Hierarchical and Syntax-Based Translation

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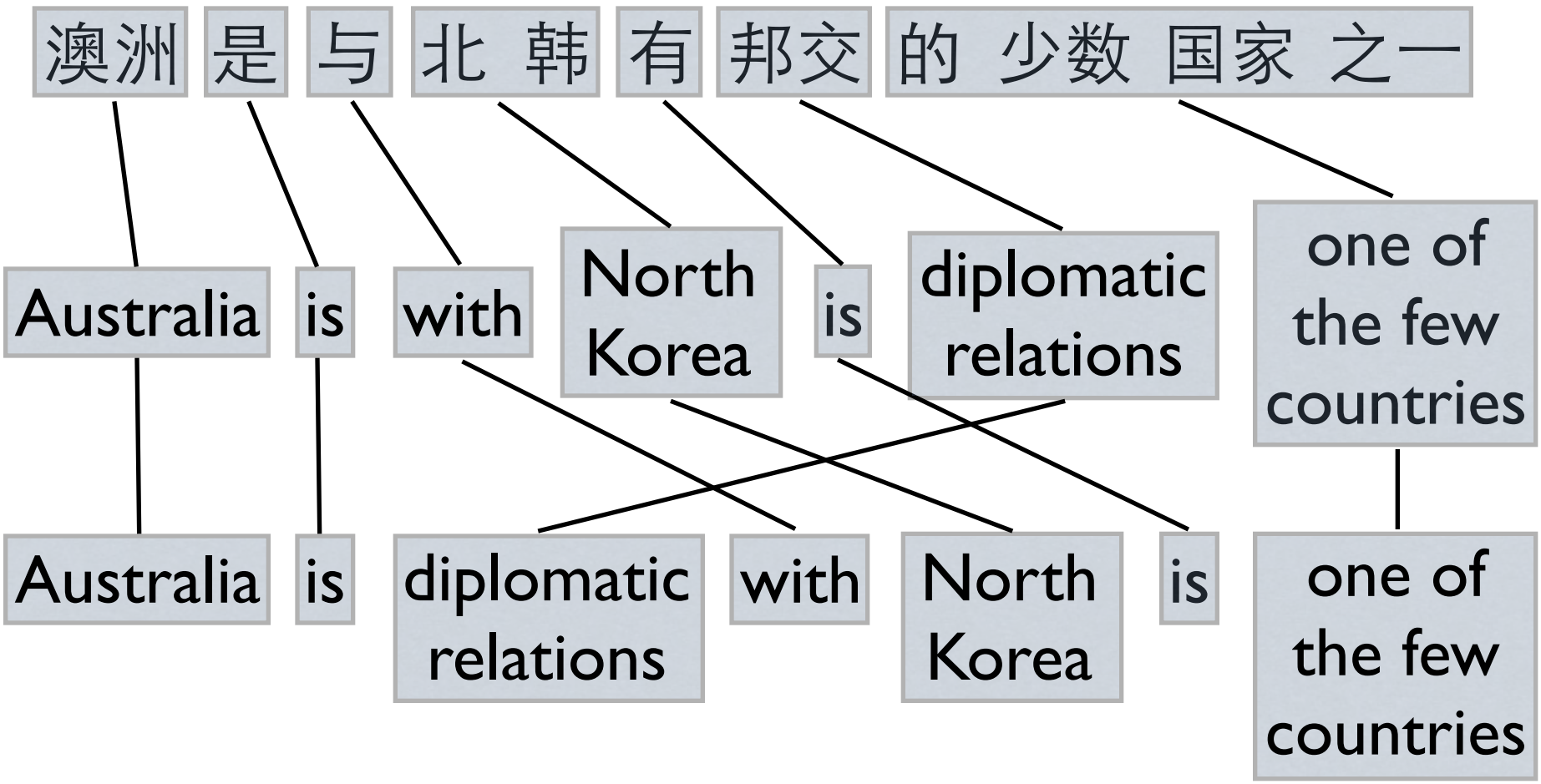
Word-based translation

澳洲 是 与 北 韩 有 邦交 的 少数 国家 之一

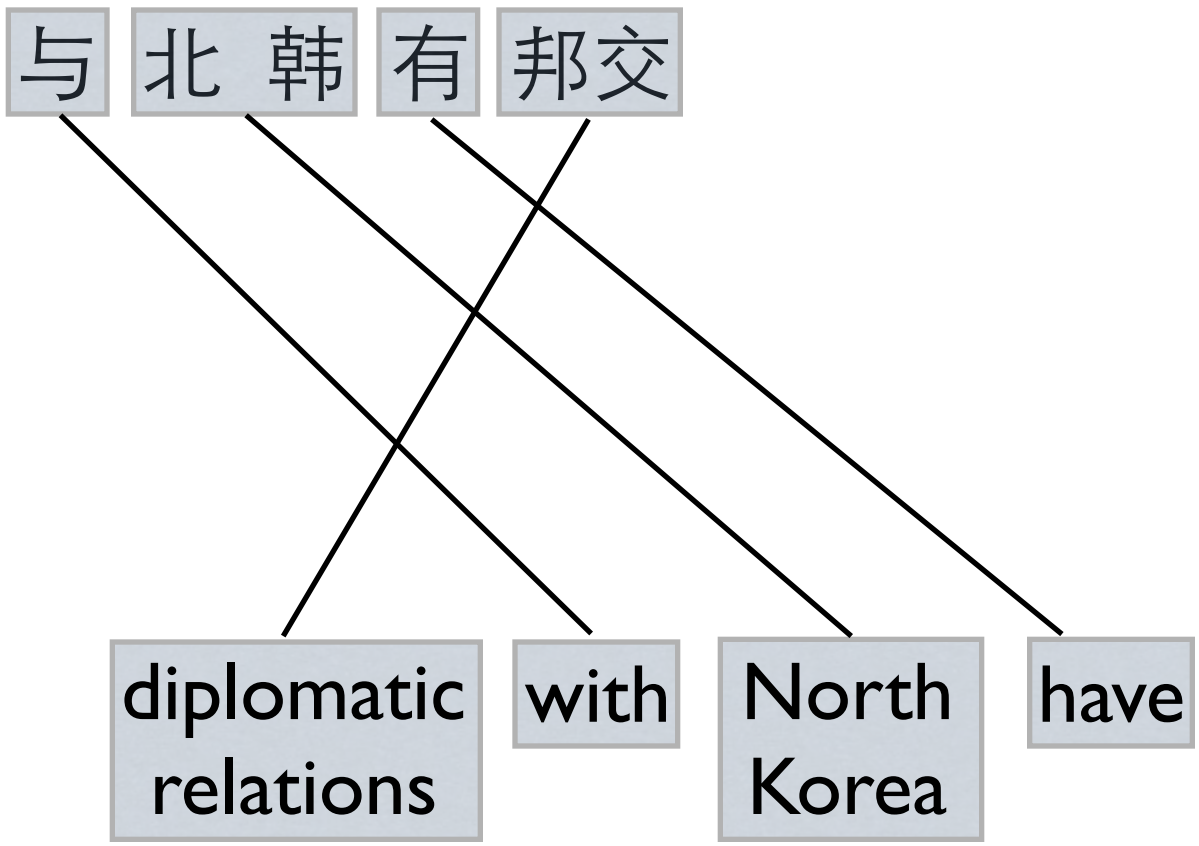
Australia is with North Korea have diplomatic relations that few countries one of

Human translation:
Australia is one of the few countries that have diplomatic relations with North Korea.

Phrase-based translation



Phrases of phrases



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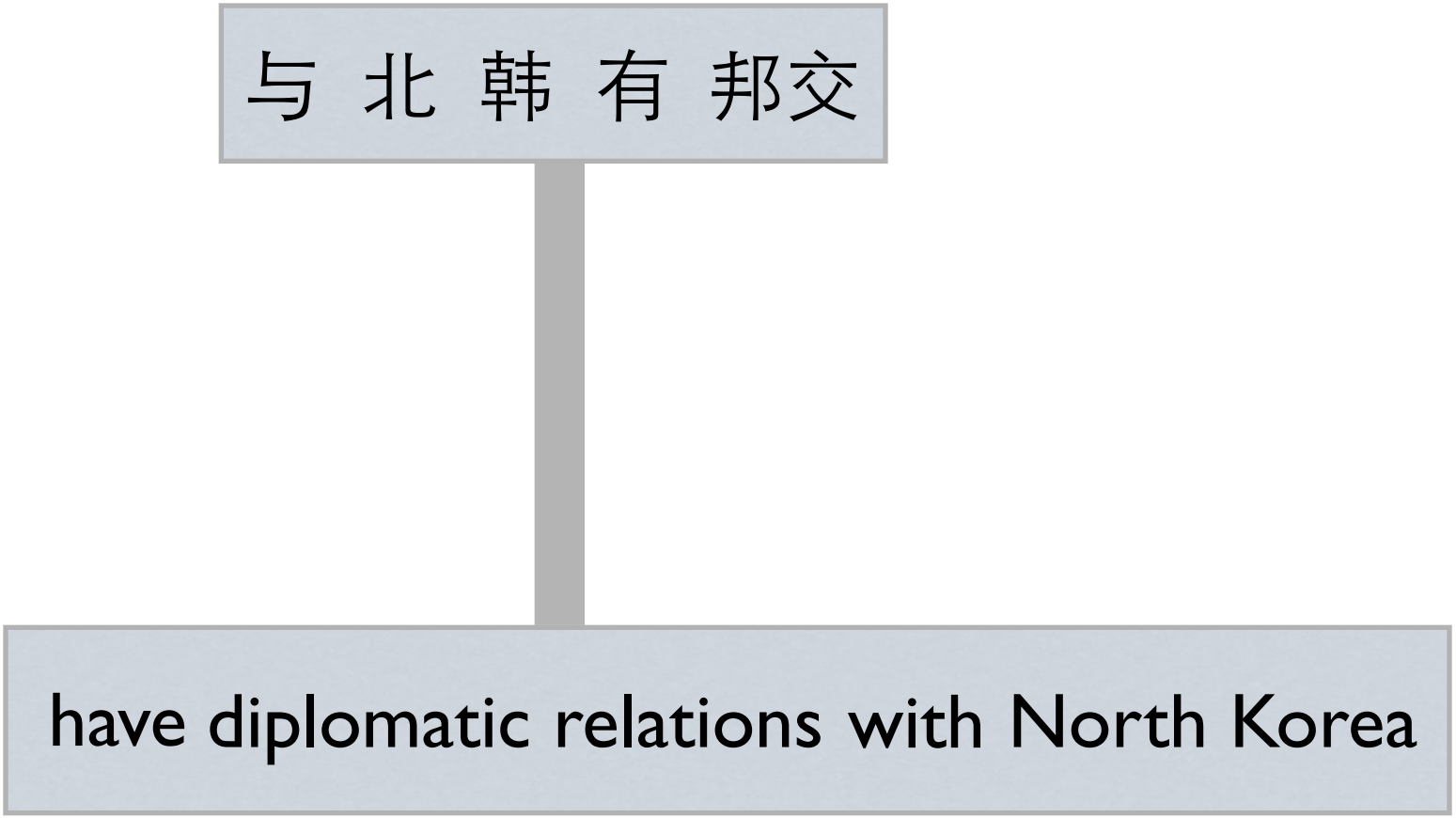
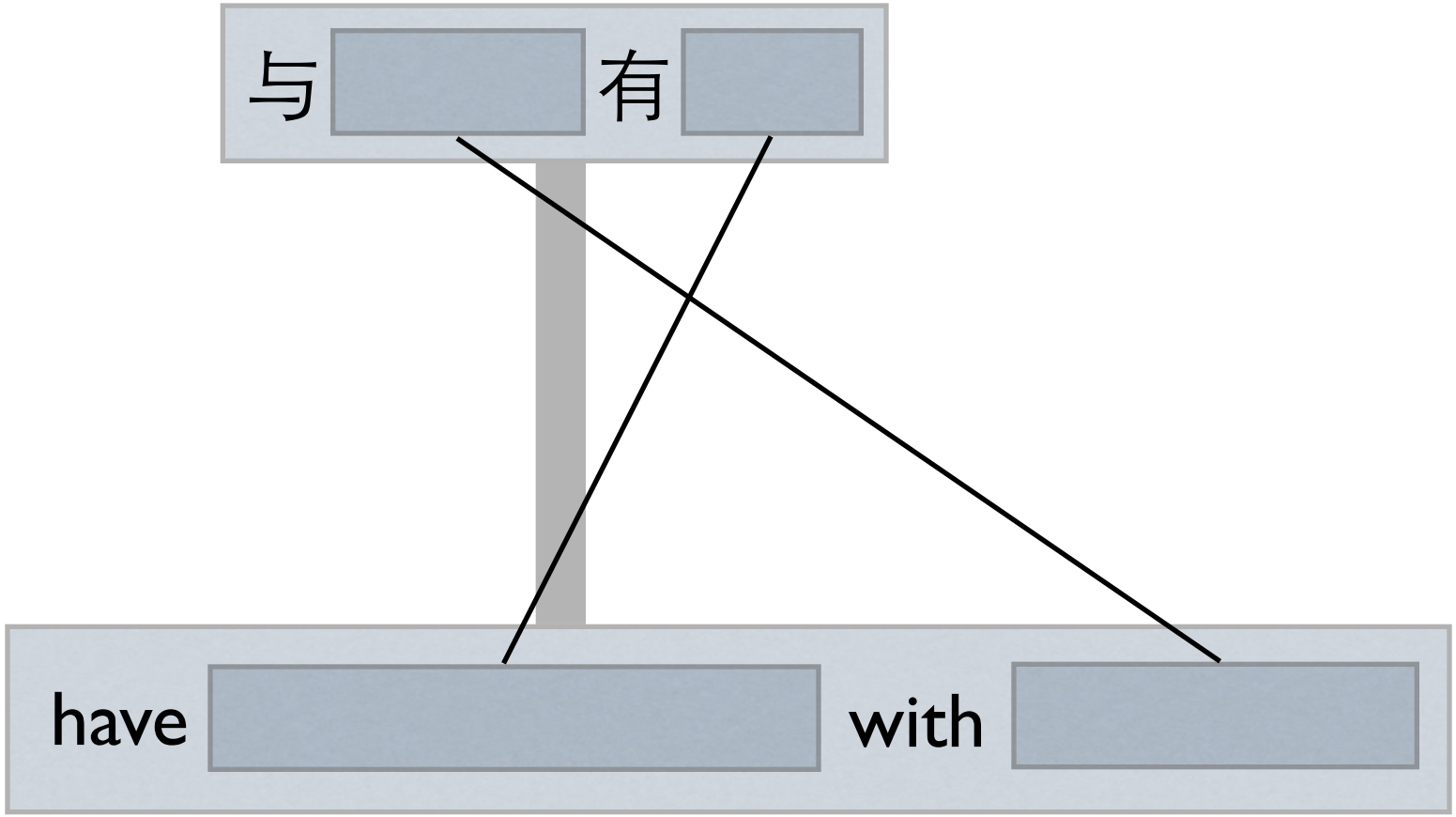
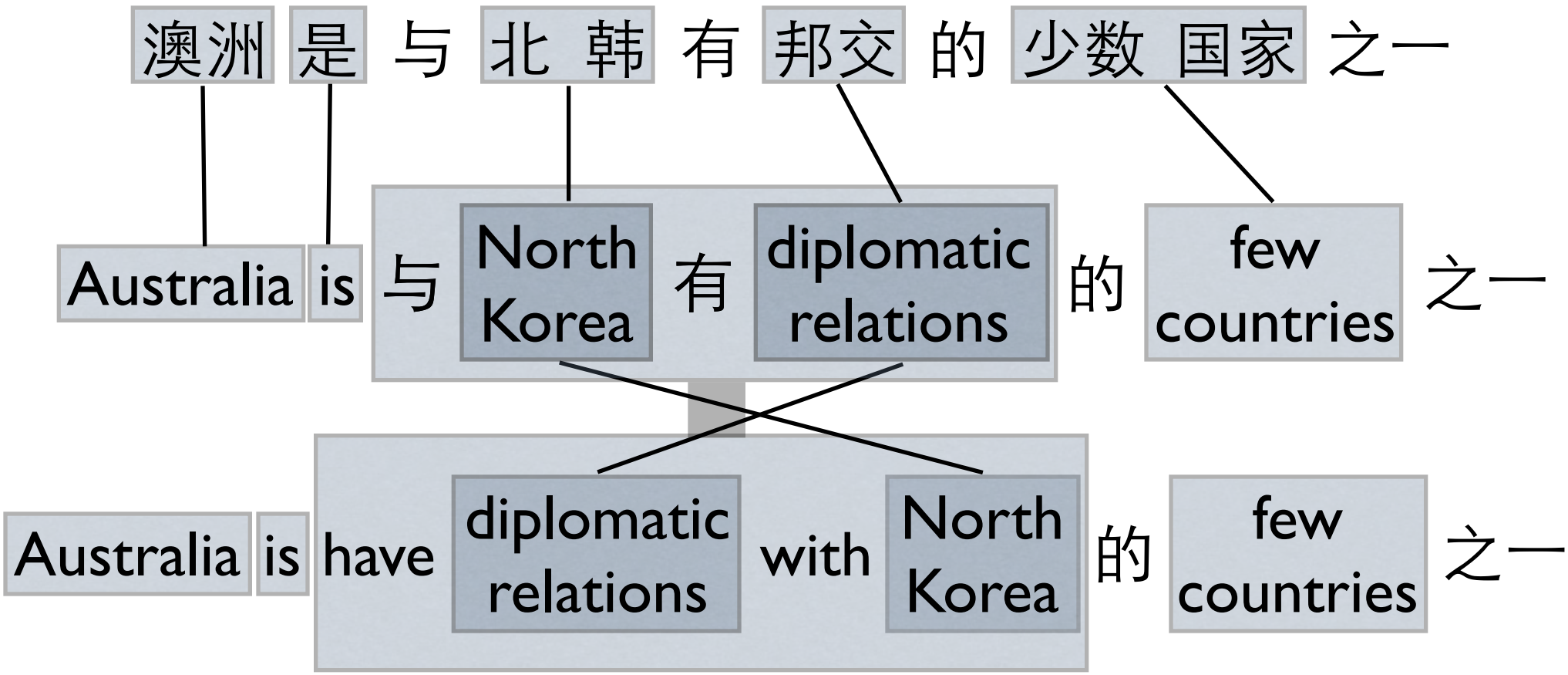


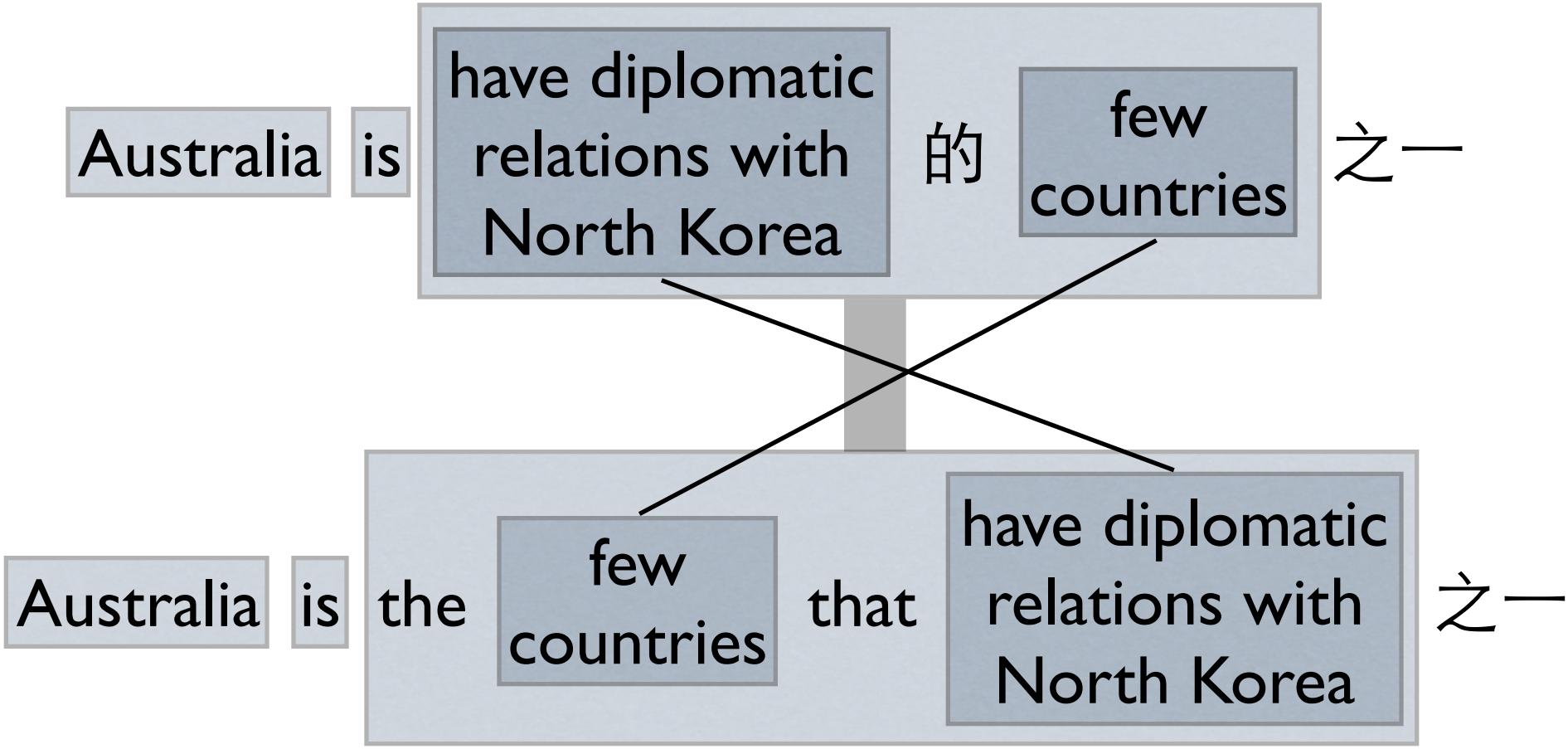
Phrases of phrases



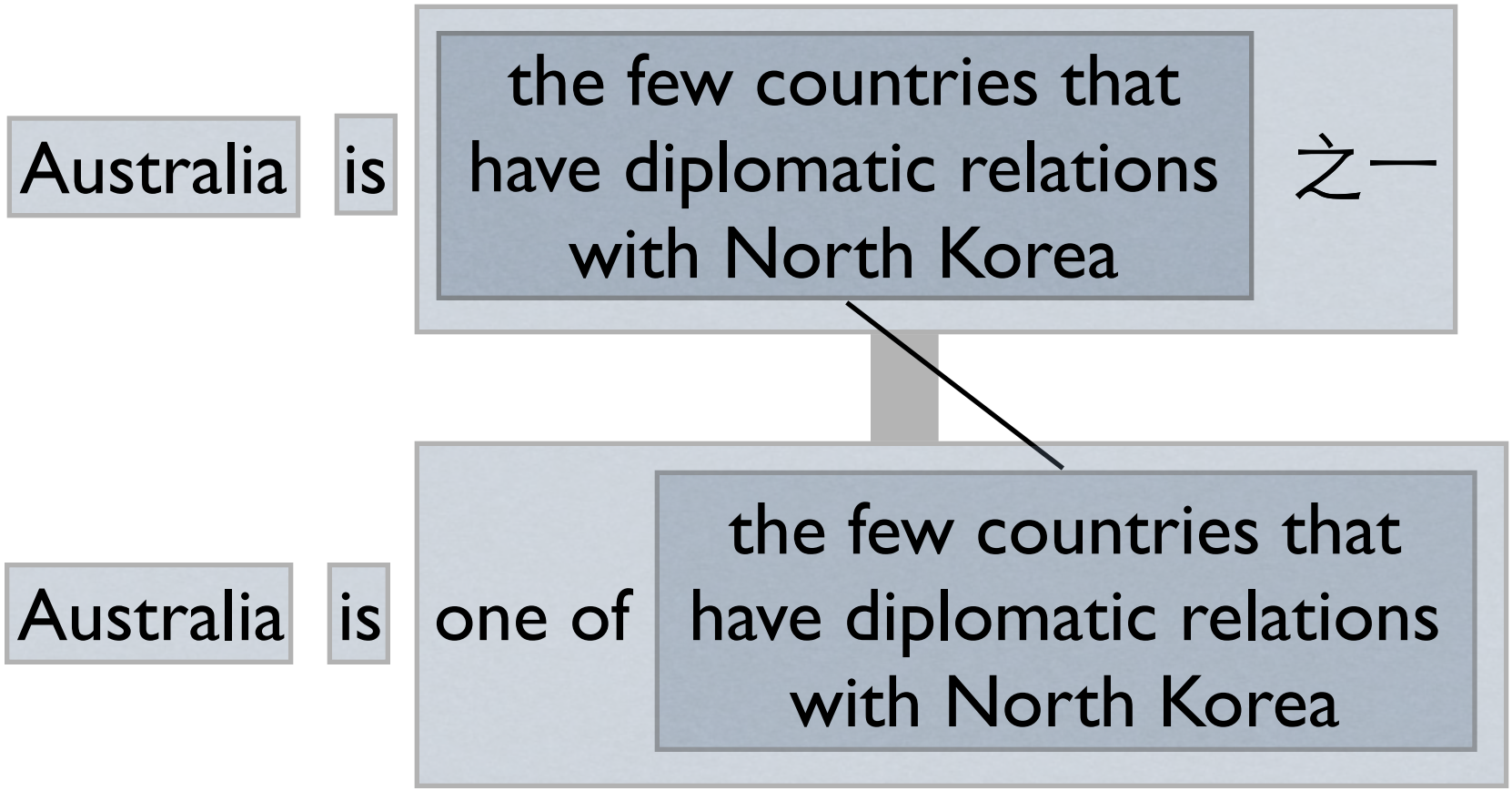
Hierarchical phrases



Hierarchical phrases



Hierarchical phrases



Definition

Context-free grammars

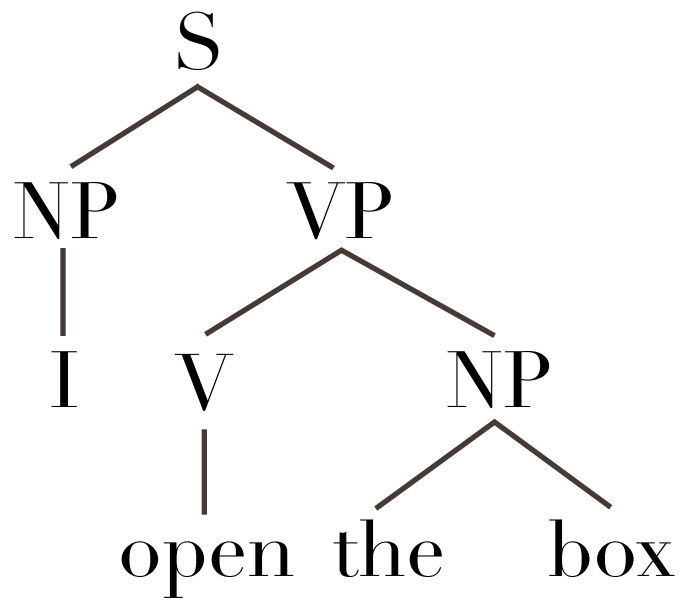
S → NP VP

NP → I

NP → the box

VP → V NP

V → open



Context-free grammars

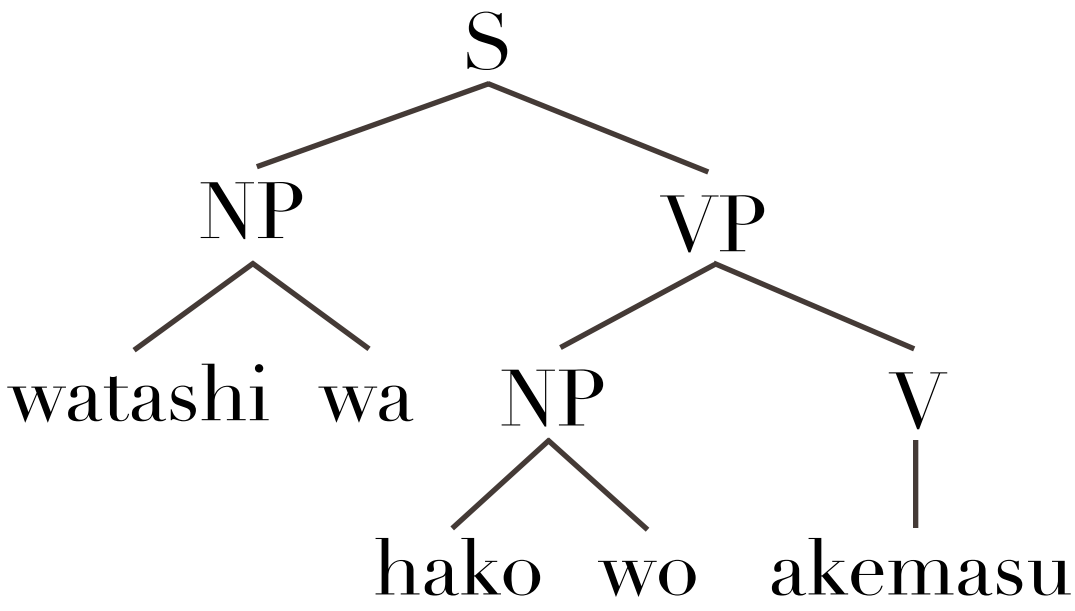
S → NP VP

NP → watashi wa

NP → hako wo

VP → NP V

V → akemasu



Synchronous CFGs

S → NP VP	S → NP VP
NP → I	NP → watashi wa
NP → the box	NP → hako wo
VP → V NP	VP → NP V
V → open	V → akemasu

Synchronous CFGs

$$S \rightarrow NP_1\, VP_2,\ NP_1\, VP_2$$

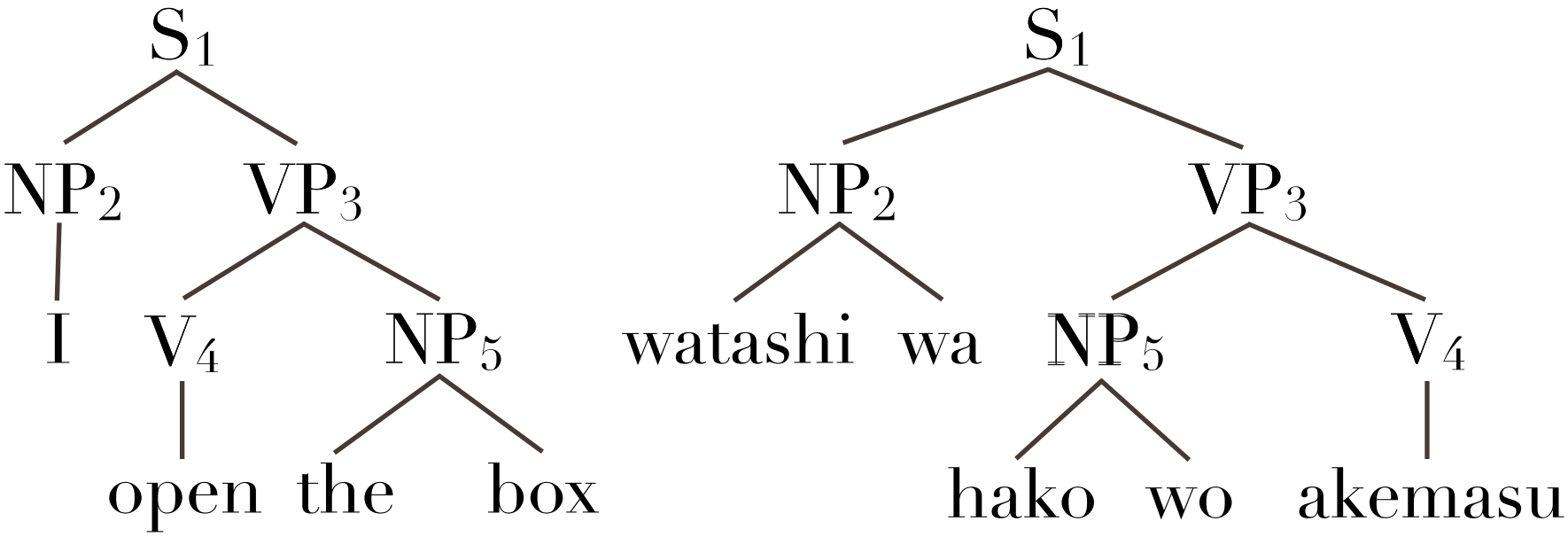
$$NP \rightarrow \text{I, watashi wa}$$

$$NP \rightarrow \text{the box, hako wo}$$

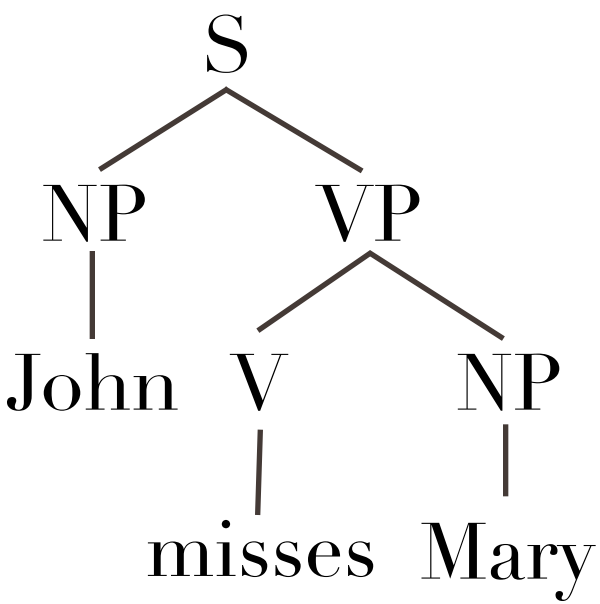
$$VP \rightarrow V_1\, NP_2,\ NP_2\, V_1$$

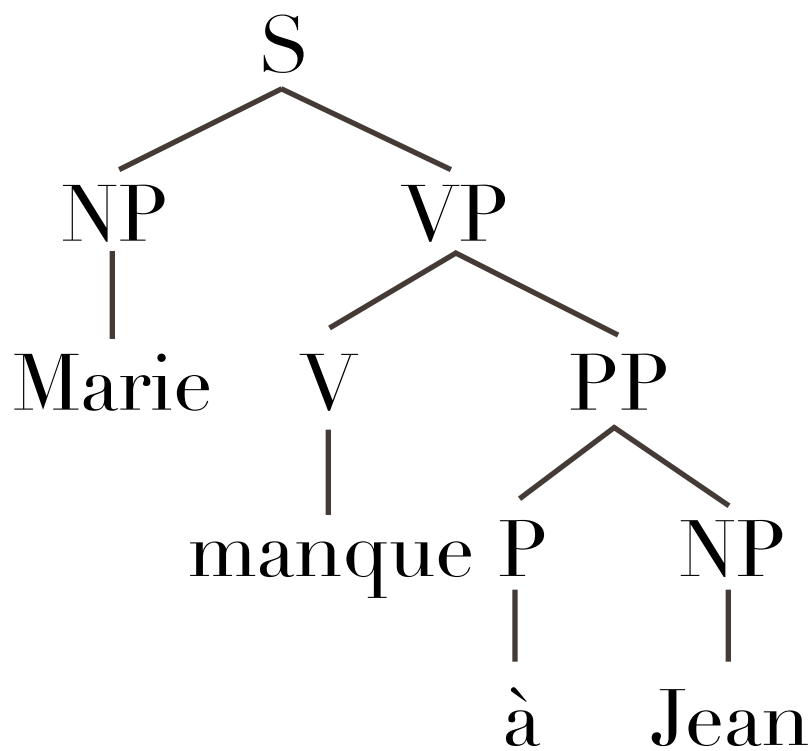
$$V \rightarrow \text{open, akemasu}$$

Synchronous CFGs

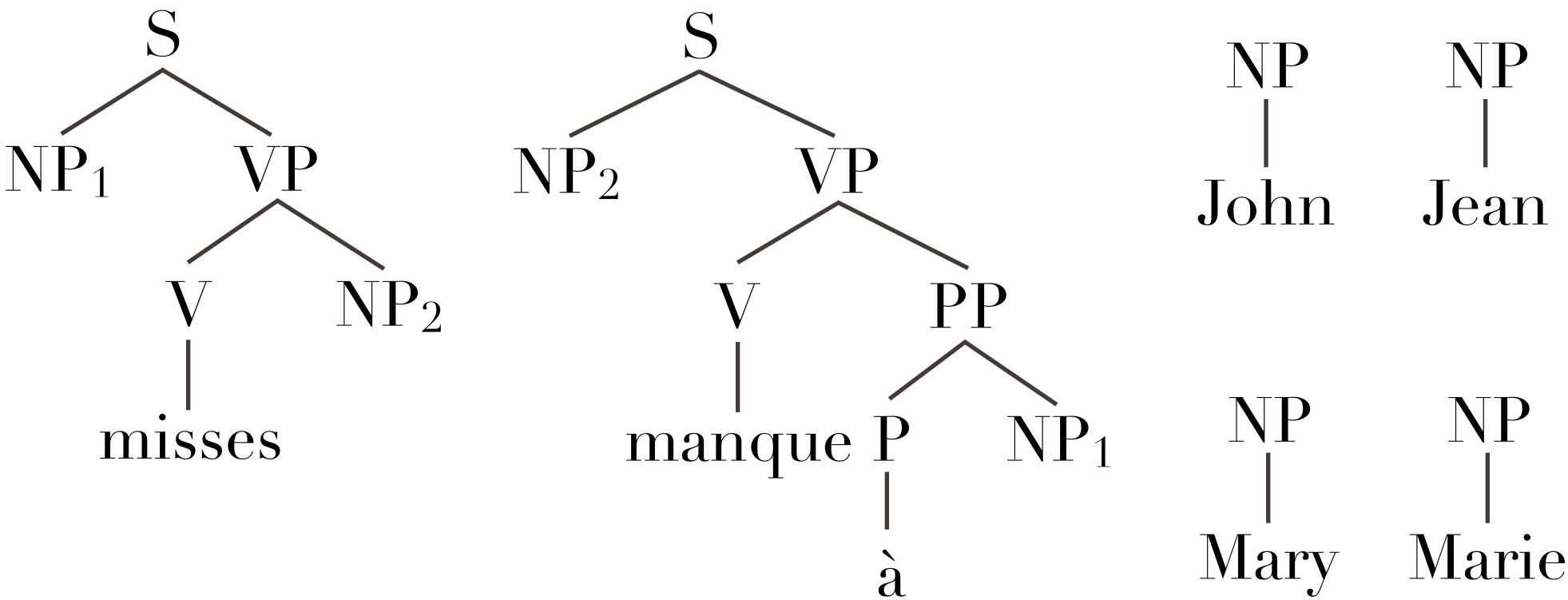


Limitations of synchronous CFGs





Synchronous tree substitution grammars



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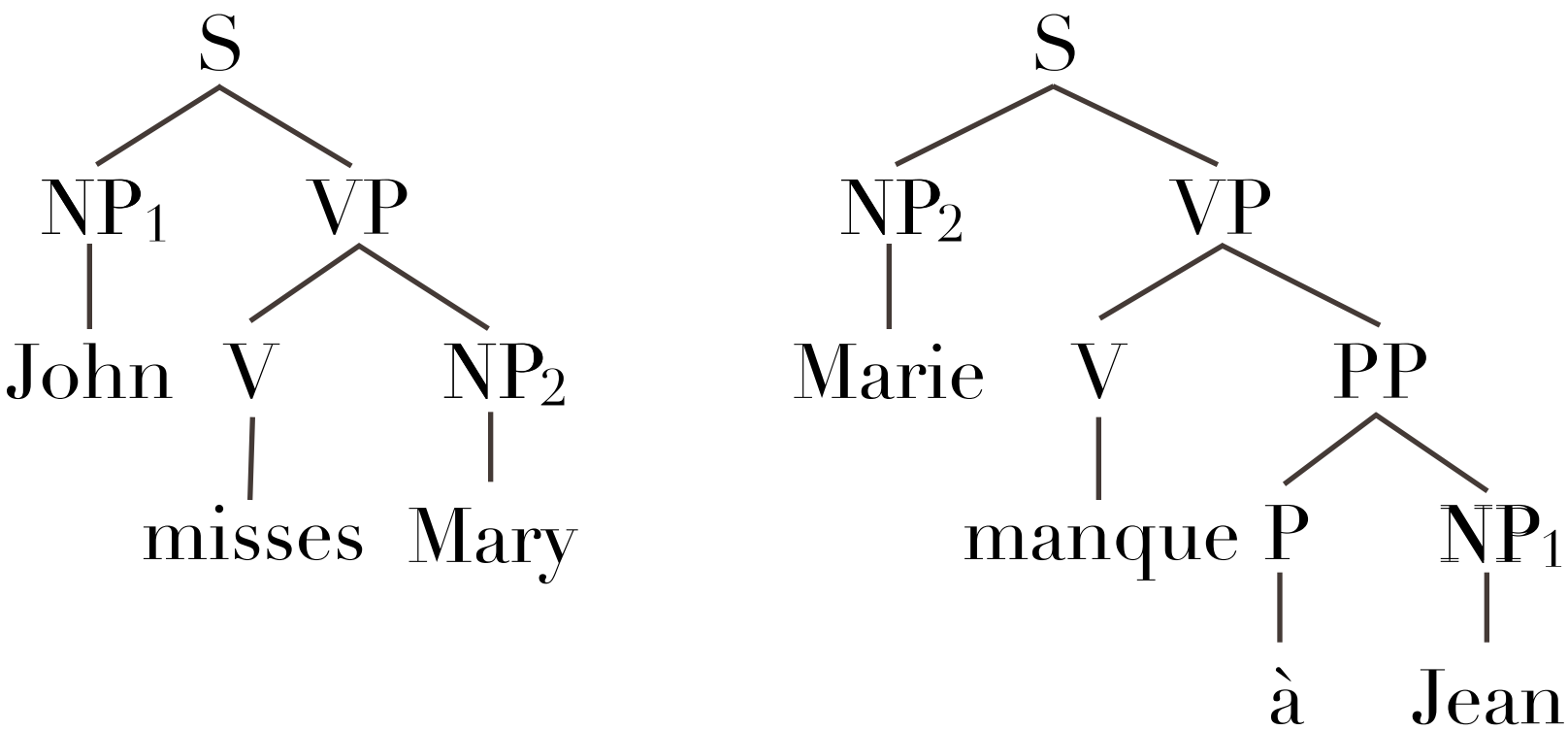

Properties

Chomsky normal form

$$X \rightarrow Y\,Z$$

$$X \rightarrow a$$

Chomsky normal form

$$A \rightarrow \quad B \quad C \quad D \quad E \quad F \qquad\qquad \textit{rank } 5$$

Chomsky normal form

$A \rightarrow [[[B\ \ C]\ D]\ E]\ F$ rank 5

$A \rightarrow V1\ F$

$V1 \rightarrow V2\ E$

$V2 \rightarrow V3\ D$

$V3 \rightarrow B\ C$

rank 2

A hierarchy of synchronous CFGs

$$\text{1-CFG} \subsetneq \text{2-CFG} = \text{3-CFG} = \text{4-CFG} = \ldots$$

$$\text{1-SCFG} \subsetneq \text{2-SCFG} = \text{3-SCFG} \subsetneq \text{4-SCFG} \subsetneq \ldots$$

$$\text{ITG}$$

(Wu, 1997)

Synchronous CNF?

$$A \rightarrow (B_1 \;\; C_2 \;\; D_3 \;, \;\; C_2 \;\; D_3 \;\; B_1)$$ rank 3

Synchronous CNF?

$$A \rightarrow (B_1\ [C_2\ \ D_3],\ [C_2\ \ D_3]\ B_1)$$

rank 3

$$A \rightarrow (B_1\ V1_2\quad ,\ V1_2\ B_1)$$

$$V1 \rightarrow (C_1\ D_2\quad ,\ C_1\ D_2)$$

rank 2

Synchronous CNF?

$$A \rightarrow (B_1\ C_2\ D_3\ E_4,\ C_2\ E_4\ B_1\ D_3)$$ rank 4

$$A \rightarrow ([B_1\ C_2]\ D_3\ E_4,\ [C_2\ E_4\ B_1]\ D_3)$$

$$A \rightarrow (B_1\ [C_2\ D_3]\ E_4,\ [C_2\ E_4\ B_1\ D_3])$$

$$A \rightarrow (B_1\ C_2\ [D_3\ E_4],\ C_2\ [E_4\ B_1\ D_3])$$

Synchronous CNF?

$$A \rightarrow (B_1\ C_2\ \ D_3,\ C_2\ D_3\ B_1)$$

	1	2	3
1			B
2	C		
3		D	

$$A \rightarrow (B_1\ C_2\ D_3\ E_4,\ C_2\ E_4\ B_1\ D_3)$$

	1	2	3	4
1			B	
2	C			
3				D
4		E		

A hierarchy of synchronous CFGs

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$$\text{1-SCFG} \subsetneq \text{2-SCFG} = \text{3-SCFG} \subsetneq \text{4-SCFG} \subsetneq \ldots$$

$$\text{ITG}$$

(Wu, 1997)

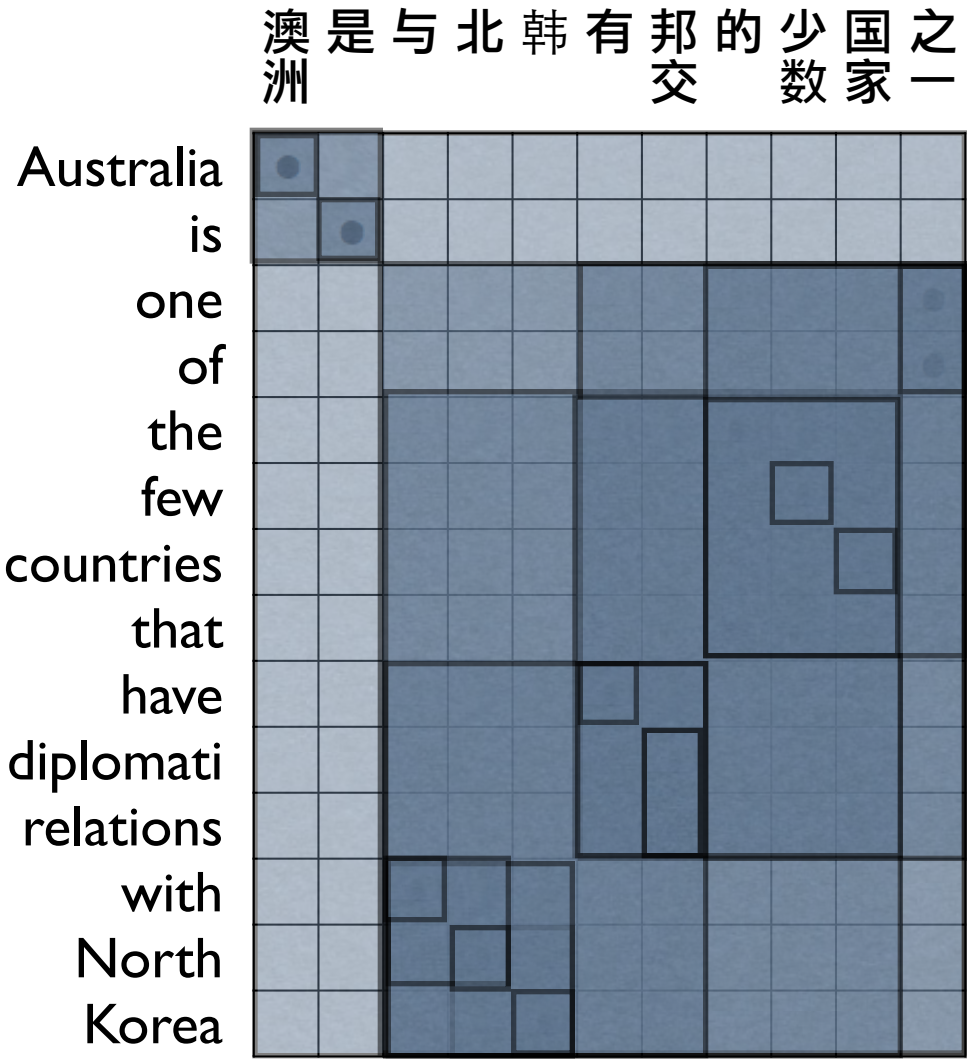
Extraction

Rule extraction

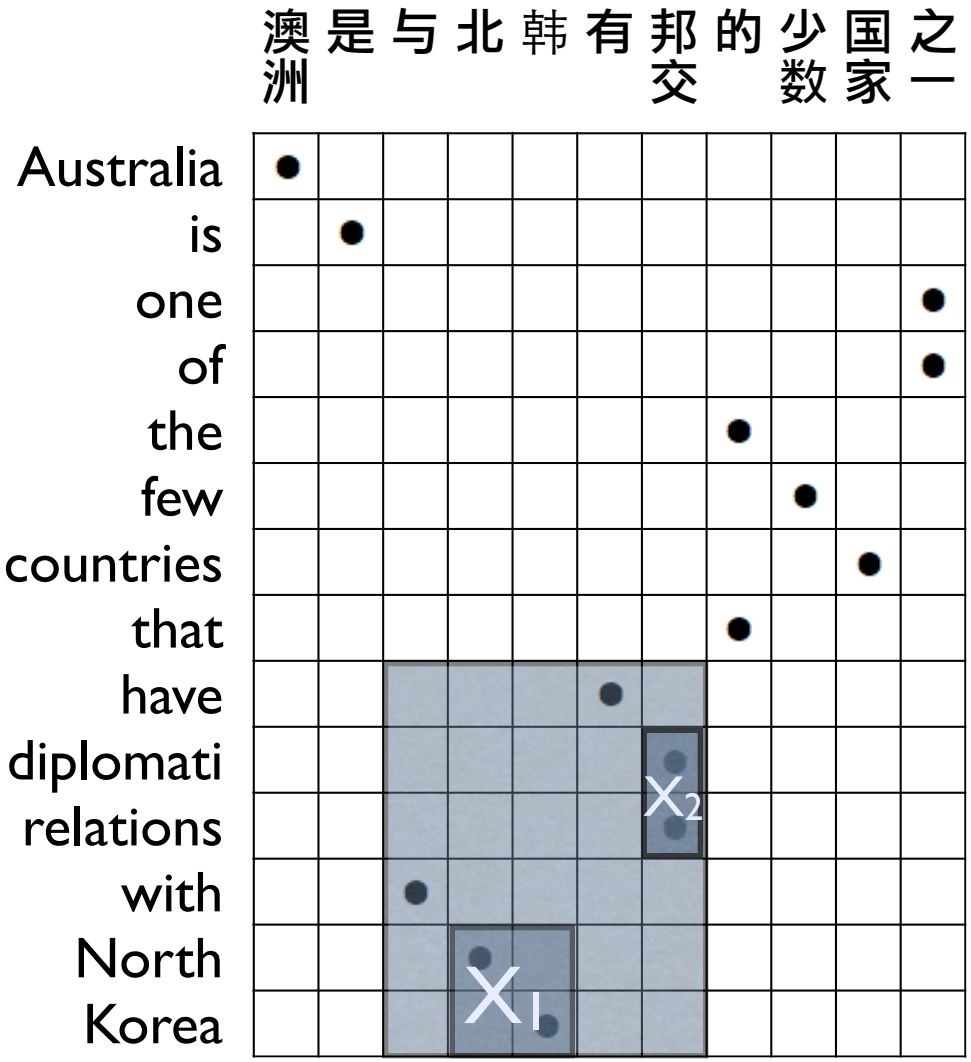
Extract *all possible* rules from each sentence pair that respect:

- Word alignments
- Syntactic structure
- Ad-hoc constraints

Grammar extraction



Grammar extraction



(与 北 韩 有 邦交, have diplomatic relations with North Korea)

(邦交, diplomatic relations)

(北 韩, North Korea)

(X → 与 X_1 有 X_2, X → have X_2 with X_1)

Ad-hoc constraints

- Hiero:
  - Initial phrases $\leq$10 words, rules $\leq$6 symbols
  - Require an aligned terminal
  - Limit to two nonterminals, nonadjacent
- Galley et al:
  - Rule must be minimal *or* have $\leq$5 English nodes (non-leaf, non-POS)

Example rules

$X \rightarrow$ 的	$X \rightarrow$'s
$X \rightarrow X_1$ 的 X_2	$X \rightarrow$ the X_2 of X_1
$X \rightarrow X_1$ 的 X_2	$X \rightarrow$ the X_2 that X_1
$X \rightarrow$ 在	$X \rightarrow$ in
$X \rightarrow$ 在 X_1 下	$X \rightarrow$ under X_1
$X \rightarrow$ 在 X_1 前	$X \rightarrow$ before X_1
$X \rightarrow$ 今年 X_1	$X \rightarrow X_1$ this year
$X \rightarrow X_1$ 之一	$X \rightarrow$ one of X_1
$X \rightarrow X_1$ 总统	$X \rightarrow$ president X_1

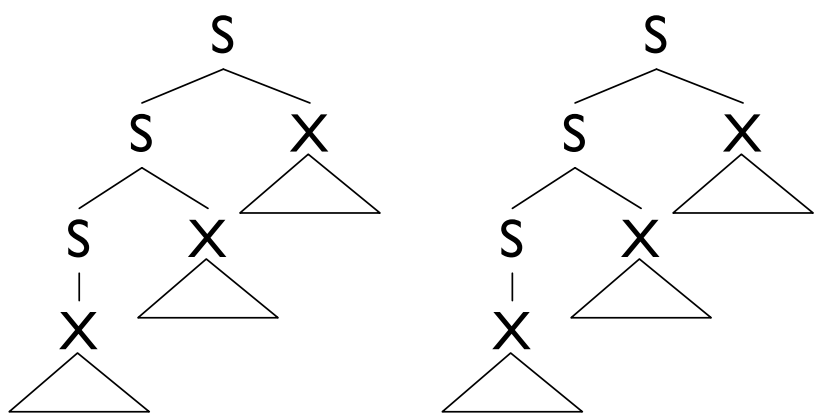
Glue rules

- Plus "glue" rules:

$$(S \rightarrow S_1 X_2, S \rightarrow S_1 X_2)$$

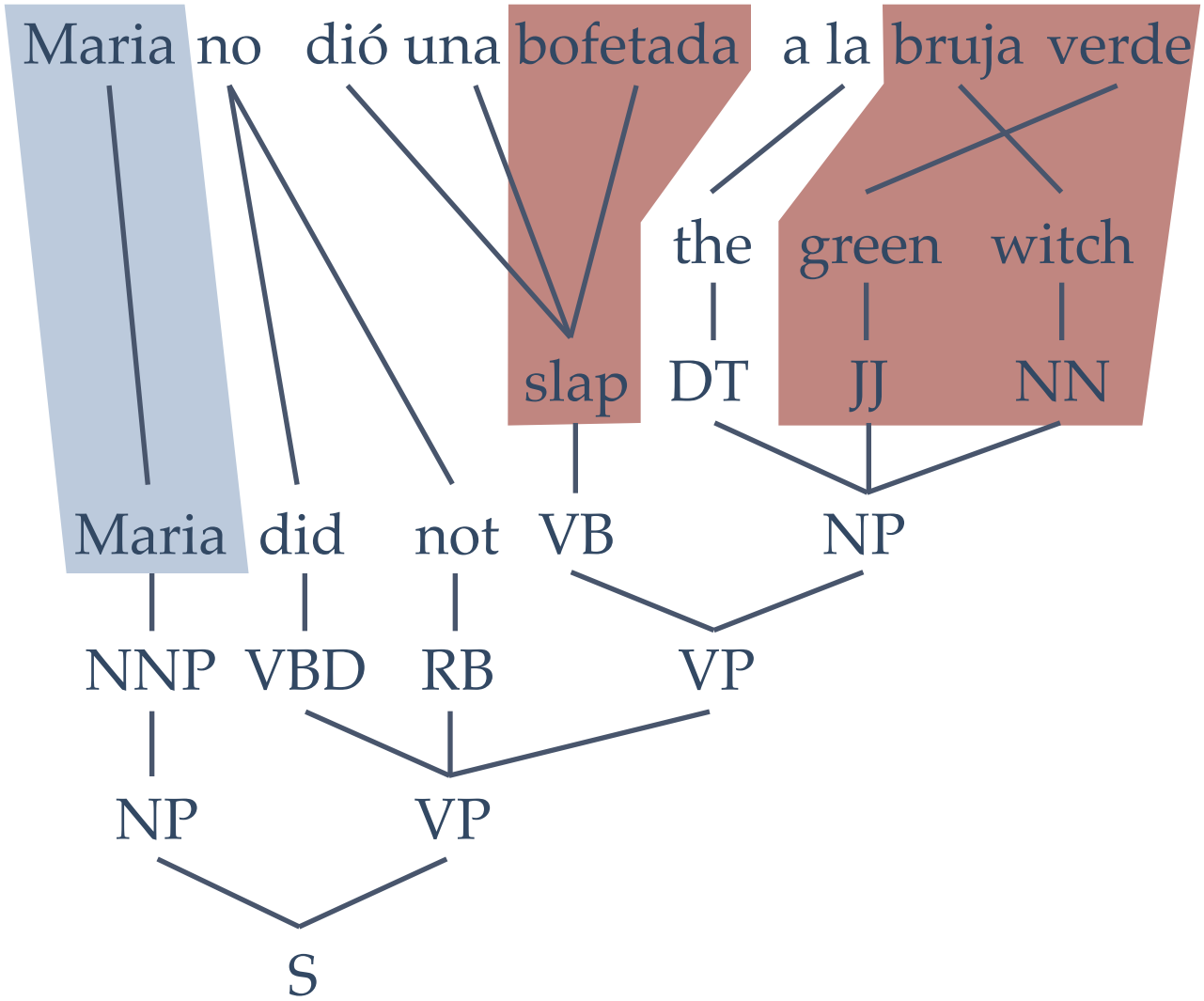
$$(S \rightarrow X_1, S \rightarrow X_1)$$

- Acts as fallback like phrase-based systems



Rule extraction

1. Phrases
   - respect word alignments
   - are syntactic constituents
2. Subtract phrases to form rules



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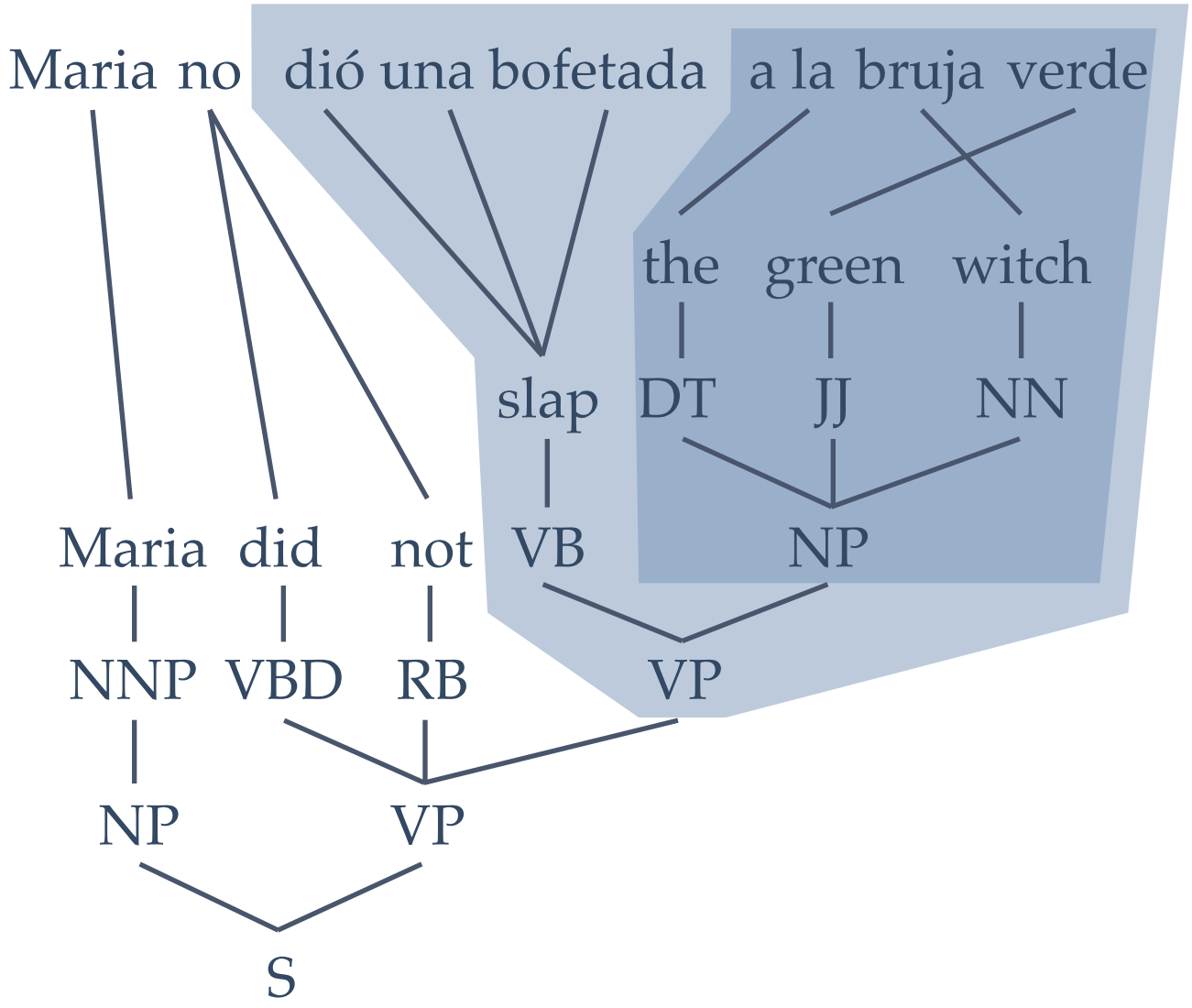

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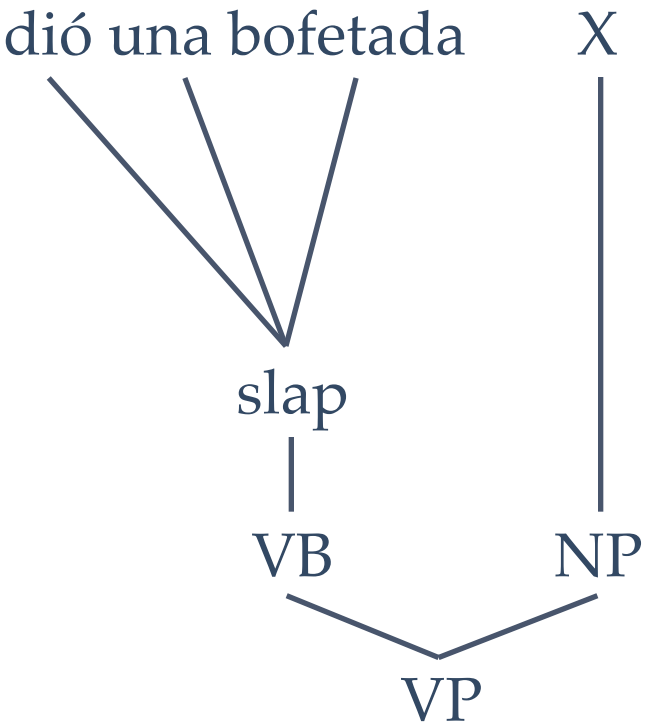
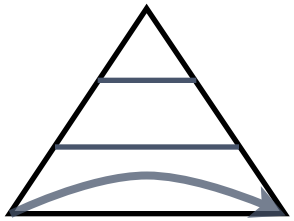
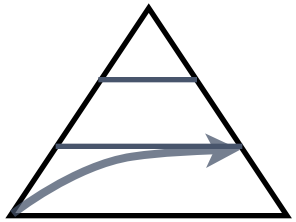
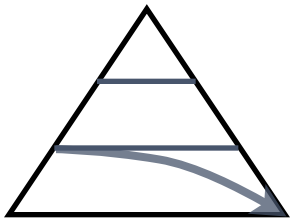
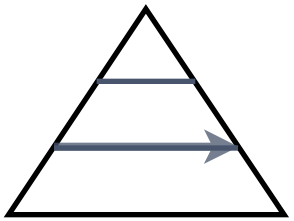
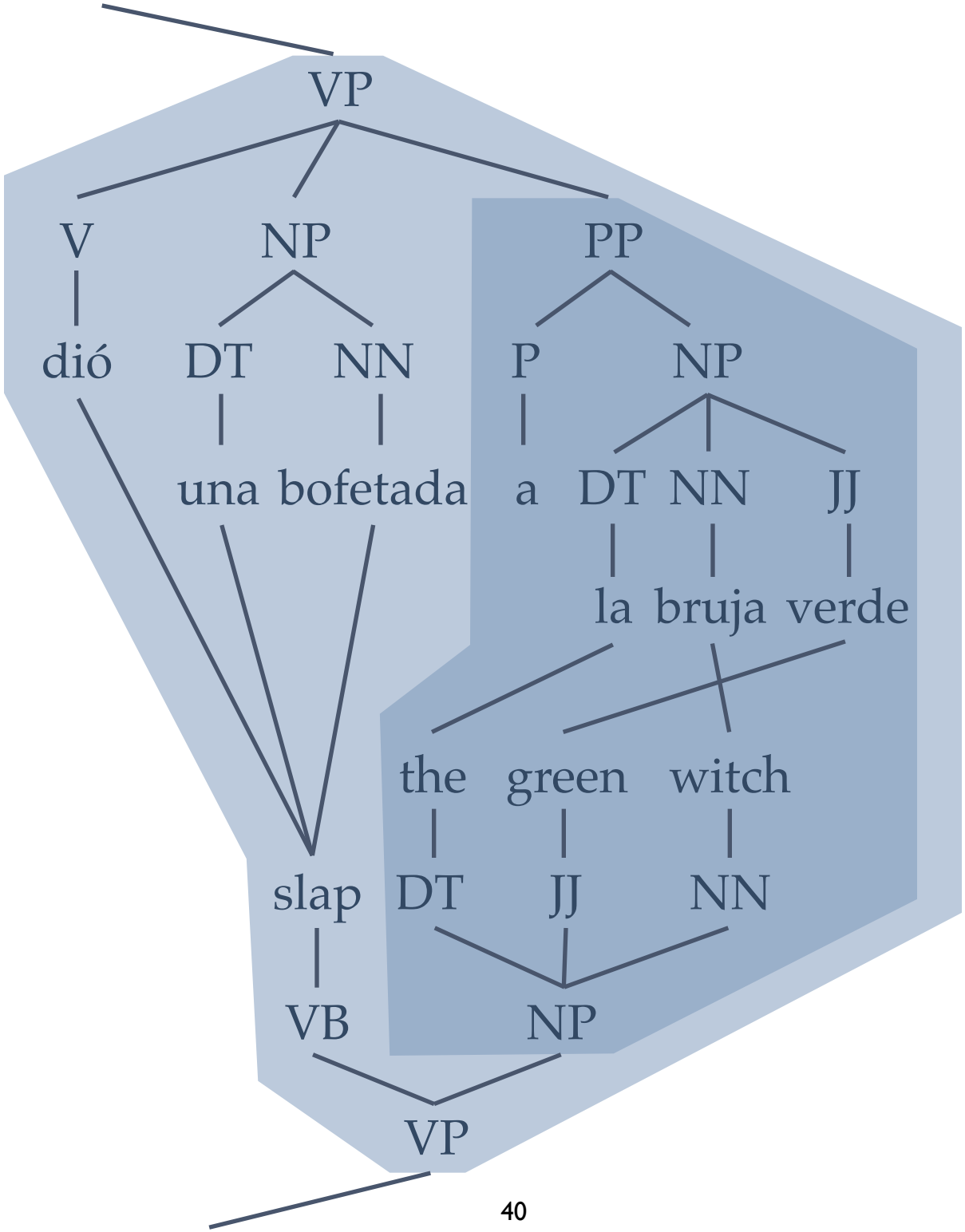


Varieties of rule extraction

	string-to-string	ITG (Wu, 1997)	Hiero (Chiang, 2005)
	string-to-tree	Yamada & Knight, 2001	Galley et al, 2004/2006
	tree-to-string		Huang et al, 2006 Liu et al, 2006
	tree-to-tree	DOT (Poutsma, 2000) Eisner, 2003	Zhang et al., 2008 Liu et al., 2009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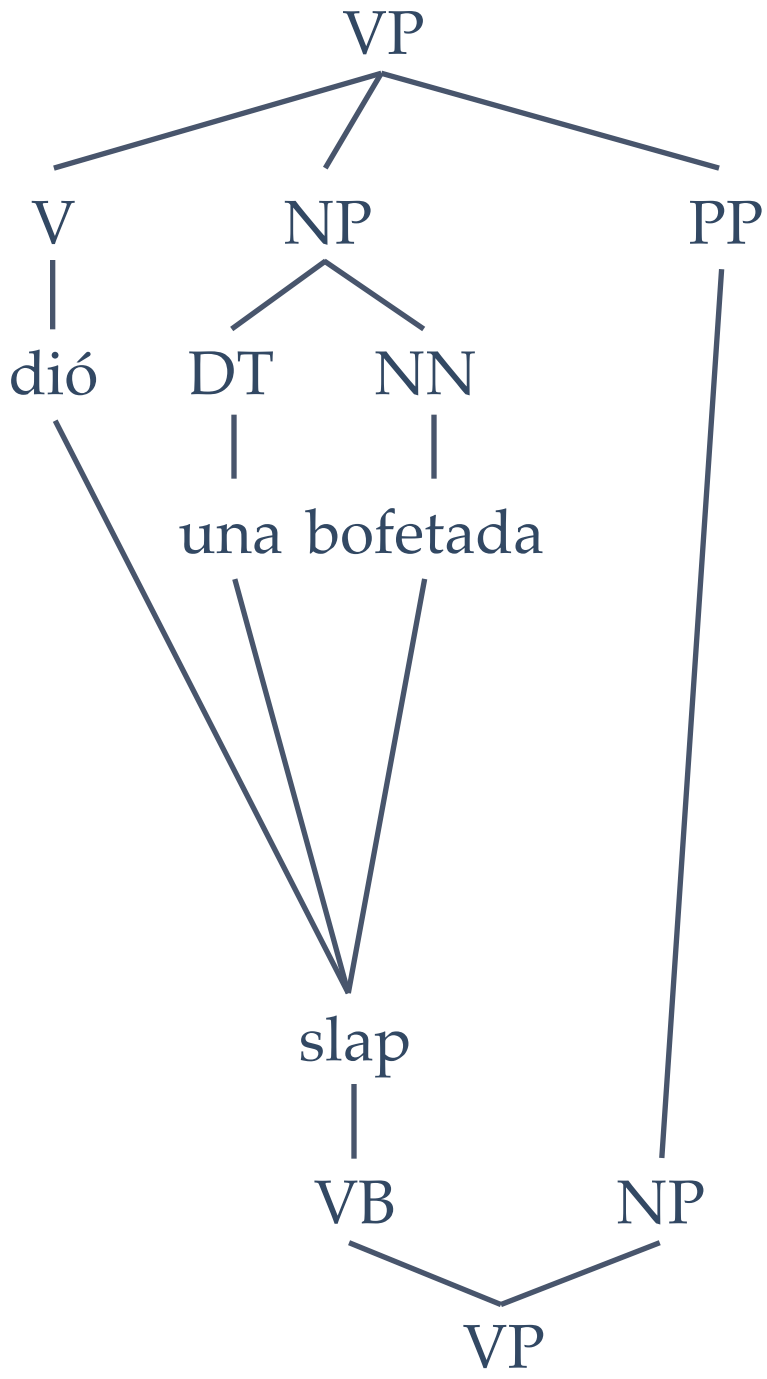
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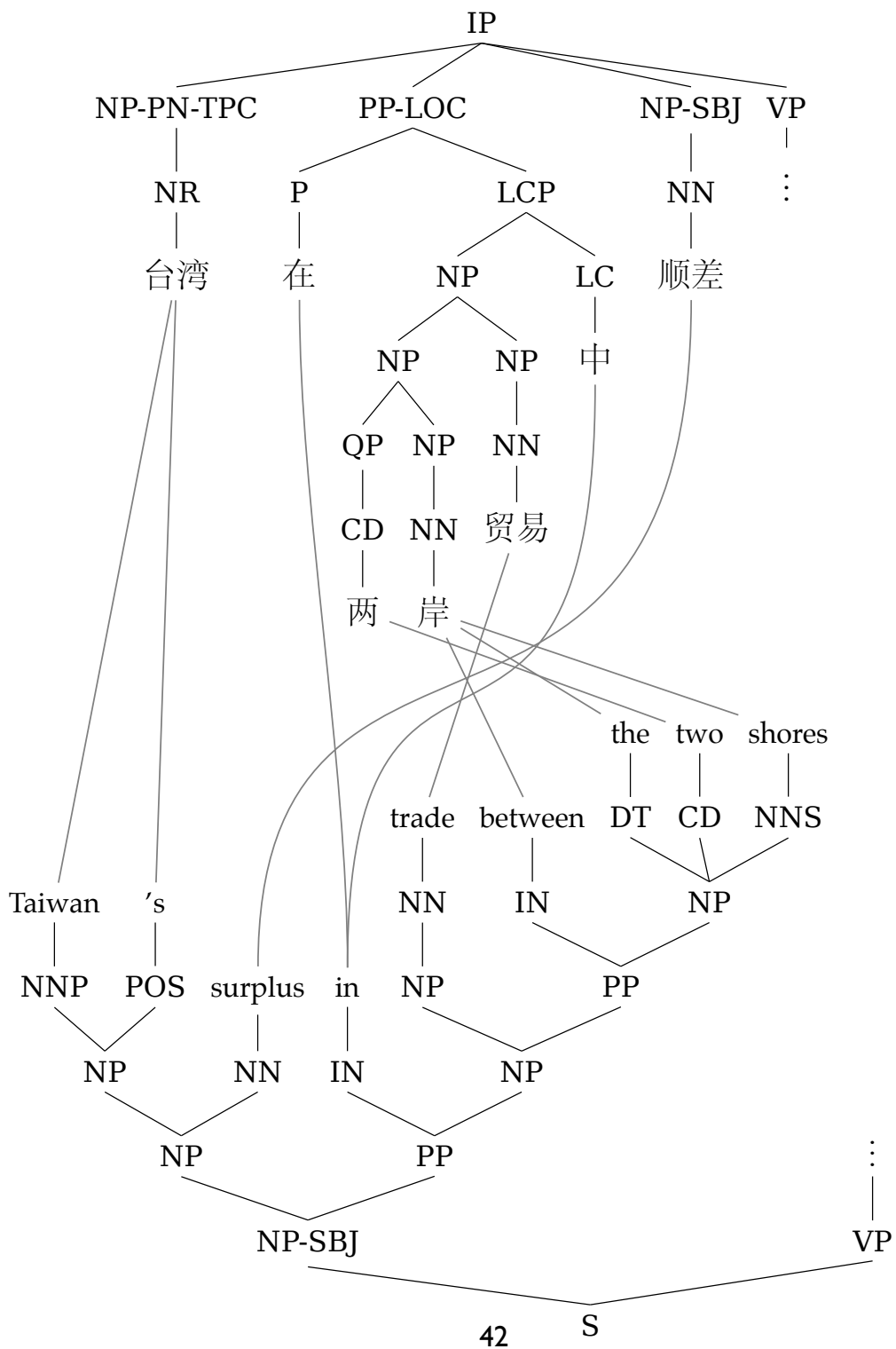
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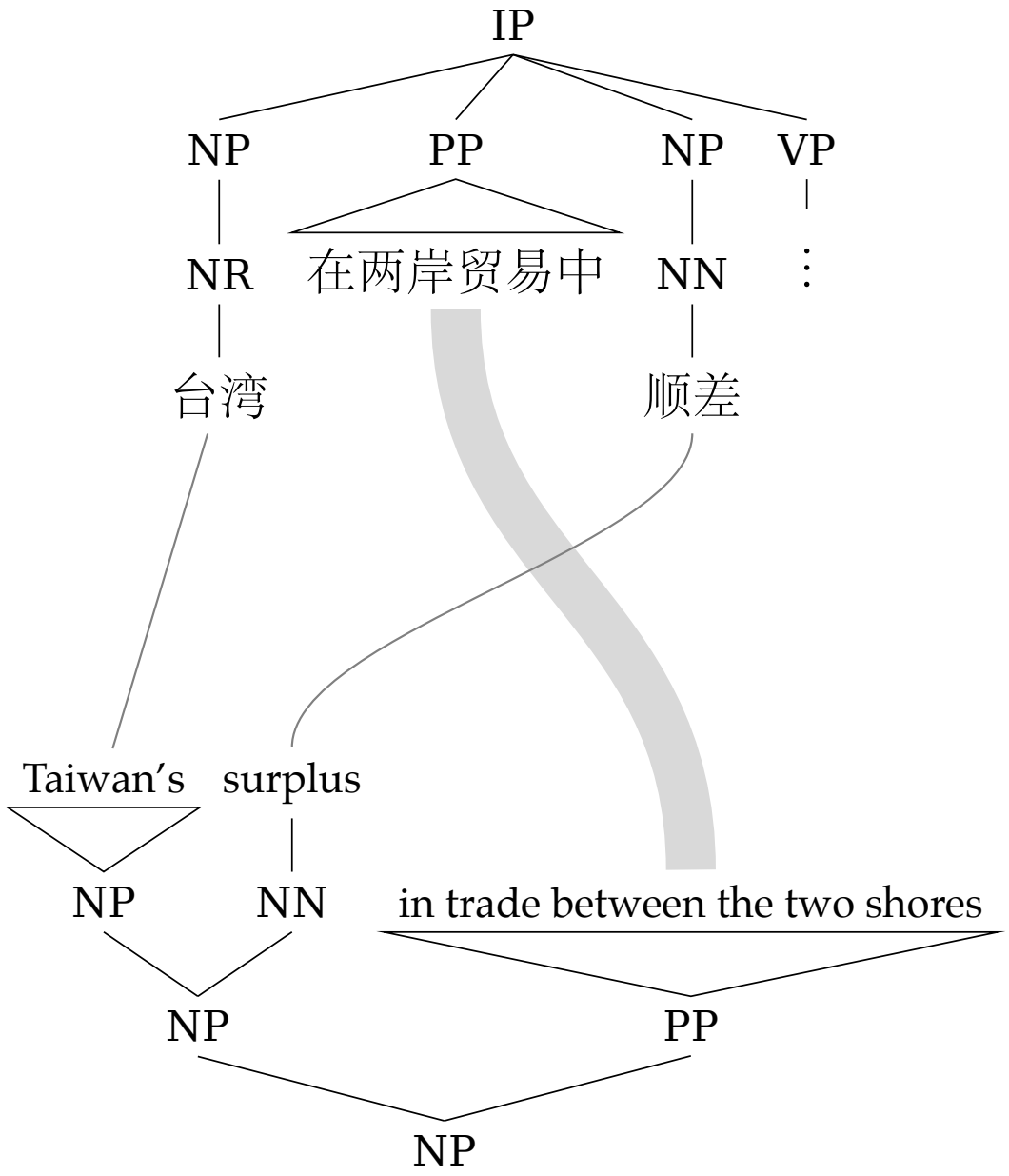
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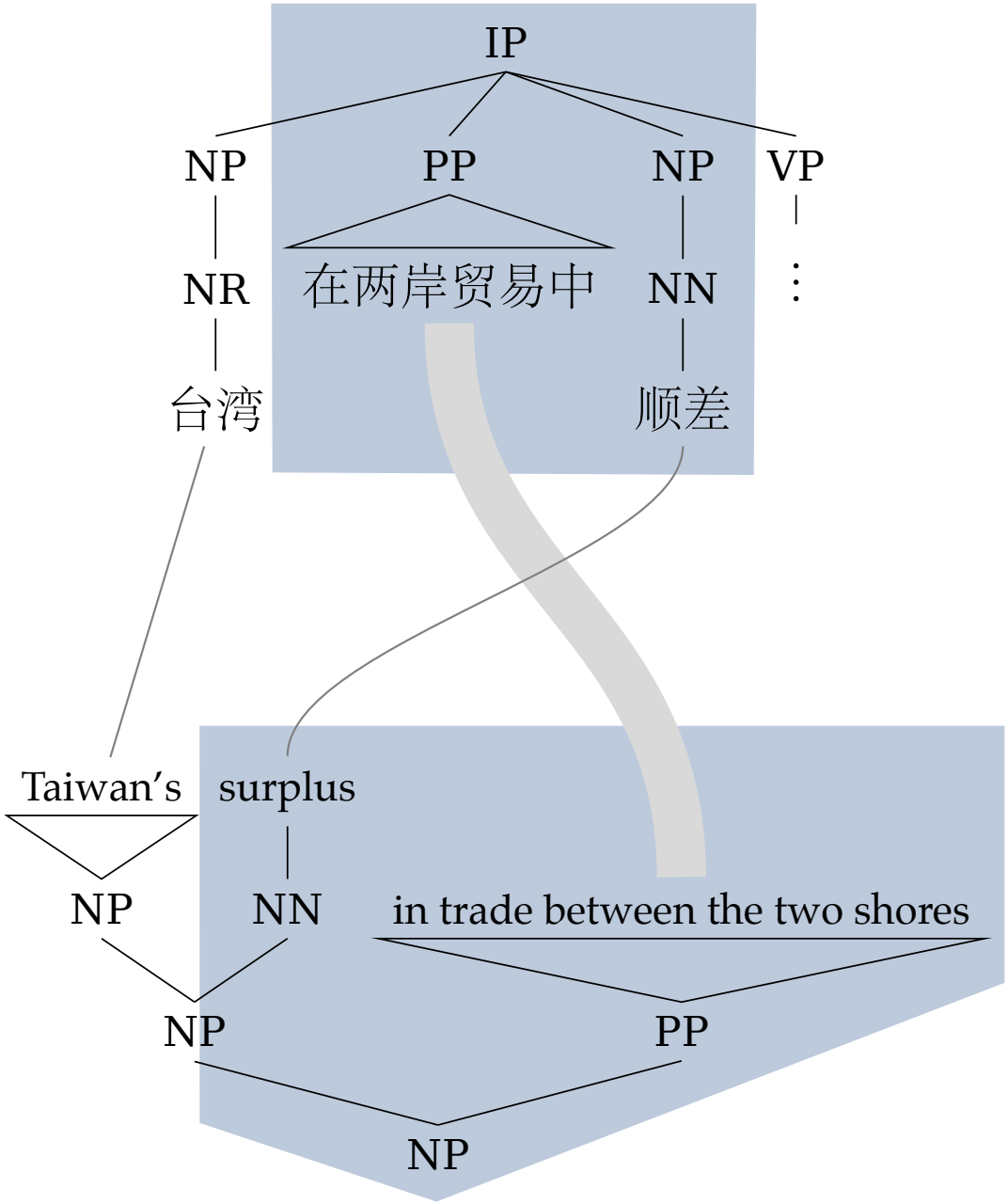
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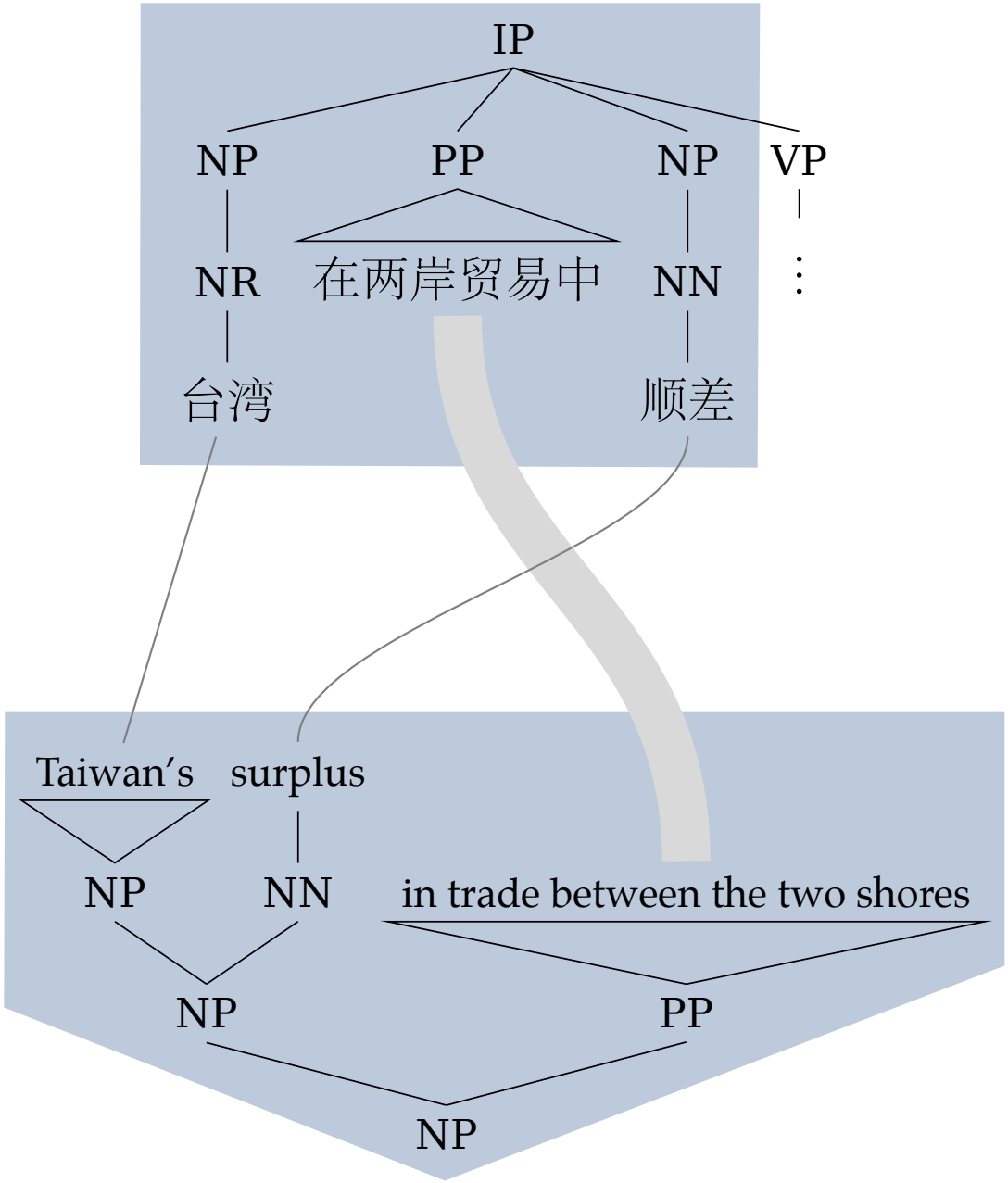
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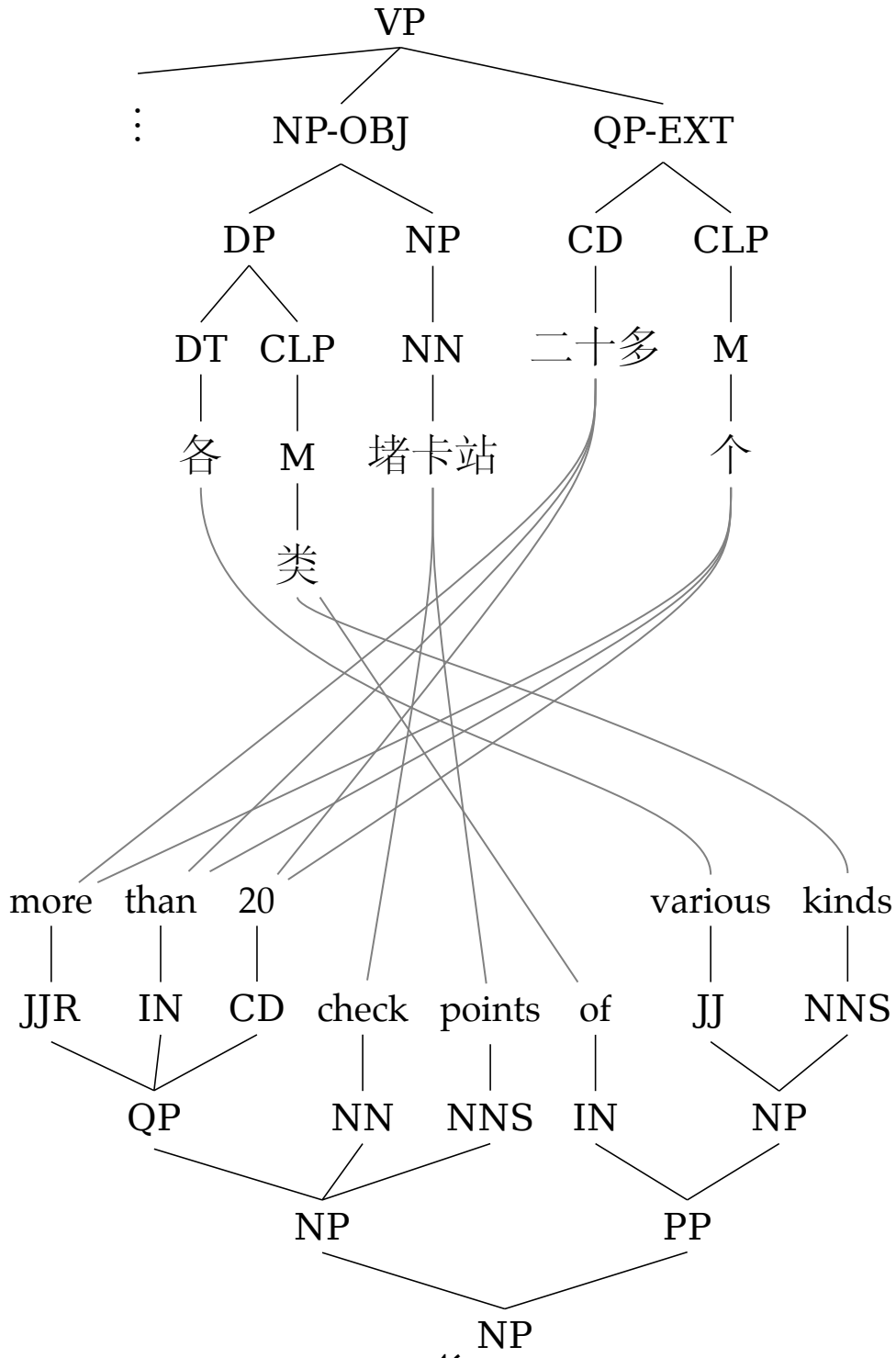
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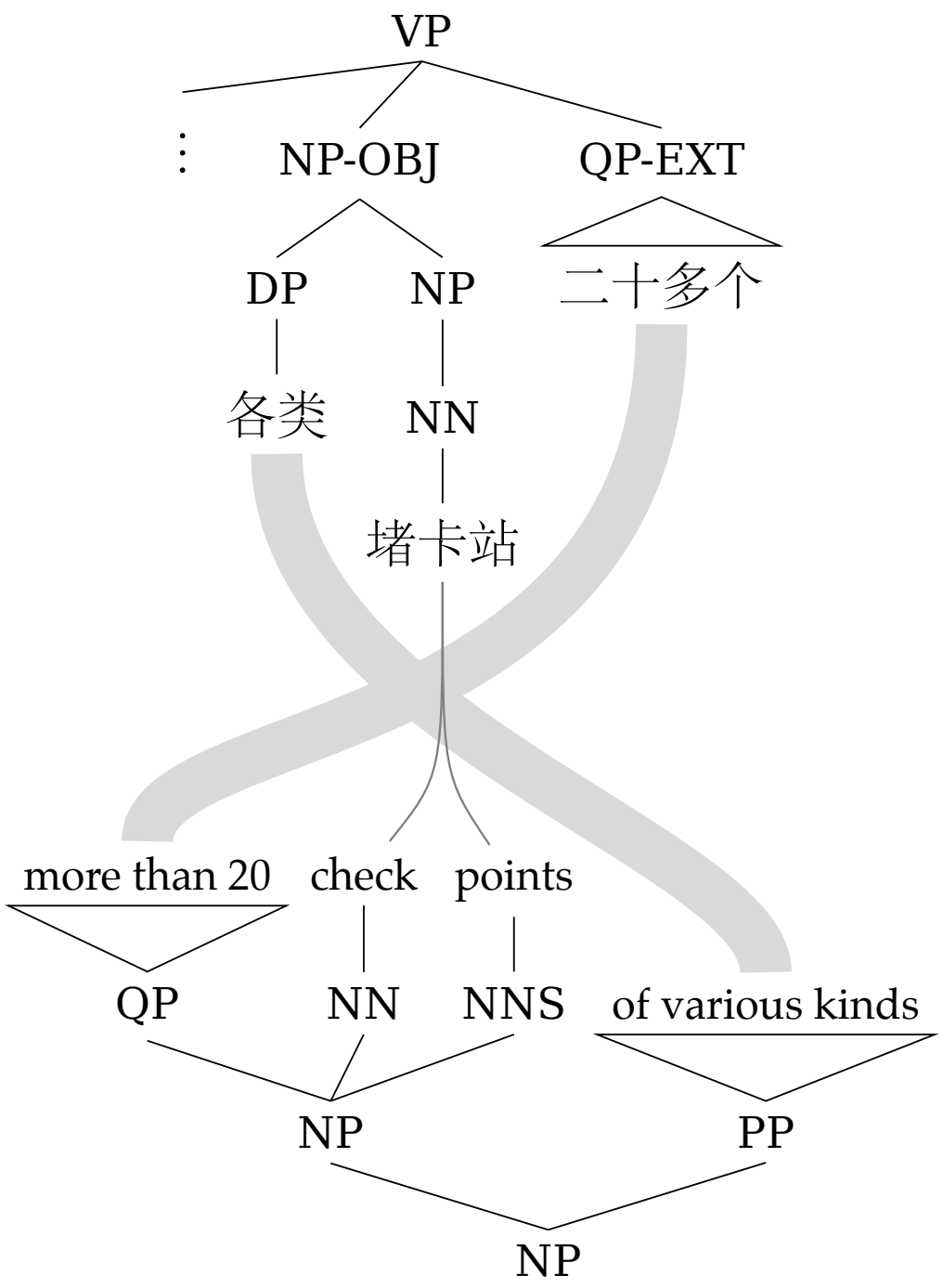
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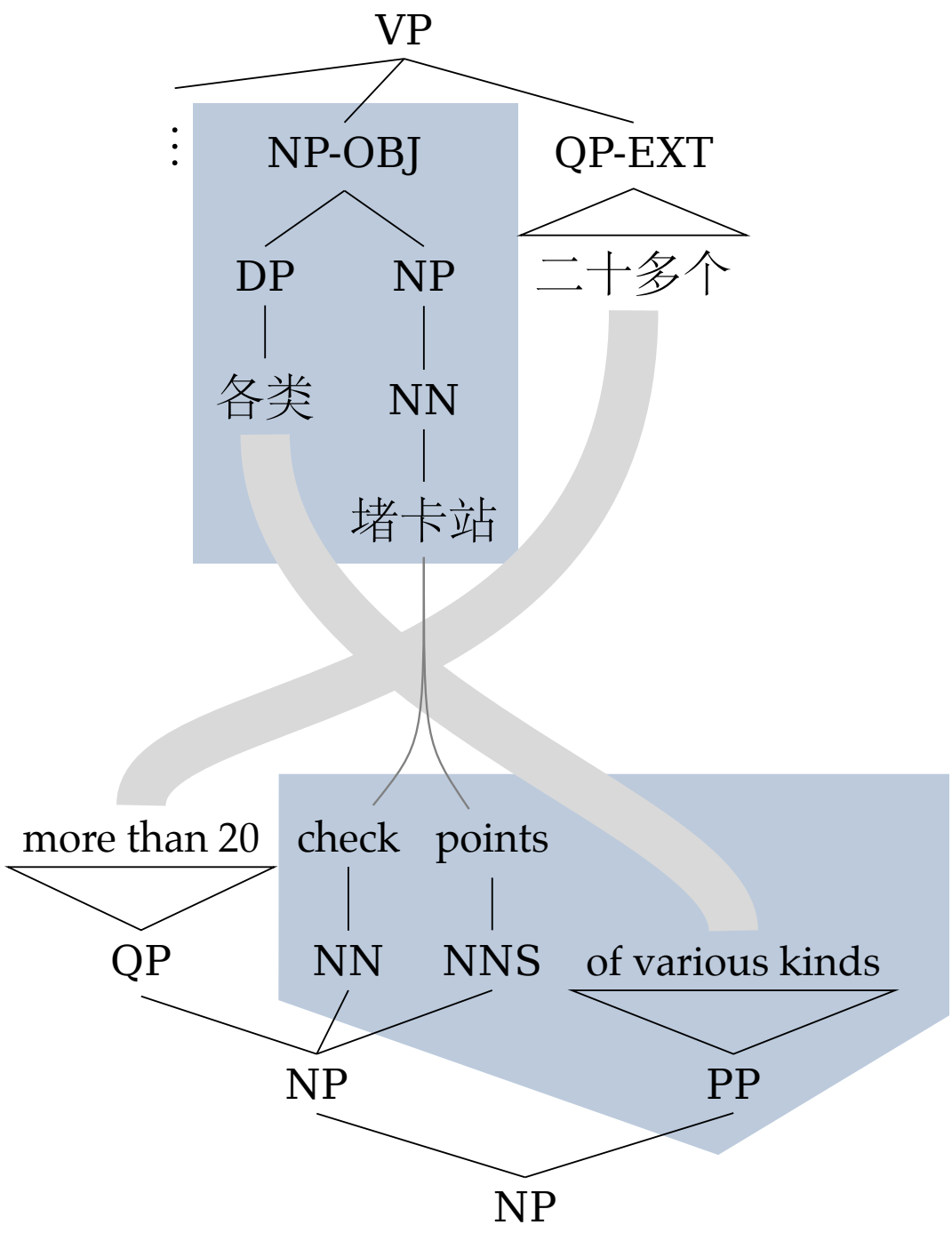
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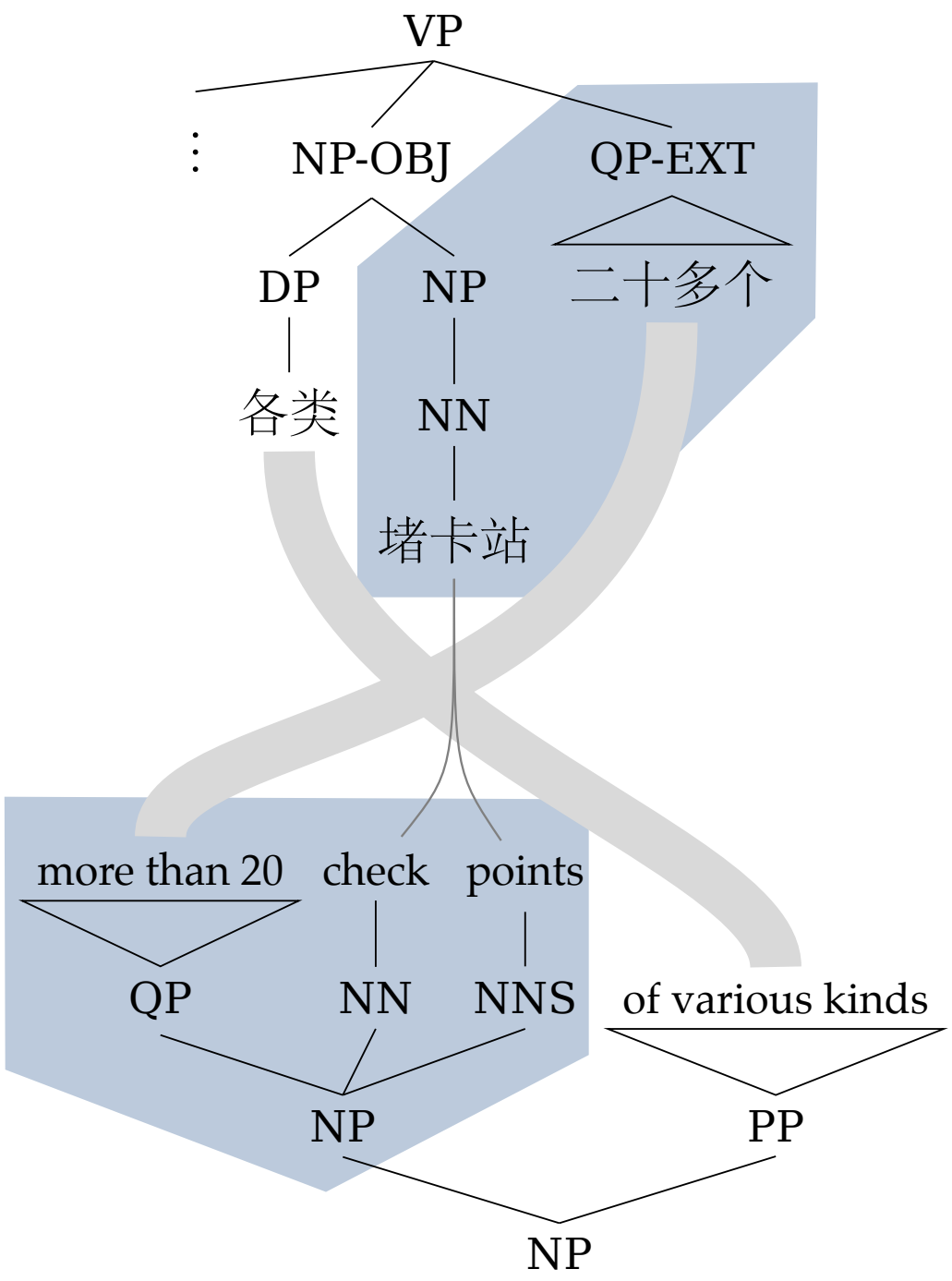
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Model

Probability model

- Synchronous CFG gives us possible translations (derivations)
- What makes one translation better than another?
- Log-linear model that combines small number of feature functions

Probability model

Log-linear model (Och and Ney, 2002)

$$P(D) \propto \prod_{r \in D} \prod_{i} v_i(r)^{\lambda_i(r)}$$

D	derivation
r	rules in D
v_i	feature functions
λ_i	feature weights

Weights λ_i learned by maximum-BLEU training (Och 2003)

Model features

- Phrase translation:

  $p(X \rightarrow X_1 \text{之一} \mid X \rightarrow \text{one of } X_1)$

  $p(X \rightarrow \text{one of } X_1 \mid X \rightarrow X_1 \text{之一})$

  - Problem: rules not actually observed?

Model features

- Lexical weighting (Koehn):

  $\frac{1}{2}[p(\text{之一} \mid \text{one}) + p(\text{之一} \mid \text{of})]$

  $p(\text{one} \mid \text{之一}) \times p(\text{of} \mid \text{之一})$

Model features

- Binary features: extracted rules; glue rule S → SX; green rules
- Number of English words
- (Word) *n*-gram language model:

$p(\text{Australia} \mid \textit{START}) \times p(\text{is} \mid \textit{START}\ \text{Australia}) \cdots$

Decoding

Review: CKY

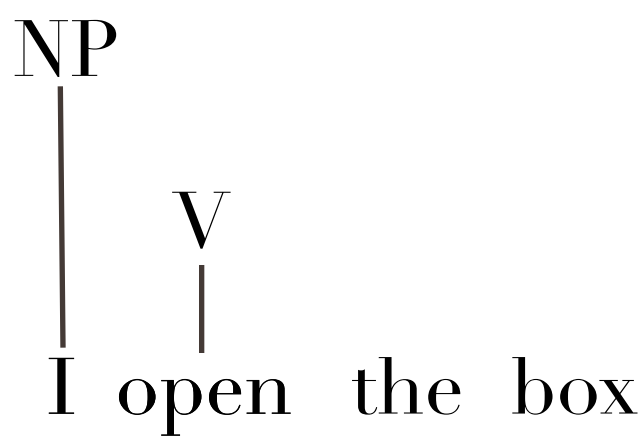
S → NP VP

NP → I

NP → the box

VP → V NP

V → open



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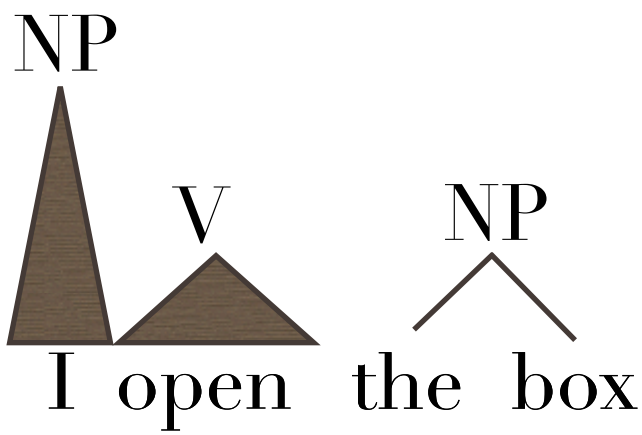

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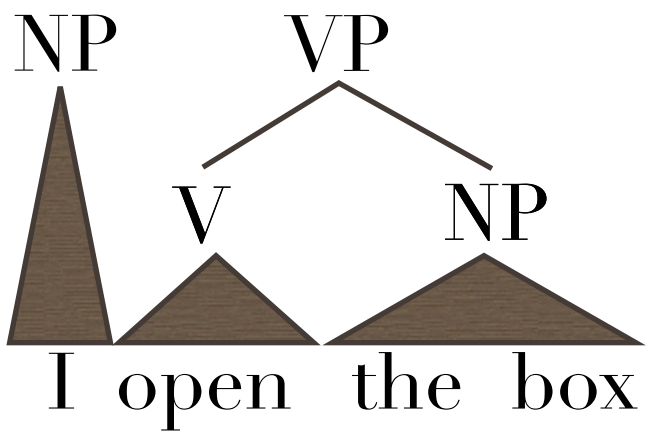

Review: CKY

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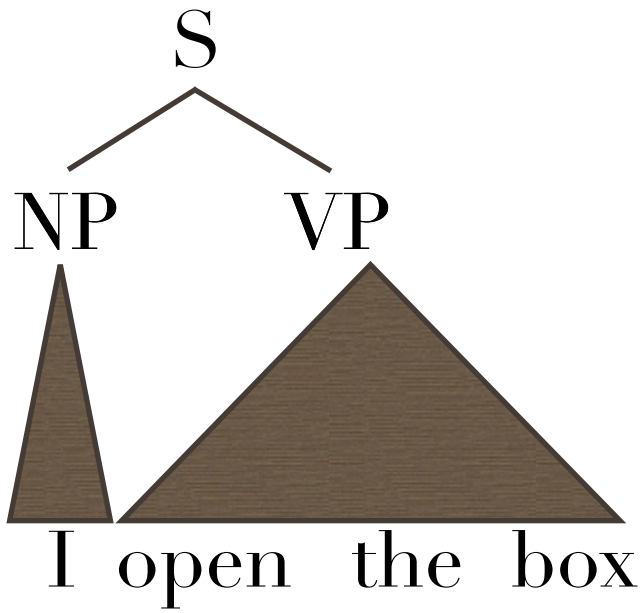
NP → I

NP → the box

VP → V NP

V → open



Review: CKY

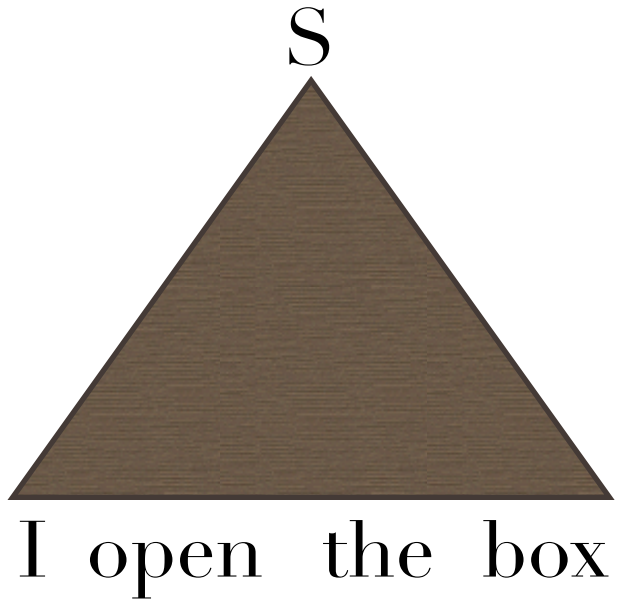
S → NP VP

NP → I

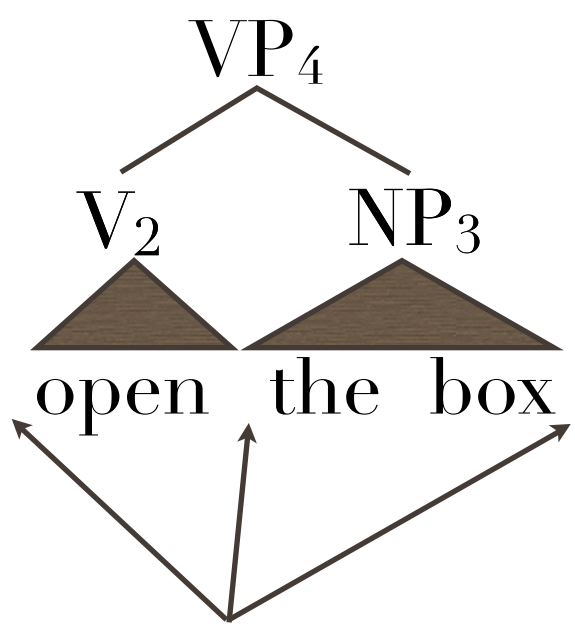
NP → the box

VP → V NP

V → open

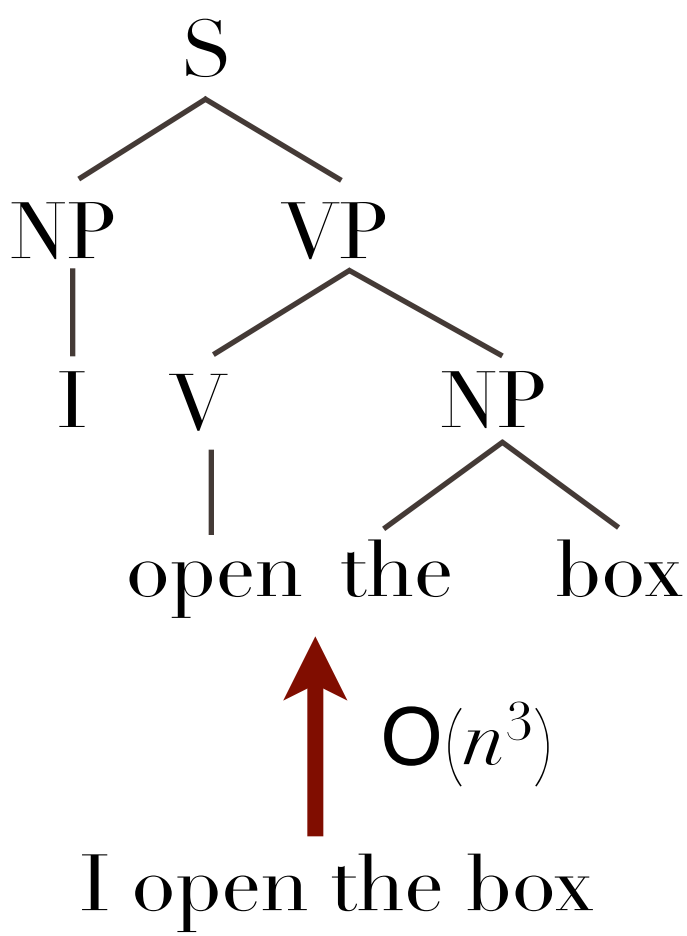


Review: CKY

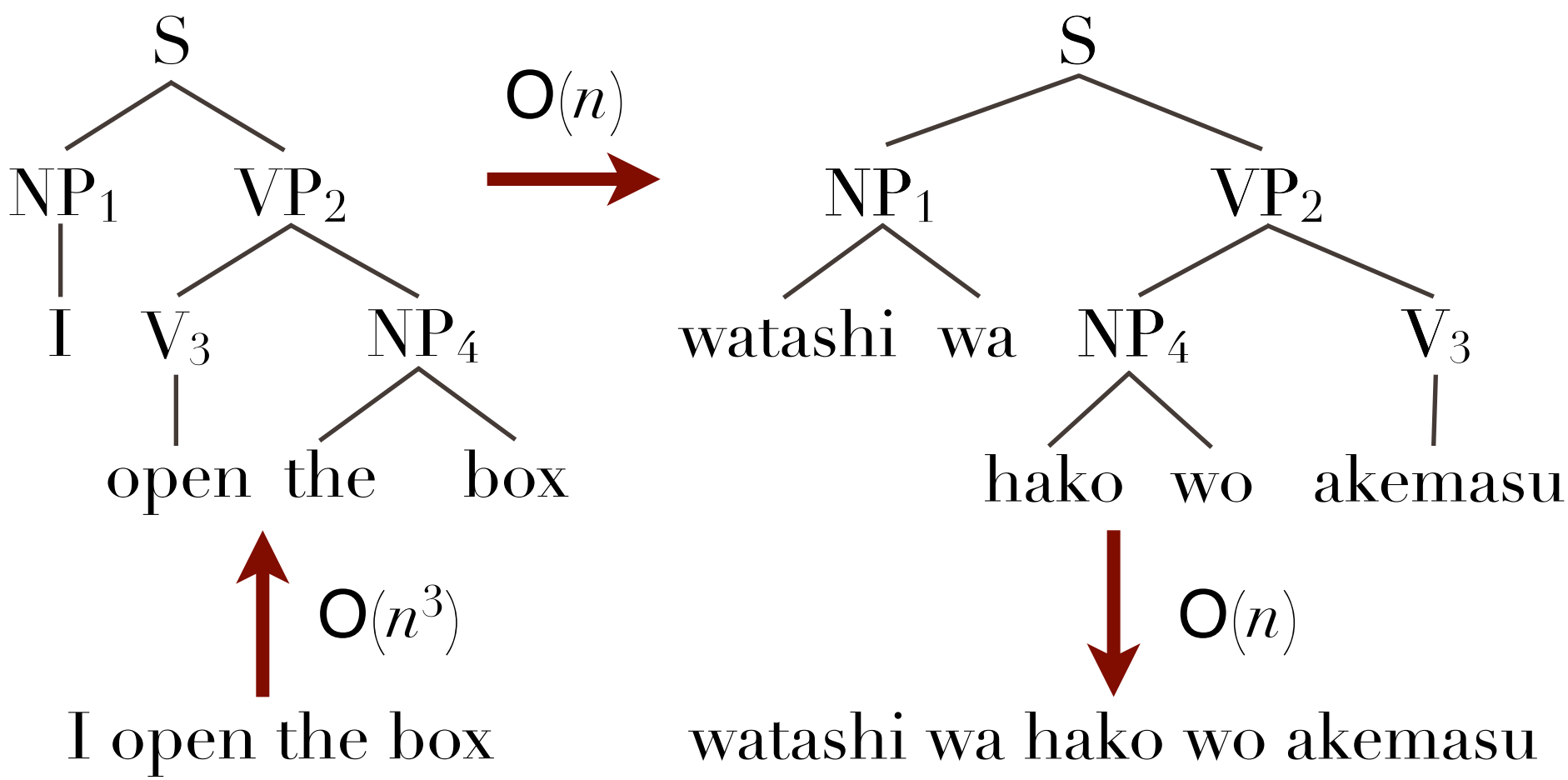


$O(n^3)$ ways of matching

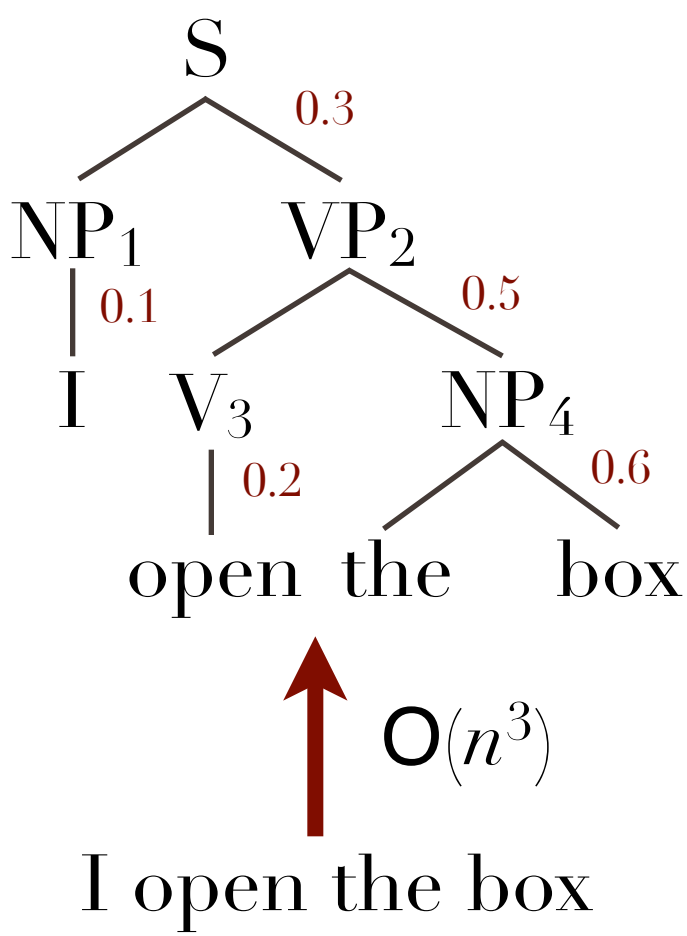
Translation



Translation

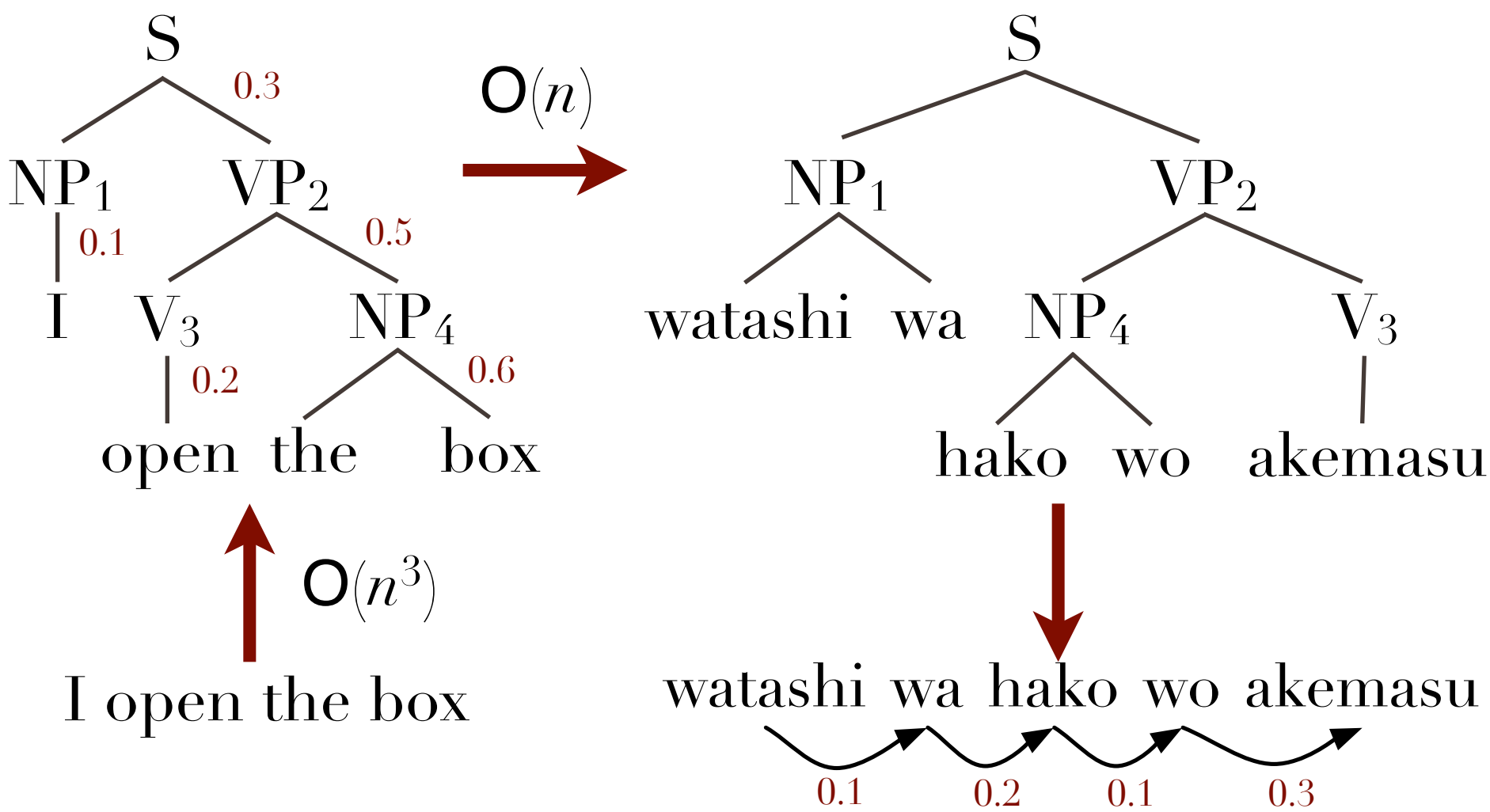


Finding the best translation

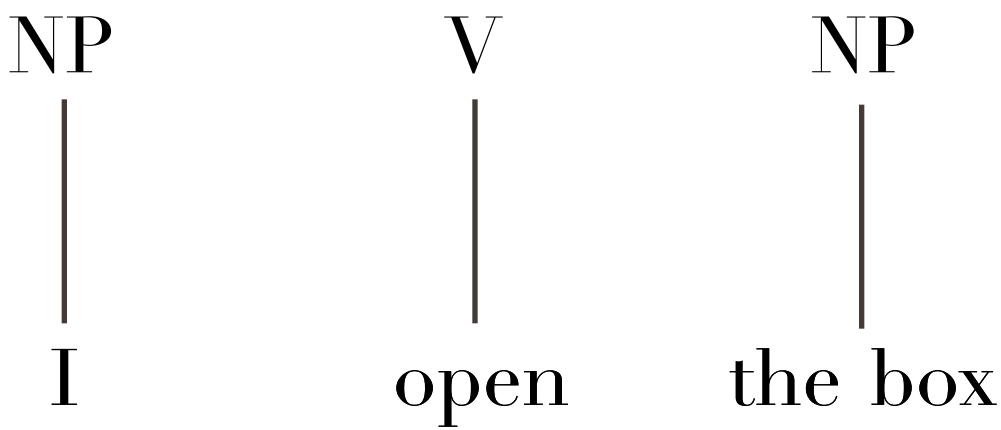


- Just like PCFG parsing
- *n*-best translations is efficient with the right tricks

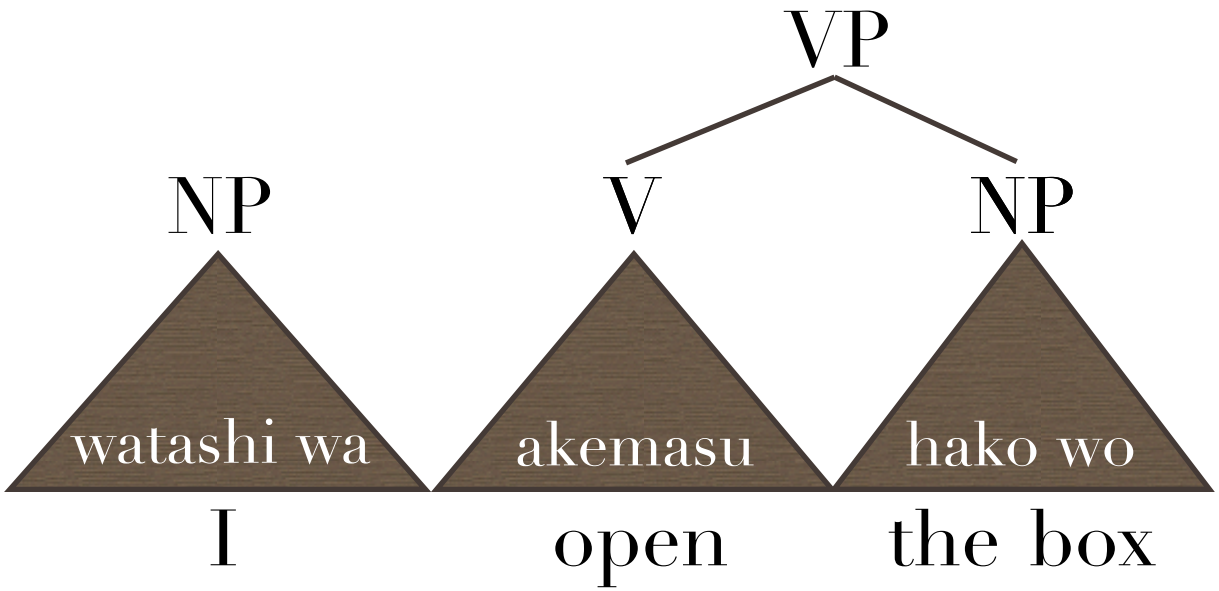
Bigram language model



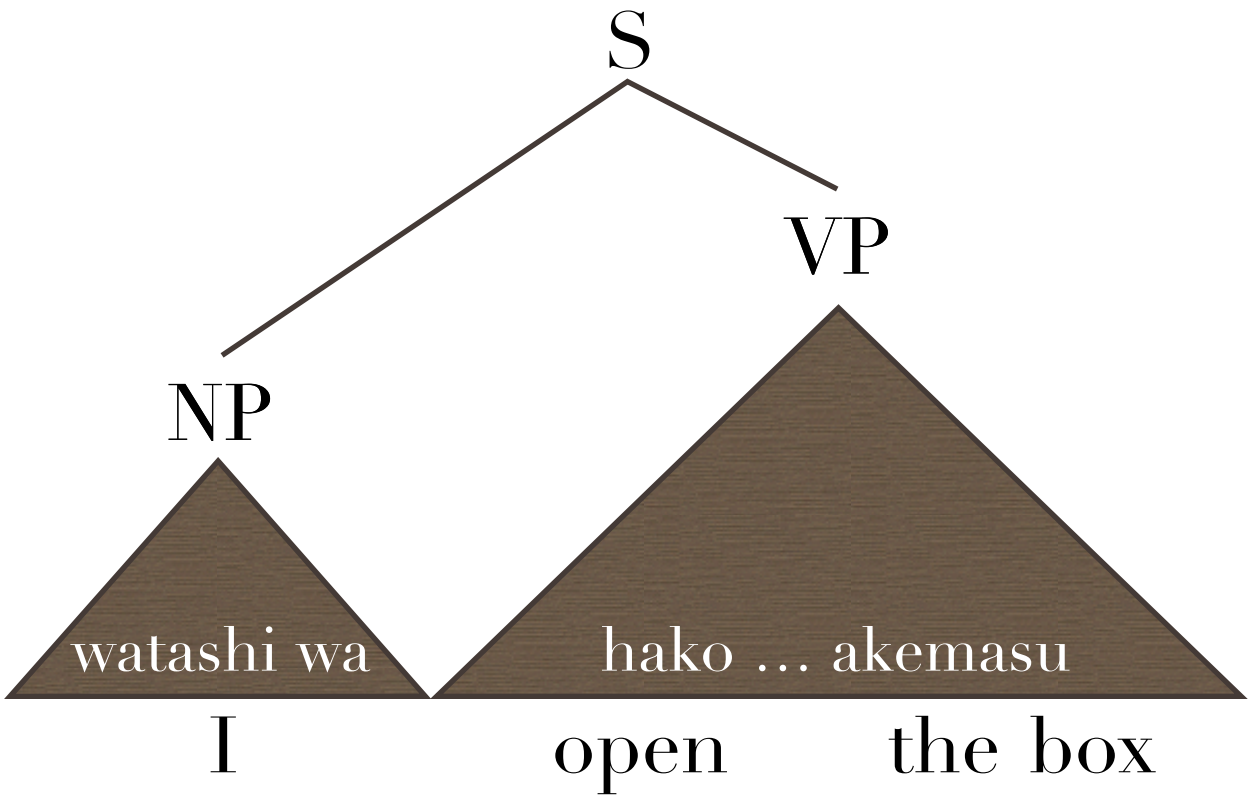
Translation with a LM



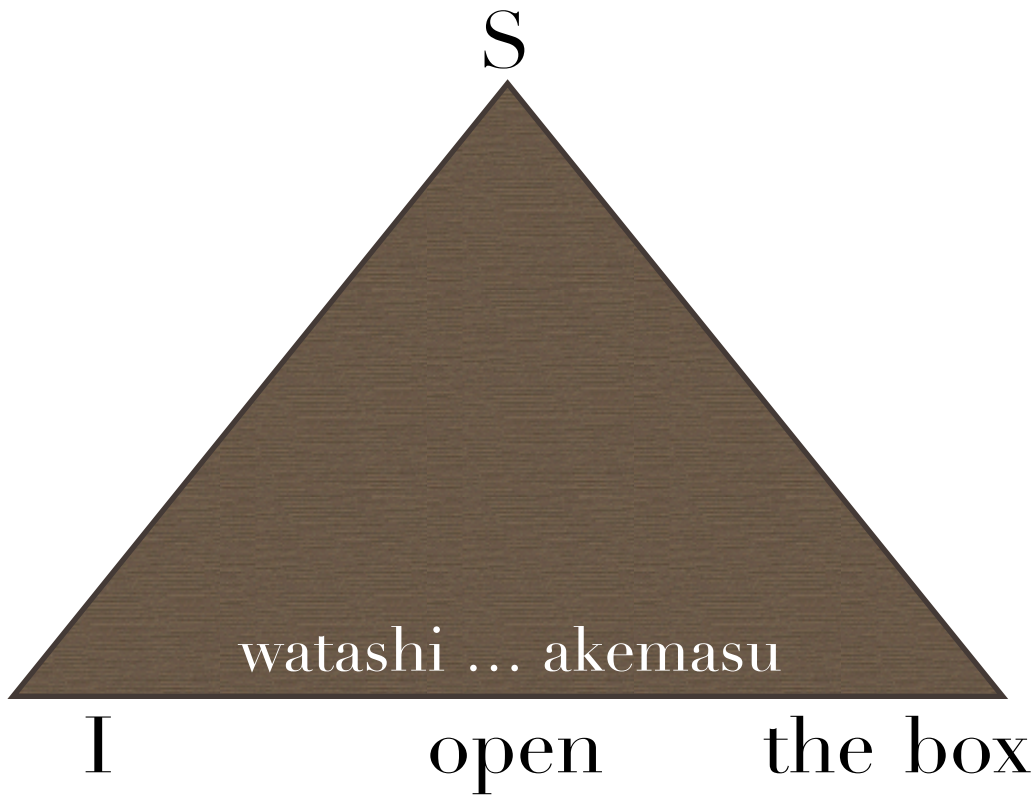
Translation with a LM



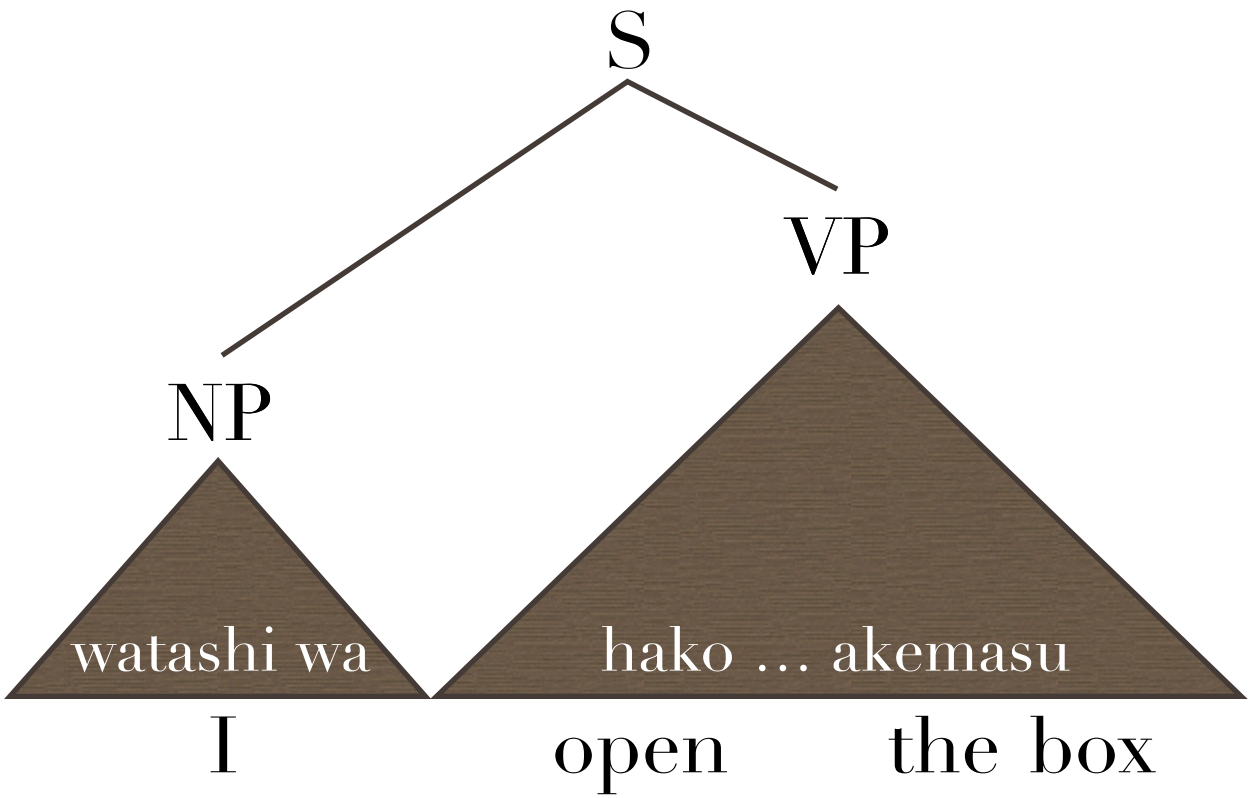
Translation with a LM



Translation with a LM

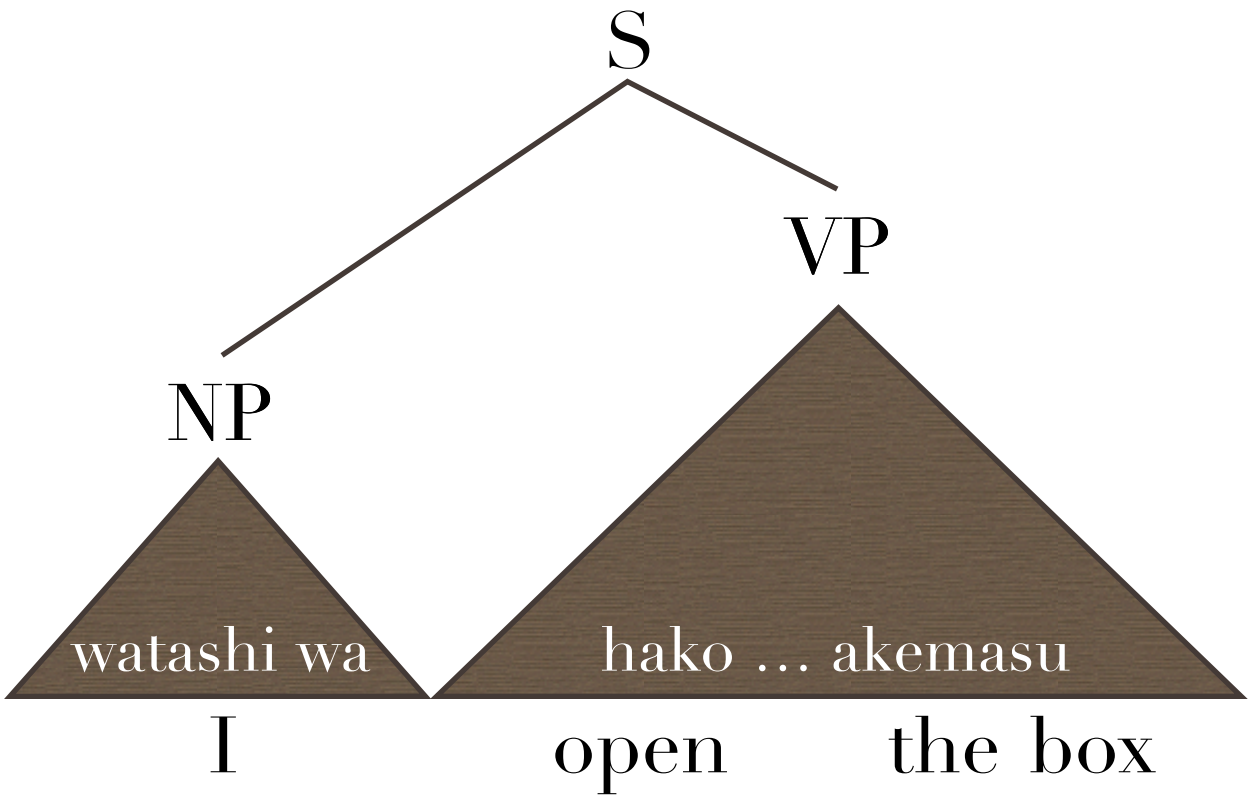


Translation with a LM



$O(n^3 V^{4(g-1)})$ combinations

Translation with a LM



$O(n^{3+4(g-1)})$ combinations

Summary

- Synchronous CFG/TSG allows translation based on hierarchical/syntactic structure
- Binarization not free
- Can be extracted from parallel data
- Tree-to-tree translation rare
- LM adds complexity to decoding