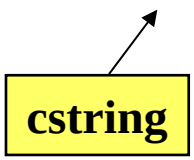
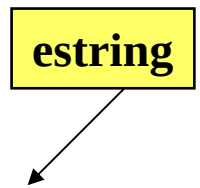
Syntax-Based Statistical MT

- Terminology
- Mathematical Framework
- Translation Model
- Language Model
- Decoder

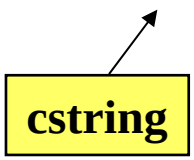
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .

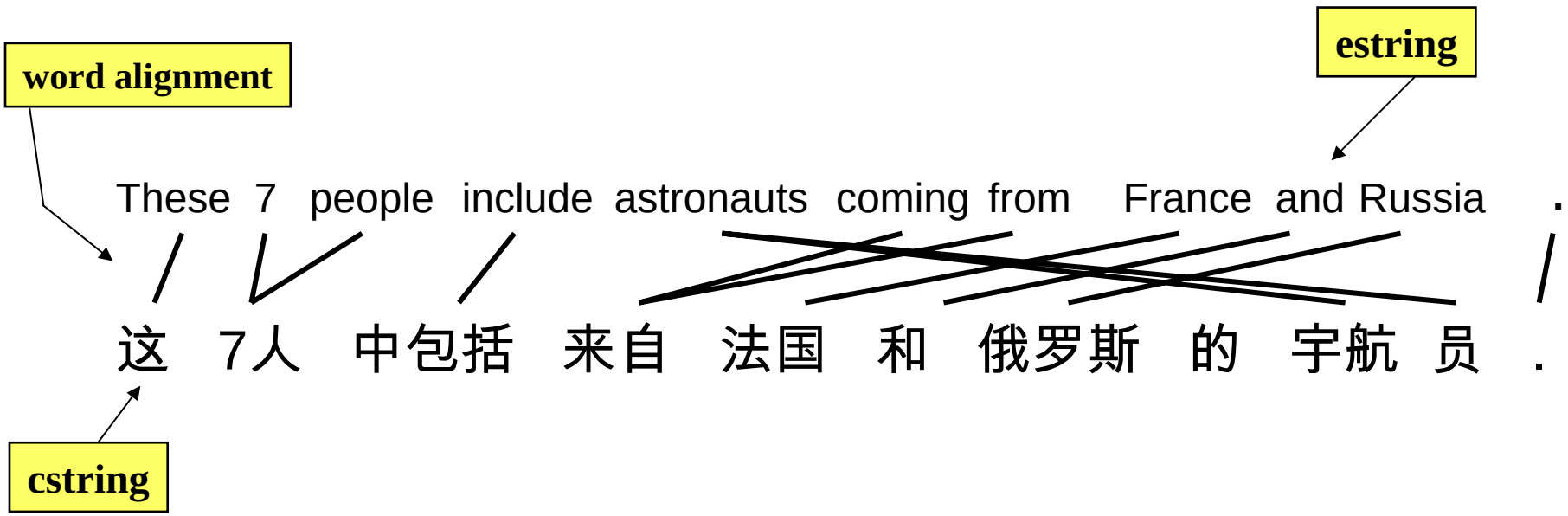


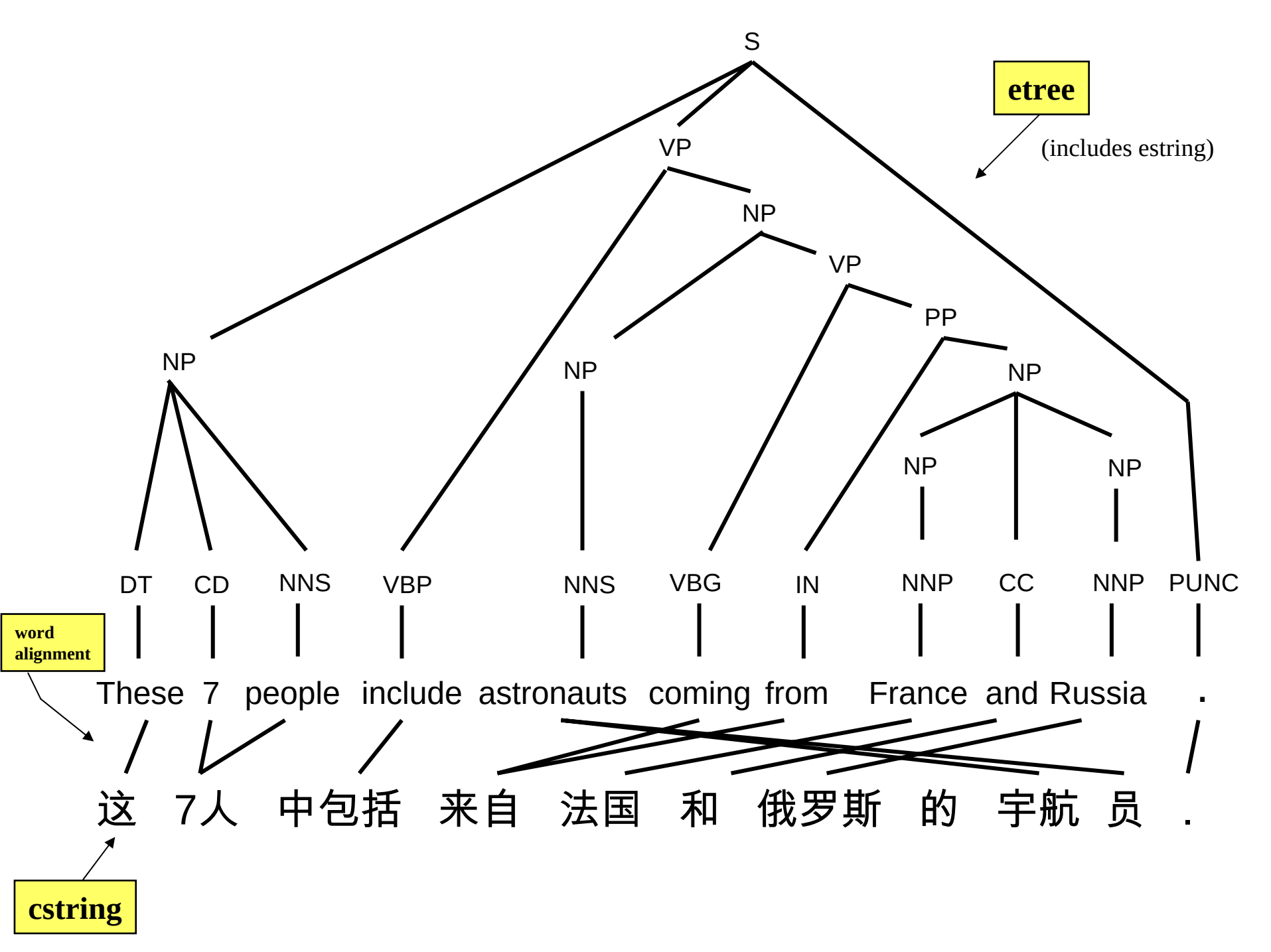


These 7 people include astronauts coming from France and Russia .

这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .




word alignment
estring
These 7 people include astronauts coming from France and Russia .
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .
cstring


S
etree
(includes estring)
VP
NP
VP
PP
NP
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NP
DT
CD
NNS
VBP
NNS
VBG
IN
NNP
CC
NNP
PUNC
word alignment
These 7 people include astronauts coming from France and Russia .
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .
cstring

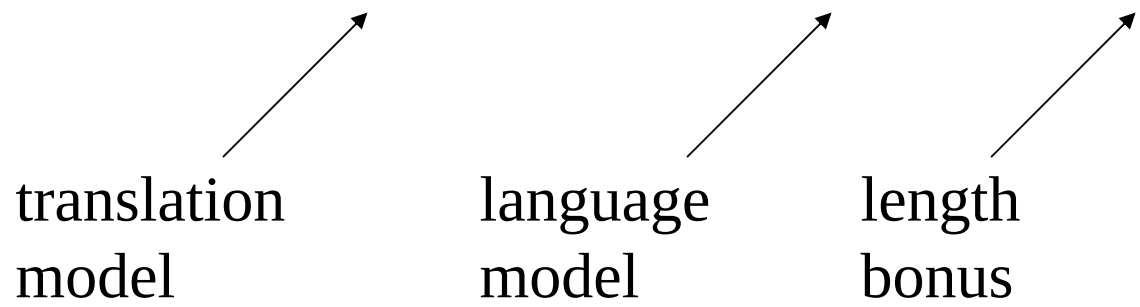
Mathematical Framework

- String-based system

$$\text{argmax}_{e,a} \quad P(e, a, c)^{\alpha} \cdot P(e)^{\beta} \cdot |e|^{\gamma} \cdot \ldots$$

- Tree-based system

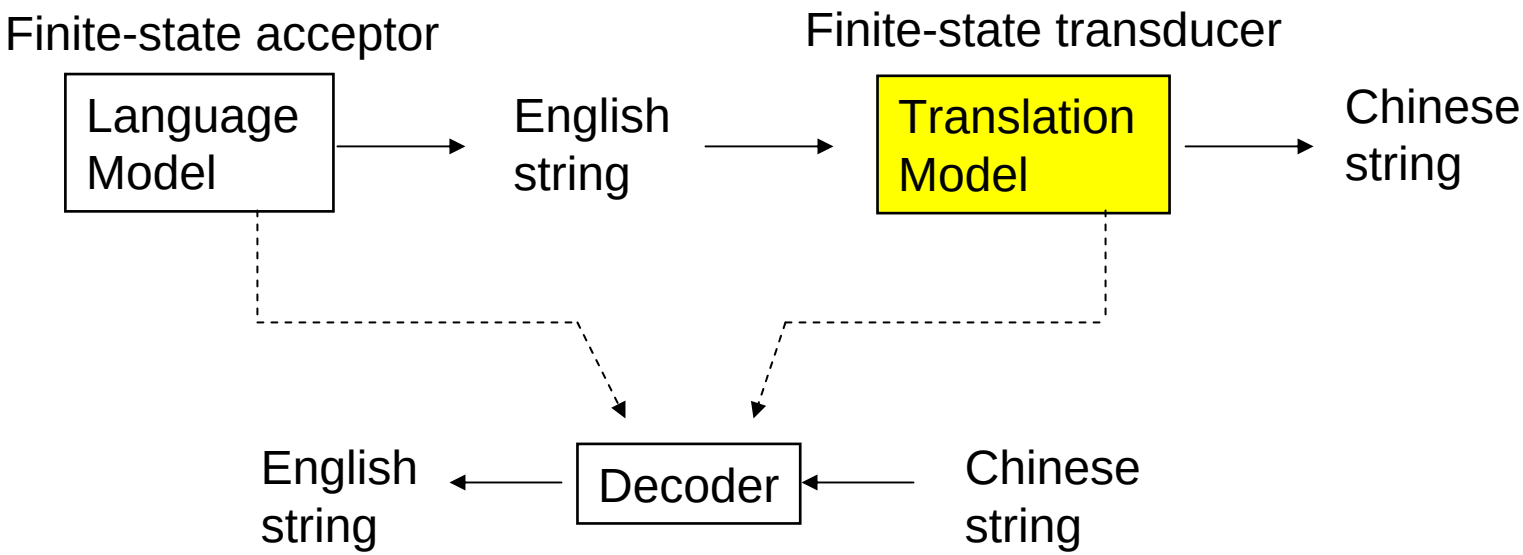
$$\text{argmax}_{etree,a} \quad P(etree, a, c)^{\alpha} \cdot P(etree)^{\beta} \cdot |etree|^{\gamma} \cdot \ldots$$



String-to-Tree

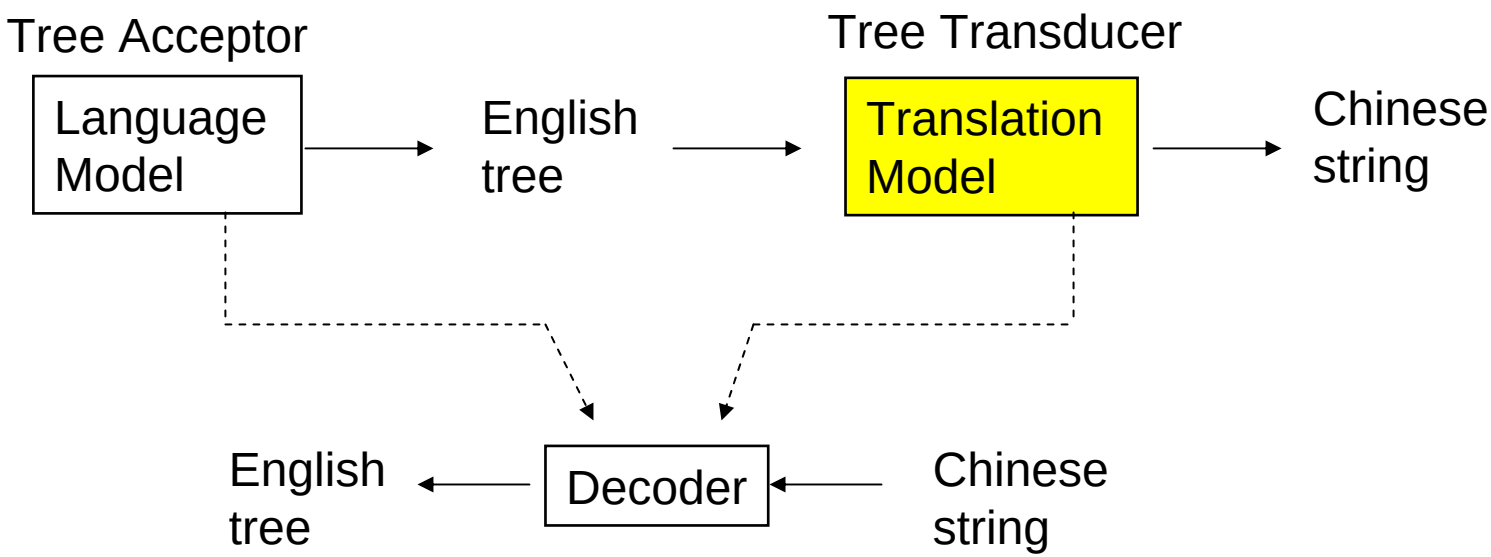
- Mathematically, we want a weighted relation with pairs drawn from:
  - (the infinite) set of Chinese strings
  - (the infinite) set of English trees
- Good pairs should have a high weight
- Bad pairs should have a low weight
- Probabilistic generative modeling approach
  - How does a Chinese string become an English tree (or vice-versa)?

Phrase-Based



- Grab a chunk of English string
- Decide how to translate it (using phrase pair inventory)
- Recurse on remaining input
  - Can be modeled by finite-state string transducer
  - [Mealy, 1959] → [Kumar & Byrne, 2003, HLT]

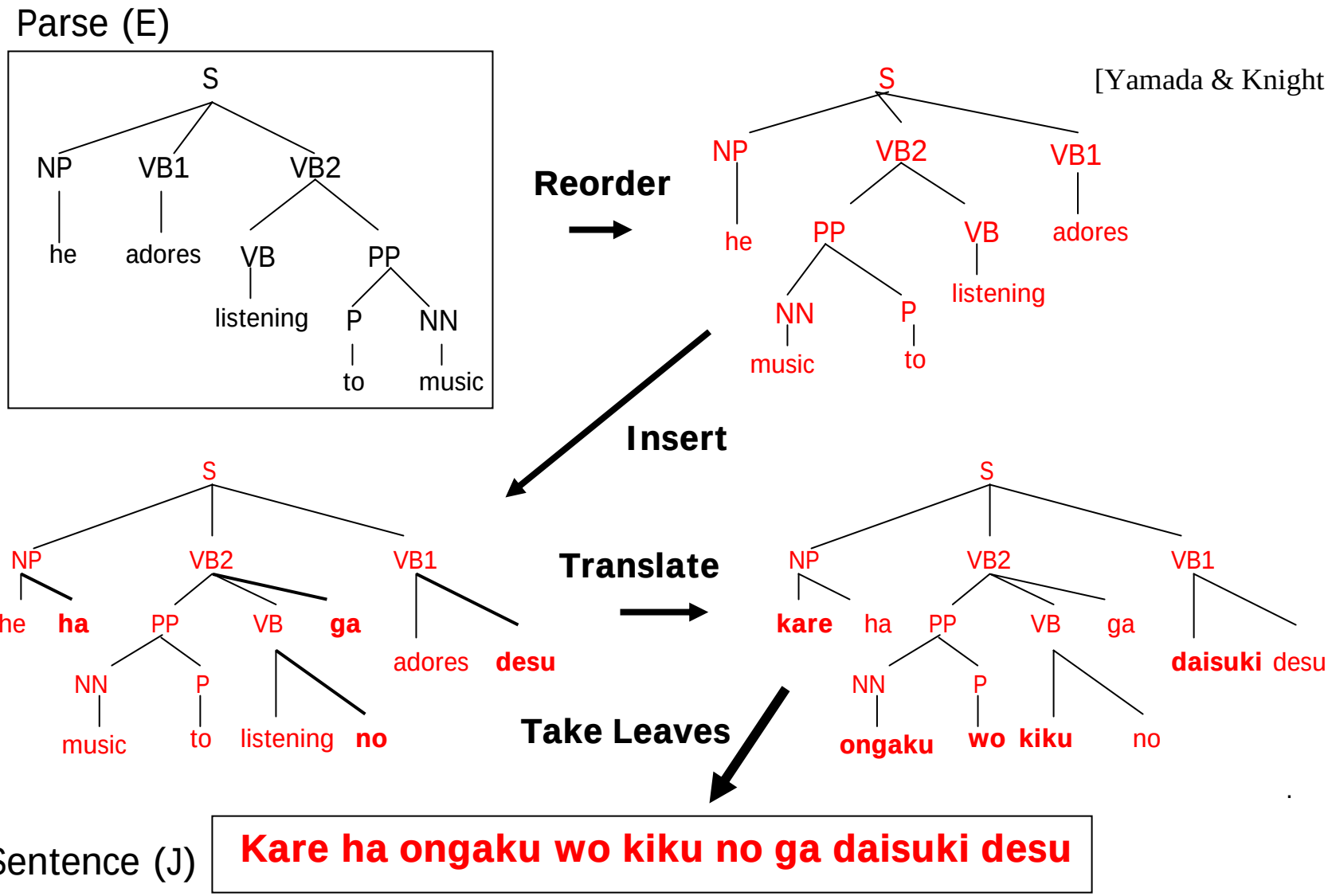
Syntax-Based



- Grab a chunk of English input tree
- Decide how to translate it
- Recurse of remaining subtrees
  - Can be modeled by tree transducer
  - [Rounds, 1970] → [Graehl & Knight, 2004, HLT]

An Early Syntactic Model of Translation

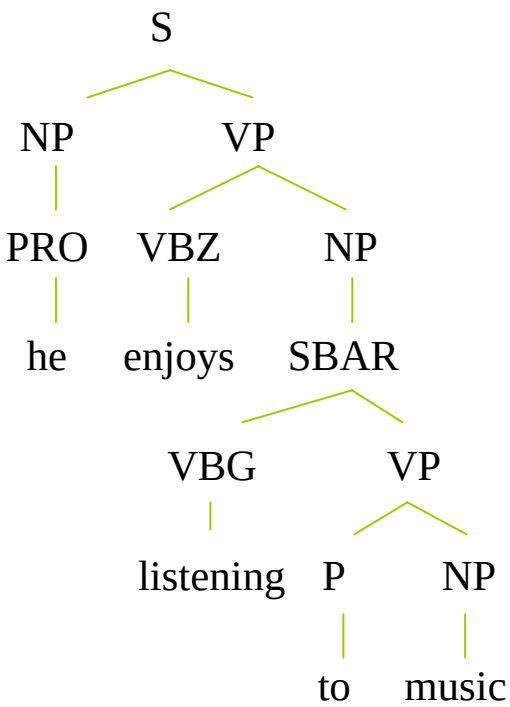
[Yamada & Knight 01]



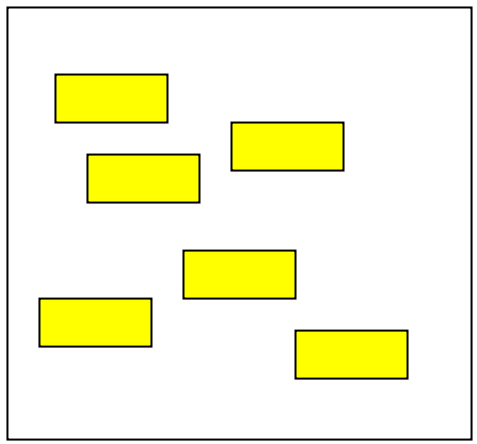
Top-Down Tree Transducer

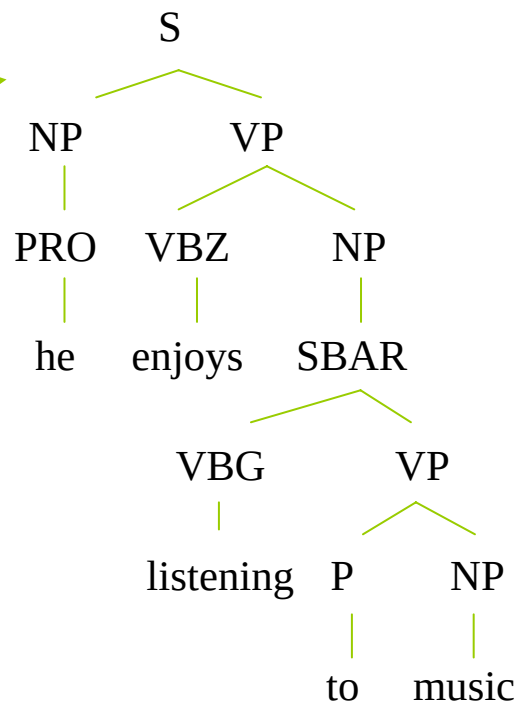
(W. Rounds 1970; J. Thatcher 1970)

Original input:



Transformation:





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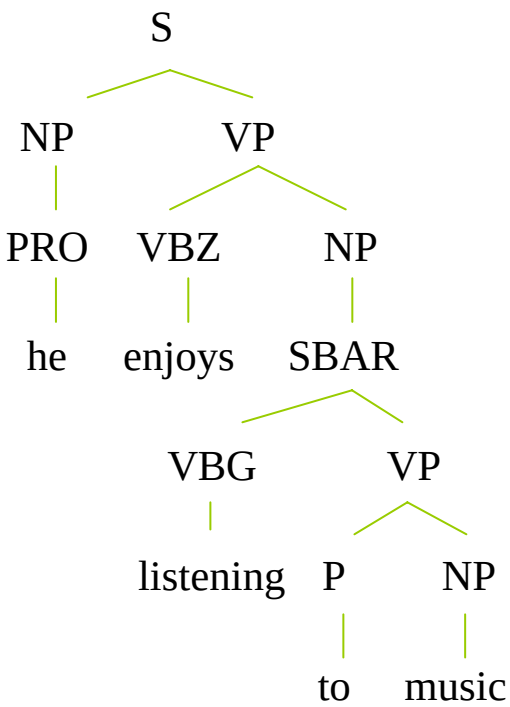
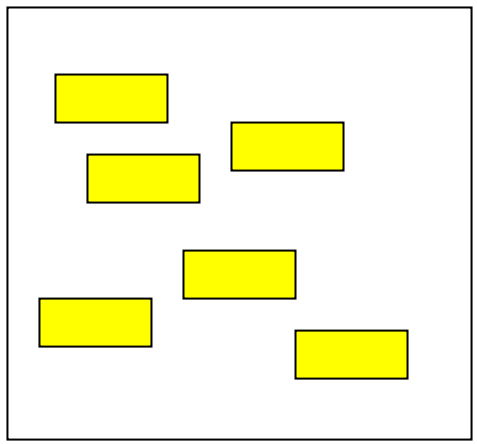
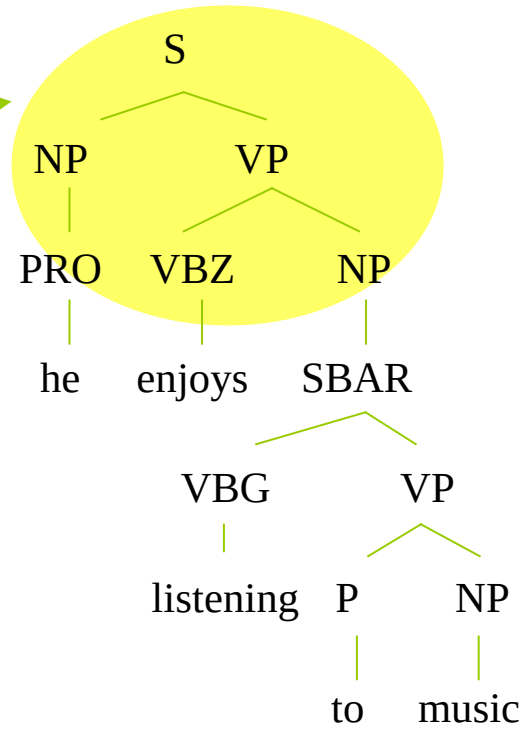




Transformation:

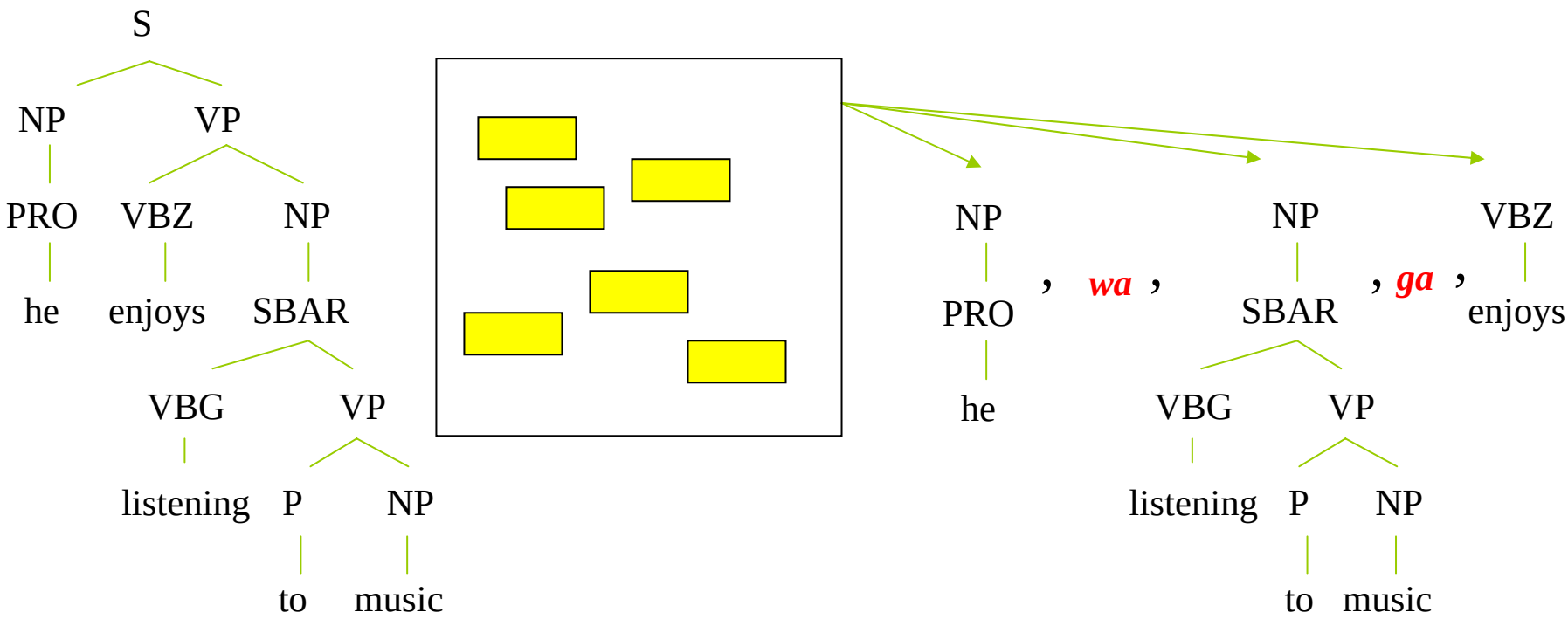


Top-Down Tree Transducer

(W. Rounds 1970; J. Thatcher 1970)

Original input:

Transformation:



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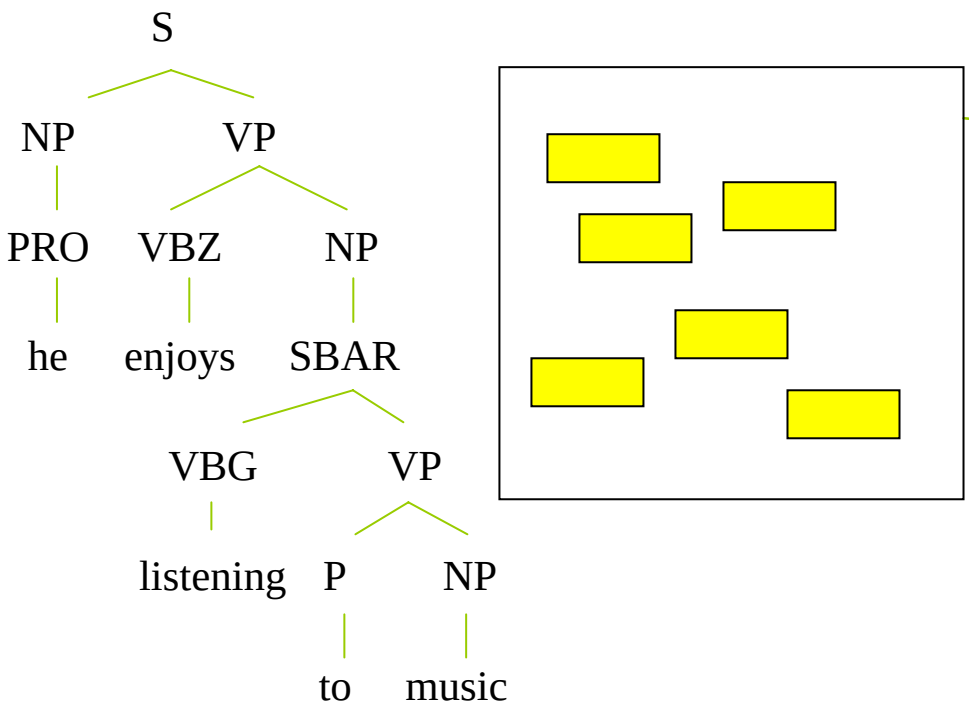
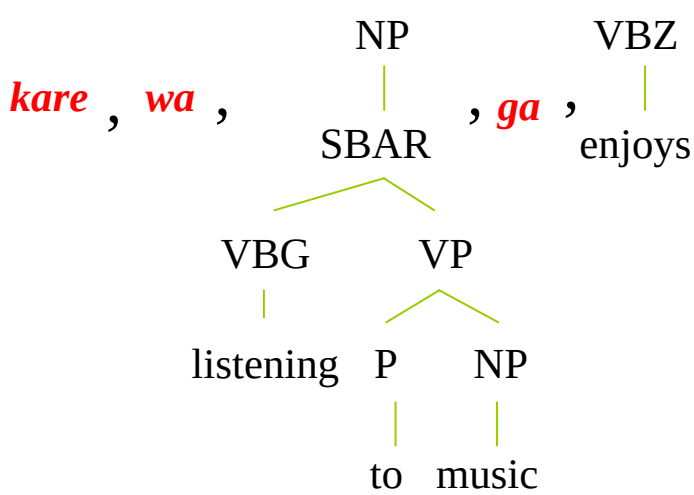


Transformation:



Top-Down Tree Transducer

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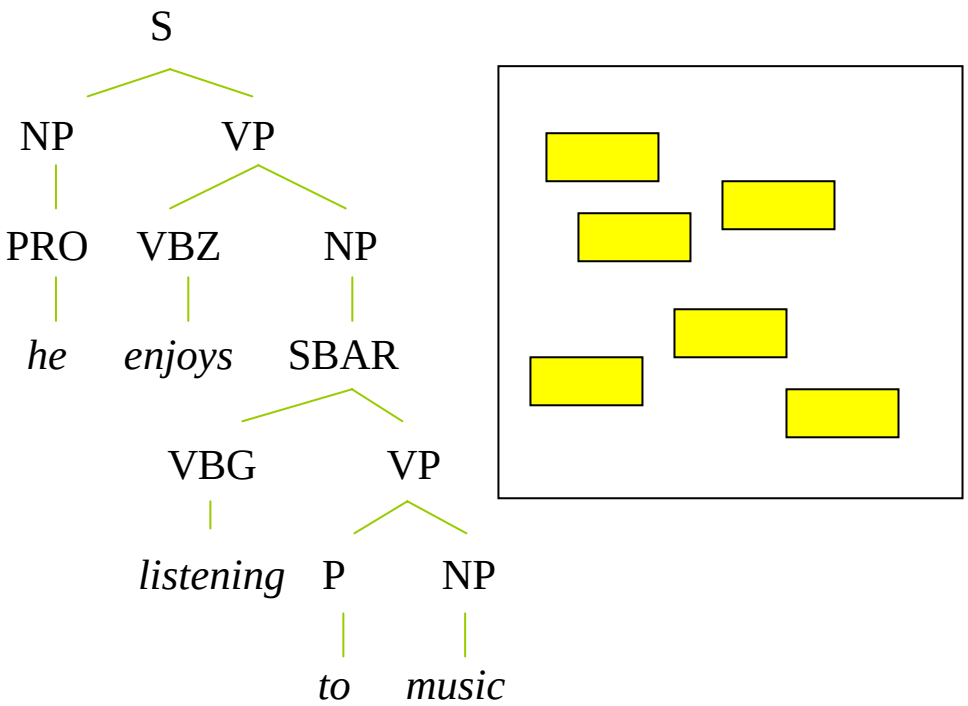


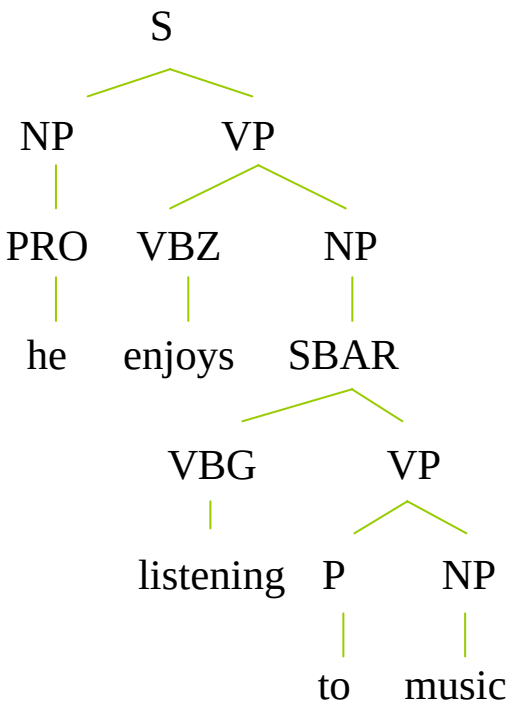
Final output:

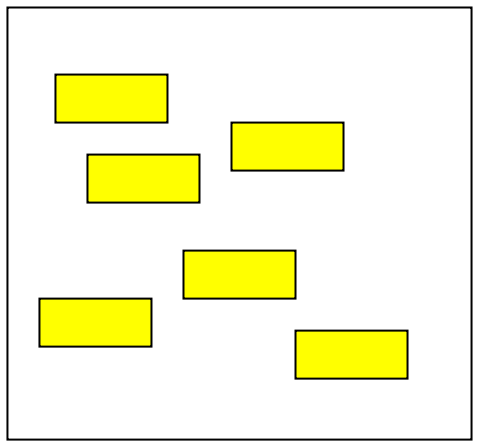
kare*, *wa* , *ongaku*, *o* , *kiku* , *no*, *ga*, *daisuki*, *desu

Top-Down Tree Transducer

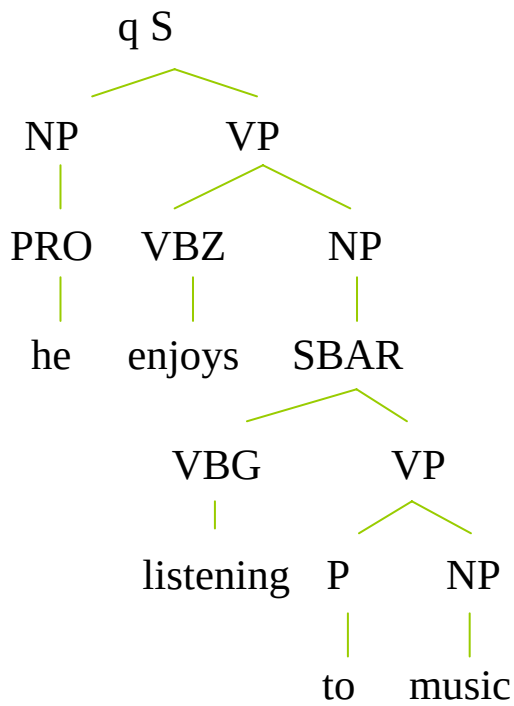
(W. Rounds 1970; J. Thatcher 1970)

Original input:





Transformation:



Top-Down Tree Transducer

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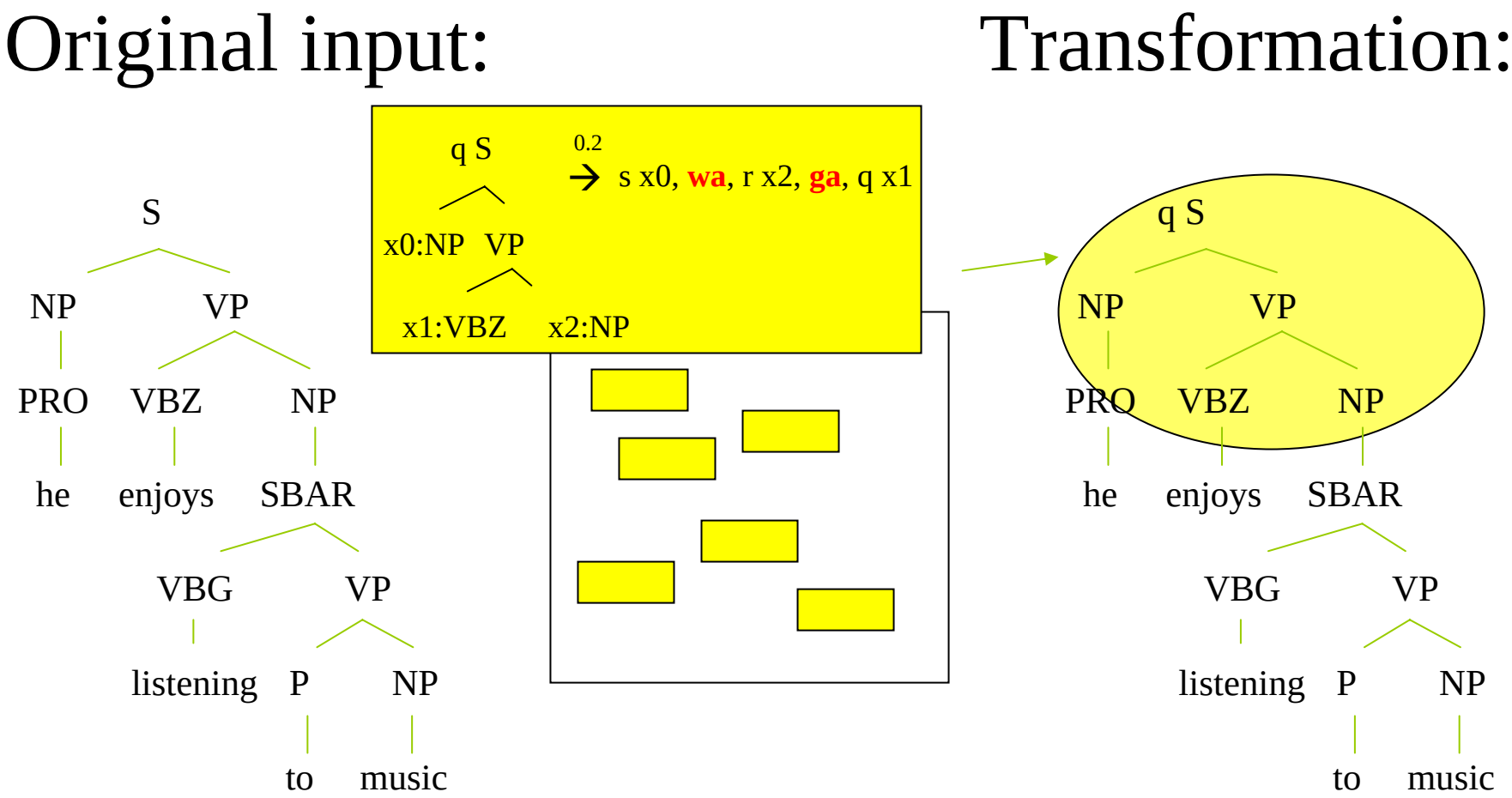
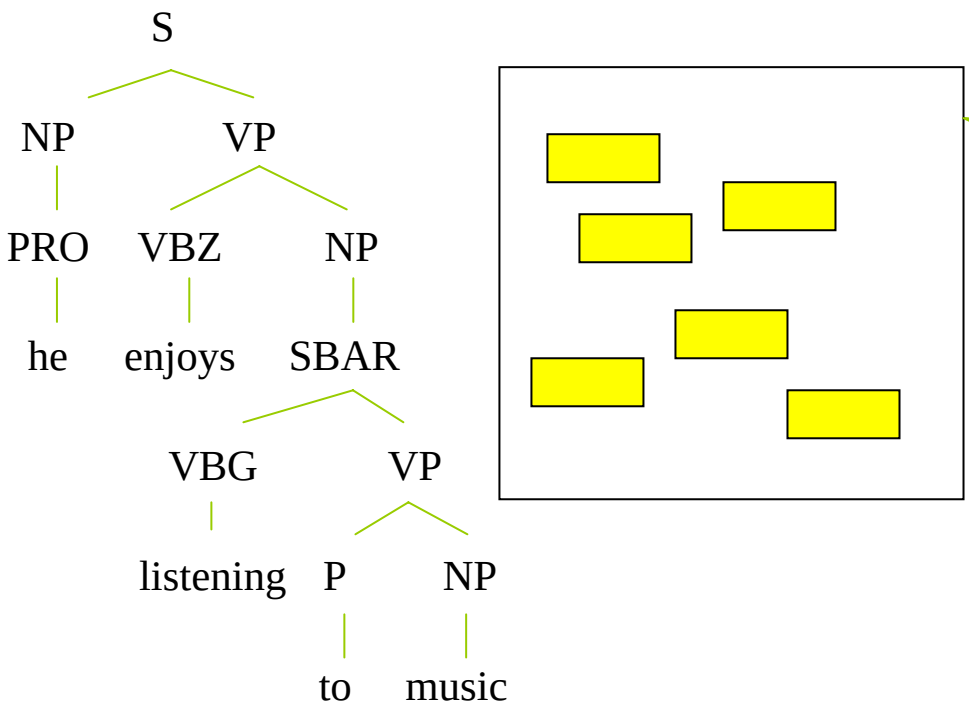


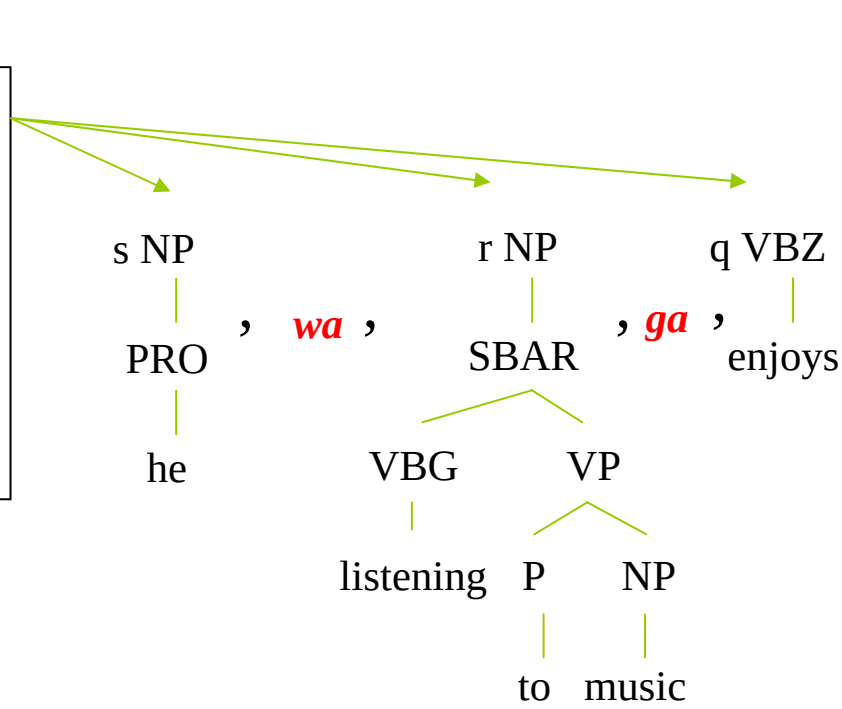
Top-Down Tree Transducer

(W. Rounds 1970; J. Thatcher 1970)

Original input:



Transformation:



Top-Down Tree Transducer

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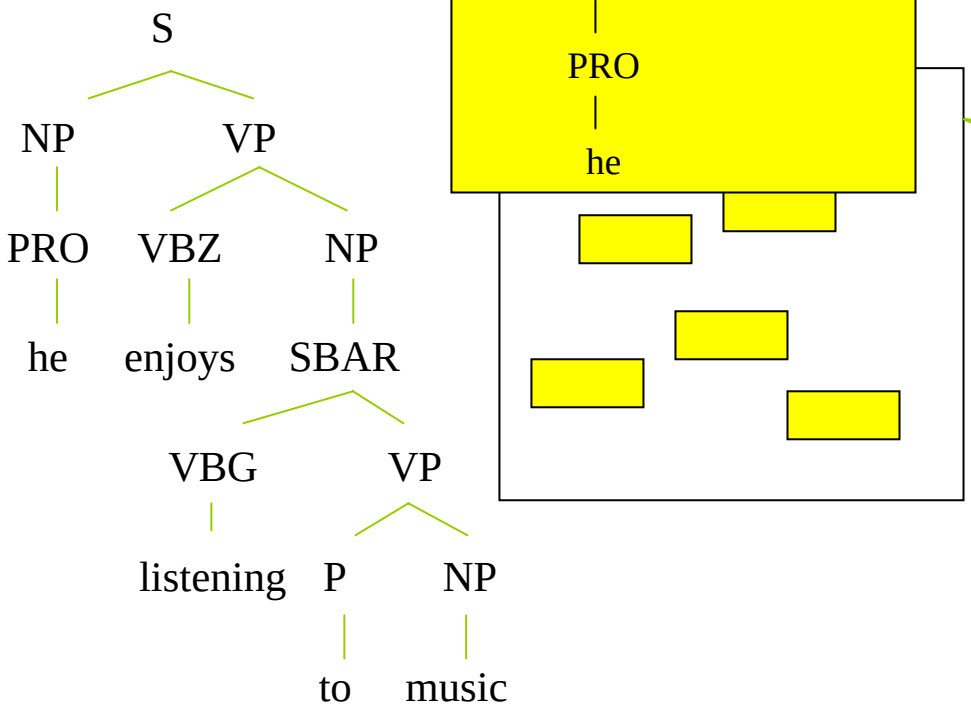
Original input:

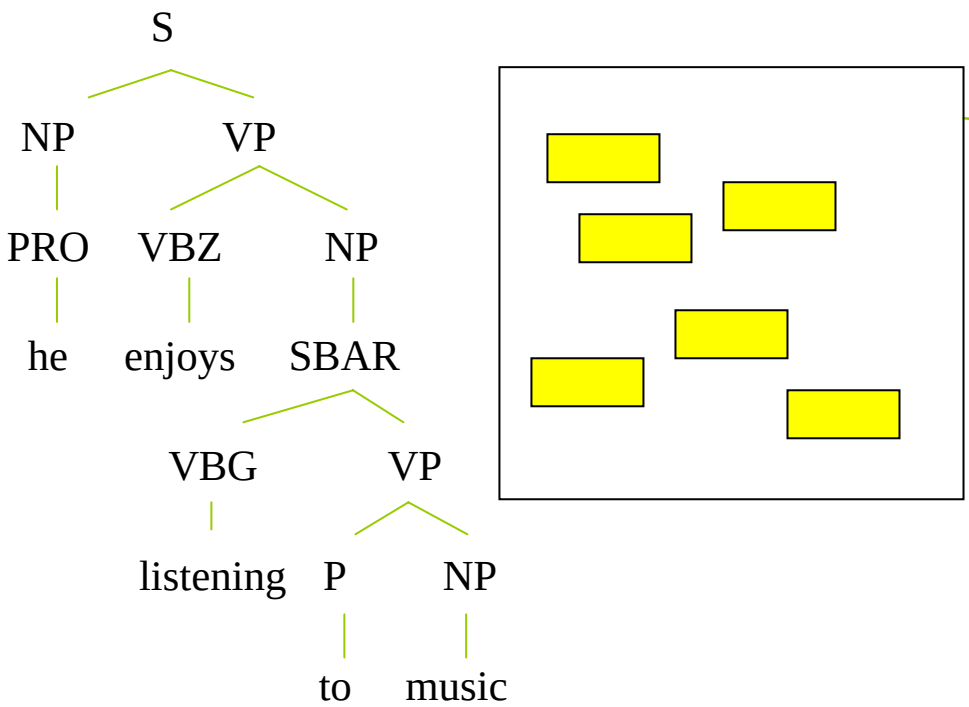


Transformation:

Top-Down Tree Transducer

(W. Rounds 1970; J. Thatcher 1970)

Original input:



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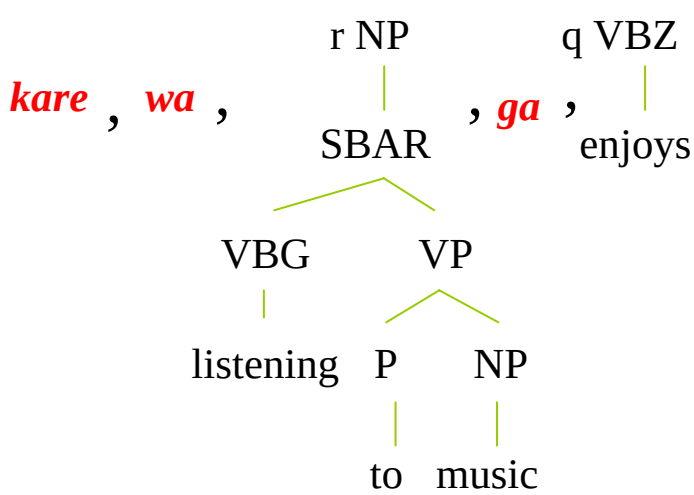

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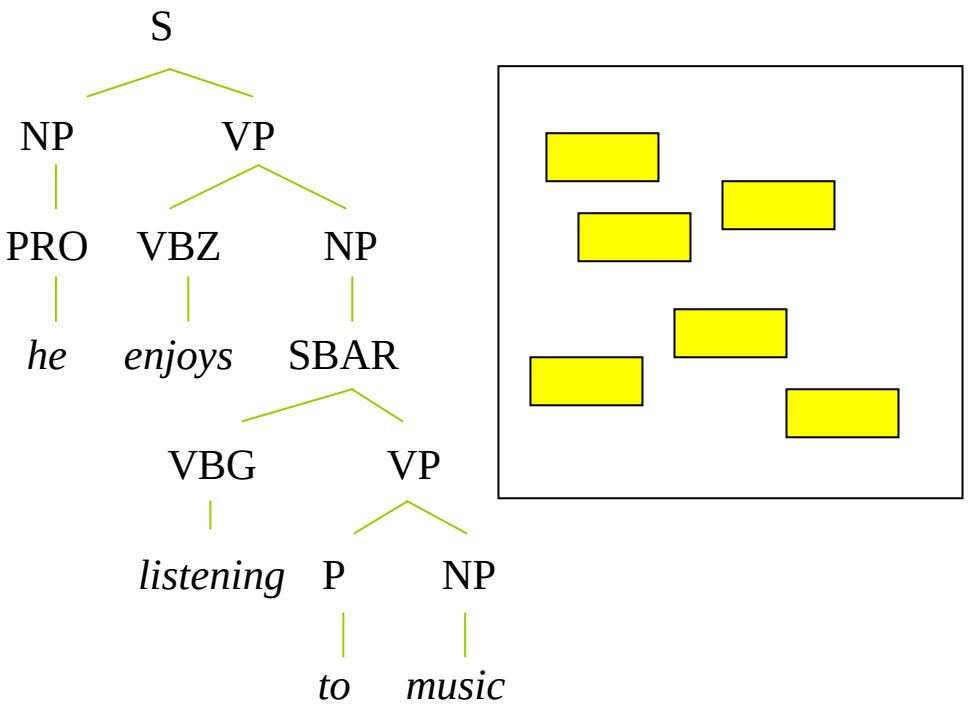


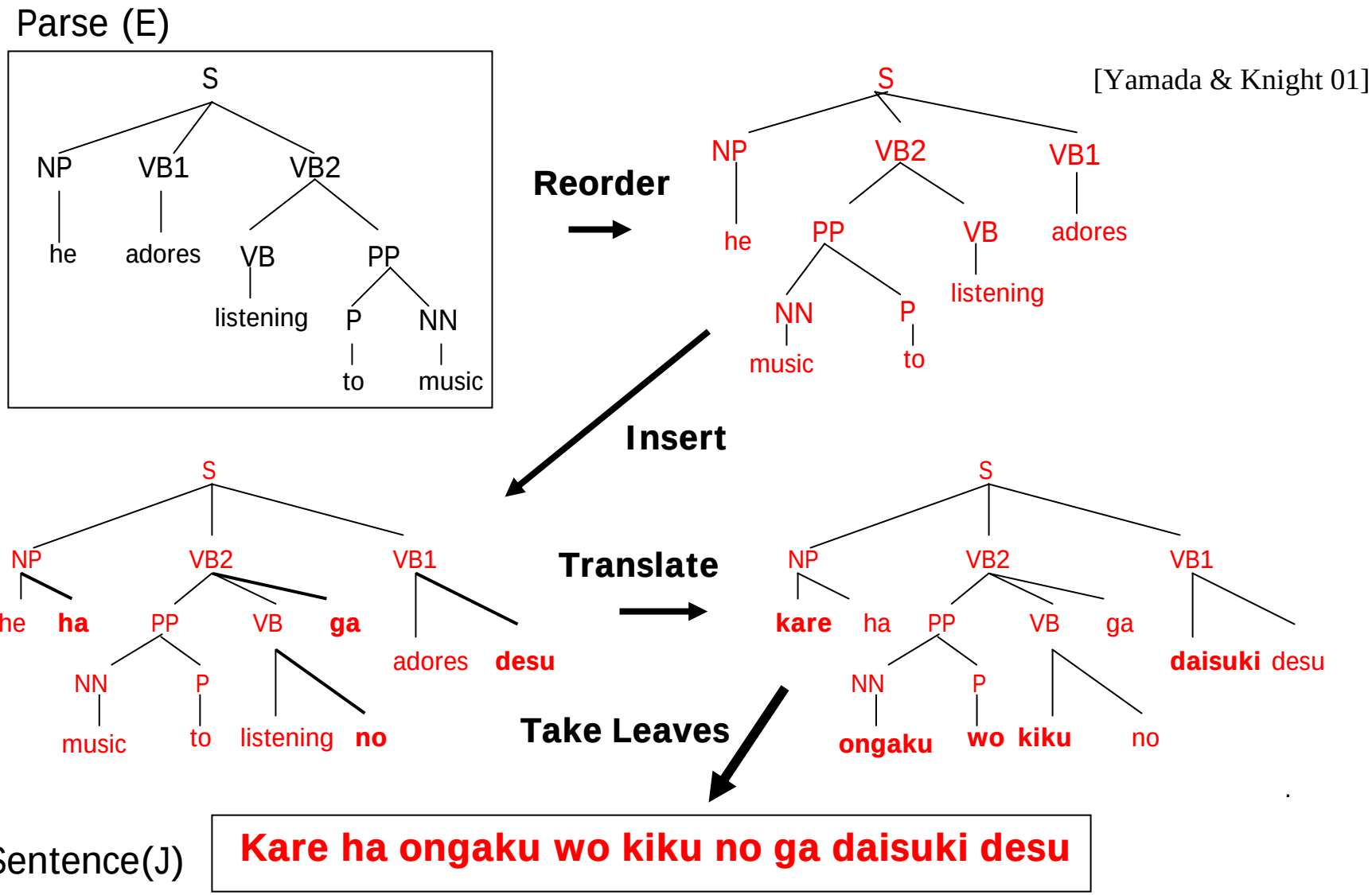
Final output:

kare , ***wa*** , ***ongaku*** , ***o*** , ***kiku*** , ***no*** , ***ga*** , ***daisuki*** , ***desu***

To get total probability, multiply probabilities of the individual steps.

An Early Syntactic Model of Translation

[Yamada & Knight 01]



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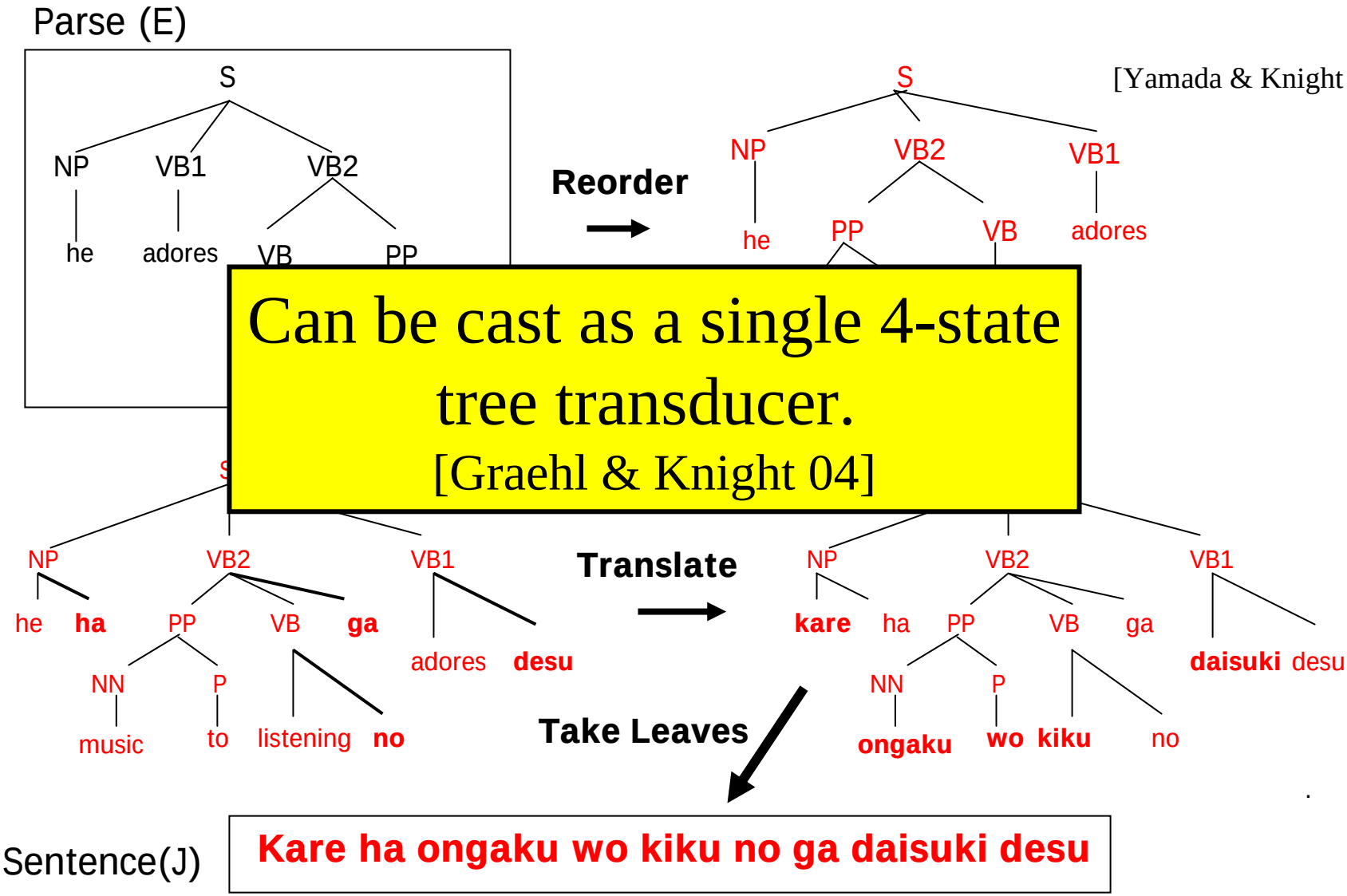
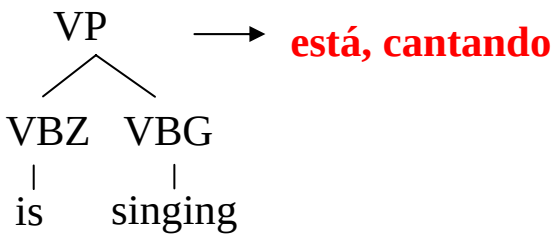
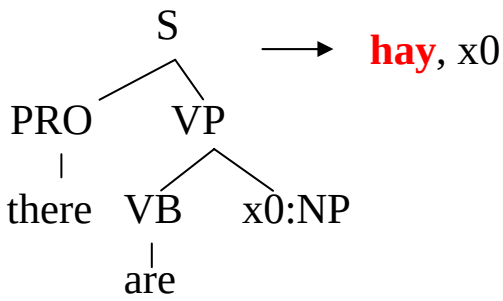


Tree Transducers are Expressive

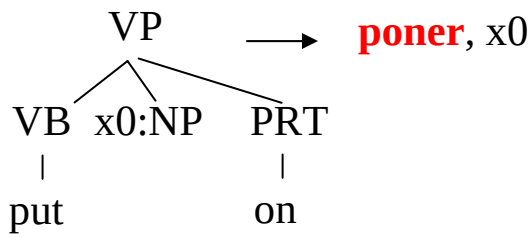
Phrasal Translation



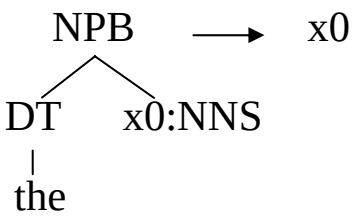
Non-constituent Phrases



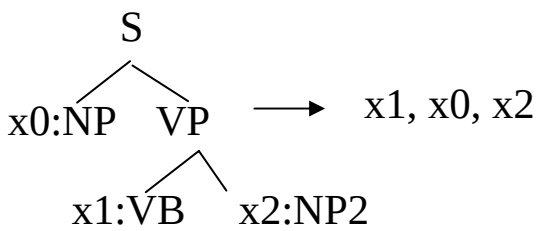
Non-contiguous Phrases



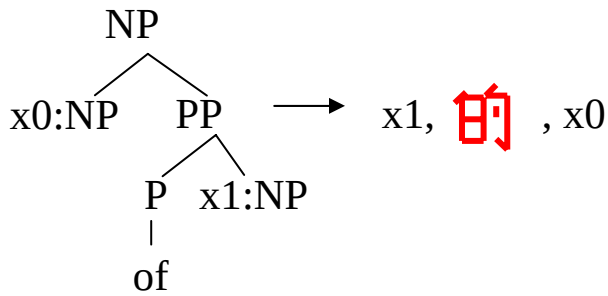
Context-Sensitive Word Insertion



Multilevel Re-Ordering



Lexicalized Re-Ordering

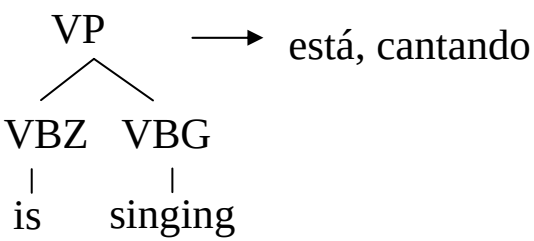


also QA, compression, paraphrasing, etc

most probabilistic tree-based models proposed 2000-2005 can be so cast

Transducer Format is Expressive

Phrasal Translation



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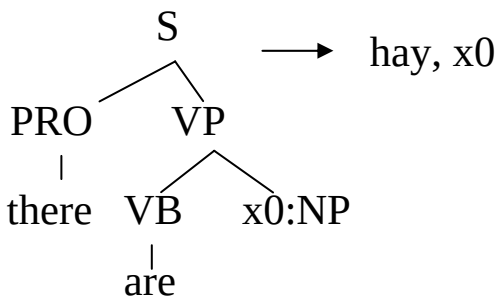
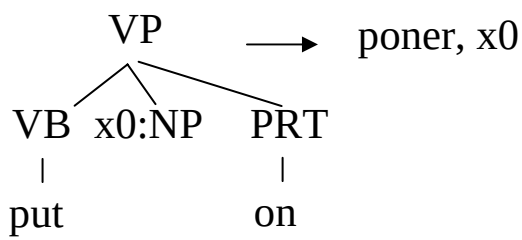


Non-contiguous Phrases



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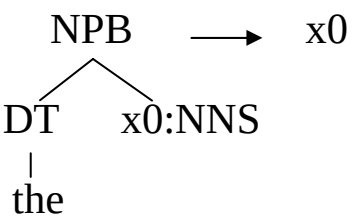
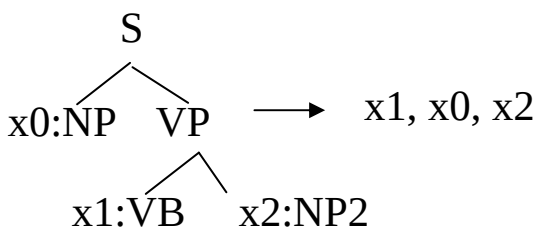
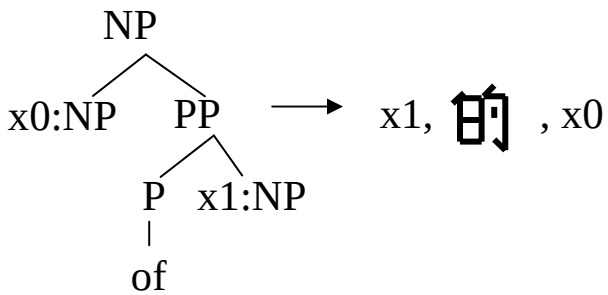


Multilevel Re-Ordering



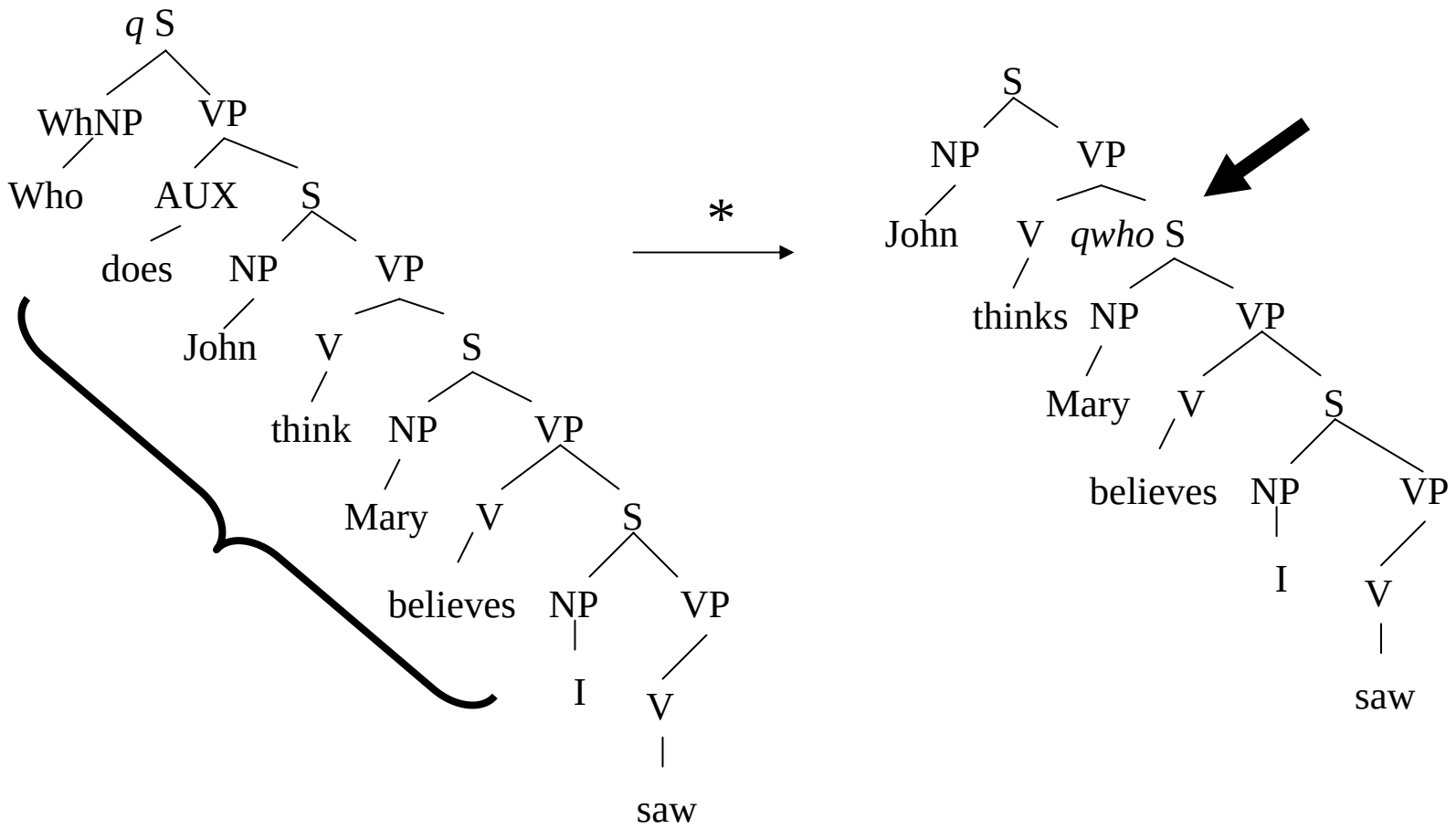
Lexicalized Re-Ordering



These transformations have been studied extensively in the computing theory literature, as tree automata (acceptors, transducers, etc). We know many of their closure properties, etc. See [Knight & Graehl, 2005] for more on these automata.

Limitations of the Top-Down Transducer Model

Who does John think Mary believes I saw? → John thinks Mary believes I saw *who*?



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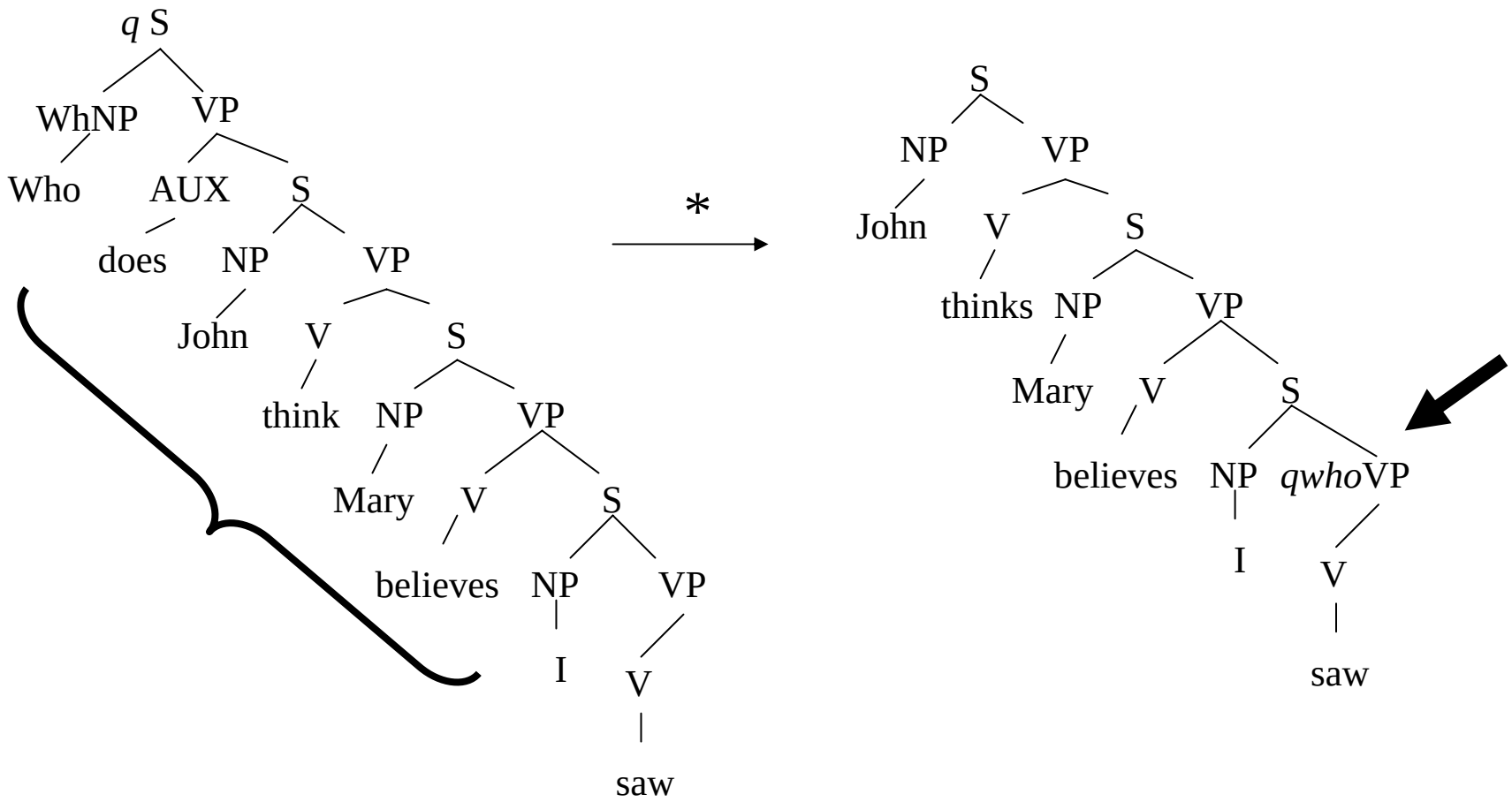

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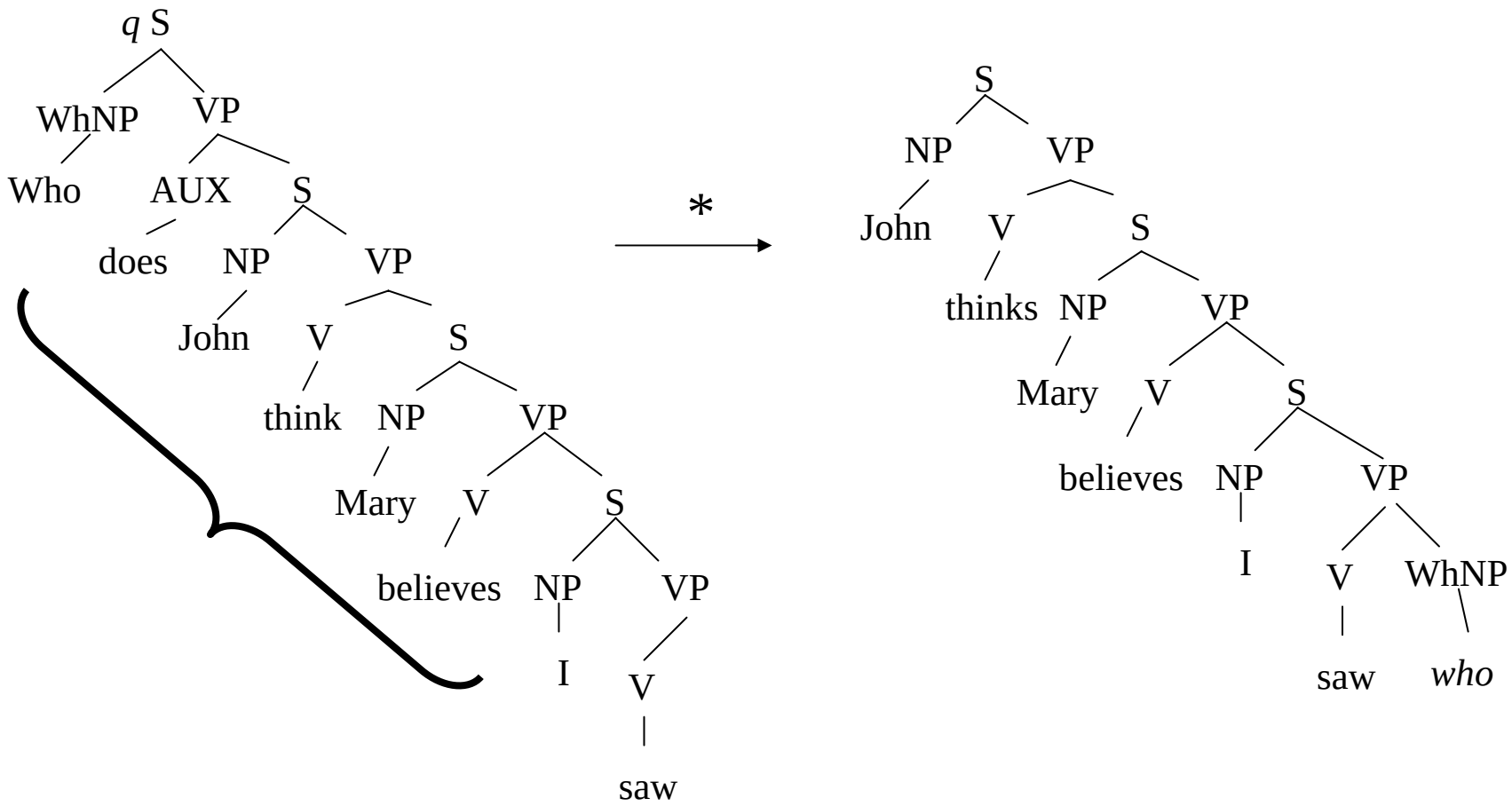
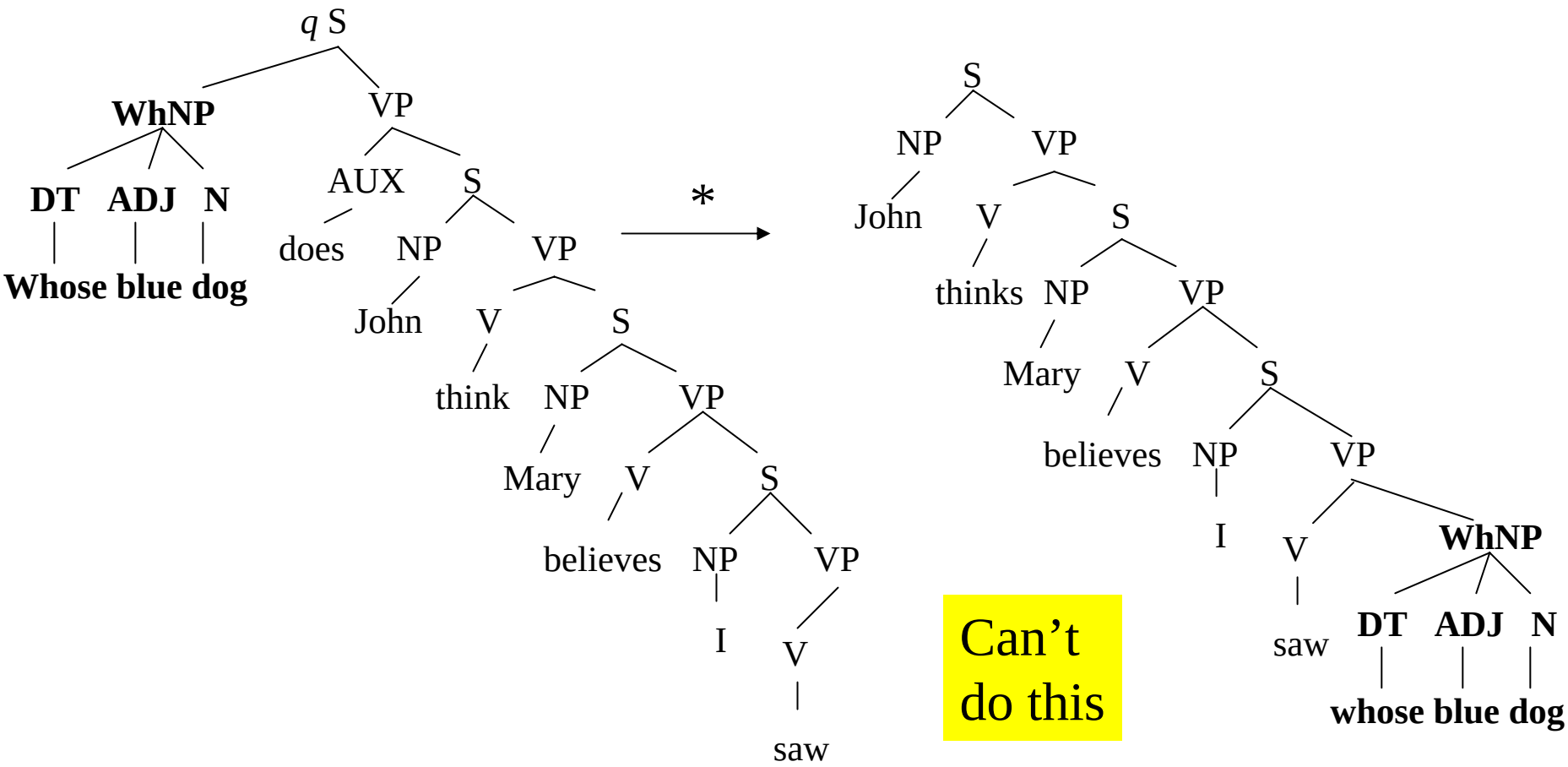


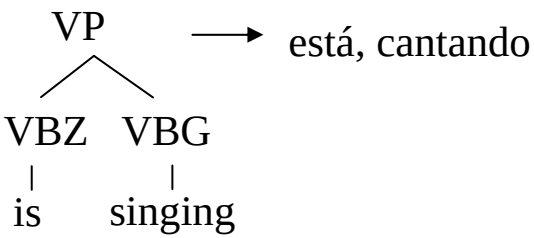
Limitations of the Top-Down Transducer Model

Whose blue dog does John think Mary believes I saw**?** → John thinks Mary believes I saw ***whose blue dog***?



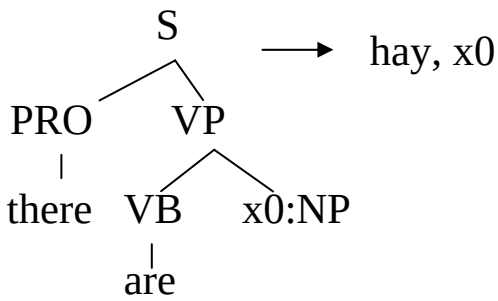
Computer-Friendly Format for Tree Transducer Rules

Phrasal Translation



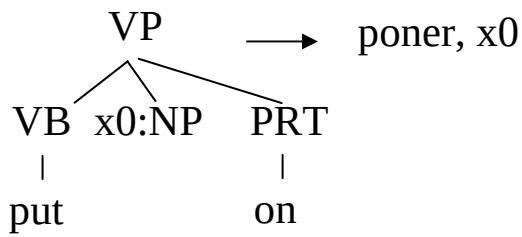
VP(VBZ(is), VBG(singing)) → está, cantando

Non-constituent Phrases

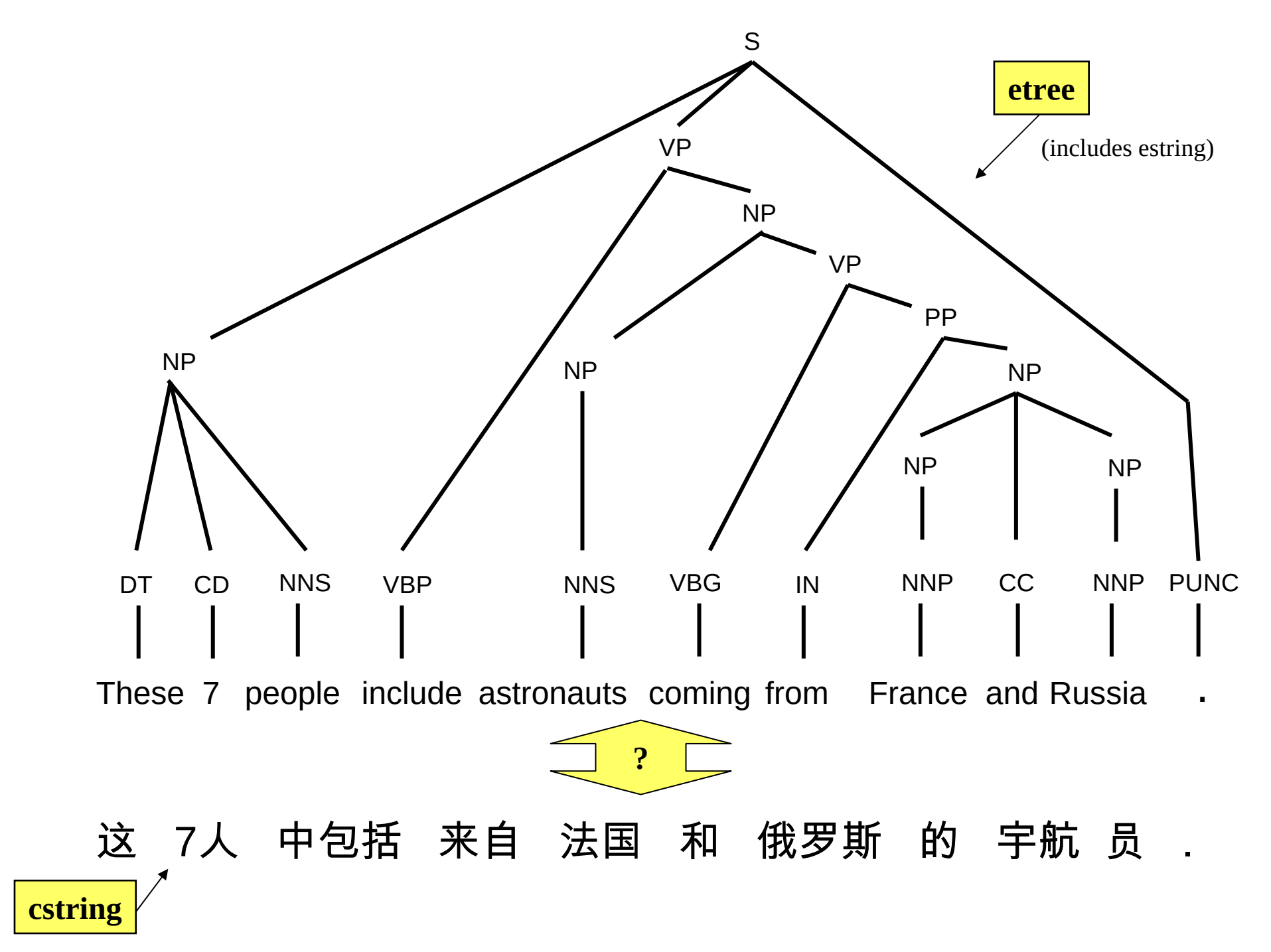


S(PRO(there), VP(VB(are), x0:NP)) → hay, x0

Non-contiguous Phrases



VP(VB(put), x0:NP, PRT(on)) → poner, x0


S
etree
(includes estring)
VP
NP
VP
PP
NP
NP
NP
NP
NP
DT
CD
NNS
VBP
NNS
VBG
IN
NNP
CC
NNP
PUNC
These 7 people include astronauts coming from France and Russia .
?
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .
cstring

Tree Transformations

1. DT(these) → 这
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3. VBP(includes) → 中包括
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6. NNP(Russia) → 俄罗斯
7. IN(of) → 的
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9. PUNC(.) → .
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11. VP(VBG(coming), PP(IN(from), x0:NP)) → 来自 , x0
12. IN(from) → 来自
13. NP(x0:NNP, x1:CC, x2:NNP) → x0 , x1 , x2
14. VP(x0:VBP, x1:NP) → x0 , x1
15. S(x0:NP, x1:VP, x2:PUNC) → x0 , x1, x2
16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT("the"), x0:JJ, x1:NN) → x0 , x1

I made these rules up – they capture what is really happening in this Chinese sentence.

Contiguous phrase pair substitution rules (alignment templates)

Higher-level rules

Tree Transformations

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2. VBP(include) → 中包括
3. VBP(includes) → 中包括
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14. VP(x0:VBP, x1:NP) → x0 , x1
15. S(x0:NP, x1:VP, x2:PUNC) → x0 , x1, x2
16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT(“the”), x0:JJ, x1:NN) → x0 , x1

Both VBP(“include”) and VBP(“includes”) will translate to “中包括” in Chinese.

In decoding Chinese, “中包括” is ambiguous and can translate back as either VBP(“include”) or VBP(“includes”).

pair

tes)

Higher-level rules

Phrase pairs learned by alignment-templates that are relevant to this particular Chinese input sentence.

这	7人	中包括	来自	法国	和	俄罗斯	的	宇航	员	.
the	7 people	including	by some		**and**	the russian	**the**	the astronauts		,
it	7 people included		by france		and the	the russian		international astronautical	of rapporteur .	
this	7 out	including the	**from**	the french	and the	russian	the fifth		.	
these	7 among	including from		the french and		of the russian	of	space	members	.
that	7 persons	including from the		of france	and to	russian	of the	aerospace	members .	
	7 include		from the	of france and		russian		**astronauts**		. the
	7 numbers include		**from france**		and russian		of astronauts who			. ”
	7 populations include		those from france		and russian			astronauts .		
	7 deportees included		come from	**france**	**and russia**		in	astronautical	personnel	;
	7 philtrum	including those from		**france and**		**russia**	a space		**member**	
		including representatives from		france and the		**russia**		astronaut		
		include	came from	**france and russia**			by cosmonauts			
		include representatives from		french	**and russia**			cosmonauts		
		include	came from france		and russia 's			cosmonauts .		
		includes	coming from	french and		russia 's		cosmonaut		
				french and russian			's	astronavigation	member .	
				french	**and russia**		**astronauts**			
					and russia 's				special rapporteur	
					, and	**russia**			rapporteur	
					, and russia				rapporteur .	
					, and russia					
					or	russia 's				

lattice

Table 1: #11# the seven - member crew includes astronauts from france and russia .

Only top 5 translations-per-Chinese-phrase are shown here – there are many more.

Phrase pairs learned by alignment-templates that are relevant to this particular Chinese input sentence.

这	7人	中包括	来自	法国	和	俄罗斯	的	宇航	员	.
the	7 people	including	by some		**and**	the russian	**the**	the astronauts		,
it	7 people included		by france		and the	the russian		international astronautical	of rapporteur .	
this	7 out	including the	**from**	the french	and the	russian	the fifth		.	
these	7 among	including from		the french and		of the russian	of	space	members	.
that	7 persons	including from the		of france	and to	russian	of the	aerospace	members .	
	7 include		from the	of france and		russian		**astronauts**		. the
	7 numbers include		**from france**		and russian		of astronauts who			. ”
	7 populations include		those from france		and russian			astronauts .		
	7 deportees included		come from	**france**	**and russia**		in	astronautical	personnel	;
	7 philtrum	including those from		**france and**		**russia**	a space		**member**	
		including representatives from		france and the		**russia**		astronaut		
		include	came from	**france and russia**			by cosmonauts			
		include representatives from		french	**and russia**			cosmonauts		
		include	came from france		and russia 's			cosmonauts .		
		includes	coming from	french and		russia 's		cosmonaut		
				french and russian			's	astronavigation	member .	
				french	**and russia**		**astronauts**			
					and russia 's				special rapporteur	
					, and	**russia**			rapporteur	
					, and russia				rapporteur .	
					, and russia					
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lattice

Table 1: #11# the seven - member crew includes astronauts from france and russia .

Only top 5 translations-per-Chinese-phrase are shown here – there are many more.

Tree Transformations

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8. NP(NNS(astronauts)) → 宇航， 员
9. PUNC(.) → .
10. NP(x0:DT, CD(7), NNS(people) → x0 , 7人
11. VP(VBG(coming), PP(IN(from), x0:NP)) → 来自 , x0
12. IN(from) → 来自
13. NP(x0:NNP, x1:CC, x2:NNP) → x0 , x1 , x2
14. VP(x0:VBP, x1:NP) → x0 , x1
15. S(x0:NP, x1:VP, x2:PUNC) → x0 , x1, x2
16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT(“the”), x0:JJ, x1:NN) → x0 , x1

The phrase “coming from” translates to “来自” only if followed by an NP (whose translation is then placed to the right of “来自”).

ase pair
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plates)

Higher-level rules

Tree Transformations

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3. VBP(includes) → 中包括
4. NNP(France) → 法国
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6. NNP(Russia) → 俄罗斯
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16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT("the"), x0:JJ, x1:NN) → x0 , x1

Translate an English NP ("astronauts") modified by a gerund VP ("coming from France and Russia") as follows:
(1) translate the gerund VP,
(2) type the Chinese word "的",
(3) translate the NP.

In decoding Chinese, if we analyze
(1) some Chinese into an English NP &
(2) some other Chinese into an English VP
and these two bits are separated by "的",
then create an English NP(NP, VP) structure.

pair

s)

Higher-level rules

Tree Trans

1. DT(these) → 这
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3. VBP(includes) → 中包括
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14. VP(x0:VBP, x1:NP) → x0 , x1
15. S(x0:NP, x1:VP, x2:PUNC) → x0 , x1, x2
16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT("the"), x0:JJ, x1:NN) → x0 , x1

To translate "the JJ NN", just translate the JJ and then translate the NN (drop "the").

When we are decoding Chinese, if we create an English JJ and an adjacent English NN, we can hook these together into an NP, and also insert the word "the."

Most frequent deficiency of lattices is the lack of critical English function words!

Higher-level rules

Tree Transformations

1. DT(these) → 这
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12. IN(from) → 来自
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14. VP(x0:VBP, x1:NP) → x0 , x1
15. S(x0:NP, x1:VP, x2:PUNC) → x0 , x1, x2
16. NP(x0:NP, x1:VP) → x1 , 的 , x0
17. NP(DT(“the”), x0:JJ, x1:NN) → x0 , x1

Note that this rule goes ahead and makes “astronauts” a full NP. Might be better to have two rules:

NNS(astronauts) → 宇航， 员

NP(x0:NNS) → x0

Higher-level rules

Tree Transformations

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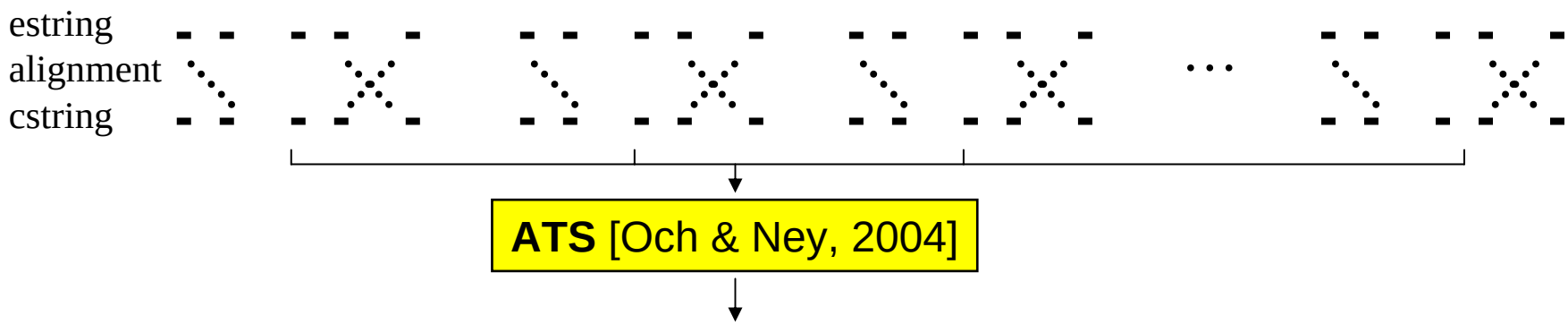
17. NP(DT(“the”), x0:JJ, x1:NN) → x0 , x1

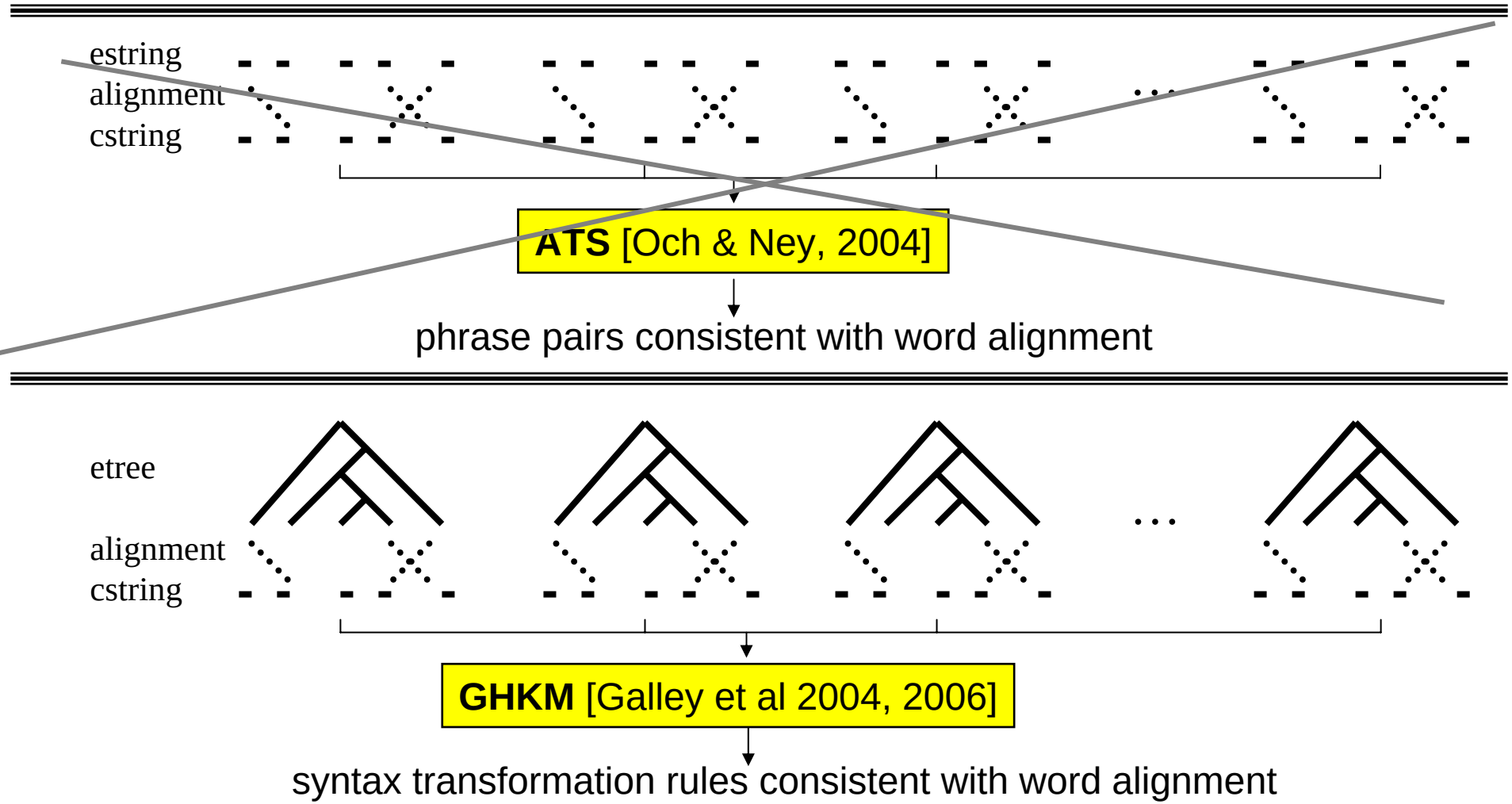
Okay, these rules look interesting.

It would be cool if we could acquire rules like these from data!!

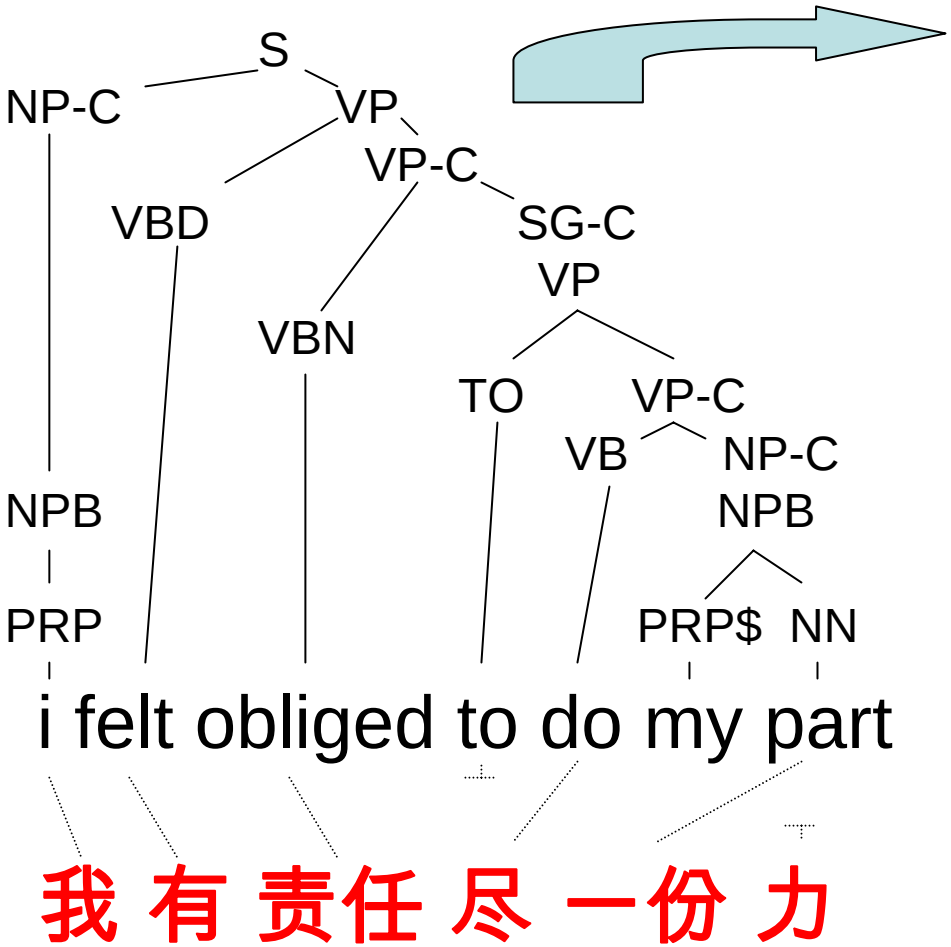
Phrase-Based and Syntax-Based Pattern Extraction



Phrase-Based and Syntax-Based Pattern Extraction



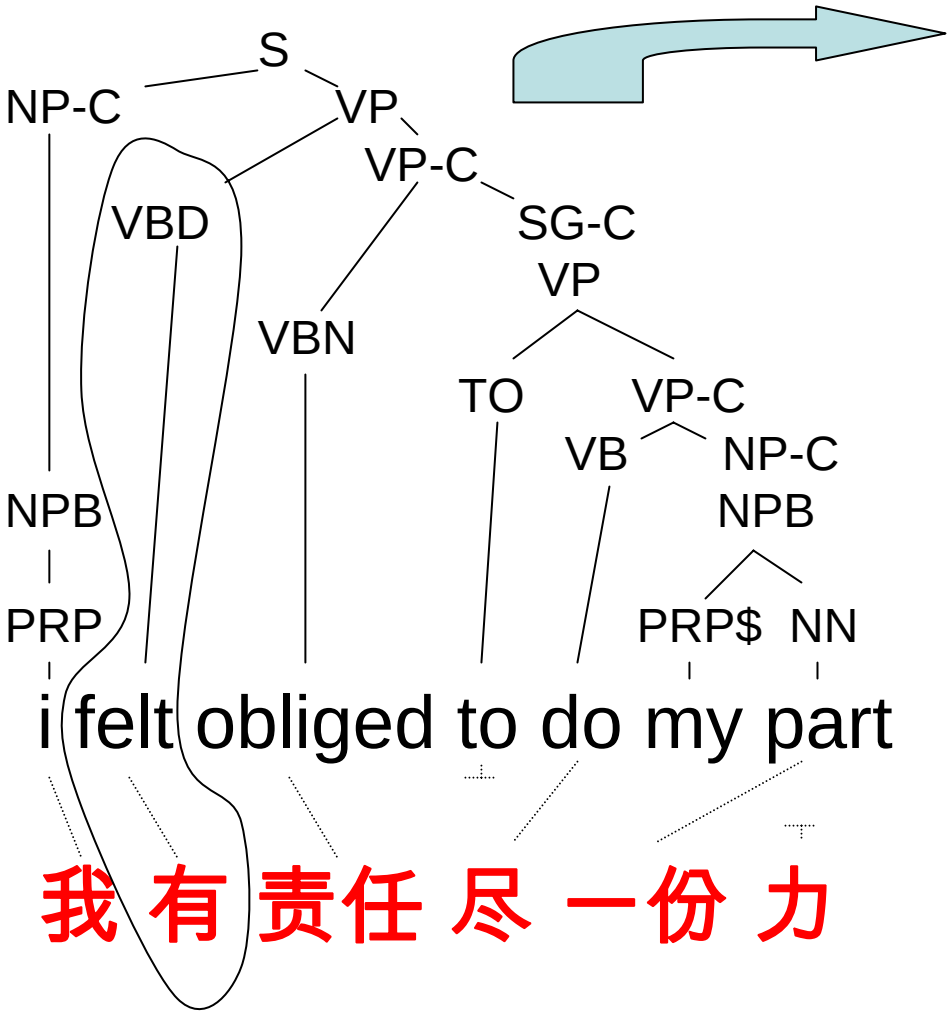
Tree Transducers Can be Extracted from Data
(Galley, Hopkins, Knight, Marcu, 2004)



RULES ACQUIRED:

VBD(felt) → 有
VBN(obliged) → 责任
VB(do) → 尽
NN(part) → 一份
NN(part) → 一份 力
VP-C(x0:VBN x1:SG-C) → x0 x1
VP(TO(to) x0:VP-C) → x0
…
S(x0:NP-C x1:VP) → x0 x1

Tree Transducers Can be Extracted from Data
(Galley, Hopkins, Knight, Marcu, 2004)



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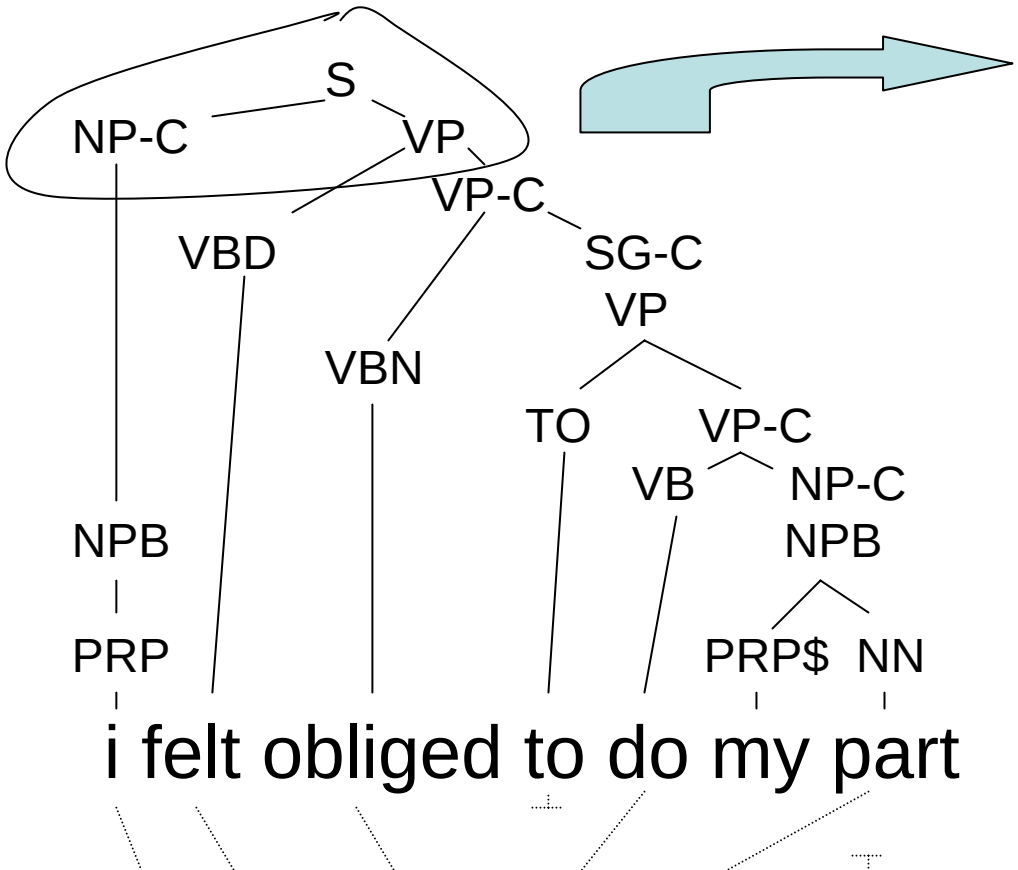

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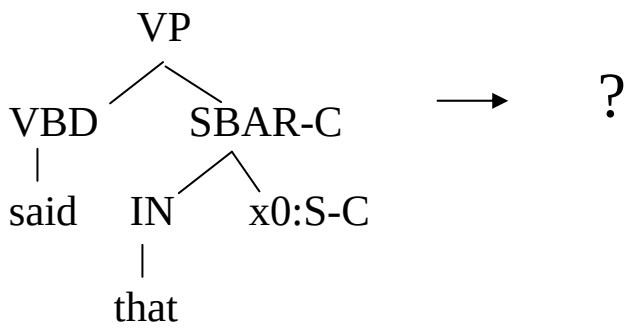
VP(TO(to) x0:VP-C) → x0
…
S(x0:NP-C x1:VP) → x0 x1

Additional extraction methods:
(Galley et al, 2006)
(Marcu et al, 2006)

Sample “said that” rules



0.57 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 说，x0

0.09 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 说 x0

0.02 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 他 说，x0

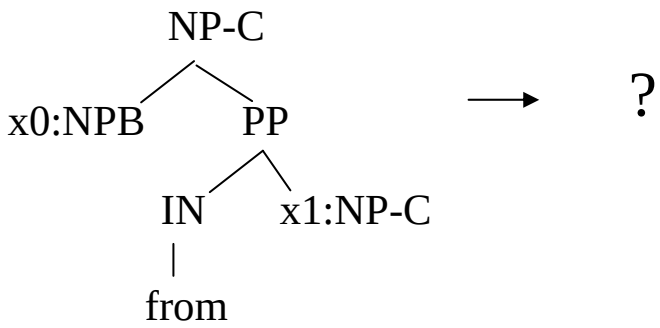
0.02 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 指出，x0

0.02 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> x0

0.01 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 表示 x0

0.01 VP(VBD("said") SBAR-C(IN("that") x0:S-C)) -> 说，x0 的

Sample “NP-from-NP” rules



0.27 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> x1 x0

0.15 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> 来自 x1 x0

0.06 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> x1 的 x0

0.06 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> 从 x1 x0

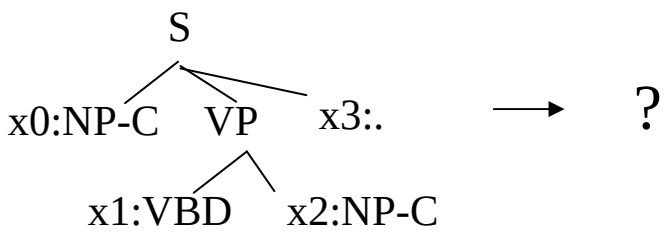
0.06 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> 来自 x1 的 x0

0.02 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> x0 从 x1

0.01 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> 自 x1 x0

0.01 NP-C(x0:NPB PP(IN("from") x1:NP-C)) -> x1 x0 ,

Sample SVO rules



CHINESE / ENGLISH

0.82 S(x0:NP-C VP(x1:VBD x2:NP-C) x3:.) -> x0 x1 x2 x3
0.02 S(x0:NP-C VP(x1:VBD x2:NP-C) x3:.) -> x0 x1 "," x2 x3
0.01 S(x0:NP-C VP(x1:VBD x2:NP-C) x3:.) -> x0 "," x1 x2 x3

ARABIC / ENGLISH

0.54 S(x0:NP-C VP(x1:VBD x2:NP-C) x3:.) -> x0 x1 x2 x3
0.44 S(x0:NP-C VP(x1:VBD x2:NP-C) x3:.) -> x1 x0 x2 x3

Extensions to Rule Extraction from Data [Galley et al 06]

GHKM also acquires many *composed* rules.

NP(x0:NP x1:PP) → x1, x0
PP(x0:IN x1:NP) → x1, x0
IN(of) → de

} Minimal rules

NP(x0:NP PP(IN(of) x1:NP)) → x1 de x0

} Composed rule

GHKM also enumerates all ways of dealing with unaligned Chinese words.

GHKM also generates rule counts.

- these can be normalized into probabilities

Language Models

- Syntax-based Language Model
  - Assigns P(tree)
    - [Collins, 1997; Charniak, 2001]
  - Unlike parser, must be trained on domain data
- Ngram Language Model
  - Standard trigram model
  - Only judges a tree by its leaves

Decoder

- Bottom-up CKY parser
- Builds English constituents on top of Chinese spans
- Record of rule applications (the derivation) provides information to construct English tree
- Returns k-best trees

Binarization for Decoding

- For efficient parsing/decoding, all rules must be *binarized*
- Rule with |RHS| > 2 must be split into rules with |RHS| = 2
  - S(x0:NP VP(x1:VBD x2:NP)) → x1 x0 x2

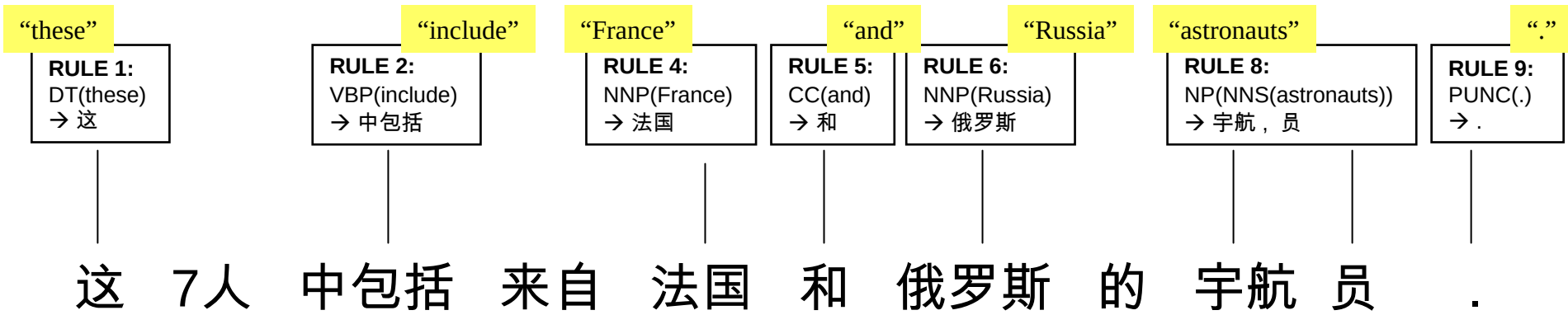
    Z(x0:NP x1:VBD) → x1 x0

    S*(x0:Z x1:NP) → x0 x1 ***tells-how-to-assemble-the-S**
- Similar to putting a CFG into Chomsky normal form
- Except that some translation rules cannot be binarized…
  - A(x0:B x1:C x2:D x3:E) → x1 x3 x0 x2
- We just delete these

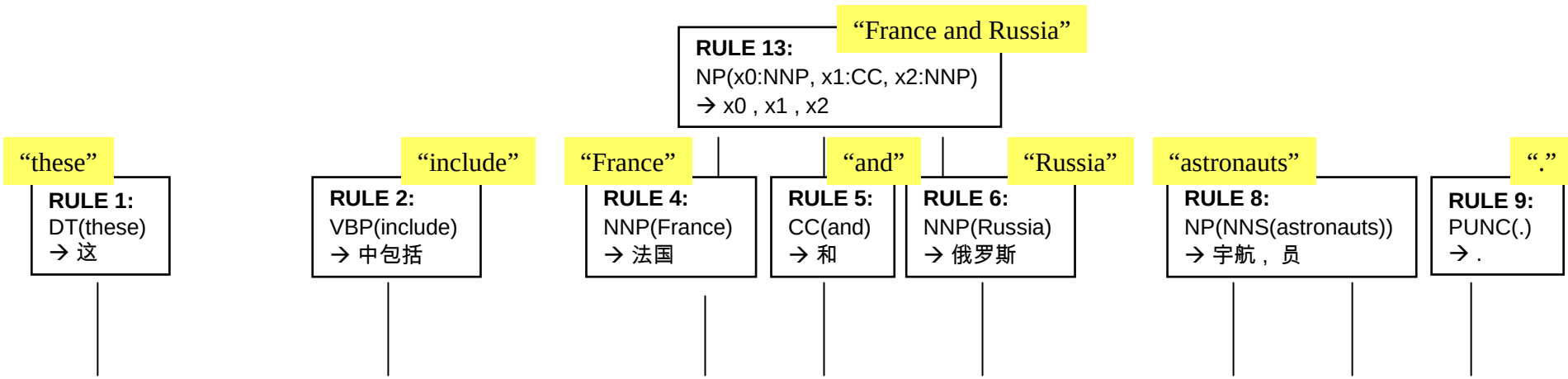
- For details: [Zhang et al 06]

Syntax-Based Decoding

Rules apply when their right-hand sides (RHS) match some portion of the input.



Syntax-Based Decoding



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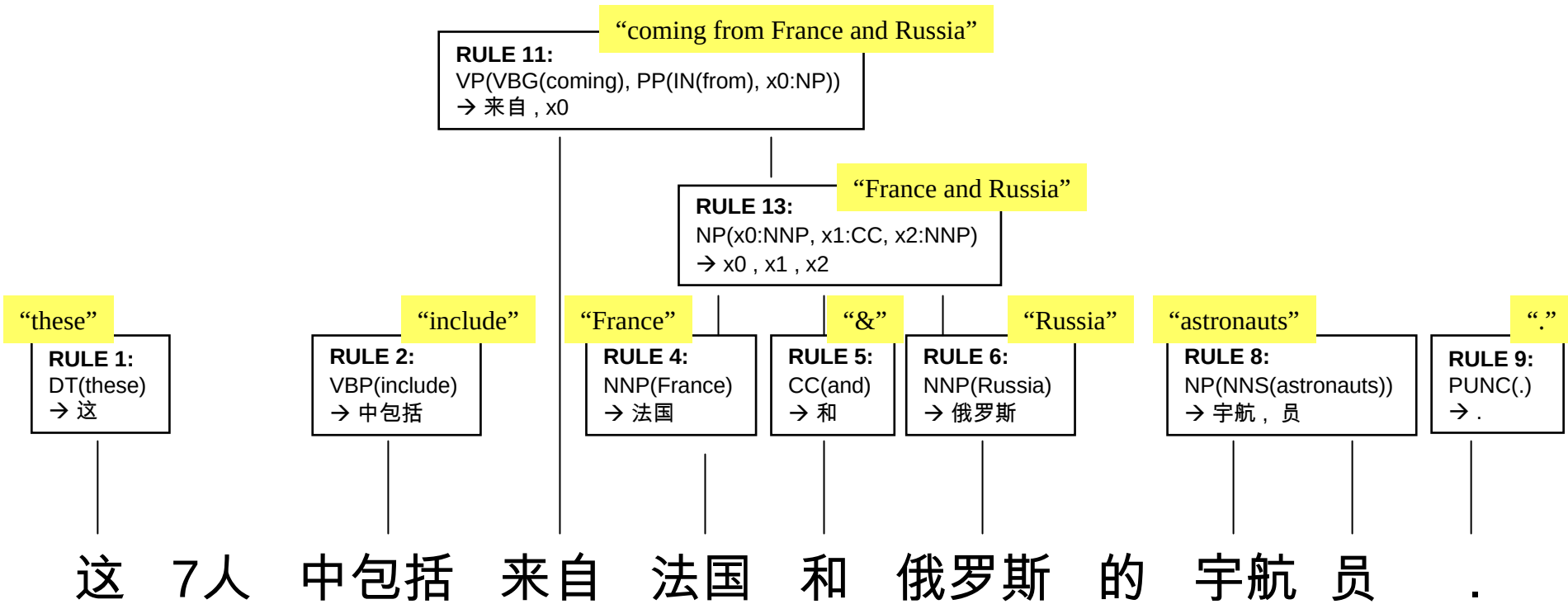
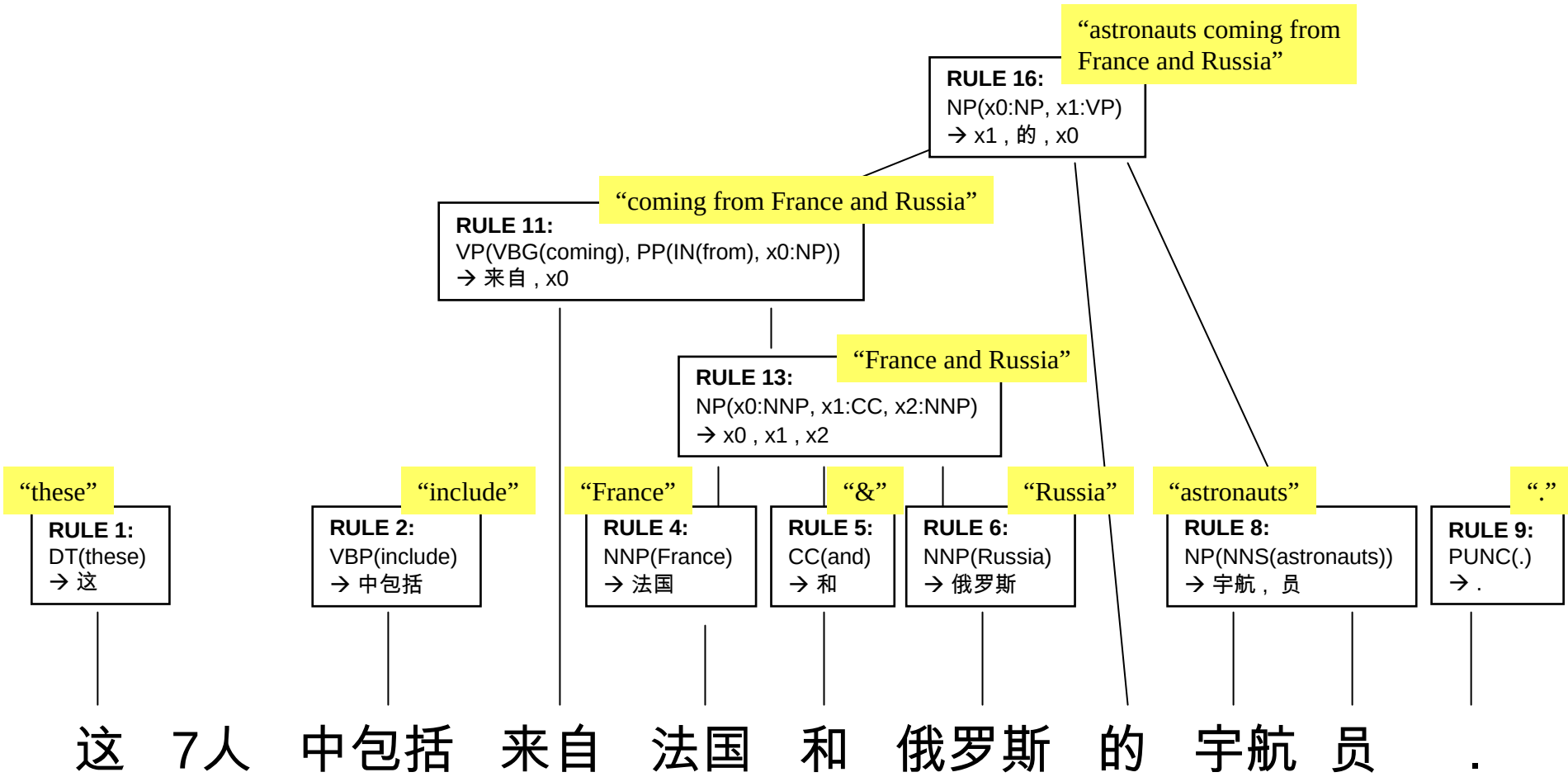
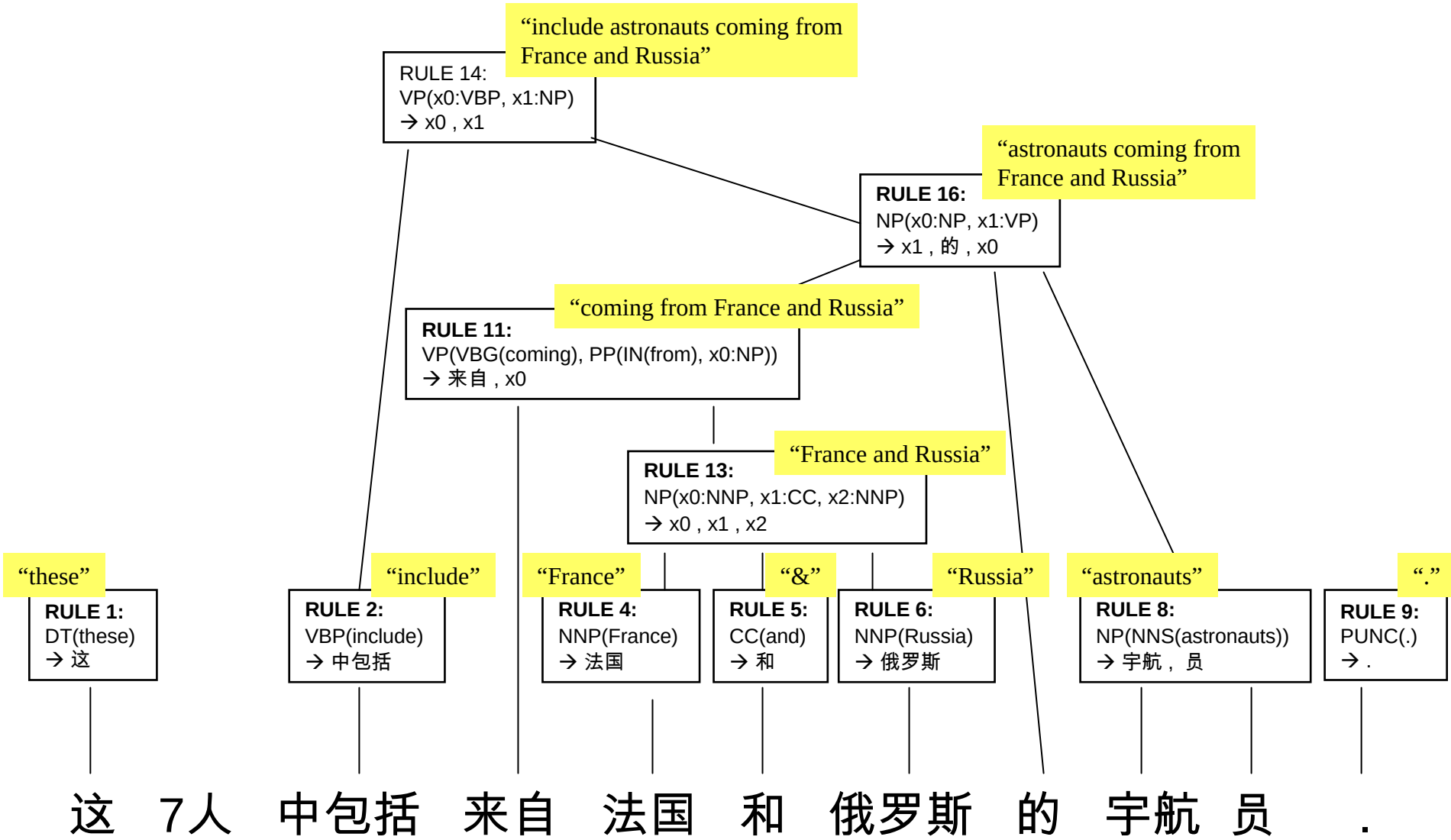
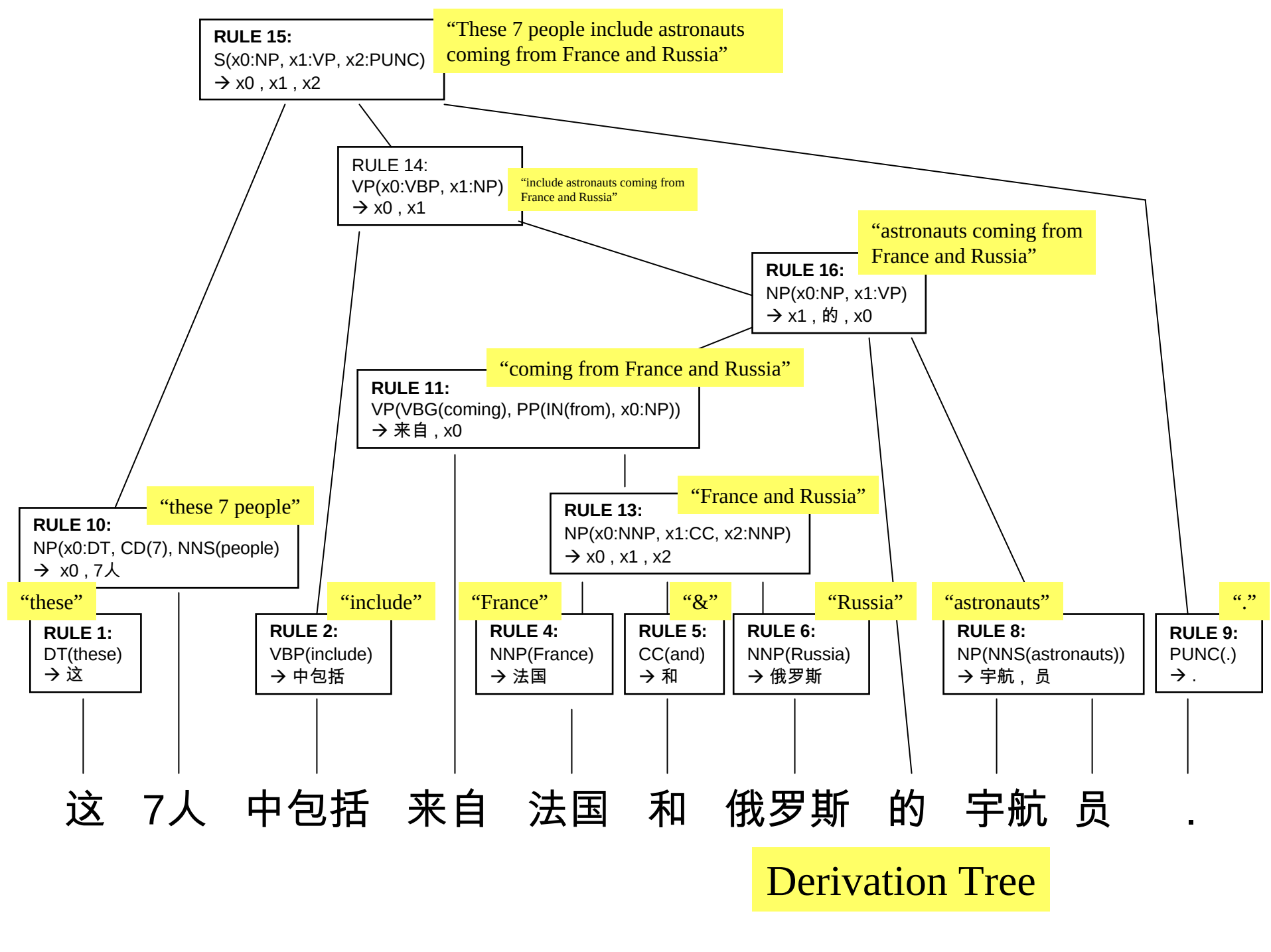


Syntax-Based Decoding




"include astronauts coming from France and Russia"
RULE 14:
VP(x0:VBP, x1:NP)
→ x0 , x1
"astronauts coming from France and Russia"
RULE 16:
NP(x0:NP, x1:VP)
→ x1 , 的 , x0
"coming from France and Russia"
RULE 11:
VP(VBG(coming), PP(IN(from), x0:NP))
→ 来自 , x0
"France and Russia"
RULE 13:
NP(x0:NNP, x1:CC, x2:NNP)
→ x0 , x1 , x2
"these"
RULE 1:
DT(these)
→ 这
"include"
RULE 2:
VBP(include)
→ 中包括
"France"
RULE 4:
NNP(France)
→ 法国
"&"
RULE 5:
CC(and)
→ 和
"Russia"
RULE 6:
NNP(Russia)
→ 俄罗斯
"astronauts"
RULE 8:
NP(NNS(astronauts))
→ 宇航 , 员
"."
RULE 9:
PUNC(.)
→ .
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .


RULE 15:
S(x0:NP, x1:VP, x2:PUNC)
→ x0 , x1 , x2
“These 7 people include astronauts coming from France and Russia”
RULE 14:
VP(x0:VBP, x1:NP)
→ x0 , x1
“include astronauts coming from France and Russia”
RULE 16:
NP(x0:NP, x1:VP)
→ x1 , 的 , x0
“astronauts coming from France and Russia”
RULE 11:
VP(VBG(coming), PP(IN(from), x0:NP))
→ 来自 , x0
“coming from France and Russia”
RULE 13:
NP(x0:NNP, x1:CC, x2:NNP)
→ x0 , x1 , x2
“France and Russia”
RULE 10:
NP(x0:DT, CD(7), NNS(people))
→ x0 , 7人
“these 7 people”
RULE 1:
DT(these)
→ 这
“these”
RULE 2:
VBP(include)
→ 中包括
“include”
RULE 4:
NNP(France)
→ 法国
“France”
RULE 5:
CC(and)
→ 和
“&”
RULE 6:
NNP(Russia)
→ 俄罗斯
“Russia”
RULE 8:
NP(NNS(astronauts))
→ 宇航， 员
“astronauts”
RULE 9:
PUNC(.)
→ .
“.”
这 7人 中包括 来自 法国 和 俄罗斯 的 宇航 员 .
Derivation Tree

Output English Tree