Multi Bottom-up Tree Transducers

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Overview

Machine translation

Translation

- Input:
  Official forecasts predicted just 3 percent, Bloomberg said.
- We:
  die die offiziellen prognosen nur 3 prozent prognostizierten hat bloomberg gesagt.
- Google:
  Offizielle Prognosen vorhergesagt nur 3 Prozent, sagte Bloomberg.

Machine translation

Translation

- Input:
  The ECB wants to hold inflation to under two percent, or somewhere in that vicinity.
- We:
  die ezb will unter zwei inflation prozent oder halten irgendwo damit benachbarten gebieten,.
- Google:
  Die EZB will die Inflation auf unter zwei Prozent zu halten, oder irgendwo in der Nähe.

Syntax-based machine translation

Syntax-based systems

Input ⟶ Parser ⟶ Machine translation system ⟶ Language model ⟶ Output

What do we have?

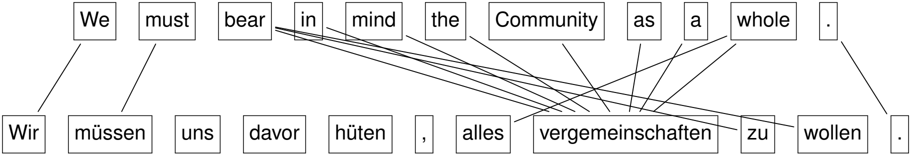
Input

- parallel text (English and German)
- here: EUROPARL

Example

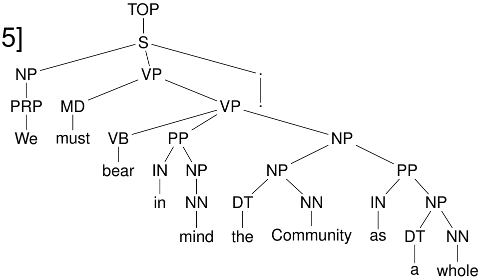
- “We must bear in mind the Community as a whole.”
- “Wir müssen uns davor hüten, alles vergemeinschaften zu wollen.”

Alignments by GIZA++ [OCH, NEY ’03]:

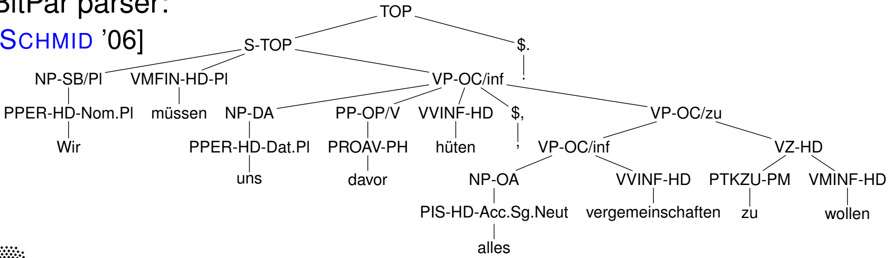


Parsing

CHARNIAK parser:
[CHARNIAK, JOHNSON '05]



BitPar parser:
[SCHMID '06]

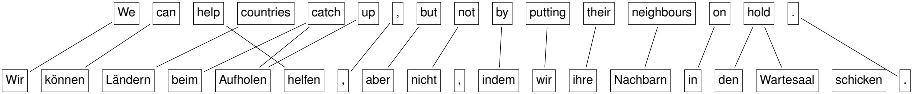


Better example

Example

- “We can help countries catch up, but not by putting their neighbours on hold.”
- “Wir können Ländern beim Aufholen helfen, aber nicht, indem wir ihre Nachbarn in den Wartesaal schicken.”

Alignments by GIZA++:



Better example

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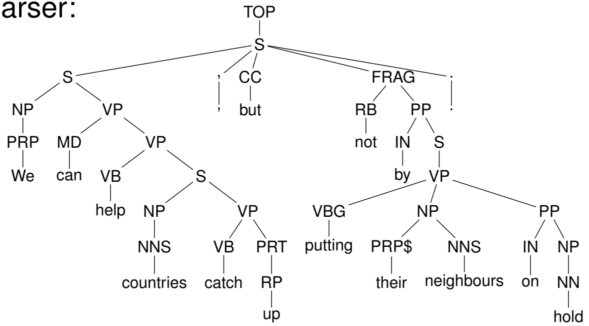

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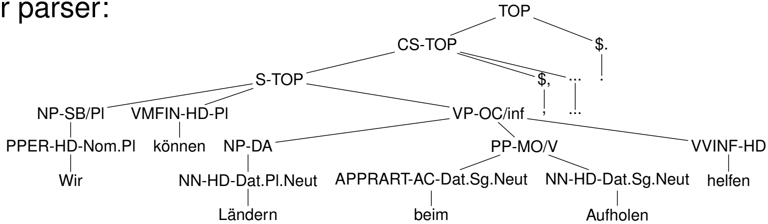


Small example

Input

Yugoslav President Voislav signed for Serbia.

و تولى التوقيع عن صربيا الرئيس اليوغوسلافي فويسلاف

Transliteration: w twlY AltwqyE En SrbyA Alr}ys AlywgwslAfy fwyslAf.

And then the matter was decided, and everything was put in place.

ف كان ان تم الحسم و وضعت الأمور في نصاب ها

Transliteration: f kAn An tm AlHsm w wDEt Al>mwr fy nSAb hA.

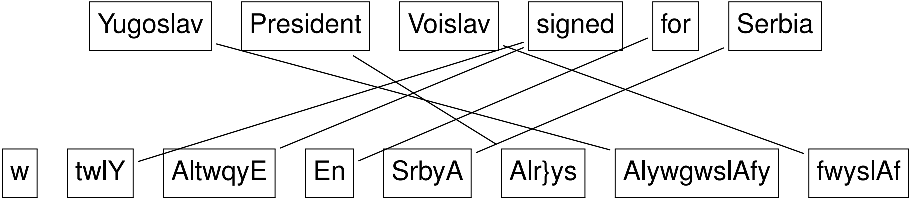
Below are the male and female winners in the different categories.

و هنا الأوائل و الأوليات في مختلف الفئات

Transliteration: w hnA Al>wA}l w Al>wlyAt fy mxtlf Alf}At.

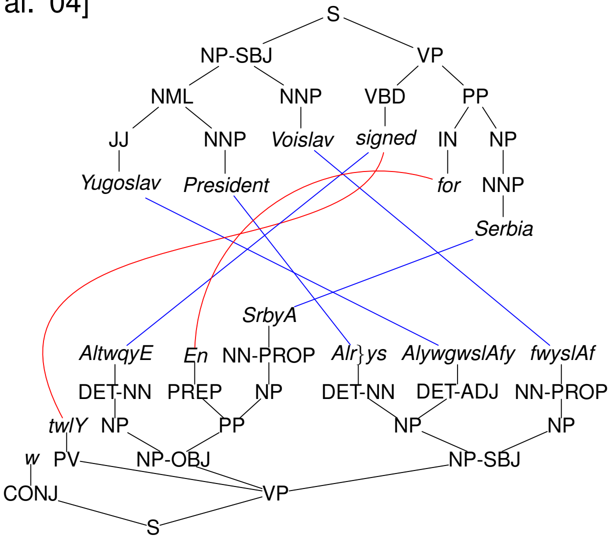
Small example

Alignment



Rule extraction

[GALLEY et al. '04]



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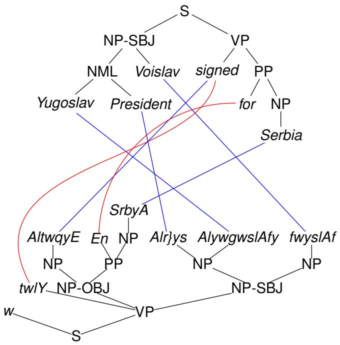
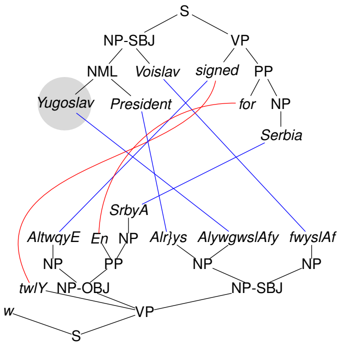


- Select next node bottom-up
- Identify maximal subtree of aligned nodes
- Identify subtree of nodes aligned to aligned nodes, etc.
- Extract rule and leave state
- Repeat

Rule extraction



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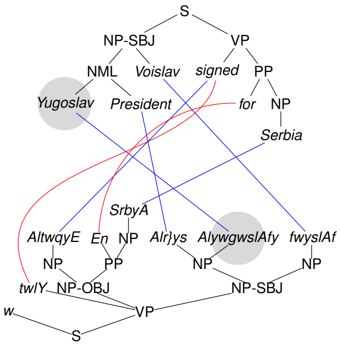

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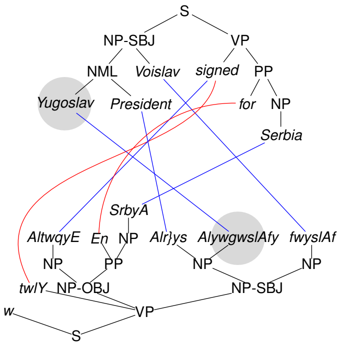

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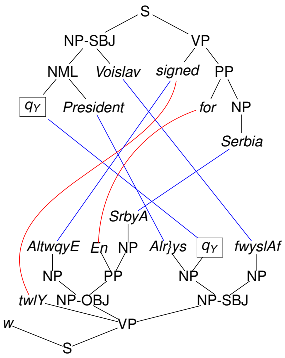

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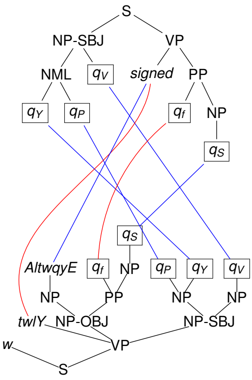
$$Yugoslav \xrightarrow{q_Y} AlywgwslAfy$$

Rule extraction



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President $\underline{\;q_P\;}$ *Alr}ys*

Voislav $\underline{\;q_V\;}$ *fwyslAf*

for $\underline{\;q_f\;}$ *En*

Serbia $\underline{\;q_S\;}$ *SrbyA*

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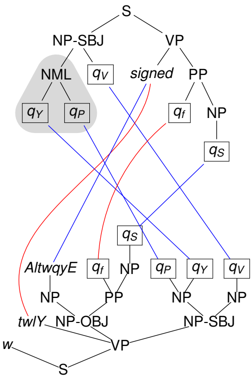

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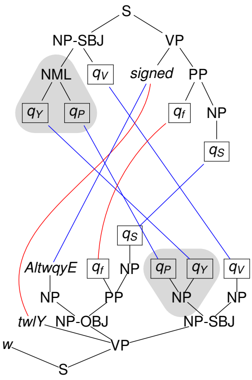
$$\textit{President} \xrightarrow{q_P} \textit{Alr\}ys}$$

$$\textit{Voislav} \xrightarrow{q_V} \textit{fwyslAf}$$

$$\textit{for} \xrightarrow{q_f} \textit{En}$$

$$\textit{Serbia} \xrightarrow{q_S} \textit{SrbyA}$$

Rule extraction



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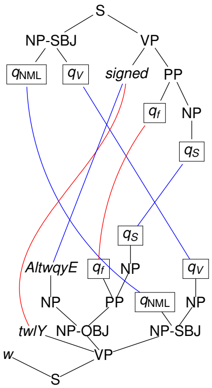
$$\text{NML}(q_Y, q_P) \xrightarrow{q_{\text{NML}}} \text{NP}(q_P, q_Y)$$

Rule extraction



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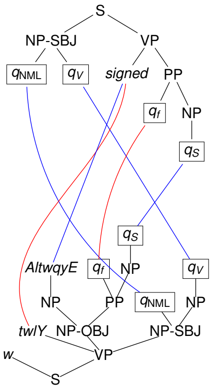

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$$\mathrm{NML}(q_Y, q_P) \xrightarrow{q_{\mathrm{NML}}} \mathrm{NP}(q_P, q_Y)$$

$$\mathrm{NP}(q_S) \xrightarrow{q_{\mathrm{NP}}} \mathrm{NP}(q_S)$$

$$\mathrm{PP}(q_f, q_{\mathrm{NP}}) \xrightarrow{q_{\mathrm{PP}}} \mathrm{PP}(q_f, q_{\mathrm{NP}})$$

$$\mathrm{NP\text{-}SBJ}(q_{\mathrm{NML}}, q_V) \xrightarrow{q_{\mathrm{NP\text{-}SBJ}}} \mathrm{NP\text{-}SBJ}(q_{\mathrm{NML}}, \mathrm{NP}(q_V))$$

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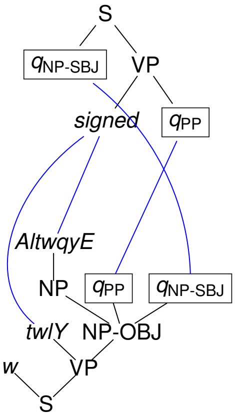

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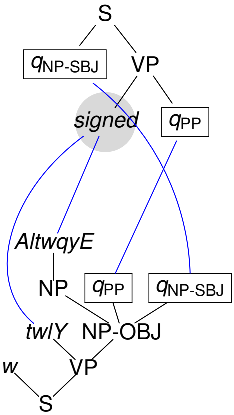

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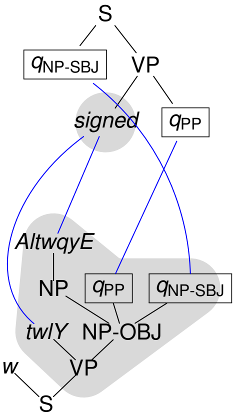

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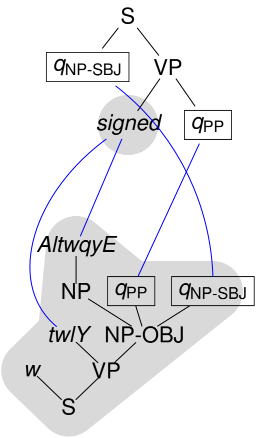

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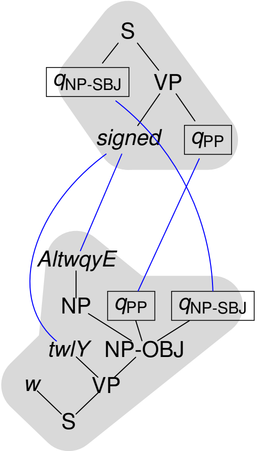

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Extended top-down tree transducer

Advantages

- ✓ simple and natural model
- ✓ easy to train (from linguistic resources) [GRAEHL et al. '08]
- ✓ symmetric

Implementation

- TIBURON [MAY, KNIGHT '06]

Extended top-down tree transducer

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Extended top-down tree transducer

Disadvantages (also of STSG)

- ✗ no discontinuities
- ✗ not binarizable
  [AHO, ULLMAN '72; ZHANG et al. '06]
- ✗ inefficient input/output restriction
  [M., SATTA '10]
- ✗ not composable
  [ARNOLD, DAUCHET '82]

Roadmap

Syntax

Definition

Extended multi bottom-up tree transducer (XMBOT)
system (Q, Σ, F, R)

- Q *ranked* alphabet (*states*)
- Σ ranked alphabet (input/output symbols)
- $F \subseteq Q_1$ (final states)
- R finite set of rules $\ell \to r$ (rules)
  - linear $\ell \in T_\Sigma(Q(X))$
  - $r \in Q(T_\Sigma(Y))$ with $Y = \text{var}(\ell)$

Definition

- linear if r is linear for all $\ell \to r \in R$
- nondeleting if $\text{var}(r) = \text{var}(\ell)$ for all $\ell \to r \in R$

Syntax

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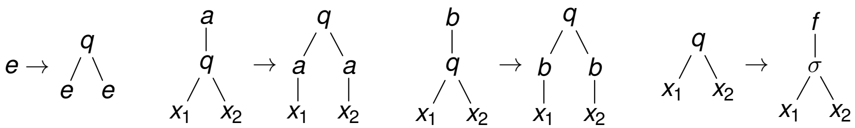
Syntax

Example

XMBOT $(Q, \Sigma, \{f\}, R)$

- $Q = \{q^{(2)}, f^{(1)}\}$
- $\Sigma = \{\sigma^{(2)}, a^{(1)}, b^{(1)}, e^{(0)}\}$
- R contains:



Note

It is linear and nondeleting

Syntax

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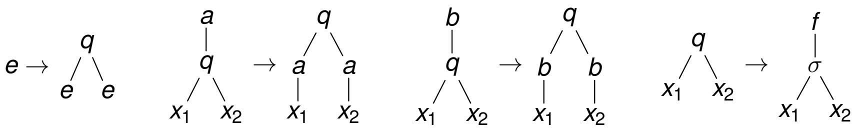

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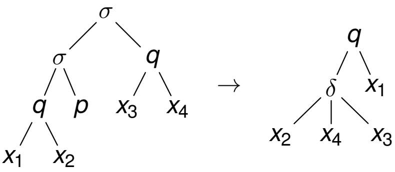
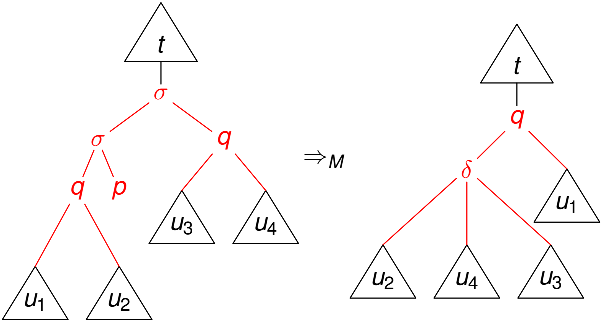
Semantics

Rule:



Derivation:



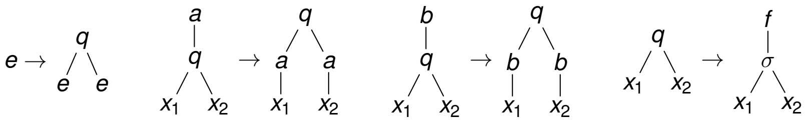
Semantics

$$e \to q(e, e) \qquad a(q(x_1, x_2)) \to q(a(x_1), a(x_2)) \qquad b(q(x_1, x_2)) \to q(b(x_1), b(x_2)) \qquad q(x_1, x_2) \to f(\sigma(x_1, x_2))$$

Example (Derivation)

$$a(b(b(e)))$$

Semantics



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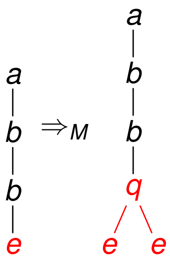

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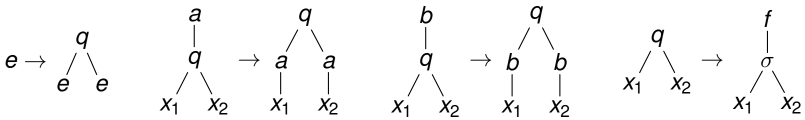

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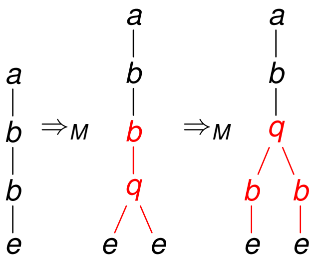

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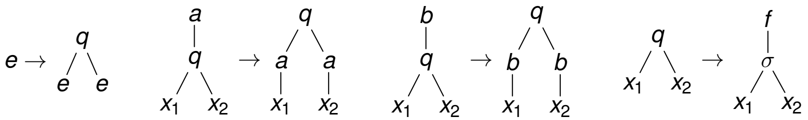

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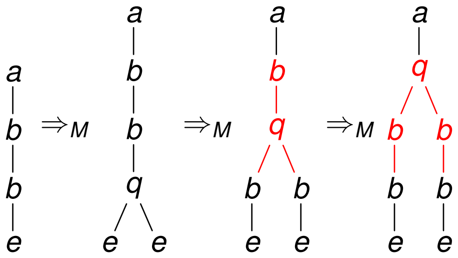

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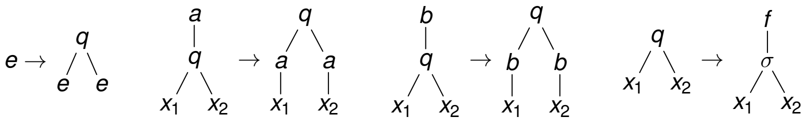

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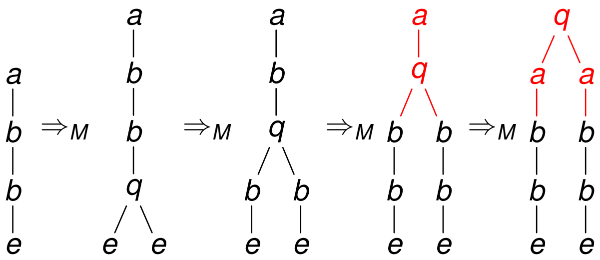

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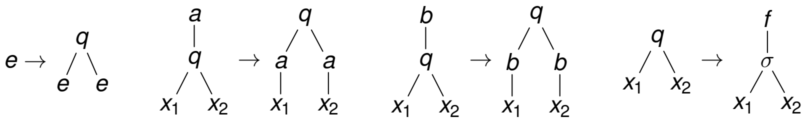

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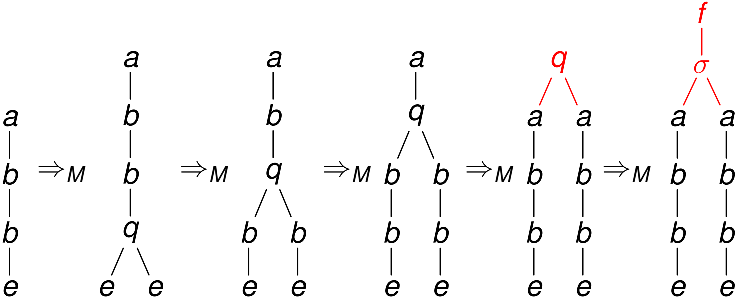

Semantics

Definition

XMBOT $M = (Q, \Sigma, F, R)$

$$\tau_M = \{(t, u) \in T_\Sigma \times T_\Sigma \mid \exists q \in F \colon t \Rightarrow_M^* q(u)\}$$

Semantics

Definition

XMBOT $M = (Q, \Sigma, F, R)$

$$\tau_M = \{(t, u) \in T_\Sigma \times T_\Sigma \mid \exists q \in F \colon t \Rightarrow_M^* q(u)\}$$

Example

It computes $\{(t, \sigma(t, t)) \mid t \in T_\Sigma\}$

Its image is not recognizable

Restrictions

Definition

XMBOT (Q, Σ, F, R) is

- XBOT if $Q = Q_1$
- MBOT if $\ell \in \Sigma(Q(X))$ for all $\ell \to r \in R$

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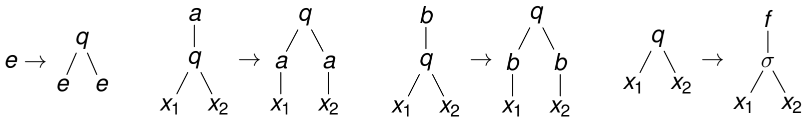

It is neither XBOT nor MBOT

Table of Contents

Proper generalization

Theorem (Engelfriet et al. '09)

All linear XTOP can be simulated by linear XBOT

Proof.

Standard construction trading input-deletion for output-deletion
see l-TOP $\subseteq$ l-BOT by [Engelfriet '75] □

Proper generalization

Theorem (Engelfriet et al. '09)

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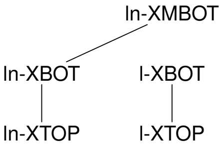

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Theorem (Engelfriet et al. '09)

All XMBOT can be simulated by nondeleting XMBOT

Proof.

- Guess subtrees that will be deleted
- Process them in nullary states (i.e. look-ahead) □

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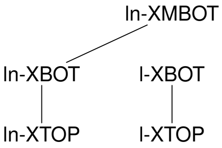

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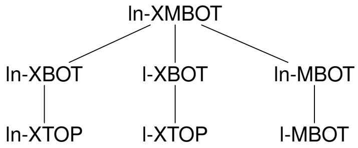

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All XMBOT without recursive ε-rules can be simulated by MBOT

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- Decompose large left-hand sides using "multi"-states
- Attach finite effect of ε-rules

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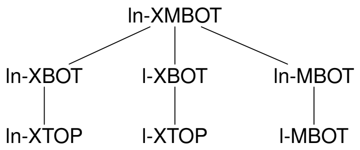

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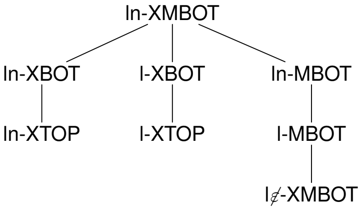

Proper generalization

Definition

- XTOP M sensible if $|u| \in \mathcal{O}(|t|)$ for all $(t, u) \in \tau_M$
- simple = linear and nondeleting

Theorem (Maletti '12)

All sensible XTOP can be simulated by simple MBOT

Proof.

- use (essentially) construction of [Engelfriet, Maneth '03]
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Proper generalization

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All relevant XTOP can be simulated by simple XMBOT

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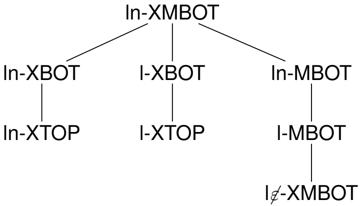

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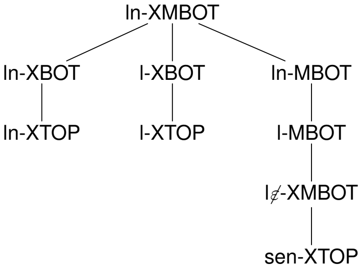

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Simple MBOT cannot be simulated by XTOP

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- even simple MBOT can copy (Example)
- see BOT $\not\subseteq$ TOP by [ENGELFRIET '75] □

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Simple MBOT cannot be weakly simulated by simple XTOP

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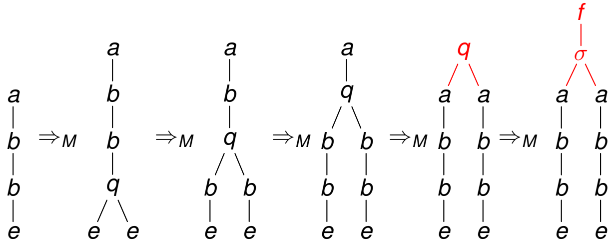
Summary

- ✓ generalize XTOP (even properly)
- (b) discontinuities
- (c) binarizable
- (d) efficient input/output restriction
- (e) efficiently trainable
- (f) closed under composition

Discontinuities

Example (Derivation)



Discontinuities

- ✗ state covers 1 input subtree $\rightarrow$ no input discontinuities
- ✓ state covers several output subtrees $\rightarrow$ output discontinuities

Summary

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Binarization

Definition

XMBOT in 1-symbol normal form
if exactly 1 (input/output) symbol occurs per rule

Theorem (ENGELFRIET et al. '09)

All XMBOT can be simulated by 1-symbol normal form XMBOT

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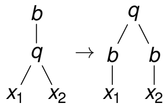
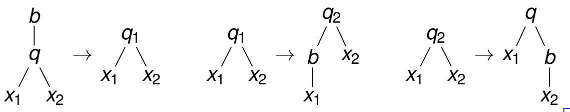
Original rule:



Replacement rules:



□

Binarization

Definition

XMBOT is fully binarized if ≤ 3 states per rule
(≤ 2 in left-hand side)

Theorem (M. ’11)

All XMBOT can be fully binarized (in linear time)

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Proof (Binarize trees and transform into 1-symbol normal form).

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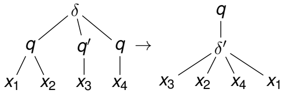
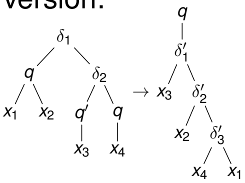
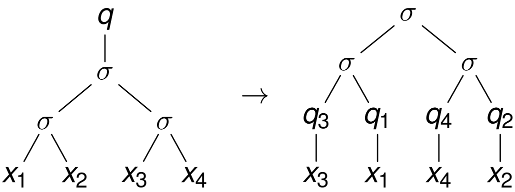


Binarized version:



□

Binarization



Comparison

STSG cannot be binarized, but people try . . .

- [ZHANG et al. '06]
- [DENERO et al. '09]

Corollary

*All XMBOT can be transformed (in linear time)
from joint to conditional distribution*

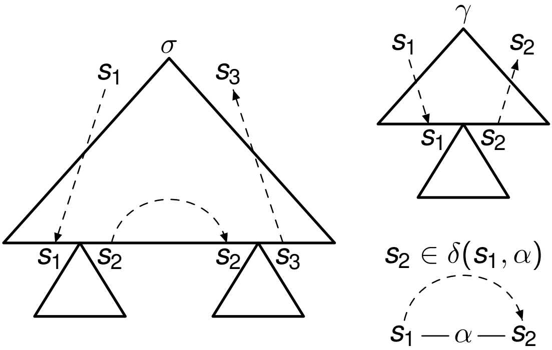
Summary

- ✓ generalize XTOP (even properly)
- ✓ discontinuities (only output side)
- ✓ binarizable
- (d) efficient input/output restriction
- (e) efficiently trainable
- (f) closed under composition

Input/output restriction

Definition

Input restriction restricts the string language of the domain of an XMBOT to a regular language



Input/output restriction

Theorem (M., Satta '10 & M. '11)

Restricting the … by FSA A is …

device	*input*	*output*
linear XMBOT M	$\mathcal{O}(\lvert M\rvert \cdot \lvert A\rvert^3)$	$\mathcal{O}(\lvert M\rvert \cdot \lvert A\rvert^x)$
simple XTOP M	$\mathcal{O}(\lvert M\rvert \cdot \lvert A\rvert^y)$	$\mathcal{O}(\lvert M\rvert \cdot \lvert A\rvert^y)$

with $x = 2\,\mathrm{rk}(M) + 2$ *and* $y = 2\,\mathrm{rk}(M) + 5$

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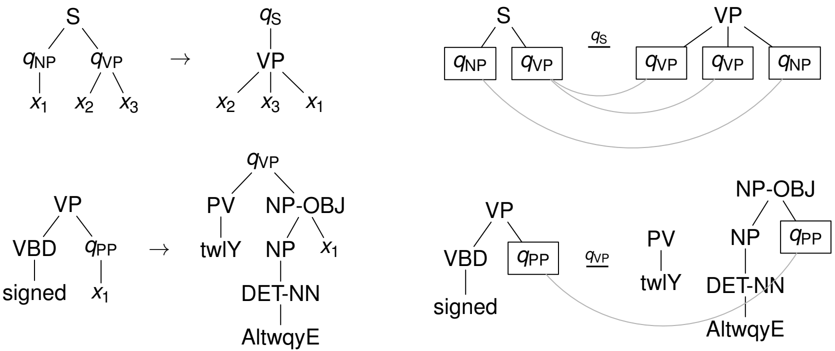
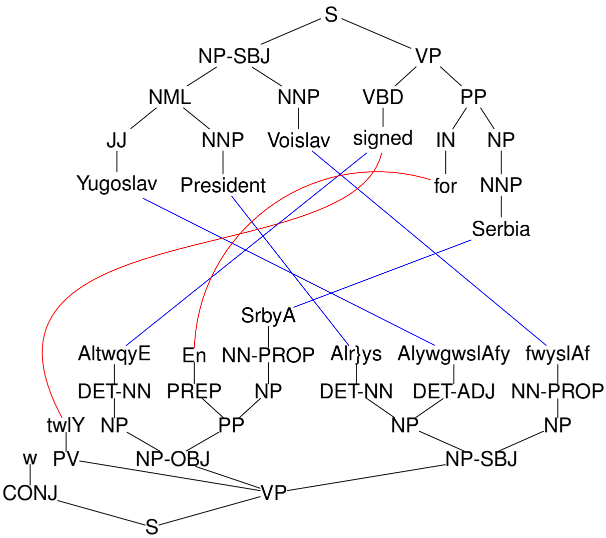
A top-down variant



[M. '11]

Rule extraction



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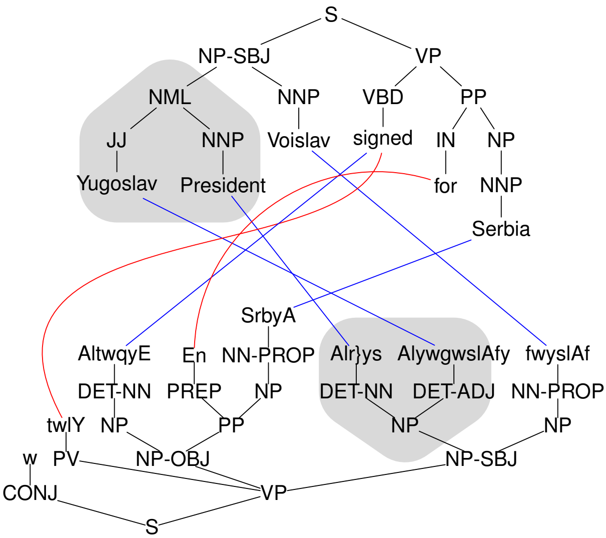

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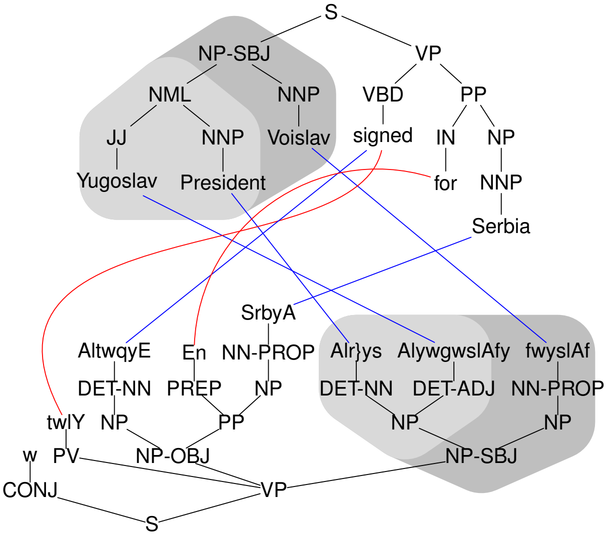

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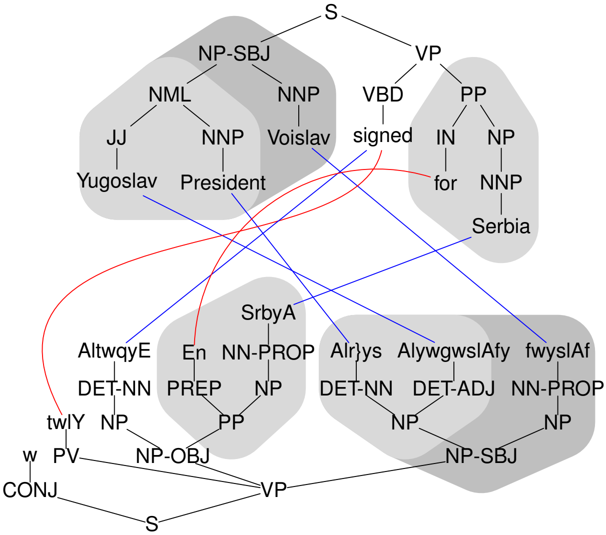

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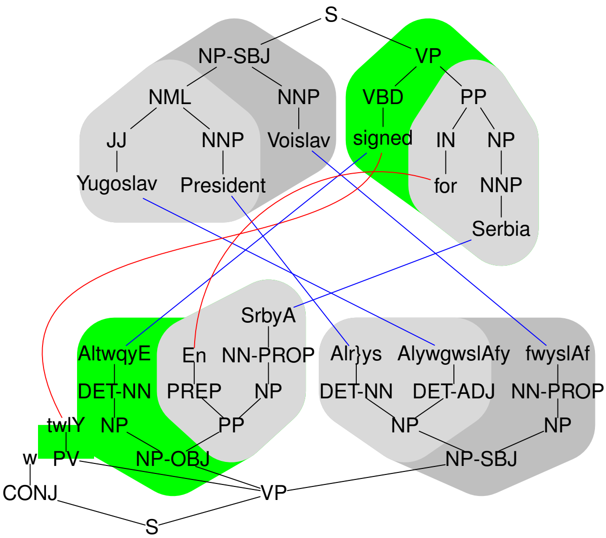

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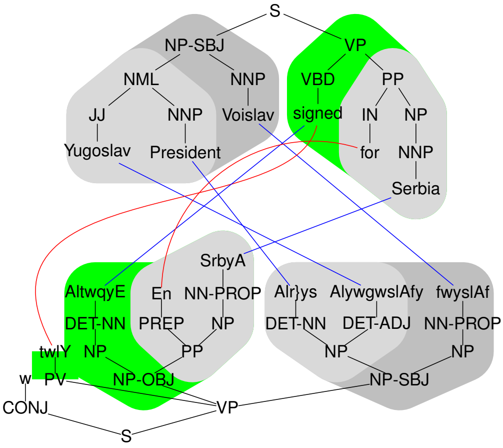

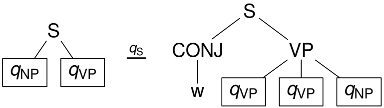

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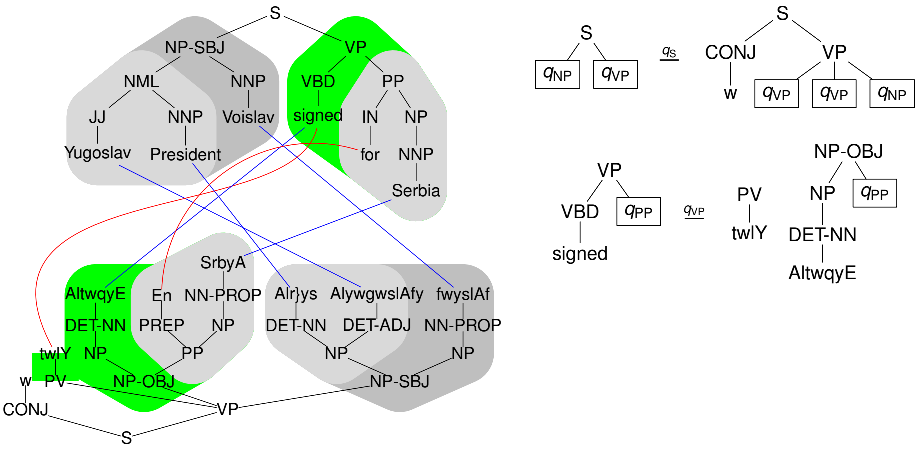

EM training

Theorem

Derivations of XMBOT are regular (even in the weighted case)

Conclusion

program of [GRAEHL et al '08] works

- given translation pair (s_1, s_2)
- input- and output restrict to s_1 and s_2
- build derivations
- compute relative "usefulness" of each rule
- move to the next training sentence (and start anew)

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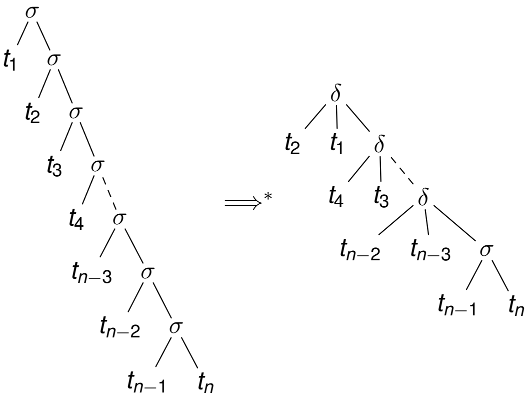
Composition of STSG



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STSGs are not composable!

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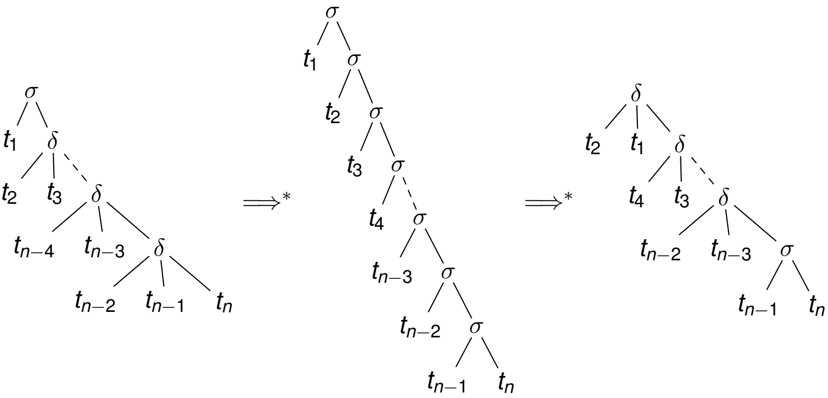

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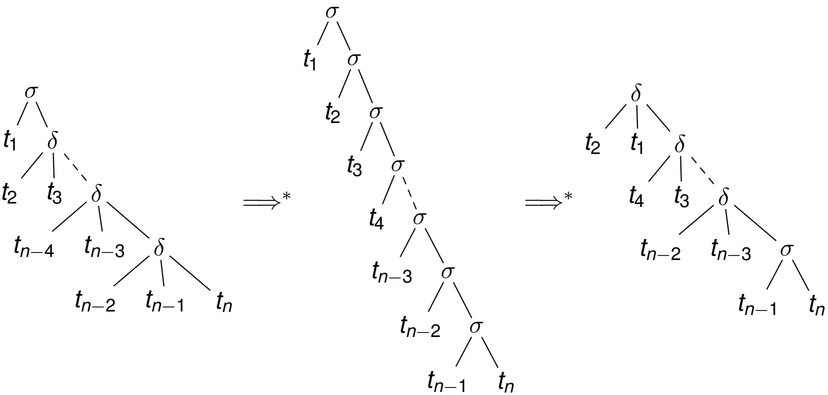

Conclusion

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Composition of XTOP

restrictions	closed?	level of closure
simple, non-erasing, ε-free	✗	2
simple, non-erasing	✗	∞
simple, ε-free	✗	∞
simple	✗	∞
linear	✗	≥ 2
linear with regular look-ahead	✗	≥ 2
general	✗	∞

Composition of XMBOT

restrictions	closed?	level of closure
simple	✓	1
linear	✓	1
general	✗	∞ (?)

Composition construction

Definition

XMBOT $M = (Q, \Sigma, F, R)$ and $N = (Q', \Sigma, G, R')$
in 1-symbol normal form

$$M \,;\, N = (Q(Q'), \Sigma, F(G), R'')$$

with

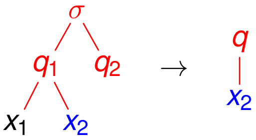
1. input-consuming rules from input-consuming rules of R
2. ε-rules from ε-rules of R'
3. ε-rules from ε-rule of R followed by input consuming rule of R'

Composition construction

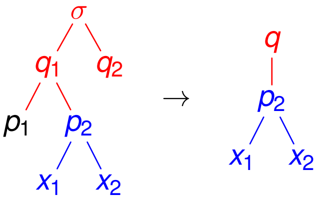
Example

(1) Input-consuming rule of R and resulting rule:

Input rule (of R):



Constructed rule:



Composition construction

Example

(2) ε-rule of R' and resulting rule:

Input rule (of R'): $p_1 \to p(\alpha)$

Constructed rule: $q_1(p_1, p_2(x_1, x_2)) \to q_1(p(\alpha), p_2(x_1, x_2))$

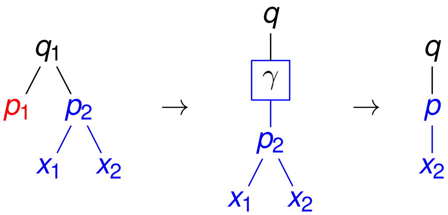
Composition construction

Example

(3) ε-rule of R and input-consuming of R' and resulting rule:

Input rules:

Constructed rule:



Composition construction

Theorem (Engelfriet et al. '09)

The standard bottom-up tree transducer composition results hold

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Summary

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- ✓ preserve regularity backward
- ✗ preserve regularity forward
- ✗ symmetric

Overview

XMBOT in machine translation

Moses [KOEHN et al. '07]

- framework for statistical MT
- implementations for many standard tasks (alignment, lexical scores, language model, BLEU scoring)
- supports syntax-based MT

We added

- XMBOT rule support
- XMBOT chart decoder
- adjusted language model calls

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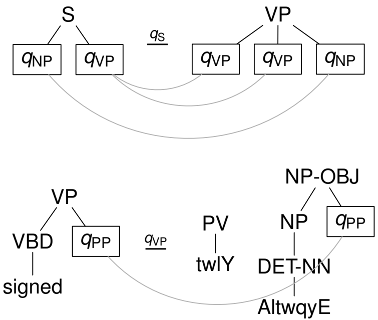
XMBOT rule encoding



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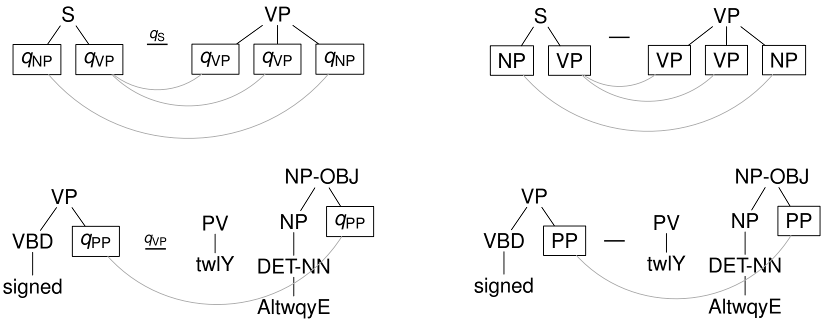

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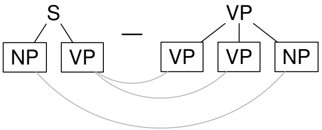
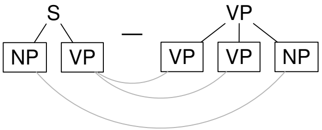



```
S(NP,VP) ||| VP(VP,VP,NP) ||| S ||| VP ||| 0-2 1-0 1-1 ||| ...
```

XMBOT rule encoding

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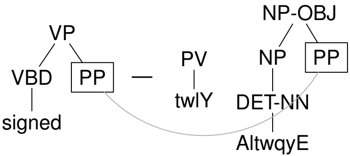


```
VP(VBD(signed),PP) ||| PV(twlY) || NP-OBJ(NP(DET-NN(AltwqyE)),PP) |||
VP ||| PV NP-OBJ ||| || 0-0 ||| ...
```

XMBOT decoder

Fabienne Braune

- CYK-like chart parser
- only forward application (backward planned)
- supports all standard features
- integrated cube pruning with language model

Notes

- reasonably fast
- generated the examples in Motivation (with only translation weights)
- we are still working on it

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XMBOT external tools

NINA SEEMANN

- rule extraction
- input/output restriction
- EM training
- conversion tools, pipeline scripts, . . .

Notes

- in PYTHON (not inside MOSES)
- computationally quite expensive
- variants for reduced POS-tags

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No BLEU score yet

No BLEU score yet, but we are close!

References

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