Syntax-based Translation

Part 2: Synchronous Grammars

March 27, 2012

Administrative

- Language in 10
- Homework 3 peer review groups
- **April 1** is the final project proposal deadline

Goals

- Revisit why people thought syntax cannot help MT
- Learn about Synchronous Context Free Grammars
- Introduce notation, and basic algorithm
- Understand how we learn SCFGs from bitterest
- Get a sense of the different flavors of SCFGs
  - Hiero
  - SAMT
  - GHKM

The Syntax Bet

- Longstanding debate about whether linguistic information can help statistical translation
- Two camps

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Syntax will improve translation

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Syntax will improve translation

Simpler data-driven models will always win

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Every time I fire a linguist my performance goes up

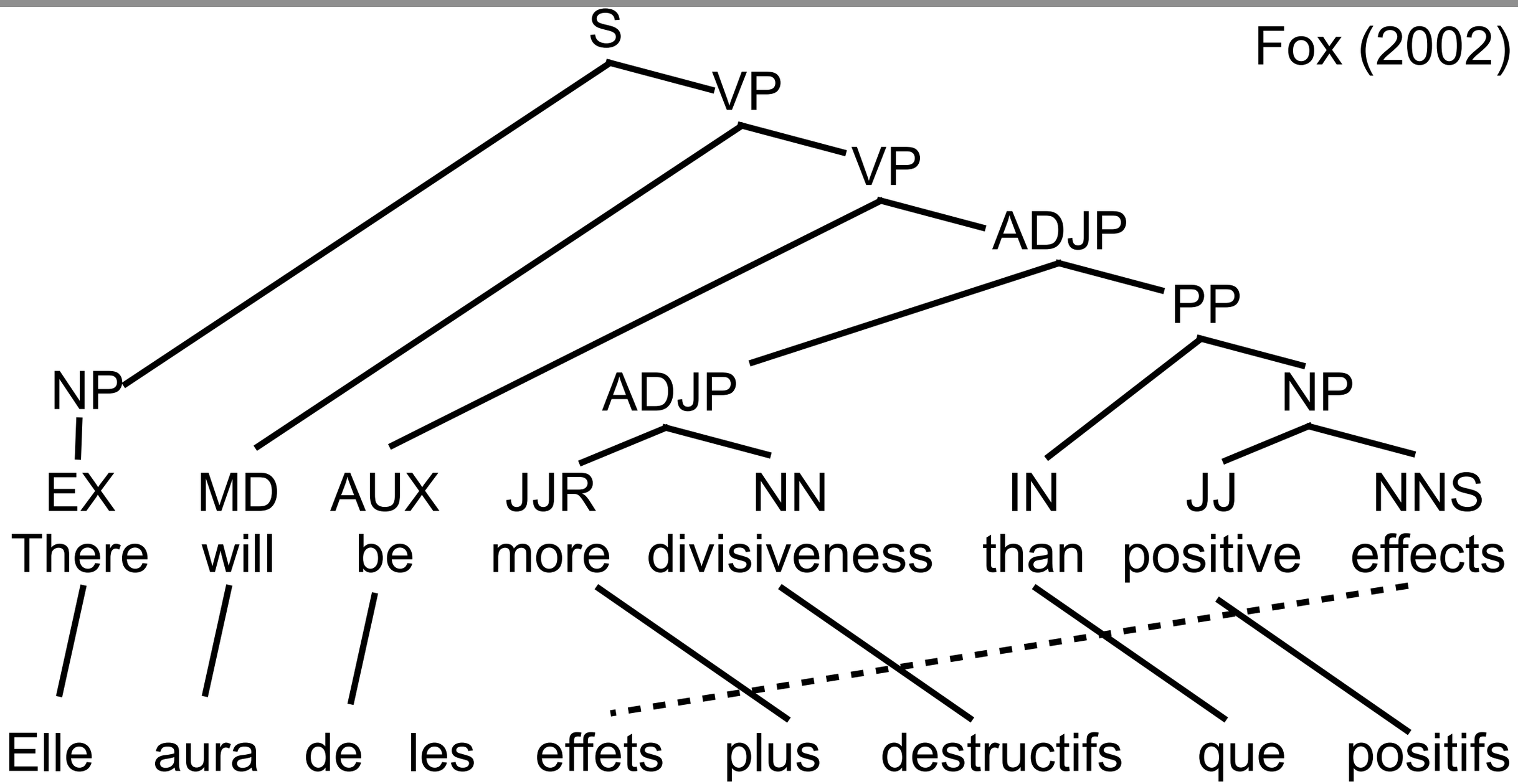
Syntax will improve translation

Simpler data-driven models will always win

Syntax is bad for translation

- The IBM Models were the dominant approach to SMT from the `90s until mid 2000s
  - Eschewed linguistic information
- A number of studies cast doubt on whether linguistic info could help SMT
  - Fox (2002) showed that "phrasal cohesion" was less common than assumed across even related languages
  - Koehn et al (2003) empirically demonstrated that syntactically motivated phrases made PBMT worse

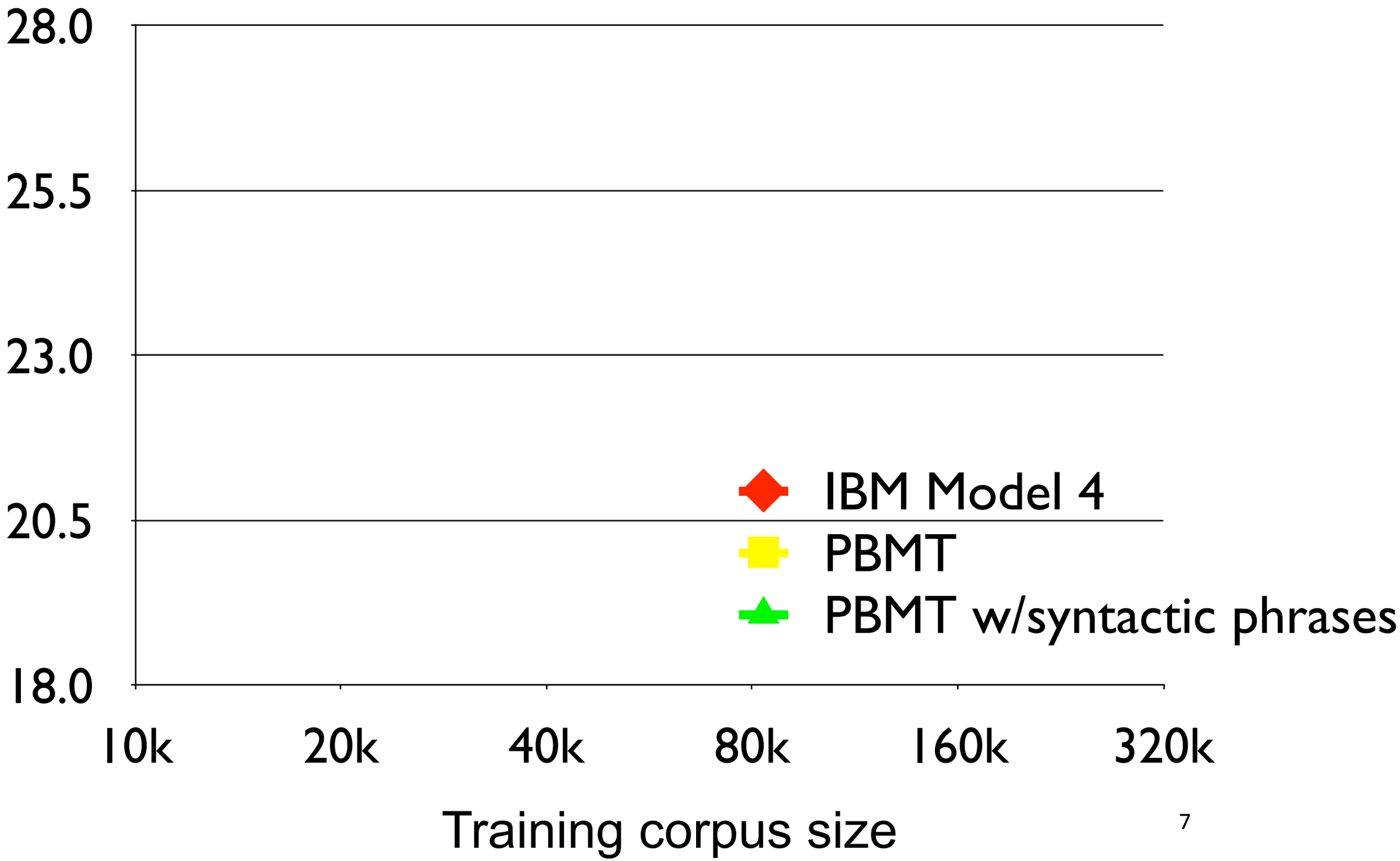
Phrases aren't coherent in bitexts



Gloss: *It will have effects more destructive than positive*

Ouch! Syntax hurts!

Koehn et al (2003)



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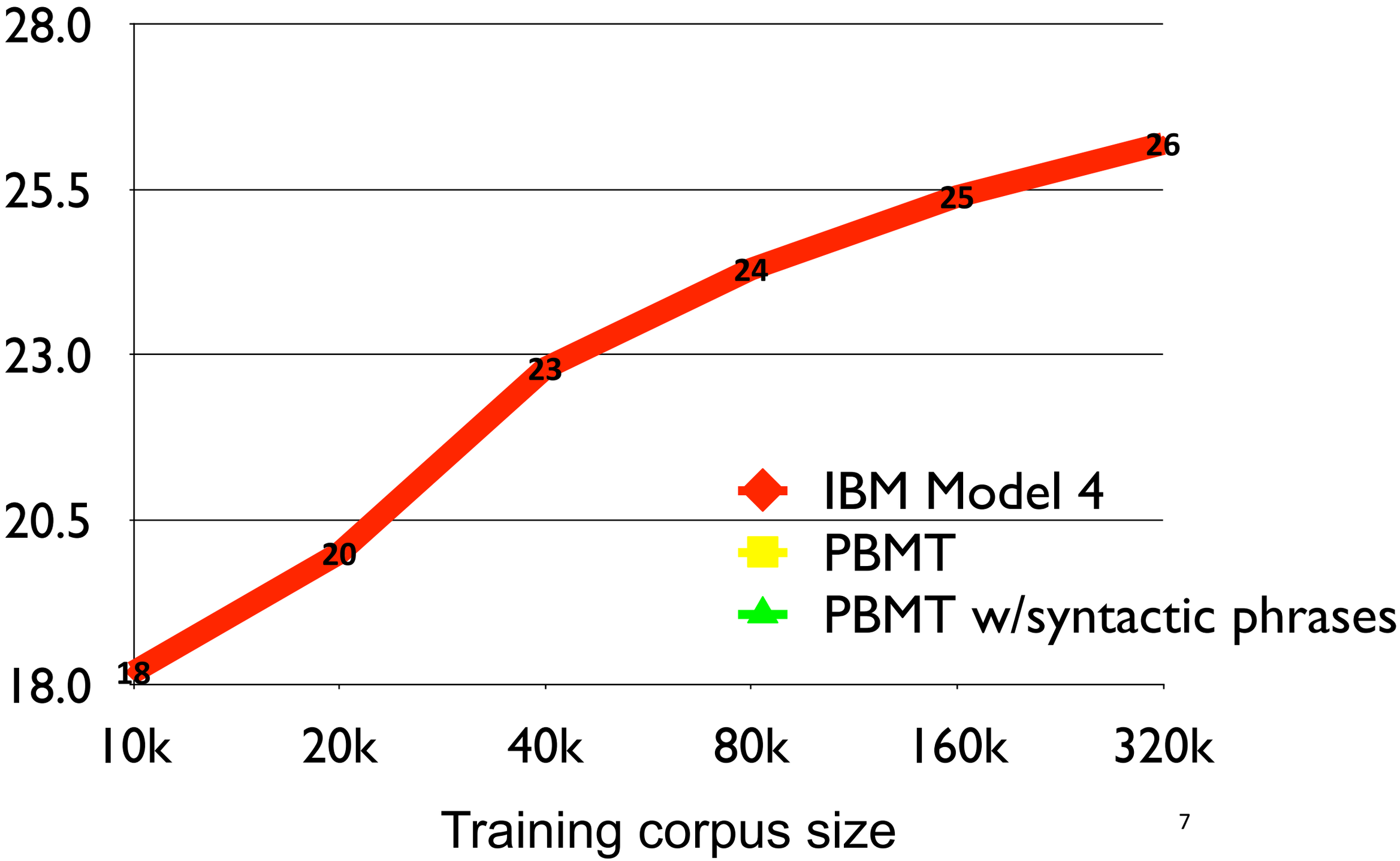

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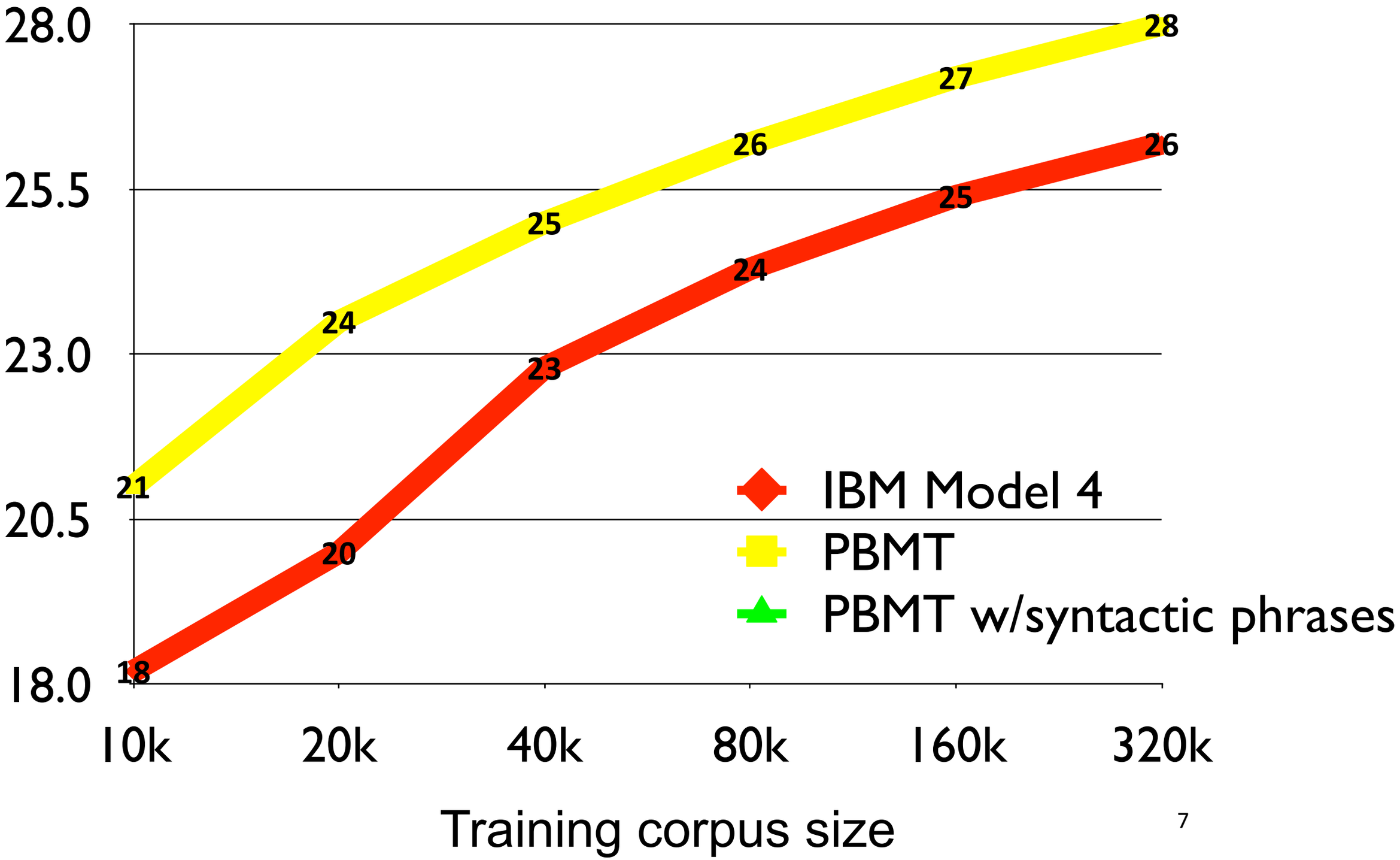

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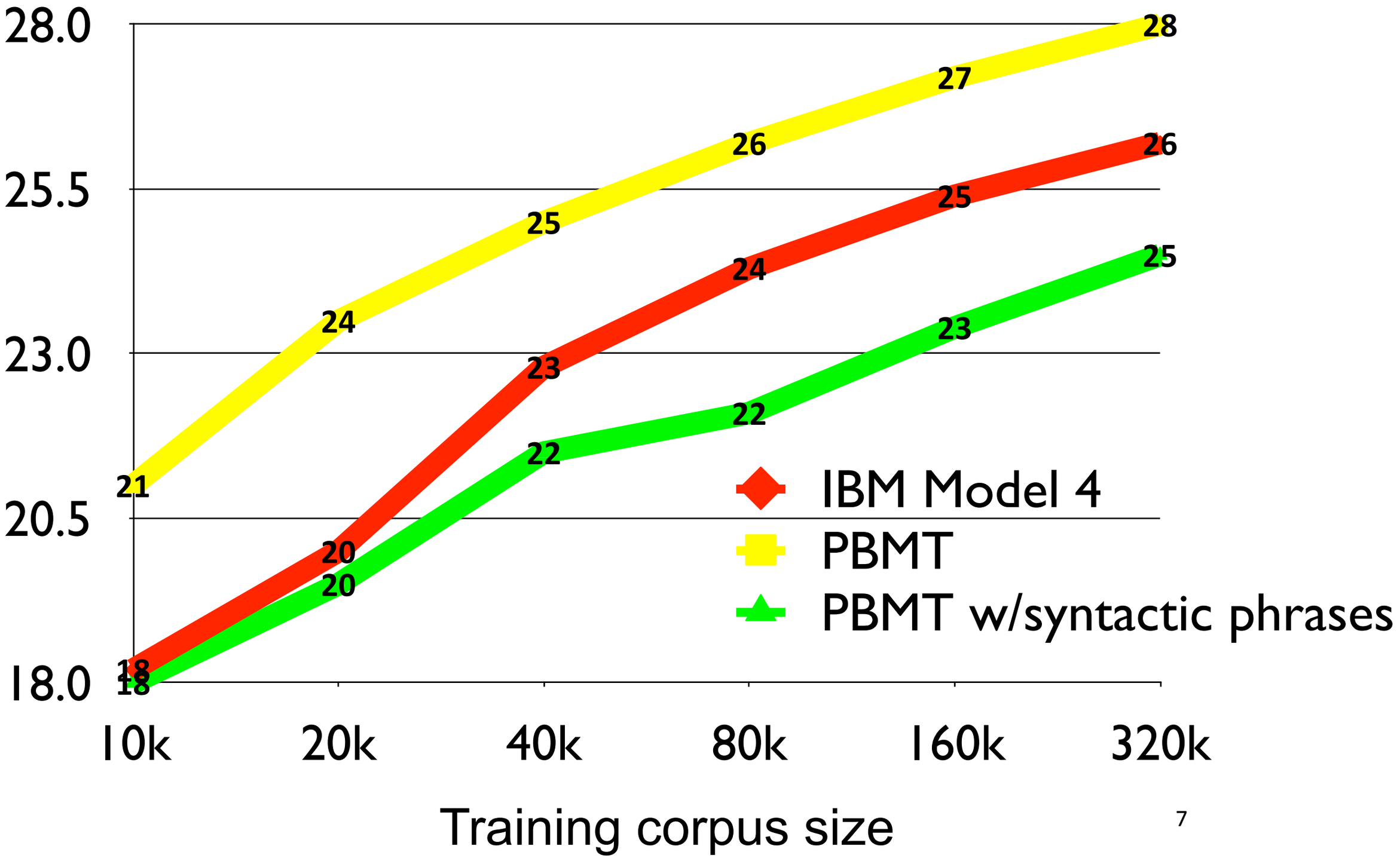
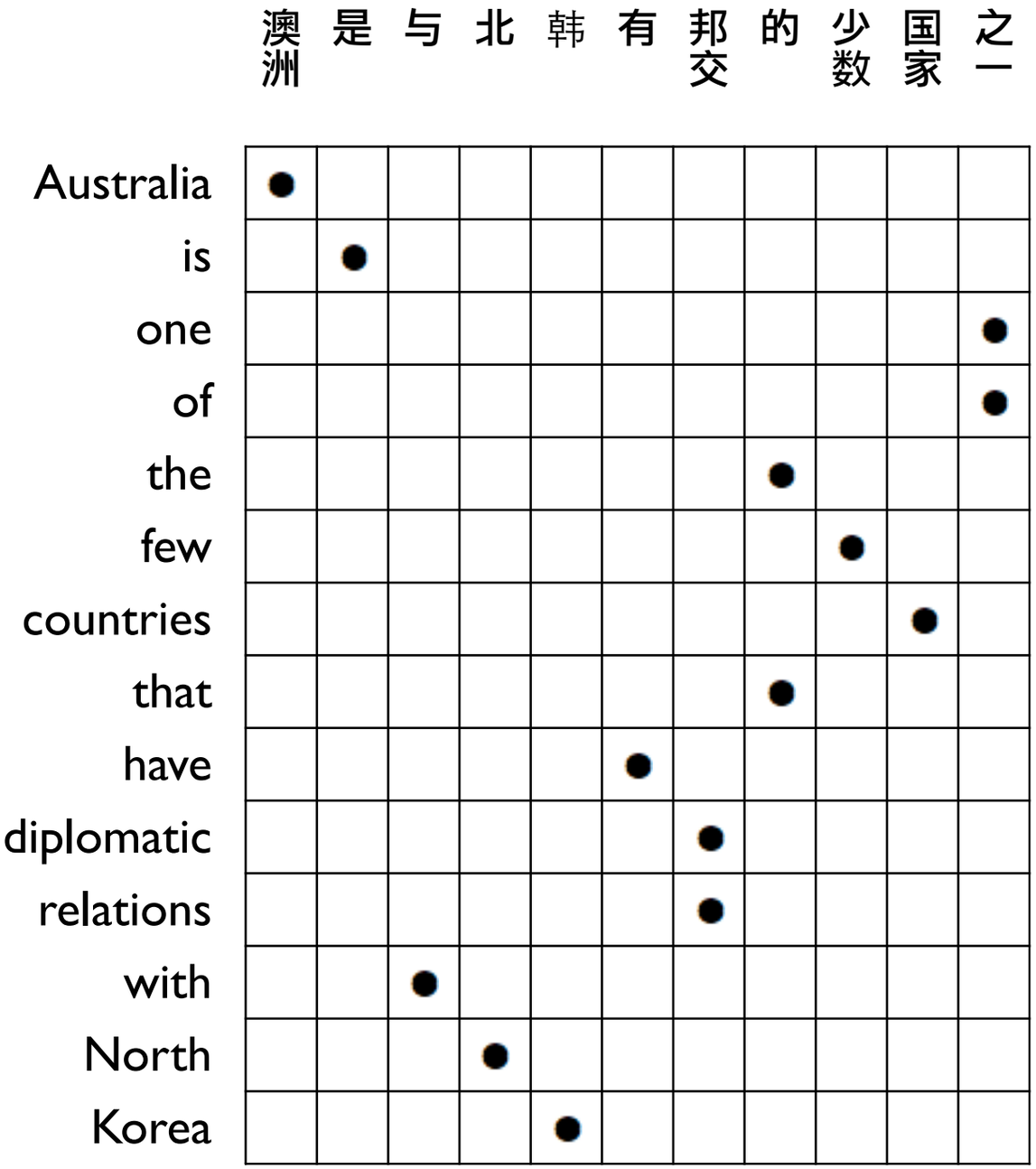
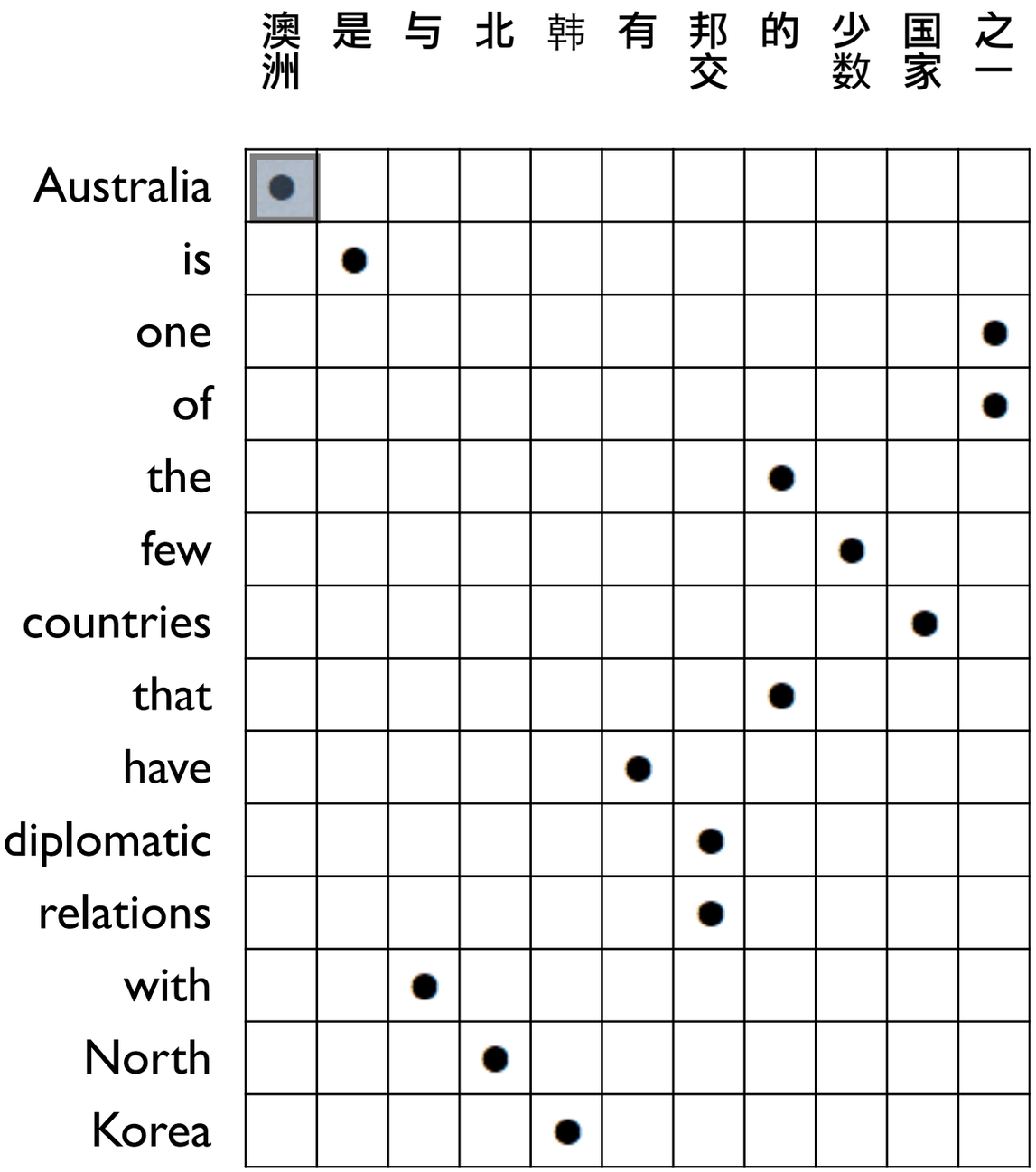


Extracting phrase pairs



Extracting phrase pairs

澳洲, Australia



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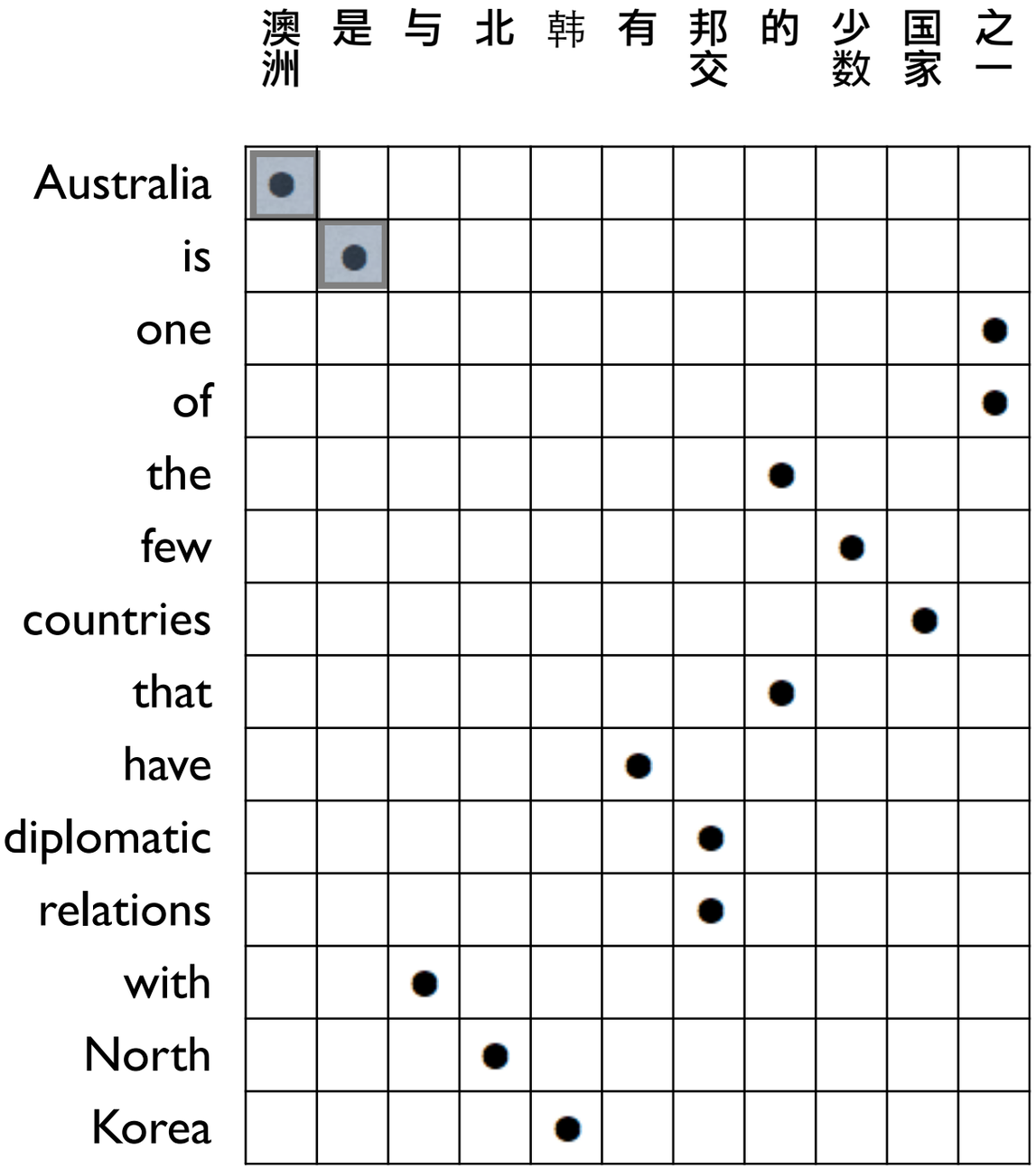
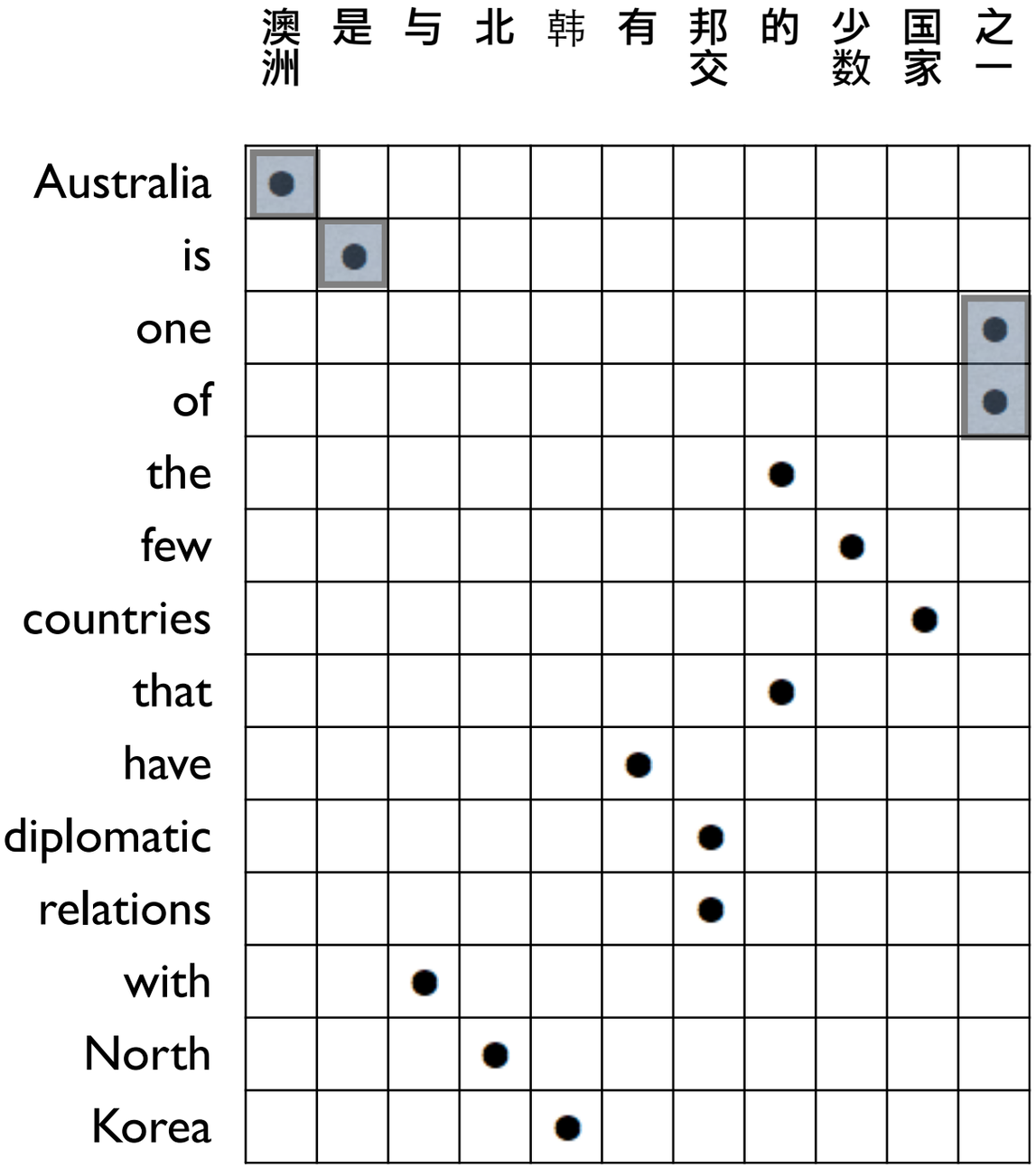


澳洲, Australia

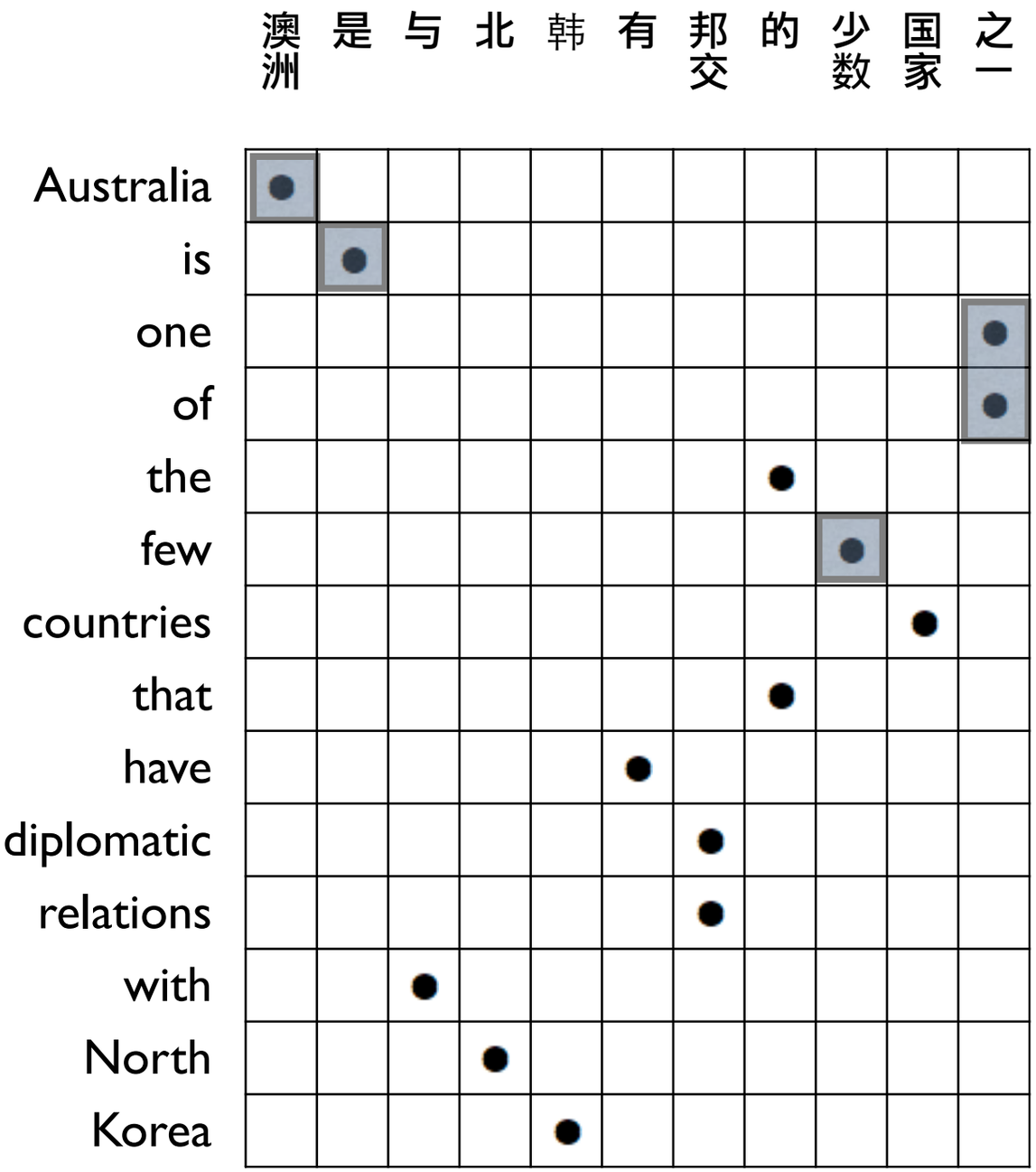
是, is

Extracting phrase pairs



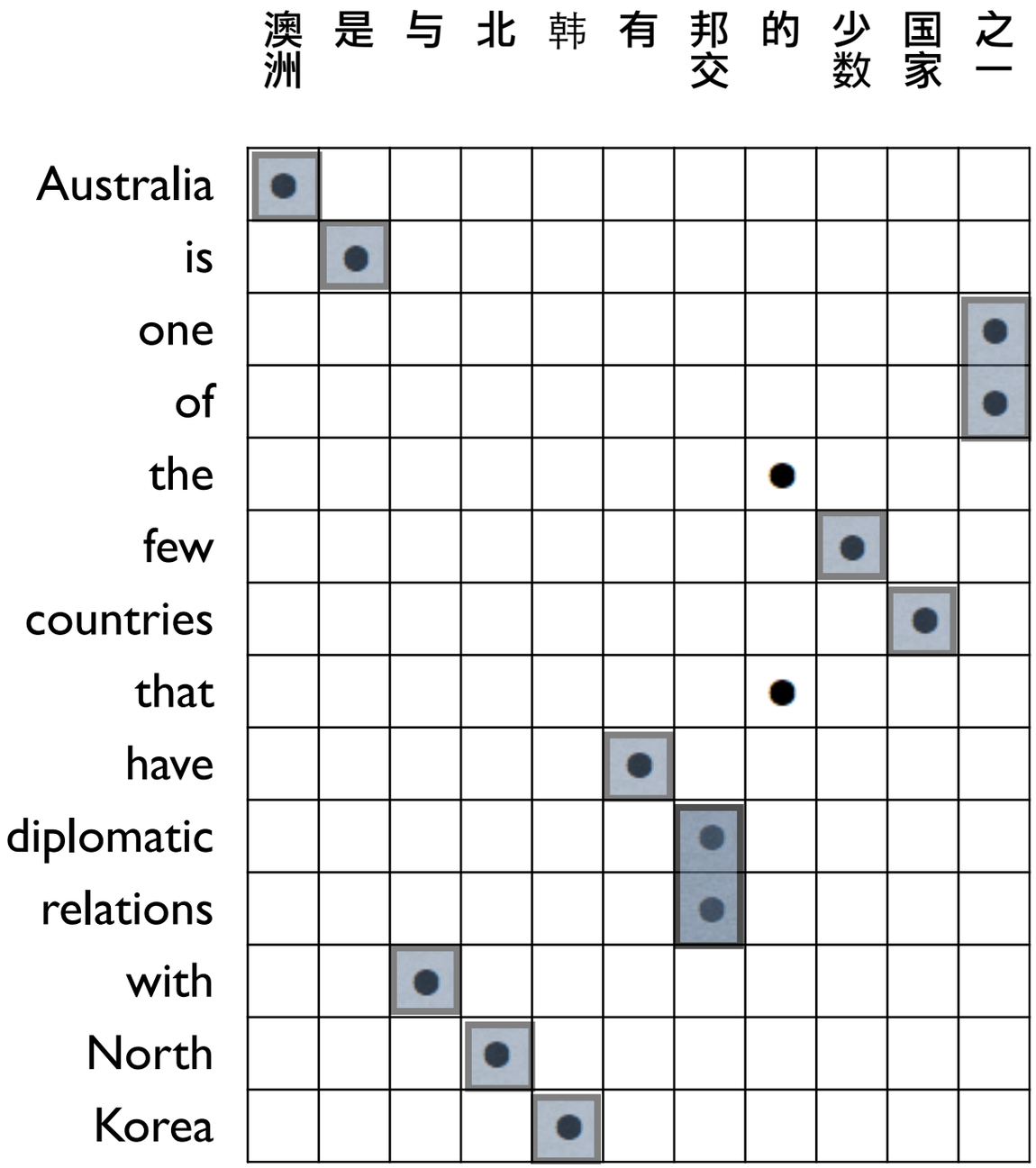
澳洲, Australia
是, is
之一, one of

Extracting phrase pairs



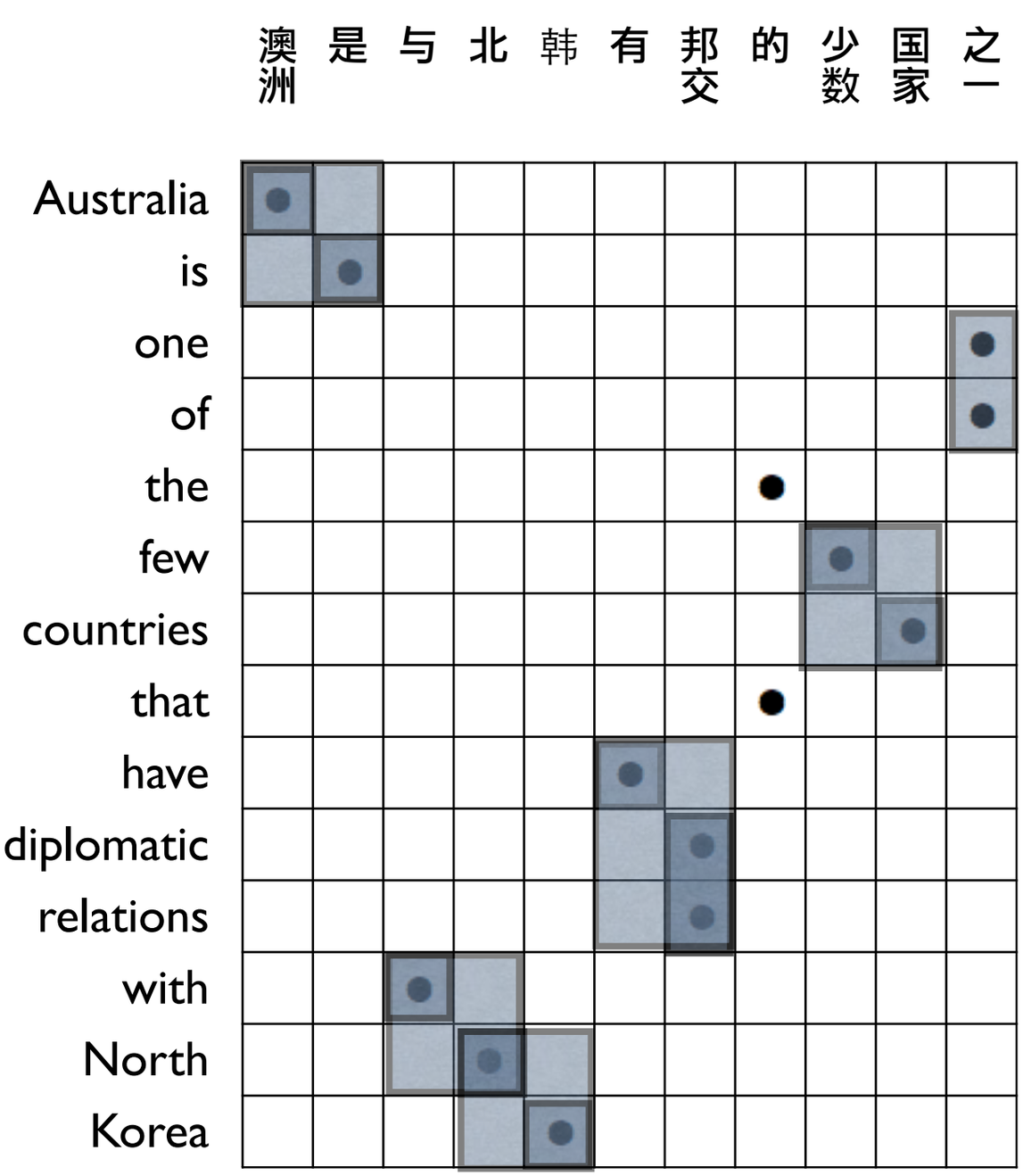
澳洲, Australia
是, is
之一, one of
少数, few

Extracting phrase pairs



澳洲，Australia
是，is
之一，one of
少数，few
国家，countries
有，have
邦交，diplomatic relations
与，with
北，North
韩，Korea

Extracting phrase pairs



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澳洲是，Australia is
少数 国家，few countries
有邦交，have diplomatic relations
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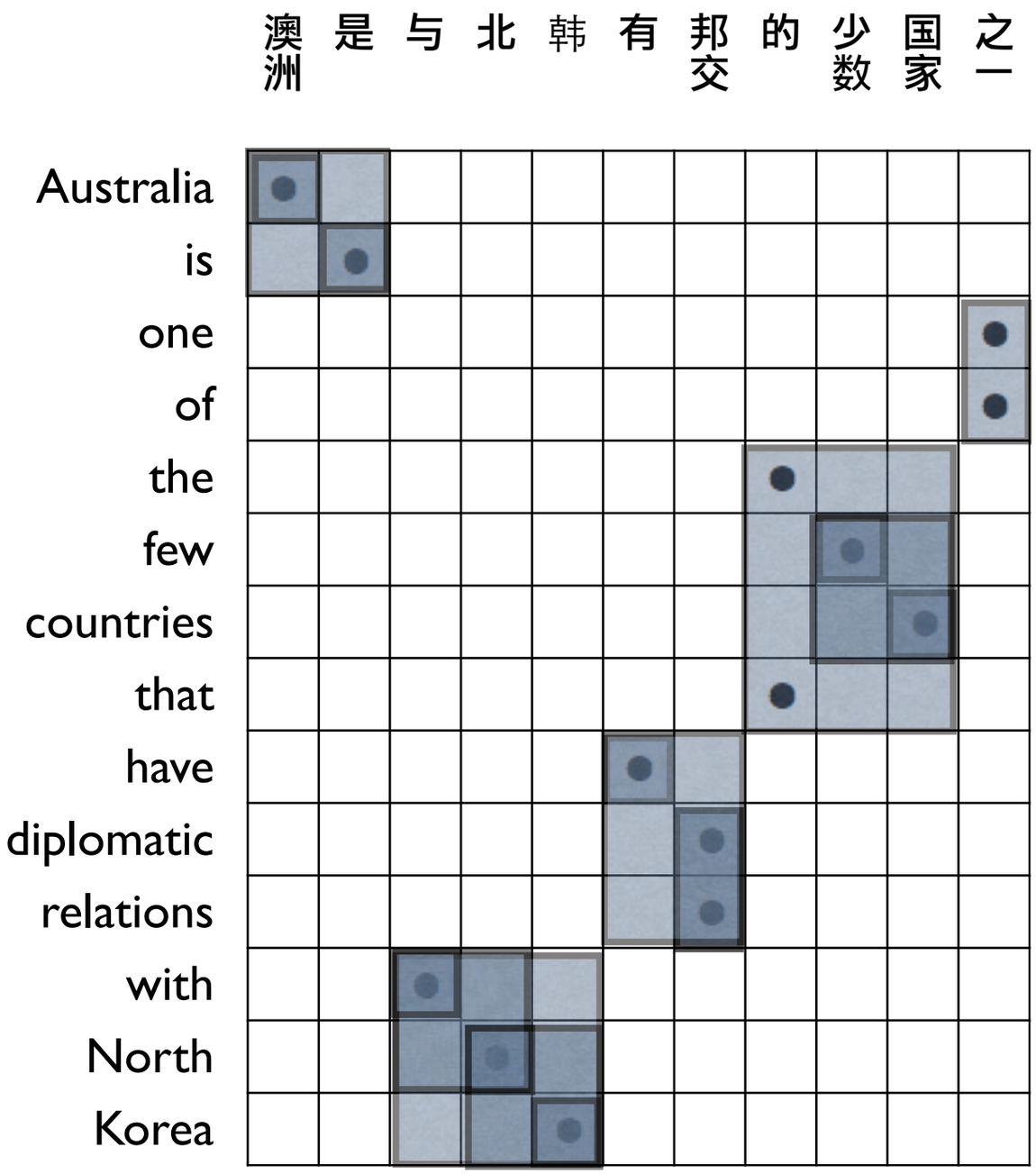

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澳洲是，Australia is
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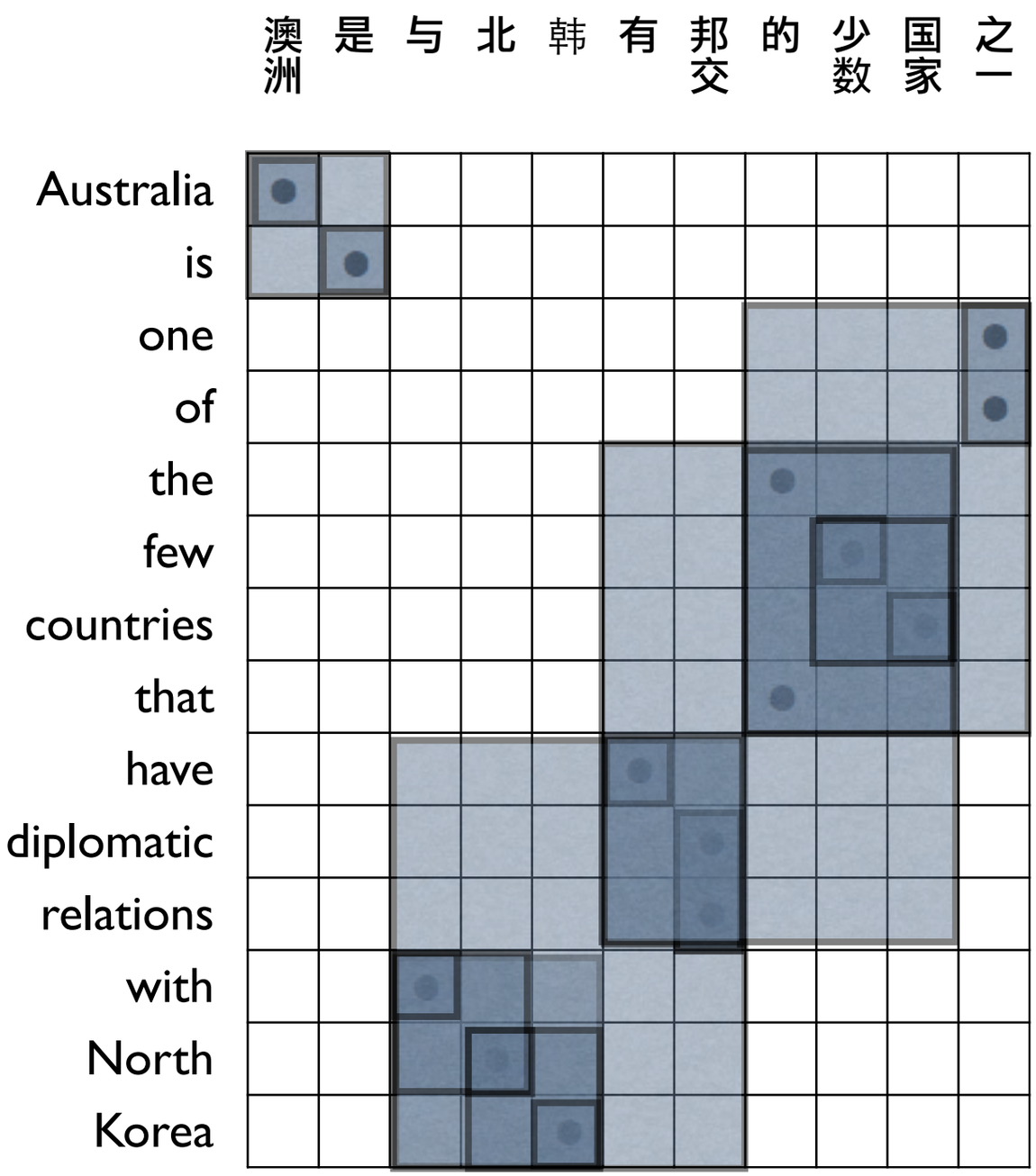
的少数 国家，the few countries that
与北韩，with North Korea

Extracting phrase pairs



澳洲, Australia
是, is
之一, one of
少数, few
国家, countries
有, have
邦交, diplomatic relations
与, with
北, North
韩, Korea

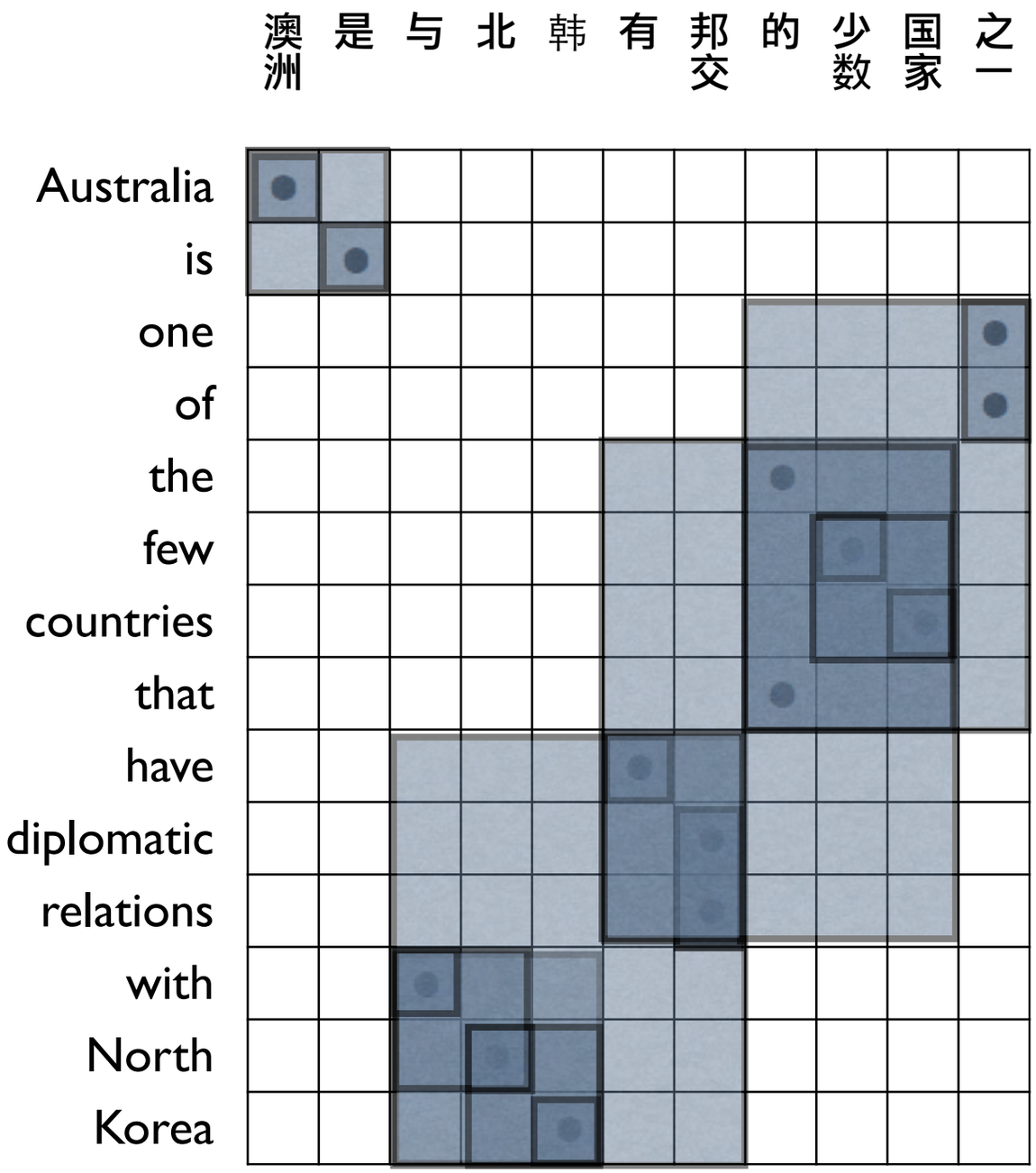
澳洲是, Australia is
少数 国家, few countries
有邦交, have diplomatic relations
与北, with North
北韩, North Korea

的少数 国家, the few countries that
与北韩, with North Korea

之一的少数 国家, one of the the few countries that
与北韩 有邦交, have diplomatic relations with North Korea

有邦交 的少数 国家, the few countries that have diplomatic relations

Extracting phrase pairs



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与北韩，with North Korea

与北韩 有邦交，have diplomatic relations with North Korea

Why does it hurt to limit to constituents?

- Massively reduces the inventory of phrases that can be used as translation units
- Eliminates non-constituent phrases, many of which are quite useful
  - *there are*
  - *note that*
  - *according to*

So, what should we do?

- Drop syntax from statistical machine translation, since syntax is a bad fit for the data
- Abandon conventional English syntax and move towards more robust grammars that adapt to the parallel training corpus
- Maintain English syntax but design different syntactic models

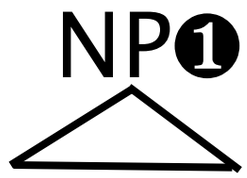
Synchronous Context Free Grammars

- A common way of representing syntax in NLP is through context free grammars
- Synchronous context free grammars generate pairs of corresponding strings
- Can be used to describe translation and re-ordering between languages
- SCFGs translate sentences by parsing them

Example SCFG for Urdu

	Urdu	English
S →	NP① VP②	NP① VP②
VP→	PP① VP②	VP② PP①
VP→	V① AUX②	AUX② V①
PP →	NP① P②	P② NP①
NP →	*hamd ansary*	*Hamid Ansari*
NP →	*na}b sdr*	*Vice President*
V →	*namzd*	*nominated*
P →	*kylye*	*for*
AUX →	*taa*	*was*

hamd ansary *na}b sdr* *kylye* *namzd* *taa*



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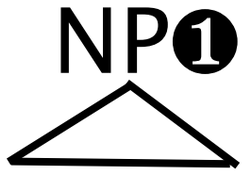
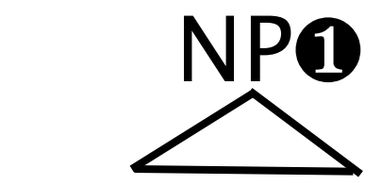
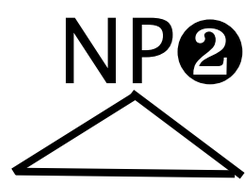


Hamid Ansari





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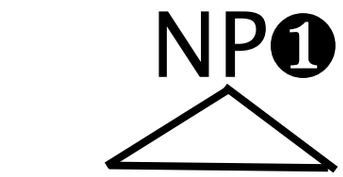

Hamid Ansari *Vice President*


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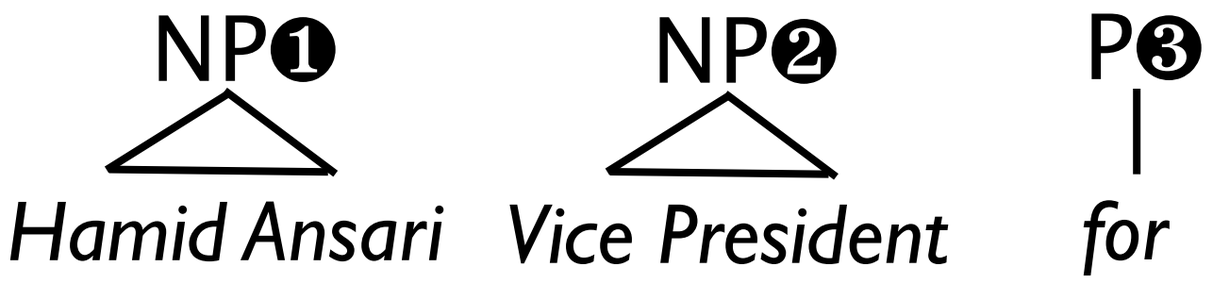
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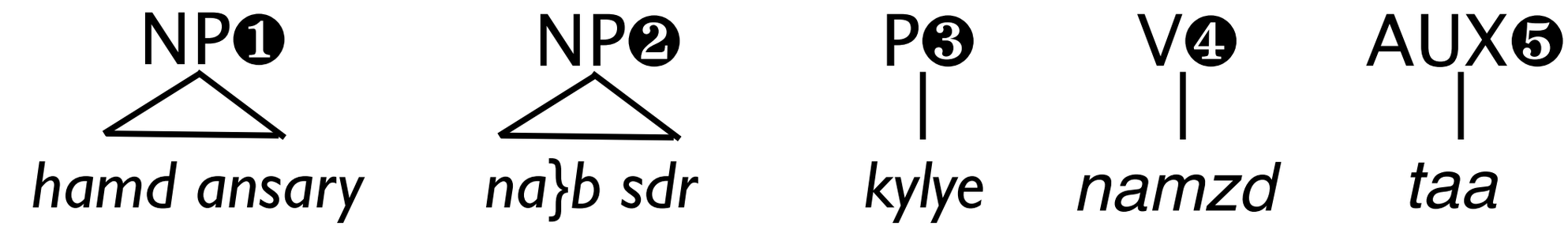
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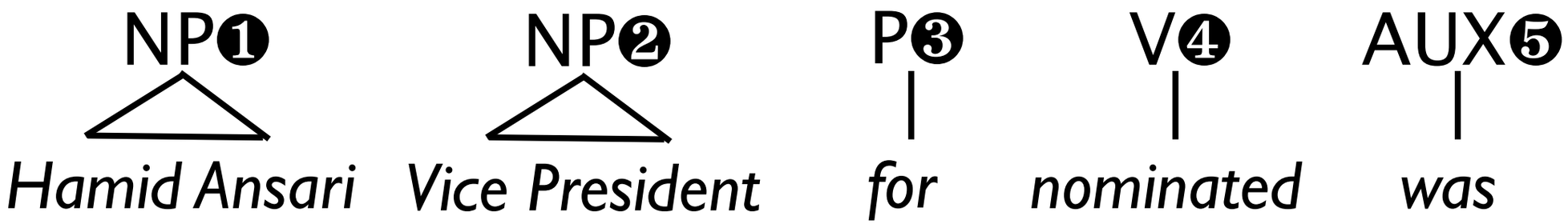
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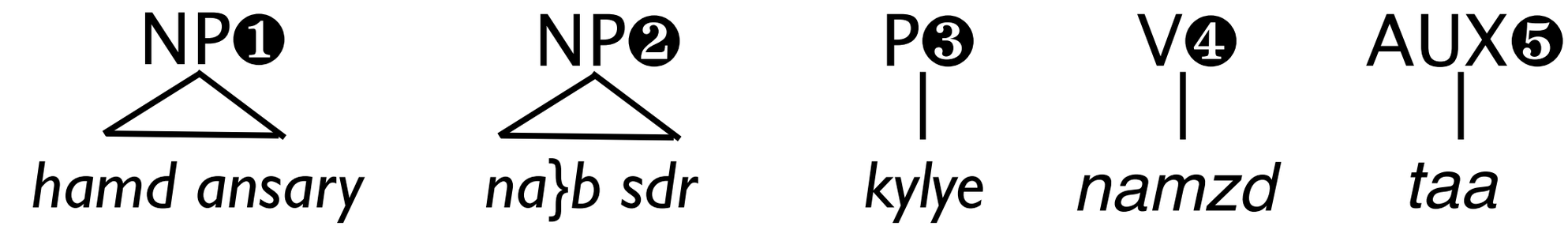
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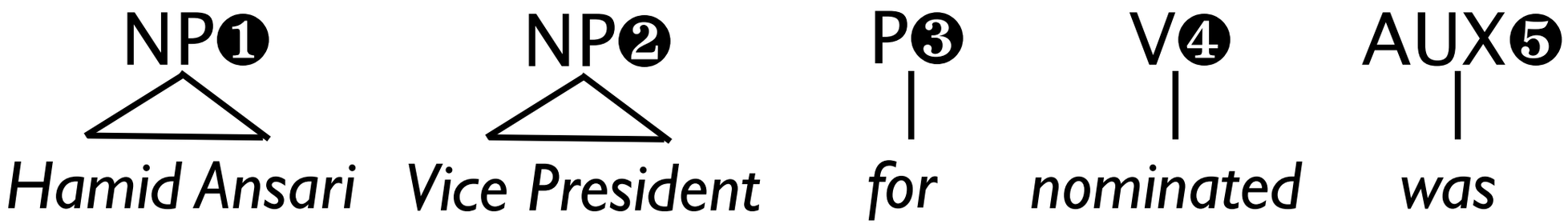
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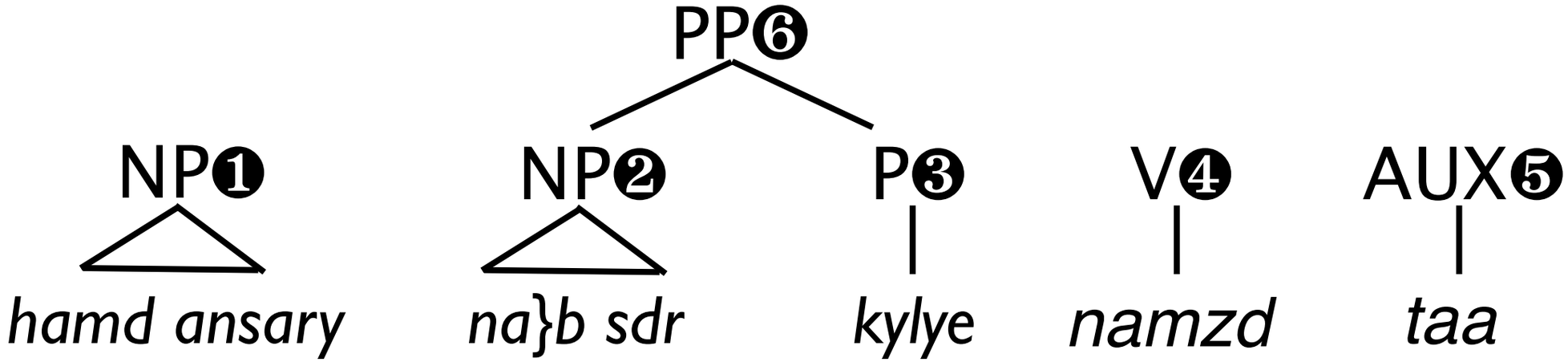
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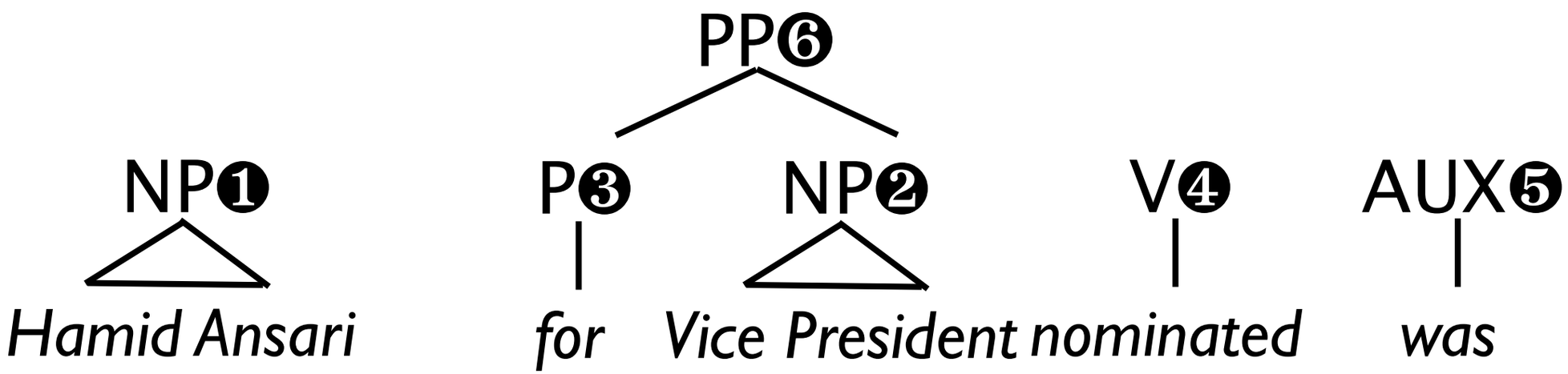
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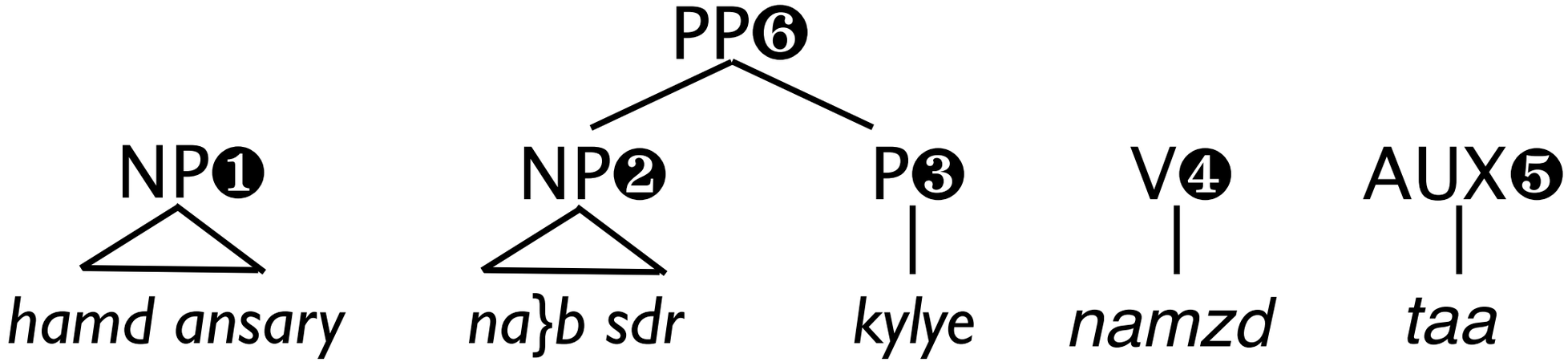
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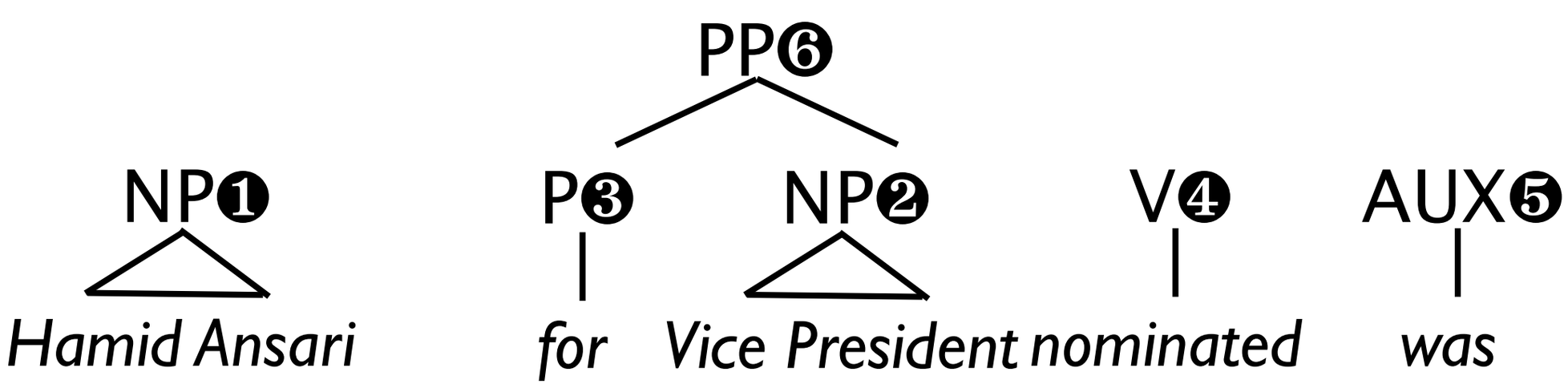
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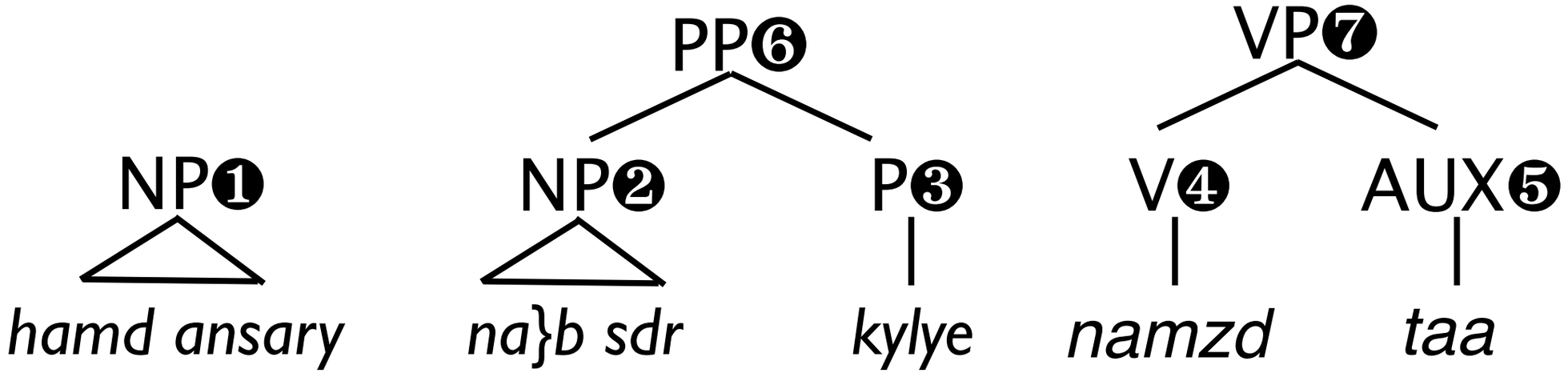
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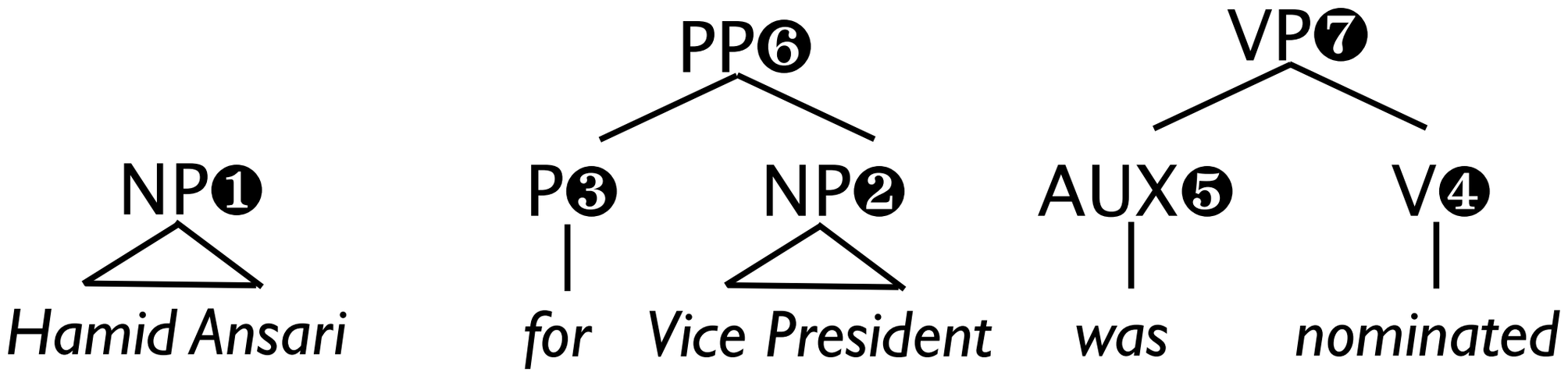
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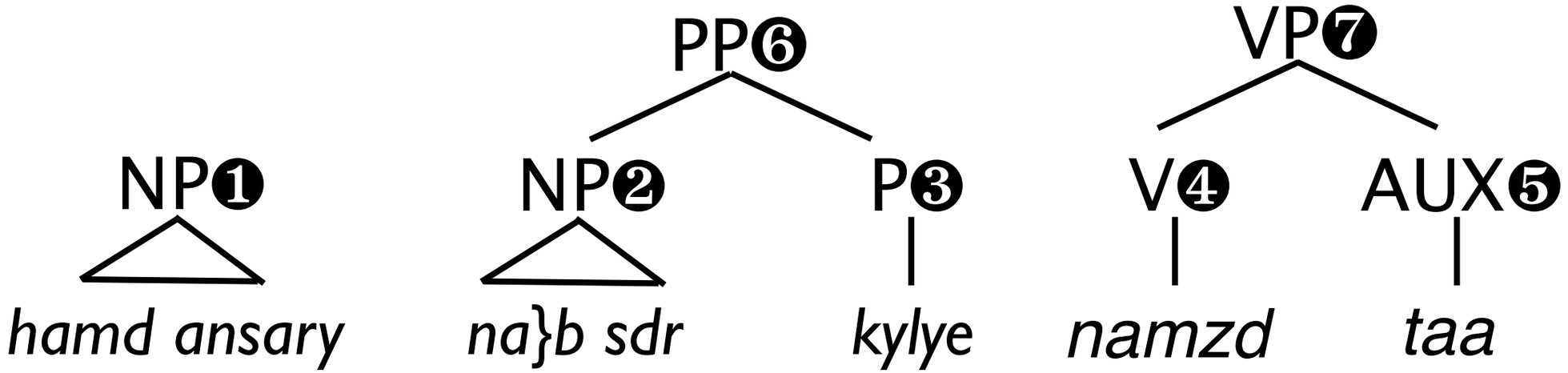
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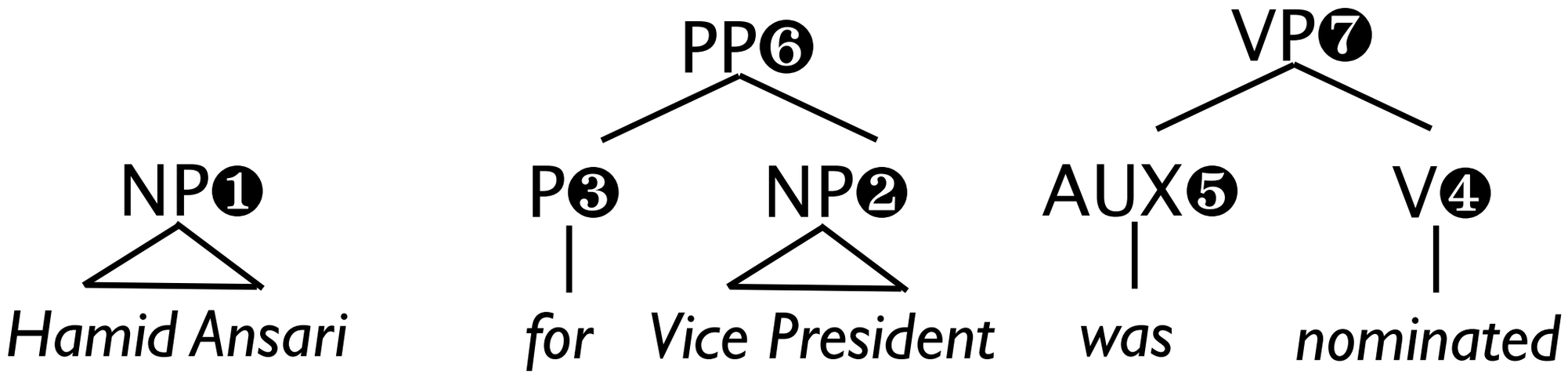
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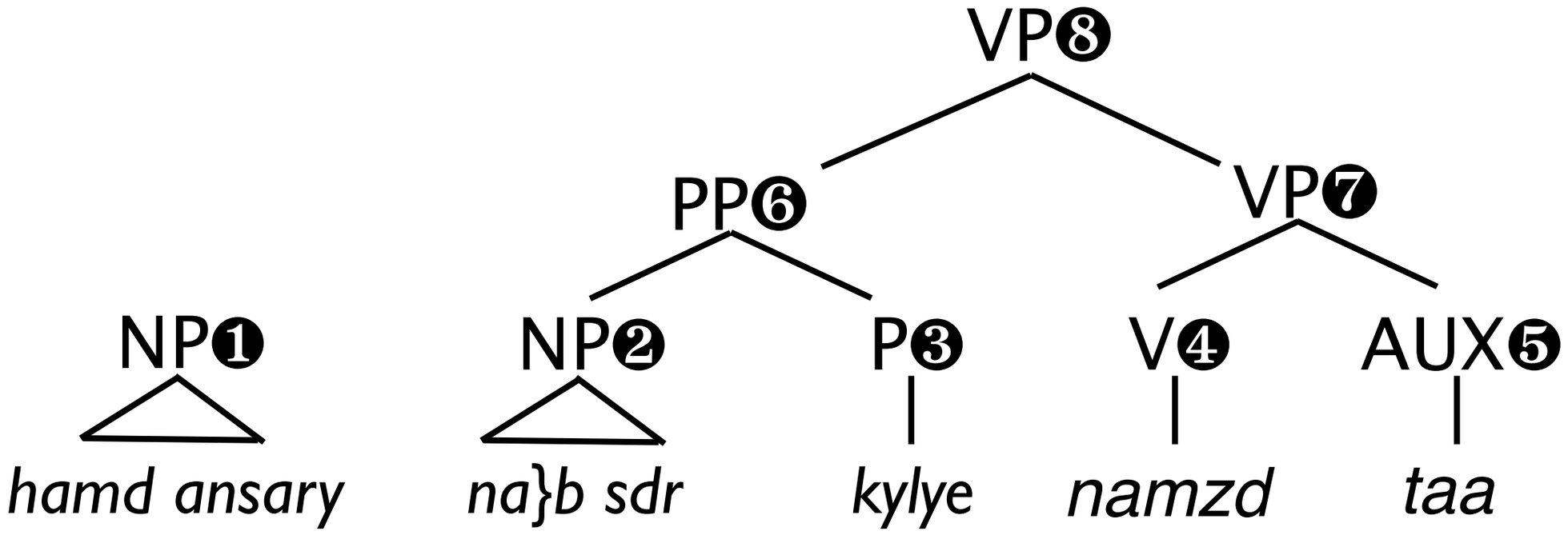
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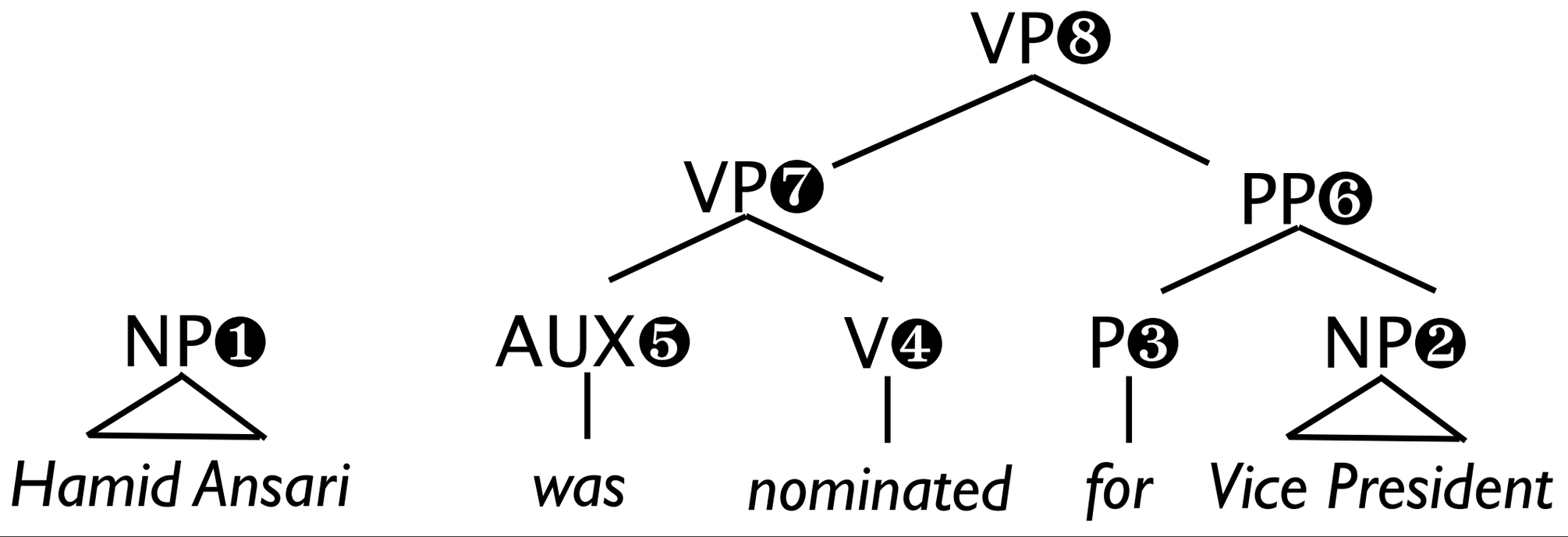
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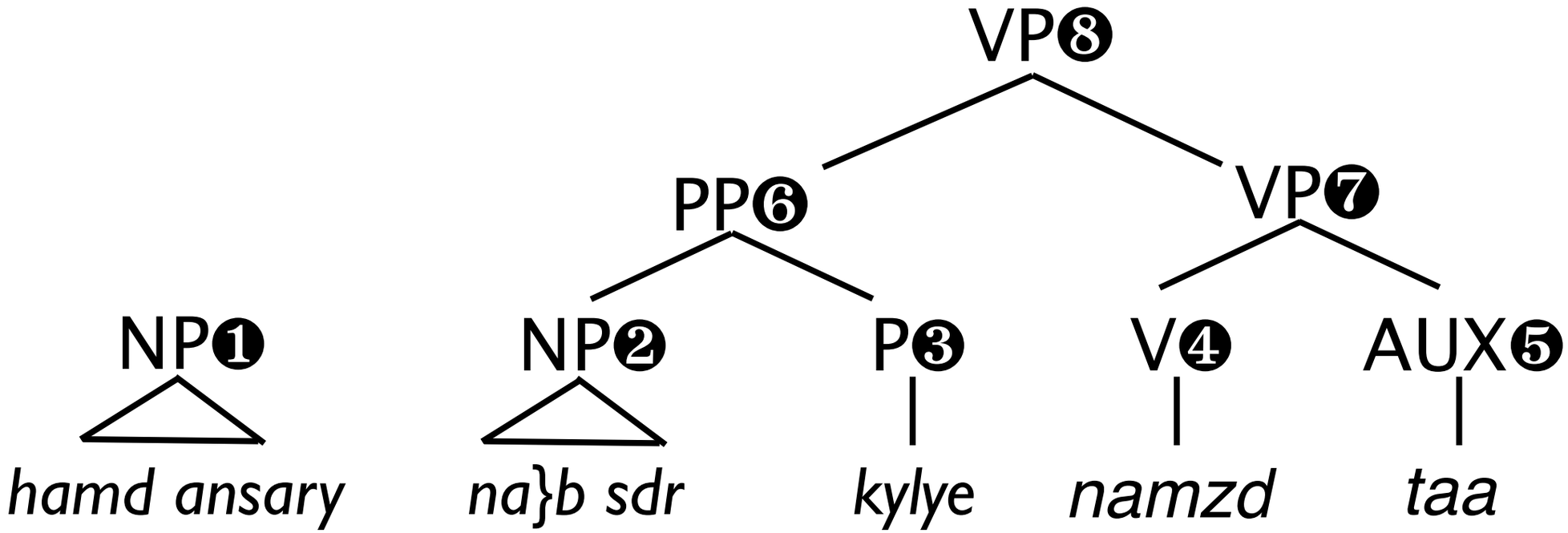
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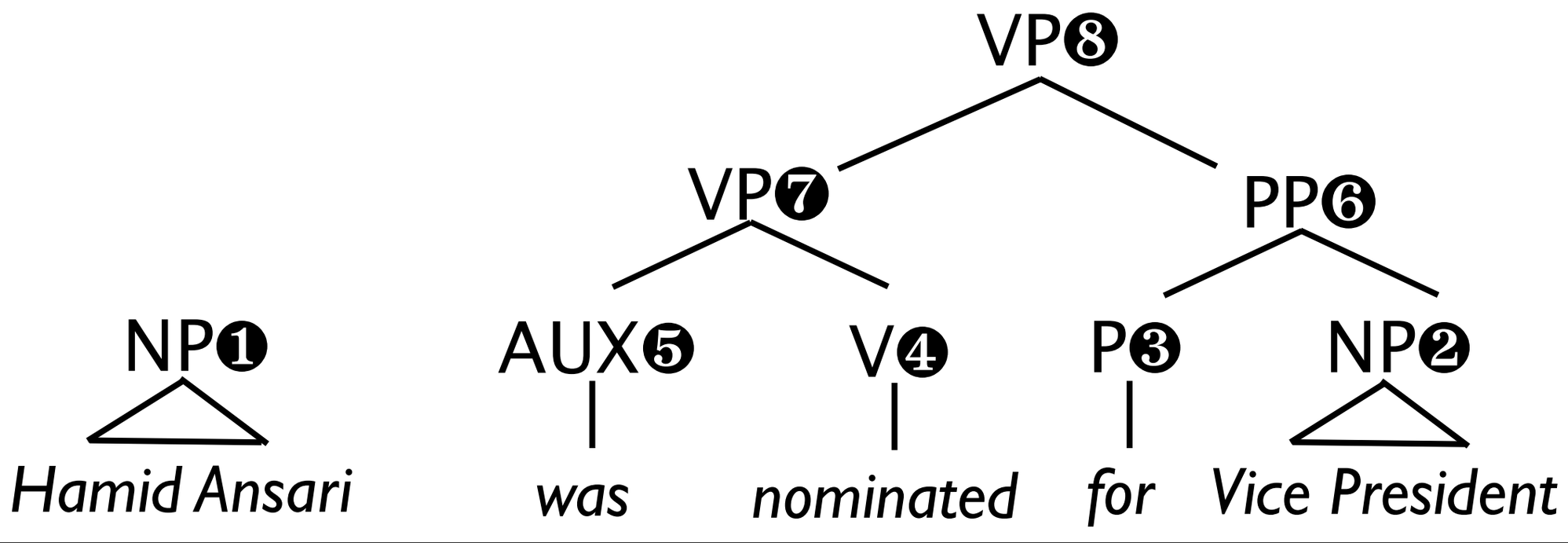
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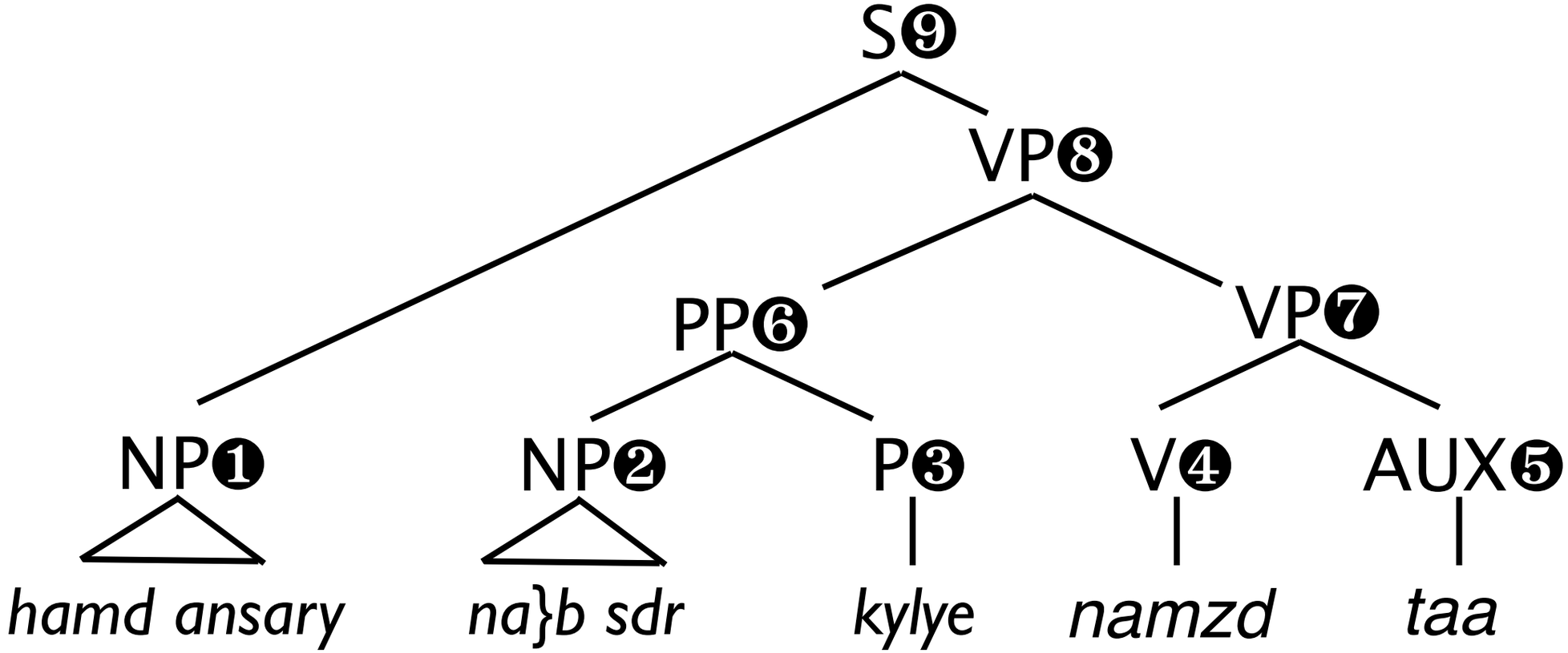
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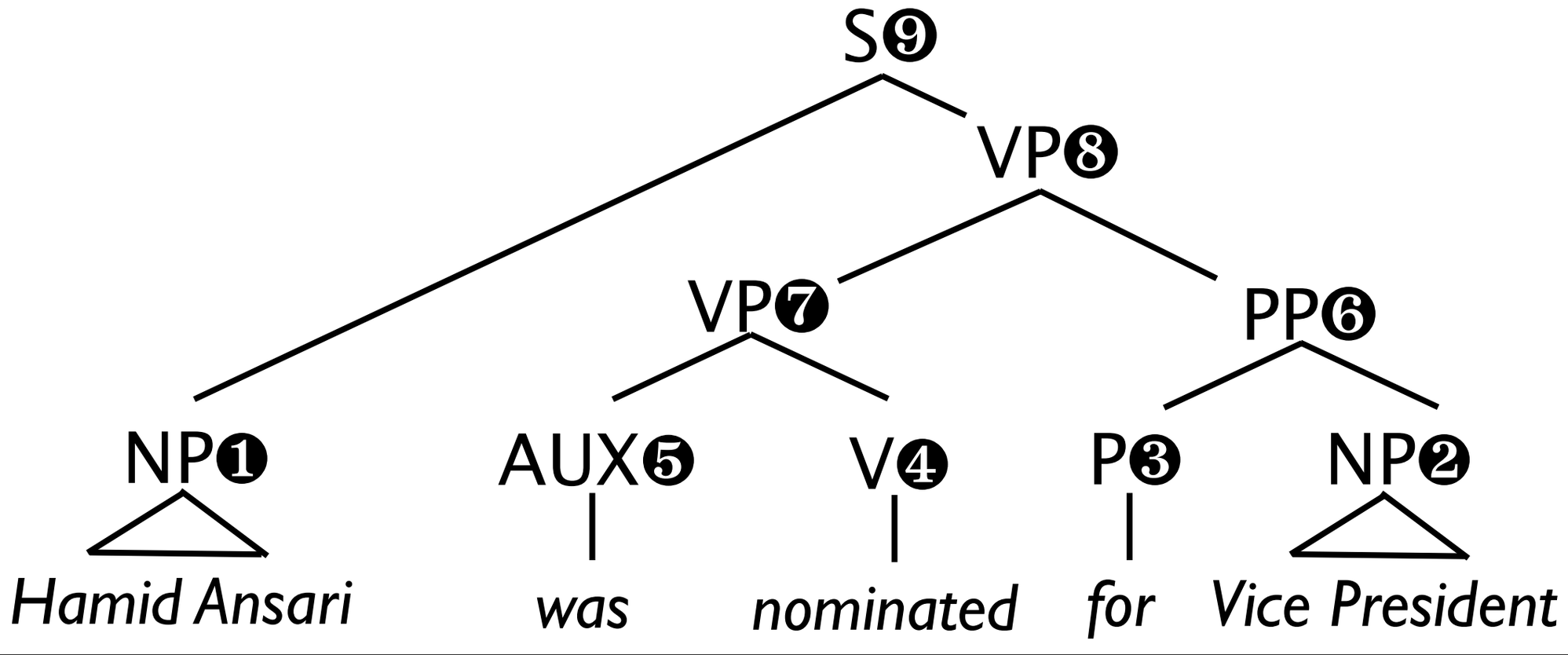
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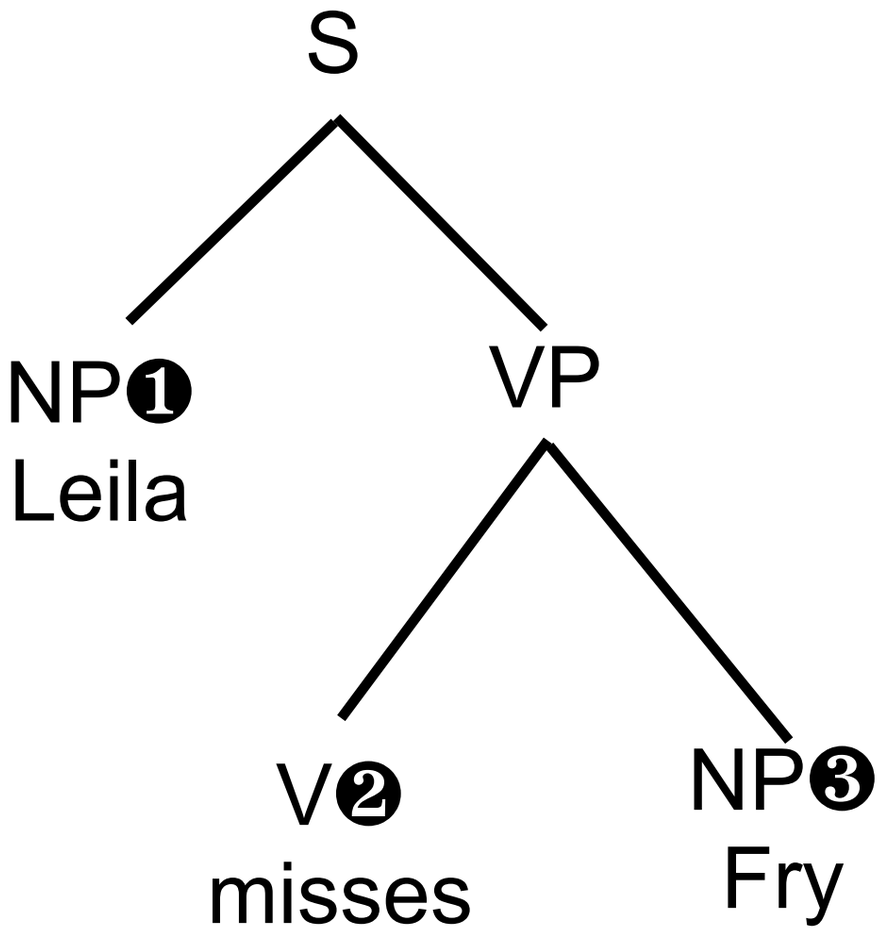
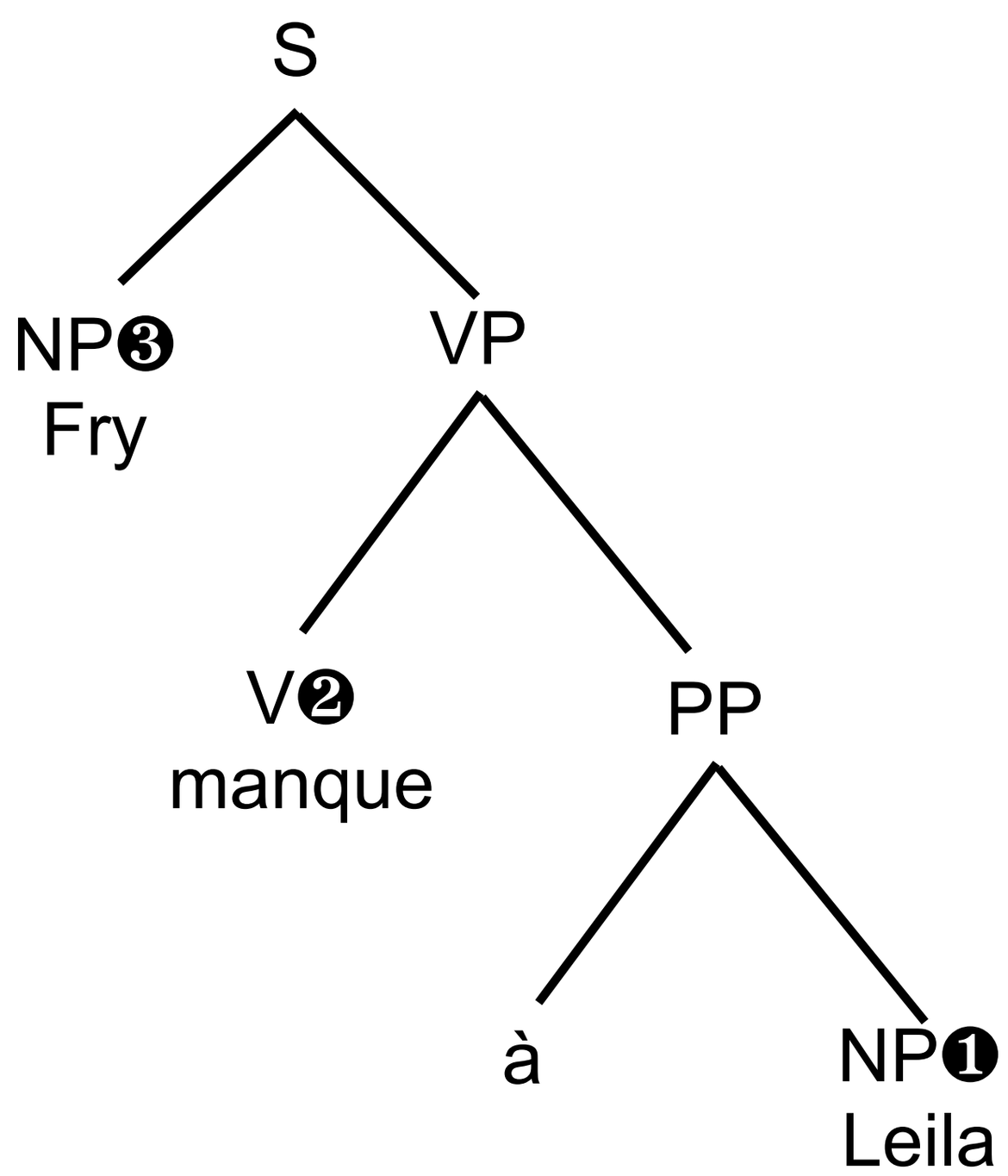
Discussion: Do you like SCFG?

- In what ways are SCFGs better for describing reordering than what we saw before?
- Is this a good model of how languages relate?
- What do you think of the synchronous requirement?

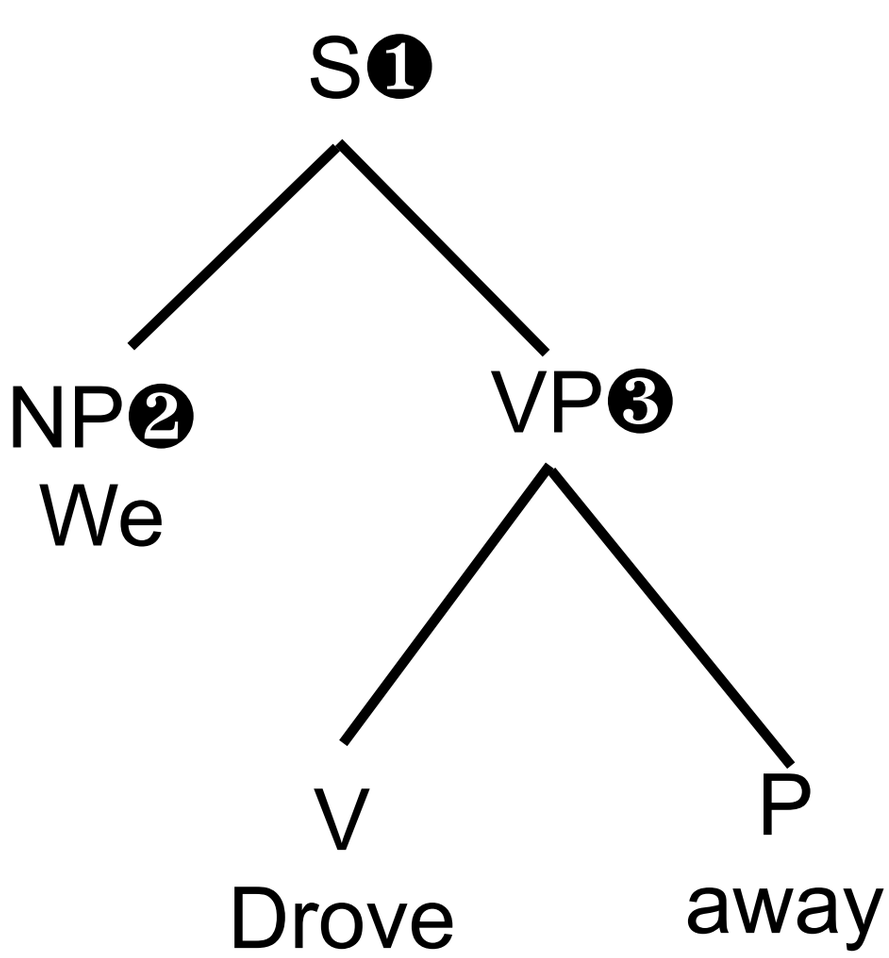
(Discuss with your neighbor)

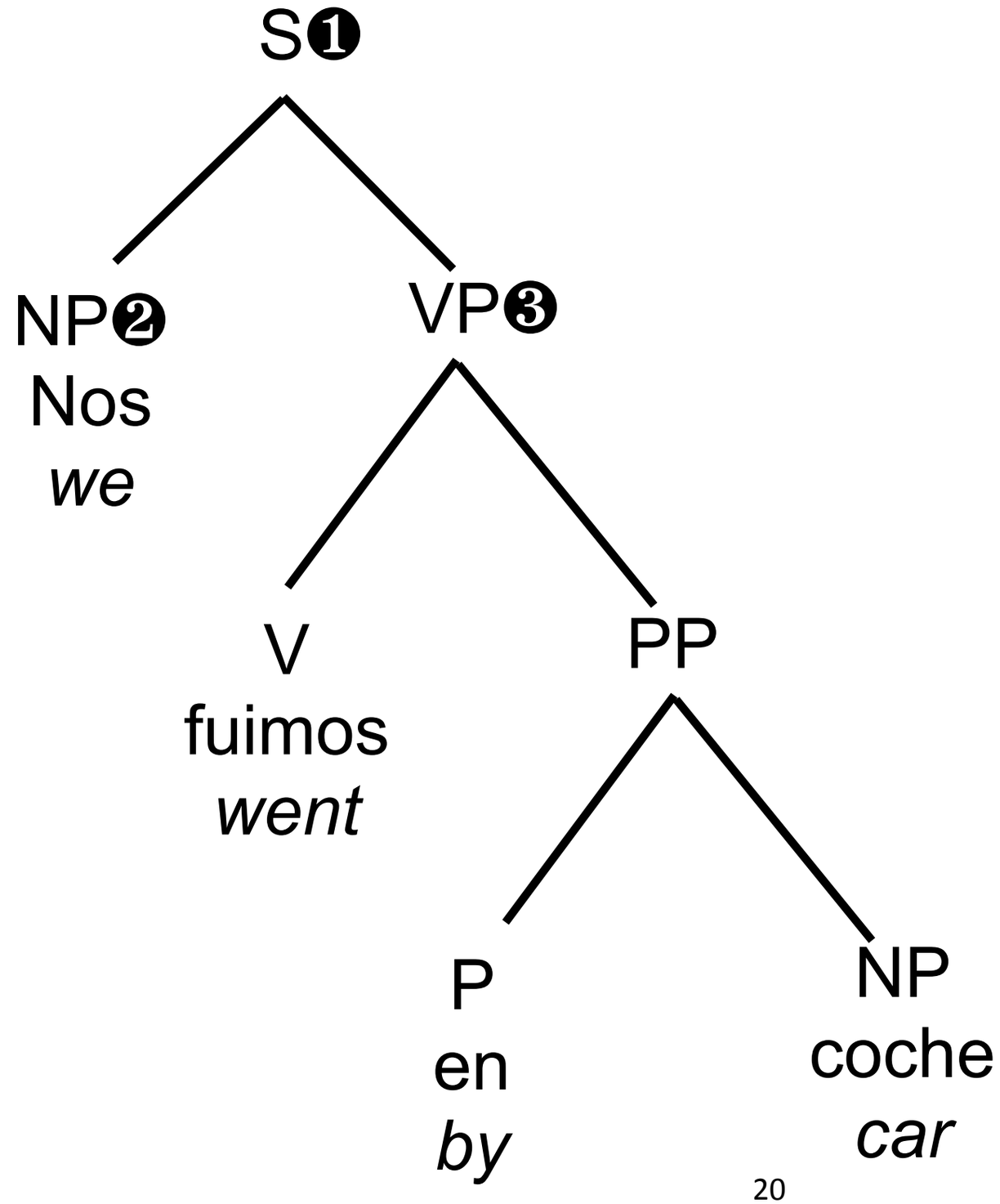
Sometimes languages are mismatched



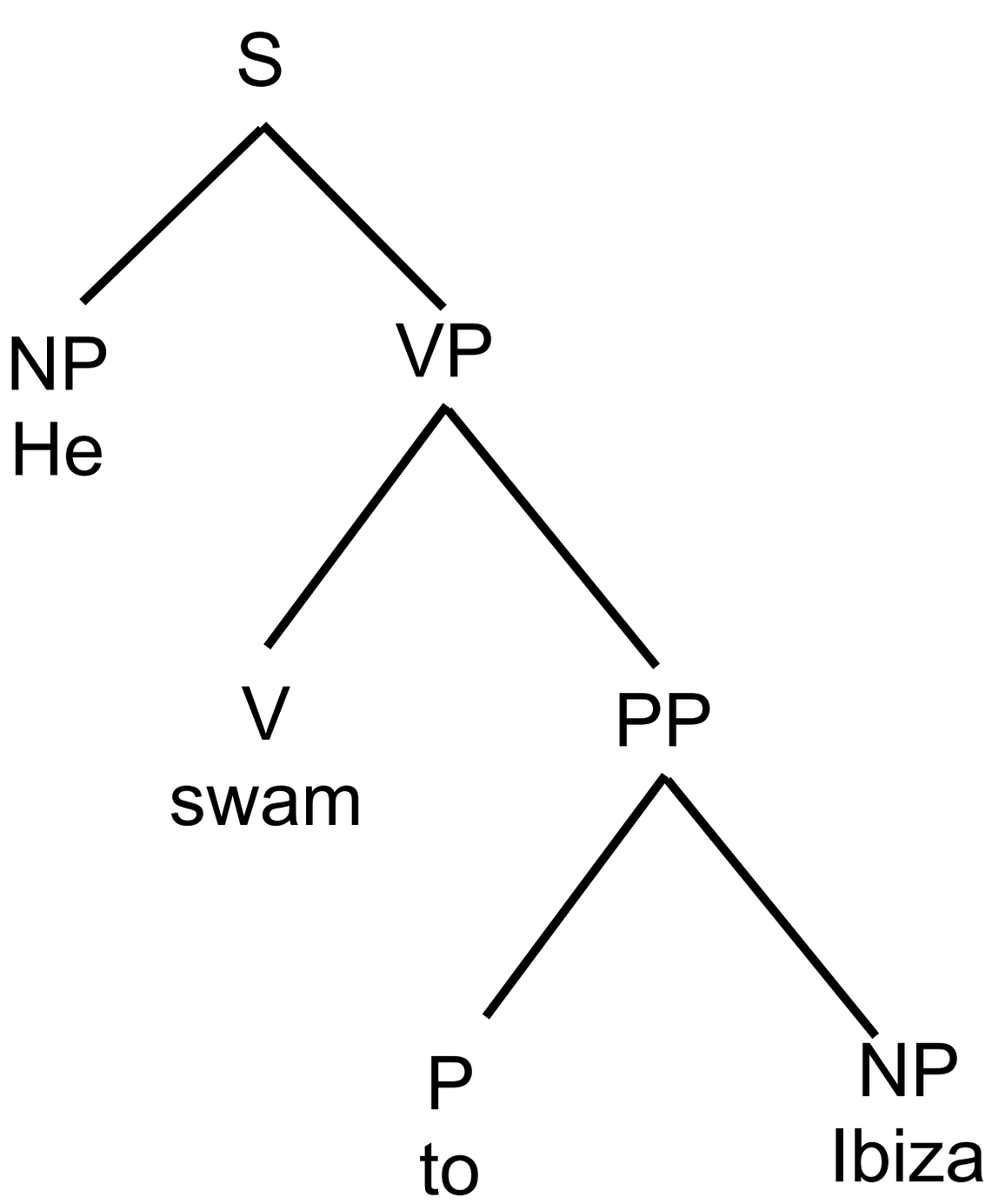


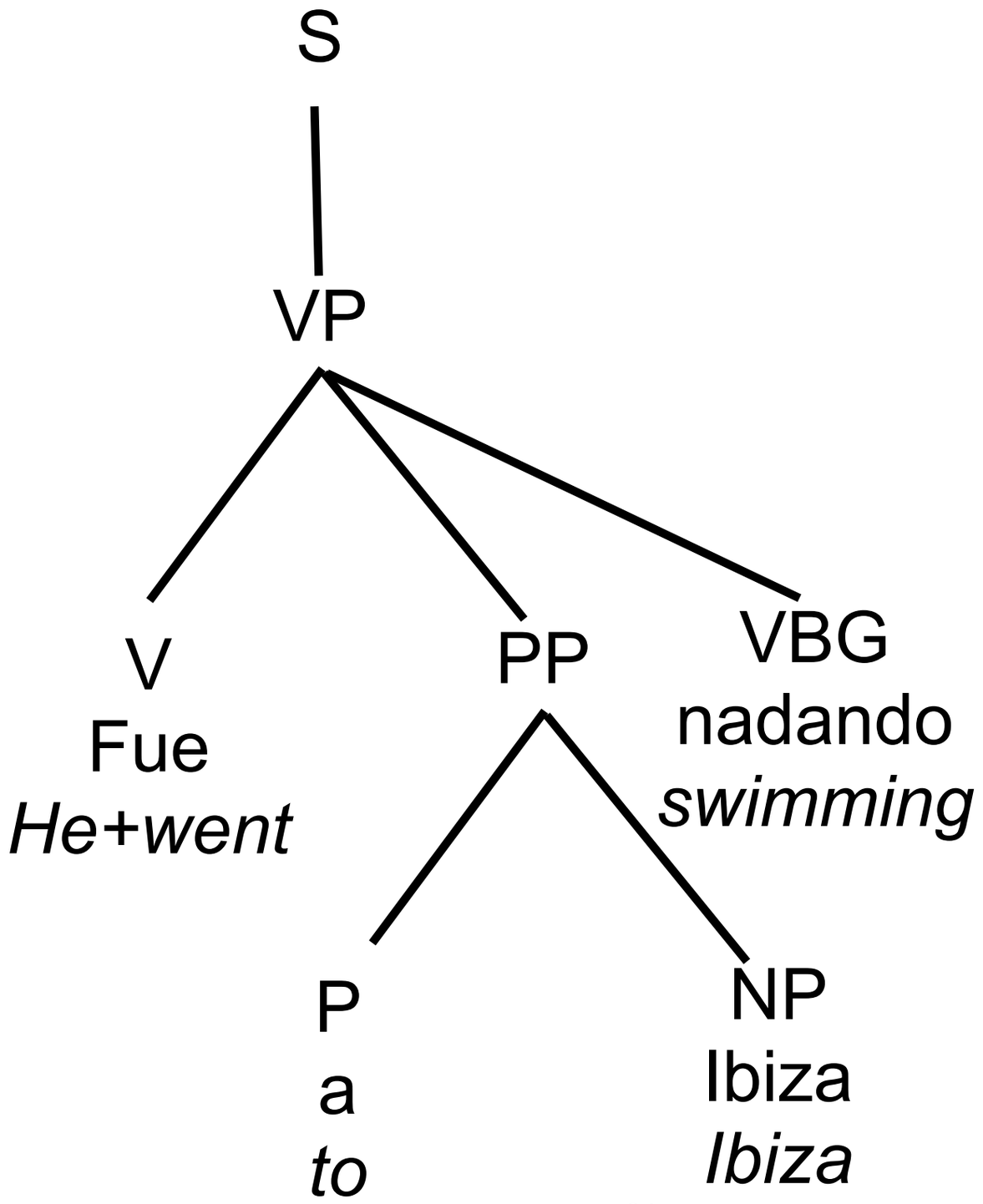
Spanish motion verb





Spanish motion verb, pro-drop

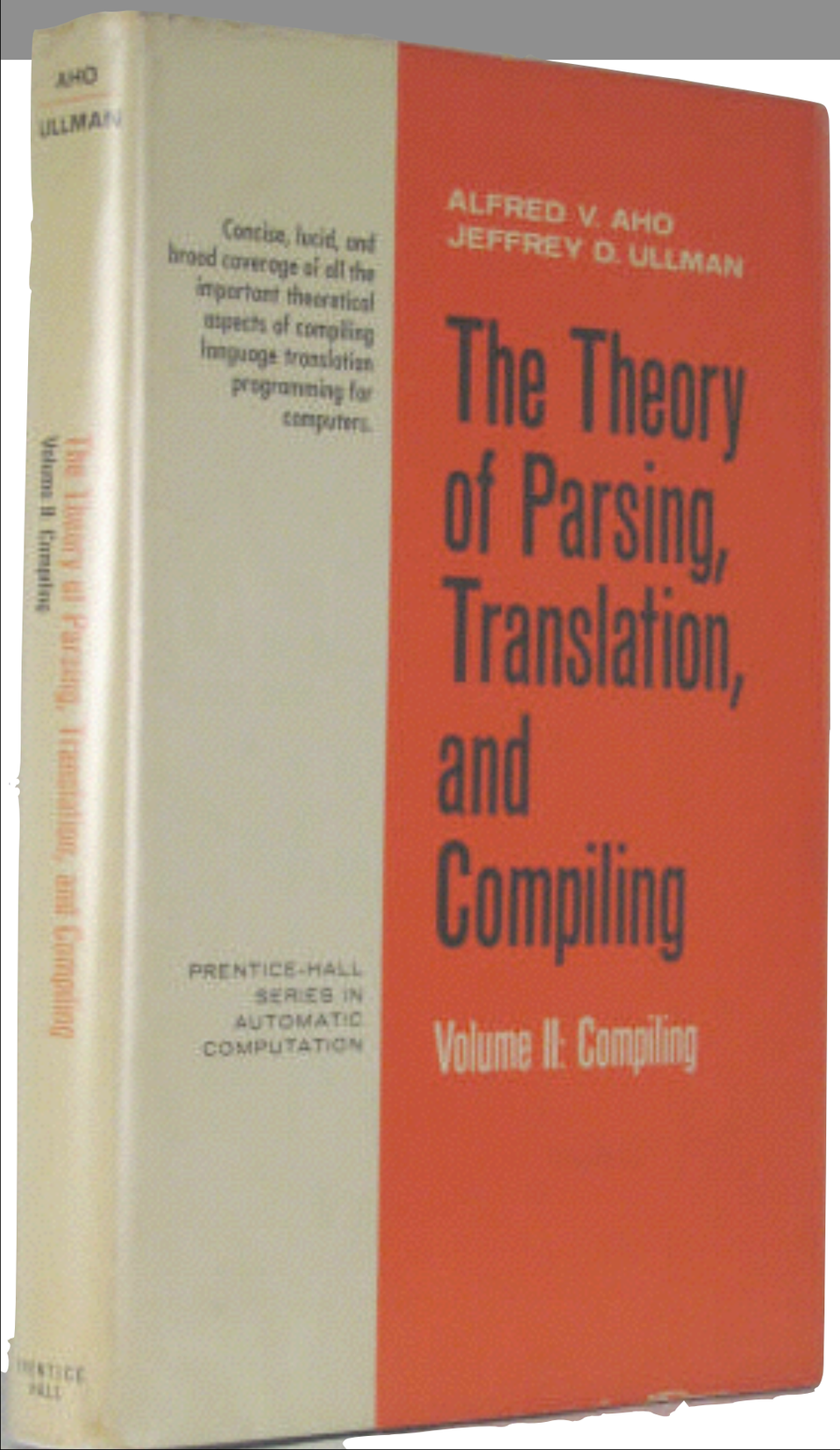




We are going to use them anyway

- SCFGs are mismatched with some linguistic phenomena
- But they have nice formal properties and well-defined algorithms

Formal definition of SCFGs



- Aho and Ullman worked all of this out in the `60s and `70s
- Compiler theory

Formal definition of SCFGs

- A synchronous context free grammar is formally defined by a tuple

$$G = \langle N, T_S, T_T, R, S \rangle$$

- Where

Formal definition of SCFGs

- A synchronous context free grammar is defined by a tuple

S, NP, VP, PP, P, V, AUX

$$G = \langle N, T_S, T_T, R, S \rangle$$

- Where
  - N is a shared set of non-terminal symbols

Formal definition of SCFGs

hamd ansary, na}b sdr, namzd, kylye, taa

S, NP, VP, PP, P, V, AUX

- A synchronous context free grammar is defined by a tuple

$$G = \langle N, T_S, T_T, R, S \rangle$$

- Where
  - N is a shared set of non-terminal symbols
  - T_S is the set of source language terminals

Formal definition of SCFGs

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for, Hamid Ansari, nominated, Vice President, was

S, NP, VP, PP, P, V, AUX

- A synchronous context free grammar is defined by a tuple

$$G = \langle N, T_S, T_T, R, S \rangle$$

- Where
  - N is a shared set of non-terminal symbols
  - T_S is the set of source language terminals
  - T_T is the set of target language terminals

Formal definition of SCFGs

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S, NP, VP, PP, P, V, AUX

- A synchronous context free grammar is defined by a tuple

$$G = <N, T_S, T_T, R, S>$$

- Where
  - N is a shared set of non-terminal symbols
  - T_S is the set of source language terminals
  - T_T is the set of target language terminals
  - R is a set of production rules

Formal definition of SCFGs

hamd ansary, na}b sdr, namzd, kylye, taa

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- A synchronous context free grammar is defined by a tuple

S, NP, VP, PP, P, V, AUX

S

$$G = \langle N, T_S, T_T, R, S \rangle$$

- Where
  - N is a shared set of non-terminal symbols
  - T_S is the set of source language terminals
  - T_T is the set of target language terminals
  - R is a set of production rules
  - $S \in N$, designated as the goal state

Formal definition of SCFGs

- Each production rule has the form

$$X \rightarrow \langle \alpha, \beta, \sim, w \rangle$$

- Where
  - $X \in N$
  - $\alpha \in (N \cup T_S)^*$
  - $\beta \in (N \cup T_T)^*$
  - ~ is a one-to-one correspondence between the non terminals in α and β
  - w is a weight assigned to the rule

Algorithms for SCFGs

- Translation with SCFGs is done via parsing
- How do we write an algorithm for parsing?
- One way to do it is as a deductive proof system

The CKY Parsing Algorithm

Axioms	$\dfrac{}{A \rightarrow \alpha}$	for all $(A \rightarrow \alpha) \in R$
Inference rules	$\dfrac{A}{[A, i, i+1]}$ $\dfrac{[B, i, j] \quad [C, j, k] \quad A \rightarrow BC}{[A, i, k]}$	
Goal	$[S, 0, n]$	

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

Goal

[S, 0, 5]

Axioms			Inference rule used	Goal
	S →	NP VP		[S, 0, 5]
	VP→	PP VP		
	VP→	V AUX		
	PP →	NP P		
	NP →	*hamd ansary*		
	NP →	*na}b sdr*		
	V →	*namzd*		
	P →	*kylye*		
	AUX →	*taa*		

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{NP} \rightarrow \textit{hamd ansary}_1}{[\text{NP}, \textit{0}, \textit{1}]}$$

Goal

[S, 0, 5]

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{NP} \rightarrow \text{hamd ansary}_1}{[\text{NP}, 0, 1]}$$

Goal

[S, 0, 5]

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

[NP, *0, 1*]

Axioms			Inference rule used	Goal
S →	NP VP			[S, 0, 5]
VP→	PP VP			
VP→	V AUX			
PP →	NP P			
NP →	*hamd ansary*			
NP →	*na}b sdr*			
V →	*namzd*			
P →	*kylye*			
AUX →	*taa*			

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

[NP, *0, 1*]

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{NP} \rightarrow \text{na}\}\text{b sdr}_2}{[\text{NP}, \textit{1}, \textit{1}]}$$

Goal

[S, 0, 5]

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

[NP, *0, 1*]

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{NP} \rightarrow \text{na}\}\text{b sdr}_2}{[\text{NP}, \textit{1}, \textit{1}]}$$

Goal

[S, 0, 5]

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

[NP, *0, 1*]	[NP, *1, 2*]

Axioms		**Inference rule used**	**Goal**
S →	NP VP		[S, 0, 5]
VP→	PP VP		
VP→	V AUX		
PP →	NP P		
NP →	*hamd ansary*		
NP →	*na}b sdr*		
V →	*namzd*		
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AUX →	*taa*		

0 *hamd ansary* *1* *na}b sdr* *2* *kylye* *3* *namzd* *4* *taa* *5*

[NP, *0, 1*]	[NP, *1, 2*]

Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{P \rightarrow kylye_3}{[P, 2, 3]}$$

Goal

[S, 0, 5]

0 *hamd ansary* 1 *na}b sdr* 2 *kylye* 3 *namzd* 4 *taa* 5

[NP, *0, 1*]	[NP, *1, 2*]

Axioms

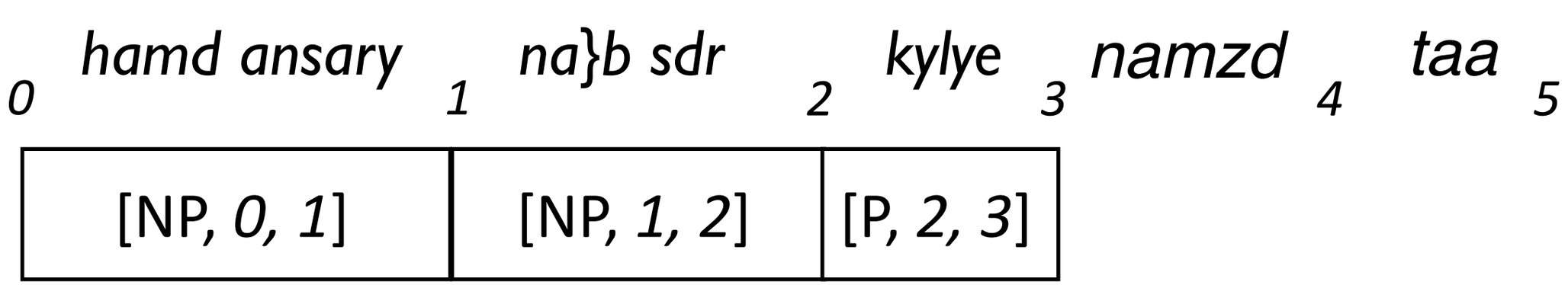
S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{P \rightarrow kylye_3}{[P, 2, 3]}$$

Goal

[S, 0, 5]



Axioms			Inference rule used	Goal
	S →	NP VP		[S, 0, 5]
	VP→	PP VP		
	VP→	V AUX		
	PP →	NP P		
	NP →	*hamd ansary*		
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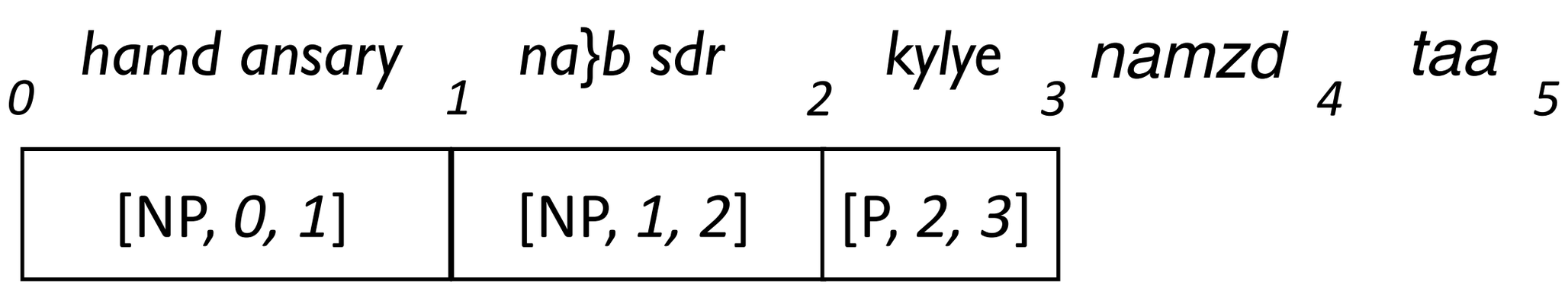


Axioms

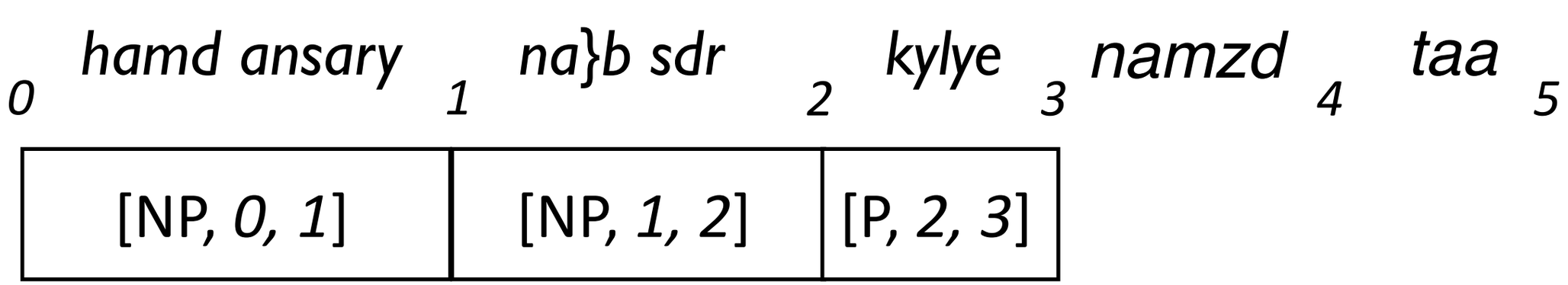
S → NP VP
VP→ PP VP
VP→ V AUX
PP → NP P
NP → *hamd ansary*
NP → *na}b sdr*
V → *namzd*
P → *kylye*
AUX → *taa*

Inference rule used

$$\frac{V \rightarrow namzd_4}{[V, 3, 4]}$$

Goal

[S, 0, 5]



Axioms

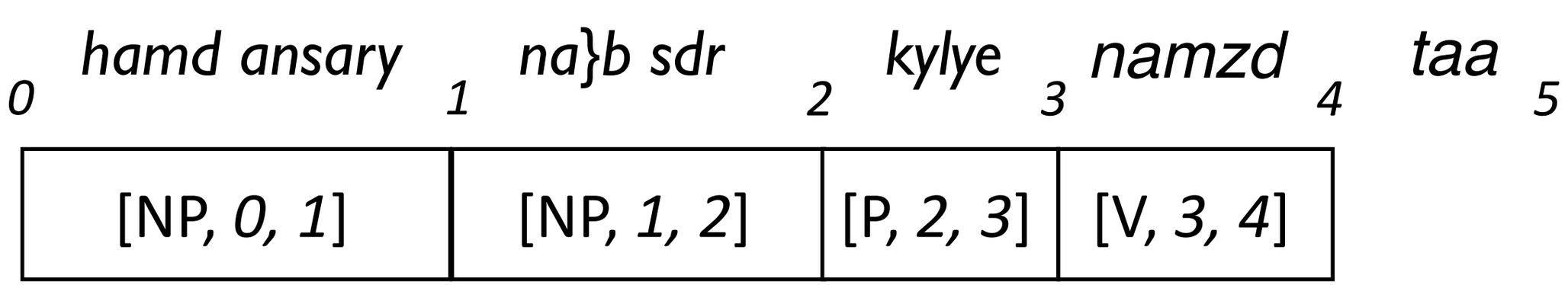
S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{V \rightarrow namzd_4}{[V, 3, 4]}$$

Goal

[S, 0, 5]



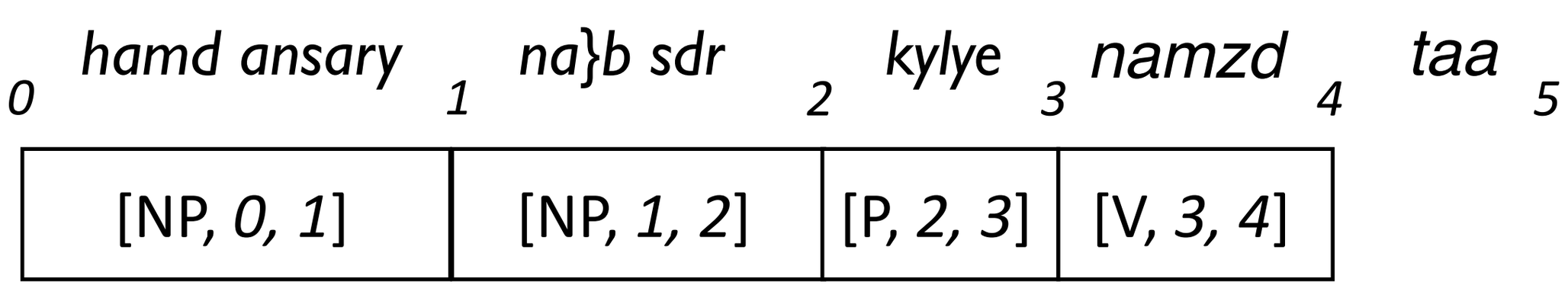
Axioms

S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

Goal

[S, 0, 5]



Axioms

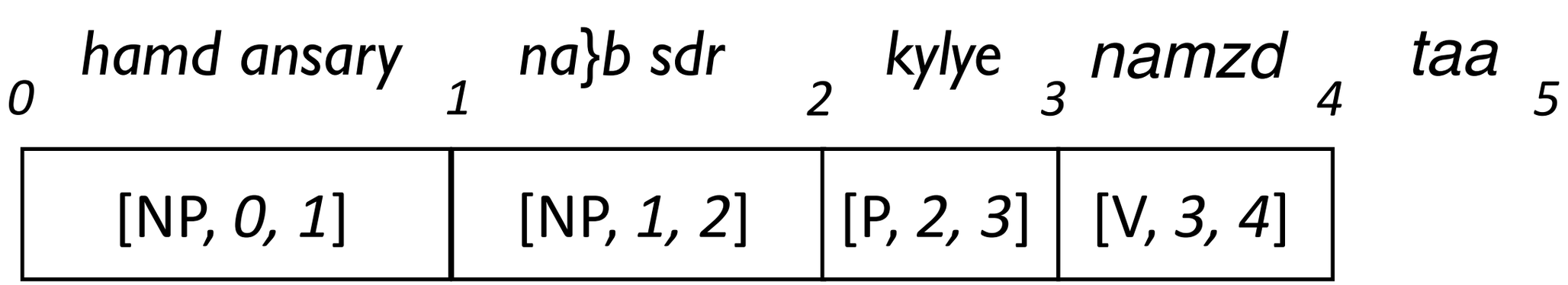
S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{AUX} \rightarrow \text{taa}_5}{[\text{AUX}, \textit{4}, \textit{5}]}$$

Goal

[S, 0, 5]



Axioms

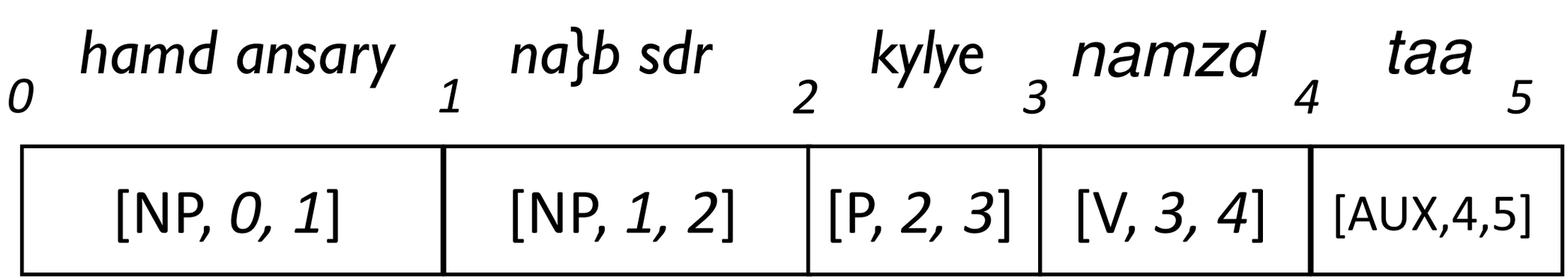
S →	NP VP
VP→	PP VP
VP→	V AUX
PP →	NP P
NP →	*hamd ansary*
NP →	*na}b sdr*
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

$$\frac{\text{AUX} \rightarrow \text{taa}_5}{[\text{AUX}, \textit{4}, \textit{5}]}$$

Goal

[S, 0, 5]



Axioms		**Inference rule used**	**Goal**
S →	NP VP		[S, 0, 5]
VP→	PP VP		
VP→	V AUX		
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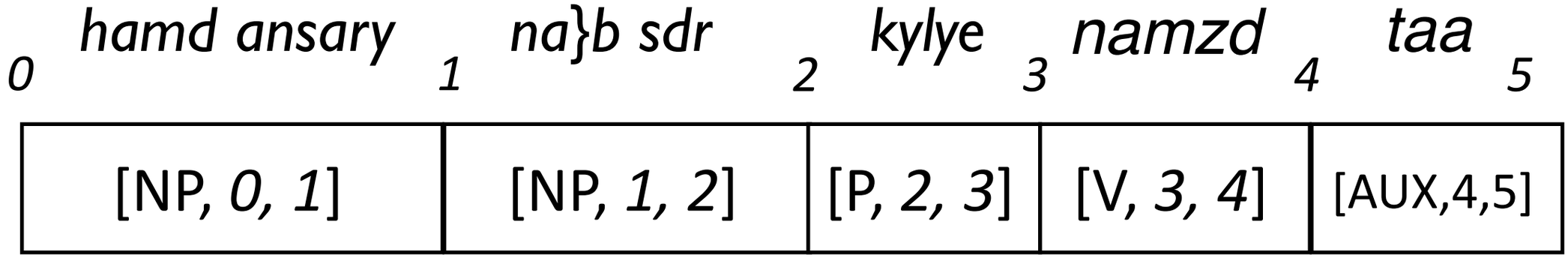

Axioms		**Inference rule used**	**Goal**
S →	NP VP		[S, 0, 5]
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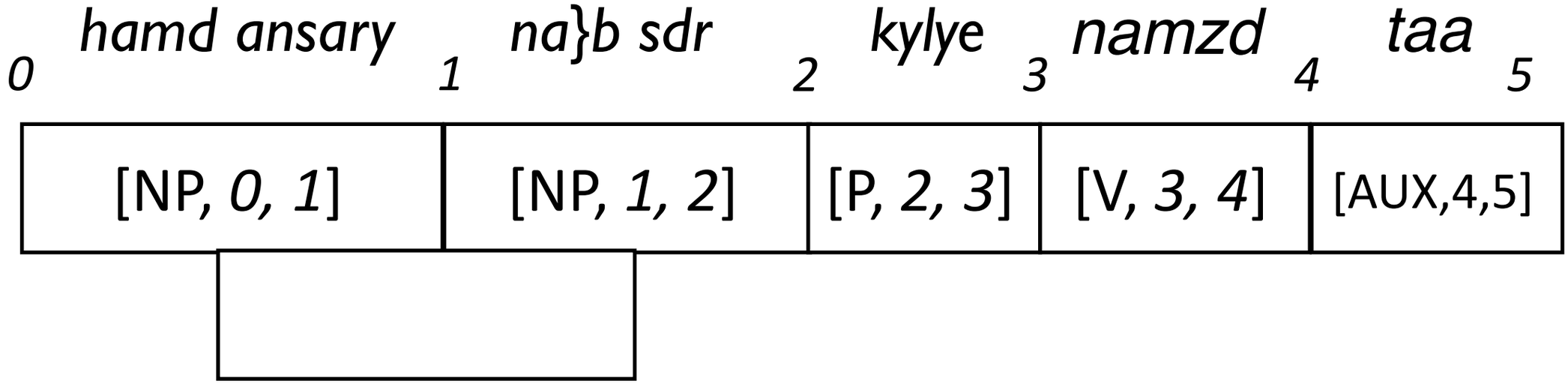

Axioms

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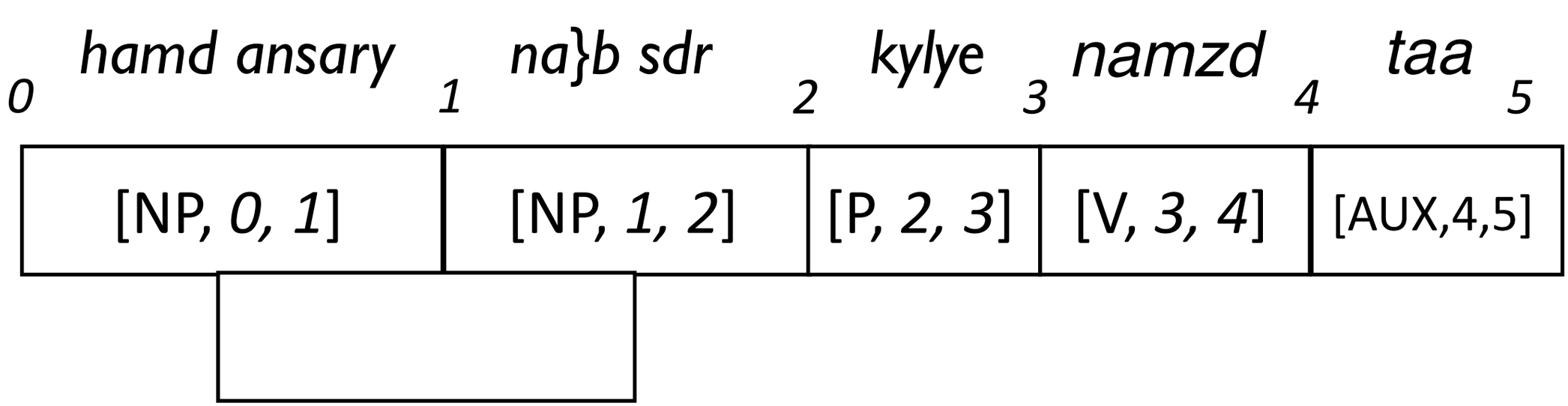
AUX → *taa*

Inference rule used

$$\frac{[NP, \mathit{1}, \mathit{2}]\ \ [P, \mathit{2}, \mathit{3}]\ \ PP \rightarrow NP\ P}{[PP, \mathit{1}, \mathit{3}]}$$

Goal

[S, 0, 5]



Axioms

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NP → *na}b sdr*
V → *namzd*
P → *kylye*
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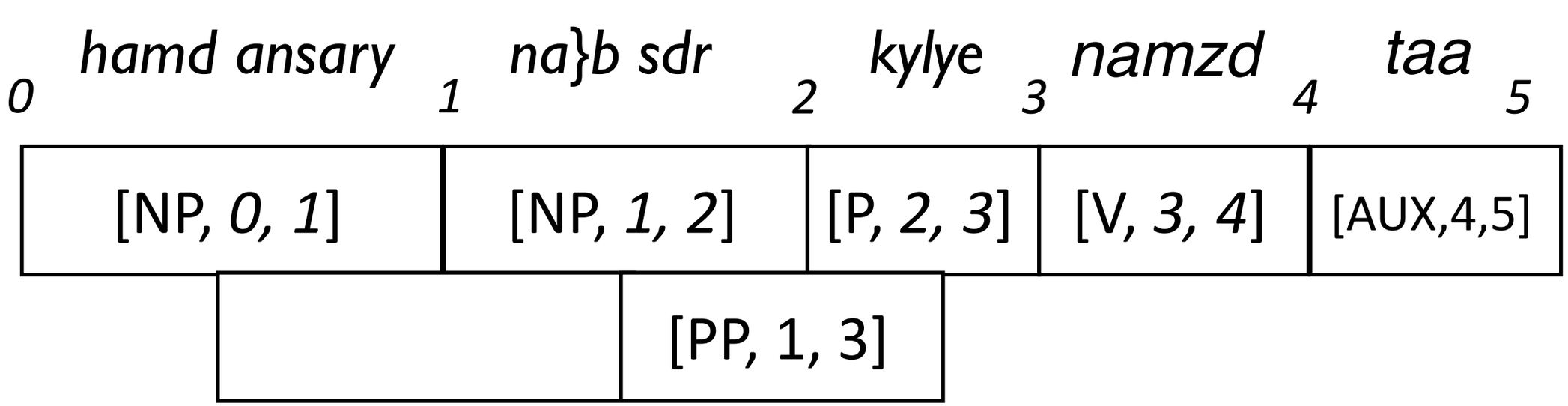
Inference rule used

$$\frac{[NP, \mathit{1}, \mathit{2}]\ \ [P, \mathit{2}, \mathit{3}]\ \ PP \rightarrow NP\ P}{[PP, \mathit{1}, \mathit{3}]}$$

Goal

[S, 0, 5]



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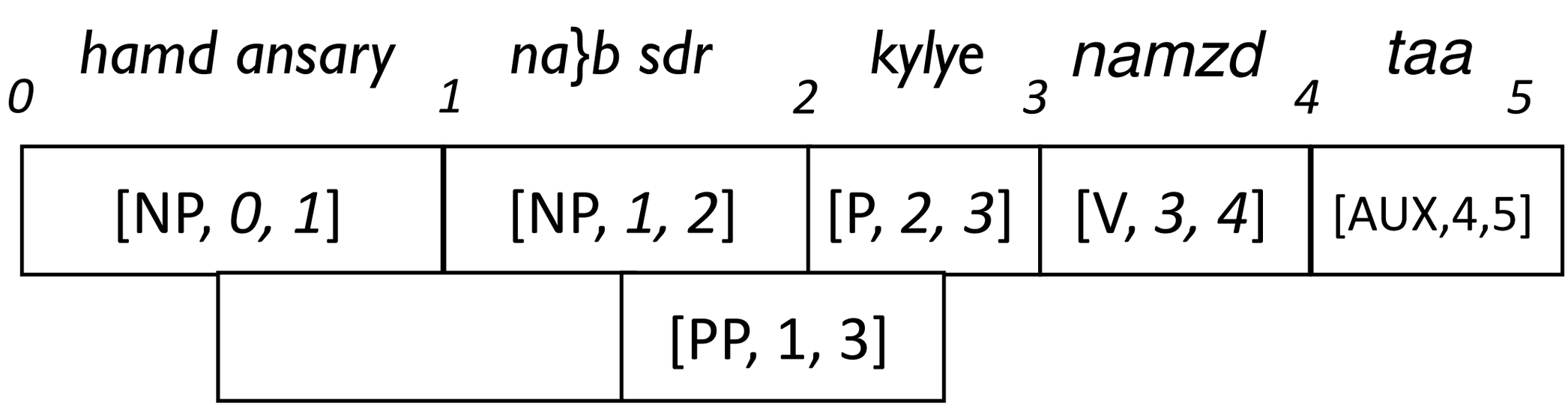
Inference rule used

Goal

[S, 0, 5]



Axioms

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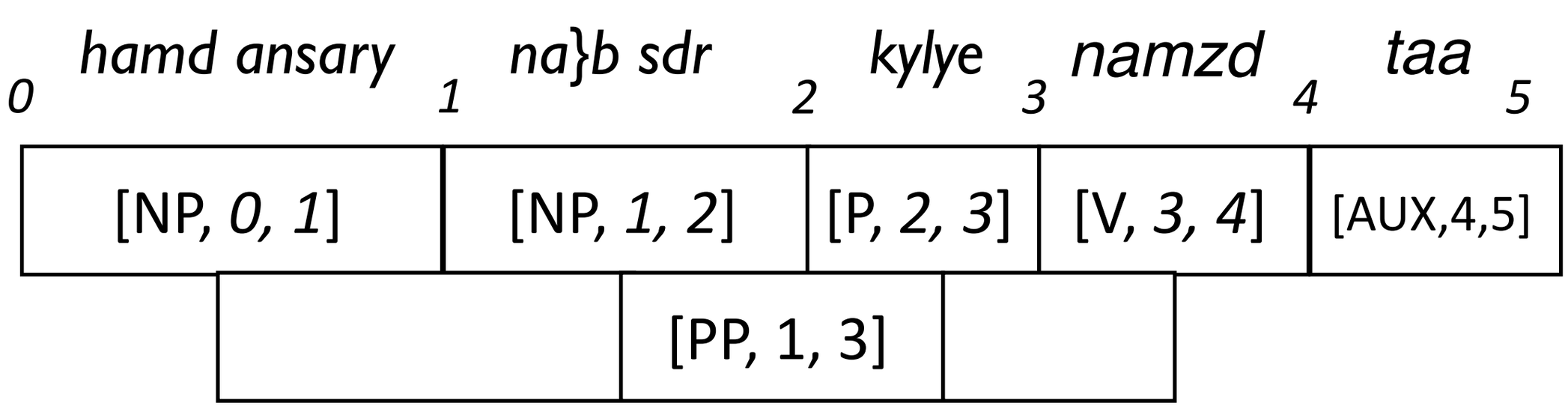
Inference rule used

Goal

[S, 0, 5]



Axioms

S → NP VP
VP→ PP VP
VP→ V AUX
PP → NP P
NP → *hamd ansary*
NP → *na}b sdr*
V → *namzd*
P → *kylye*
AUX → *taa*

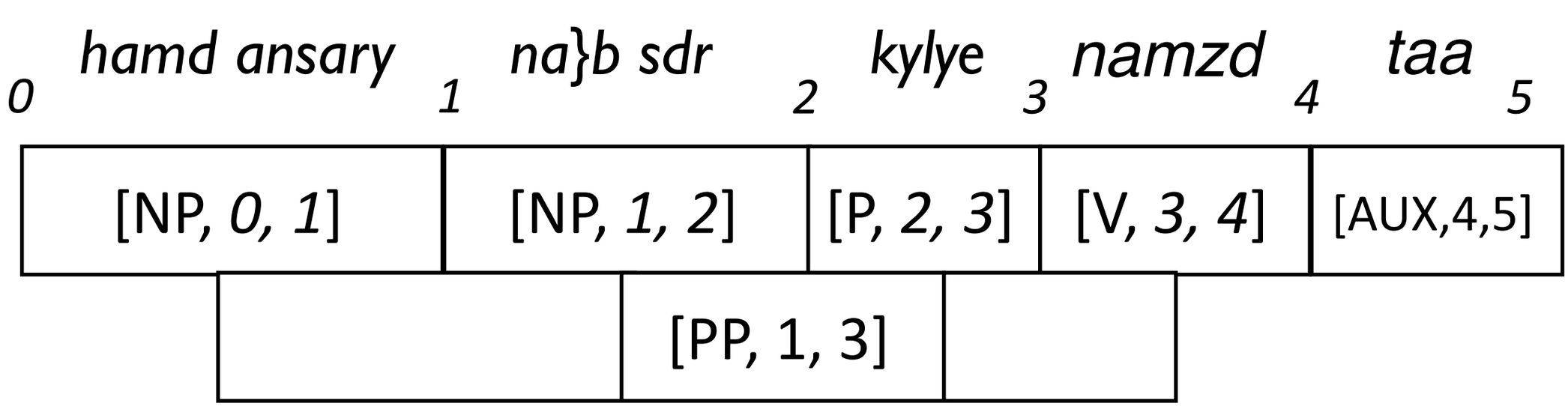
Inference rule used

[V, *3, 4*] [AUX, *4, 5*] VP → V AUX

[VP, *3, 5*]

Goal

[S, 0, 5]



Axioms

S →	NP VP	
VP→	PP VP	
VP→	V AUX	
PP →	NP P	
NP →	*hamd ansary*	
NP →	*na}b sdr*	
V →	*namzd*	
P →	*kylye*	
AUX →	*taa*	

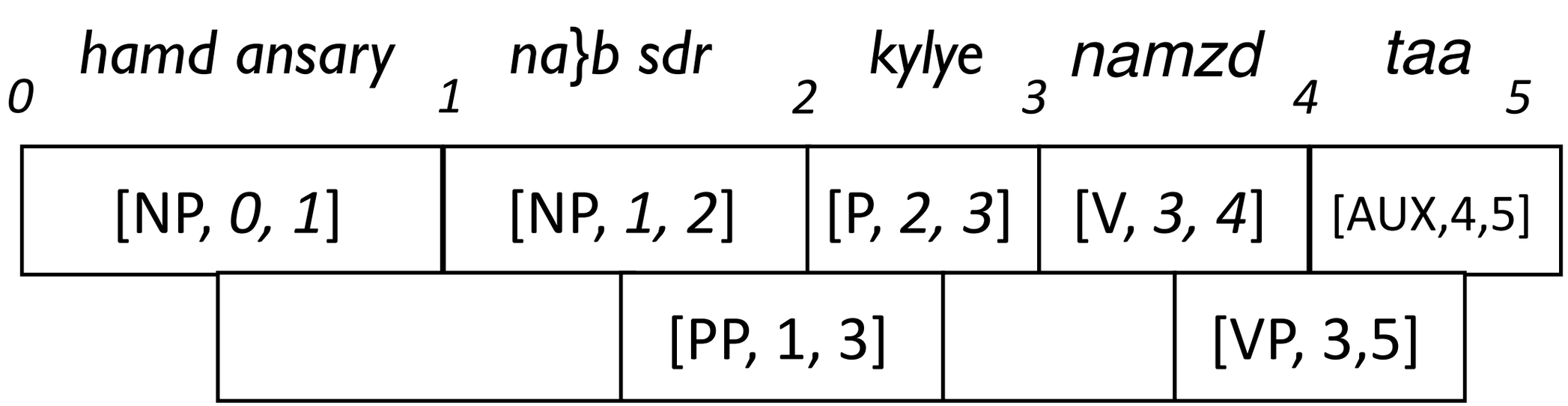
Inference rule used

[V, *3, 4*] [AUX, *4, 5*] VP → V AUX

[VP, *3, 5*]

Goal

[S, 0, 5]



Axioms			**Inference rule used**	**Goal**
	S →	NP VP		[S, 0, 5]
	VP→	PP VP		
	VP→	V AUX		
	PP →	NP P		
	NP →	*hamd ansary*		
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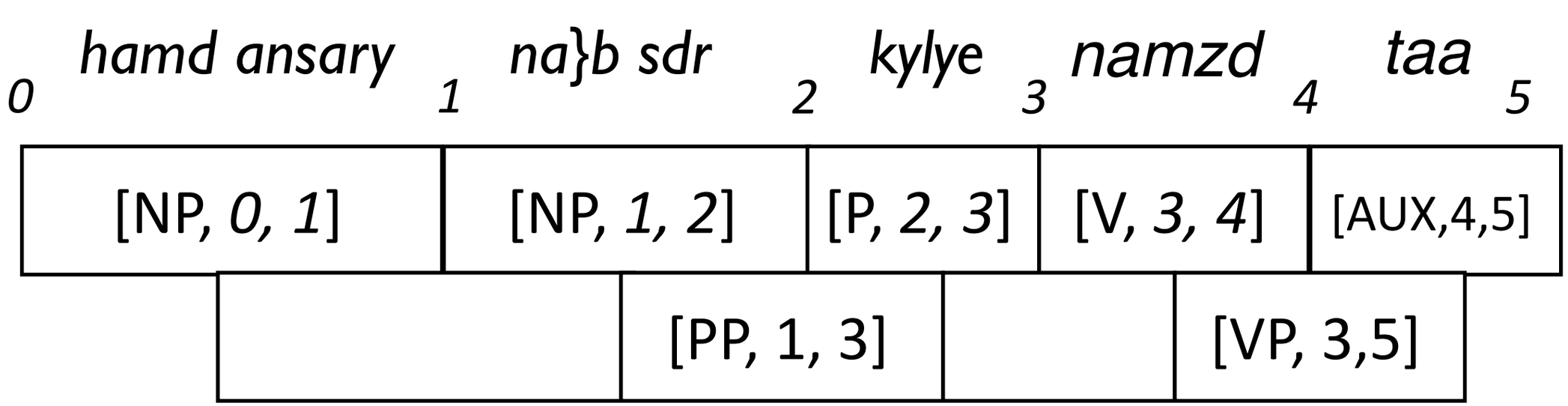

Axioms

S →	NP VP
VP→	PP VP
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PP →	NP P
NP →	*hamd ansary*
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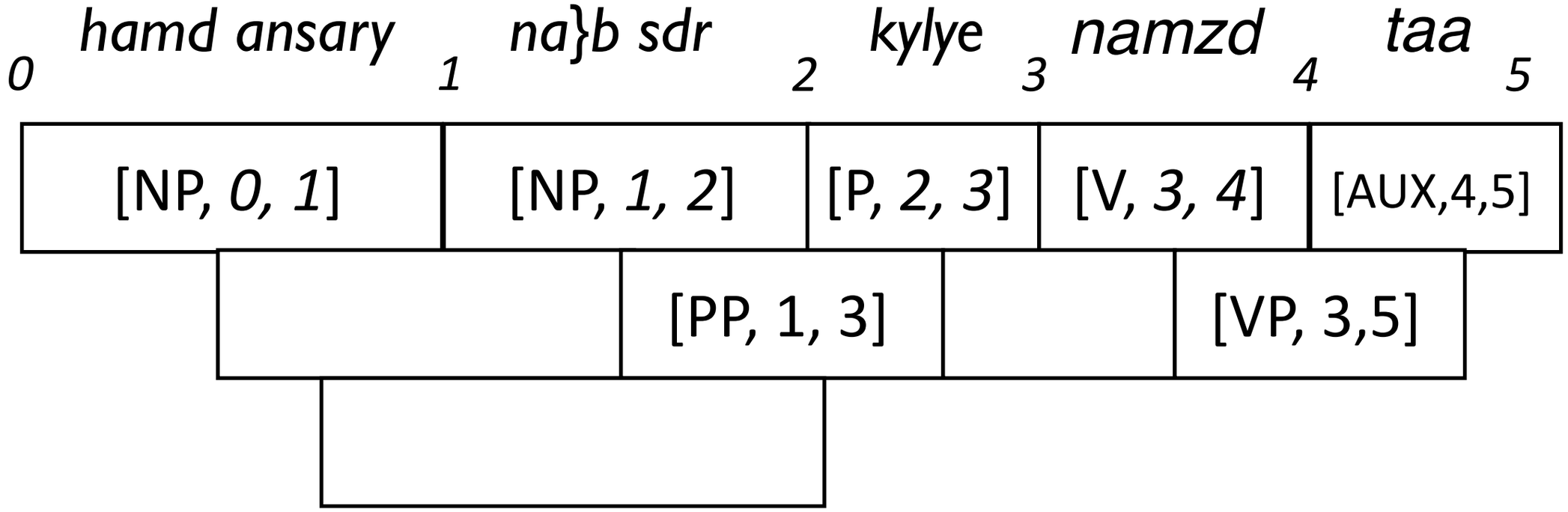
V →	*namzd*
P →	*kylye*
AUX →	*taa*

Inference rule used

Goal

[S, 0, 5]



Axioms

S → NP VP
VP→ PP VP
VP→ V AUX
PP → NP P
NP → *hamd ansary*
NP → *na}b sdr*
V → *namzd*
P → *kylye*
AUX → *taa*

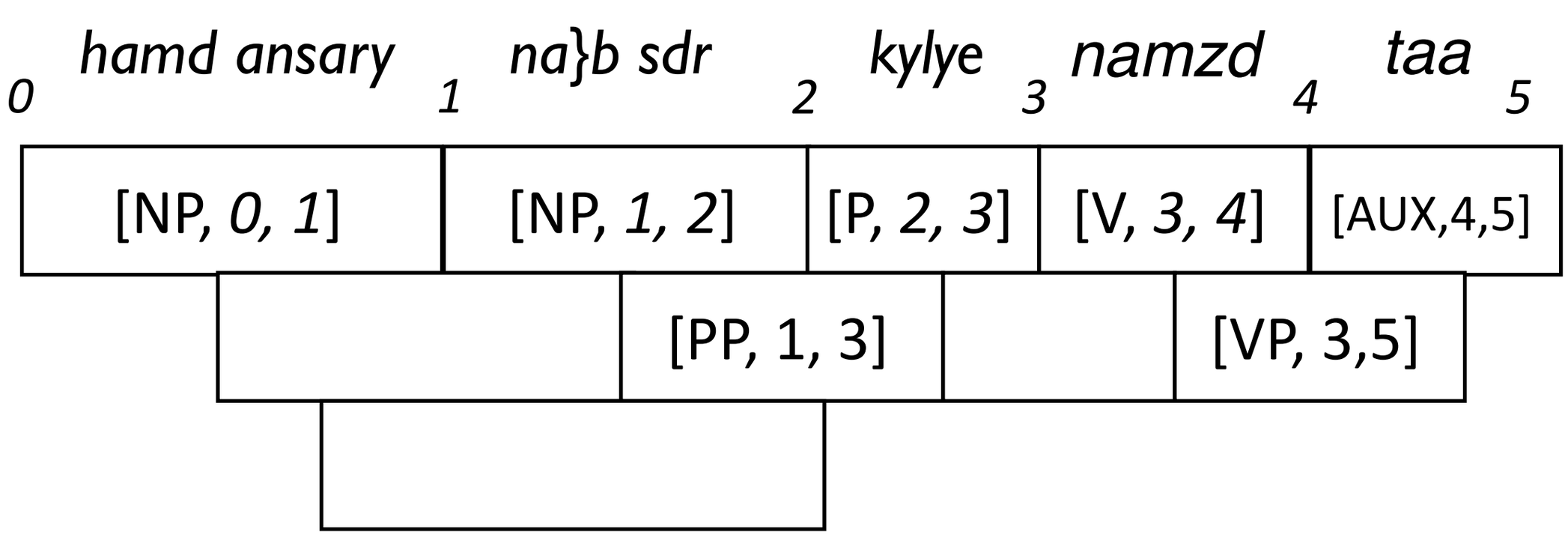
Inference rule used

[PP, *1, 3*] [VP, *3, 5*] VP → PP CP

[VP, *1, 5*]

Goal

[S, 0, 5]



Axioms

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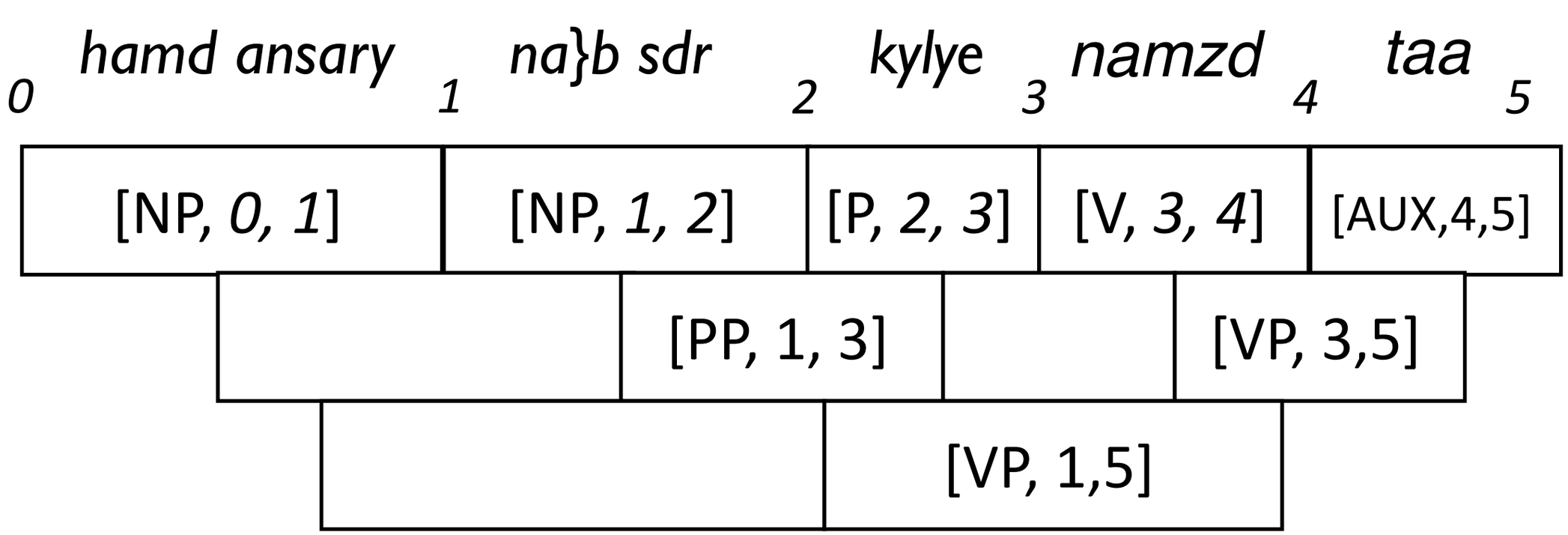
VP→ PP VP
VP→ V AUX
PP → NP P
NP → *hamd ansary*
NP → *na}b sdr*
V → *namzd*
P → *kylye*
AUX → *taa*

Inference rule used

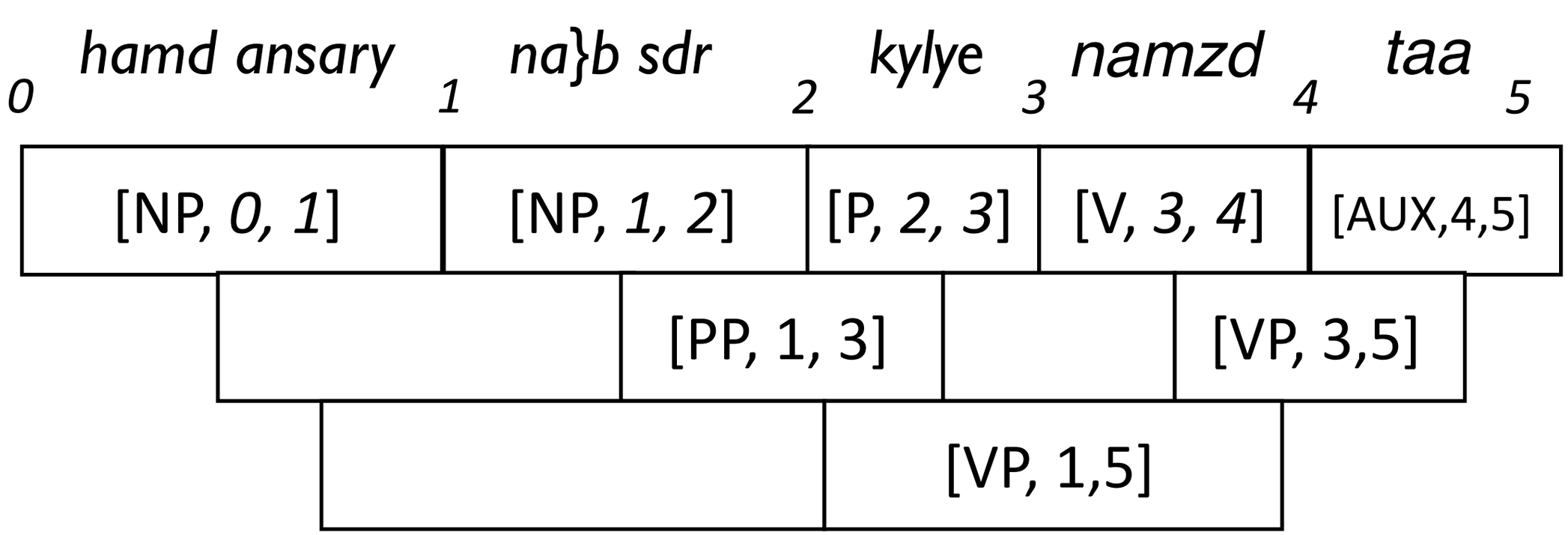
$$\frac{[PP, \textit{1}, \textit{3}]\ \ [VP, \textit{3}, \textit{5}]\ \ VP \rightarrow PP\ CP}{[VP, \textit{1}, \textit{5}]}$$

Goal

[S, 0, 5]



Axioms			Inference rule used	Goal
	S →	NP VP		[S, 0, 5]
	VP→	PP VP		
	VP→	V AUX		
	PP →	NP P		
	NP →	*hamd ansary*		
	NP →	*na}b sdr*		
	V →	*namzd*		
	P →	*kylye*		
	AUX →	*taa*		



Axioms

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PP → NP P
NP → *hamd ansary*
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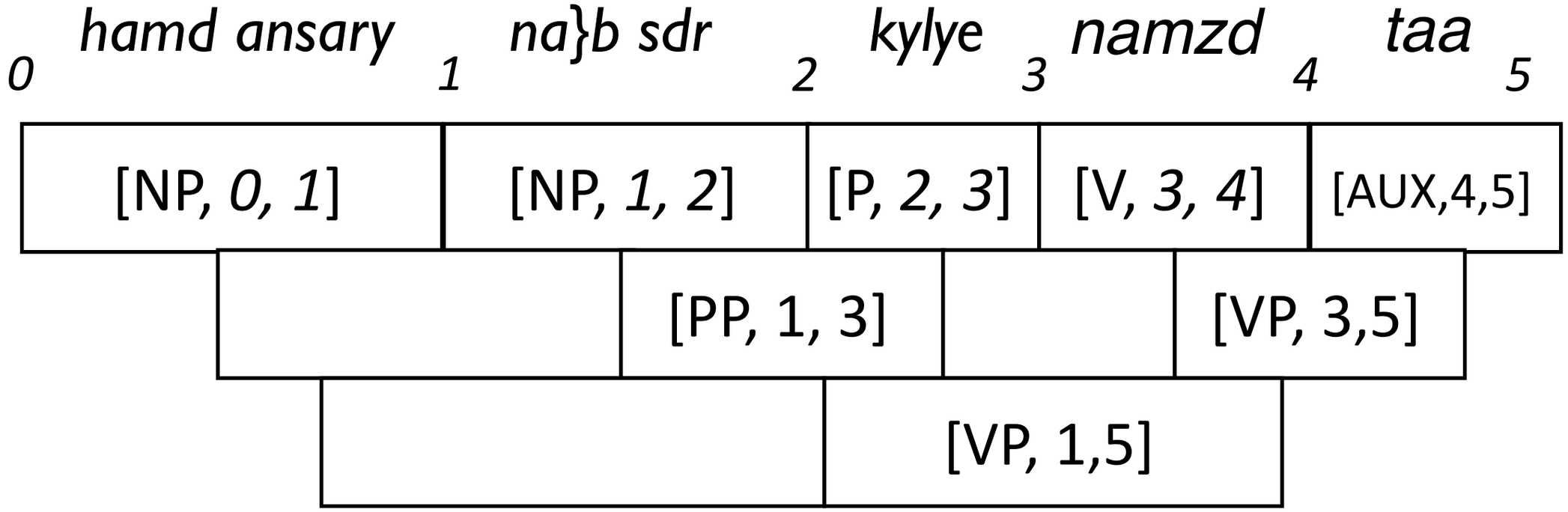
Inference rule used

$$\frac{[\text{NP}, \textit{0}, \textit{1}]\ \ [\text{VP}, \textit{1}, \textit{5}]\ \ \text{S} \rightarrow \text{NP VP}}{[\text{S}, \textit{0}, \textit{5}]}$$

Goal

[S, 0, 5]



Axioms

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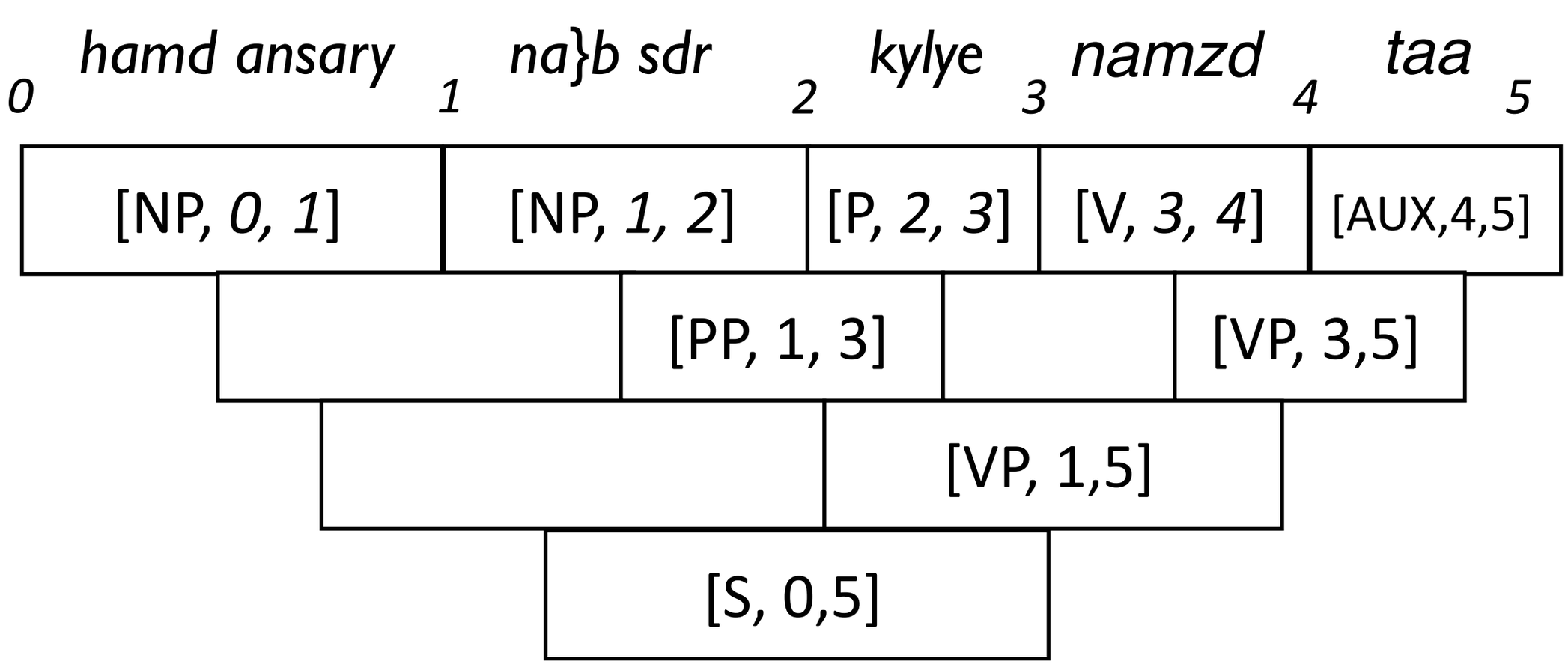
Goal

[S, 0, 5]



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S →	NP VP		[S, 0, 5]
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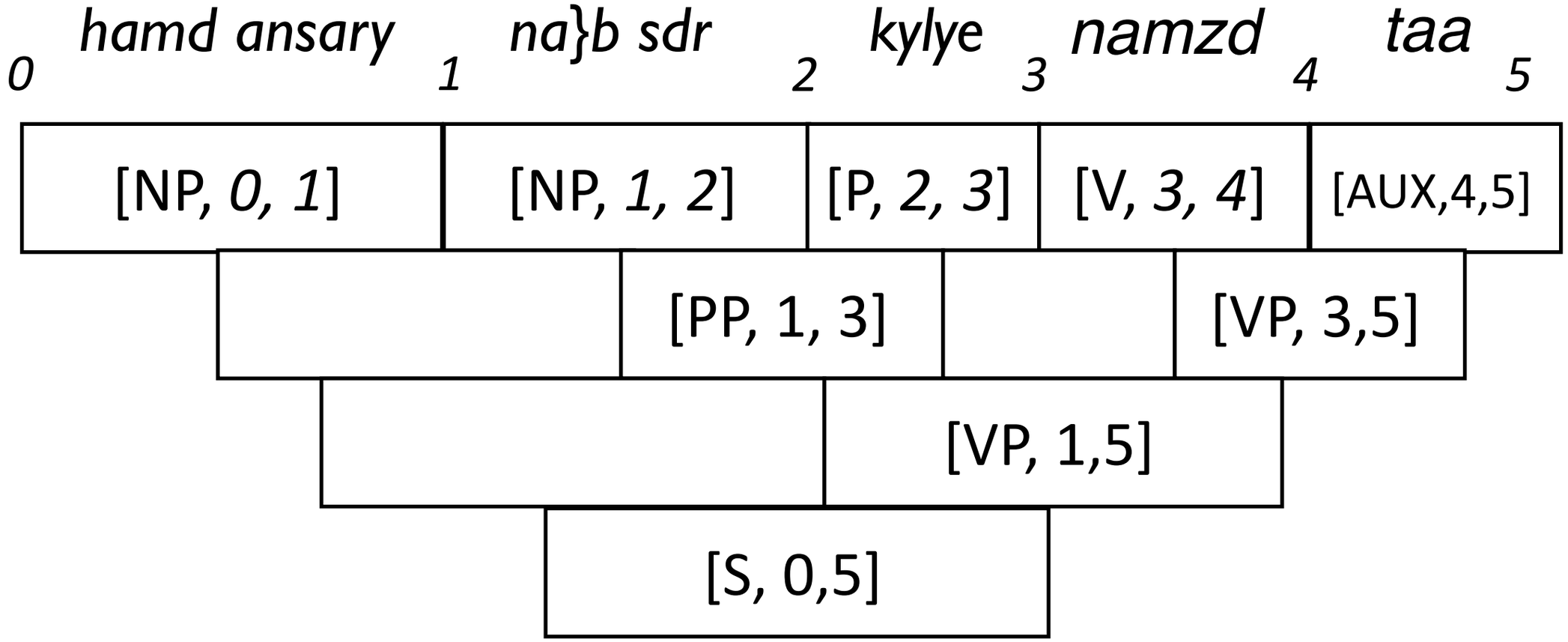

The CKY Parsing Algorithm

Axioms	$\dfrac{}{A \rightarrow \alpha}$	for all $(A \rightarrow \alpha) \in R$
Inference rules	$\dfrac{A}{[A, i, i+1]}$ $\dfrac{[B, i, j] \quad [C, j, k] \quad A \rightarrow BC}{[A, i, k]}$	
Goal	$[S, 0, n]$	

The CKY Translation Algorithm

Axioms	$\frac{}{\mathbf{A \rightarrow \alpha,\ \beta}}$	for all $(\mathbf{A \rightarrow \alpha,\ \beta}) \in R$
Inference rules	$\frac{A}{[A, i, i+1]}$ $\frac{[B, i, j] \quad [C, j, k] \quad A \rightarrow BC}{[A, i, k]}$	
Goal	$[S, 0, n]$	

Next week

- We now have
  - a formalism for describing the relationship between two languages,
  - an algorithm for producing translations
- Next week:

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- We now have
  - a formalism for describing the relationship between two languages,
  - an algorithm for producing translations
- Next week:
  - where do synchronous grammars come from?
  - how do we decode with an ngram integrated language model?