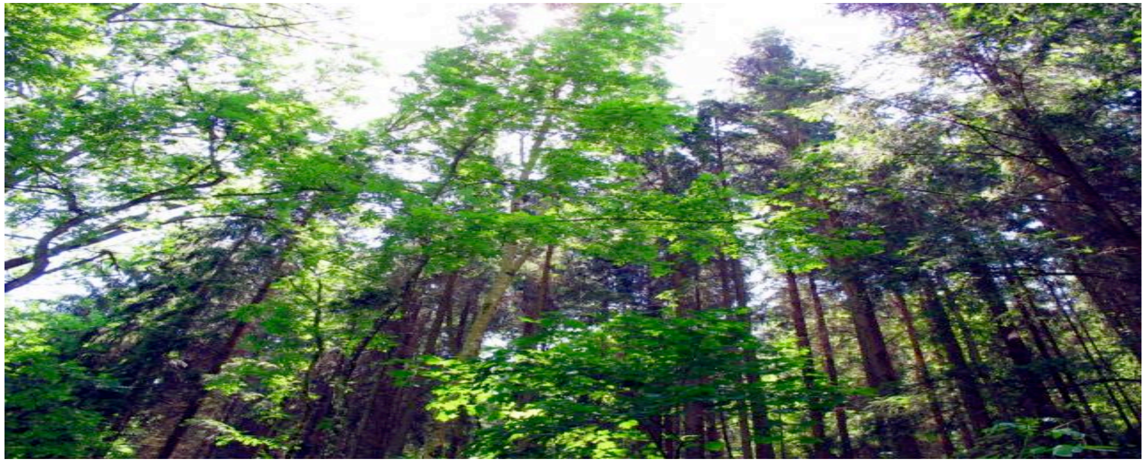
Tree-based and Forest-Based Translation



Liang Huang

Penn University of Pennsylvania → Google Research

ISI Information Sciences Institute USC Viterbi School of Engineering

Joint work with Kevin Knight (ISI), Aravind Joshi (Penn), Haitao Mi and Qun Liu (ICT)

UC Berkeley, Feb 6, 2009

Translation is hard!

zi zhu zhong duan
自 助 终 端

self help terminal device

help oneself terminating machine

(ATM, “self-service terminal”)

Translation is hard!

Translation is hard!

Translation is hard!

Google Research

Translation is hard!

or even...

or even...

clear evidence that MT is used in real life.

How do people translate?

1. understand the source language sentence
2. generate the target language translation

布什	与	沙龙	举行	了	会谈
Bùshí	*yu*	*Shalóng*	*juxíng*	*le*	*huìtán*
Bush	and/ with	Sharon	hold	[*past.*]	meeting

Google Research

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"Bush held a meeting with Sharon"

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2. generate intermediate or machine code accordingly

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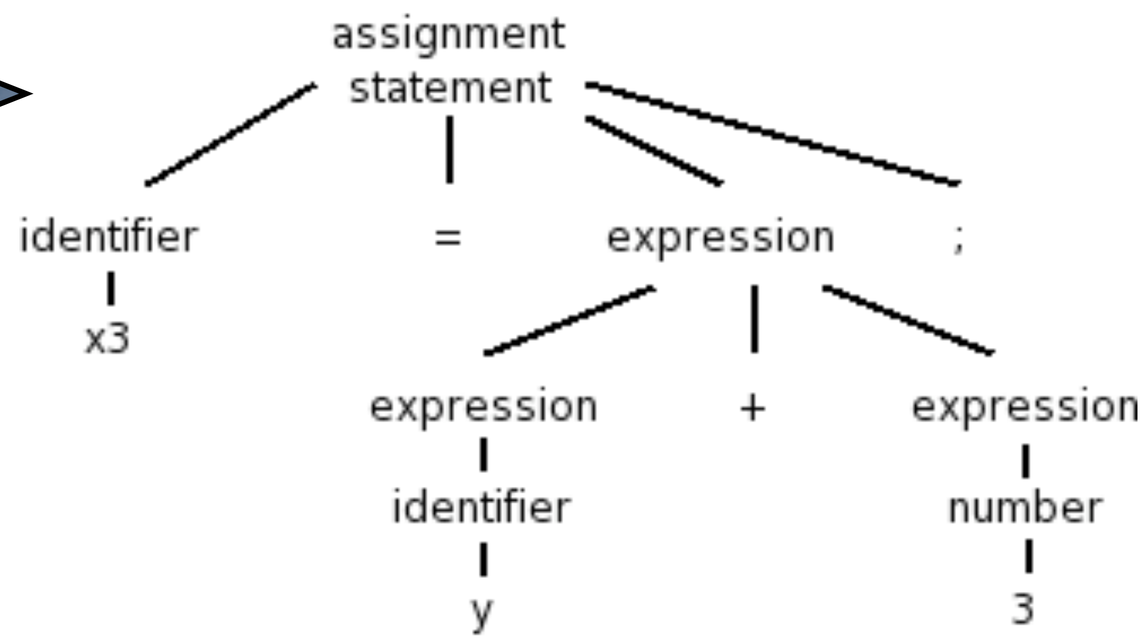

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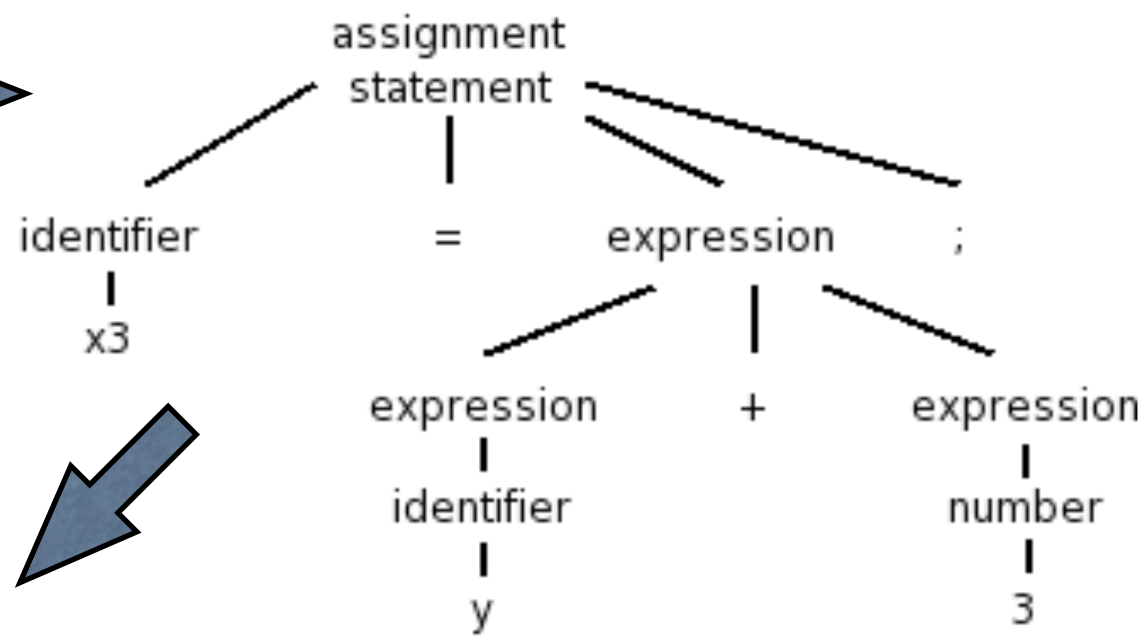


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ADDF    R1,  R1, #3.0   // add float
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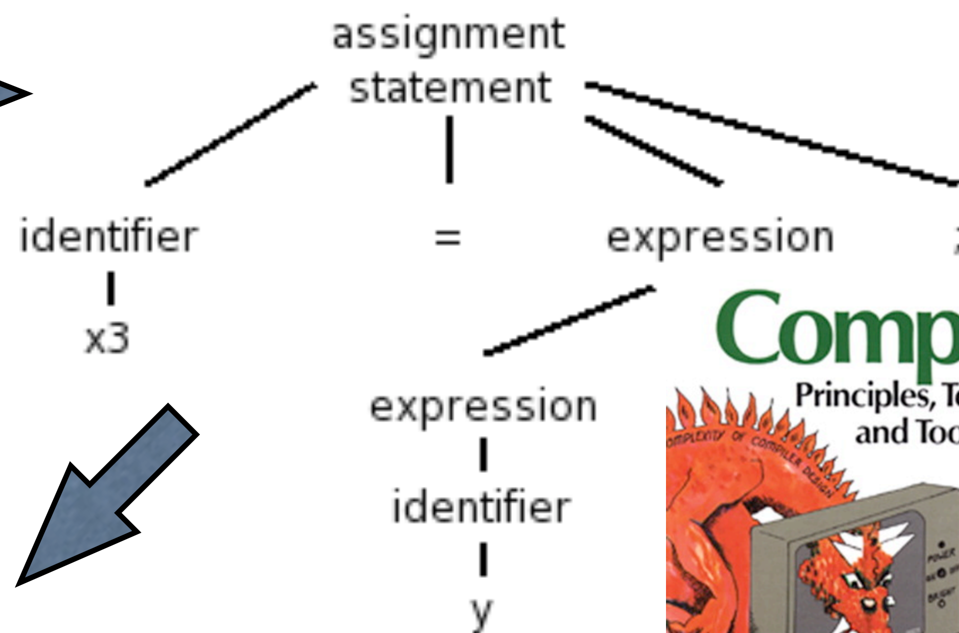


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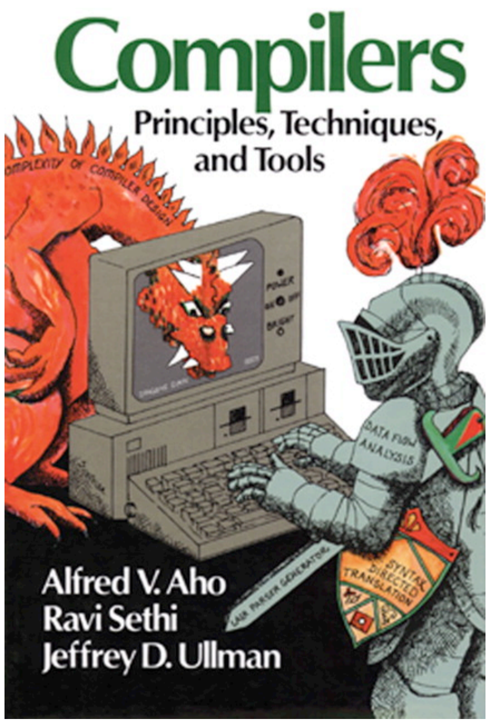
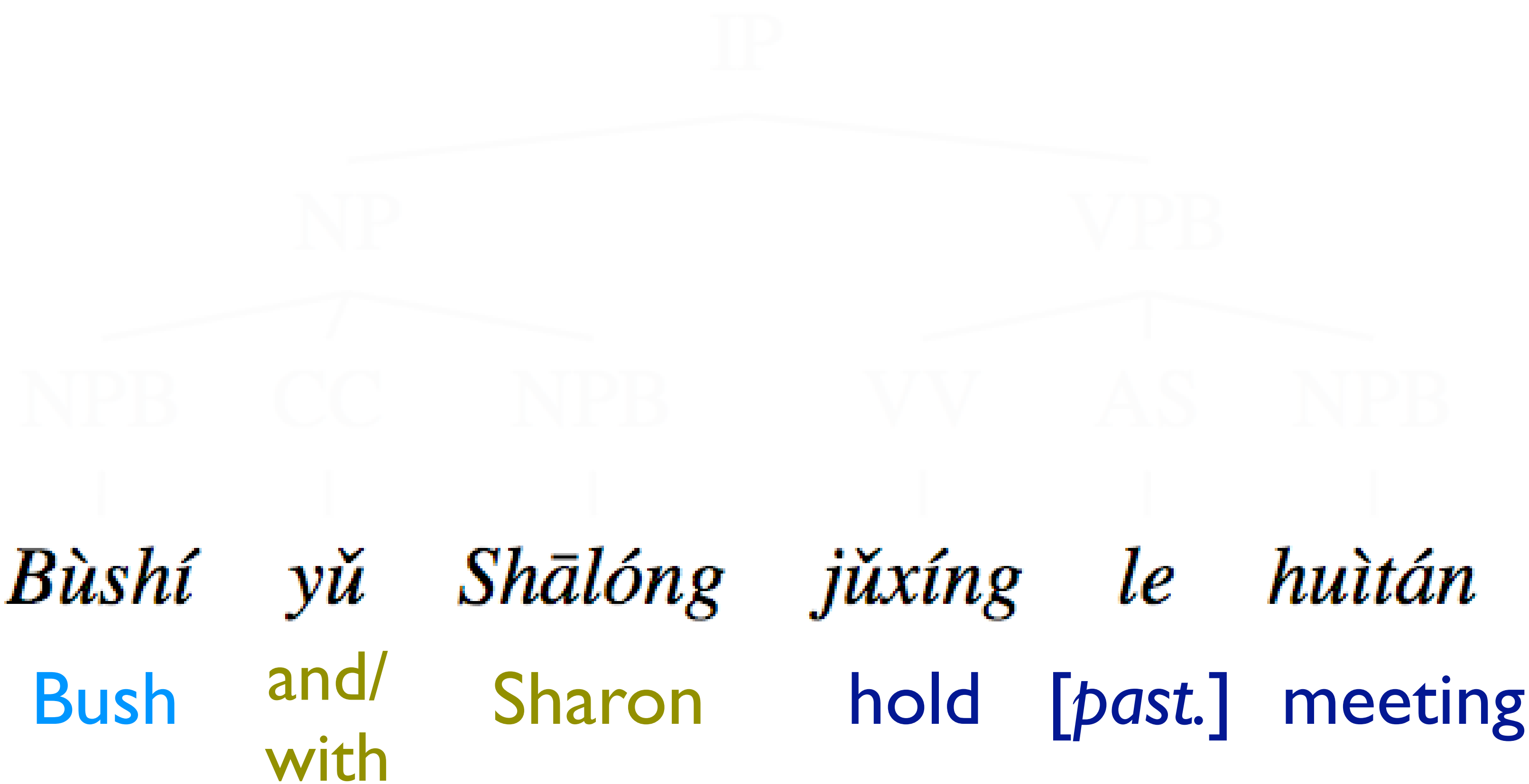
syntax-directed translation (~1960)



Syntax-Directed Machine Translation

1. parse the source-language sentence into a tree
2. recursively convert it into a target-language sentence



(Irons 1961; Lewis, Stearns 1968; Aho, Ullman 1972) ==> (Huang, Knight, Joshi 2006)

Syntax-Directed Machine Translation

1. parse the source-language sentence into a tree
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IP

NP VPB

NPB CC NPB VV AS NPB

Bùshí *yǔ* *Shālóng* *jǔxíng* *le* *huìtán*

Bush and/with Sharon hold [*past.*] meeting

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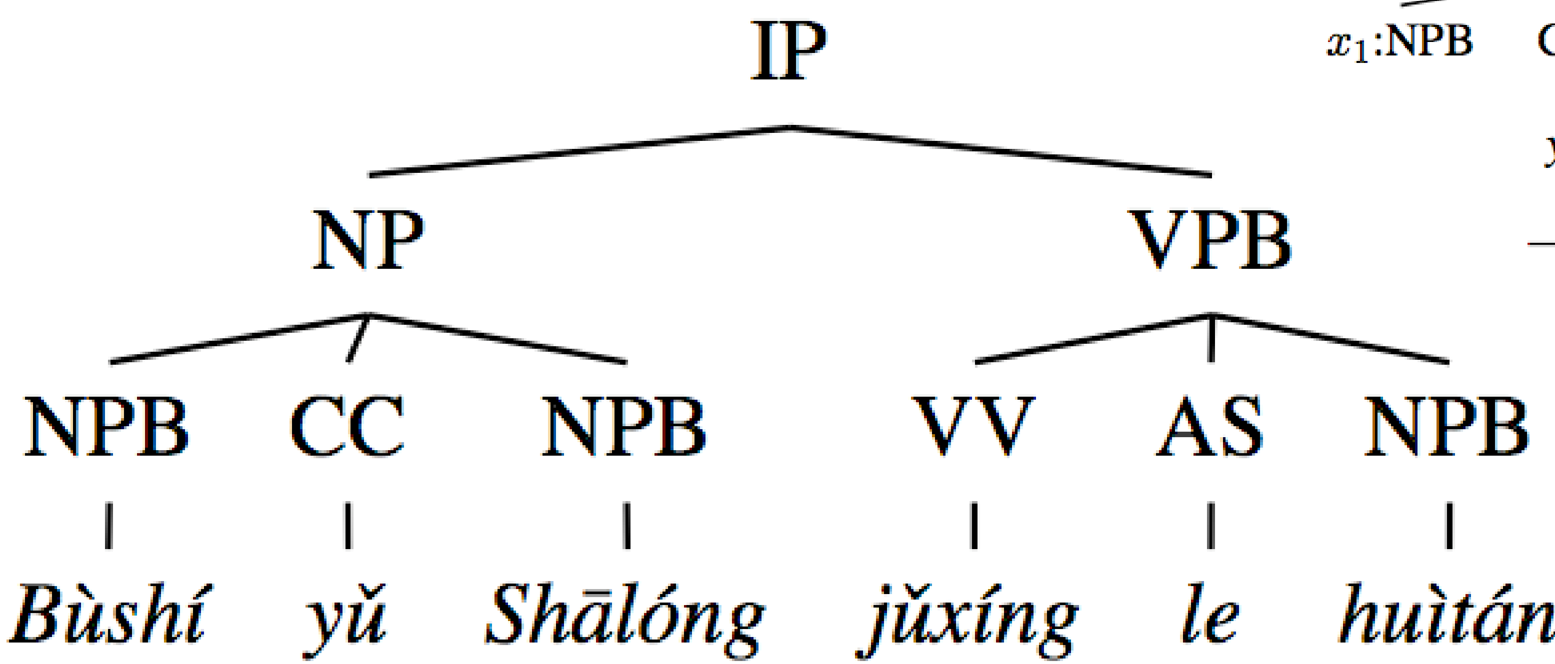
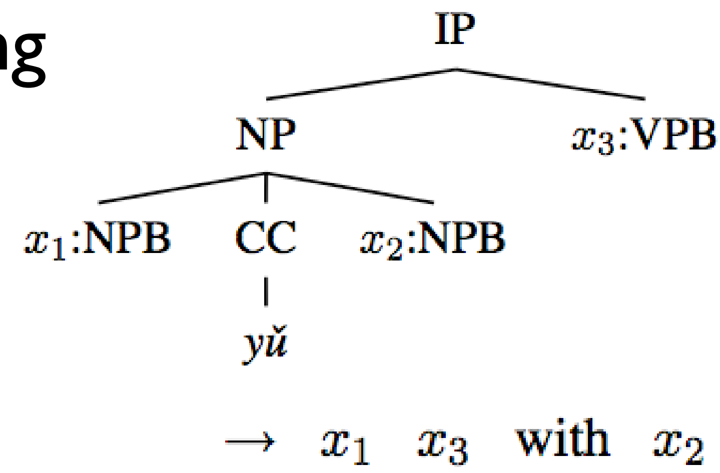
Syntax-Directed Machine Translation

- recursive rewrite by pattern-matching





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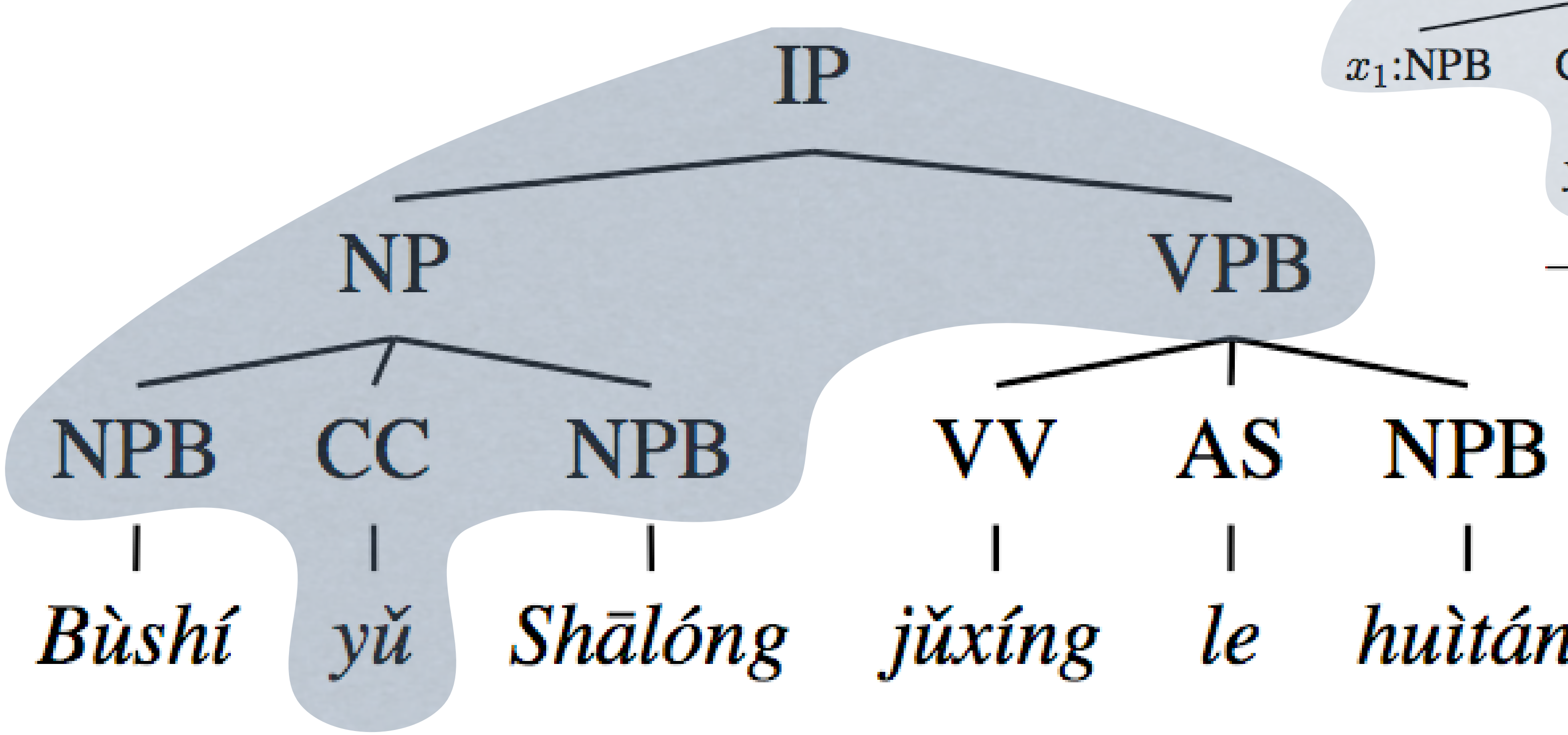

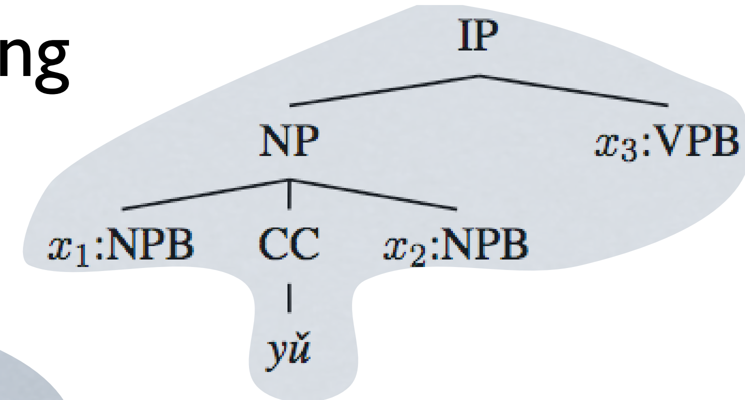

$\rightarrow \quad x_1 \quad x_3 \quad \text{with} \quad x_2$

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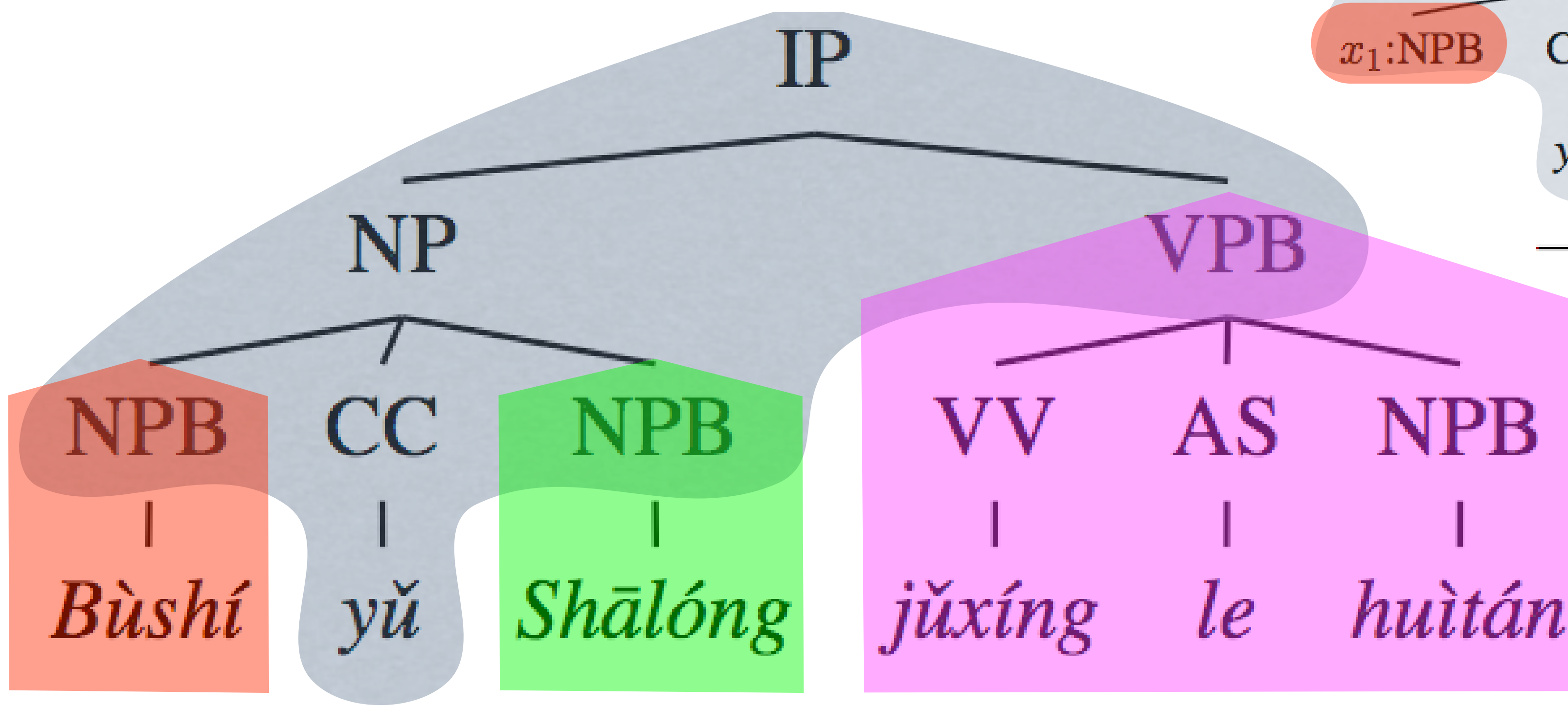

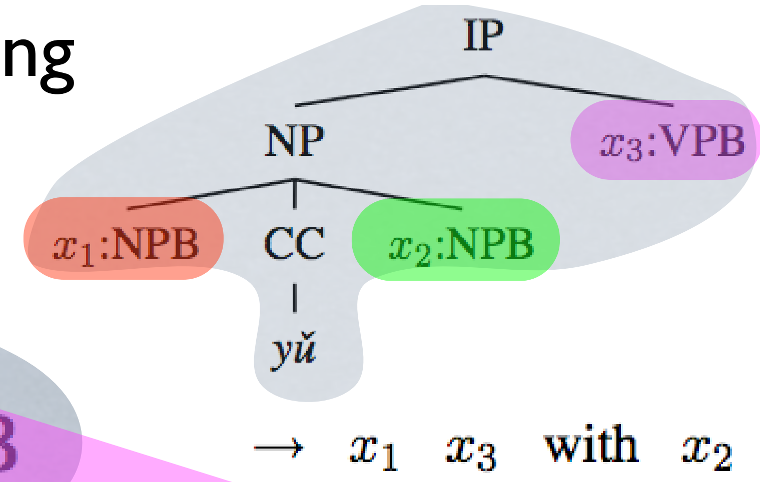

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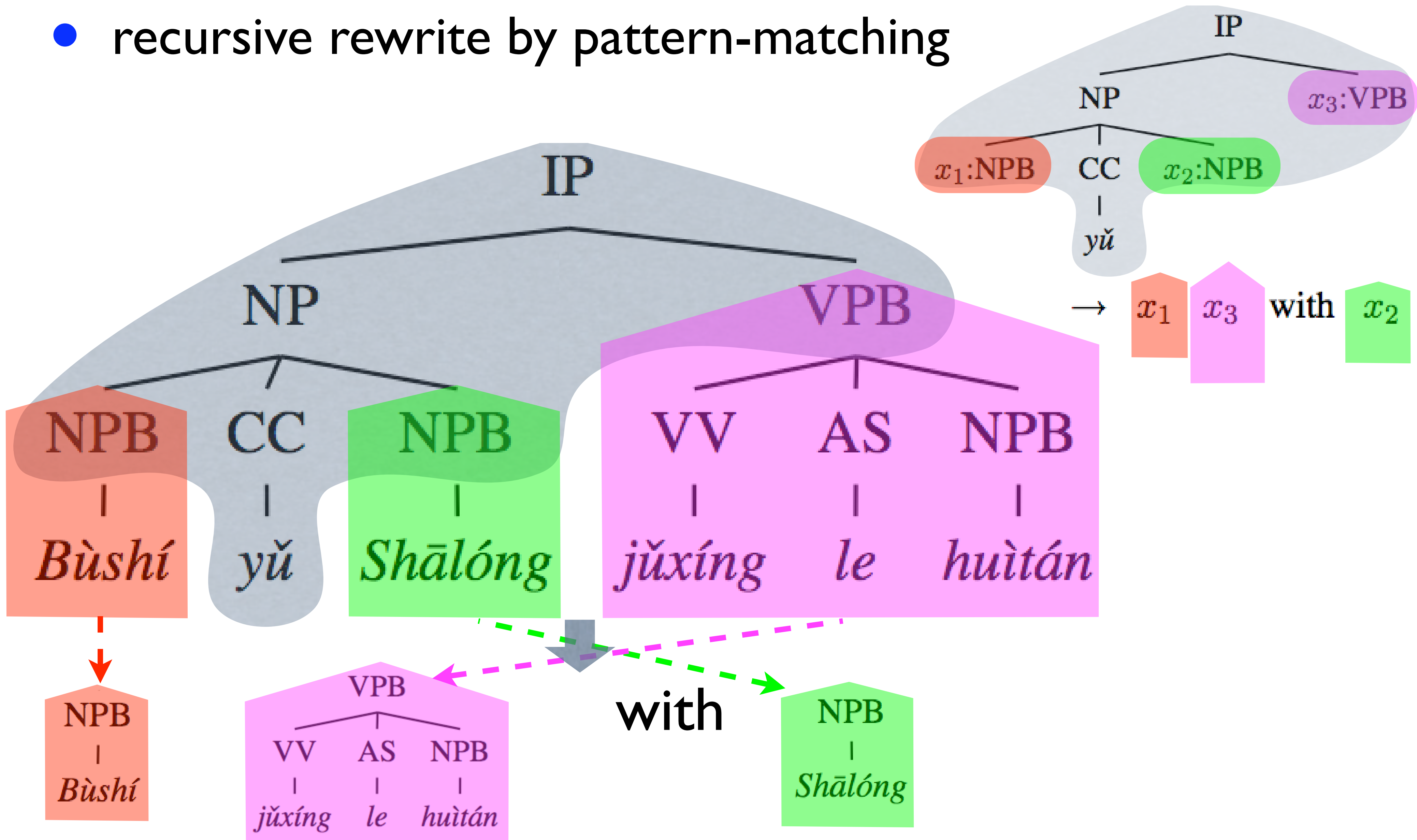

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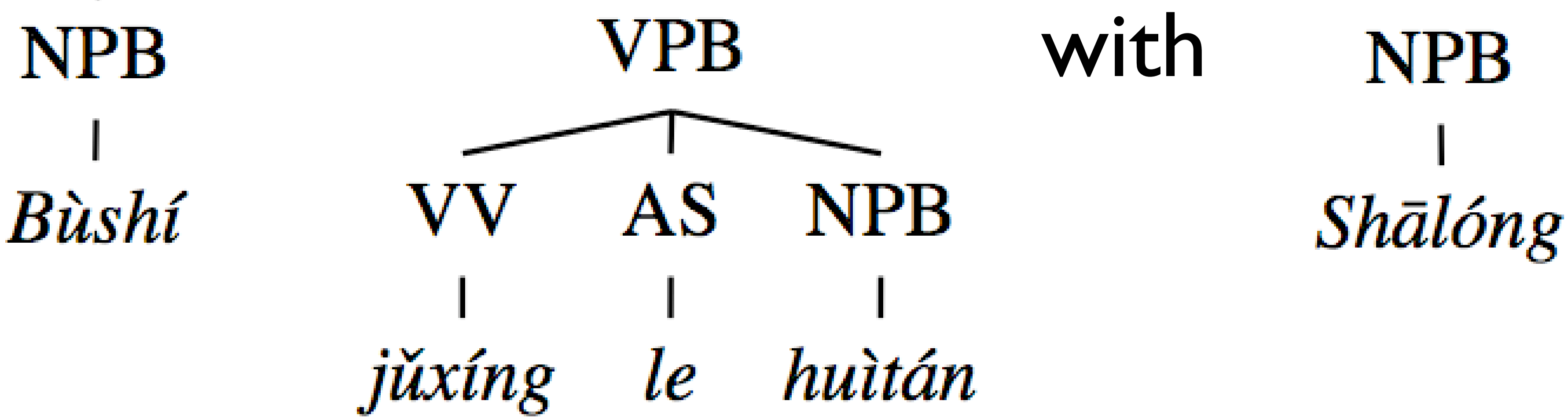
Syntax-Directed Machine Translation?

- recursively solve unfinished subproblems



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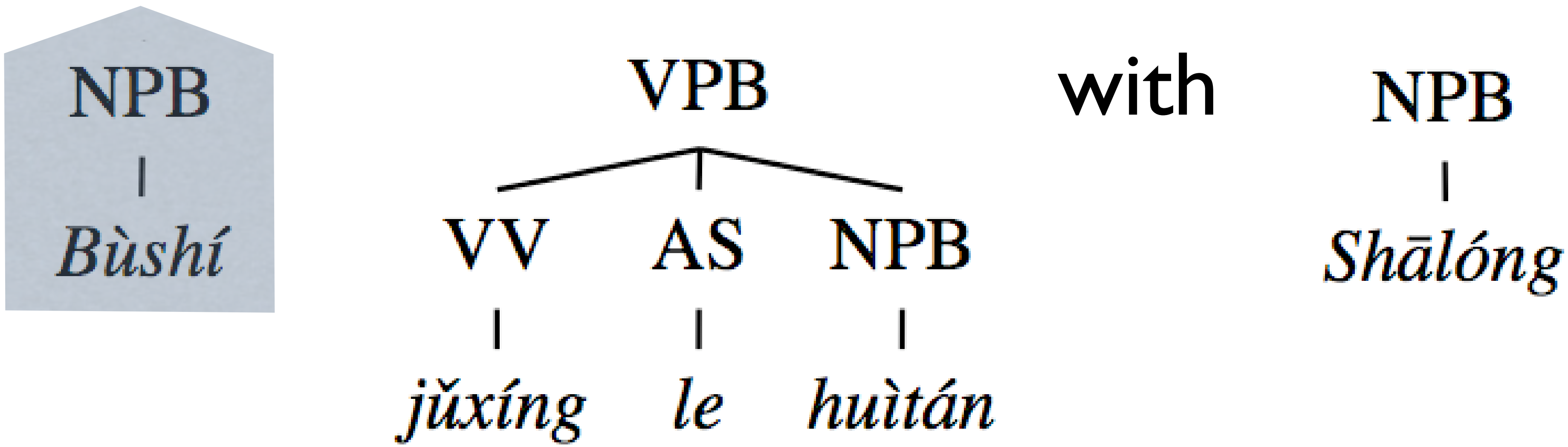

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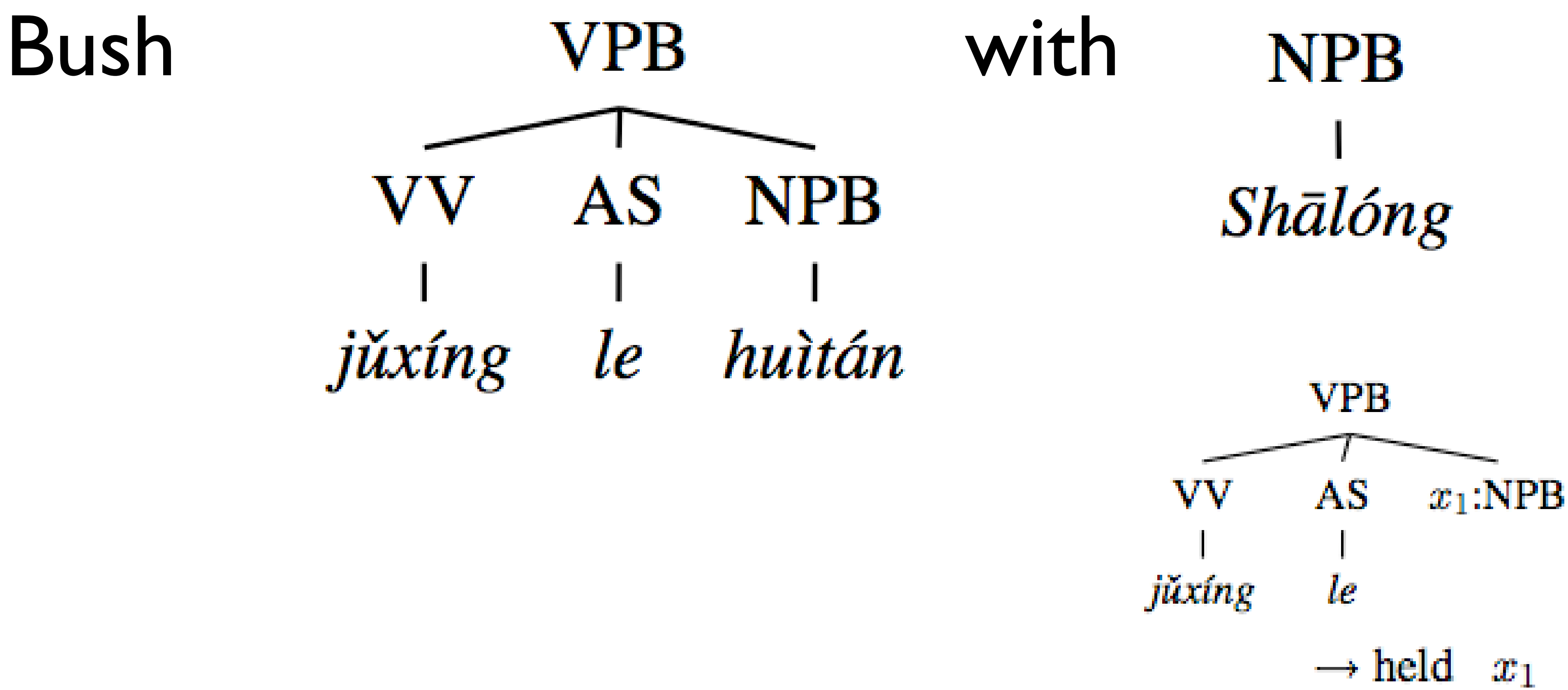

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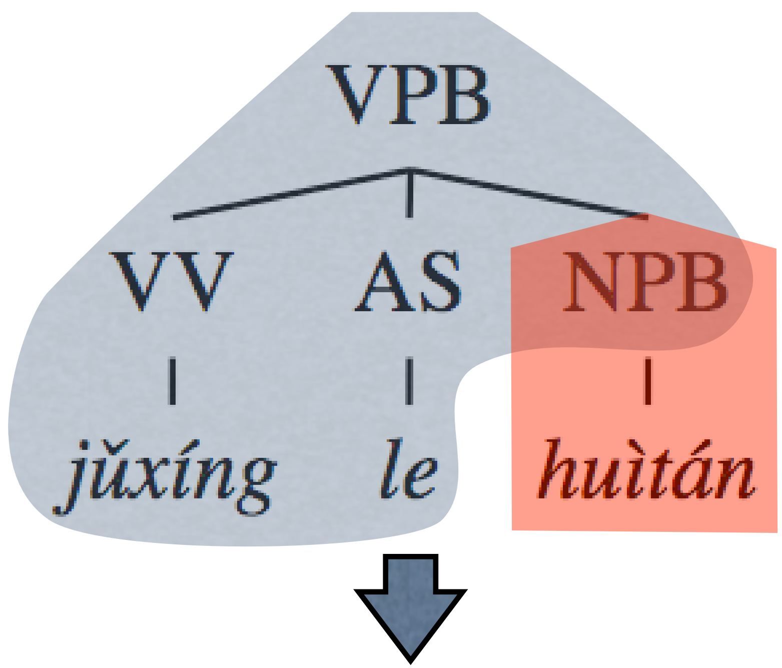
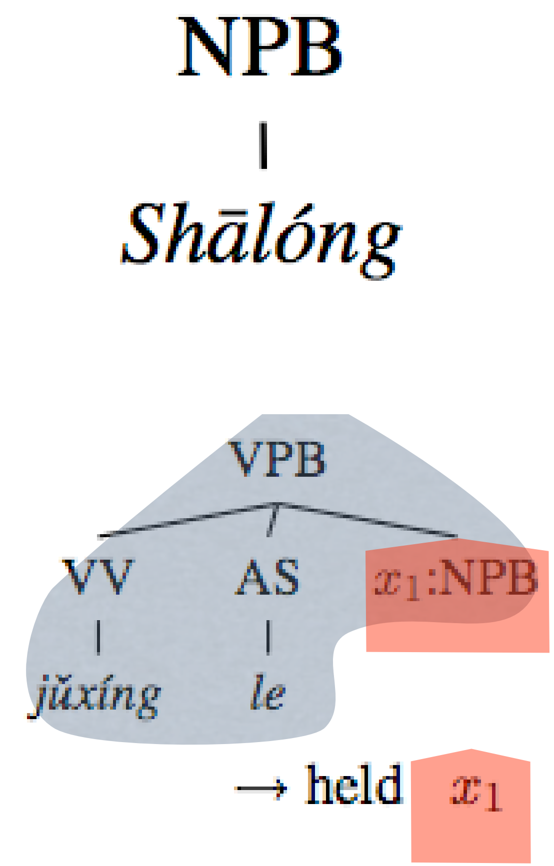
Bush



with



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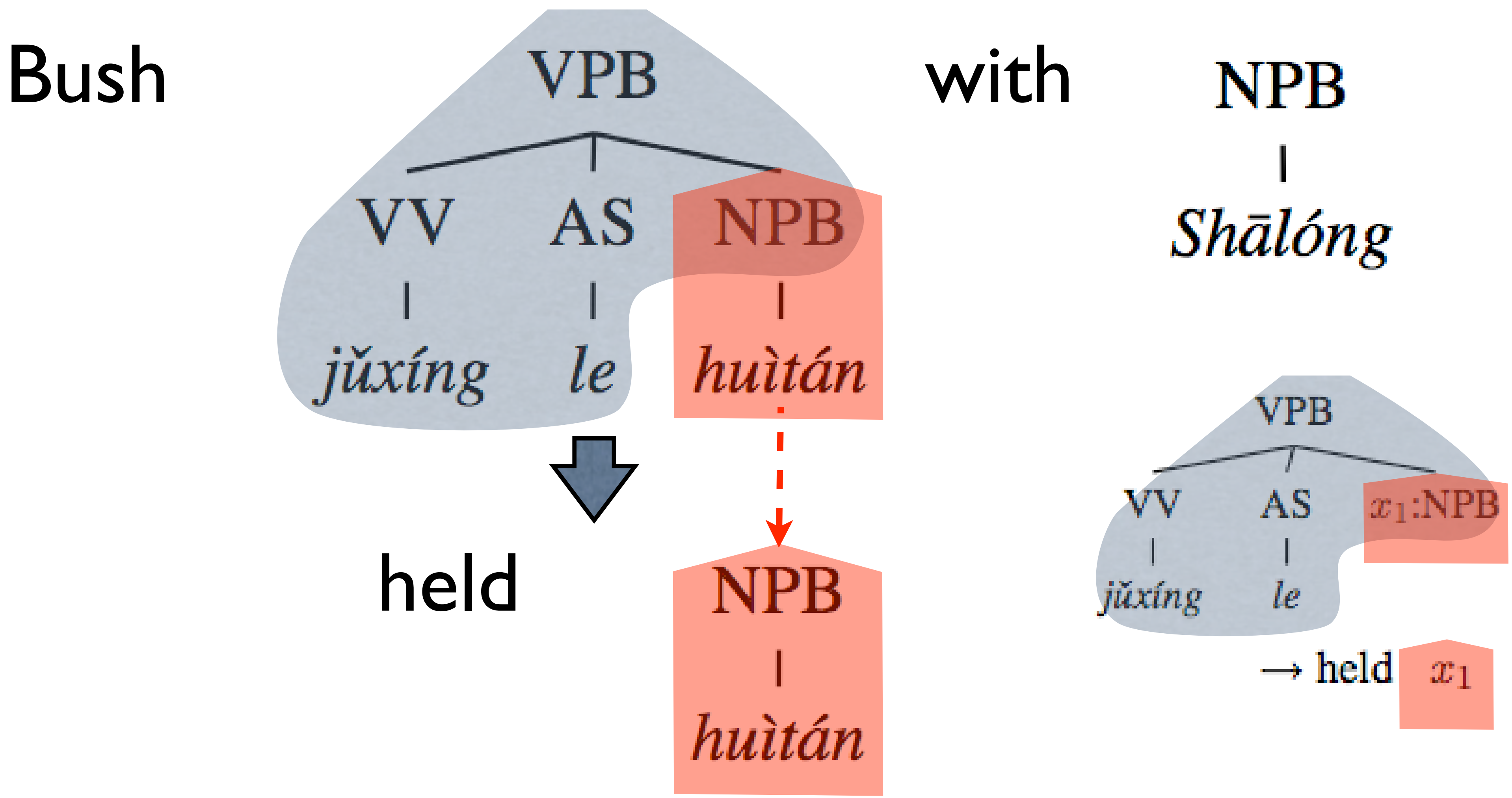

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Syntax-Directed Machine Translation?

- continue pattern-matching

Bush held NPB with NPB

NPB → *huìtán*

NPB → *Shālóng*

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Syntax-Directed Machine Translation?

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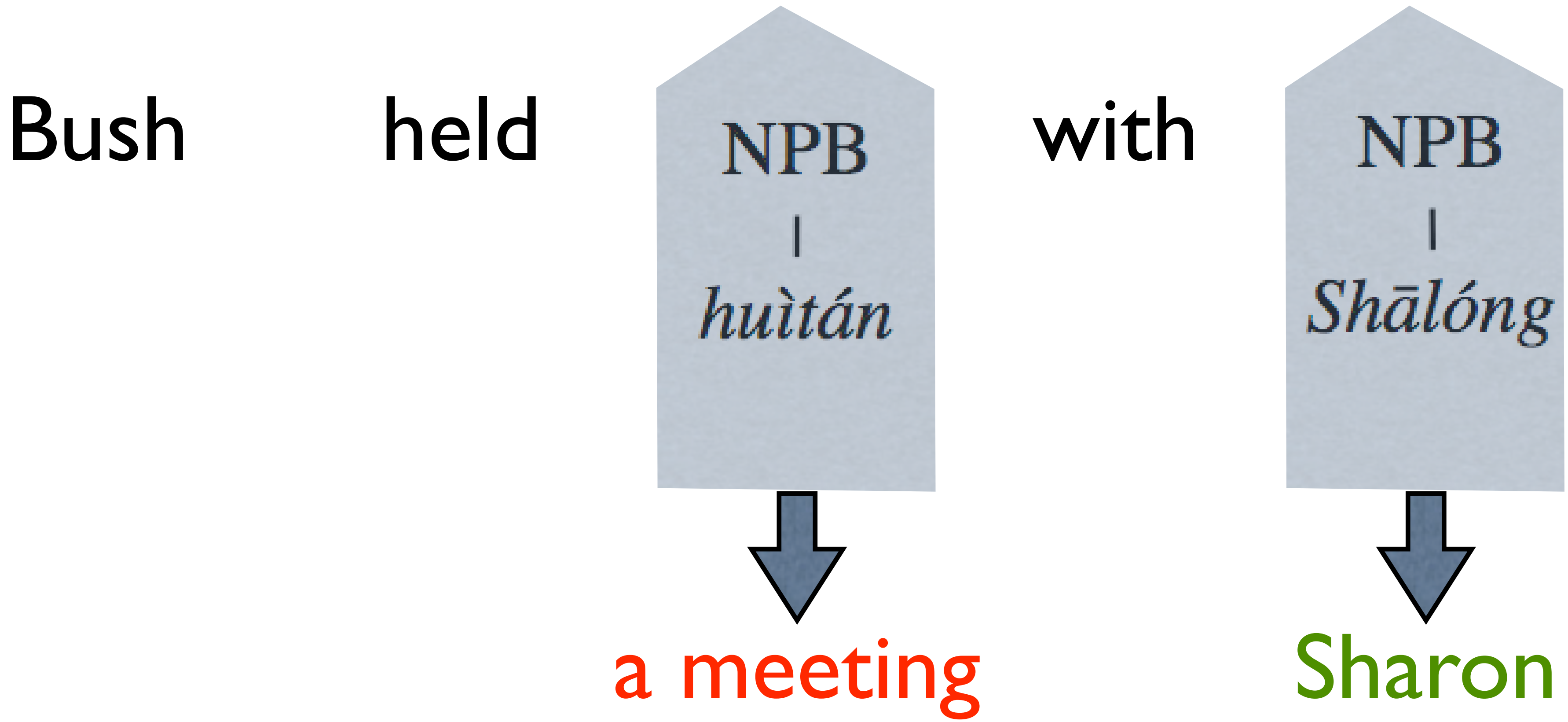

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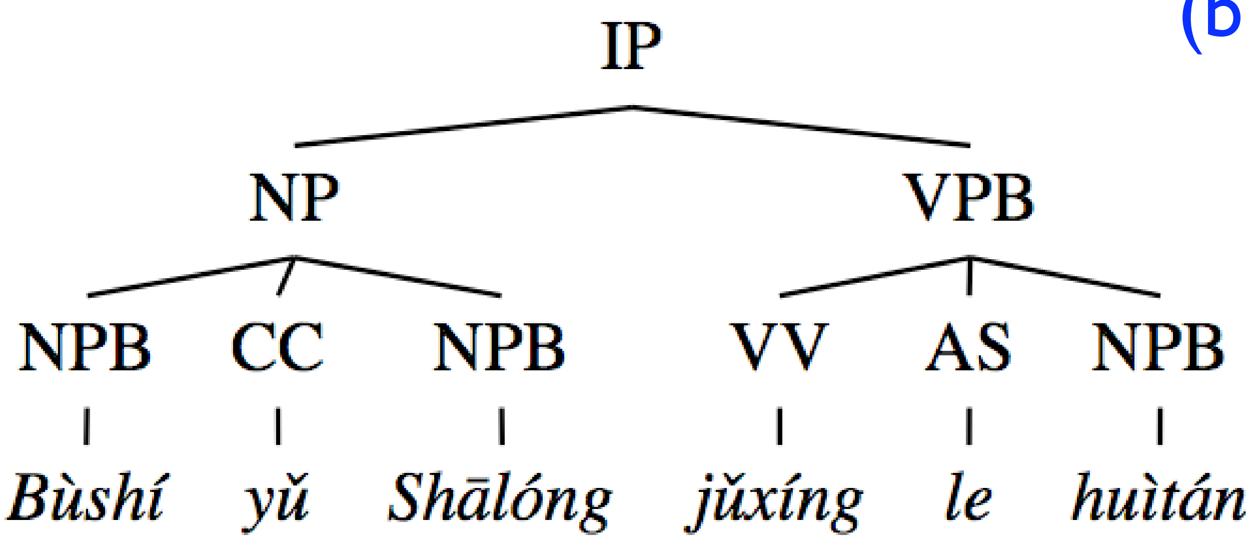
Pros: simple, fast, and expressive

- simple architecture: separate parsing and translation
- efficient linear-time dynamic programming
  - "soft decision" at each node on which rule to use
  - (trivial) depth-first traversal with memoization
- expressive multi-level rules for syntactic divergence

(beyond CFG)



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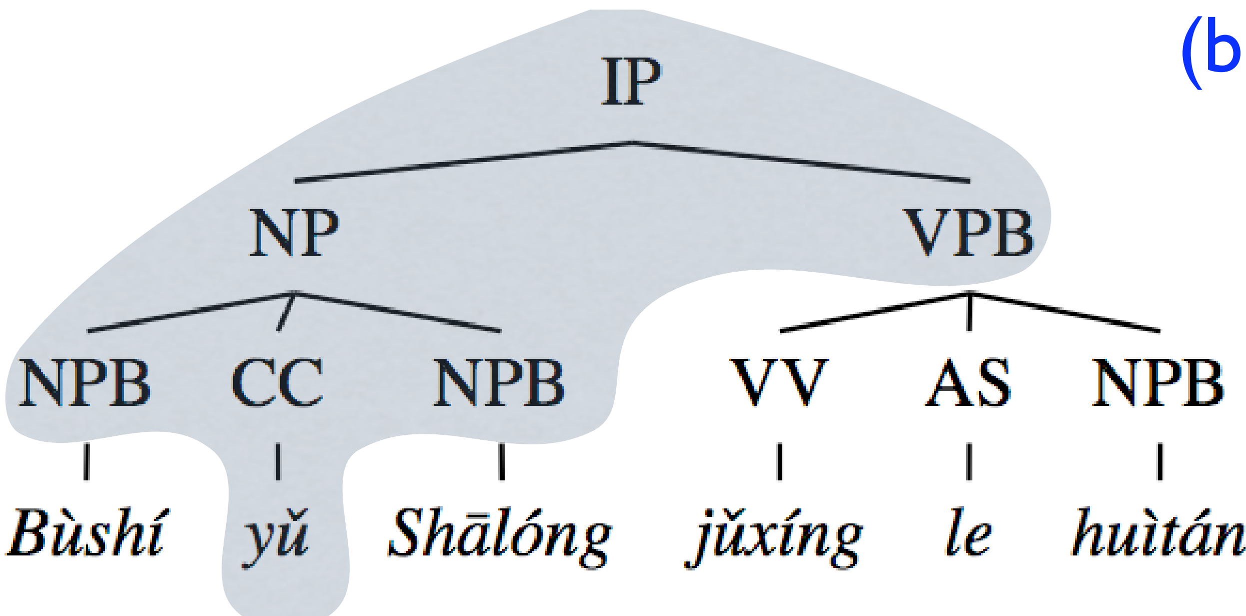

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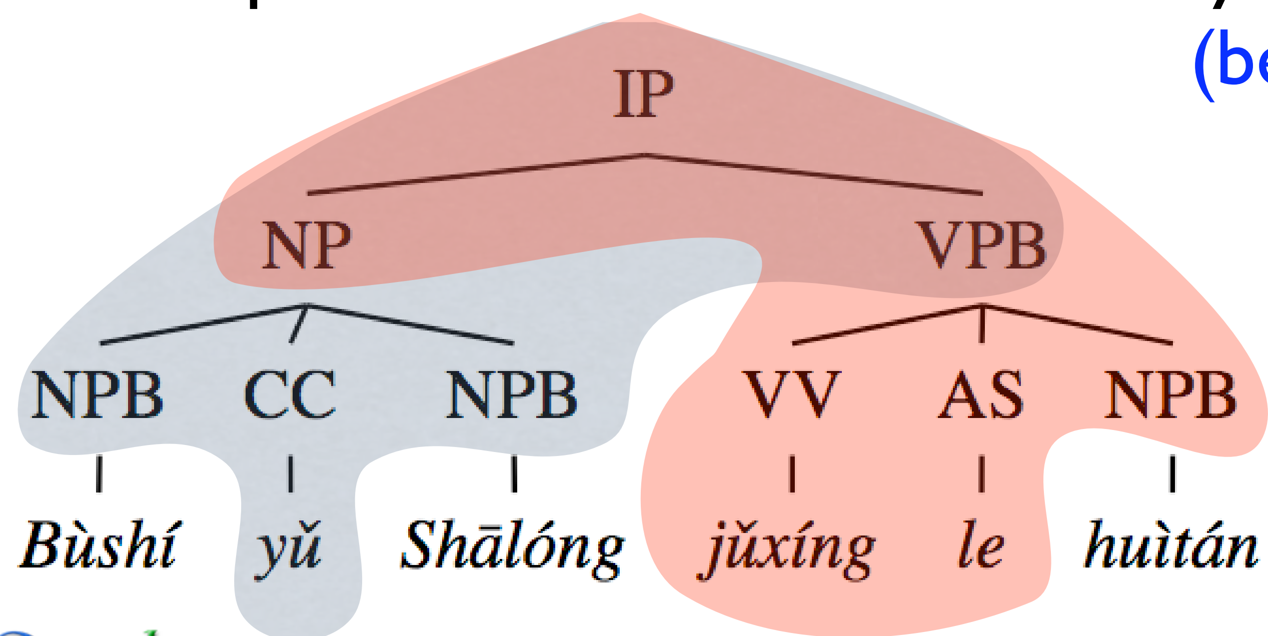

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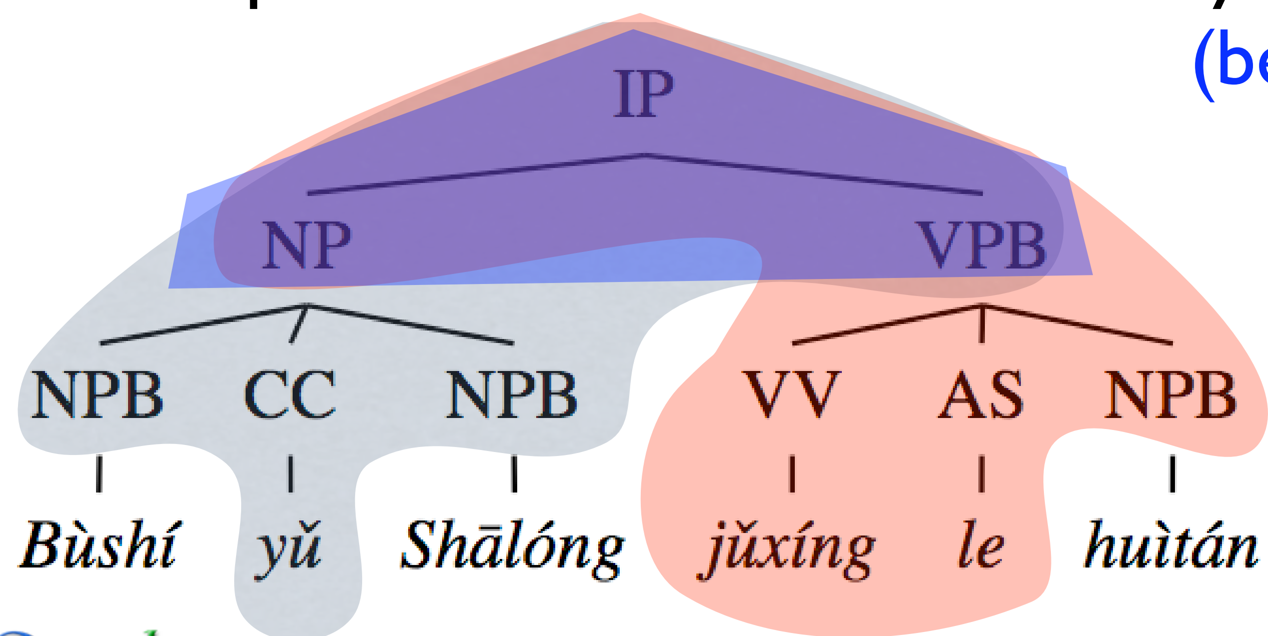

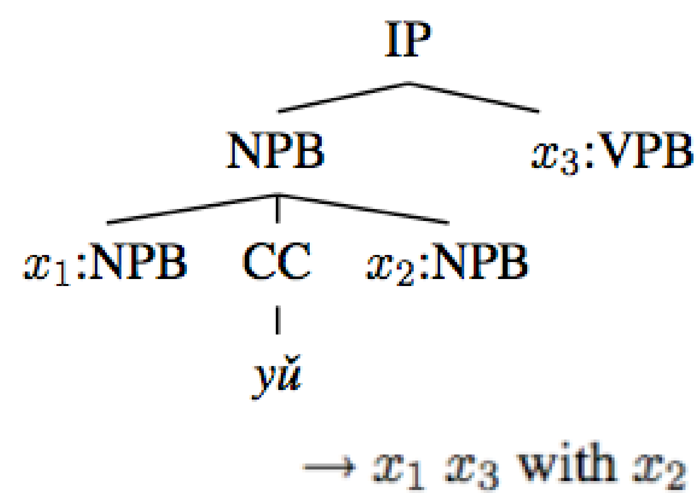

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- ambiguity is a fundamental problem in natural languages
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emergency exit
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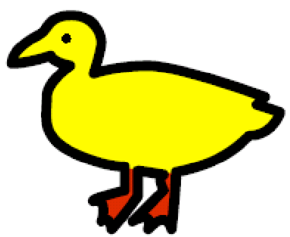
mind your head
or "meet cautiously"?

Google Research

Exponential Explosion of Ambiguity

I saw her duck.



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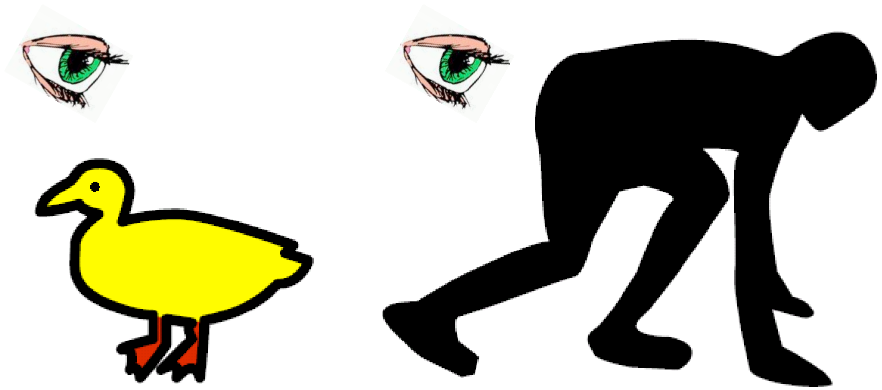

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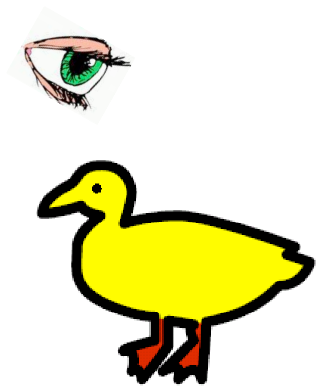

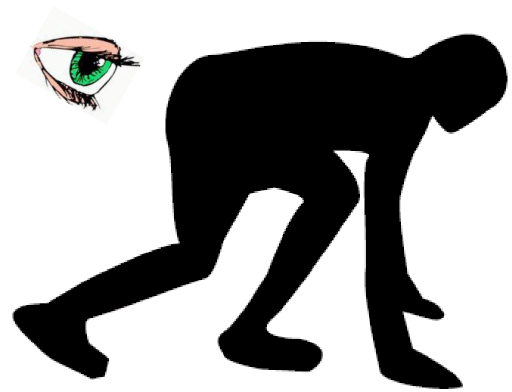

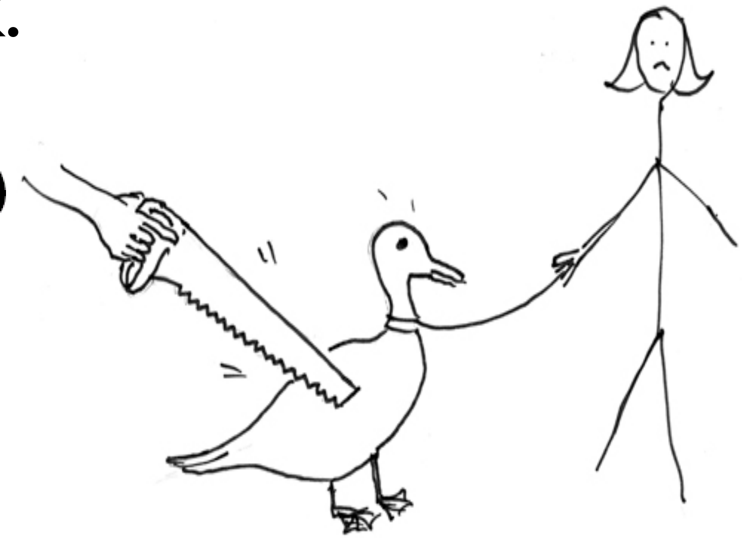

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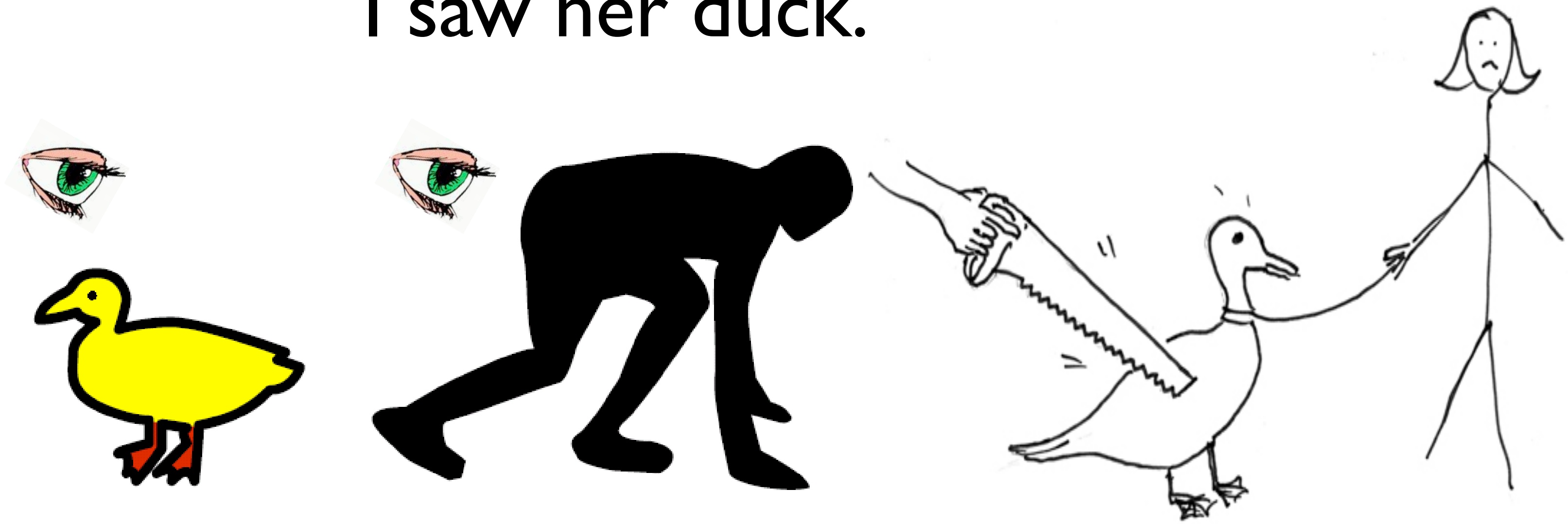

- how about...
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  - I saw her duck with a telescope in the garden...

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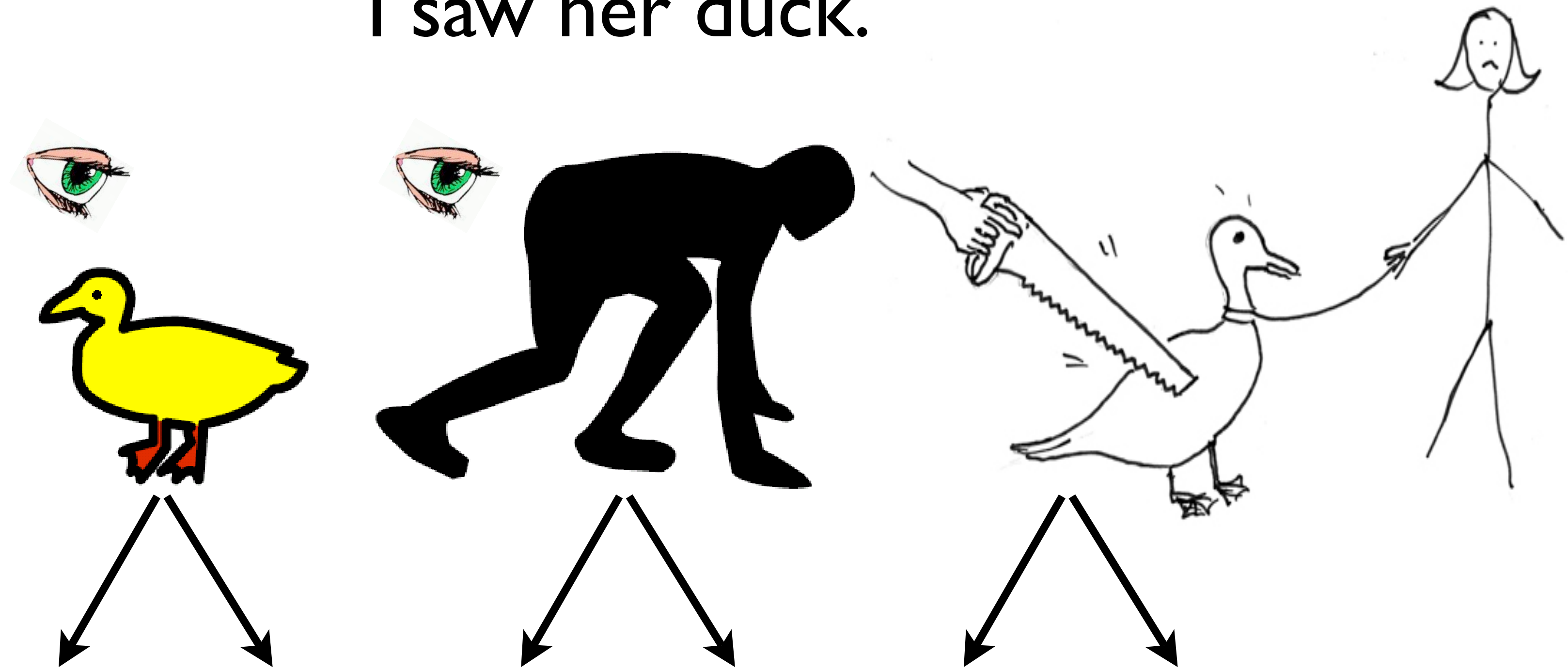

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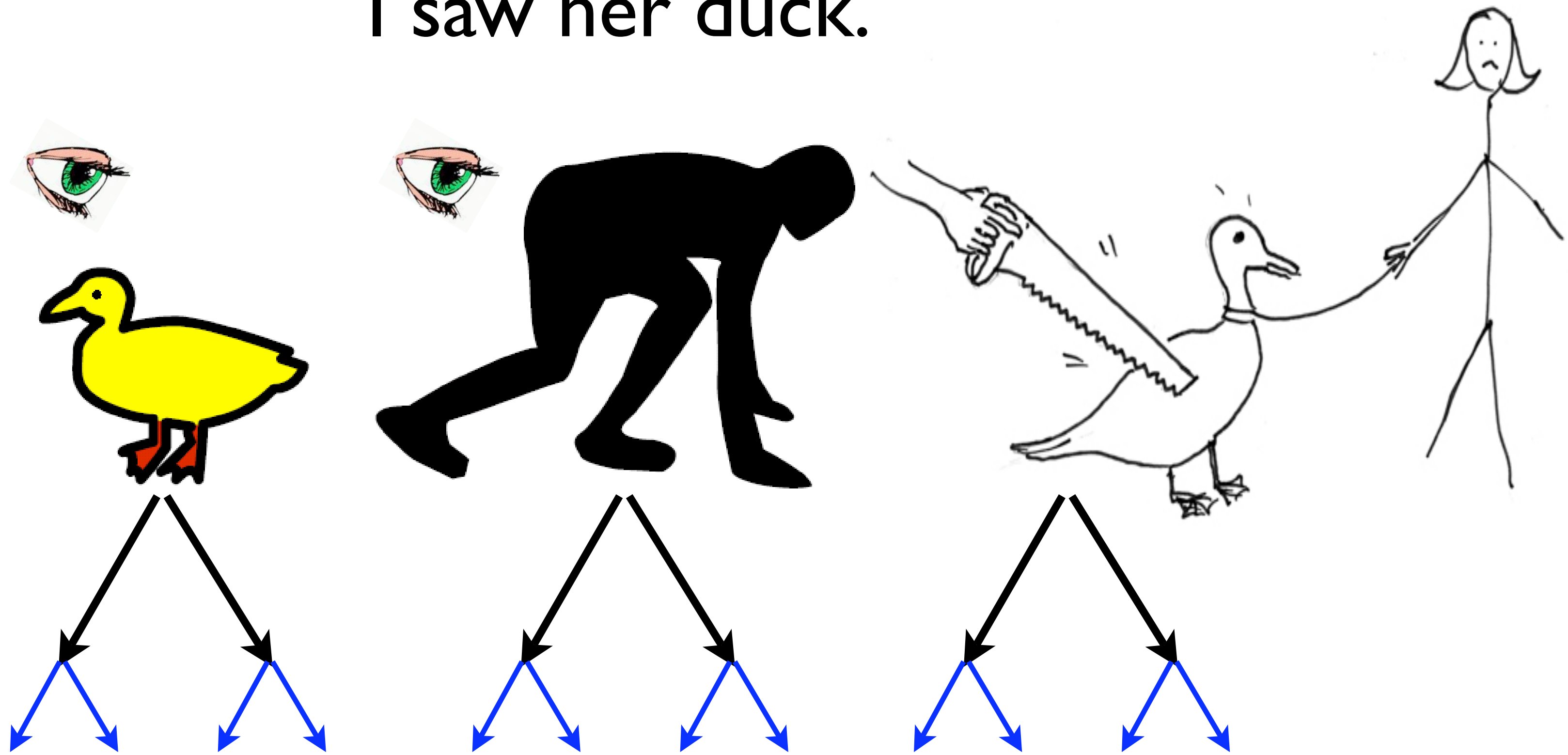

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NLP == dealing with ambiguities.

Tackling Ambiguities in Translation

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- simplest idea: take top-*k* trees rather than 1-best parse
  - but only covers tiny fraction of the exponential space
  - and these *k*-best trees are very similar
    - e.g., 50-best trees ~ 5-6 binary ambiguities ($2^5 < 50 < 2^6$)
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Google Research

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- most ambitious idea: combining parsing and translation
  - start from the input string, rather than 1-best tree
  - essentially considering all trees (search space too big)
- our approach: *packed forest* *(poly. encoding of exp. space)*
  - almost as fast as 1-best, almost as good as combined

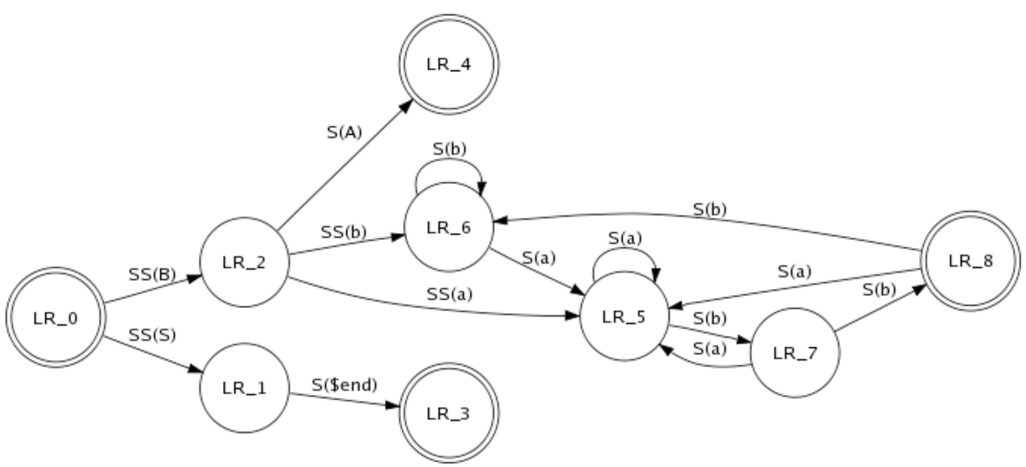
Outline

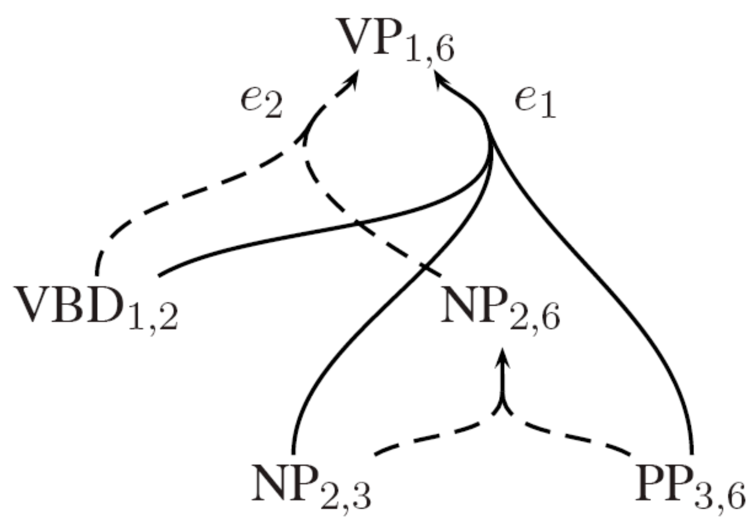
- Overview: Tree-based Translation
- Forest-based Translation
  - Packed Forest
  - Translation on a Forest
  - Experiments
- Forest-based Rule Extraction
  - Large-scale Experiments

Google Research

From Lattices to Forests

- common theme: polynomial encoding of exponential space
  - forest generalizes "lattice/graph" from finite-state world
    - paths => trees (in DP: knapsack vs. matrix-chain multiplication)
    - graph => hypergraph; regular grammar => CFG

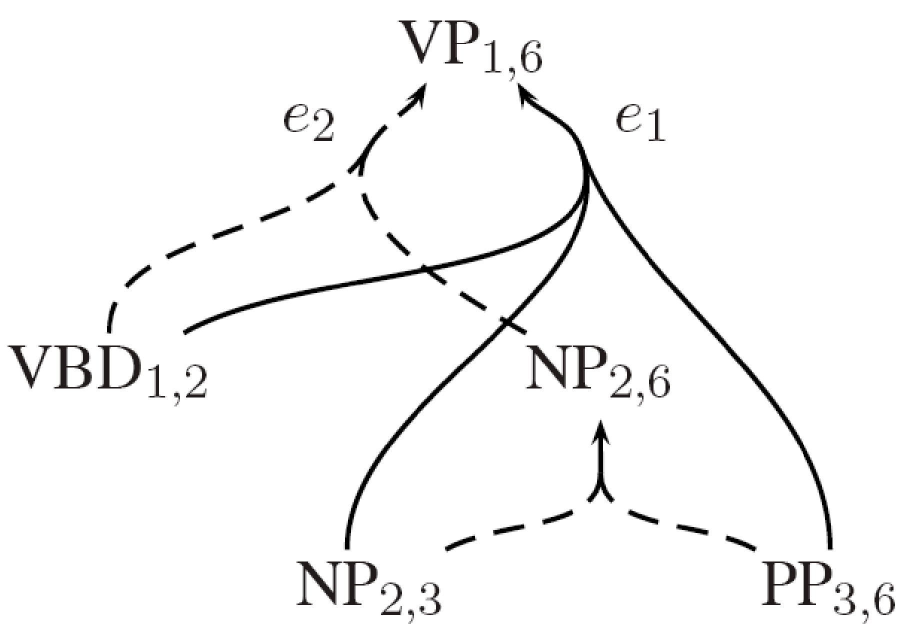




(Earley 1970; Billot and Lang 1989)

Packed Forest

- a compact representation of many many parses
  - by sharing common sub-derivations
  - polynomial-space encoding of exponentially large set



$$e_1 \quad \frac{VBD_{1,2} \quad NP_{2,3} \quad PP_{3,6}}{VP_{1,6}}$$

$_0$ I $_1$ saw $_2$ him $_3$ with $_4$ a $_5$ mirror $_6$

(Klein and Manning, 2001; Huang and Chiang, 2005)

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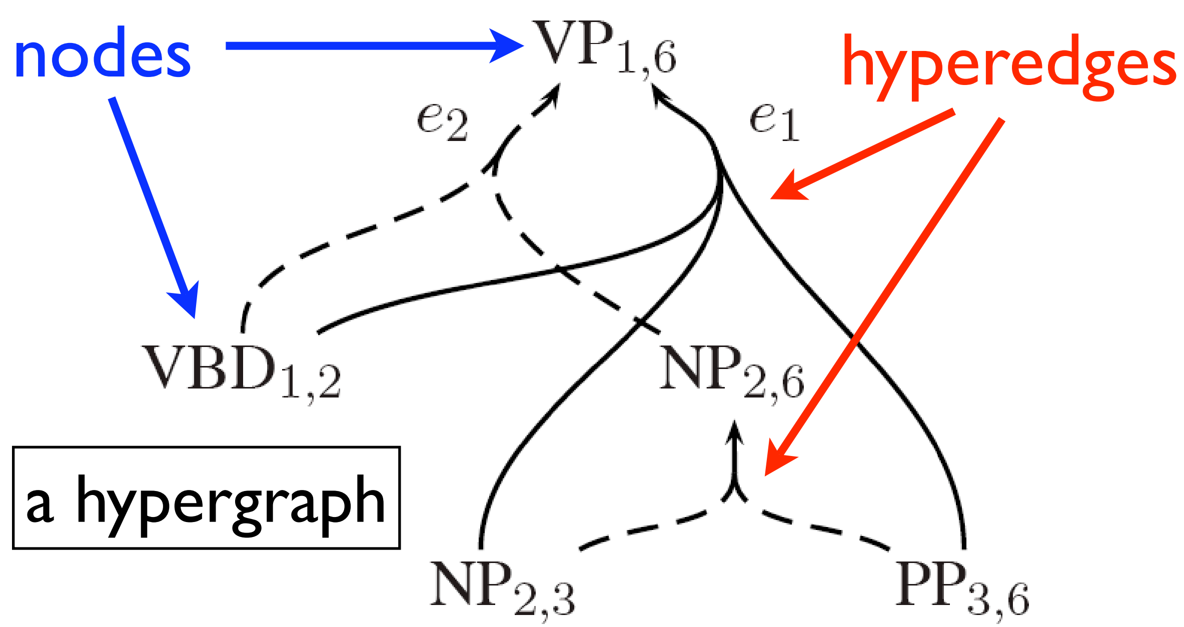

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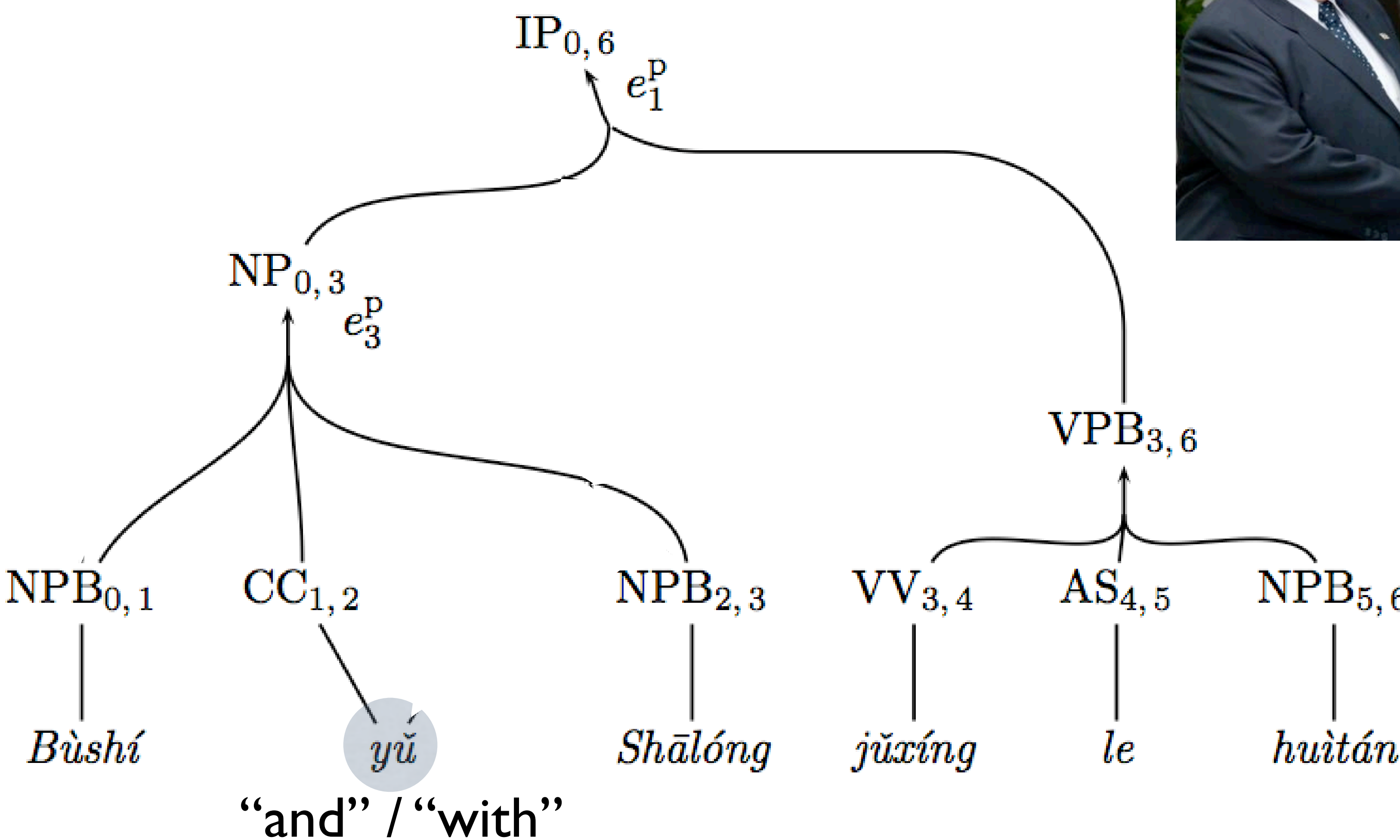
Forest-based Translation



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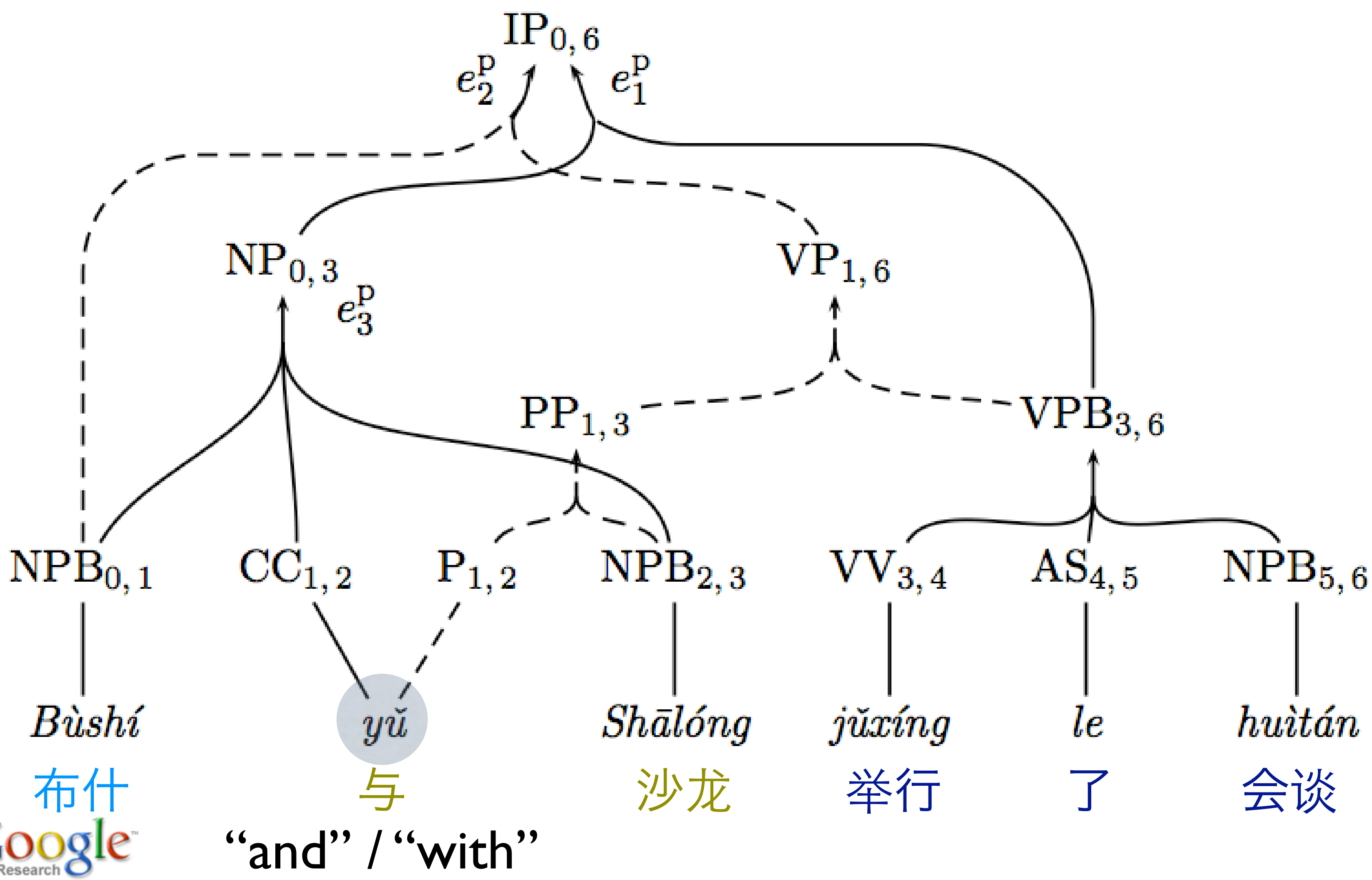

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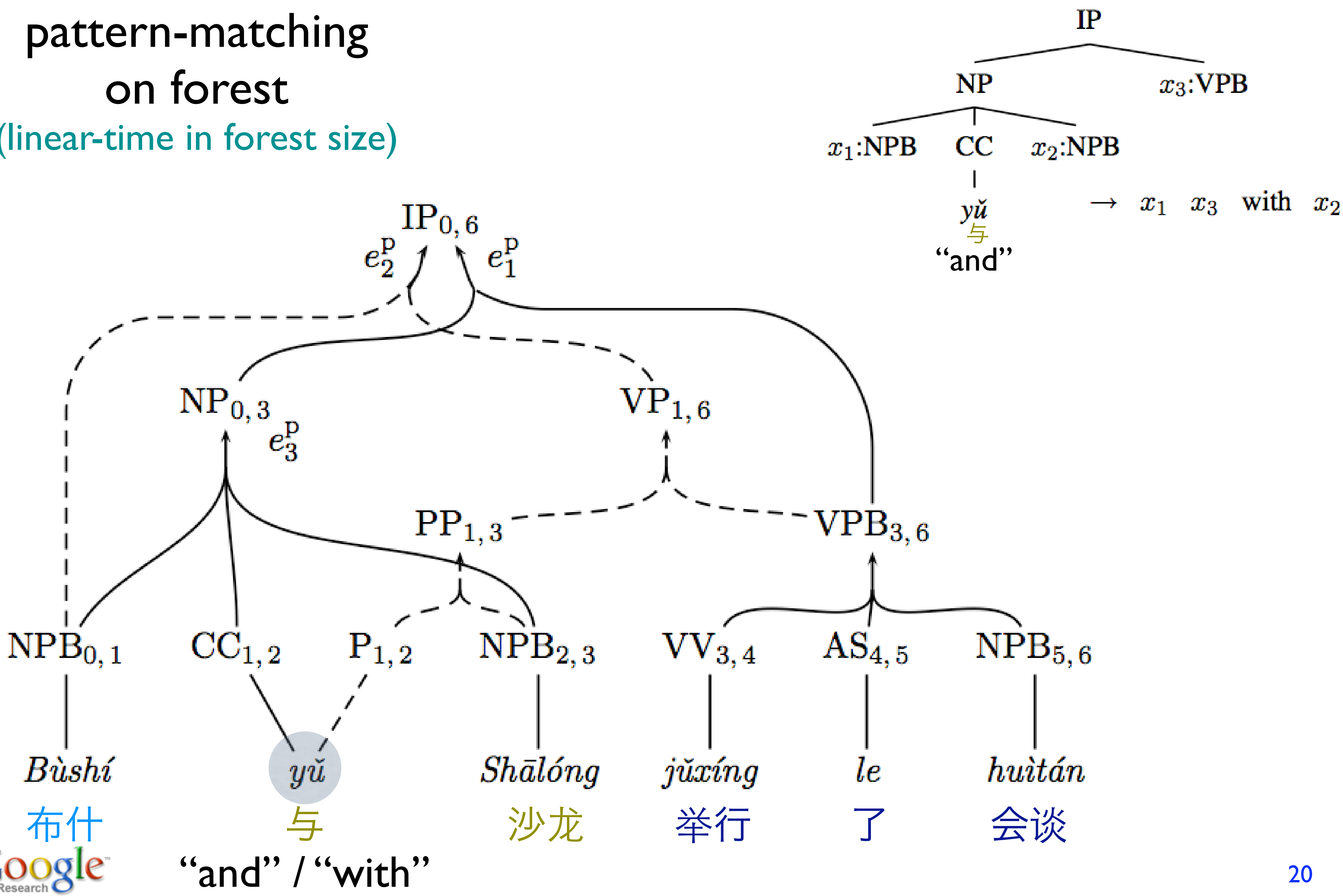
Forest-based Translation

pattern-matching
on forest
(linear-time in forest size)



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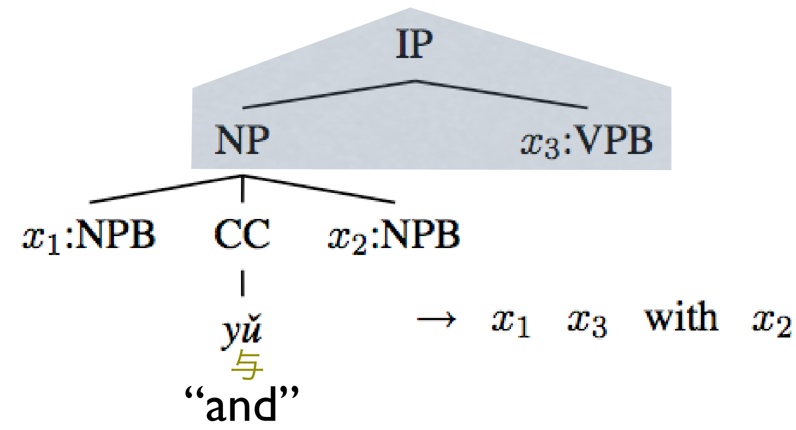

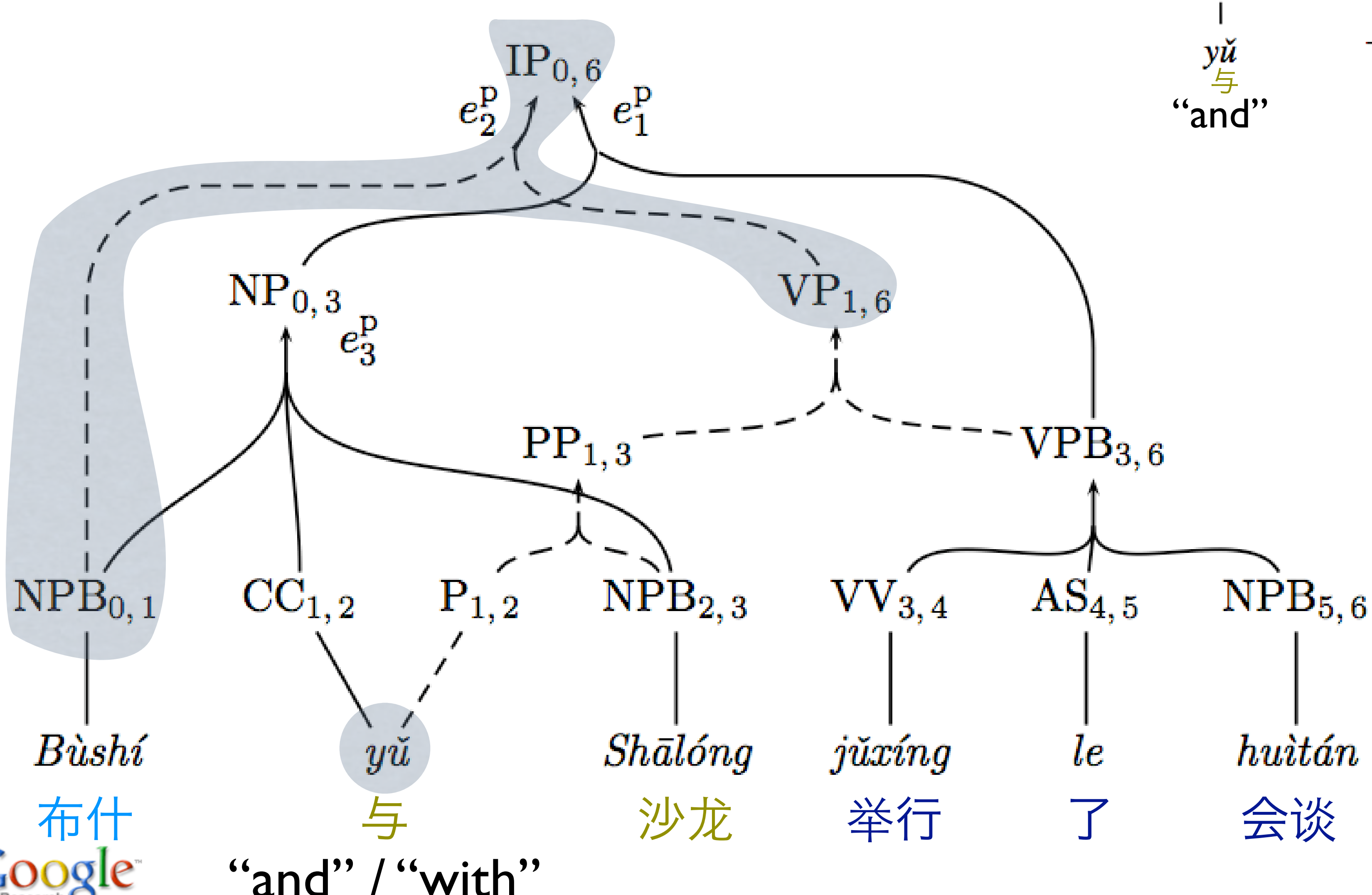

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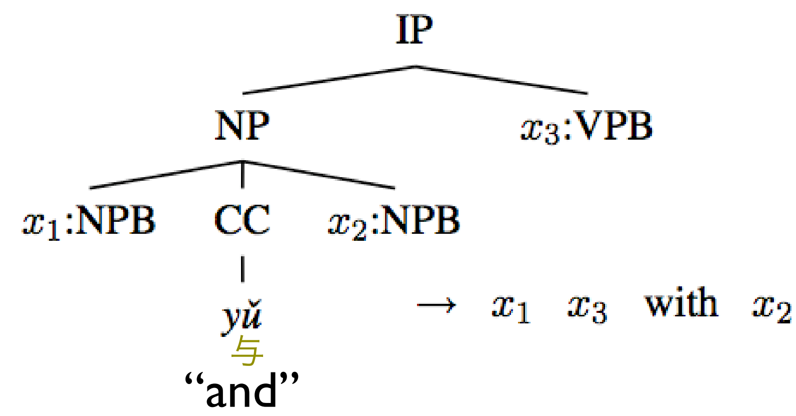

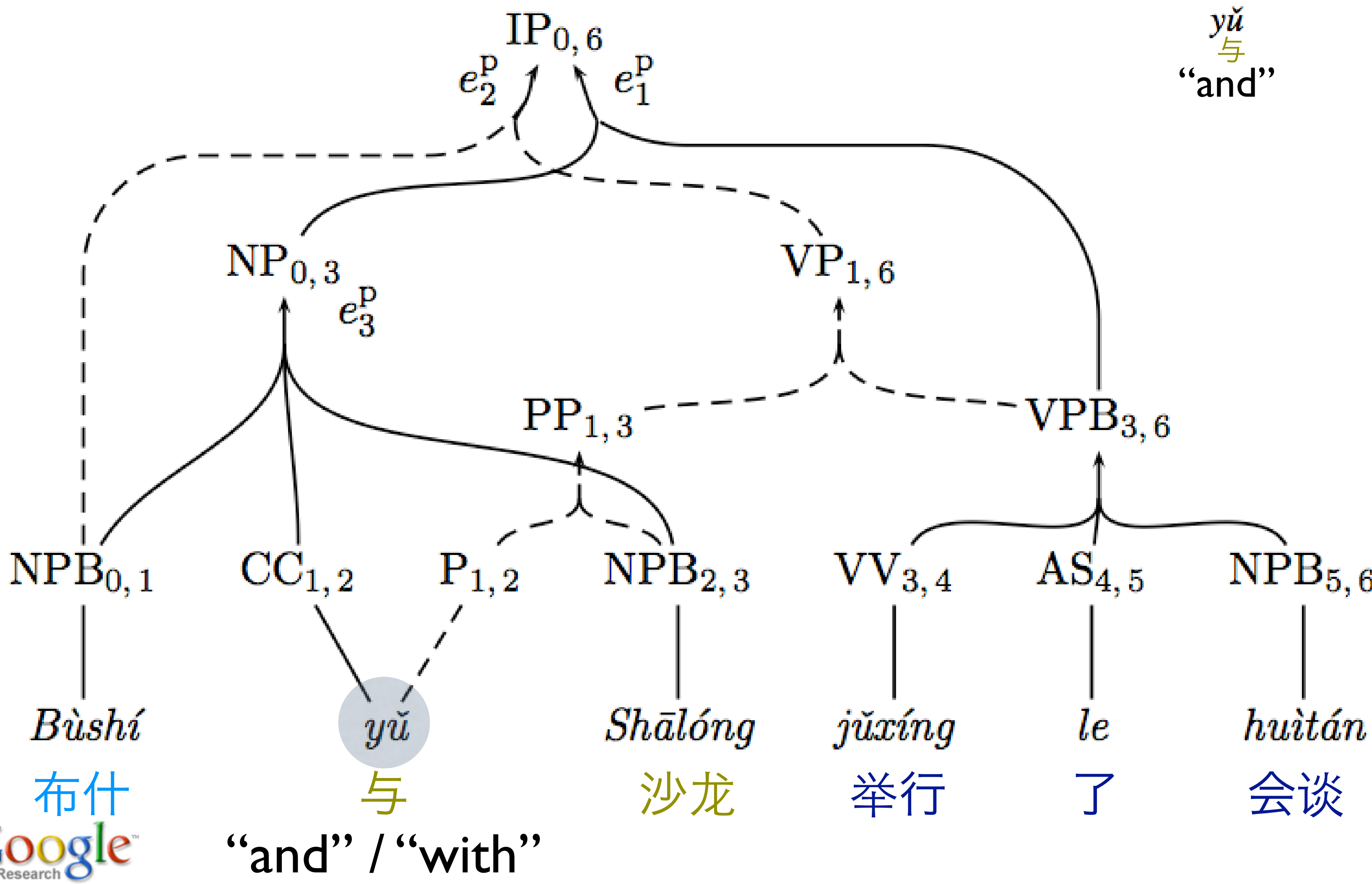

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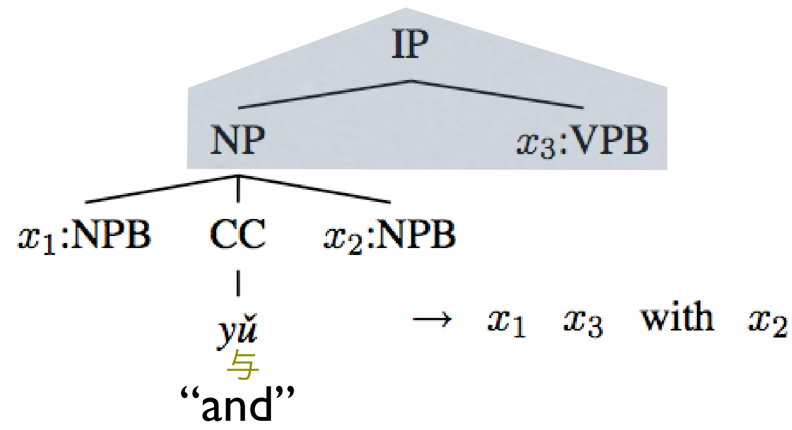

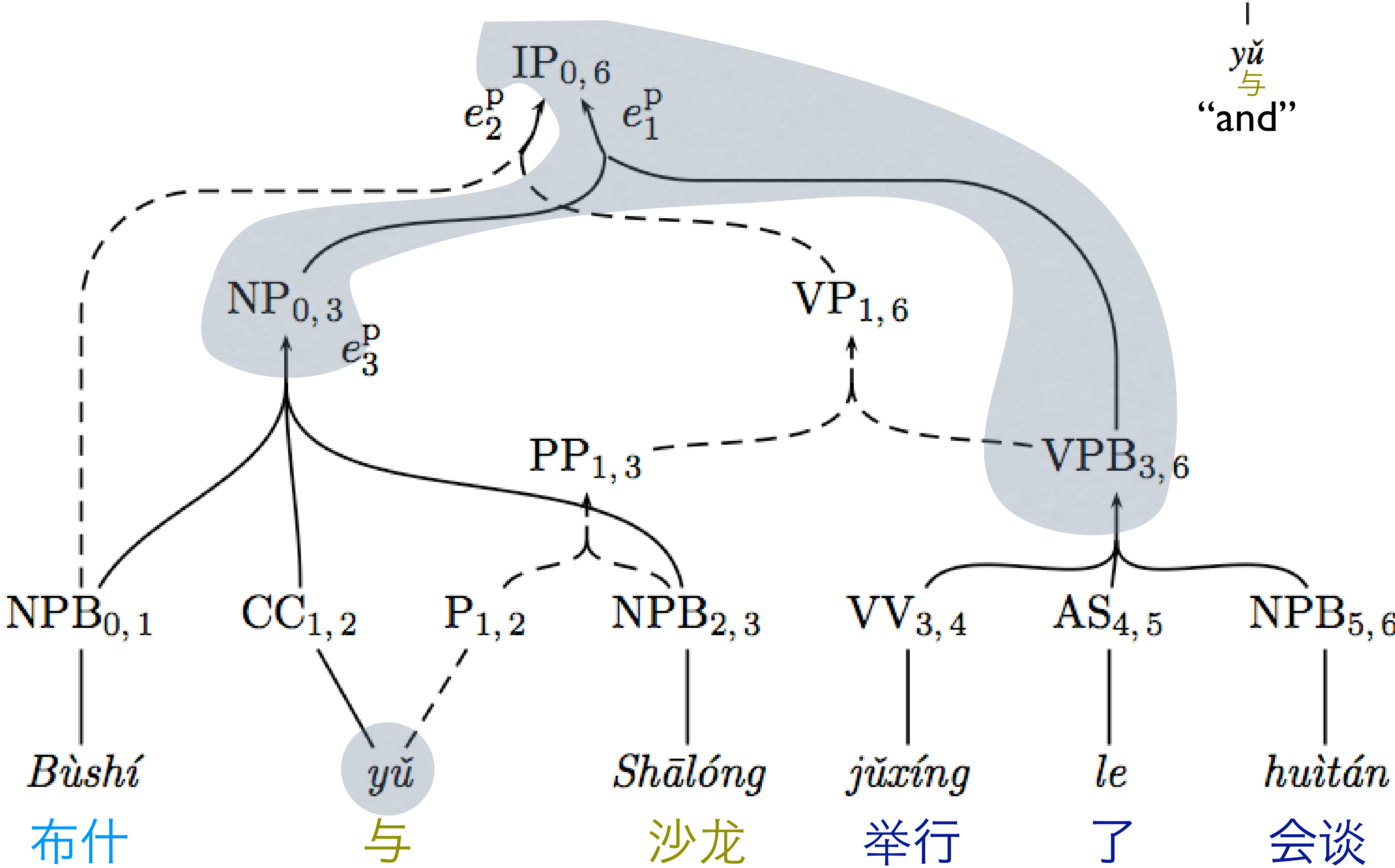

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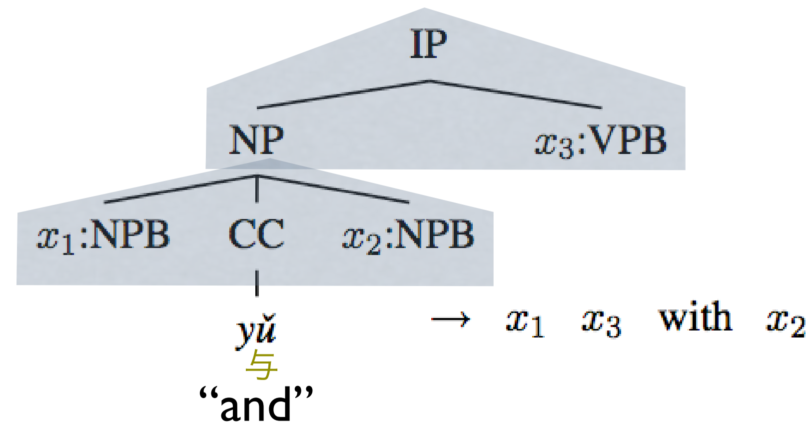
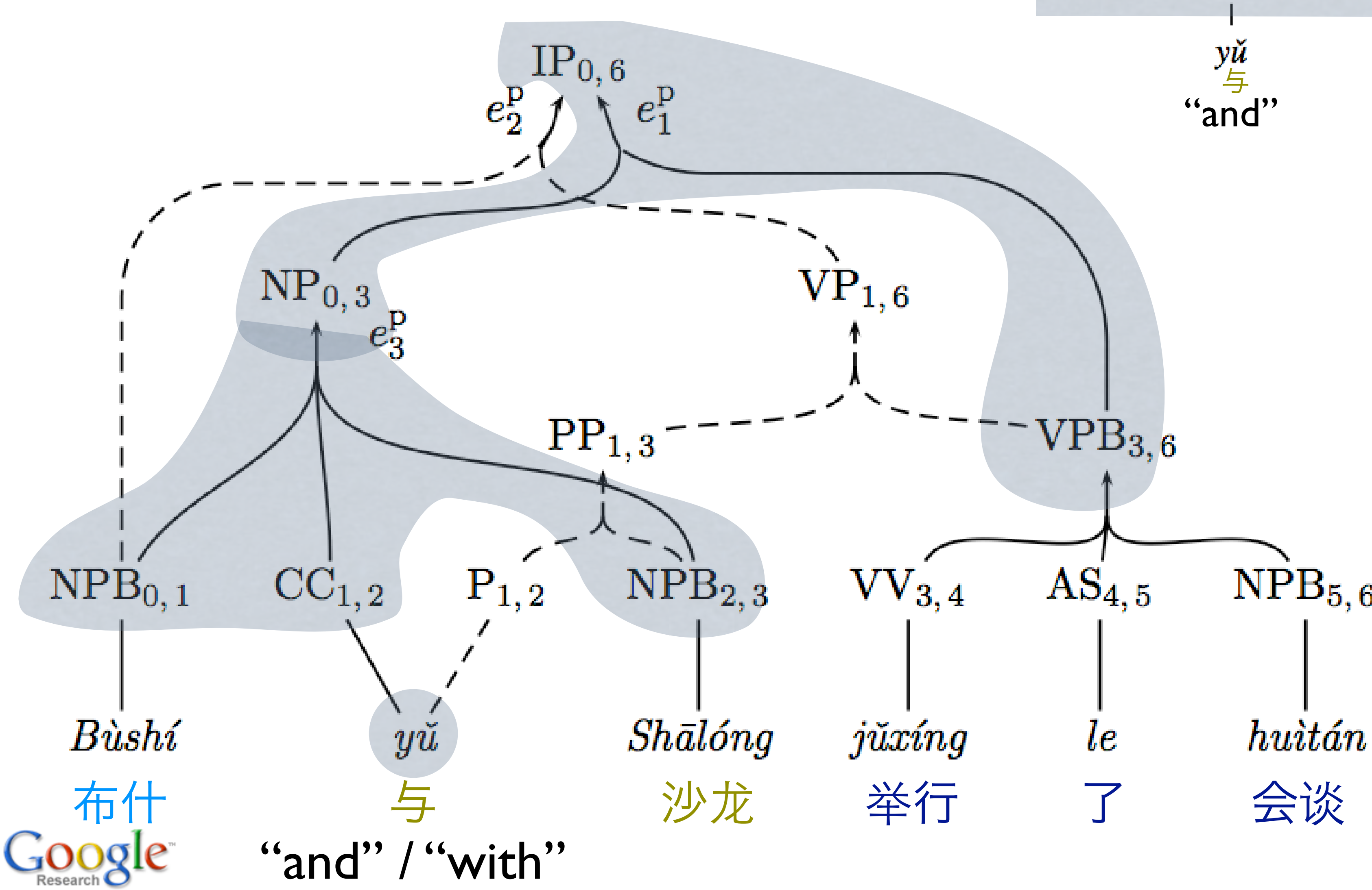
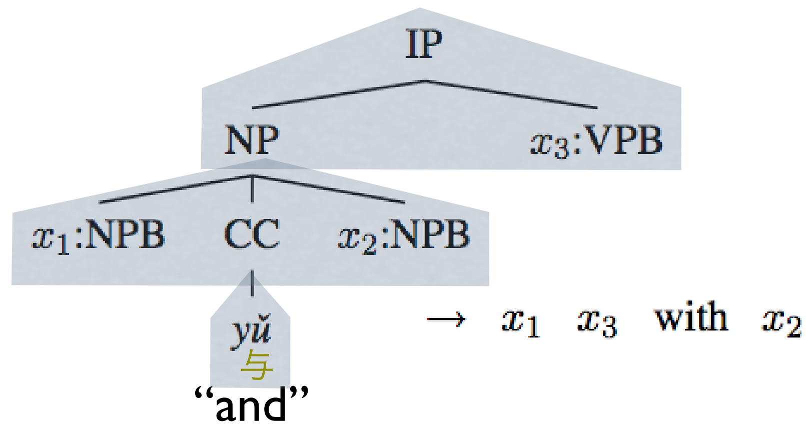
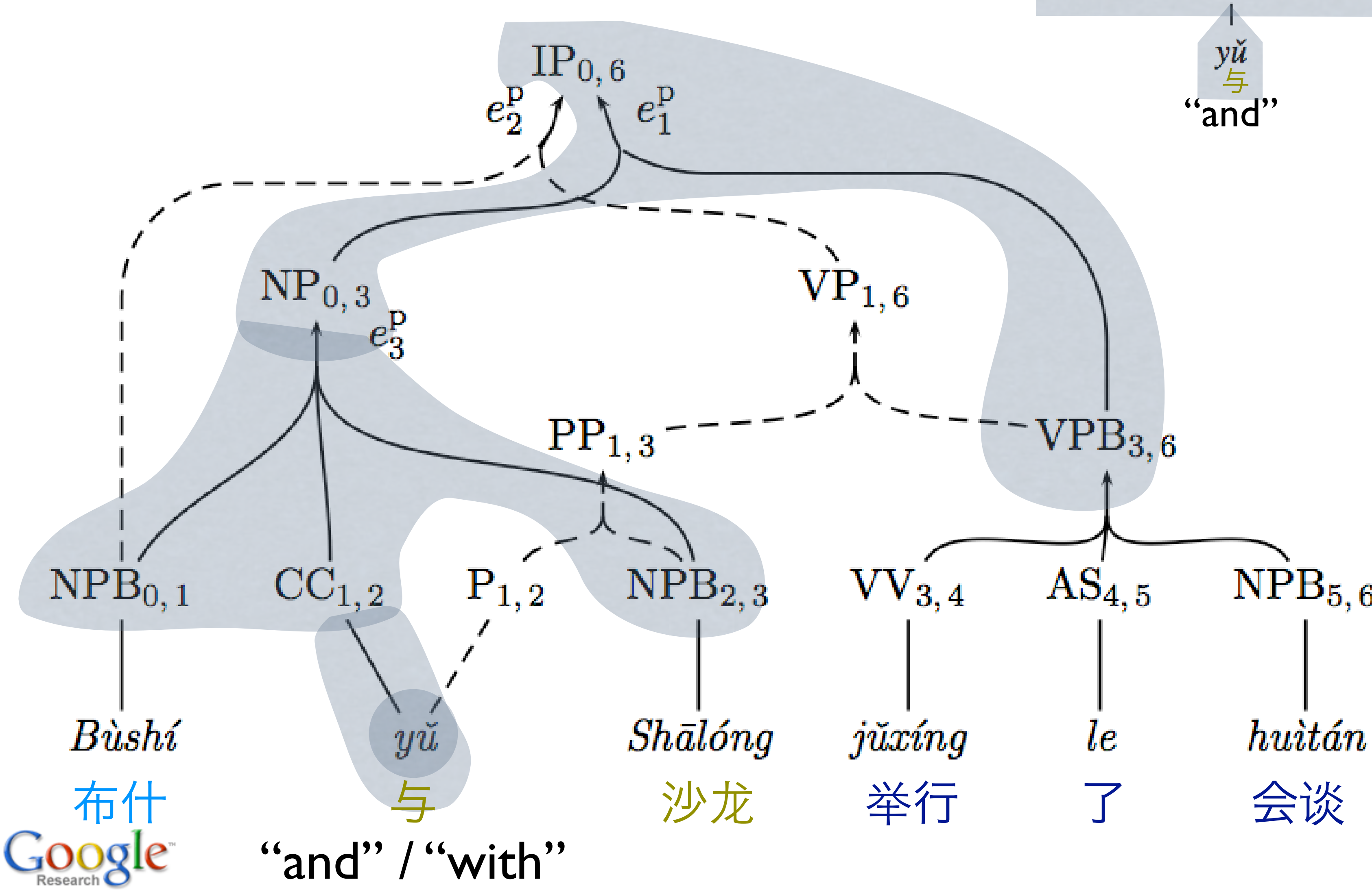




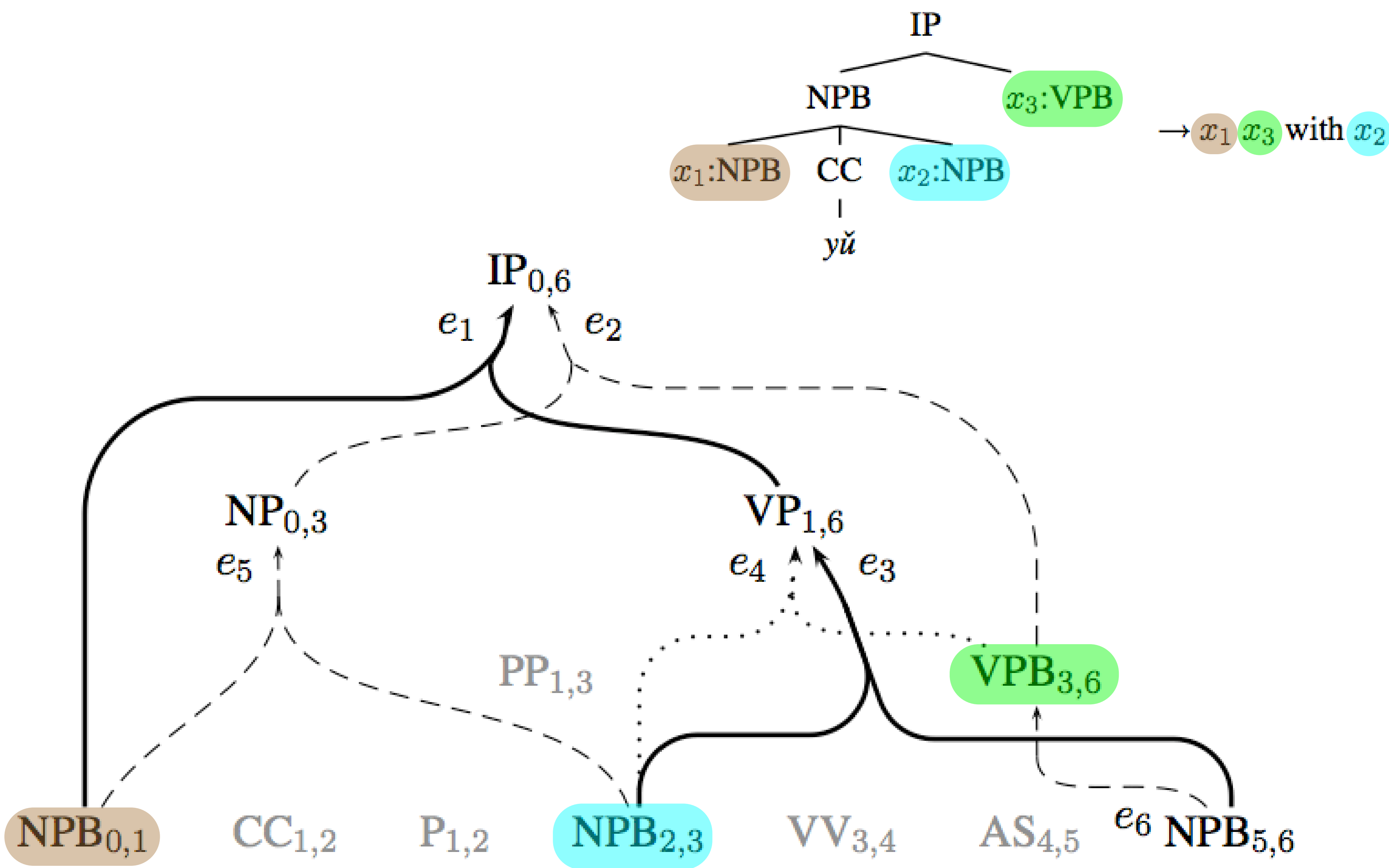
Forest-based Translation

pattern-matching
on forest
(linear-time in forest size)

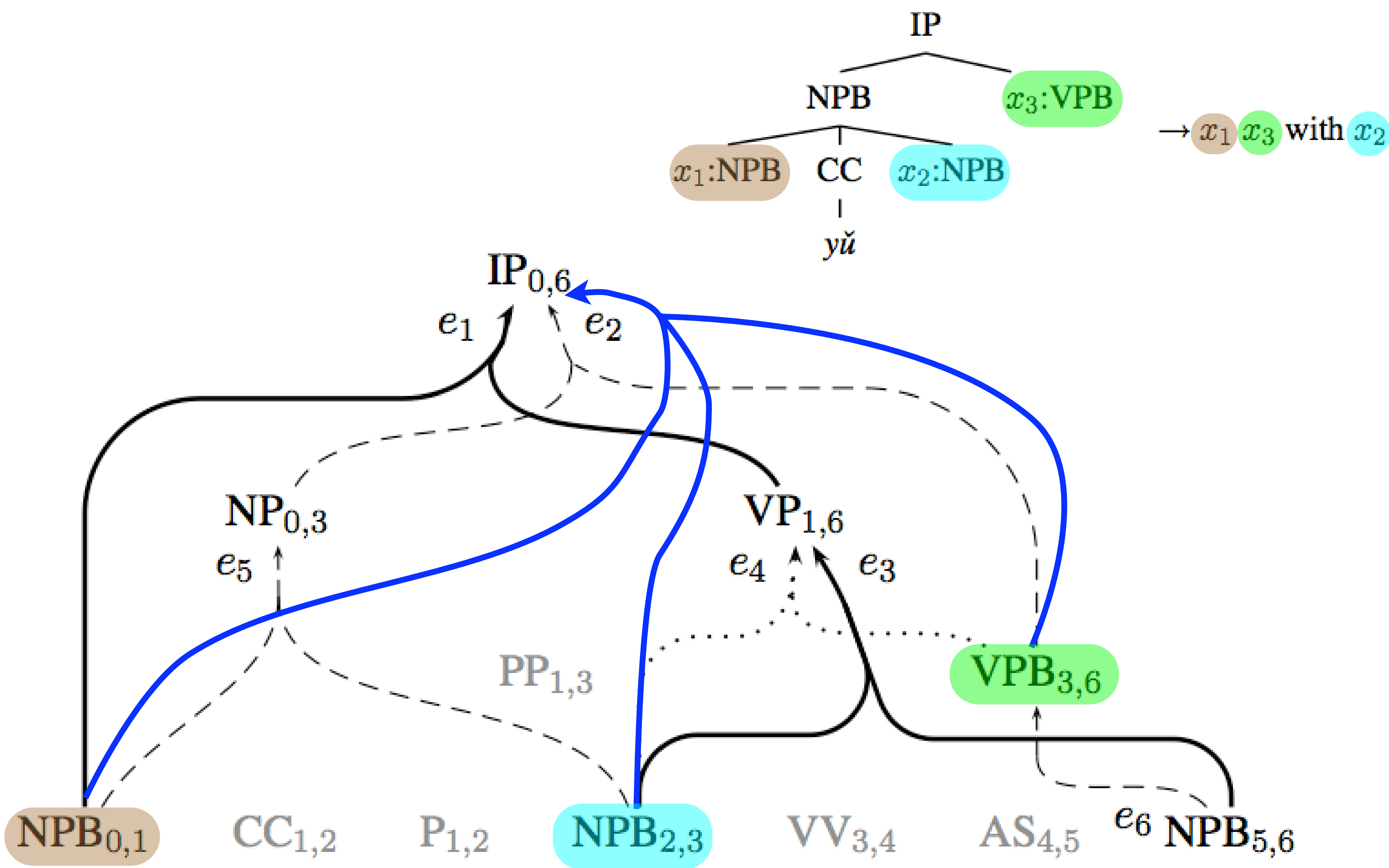




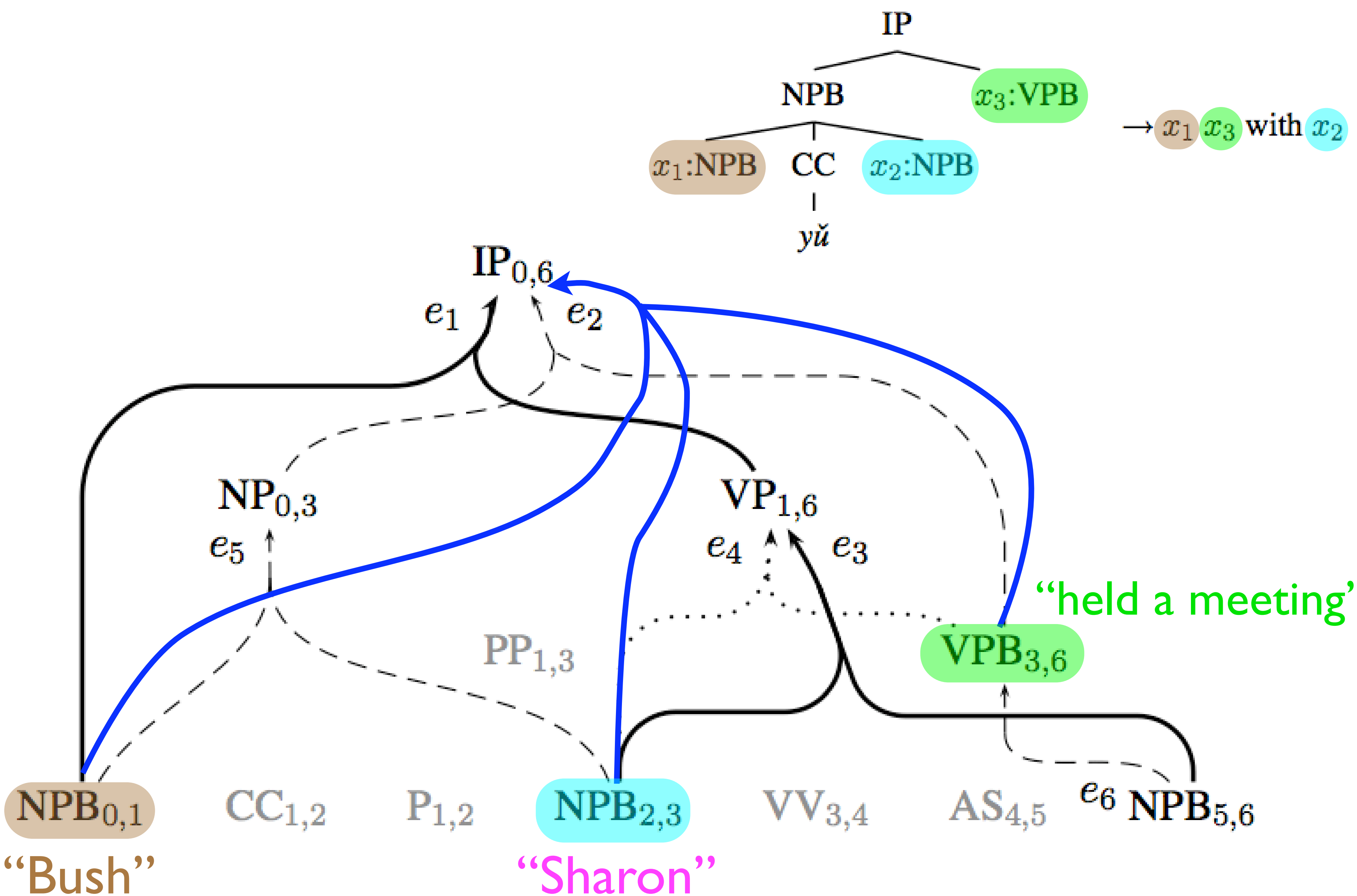
Translation Forest



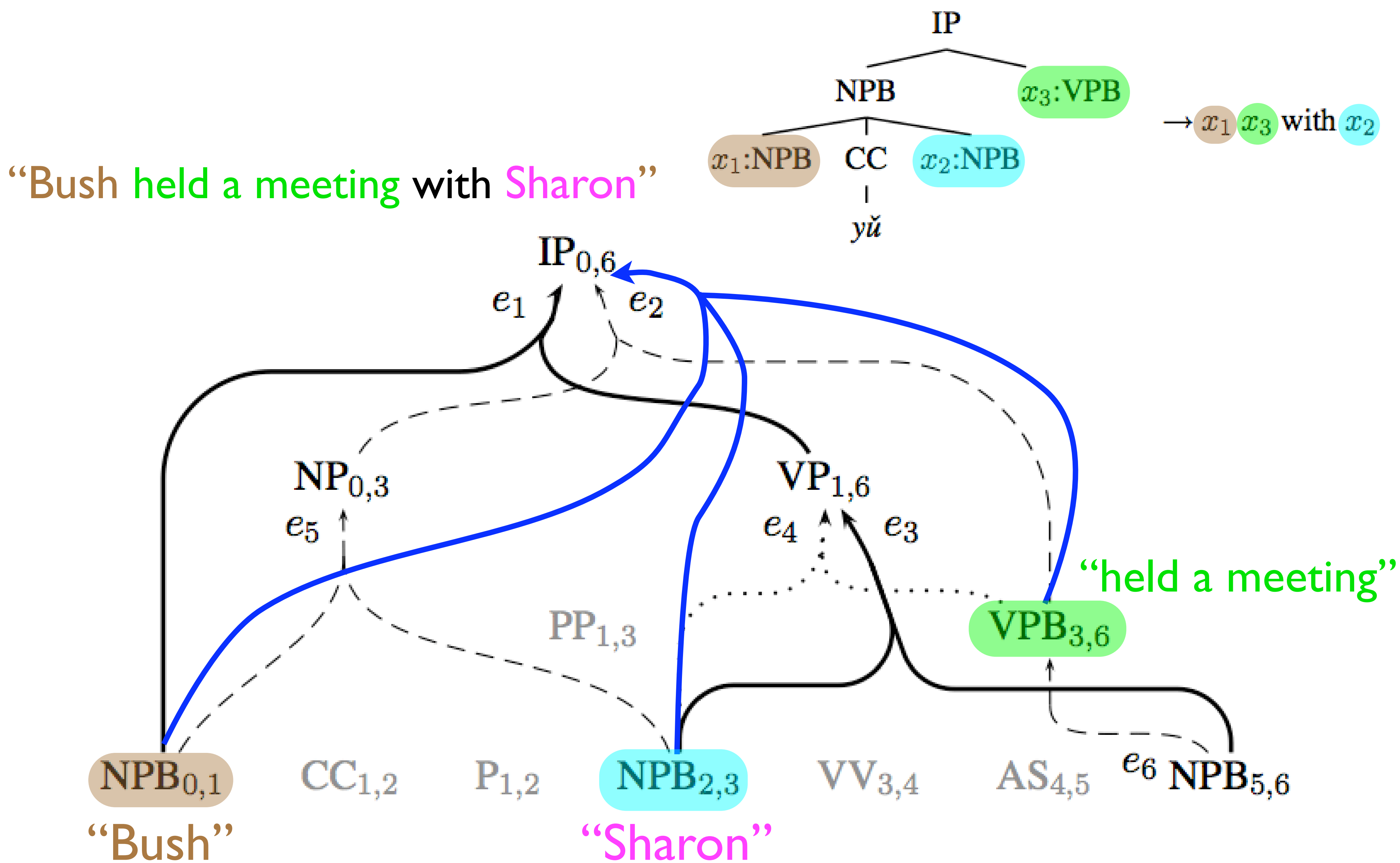
Translation Forest



Translation Forest



Translation Forest



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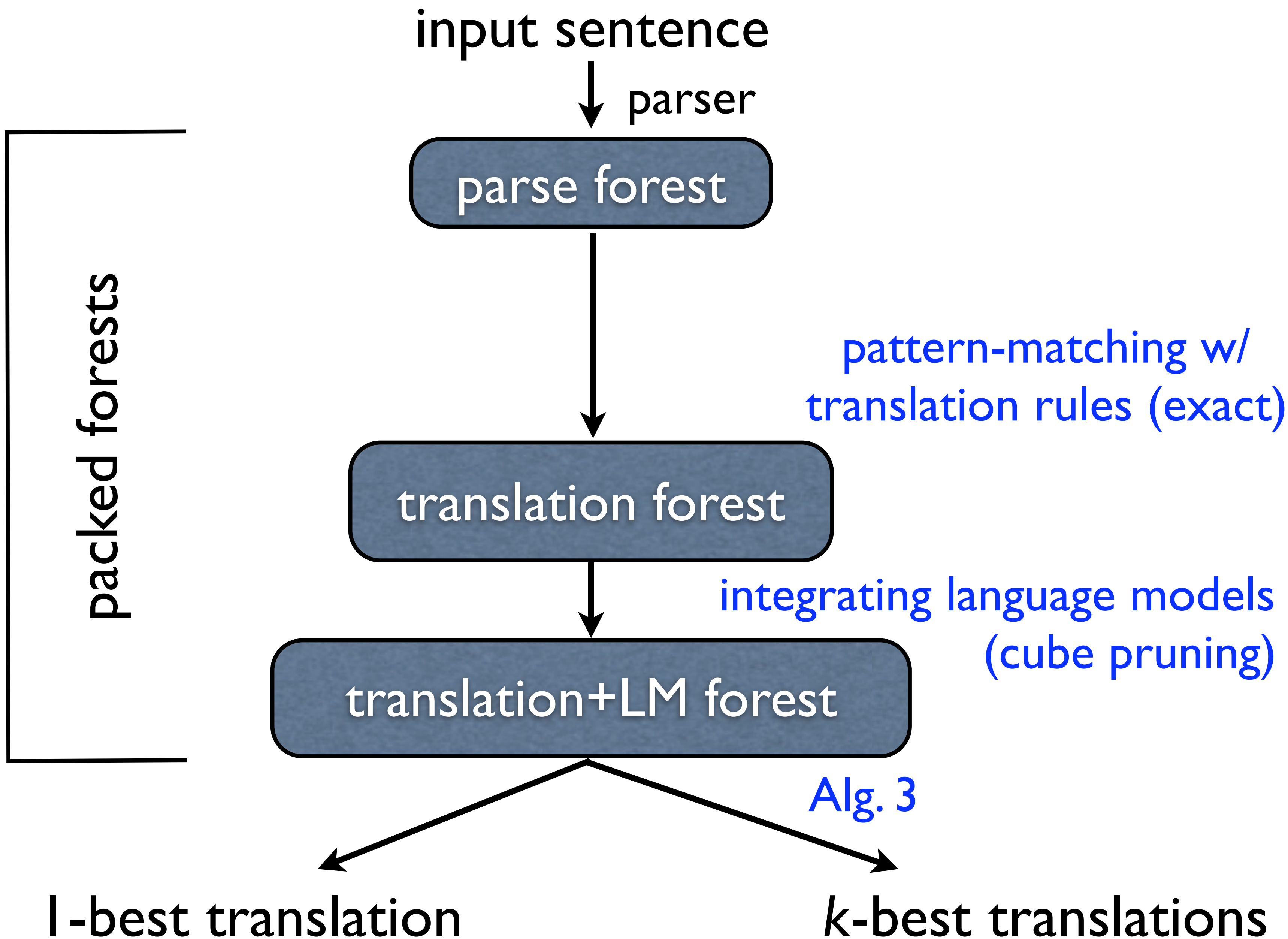
The Whole Pipeline



(Huang and Chiang, 2005; 2007; Chiang, 2007)

The Whole Pipeline

input sentence

↓ parser

parse forest

↓ forest pruning

pruned forest

↓ pattern-matching w/ translation rules (exact)

translation forest

↓ integrating language models (cube pruning)

translation+LM forest

Alg. 3

1-best translation

k-best translations

packed forests

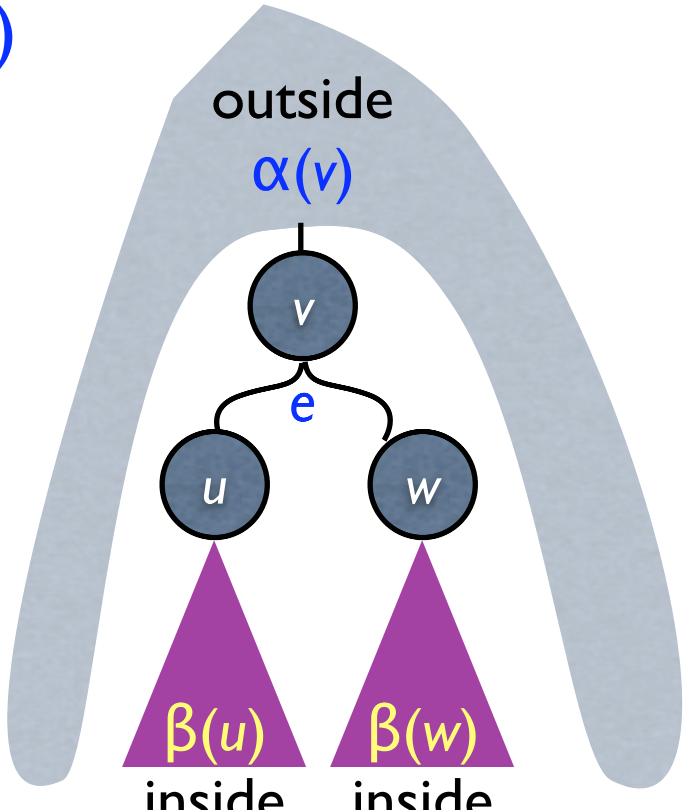
(Huang and Chiang, 2005; 2007; Chiang, 2007)

Parse Forest Pruning

- prune *unpromising* hyperedges
- principled way: inside-outside
  - first compute Viterbi inside β, outside α
- then $\alpha\beta(e) = \alpha(v) + c(e) + \beta(u) + \beta(w)$
  - cost of best deriv that traverses e
  - similar to "expected count" in EM
- prune away hyperedges that have

  $\alpha\beta(e) - \alpha\beta(\textsc{top}) > p$

  for some threshold p

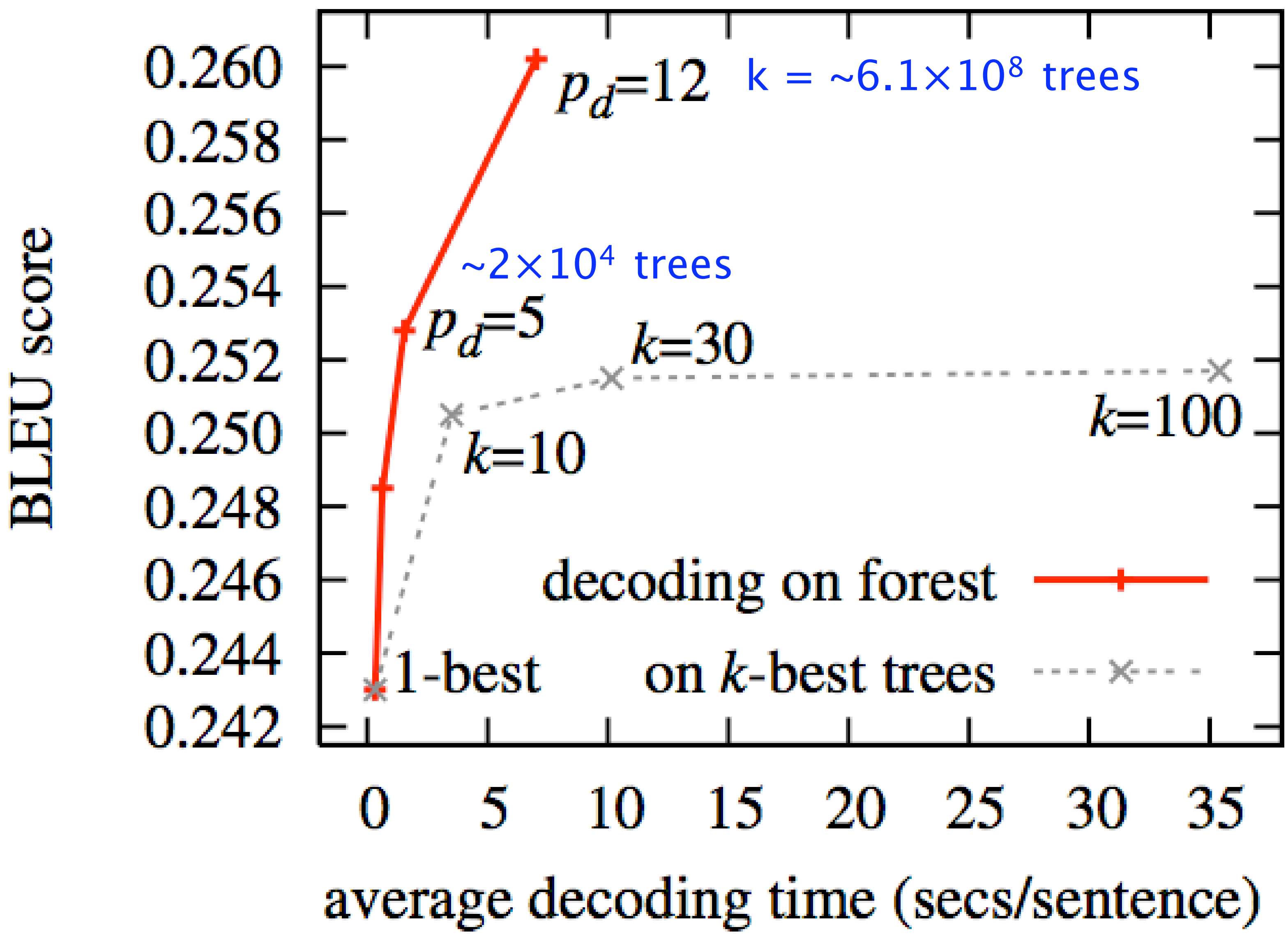


Small-Scale Experiments

- Chinese-to-English translation
  - on a tree-to-string system similar to (Liu et al, 2006)
- 31k sentences pairs (0.8M Chinese & 0.9M English words)
- GIZA++ aligned
- trigram language model trained on the English side
- dev: NIST 2002 (878 sent.); test: NIST 2005 (1082 sent.)
- Chinese-side parsed by the parser of Xiong et al. (2005)
  - modified to output a forest for each sentence (Huang 2008)
- BLEU score: 1-best baseline: 0.2430 vs. Pharaoh: 0.2297

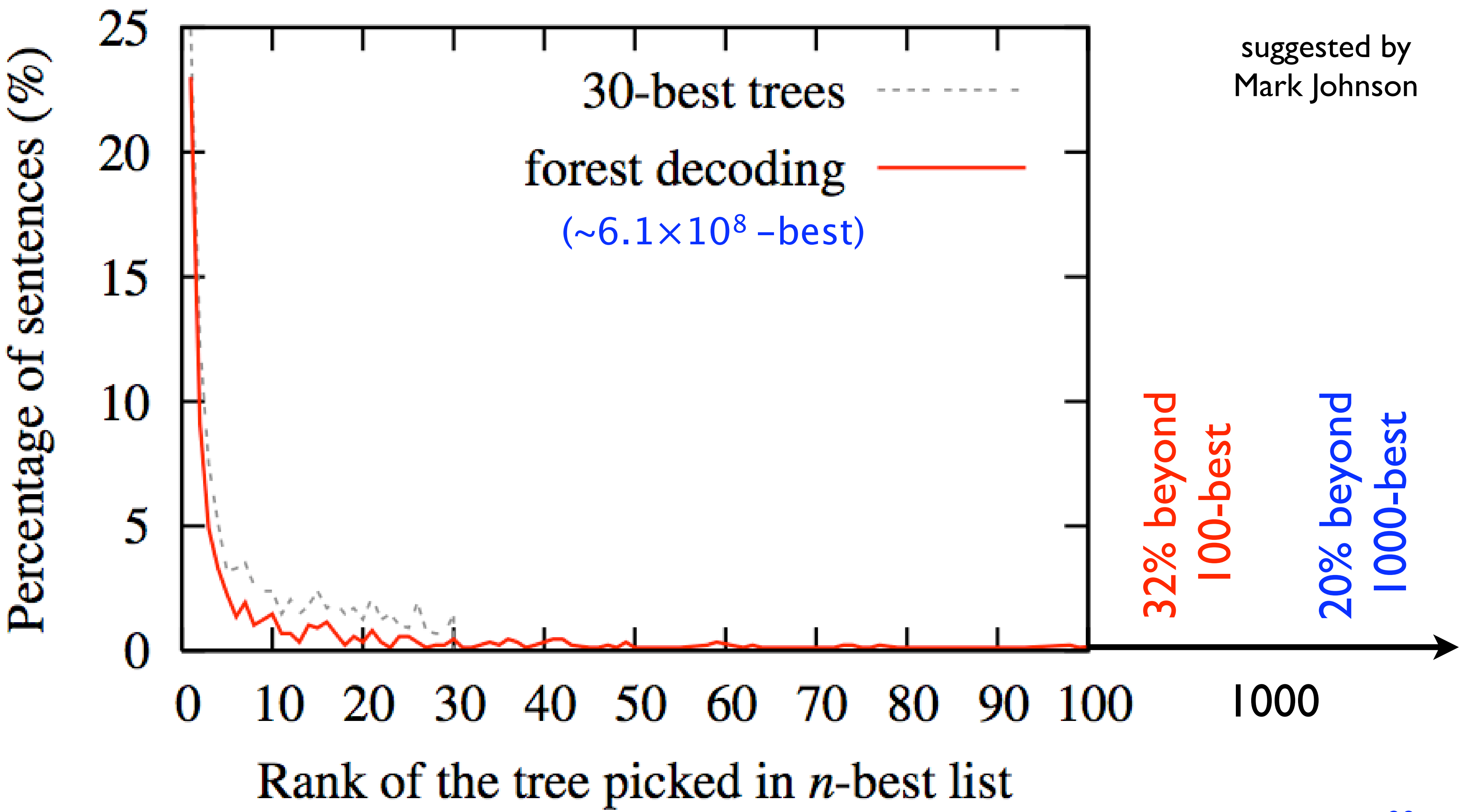
k-best trees vs. forest-based

1.7 Bleu improvement over 1-best,
0.8 over 30-best, and even faster!



forest as virtual ∞-best list

- how often is the *i*th-best tree picked by the decoder?



suggested by Mark Johnson

wait a sec... where are the rules from?

wait a sec... where are the rules from?

xiǎoxīn

小心 X <=> be careful not to X

wait a sec... where are the rules from?

xiǎoxīn gǒu 小心 狗 <=> be aware of dog	xiǎoxīn 小心 X <=> be careful not to X

wait a sec... where are the rules from?

小心 VP <=> be careful not to VP

小心 NP <=> be careful of NP

. . .

xiǎoxīn gǒu
小心 狗 <=> be aware of dog

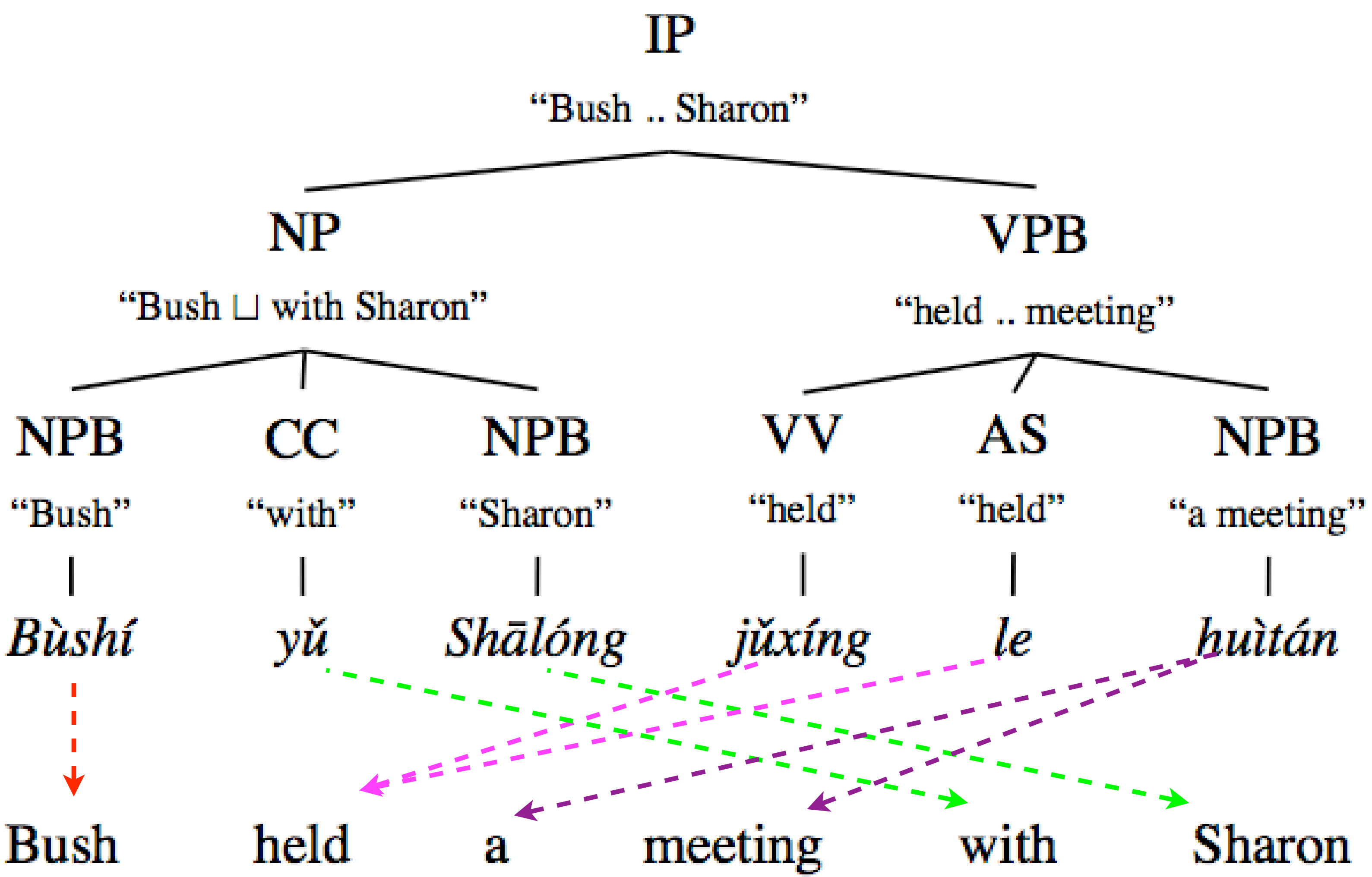
xiǎoxīn
小心 X <=> be careful not to X

Outline

- Overview: Tree-based Translation
- Forest-based Translation
- Forest-based Rule Extraction
  - background: tree-based rule extraction (Galley et al., 2004)
  - extension to forest-based
  - large-scale experiments

Where are the rules from?

- source parse tree, target sentence, and alignment
- compute target spans



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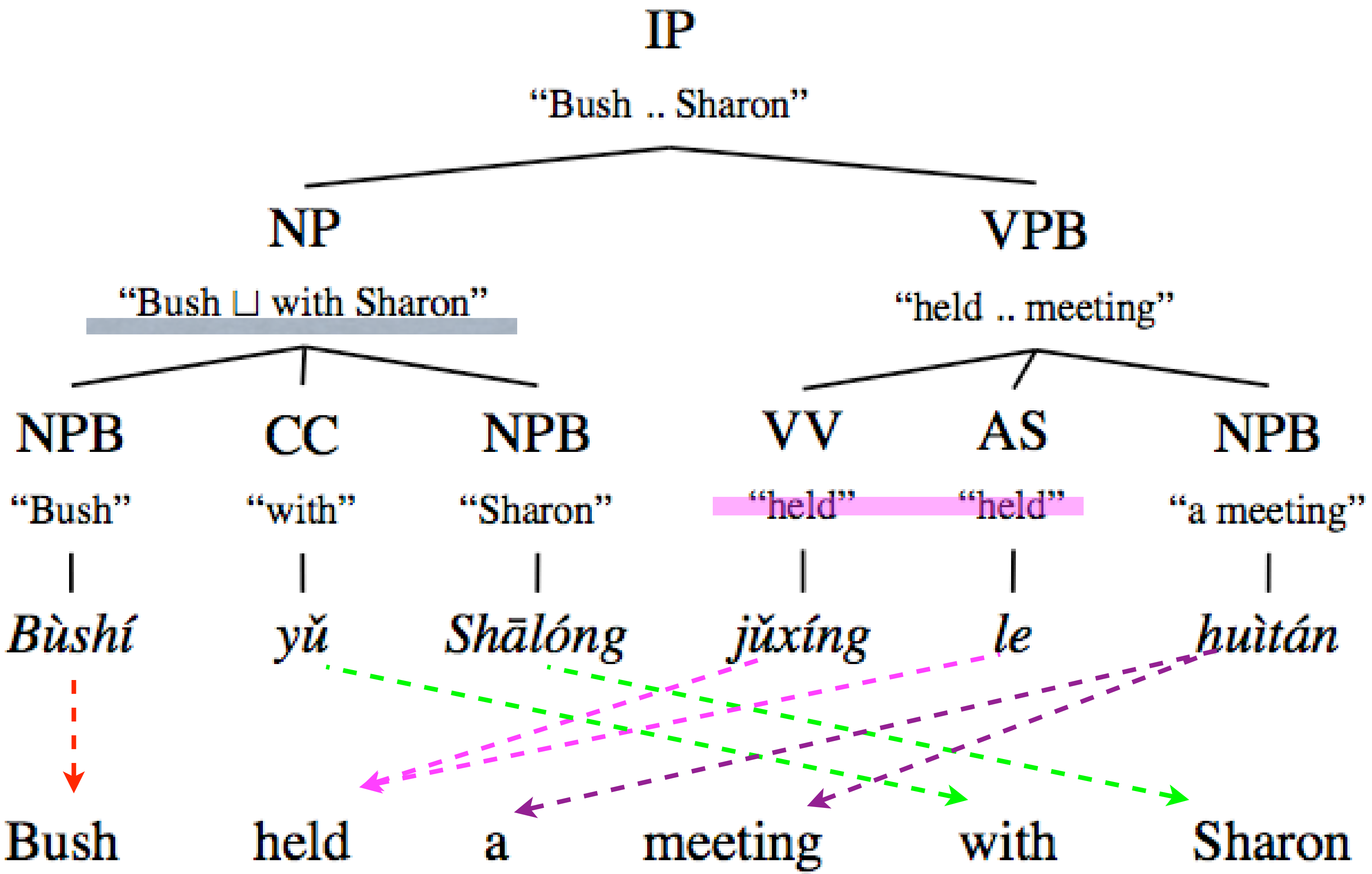
GHKM - (Galley et al 2004; 2006)

Where are the rules from?

- source parse tree, target sentence, and alignment
- well-formed fragment: contiguous and faithful t-span



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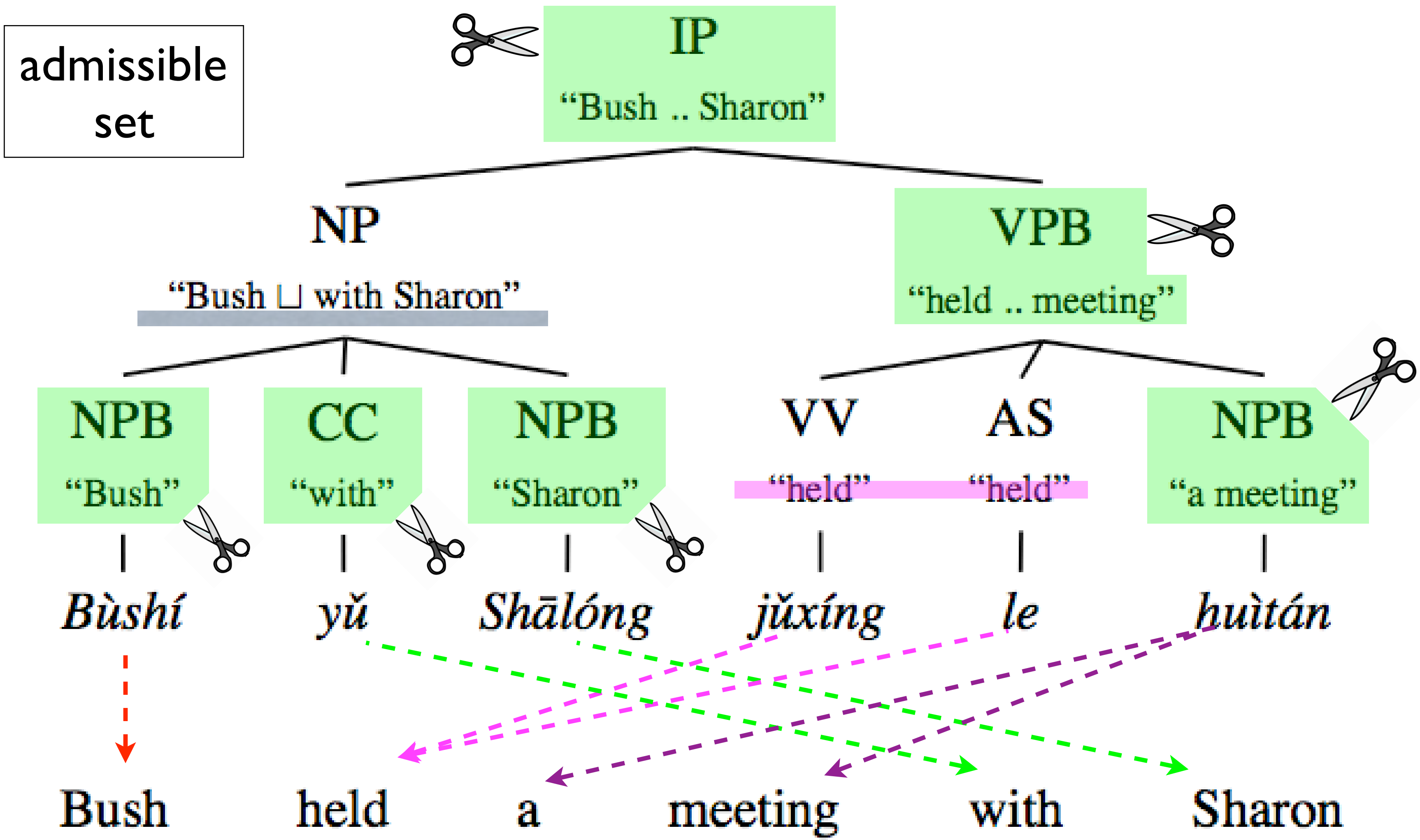

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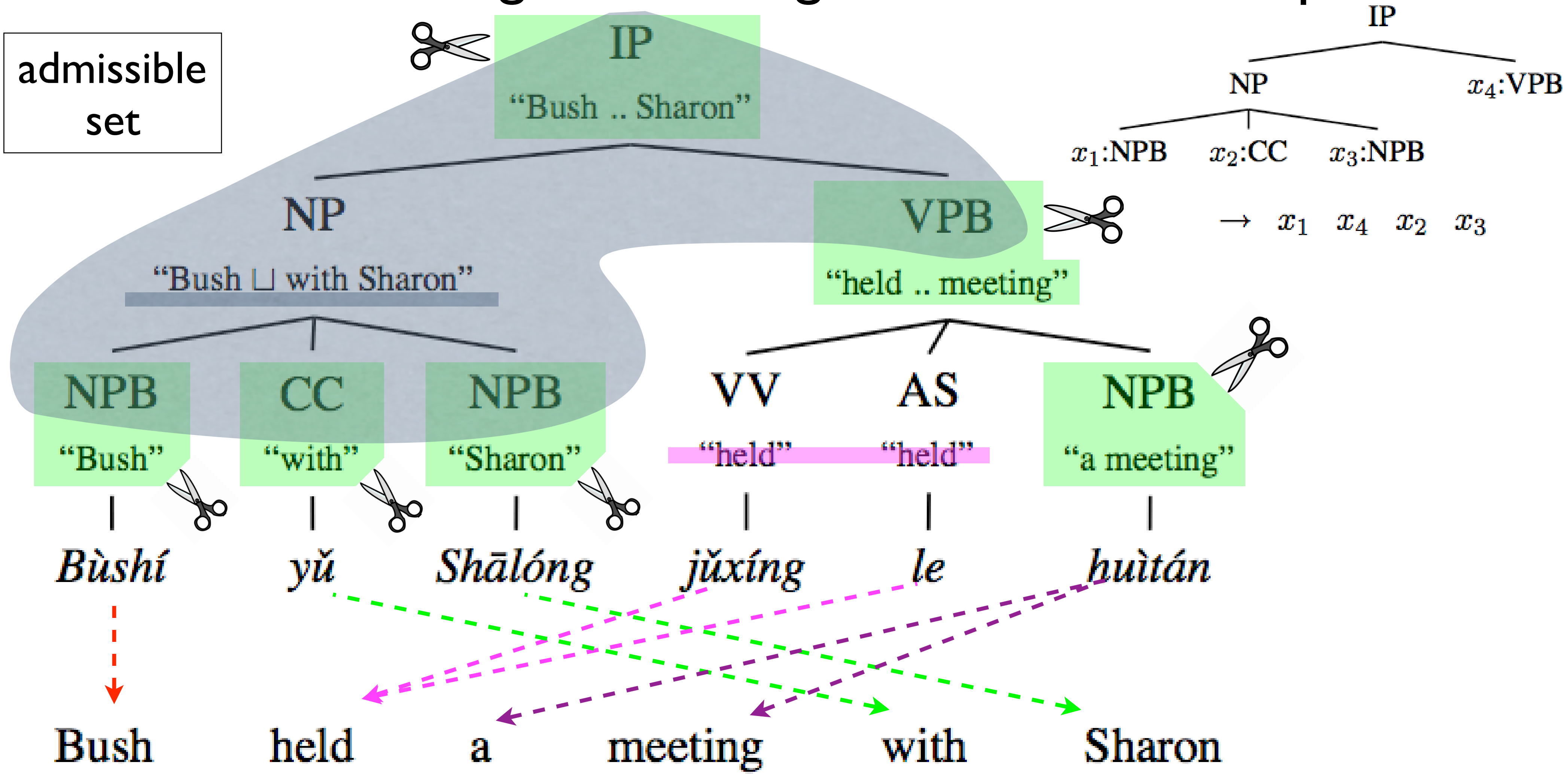

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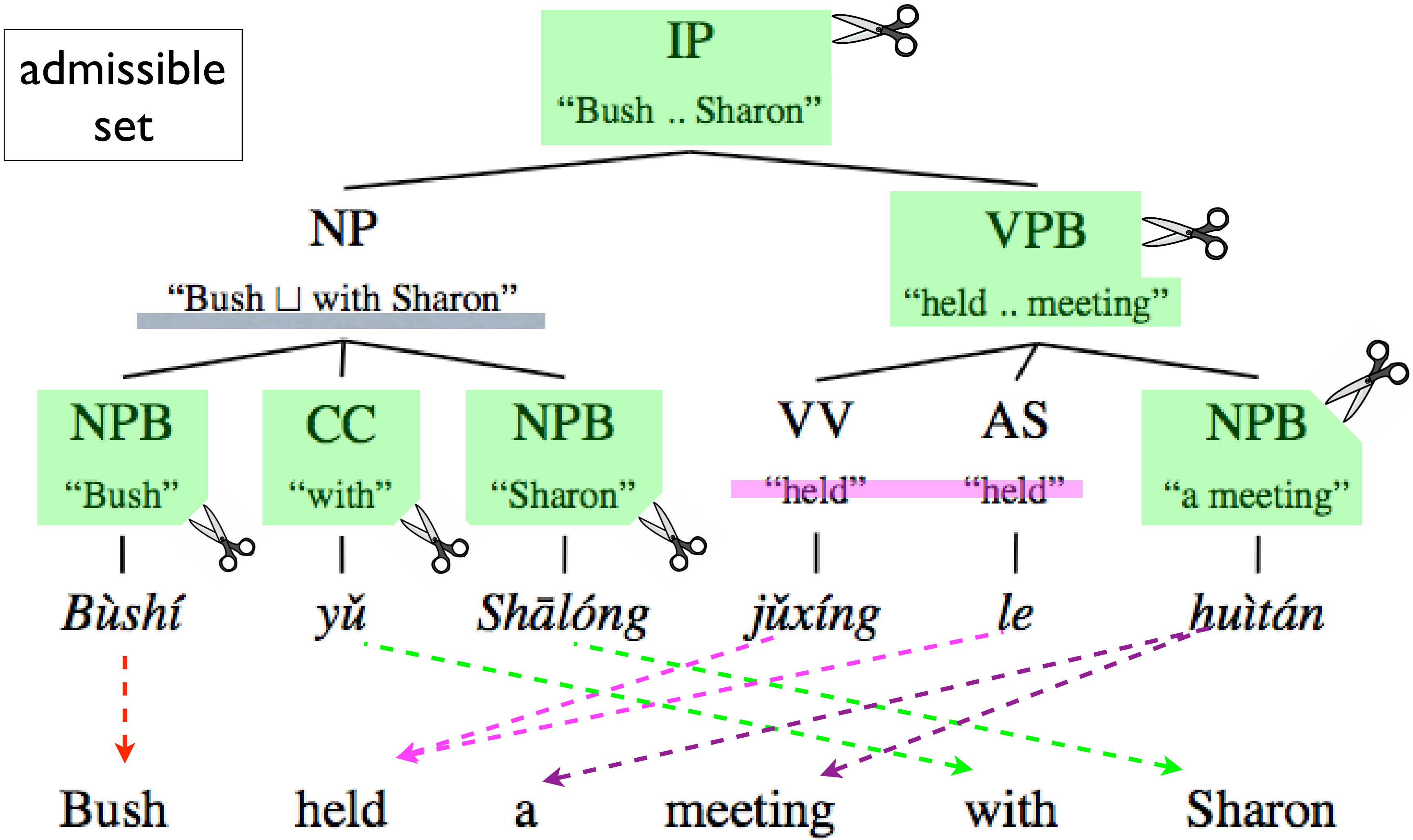

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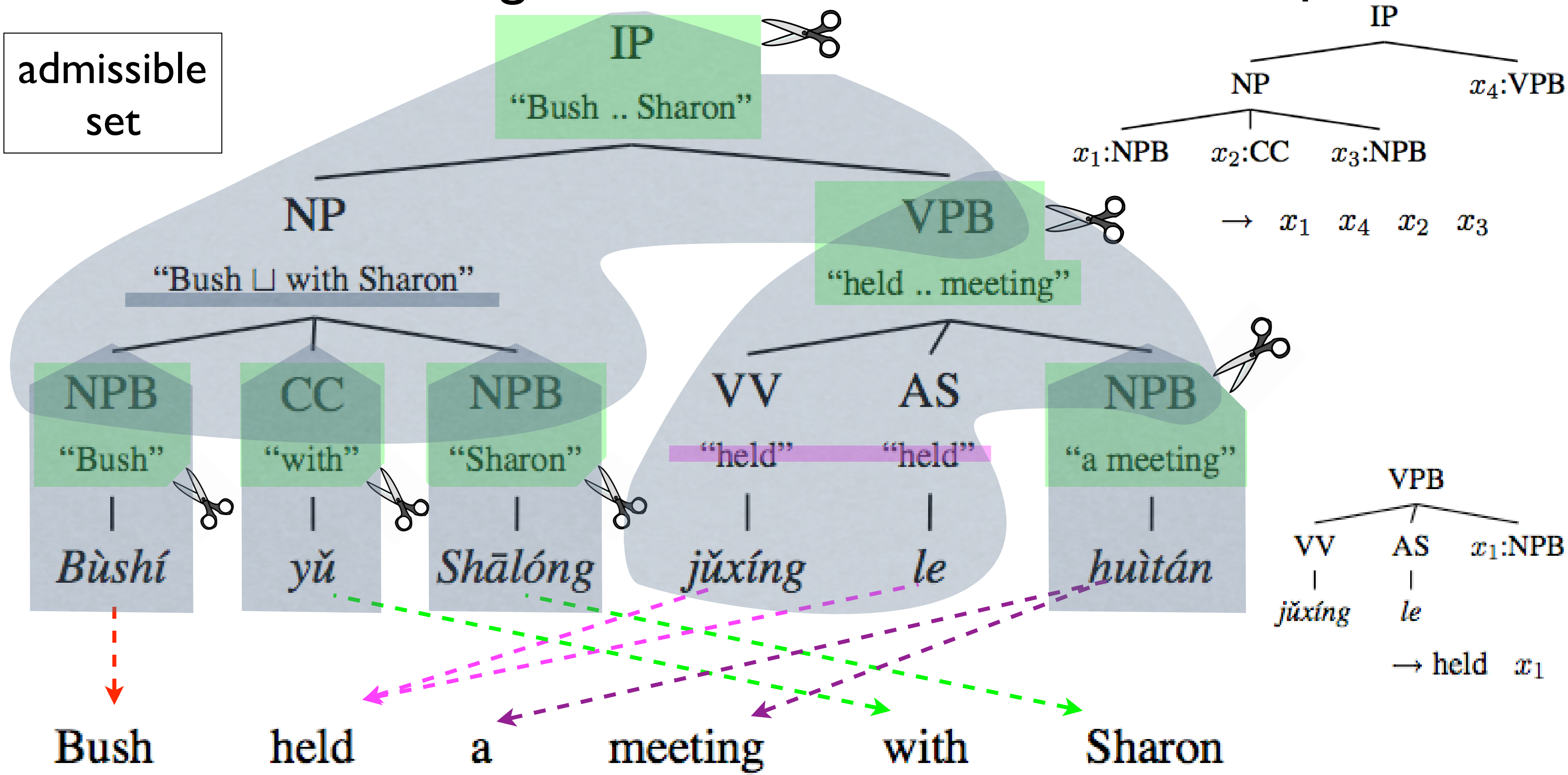
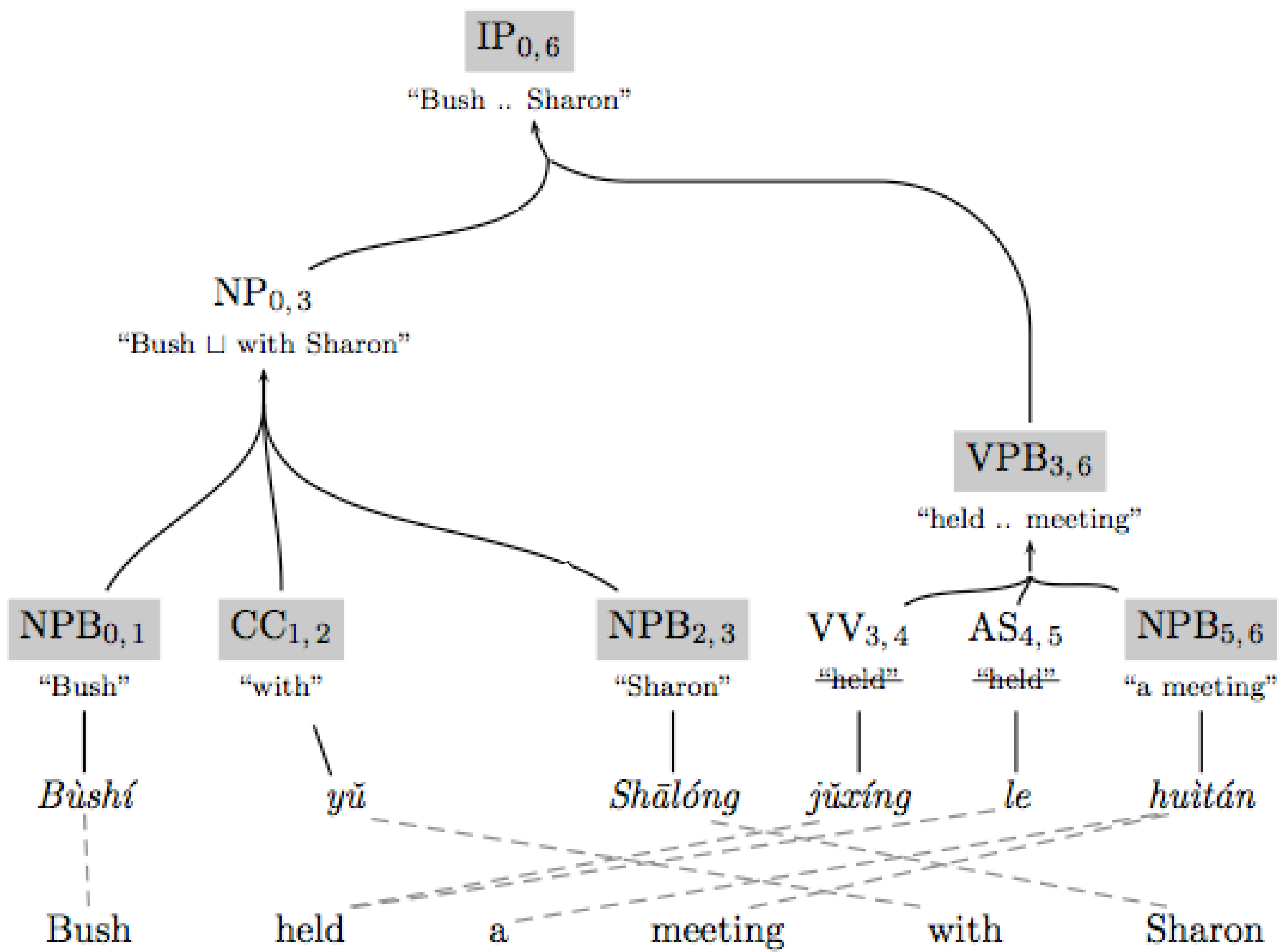


GHKM - (Galley et al 2004; 2006)

Forest-based Rule Extraction

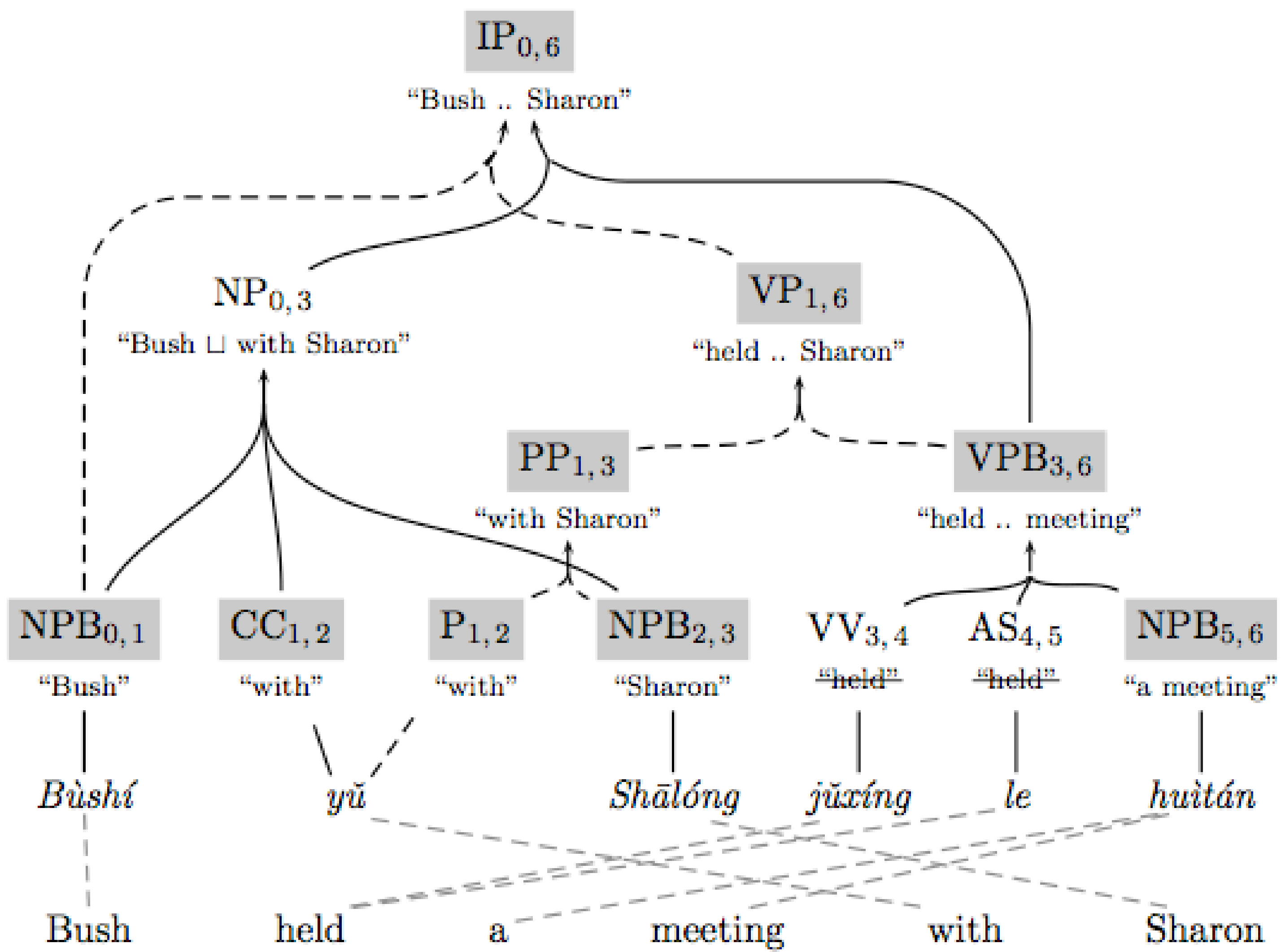
- same cut set computation; different fragmentation



also in (Wang, Knight, Marcu, 2007)

Forest-based Rule Extraction

- same cut set computation; different fragmentation



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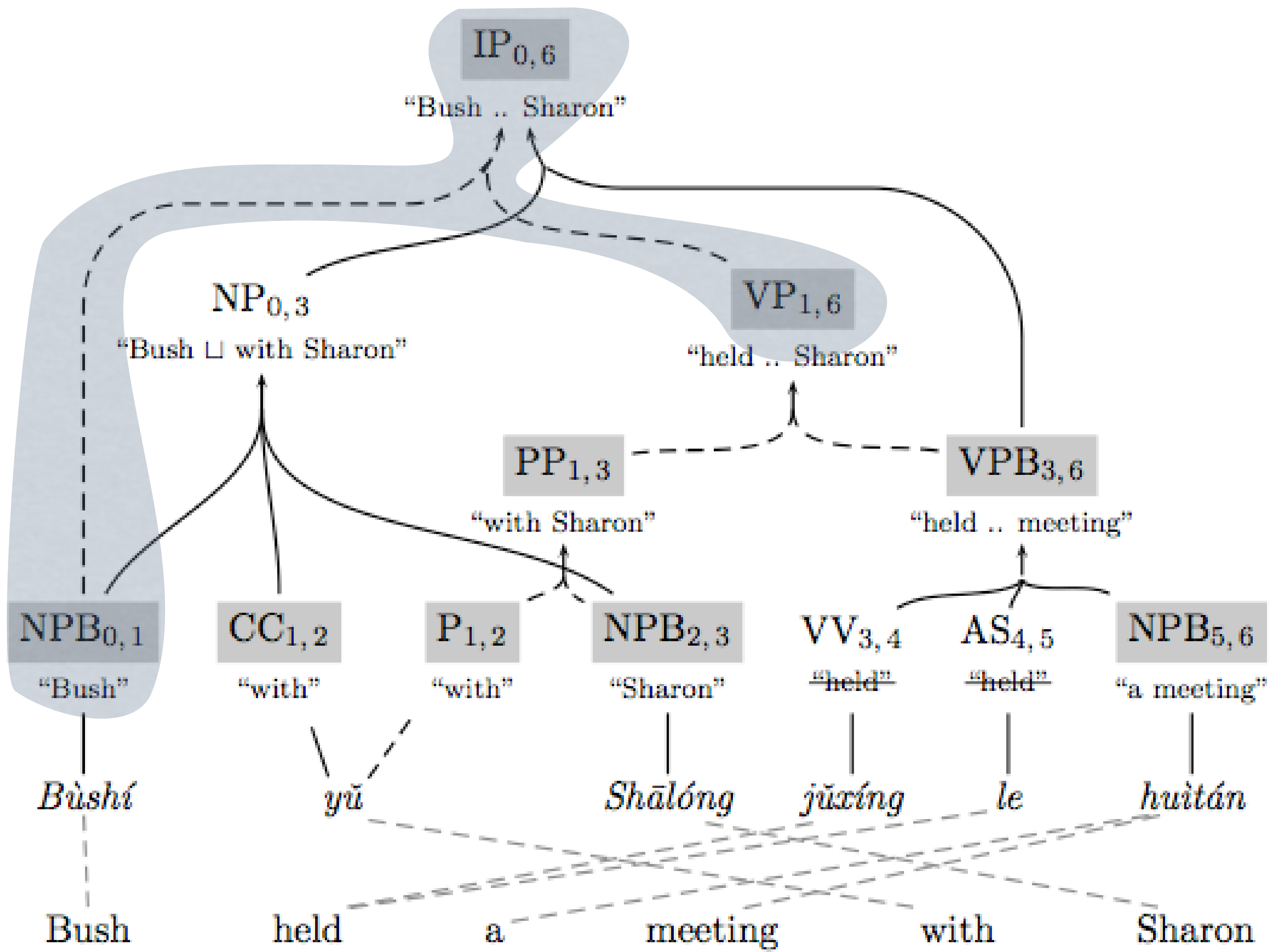

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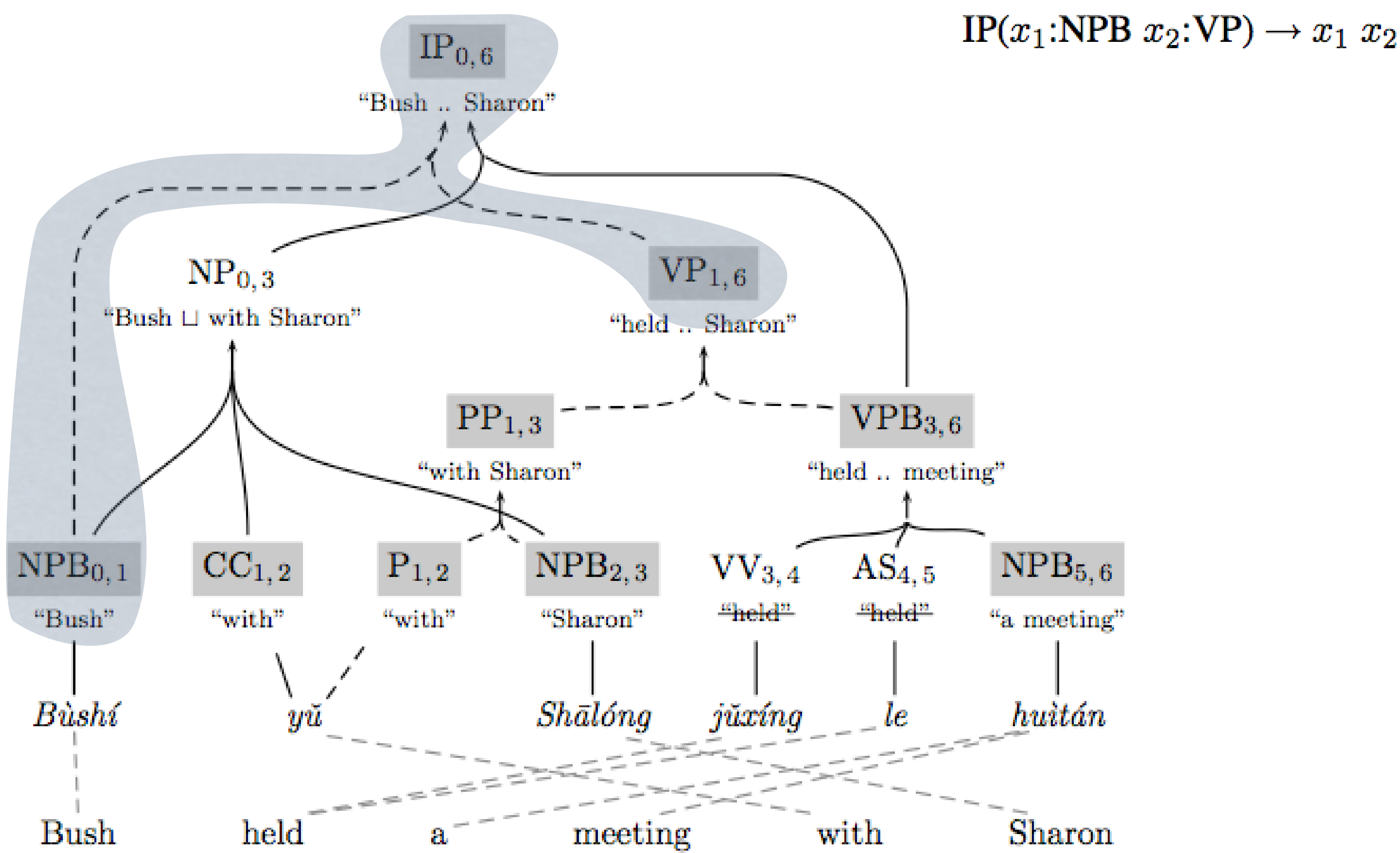
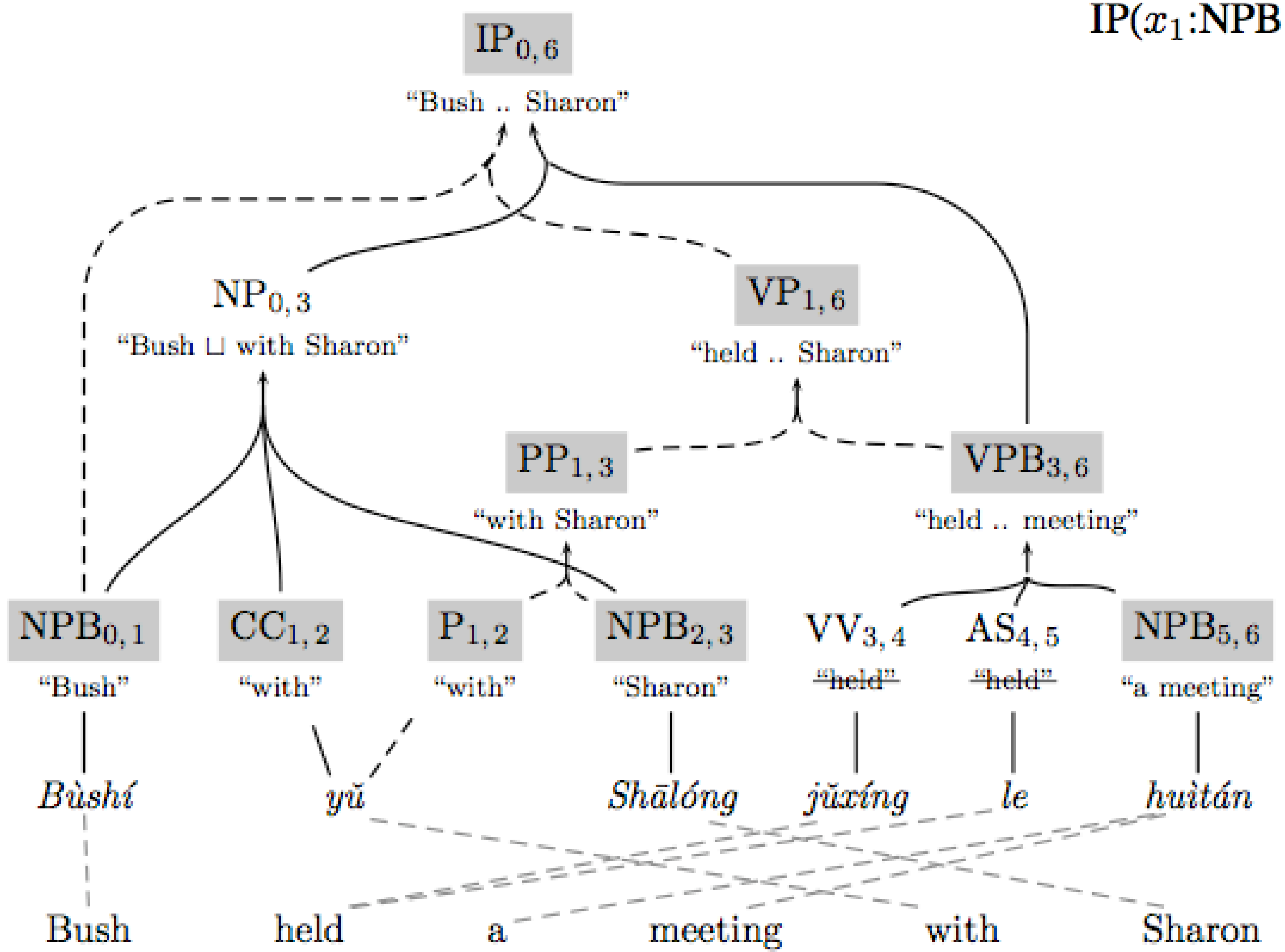


also in (Wang, Knight, Marcu, 2007)

Forest-based Rule Extraction

- same admissible set definition; different fragmentation

$$\text{IP}(x_1\text{:NPB } x_2\text{:VP}) \rightarrow x_1\ x_2$$



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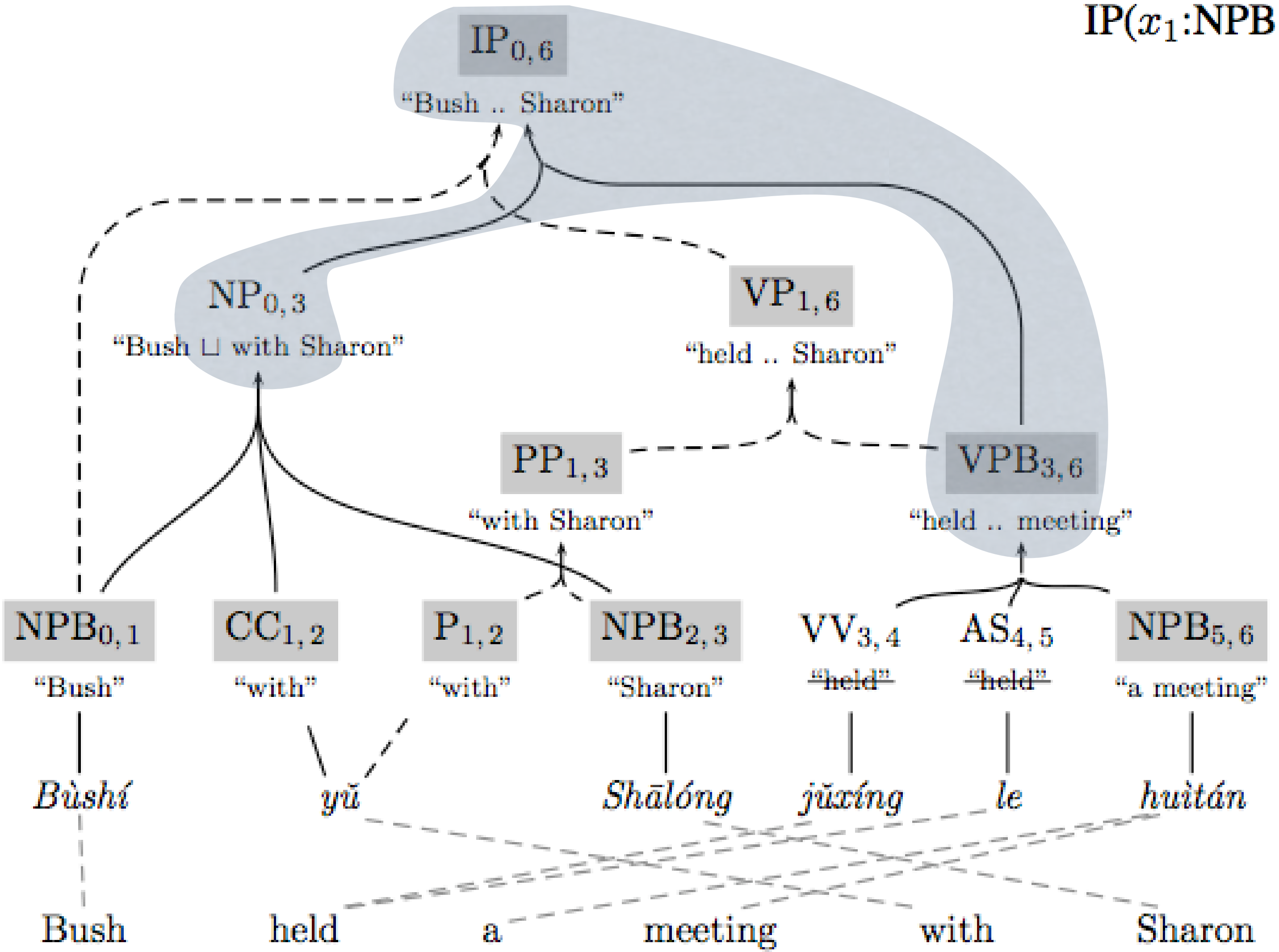

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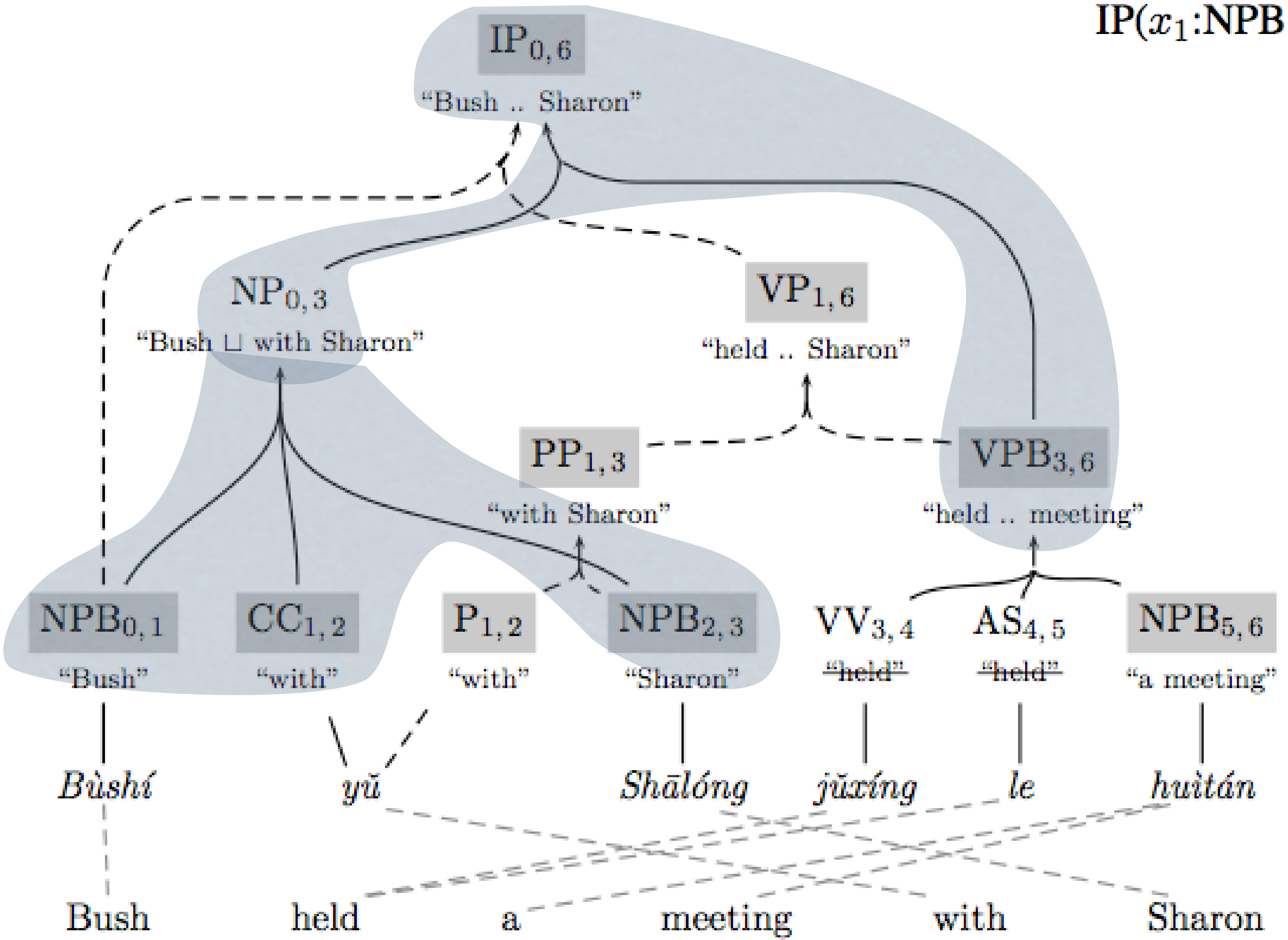

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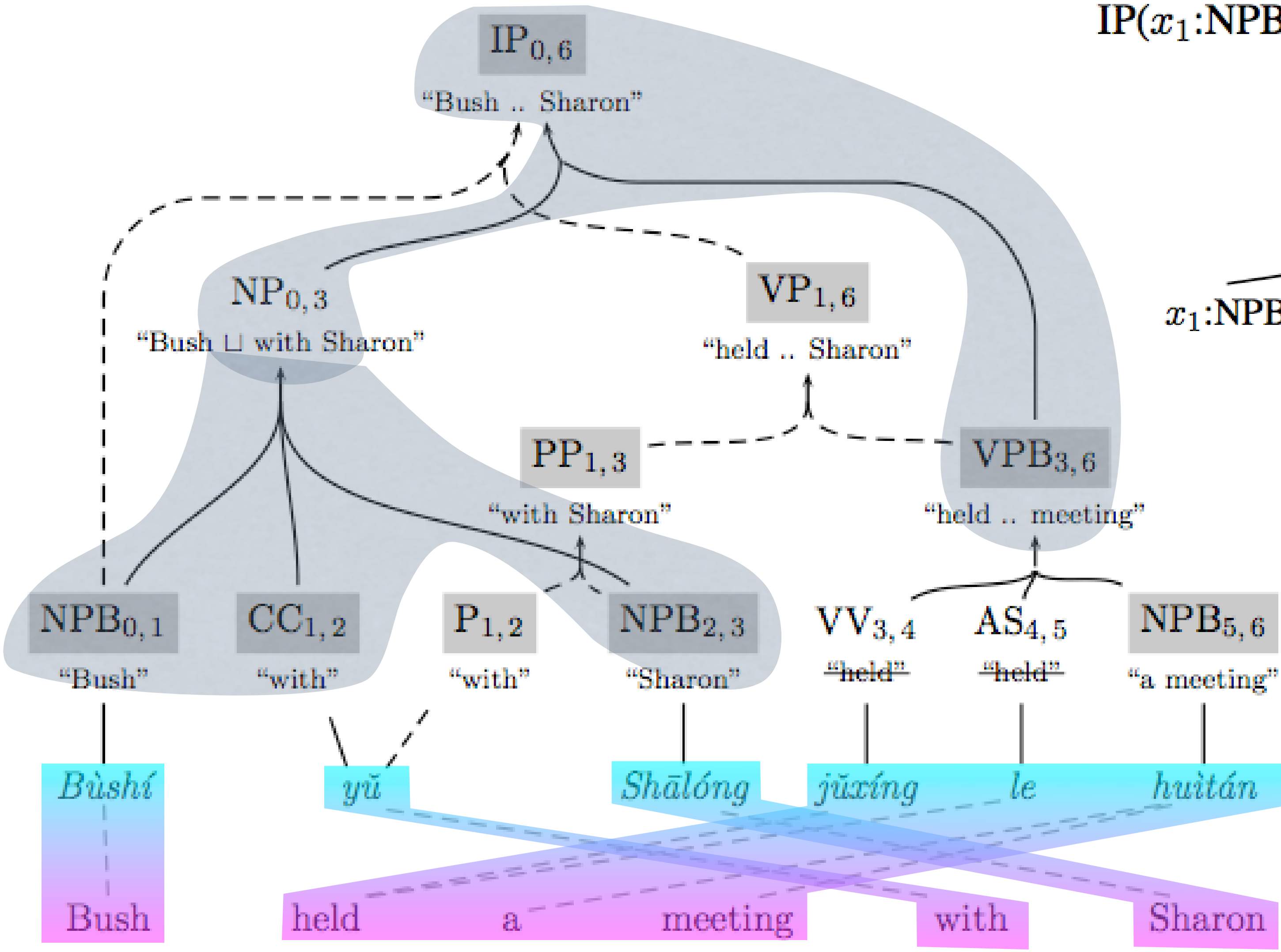
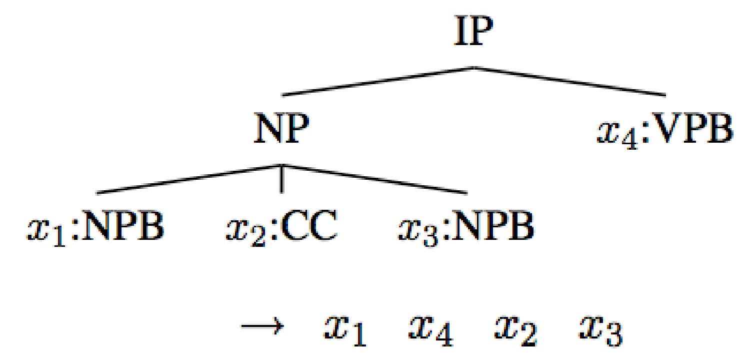
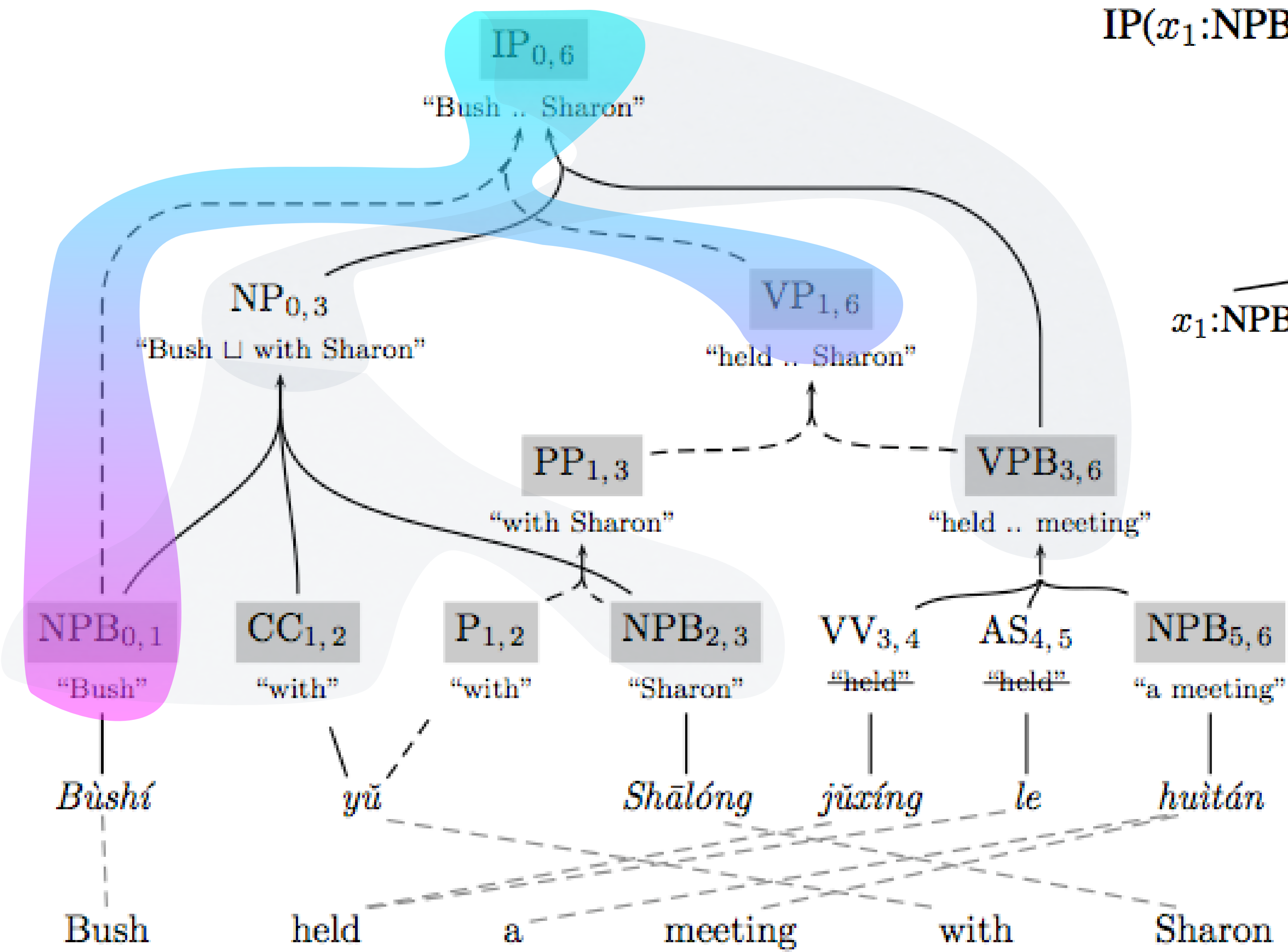


$$\text{IP}(x_1\text{:NPB}\ x_2\text{:VP}) \rightarrow x_1\ x_2$$

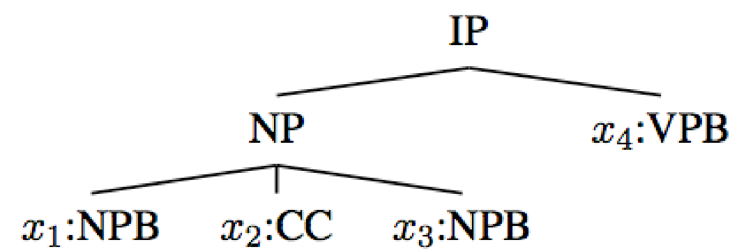


Forest-based Rule Extraction

- forest can extract smaller chunks of rules



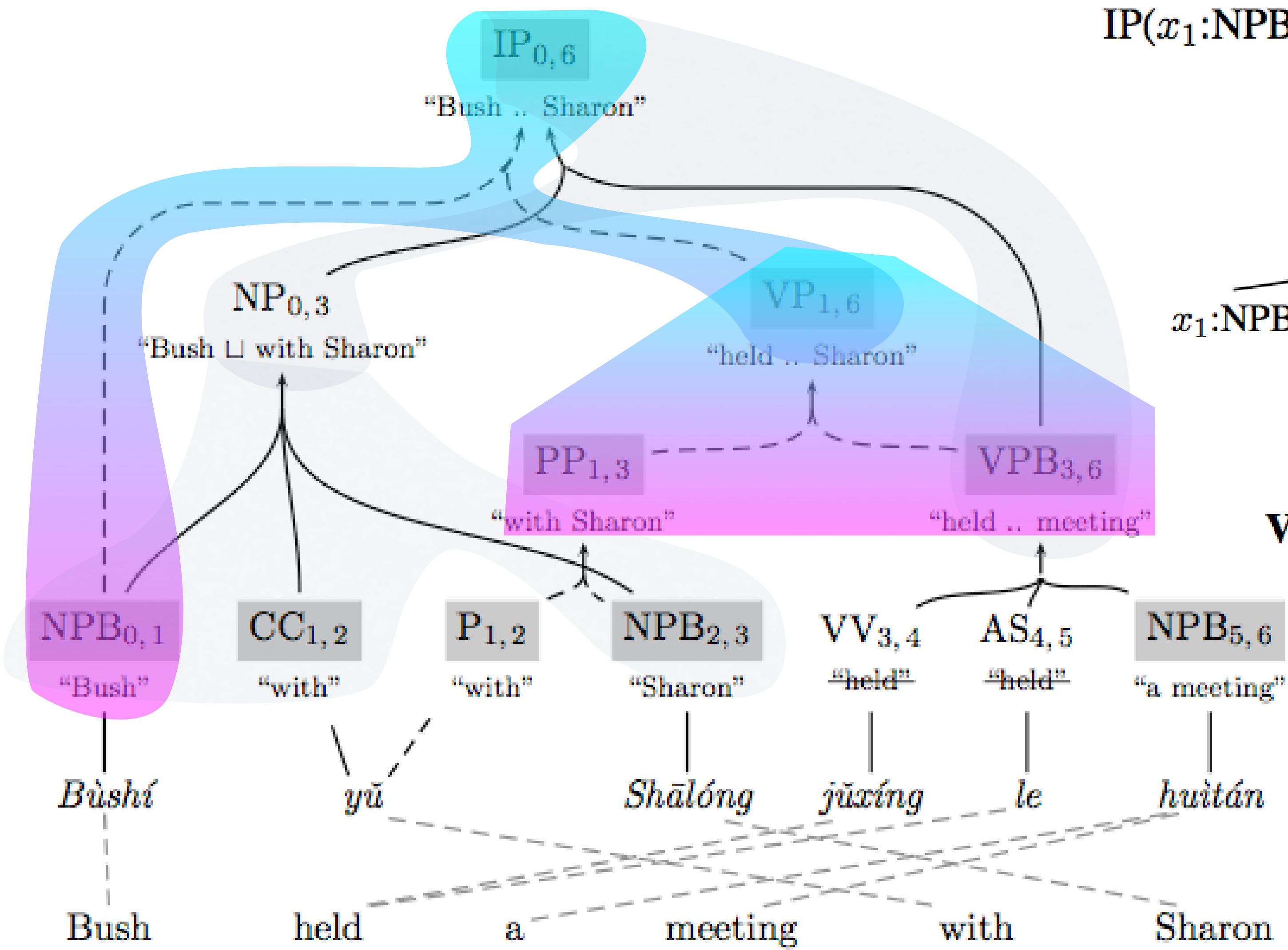
$\mathrm{IP}(x_1{:}\mathrm{NPB}\ x_2{:}\mathrm{VP}) \rightarrow x_1\ x_2$



$\rightarrow\ x_1\ \ x_4\ \ x_2\ \ x_3$

Forest-based Rule Extraction

- forest can extract smaller chunks of rules



$\mathrm{IP}(x_1{:}\mathrm{NPB}\ x_2{:}\mathrm{VP}) \rightarrow x_1\ x_2$

IP

NP $\quad x_4$:VPB

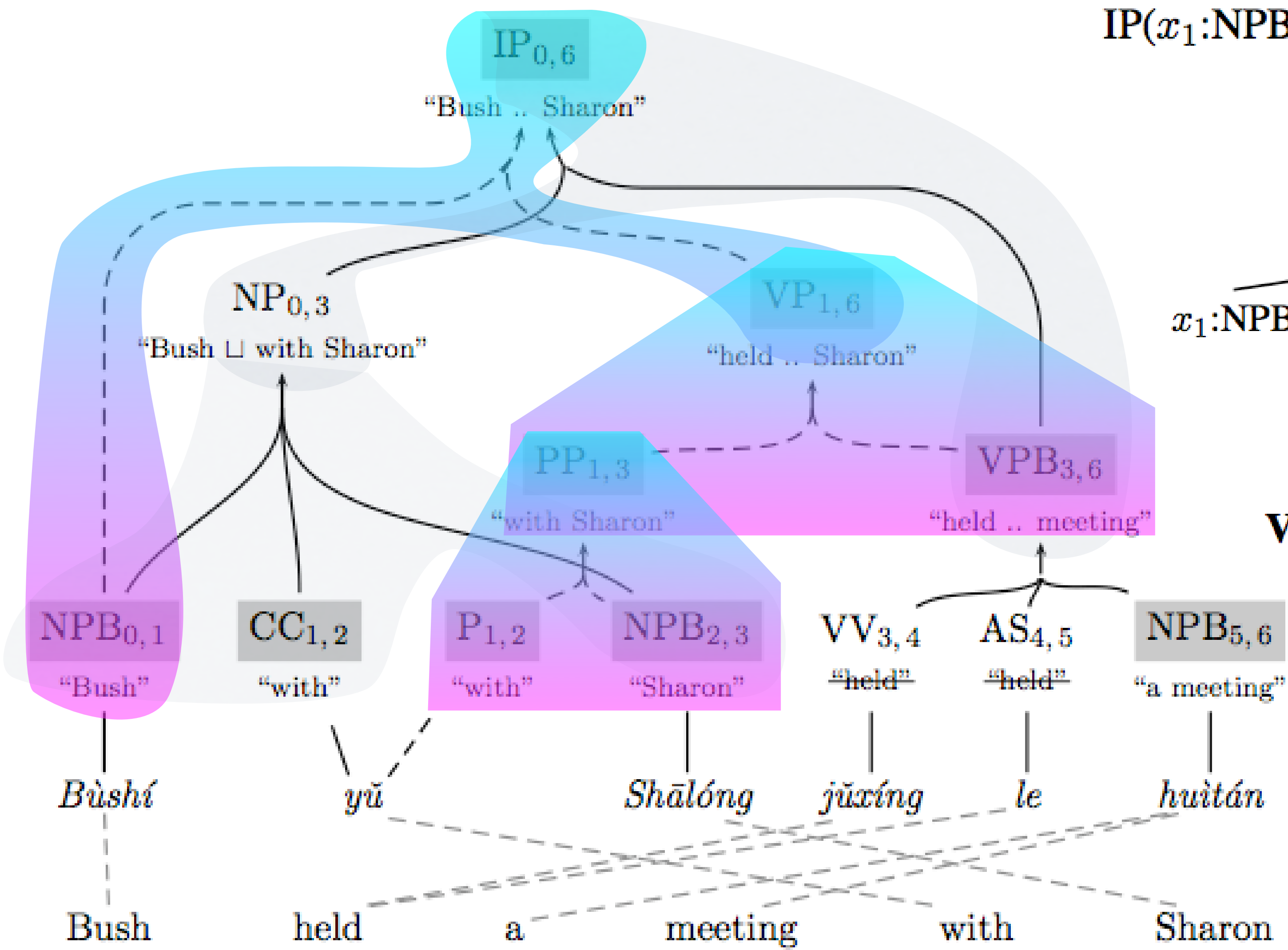
x_1:NPB $\quad x_2$:CC $\quad x_3$:NPB

$\rightarrow \quad x_1 \quad x_4 \quad x_2 \quad x_3$

VP $(x_1{:}\mathrm{PP}\quad x_2{:}\mathrm{VPB}) \rightarrow x_2\ x_1$

Forest-based Rule Extraction

- forest can extract smaller chunks of rules



$\mathrm{IP}(x_1{:}\mathrm{NPB}\ x_2{:}\mathrm{VP}) \rightarrow x_1\ x_2$

$\mathrm{IP}(\mathrm{NP}(x_1{:}\mathrm{NPB}\ x_2{:}\mathrm{CC}\ x_3{:}\mathrm{NPB})\ x_4{:}\mathrm{VPB}) \rightarrow x_1\ x_4\ x_2\ x_3$

$\textbf{VP}\ (x_1{:}\mathrm{PP}\ \ x_2{:}\mathrm{VPB}) \rightarrow x_2\ x_1$

$\textbf{PP}\ (x_1{:}\mathrm{P}\ \ x_2{:}\mathrm{NPB}) \rightarrow x_1\ x_2$

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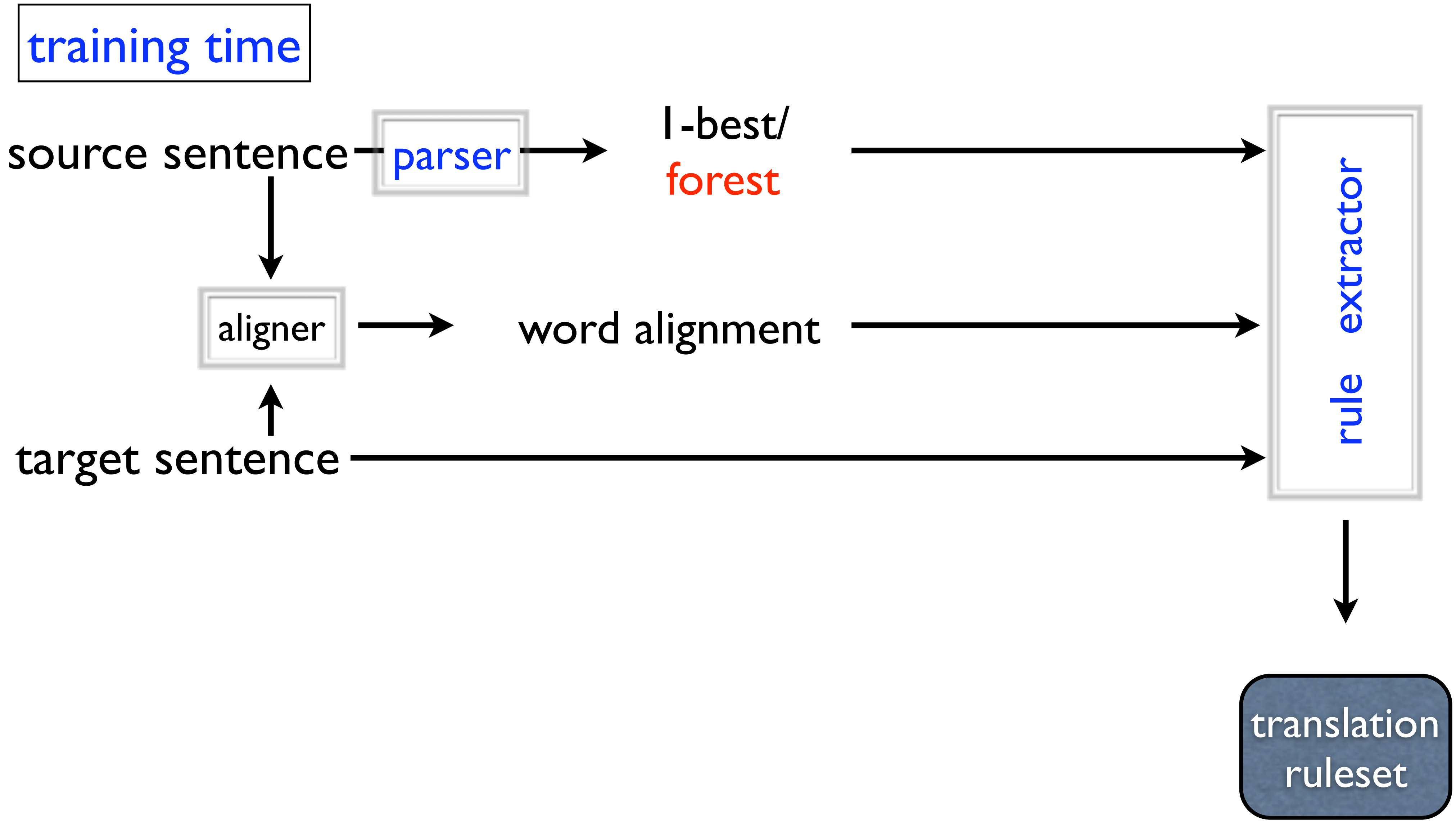
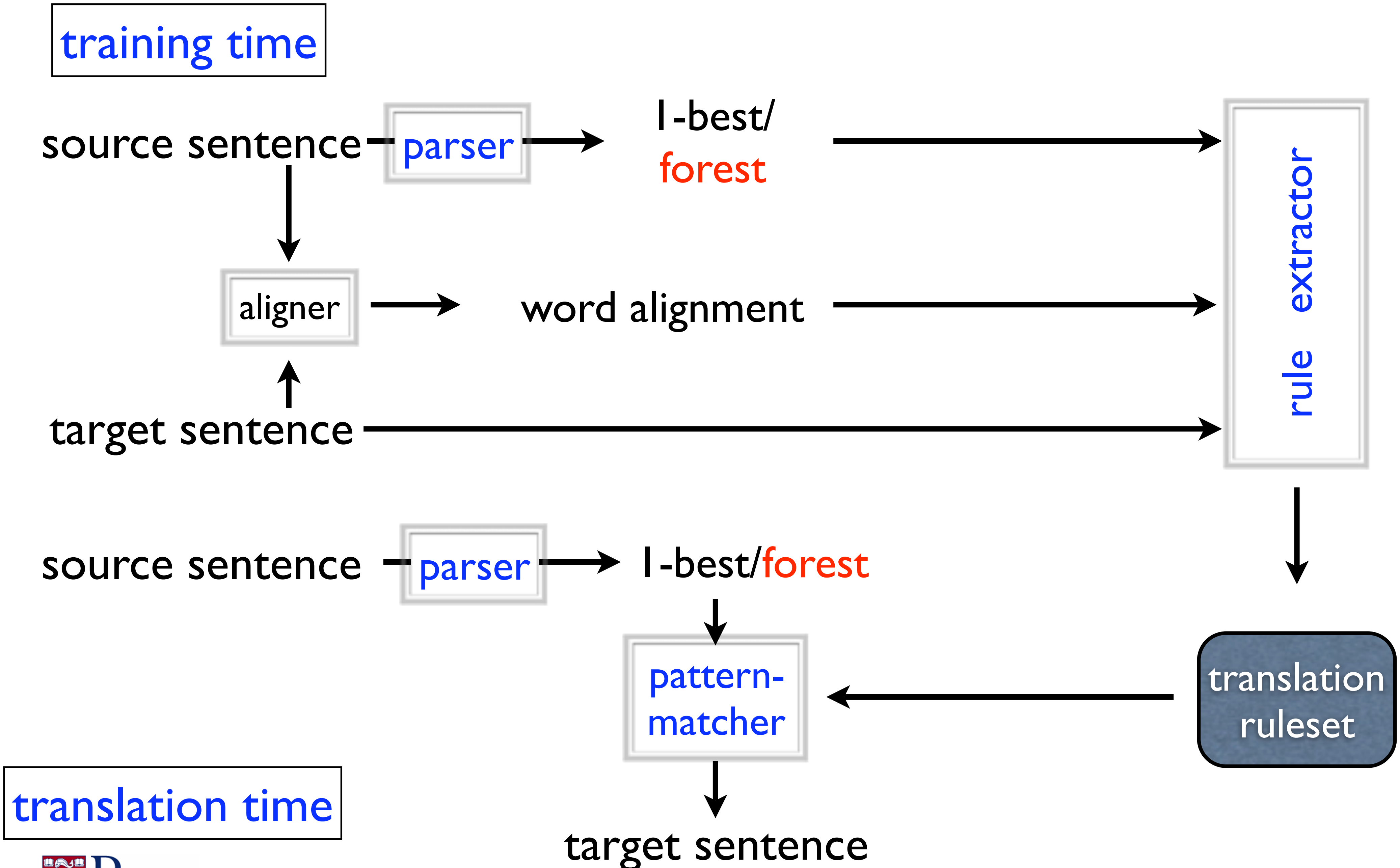
The Forest^2 Pipeline

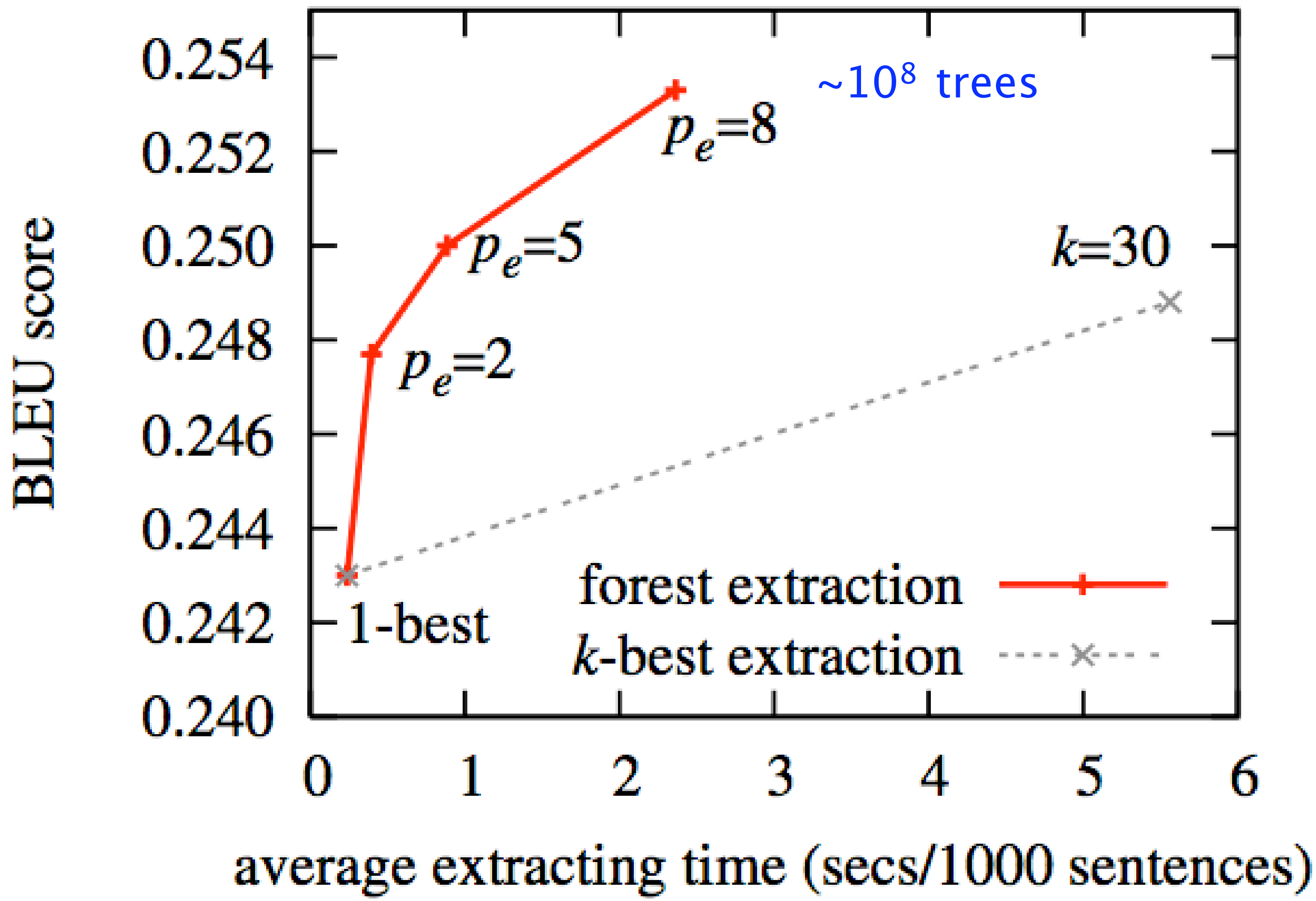


The Forest^2 Pipeline



Forest vs. *k*-best Extraction

1.0 Bleu improvement over 1-best,
twice as fast as 30-best extraction



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Forest^2

- FBIS: 239k sentence pairs (7M/9M Chinese/English words)
- forest in both extraction and decoding
- forest^2 results is 2.5 points better than 1-best^2
  - and outperforms Hiero (Chiang 2007) by quite a bit

translating on ...

rules from ...

	1-best tree	forest
1-best tree	0.2560	0.2674
30-best trees	0.2634	0.2767
forest	0.2679	0.2816
Hiero	0.2738	

Translation Examples

- src 鲍威尔 说 与 阿拉法特 会谈 很 重要

  Bàowēir shūo yǔ Alāfǎtè huìtán hěn zhòngyào

  Powell say with Arafat talk very important

- 1-best[2] Powell said the very important talks with Arafat
- forest[2] Powell said his meeting with Arafat is very important
- hiero Powell said very important talks with Arafat

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Conclusions

- main theme: efficient syntax-directed translation
- forest-based translation
    - forest = "underspecified syntax": polynomial vs. exponential
    - still fast (with pruning), yet does not commit to 1-best tree
    - translating millions of trees is faster than just on top-*k* trees
- forest-based rule extraction: improving rule set quality
- very simple idea, but works well in practice
    - significant improvement over 1-best syntax-directed
    - final result outperforms hiero by quite a bit

Forest is your friend in machine translation.

help save the forest.

More "forest-based" algorithms in my thesis (this talk is about Chap. 6).

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self-service terminals

carefully slide

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Larger Decoding Experiments (ACL)

- 2.2M sentence pairs (57M Chinese and 62M English words)
- larger trigram models (1/3 of Xinhua Gigaword)
- also use bilingual phrases (BP) as flat translation rules
  - phrases that are consistent with syntactic constituents
- forest enables larger improvement with BP

	T2S	T2S+BP
1-best tree	0.2666	0.2939
30-best trees	0.2755	0.3084
forest	0.2839	0.3149
improvement	1.7	2.1

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