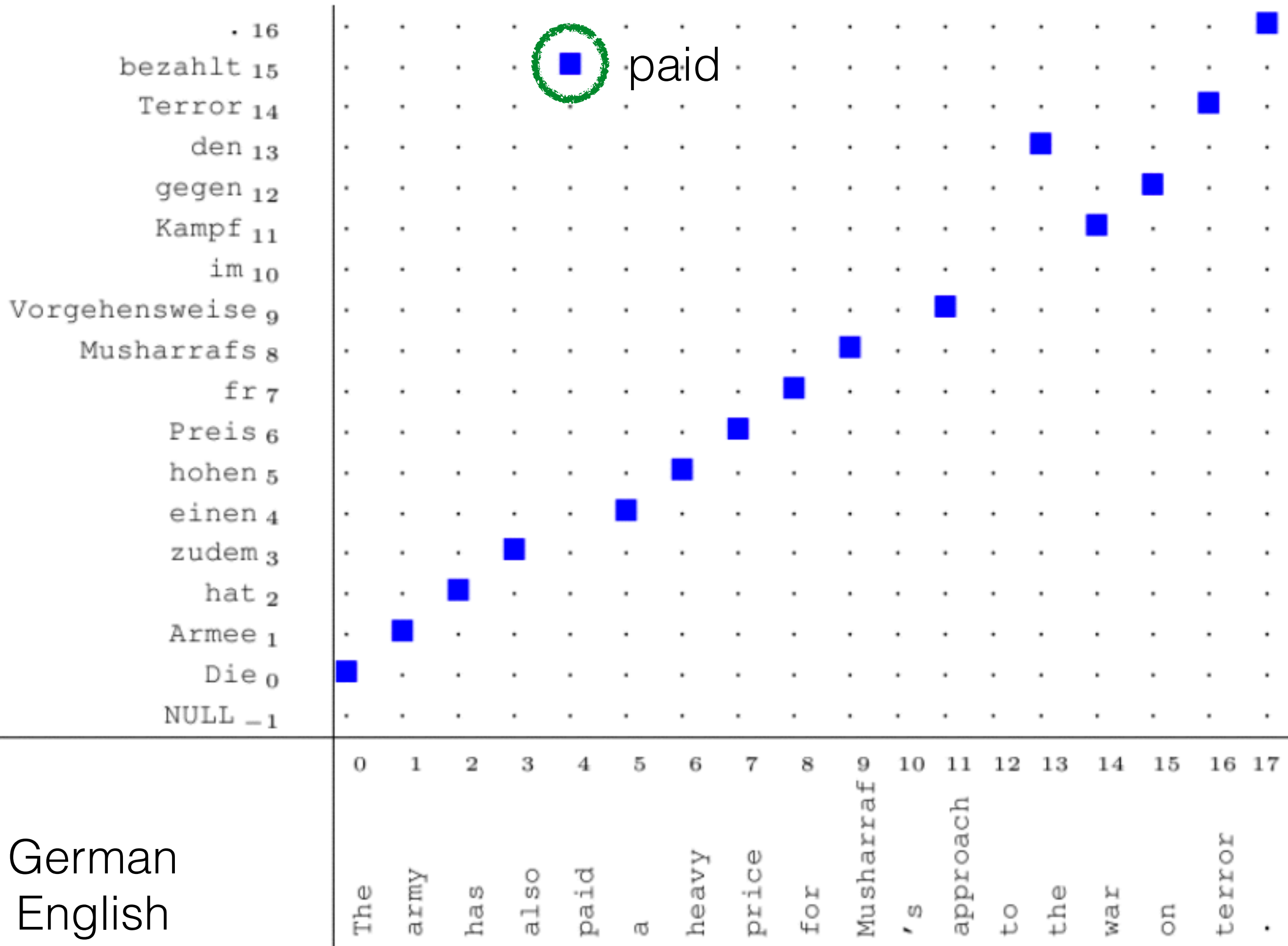
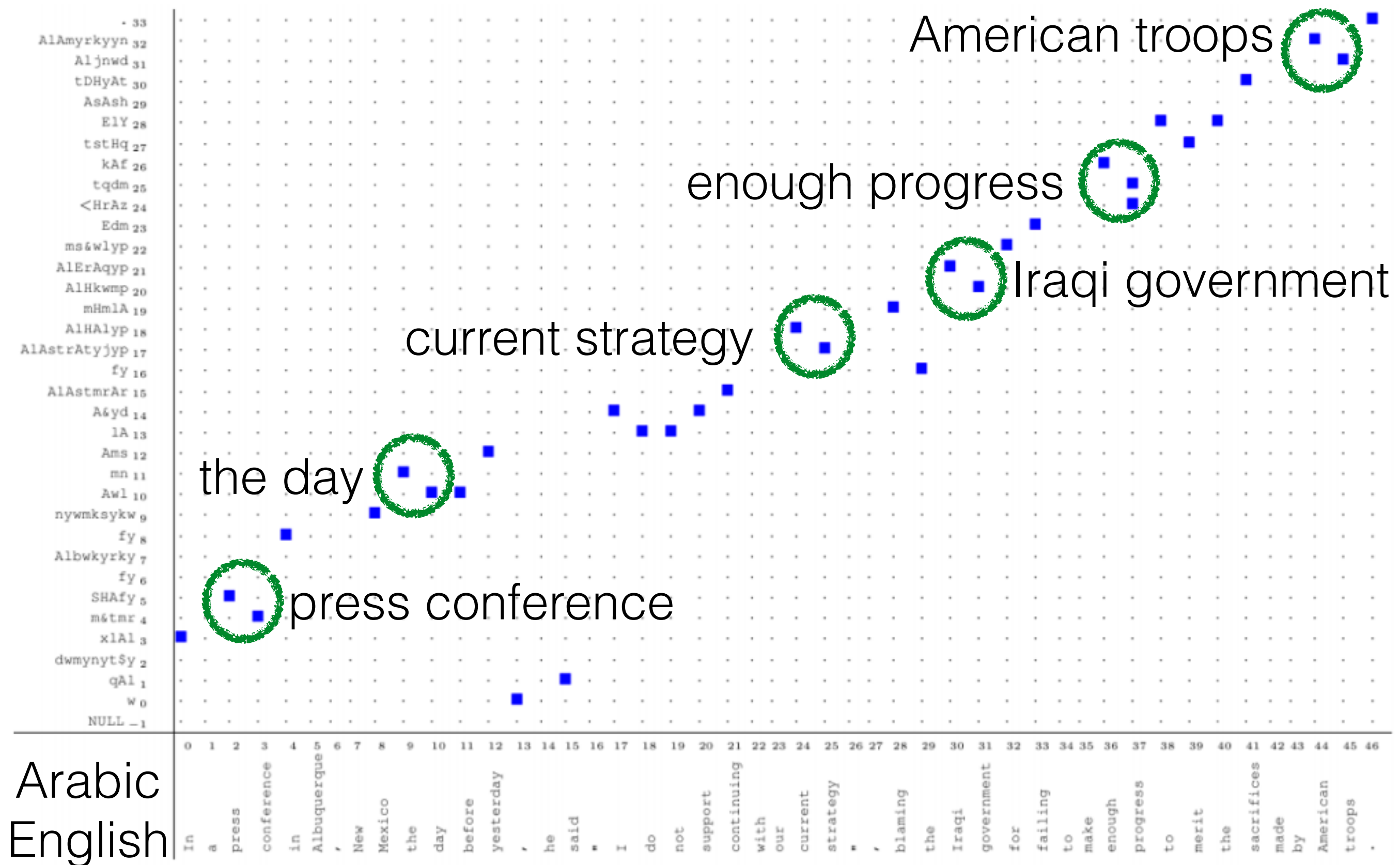
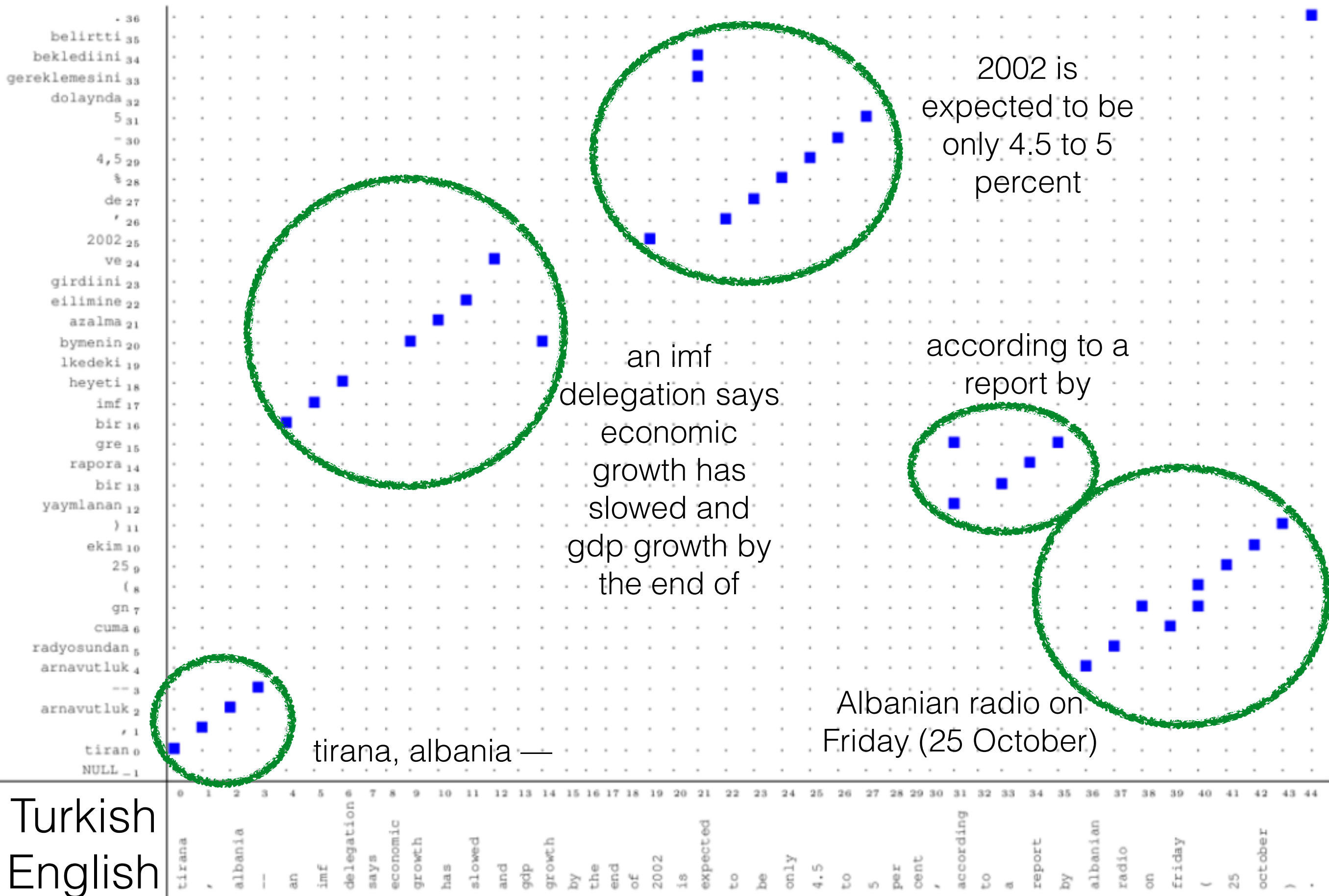


Syntax and translation



Arabic
English





Substitution tests

Kim saw the { elephant, movie, mountain, error } before we did.

Substitution tests

Kim saw the { elephant, movie, mountain, error } before we did.

Kim saw the the big pink elephant before we did.

Substitution tests

Kim [read a book], [gave it to Sandy], and [left].

You said I should read the book and [read it] I did.

Kim read [a very interesting book about grammar].

Kim read [it].

Language is hierarchical

negative polarity items

The lecture that I gave did **not** appeal to **anybody**.

* The lecture that I gave appealed to **anybody**.

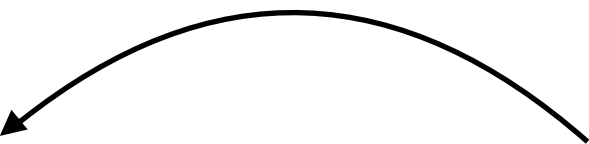
Language is hierarchical

negative polarity items

The lecture that I gave did **not** appeal to **anybody**.



* The lecture that I gave appealed to **anybody**.



Taroo-wa **nani-mo** tabe-**nakat**-ta
Taroo-Top what-MO eat-NEG-PST
'Taro didn't eat anything'

* Taroo-wa **nani-mo** tabe-ta
Taroo-Top **what-MO** eat-PST

Language is hierarchical

negative polarity items

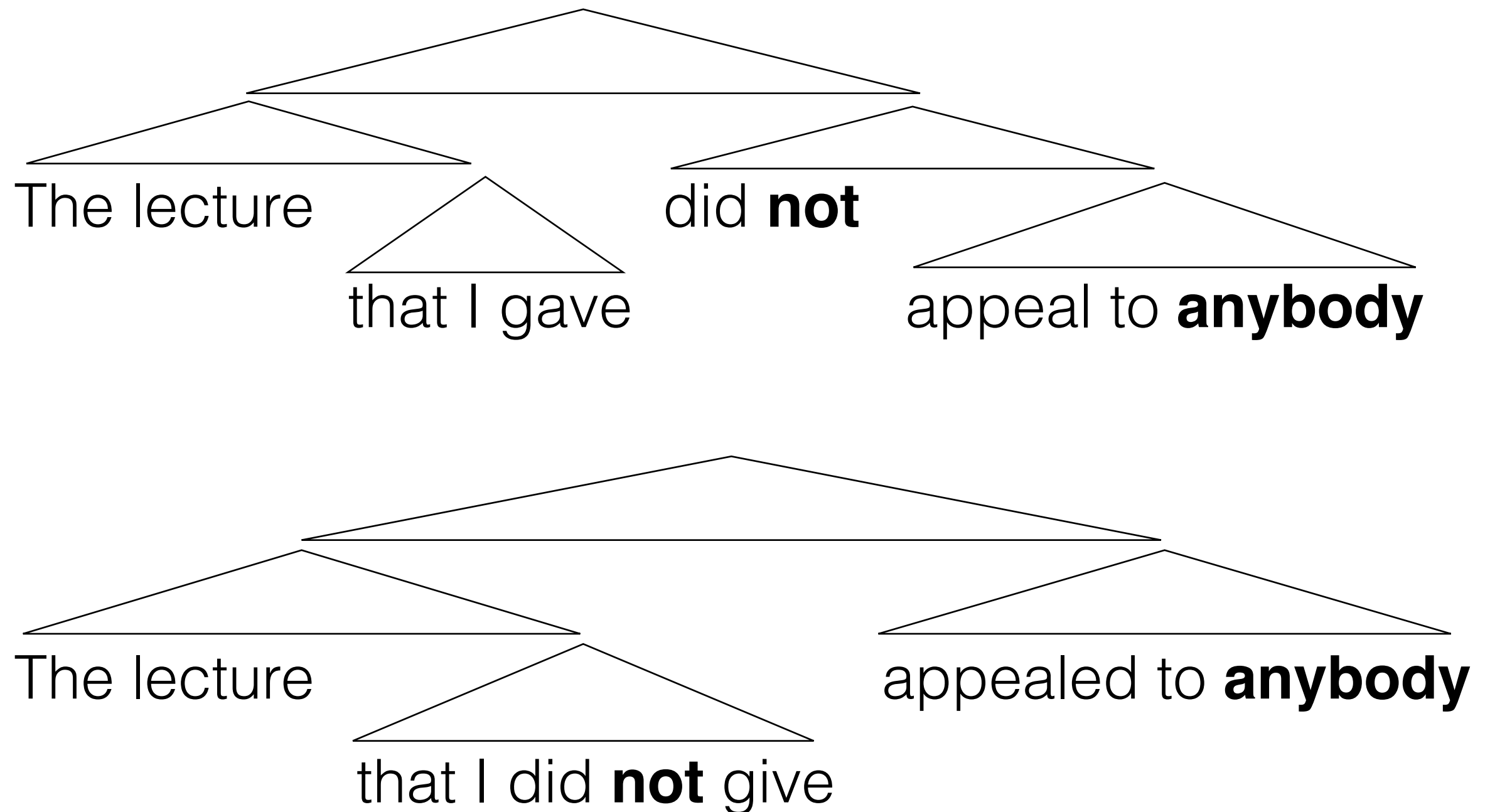
The lecture that I gave did **not** appeal to **anybody**.

* The lecture that I gave appealed to **anybody**.

* The lecture that I did **not** give appealed to **anybody**.

Language is hierarchical

negative polarity items



Syntax matters

- The brown dog on the mat saw the striped cat through the window.
- The brown cat saw the striped dog through the window on the mat.
- Dog the mat brown on striped the window saw through cat the the.

SUBJECT

VERB

OBJECT

English

I ♥ NY

Welsh

♥ I NY

Malagasy

♥ NY I

Japanese

I NY ♥

Hixkaryana

NY I ♥

Nadëb

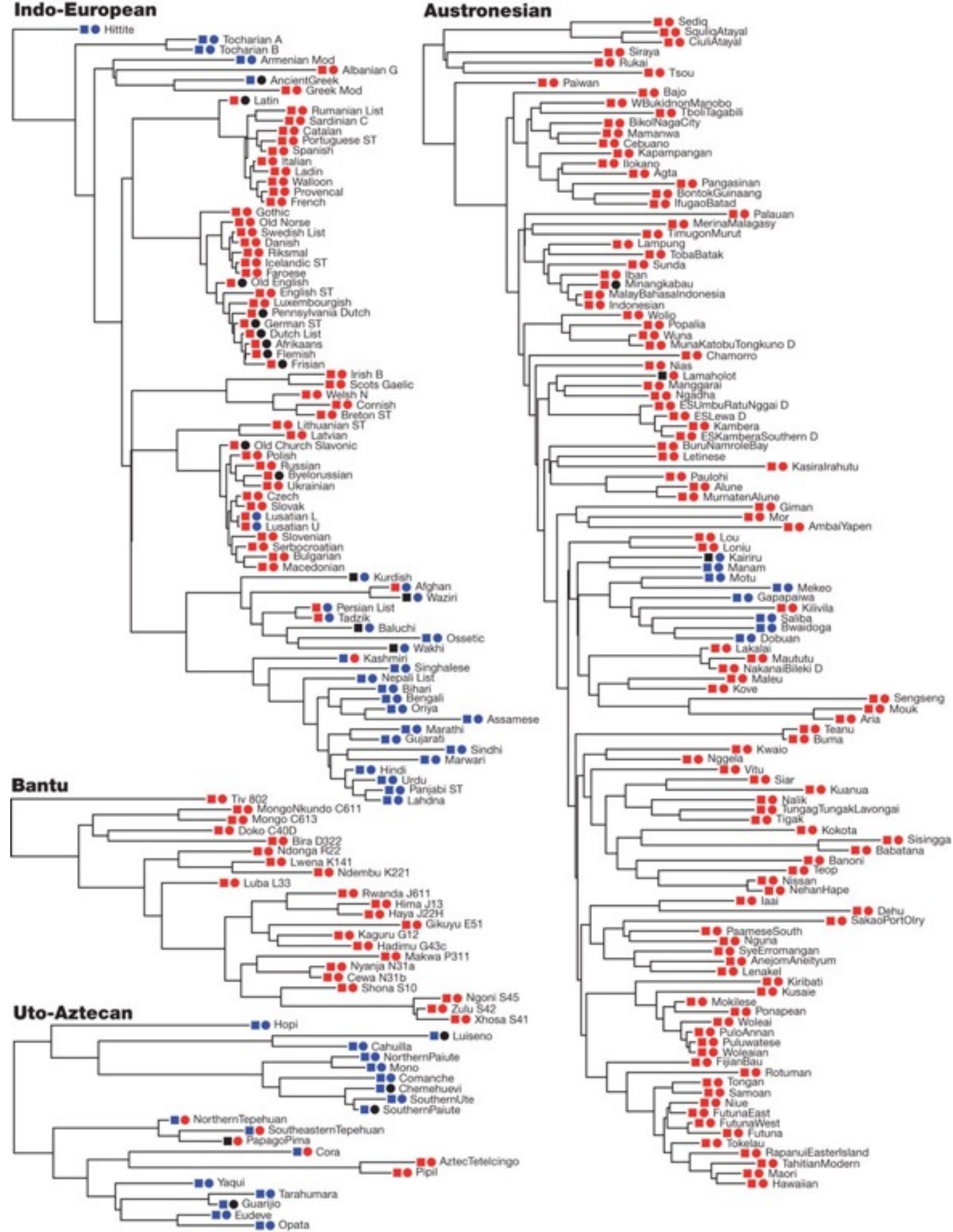
NY ♥ I

Variation in word order is a large area of research in linguistics. In the 1960's, a linguist from Brooklyn, Joseph

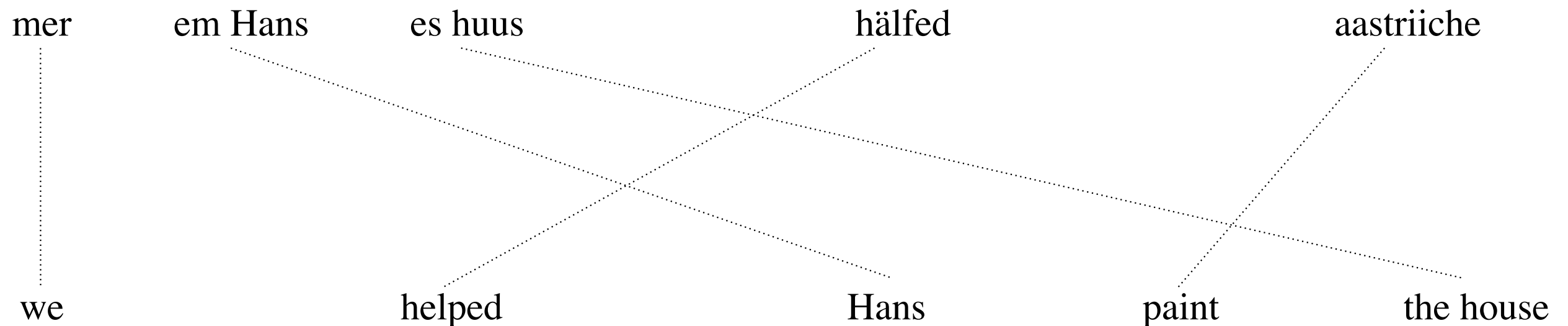
		<i>Indo-European</i>			<i>Afro-Asiatic</i>	<i>Altaic</i>	<i>Japanese</i>	<i>Sino-Tibet.</i>
Features		English	German	French	Arabic	Turkish	Japanese	Chinese
Clause-level	Subject,Object,Verb [Tom] [chases] [Jerry]	S-V-O	S-V-O/ S-O-V	S-V-O	V-S-O/ S-V-O*	S-O-V	S-O-V	S-V-O
	Oblique Phrase [chases] [Jerry] [with a stick]	V-O-X	mixed	V-O-X	V-O-X	X-O-V	X-O-V	X-V-O
	Noun,RelClause [a stick] [that he stole]	N-Rel	N-Rel	N-Rel	N-Rel*	Rel-N	Rel-N	Rel-N
	Subordinator,Clause [because] [he was hungry]	Sub-C	Sub-C	Sub-C	Sub-C	C-Sub/ Sub-C	C-Sub	mixed**
	PolarQuest.Particle ∅ [did Tom steal it?]	<i>none</i>	<i>none</i>	initial	initial	final	final	final
	ContentQuest.Phrase [what] [did Tom steal?]	initial	initial	initial	initial*	other	other	other
	Negation,Verb he did [not] [steal]	Neg-V	Neg-V/ V-Neg	Neg-V-Neg/ V-Neg	Neg-V	V-Neg	V-Neg	Neg-V

		<i>Indo-European</i>			<i>Afro-Asiatic</i>	<i>Altaic</i>	<i>Japanese</i>	<i>Sino-Tibet.</i>
Features		English	German	French	Arabic	Turkish	Japanese	Chinese
Phrase-level	Noun,Adpositions [with] [a stick]	Adp-N	Adp-N	Adp-N	Adp-N	N-Adp	N-Adp	N-Adp/ Adp-N
	Noun,Genitive [Tom's] [stick]	N-Gen/ Gen-N	N-Gen	N-Gen	N-Gen	Gen-N	Gen-N	Gen-N
	Noun,Adjective [hungry] [Tom]	A-N	A-N	N-A	N-A	A-N	A-N	A-N
	Noun,Demonstrative [this] [stick]	Dem-N	Dem-N	Dem-N	Dem-N	Dem-N	Dem-N	Dem-N
	Noun,Numeral [two] [sticks]	Num-N	Num-N	Num-N	Num-N	Num-N	Num-N	Num-N
	Adjective,DegreeW. [very] [hungry]	Deg-A	Deg-A	Deg-A	A-Deg	Deg-A	Deg-A	Deg-A
Feature		English	German	French	Arabic	Turkish	Japanese	Chinese

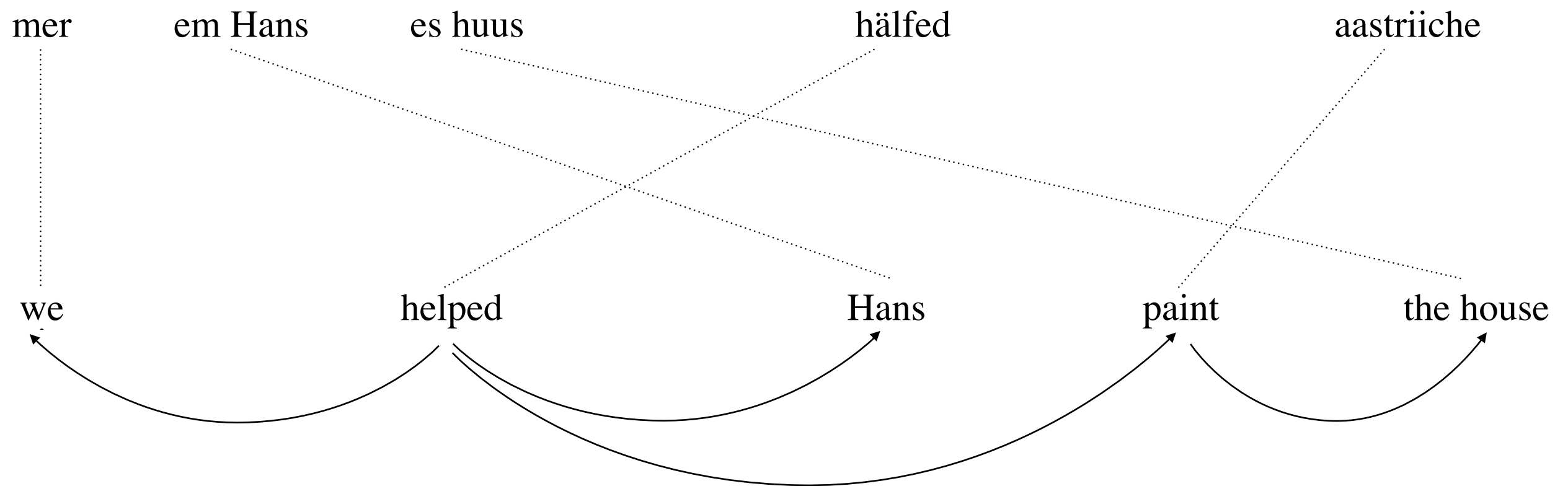




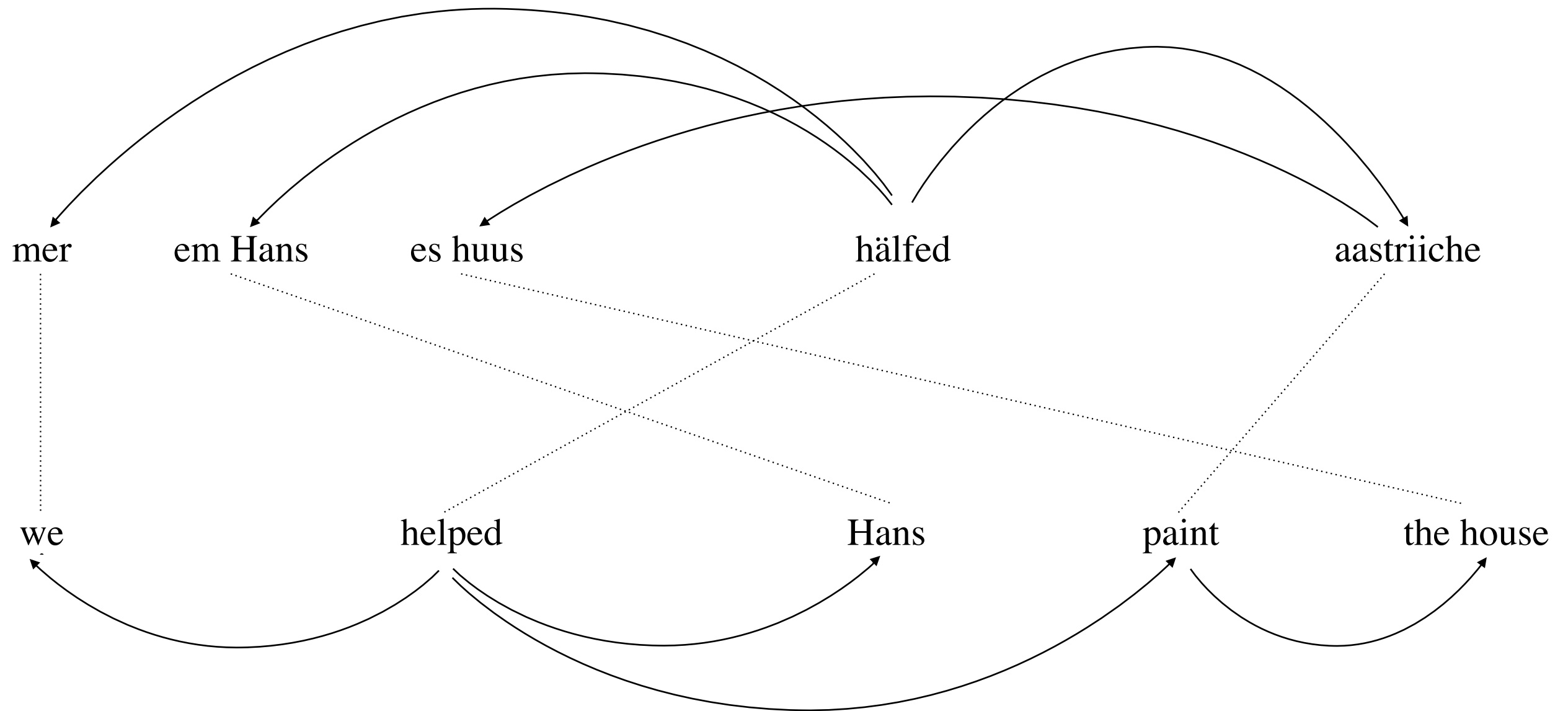
Permutation is hierarchical



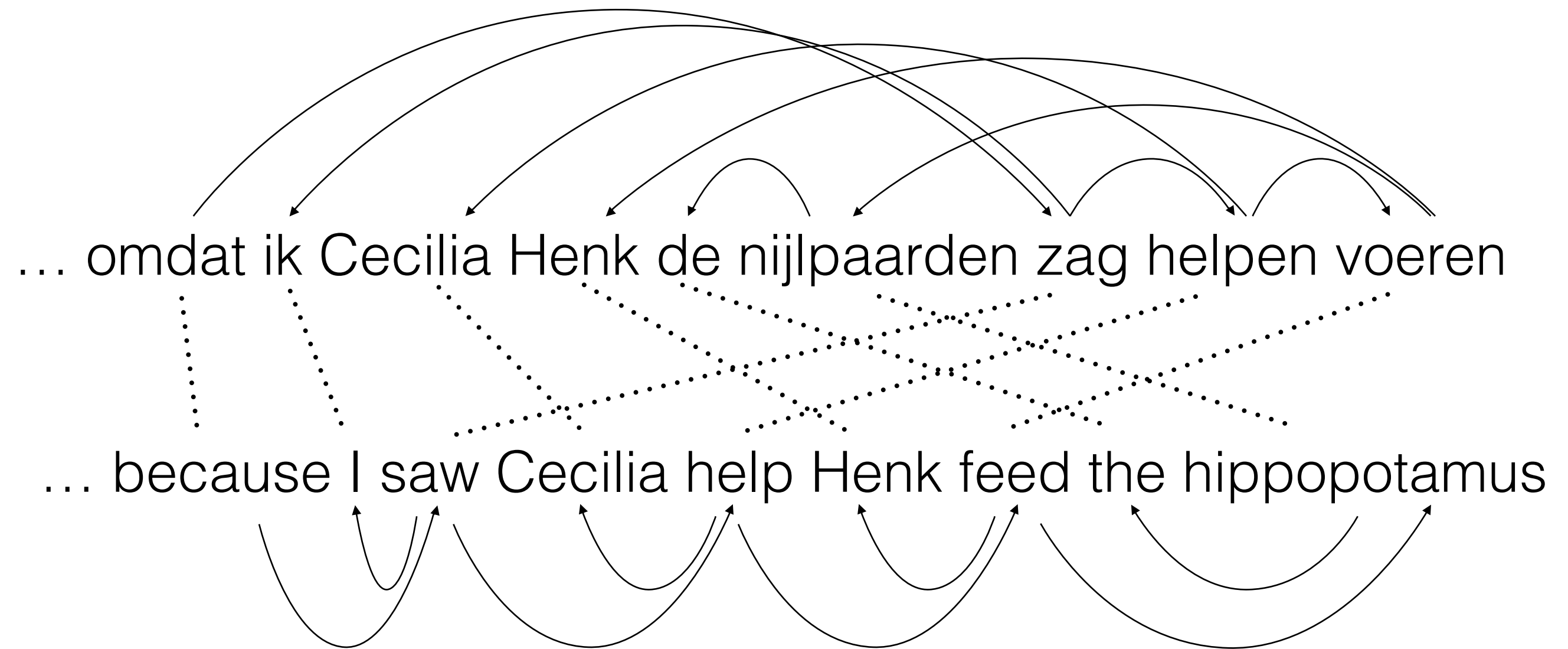
Permutation is hierarchical



Permutation is hierarchical



Permutation is hierarchical



la empresa tiene enemigos fuertes en Europa .
the company has strong enemies in Europe .

Garcia and associates .

Garcia y asociados .

Carlos Garcia has three associates .

Carlos Garcia tiene tres asociados .

his associates are not strong .

sus asociados no son fuertes .

Garcia has a company also .

Garcia tambien tiene una empresa .

its clients are angry .

sus clientes estan enfadados .

the associates are also angry .

los asociados tambien estan enfadados .

the clients and the associates are enemies .

los clientes y los asociados son enemigos .

the company has three groups .

la empresa tiene tres grupos .

its groups are in Europe .

sus grupos estan en Europa .

the modern groups sell strong pharmaceuticals .

los grupos modernos venden medicinas fuertes .

the groups do not sell zanzanine .

los grupos no venden zanzanina .

the small groups are not modern .

los grupos pequenos no son modernos .

la empresa tiene enemigos fuertes en Europa .

the company has **strong enemies** in Europe .

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Same pattern:
NN JJ → JJ NN

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the company has **strong enemies** in Europe .

Same pattern:
NN JJ → JJ NN

Phrase-based models do not capture
this generalization. Do NMT models?

sus asociados no son fuertes .

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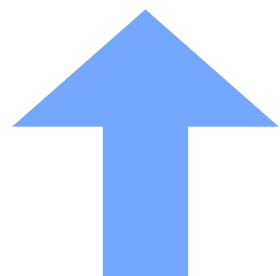
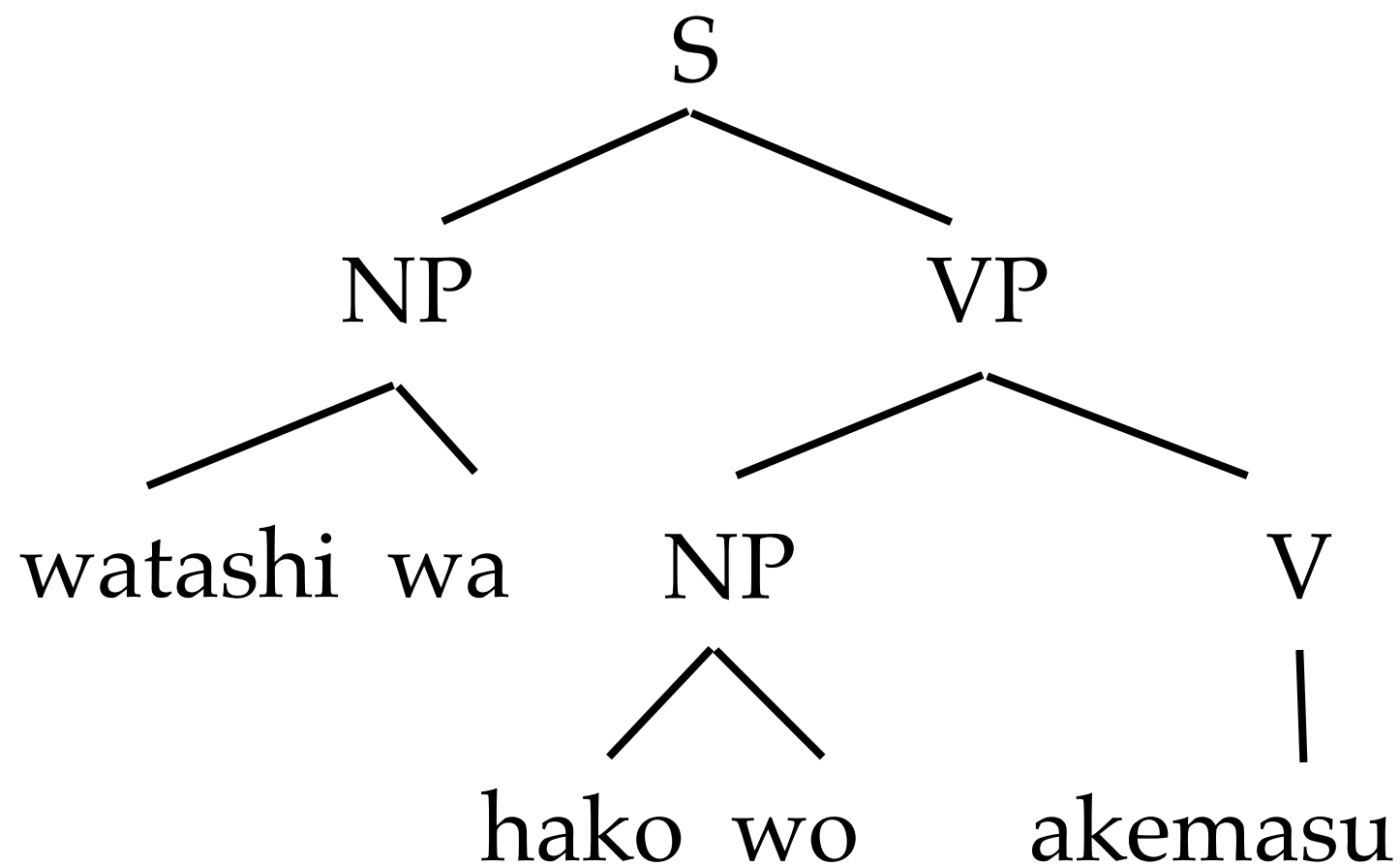
A brief history of a bad idea

- Syntax-based translation
- Dominated much of academic MT research between 2003-2013 (but Google also did a lot of experimentation with it internally).
- Based on observations above.

Syntax-based Translation

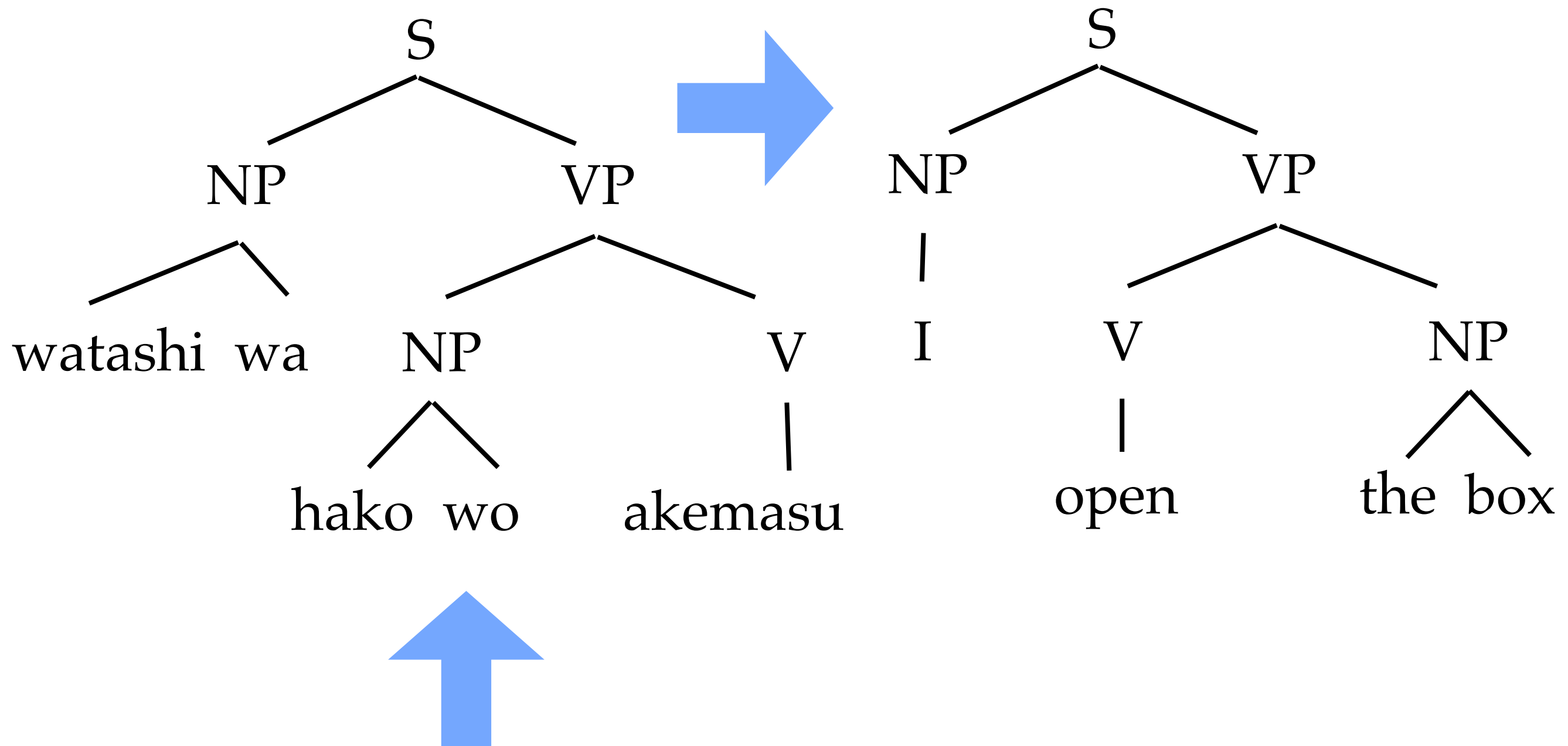
watashi wa hako wo akemasu

Syntax-based Translation



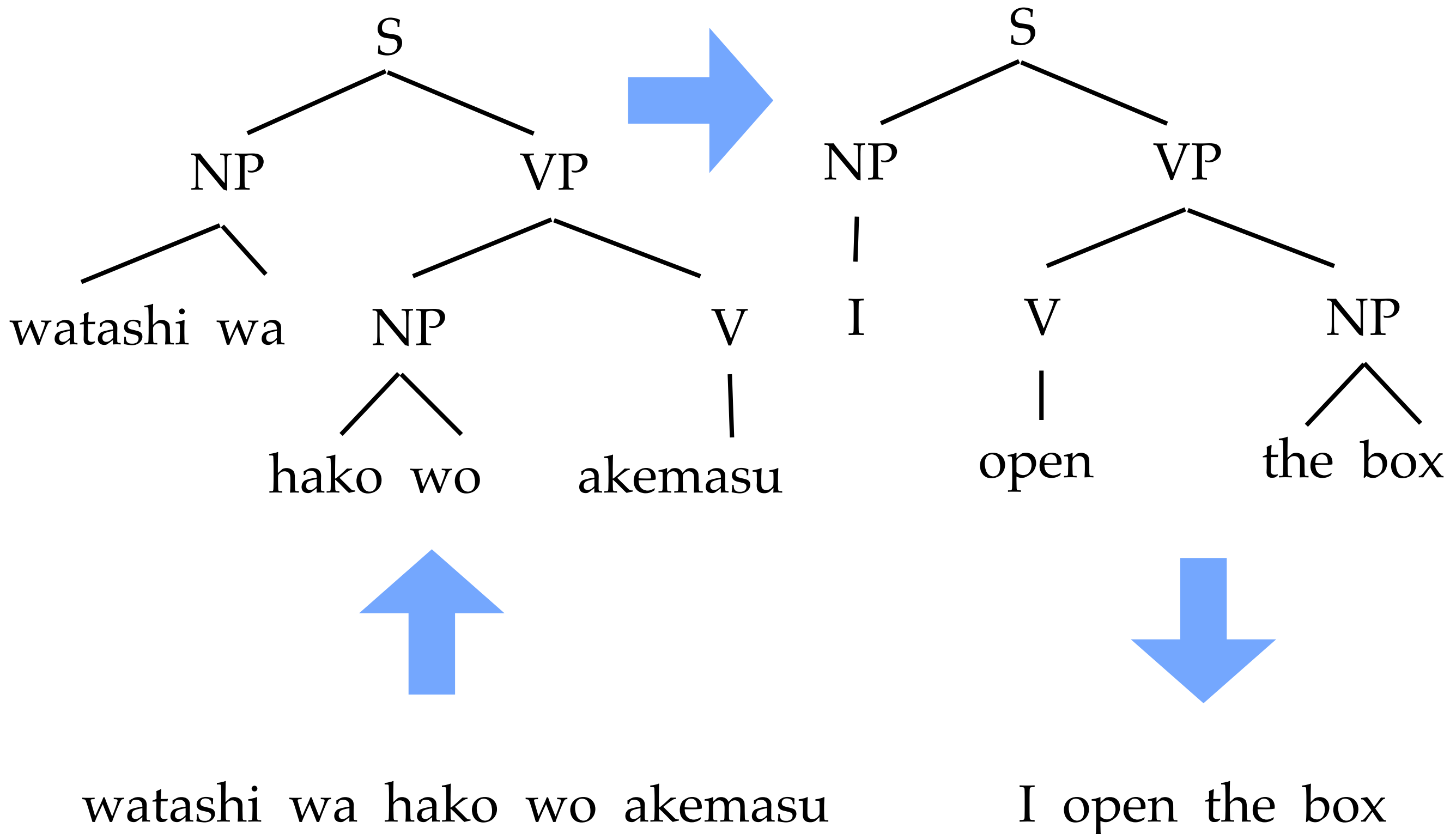
watashi wa hako wo akemasu

Syntax-based Translation



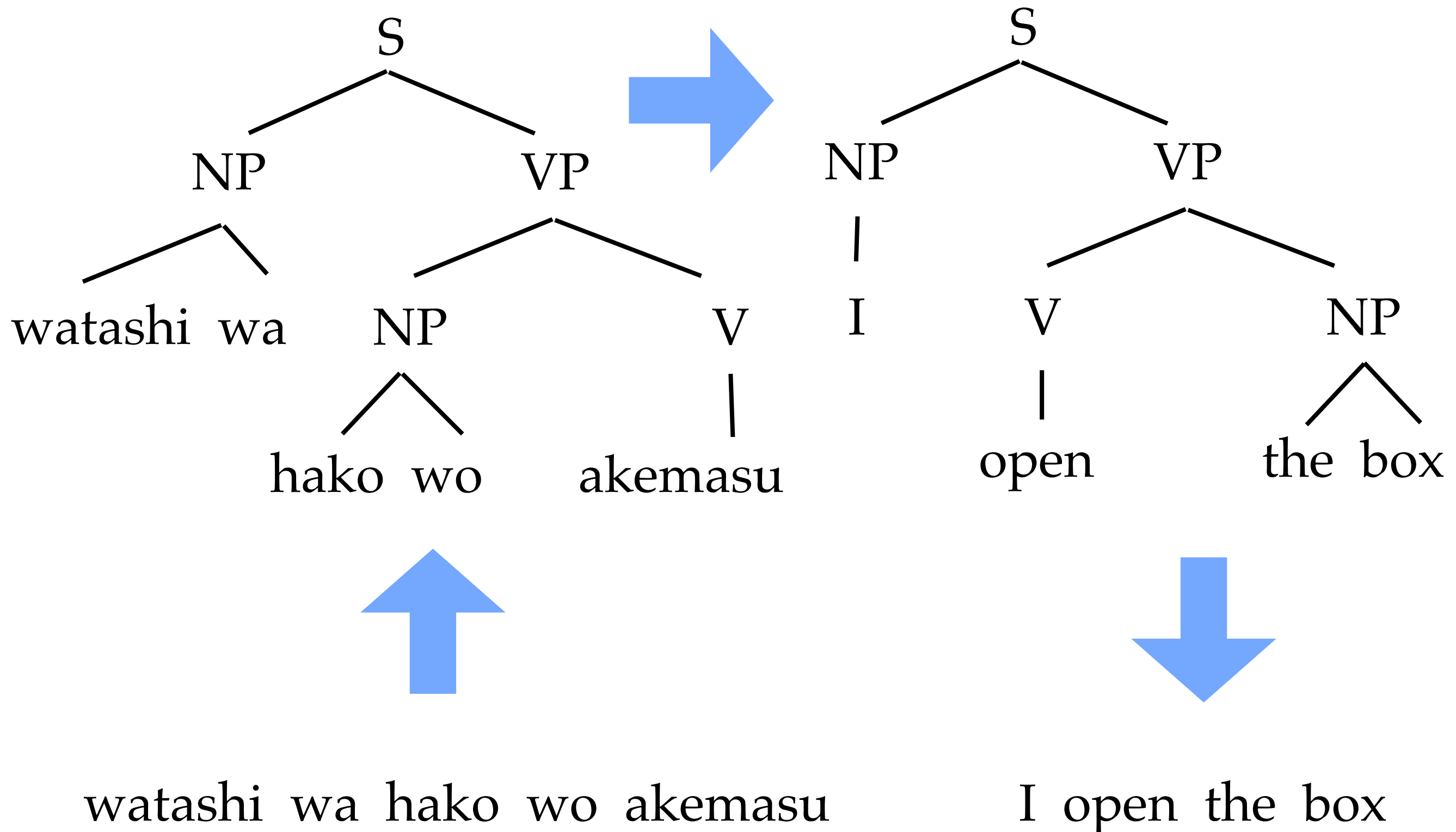
watashi wa hako wo akemasu

Syntax-based Translation



Syntax-based Translation

= Pushdown assembler (Aho and Ullman 1969)



Synchronous Context-Free Grammar

Originally: syntax-directed transduction (Lewis & Stearns 1966; Aho and Ullman 1969)

$S \rightarrow NP VP$

$NP \rightarrow watashi wa$

$NP \rightarrow hako wo$

$VP \rightarrow NP V$

$V \rightarrow akemasu$

Synchronous Context-Free Grammar

Originally: syntax-directed transduction (Lewis & Stearns 1966; Aho and Ullman 1969)

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$NP \rightarrow watashi wa$

$NP \rightarrow hako wo$

$VP \rightarrow NP V$

$V \rightarrow akemasu$

$S \rightarrow NP VP$

$NP \rightarrow I$

$NP \rightarrow the\ box$

$VP \rightarrow V NP$

$V \rightarrow open$

Synchronous Context-Free Grammar

Originally: syntax-directed transduction (Lewis & Stearns 1966; Aho and Ullman 1969)

$S \rightarrow NP_1 VP_2, NP_1 VP_2$

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

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

$VP \rightarrow NP_1 V_2, V_2 NP_1$

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

Synchronous Context-Free Grammar

$S \rightarrow NP_1 VP_2 , NP_1 VP_2$

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

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

$VP \rightarrow NP_1 V_2 , V_2 NP_1$

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

Synchronous Context-Free Grammar

S

S

$S \rightarrow NP_1 VP_2 , NP_1 VP_2$

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

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$VP \rightarrow NP_1 V_2 , V_2 NP_1$

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

Synchronous Context-Free Grammar

$S \cdots S$

$S \rightarrow NP_1 VP_2 , NP_1 VP_2$

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

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

$VP \rightarrow NP_1 V_2 , V_2 NP_1$

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

Synchronous Context-Free Grammar

$S \dots\dots\dots S$

$S \rightarrow NP_1 VP_2, NP_1 VP_2$

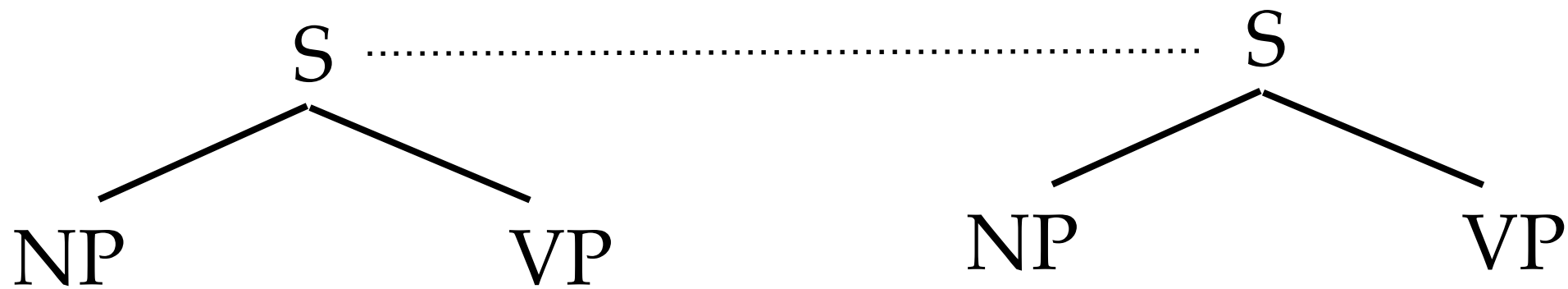
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Synchronous Context-Free Grammar



$S \rightarrow NP_1 VP_2, NP_1 VP_2$

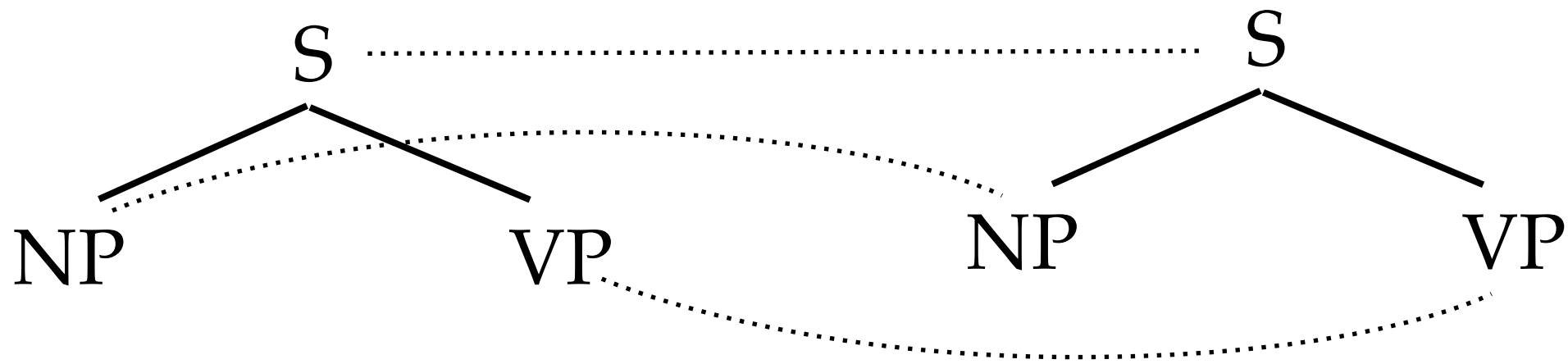
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Synchronous Context-Free Grammar



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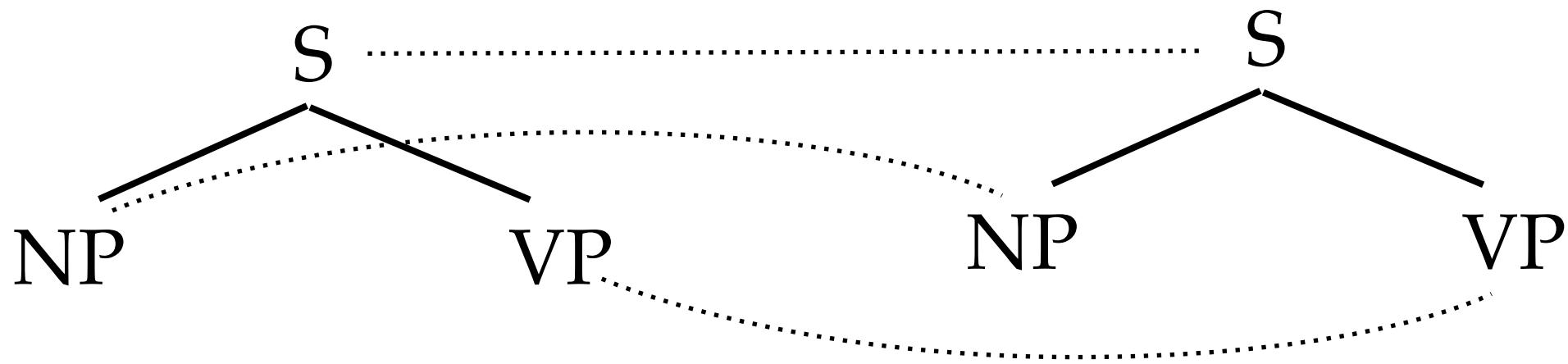
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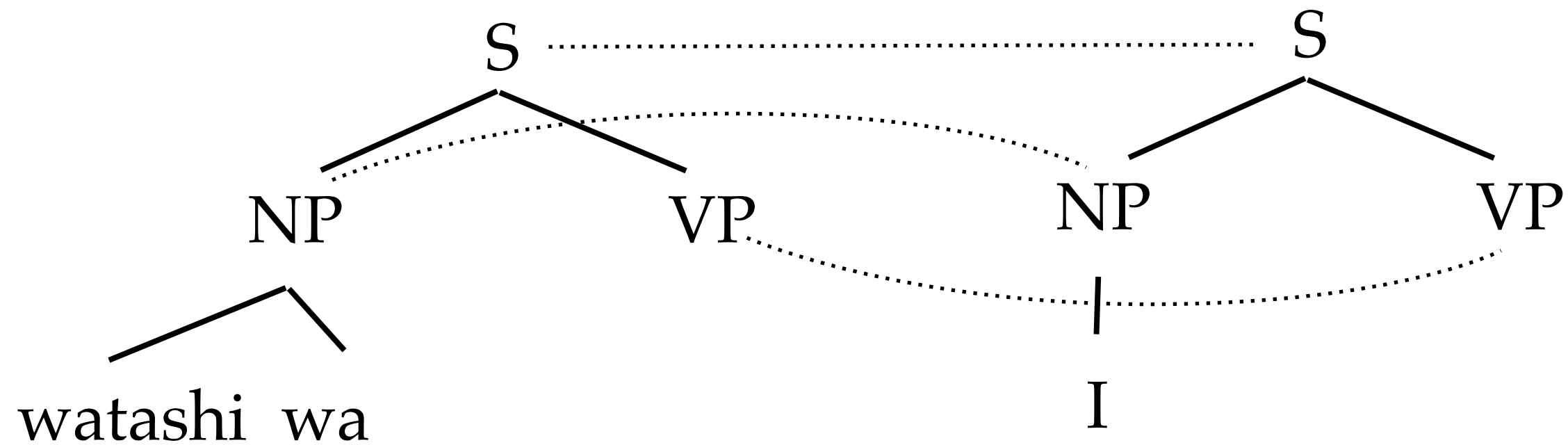
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Synchronous Context-Free Grammar



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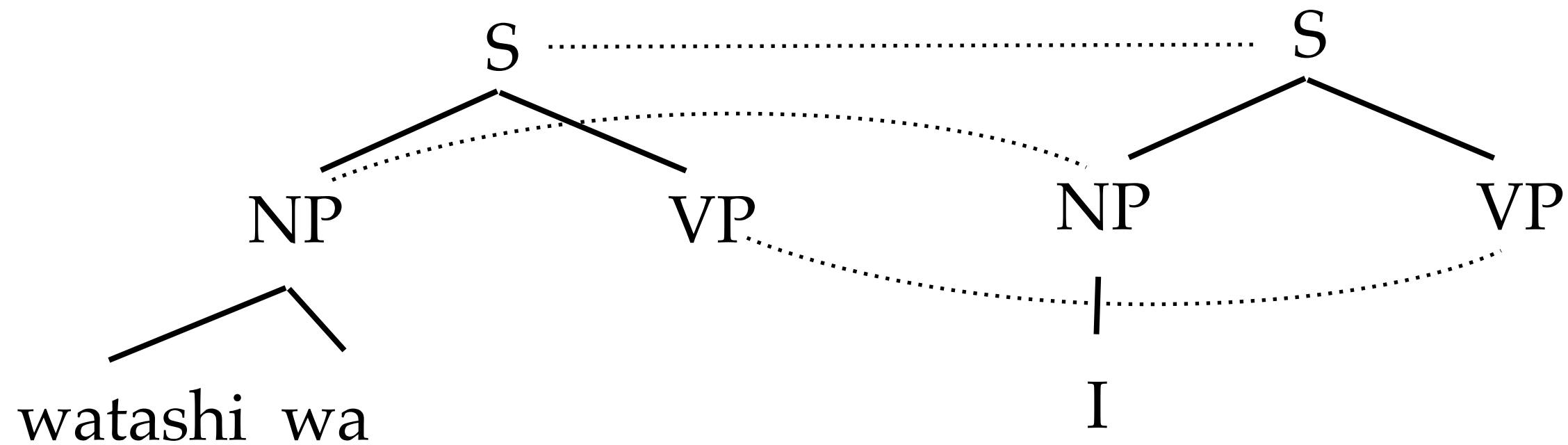
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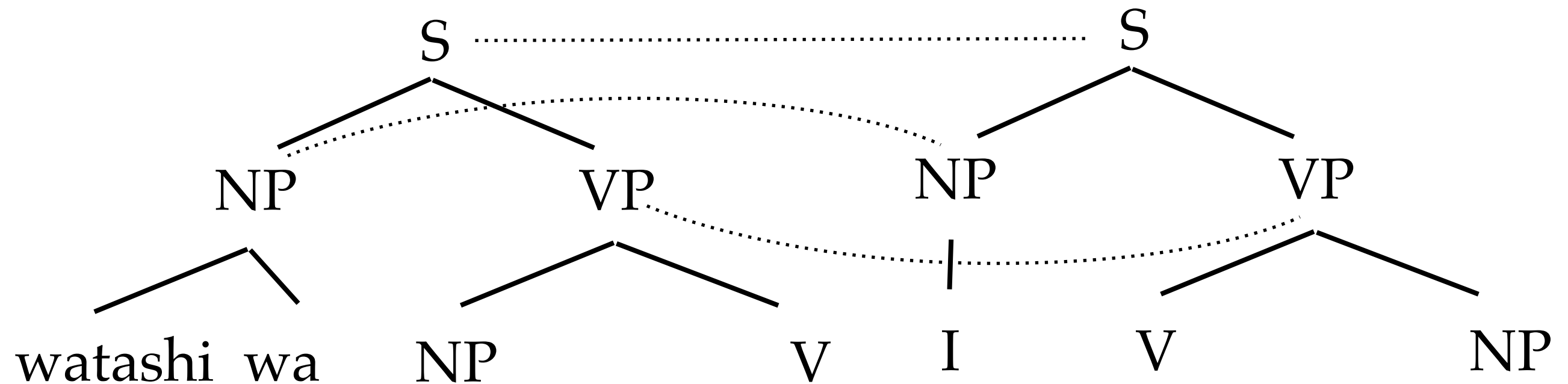
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$S \rightarrow NP_1 VP_2, NP_1 VP_2$

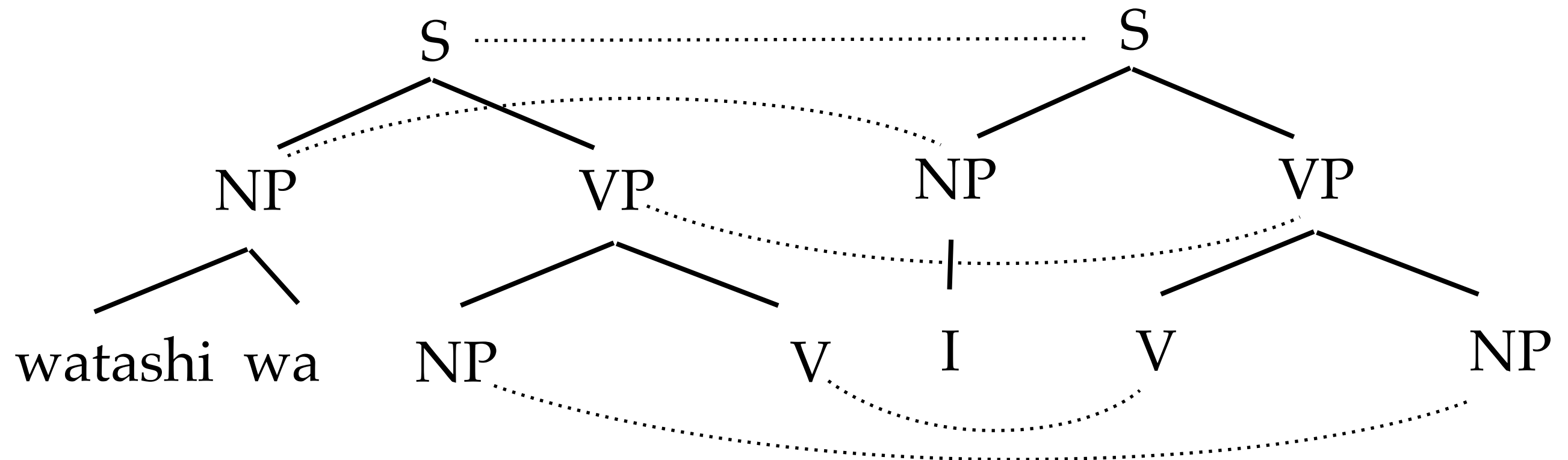
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Synchronous Context-Free Grammar



$S \rightarrow NP_1 VP_2, NP_1 VP_2$

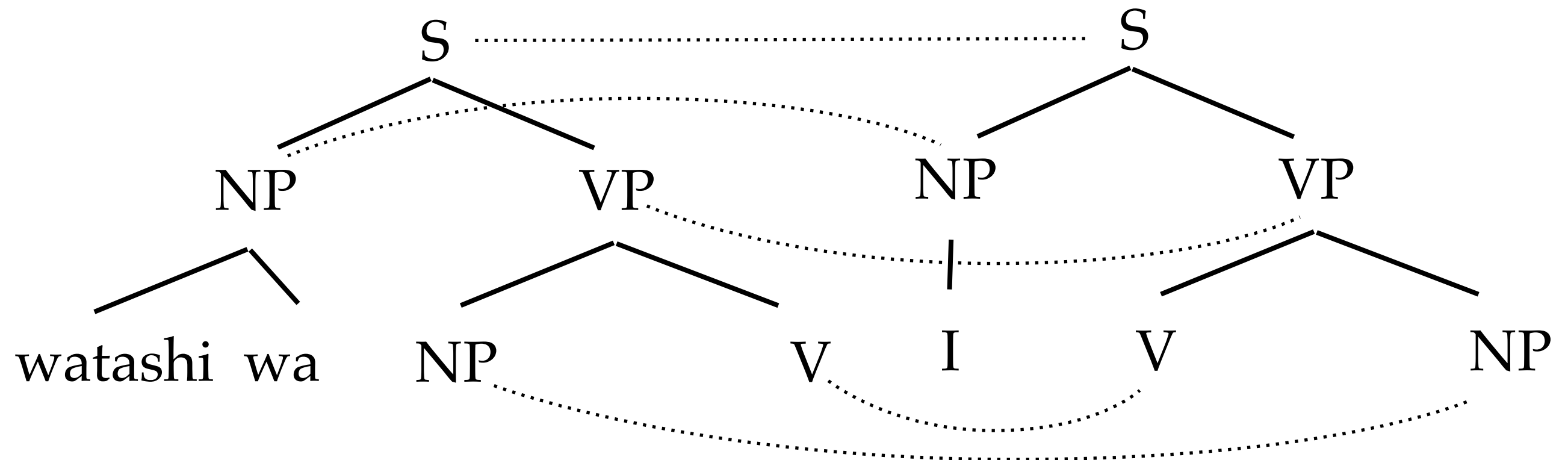
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Synchronous Context-Free Grammar



$S \rightarrow NP_1 VP_2, NP_1 VP_2$

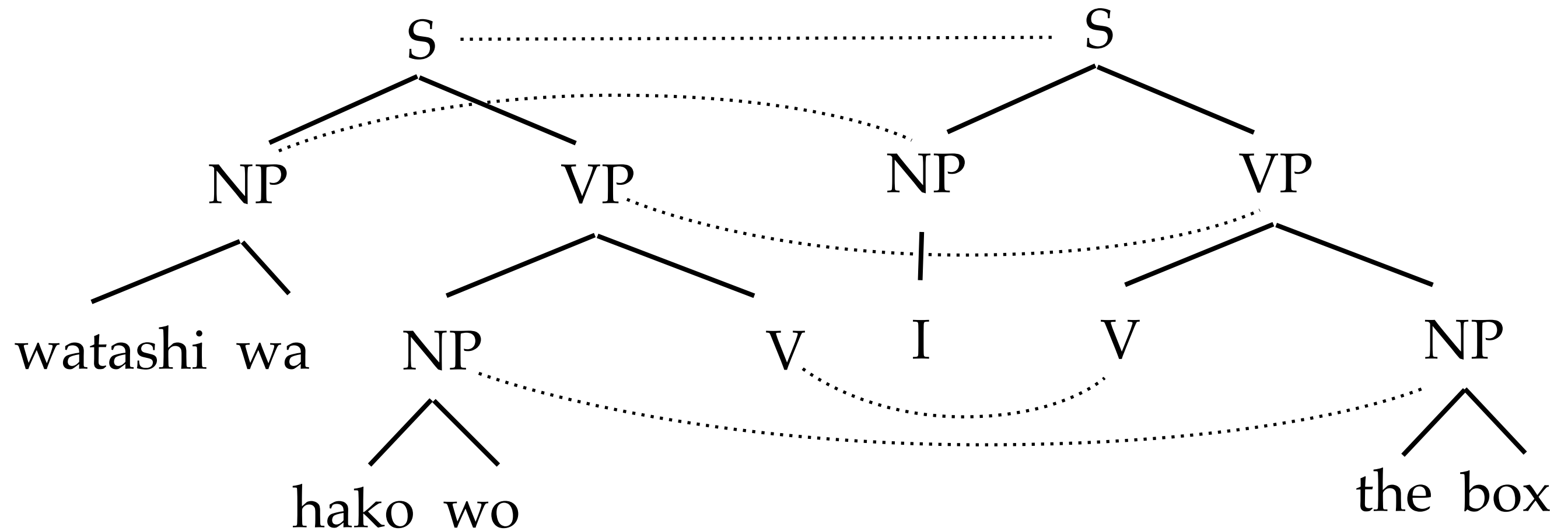
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Synchronous Context-Free Grammar



$S \rightarrow NP_1 VP_2, NP_1 VP_2$

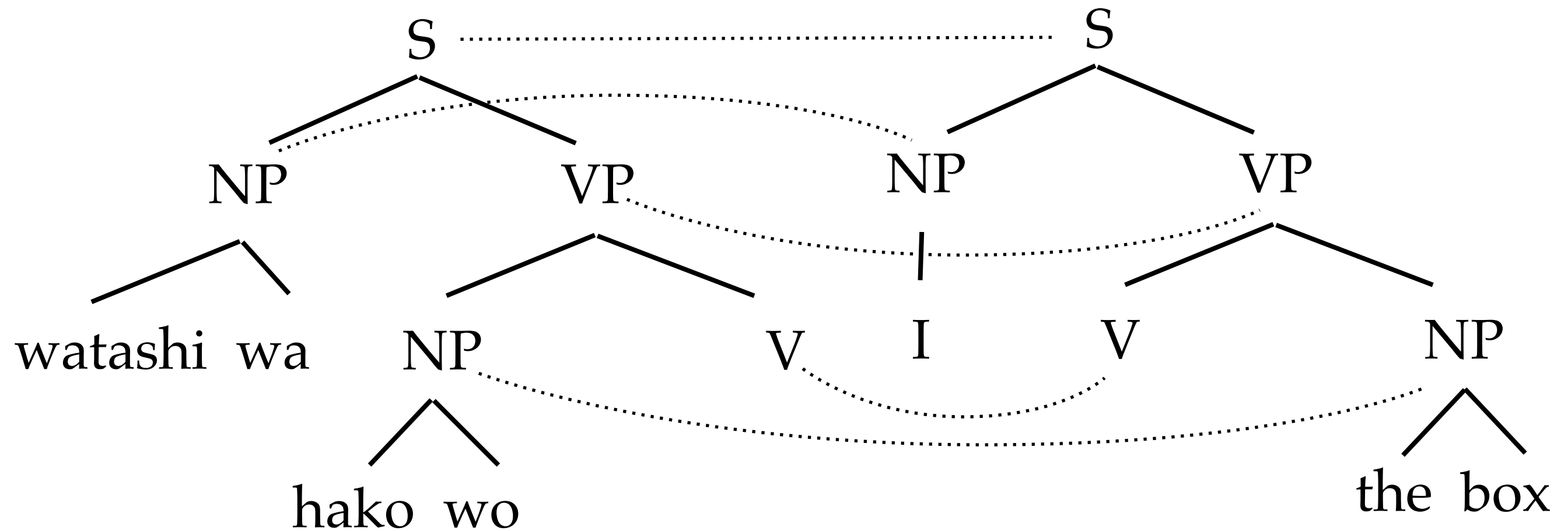
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Synchronous Context-Free Grammar



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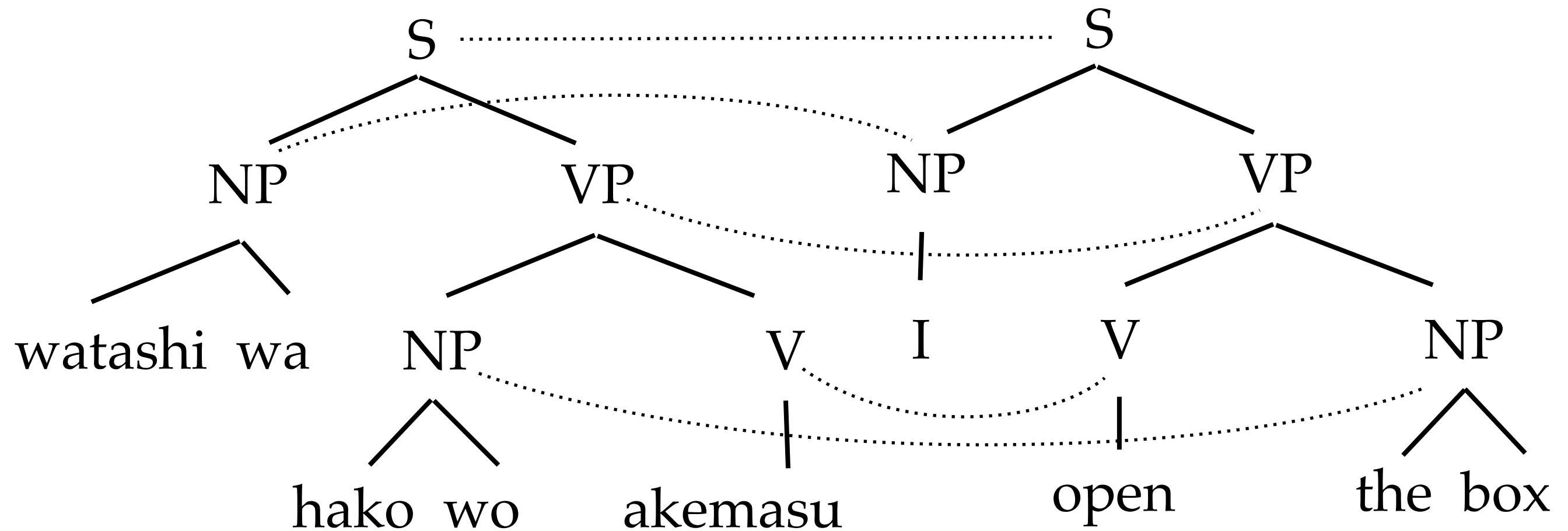
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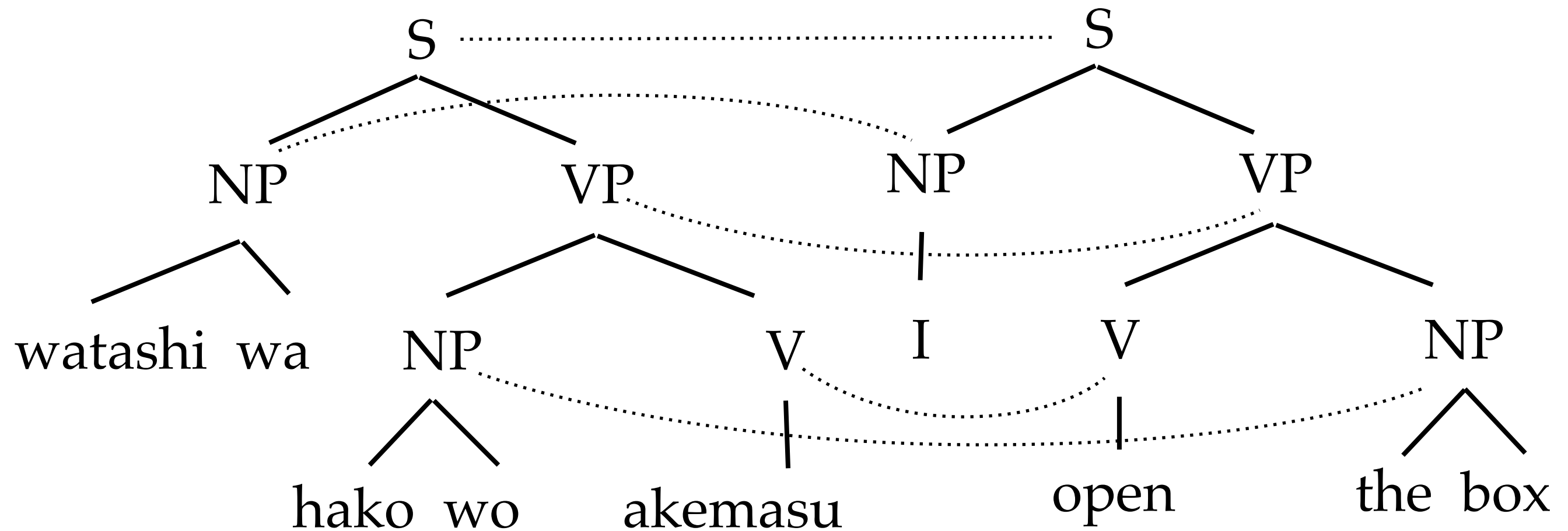
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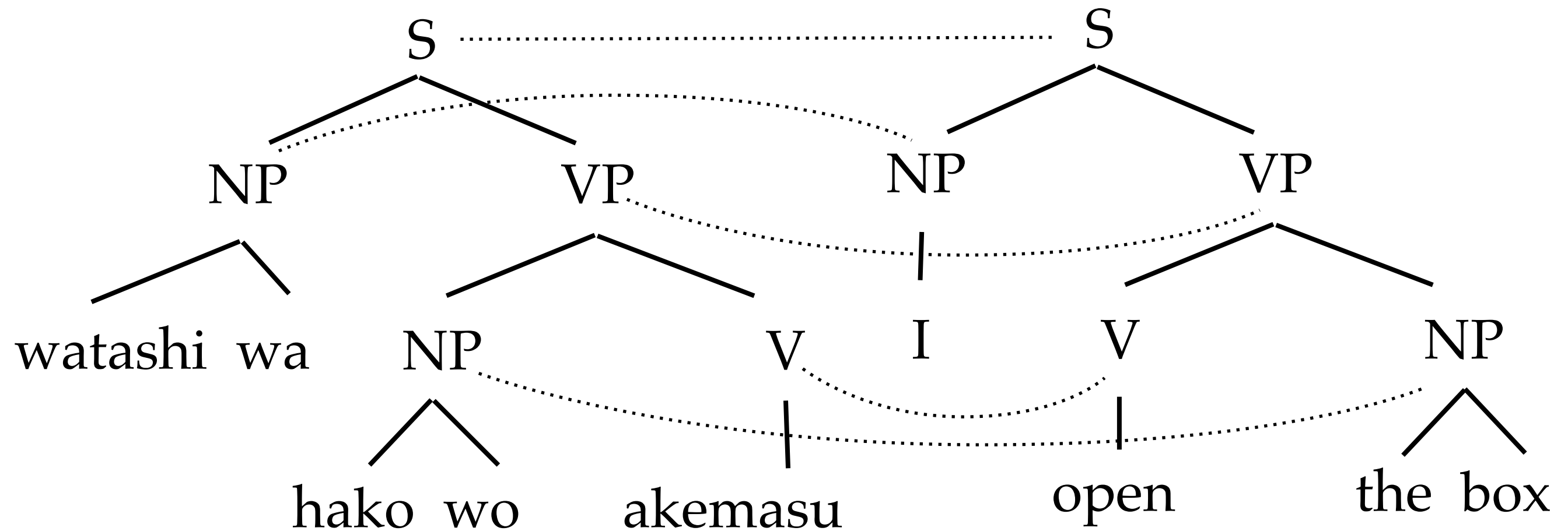
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$V \rightarrow \text{akemasu}, \text{open}$

Synchronous Context-Free Grammar

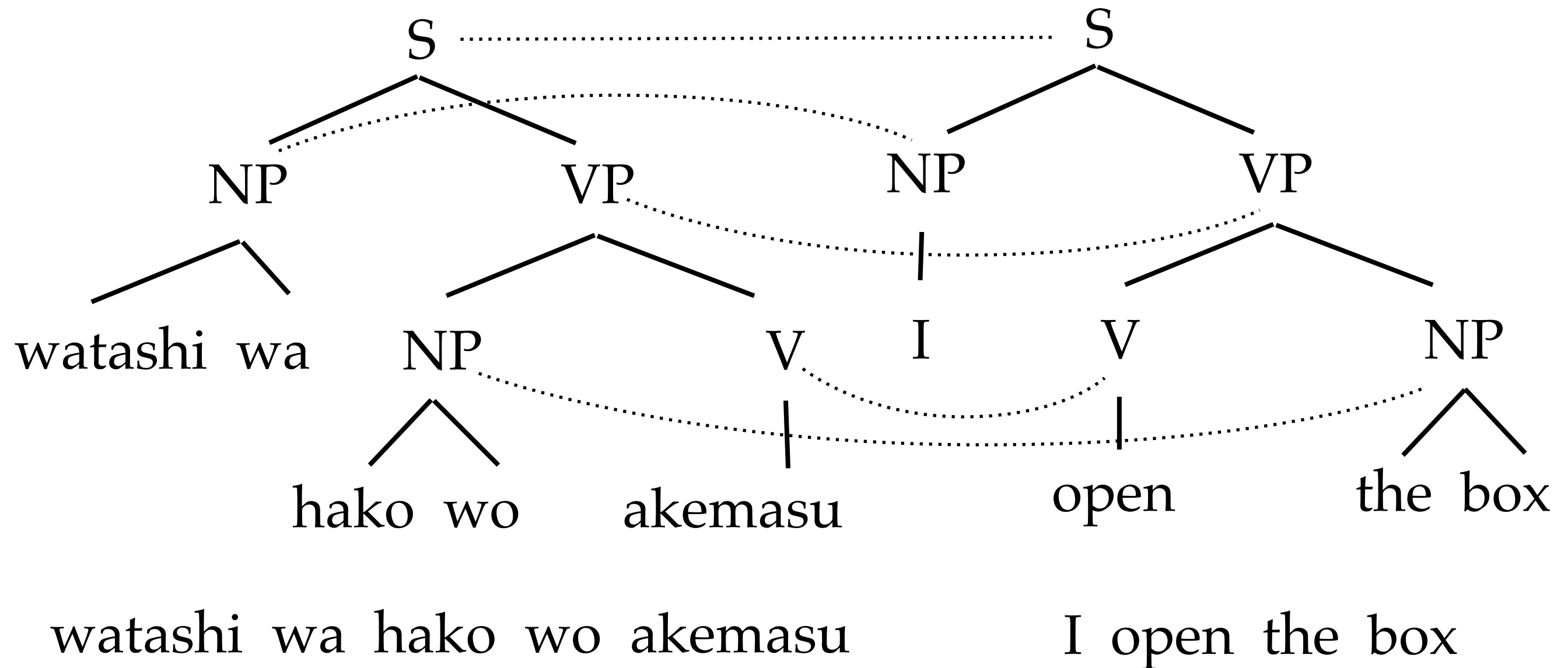


Synchronous Context-Free Grammar



watashi wa hako wo akemasu

Synchronous Context-Free Grammar



Important Note on Permutations

A rank-2 SCFG:

$$A \rightarrow A_1 A_2, A_1 A_2$$

$$A \rightarrow A_1 A_2, A_2 A_1$$

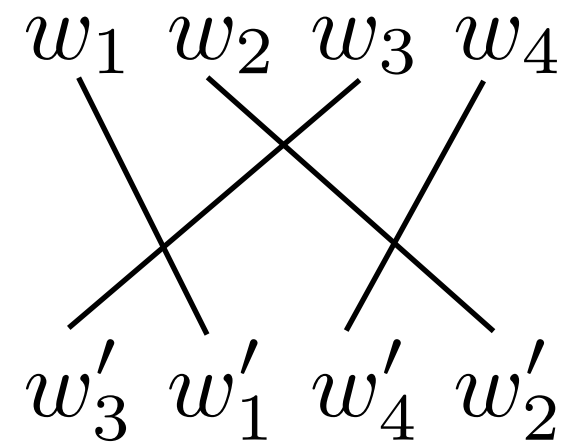
$$A \rightarrow w_1, w'_1$$

$$A \rightarrow w_2, w'_2$$

$$A \rightarrow w_3, w'_3$$

$$A \rightarrow w_4, w'_4$$

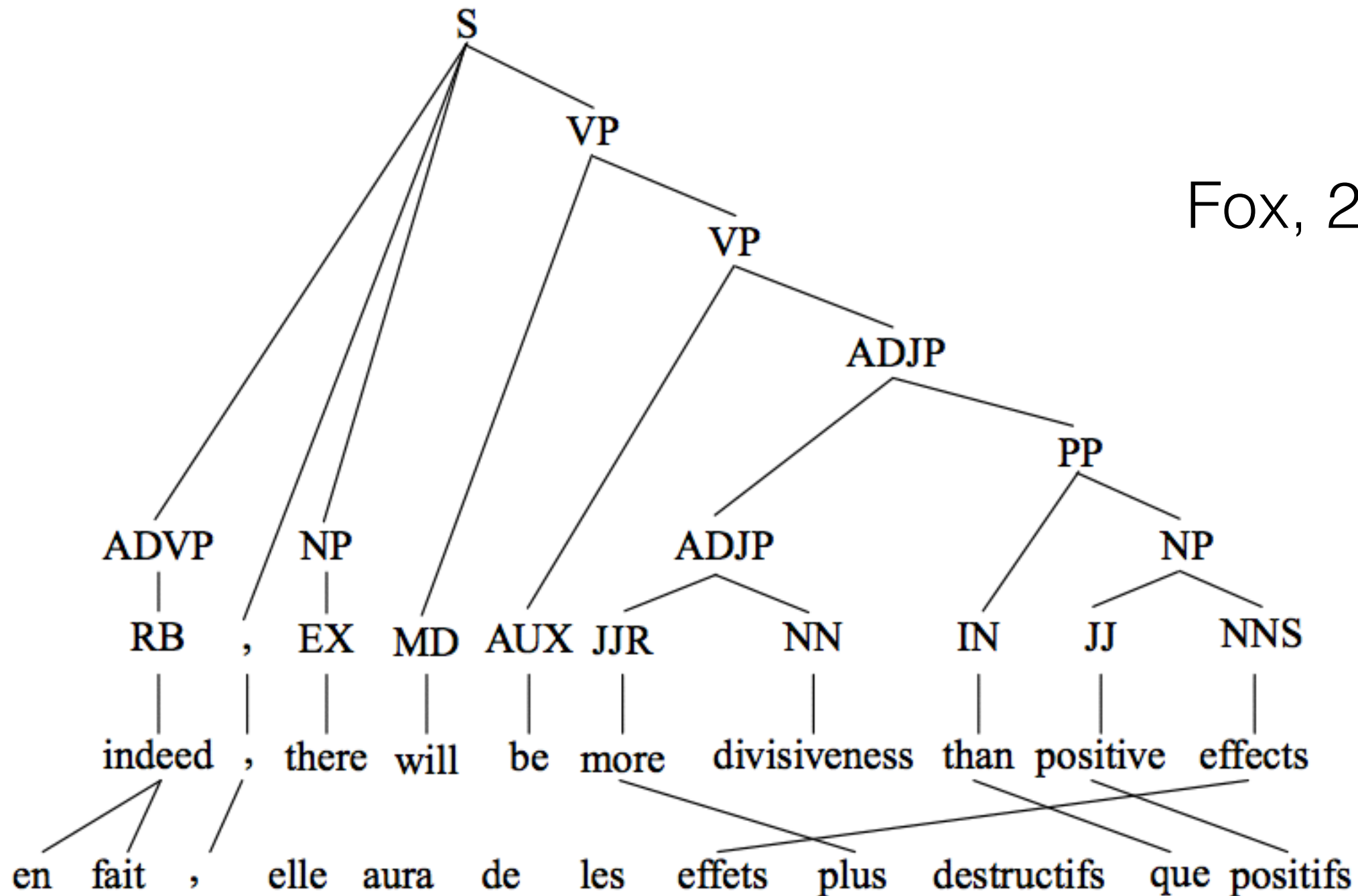
Cannot represent alignment:



This doesn't work. Why?

This doesn't work. Why?

Fox, 2002



This doesn't work. Why?

Fox, 2002

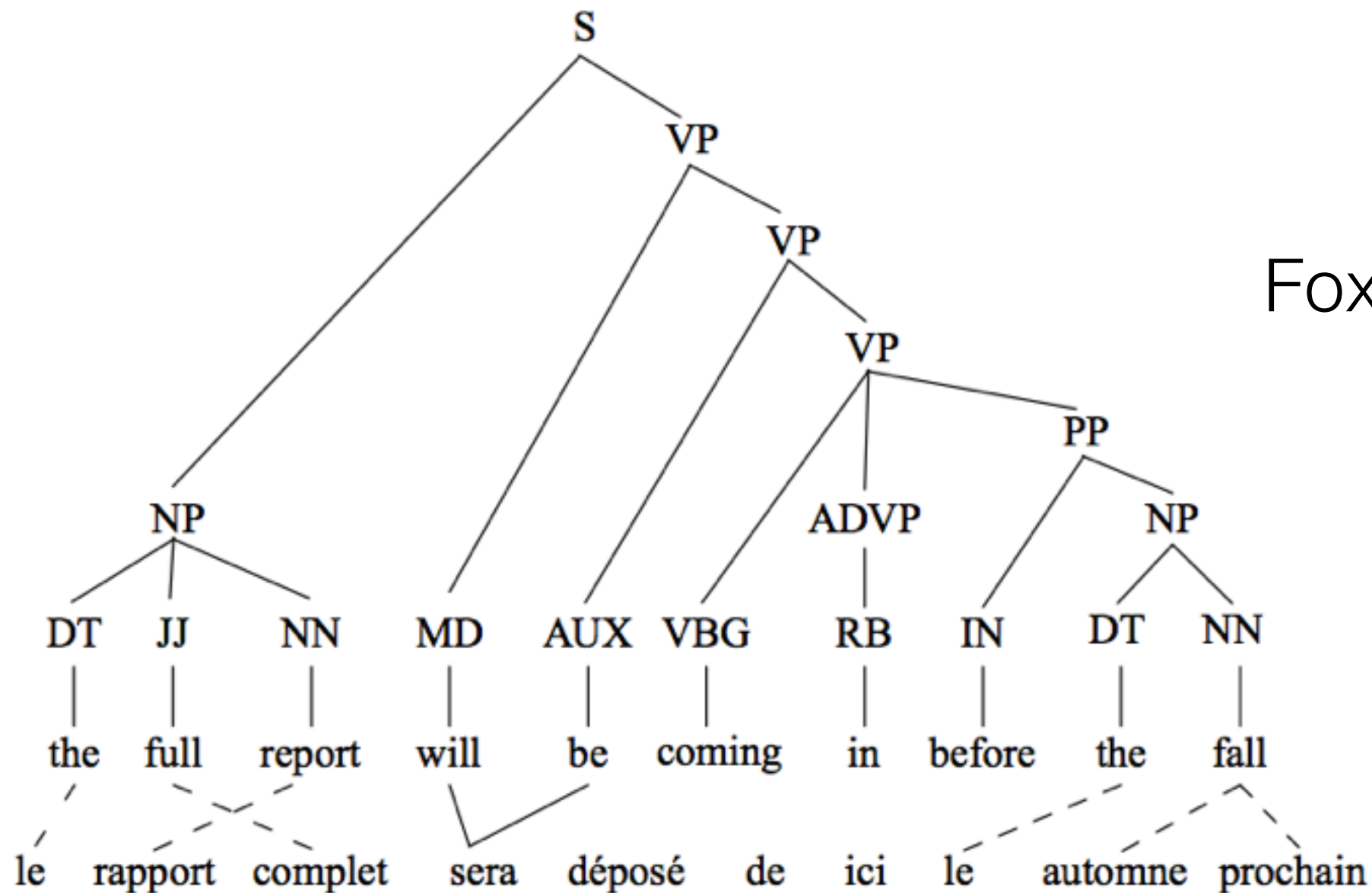
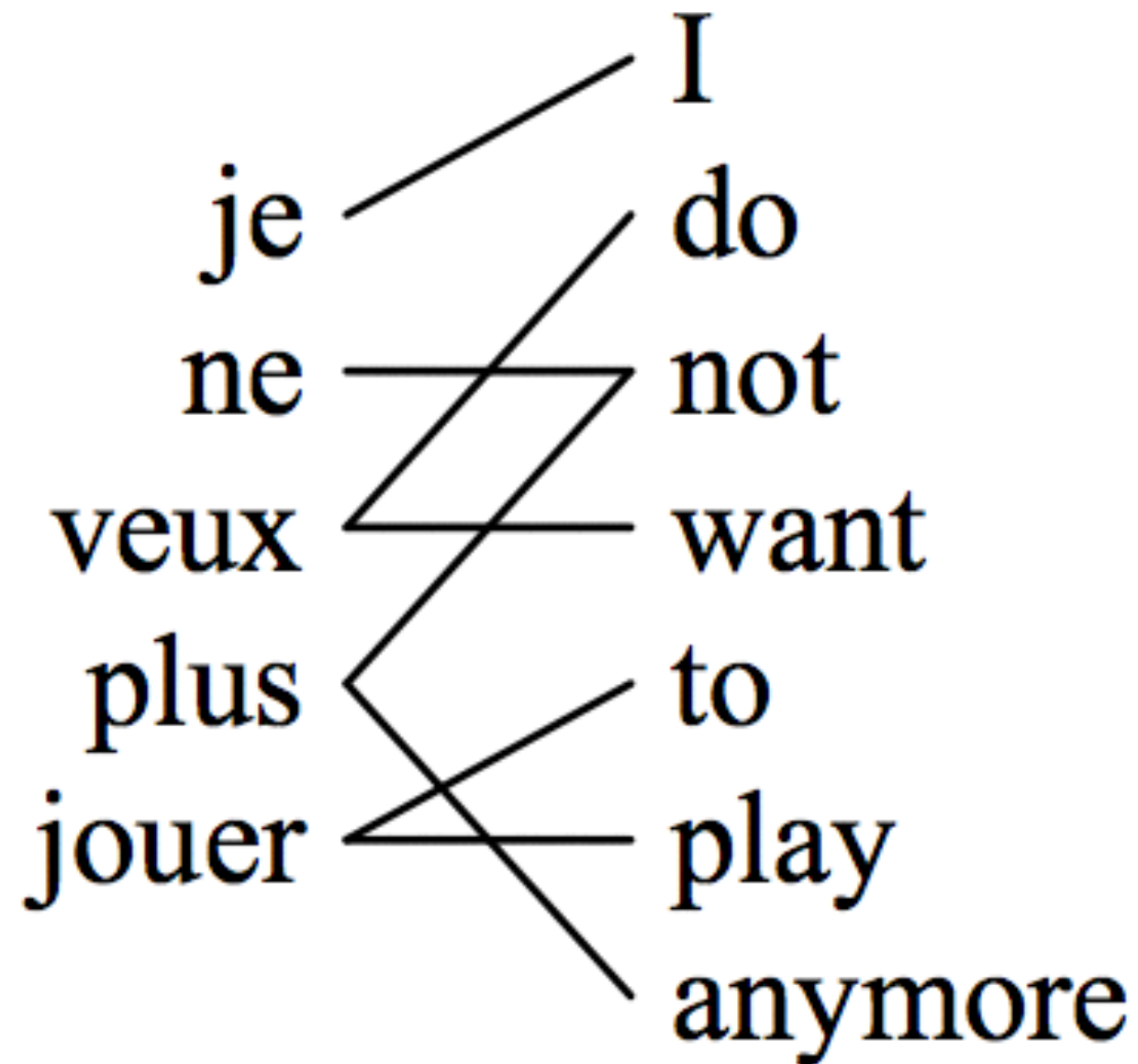


Figure 6: Crossing Due to Modal

This doesn't work. Why?



A brief history of a bad idea

- Constraints of syntax-based translation are too rigid, and based on assumptions that do not hold up empirically.
- But, there is still substantial evidence that hierarchical structure that affects translation
- ... in a probabilistic rather than deterministic way
- Do our universal function approximators learn this hierarchical structure? Can they?