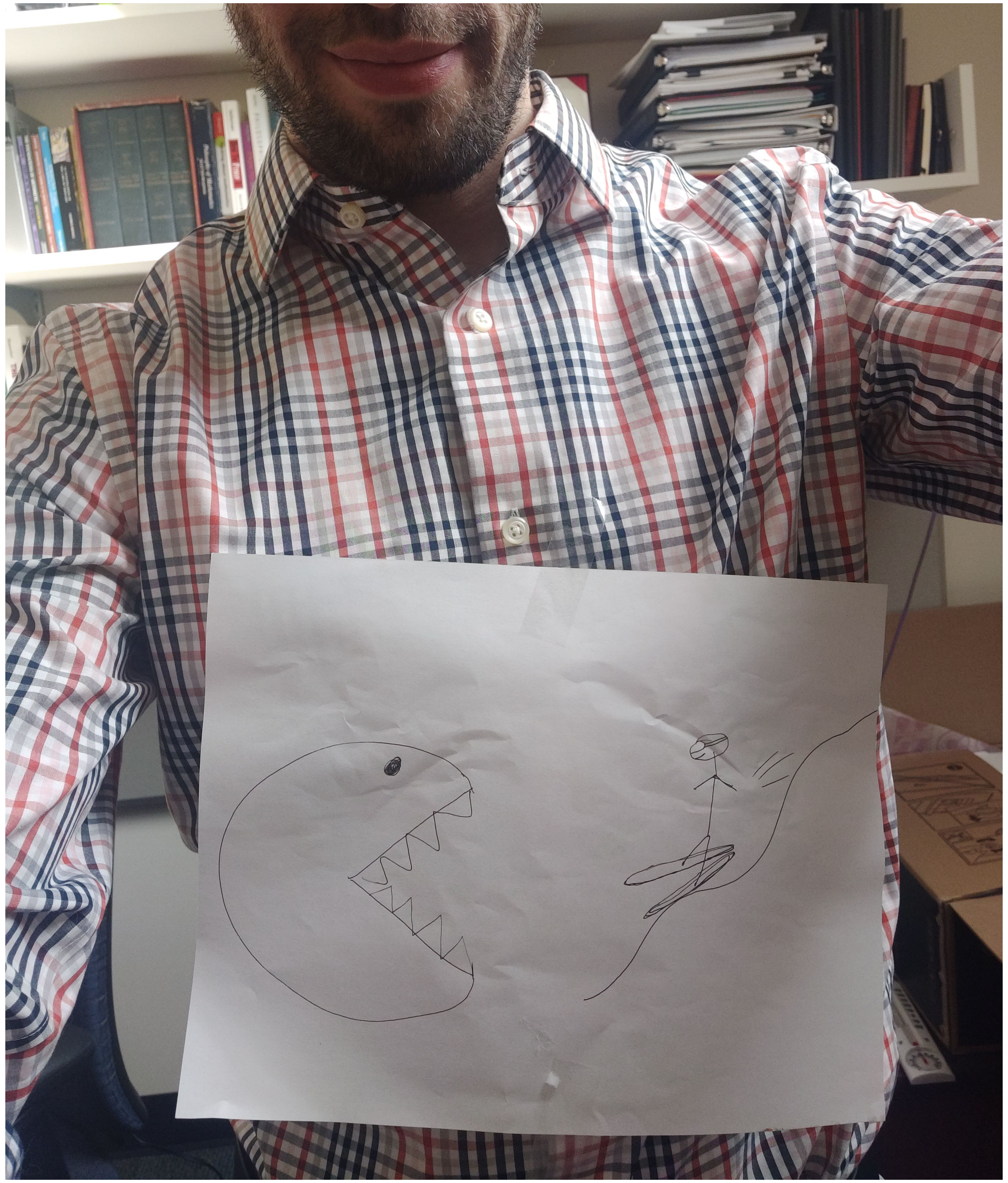
Feature-based Parsing
+
Computational Semantics

LING 571 — Deep Processing for NLP

October 27, 2021

Shane Steinert-Threlkeld

Happy (early) Halloween!



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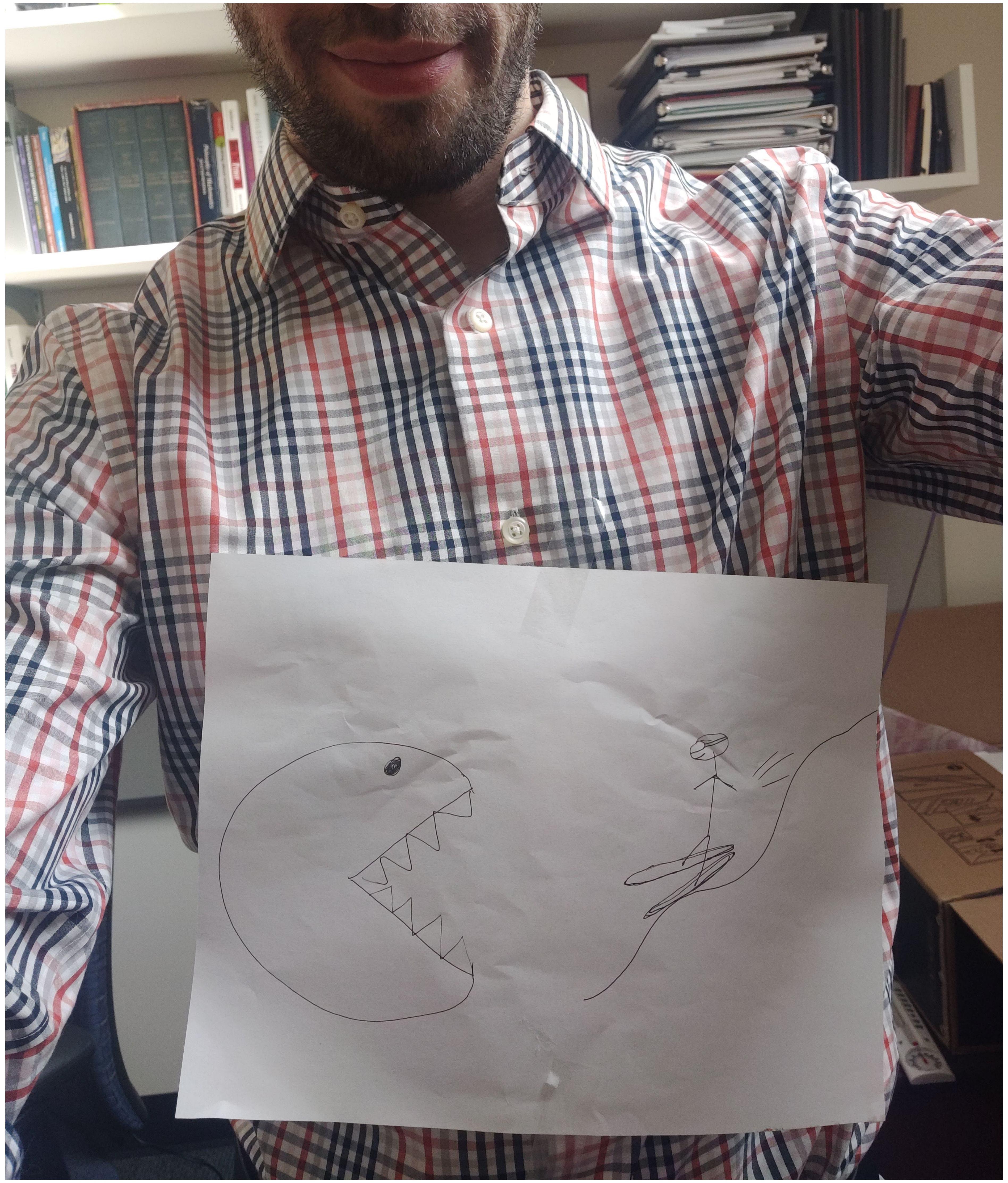

2019: Chomp + Ski = Chomsky

Punny Department

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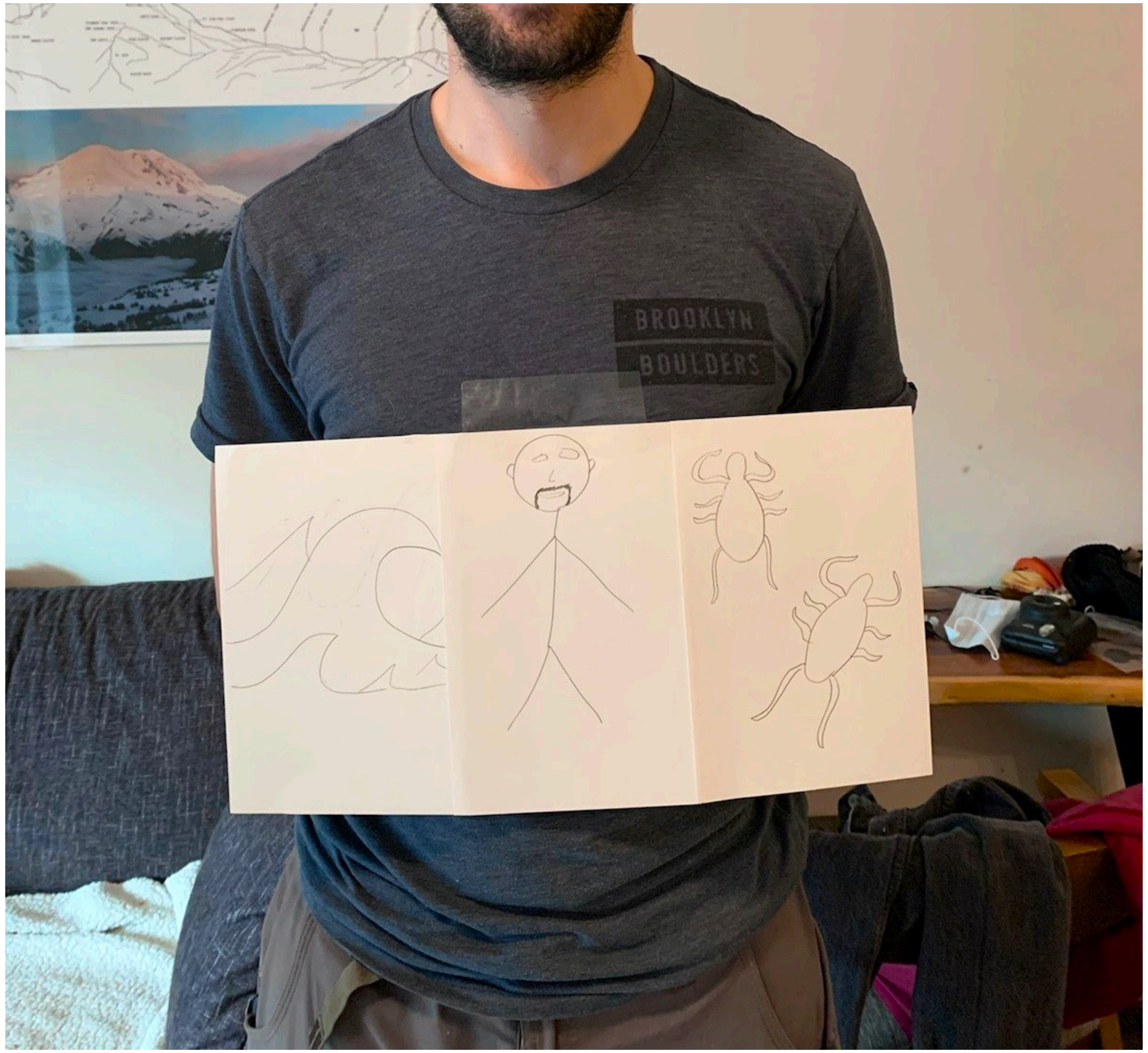

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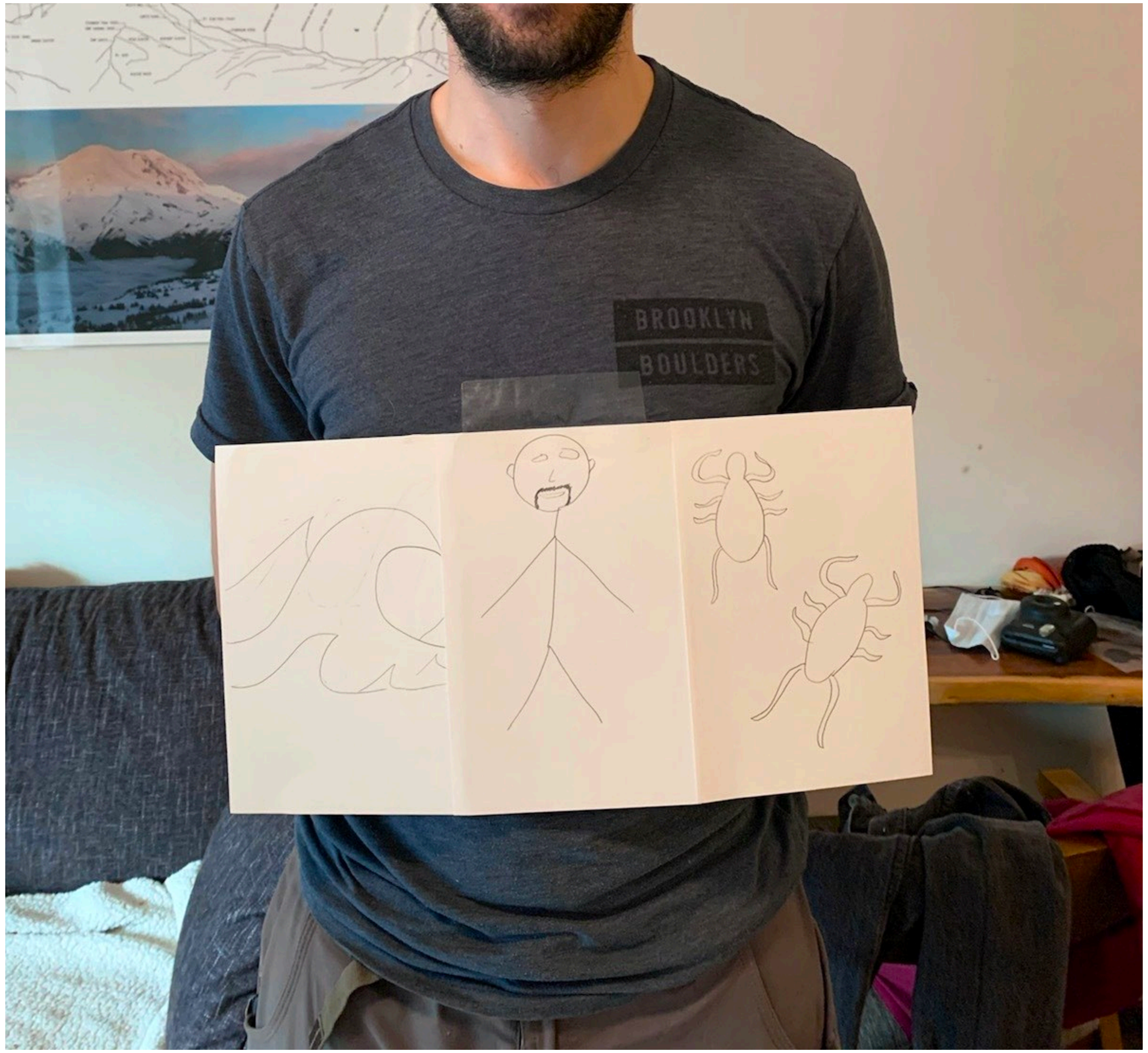

2020: Sea + Man + Ticks = Semantics

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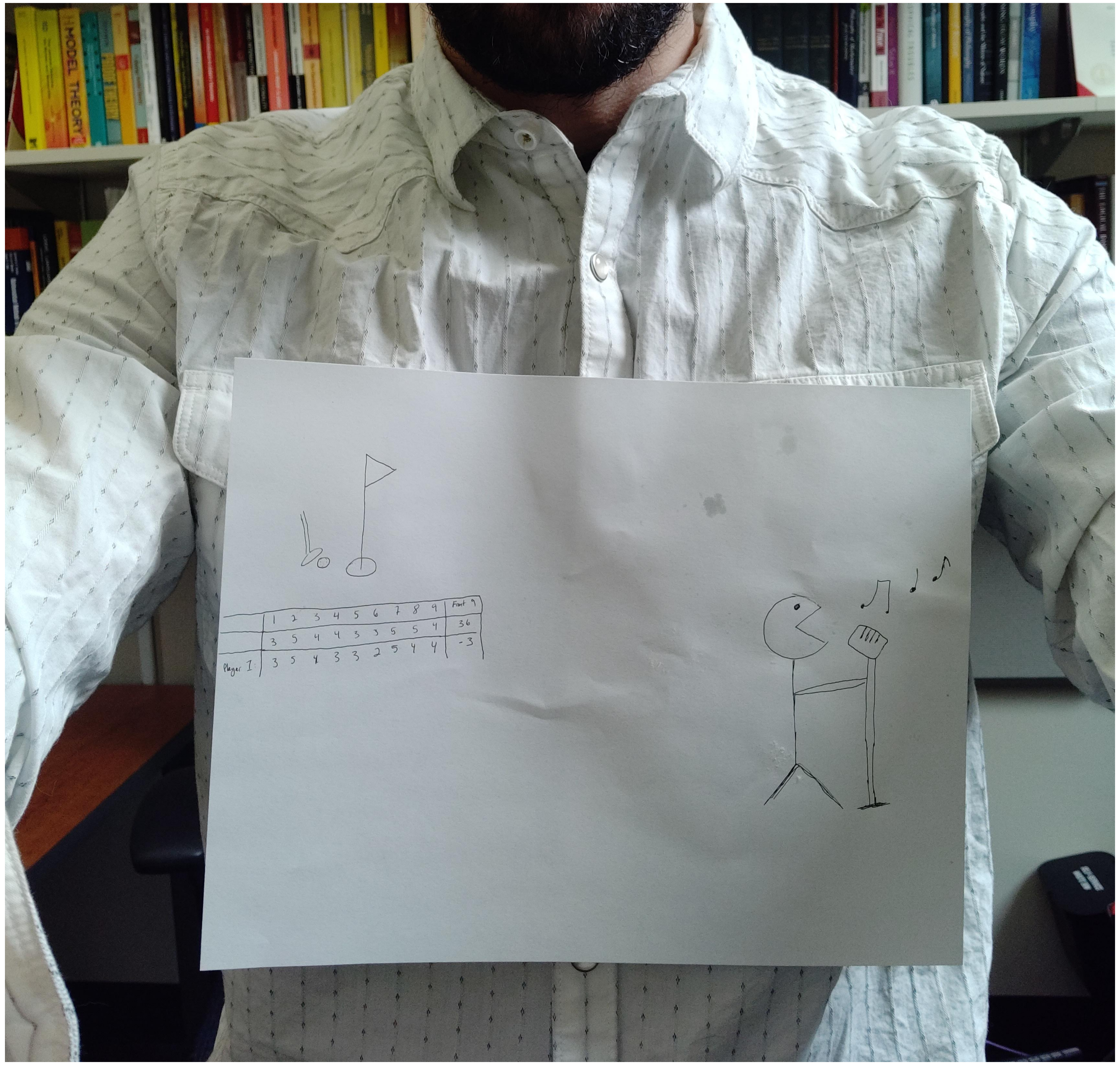

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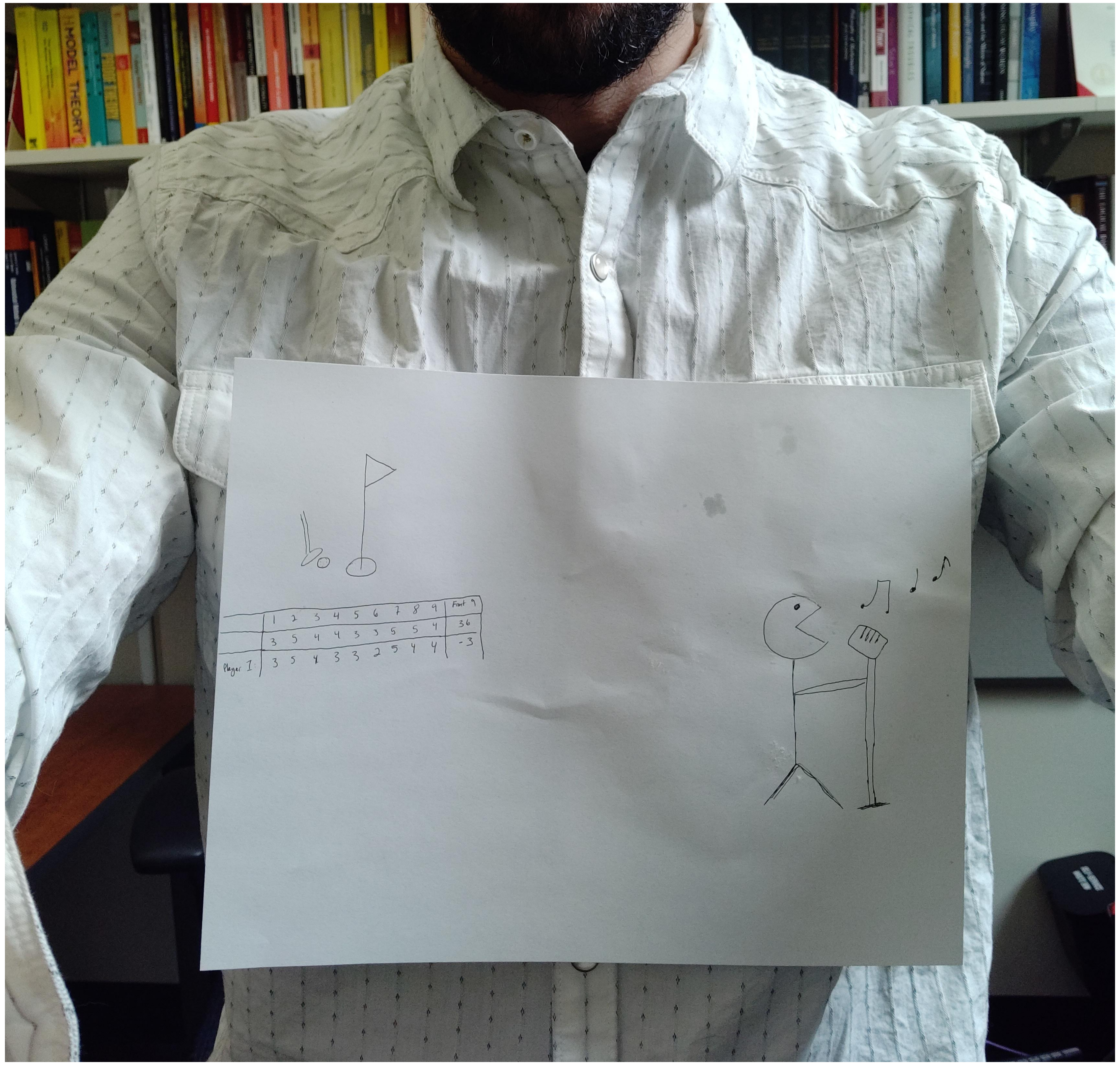

2021: ???

Guess the costume (one word)!

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?*

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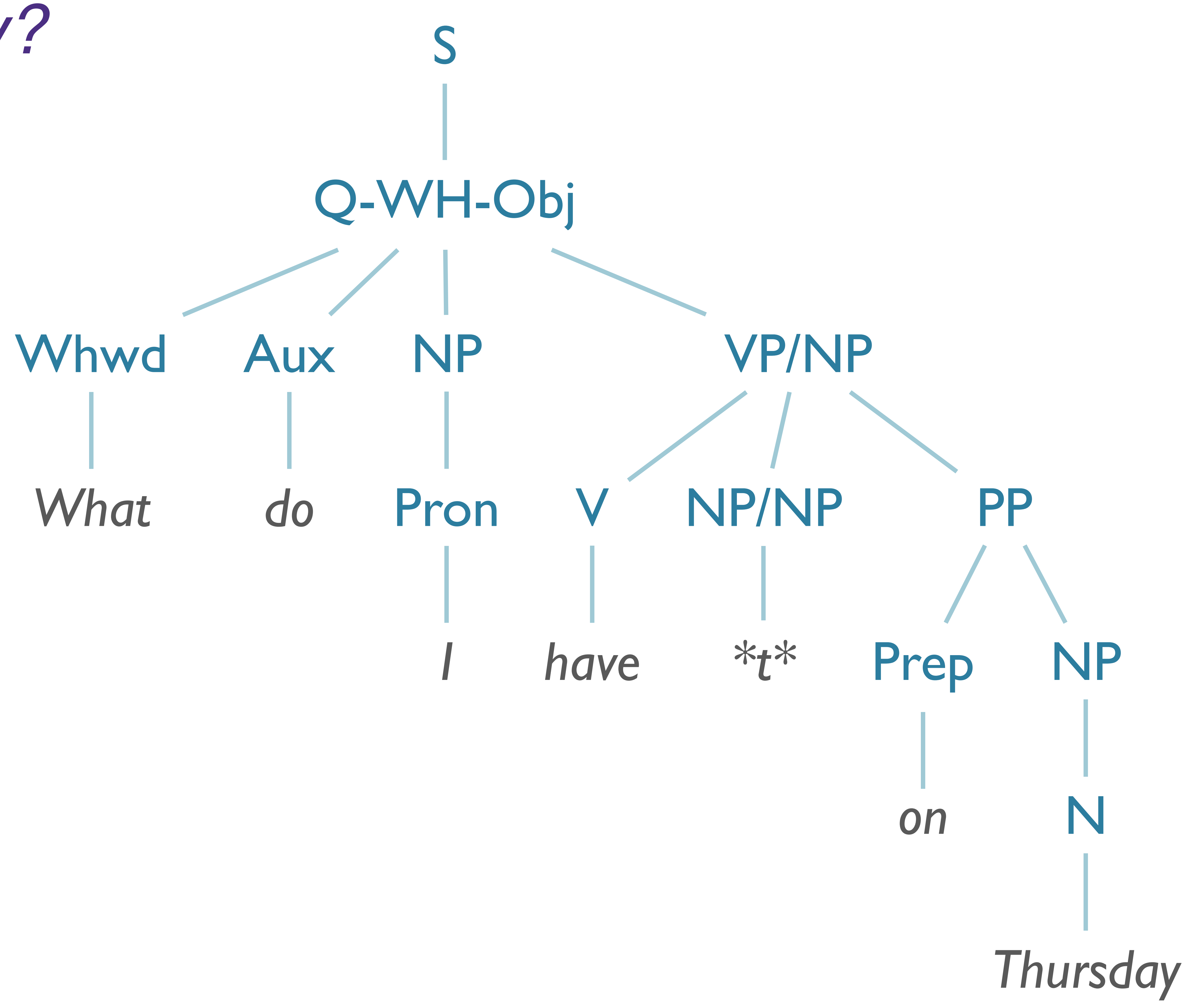

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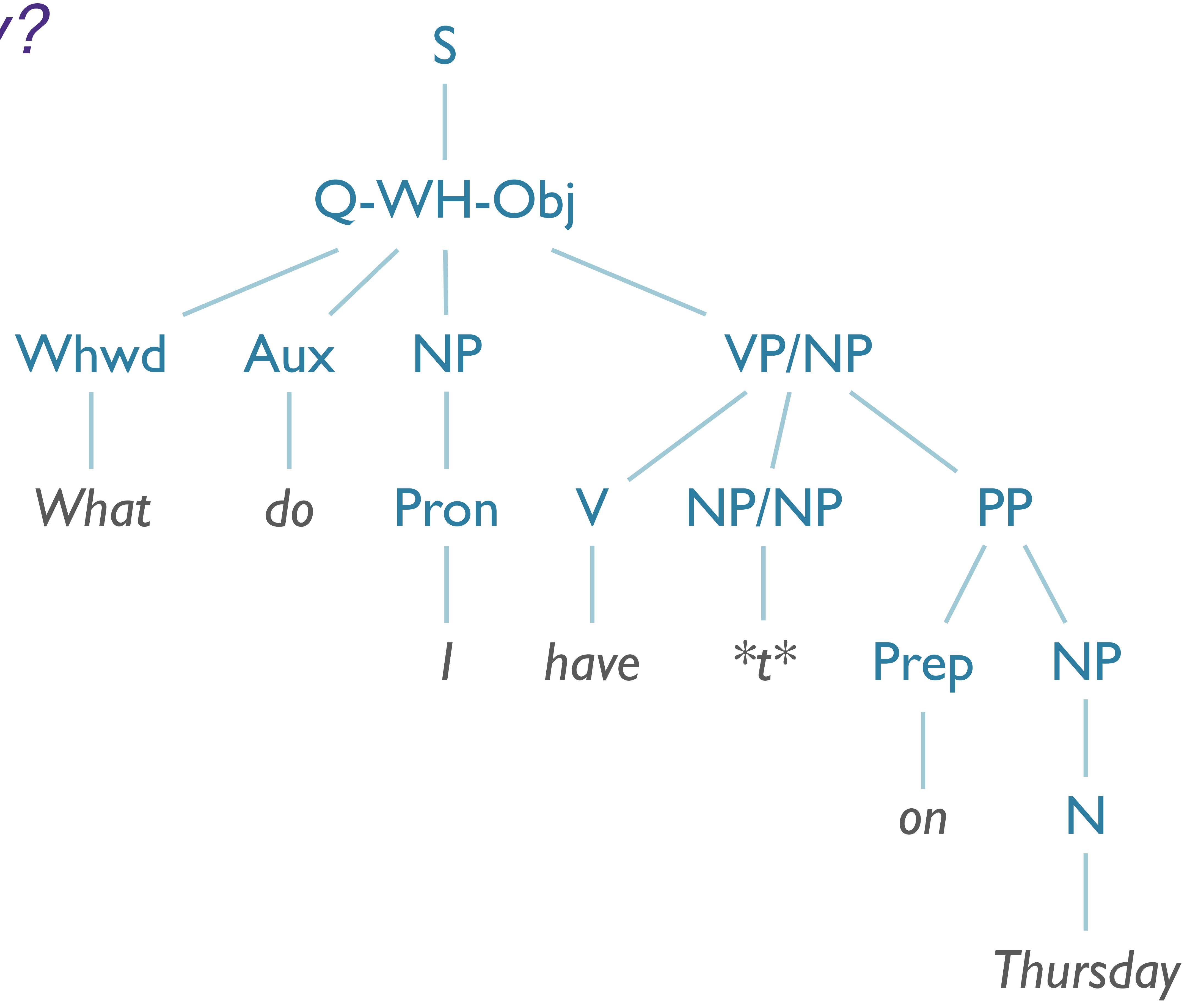

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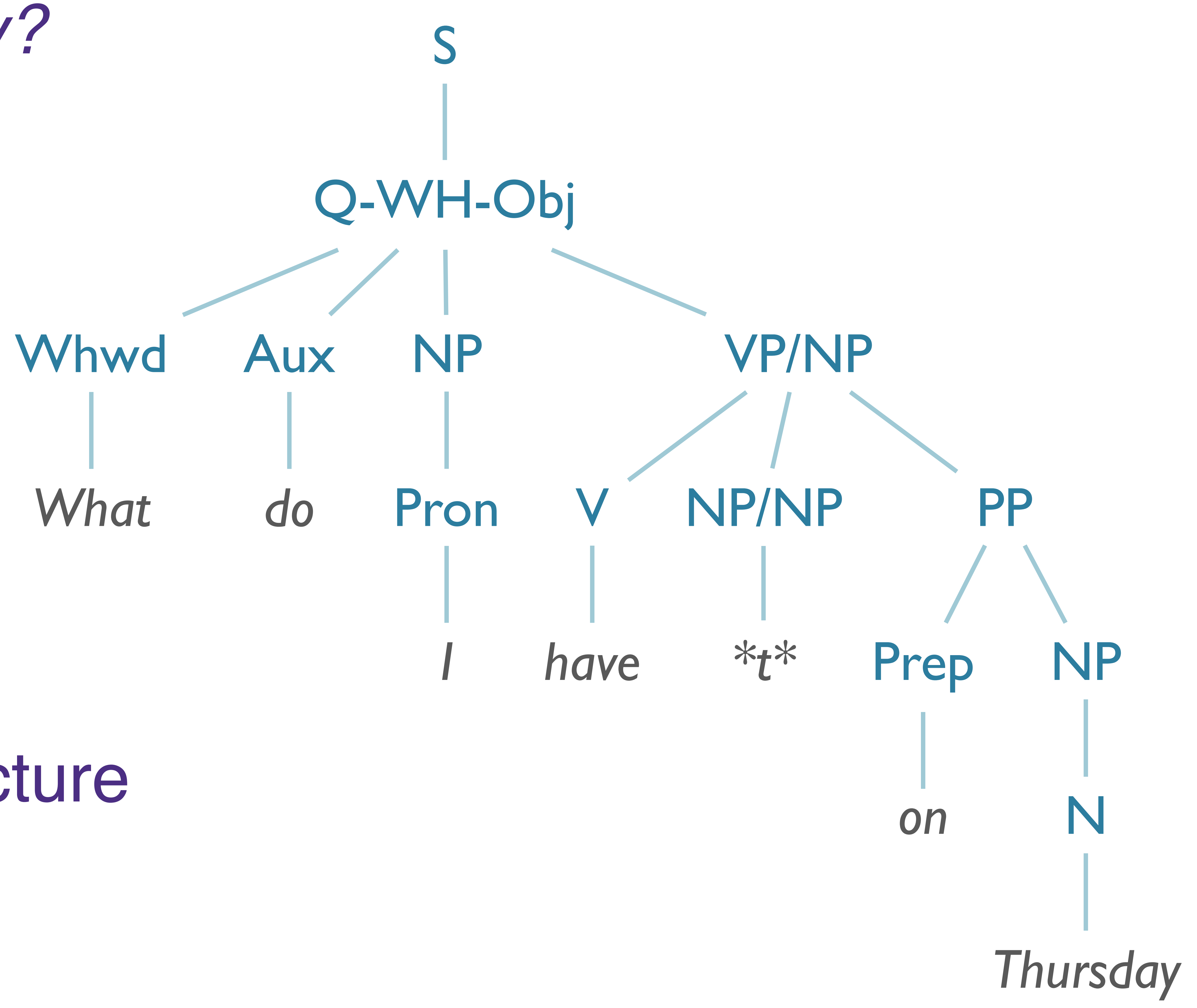
- Need to associate meaning w/structure



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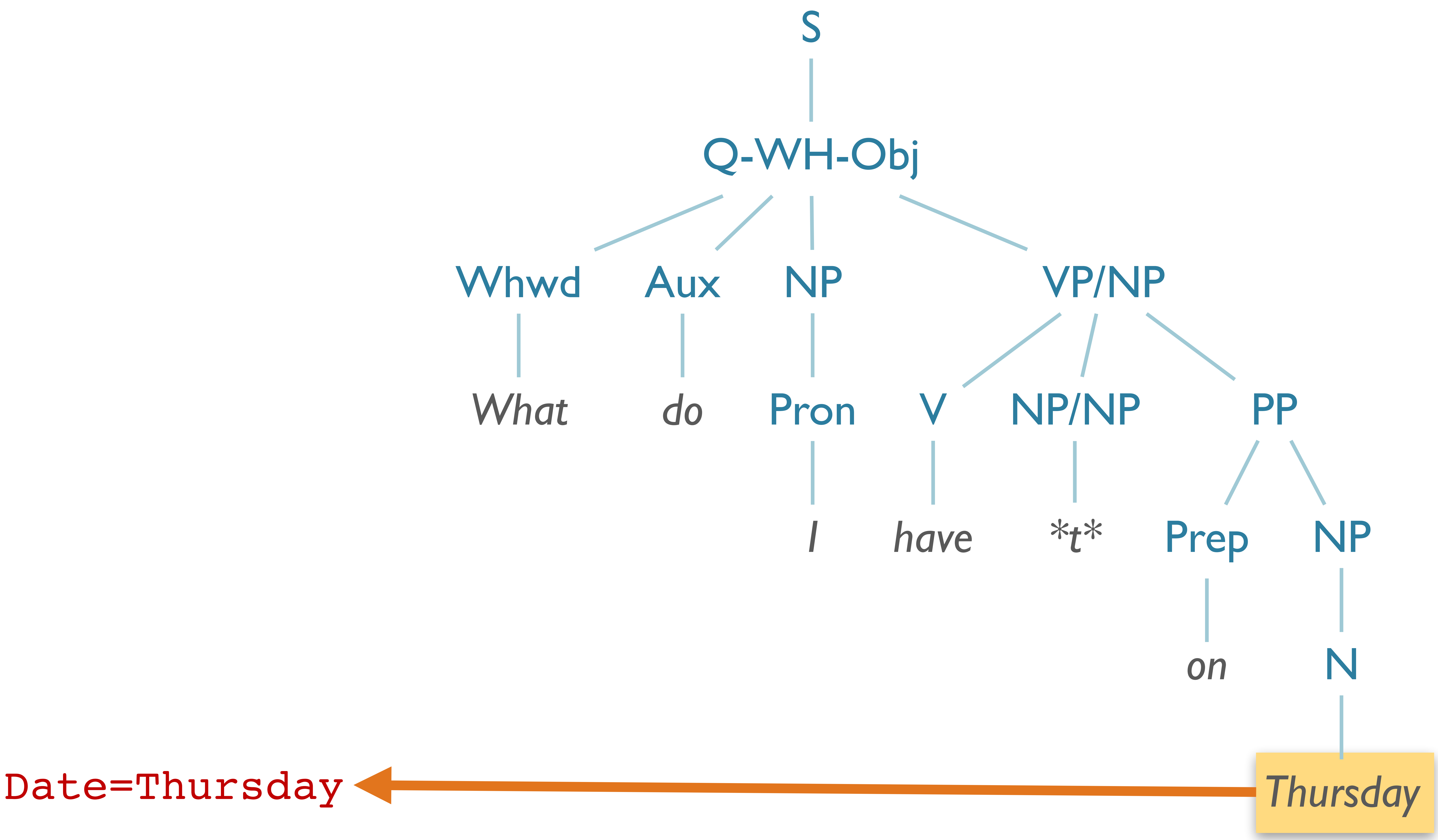

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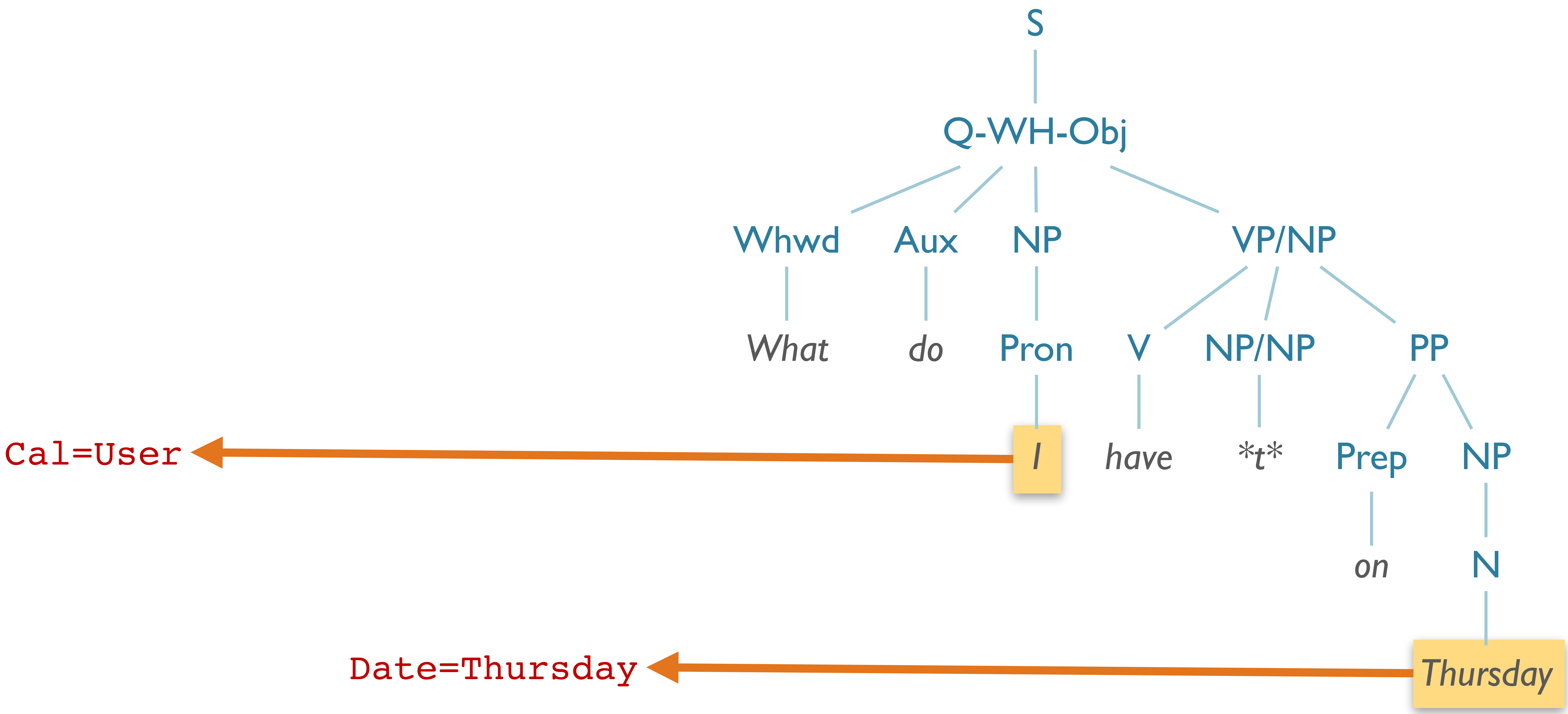

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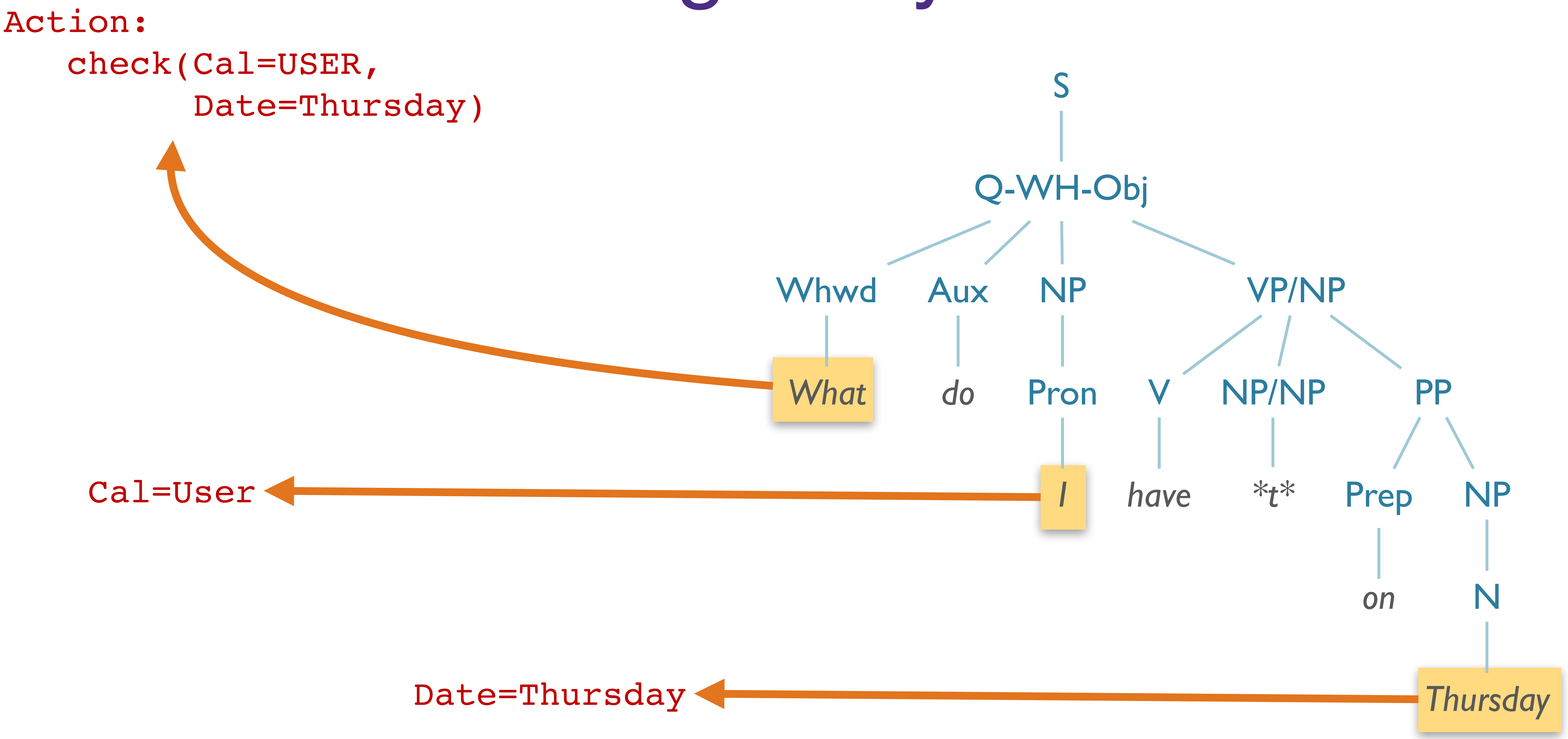

Syntax vs. Semantics

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

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- Semantics:
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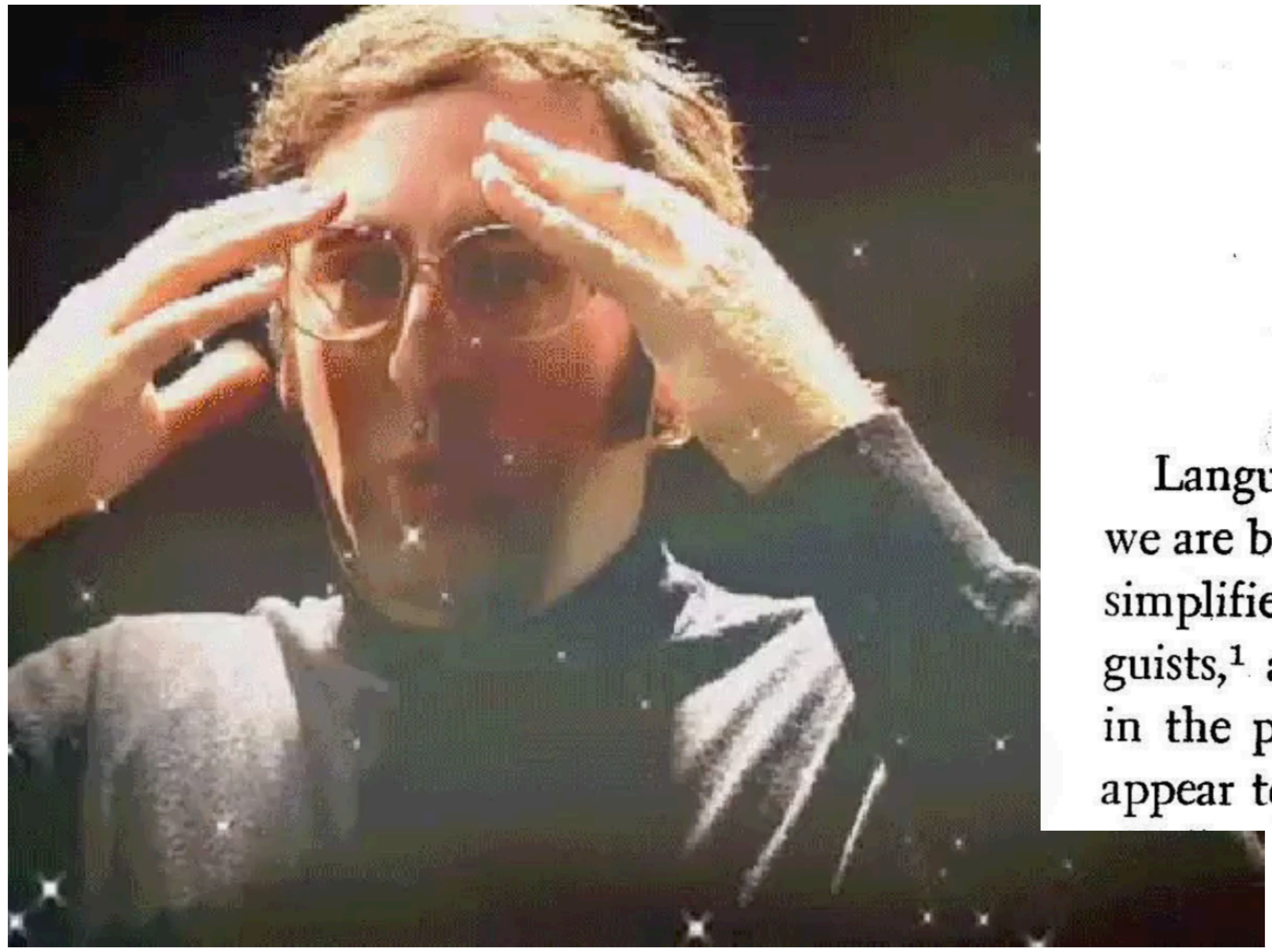

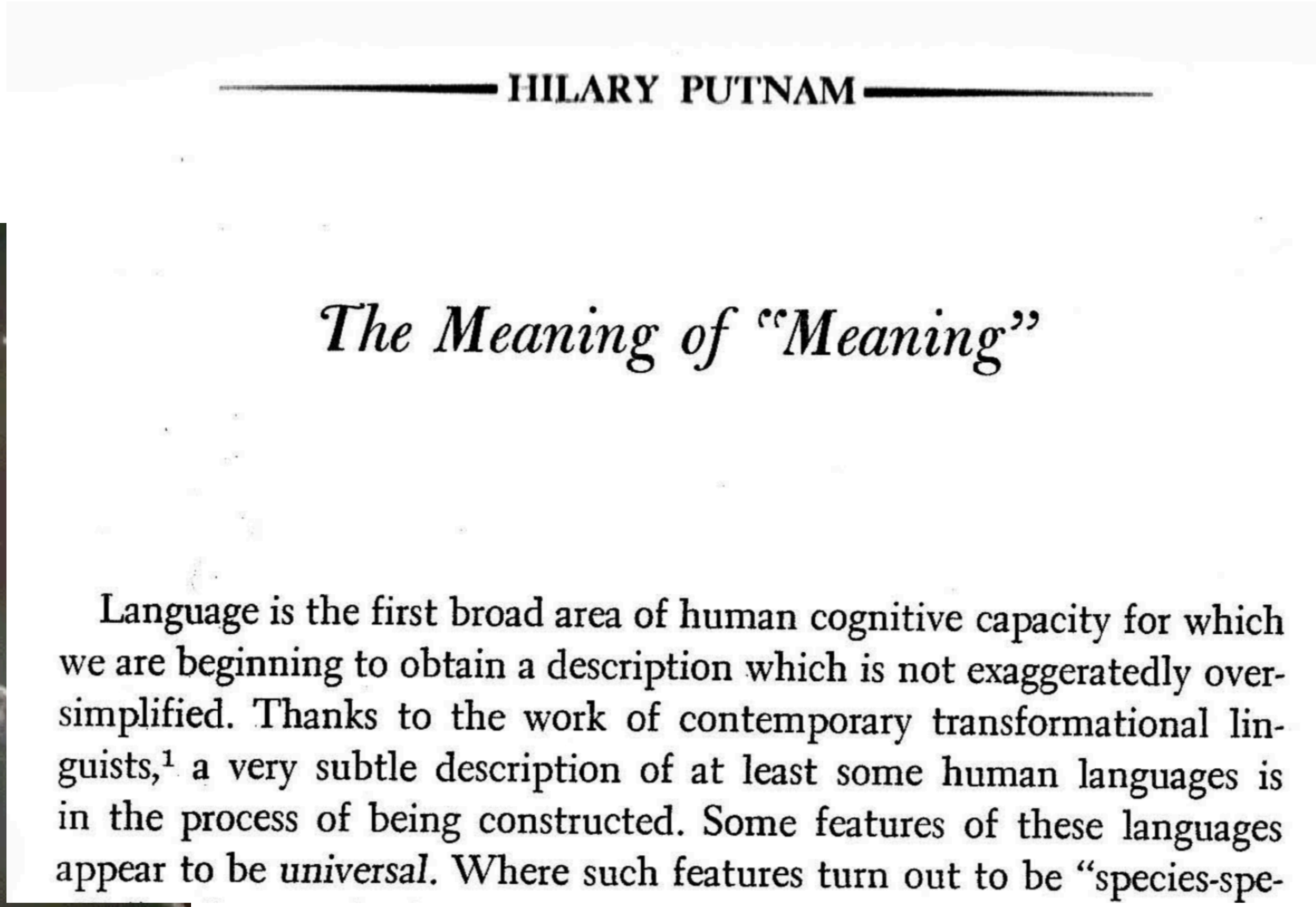

HILARY PUTNAM

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

Logic

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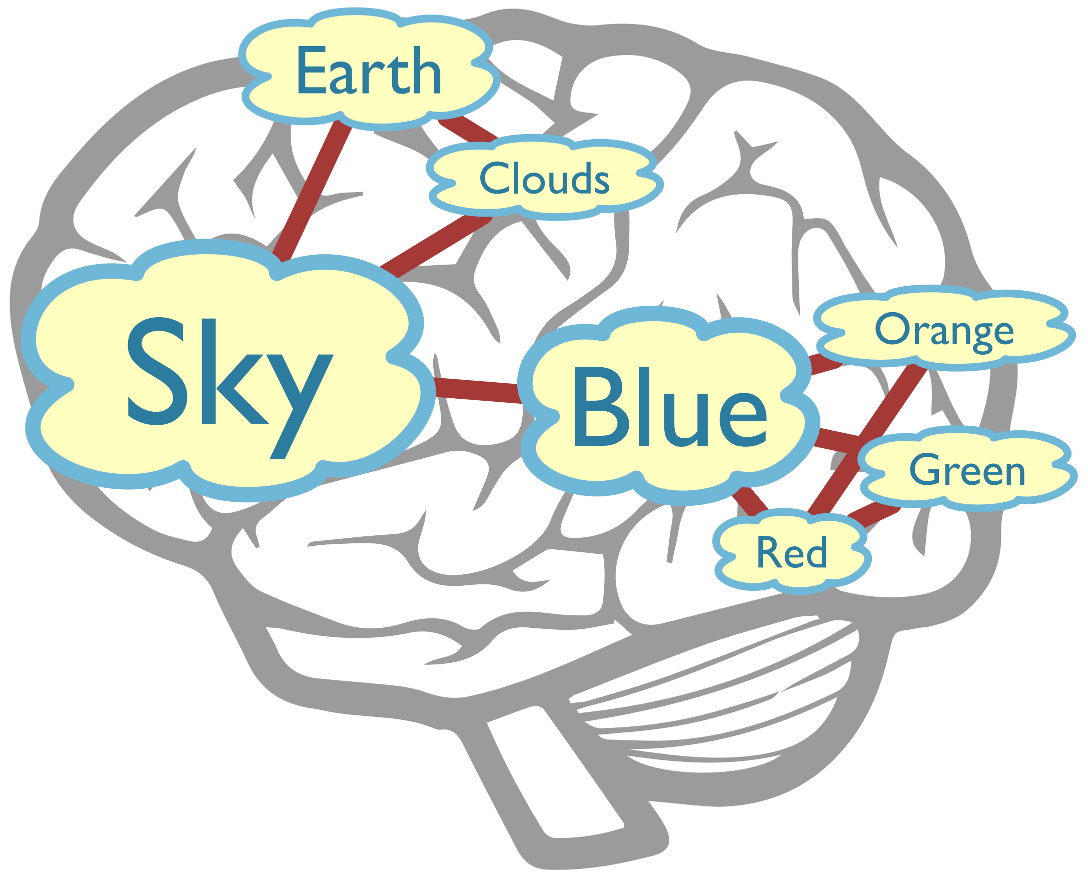

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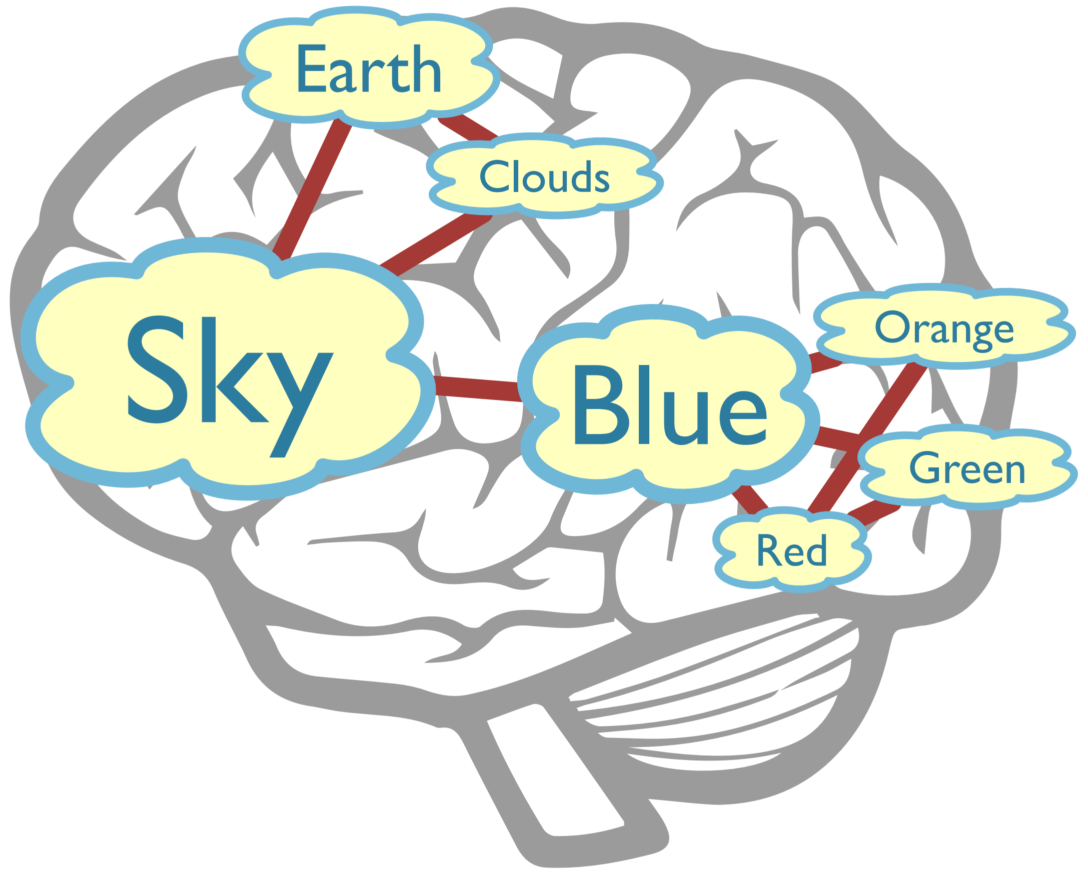

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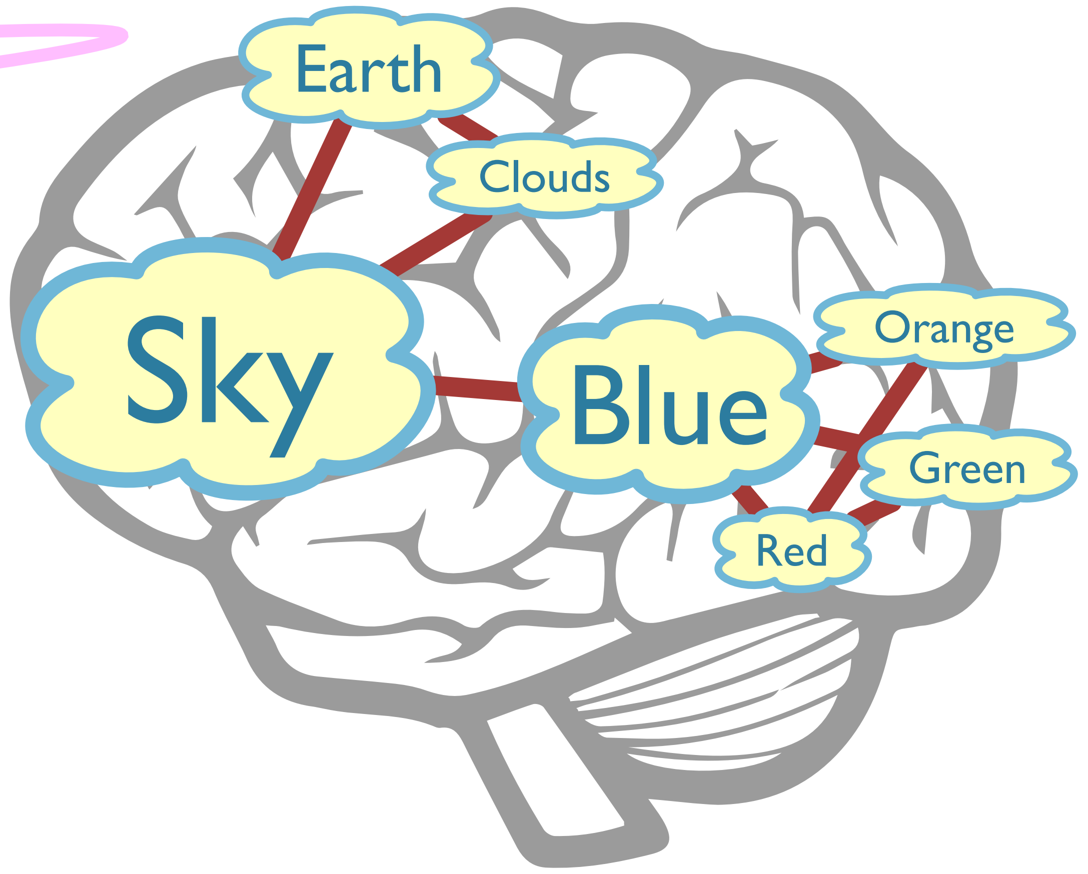


Psychology

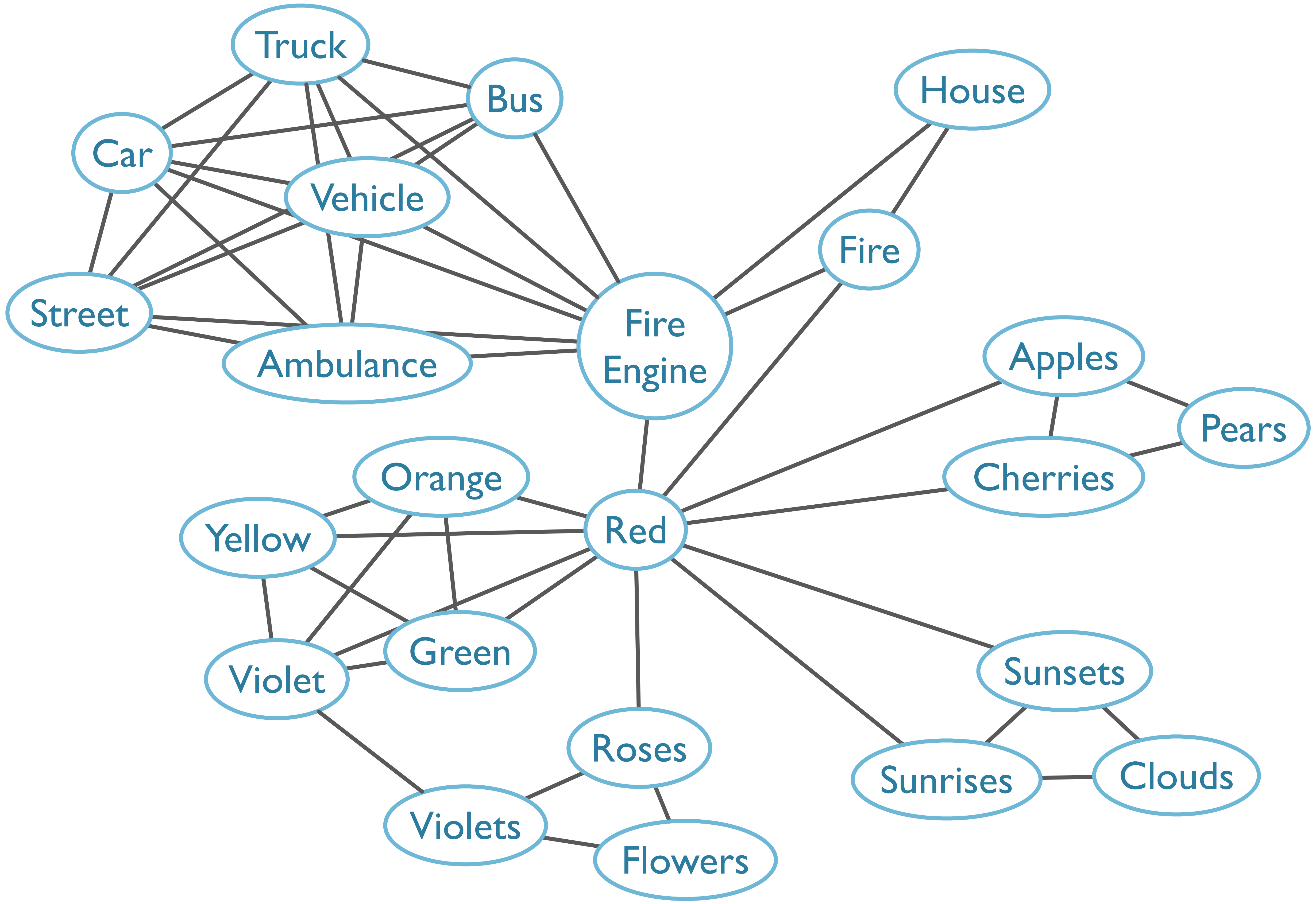
Epistemology

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



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- Computational Semantics
  - 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

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

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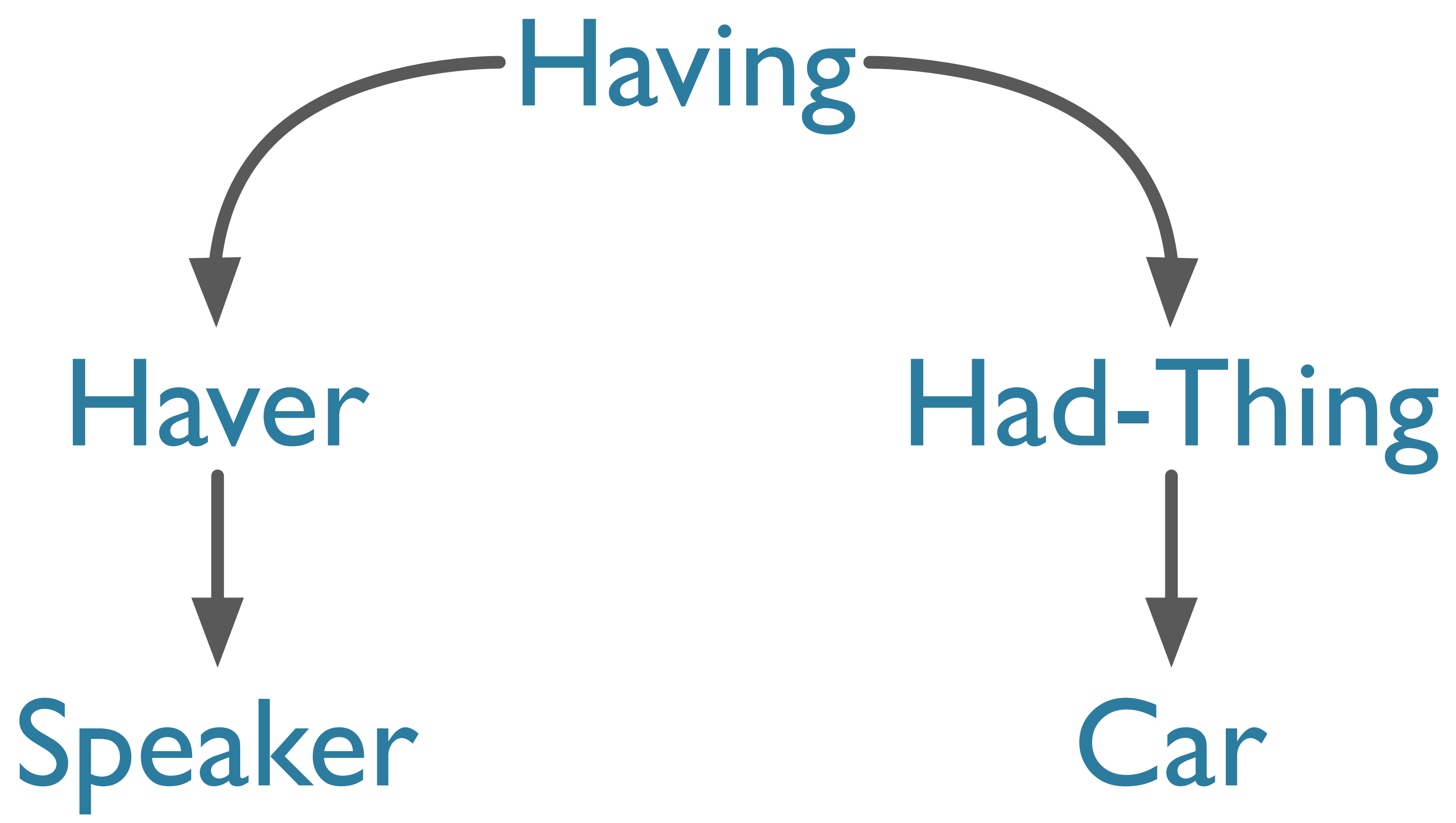

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Semantic Network:

Having

Haver | Had-Thing

Speaker | Car

Conceptual Dependency:

$$\begin{array}{c} \textit{Car} \\ \Uparrow \ \textsc{Poss-By} \\ \textit{Speaker} \end{array}$$

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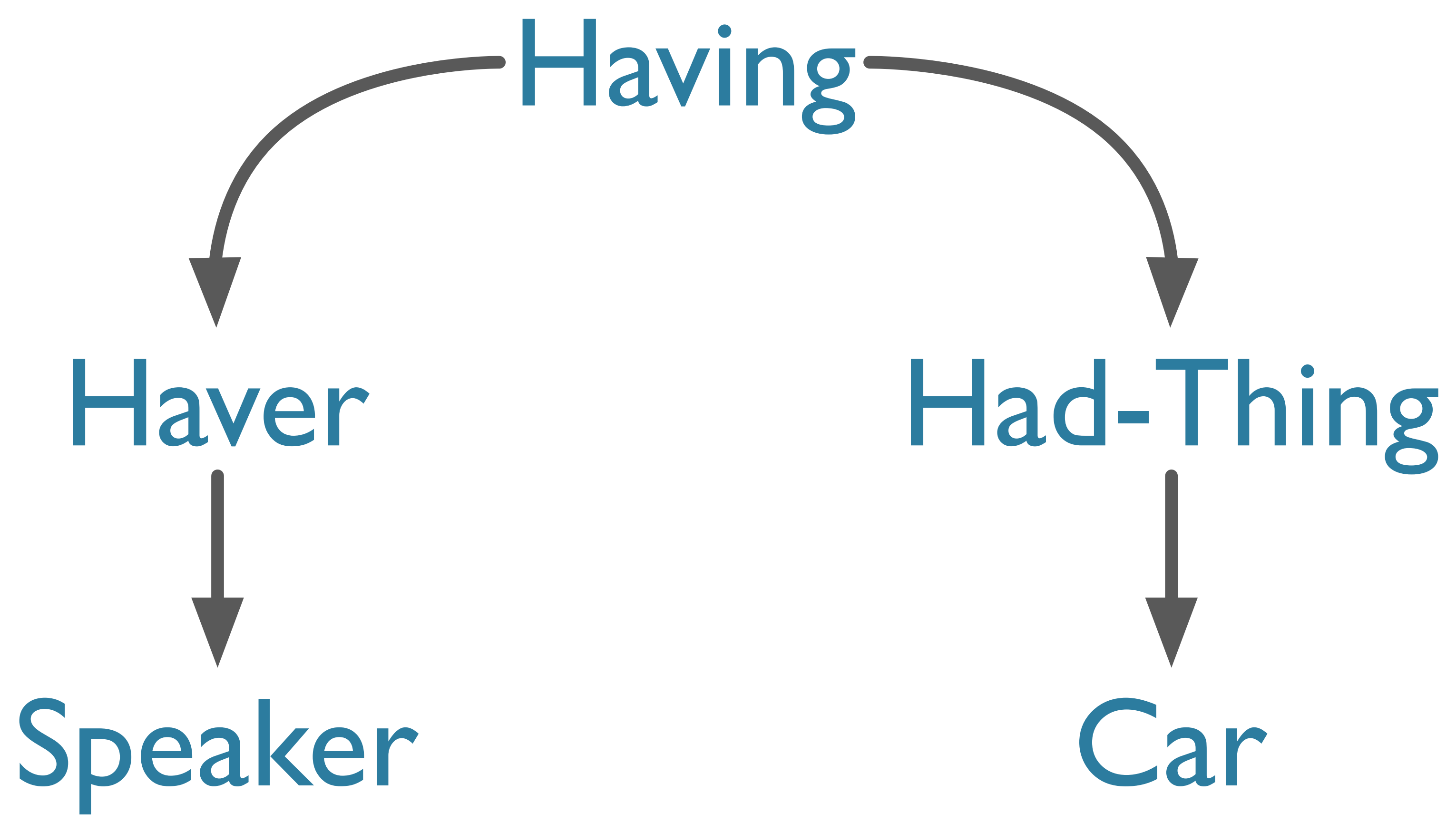

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Frame-Based:

```
Having
    Haver: Speaker
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```

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

Representational Requirements

- Verifiability
- Unambiguous representations
- Canonical Form
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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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- Subcategorization frames indicate:
  - Number, Syntactic category, order of args, possibly other features of args

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

Quantifiers

- $\exists$: **existential** quantifier: *“there exists”*

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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

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

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  - **All flights include beverages.**

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

FOL Syntax Summary

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

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

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:
  - $loves(John,\ Mary)$

Compositionality

- …how can we derive:
  - $loves(John,\ Mary)$
- from:
  - $John$
  - $loves(x,\ y)$
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Compositionality

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

λ-Reduction

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

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

- Equivalent to function application

Nested λ-Reduction

- Lambda expression as body of another

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

Nested λ-Reduction

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

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$$Near(Midway,\ Chicago)$$

Nested λ-Reduction

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

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

Nested λ-Reduction

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

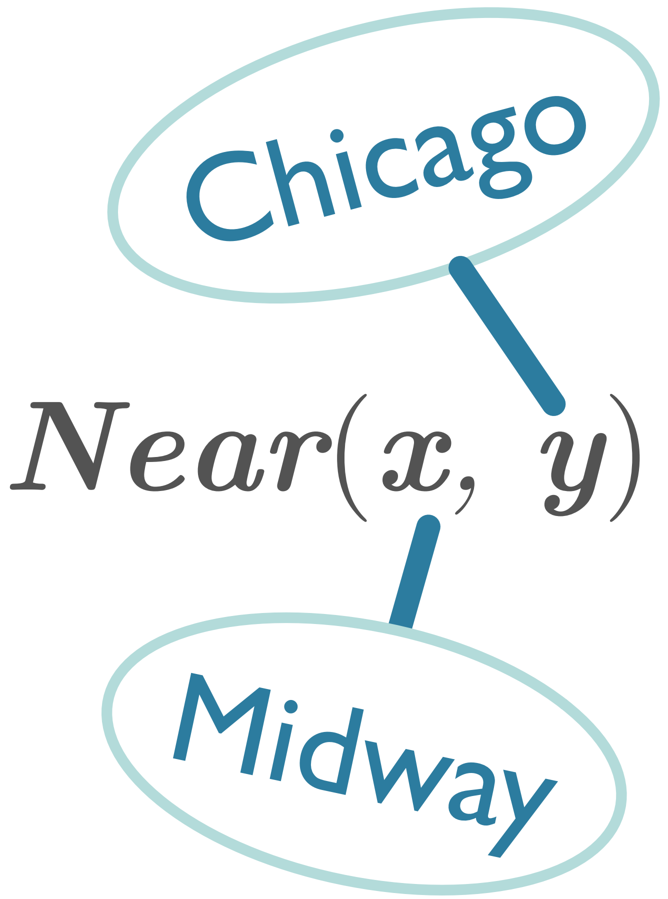
Chicago

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

Midway

Nested λ-Reduction

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



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

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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*
  - …use $\veebar$ or $\oplus$

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

Inference

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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

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  - Modus Ponens
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  - 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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  - *The flight arrived*
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  - *The flight arrived in Seattle on Saturday.*
  - *The flight arrived on Saturday.*
  - *The flight arrived in Seattle from SFO.*
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- Variable number of arguments; many entailment relations here.

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    - $\exists \boldsymbol{e}\ Arrival(\boldsymbol{e}, Flight, Seattle, SFO) \wedge Time(\boldsymbol{e}, Saturday)$

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

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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  - 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 #4

Probabilistic Parsing

- Goals:
  - Learn about PCFGs
  - Implement PCKY
  - Analyze Parsing Evaluation
  - Assess improvements to PCFG Parsing

Tasks

1. Train a PCFG
    1. Estimate rule probabilities from treebank
    2. Treebank is already in CNF
    3. More ATIS data from Penn Treebank
2. Build CKY Parser
    1. Modify (your) existing CKY implementation

Tasks

3. Evaluation
   1. Evaluate your parser using standard metric
   2. We will provide **evalb** program and gold standard
4. Improvement
   1. Improve your parser in some way:
      1. Coverage
      2. Accuracy
      3. Speed
   2. Evaluate new parser

Improvement Possibilities

- Coverage:
  - Some test sentences won't parse as is!
    - Lexical gaps (aka out-of-vocabulary [OOV] tokens)
      - …remember to model the probabilities, too
- Better context modeling
  - e.g. — Parent Annotation
- Better Efficiency
  - e.g. — Heuristic Filtering, Beam Search
- No "cheating" improvements:
  - improvement can't change training by looking at test data

`evalb`

- `evalb` available in `dropbox/21-22/571/hw4/tools`
- `evalb […] <gold-file> <test-file>`
- `evalb --help` for more info
- NB: specify **full/absolute path** to evalb when invoking in your scripts