

# Montague Grammar Induction

Gene Louis Kim & Aaron Steven White  
University of Rochester

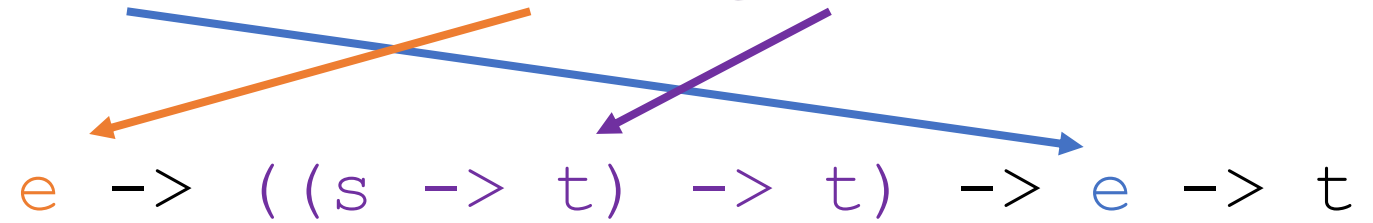
Semantics and Linguistic Theory  
Cornell University  
18 August 2020



# Semantic Selection

What semantic type signatures can predicates have?

$\llbracket ask \rrbracket : \text{Ent} \text{ \_\_\_ } \text{Ent Ques}$



## Semantic Selection

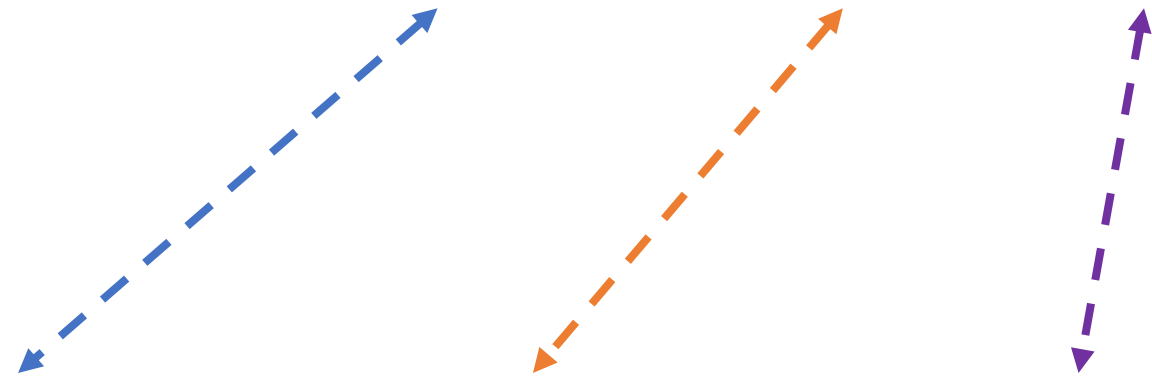
What semantic type signatures can predicates have?

## Projection

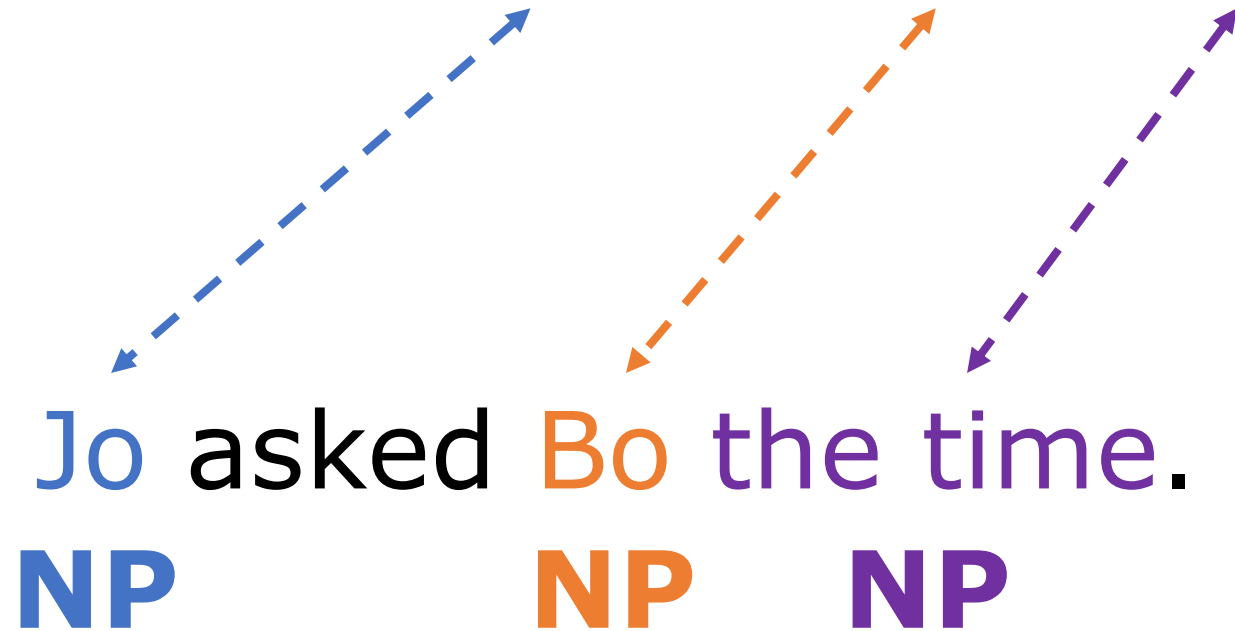
How are semantic type signatures related to syntactic types?

$[ask]:$  **Ent** — **Ent** **Ques**

**Jo** asked **Bo** what time it was.  
**NP** **NP** **S[+Q, +WH]**



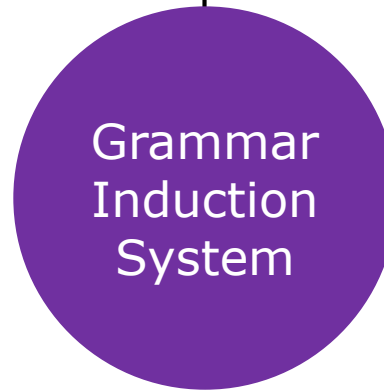
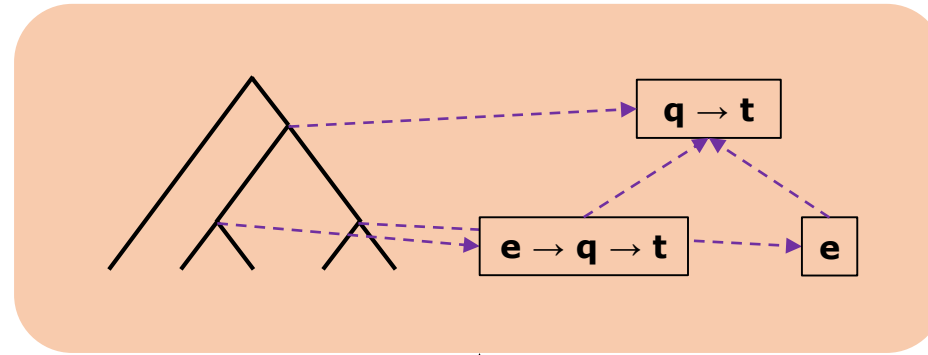
$[ask]:$  **Ent** — **Ent** **Ques**




## Approach

A computational model for inducing syntactic structure and semantic types using lexicon-scale experimental data

## Montague grammar



Someone asked someone something. 

Someone wondered someone something. 

## Acceptability judgments



## Case Studies

1. Interrogatives v. declaratives
2. Finite v. infinitival complements

## Findings

1. Both primarily denote question types
2. Infinitivals produce contentful variants of finite complement denotations

## Prior Models + Data

Selection and Projection via matrix factorization + MegaAttitude datasets

## Our Model

Combinatory Categorical Grammar  
Induction

## Results

*Case Study:* interrogative and declarative-taking predicates

# Prior Models + Data

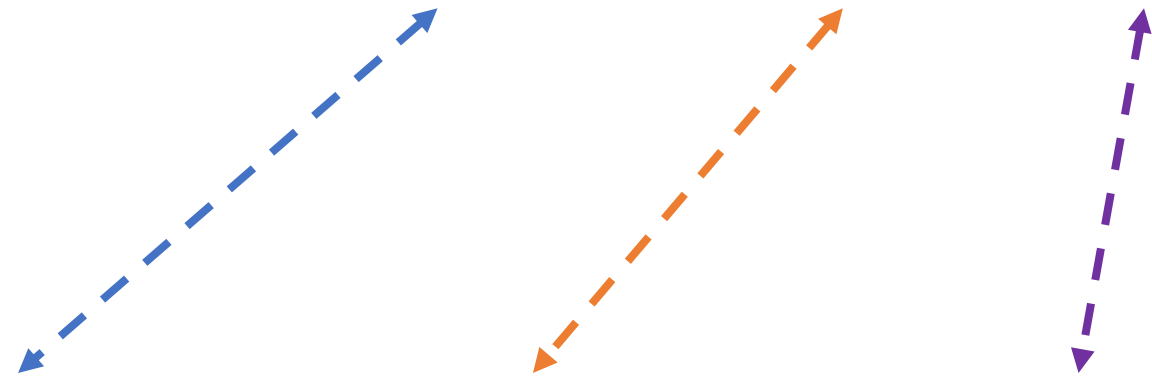


# Main Challenge

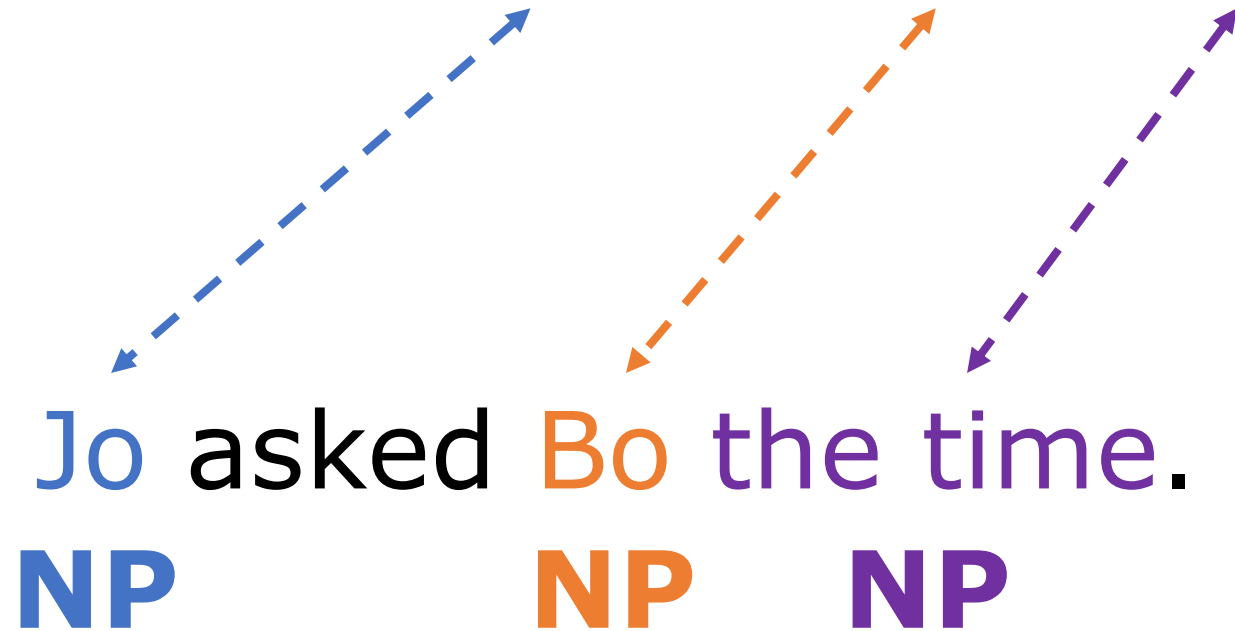
Lexical items are idiosyncratic

$[\textit{ask}]$ : **Ent** — **Ent** **Ques**

**Jo** asked **Bo** what time it was.  
**NP** **NP** **S[+Q, +WH]**



$[ask]:$  **Ent** — **Ent** **Ques**



$[[wonder]]$ : **Ent** — **Ques**

**Jo** wondered what time it was.  
**NP** **S[+Q, +WH]**



$[wonder]: \text{Ent} \text{ \_\_\_ } \text{Ques}$

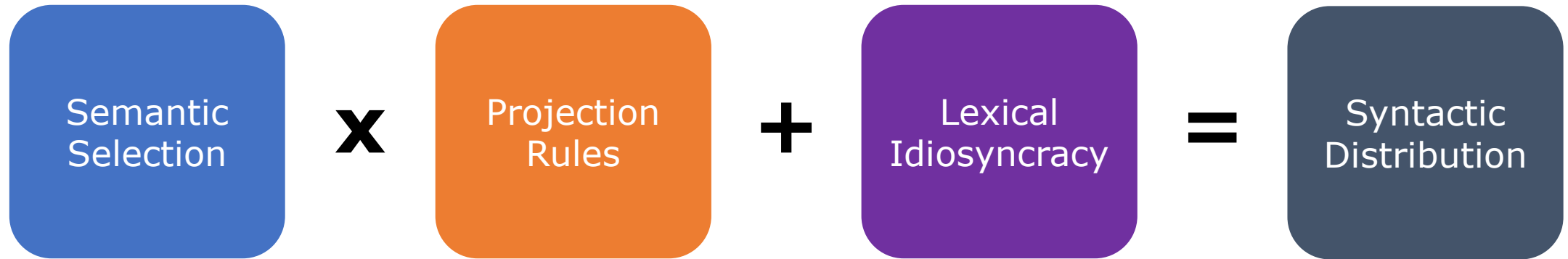
\* Jo wondered the time.  
NP NP



# Foundational Idea

Predicates' syntactic distribution is a product of three factors

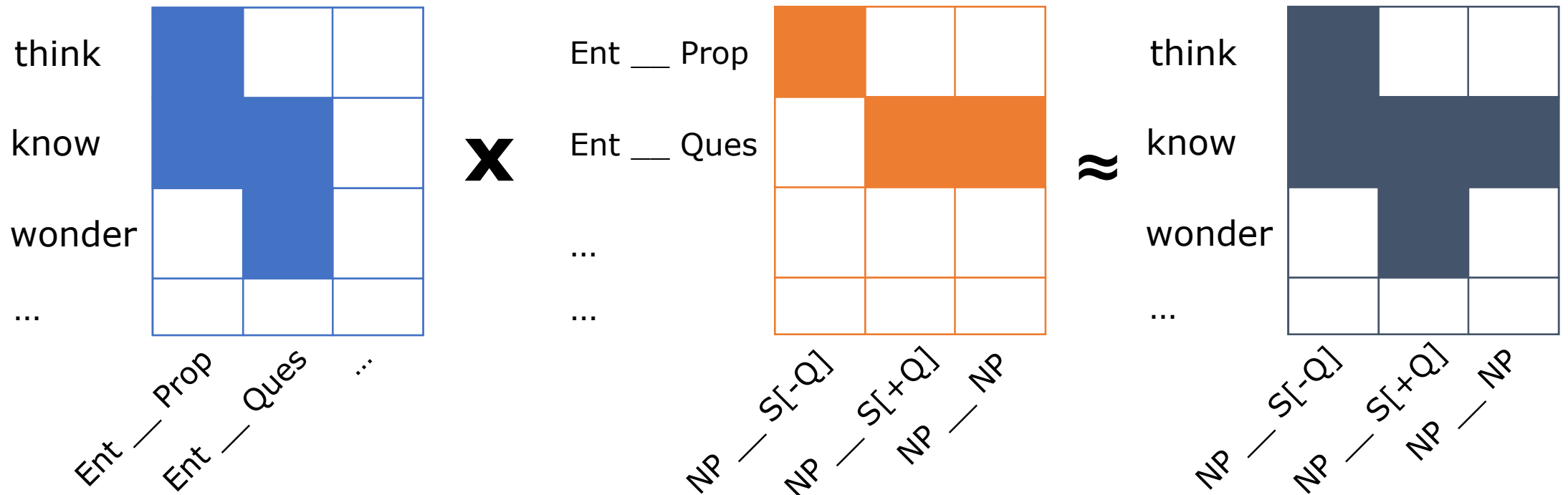
Grimshaw, 1979, 1990; Pesetsky, 1982, 1991



# White & Rawlins' Implementation

Unified additive + multiplicative model  
as matrix factorization

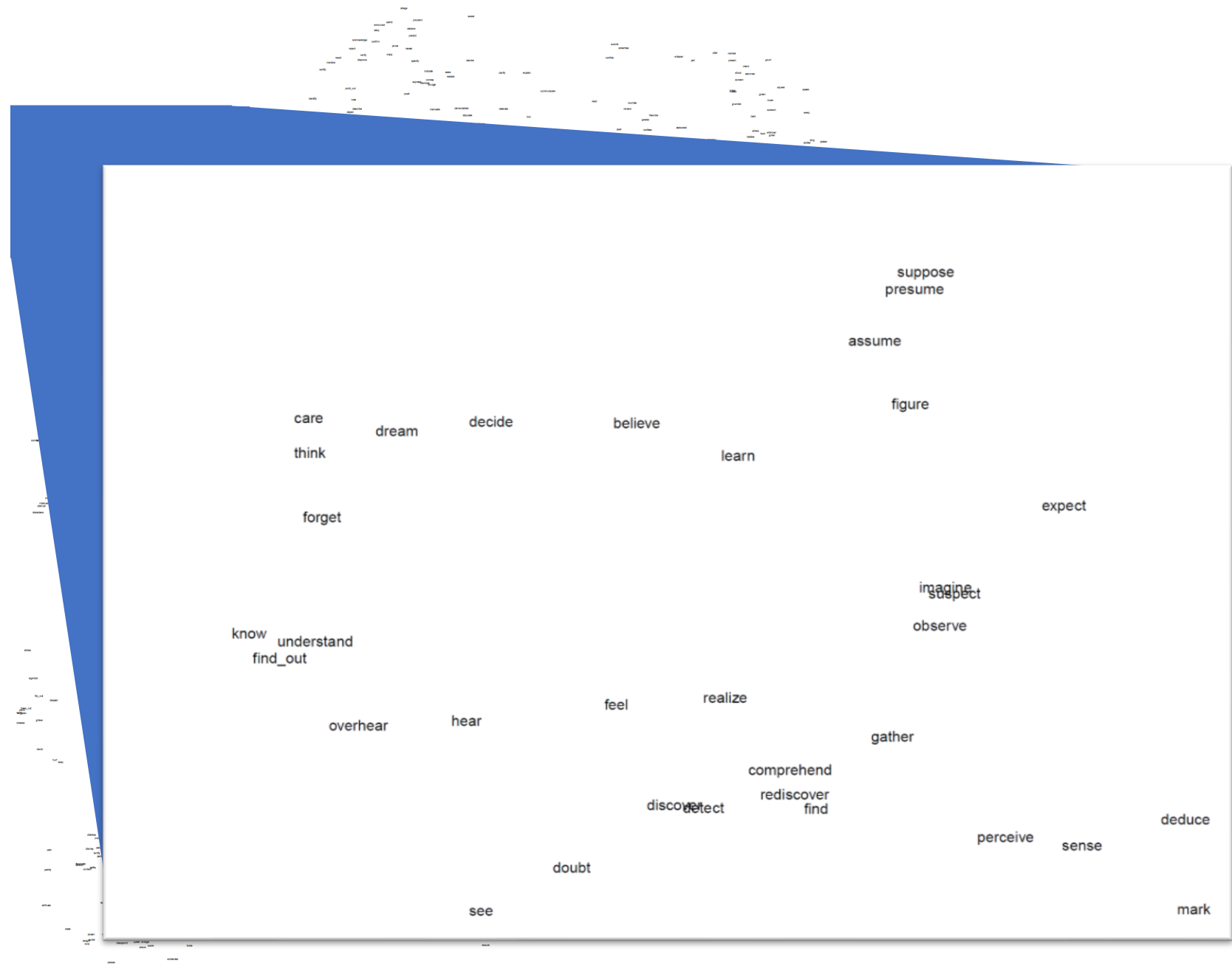
White & Rawlins 2016

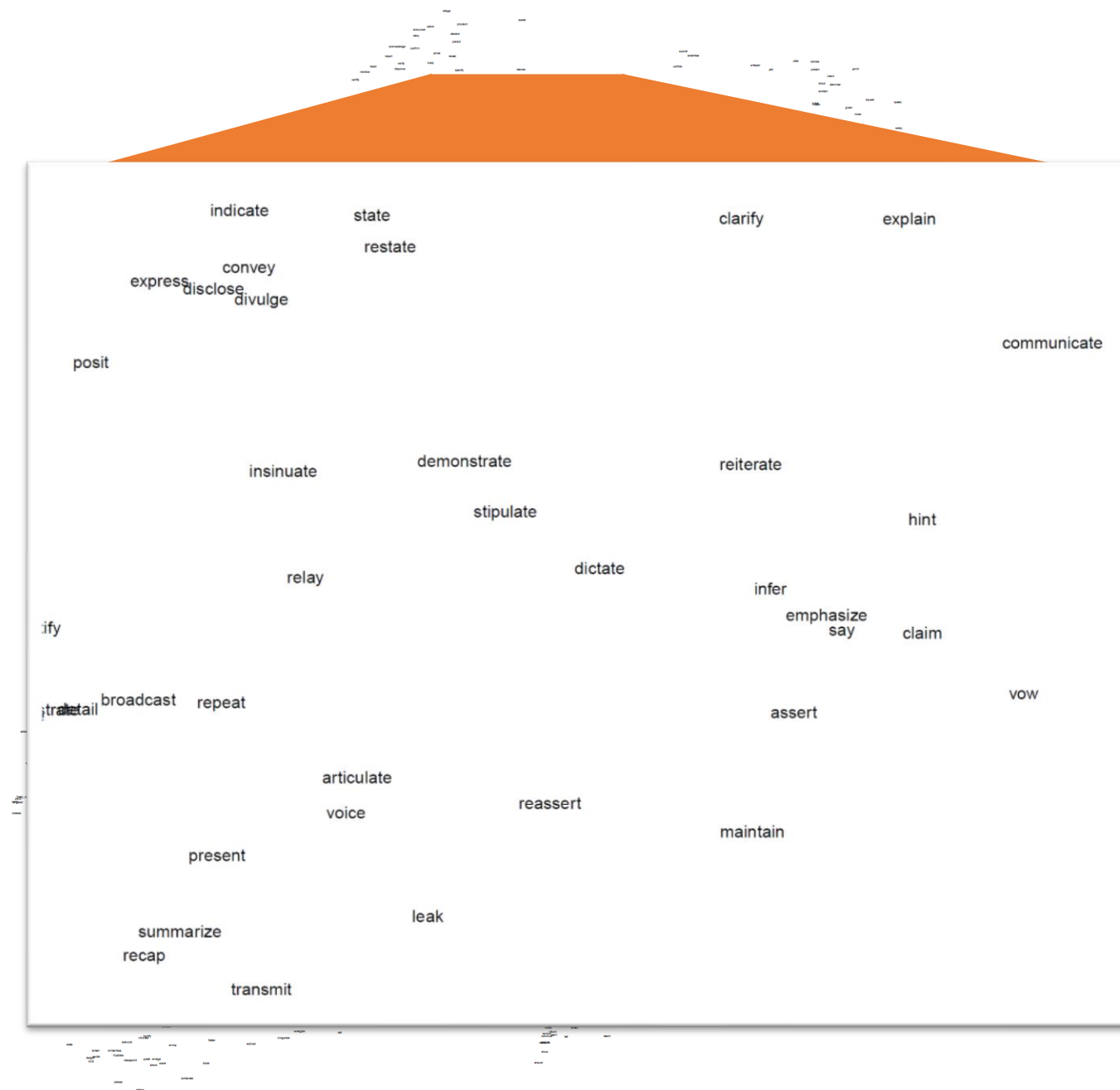


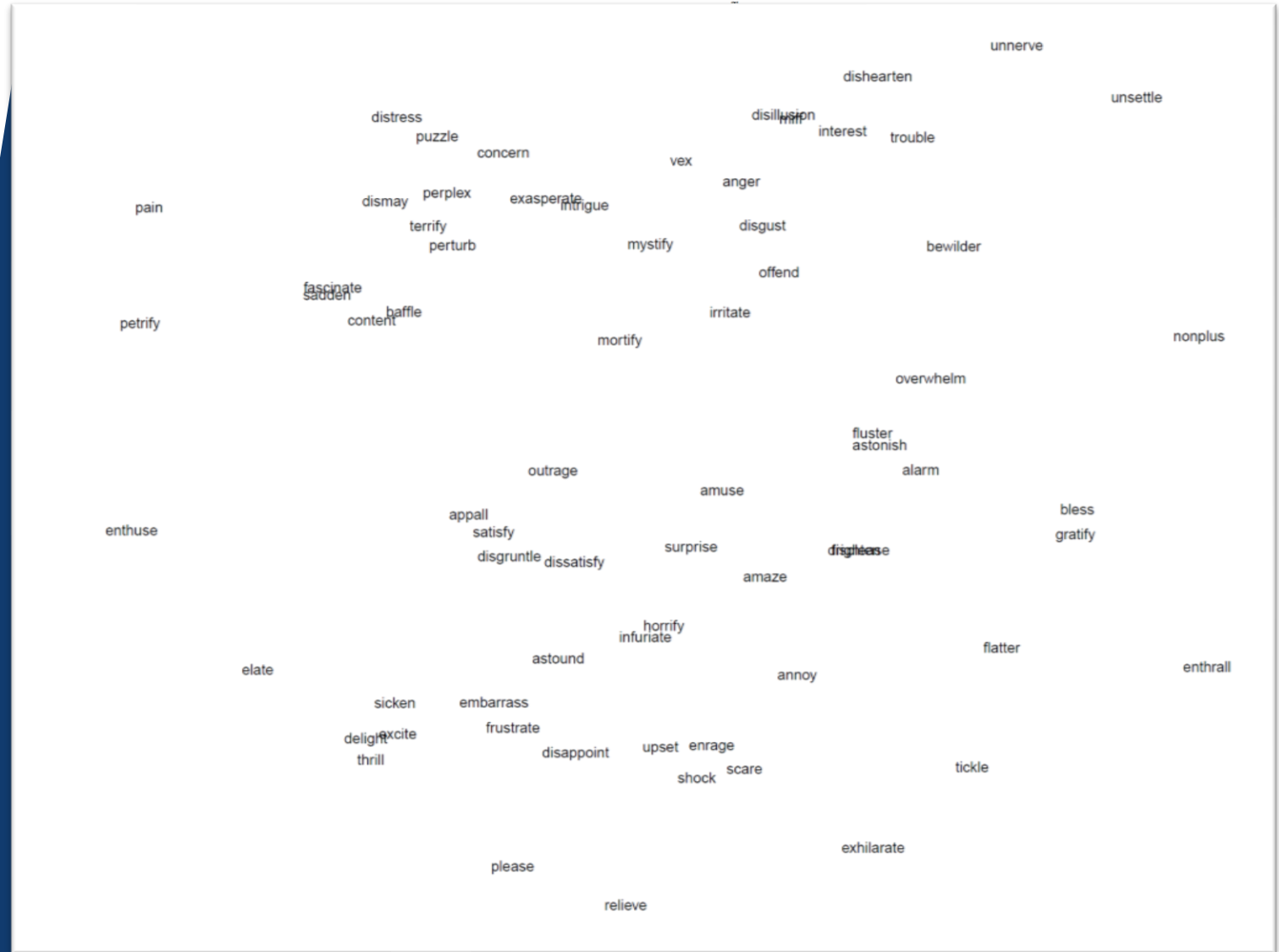
# MegaAcceptability

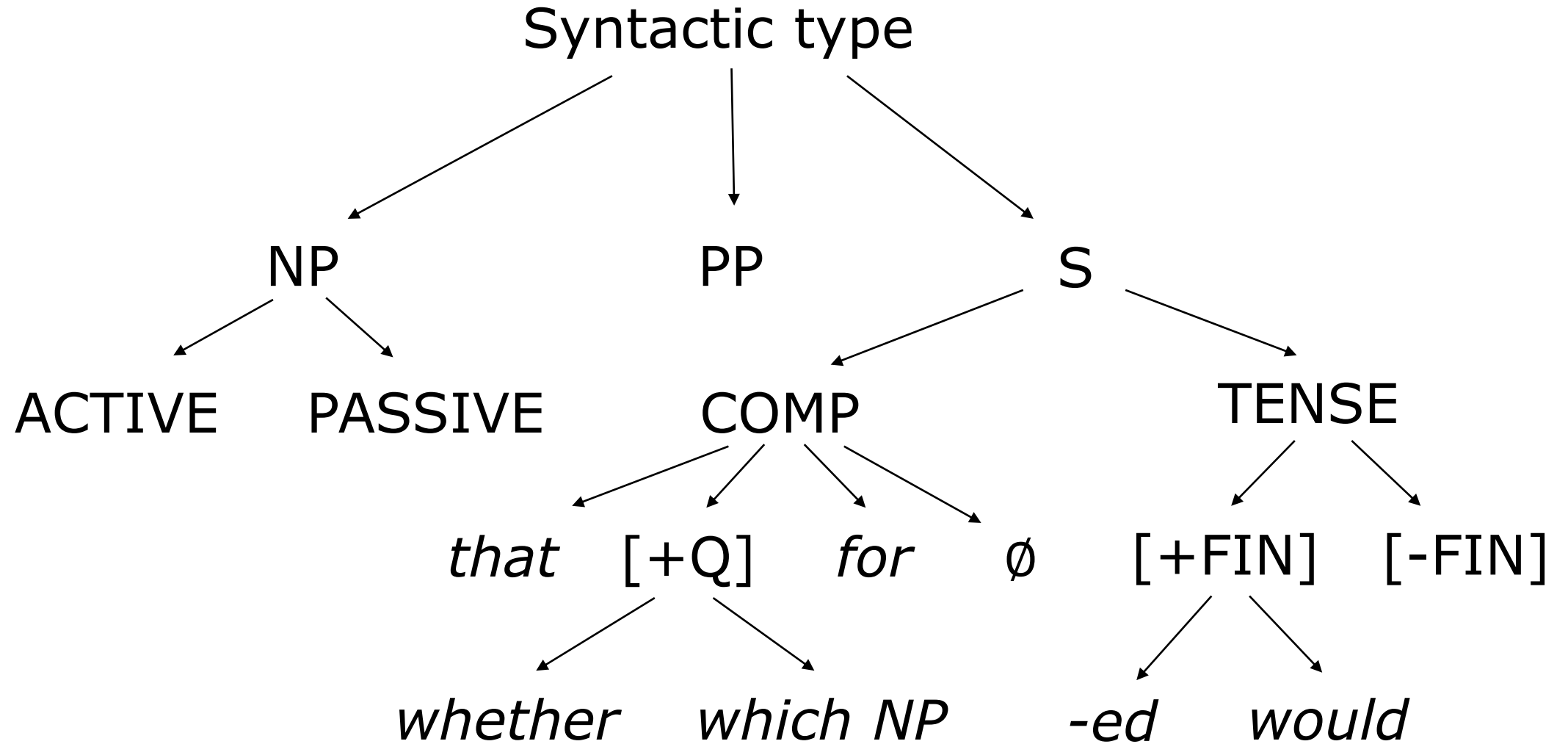
Acceptability judgments for 50,000 sentences constructed from:

1. 1,000 clause-embedding verbs
2. 50 syntactic frames









*know* + **NP V that S**

Someone knew that something happened



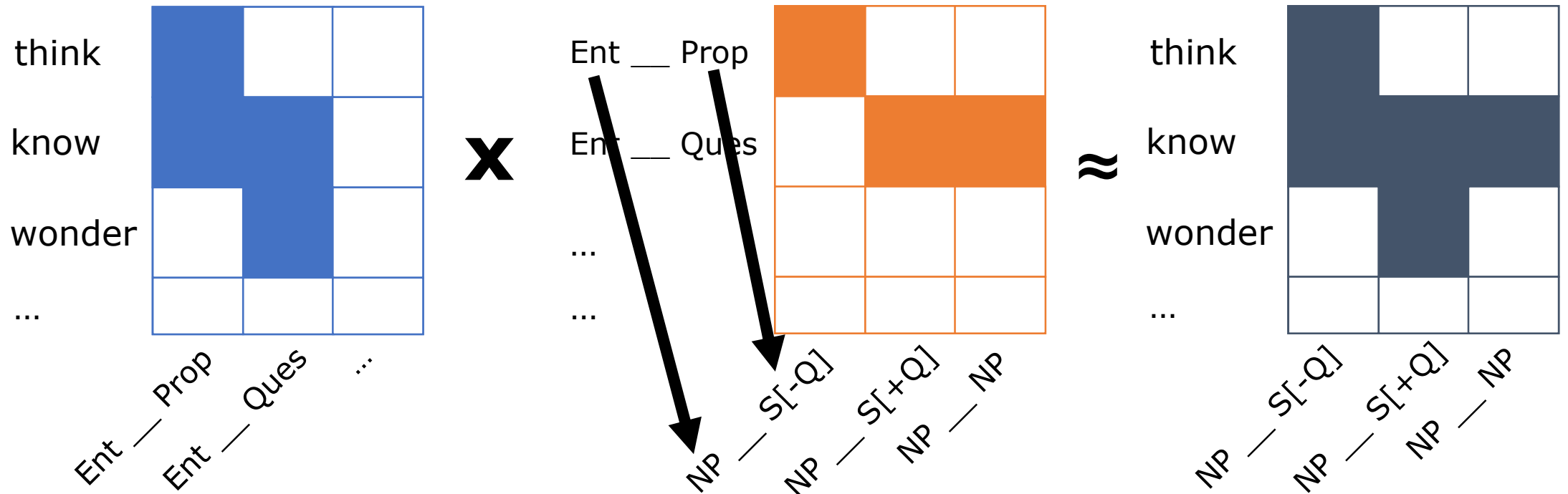
# Challenges

No representation of structure in semantic type signatures or syntax

# White & Rawlins' Implementation

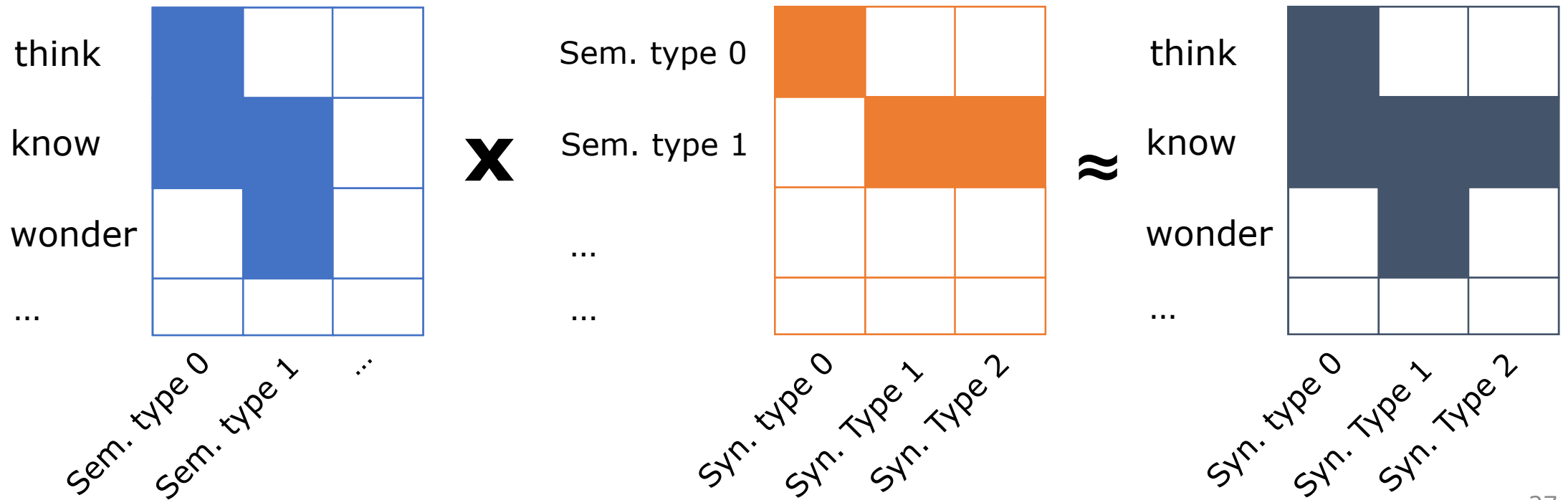
Unified additive + multiplicative model  
as matrix factorization

White & Rawlins 2016



# White & Rawlins' Implementation

Unified additive + multiplicative model  
as matrix factorization White & Rawlins 2016



# Our Model



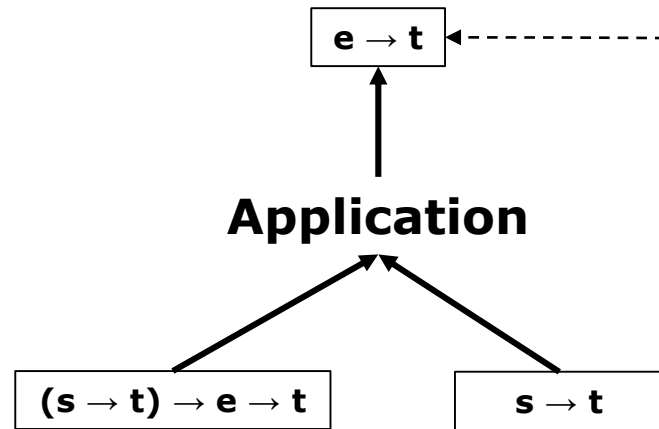
# Goal

From acceptability, jointly induce:

1. syntactic structure
2. coherent mapping from syntactic structure to semantic types

see also Bisk & Hockenmaier 2012, 2013

# Vector Space Interpretation



# Vector Space Type Grammar

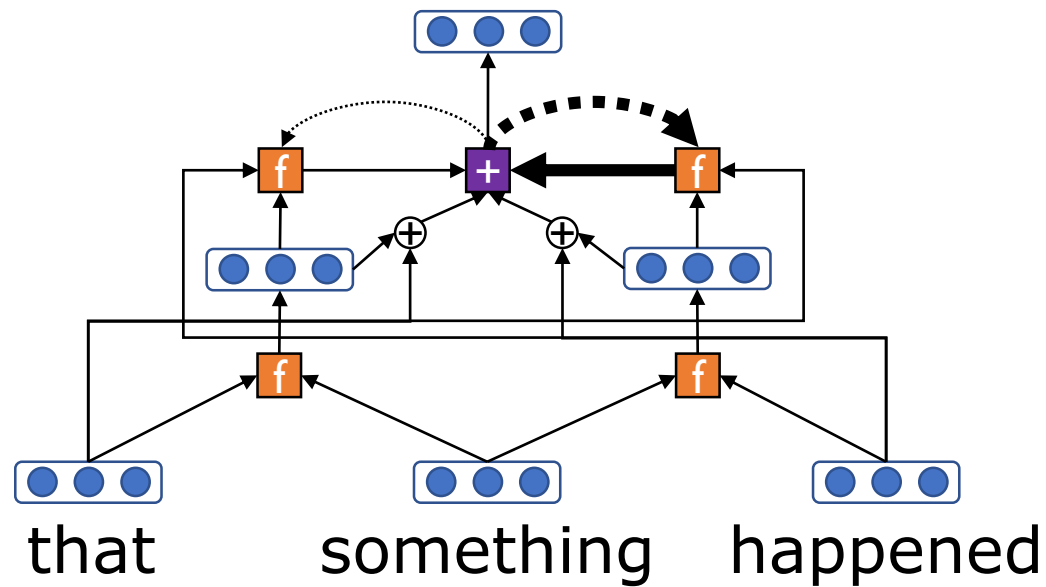
Vector Space Parser

Someone knew that something happened

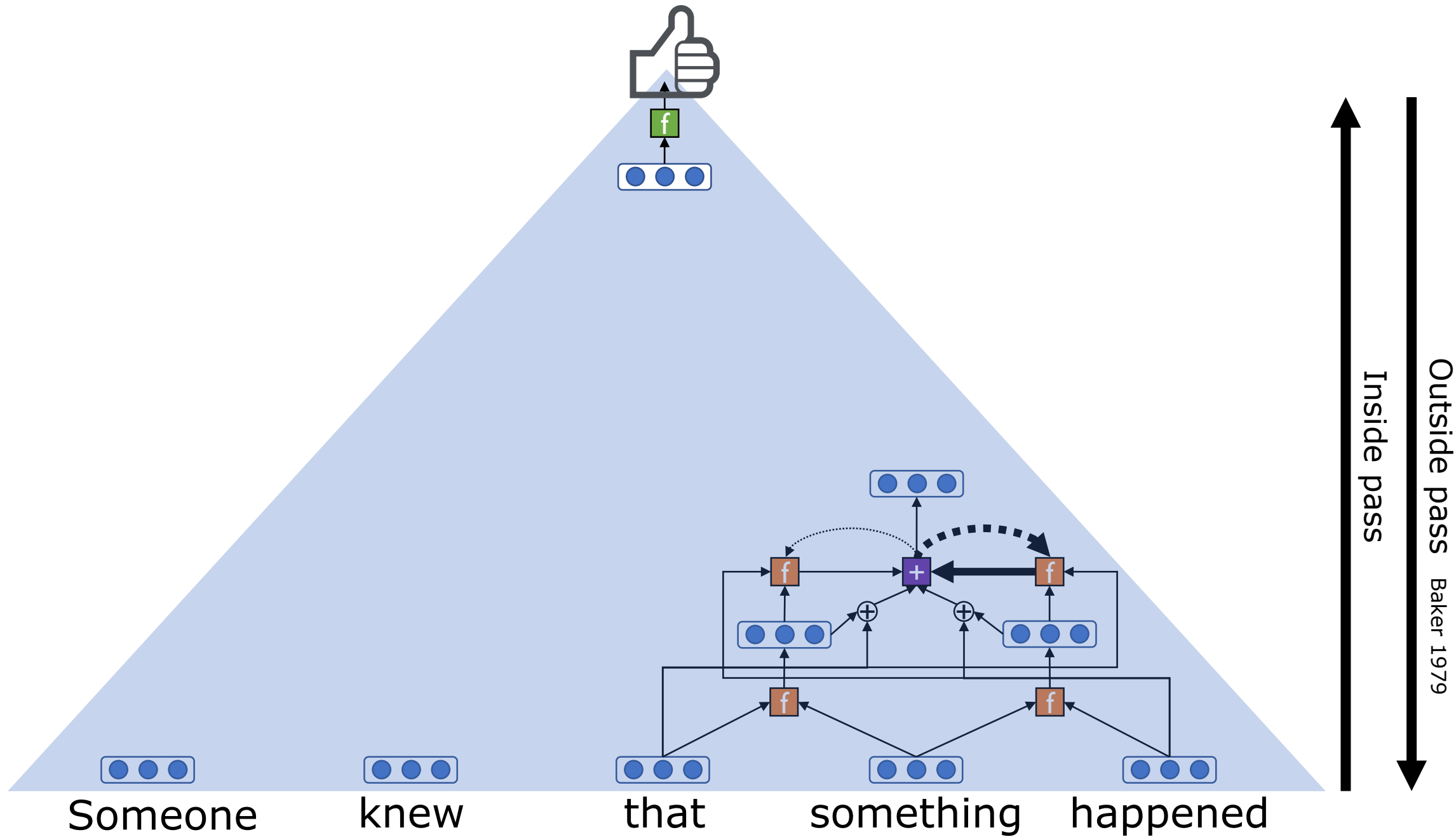
# Parser



Someone knew

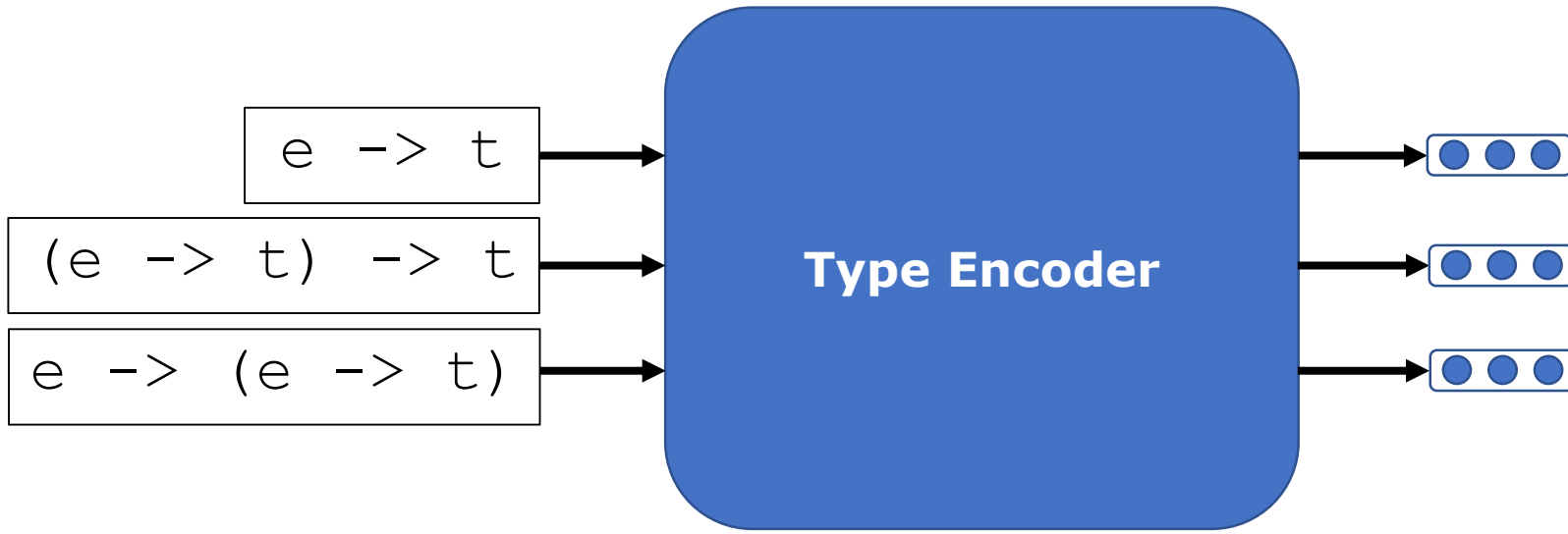


# Parser

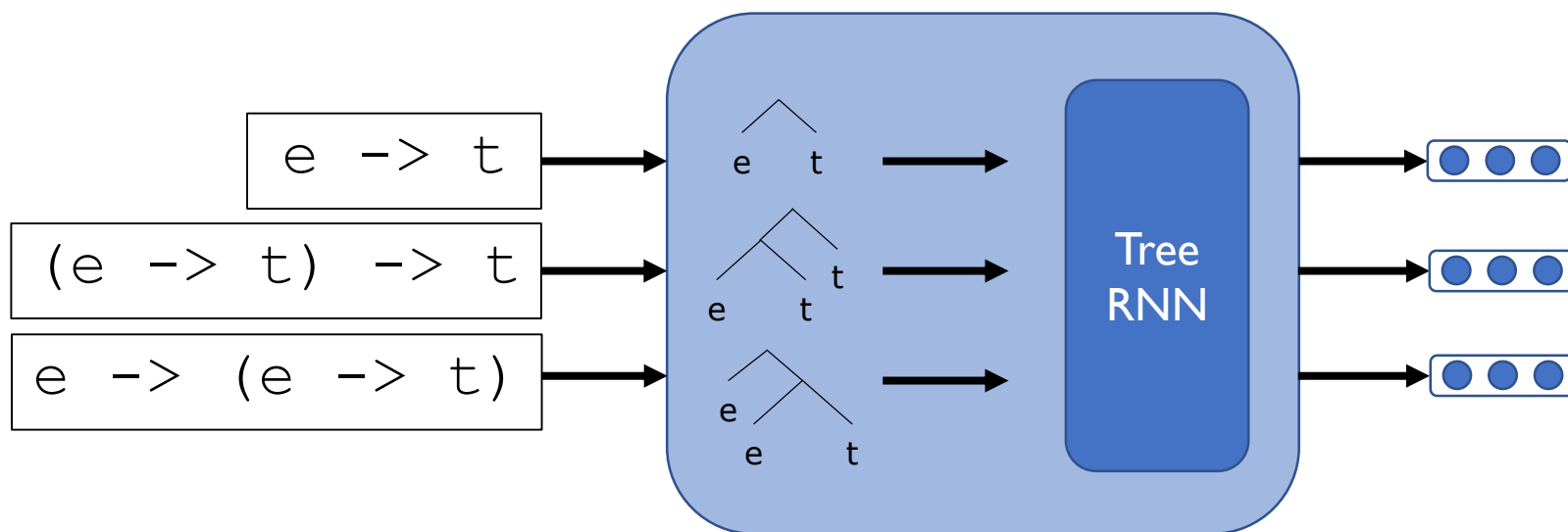




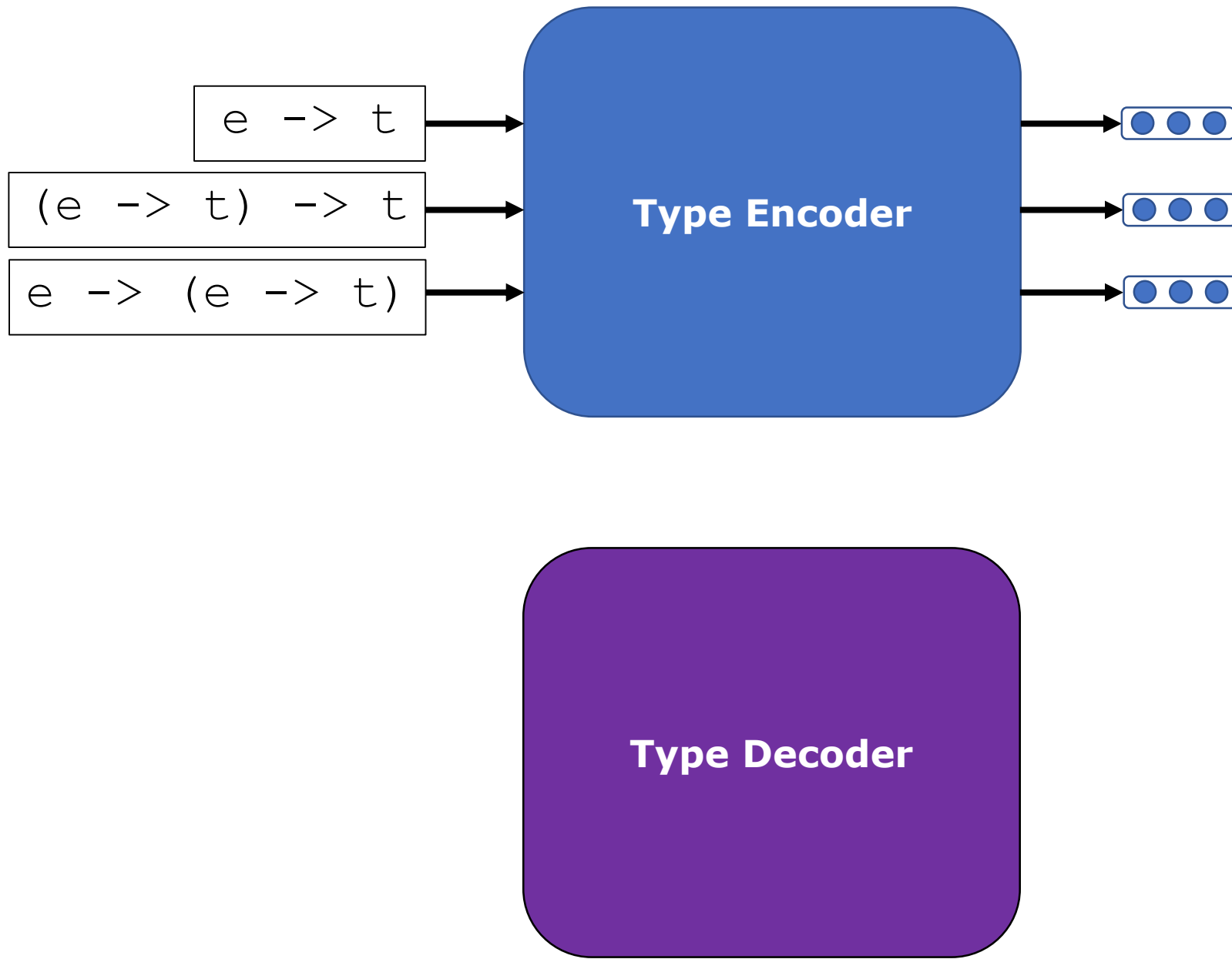
# Type Grammar



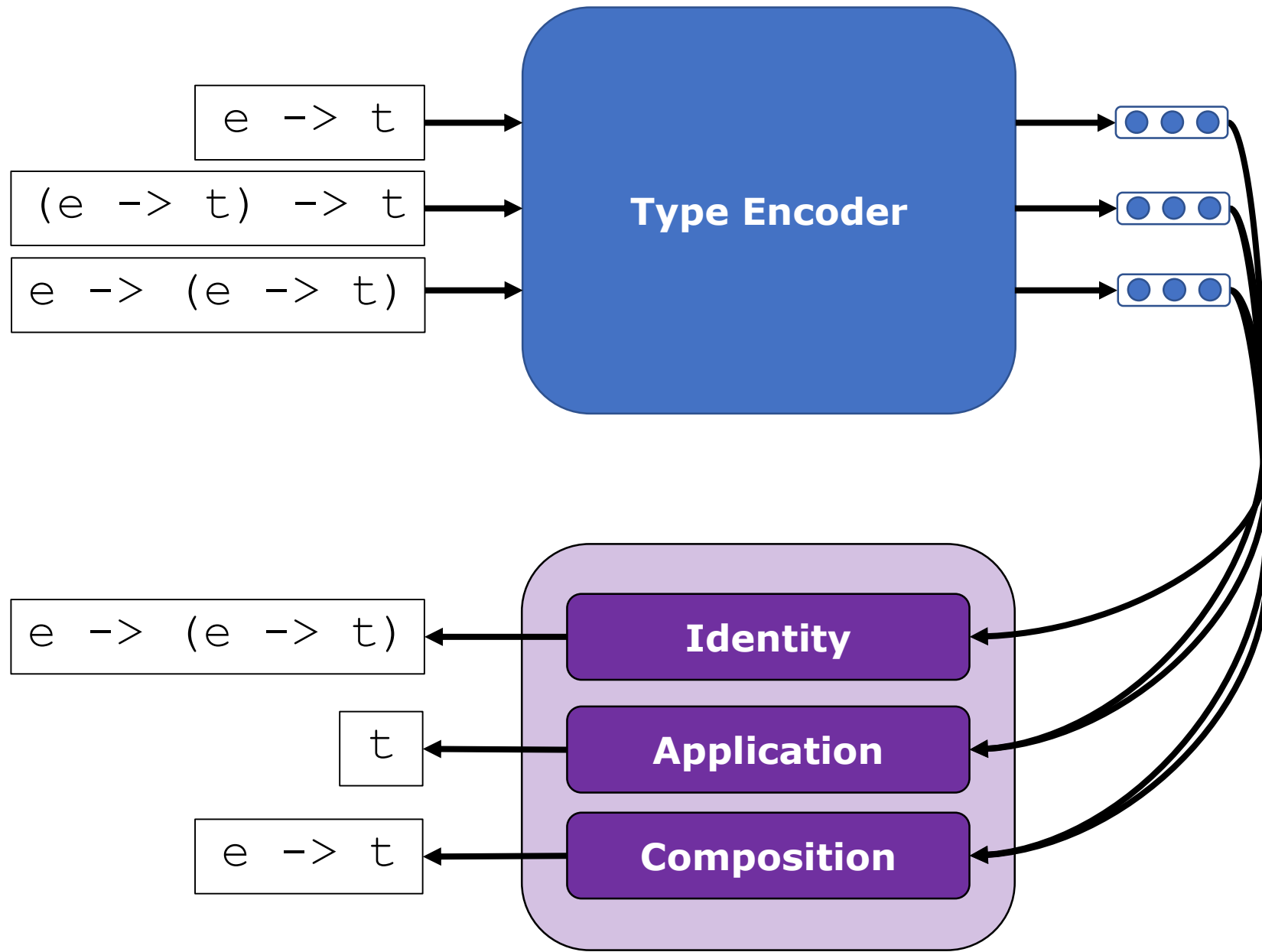
# Type Grammar



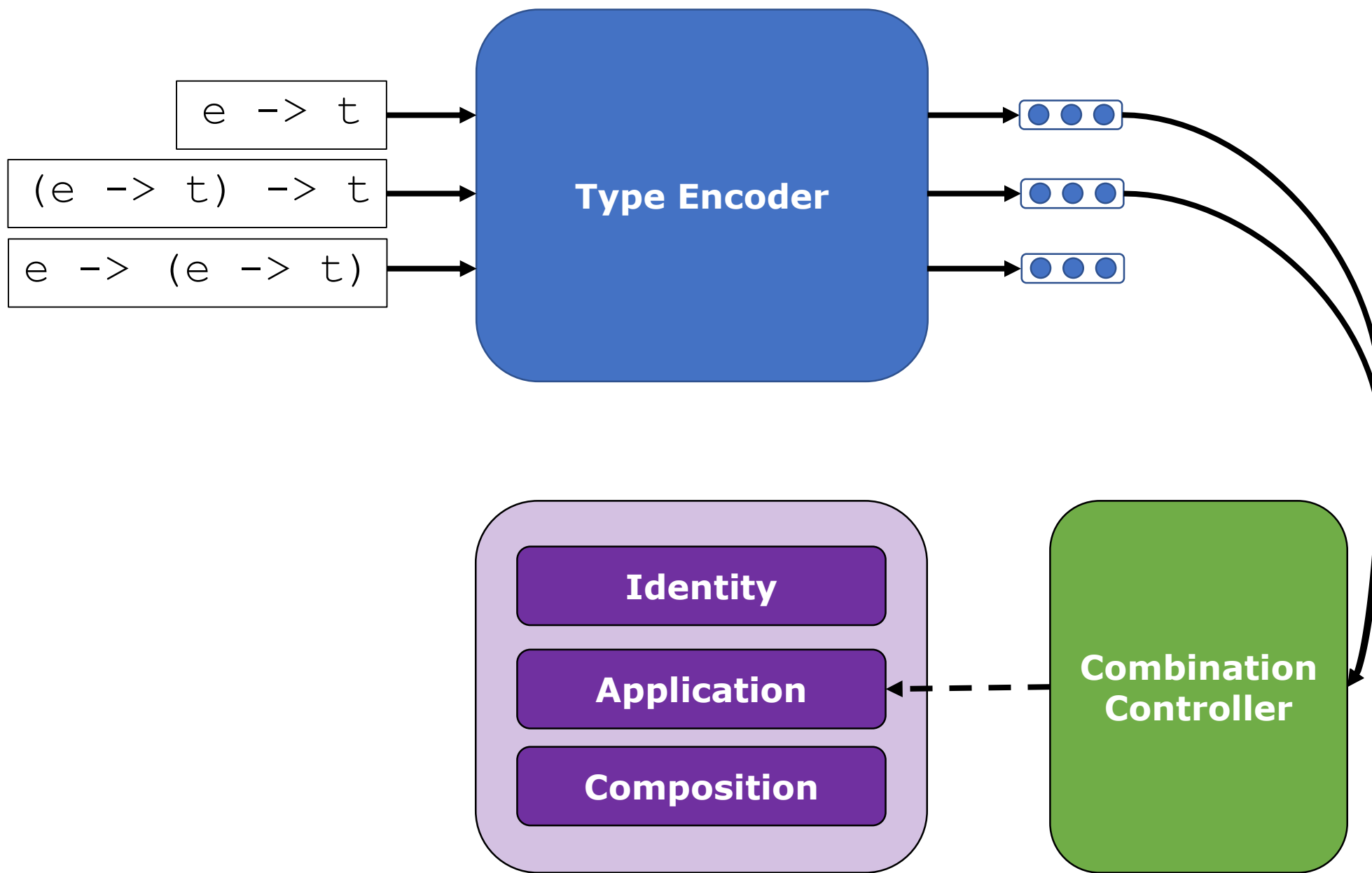
# Type Grammar



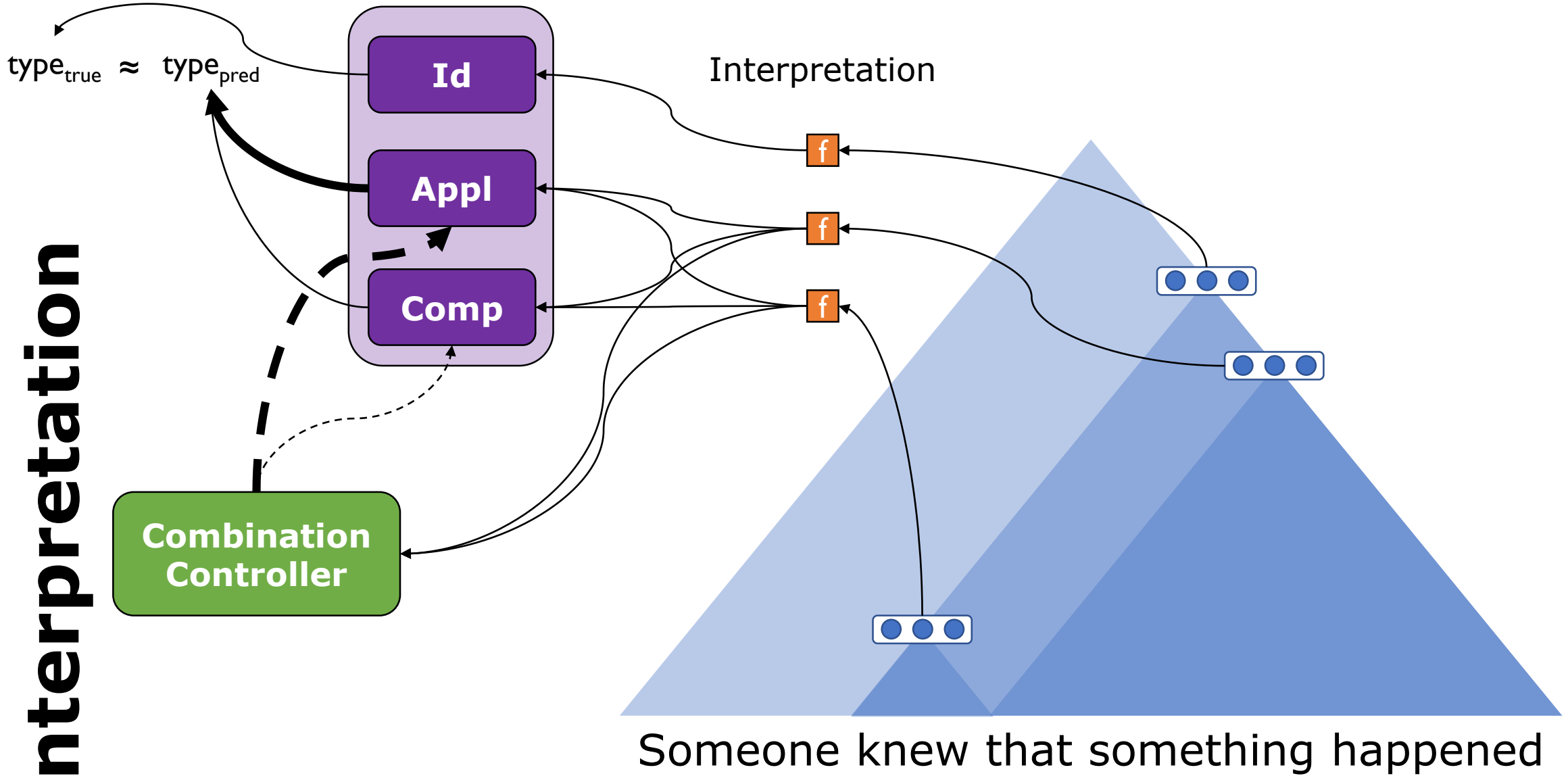
# Type Grammar



# Type Grammar



# Interpretation



# Experiments

1. Assume 3 primitive types ( $s, e, t$ )
2. Constrain *someone/something* to decode to  $\langle \langle e, \langle s, t \rangle \rangle, \langle s, t \rangle \rangle$  and root node to  $\langle s, t \rangle$
3. Supertag-factored  $A^*$  decoding to find constituent types

Lewis & Steedman 2014, 2016

# Results





## Preliminaries

1. Does the parser explain acceptability?
2. Do the parser's syntactic representations make sense?

## Case studies

What types are assigned to:

1. declaratives and interrogatives?
2. finite and infinitival complements?

**Does the parser explain  
acceptability?**

**Predicted Acceptability**

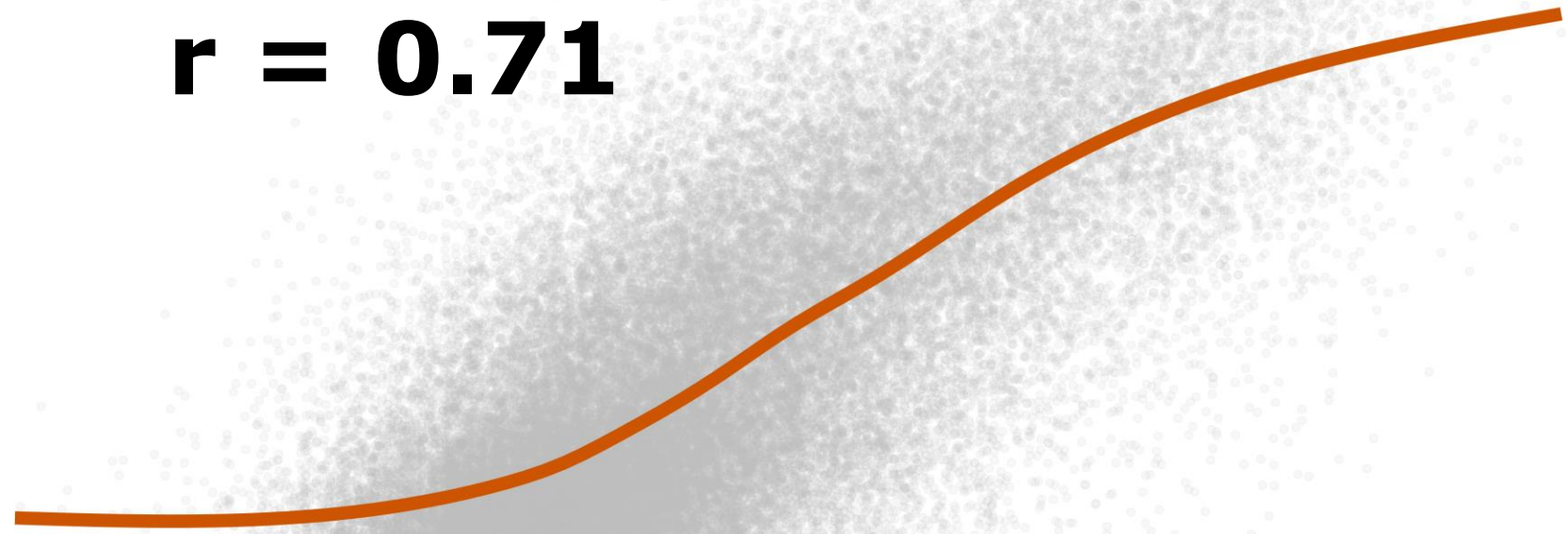
**Interannotator agreement  
among trained linguists**

$$r = 0.70 [0.62, 0.78]$$

**True Acceptability**

Predicted Acceptability

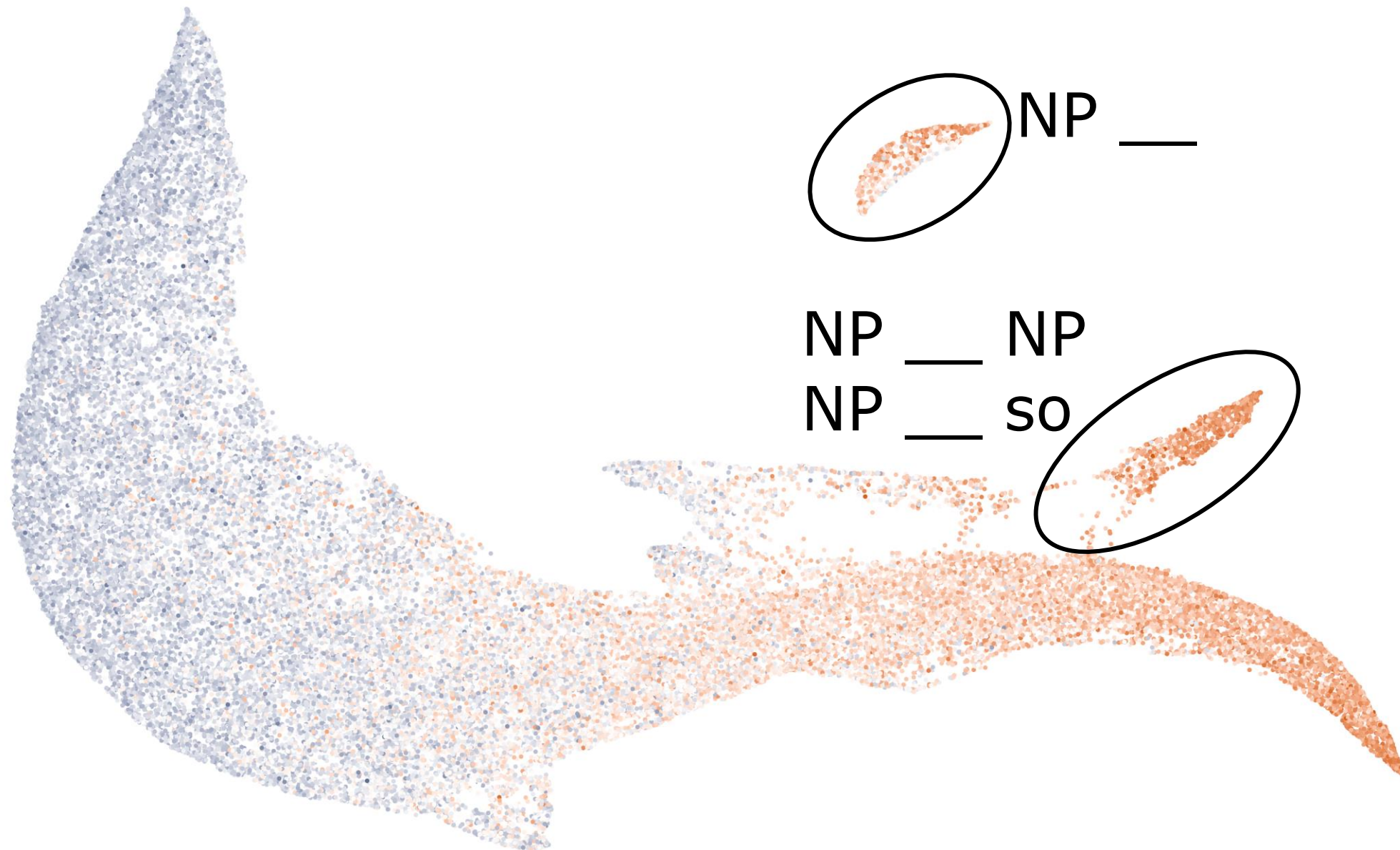
**Cross-validated**  
 **$r = 0.71$**



True Acceptability

**Do the parser's syntactic  
representations make sense?**





Acceptability 



**Clauses**

**Noun +  
Preposition  
Phrases**



**that  
something  
happened**

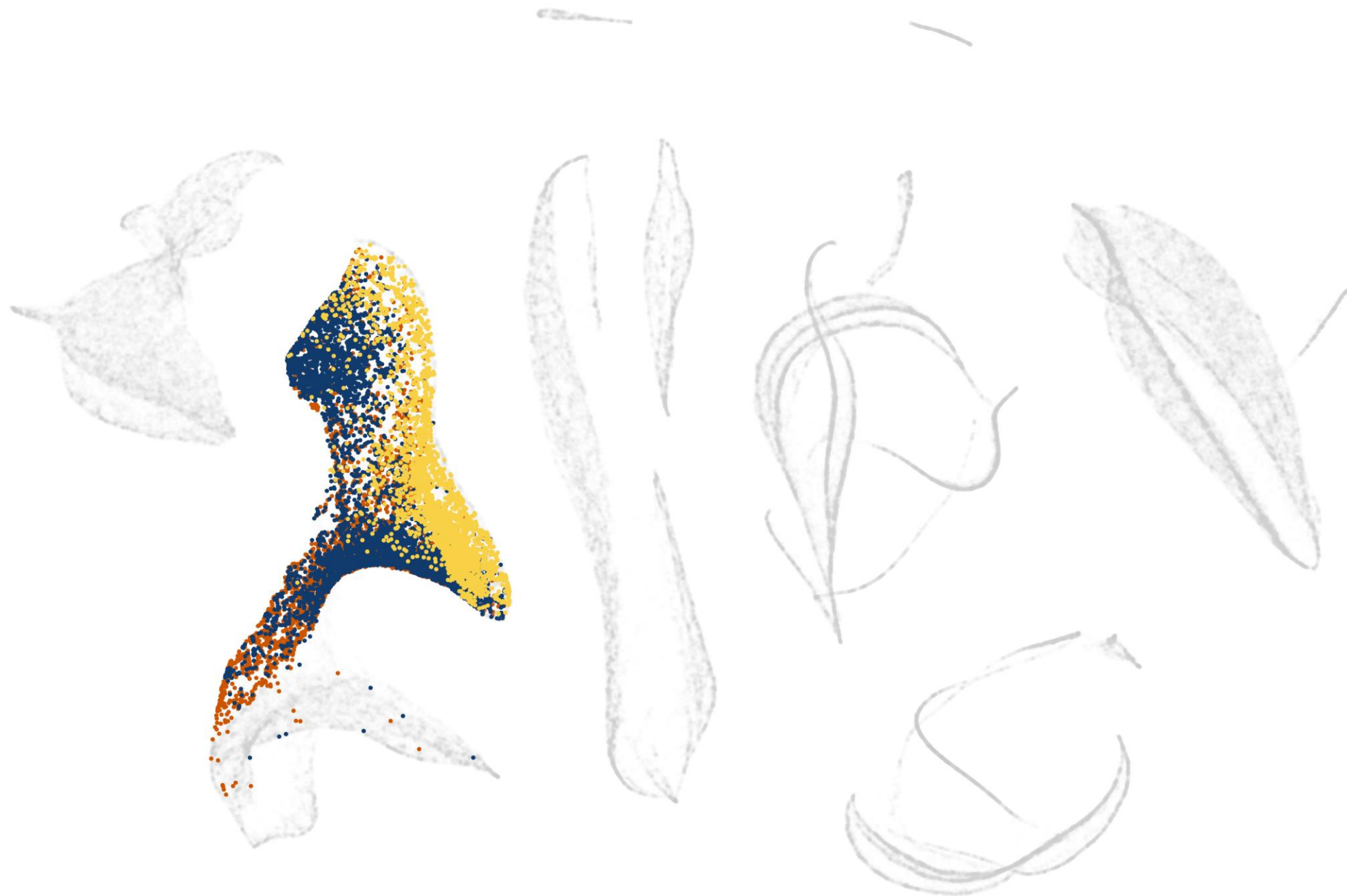


**whether  
something  
happened**



**which  
thing  
happened**







**to do  
something**

**whether to  
do something**

**which thing  
to do**









**about  
something**



**to someone**



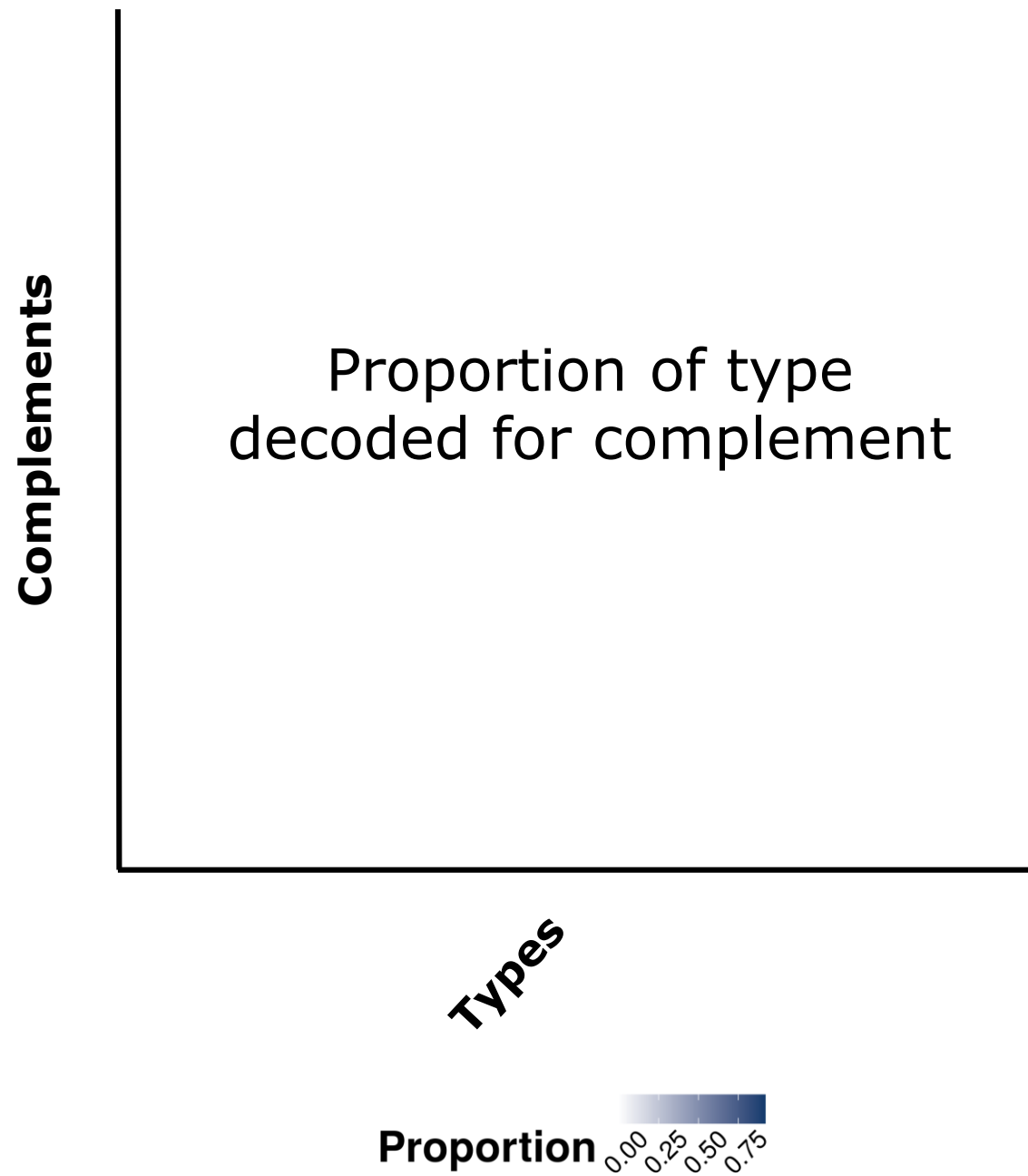


**What types are assigned  
to clausal complements?**

**Complements**

Proportion of type  
decoded for complement

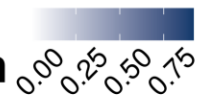
**Types**



**Complements**

**Types**

**Proportion**





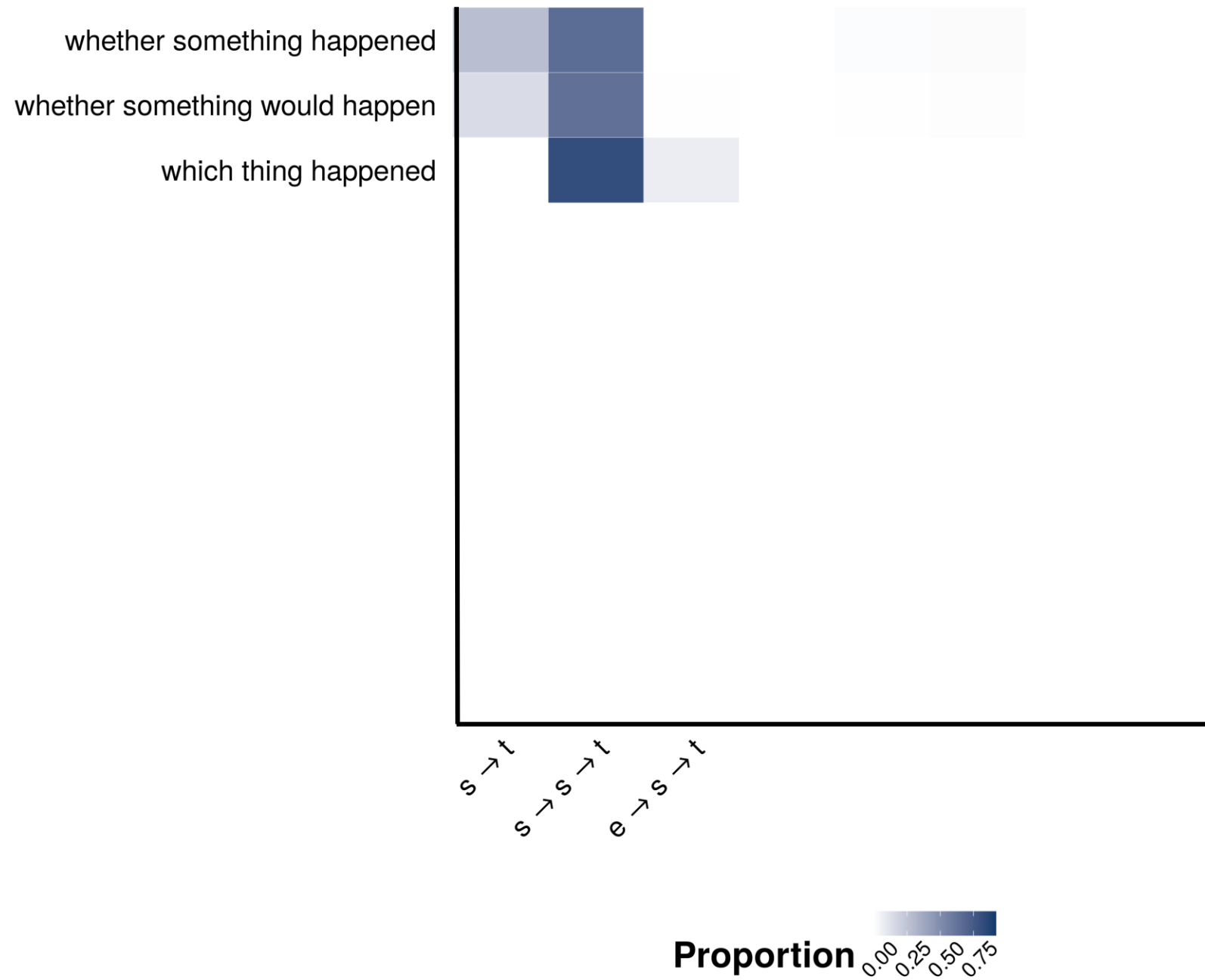
**Types**











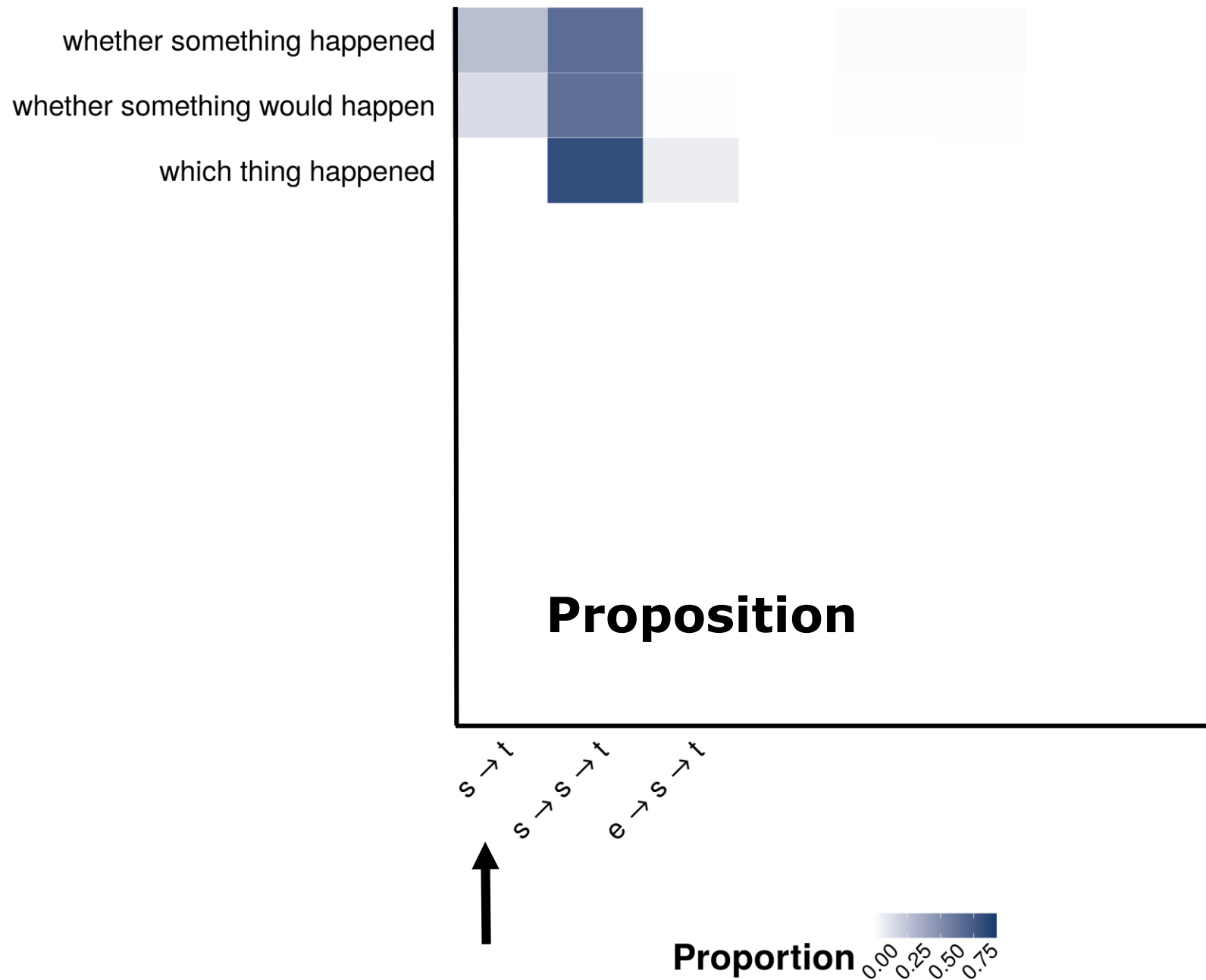


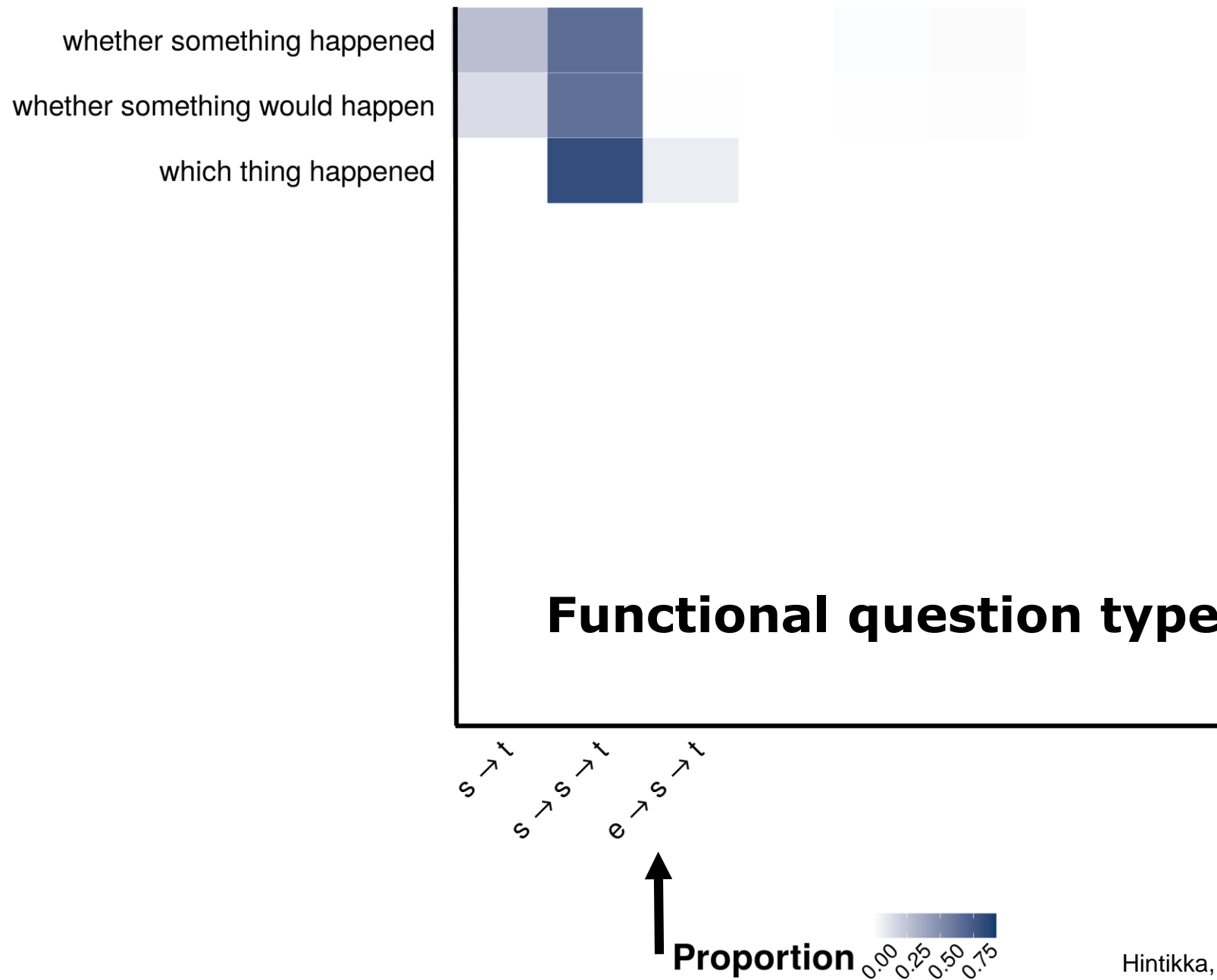
## Question partition representation

s → t    s → s → t    e → s → t

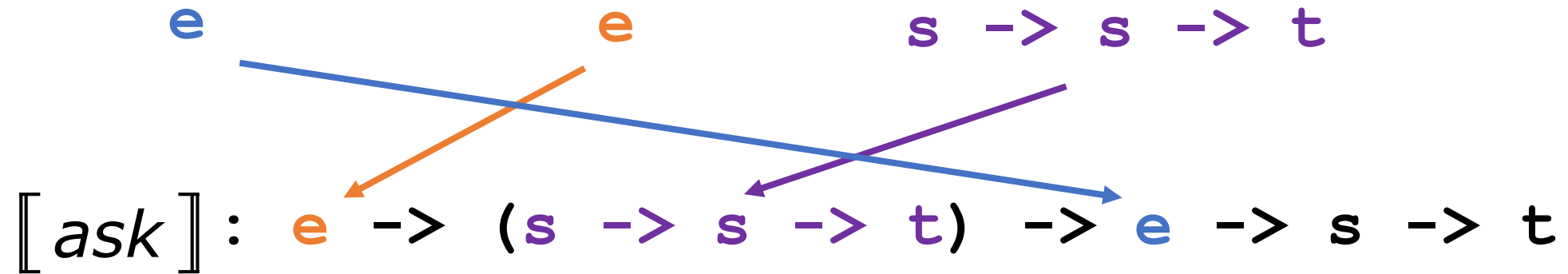


**Proportion** 0.00 0.25 0.50 0.75





Someone **asked** *someone* whether something happened

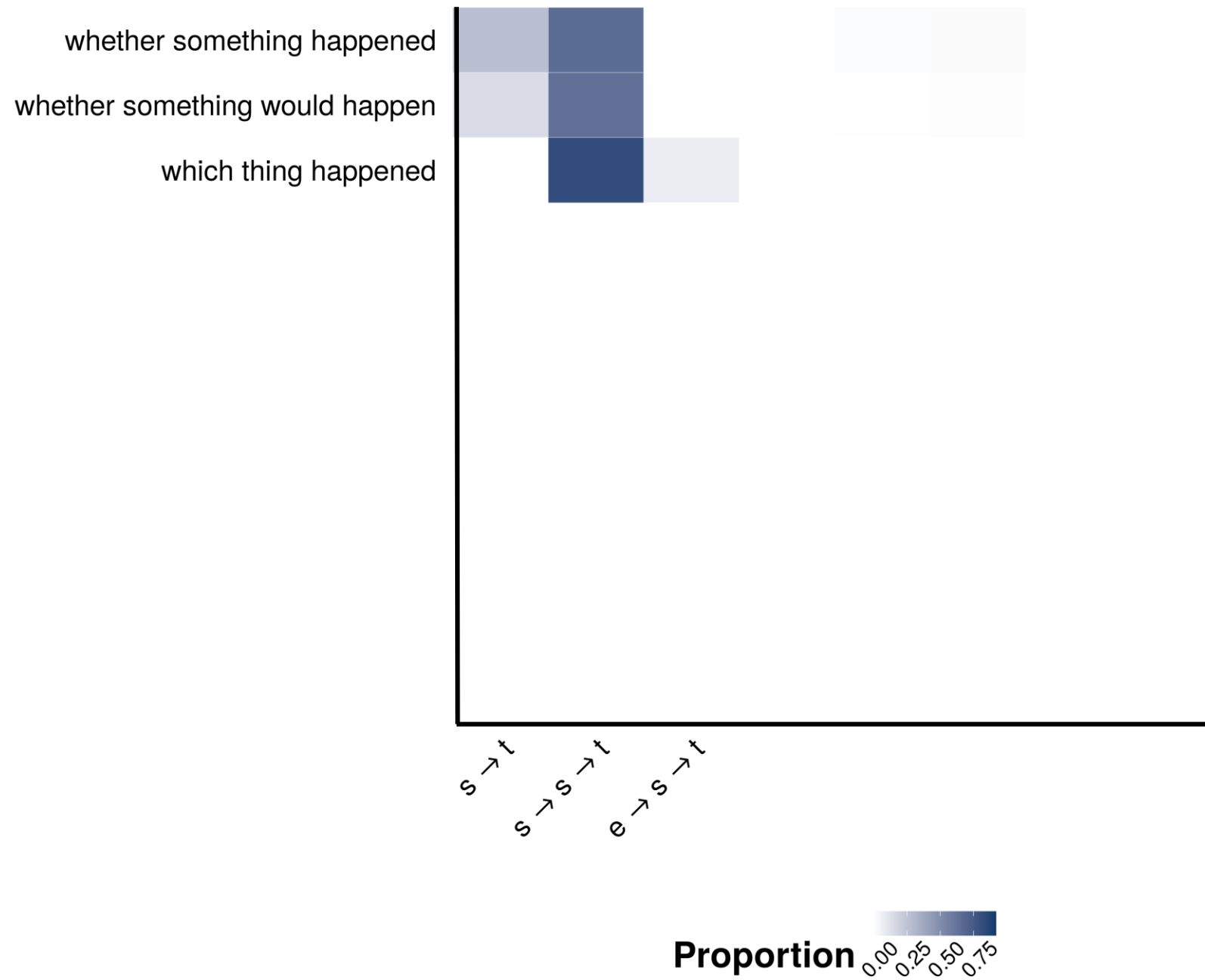


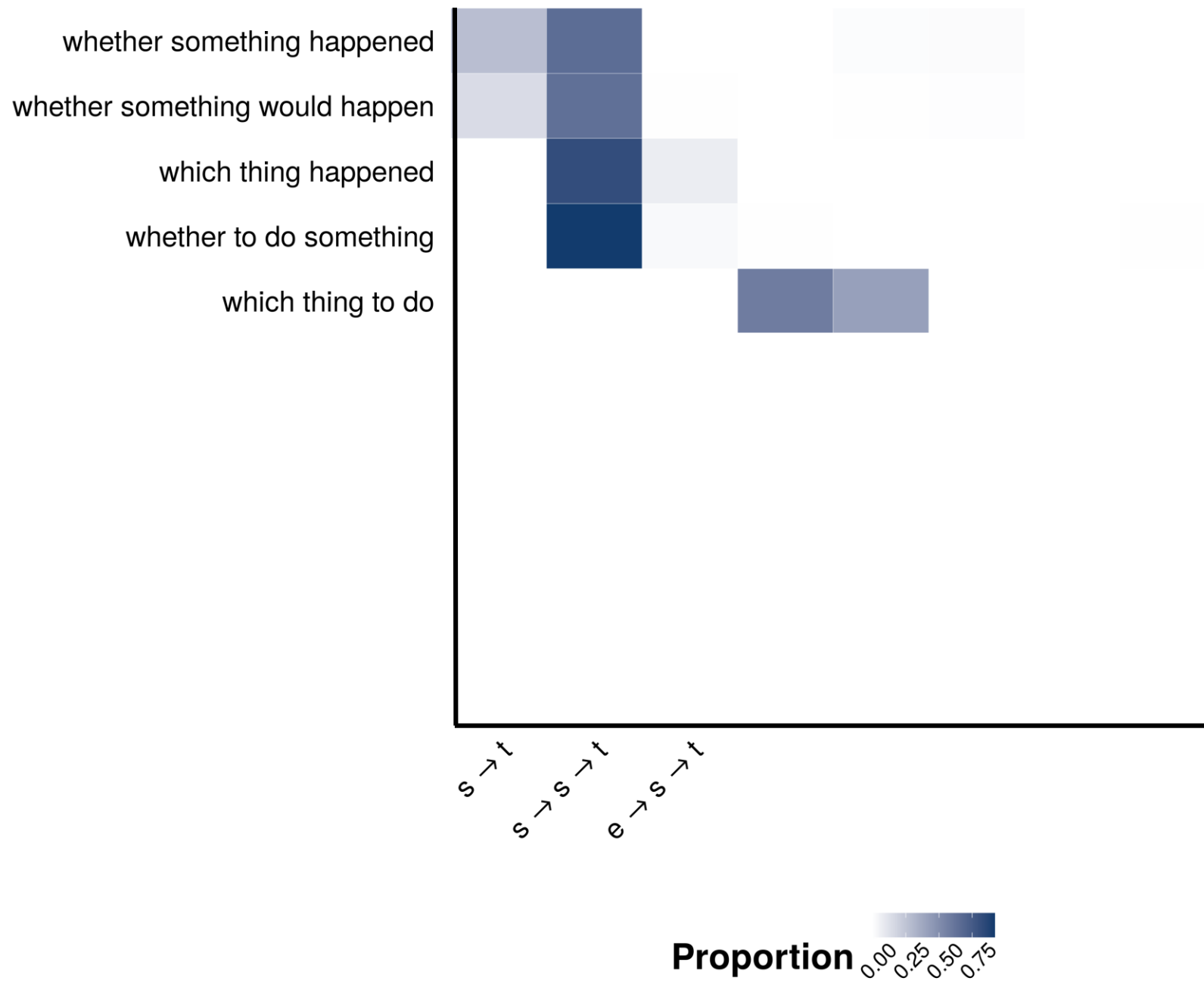
Someone **wondered** whether something happened

$s \rightarrow s \rightarrow t$

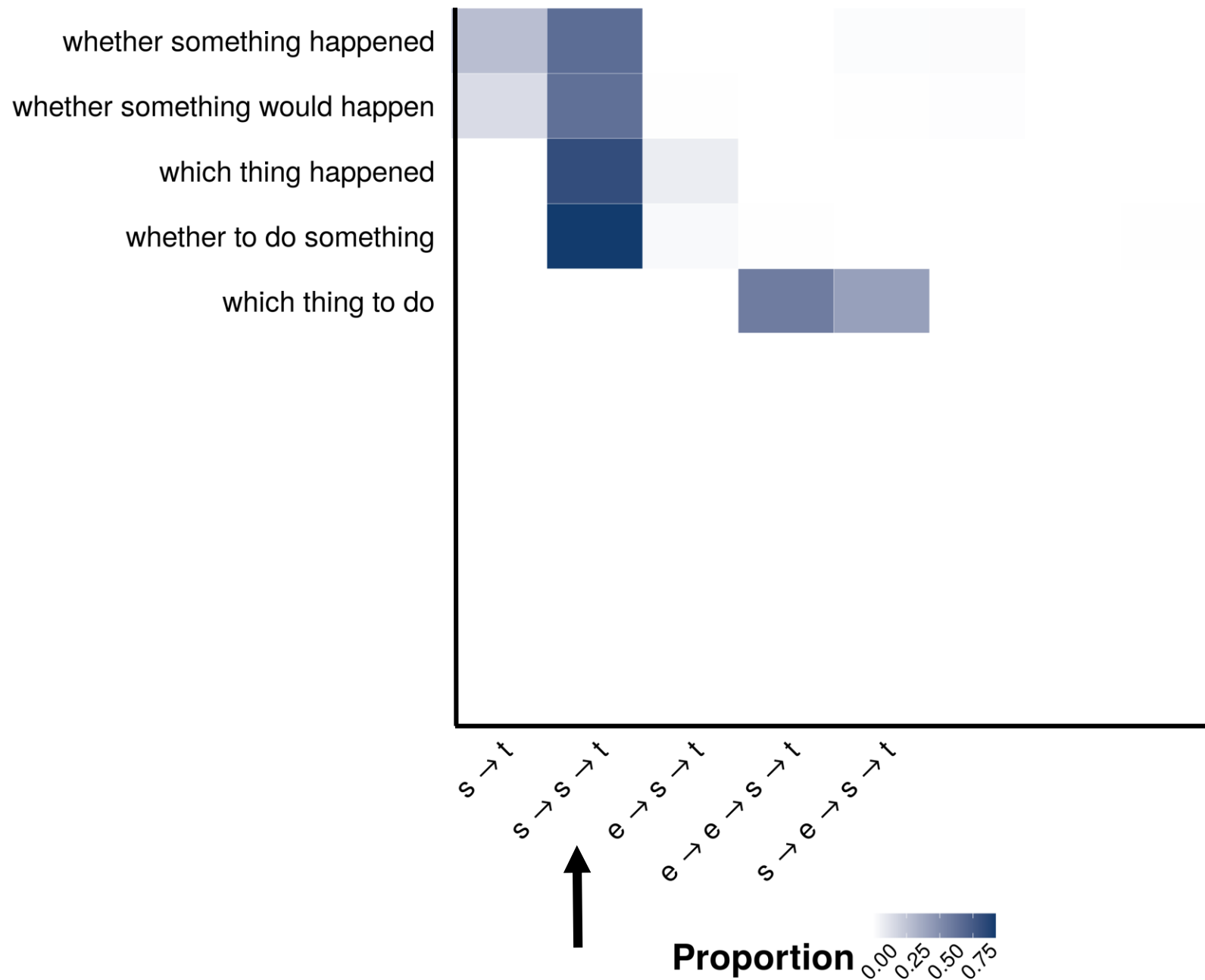
Someone **investigated** which thing happened

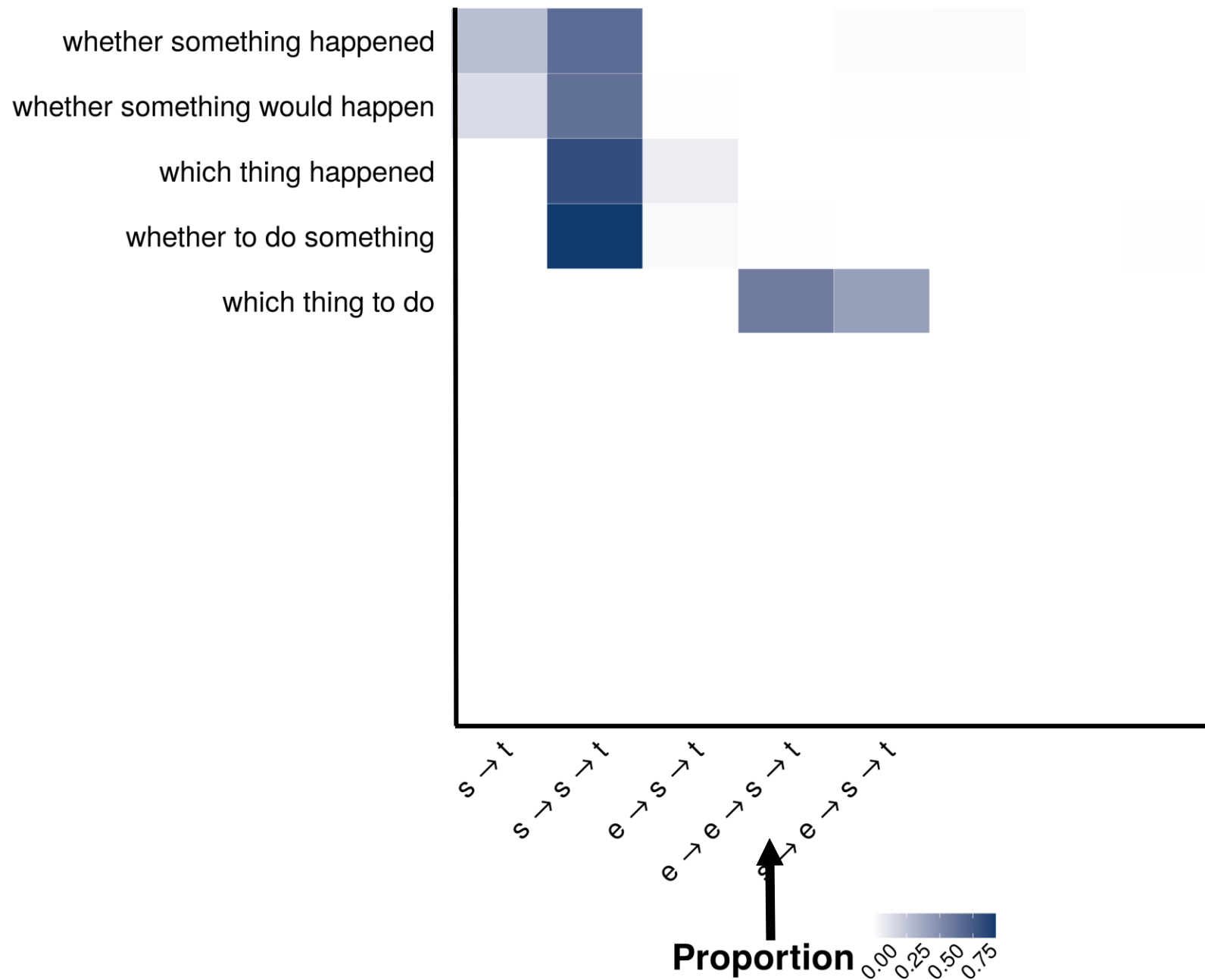
$s \rightarrow s \rightarrow t$











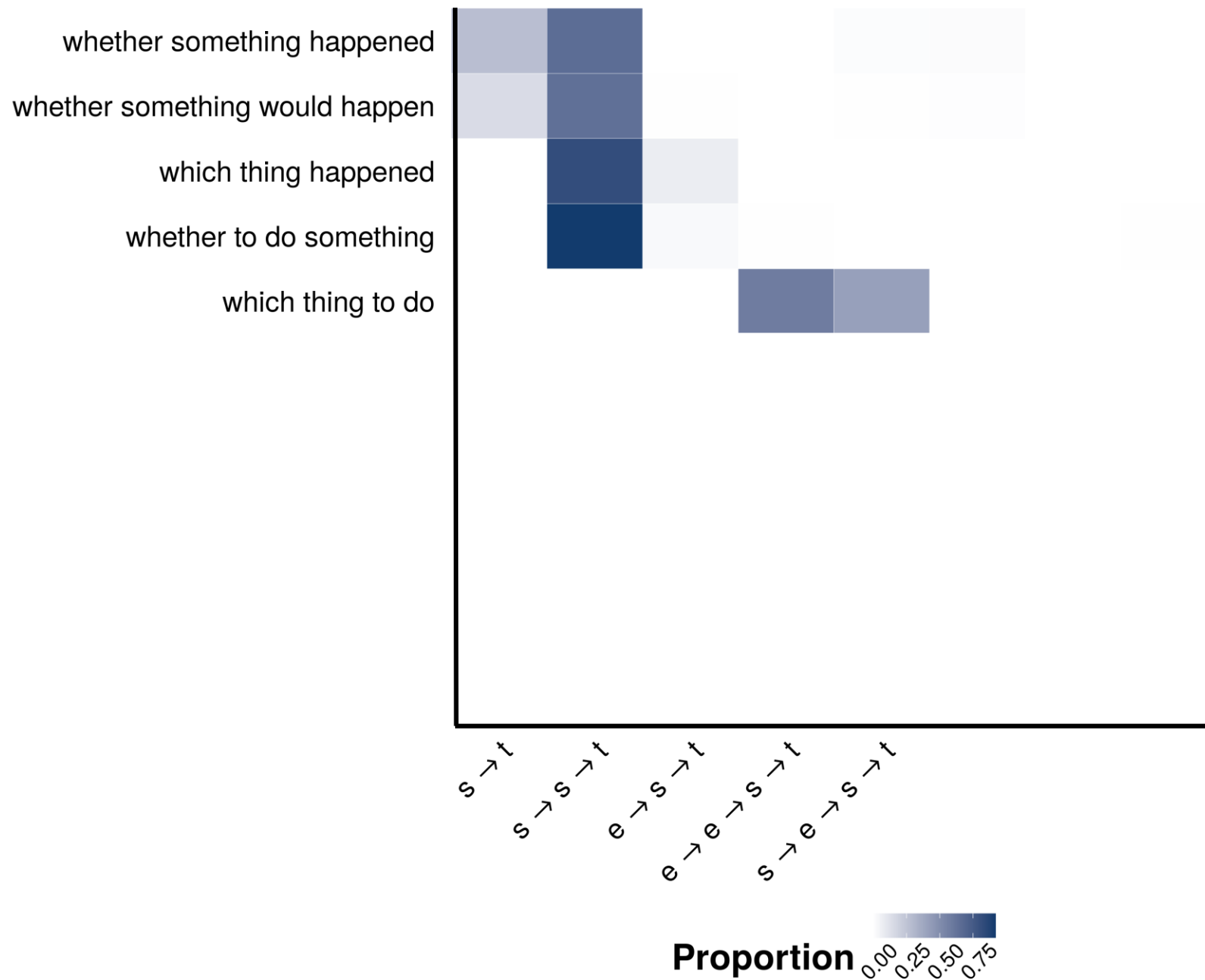
Someone **learned** *whether to do something*

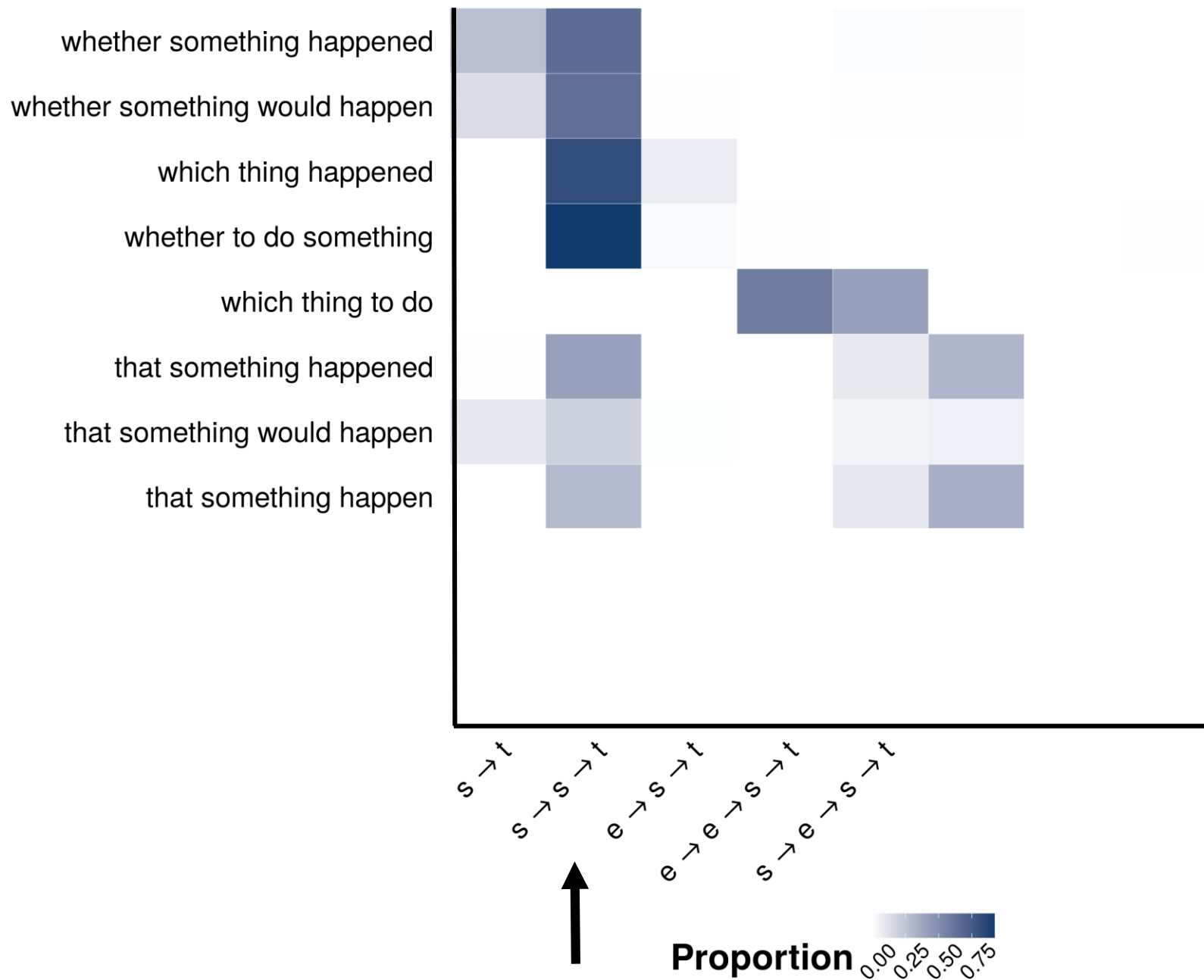
$s \rightarrow s \rightarrow t$

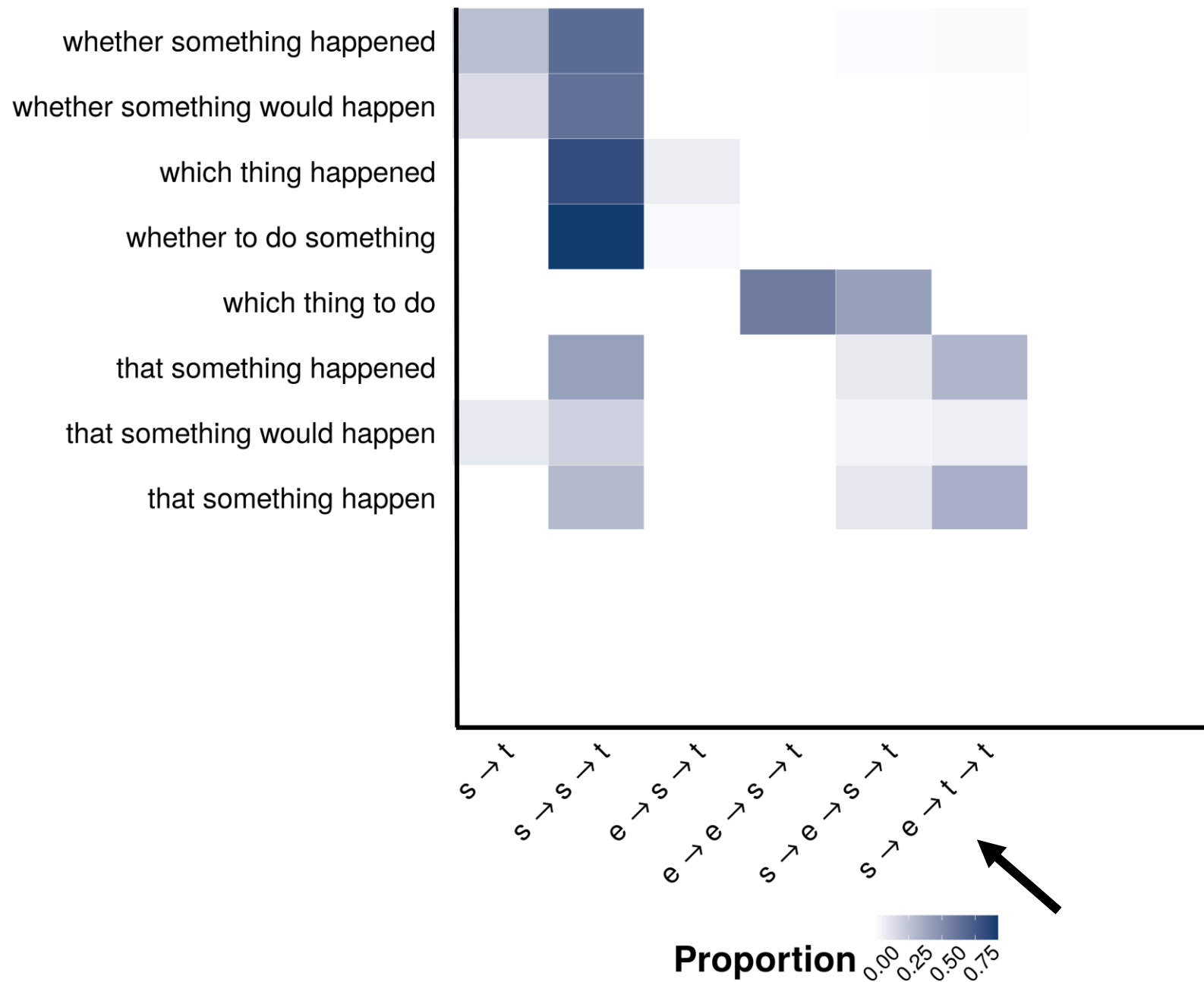
Someone **learned** *which thing to do*

$e \rightarrow e \rightarrow s \rightarrow t$

**What about declaratives?**





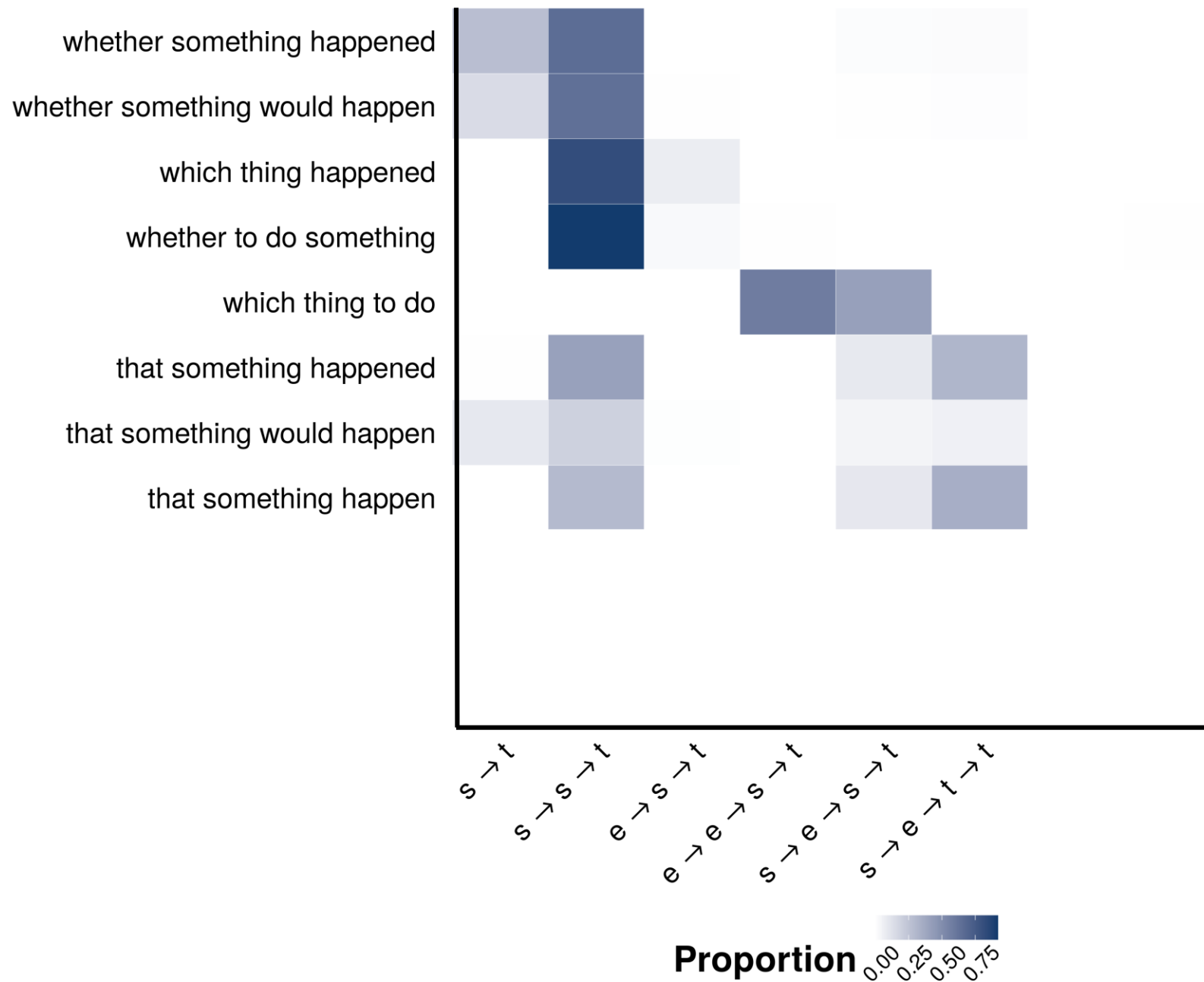


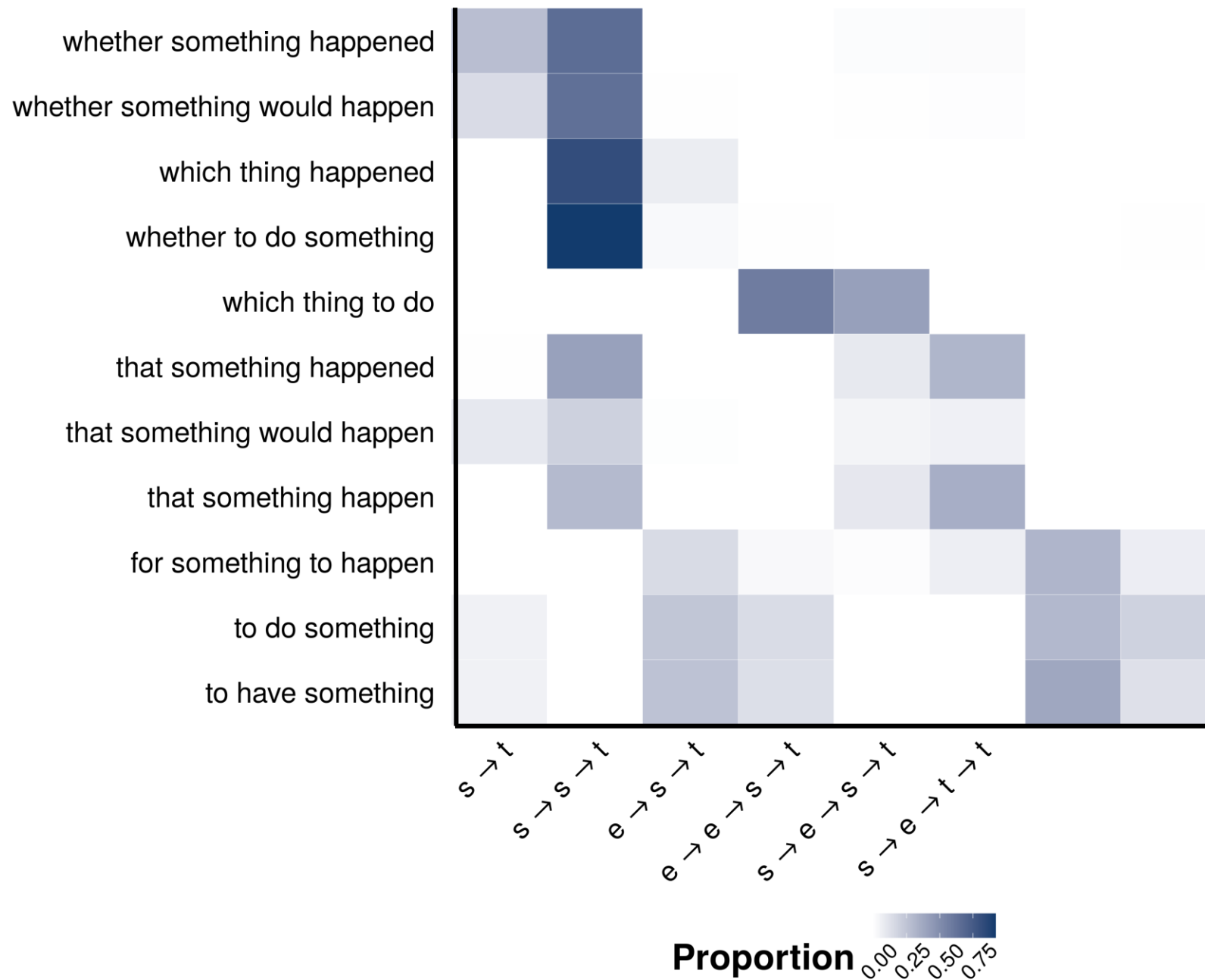
Someone was  $\left\{ \begin{array}{l} \textit{upset} \\ \textit{angered} \\ \textit{horrified} \\ \textit{elated} \end{array} \right\}$  *that something happened*  
s -> e -> t -> t

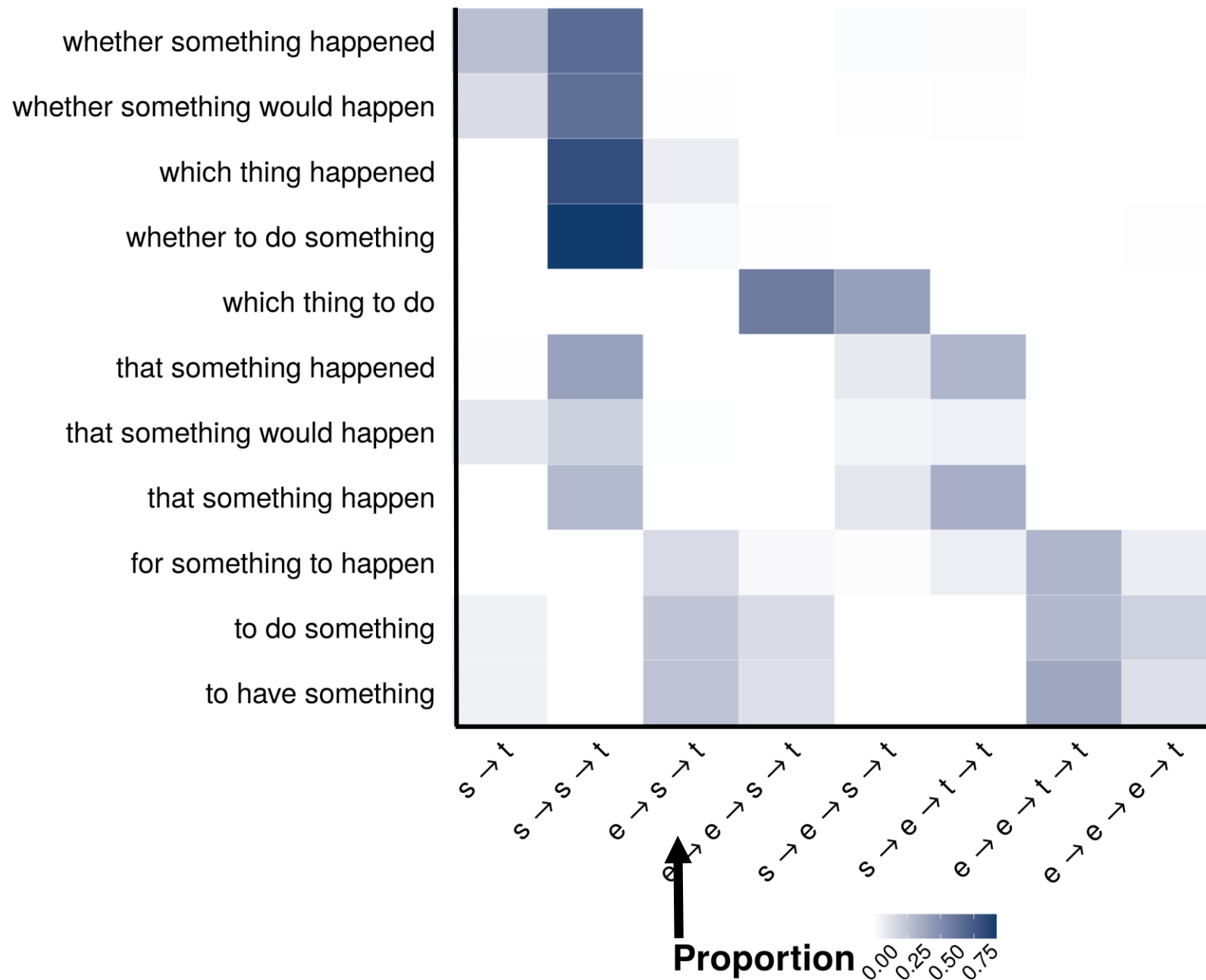
Someone was  $\left\{ \begin{array}{l} \textit{told} \\ \textit{informed} \end{array} \right\}$  *that something happened*  
s -> s -> t

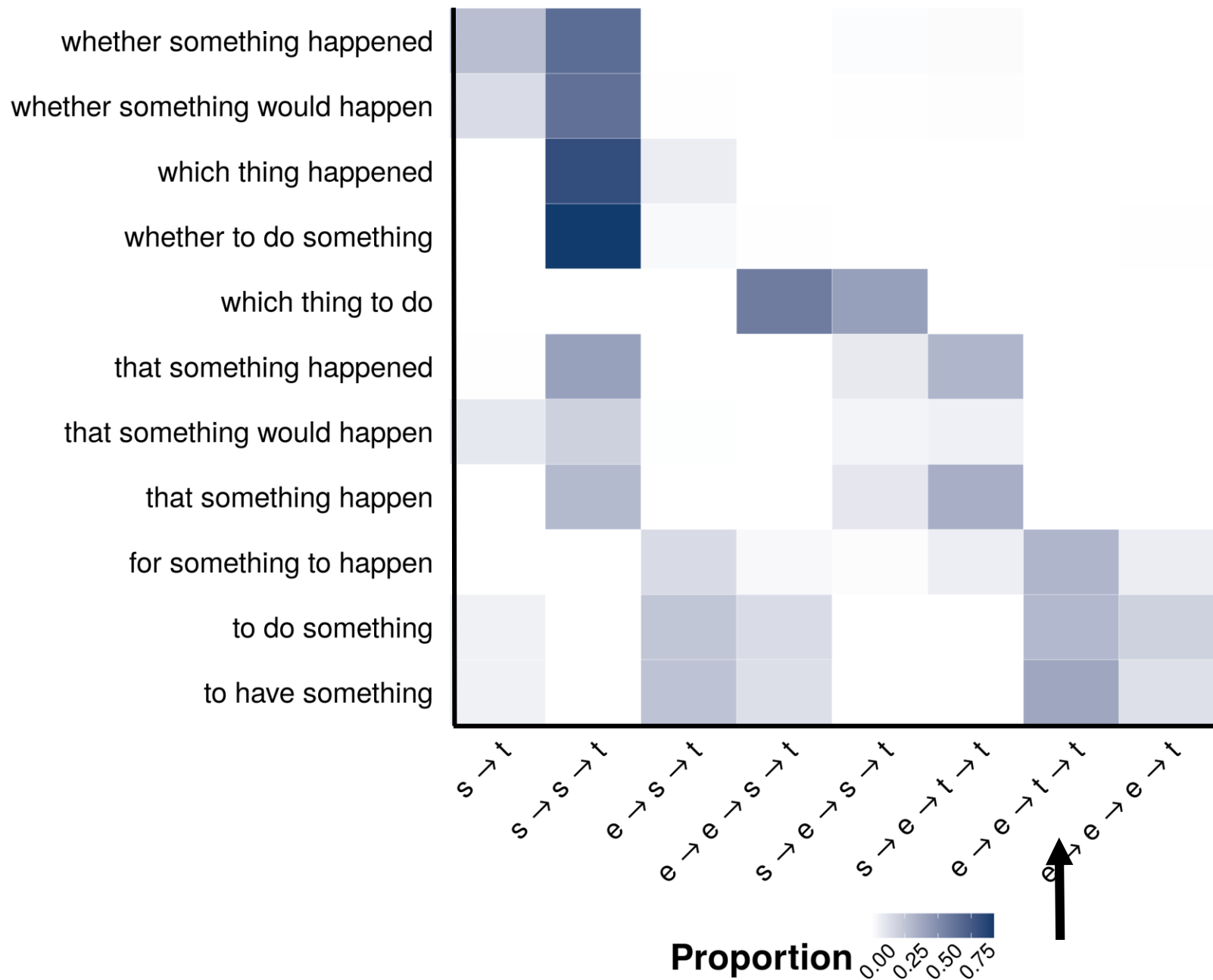
Someone  $\left\{ \begin{array}{l} \textit{believed} \\ \textit{thought} \\ \textit{learned} \end{array} \right\}$  *that something happened*  
s -> s -> t











Someone was  $\left\{ \begin{array}{l} \textit{known} \\ \textit{believed} \end{array} \right\}$  *to do something*  
 $e \rightarrow e \rightarrow t \rightarrow t$

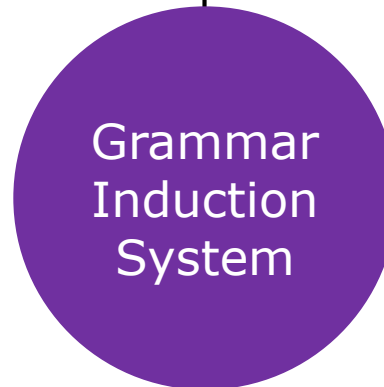
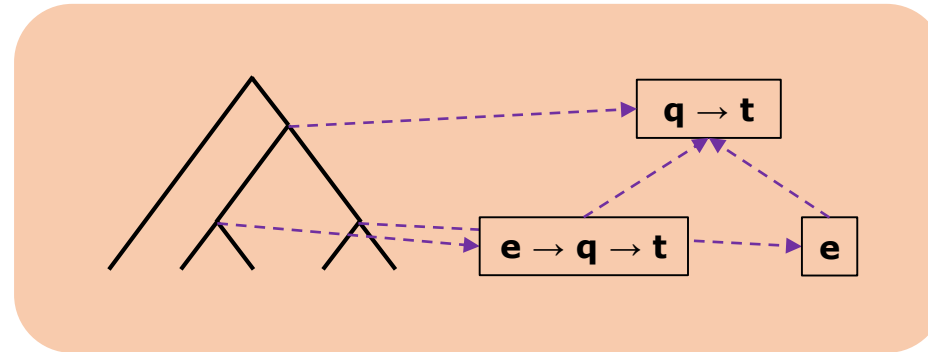
Someone was  $\left\{ \begin{array}{l} \textit{told} \\ \textit{ordered} \\ \textit{informed} \end{array} \right\}$  *to do something*  
 $e \rightarrow s \rightarrow t$


Someone  $\left\{ \begin{array}{l} \textit{wanted} \\ \textit{wished} \end{array} \right\}$  *to do something*  
 $e \rightarrow s \rightarrow t$

# Conclusion



## Montague grammar



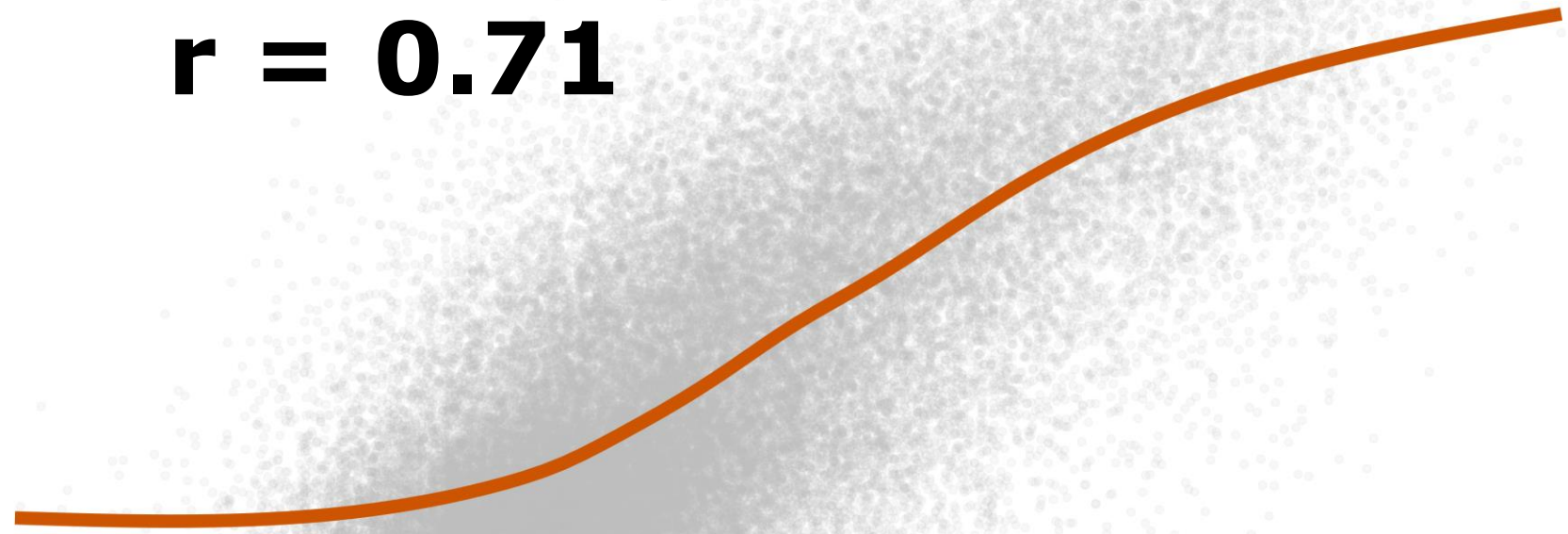
Someone asked someone something. 

Someone wondered someone something. 

## Acceptability judgments

Predicted Acceptability

**Cross-validated**  
 **$r = 0.71$**



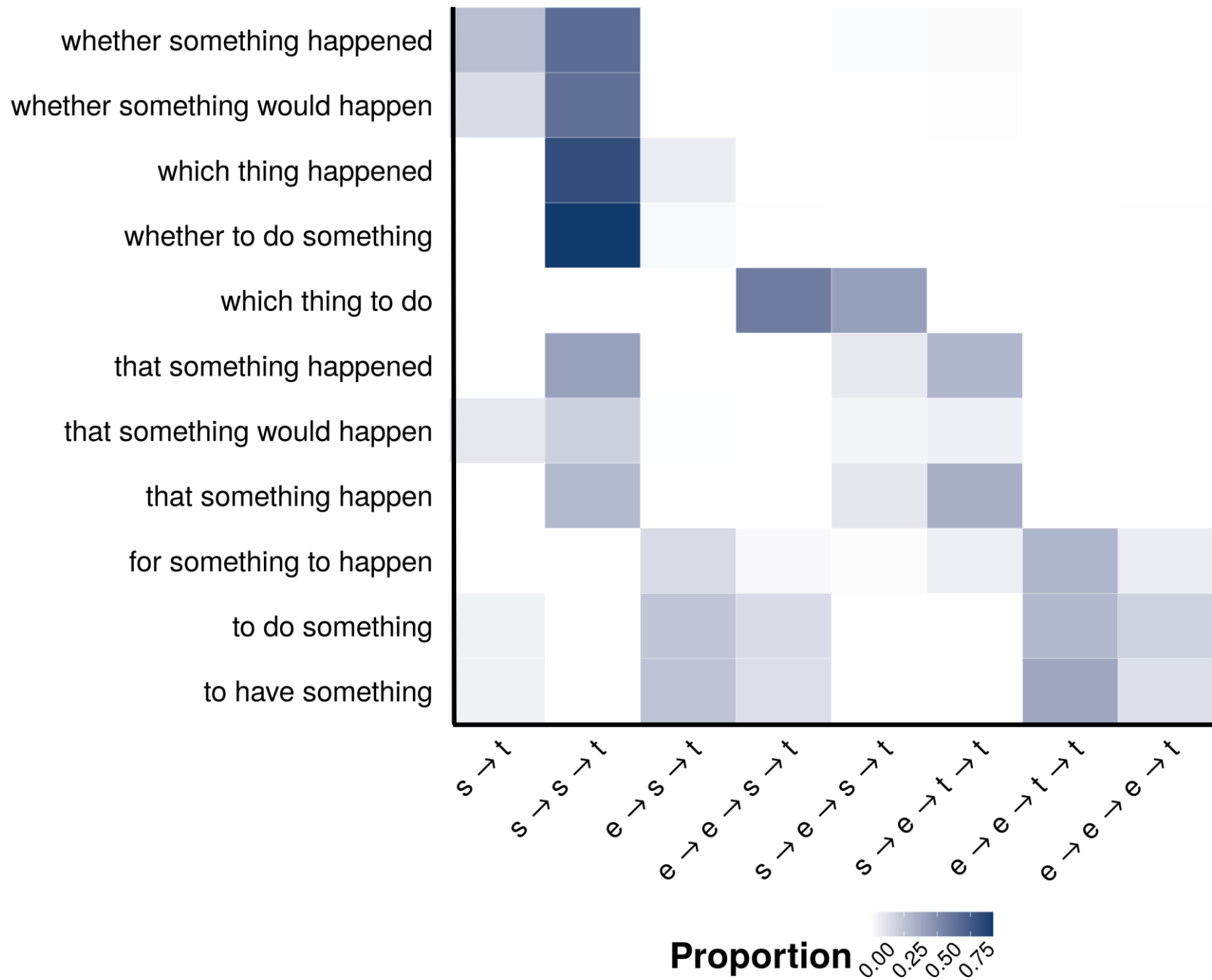
True Acceptability





**Clauses**

**Noun +  
Preposition  
Phrases**



## Current Directions #1

Incorporation of inference judgments alongside acceptability judgments

## Interim Findings

Parser can jointly predict acceptability and veridicality judgments at native speaker levels

## **Current Directions #2**

Training on corpus data rather than behavioral data

## **Current Directions #3**

Jointly inferring syntactic and semantic combinatorial categorial grammar

# **Future Directions**

Decoding of typed denotations

# Thanks!



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*The MegaAttitude Project: Investigating selection  
and polysemy at the scale of the lexicon*