Computational Semantics

LING 571 — Deep Processing for NLP

November 2, 2020

Assignments

- HW4
  - Delay in grade posting due to computer problems.
  - Use check_hwX.sh before submitting!

Announcements

- HW5: your grammar should use rules and features that are linguistically motivated (e.g. number, gender, aspect, animacy, ….)
- Consider grammars for the following suite of examples:
  - This sentence is grammatical.
  - *This grammatical sentence is.
- The following is not an acceptable grammar (you would lose some points):
  - S[+grammatical] -> ‘This sentence is grammatical.’
  - S[-grammatical] -> ‘This grammatical sentence is.’

NP of the Week

https://www.theguardian.com/politics/2020/oct/28/dfids-brexit-soy-sauce-price-cut-claim-prompts-backlash-bake-off

Varieties of Entailment in the News

Presuppositions, etc

Behold Trump's pre-election secret weapon: Nigel Farage, 'king of Europe'

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- Contrast:
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  - "We are NOT talking on Zoom right now."
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  - "We are NOT talking on Zoom right now."
  - The former, but not the latter, entails that we are talking right now.
- Presuppositions (that there is a king) "project out" from negation (and other operators, like questions, conditionals, etc). Standard logical entailments do not.
  - Presuppositions must be true in order for a sentence to be true or false at all.

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  - Common examples of scales: {some, all}, {or, and}, {may, must}, …
- Trump's doctor when he was at the hospital:
  - Press: "Has he ever been on supplemental oxygen?"
  - Doc: "He hasn't had supplemental oxygen today or yesterday."

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  - There is an exam.
  - A student was told that the exam will be postponed.
  - The exam will be postponed.
  - Not every student was told that the exam will be postponed.

An Interesting Example

A top baseball prospect's Southern California scholarship was lost to the pandemic

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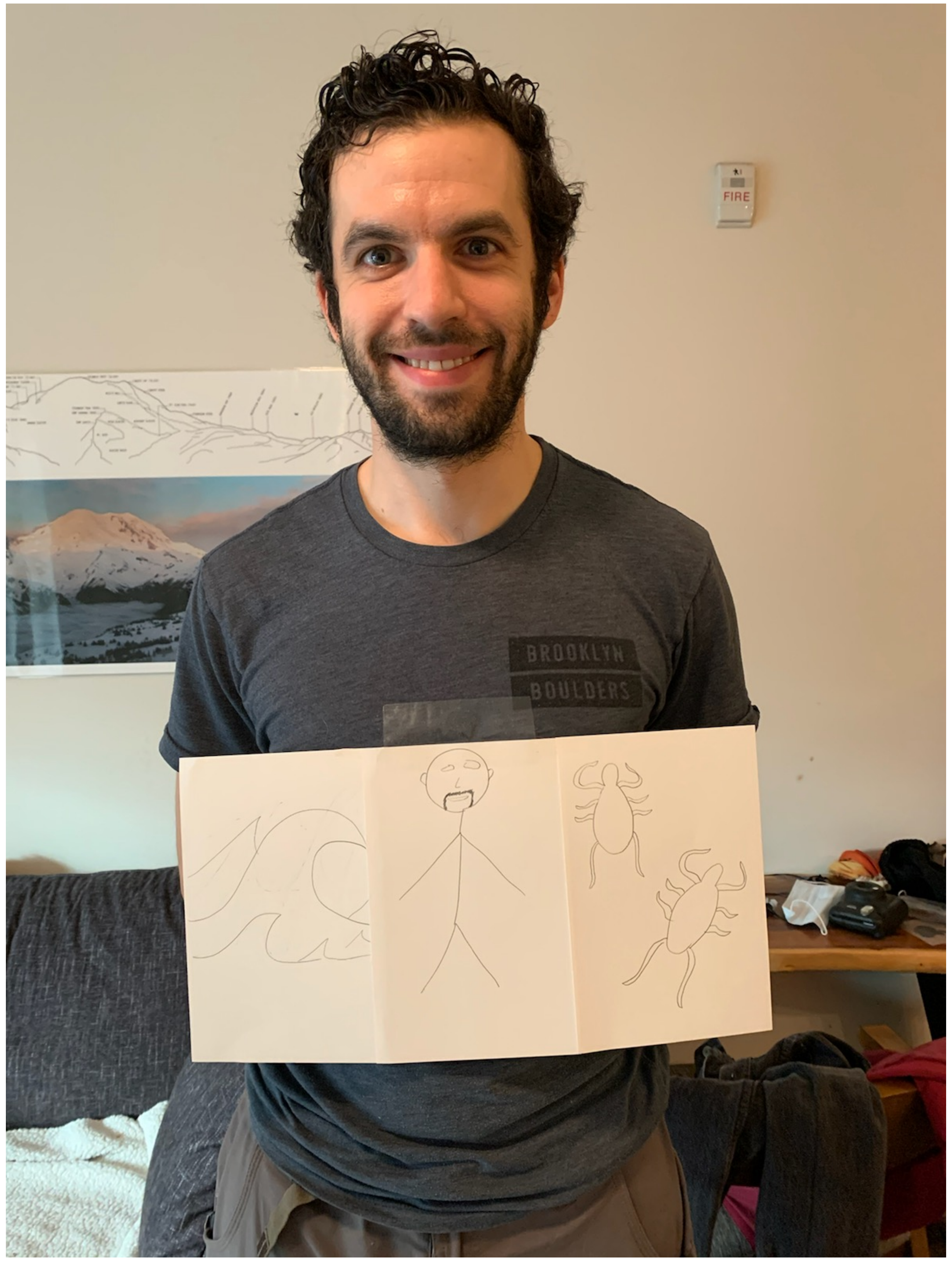
Poll!

Guess My "Costume"!



It's topical!
Each picture is a syllable;
together the form one word.

Roadmap

- First-order Logic: Syntax and Semantics
- Inference + Events
- Rule-to-rule Model
  - More lambda calculus

FOL Syntax + Semantics

Example Meaning Representation

- **A non-stop flight** that **serves Pittsburgh**:

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

FOL Syntax Summary

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

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

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

Model-Theoretic Semantics

- A “model” represents a particular state of the world
- Our language has **logical** and **non-logical** elements.
  - **Logical:** Symbols, operators, quantifiers, etc
  - **Non-Logical**: Names, properties, relations, etc

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- **Properties** — sets of elements
  - ***red***: *{fire hydrant, apple,…}*
- **Relations** — *sets of tuples of elements*
  - ***CapitalCity***: {(*Washington, Olympia*), (*Yamoussokro, Cote d'Ivoire*), (*Ulaanbaatar, Mongolia*),…}

Sample Domain $\mathscr{D}$

via J&M, p. 554

Objects

Matthew, Franco, Katie, Caroline	*a,b,c,d*
Frasca, Med, Rio	*e,f,g*
Italian, Mexican, Eclectic	*h,i,j*

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Noisy	Frasca, Med, and Rio are noisy	***Noisy***={*e,f,g*}

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Relations

Likes	Matthew likes the Med Katie likes the Med and Rio Franco likes Frasca Caroline likes the Med and Rio	***Likes***=$\{ \langle a,f\rangle , \langle c,f\rangle , \langle c,g\rangle , \langle b,e\rangle , \langle d,f\rangle , \langle d,g\rangle \}$

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Serves	Med serves eclectic Rio serves Mexican Frasca serves Italian	***Serves***=$\{ \langle c,f \rangle, \langle f,i \rangle, \langle e,h \rangle \}$

Inference + Events

(last Wednesday's slides)

Rule-to-Rule Model

Recap

- **Meaning Representation**
  - Can represent meaning in natural language in many ways
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Recap

- **Meaning Representation**
  - Can represent meaning in natural language in many ways
  - We are focusing on First-Order Logic (FOL)
- **Principle of compositionality**
  - The meaning of a complex expression is a function of the meaning of its parts
- **Lambda Calculus**
  - λ-expressions denote functions
  - Can be nested
  - Reduction = function application

Semantics Reflects Syntax

Chiasmus:
Syntax affects Semantics!

Bowie playing Tesla

The Prestige (2006)

Tesla playing Bowie

SpaceX Falcon Heavy Test Launch (2/6/2018)

Chiasmus:
Syntax affects Semantics!

- *“Never let a fool kiss you or a kiss fool you”* (Grothe, 2002)

- *“Then you should say what you mean,” the March Hare went on.*

  “I do,” Alice hastily replied; “at least—at least I mean what I say—that’s the same thing, you know.”

  “Not the same thing a bit!” said the Hatter. “Why, you might just as well say that ‘I see what I eat’ is the same thing as ‘I eat what I see’!”

  “You might just as well say,” added the March Hare, “that ‘I like what I get’ is the same thing as ‘I get what I like’!”

  “You might just as well say,” added the Dormouse, which seemed to be talking in his sleep, “that ‘I breathe when I sleep’ is the same thing as ‘I sleep when I breathe’!”

  —*Alice in Wonderland*, Lewis Carrol

Ambiguity & Models

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State of known Universe: 02/05/2018

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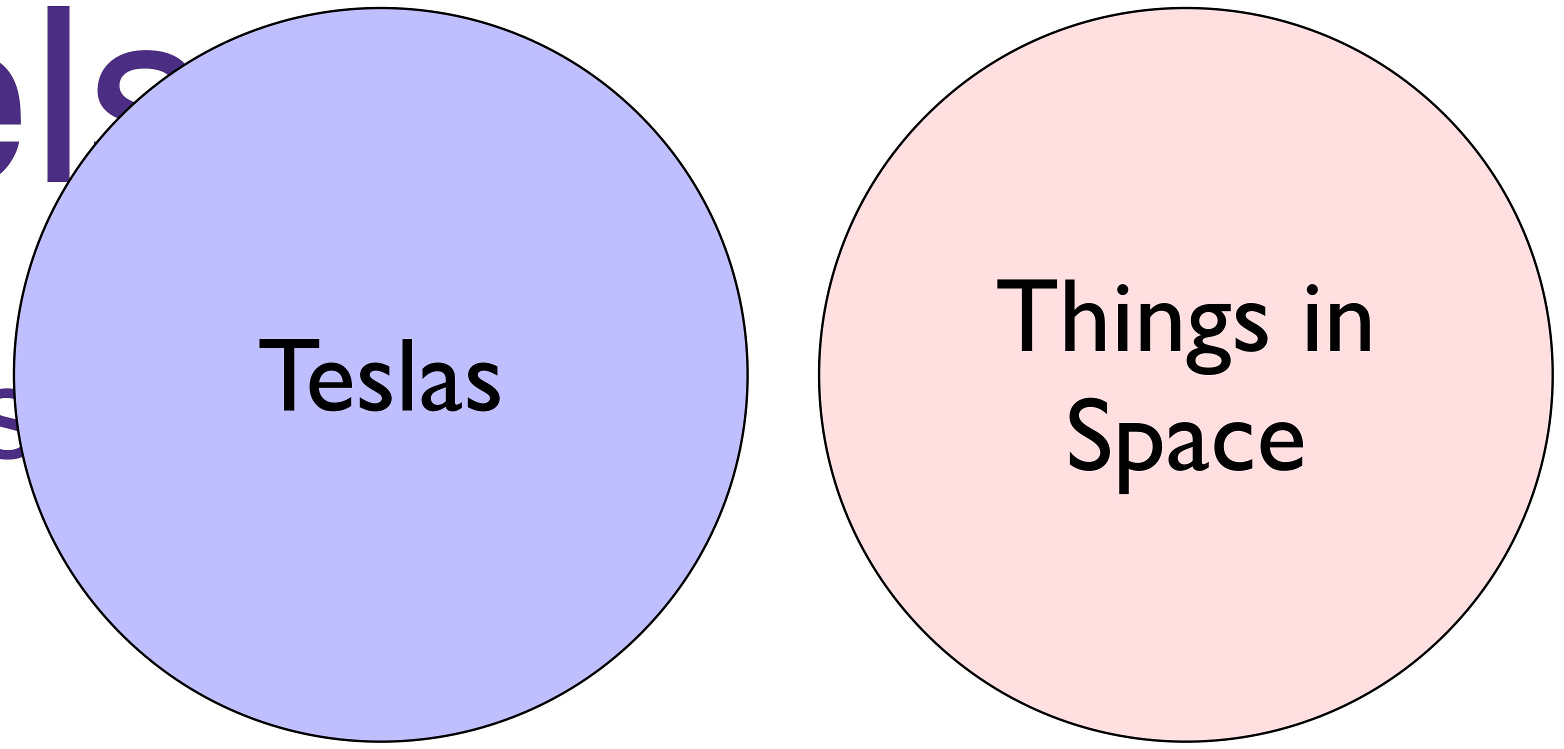

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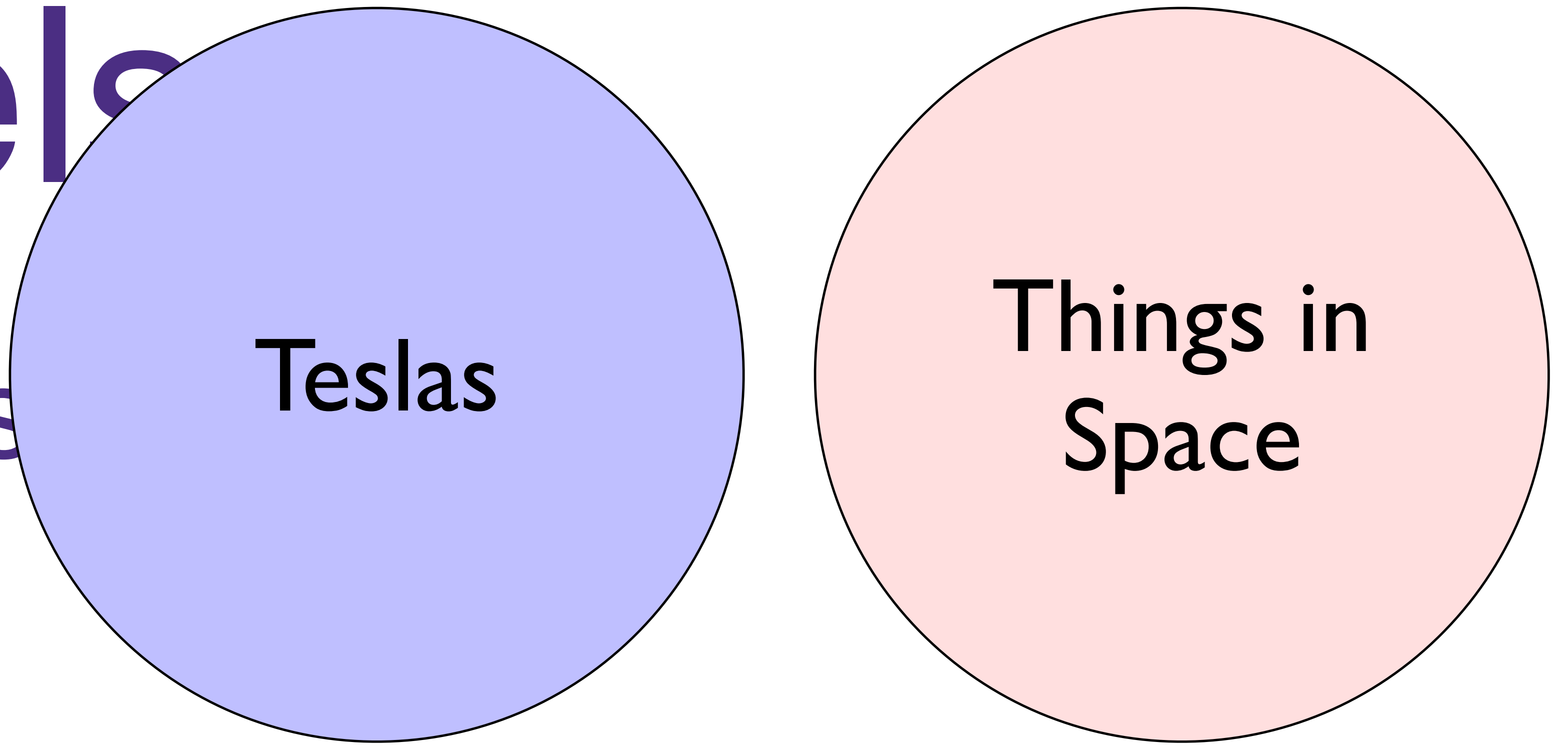

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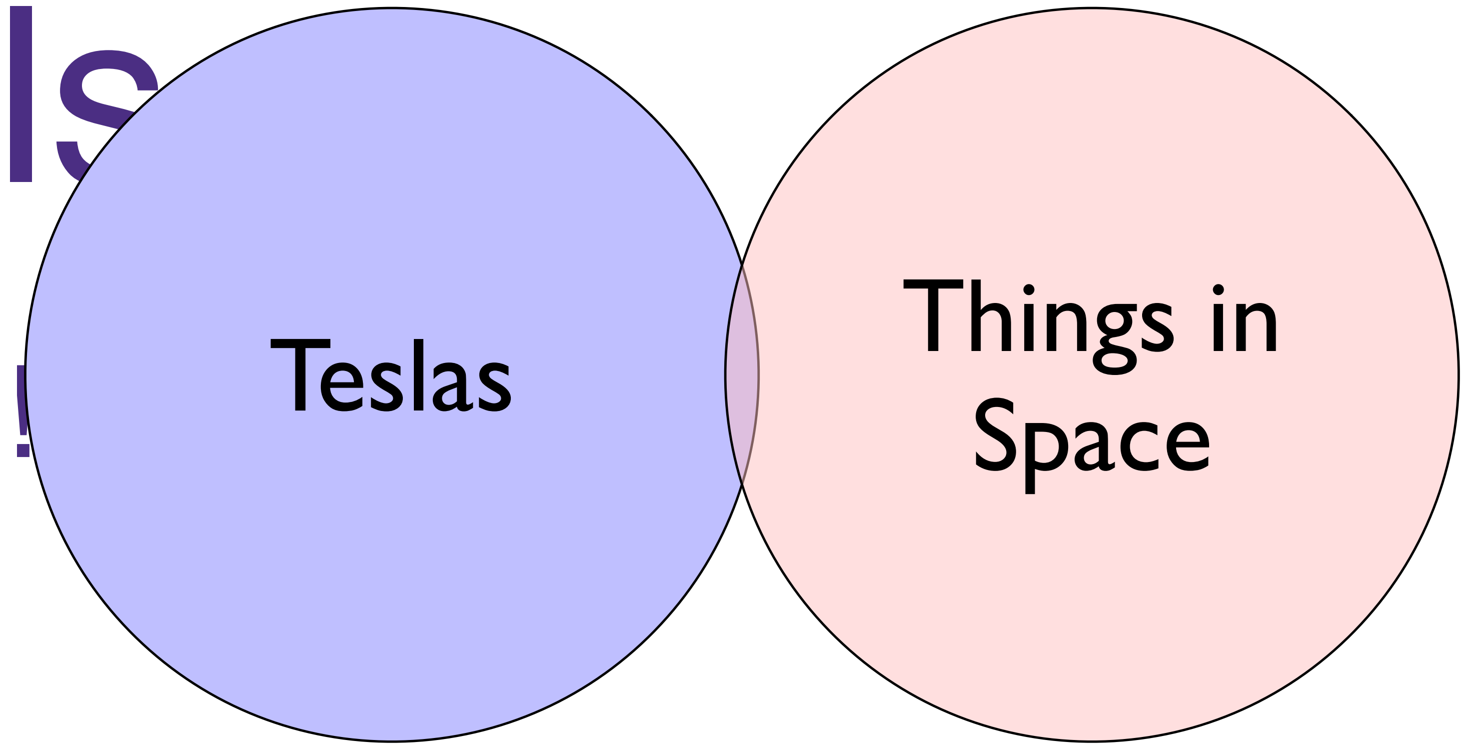

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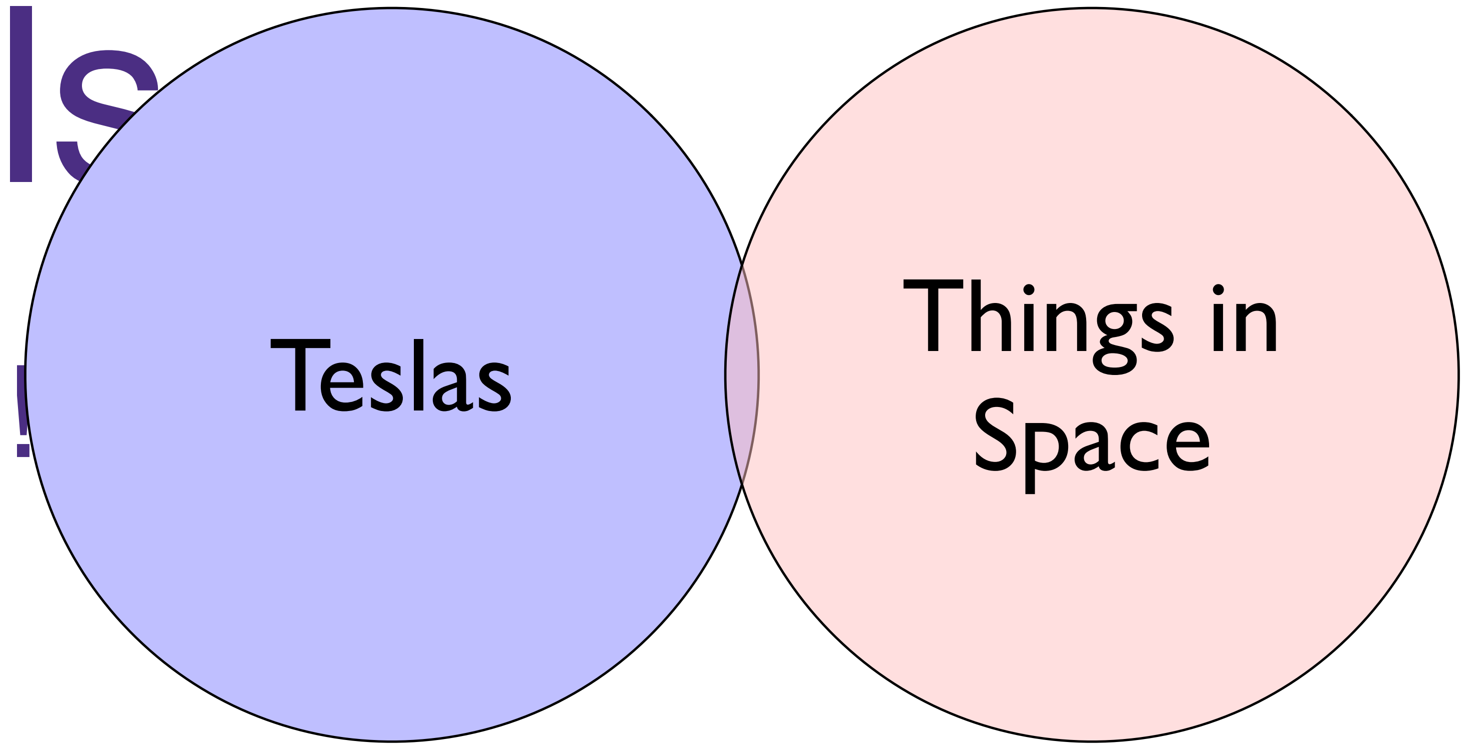

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Scope Ambiguity

- Potentially $O(n!)$ scope interpretations ("scopings")
  - Where n=number of scope-taking operators.
    - (*every*, *a, all, no,* modals, negations, conditionals, …)
- Different interpretations correspond to different syntactic parses!

Poll!

Integrating Semantics into Syntax

1. Pipeline System

- Feed parse tree and sentence to semantic analyzer
- How do we know which pieces of the semantics link to which part of the analysis?
- Need detailed information about sentence, parse tree
- Infinitely many sentences & parse trees
- Semantic mapping function per parse tree → intractable

Integrating Semantics into Syntax

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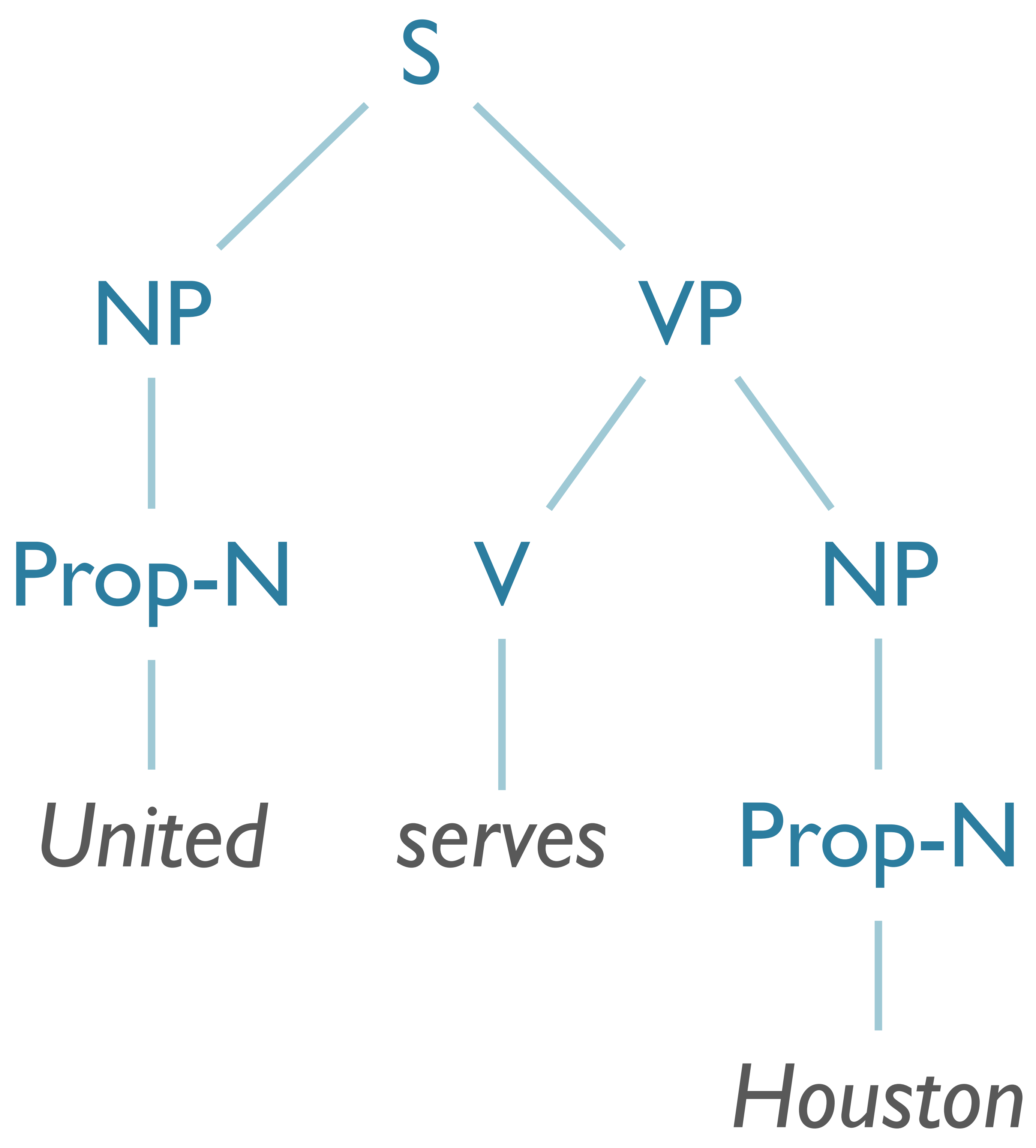
2. Integrate Directly into Grammar

- This is the "rule-to-rule" approach we've been implicitly examining and will now make more explicit
- Tie semantics to finite components of grammar (rules & lexicon)
- Augment grammar rules with semantic info
  - a.k.a. "attachments" — specify how RHS elements compose to LHS

Simple Example

- *United serves Houston*



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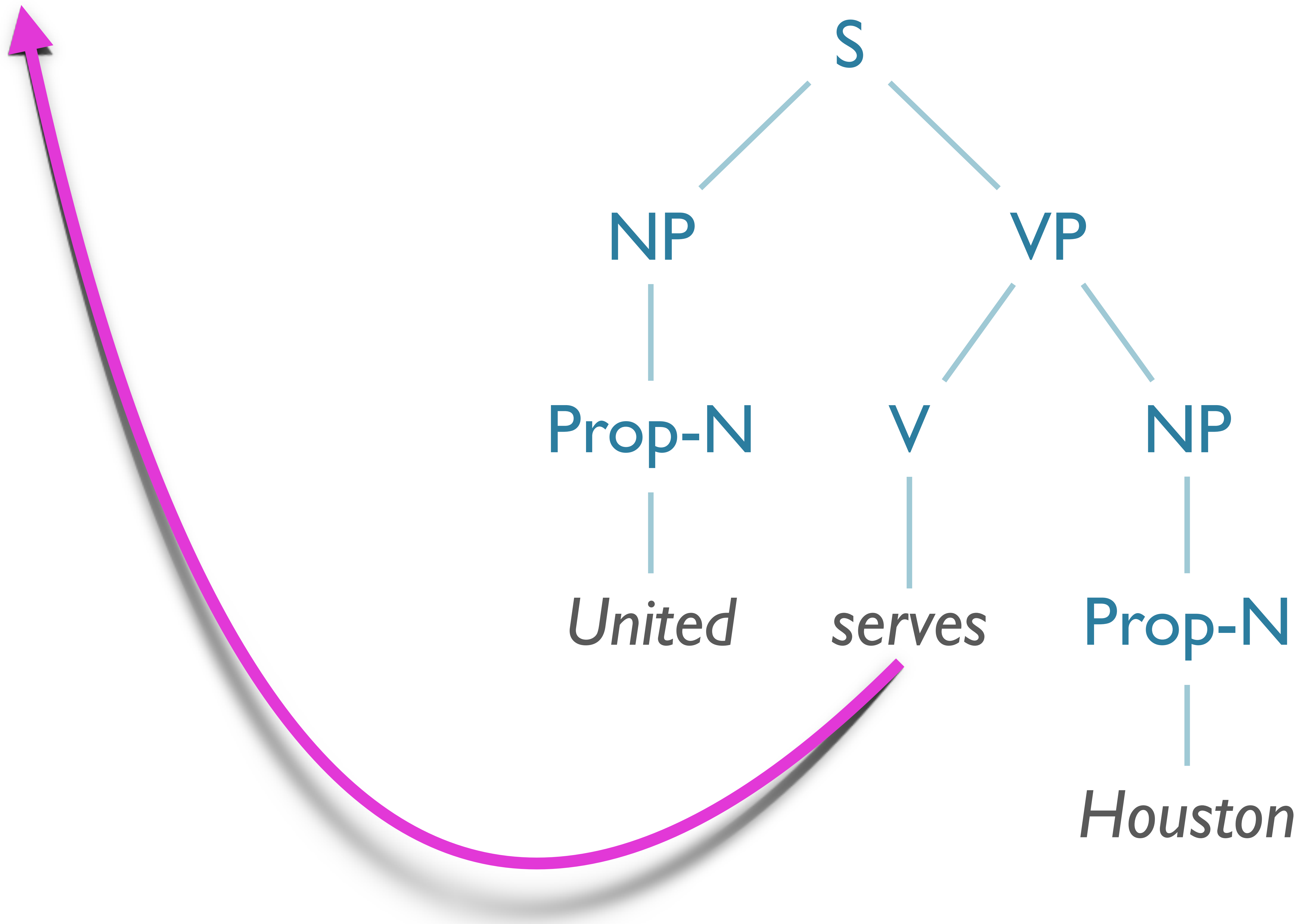
$\exists e\left(Serving(e) \wedge\right.$



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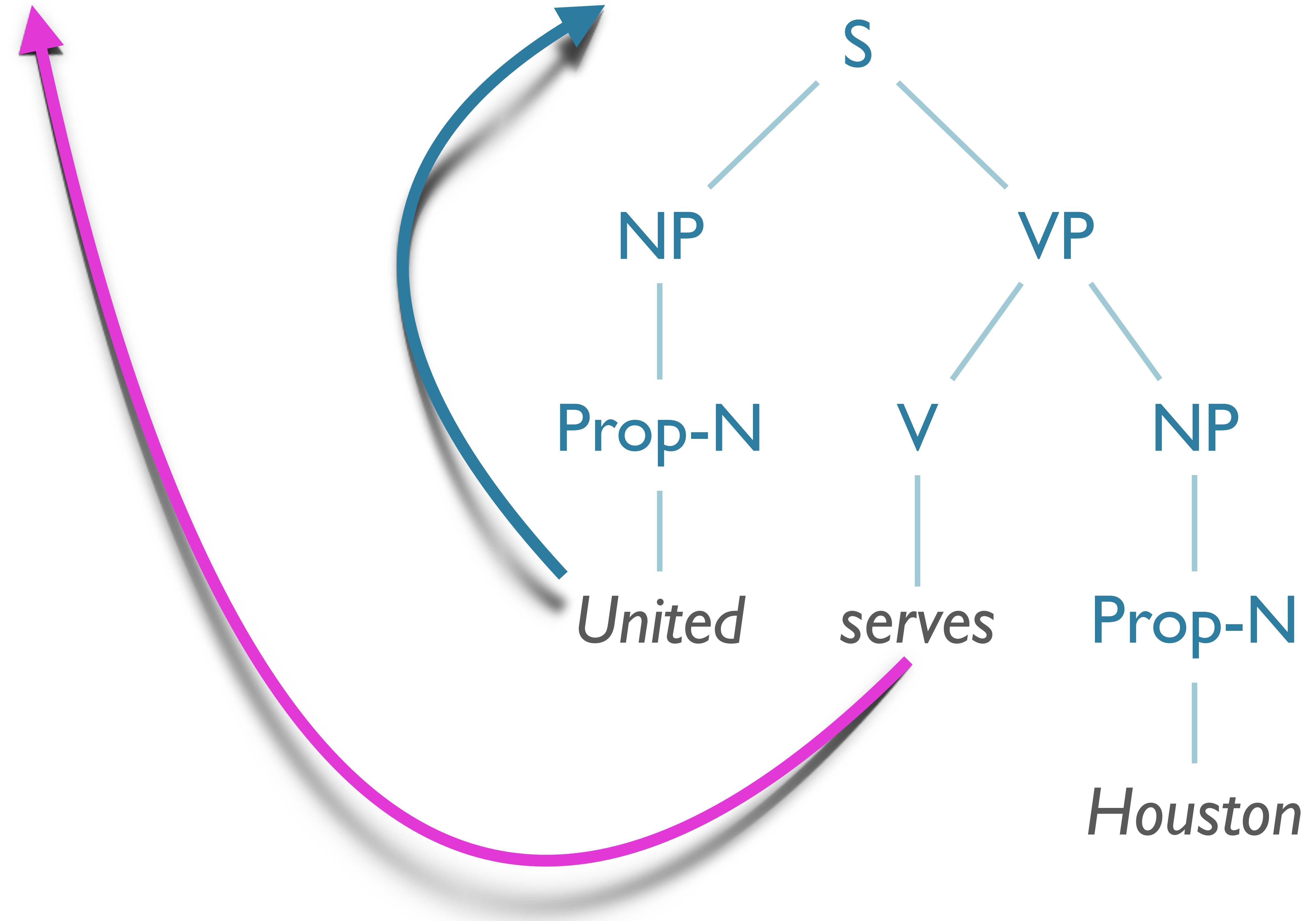

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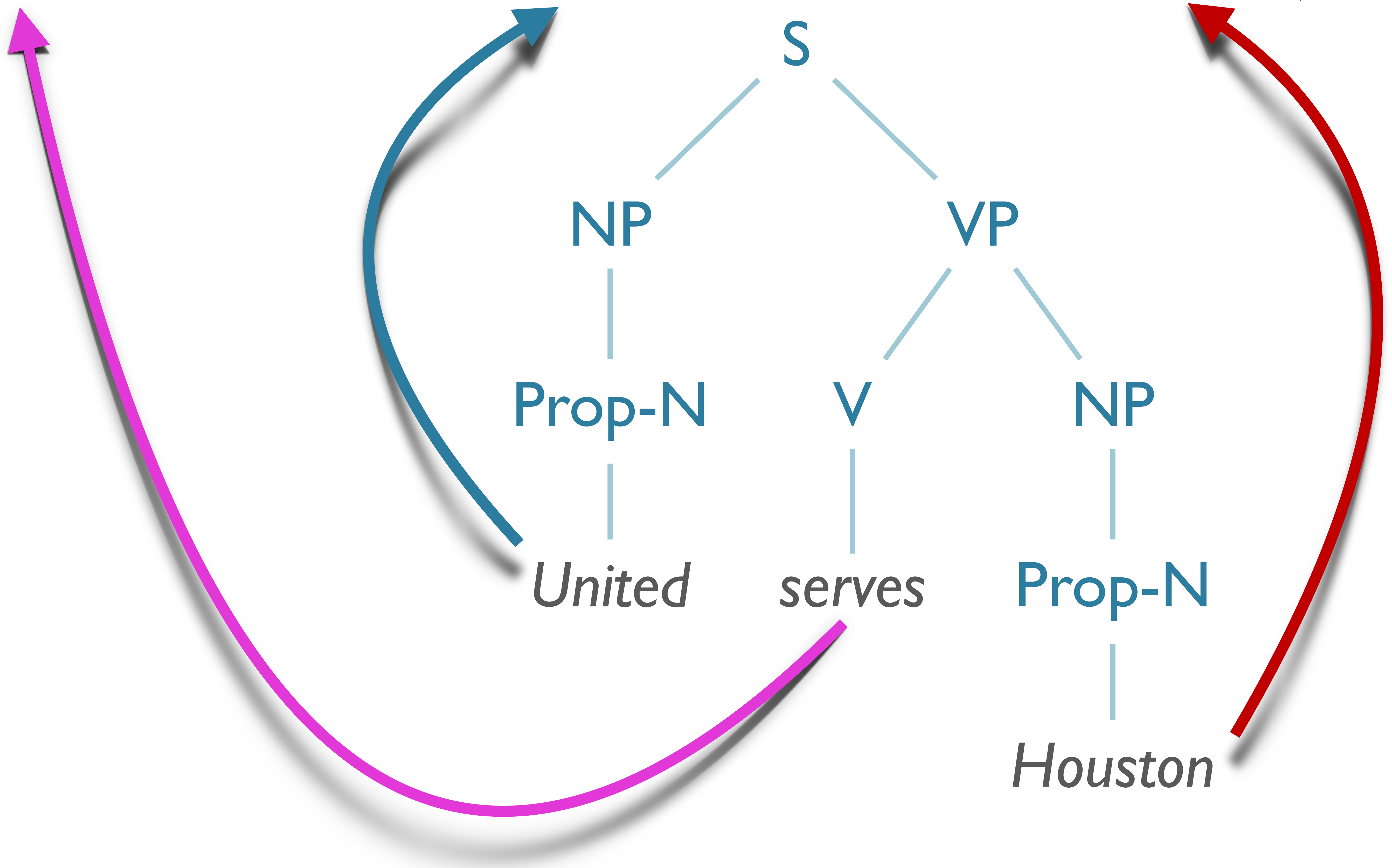

Rule-to-rule Model

- **Lambda Calculus** and the **Rule-to-Rule Hypothesis**
  - λ-expressions can be attached to grammar rules
  - used to compute meaning representations from syntactic trees based on the principle of compositionality
  - Go up the tree, using reduction (function application) to compute meanings at non-terminal nodes

Semantic Attachments

- Basic Structure:

$$A \rightarrow a_1, \ \dots, \ a_n \ \{\underbrace{f(a_j.\mathrm{sem}, \ \dots \ a_k.\mathrm{sem})}_{\text{Semantic Function}}\}$$

- In NLTK syntax (more later):

```
A → a₁ … aₙ[SEM=<f(?aⱼ.sem …)>]
```

Attachments as SQL!

NLTK book, ch. 10

```
>>> nltk.data.show_cfg('grammars/book_grammars/sql0.fcfg')
% start S
S[SEM=(?np + WHERE + ?vp)] -> NP[SEM=?np] VP[SEM=?vp]
VP[SEM=(?v + ?pp)] -> IV[SEM=?v] PP[SEM=?pp]
VP[SEM=(?v + ?ap)] -> IV[SEM=?v] AP[SEM=?ap]
NP[SEM=(?det + ?n)] -> Det[SEM=?det] N[SEM=?n]
PP[SEM=(?p + ?np)] -> P[SEM=?p] NP[SEM=?np]
AP[SEM=?pp] -> A[SEM=?a] PP[SEM=?pp]
NP[SEM='Country="greece"'] -> 'Greece'
NP[SEM='Country="china"'] -> 'China'
Det[SEM='SELECT'] -> 'Which' | 'What'
N[SEM='City FROM city_table'] -> 'cities'
IV[SEM=''] -> 'are'
A[SEM=''] -> 'located'
P[SEM=''] -> 'in'
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```

'What cities are located in China'

```
parses[0]: SELECT City FROM city_table WHERE Country="china"
```

Semantic Attachments: Options

- Why not use SQL? Python?
  - Arbitrary power but hard to map to logical form
  - No obvious relation between syntactic, semantic elements

- Why Lambda Calculus?
  - First Order Predicate Calculus (FOPC) + function application is highly expressive, integrates well with syntax
  - Can extend our existing feature-based model, using unification
  - Can ‘translate’ FOL to target / task / downstream language (e.g. SQL)

Semantic Analysis Approach

- Semantic attachments:
  - Each CFG production gets semantic attachment

- Semantics of a phrase is function of combining the children
  - Complex functions need to have parameters
  - $Verb \rightarrow \text{'arrived'}$
    - Intransitive verb, so has one argument: ***subject***
    - …but we don't have this available at the preterminal level of the tree!

Defining Representations

- Proper Nouns
- Intransitive Verbs
- Transitive Verbs
- Quantifiers

Proper Nouns & Intransitive Verbs

- Our instinct for names is to just use the constant:
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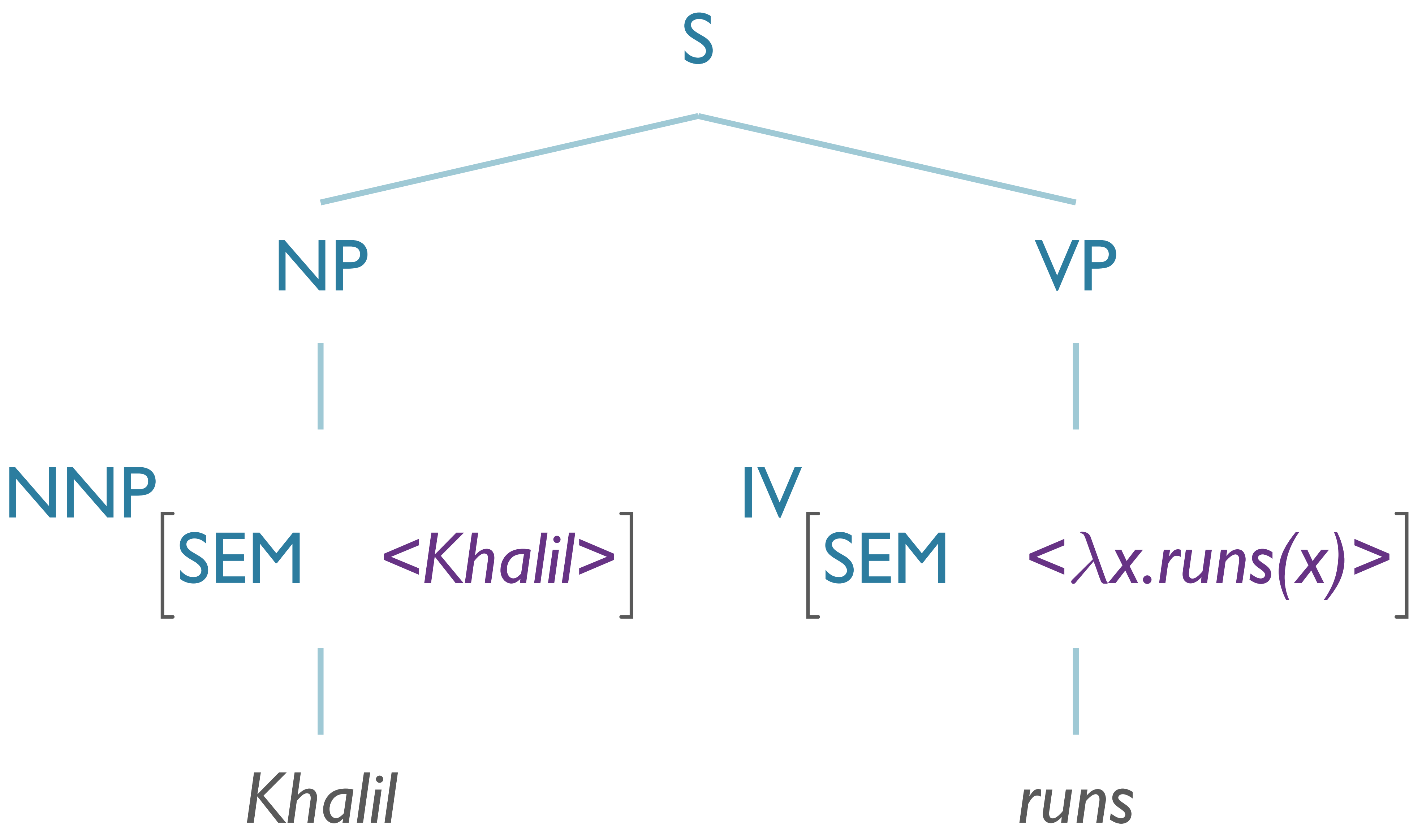

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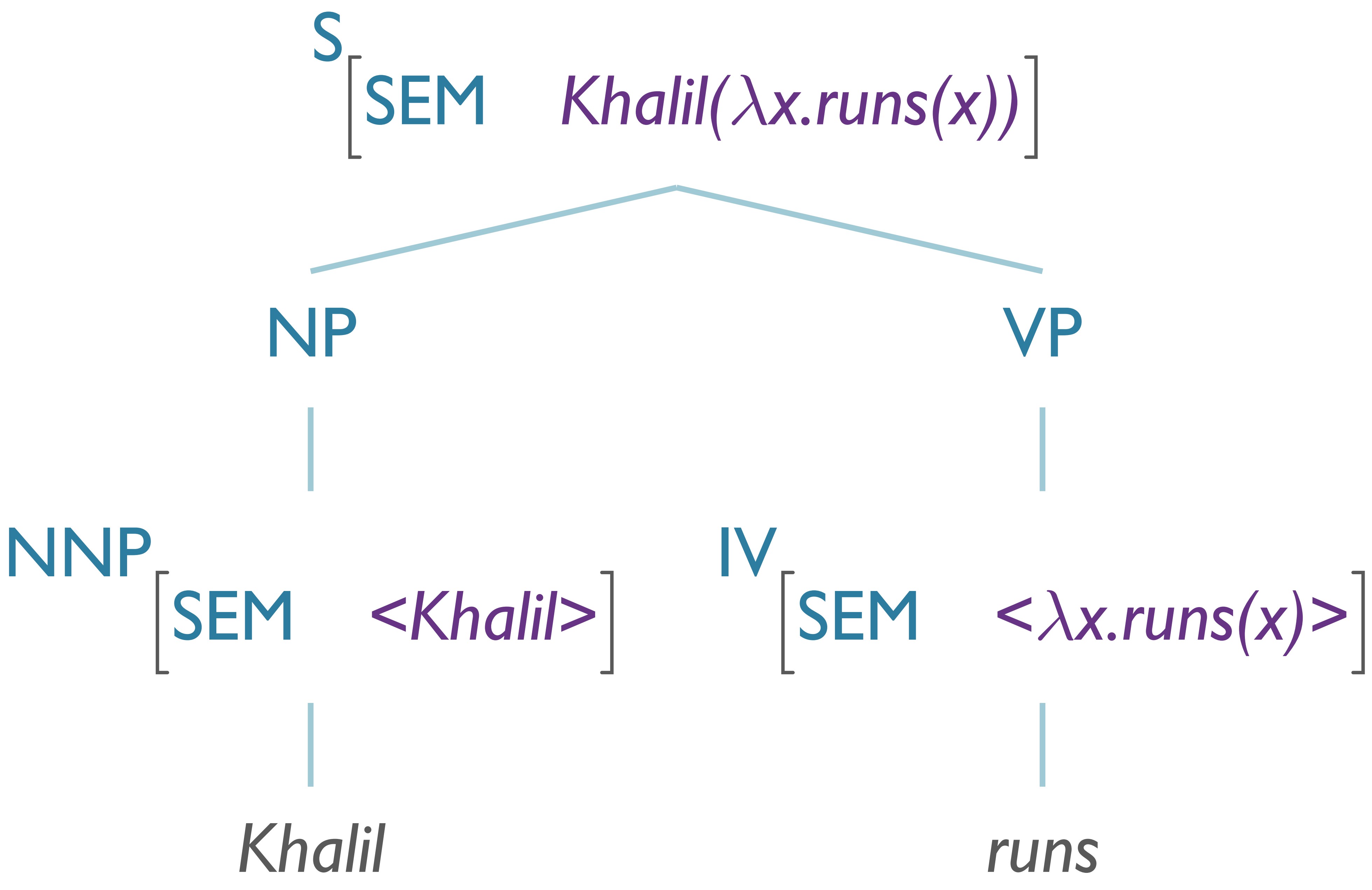

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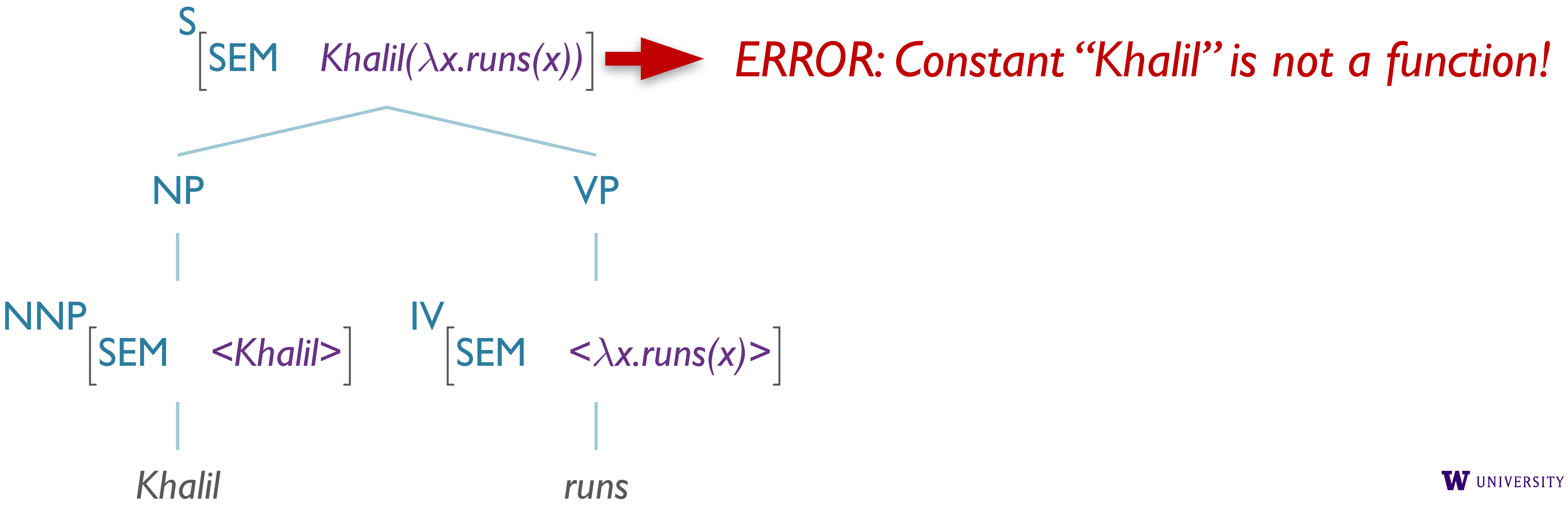

Proper Nouns & Intransitive Verbs

- Instead, we use a ***dummy predicate:***
  - $\lambda Q.Q(Khalil)$

- *"Generalizing to the worst case" (cf. Montague; Partee on type-shifting)*

Proper Nouns & Intransitive Verbs

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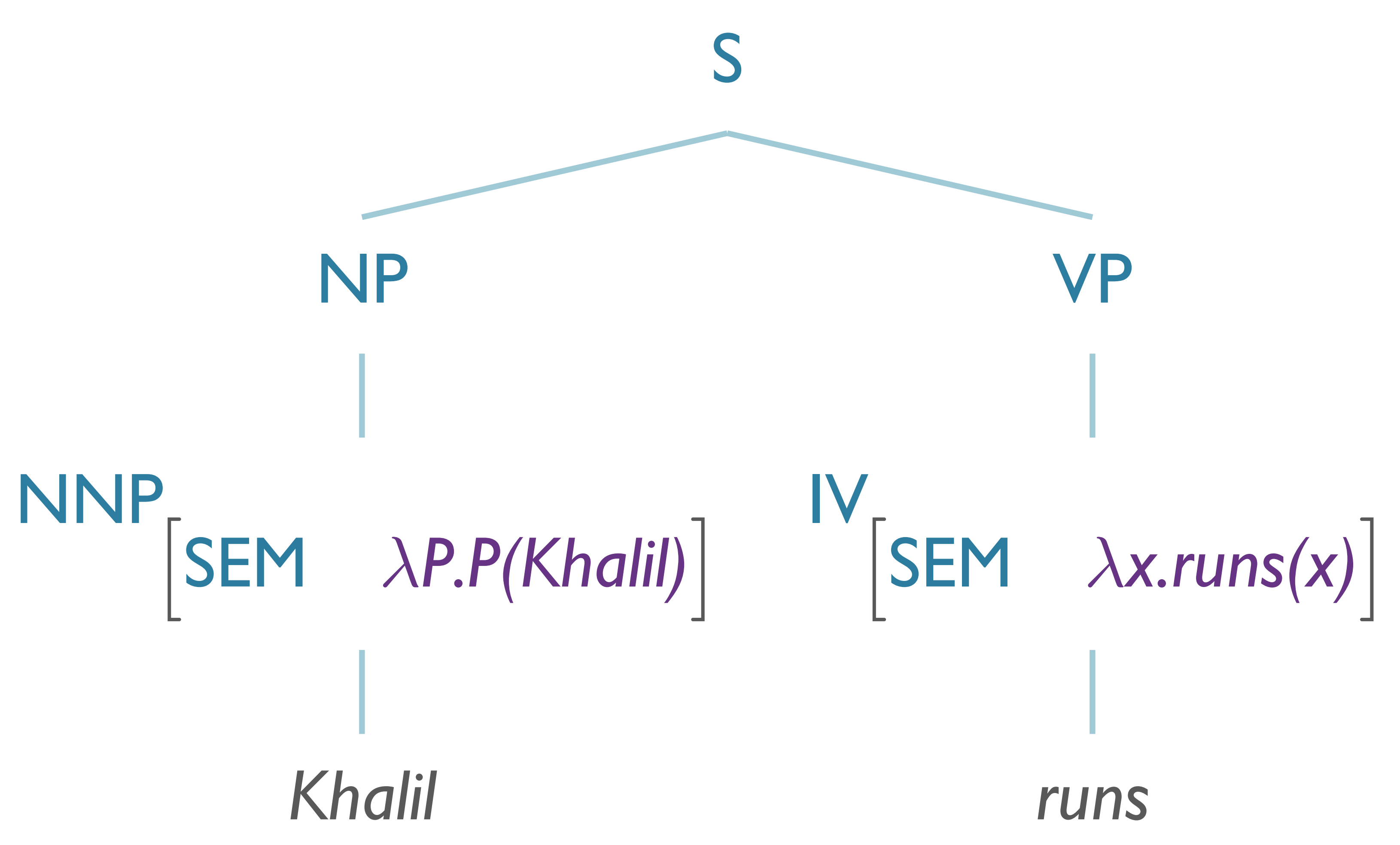

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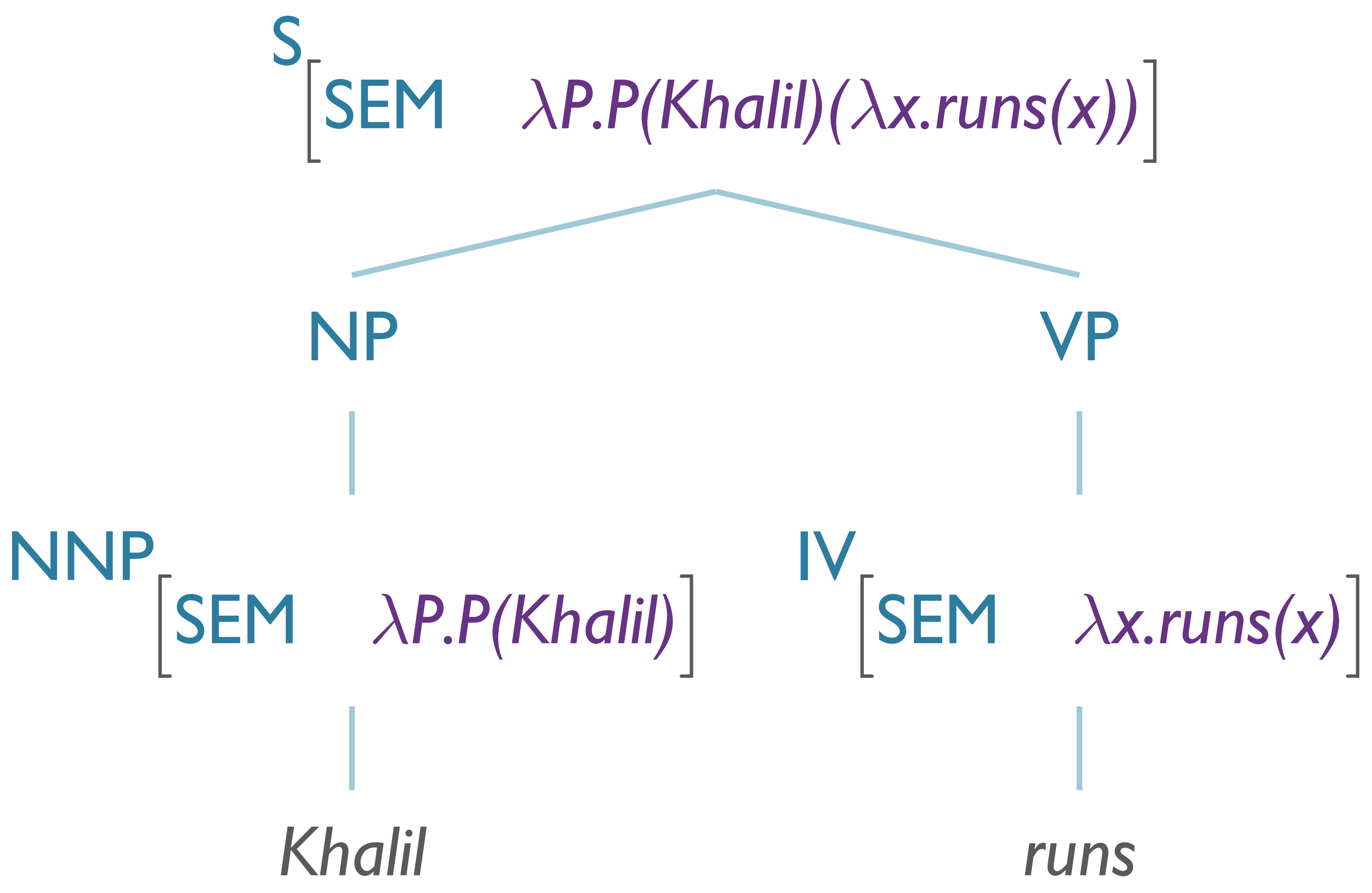

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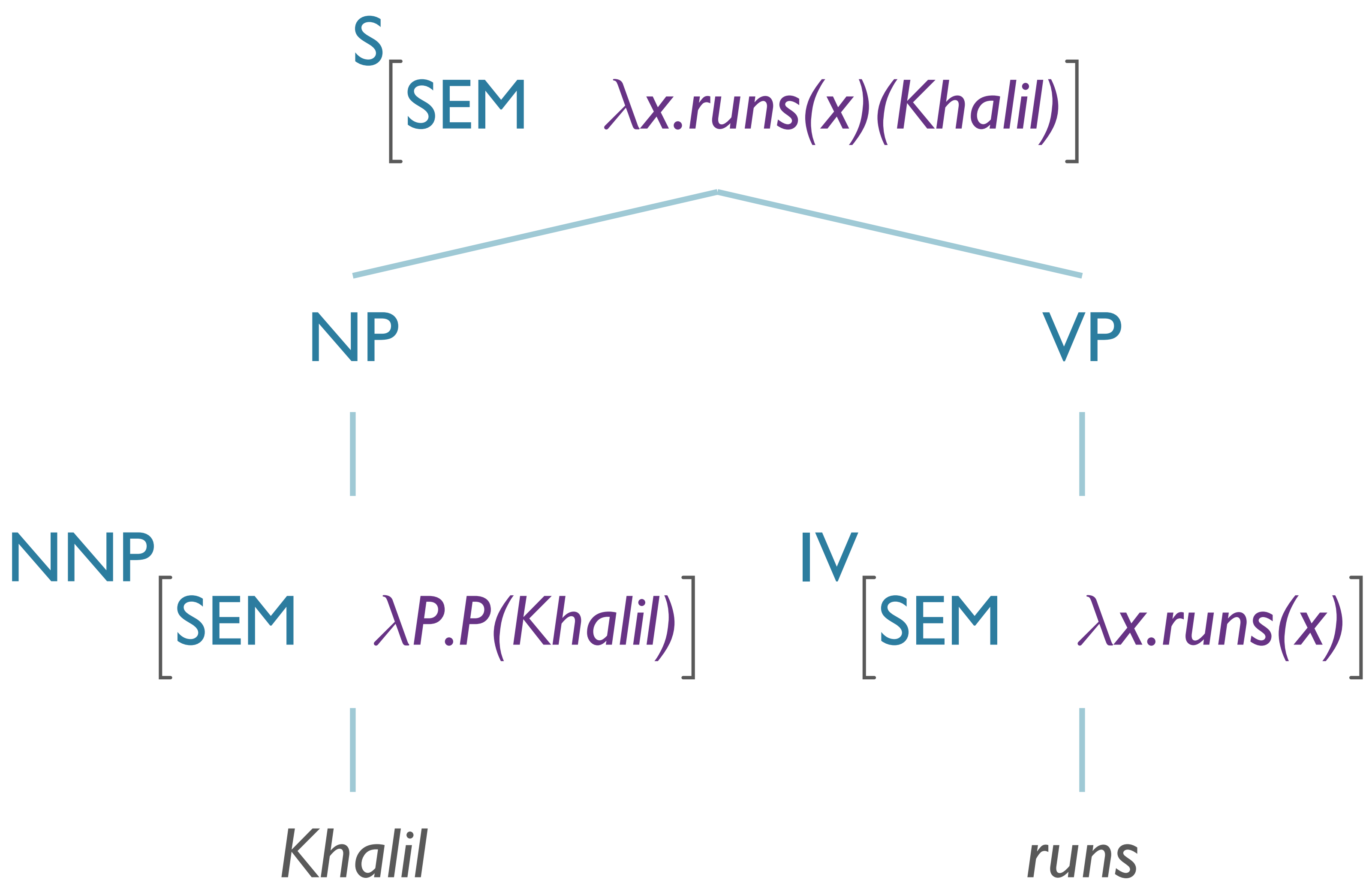

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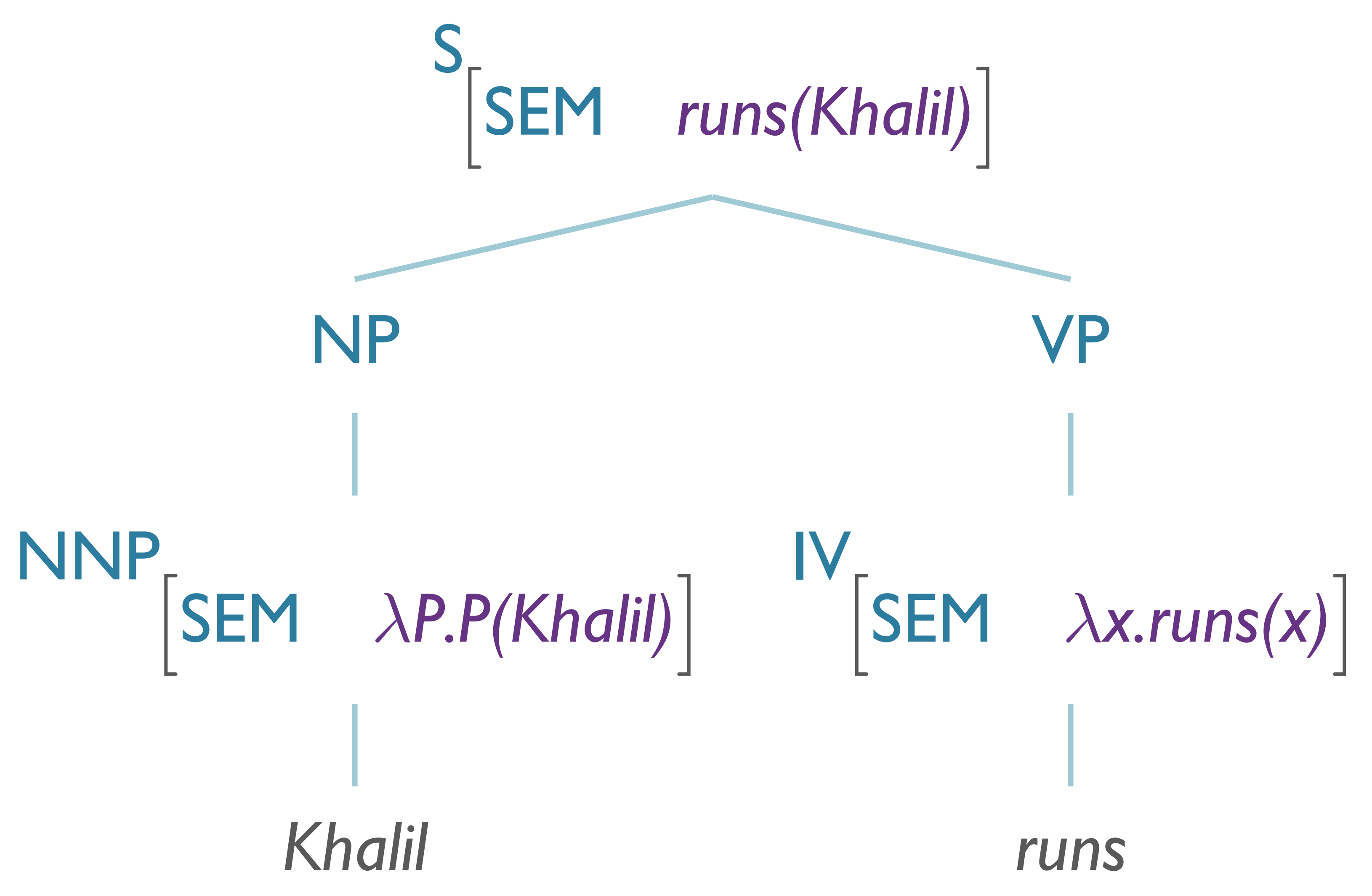

Transitive Verbs

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- So, if we want to say "*Alex loves Jim*" we would want `λy.λx.loves(x,y)`
- …but going in linear order, we have one arg to the left and one to the right.
- So, instead:
  - `λX y.X(λx.loves(x,y))`

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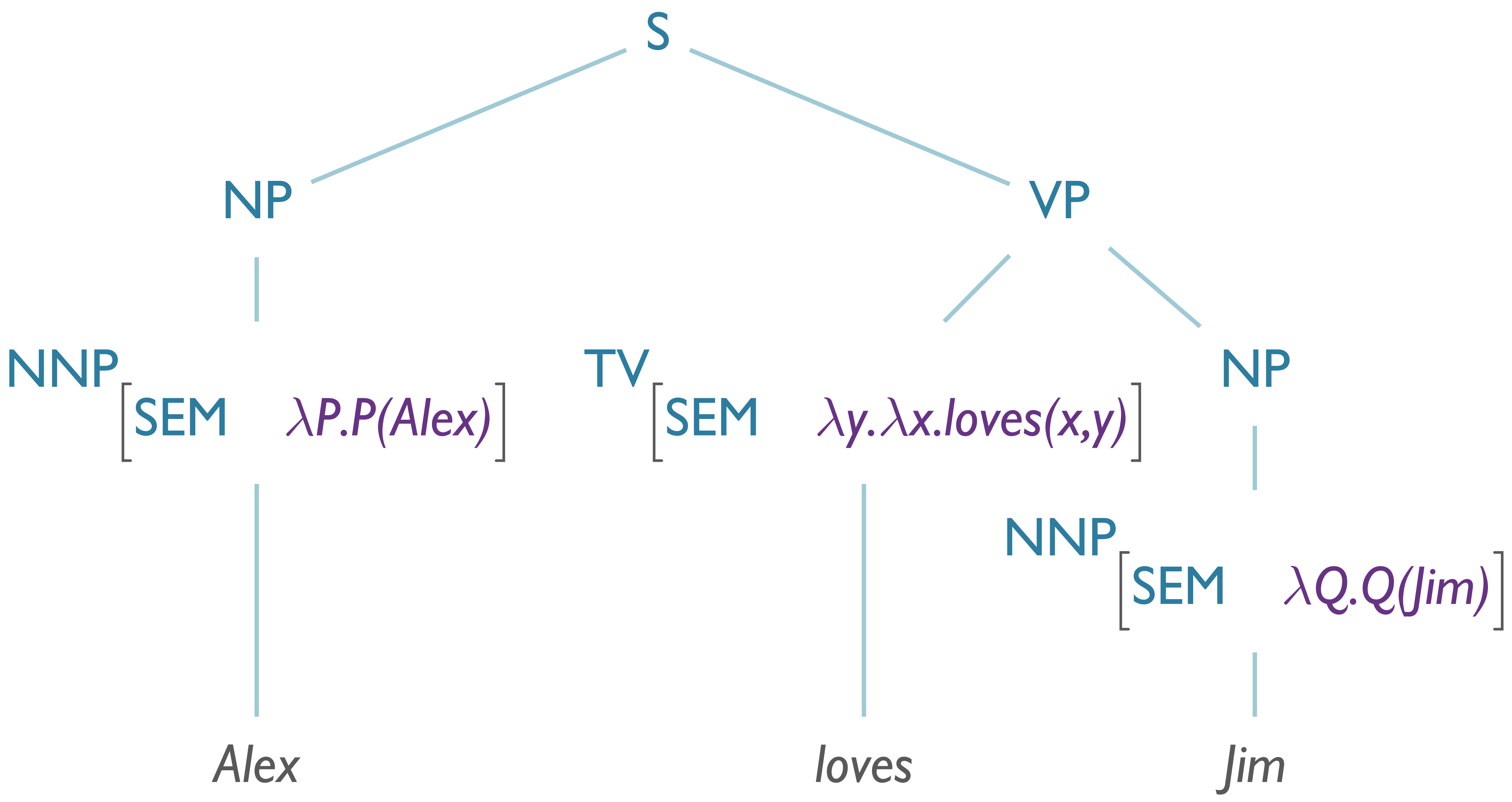

Transitive Verbs

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    - → ***Error!*** We can't reduce Alex.

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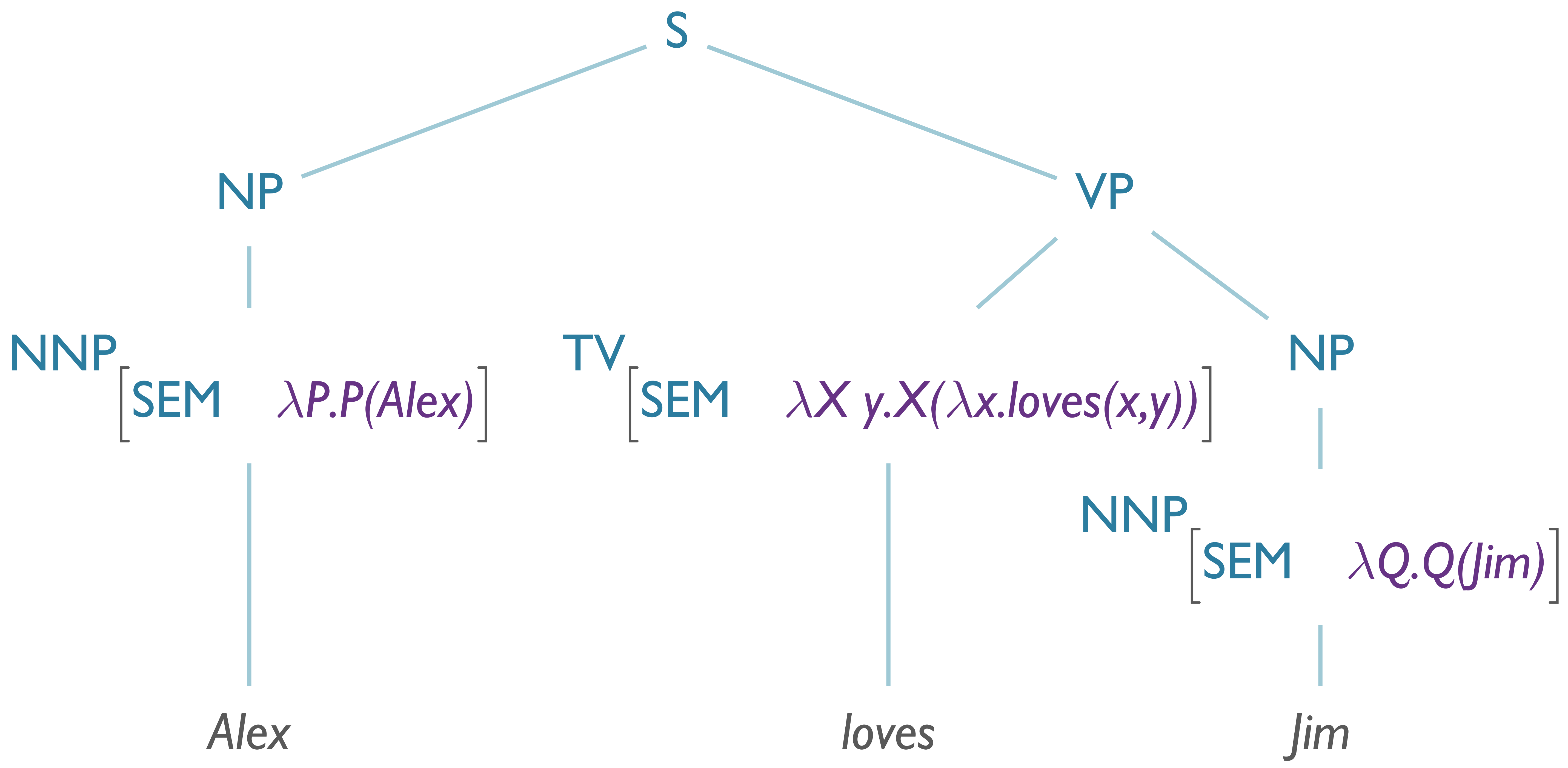

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  - loves(Jim,Alex)

Converting to an Event

- "y loves x," Originally:
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Converting to an Event

- “y loves x,” Originally:
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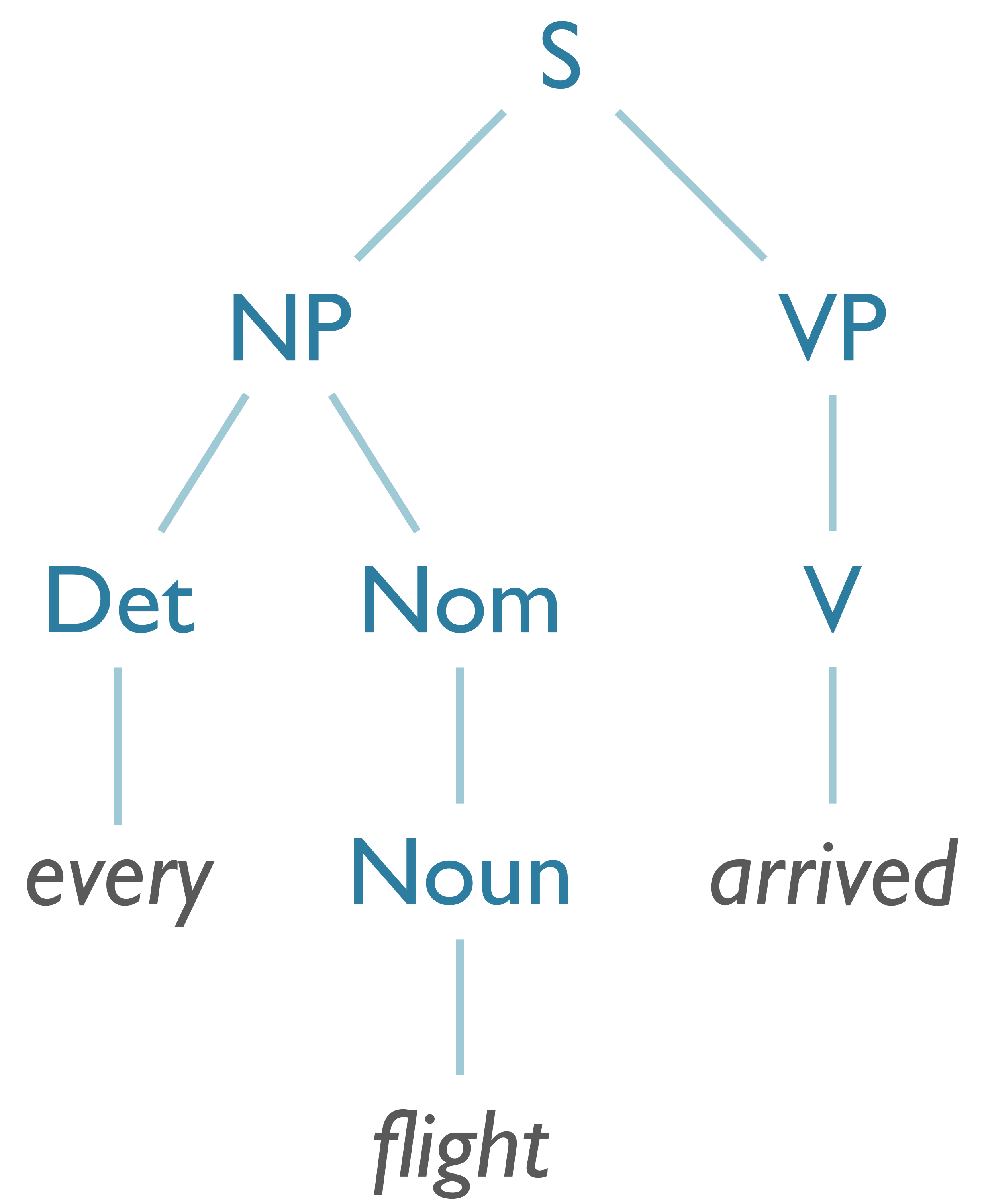
- as a Neo-Davidsonian event:
  - `λX y.X(λx.∃e love(e) ∧ lover(e,y) ∧ loved(e,x))`

Quantifiers & Scope

Semantic Analysis Example

- Basic model
  - Neo-Davidsonian event-style model
  - Complex quantification



- Example: *Every flight arrived*

$$\forall x\ Flight(x) \Rightarrow \exists e\ Arrived(e) \wedge ArrivedThing(e,x)$$

“*Every flight arrived*”

- First intuitive approach:
  - Every flight = $\forall x\ Flight(x)$

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- …so what is the representation for "**every**"?
  - $\lambda P.\lambda Q.\forall x\, P(x) \Rightarrow Q(x)$

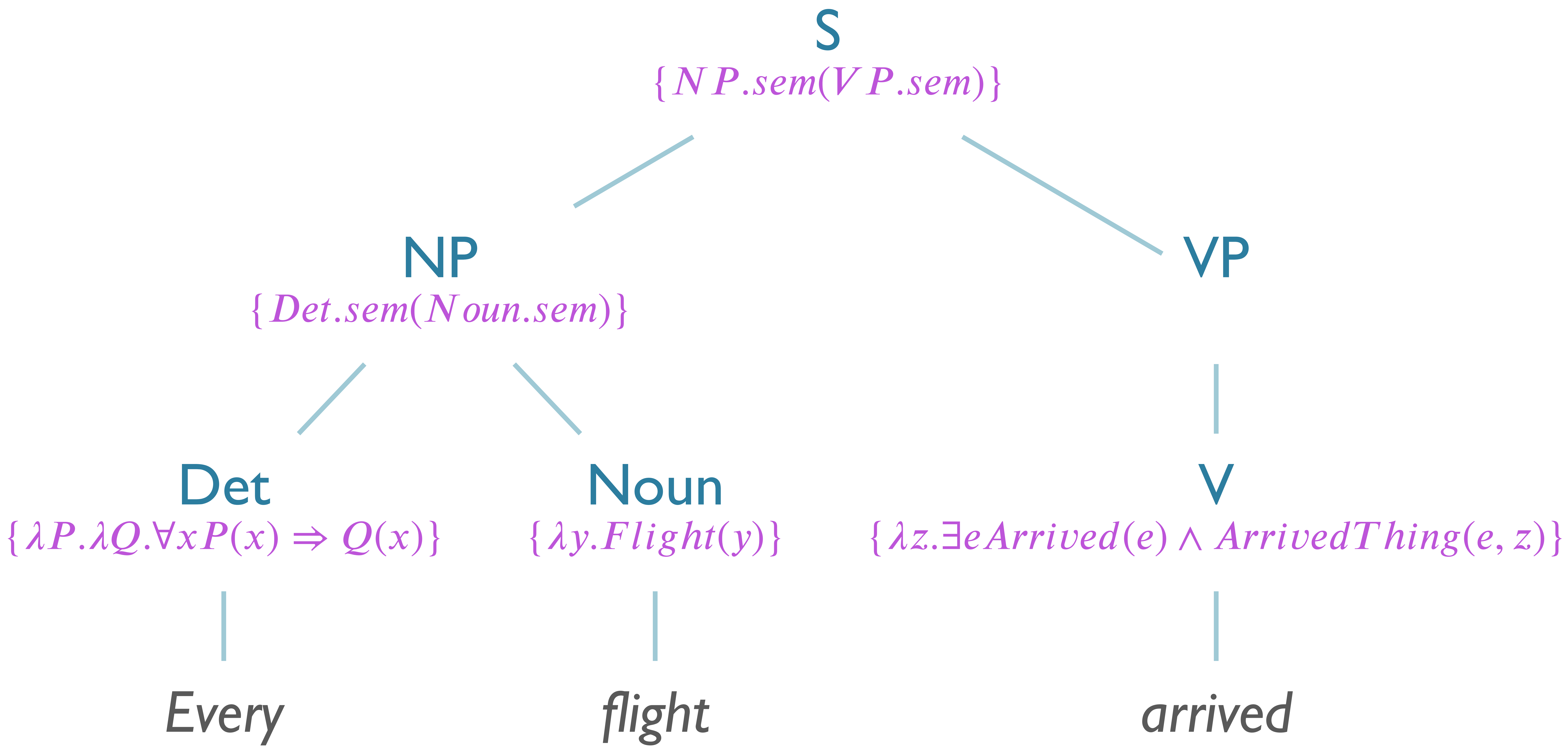
"*A flight arrived*"

- We just need one item for truth value
  - So, start with ∃x…
  - $\lambda P.\lambda Q.\exists x\ P(x) \wedge Q(x)$

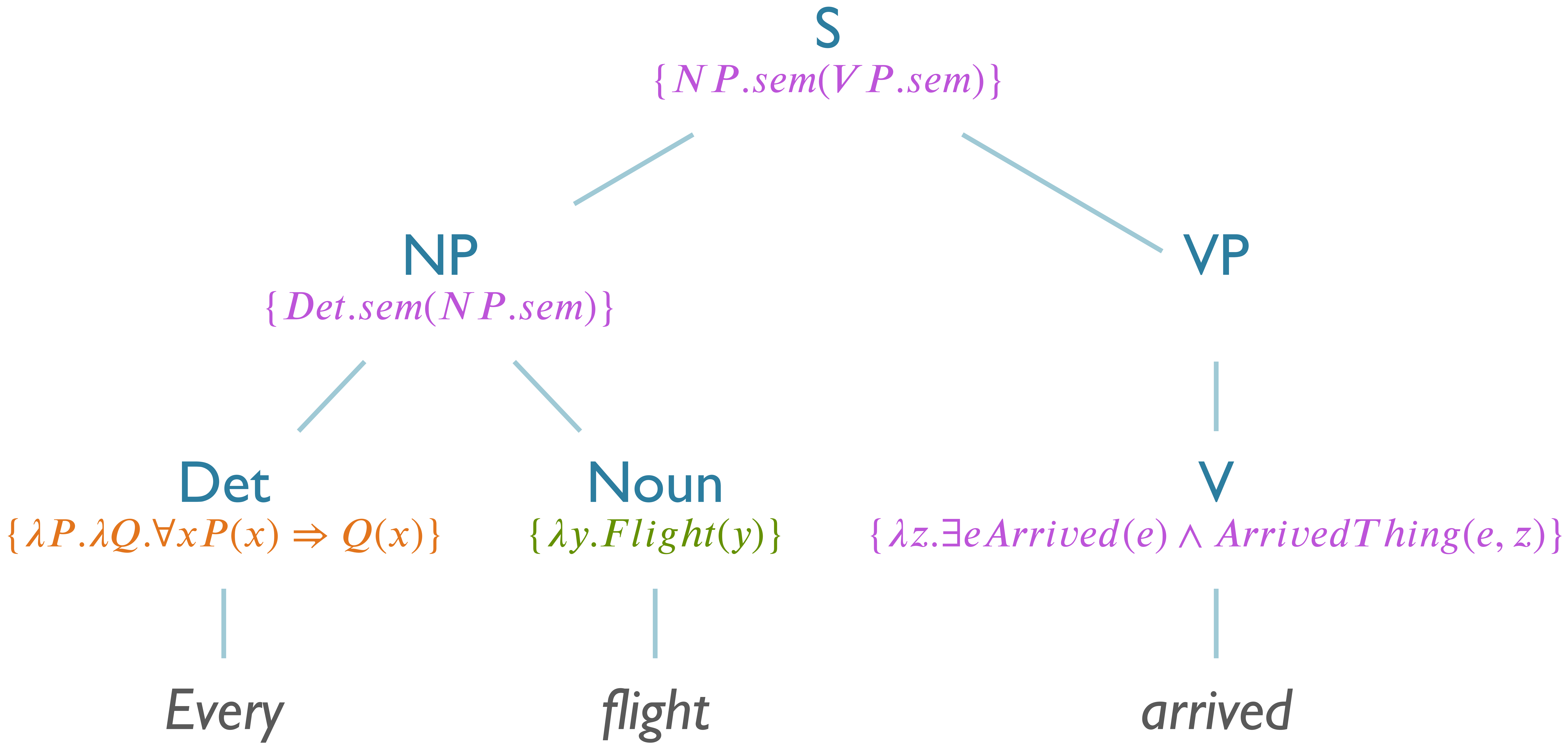
Creating Attachments

"Every flight arrived"

Det	$\rightarrow$ 'Every'	$\{\ \lambda P.\lambda Q.\forall \boldsymbol{x}\ P(\boldsymbol{x}) \Rightarrow Q(\boldsymbol{x})\ \}$
$Noun$	$\rightarrow$ 'flight'	$\{\ \lambda \boldsymbol{x}.Flight(\boldsymbol{x})\ \}$
$Verb$	$\rightarrow$ 'arrived'	$\{\lambda \boldsymbol{y}.\exists \boldsymbol{e} Arrived(\boldsymbol{e}) \wedge ArrivedThing(\boldsymbol{e},\ \boldsymbol{y})\}$
VP	$\rightarrow Verb$	$\{\ Verb.sem\ \}$
Nom	$\rightarrow Noun$	$\{\ Noun.sem\ \}$
S	$\rightarrow NP\ VP$	$\{\ NP.sem(VP.sem)\ \}$
NP	$\rightarrow Det\ Nom$	$\{\ Det.sem(Nom.sem)\ \}$


S
{NP.sem(VP.sem)}
NP
{Det.sem(Noun.sem)}
VP
Det
{λP.λQ.∀xP(x) ⇒ Q(x)}
Noun
{λy.Flight(y)}
V
{λz.∃eArrived(e) ∧ ArrivedThing(e, z)}
Every
flight
arrived

$$NP \rightarrow Det.sem(NP.sem)$$



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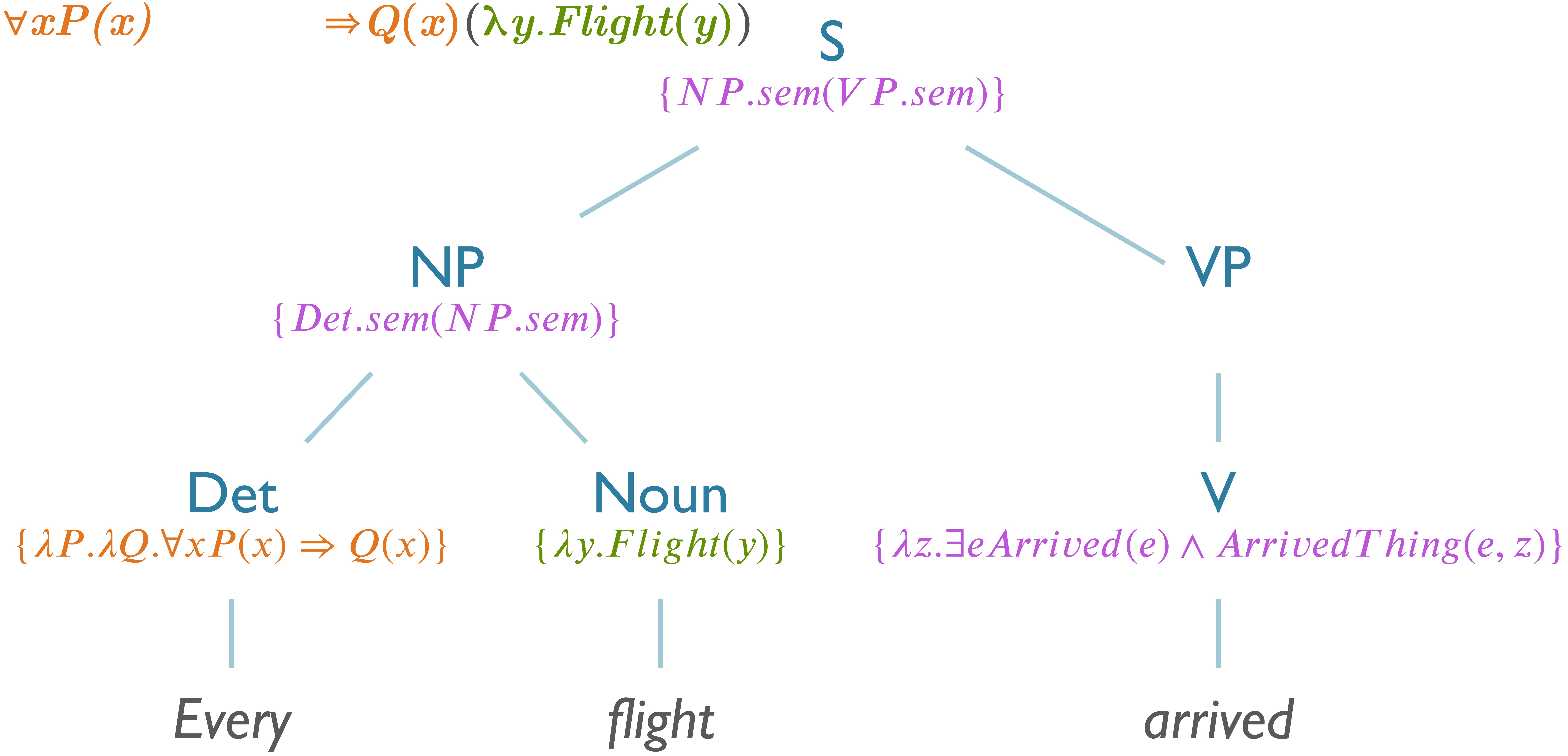

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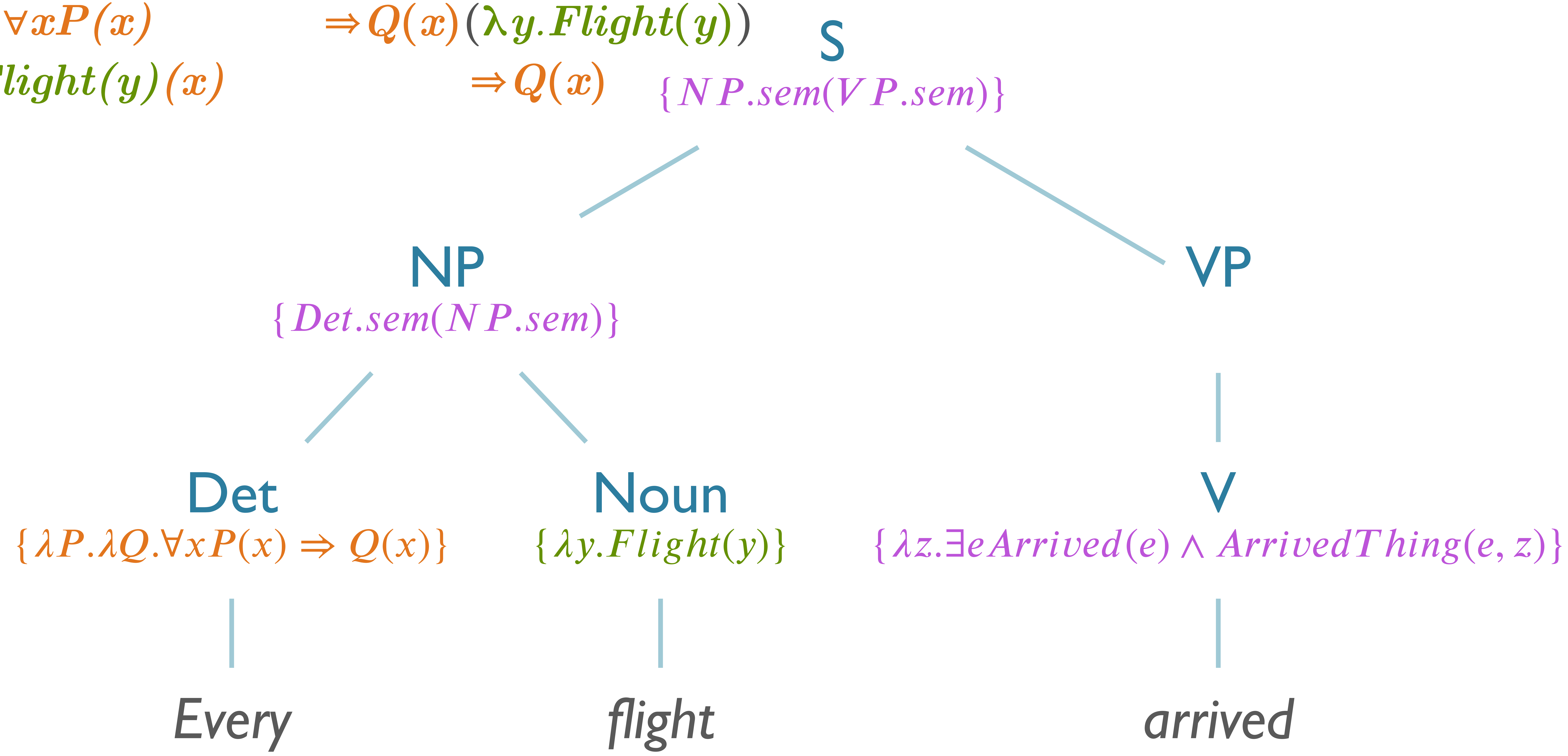
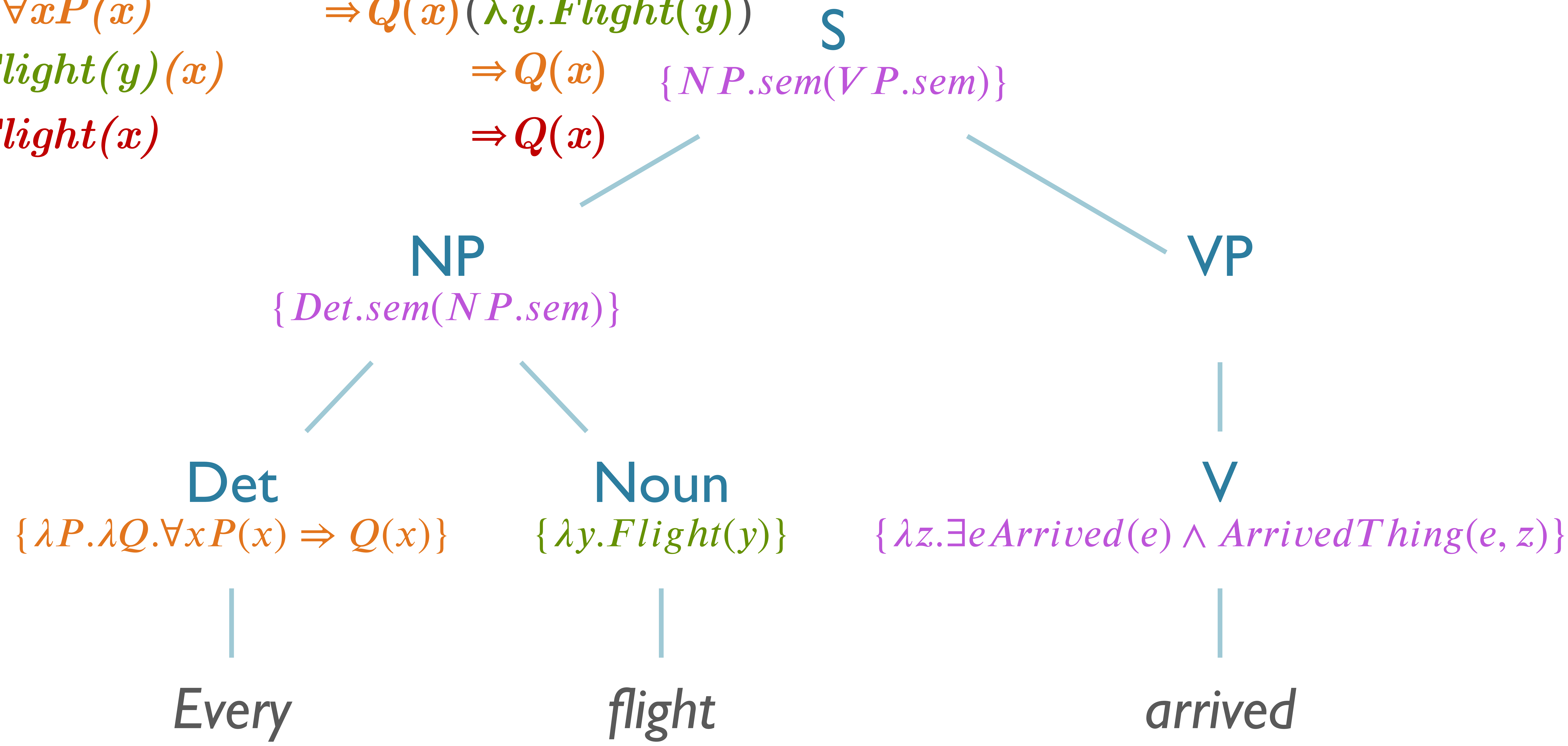


$$\begin{aligned}
NP &\rightarrow Det.sem(NP.sem)\\
\lambda P.\lambda Q.\forall x P(x) &\Rightarrow Q(x)(\lambda y.Flight(y))\\
\lambda Q.\forall x \lambda y.Flight(y)(x) &\Rightarrow Q(x)\\
\lambda Q.\forall x Flight(x) &\Rightarrow Q(x)
\end{aligned}$$



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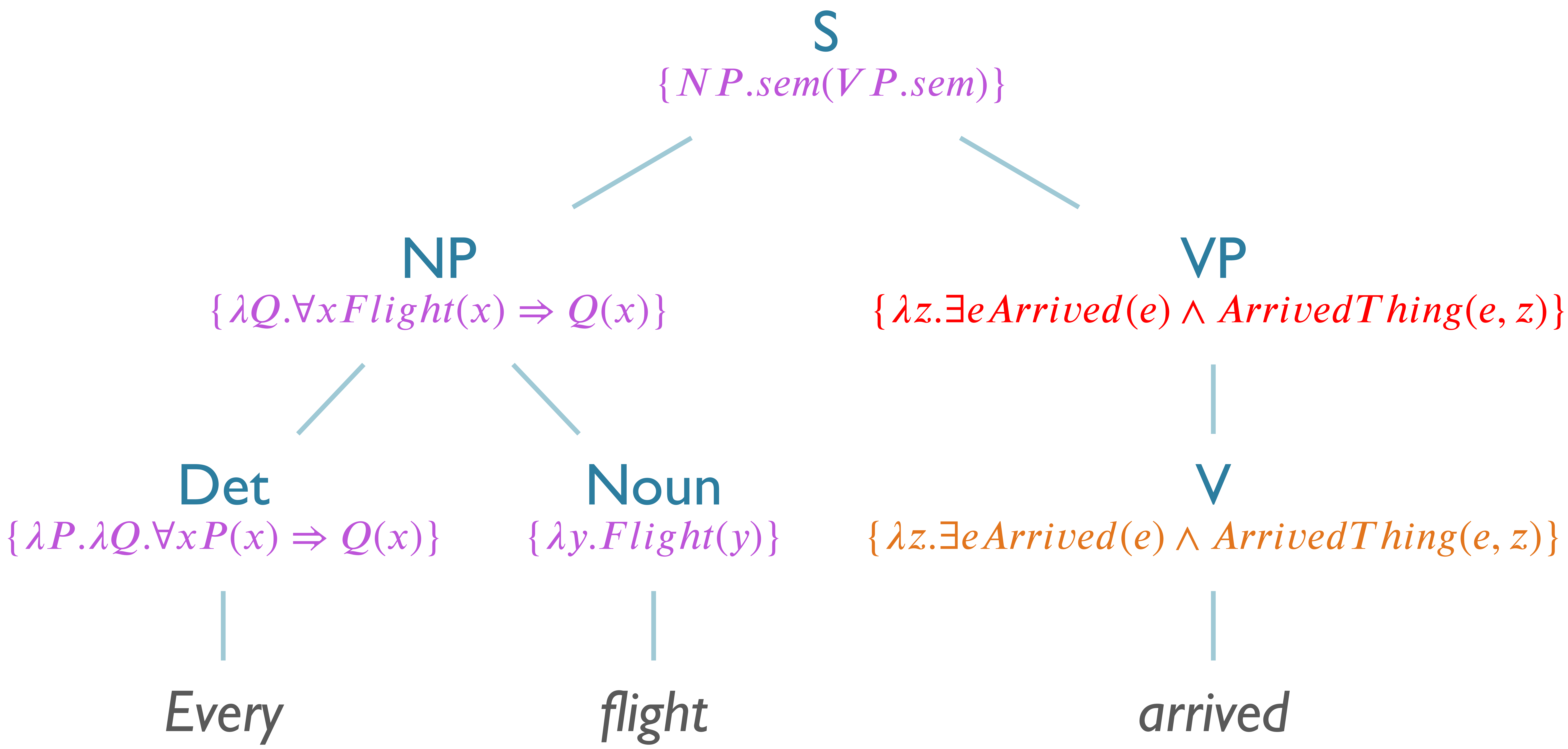
- S $\{NP.sem(VP.sem)\}$
  - NP $\{\lambda Q.\forall x Flight(x) \Rightarrow Q(x)\}$
    - Det $\{\lambda P.\lambda Q.\forall x P(x) \Rightarrow Q(x)\}$
      - *Every*
    - Noun $\{\lambda y.Flight(y)\}$
      - *flight*
  - VP
    - V $\{\lambda z.\exists e Arrived(e) \wedge ArrivedThing(e,z)\}$
      - *arrived*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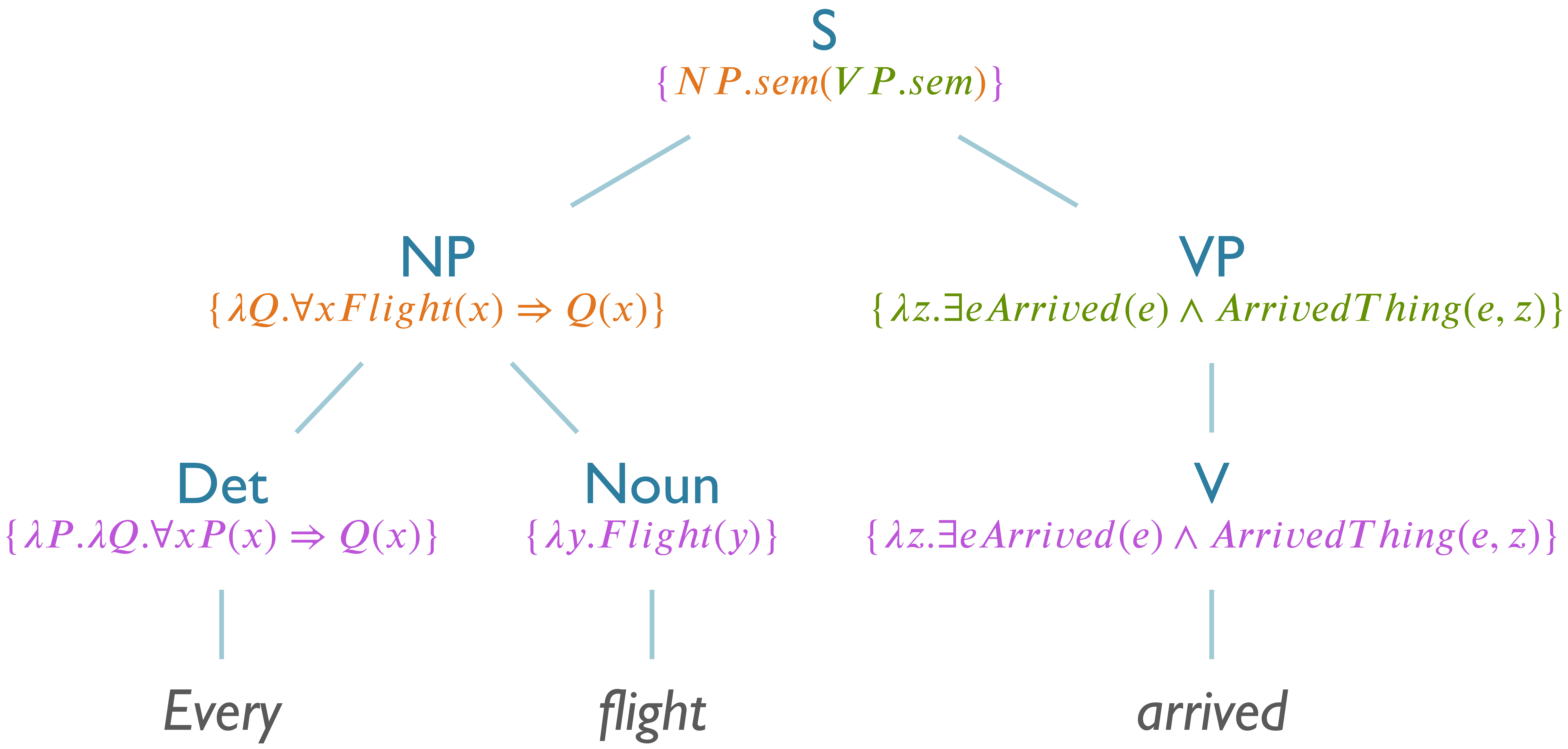
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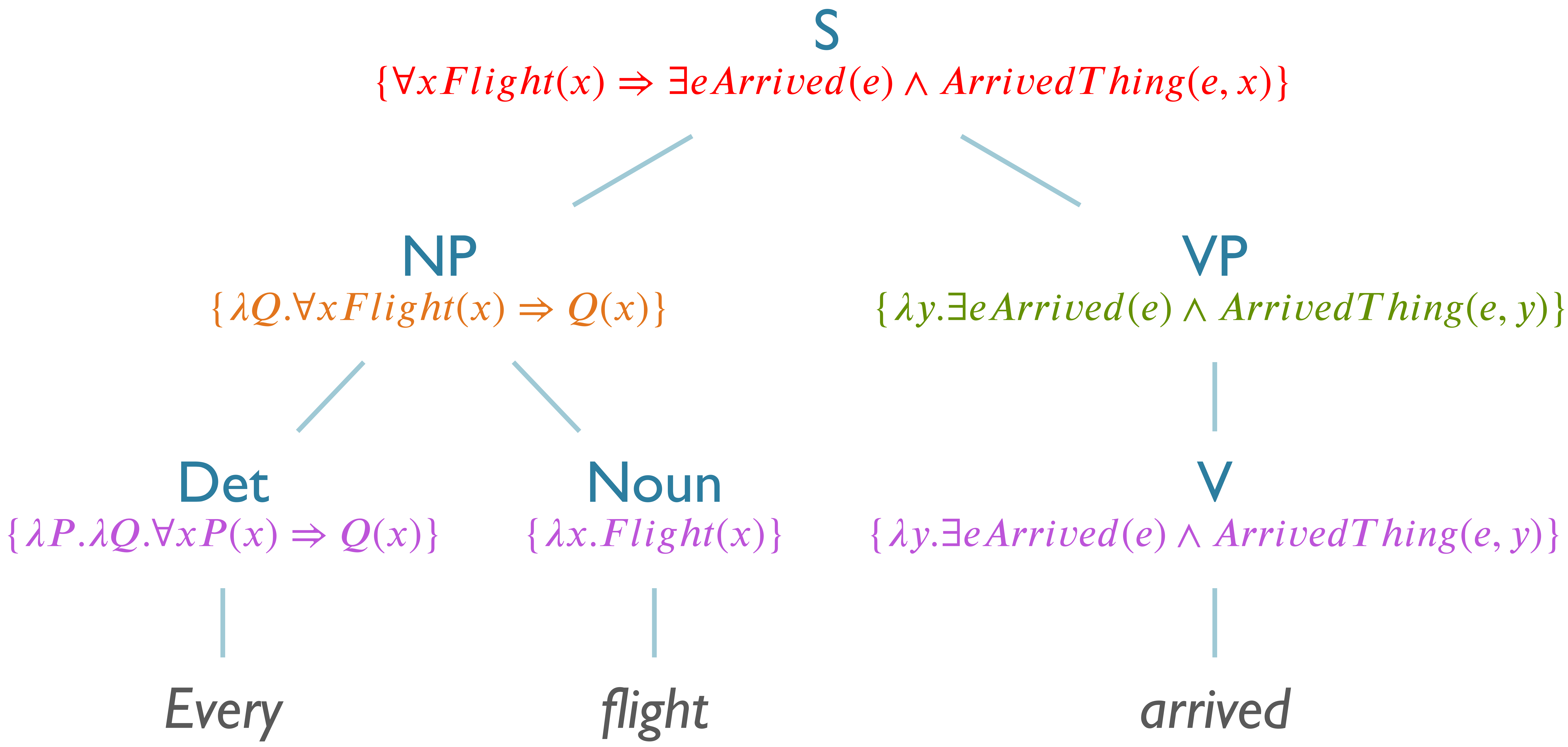
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'John Booked A Flight'

$Det \rightarrow$ 'a'	$\{ \lambda P.\lambda Q.\exists x\ P(x) \wedge Q(x) \}$
$Det \rightarrow$ 'every'	$\{ \lambda P.\lambda Q.\forall x\ P(x) \Rightarrow Q(x) \}$
$NN \rightarrow$ 'flight'	$\{\lambda x.Flight(x)\}$
$NNP \rightarrow$ 'John'	$\{\lambda X.X(John)\}$
$NP \rightarrow NNP$	$\{NNP.sem\}$
$S \rightarrow NP\ VP$	$\{NP.sem(VP.sem)\}$
$VP \rightarrow Verb\ NP$	$\{Verb.sem(NP.sem)\}$
$Verb \rightarrow$ 'booked'	$\{\lambda W.\lambda z.W(\exists e Booked(e) \wedge Booker(e,z) \wedge BookedThing(e,y))\}$

…we'll step through this next time.

Strategy for Semantic Attachments

- General approach:
  - Create complex lambda expressions with lexical items

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  - Apply semantics of one child to other through lambda
    - <u>Combine</u> elements, don't introduce new ones

Parsing with Semantics

- Implement semantic analysis in parallel with syntactic parsing
  - Enabled by this rule-to-rule compositional approach

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- Implement semantic analysis in parallel with syntactic parsing
  - Enabled by this rule-to-rule compositional approach
- Required modifications
  - Augment grammar rules with semantics field
  - Augment chart states with meaning expression
  - Incrementally compute semantics

Sidenote: Idioms

- Not purely compositional
  - *kick the bucket* → die
  - *tip of the iceberg* → small part of the entirety
- Handling
  - Mix lexical items with constituents
  - Create idiom-specific construct for productivity
  - Allow non-compositional semantic attachments
- Extremely complex, e.g. metaphor