Rule Markov Models for Fast Tree-to-String Translation

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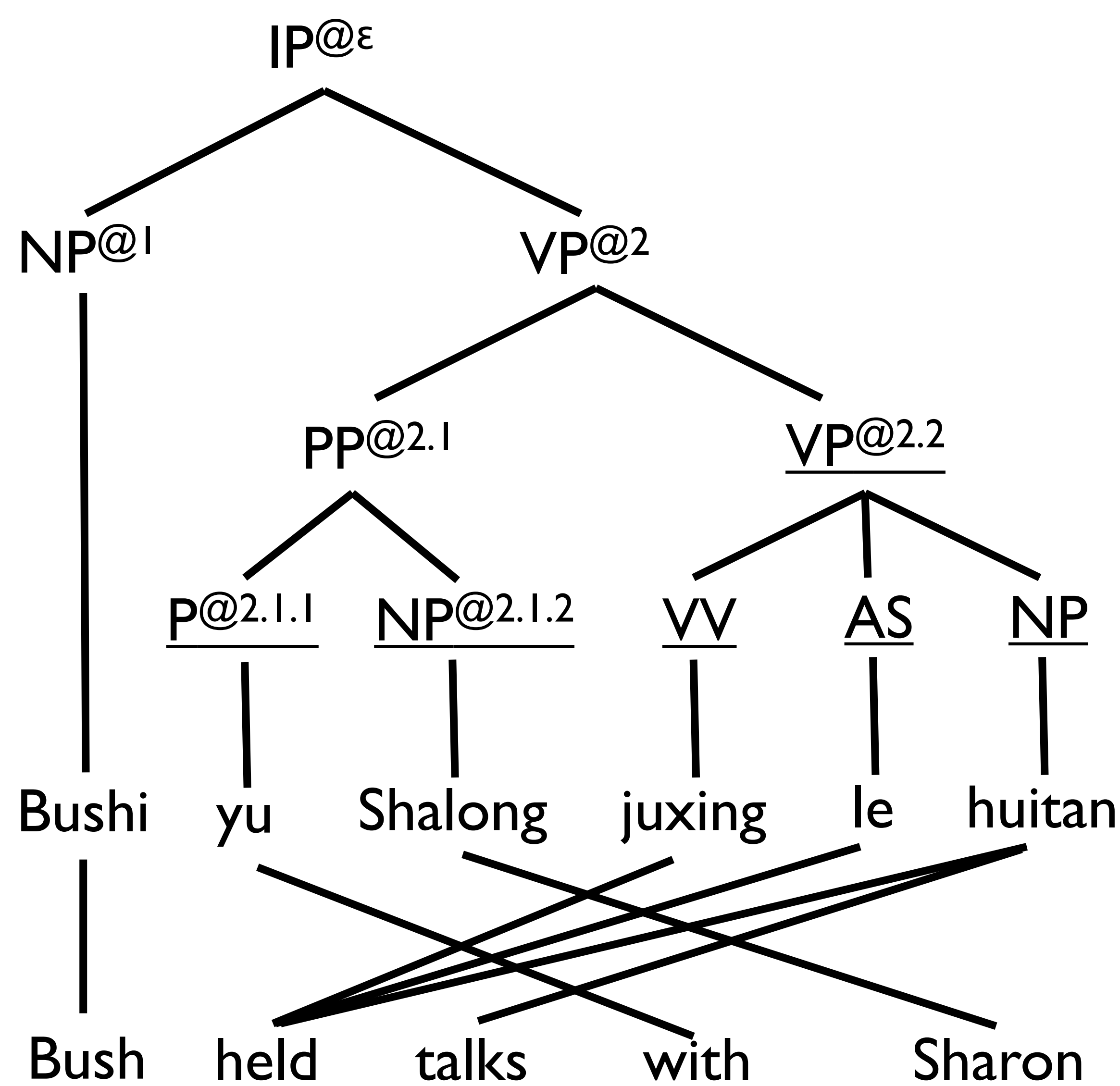
Syntax Based Machine Translation (SBMT)



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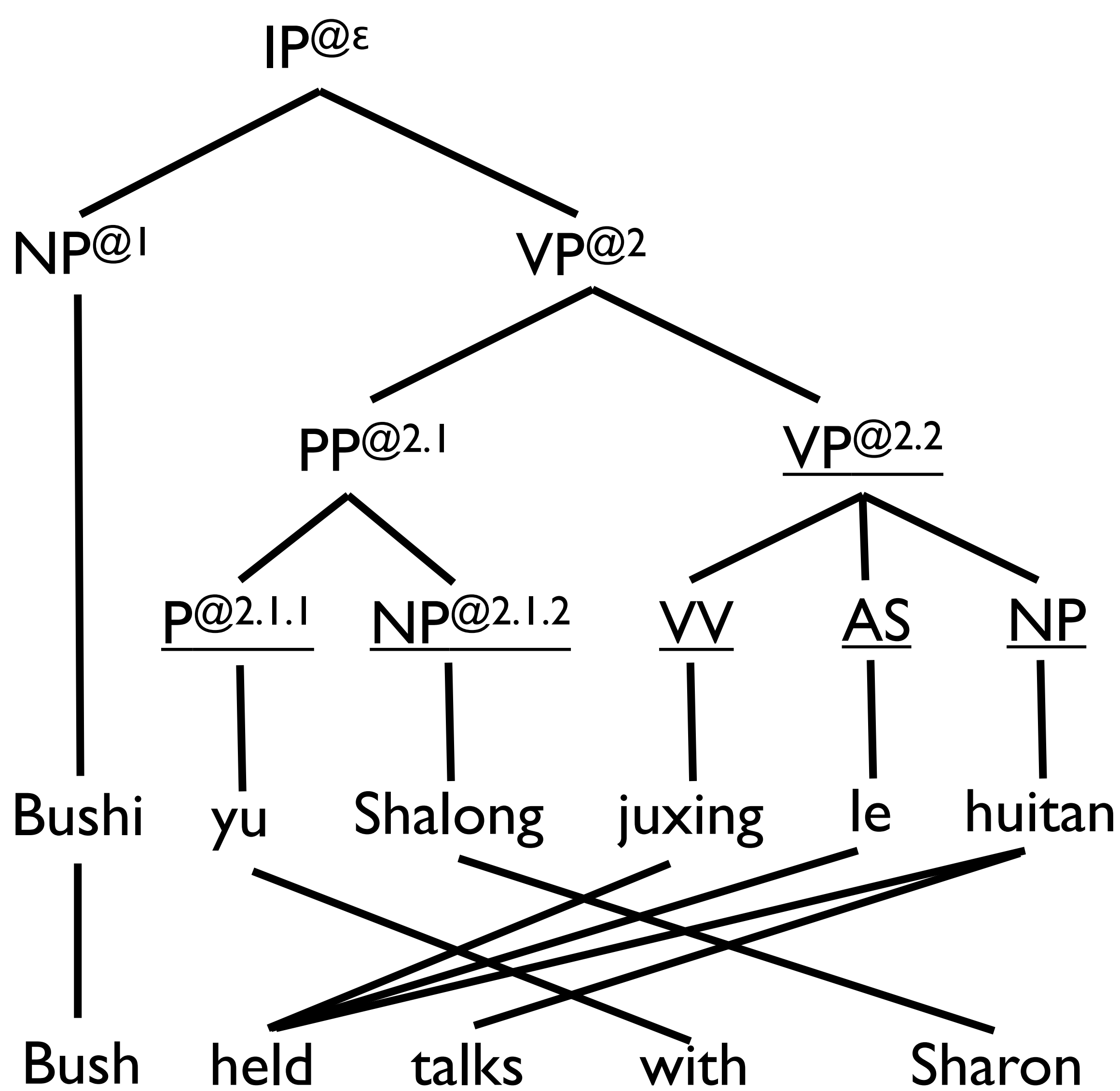

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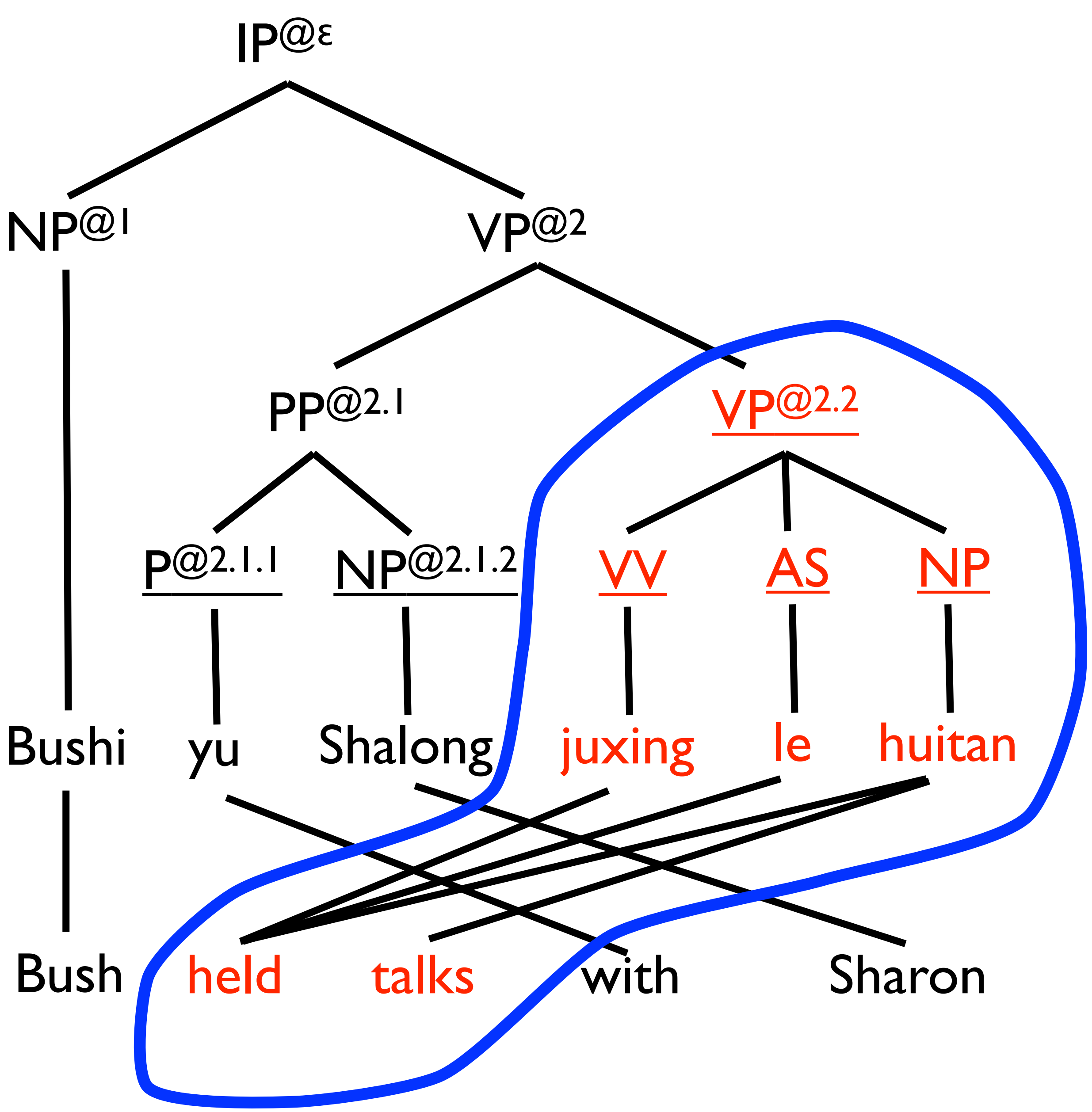

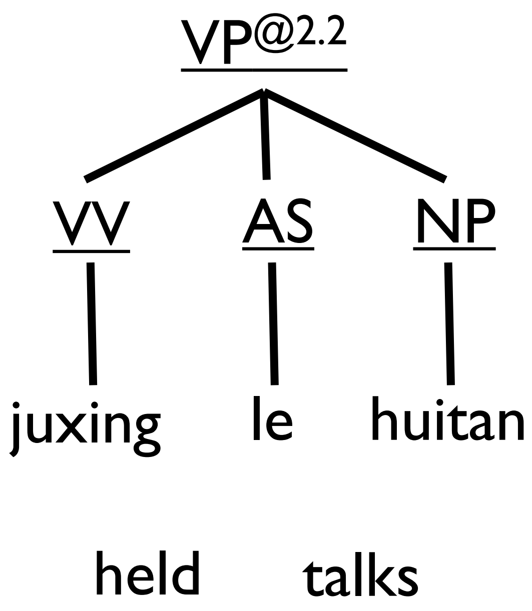

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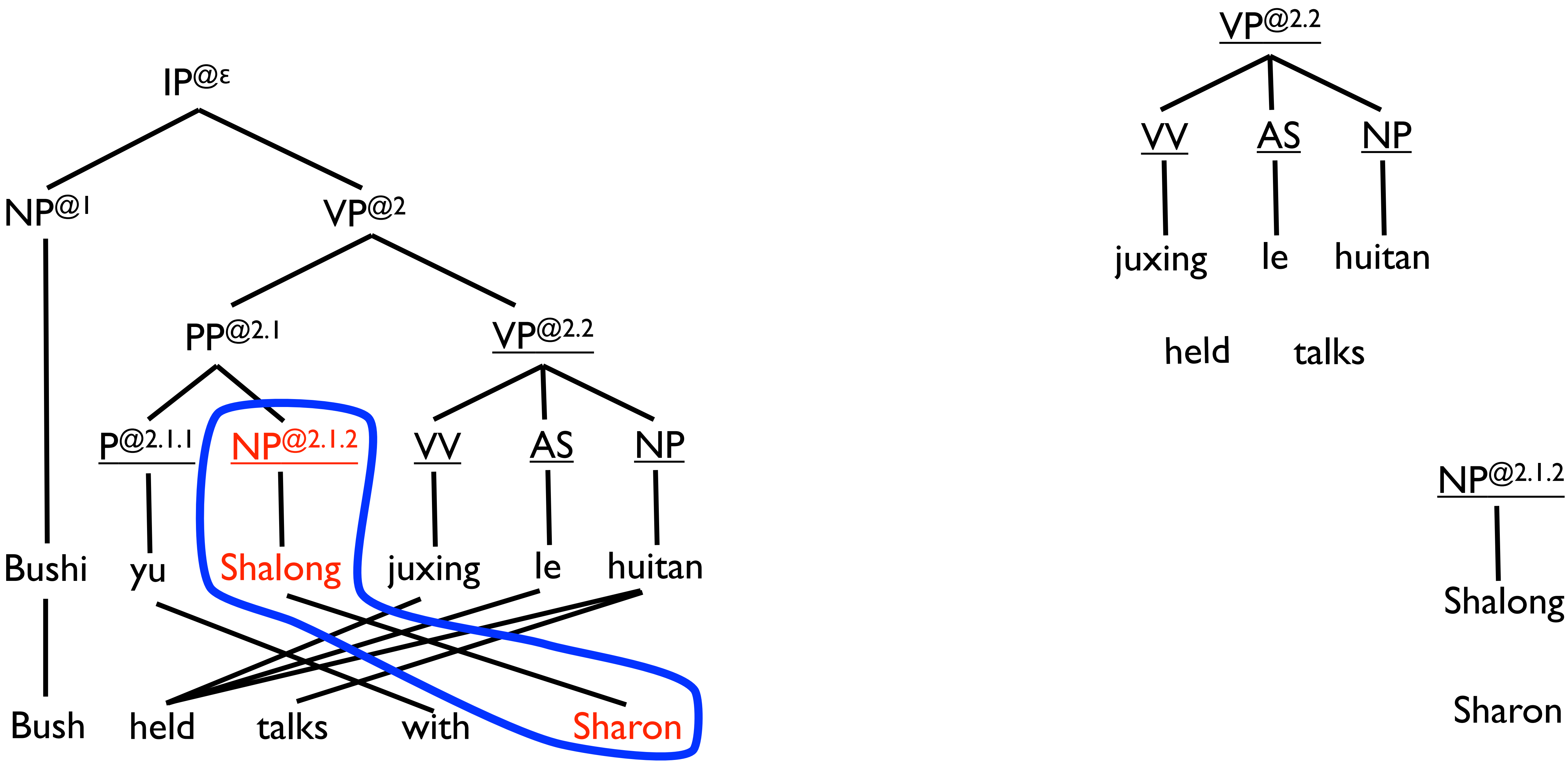

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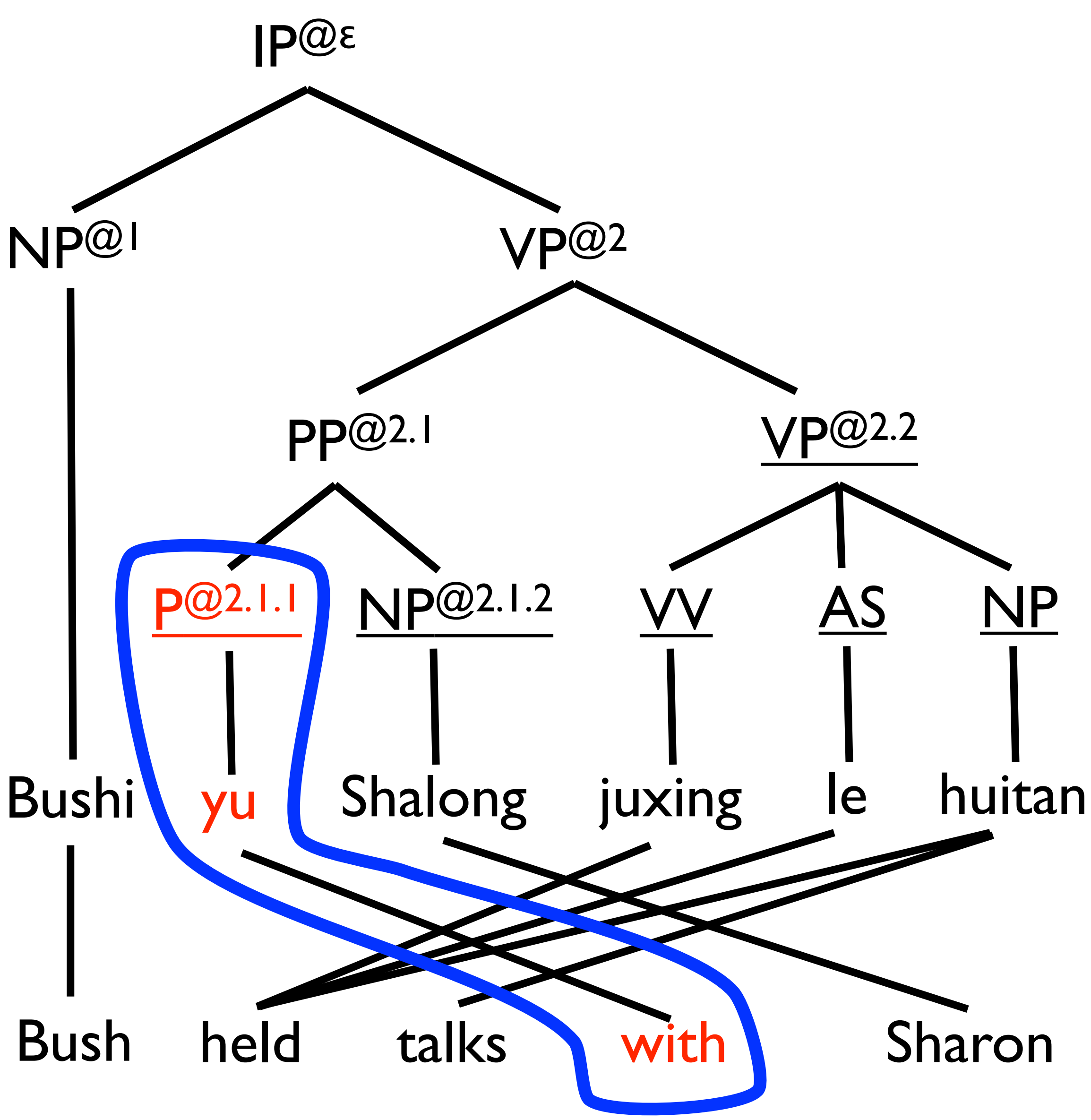

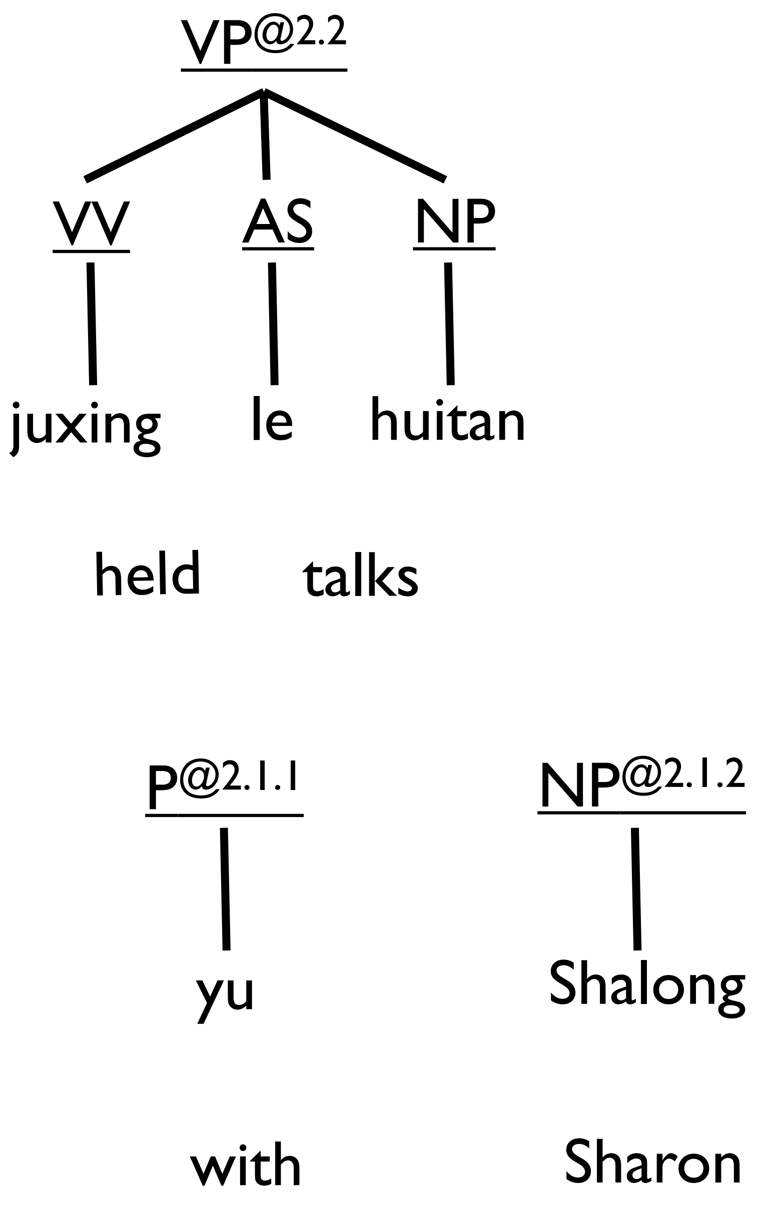

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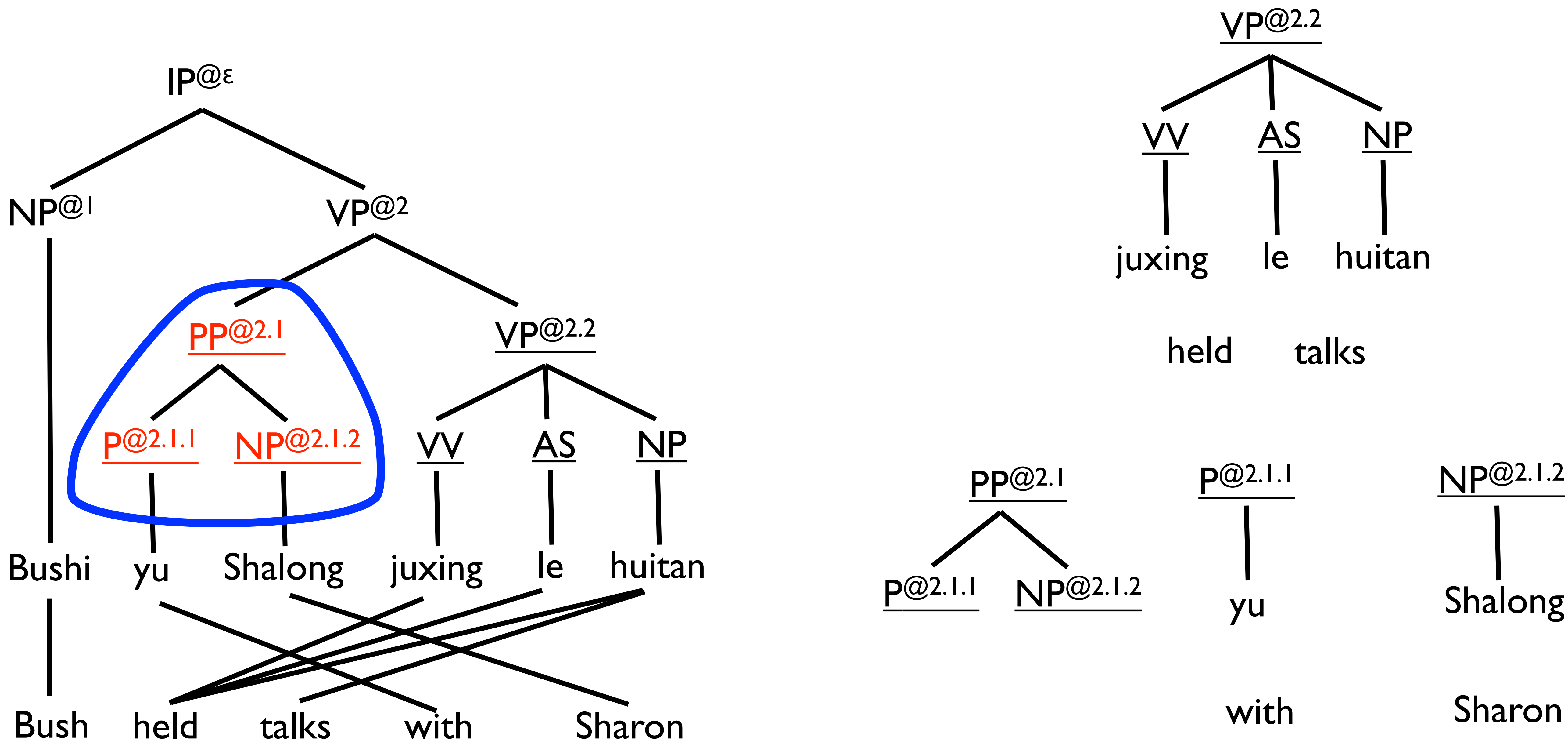

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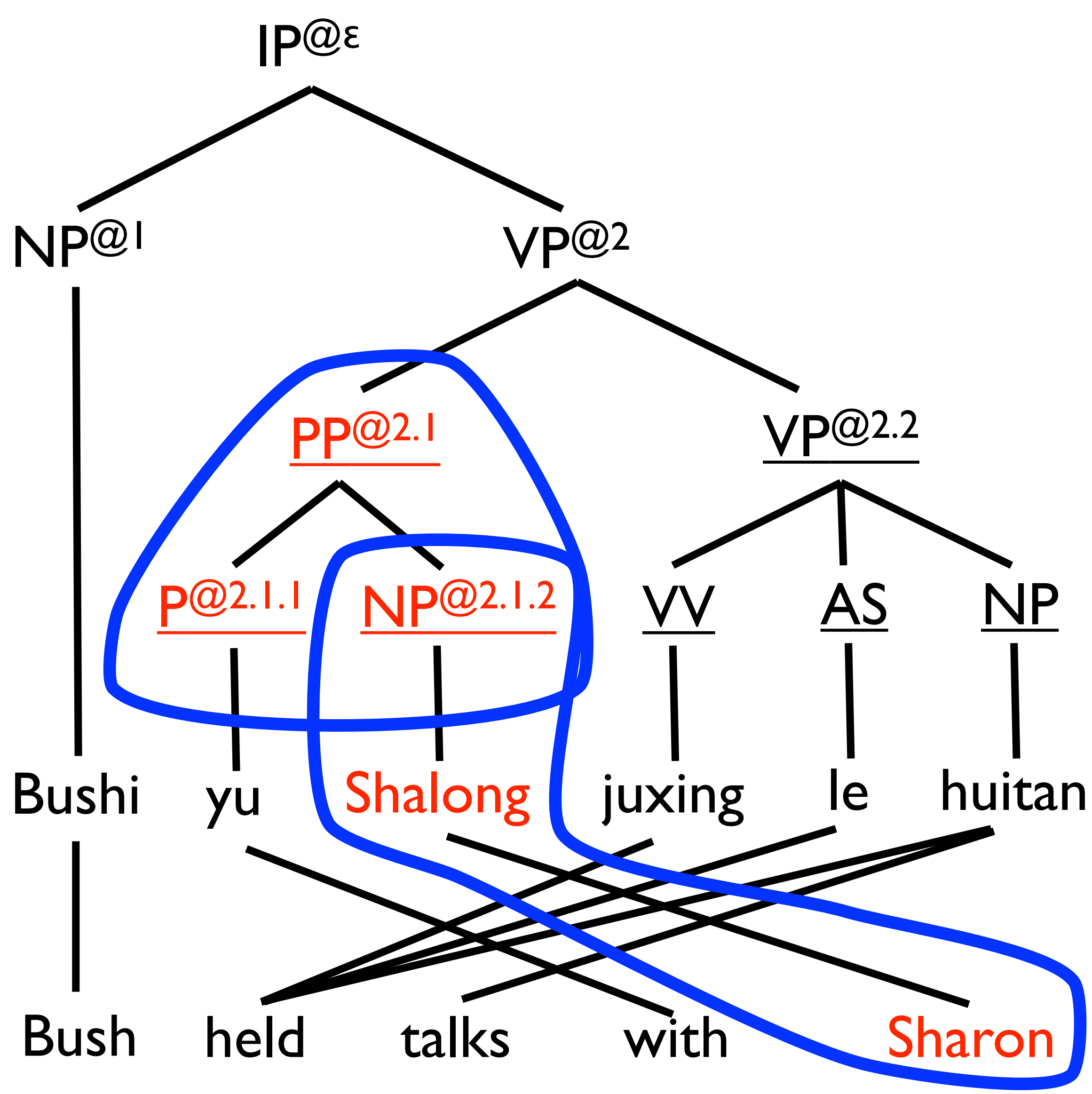

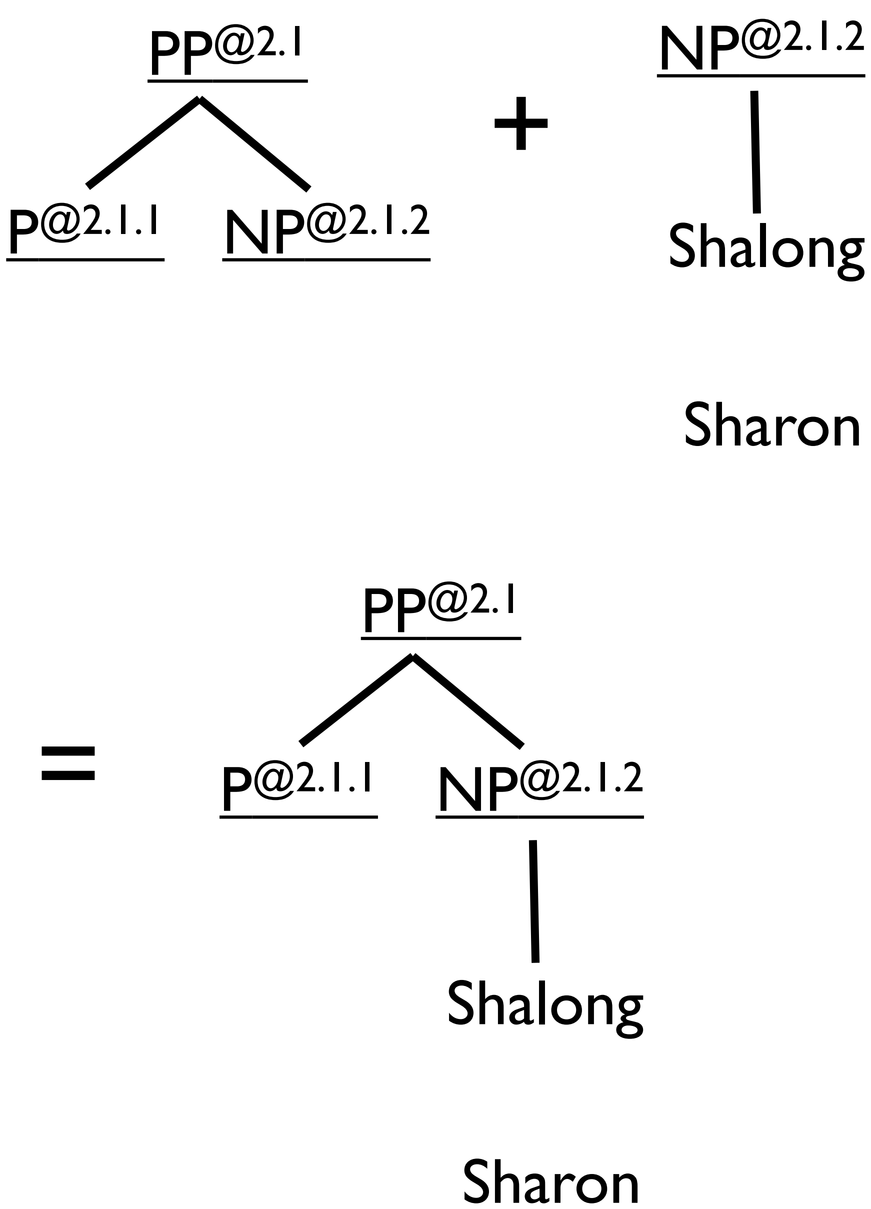

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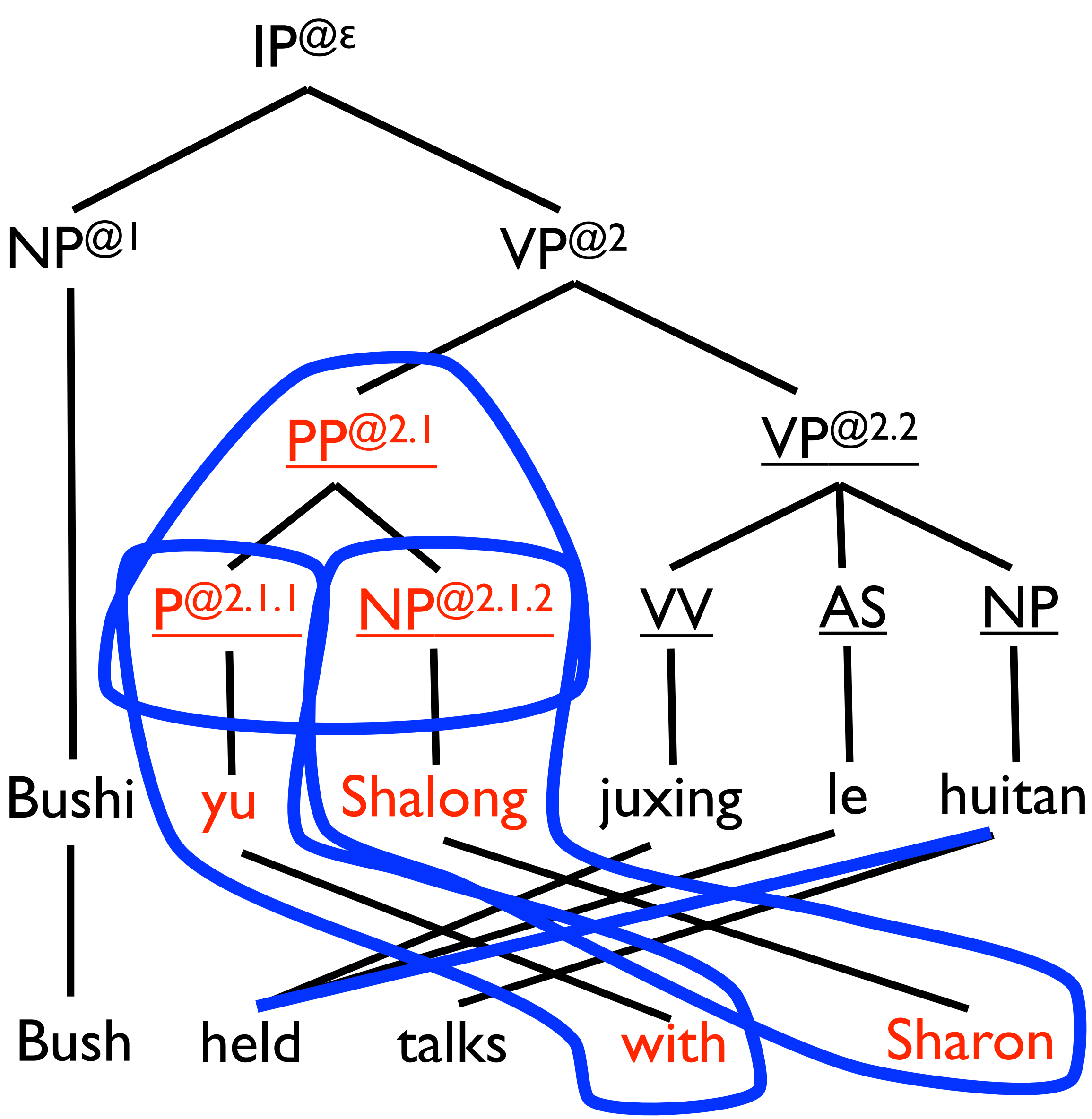

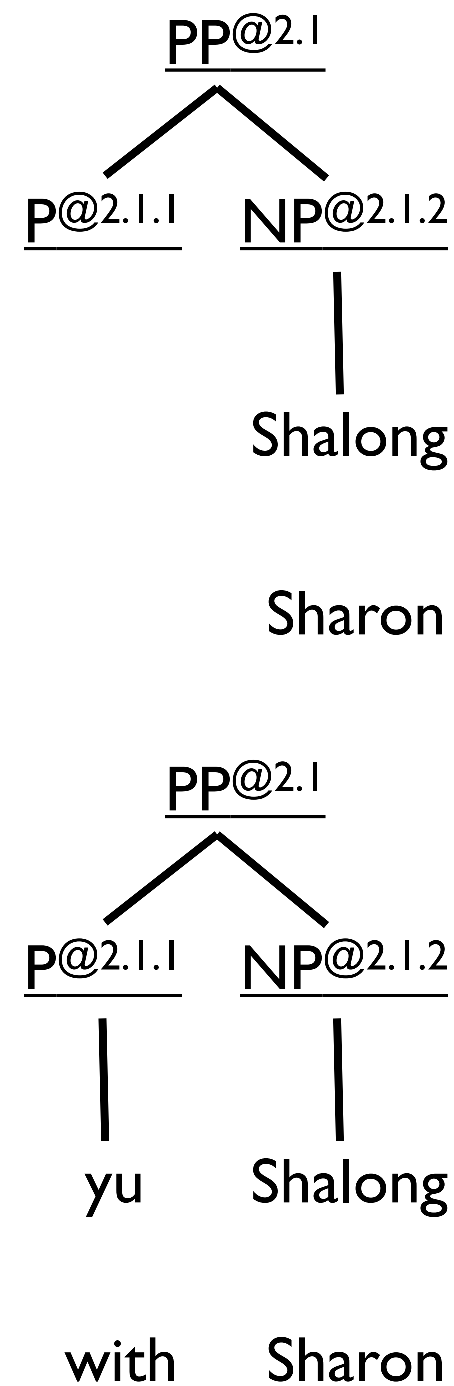

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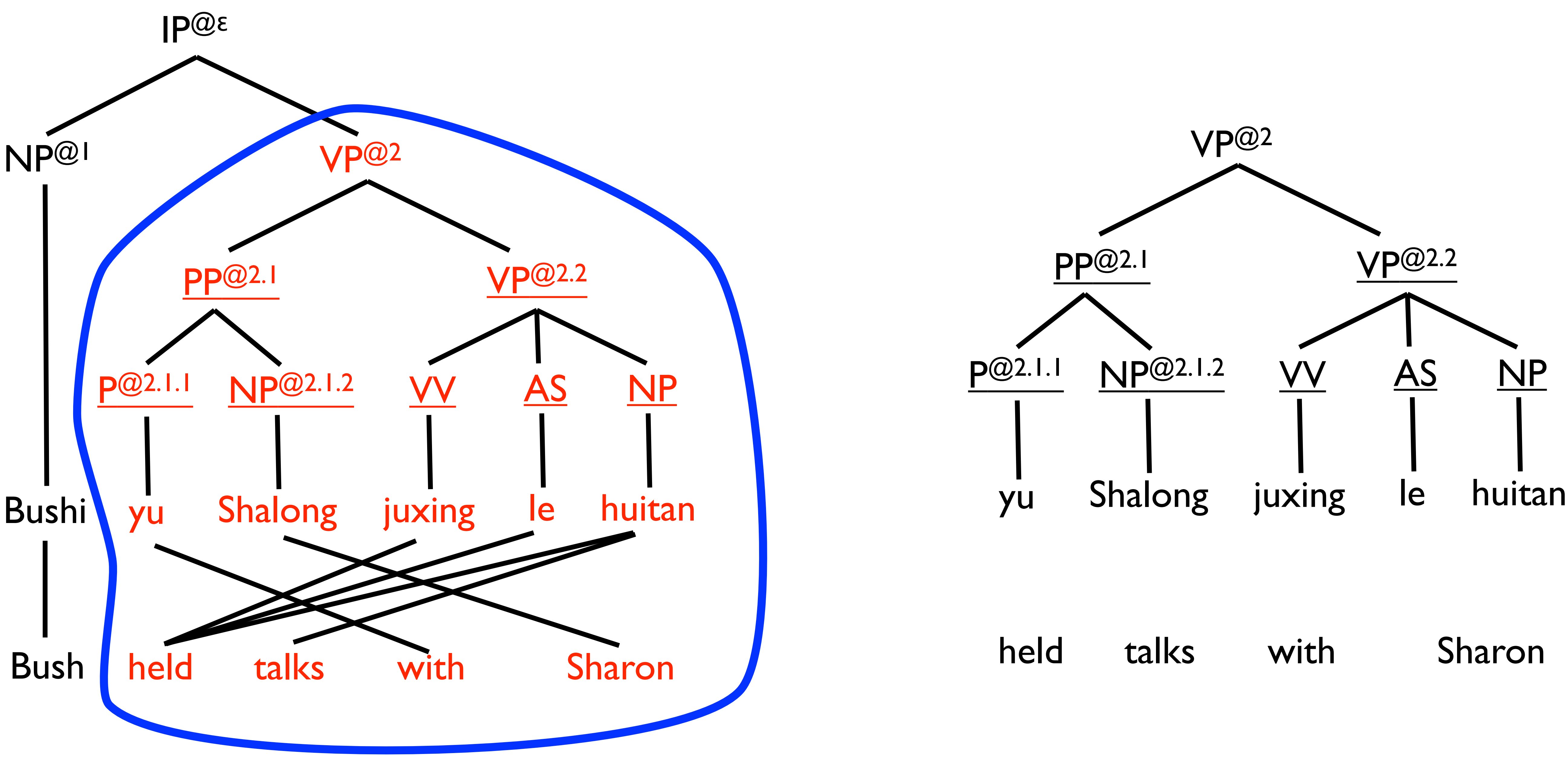


Goal

	BLEU	Decoding time	Grammar size
composed	✓		
minimal		✓	✓
??	✓	✓	✓

Our Approach: Rule Markov Models

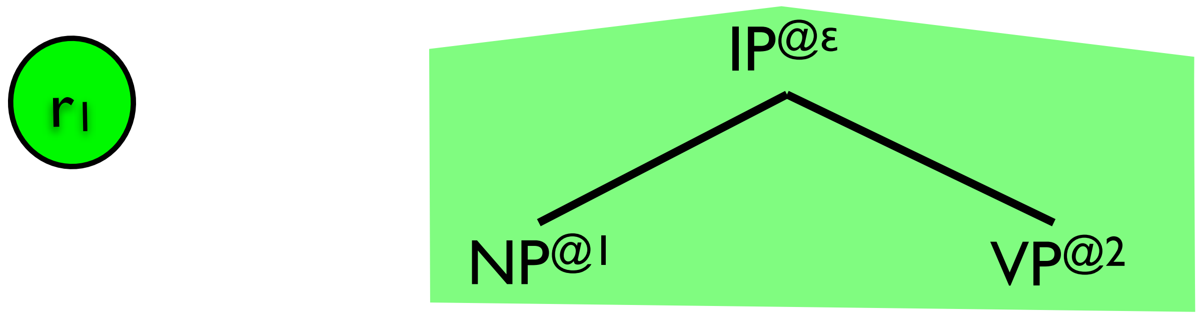
- composed rules alleviate independence b/w rules
- but we can explicitly model this dependence by conditioning on the history (grammar annotation)

- Learn the ancestral dependencies between minimal rules with rule Markov models (RMM)
- Use rule Markov models with top down incremental decoder (Huang and Mi, 2010)

Generative Story

IP@ε

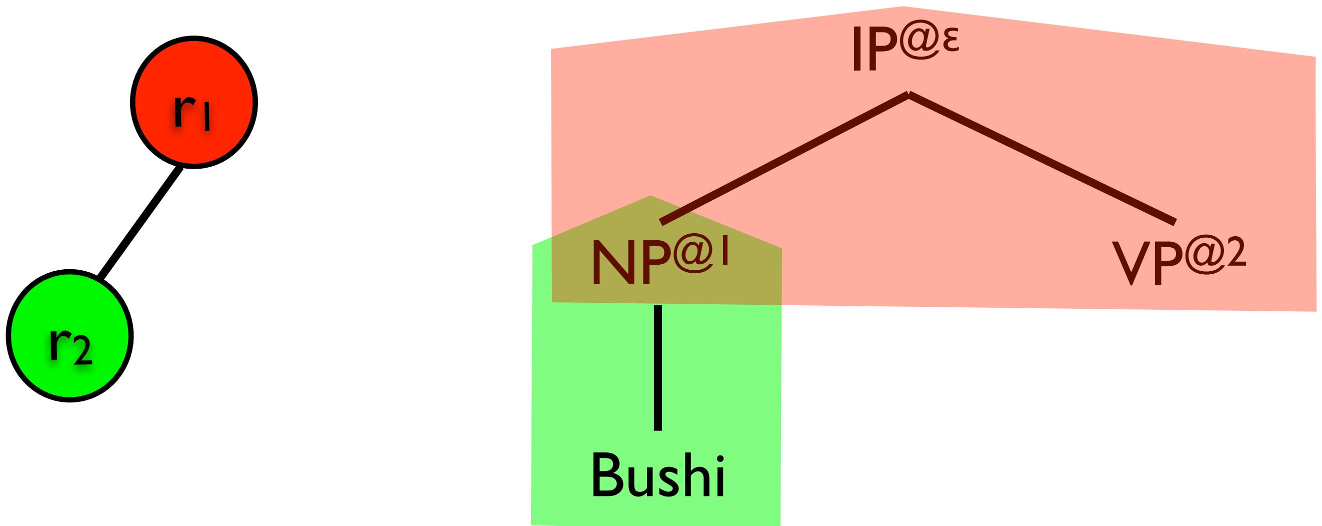
Generative Story



$P(r_1|\varepsilon)$

NP@1 VP@2

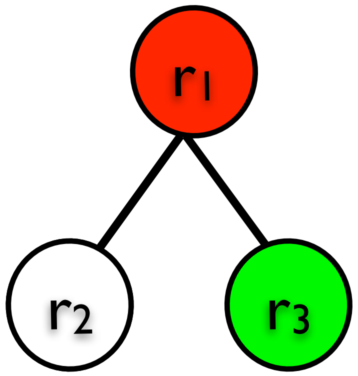
Generative Story

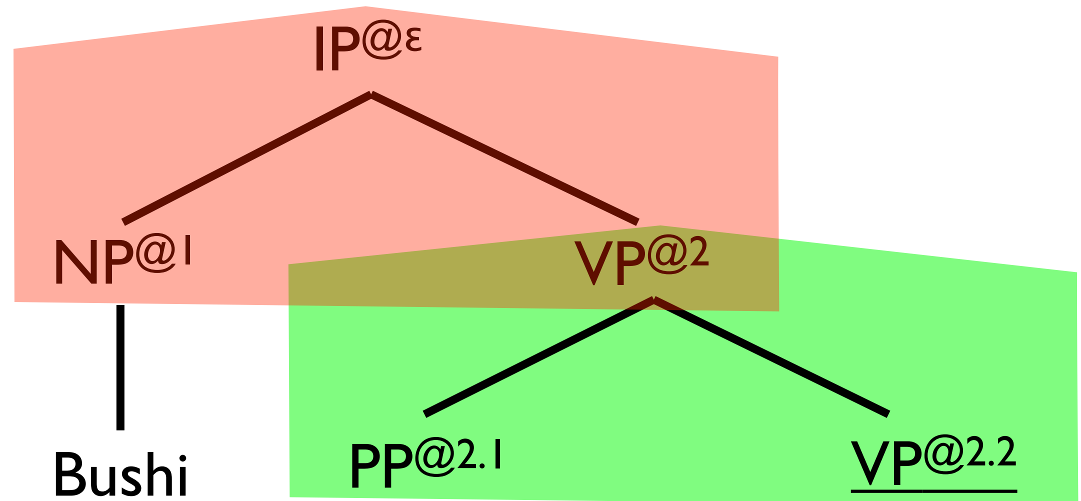


$P(r_2|r_1)$

Bush VP@2

Generative Story

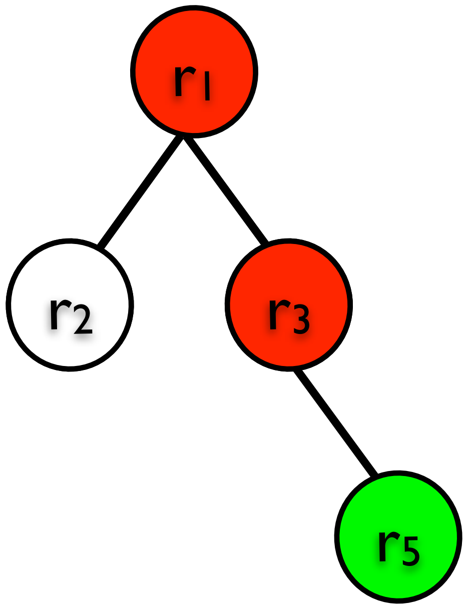


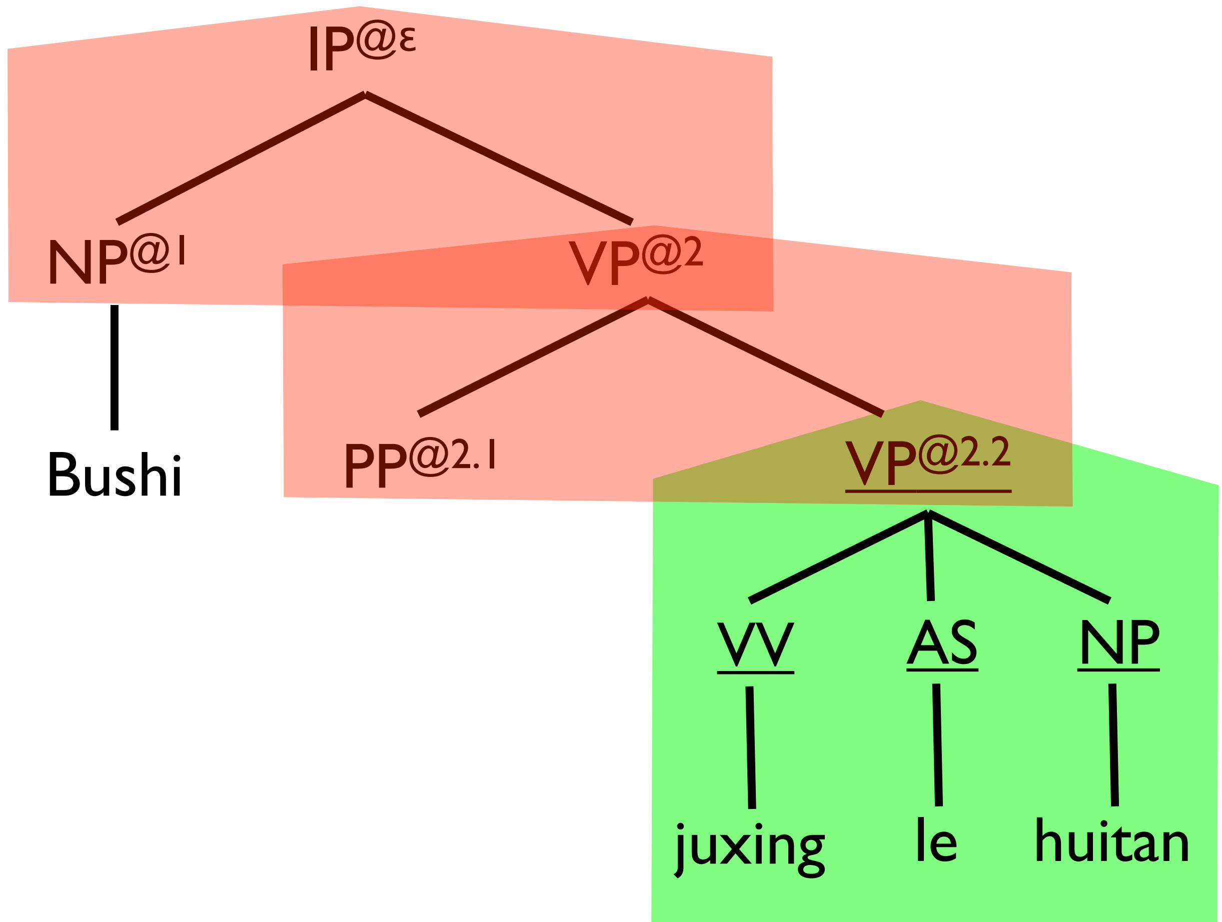


$P(r_3|r_1)$

Bush VP@2.2 PP@2.1

Generative Story

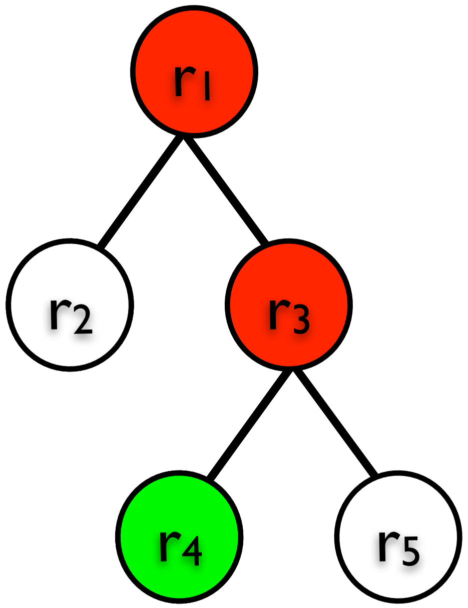


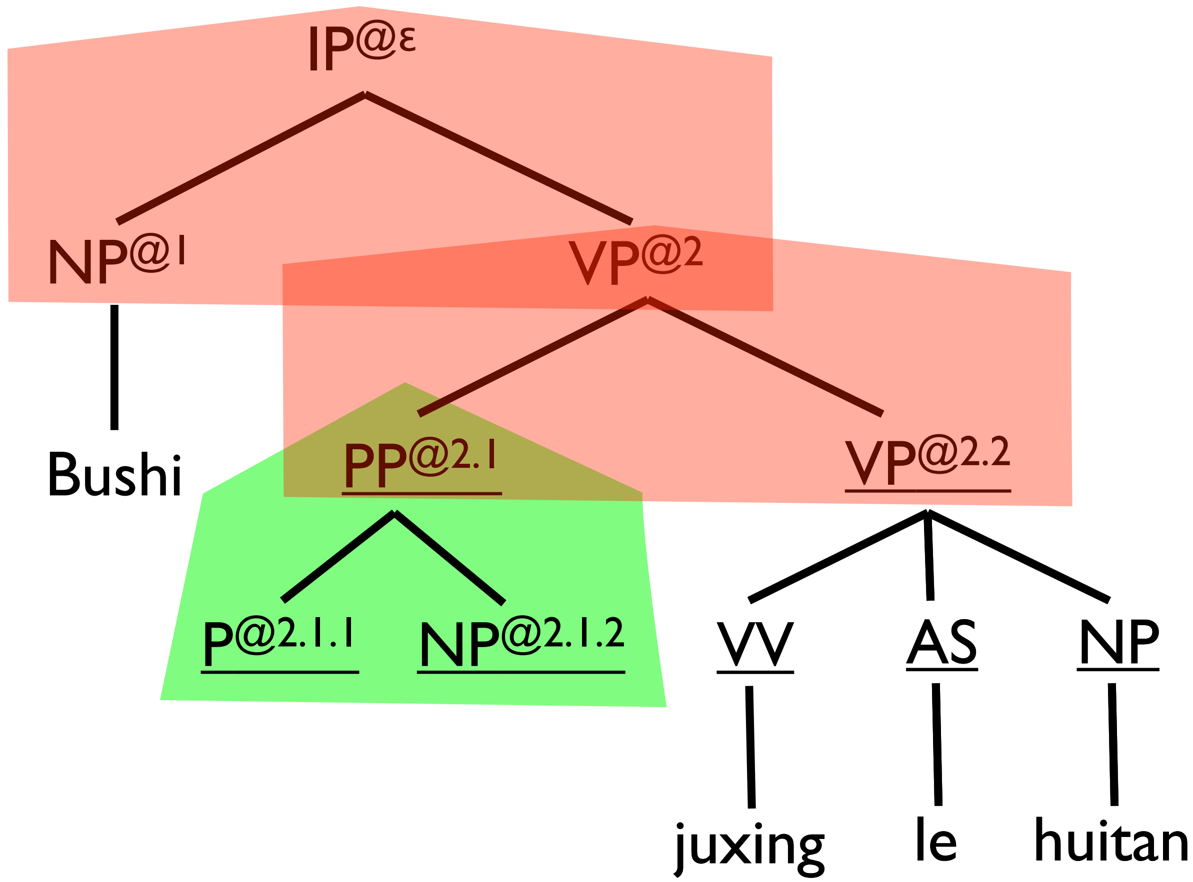


$P(r_5|r_1,r_3)$

Bush held talks PP@2.1

Generative Story

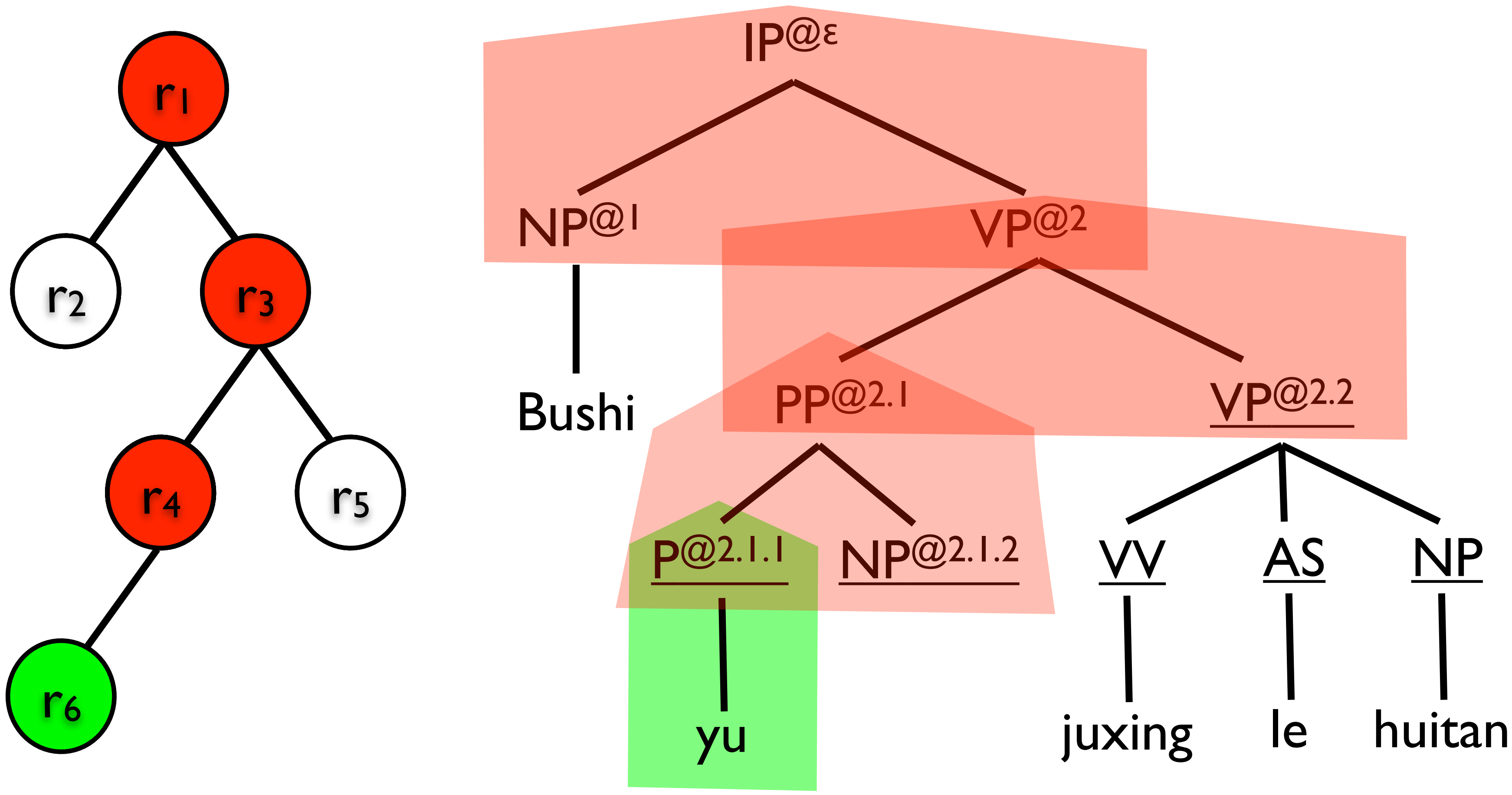




$P(r_4|r_1,r_3)$

Bush held talks P@2.1.1 NP@2.1.2

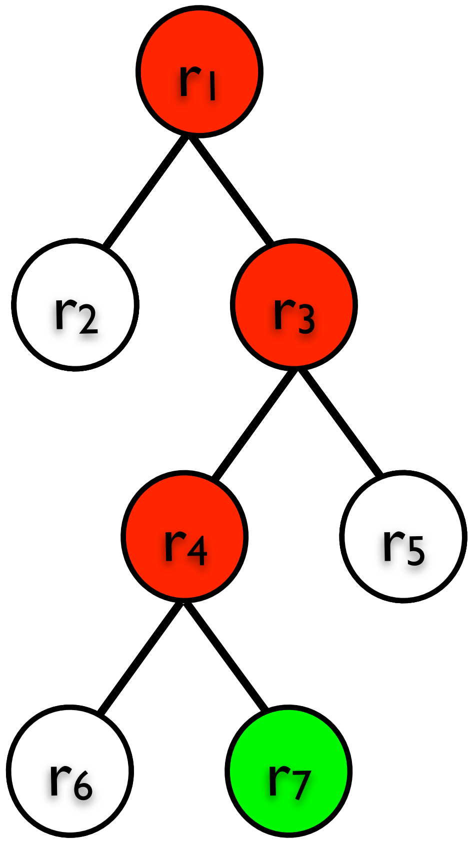
Generative Story

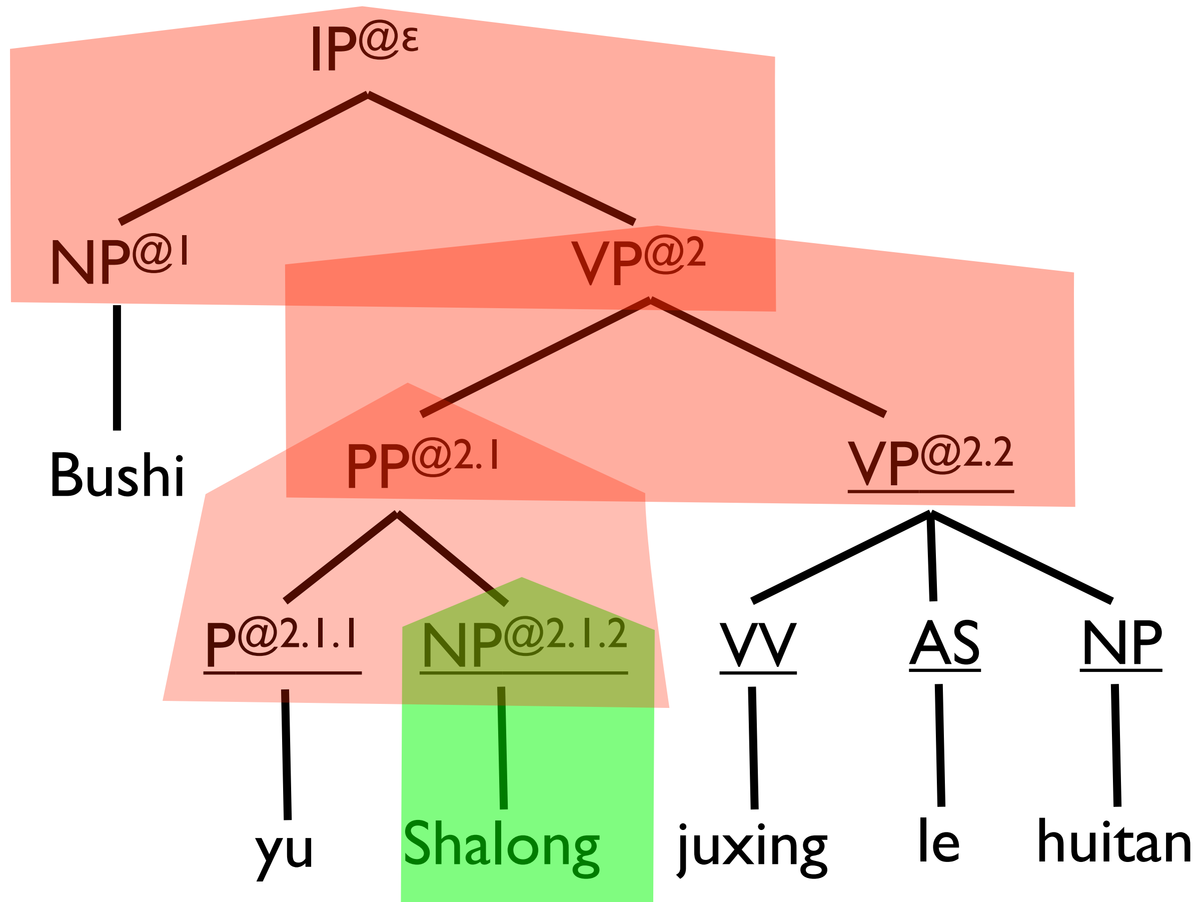


$P(r_6|r_1,r_3,r_4)$

Bush held talks with NP@2.1.2

Generative Story

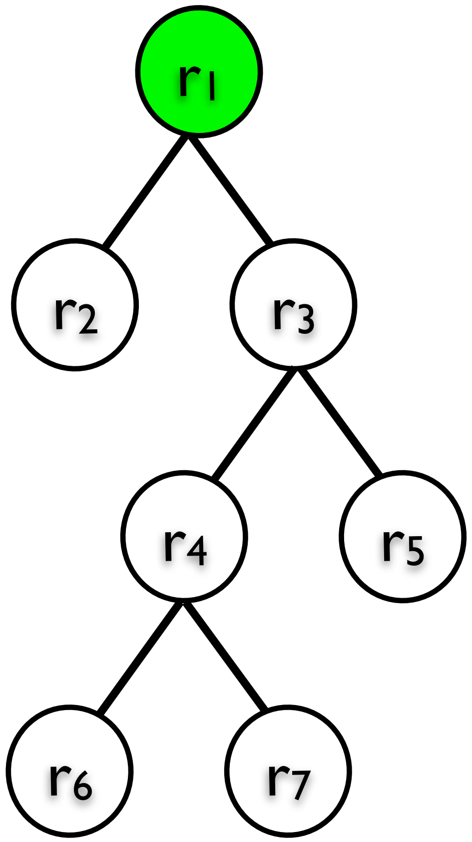




$P(r_7|r_1,r_3,r_4)$

Bush held talks with Sharon

Probability of a Derivation Tree



$$P(T) = P(r_1|\varepsilon) \cdot P(r_2|r_1) \cdot P(r_3|r_1)$$
$$P(r_5|r_1,r_3) \cdot P(r_4|r_1,r_3)$$
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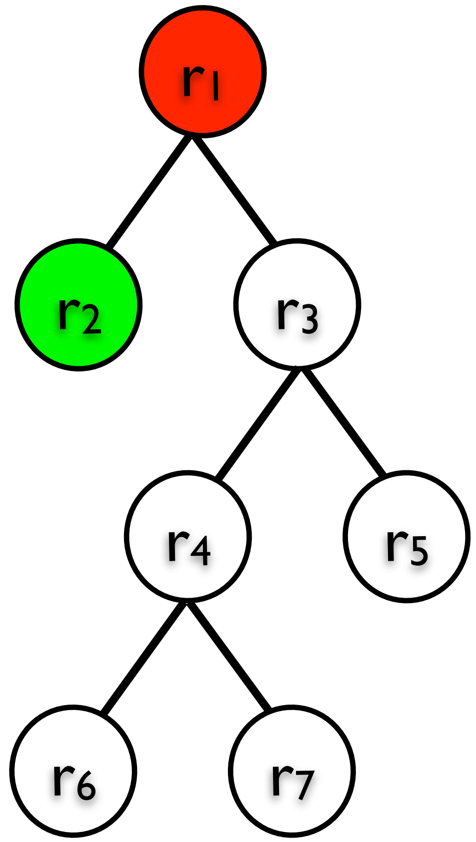

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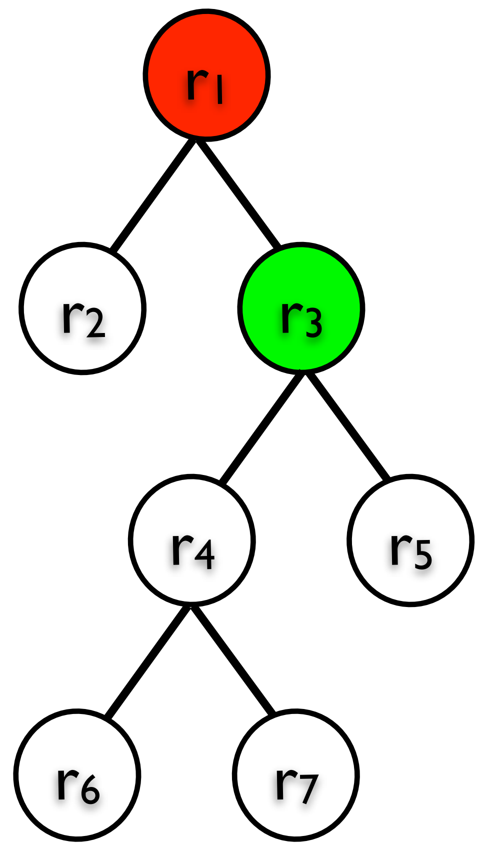

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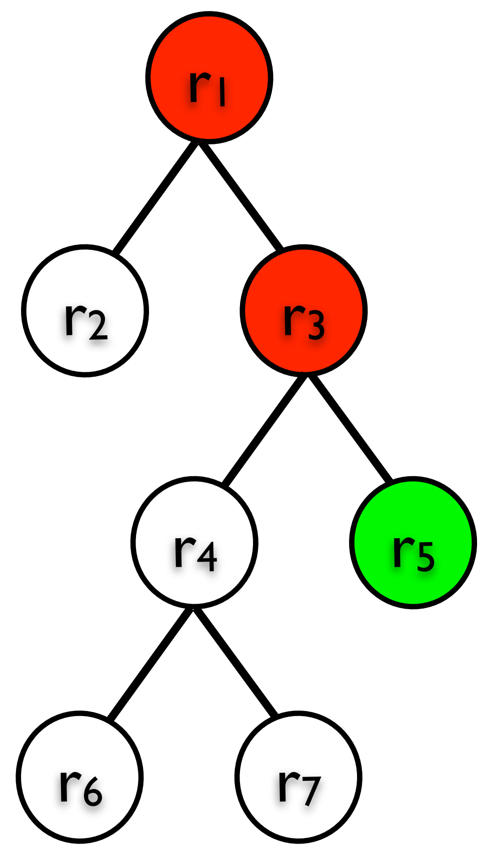

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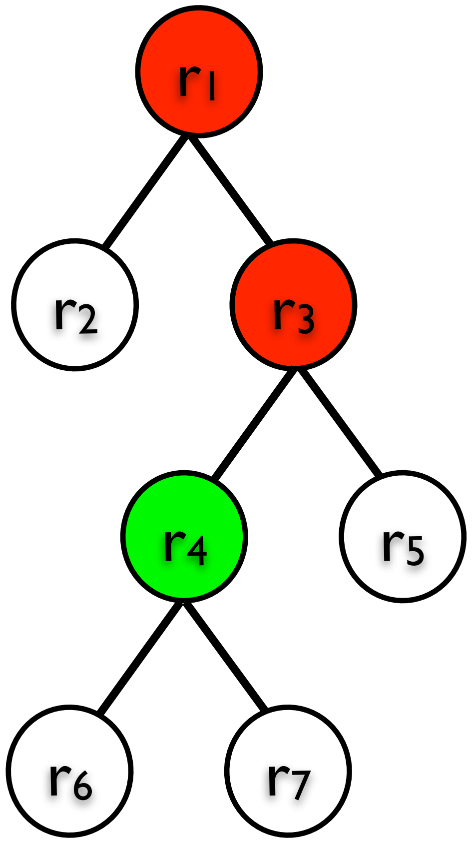

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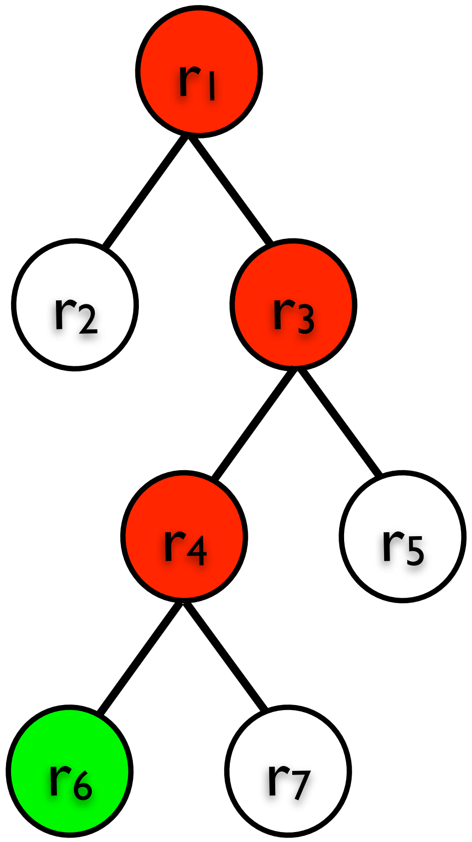

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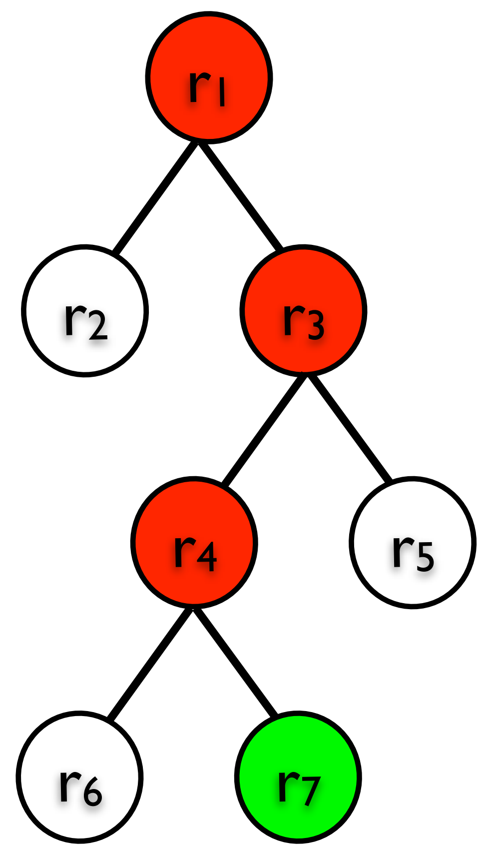

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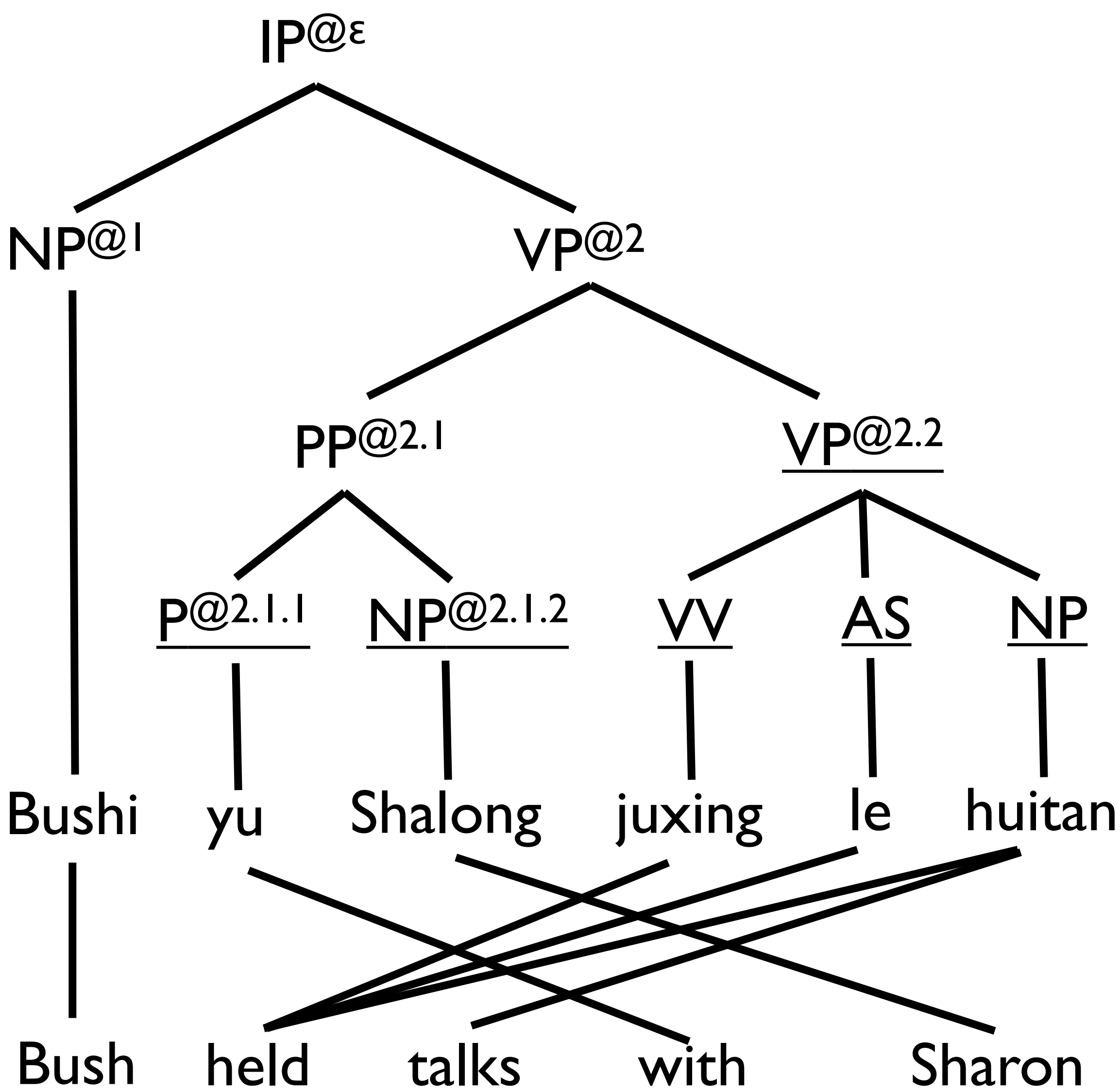
Learning Rule Markov Models



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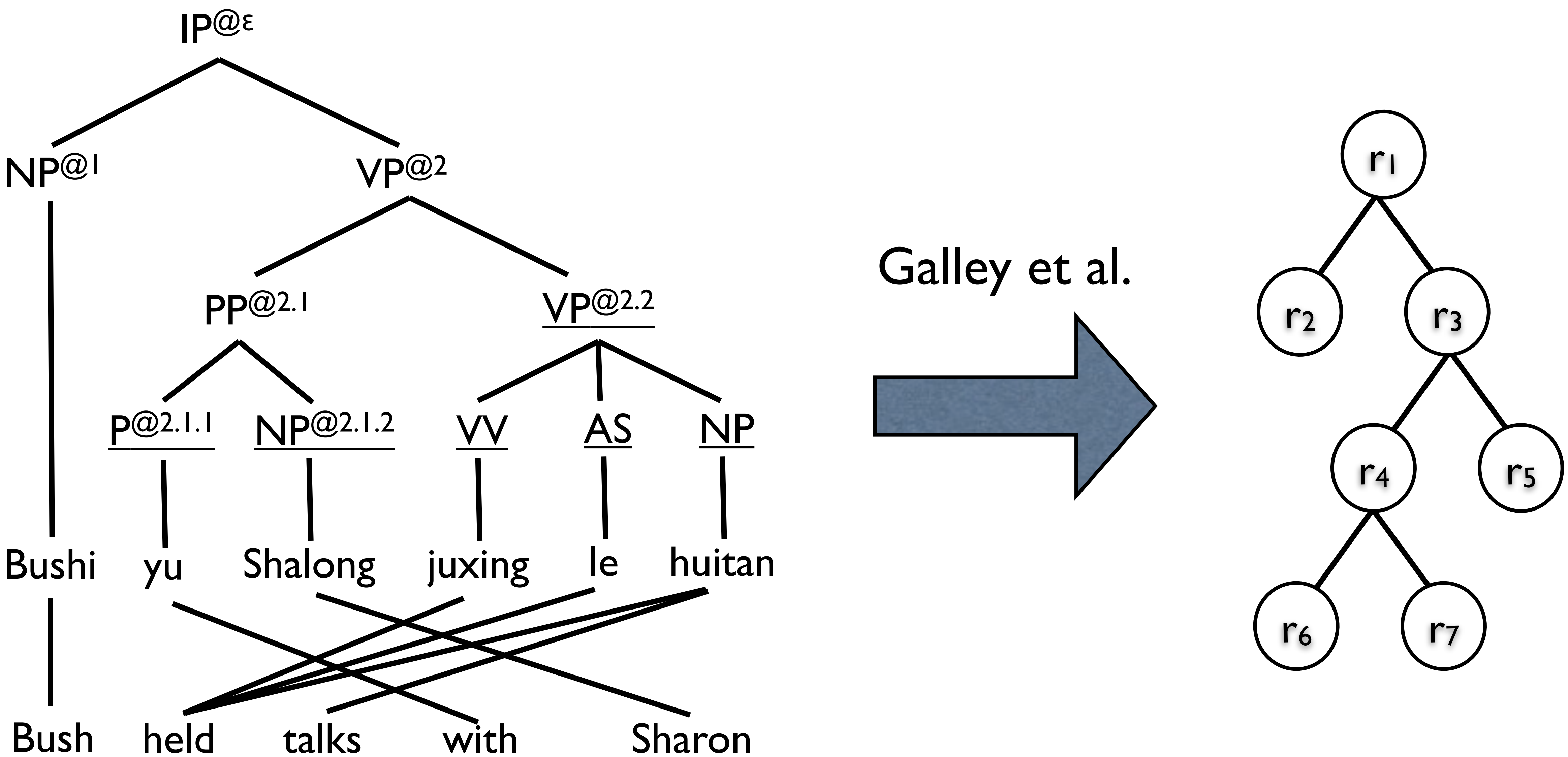

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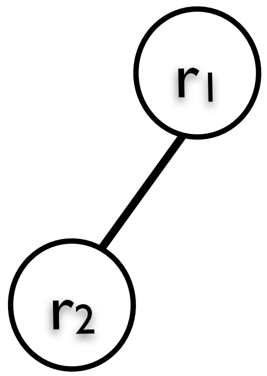

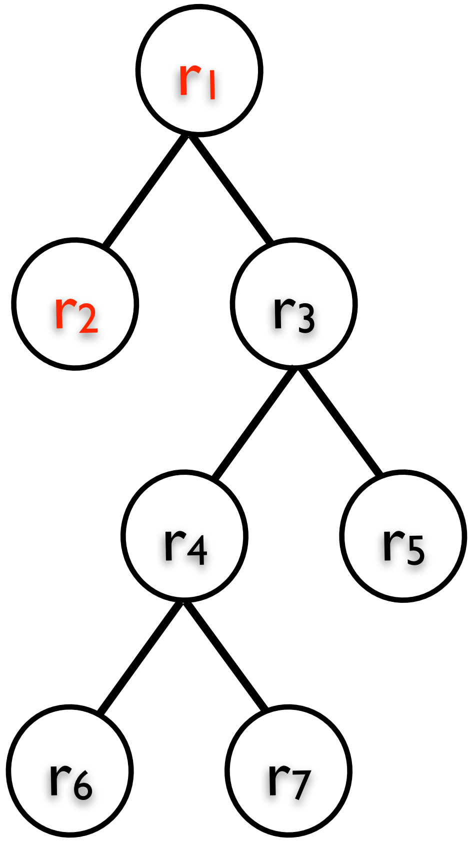

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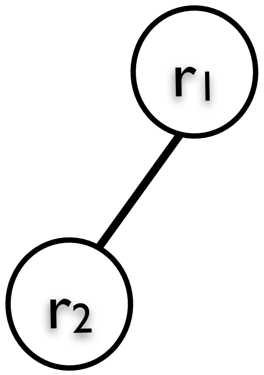

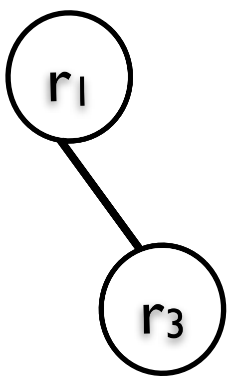

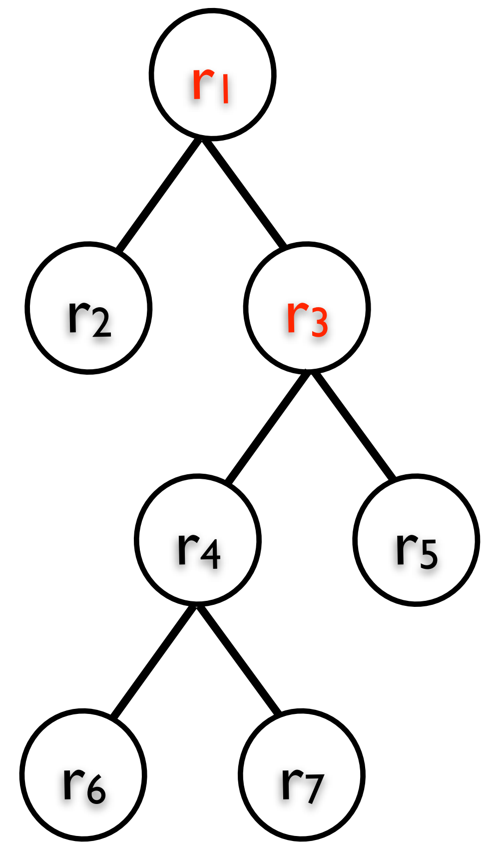

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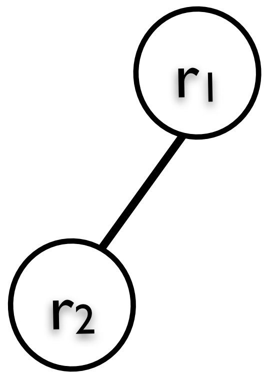

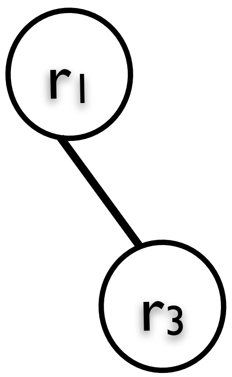

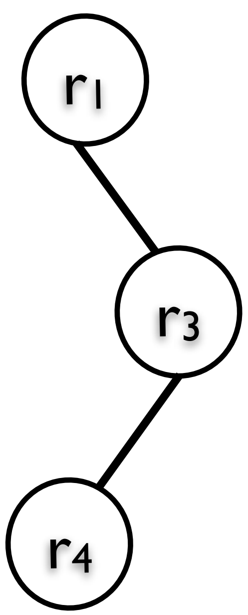

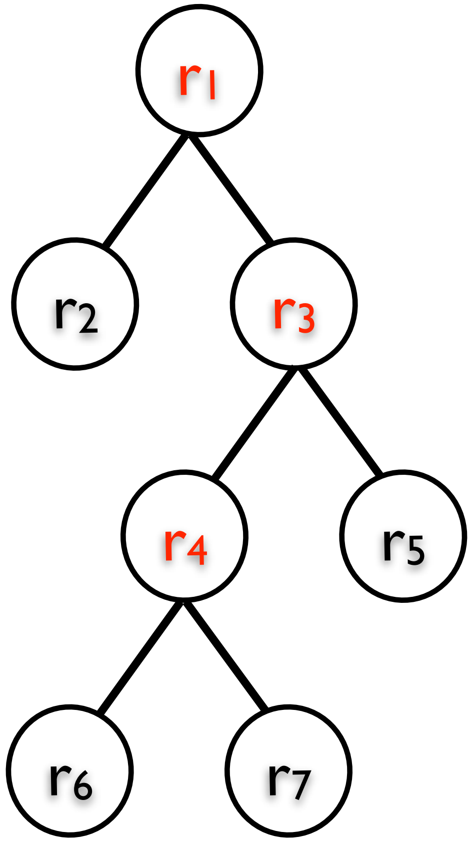

Smaller rule Markov models

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- RM-A: Keep only those contexts in which more than *P* items were observed. Tune *P* for BLEU on dev

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- RM-C: Build Prediction Suffix Trees using the approach of Bejerano and Yona (1999)

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Incremental decoding with RMMs

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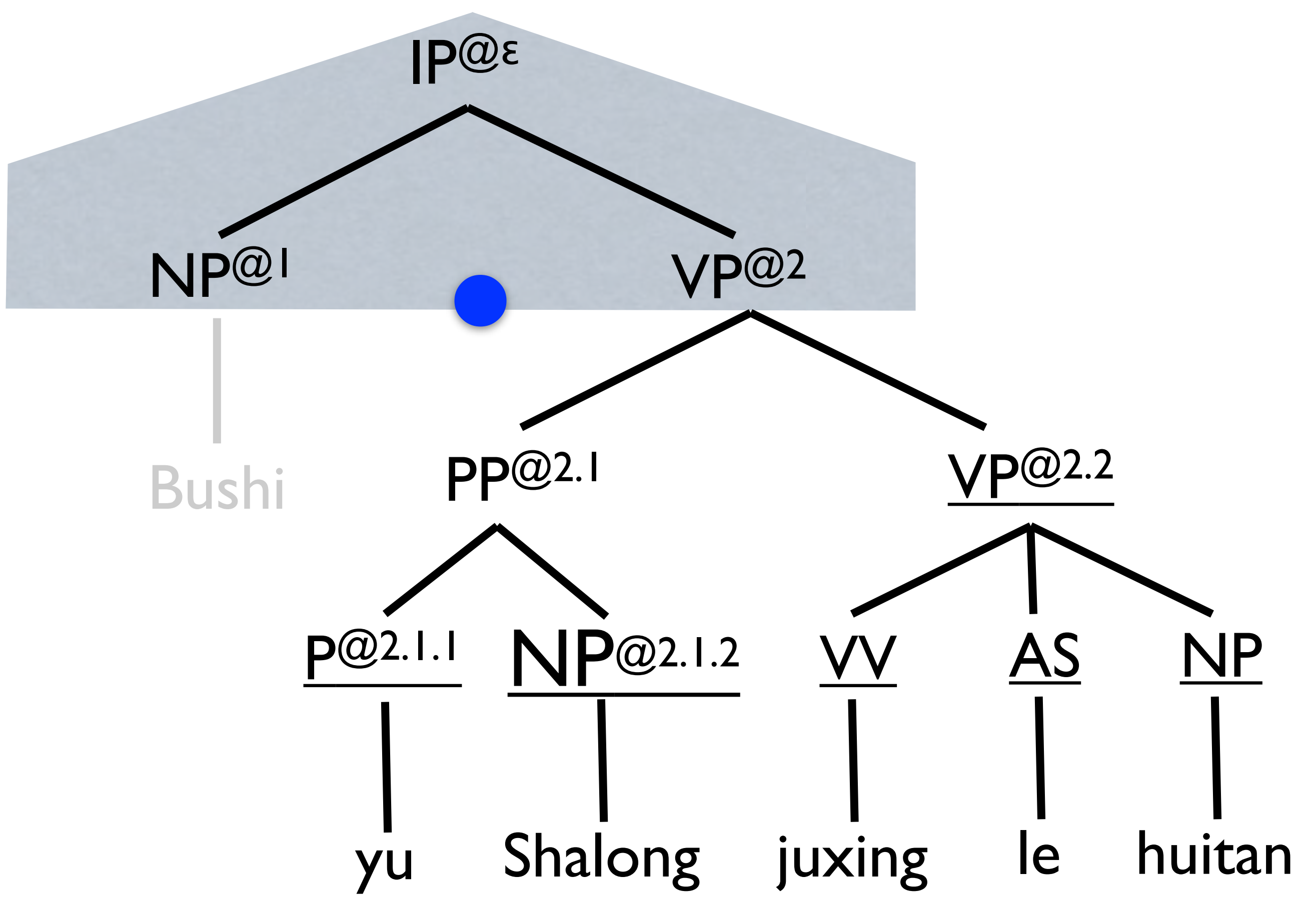
- rule Markov models using only vertical context are a natural fit for Incremental decoding (Huang and Mi, 2010)

Incremental decoding with RMMs

- rule Markov models using only vertical context are a natural fit for Incremental decoding (Huang and Mi, 2010)
- The top-down decoder maintains the vertical context as part of its state which is used in predicting the next rule

Incremental Decoding

- stack (*active* derivation history): [.IP@ε] [NP@1 .VP@2]
- three colors for nodes: white (uncovered), grey (partially covered), and black (covered)



(Huang and Mi, 2010)

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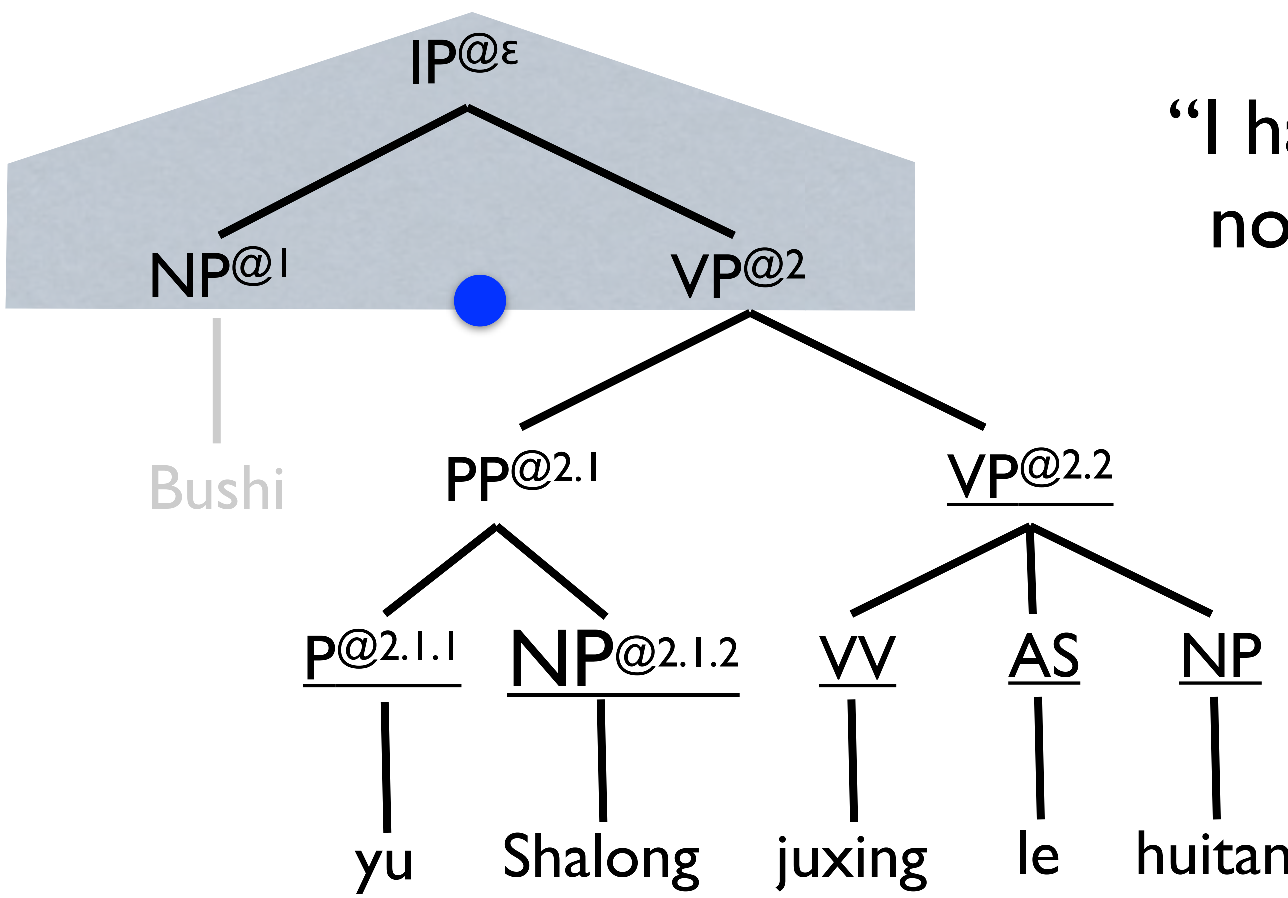


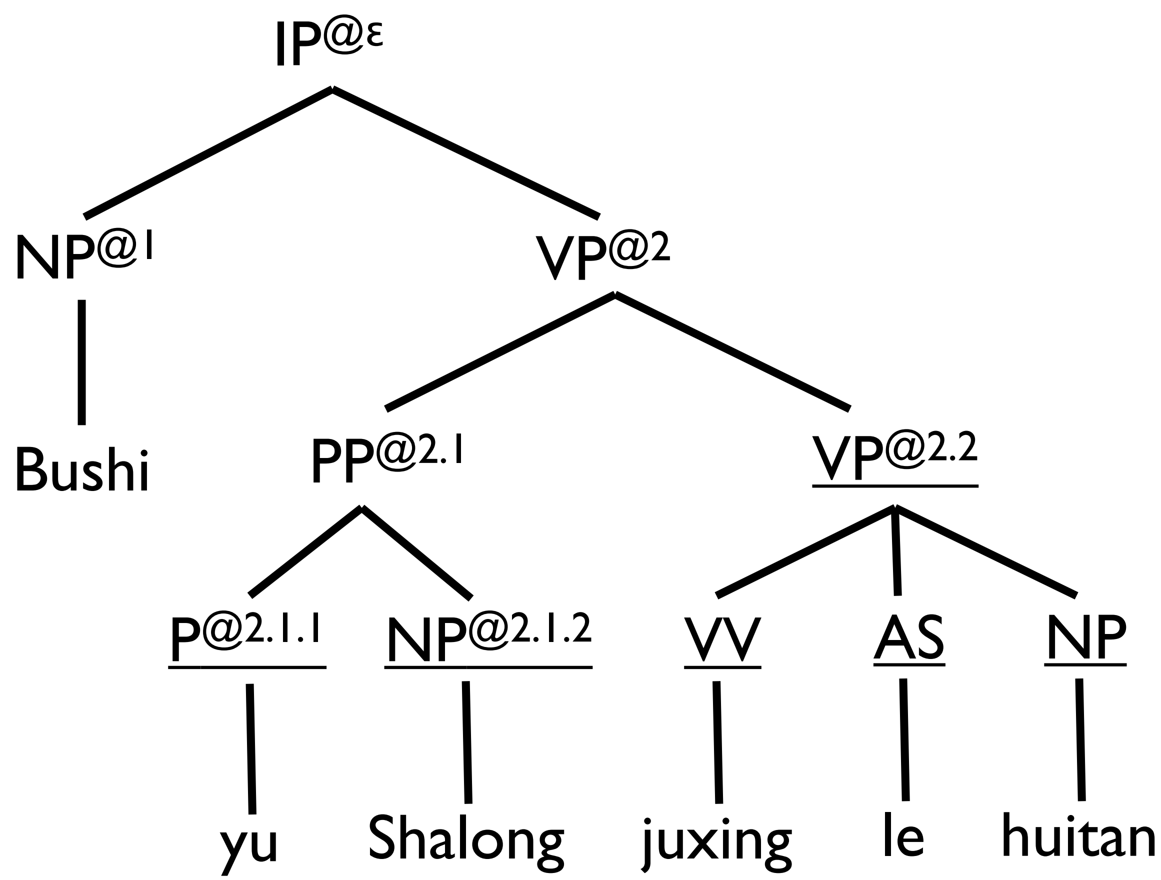
"I have finished NP subtree but not started with VP subtree"

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] *stack*

<s> *hypothesis*



(Huang and Mi, 2010)

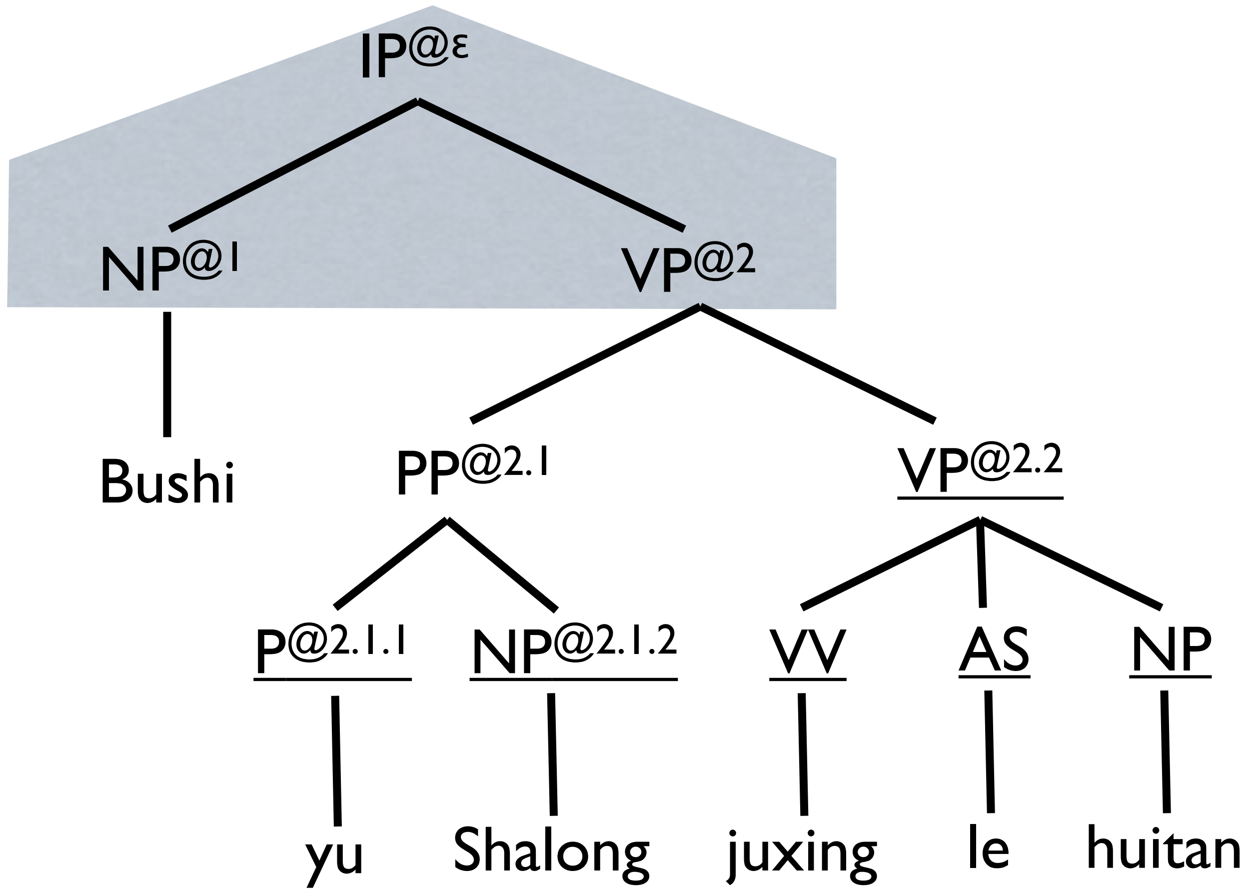
Example Incremental Decoding

[<s> . $IP^{@\varepsilon}$ </s>] [. $NP^{@1}$ $VP^{@2}$]
r_1

stack

<s>

hypothesis



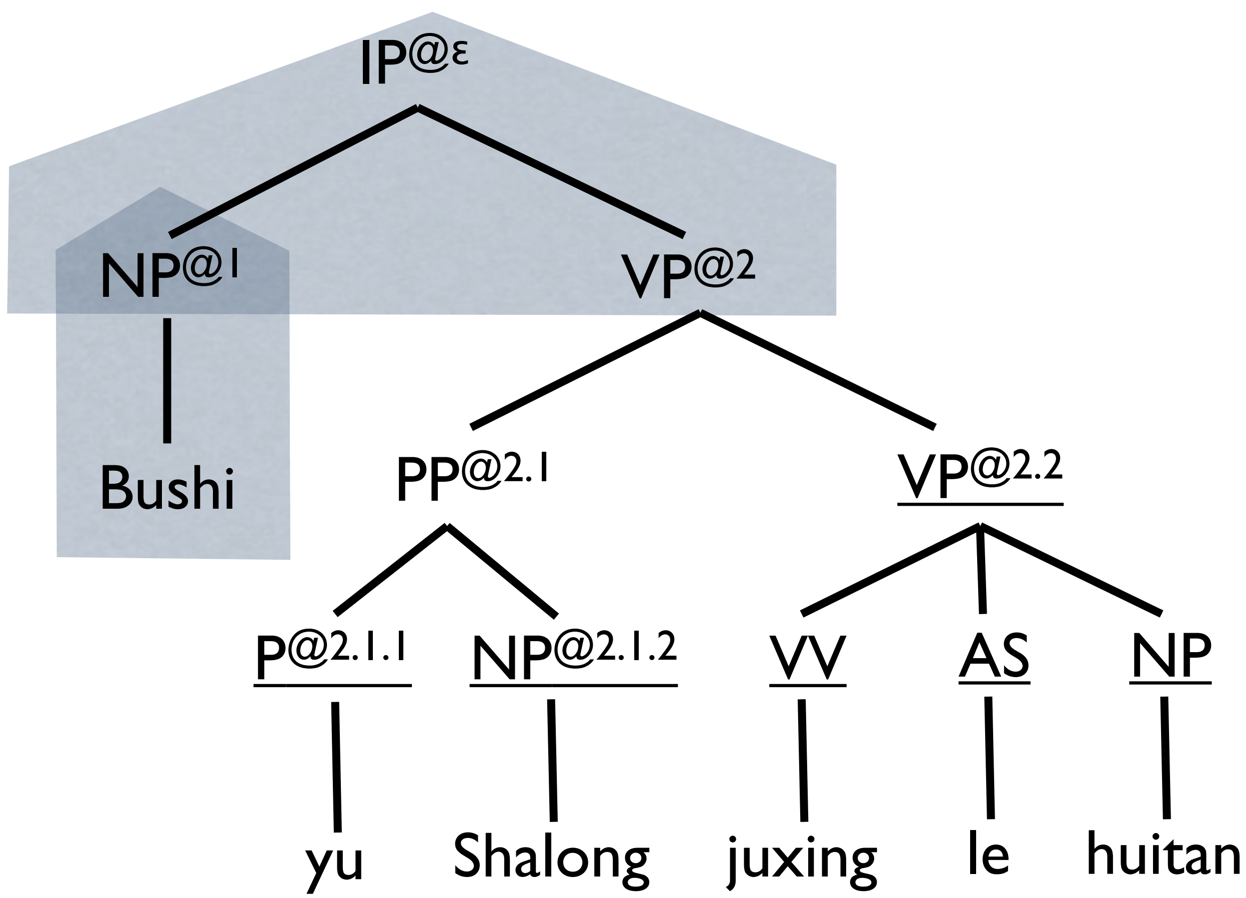
action: predict (push)

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [. NP@1 VP@2] [. Bush] *stack*
r1 r2

<s> *hypothesis*



action: predict

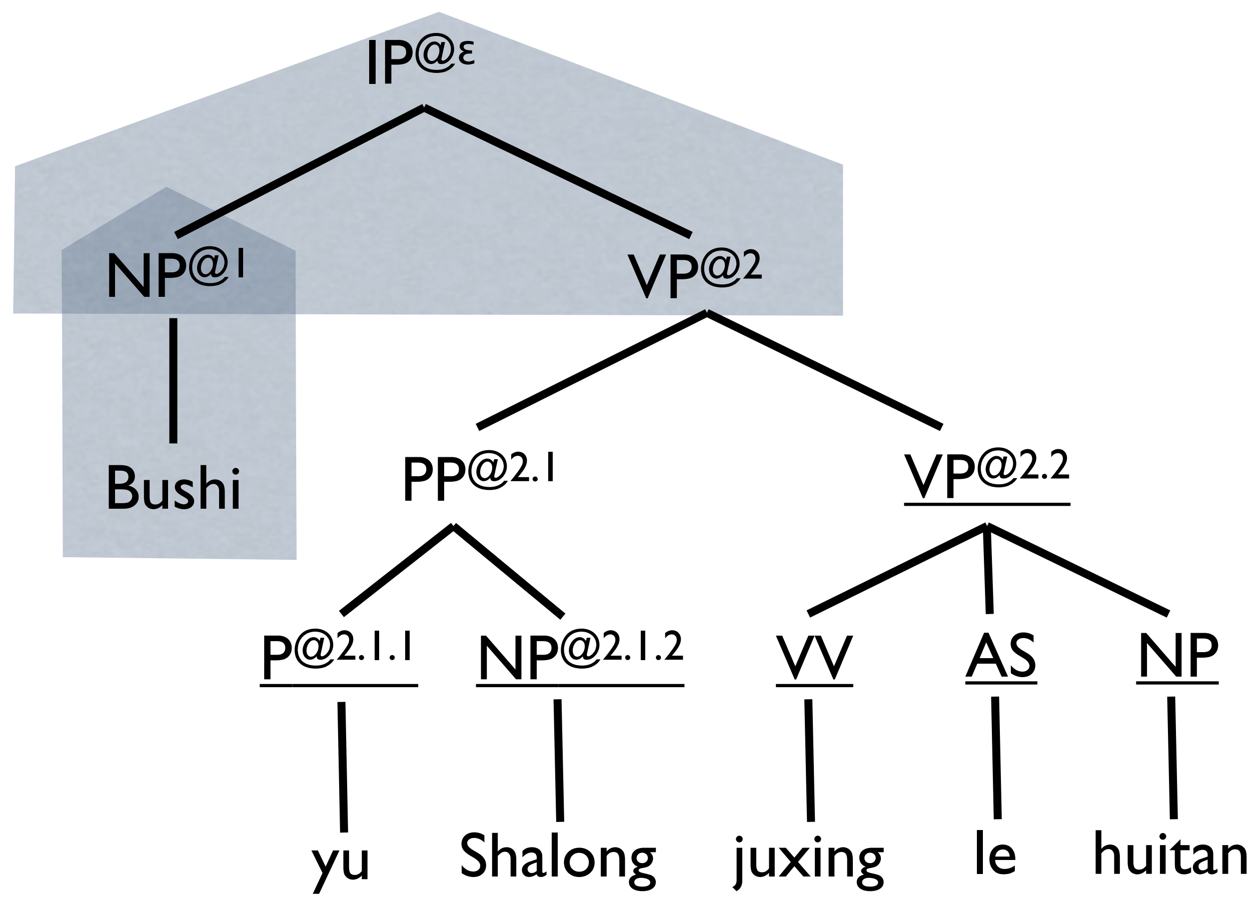
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP$^{@\varepsilon}$ </s>] [. NP$^{@1}$ VP$^{@2}$] [Bush .] *stack*

r_1 r_2

<s> Bush *hypothesis*



action: scan

(Huang and Mi, 2010)

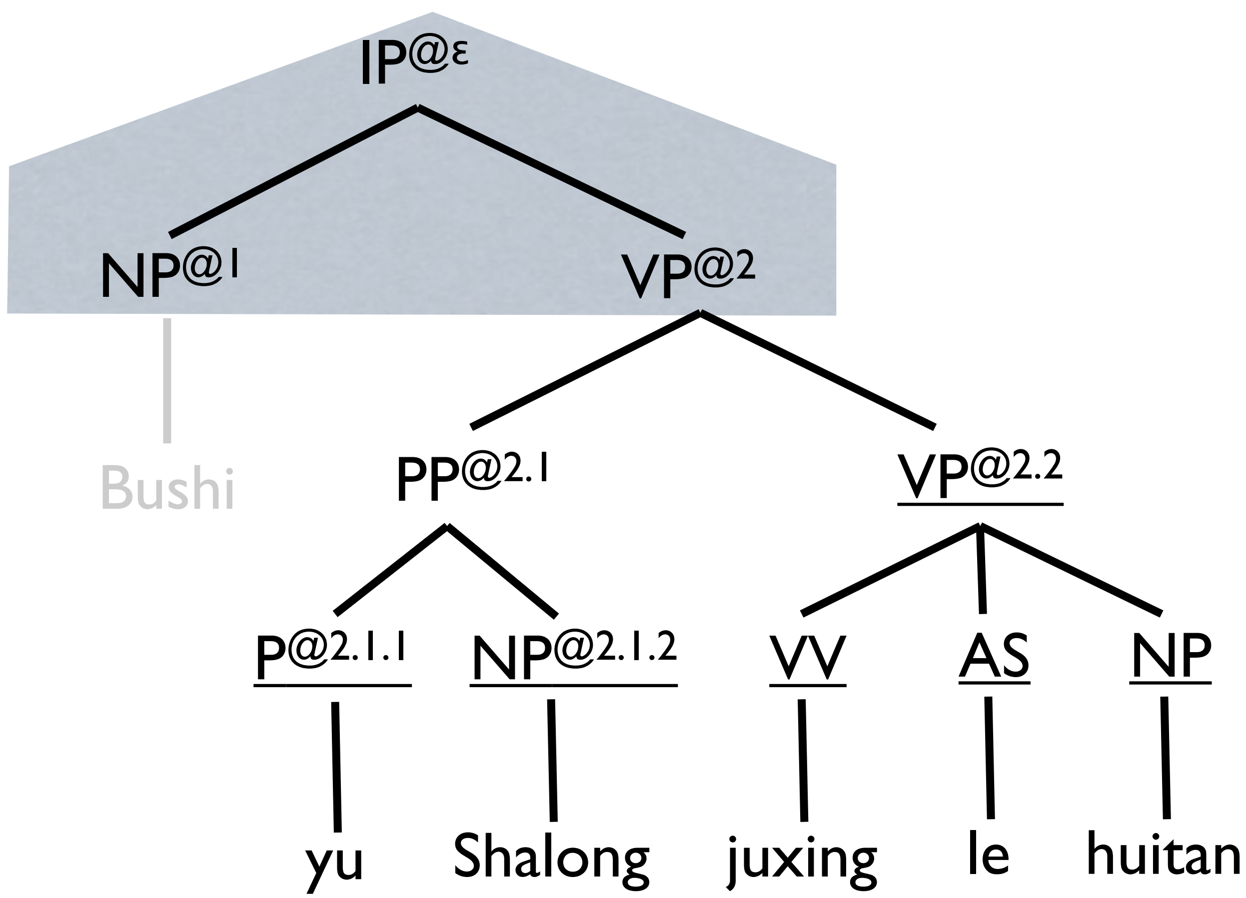
Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2]
r_1

stack

<s> Bush

hypothesis



action: pop

(Huang and Mi, 2010)

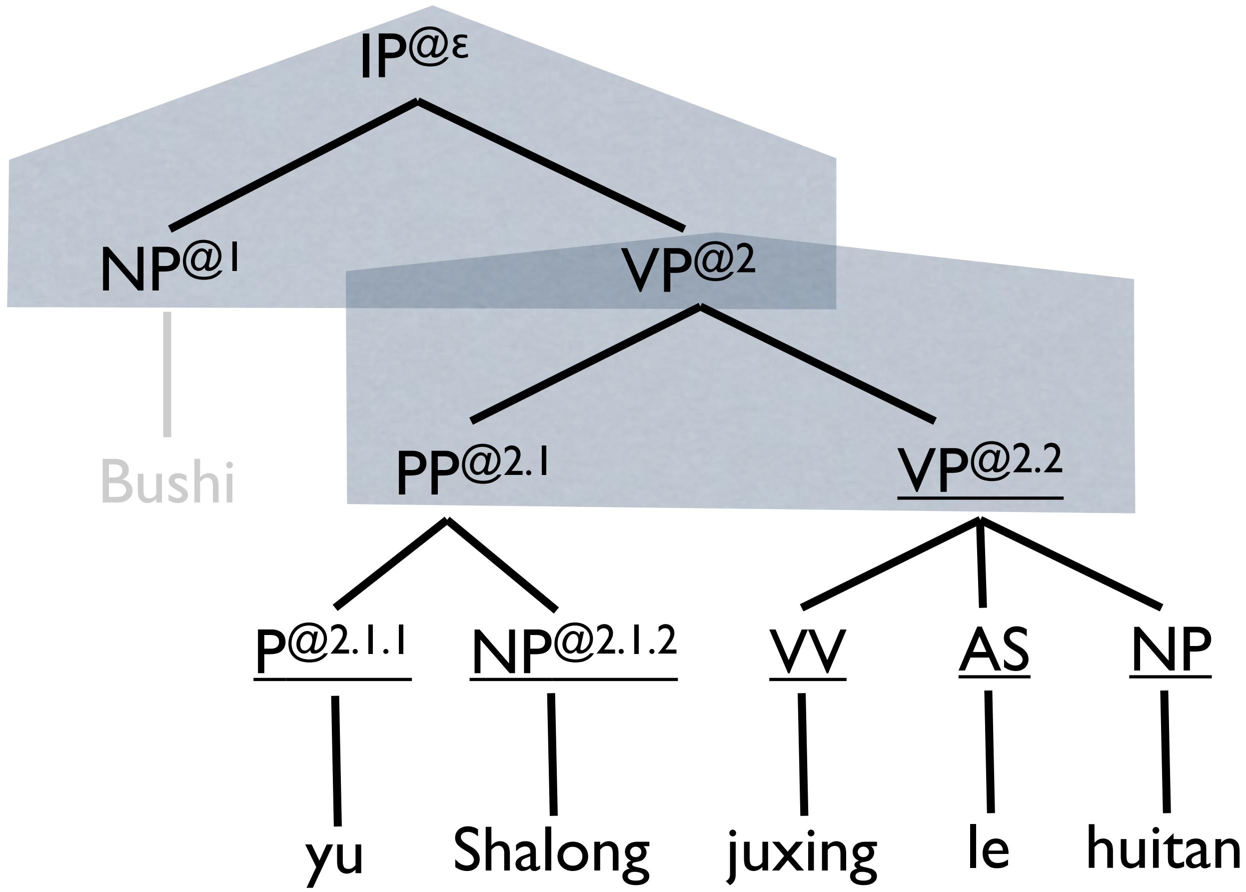
Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [. VP@2.2 PP@2.1]
r_1 r_3

stack

<s> Bush

hypothesis



action: predict

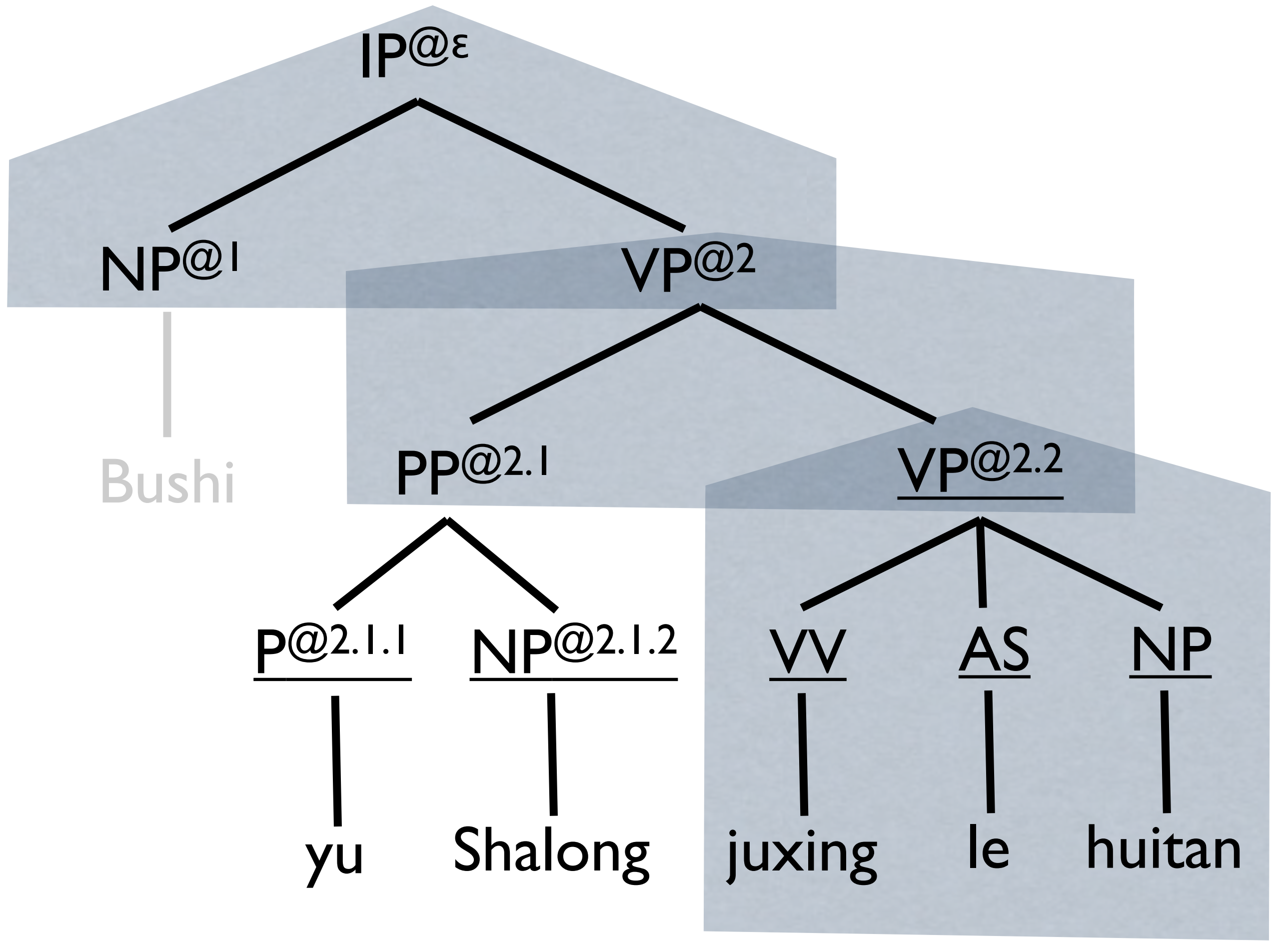
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [. VP@2.2 PP@2.1] [. held talks] *stack*

r_1 r_3 r_5

<s> Bush *hypothesis*



action: predict

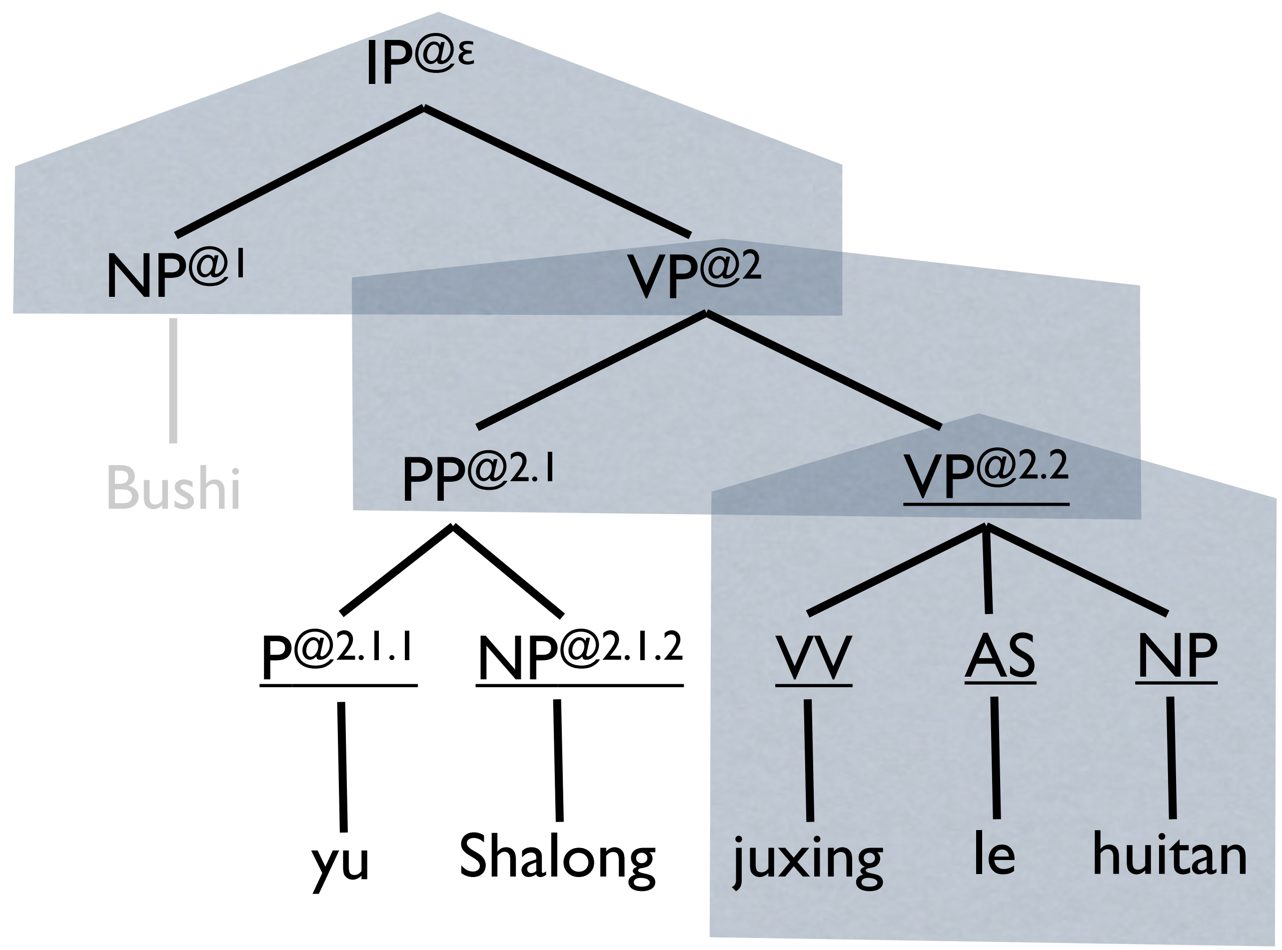
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [. VP@2.2 PP@2.1] [held talks .] *stack*

r1 r3 r5

<s> Bush held talks *hypothesis*



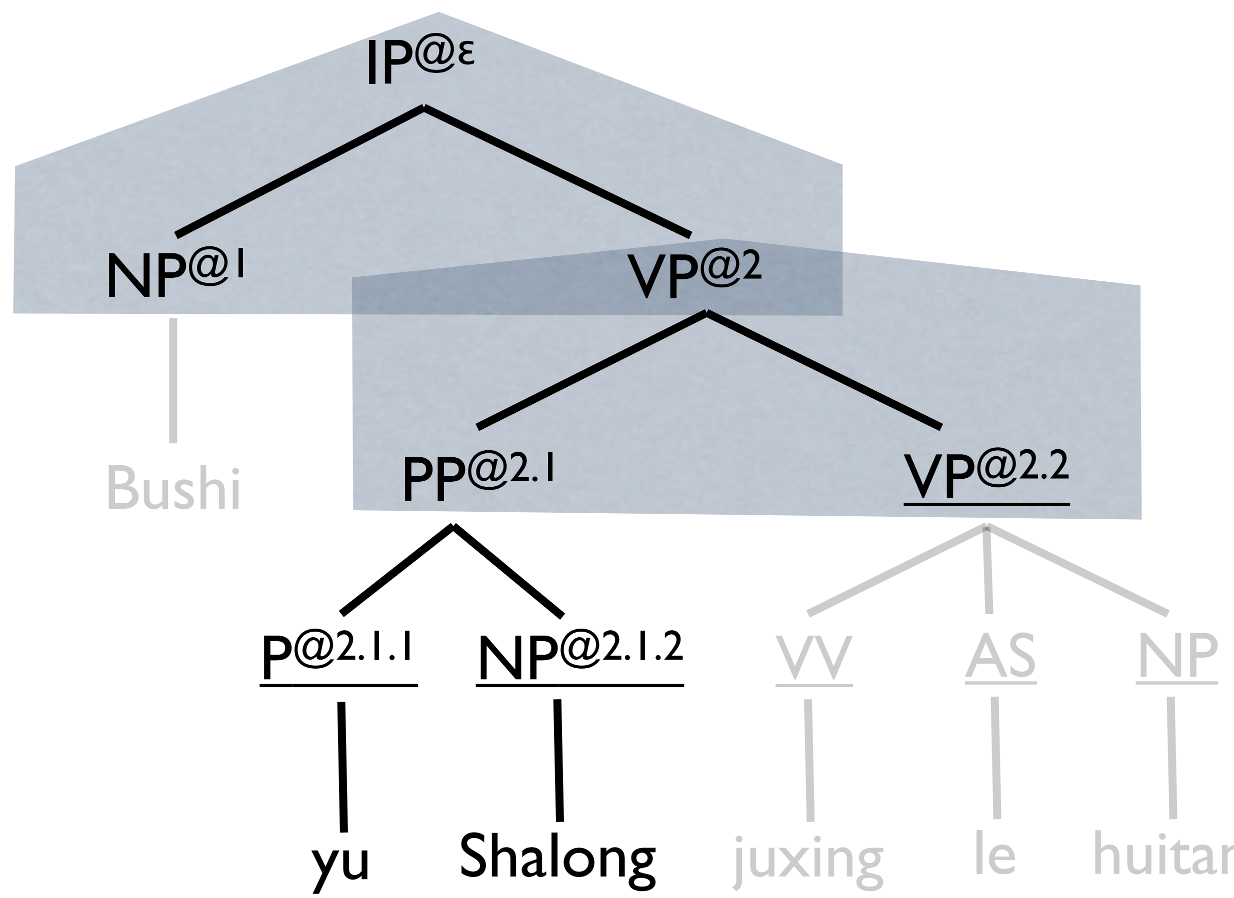
action: scan

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 $\underset{r_1}{.}$ VP@2] [. $\underline{\text{VP@2.2}}_{\ r_3}$ $\underline{\text{PP@2.1}}$] *stack*

<s> Bush held talks *hypothesis*



action: pop

(Huang and Mi, 2010)

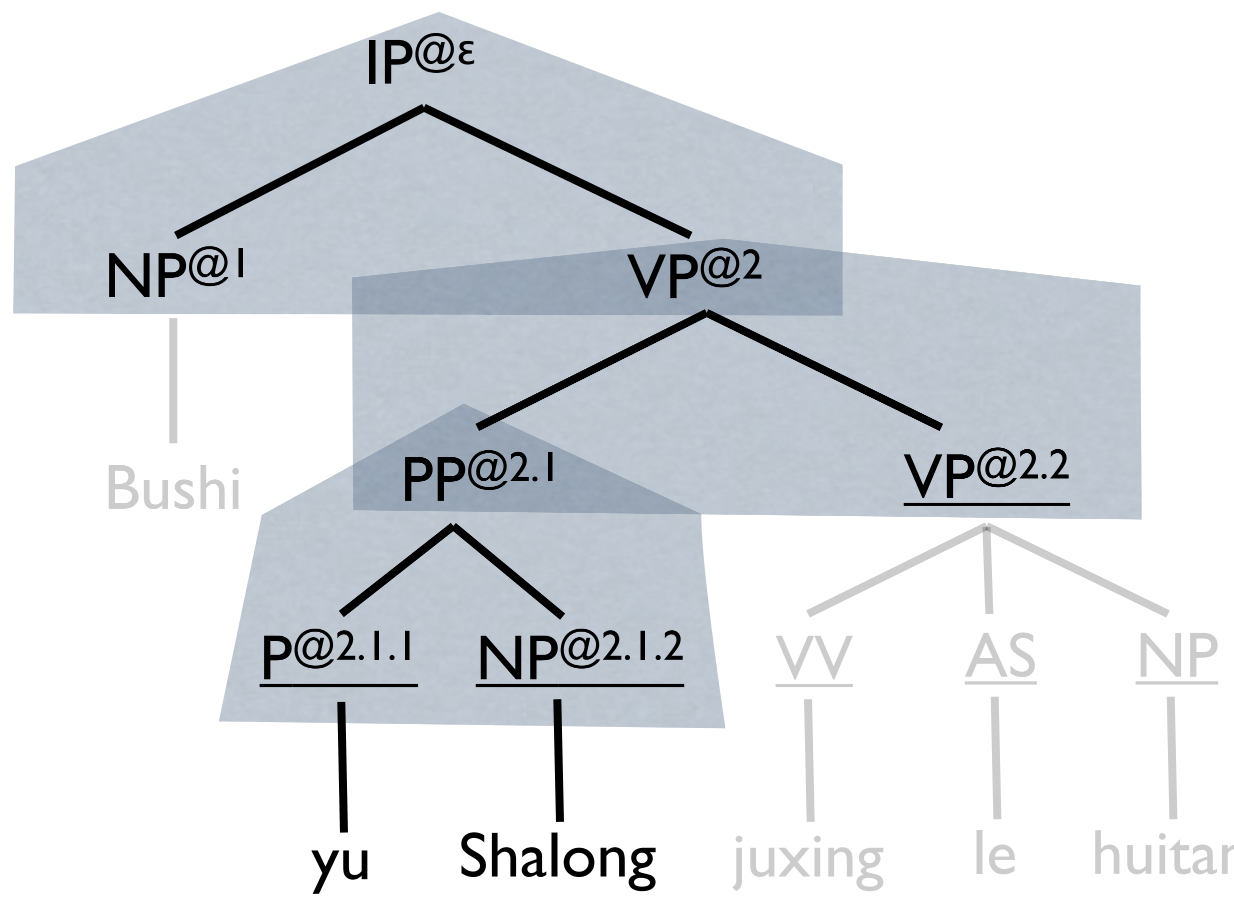
Example Incremental Decoding

$$[\langle s\rangle \bullet \mathrm{IP}^{@\epsilon} \langle /s\rangle]\ \underset{r_1}{[\mathrm{NP}^{@1} \bullet \mathrm{VP}^{@2}]}\ \underset{r_3}{[\underline{\mathrm{VP}^{@2.2}} \bullet \underline{\mathrm{PP}^{@2.1}}]}\ \underset{r_4}{[\bullet\ \underline{\mathrm{P}^{@2.1.1}}\ \underline{\mathrm{NP}^{@2.1.2}}]}$$

stack

<s> Bush held talks

hypothesis



action: predict

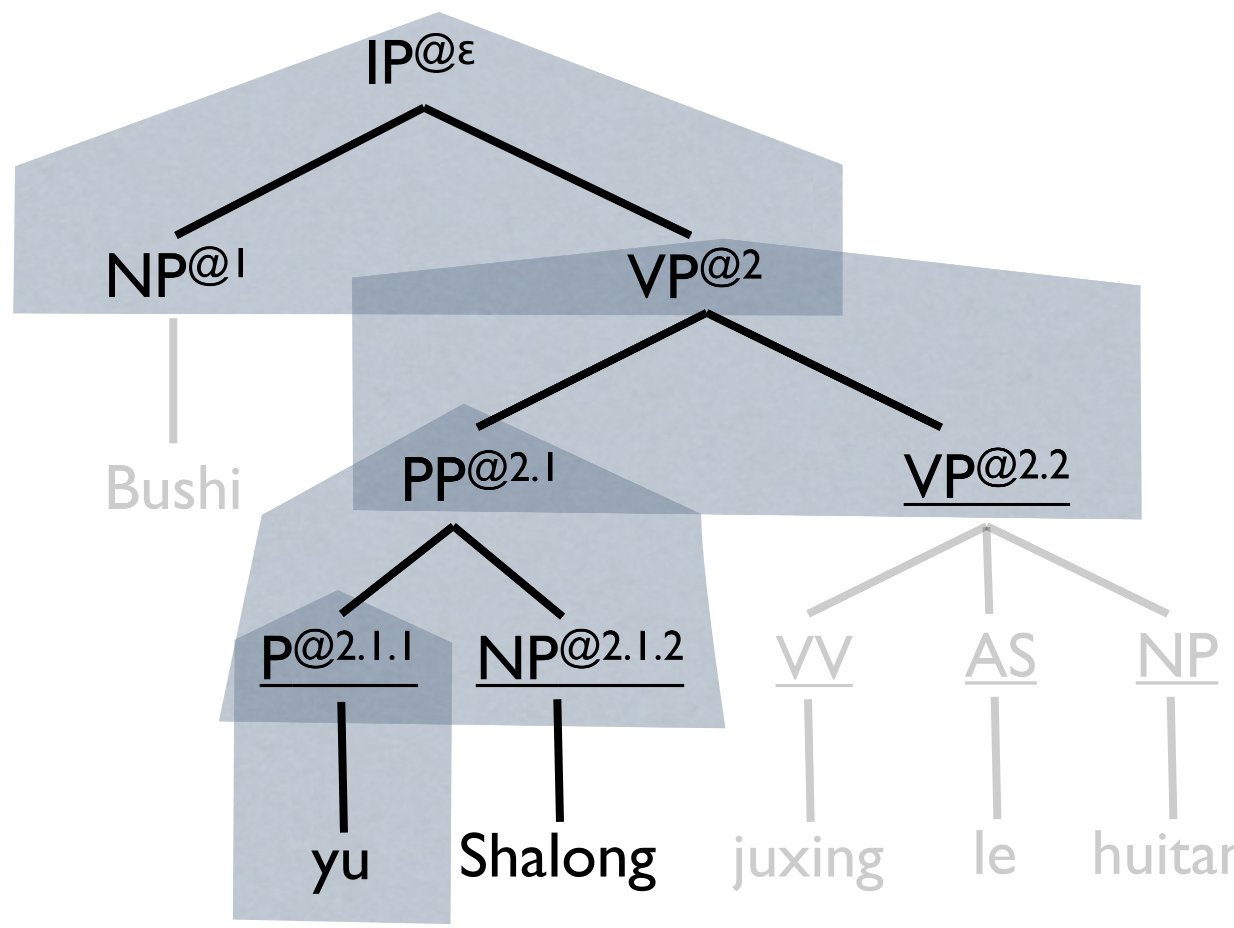
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [. P@2.1.1 NP@2.1.2] [. with/and] *stack*

r1 r3 r4 r_6/r'_6

<s> Bush held talks *hypothesis*



action: predict

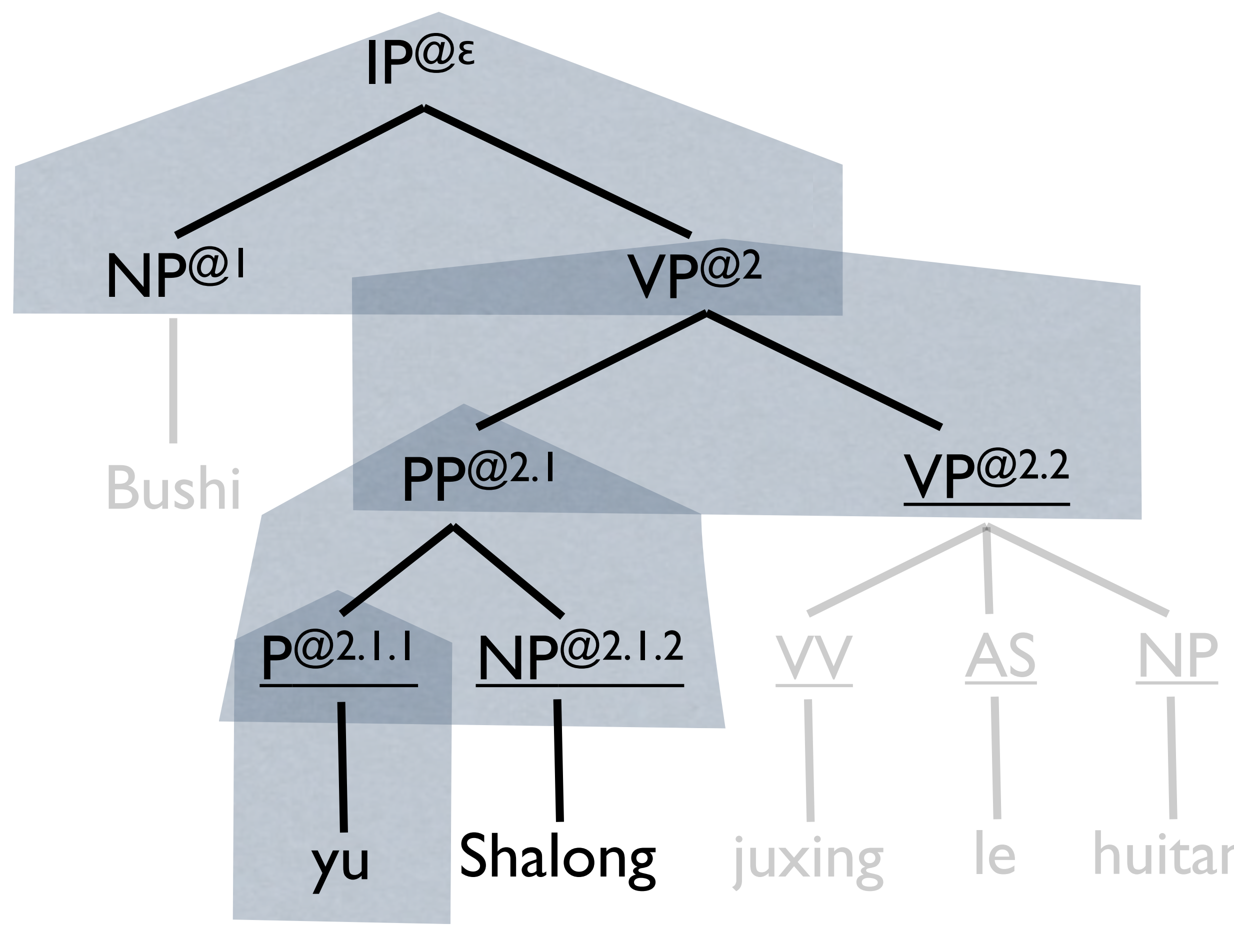
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> • IP@ε </s>] [NP@1 • VP@2] [VP@2.2 • PP@2.1] [• P@2.1.1 NP@2.1.2] [and •] *stack*

r1 r3 r4 r'6

<s> Bush held talks and *hypothesis*



action: scan

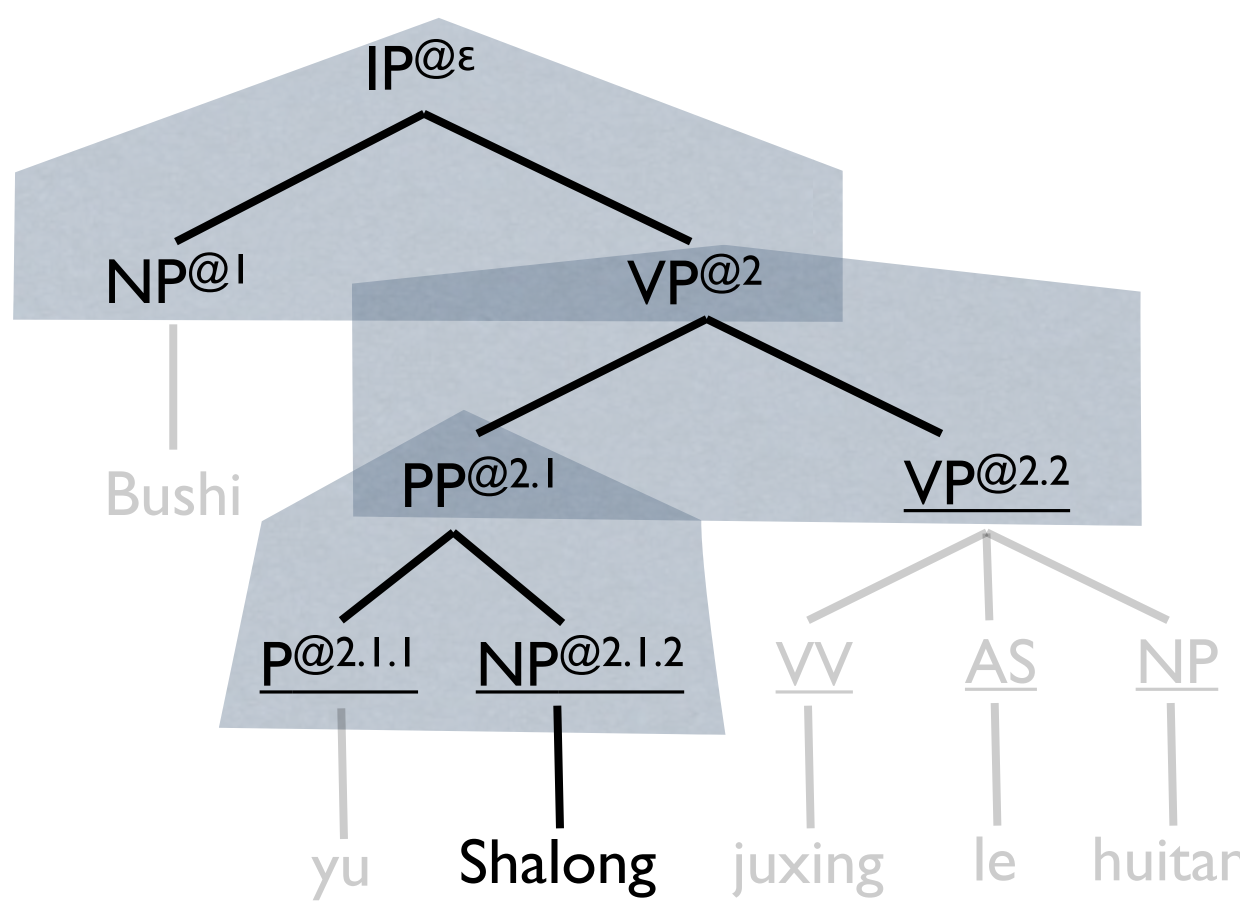
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [P@2.1.1 . NP@2.1.2] *stack*

r_1 r_3 r_4

<s> Bush held talks and *hypothesis*



action: pop

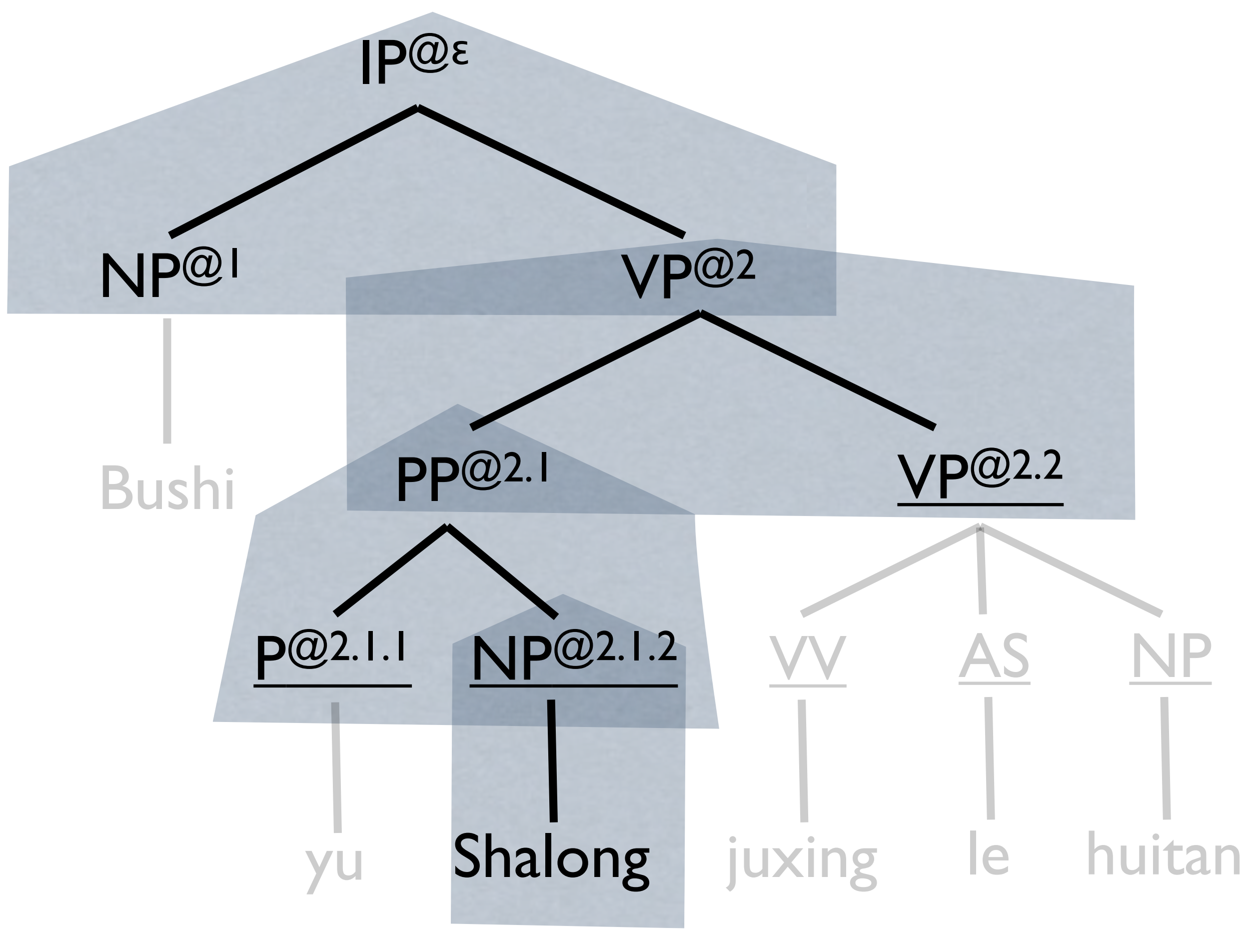
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . $IP^{@\varepsilon}$ </s>] [$NP^{@1}$. $VP^{@2}$] [$\underline{VP^{@2.2}}$. $\underline{PP^{@2.1}}$] [$\underline{P^{@2.1.1}}$. $\underline{NP^{@2.1.2}}$] [. Sharon] *stack*

r_1 r_3 r_4 r_7

<s> Bush held talks and *hypothesis*



action: predict

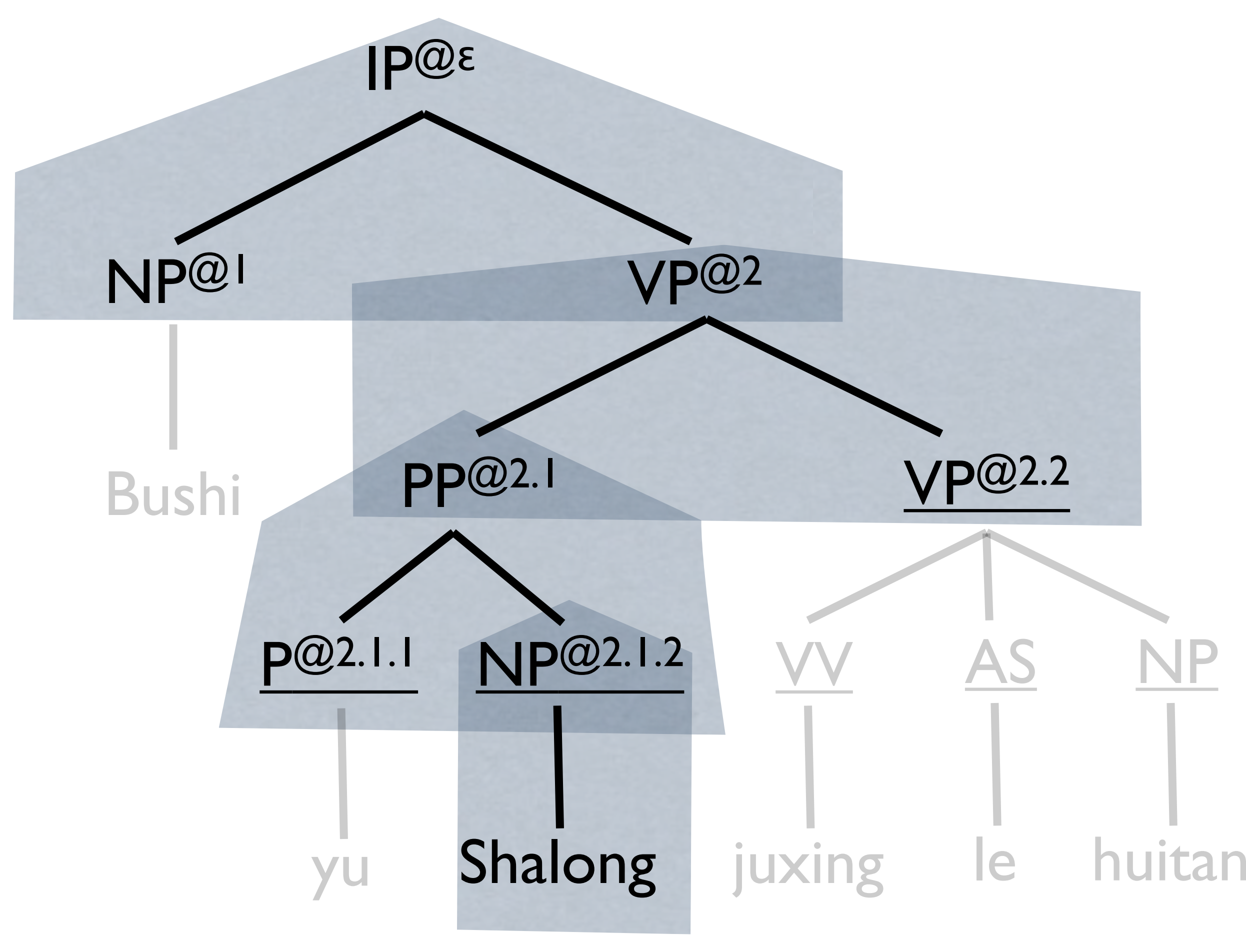
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [P@2.1.1 . NP@2.1.2] [Sharon .] *stack*

r1 r3 r4 r7

<s> Bush held talks and Sharon *hypothesis*



action: scan

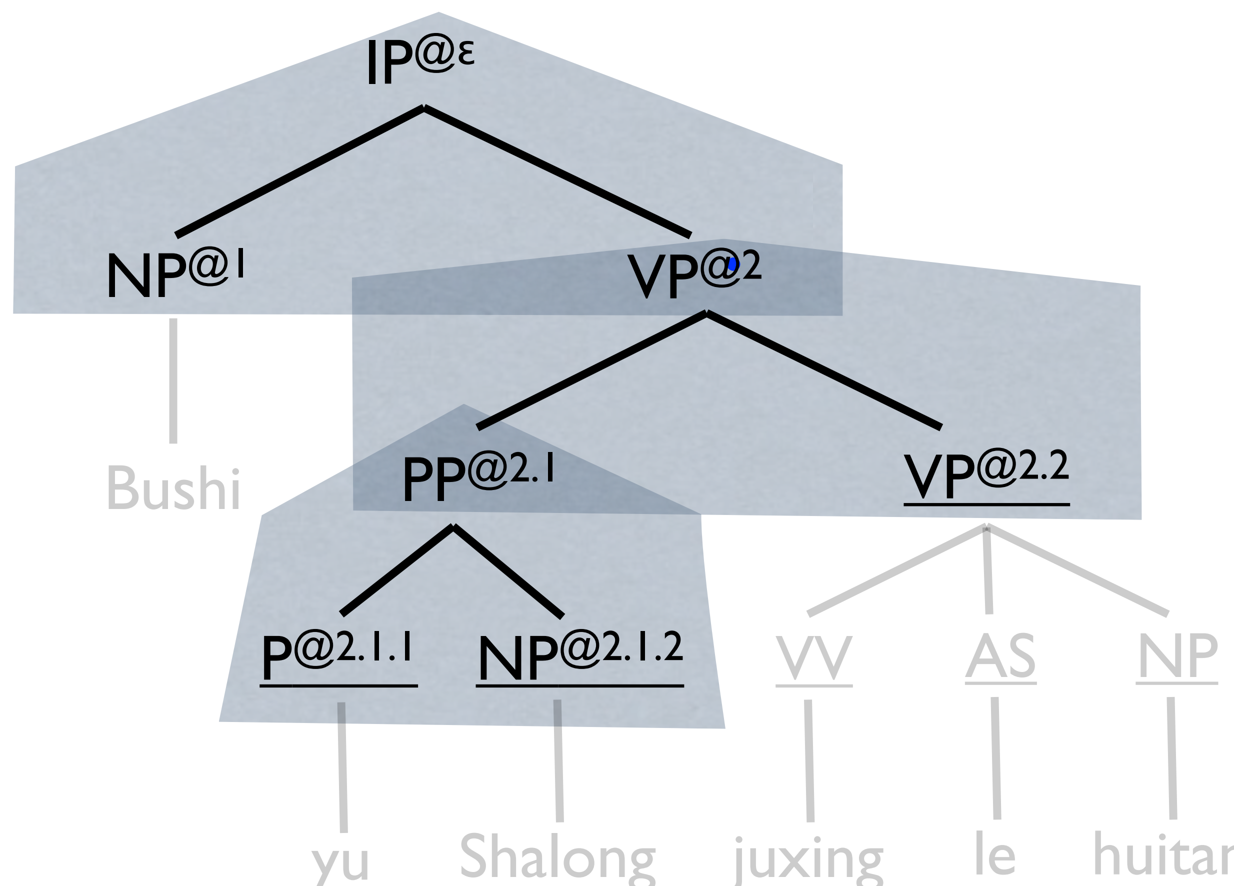
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@$^{\varepsilon}$ </s>] [NP@^{1} . VP@^{2}] [<u>VP@$^{2.2}$</u> . <u>PP@$^{2.1}$</u>] [<u>P@$^{2.1.1}$</u> <u>NP@$^{2.1.2}$</u> .] *stack*

r$_1$ r$_3$ r$_4$

<s> Bush held talks and Sharon *hypothesis*



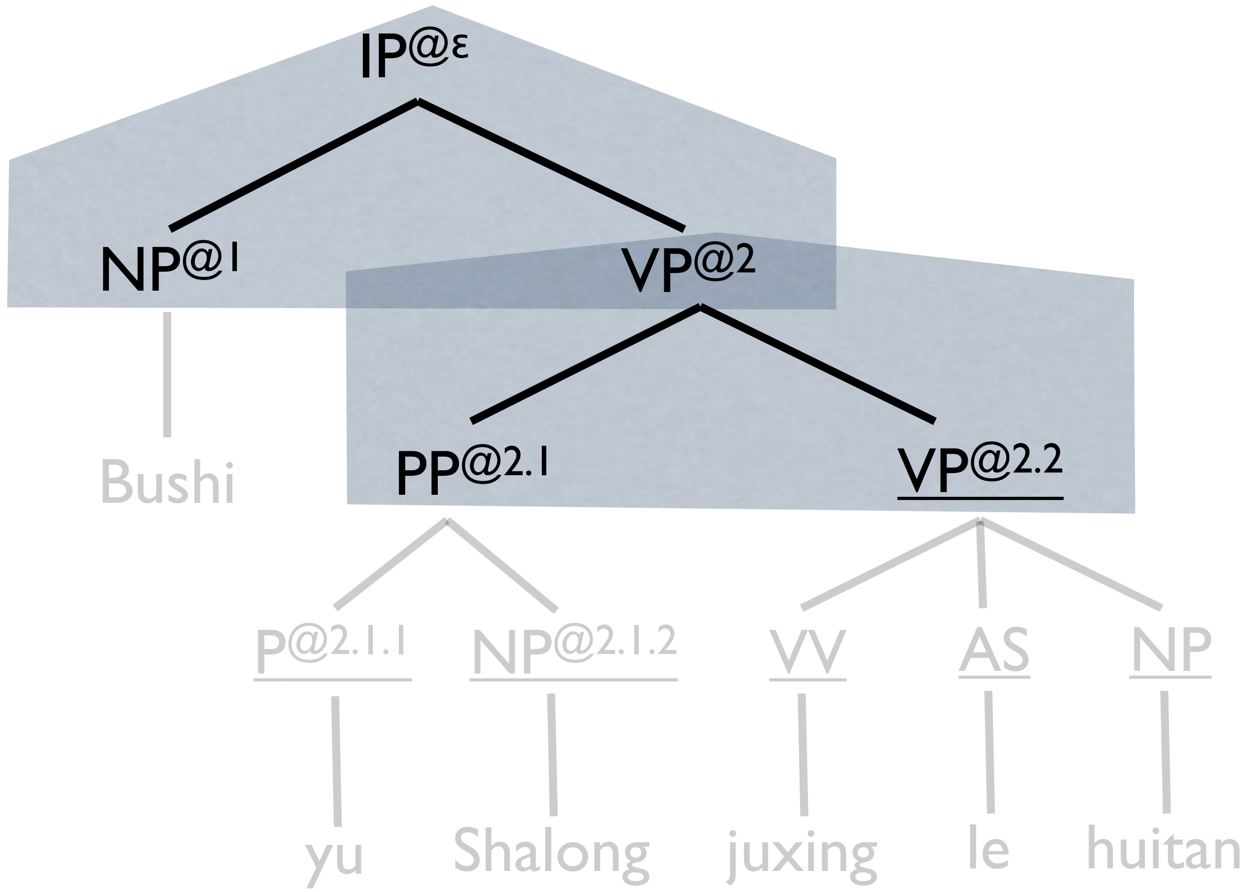
action: pop

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . $IP^{@\epsilon}$ </s>] [$NP^{@1}$. $VP^{@2}$]$_{r_1}$ [$\underline{VP^{@2.2}}$ $\underline{PP^{@2.1}}$.]$_{r_3}$ *stack*

<s> Bush held talks and Sharon *hypothesis*



action: pop

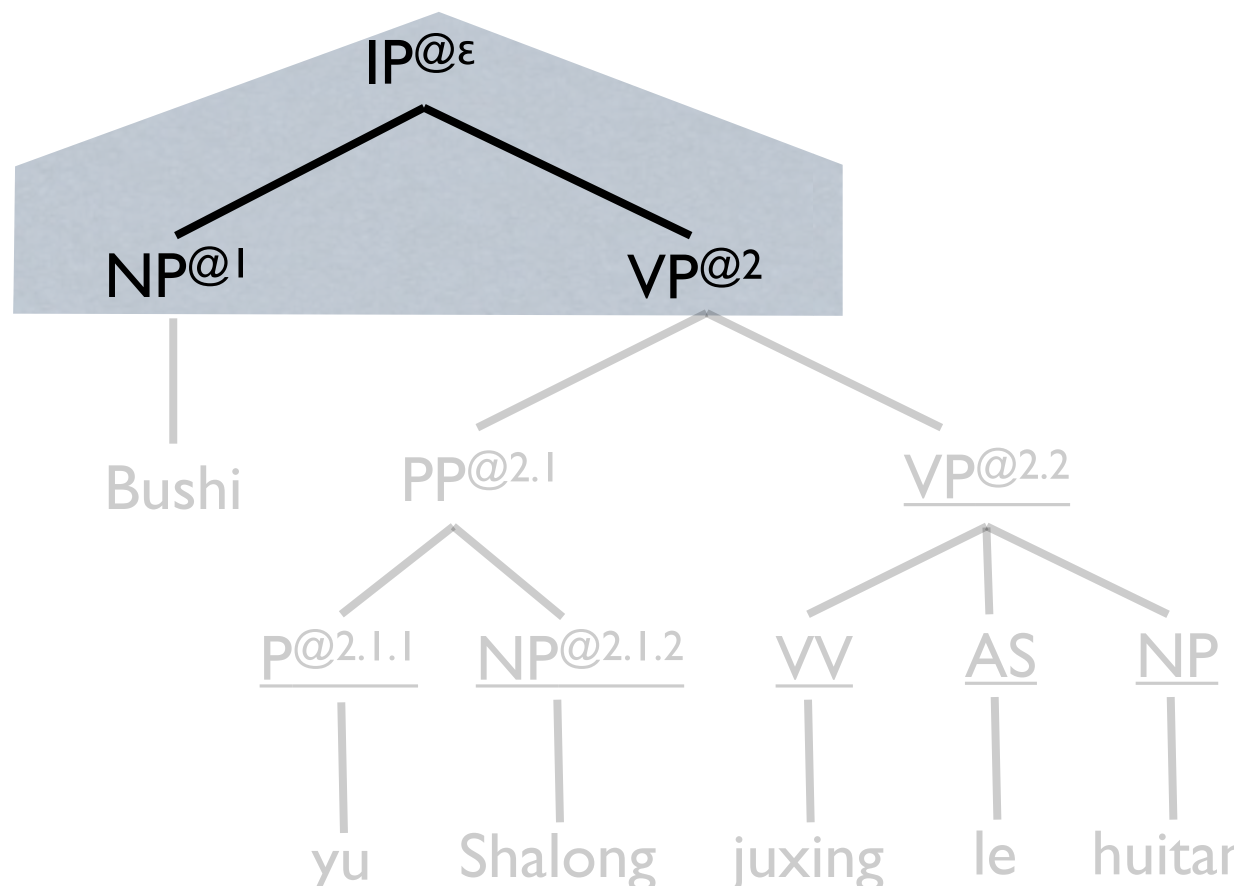
(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 VP@2 .] *stack*

r_1

<s> Bush held talks and Sharon *hypothesis*



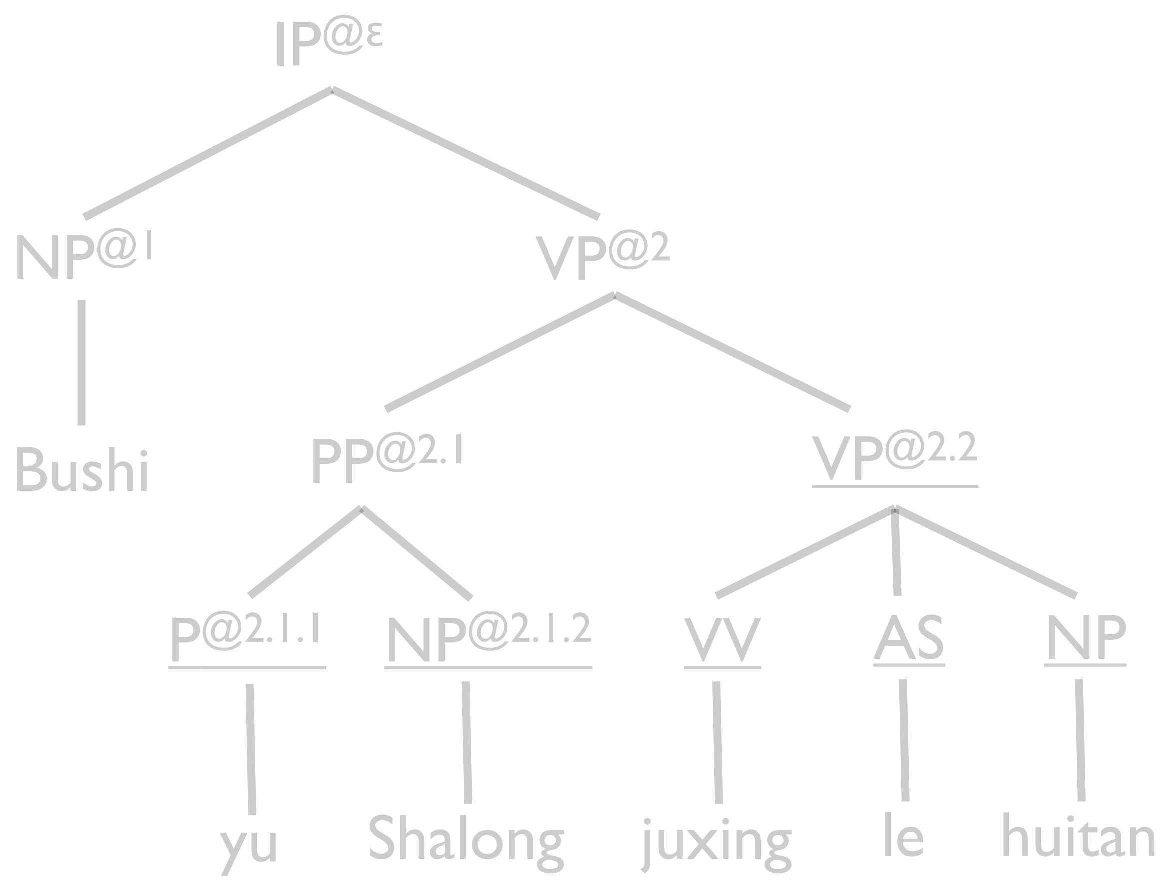
action: pop

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> IP@ε •</s>] *stack*

<s> Bush held talks and Sharon *hypothesis*



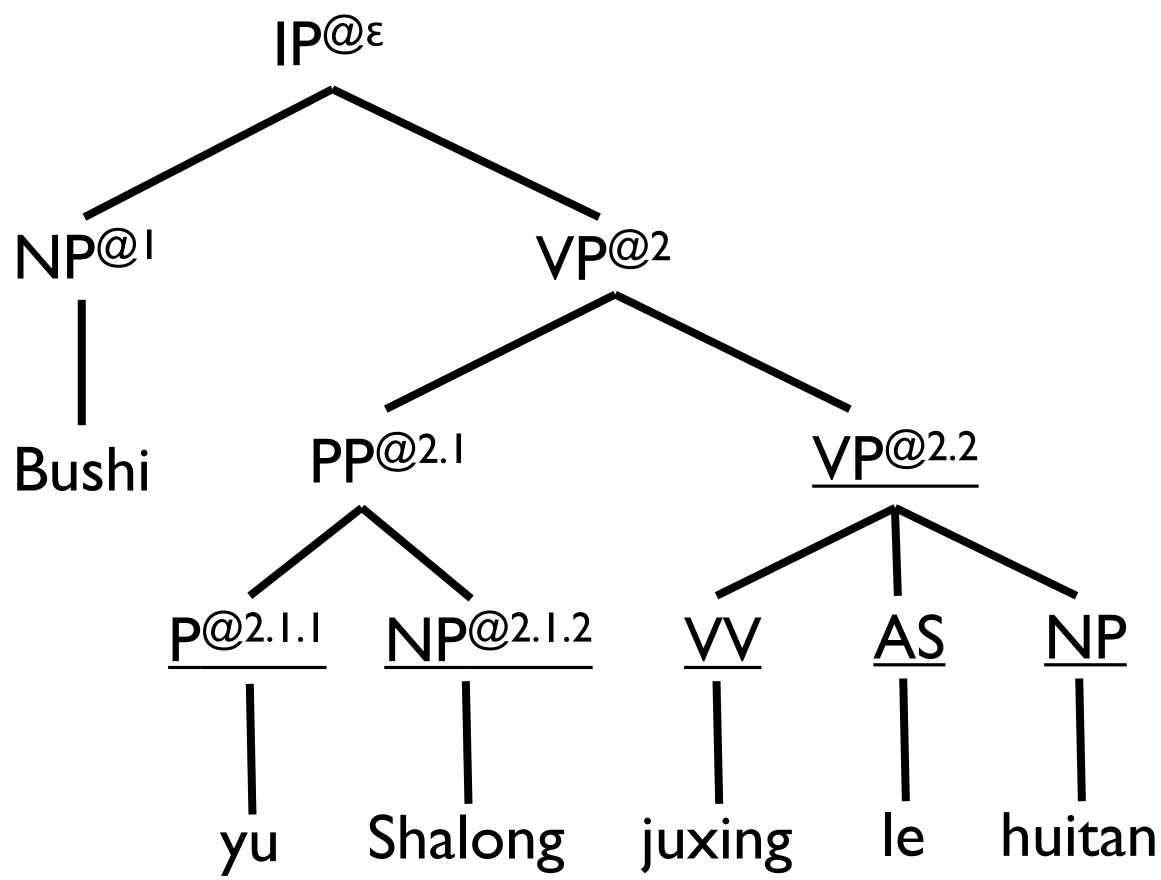
action: pop

(Huang and Mi, 2010)

Example Incremental Decoding

[<s> . $IP^{@\varepsilon}$ </s>] *stack*

<s> *hypothesis*



this work: adding rule LM

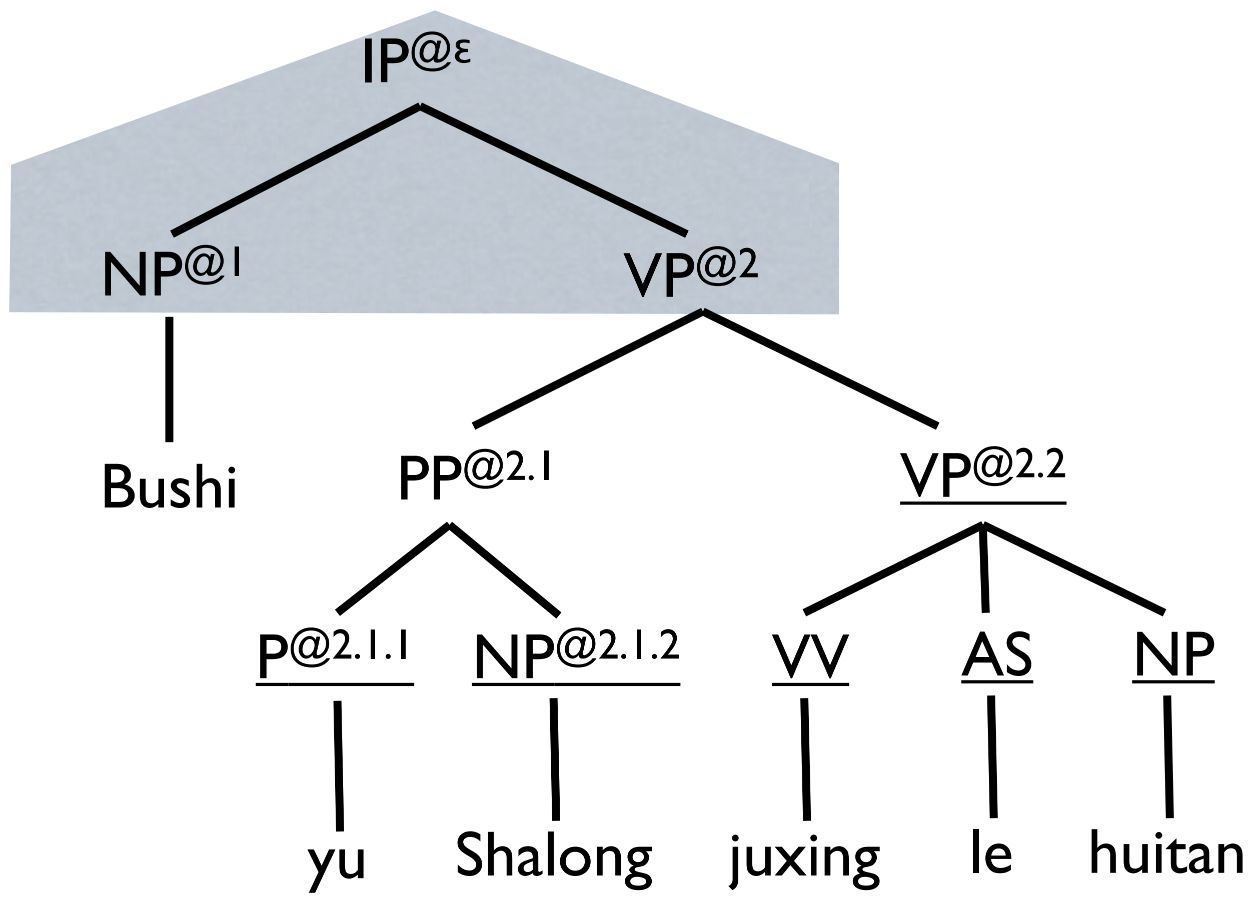
Example Incremental Decoding

[<s> . IP@$^{\epsilon}$ </s>] [. NP@^{1} VP@^{2}]
r_1

stack

<s>

hypothesis



rule probability

$P(r_1|\epsilon)$

action: predict (push)

this work: adding rule LM

Example Incremental Decoding

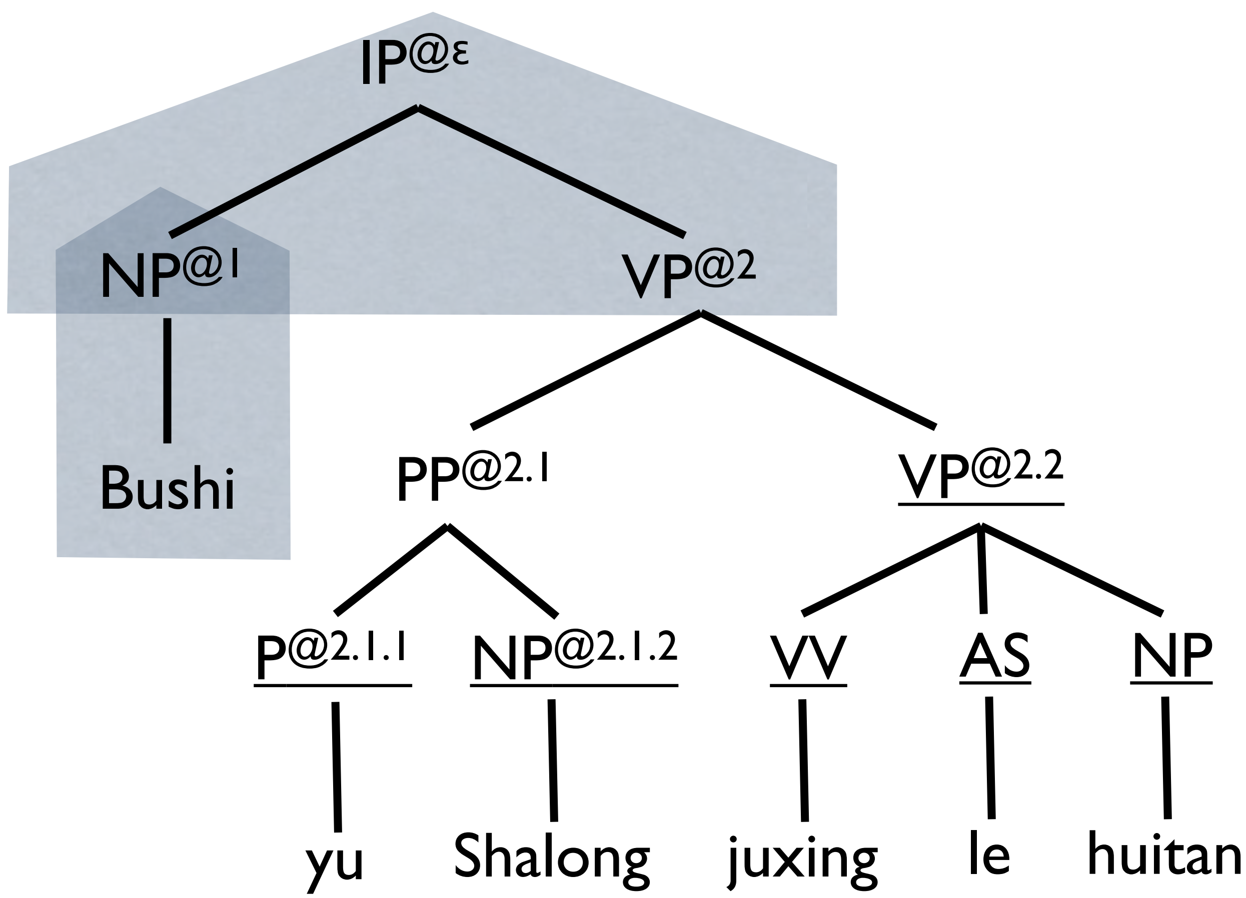
[<s> . $IP^{@\varepsilon}$ </s>] [. $NP^{@1}$ $VP^{@2}$] [. Bush]

r_1 r_2

stack

<s>

hypothesis



rule probability

$P(r_2|r_1)$

action: predict

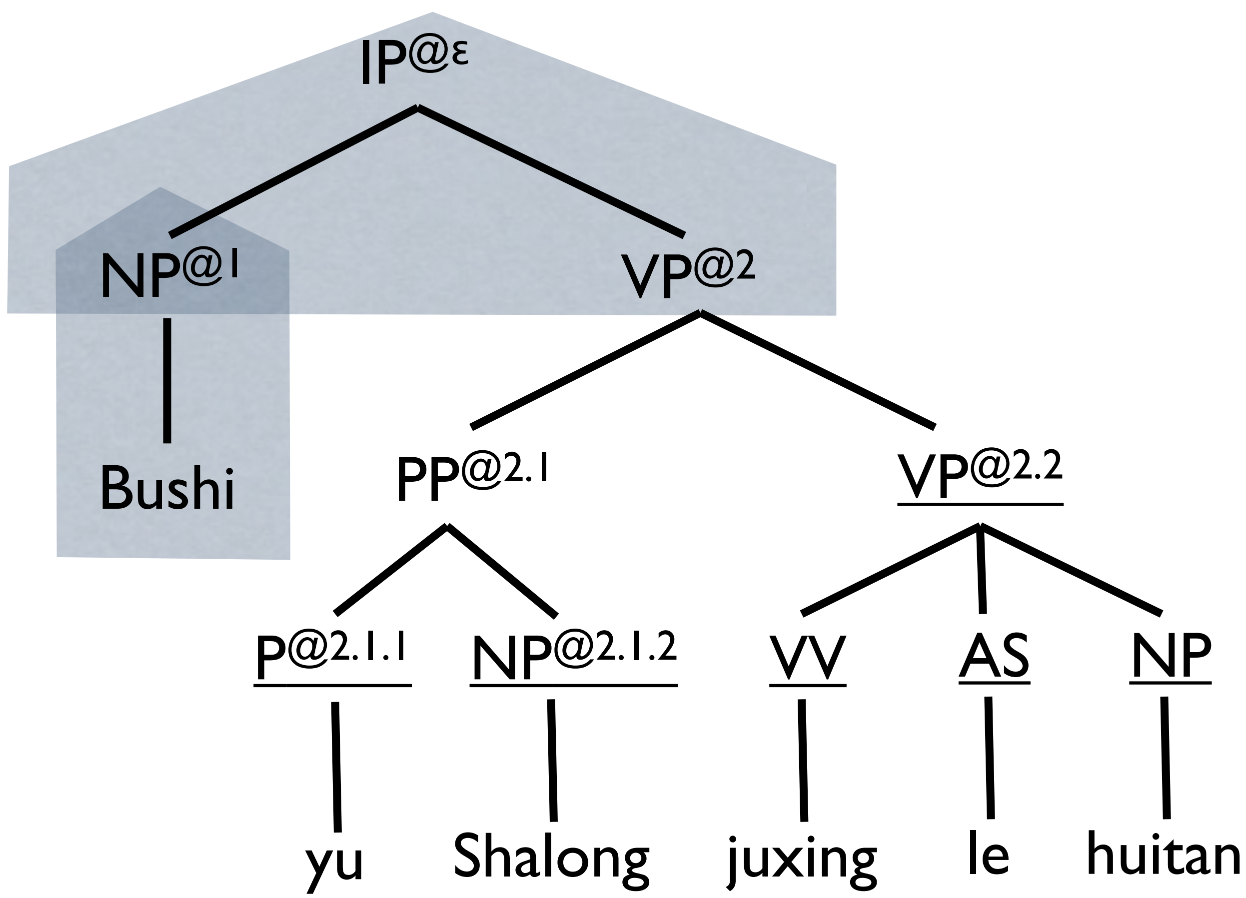
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [. NP@1 VP@2] [Bush .] *stack*

r_1 r_2

<s> Bush *hypothesis*



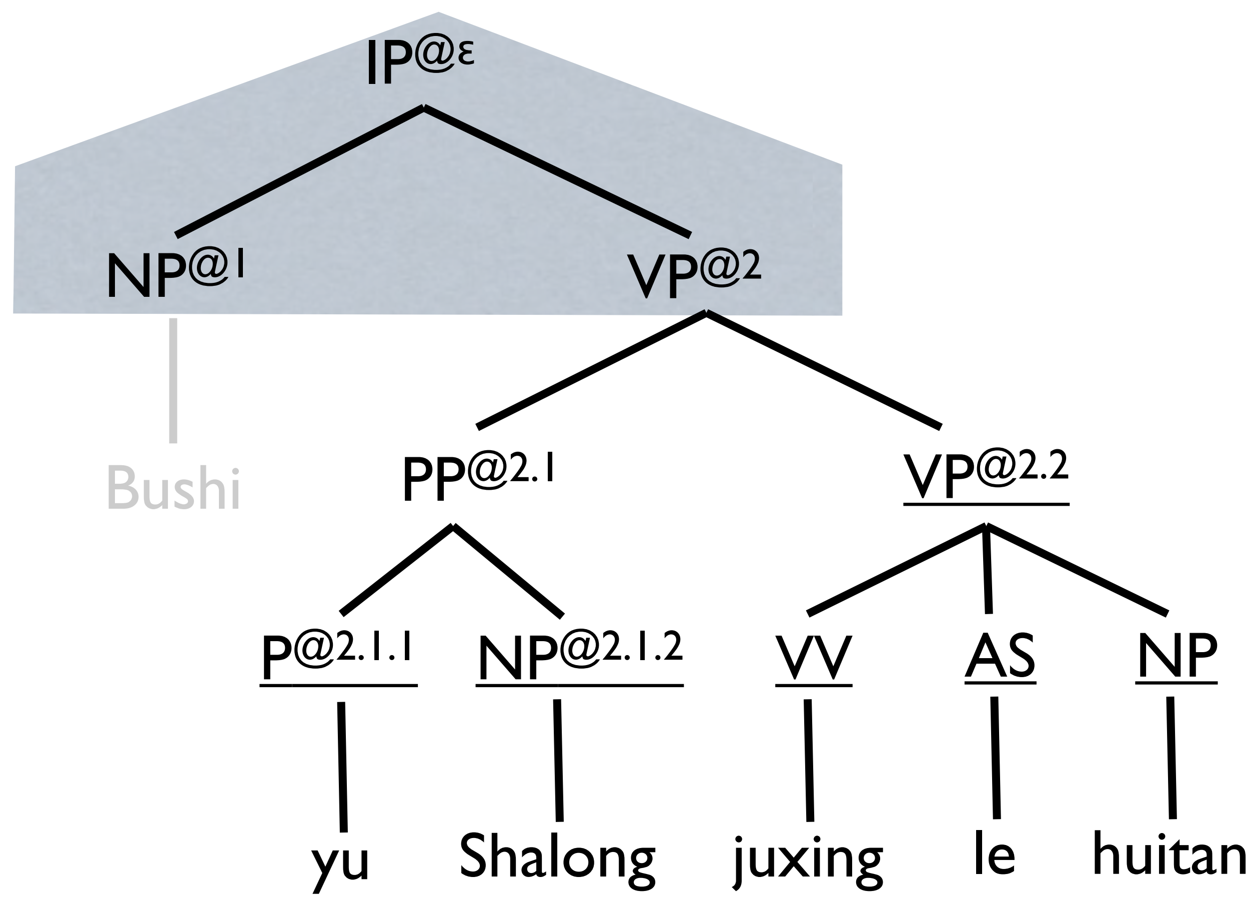
action: scan

this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 $_{r_1}$. VP@2] *stack*

<s> Bush *hypothesis*



action: pop

this work: adding rule LM

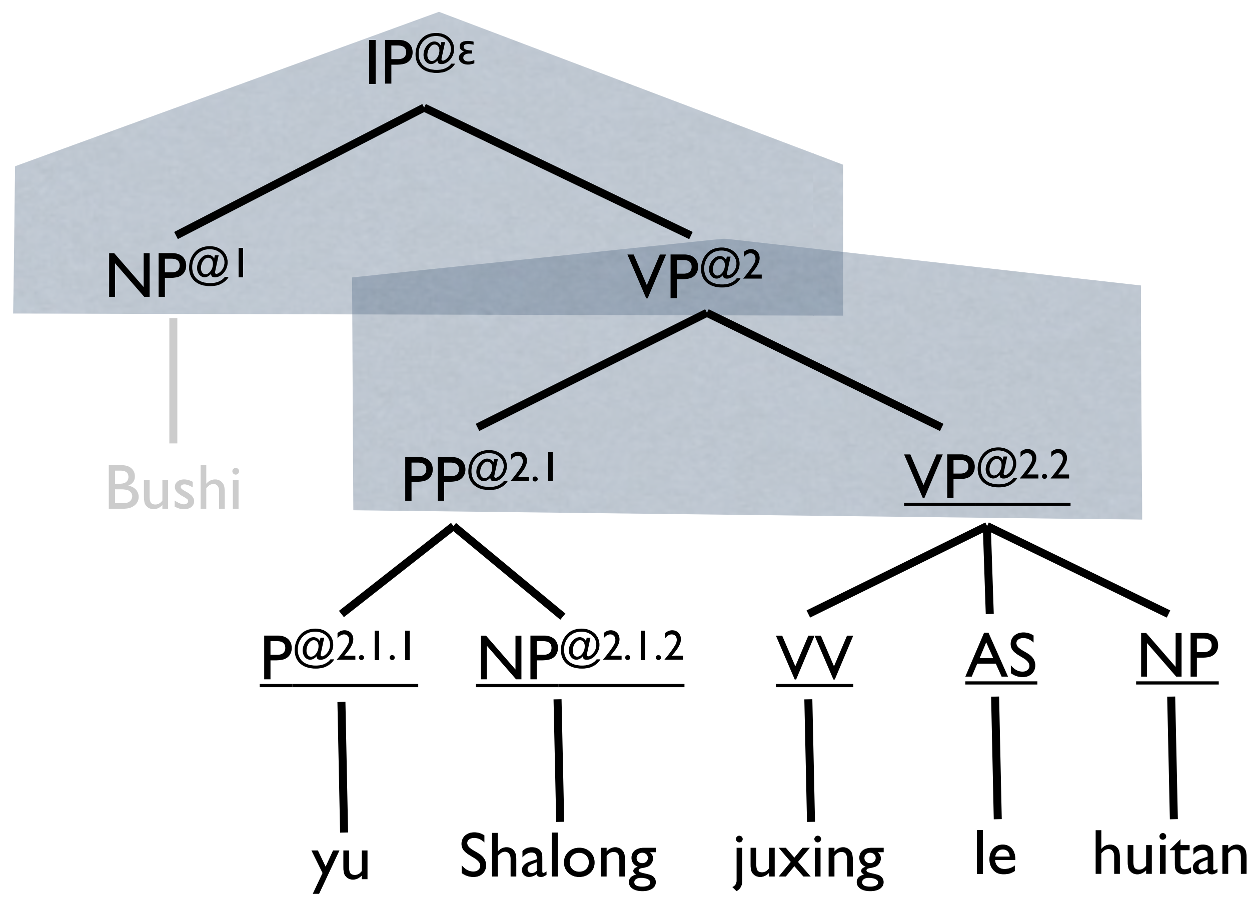
Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [. VP@2.2 PP@2.1]
r_1 r_3

stack

<s> Bush

hypothesis



rule probability

$P(r_3|r_1)$

action: predict

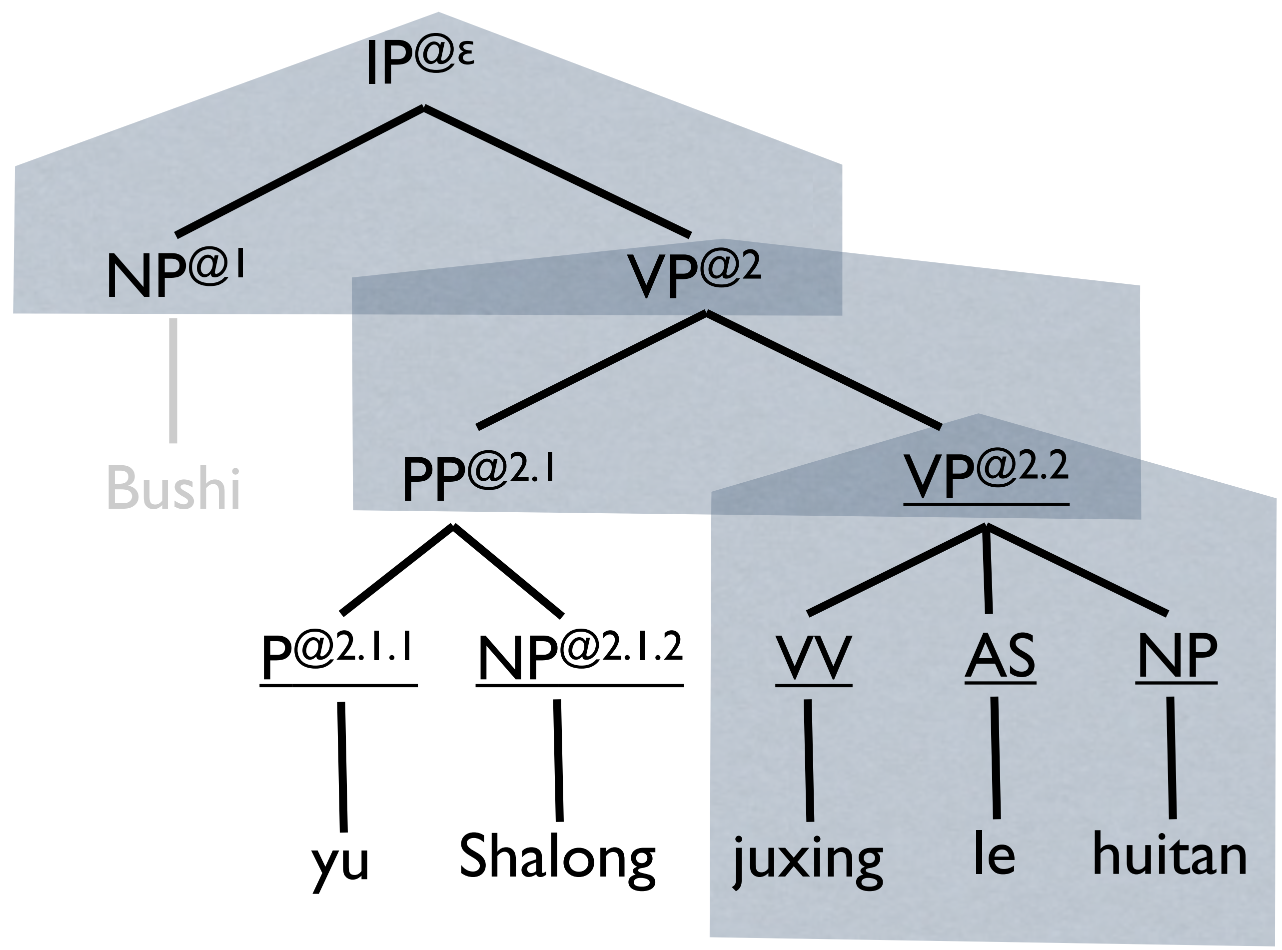
this work: adding rule LM

Example Incremental Decoding

[<s> . $IP^{@\varepsilon}$ </s>] [$NP^{@1}$. $VP^{@2}$] [. $\underline{VP^{@2.2}}$ $\underline{PP^{@2.1}}$] [. held talks] *stack*

r_1 r_3 r_5

<s> Bush *hypothesis*



rule probability

$P(r_5|r_1,r_3)$

action: predict

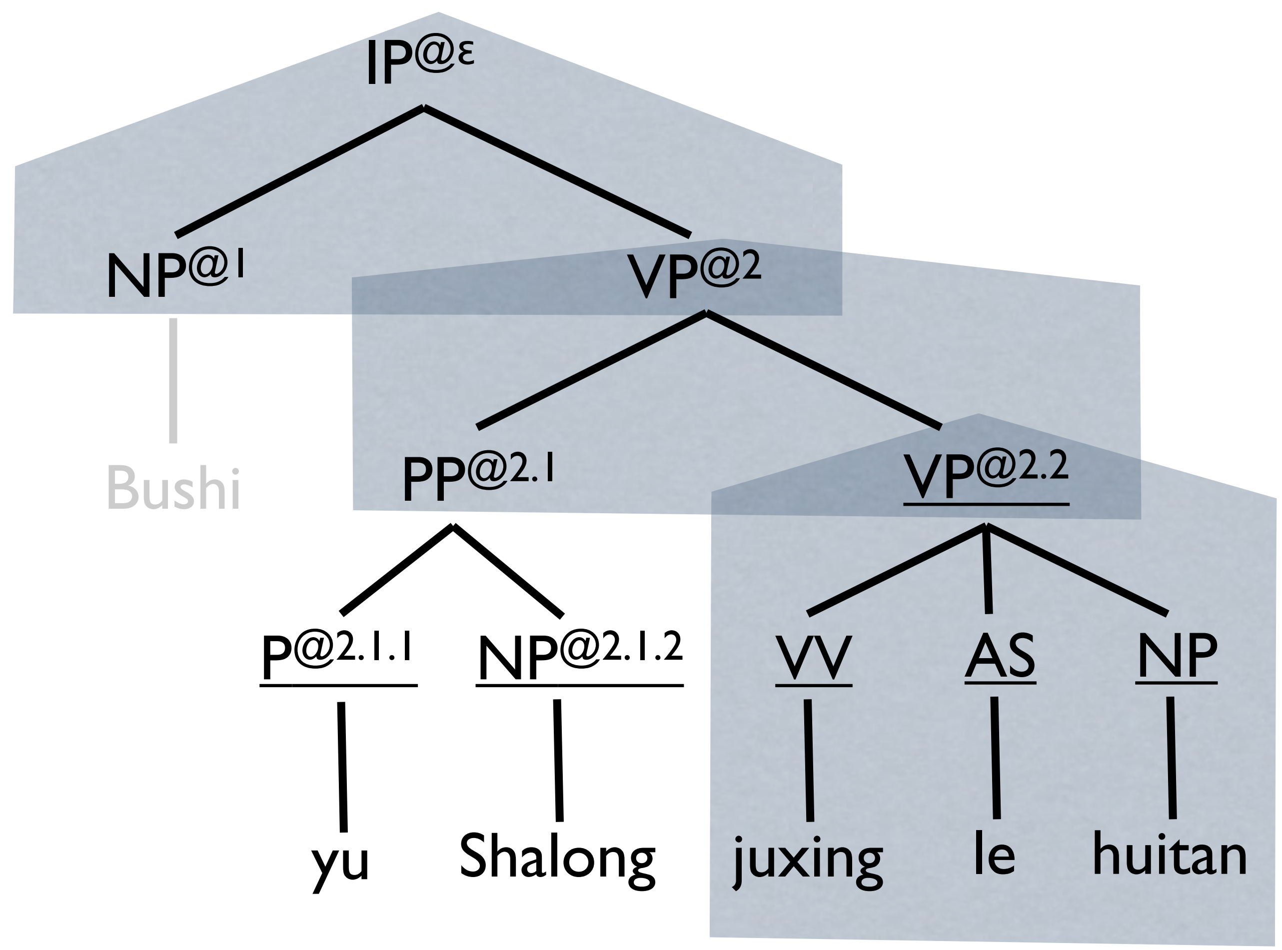
this work: adding rule LM

Example Incremental Decoding

[<s> . IP$^{@\varepsilon}$ </s>] [NP$^{@1}$. VP$^{@2}$] [. $\underline{\text{VP}^{@2.2}}$ $\underline{\text{PP}^{@2.1}}$] [held talks .] *stack*

r_1 r_3 r_5

<s> Bush held talks *hypothesis*



action: scan

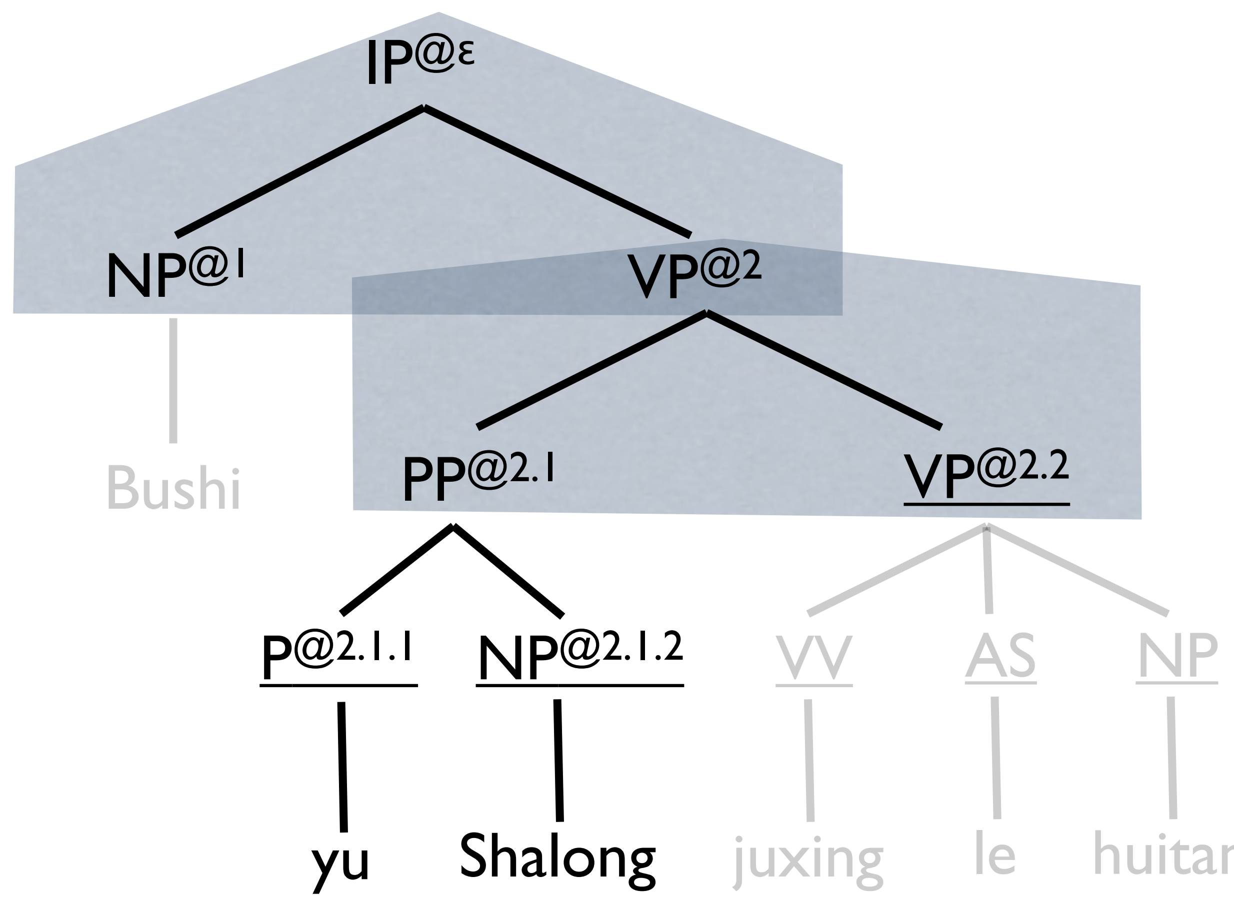
this work: adding rule LM

Example Incremental Decoding

[<s> . IP$^{@\varepsilon}$ </s>] [NP$^{@1}$. VP$^{@2}$] [. VP$^{@2.2}$ PP$^{@2.1}$] *stack*

r_1 r_3

<s> Bush held talks *hypothesis*



action: pop

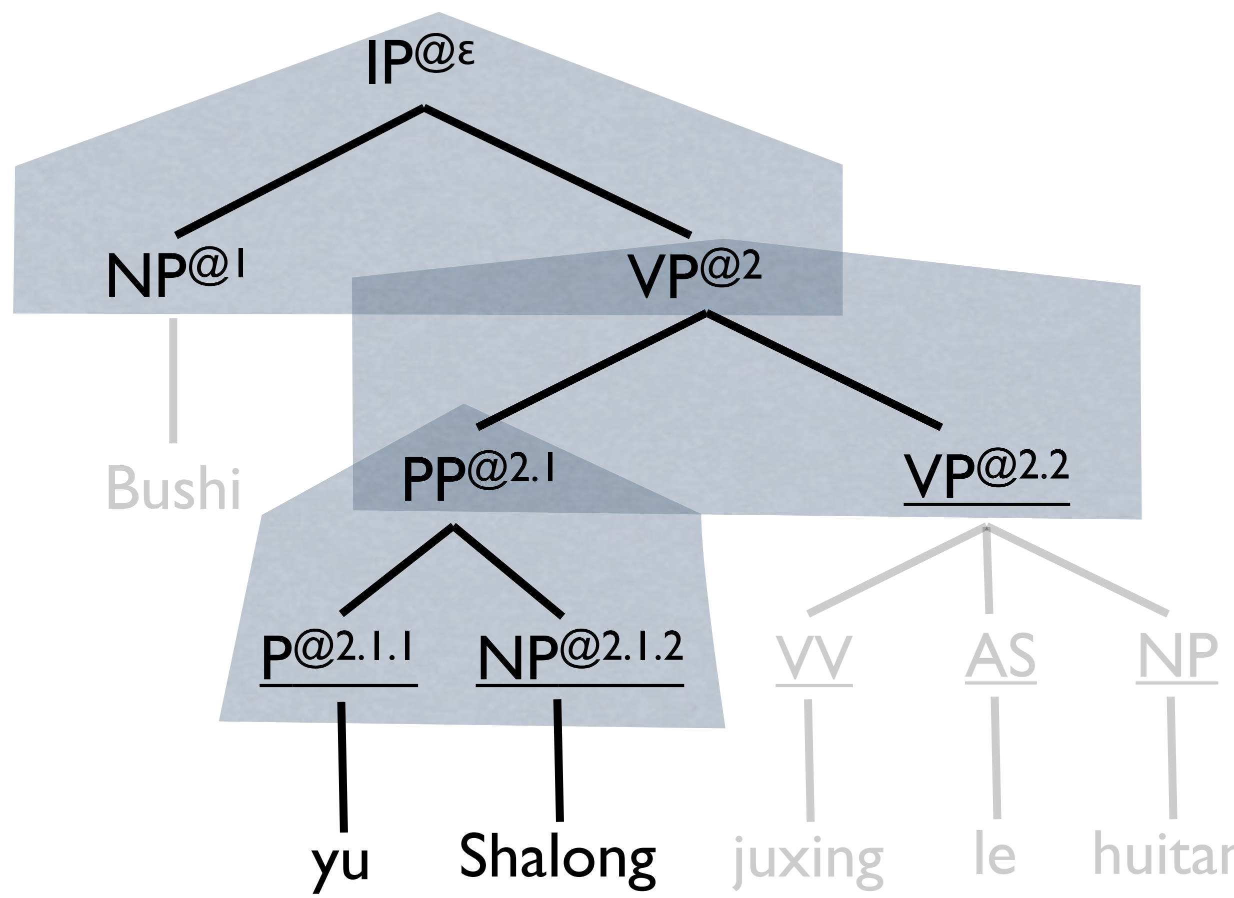
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [. P@2.1.1 NP@2.1.2] *stack*

r_1 r_3 r_4

<s> Bush held talks *hypothesis*



rule probability

$P(r_4|r_1,r_3)$

action: predict

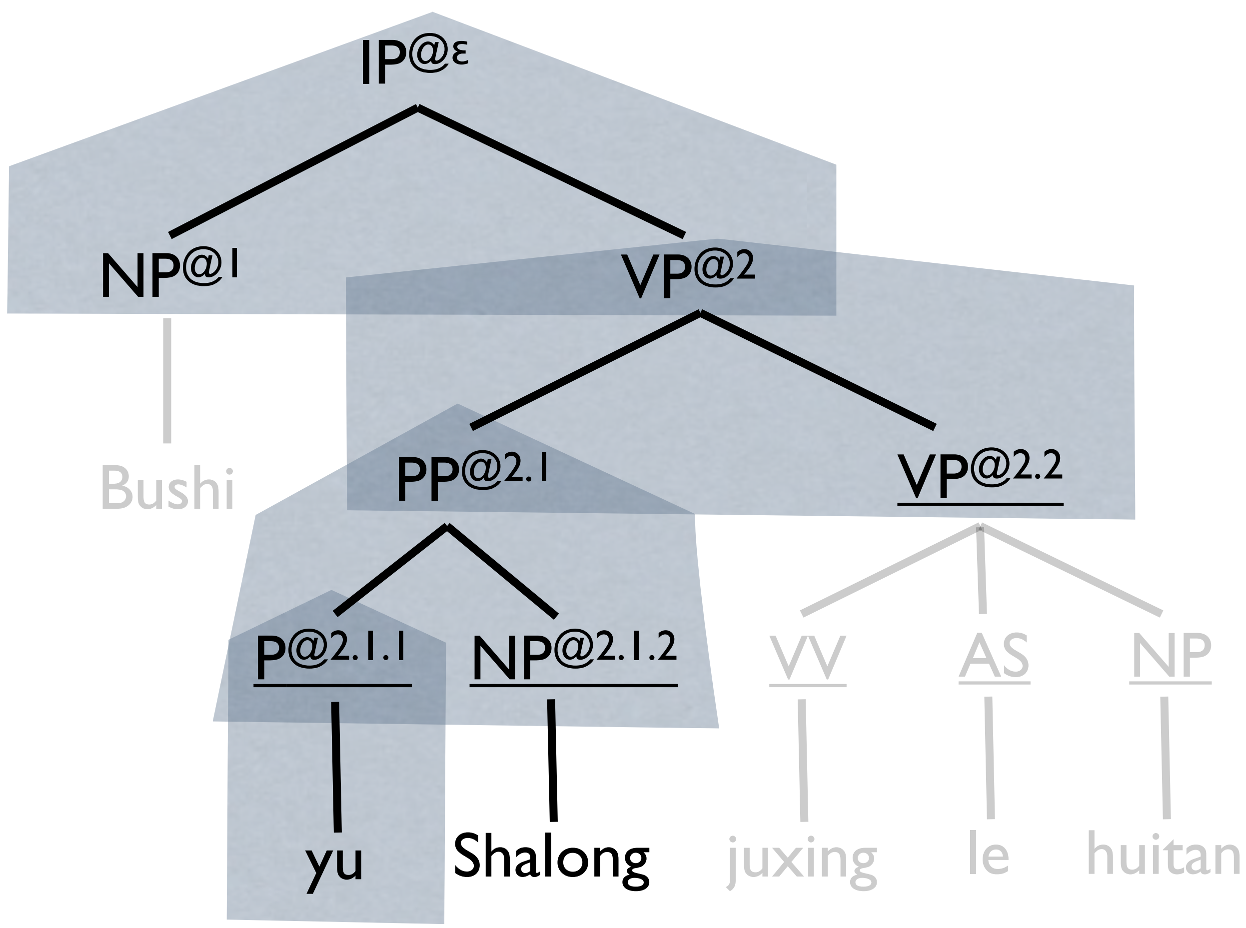
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [. P@2.1.1 NP@2.1.2] [. with/and] *stack*

r_1 r_3 r_4 r_6/r'_6

<s> Bush held talks *hypothesis*



rule probability

$P(r_6/r'_6 \mid r_3, r_4)$

action: predict

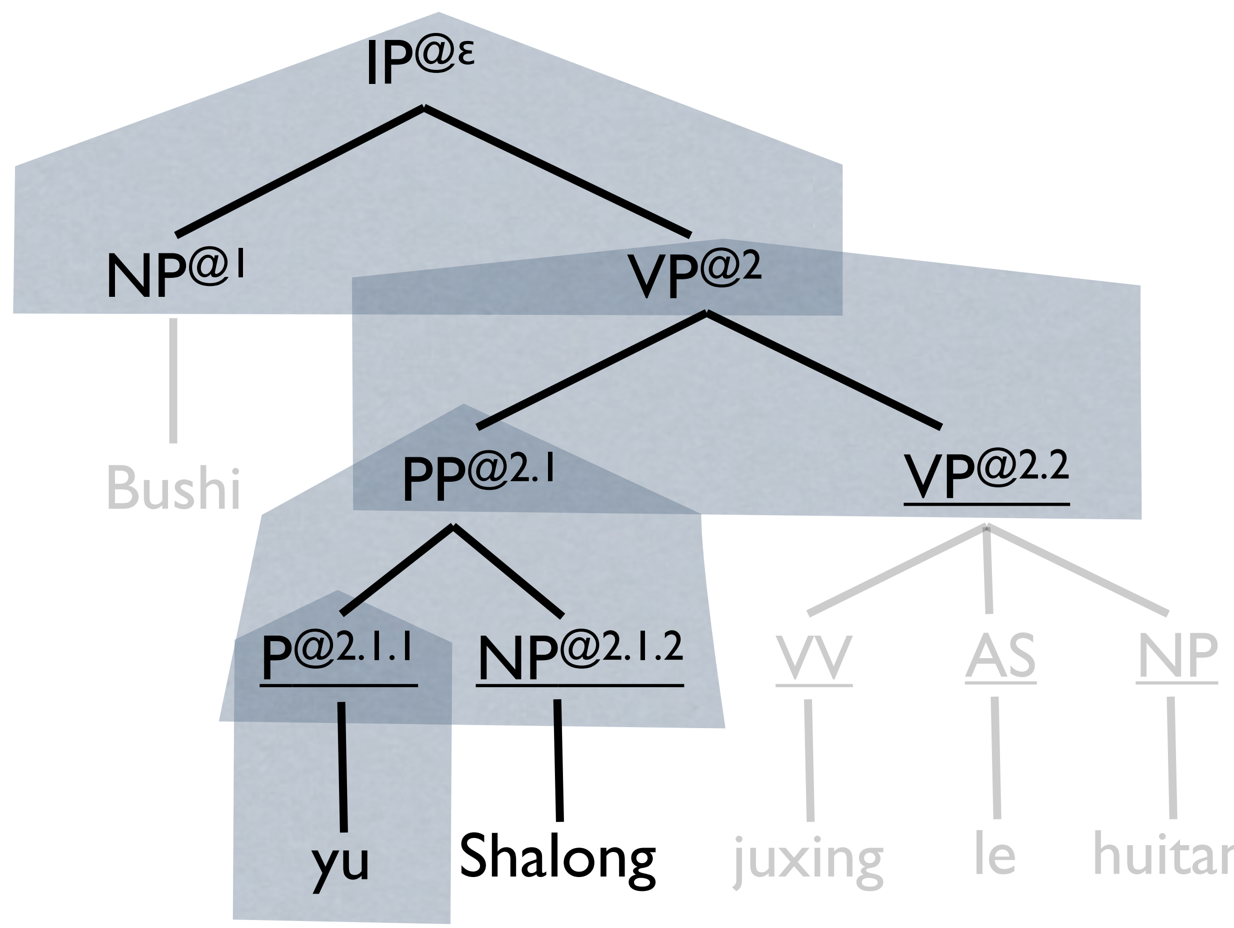
this work: adding rule LM

Example Incremental Decoding

[<s> . $IP^{@\varepsilon}$ </s>] [$NP^{@1}$. $VP^{@2}$] [$\underline{VP^{@2.2}}$. $\underline{PP^{@2.1}}$] [. $\underline{P^{@2.1.1}}$ $\underline{NP^{@2.1.2}}$] [with .] *stack*

r_1 r_3 r_4 r_6

<s> Bush held talks with *hypothesis*



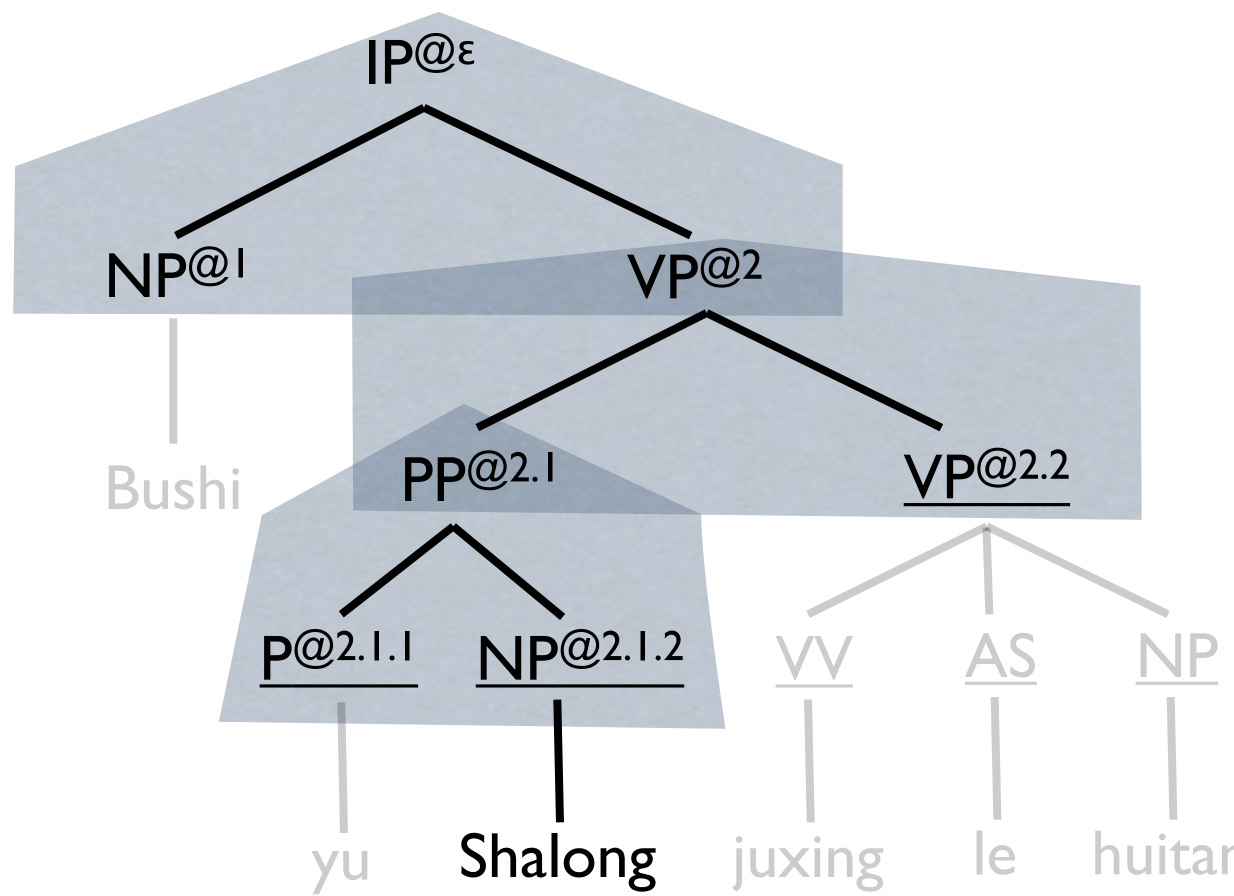
action: scan

this work: adding rule LM

Example Incremental Decoding

$[\langle s\rangle \bullet \text{IP}^{@\varepsilon}\ \langle/s\rangle]\ [\text{NP}^{@1} \underset{r_1}{\bullet} \text{VP}^{@2}]\ [\underline{\text{VP}^{@2.2}} \underset{r_3}{\bullet} \underline{\text{PP}^{@2.1}}]\ [\underline{\text{P}^{@2.1.1}} \underset{r_4}{\bullet} \underline{\text{NP}^{@2.1.2}}]$ *stack*

<s> Bush held talks with *hypothesis*



action: pop

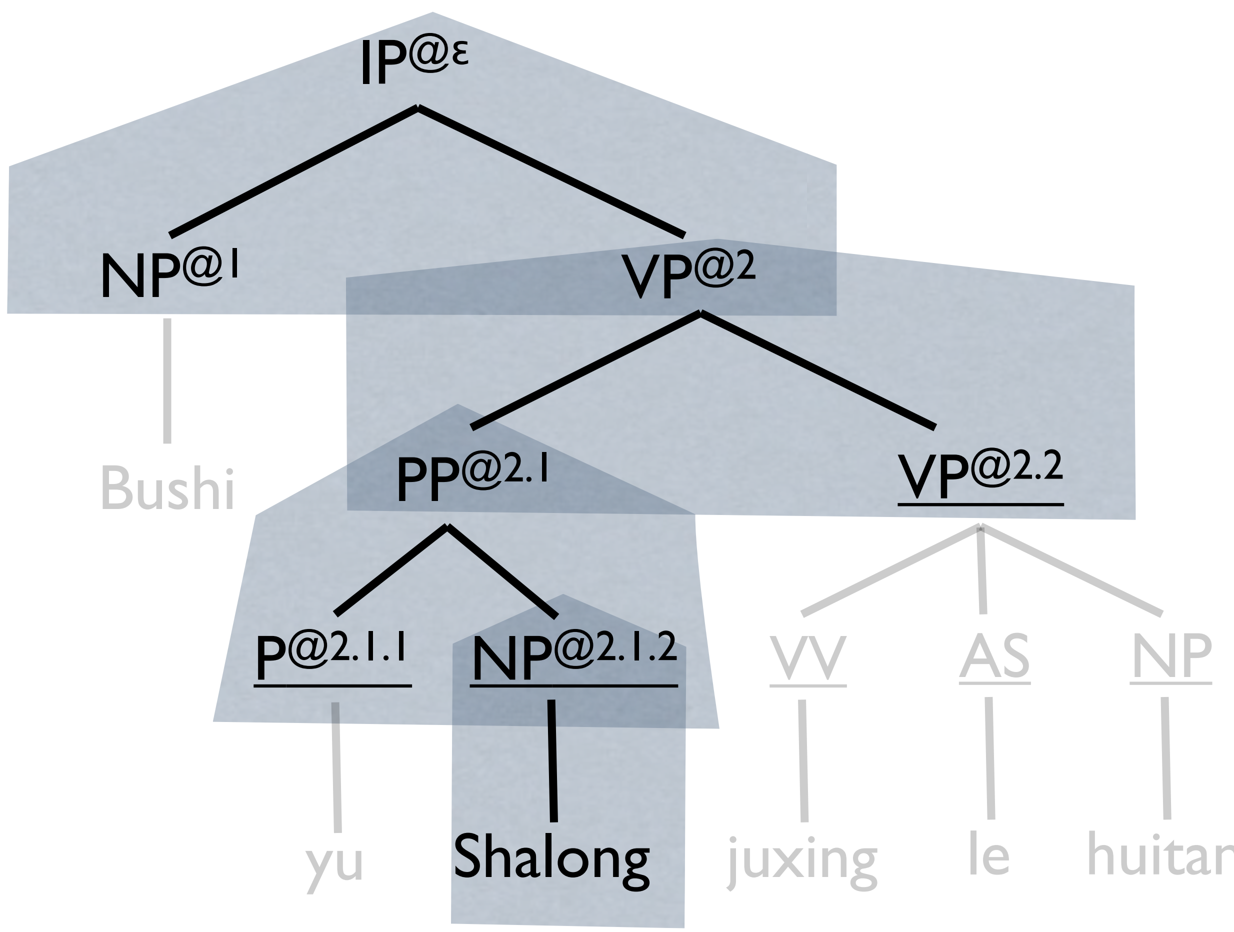
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [P@2.1.1 . NP@2.1.2] [. Sharon] *stack*

r_1 r_3 r_4 r_7

<s> Bush held talks with *hypothesis*



rule probability

$P(r_7 \mid r_3, r_4)$

action: predict

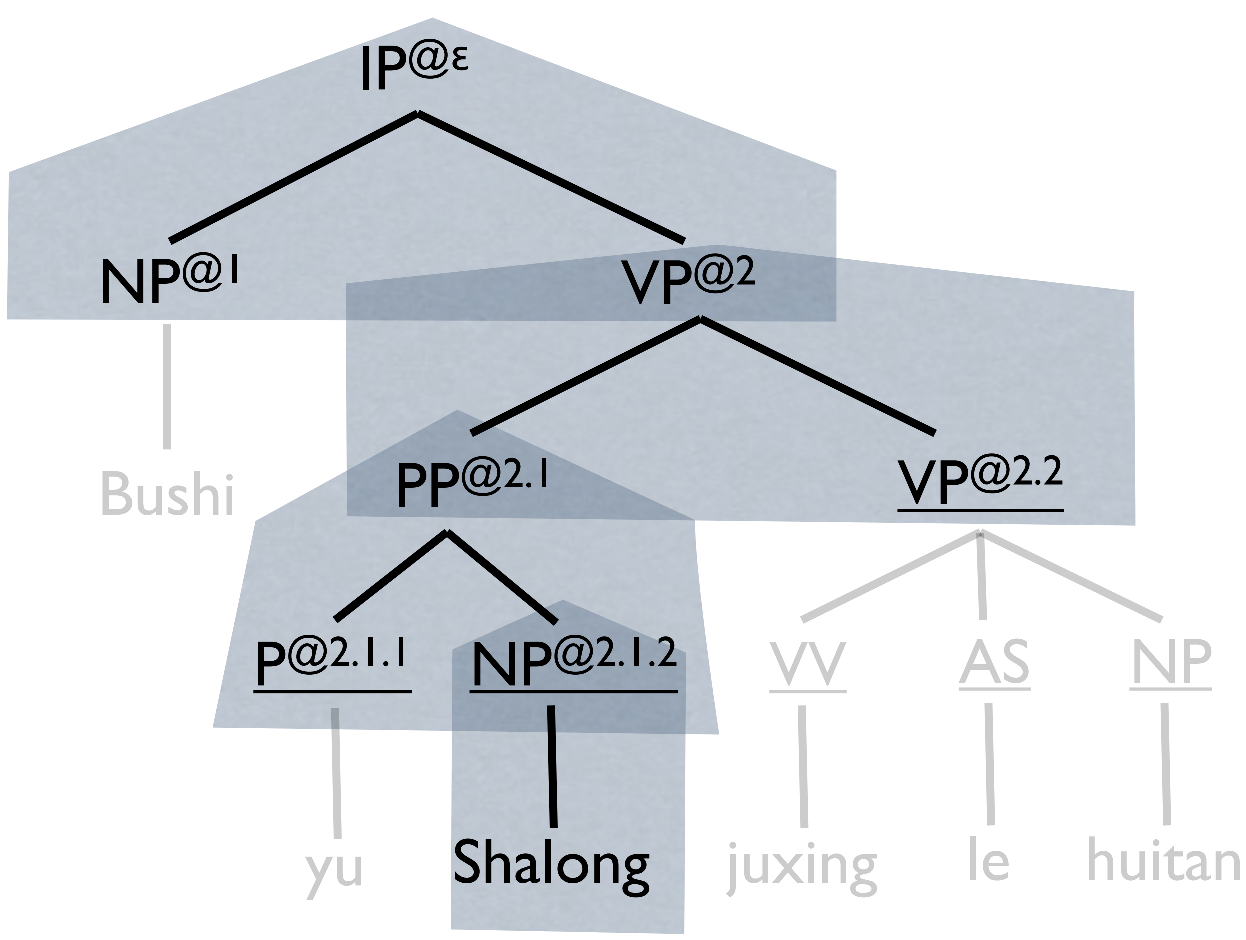
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [P@2.1.1 . NP@2.1.2] [Sharon .] *stack*

r1 r3 r4 r7

<s> Bush held talks with Sharon *hypothesis*



action: scan

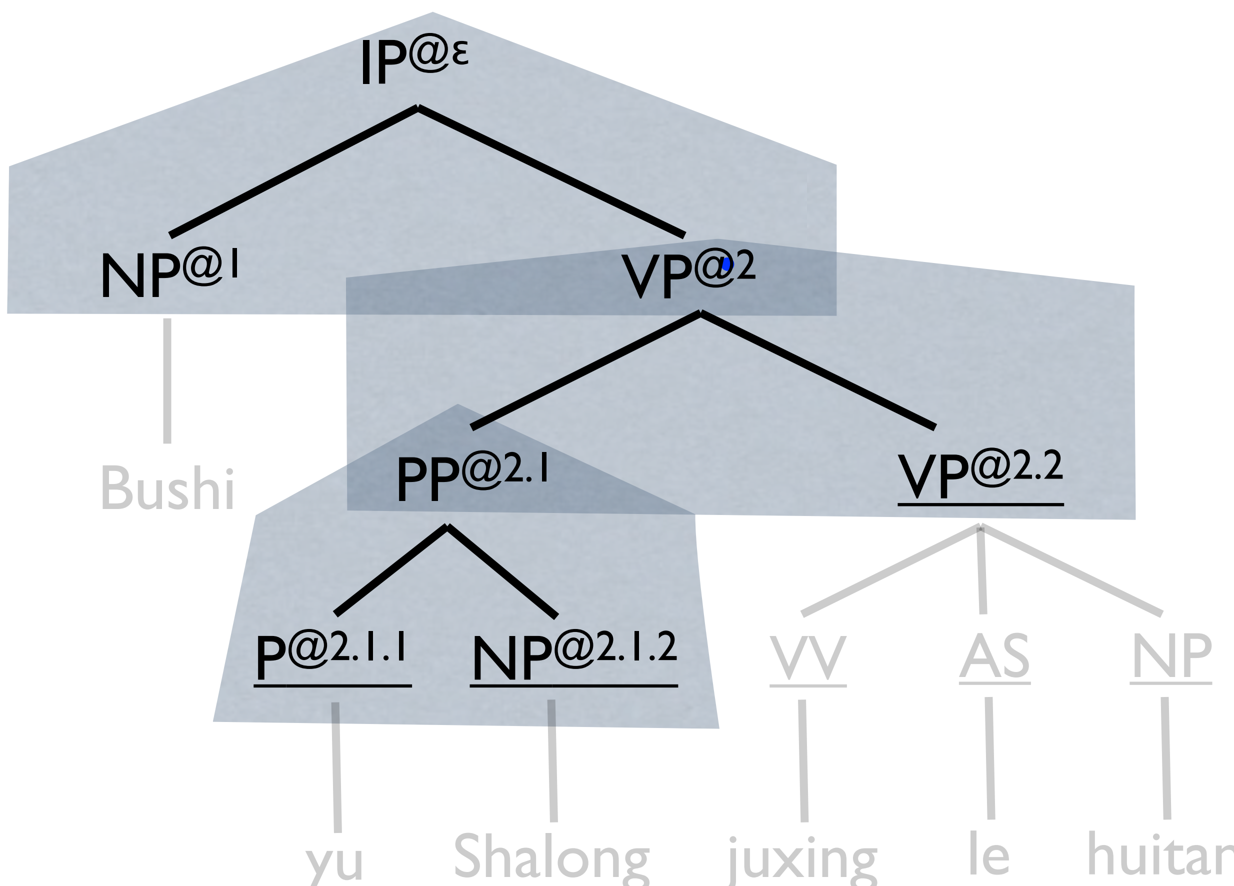
this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 . VP@2] [VP@2.2 . PP@2.1] [P@2.1.1 NP@2.1.2 .] *stack*

r1 r3 r4

<s> Bush held talks with Sharon *hypothesis*



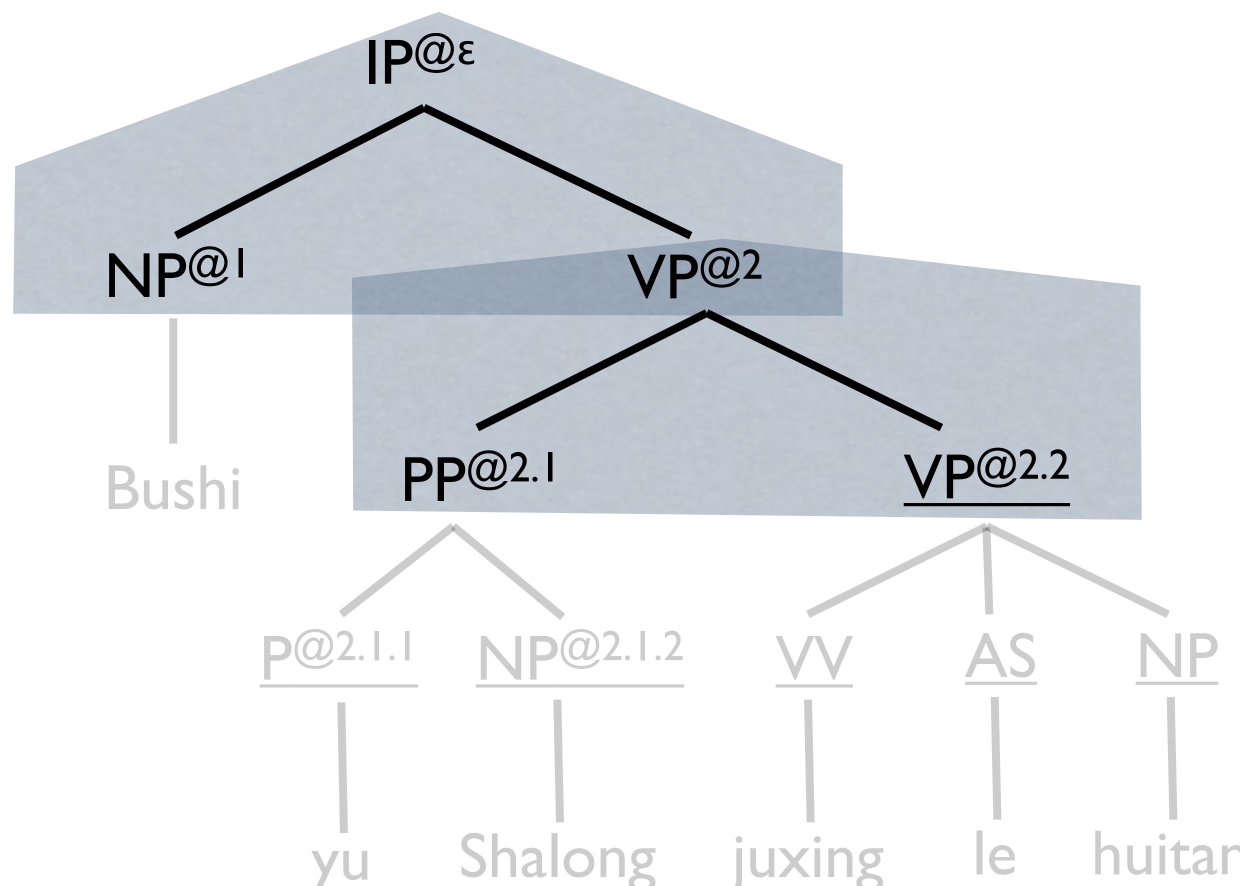
action: pop

this work: adding rule LM

Example Incremental Decoding

$[\langle s\rangle \cdot \mathrm{IP}^{@\varepsilon}\ \langle /s\rangle]\ [\mathrm{NP}^{@1} \underset{r_1}{\cdot} \mathrm{VP}^{@2}]\ [\underline{\mathrm{VP}^{@2.2}}\ \underset{r_3}{\underline{\mathrm{PP}^{@2.1}}} \cdot]$ *stack*

<s> Bush held talks with Sharon *hypothesis*



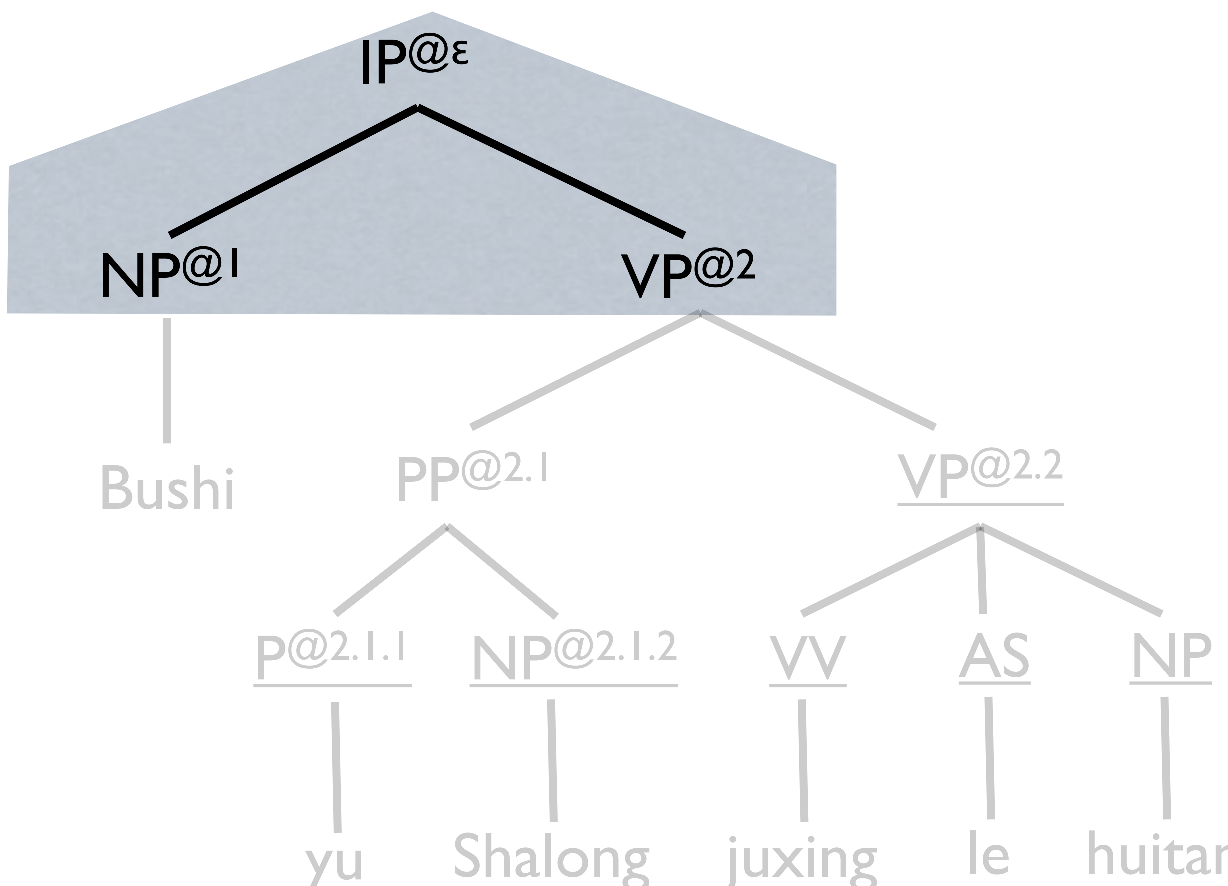
action: pop

this work: adding rule LM

Example Incremental Decoding

[<s> . IP@ε </s>] [NP@1 VP@2 .] *stack*
r_1

<s> Bush held talks with Sharon *hypothesis*



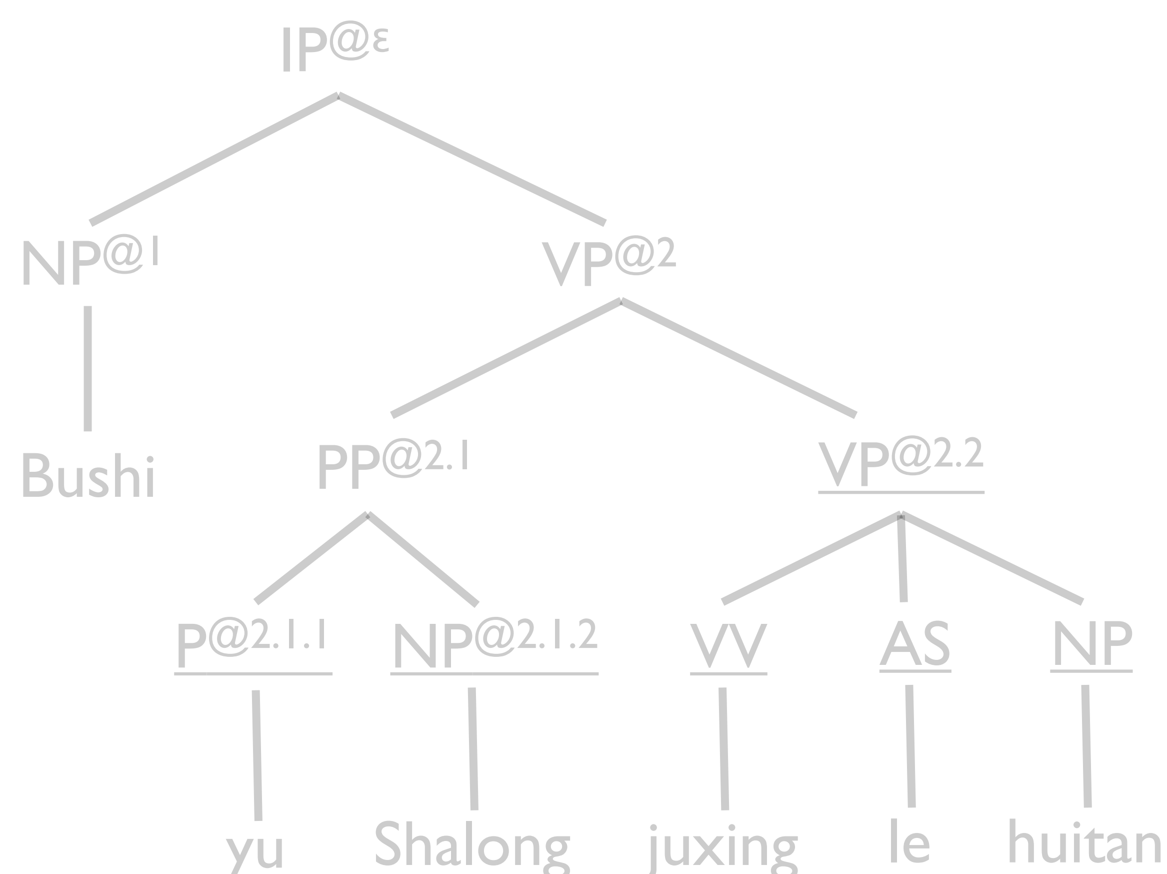
action: pop

this work: adding rule LM

Example Incremental Decoding

[<s> IP@ε .</s>] *stack*

<s> Bush held talks with Sharon *hypothesis*



action: pop

this work: adding rule LM

Experiments

- 1.5 million sentence pairs with 38/32 million words of Chinese/English
- Dev set : 616 sentences of the Newswire portion of 2006 NIST MT evaluation test set
- Test set: 619 sentences of the Newswire portion of 2006 NIST MT evaluation test set

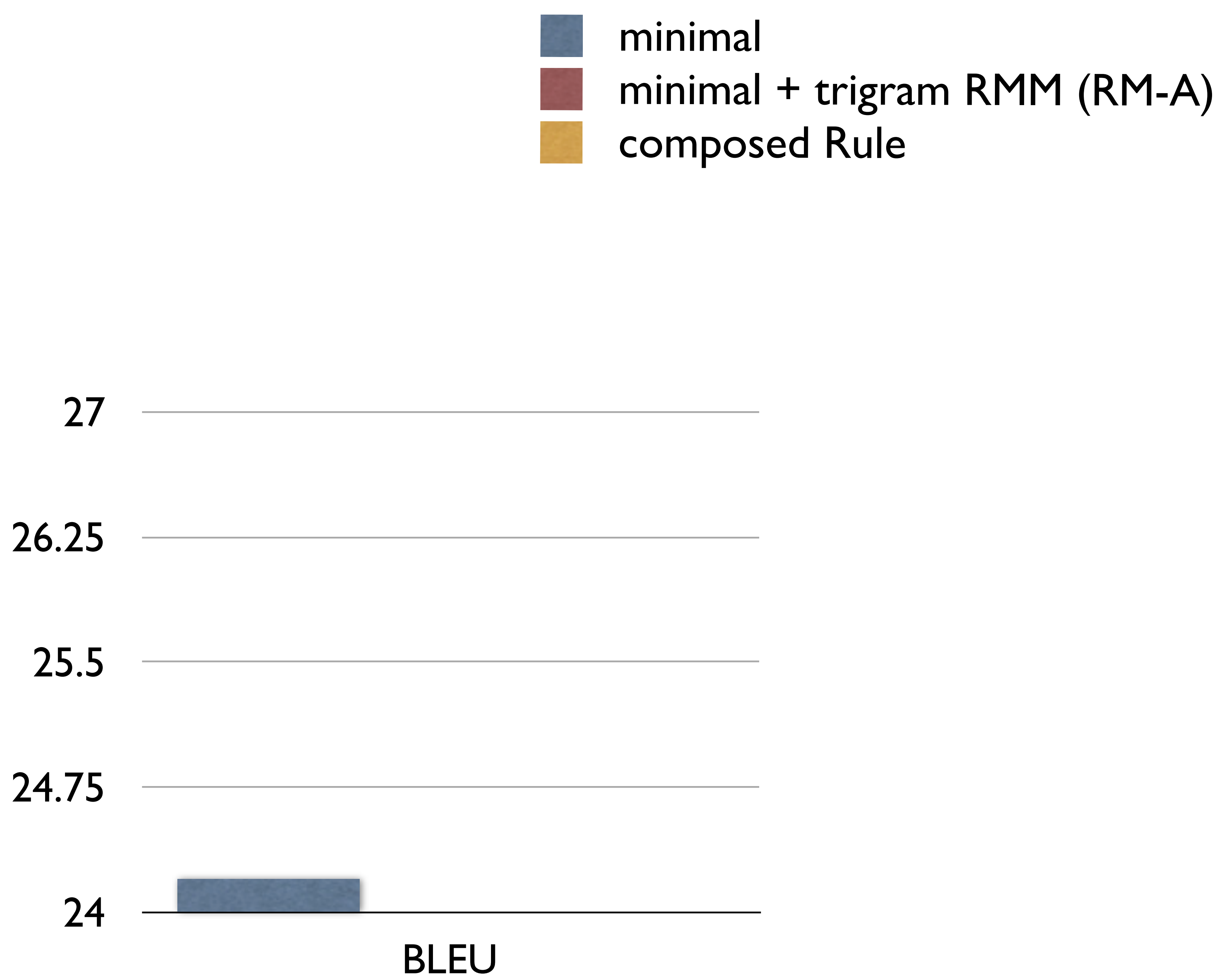
Results

- minimal
- minimal + trigram RMM (RM-A)
- composed Rule

Results

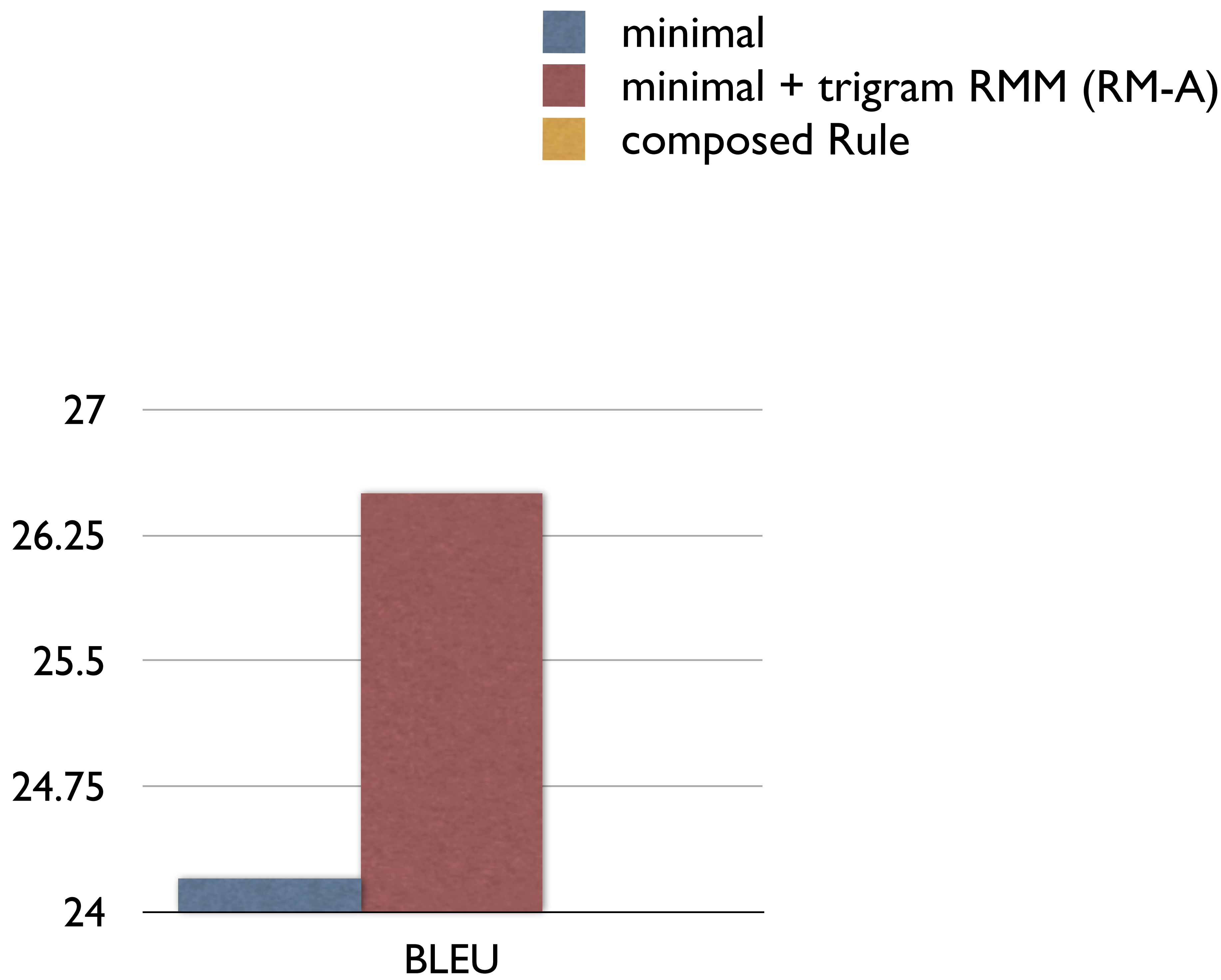

minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU

Results

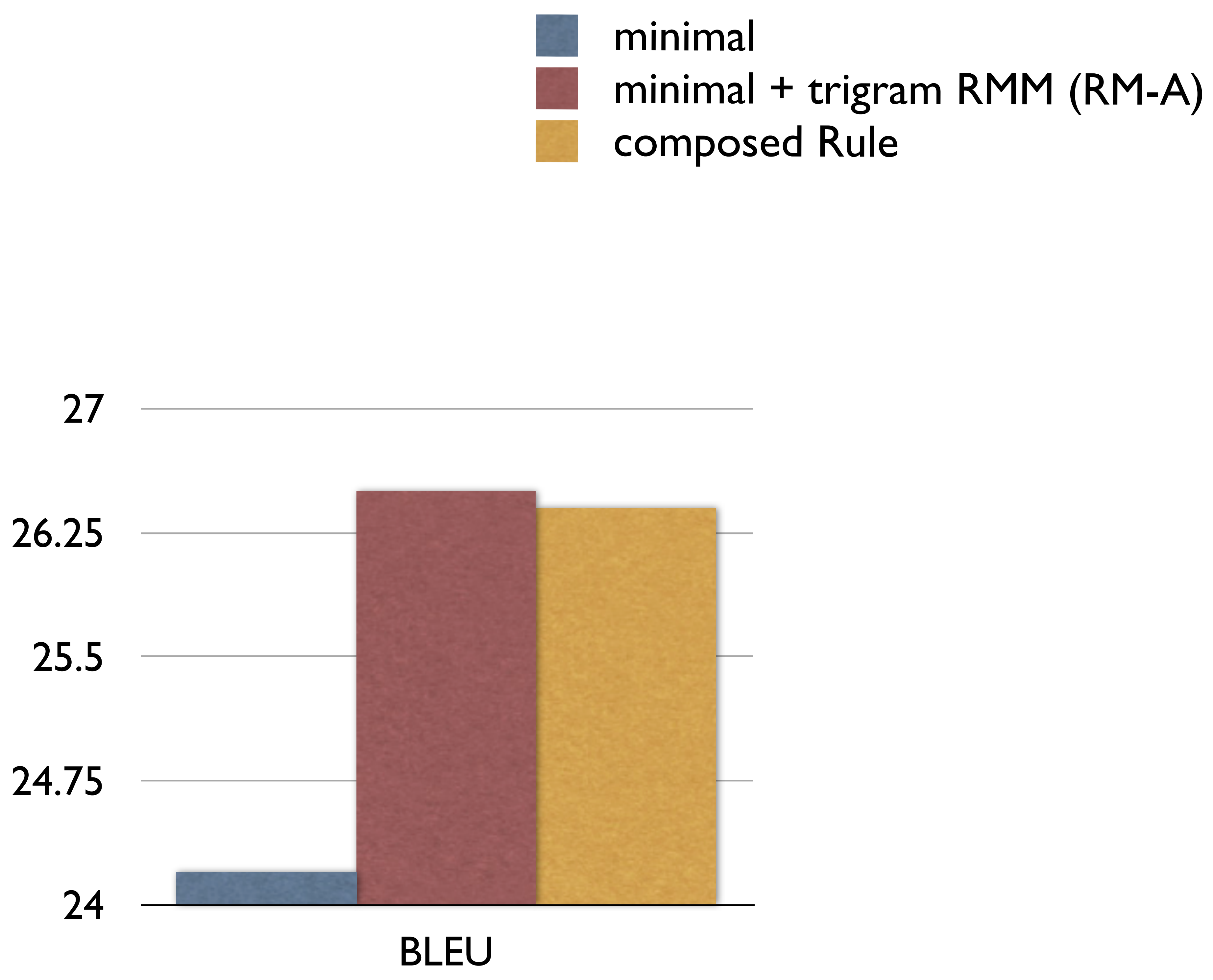


minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU

Results

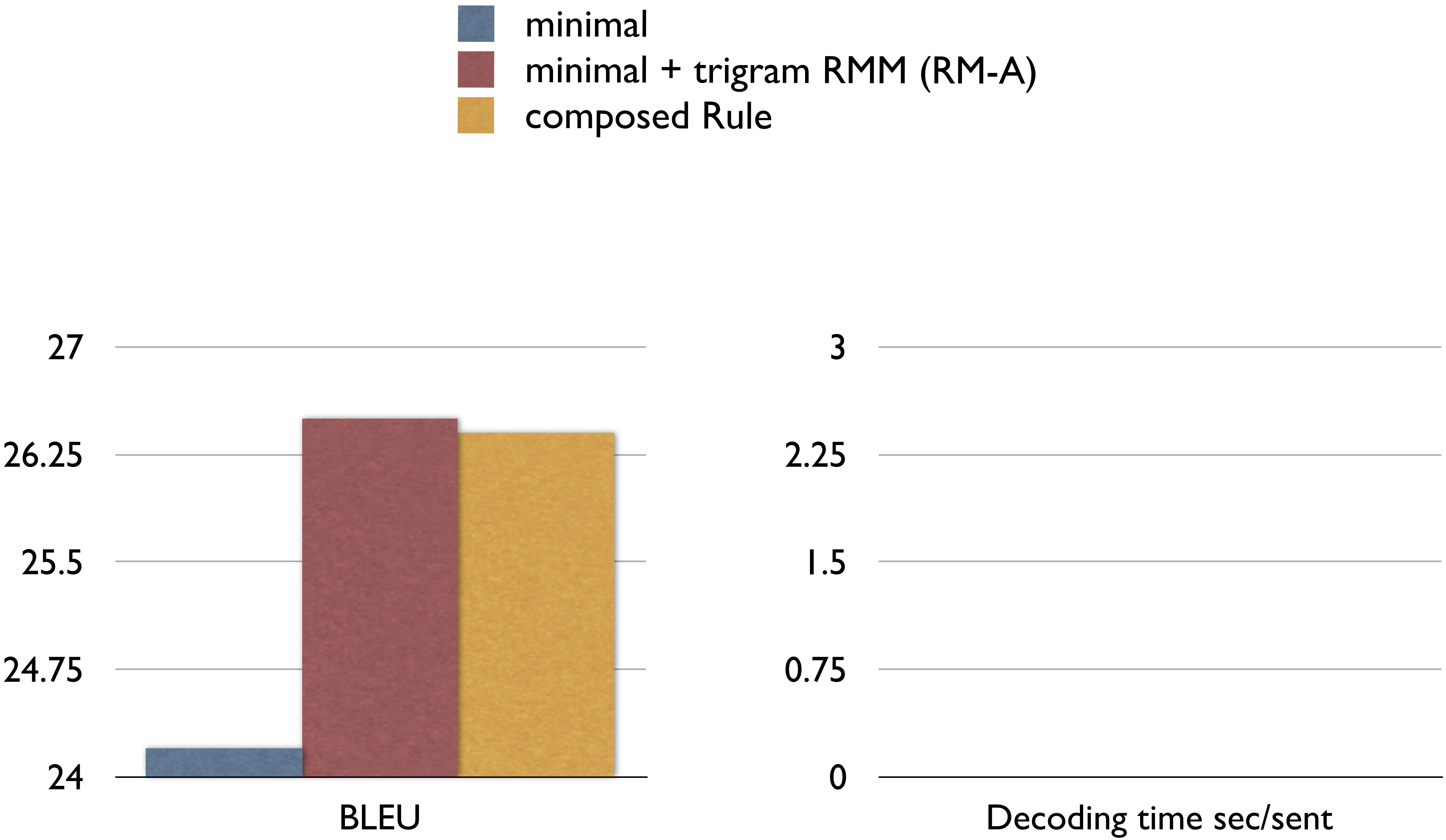

minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU

Results



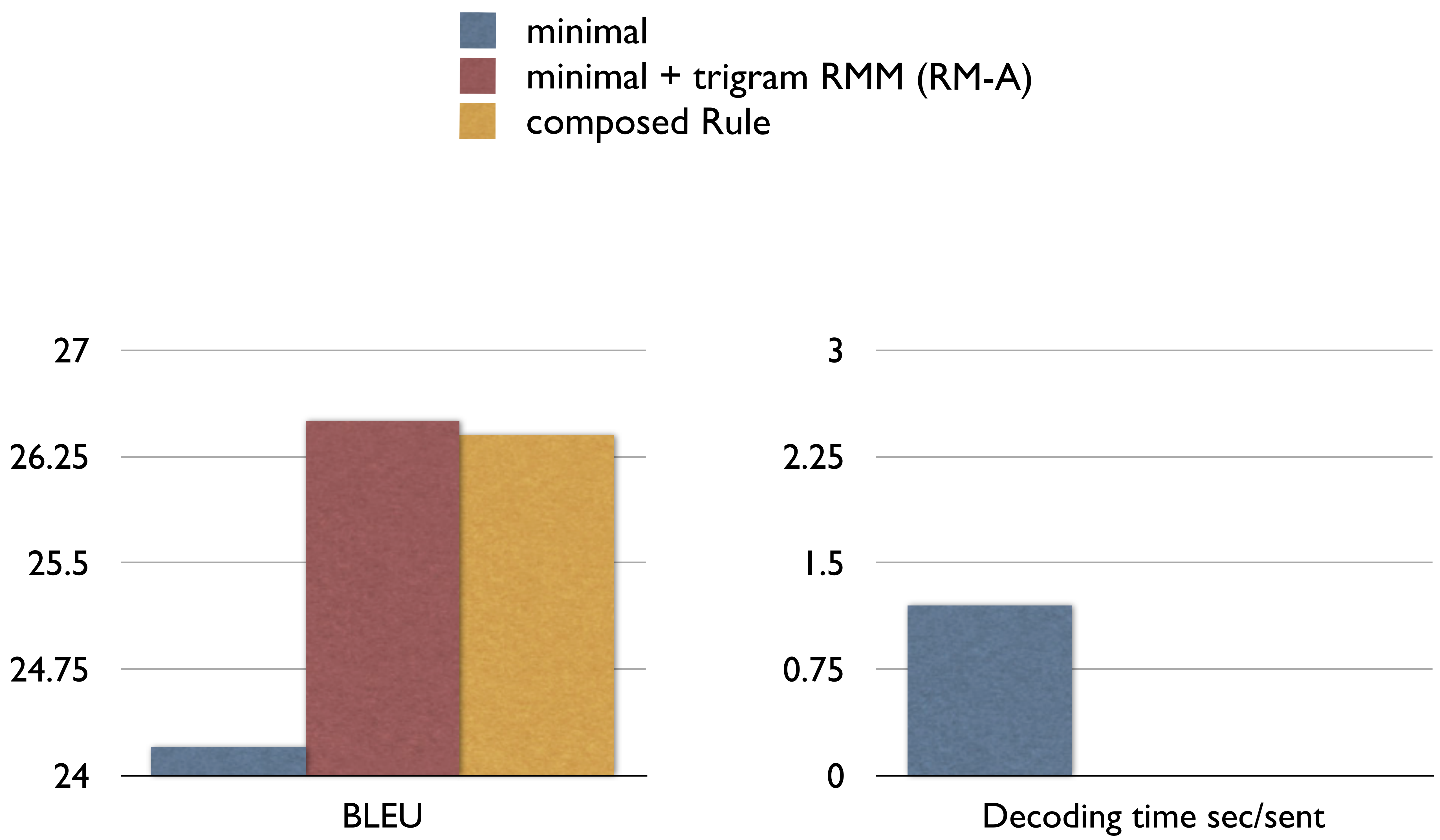
minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU

Results



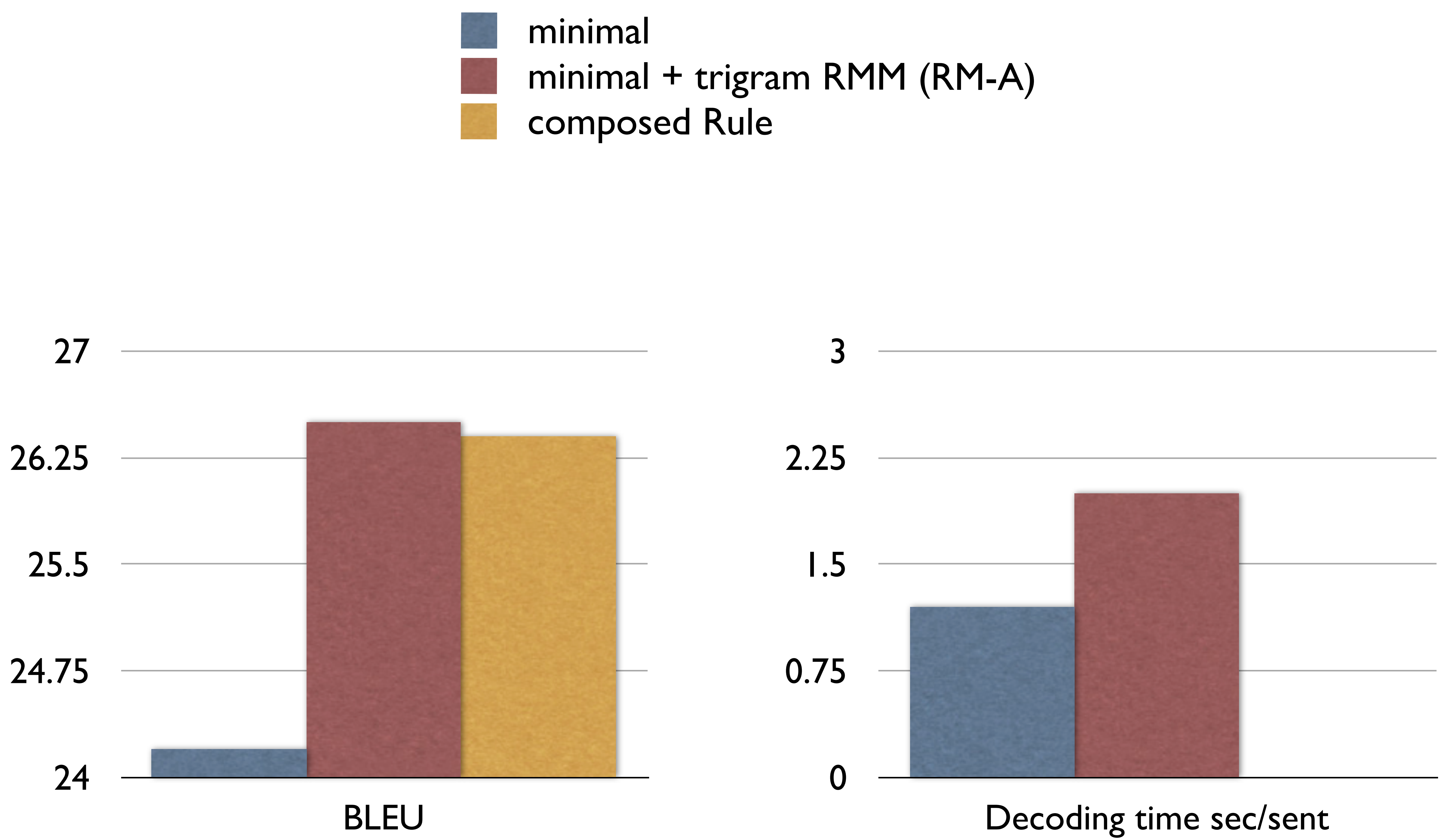
minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU
3
2.25
1.5
0.75
0
Decoding time sec/sent

Results

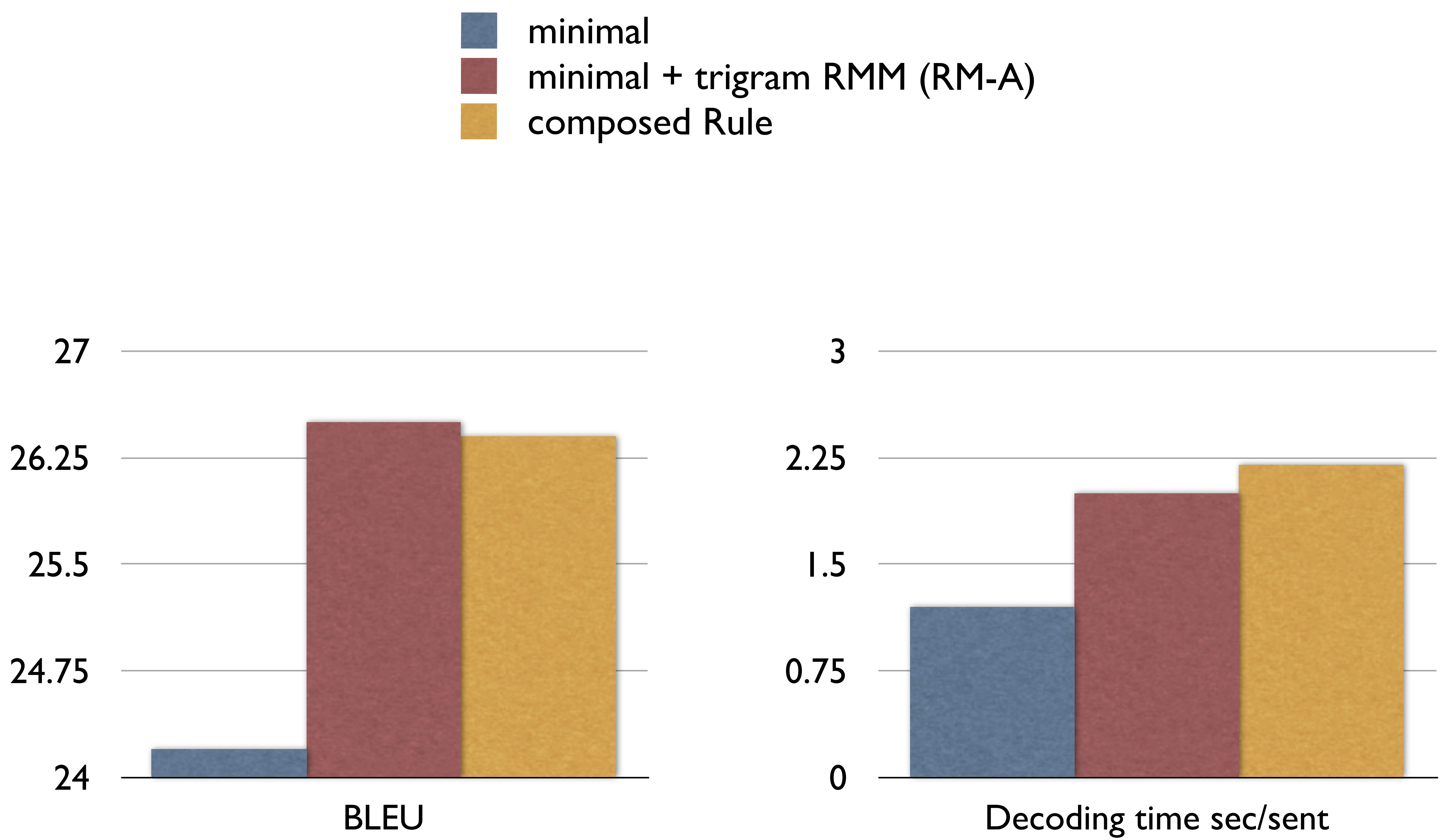


minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU
3
2.25
1.5
0.75
0
Decoding time sec/sent

Results


minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU
3
2.25
1.5
0.75
0
Decoding time sec/sent

Results



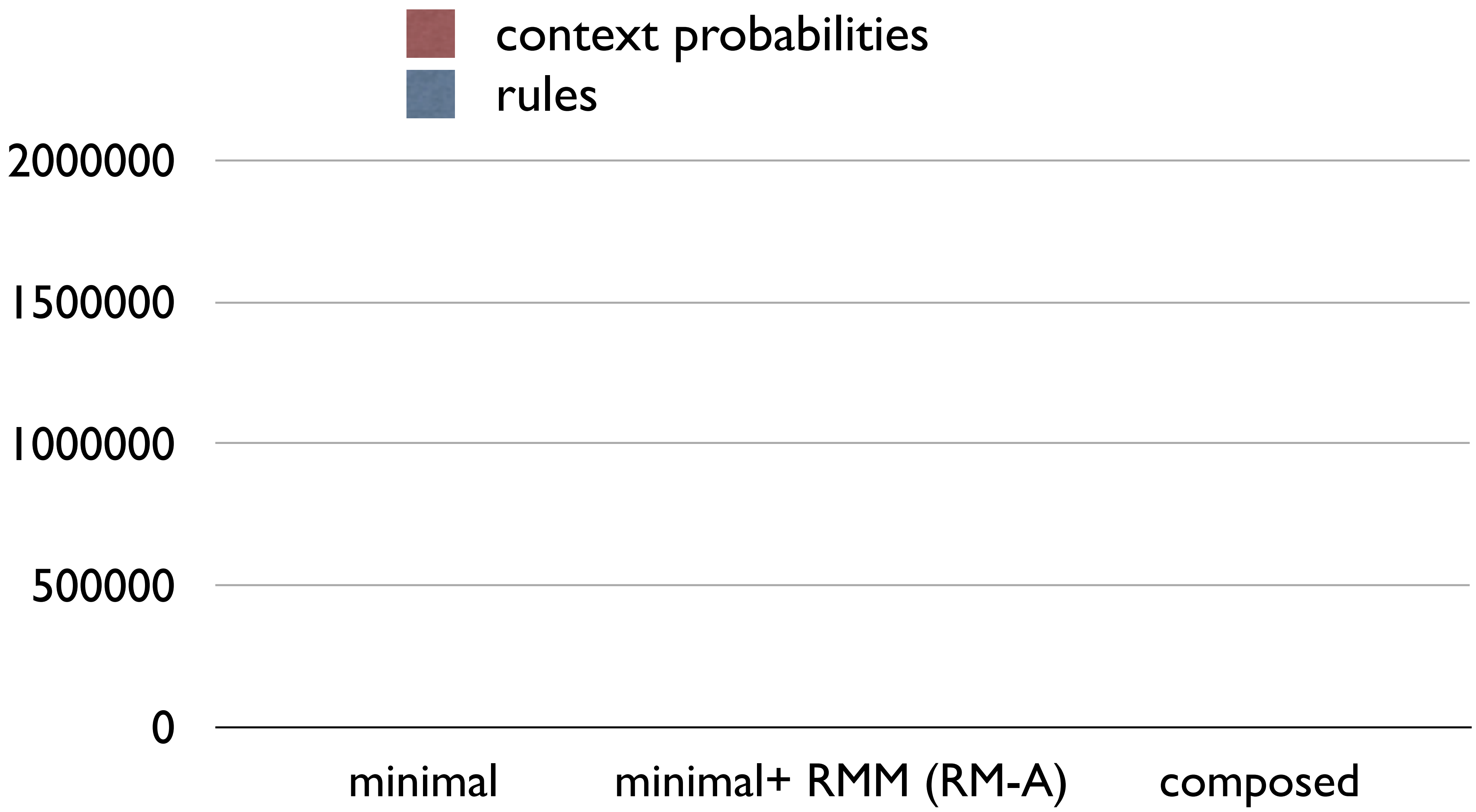
minimal
minimal + trigram RMM (RM-A)
composed Rule
27
26.25
25.5
24.75
24
BLEU
3
2.25
1.5
0.75
0
Decoding time sec/sent

Results

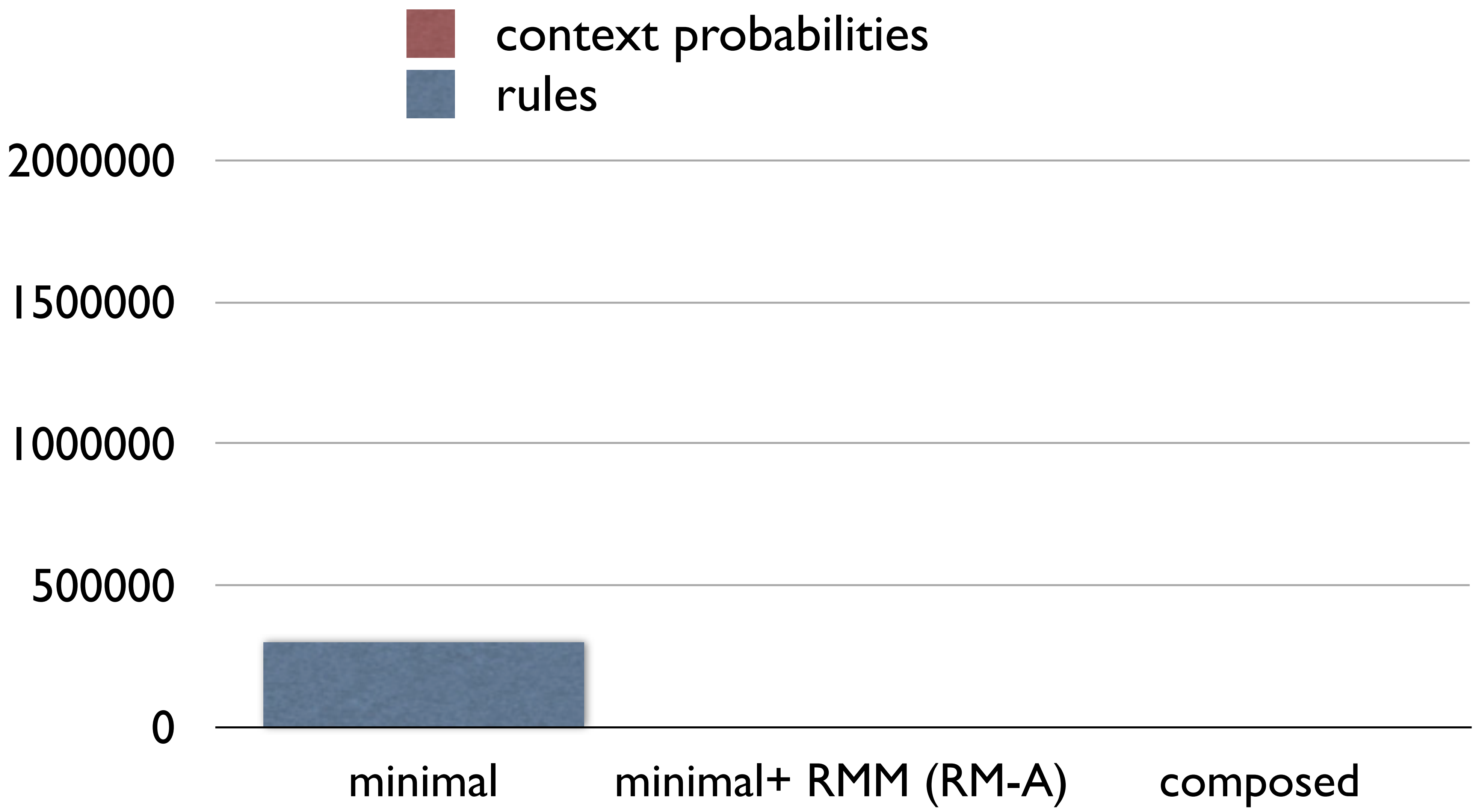
context probabilities

rules

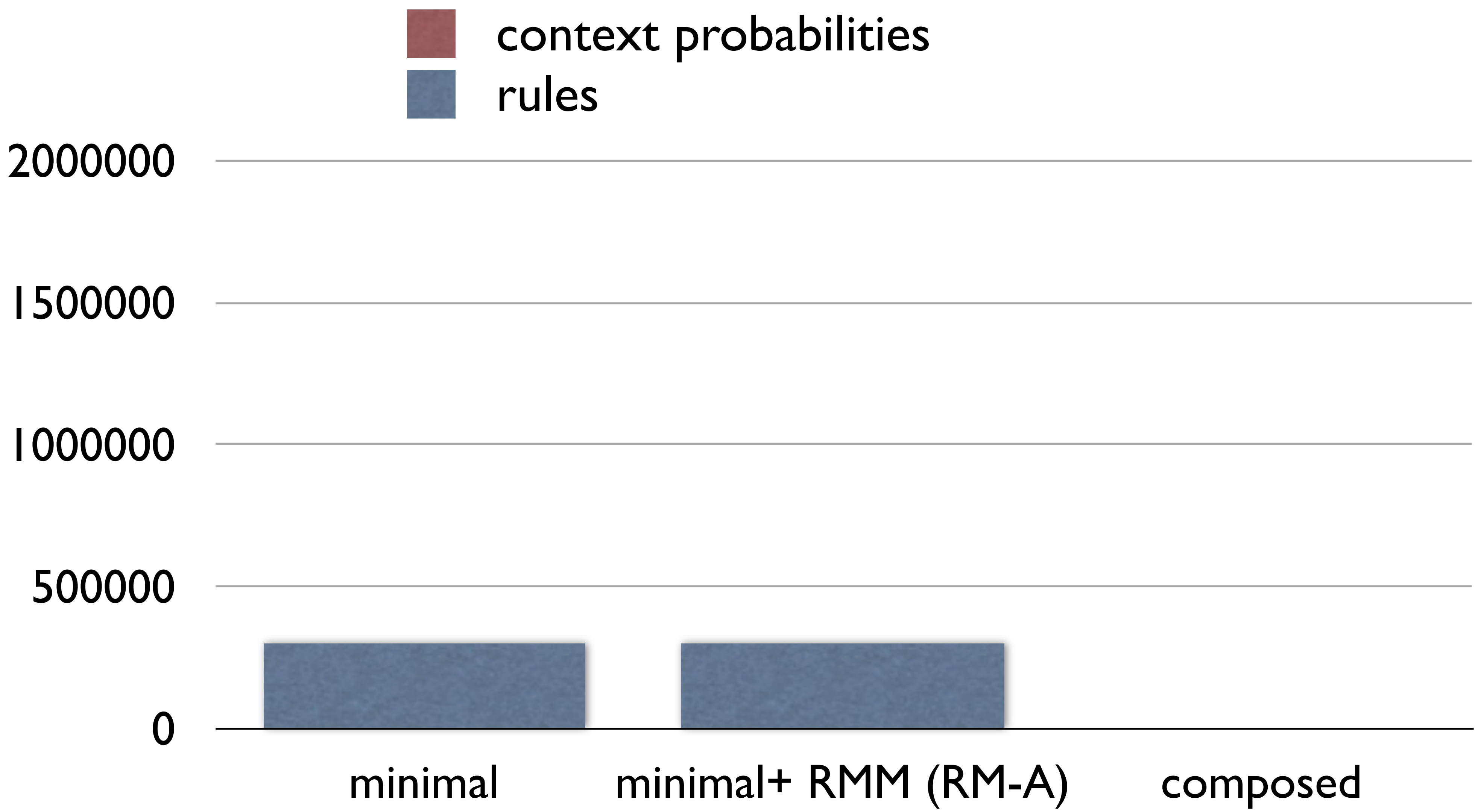
Results


context probabilities
rules
2000000
1500000
1000000
500000
0
minimal
minimal+ RMM (RM-A)
composed

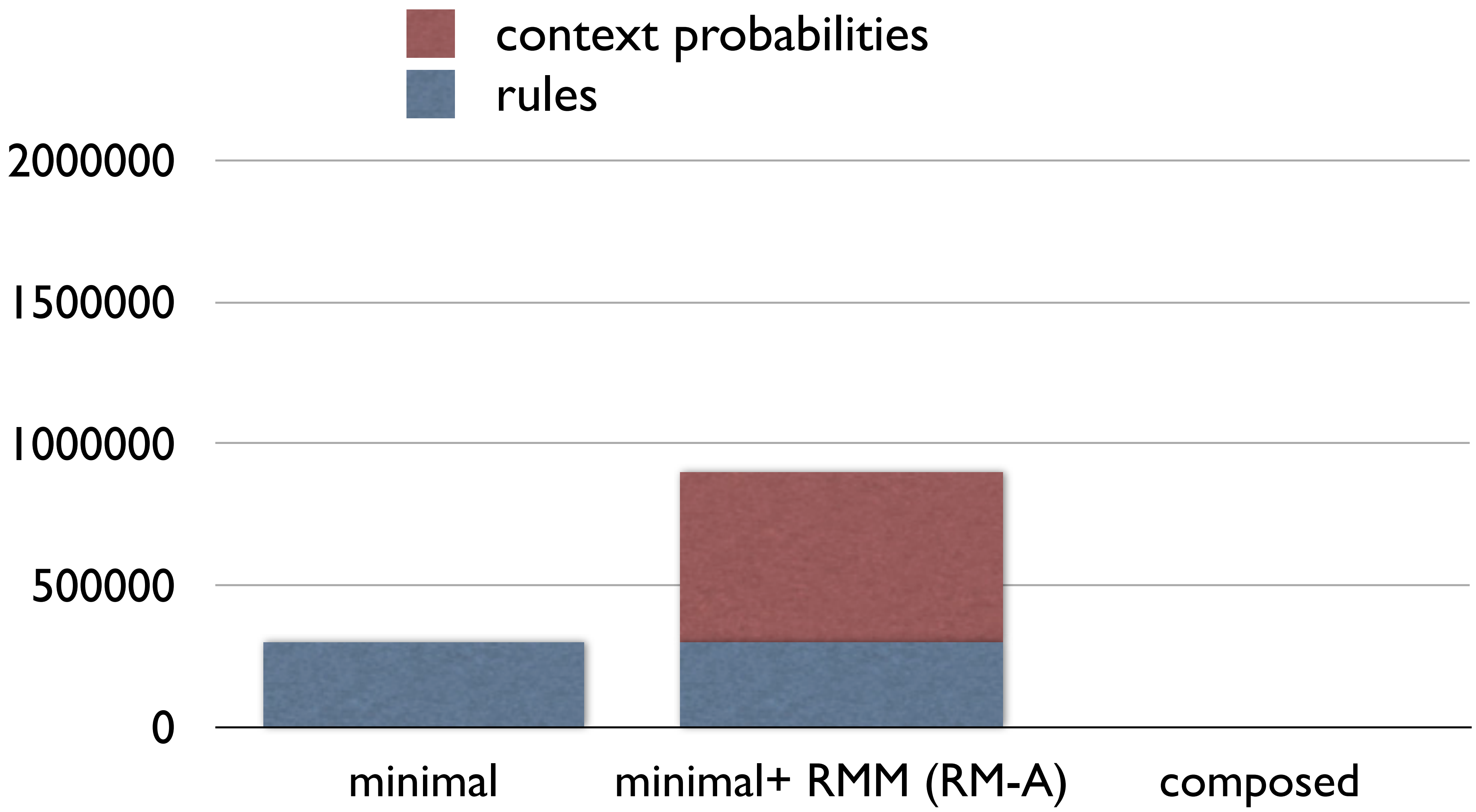
Results


context probabilities
rules
2000000
1500000
1000000
500000
0
minimal
minimal+ RMM (RM-A)
composed

Results

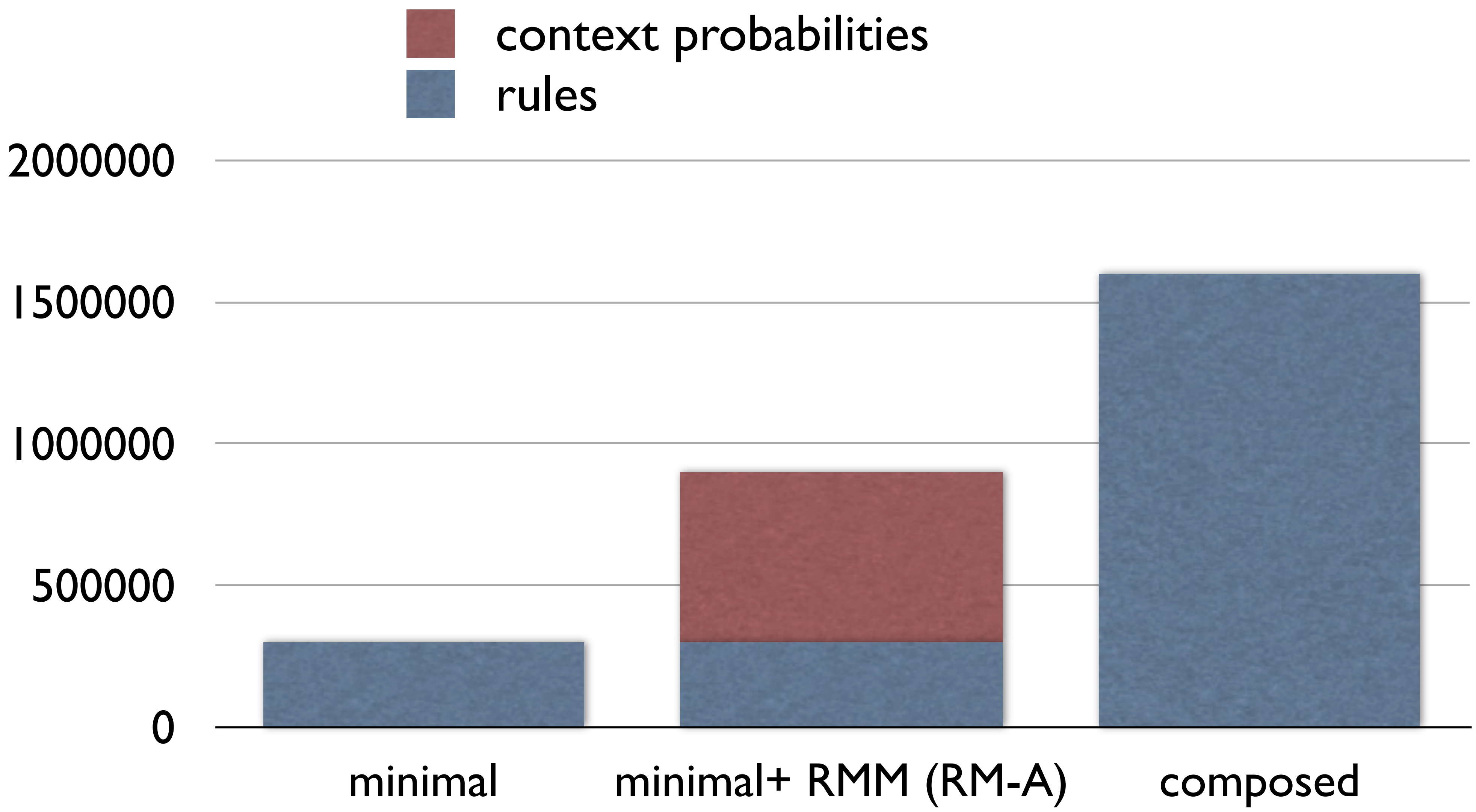

context probabilities
rules
2000000
1500000
1000000
500000
0
minimal
minimal+ RMM (RM-A)
composed

Results



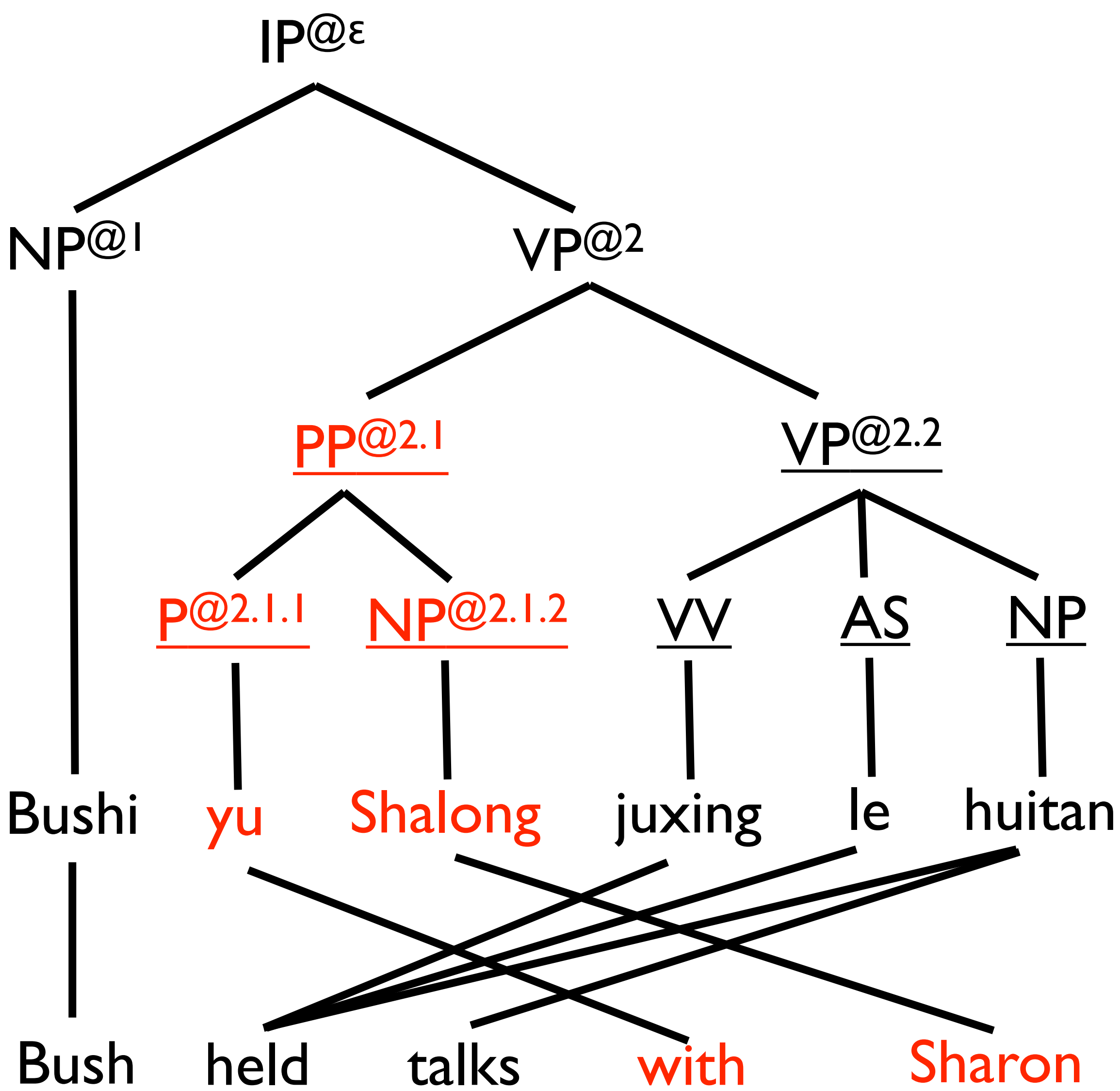
context probabilities
rules
2000000
1500000
1000000
500000
0
minimal
minimal+ RMM (RM-A)
composed

Results

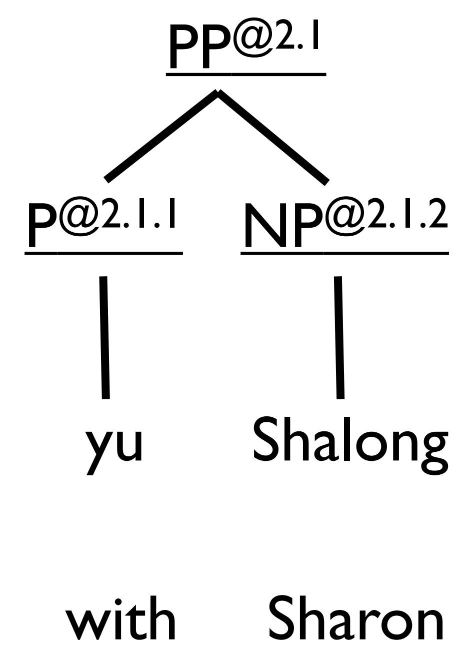


context probabilities
rules
2000000
1500000
1000000
500000
0
minimal
minimal+ RMM (RM-A)
composed

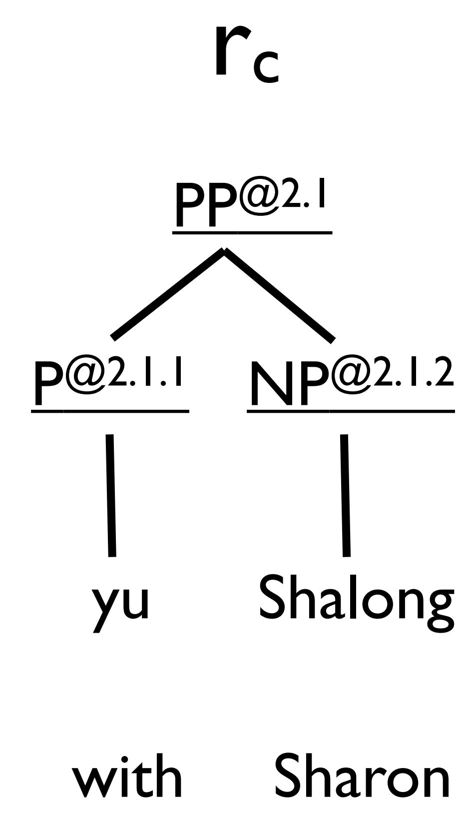
RMMs with composed Rules



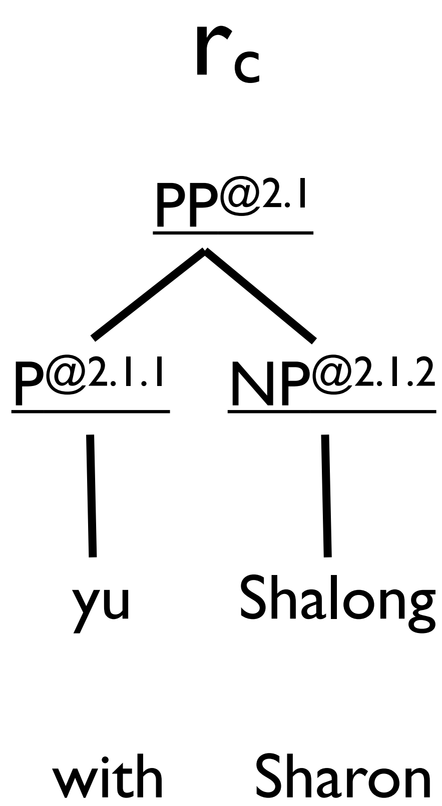
r_c



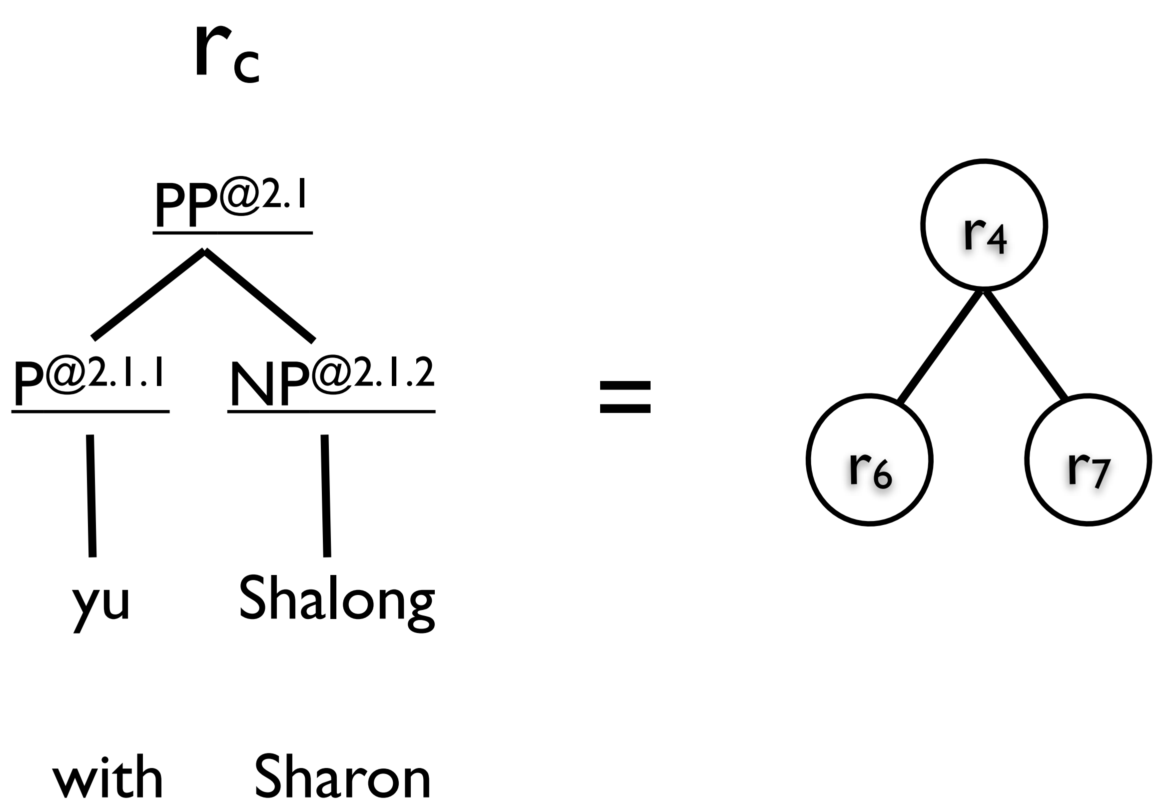
RMMs with composed Rules



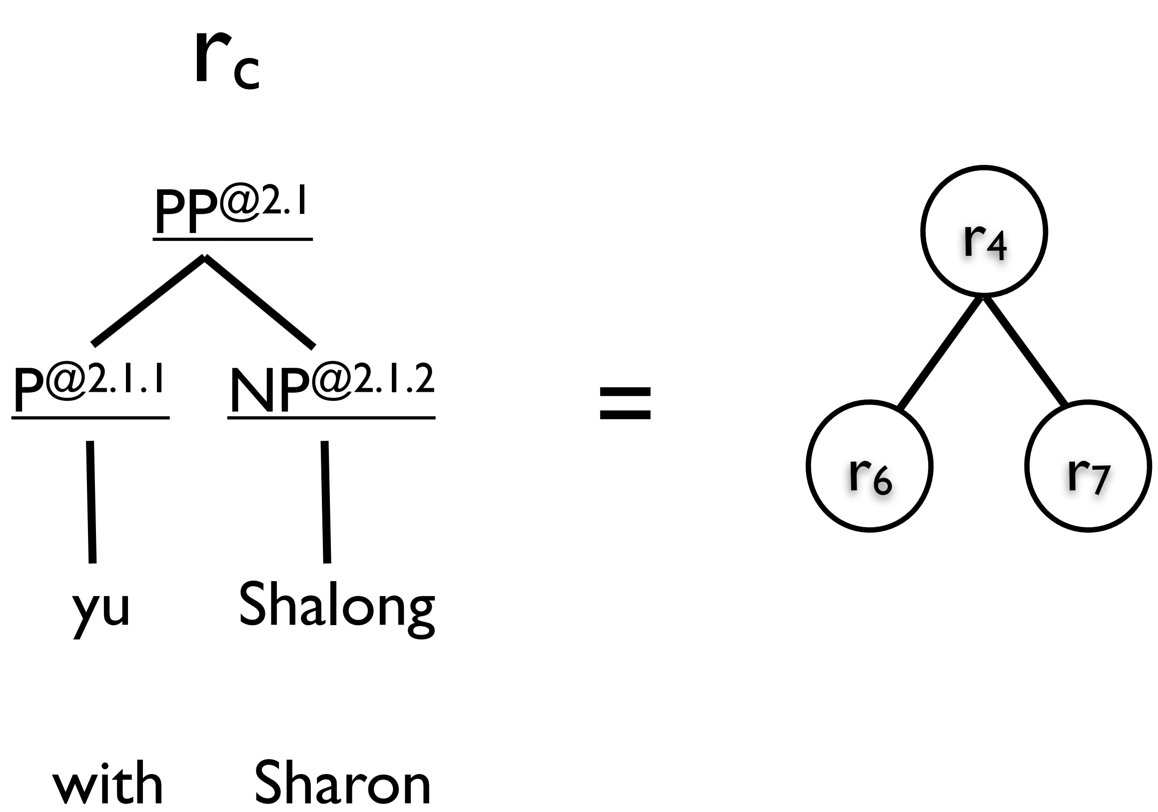
RMMs with composed Rules

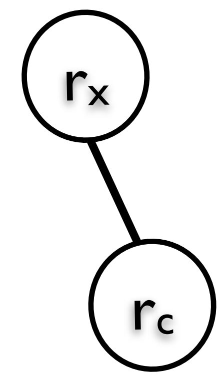


RMMs with composed Rules

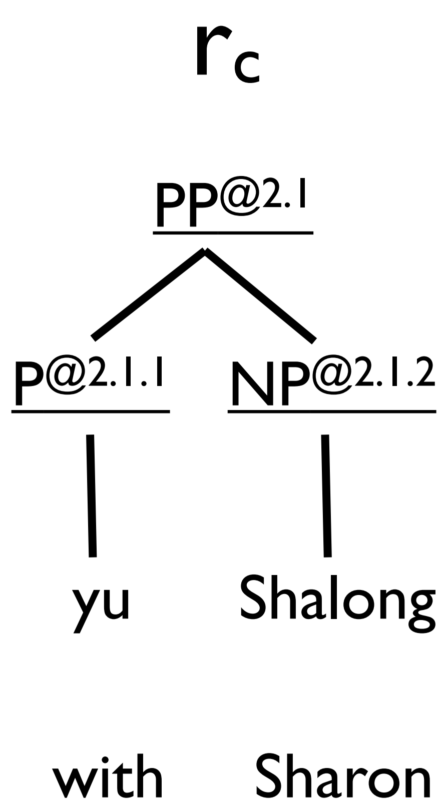


RMMs with composed Rules





RMMs with composed Rules



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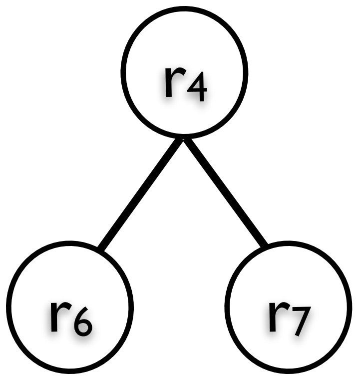
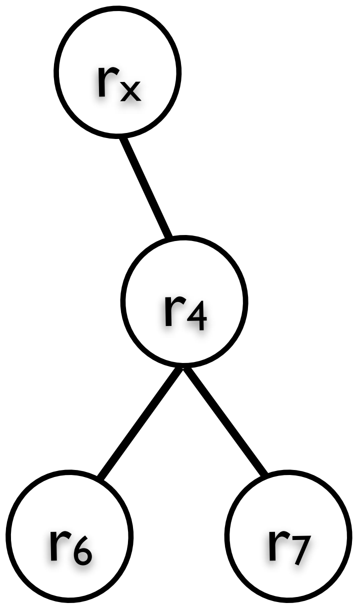
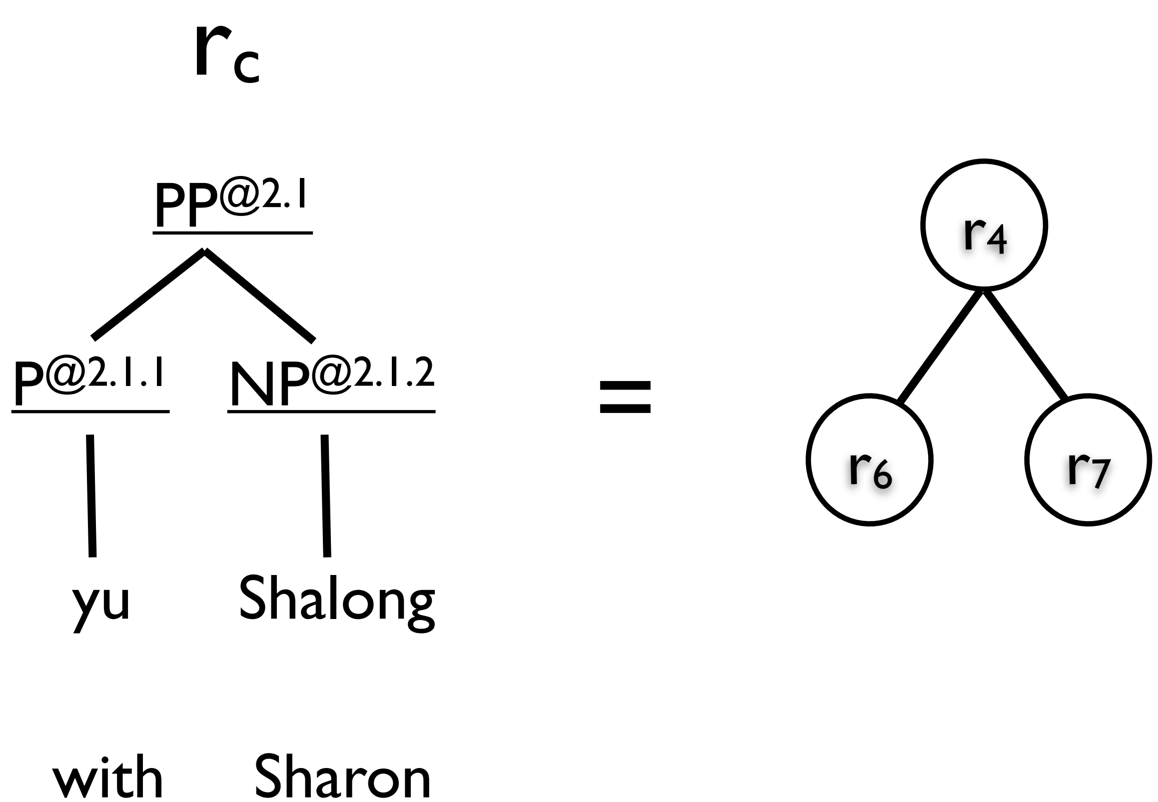
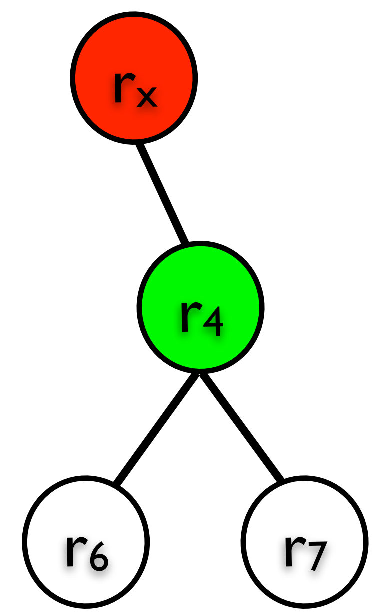




RMMs with composed Rules

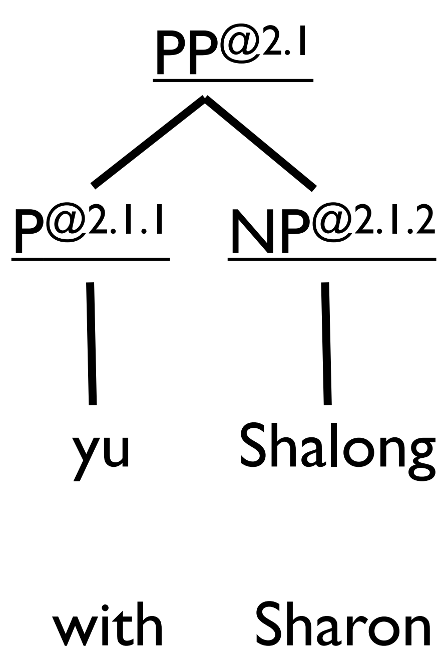




$$P(r_c|r_x) = P(r_4|r_x) \cdot P(r_6|r_4,r_x) \cdot P(r_7|r_4,r_x)$$

RMMs with composed Rules

r_c



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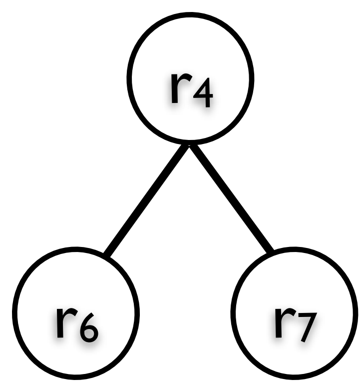
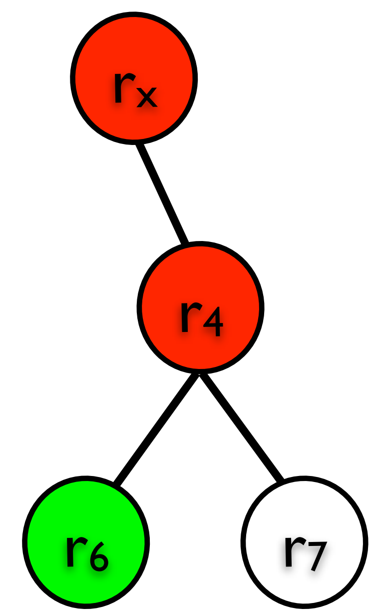
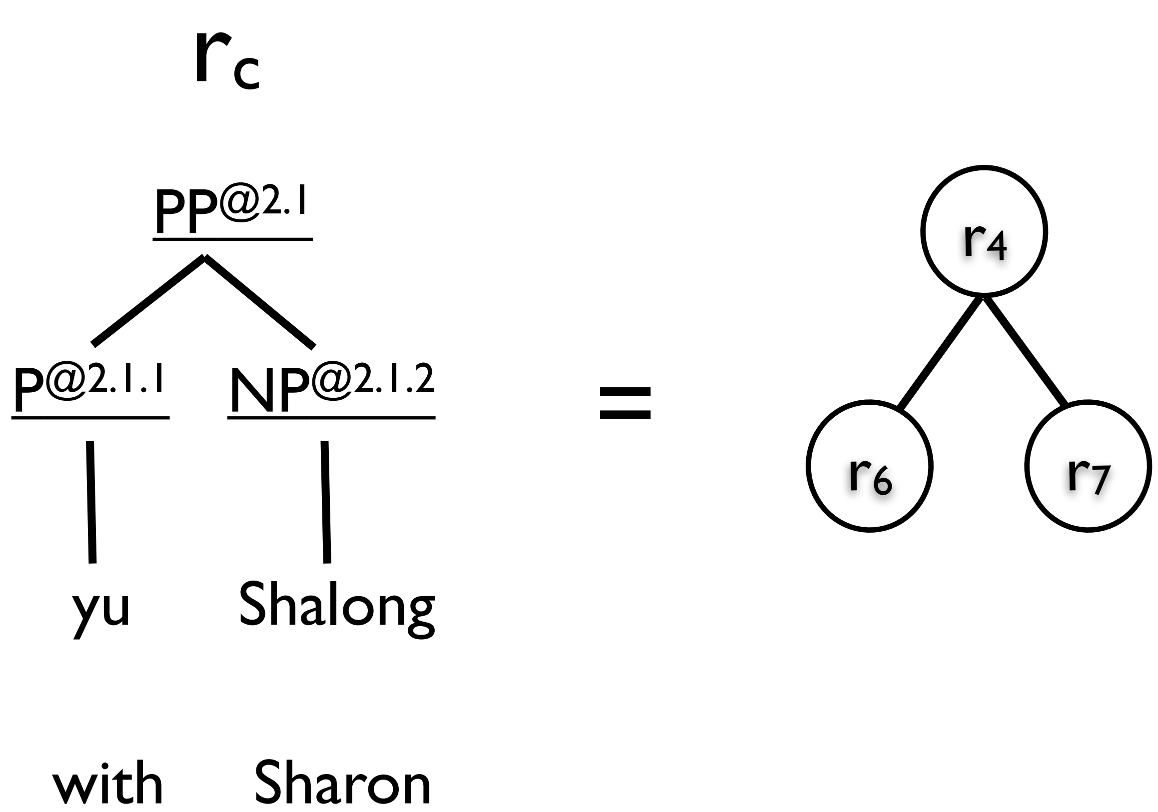
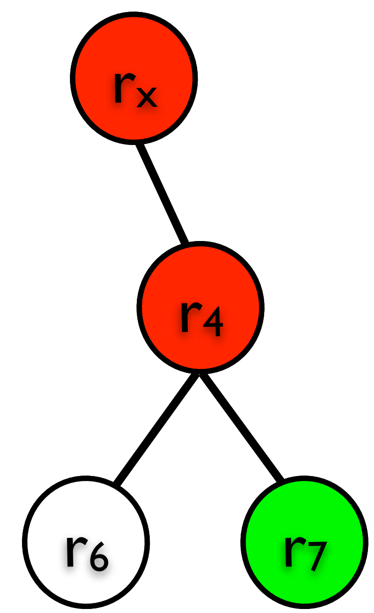




$$P(r_c|r_x) = P(r_4|r_x) \cdot P(r_6|r_4,r_x) \cdot P(r_7|r_4,r_x)$$

RMMs with composed Rules



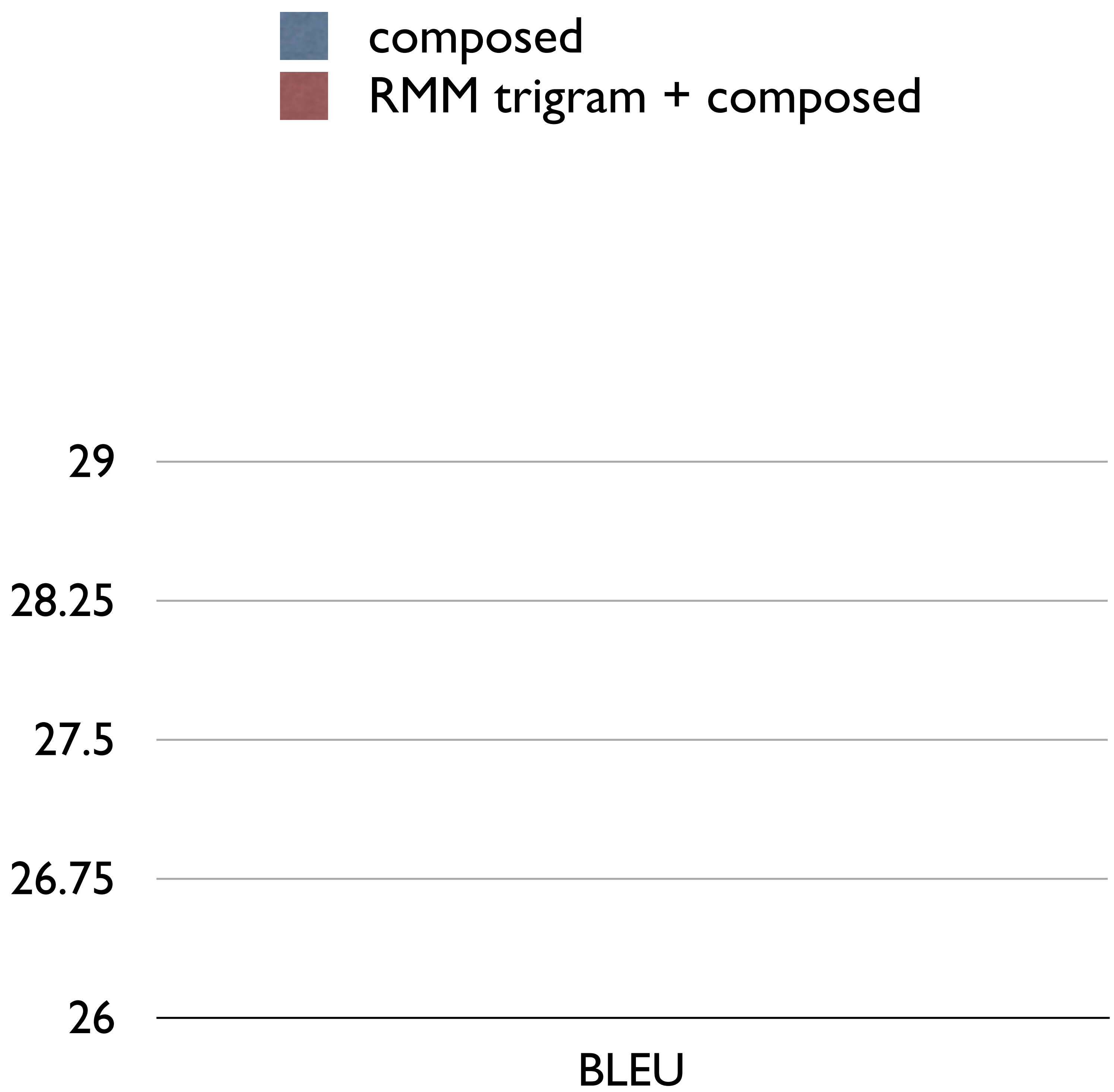


$$P(r_c|r_x) = P(r_4|r_x) \cdot P(r_6|r_4,r_x) \cdot P(r_7|r_4,r_x)$$

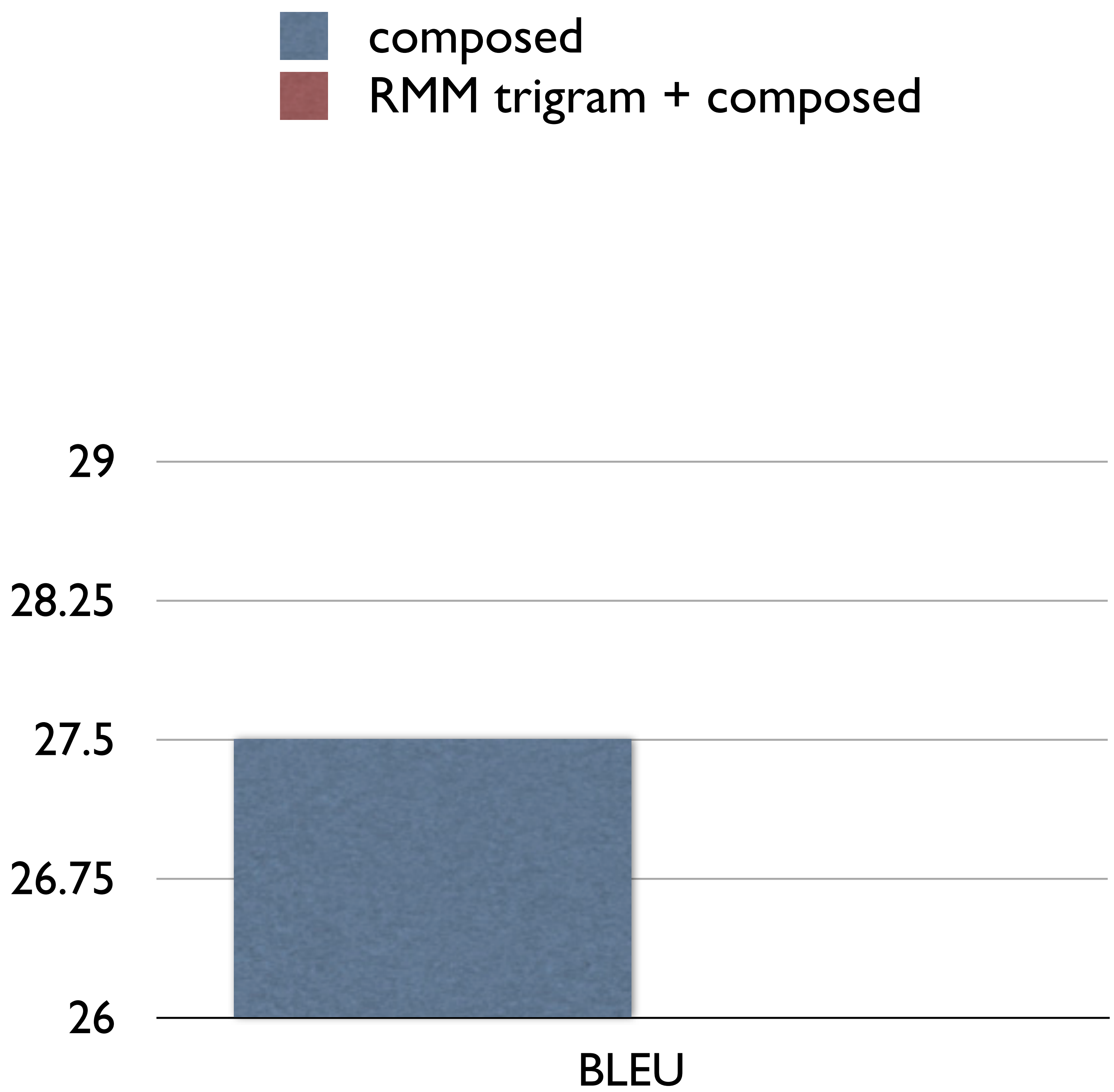
Results: RMMs improve over composed rules

composed
RMM trigram + composed

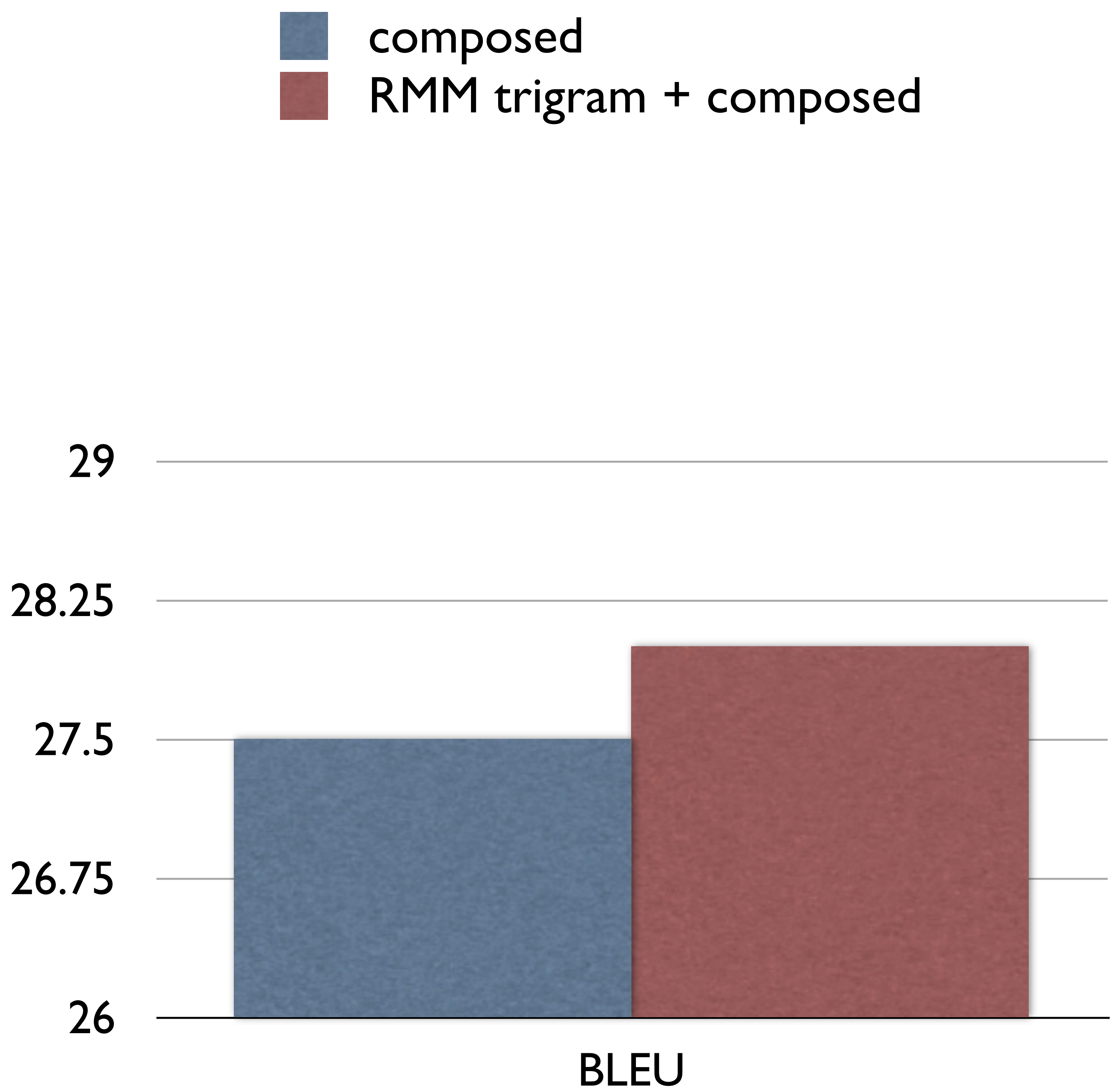
Results: RMMs improve over composed rules



Results: RMMs improve over composed rules



Results: RMMs improve over composed rules



Related Work

- Quirk and Menezes (2006)
- Ding and Palmer (2005)
- Liu and Gildea (2008)

Conclusion

- Using rule Markov models, we are able to get significant improvements in BLEU score.
- The grammar size and decoding time is less than the composed rule grammar
- Using rule Markov models with composed rule grammars further improves the BLEU score.

THANKS