# Binarization for Machine Translation

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Joint work with Hao Zhang 張 浩 (Rochester),
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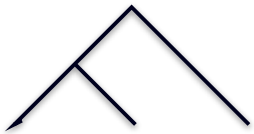
# Overview of Binarization

| parsing | machine translation |
| --- | --- |
| CFG | Synchronous CFG |
| $\mathbf{S} \rightarrow \mathbf{NP\ VP\ PP}$ | $\mathbf{S} \rightarrow \begin{matrix}\mathbf{NP\ PP\ VP} \\ \mathbf{NP\ VP\ PP}\end{matrix}$ |

# Overview of Binarization

## parsing

CFG



$S \rightarrow NP\ VP\ PP$

## machine translation

Synchronous CFG

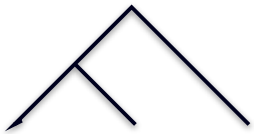
$$S \rightarrow \begin{matrix} NP & PP & VP \\ NP & VP & PP \end{matrix}$$

for cubic time parsing

# Overview of Binarization

## parsing

CFG => CNF



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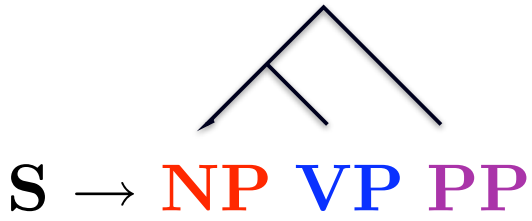


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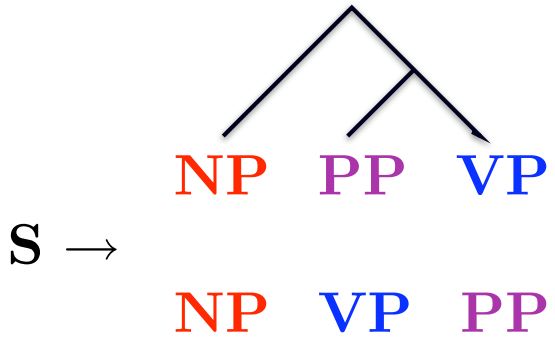
Synchronous CFG




for polynomial time decoding

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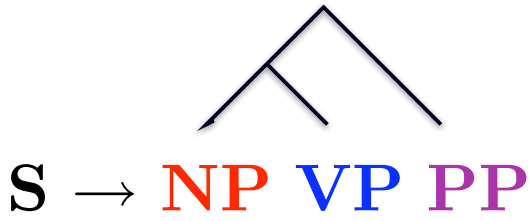


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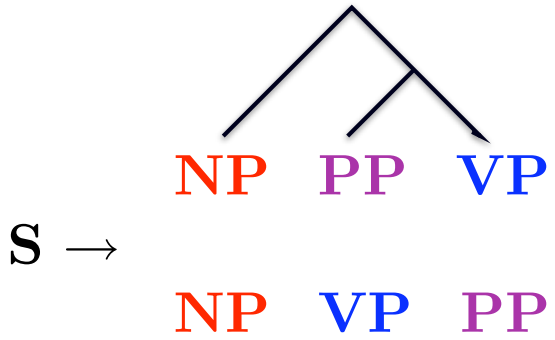
## machine translation

Synchronous CFG => ITG

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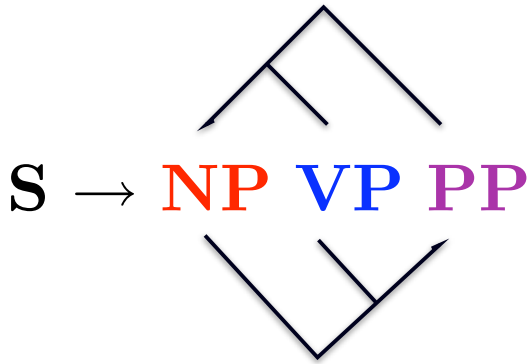


for cubic time parsing

different schemes
work equally well

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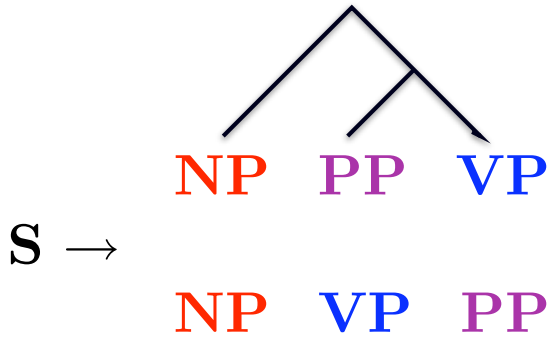


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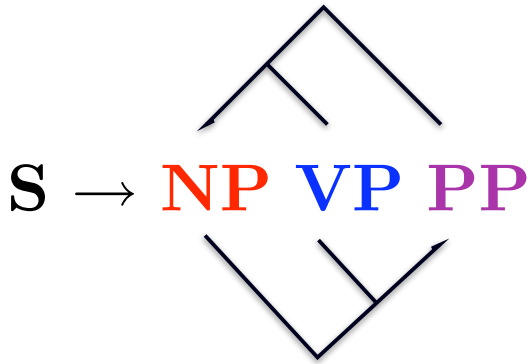


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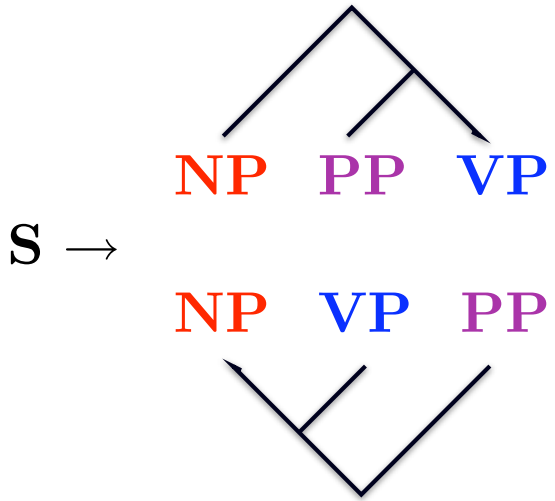


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# Outline

- Overview: Syntax-based Machine Translation
  - Synchronous Grammars
  - Translation as Parsing
  - ISI Syntax-based System
- The Problem of Binarization
- Our Solution: Synchronous Binarization
  - Linear-time Binarization Algorithm
- Experiments
- Application: Testing the ITG Hypothesis

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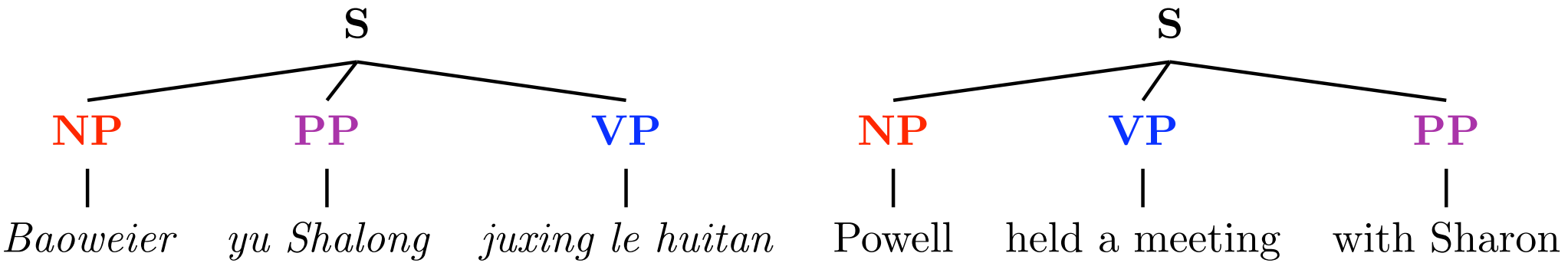
# Synchronous CFGs

- Synchronous Context-Free Grammar (SCFG)
  - CFG in two dimensions, generating pairs of trees/strings
  - co-indexed nonterminal further rewritten as a unit

| | | | |
|---|---|---|---|
| **S** | → | **NP**$^{(1)}$ **PP**$^{(2)}$ **VP**$^{(3)}$, | **NP**$^{(1)}$ **VP**$^{(3)}$ **PP**$^{(2)}$ |
| **NP** | → | *Baoweier*, | Powell |
| **PP** | → | *yu Shalong*, | with Sharon |
| **VP** | → | *juxing le huitan*, | held a meeting |




(Aho/Ullman, 1972) (Wu, 1997) (Yamada/Knight, 2001) (Chiang, 2005) (Satta/Peserico, 2005)

# Translation as Parsing

- Many problems in syntax-based MT reduce to parsing
  - here we consider decoding as monolingual parsing

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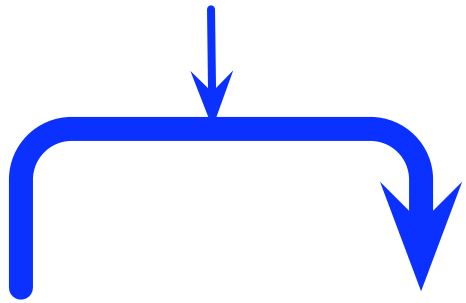

*Baoweier yu Shalong juxing le huitan* Powell held a meeting with Sharon

(Wu, 1996) (Melamed, 2004) (Chiang, 2005) (Satta and Peserico, 2005)

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*Baoweier yu Shalong juxing le huitan*

1 2 3 4 5 6 7

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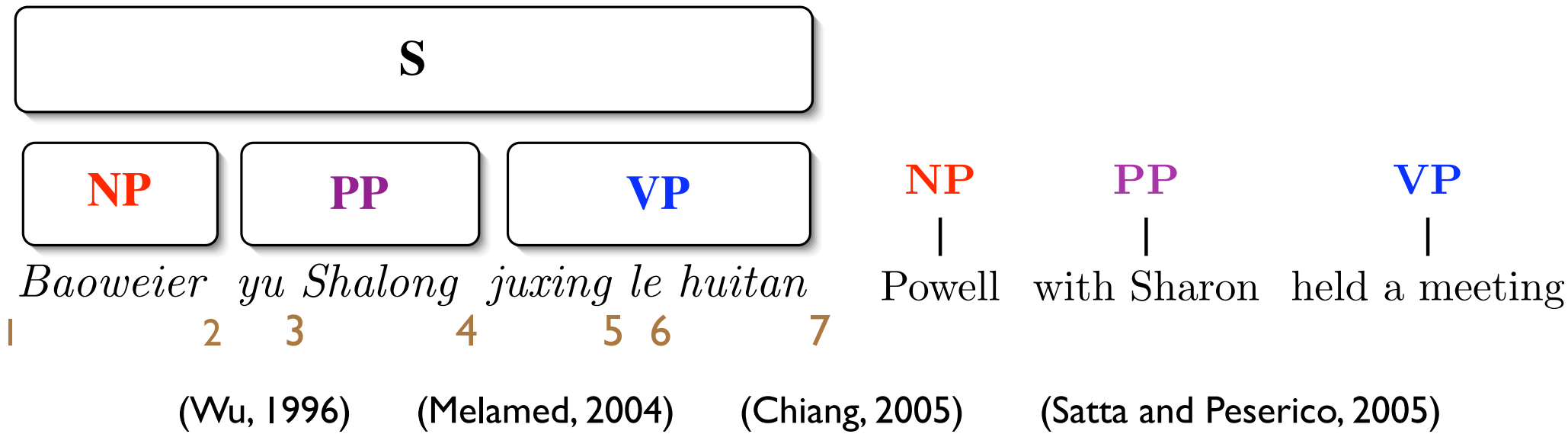


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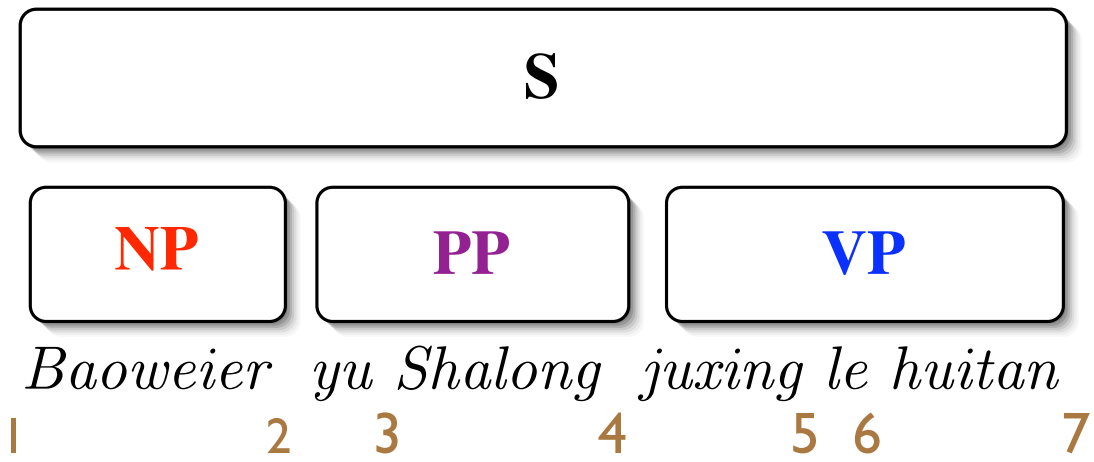


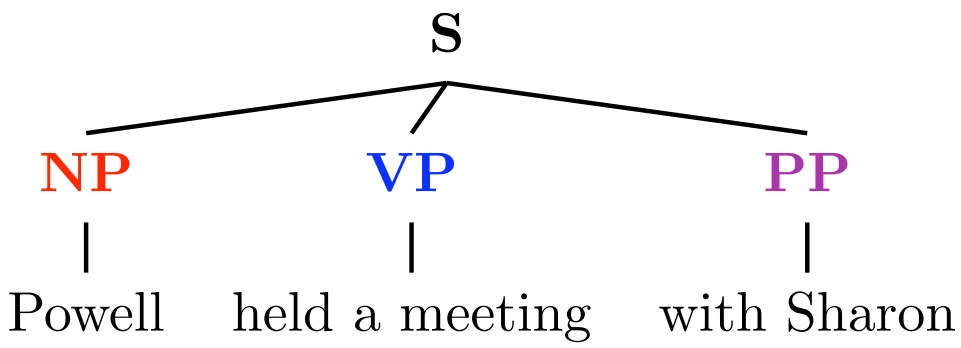


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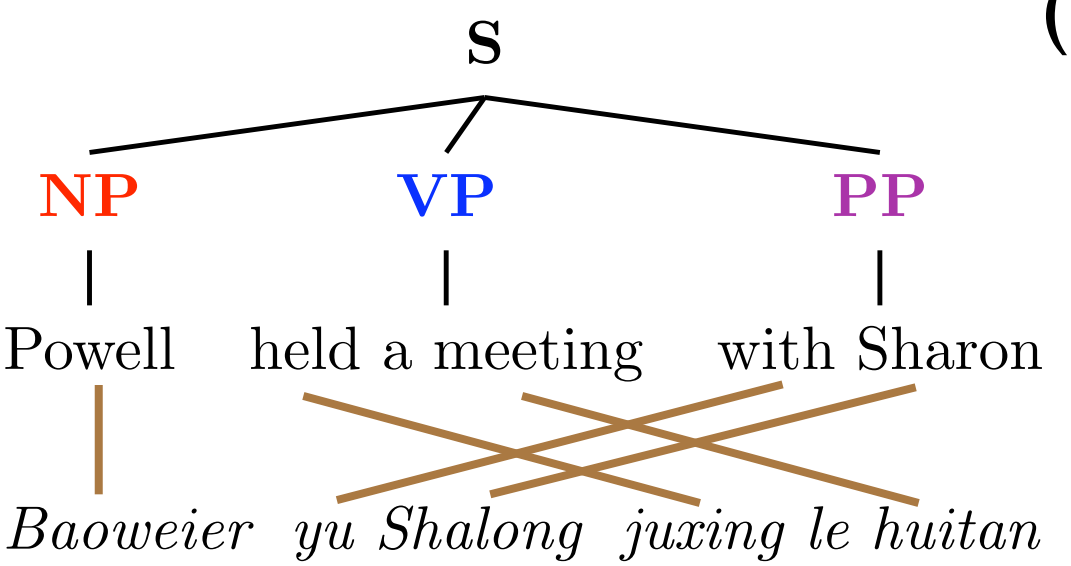
# Where are these rules from?

- Induce synchronous grammars from parallel corpora
  - ISI syntax-based system

(e-tree, f-string, alignment)




GHKM extraction
(Galley et al., 2004)

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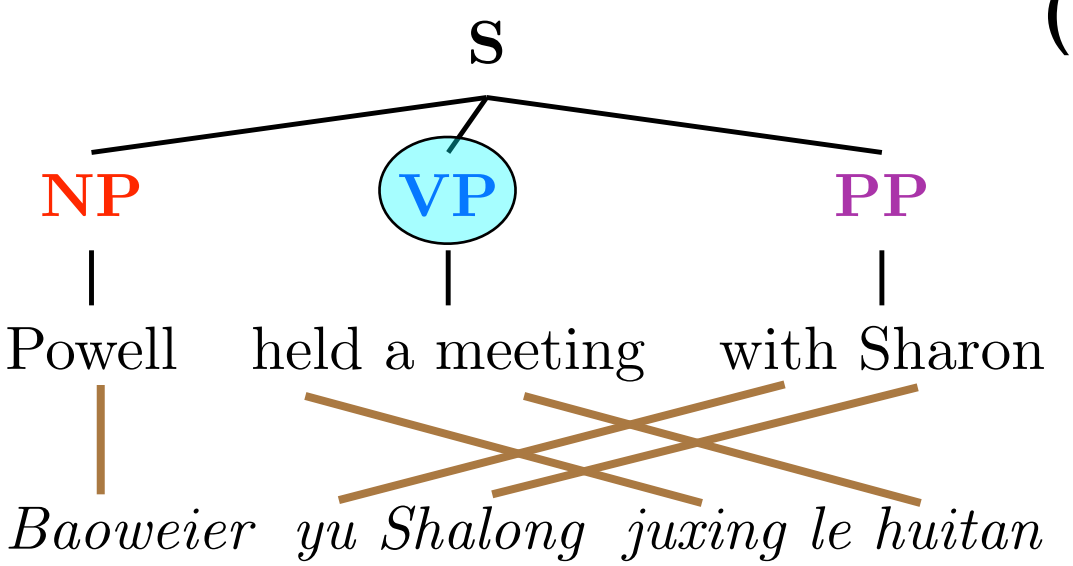


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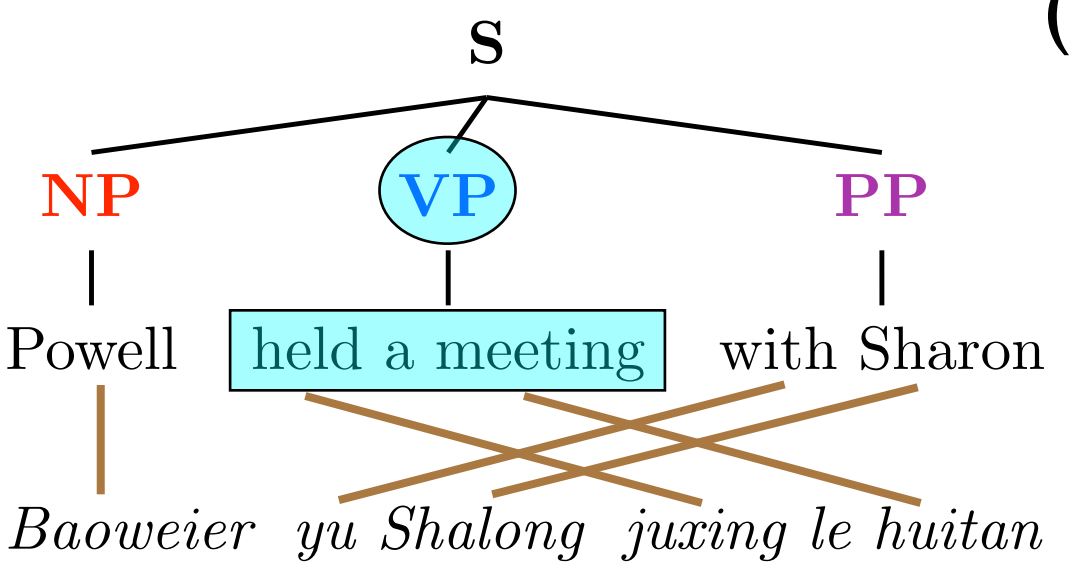


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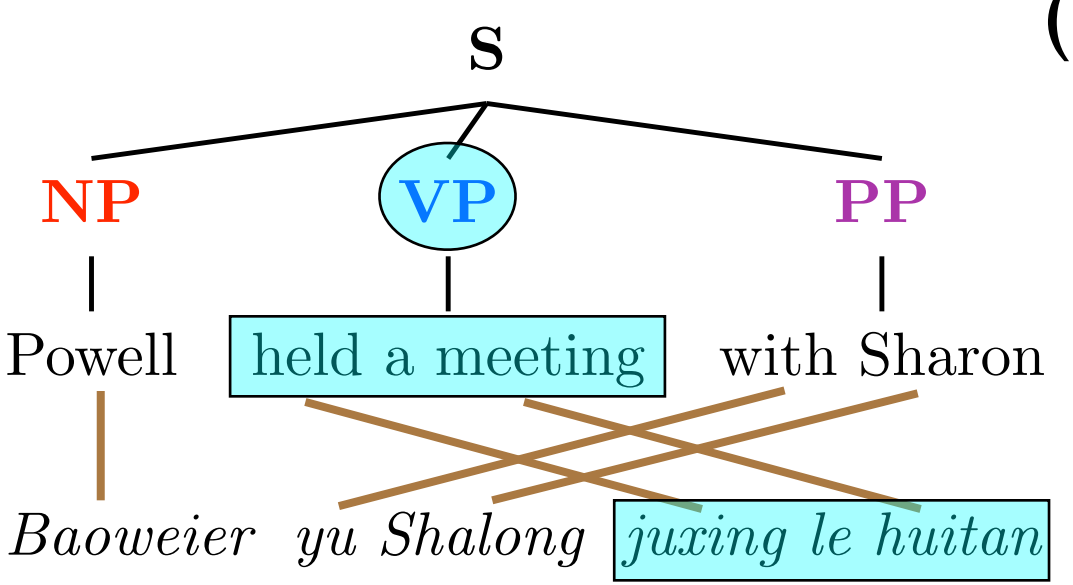


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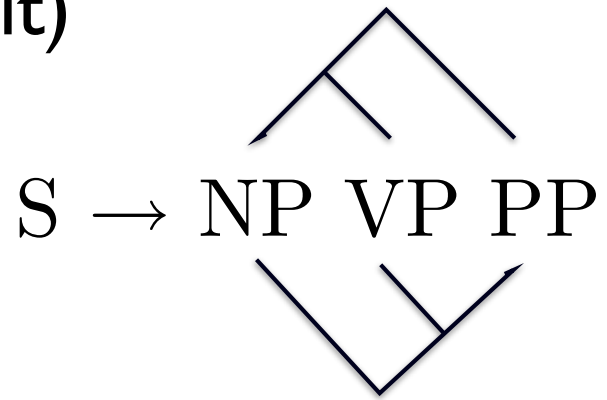
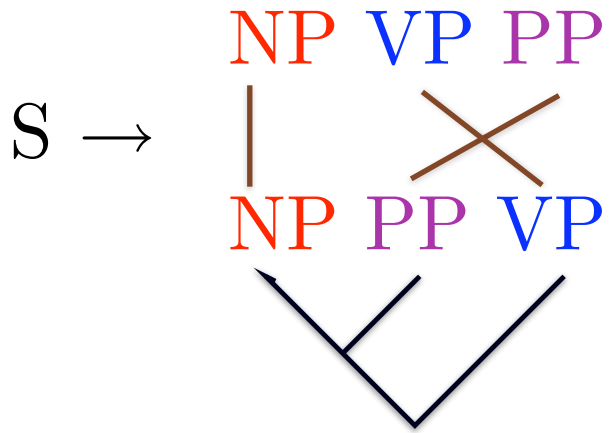
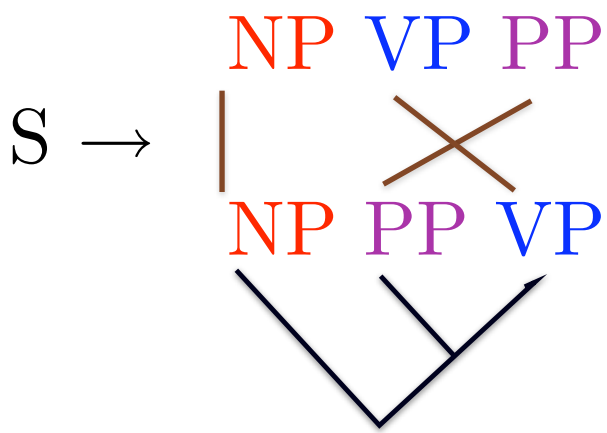
# CKY / binarization

- Efficient parsing requires binary-branching grammars
  - e.g., CKY (explicit) or Earley (implicit)
- Many ways to binarize
  - They all work fine



# Integrating Language Models

- dynamic programming algorithm
  - remembering "boundary words"
- different binarization has very different effect


*Baoweier yu Shalong juxing le huitan*

(Wu, 1996) (Chiang, 2005)

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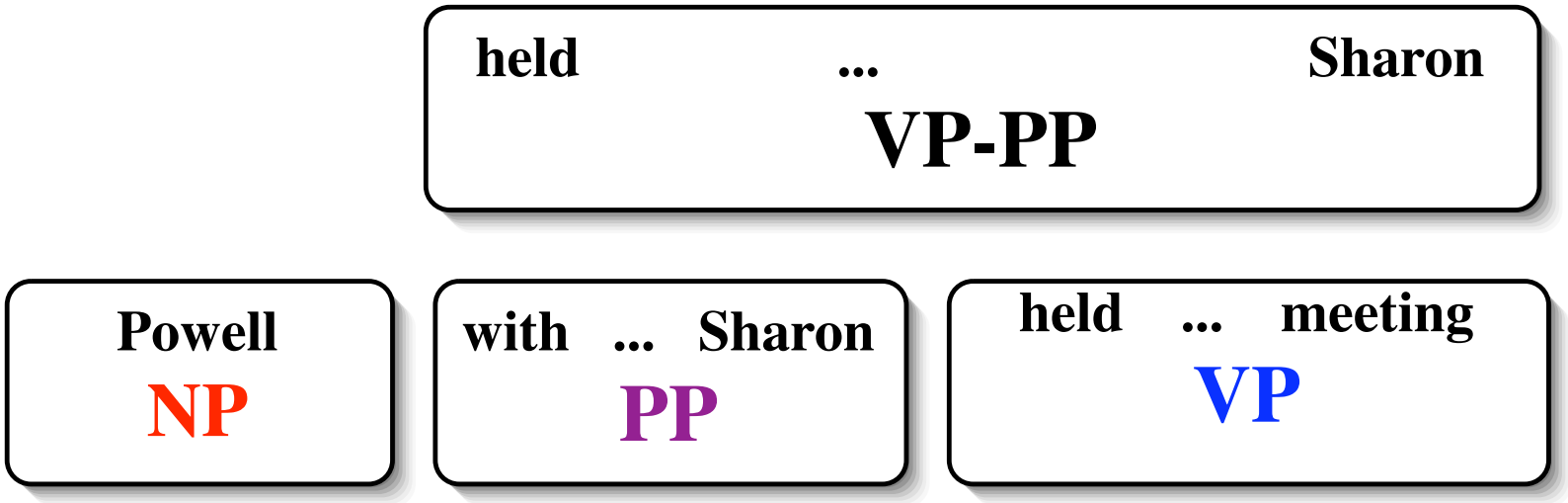


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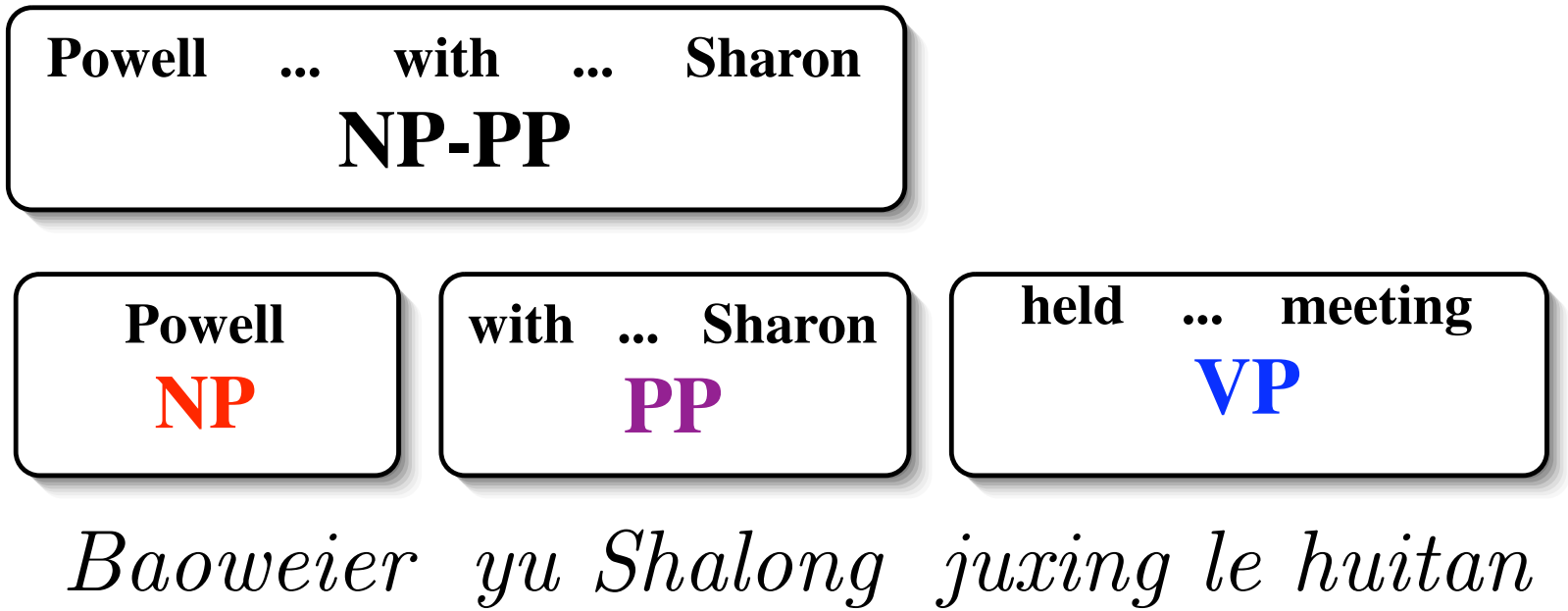

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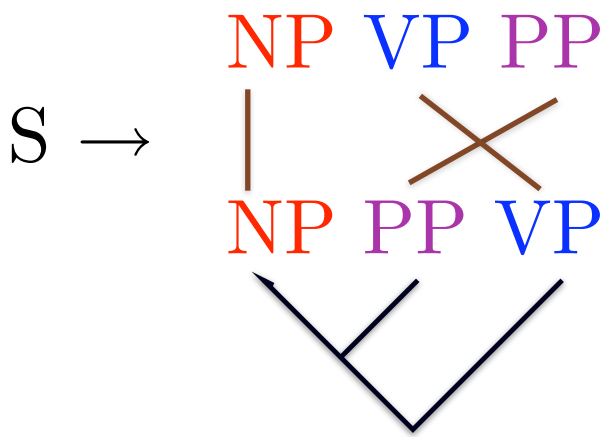


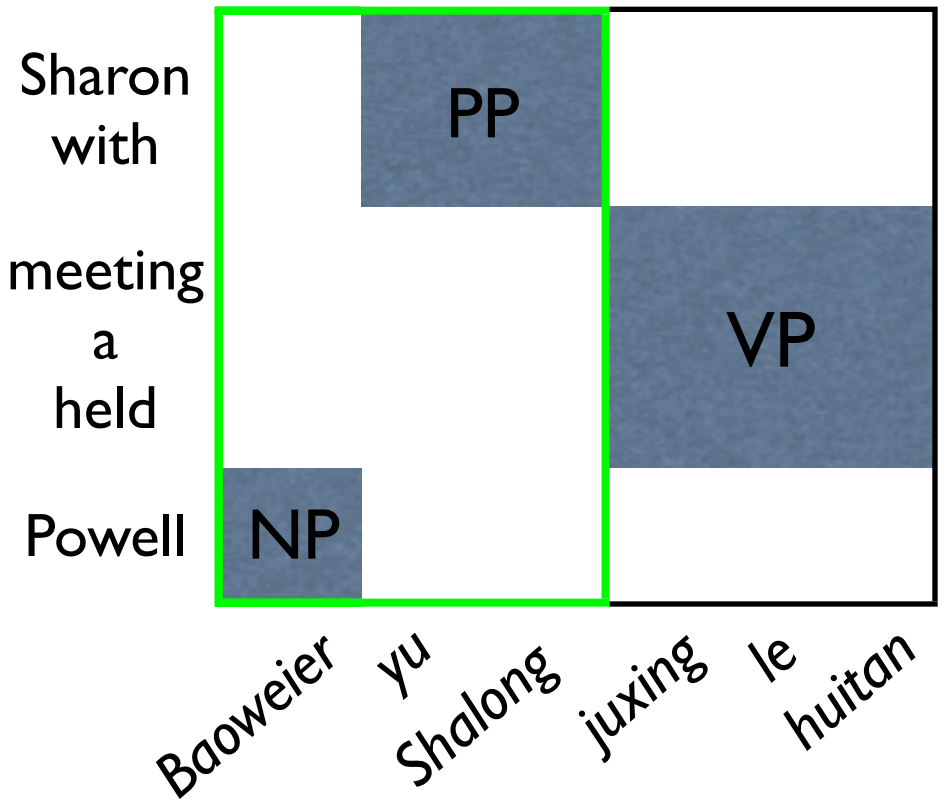

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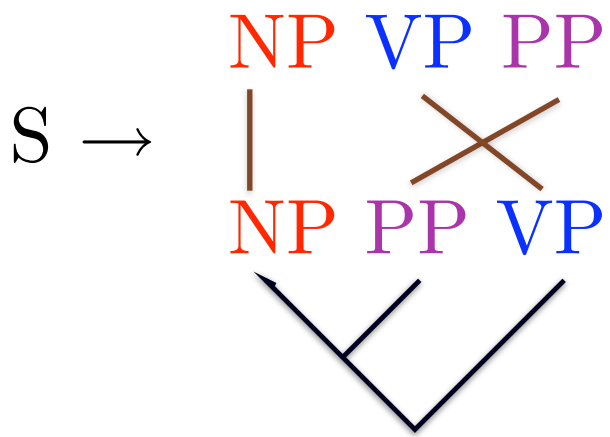


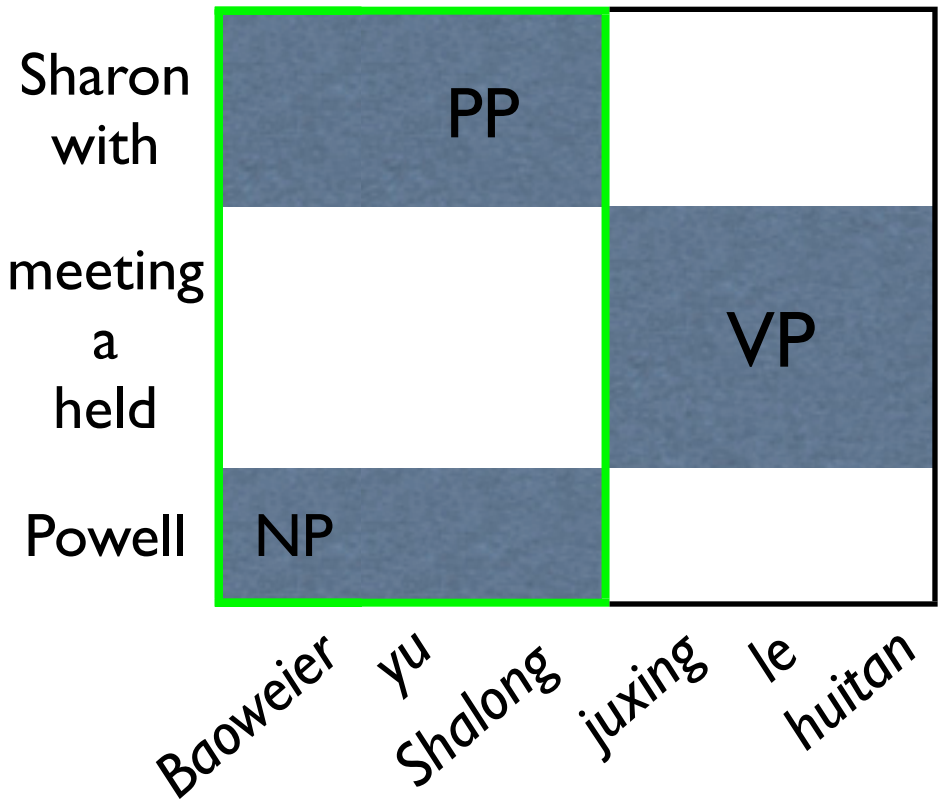

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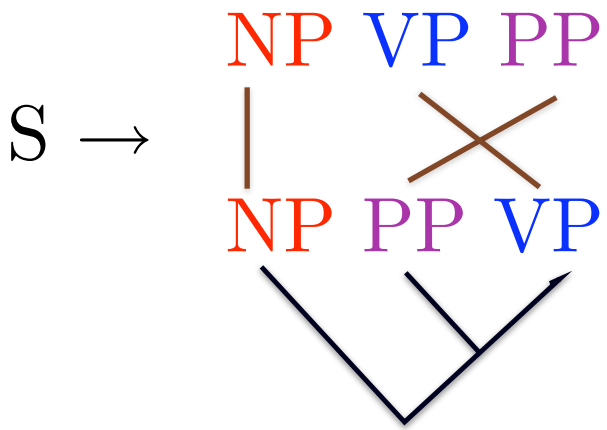


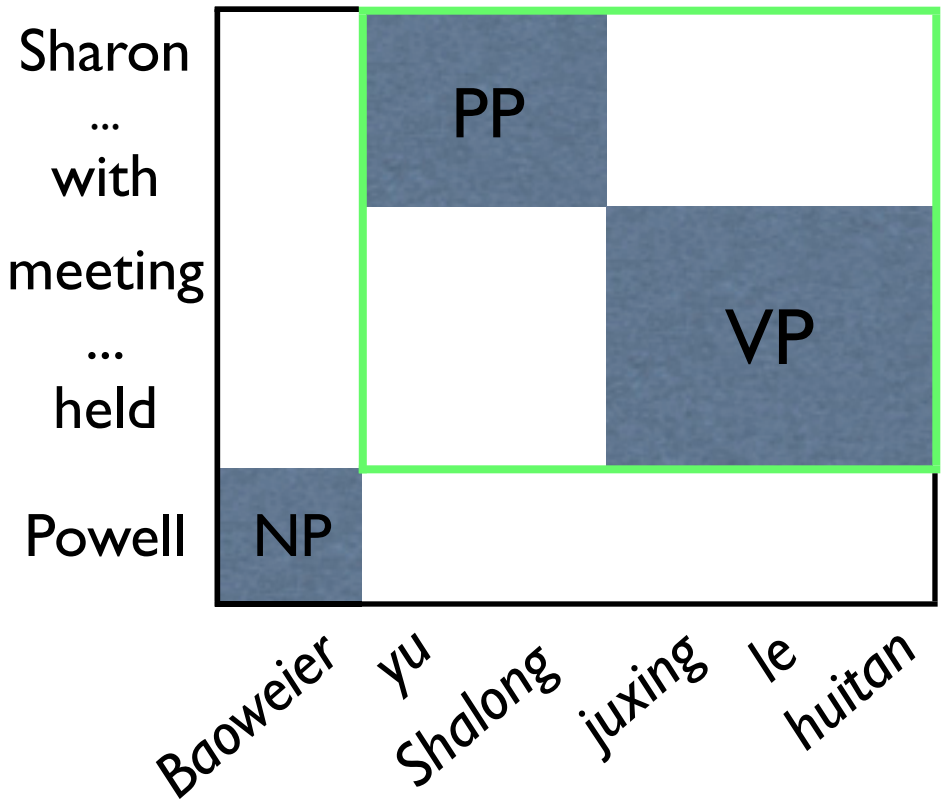

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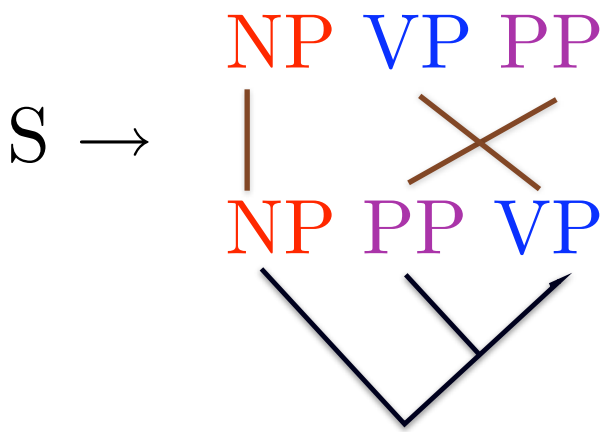


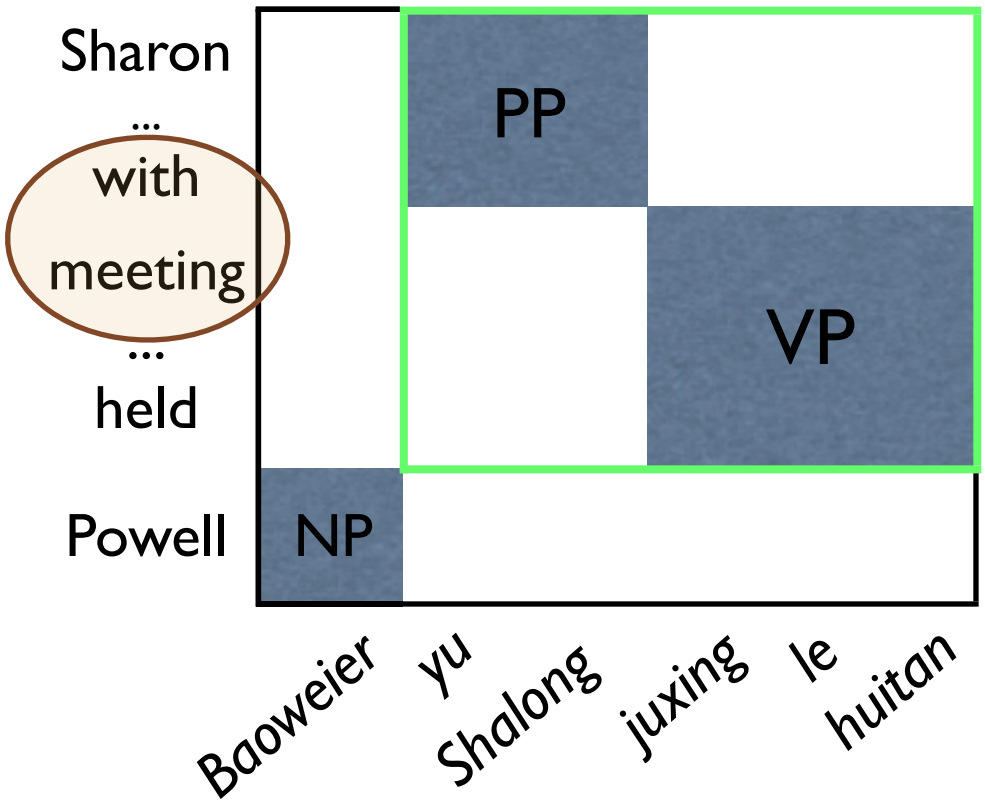

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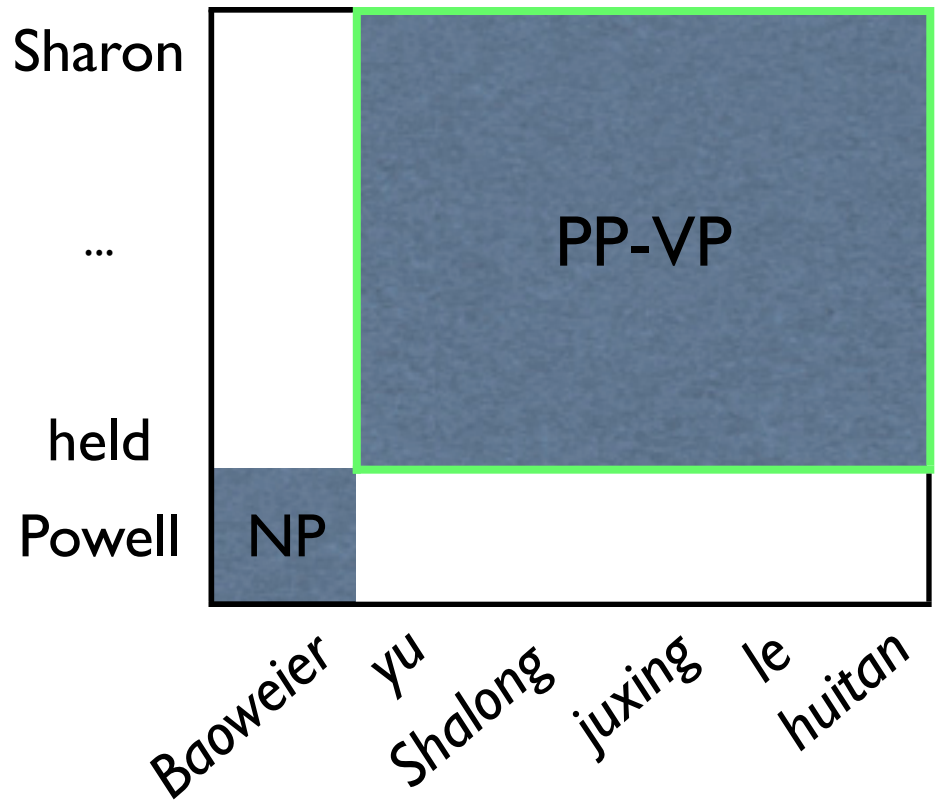
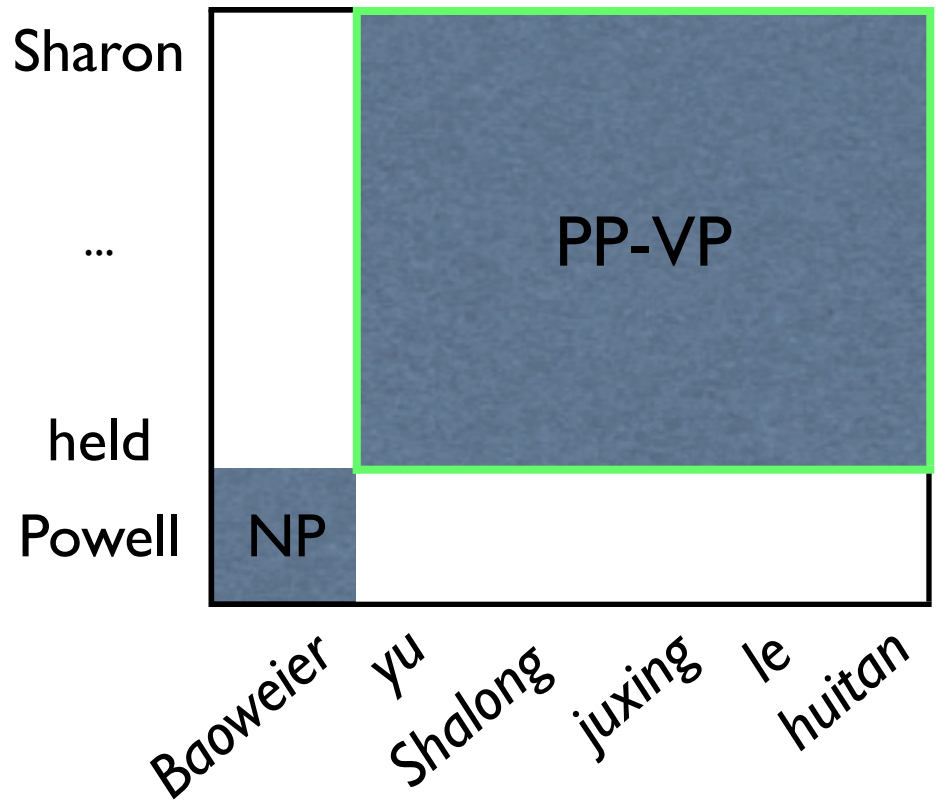


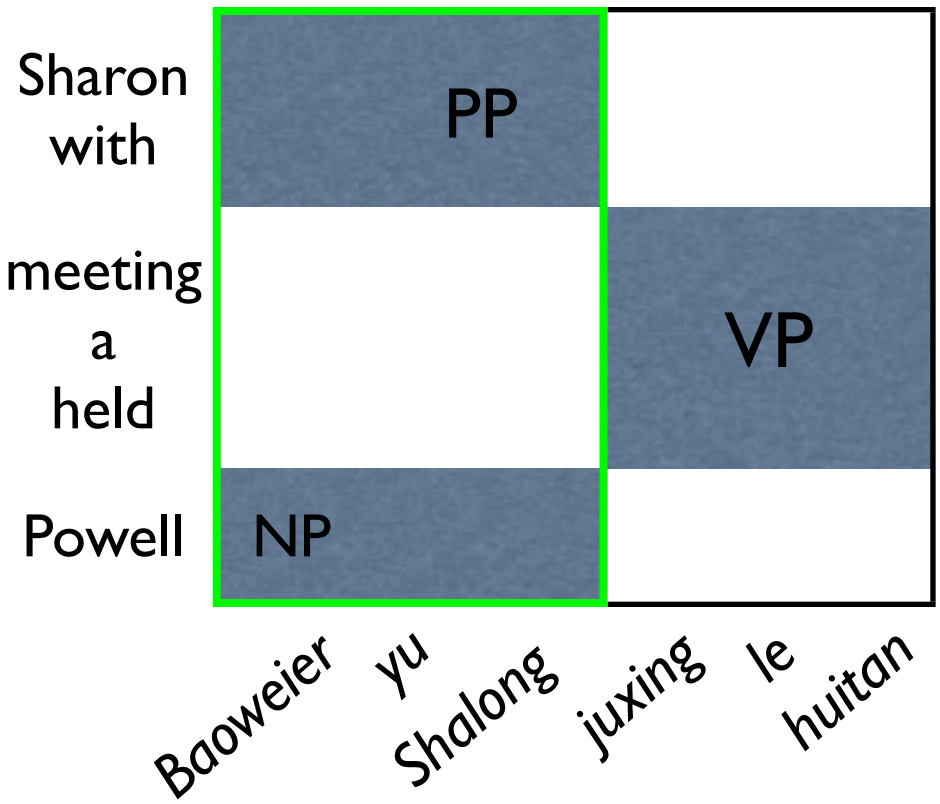
# Binarization in 2D

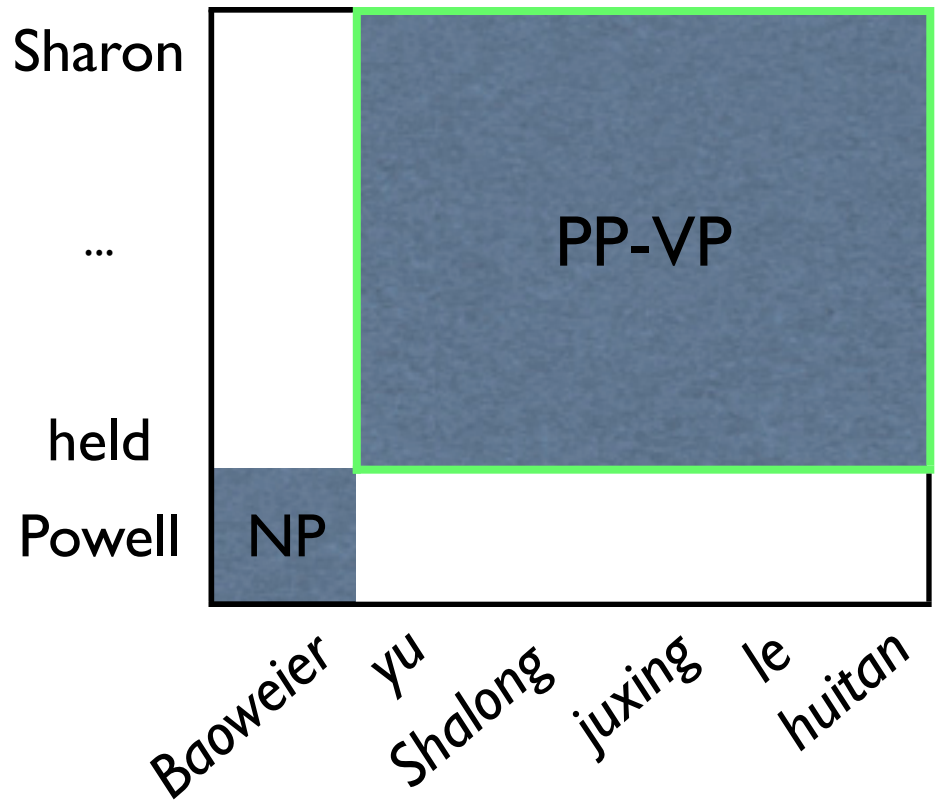
- good binarization: can score n-gram combo costs ASAP; only storing two (sets of) boundary words



# Binarization in 2D

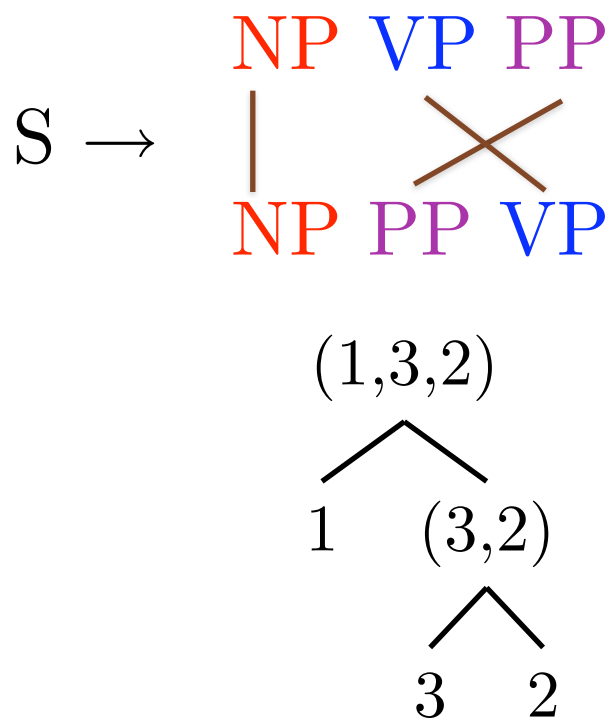
- good binarization: can score n-gram combo costs ASAP; only storing two (sets of) boundary words
- bad binarization: have to wait till all nonterminals of a rule have been recognized; storing all LM words

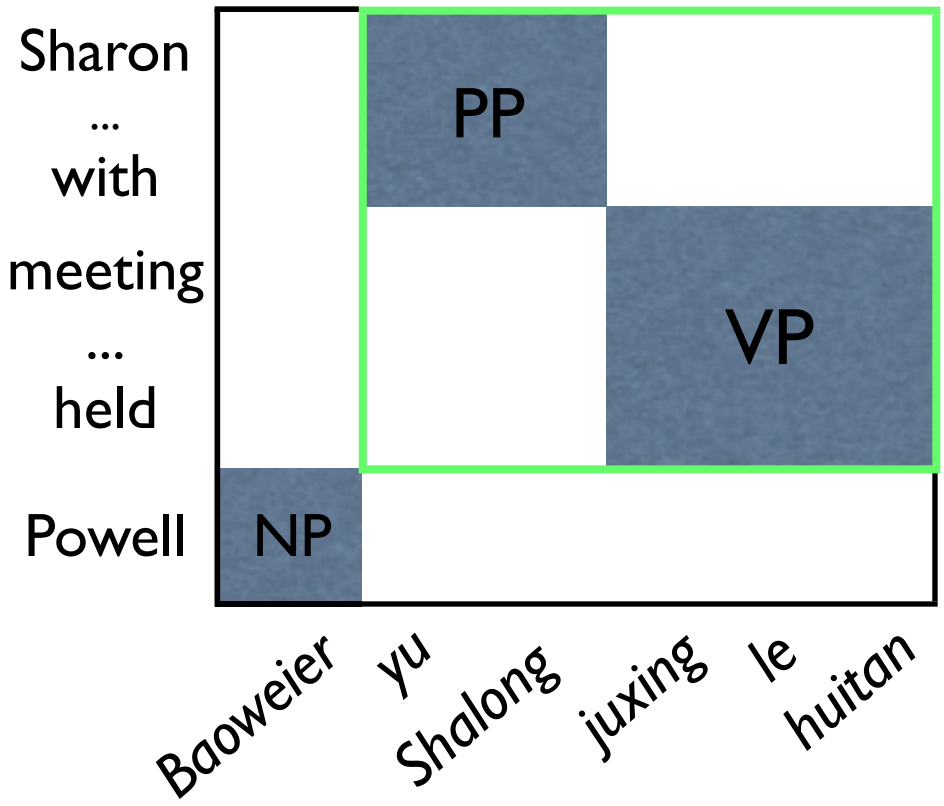


# Synchronous Binarization

- converts an SCFG into binary-branching
- intuition: should have contiguous spans on both sides
- binarizing the permutation of nonterminals



# Is every rule binarizable?

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- for n < 4, yes

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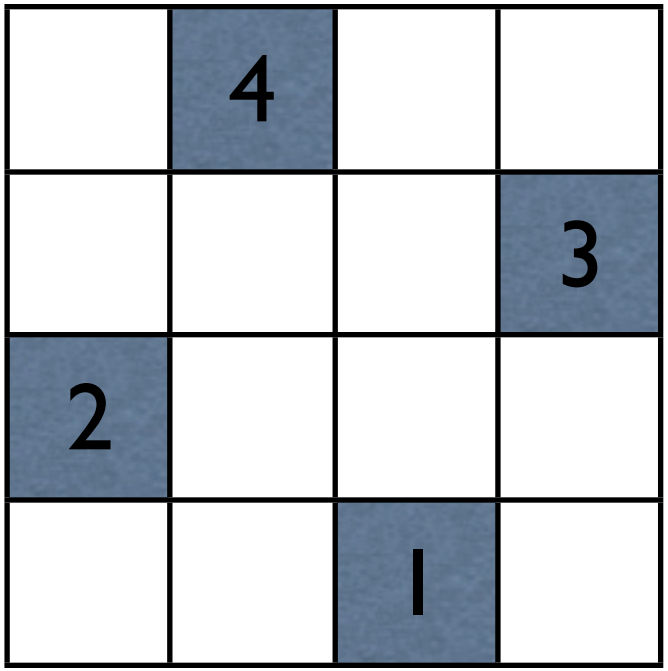
- for n < 4, yes
- for n >= 4, many permutations non-binarizable



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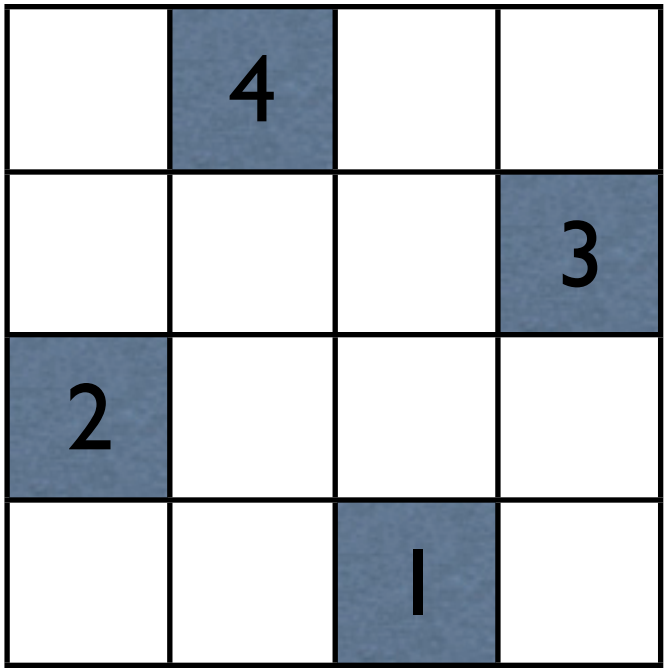
- Q: are these bad cases linguistically motivated?



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- for n >= 4, many permutations non-binarizable
- Q: are these bad cases linguistically motivated?
  - ITG hypothesis: no

... unable to find "real-examples", at least in fixed-word-order languages

Wu (1997)

| | | | |
|---|---|---|---|
| | 4 | | |
| | | | 3 |
| 2 | | | |
| | | 1 | |

# Is every rule binarizable?

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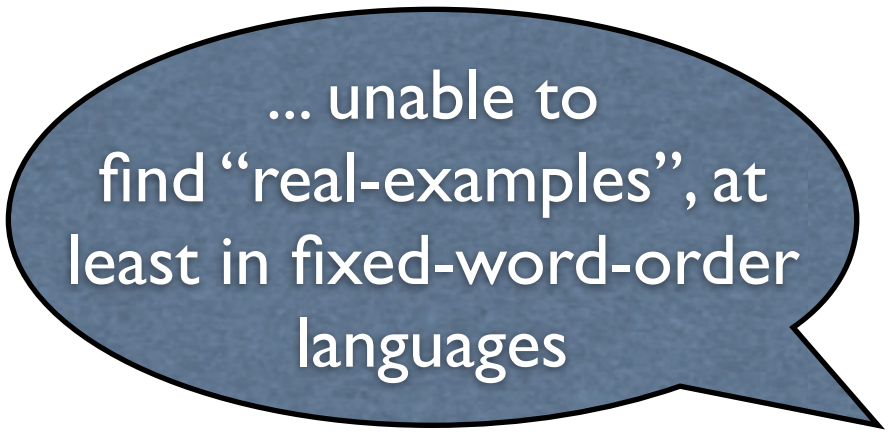
  - ITG hypothesis: no
  - we will answer it empirically

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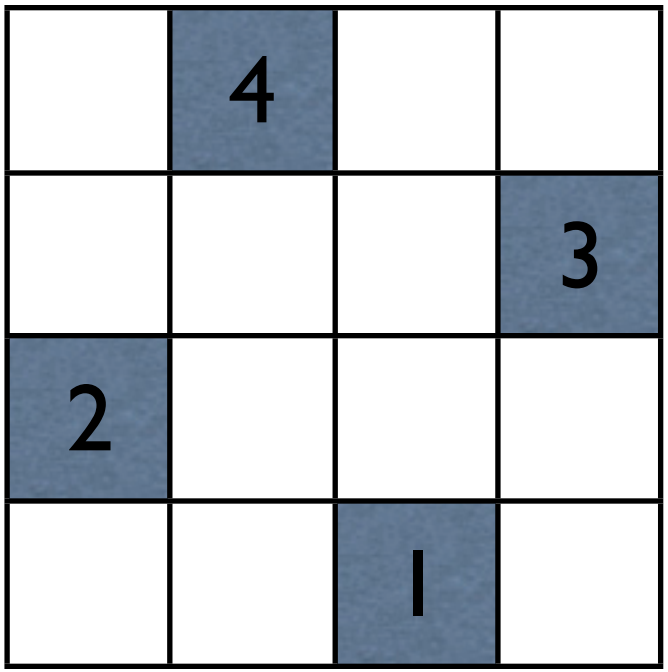
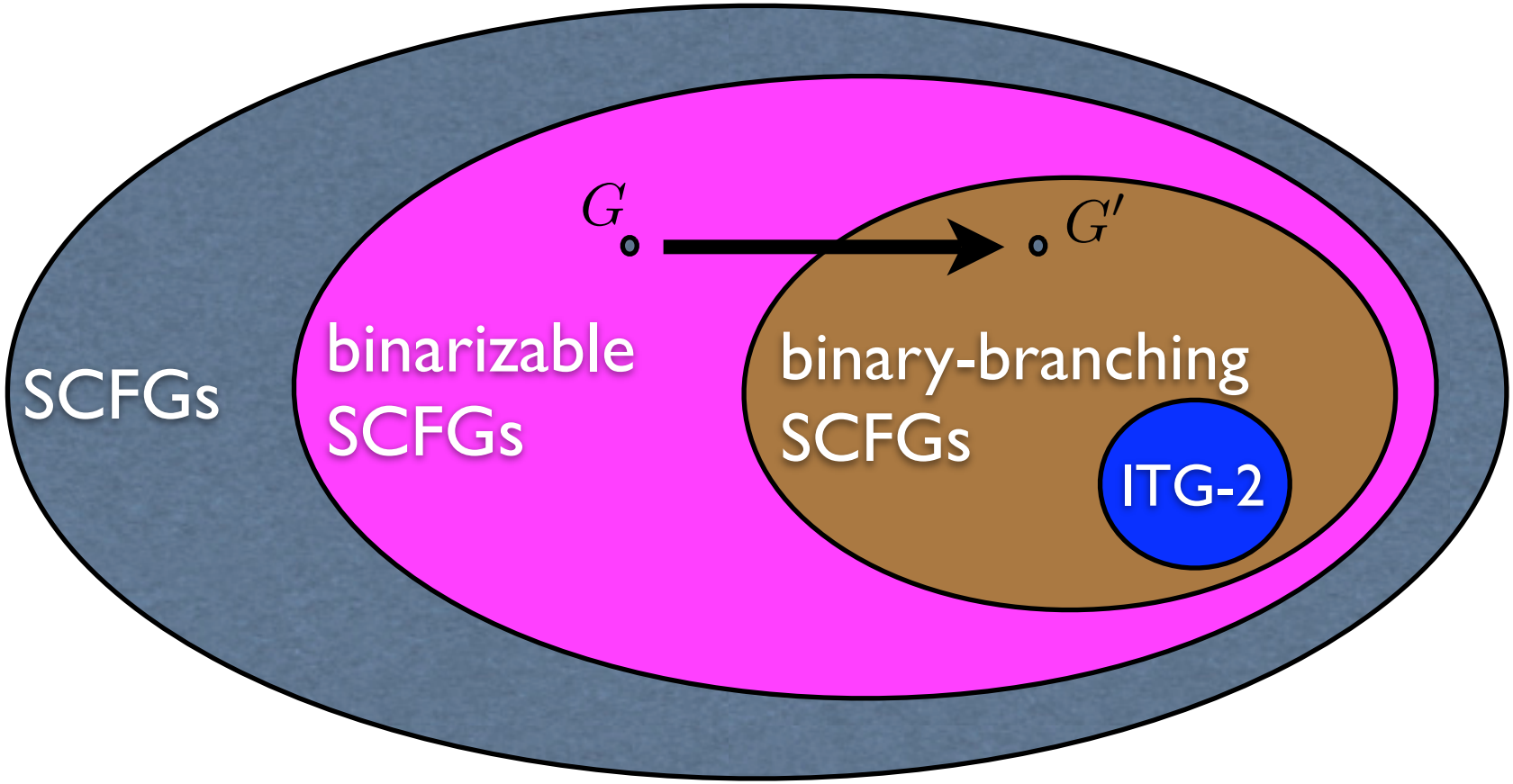


# The Big Picture

- synchronous binarization
  - *n*-ary SCFG *G* => binary-branching *G'*, if possible



# How to find good binarizations?

# Naïve Algorithm

# Naïve Algorithm

- Try all binary bracketings
  - finds all possible binarizations
  - exponential complexity (Catalan number)

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(1 ((3 2) 4))
(1 (3 (2 4)))
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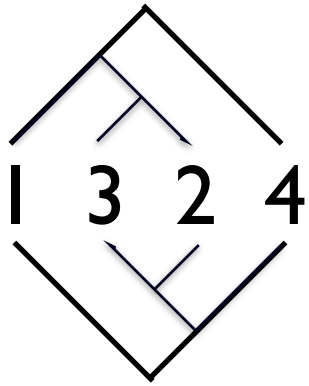
...

- However
  - we need a much faster algorithm!
  - one synchronous binarization is enough
  - we prefer unique solution for each permutation
    - sharing sub-binarizations



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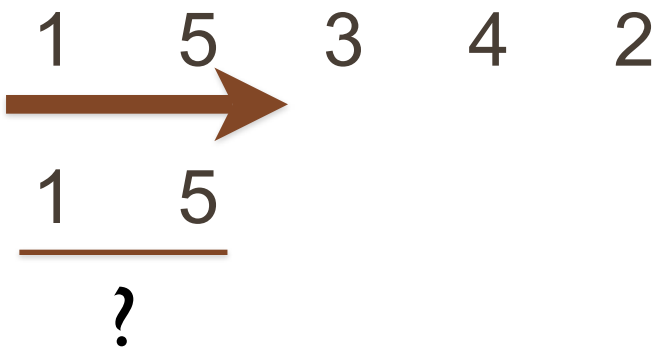


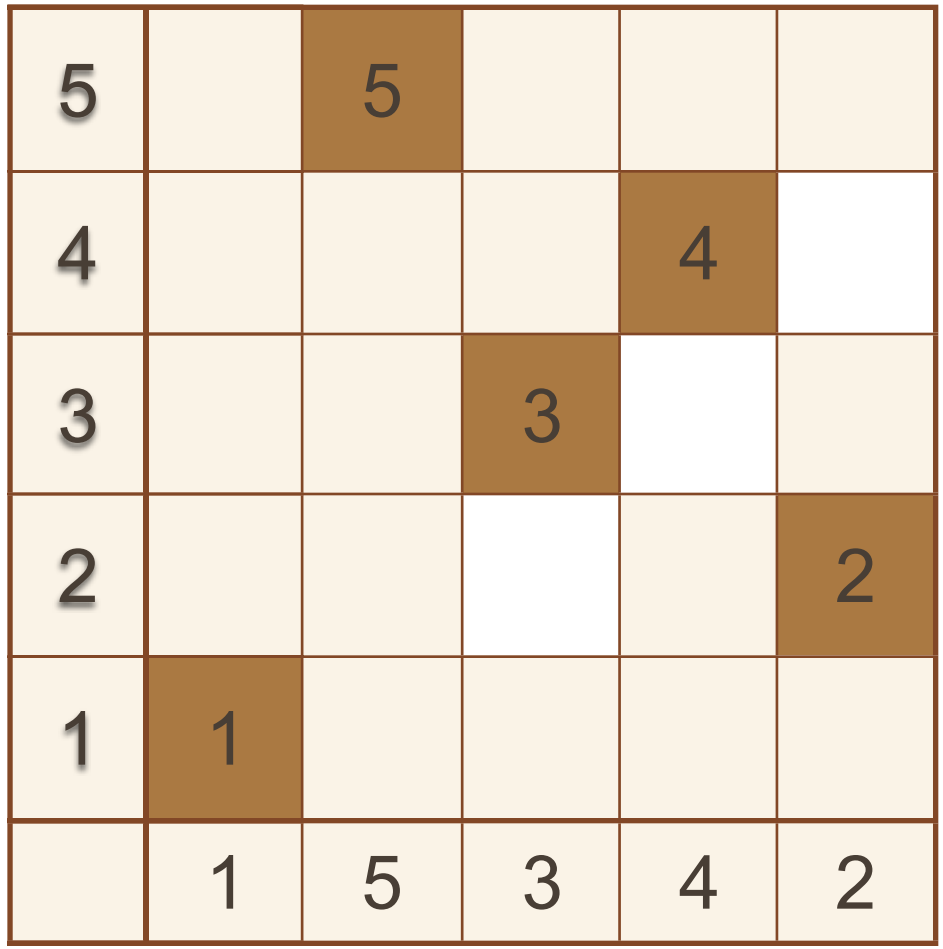

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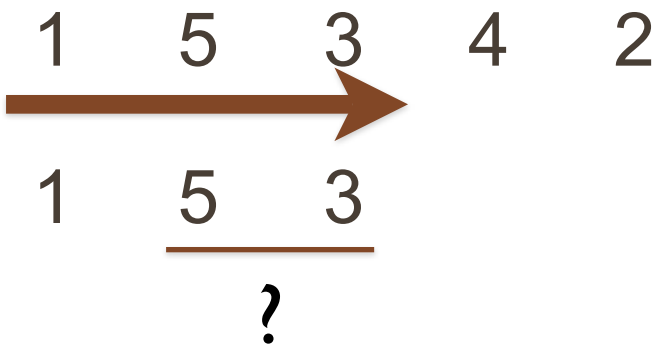


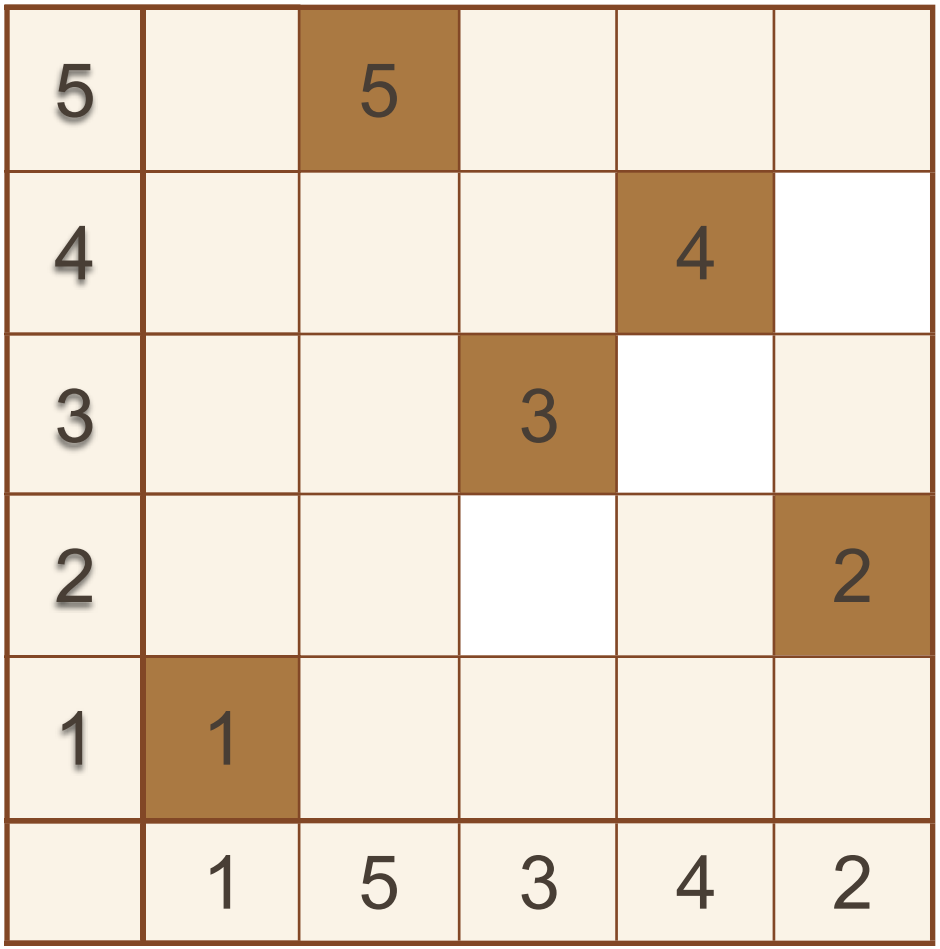

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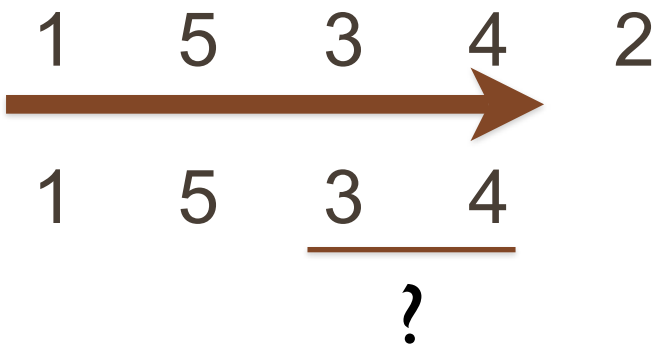


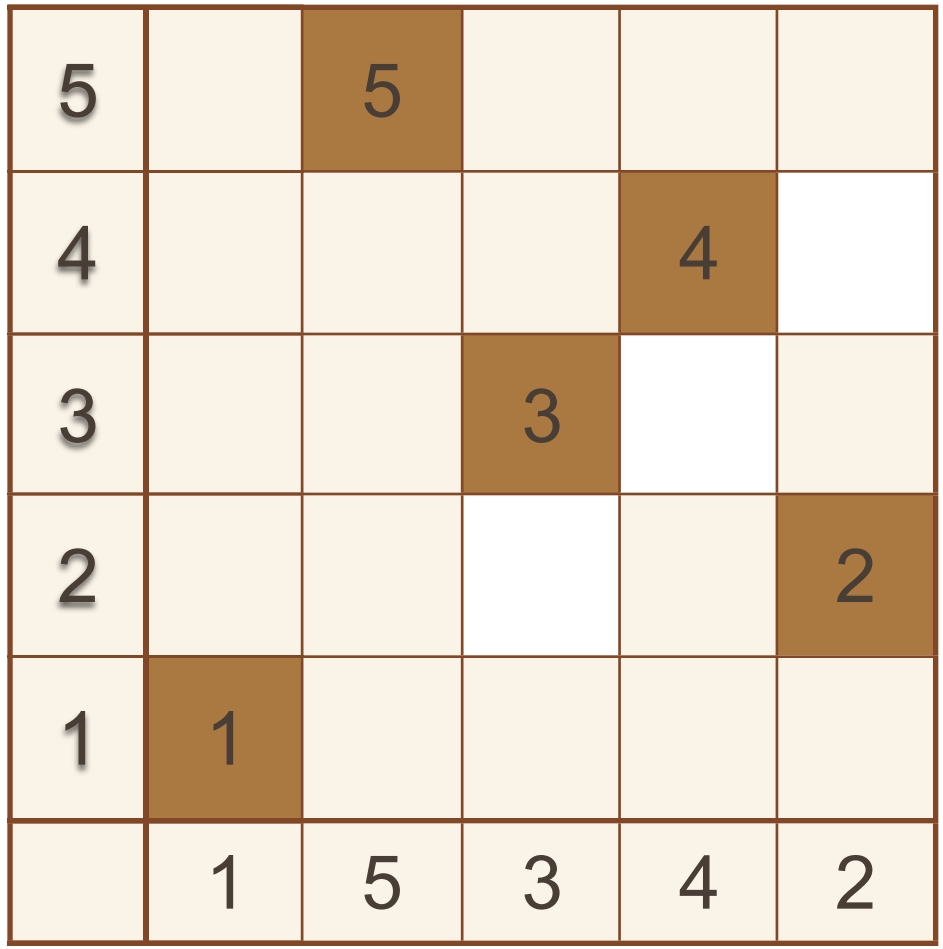

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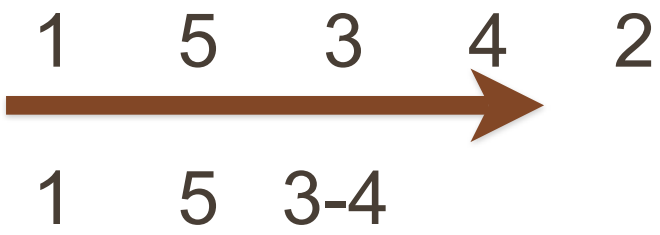


[3, 4]

| | | | | |
|---|---|---|---|---|
| 5 | | 5 | | |
| 4<br>\|<br>3 | | | 3-4 | |
| 2 | | | | 2 |
| 1 | 1 | | | |
| | 1 | 5 | 3-4 | 2 |

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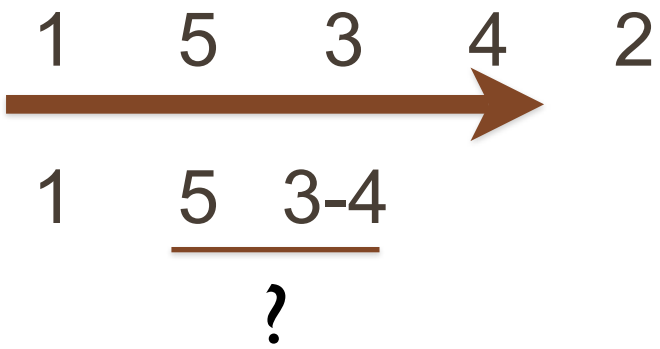


| | | | | |
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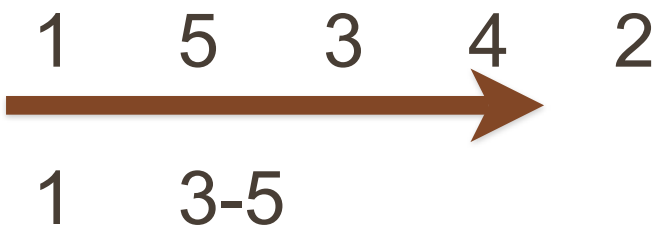


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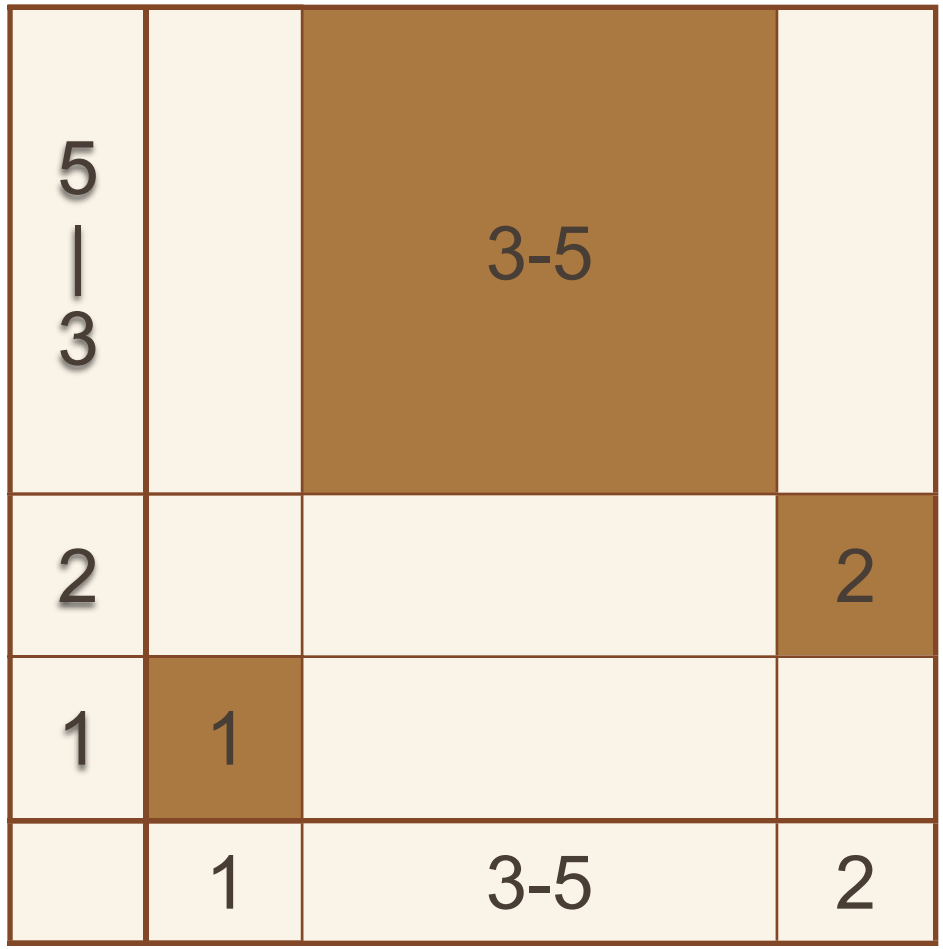

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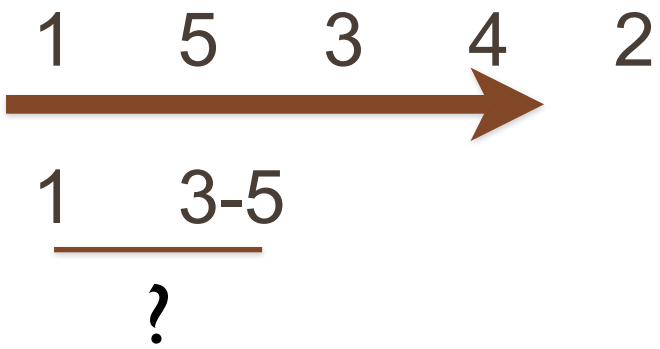


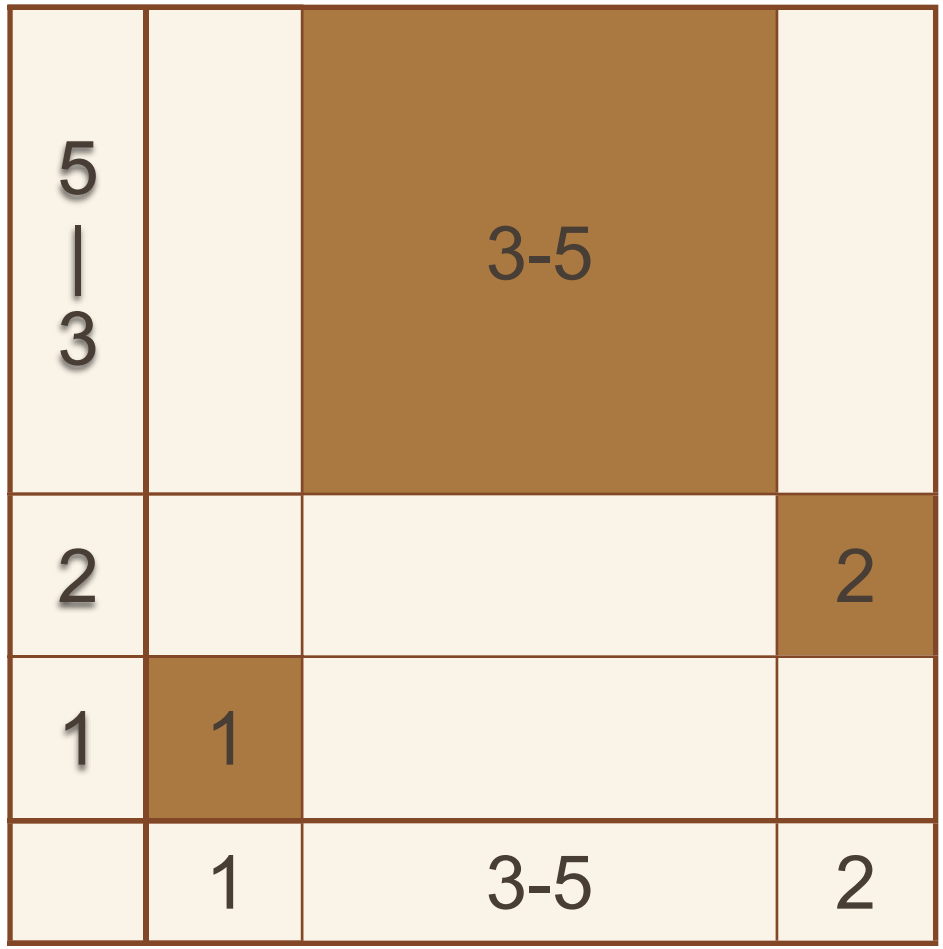

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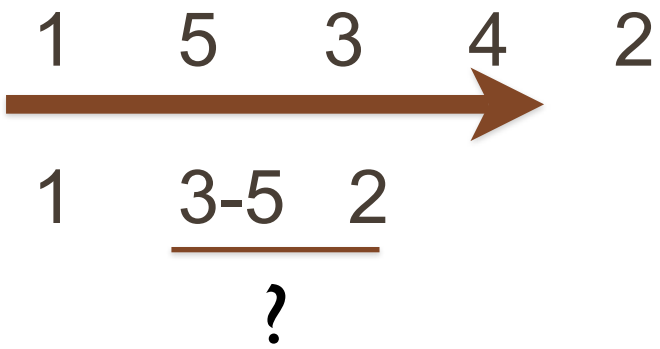


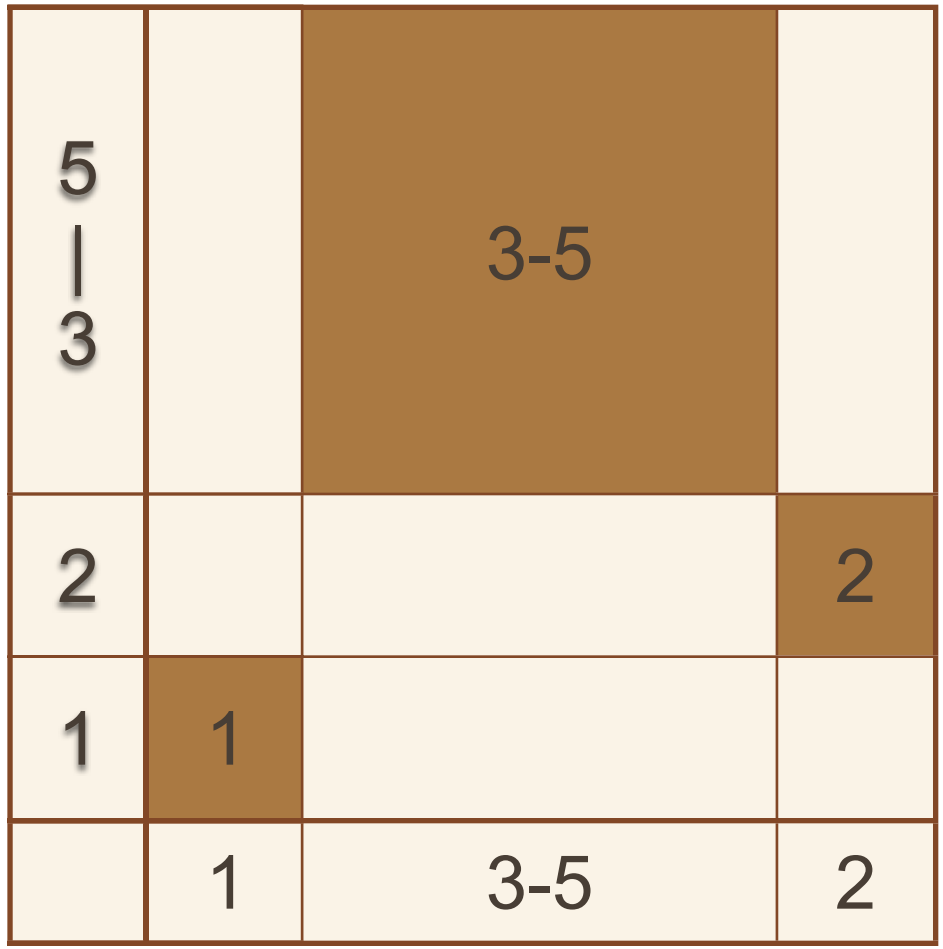

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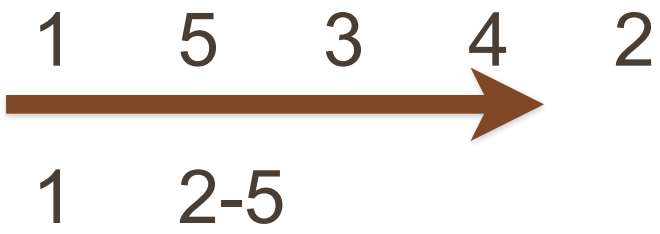


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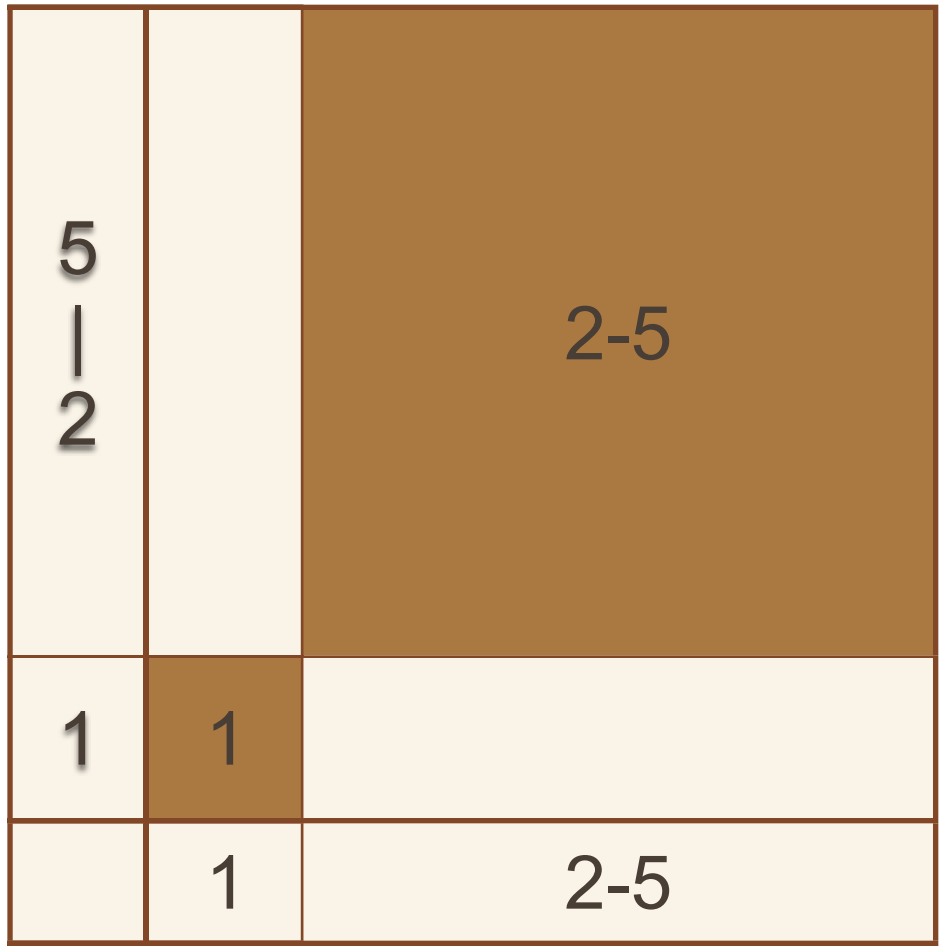

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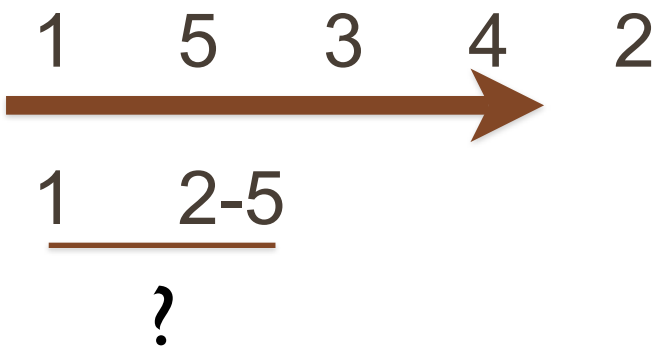


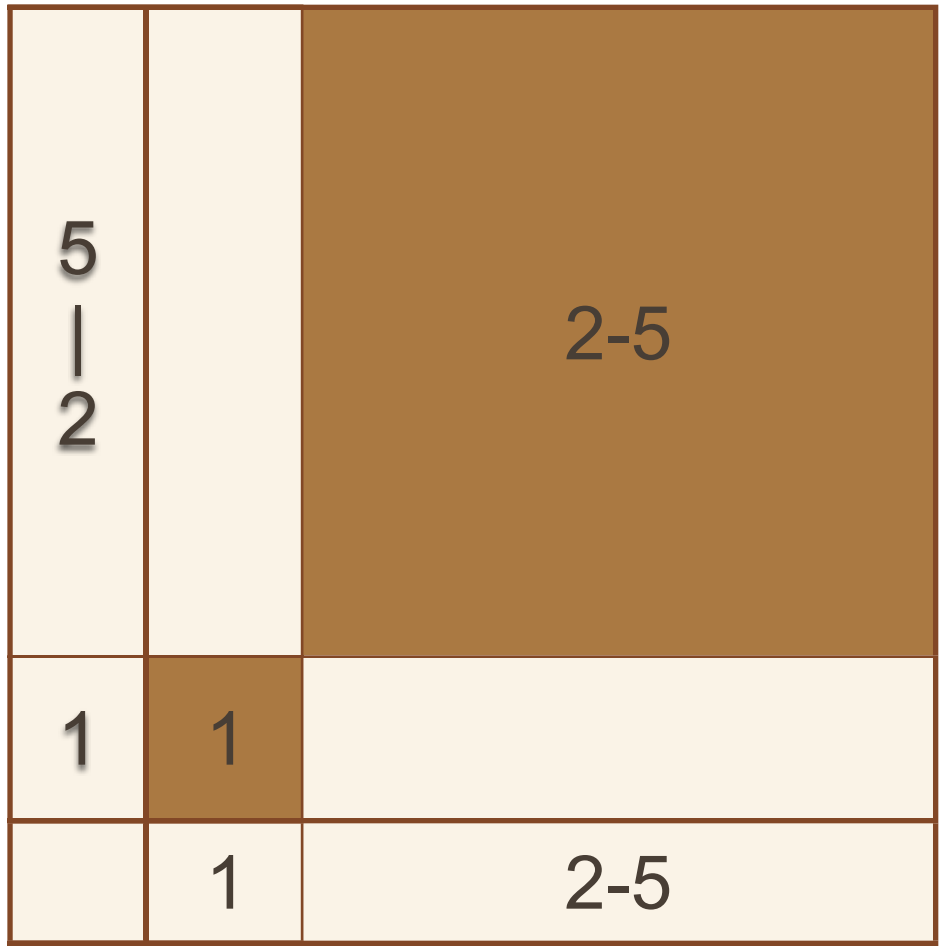

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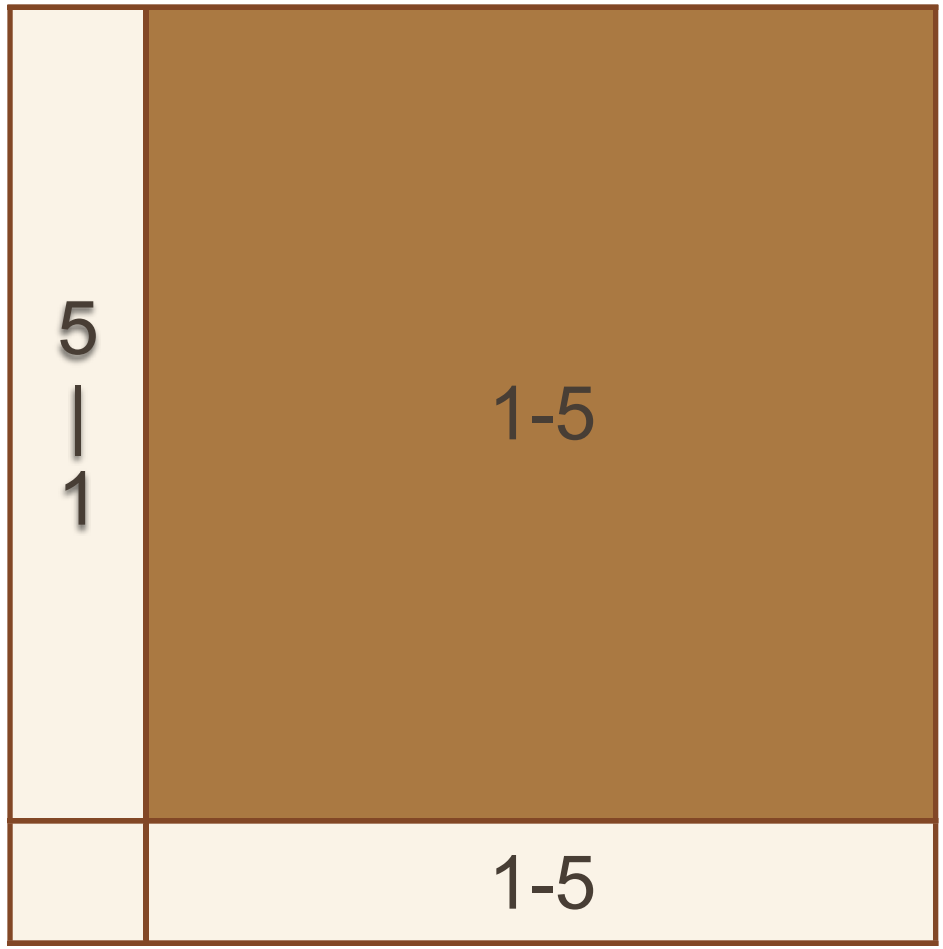

# Properties of the Algorithm

- runs in $O(n)$ time
  - $n$ shifts and at most $(n-1)$ reductions
- the permutation is synchronously binarizable
  - iff. it is reduced to exactly one element at the end
  - and in such case, the algorithm will return
    - the unique left-heavy binarization tree
    - corresponding to the non-ambiguous ITG (Wu, 1997)

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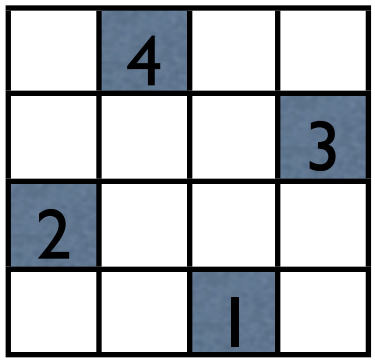
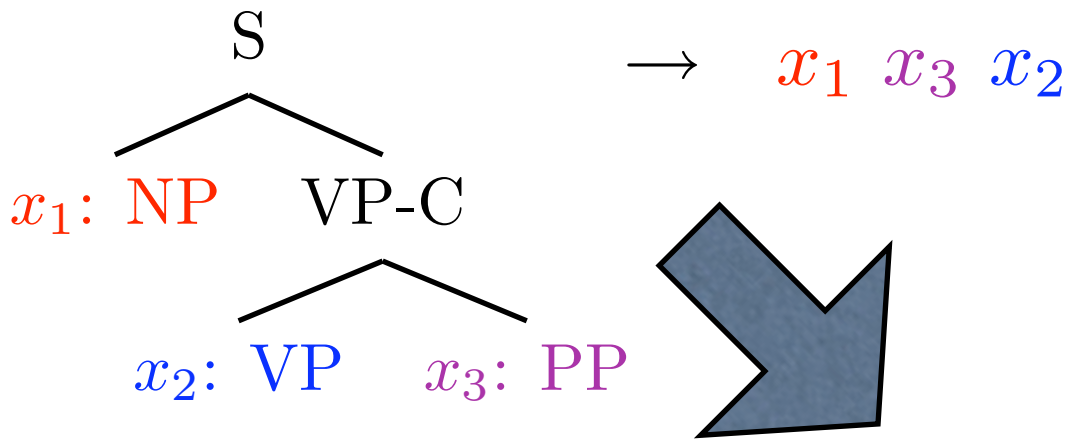


# Experiments

# System

- ISI syntax-based MT system (Galley et al., 2004)
- based on tree-to-string rules
  - English-side subtrees and Chinese-side strings
    - when decoding, internally flattened to SCFGs




S $\rightarrow$ NP VP PP, NP PP VP

# Data

- training data
  - English/Chinese parallel corpus
    - 2.9 M sentence pairs (50 M English words)
  - word-aligned by GIZA++ (symmetrized by "union")
  - English side parsed by a variant of Collins parser
  - 50.8 M tree-to-string rules extracted
- test data
  - 116 short sentences (<= 16 words) from NIST 2002

# Binarizability

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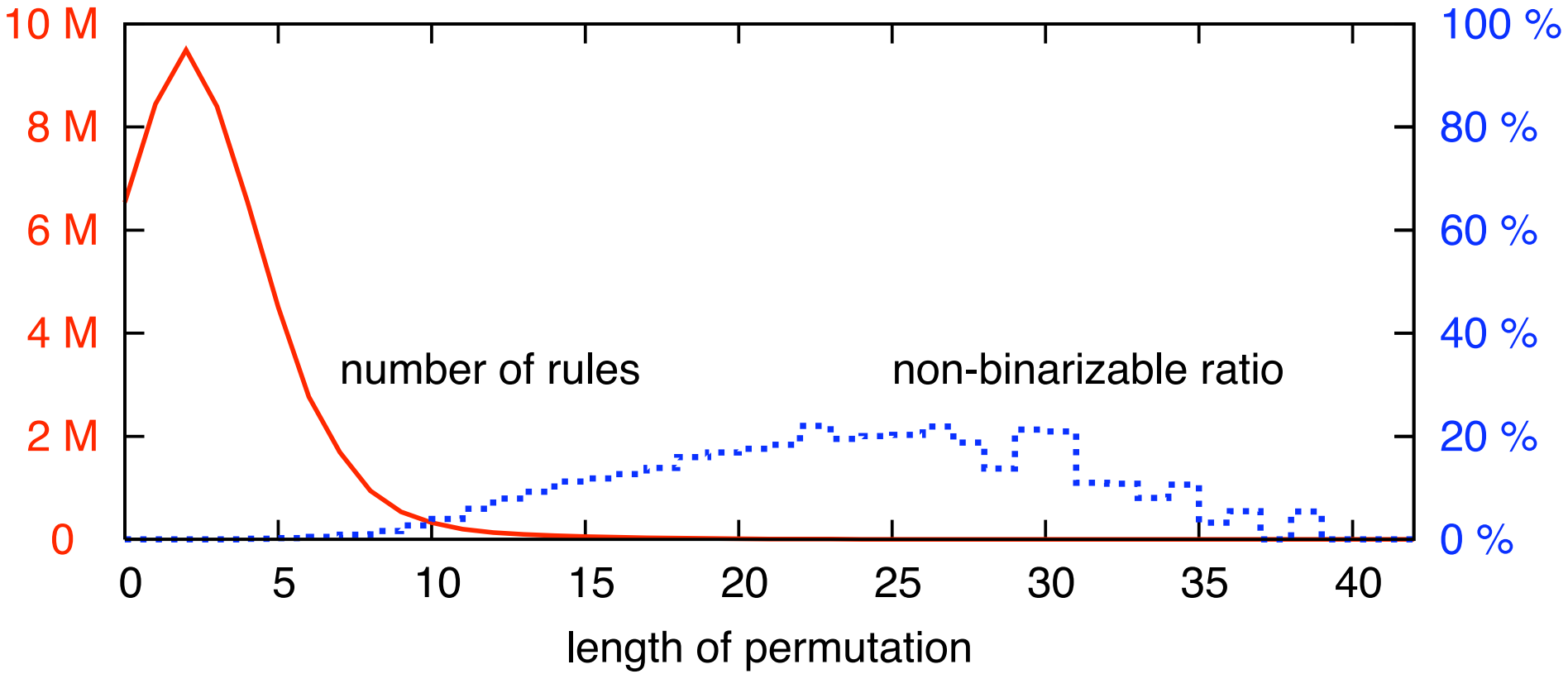

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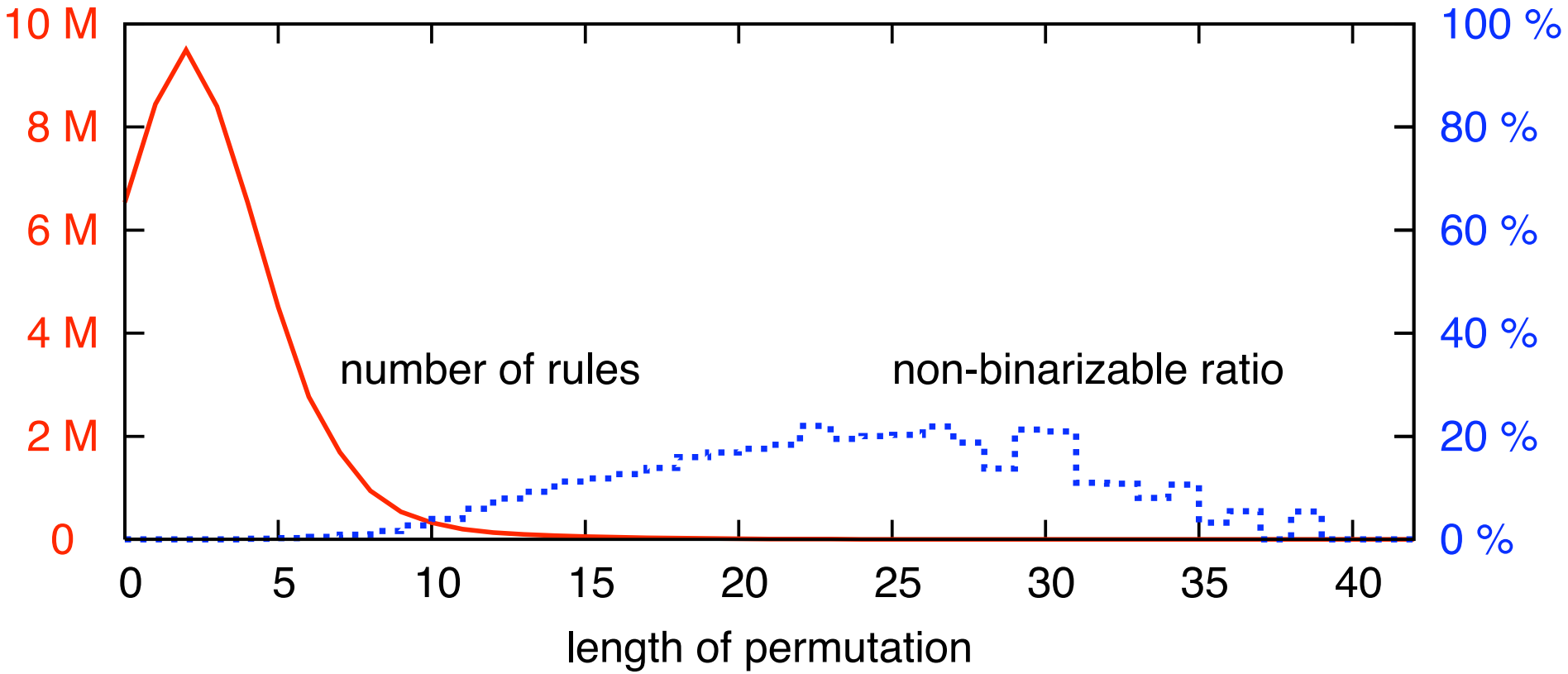


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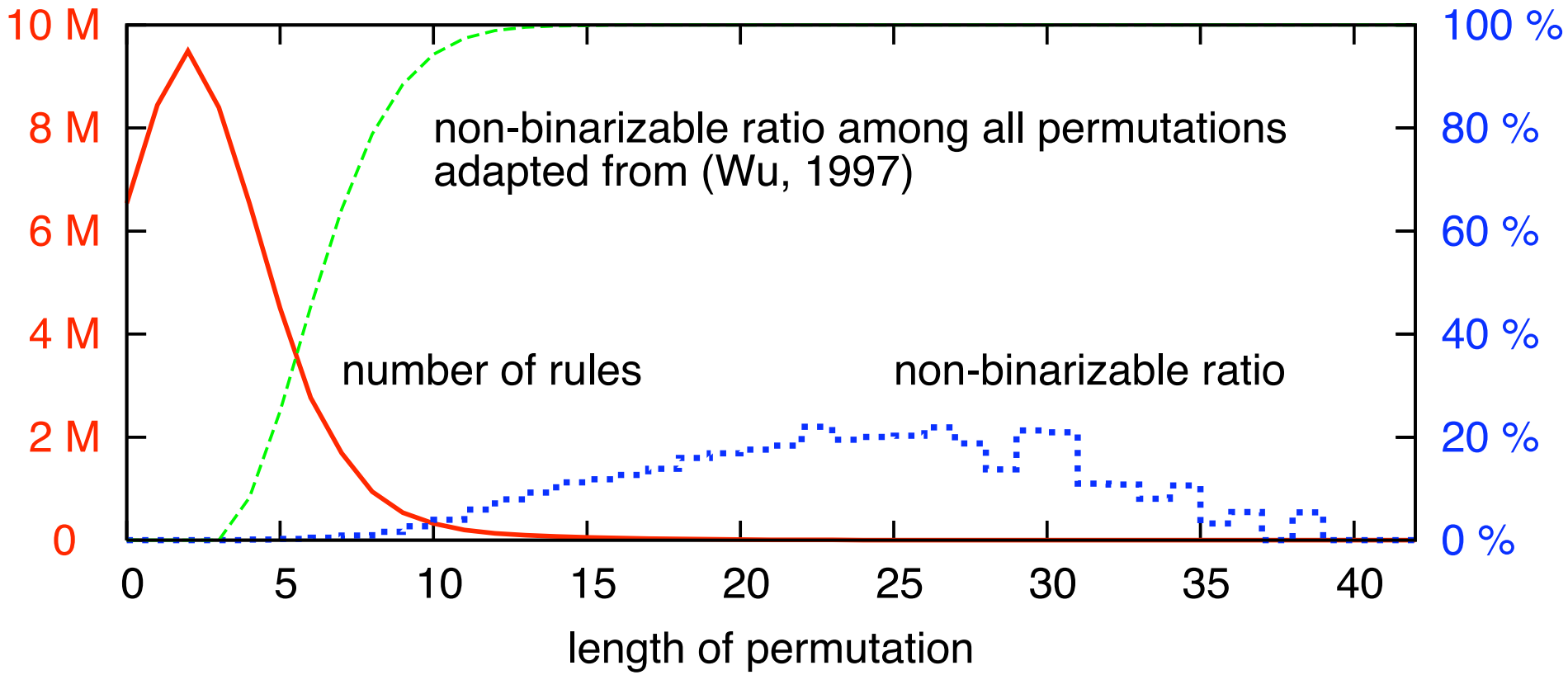


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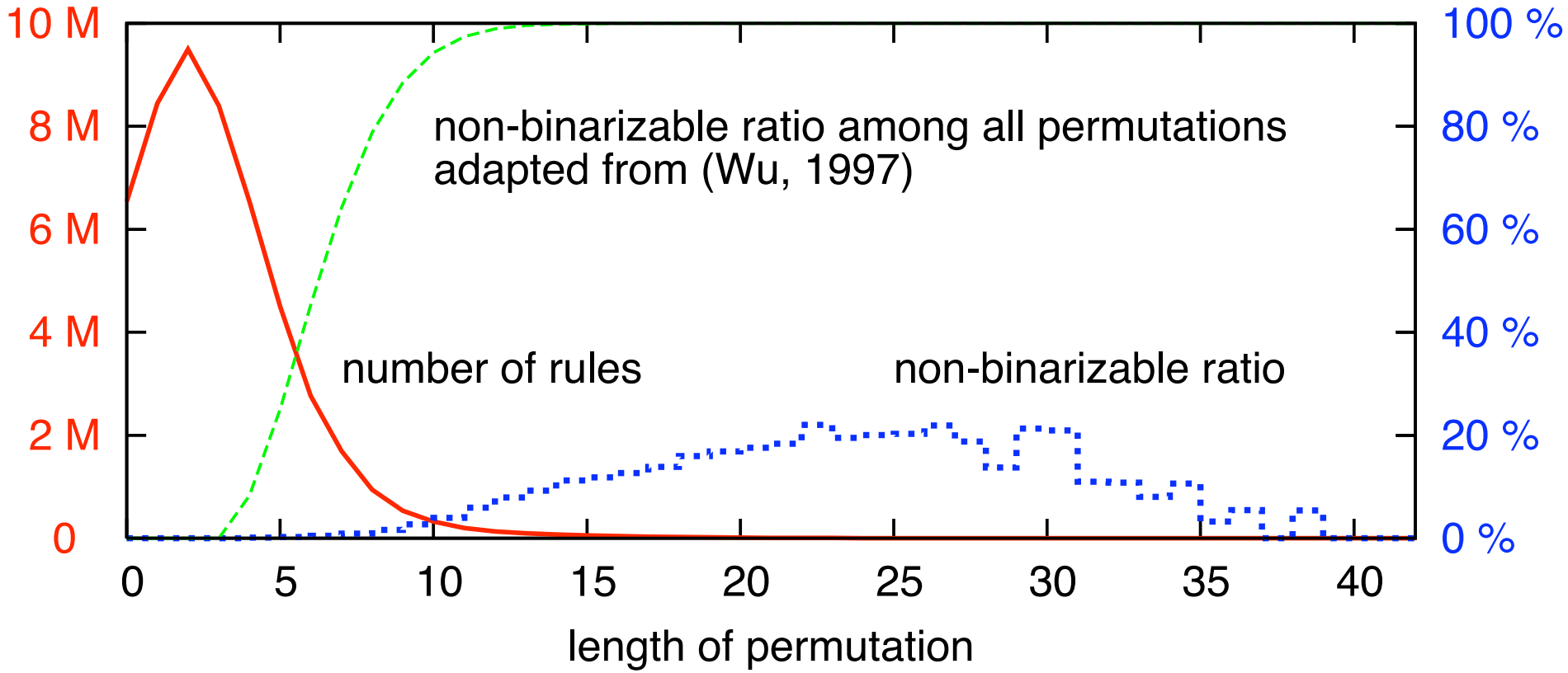
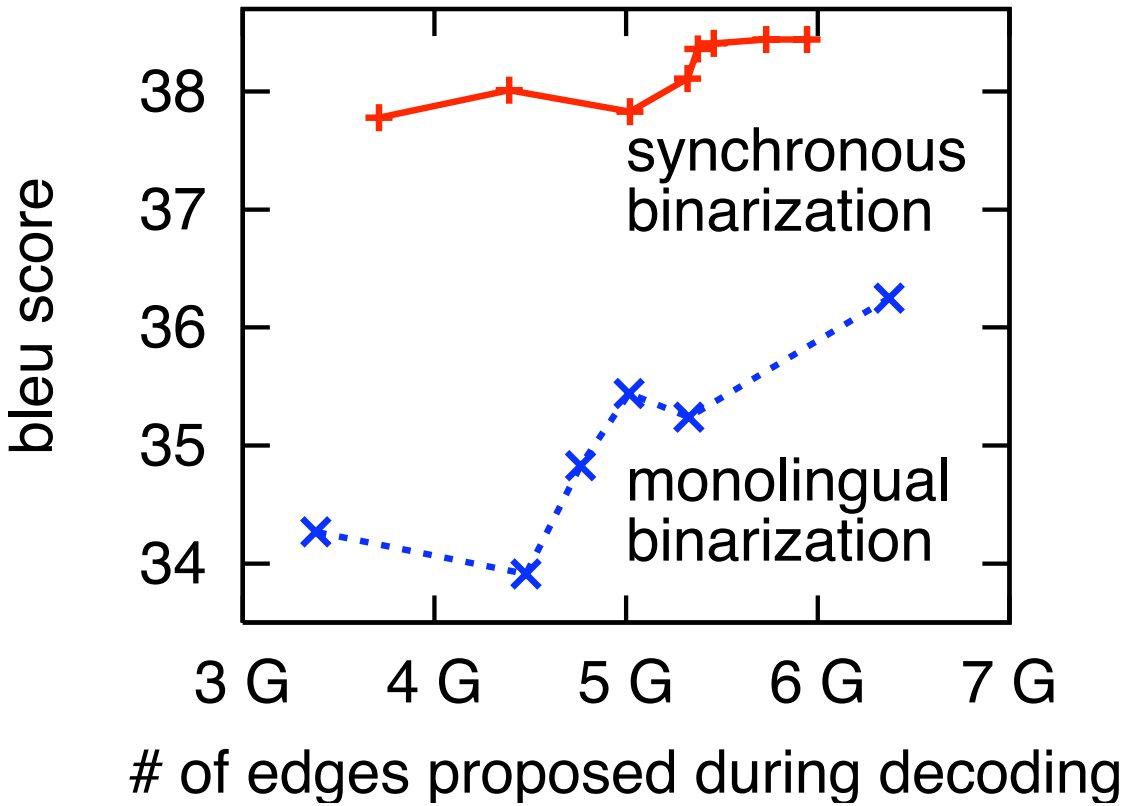



- Among 50.8 M rules, only 0.3 % are non-binarizable
  - although theoretically this ratio is much higher
- identical decoding results without these non-bin rules

# Better Decoding

- decoding is based on the CKY algorithm
- BLEU scores at various beam settings
  - synchronous binarization consistently better




| binarization | BLEU |
|---|---|
| monolingual | 36.25 |
| synchronous | 38.44 |

(~ CPU time)

# Examples

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- turkey has agreed in principle to take command of afghan peacekeeping force there from britain .

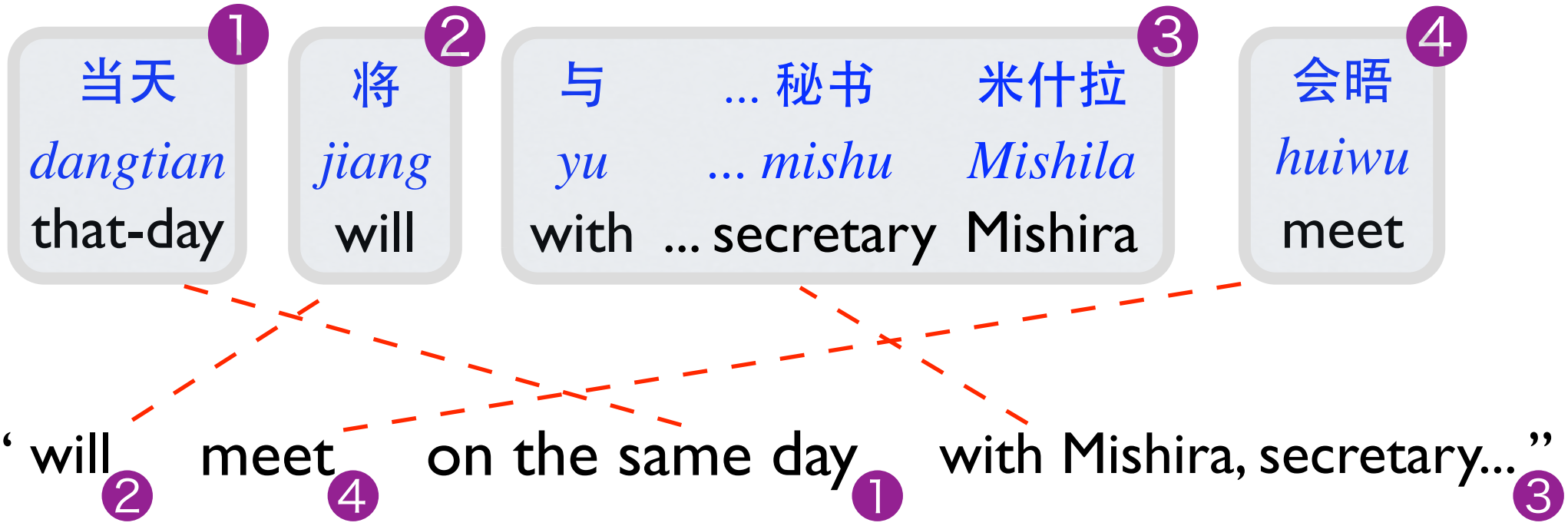
# Application: Testing the ITG Hypothesis

general approach:

1. obtain hand-aligned parallel text
2. parse the English-side
3. do GHKM-style rule extraction
4. verify non-binarizable examples

# Chinese-English

- 935 hand-aligned sentences from (Liu, Liu, Lin, 2005)
  - non-binarizability: 0.3%



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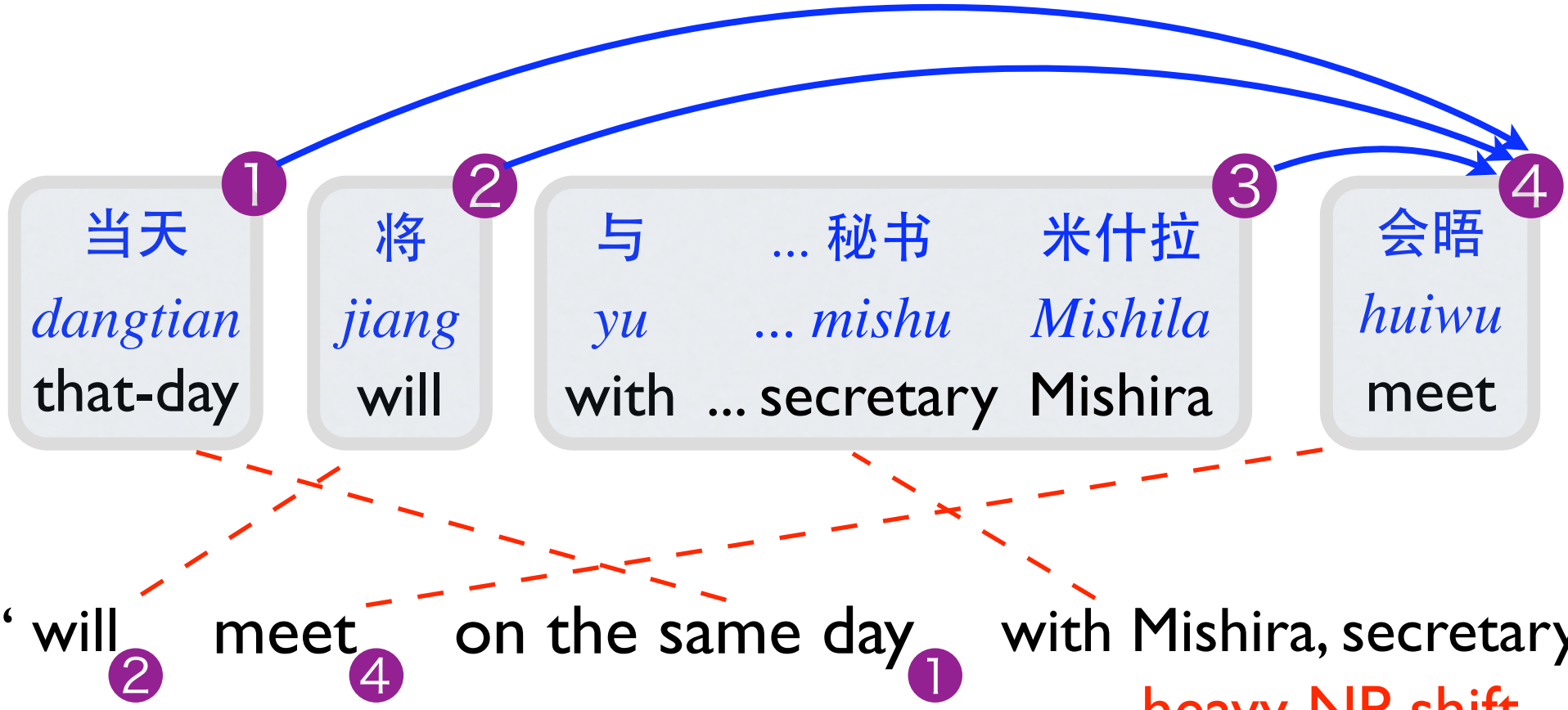

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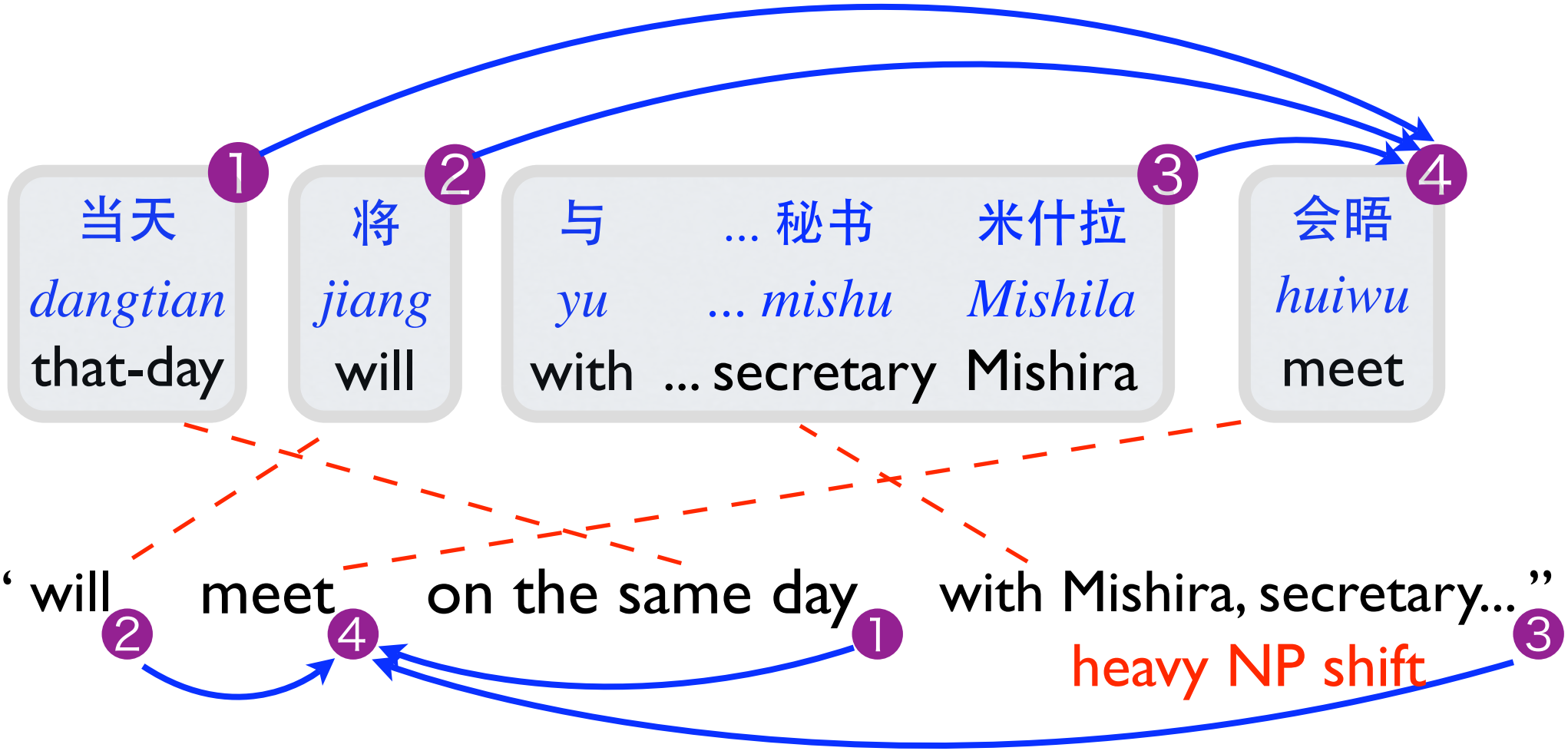

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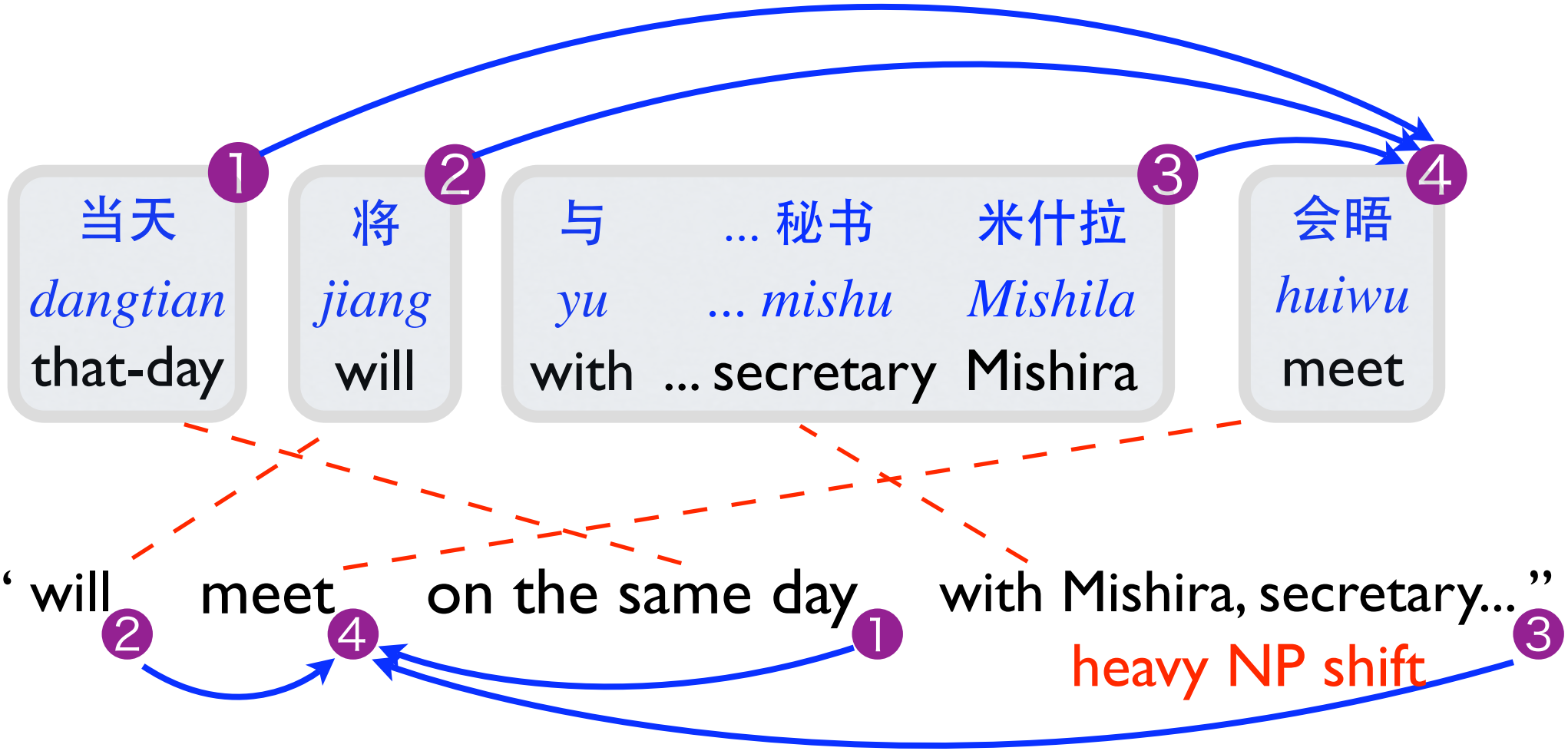
isomorphic dep-trees

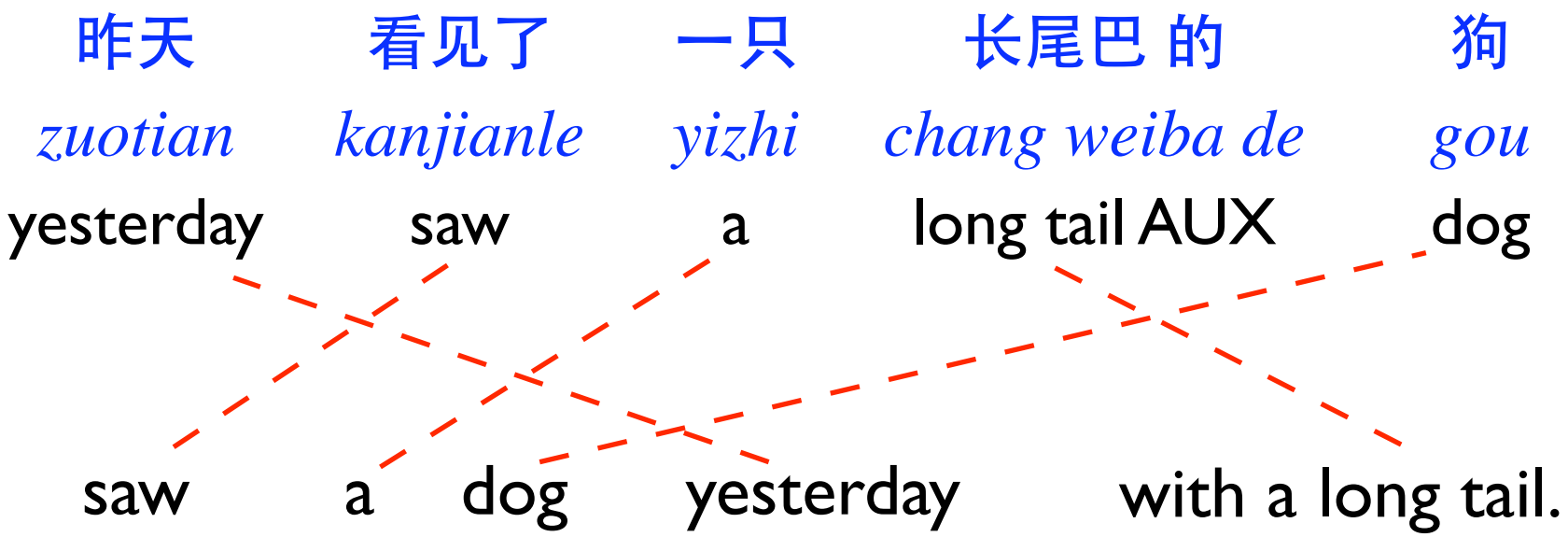


# Chinese-English

- example 2: slightly non-literal translation
  - non-isomorphic dependency trees (Eisner, 2003)

# Side note: Non-Projectivity

- synthetic example (Chris Quirk, p.c.) with a non-projective English side
- clearly non-binarizable, but even the English side alone is beyond CFG! => this pair is beyond SCFG



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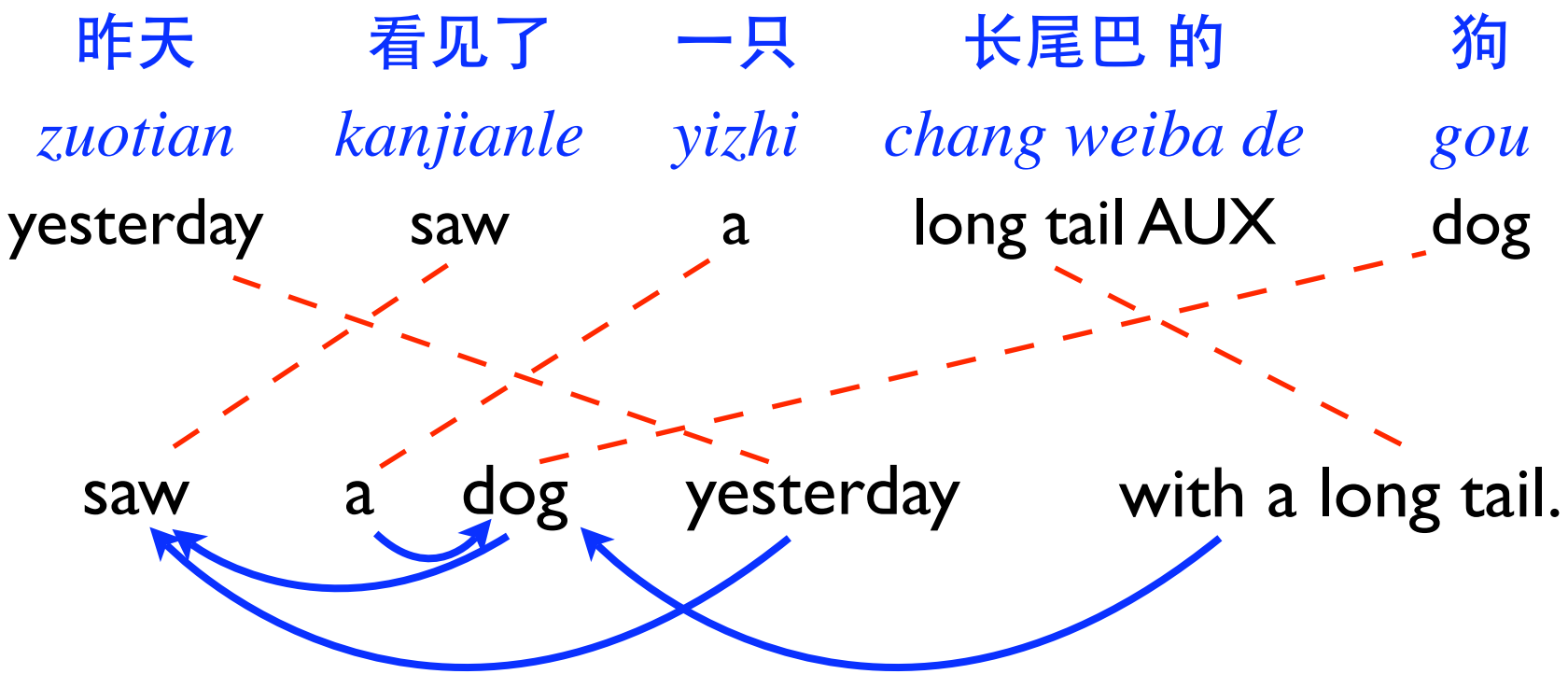

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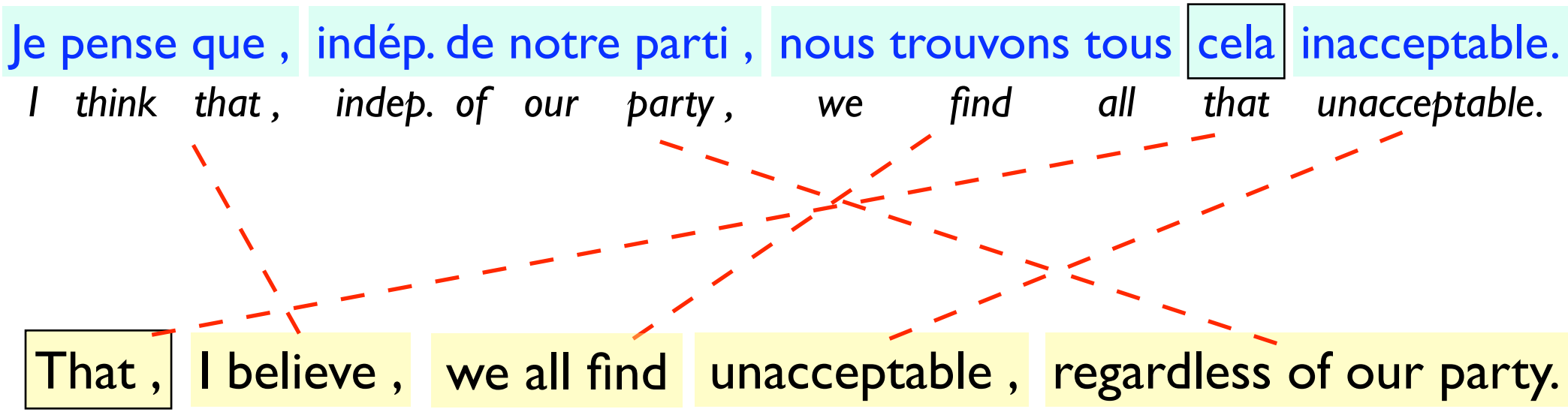

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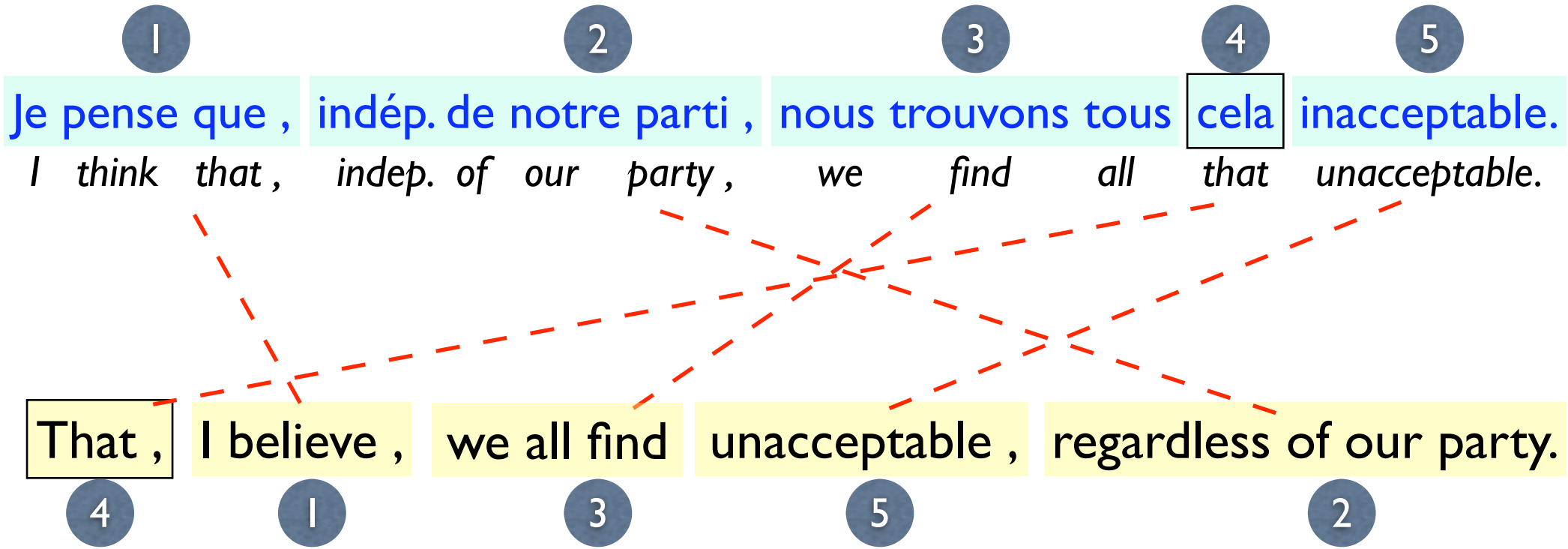

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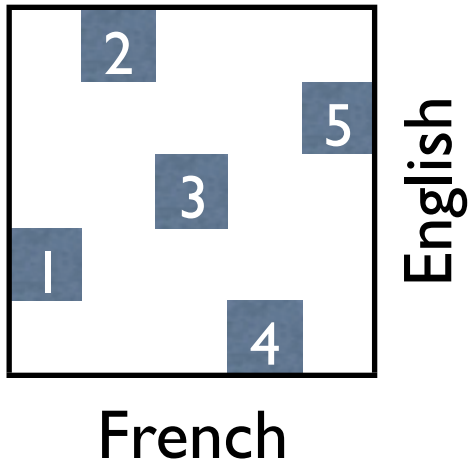
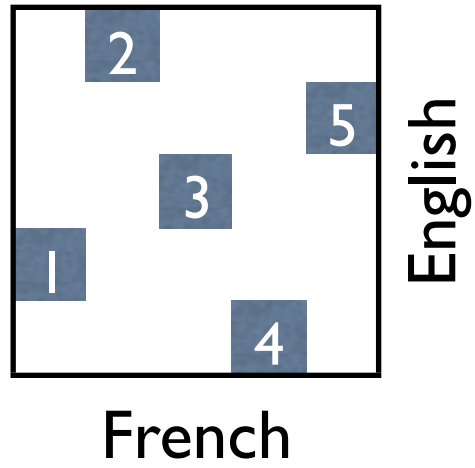



| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Je pense que , | indép. de notre parti , | nous trouvons tous | cela | inacceptable. |
| *I think that ,* | *indep. of our party ,* | *we find all* | *that* | *unacceptable.* |

| That , | I believe , | we all find | unacceptable , | regardless of our party. |
|---|---|---|---|---|
| 4 | 1 | 3 | 5 | 2 |

# French-English

- example 2: movement of adverbials




1 2 3 4 5

Le entreprise , dans le secteur privé , fut rebaptisée en 1934 ...

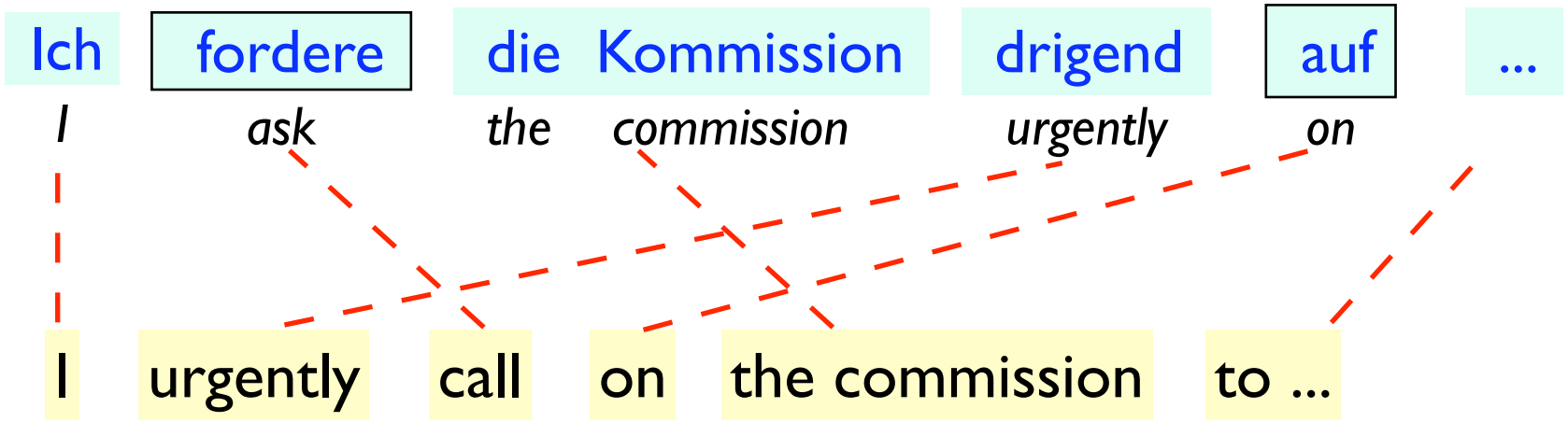
NP

In 1934 , the company was renamed ... , still under private ownership.

4 1 3 5 2

# German-English

- 220 sentences in Europarl, annotated by a German native speaker (Callison-Burch, p.c.)
- 2328 rules, 13 non-binarizable (0.6%)
- many long rules due to German word order
  - V-2, V-final, extraposition, separable prefixes, ...



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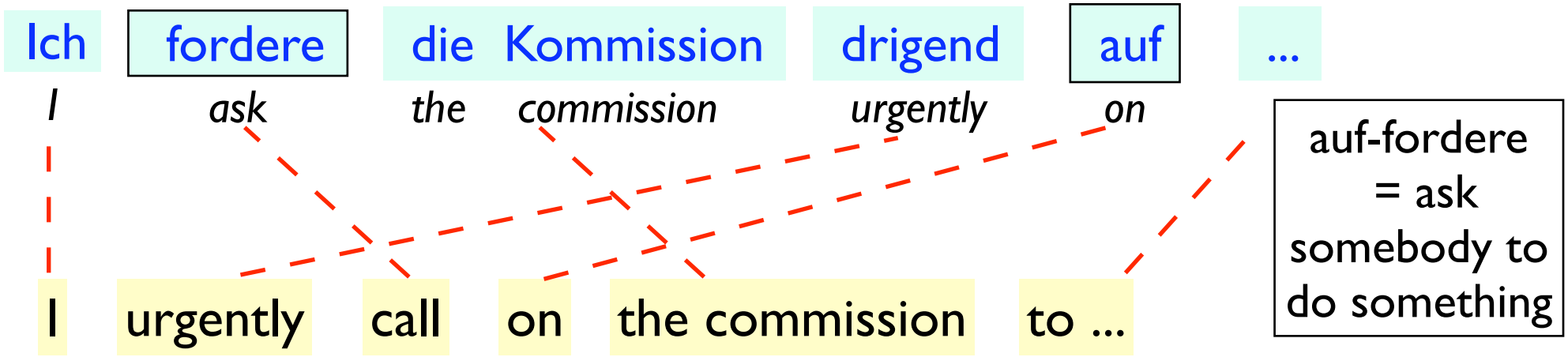

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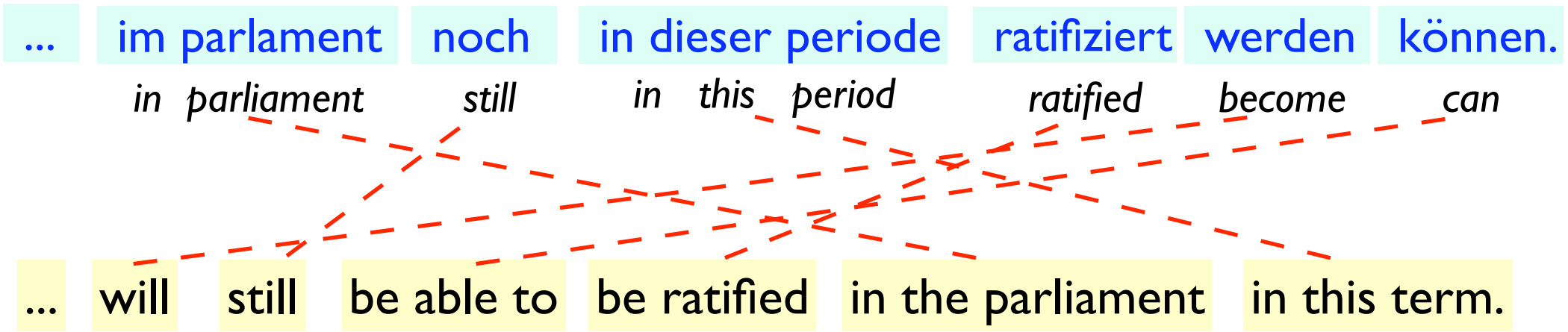

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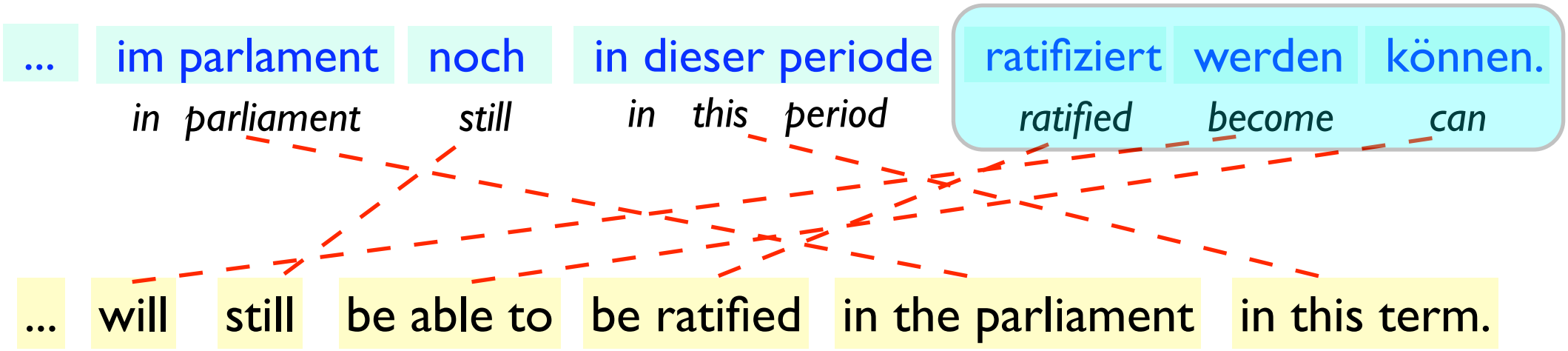

# Summary of Testings

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- but there do exist linguistically interesting examples beyond ITG, even between fixed word-order languages.

| | # of sentences | # of rules | non-bin ratio | major reasons for non-bin |
|---|---|---|---|---|
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*how about German-Czech?* *Japanese-English?*

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- Future Work: binarizing other formalisms like STAGs

# Thank you!
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Questions?
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