Hierarchical MT with Discontinuous Phrases

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Thanks to Laura Kallmeyer and Wolfgang Maier

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Idea

Use Synchronous LCFRS instead of SCFG for translation modeling

LCFRS: Linear Context-Free Rewriting Systems

(Vijay-Shanker et al., 1987; Weir, 1988)

- mildly context-sensitive formalism
- suitable for the direct modeling of discontinuous constituents
- Probabilistic data-driven parsing with LCFRS is feasible. (Maier, 2010; van Cranenburgh and Bod, 2013; Kallmeyer and Maier, 2013)

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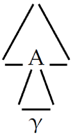
Discontinuous phrase-based SMT (Galley and Manning, 2010)

→ improvement in BLEU score for Chinese-English

→ this work: hierarchical, tree-based counterpart

Inspiration from Parsing

CFG:



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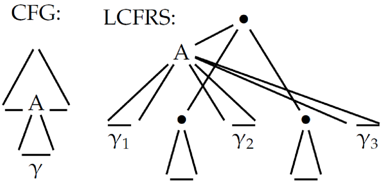

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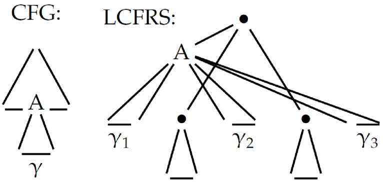

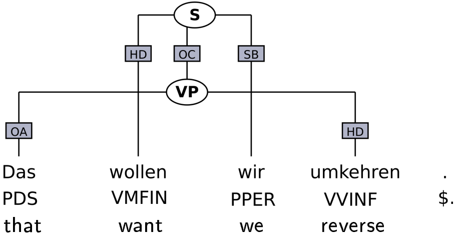

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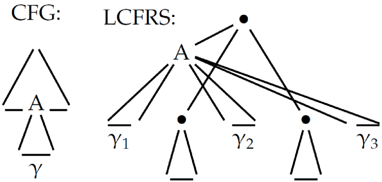

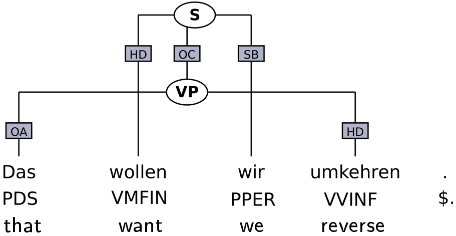

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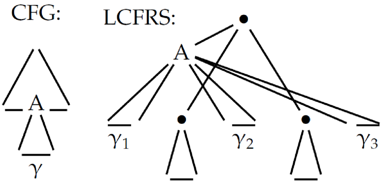

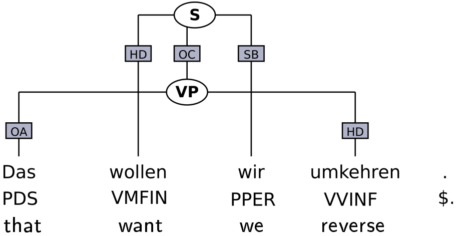

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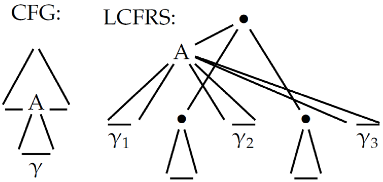

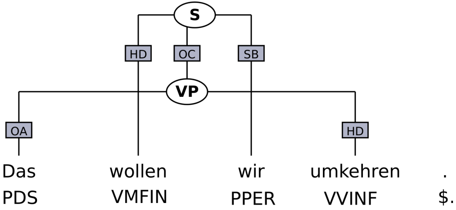

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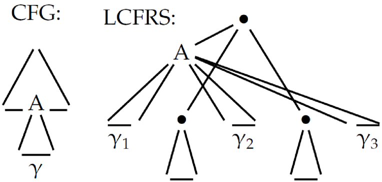

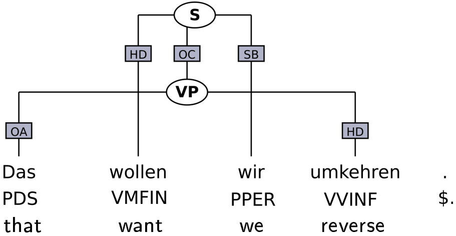

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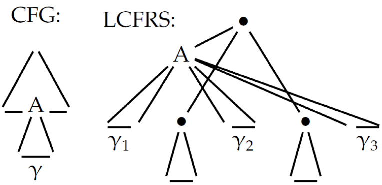

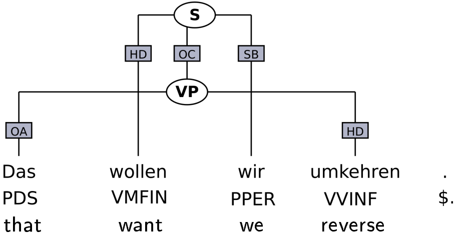

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- G with fan-out 1: equivalent to CFG

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Synchronous LCFRS (SLCFRS)

A tuple $G = (N_s, N_t, T_s, T_t, V_s, V_t, P, S_s, S_t)$ where

- N_s, T_s, V_s, S_s, resp. N_t, T_t, V_t, S_t are defined as for LCFRS
  $\rightarrow$ alphabets for the *source* and *target side* respectively.
- P is a finite set of synchronous rewriting rules $\langle r_s, r_t, \sim \rangle$ where
  - r_s and r_t are LCFRS rewriting rules based on N_s, T_s, V_s and N_t, T_t, V_t respectively, and
  - $\sim$ is a bijective mapping of the non-terminals in the RHS of r_s to the non-terminals in the RHS of r_t.
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  - $\sim$ is a bijective mapping of the non-terminals in the RHS of r_s to the non-terminals in the RHS of r_t.
    $\rightarrow$ co-indexation
- During a derivation, the yields of two co-indexed non-terminals have to be explained from one synchronous rule. $\langle S_s, S_t \rangle$ is the start pair.
- Fan-out v of G: $v_{G_s} + v_{G_t}$ (Notation: $v_{v_{G_s}|v_{G_t}}$)

SLCFRS Example

SCFG:

$\langle X \rightarrow \text{ne veux plus } X_{\boxed{1}} \quad , \quad X \rightarrow \text{do not want to } X_{\boxed{1}} \text{ anymore}\rangle$

$\langle X \rightarrow \text{jouer} \quad , \quad X \rightarrow \text{to play}$

SLCFRS:

$\langle X(\text{ne veux plus } Y_1) \rightarrow X_{\boxed{1}}(Y_1) \quad , \quad X(\text{do not want to } Z_1 \text{ anymore}) \rightarrow X_{\boxed{1}}(Z_1)\rangle$

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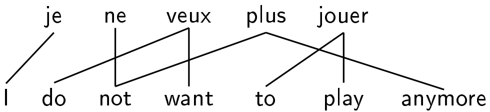

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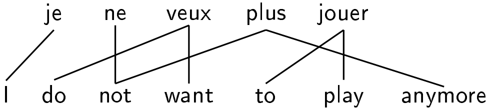
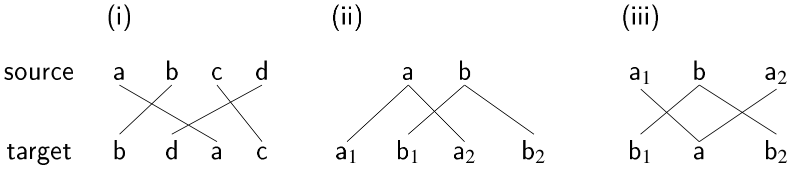
$\langle X(\text{veux}) \rightarrow \varepsilon \quad , \quad X(\text{do , want}) \rightarrow \varepsilon \rangle$

$\langle X(\text{ne } Y_1 \text{ plus } Y_2) \rightarrow X_{\boxed{1}}(Y_1) X_{\boxed{2}}(Y_2) \quad , \quad X(Z_1 \text{ not } Z_2 Z_3 \text{ anymore}) \rightarrow X_{\boxed{1}}(Z_1, Z_2) X_{\boxed{2}}(Z_3) \rangle$



Alignment Configurations Beyond SCFG



Inside-out alignment
Wu (1997)

Cross-serial disc. translation unit
Søgaard & Kuhn (2009)

Bonbon alignment
Simard et al. (2005)

⇒ Beyond the alignment capacity of ITG/SCFG of rank 2

- 5% of Chinese-English sentences have IO alignments (Wellington et al., 2006)
- 9% of Spanish-French sentences and 5.5% of English-German sentences are beyond 2-SCFG (Kaeshammer, 2013)

Training

- Rule extraction from a word-aligned parallel corpus as for *hierarchical phrase-based MT* (SCFG)
  1. Extraction of initial phrase pairs
  2. Creation of hierarchical rules by replacing phrase pairs which are contained within other phrase pairs with non-terminals/variables

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- Additional features: source gap degree and target gap degree (number of gaps during a derivation)

Decoder (1)

- Same methodology as for SCFG-based decoding
- Bottom-up CYK parser using the source side of the translation grammar
  - → monolingual weighted LCFRS parsing
  - → parse items $[A, \boldsymbol{\rho}, v_t]$
  - → Specific $(2,2)$-LCFRS parser because of the specific form of the grammar (rank 2, fan-out $4_{2|2}$) : $\boldsymbol{\rho} = (\langle i_1, j_1 \rangle, \langle i_2, j_2 \rangle)$

Decoder (2)

- Intersection of the parse hypergraph with an n-gram LM: Cube pruning (Huang and Chiang, 2007)
  - → target string of a hypothesis is a tuple of continuous blocks of target words, e.g. ⟨do not want, anymore⟩
  - → score each block separately
  - → store a LM state for each block
- Extraction of k-best translations on the hypergraph after cube pruning
- Implementation in C++, including code from KenLM for language modeling

Experimental Setup

- German-to-English translation
- Data from the WMT 2014 translation task (max. 30 words)
- Standard preprocessing and word alignment
- Filter the translation grammar w.r.t. input data set by extracting per-sentence-grammars
- 3-gram LM, KenLM
- For decoding: cube pruning buffer size 400, no limits on the number of words a non-terminal can span
- Tuning the feature weights with MERT, maximizing BLEU-4, using 200-best translations (ZMERT, mert-moses.pl)
- multi-bleu.perl for calculating BLEU scores (lc), repeating each experiment four times, reporting the average

Results

system	feat	devtest BLEU	test BLEU
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sys(1,2)	-	23.39	23.24
sys(2,1)	-	24.17	**23.41**

Manual Evaluation

- sys(1,1) vs. sys(2,1) system comparison using Appraise
- 95 sentences where sys(2,1) uses at least one SLCFRS rule
- two native speakers of English with basic knowledge of German

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	sys(1,1)	sys(2,1)	=
e1	43	49	3
e2	46	47	2

Table: Result of the manual system comparison

Translation Example

Source	er wäre damit auch geeignet gewesen , um die . . . zu fördern
Reference	it would thus be suitable to assist . . .
sys(1,1)	it would also have to be , in order to promote the . . .
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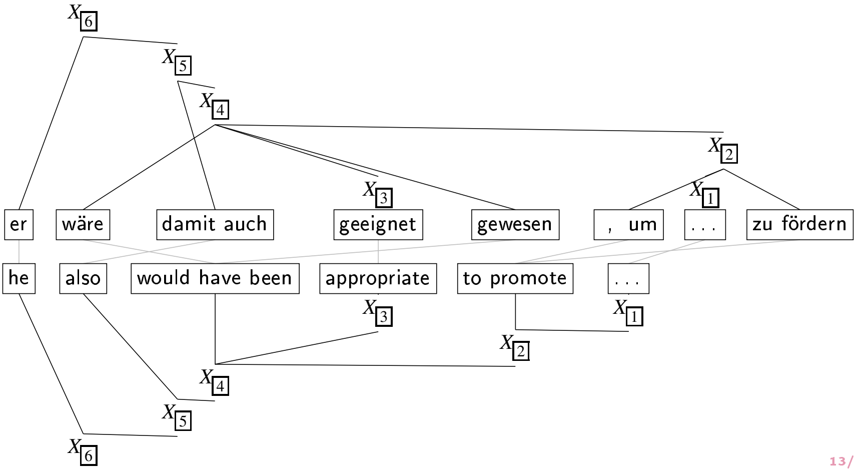
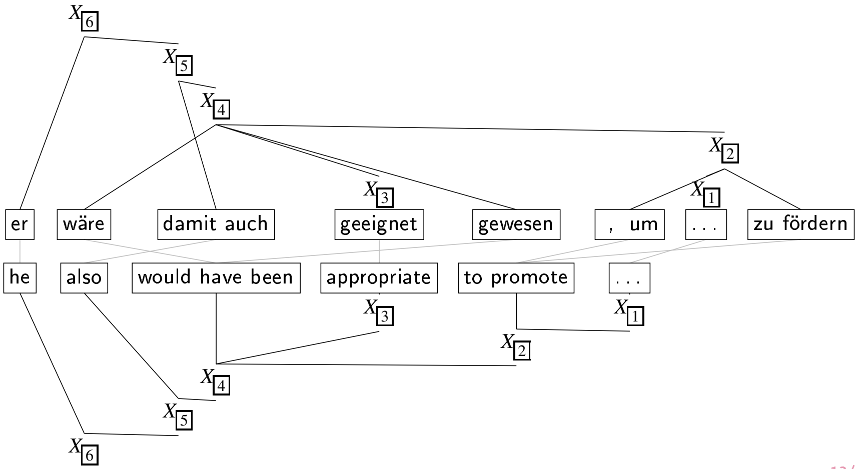


Translation Example

$\langle X(\text{wäre}\ ,Y_1\ \text{gewesen}\ Y_2) \rightarrow X_{\boxed{1}}(Y_1)X_{\boxed{2}}(Y_2)\ ,X(\text{would have been}\ Y_1Y_2) \rightarrow X_{\boxed{1}}(Y_1)X_{\boxed{2}}(Y_2)\rangle$



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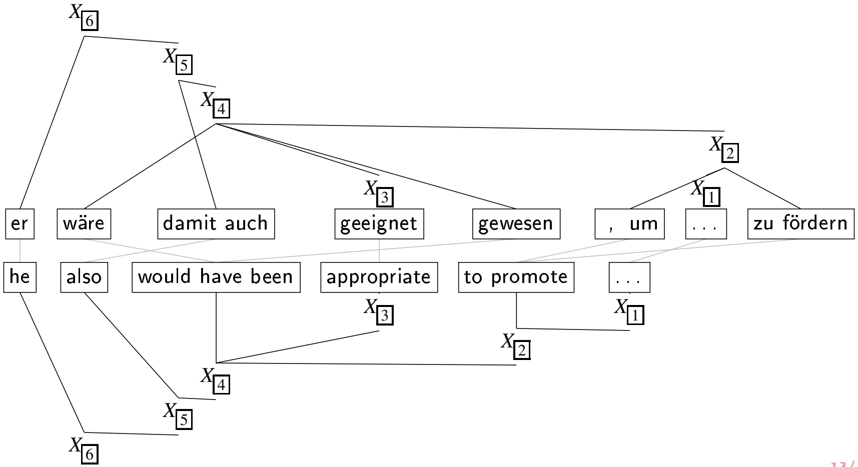
$\langle X(Y_1 \text{ damit auch } Y_2) \rightarrow X_{\boxed{1}}(Y_1, Y_2)\ , X(\text{also } Y_1) \rightarrow X_{\boxed{1}}(Y_1)\rangle$



Conclusions & Future Work

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- More detailed evaluation
- Experiments with other language pairs

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moses		24.33	23.34

Derivation

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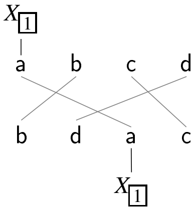

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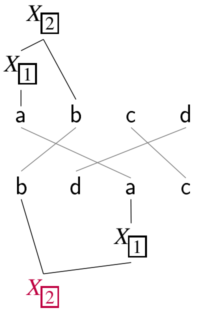

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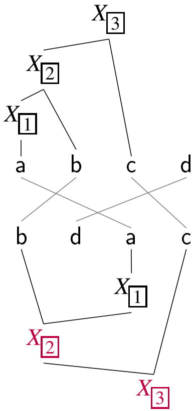

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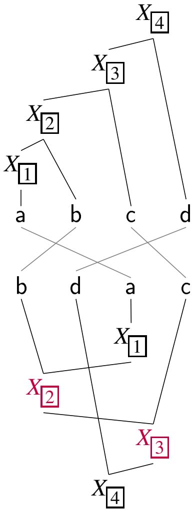
$$\langle X(Y\mathsf{b}) \rightarrow X_{\boxed{1}}(Y) \ , X(\mathsf{b}, Z) \rightarrow X_{\boxed{1}}(Z) \rangle$$
$$\langle X(Y\mathsf{c}) \rightarrow X_{\boxed{1}}(Y) \ , X(Z_1, Z_2\mathsf{c}) \rightarrow X_{\boxed{1}}(Z_1, Z_2) \rangle$$

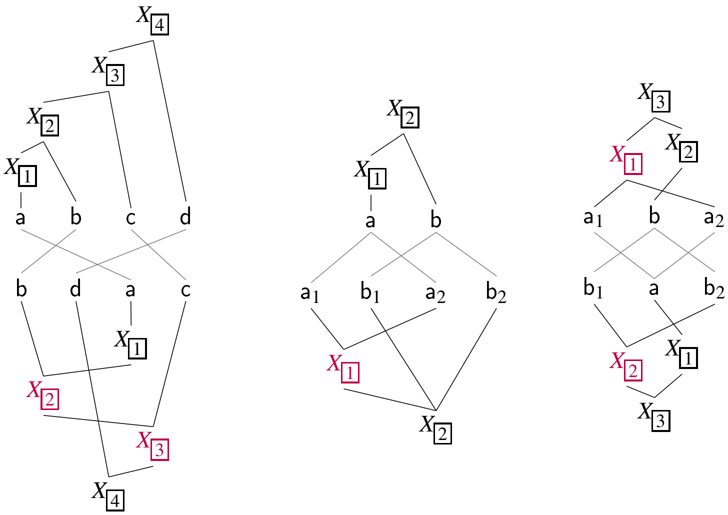
Derivation



$$\langle X(\mathsf{a}) \rightarrow \varepsilon \quad , X(\mathsf{a}) \rightarrow \varepsilon \rangle$$
$$\langle X(Y\mathsf{b}) \rightarrow X_{\boxed{1}}(Y) \ , X(\mathsf{b}, Z) \rightarrow X_{\boxed{1}}(Z) \rangle$$
$$\langle X(Y\mathsf{c}) \rightarrow X_{\boxed{1}}(Y) \ , X(Z_1, Z_2\mathsf{c}) \rightarrow X_{\boxed{1}}(Z_1, Z_2) \rangle$$
$$\langle X(Y\mathsf{d}) \rightarrow X_{\boxed{1}}(Y) \ , X(Z_1\mathsf{d}Z_2) \rightarrow X_{\boxed{1}}(Z_1, Z_2) \rangle$$

or ...

Derivation


X 4
X 3
X 2
X 1
a b c d
b d a c
X 1
X 2
X 3
X 4
X 2
X 1
a b
a1 b1 a2 b2
X 1
X 2
X 3
X 1 X 2
a1 b a2
b1 a b2
X 2 X 1
X 3

Related Work

- Studies addressing the alignment coverage of a formalism w.r.t. gold alignments (Søgaard and Wu, 2009; Søgaard and Kuhn, 2009; Wellington et al., 2006; Søgaard, 2010; Kaeshammer, 2013)
  - → 5% of Chinese-English sentences have IO alignments
  - → 9% of Spanish-French sentences and 5.5% of English-German sentences are beyond 2-SCFG
- SLCFRS are equivalent to Simple Range Concatenation Transducers (Bertsch and Nederhof, 2001) and Generalized Multitext Grammars (Melamed et al., 2004)
- Discontinuous phrase-based SMT (Galley and Manning, 2010)
  - → improvement in BLEU score for Chinese-English
  - → this work: hierarchical, tree-based counterpart

Features

- Standard features: direct and inverse translation probabilities, lexical translation probabilities, number of rules etc.
- MLE on the distribution of the extracted rules to obtain the translation probabilities
- Additional: number of gaps during a derivation (source gap degree and target gap degree of a rule)

Experimental Setup

- German-to-English translation
- Data from the WMT 2014 translation task (max. 30 words)
- Punctuation normalization, tokenization, truecasing, compound splitting for German with the Moses scripts
- Multi-threaded GIZA++ and `grow-diag-final-and` heuristics for word-aligning the training data
- Filter the translation grammar w.r.t. input data set by extracting per-sentence-grammars
- 3-gram LM, KenLM
- For decoding: cube pruning buffer size 400, no limits on the number of words a non-terminal can span
- Tuning the feature weights with MERT, maximizing BLEU-4, using 200-best translations (ZMERT, mert-moses.pl)
- multi-bleu.perl for calculating BLEU scores (lc), repeating each experiment four times, reporting the average

Manual Evaluation

- sys(1,1) vs. sys(2,1) system comparison using Appraise
- 95 sentences where sys(2,1) uses at least one SLCFRS rule
- two native speakers of English with basic knowledge of German

	sys(1,1)	sys(2,1)	=
e1	43	49	3
e2	46	47	2

Table: Result of the manual system comparison

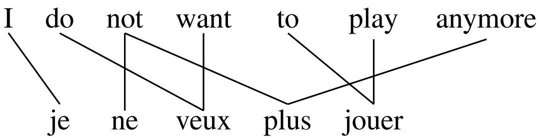
		e2		
		sys(1,1)	sys(2,1)	=
e1	sys(1,1)	**29**	13	1
	sys(2,1)	15	**33**	1
	=	2	1	0

Table: Confusion matrix of the decisions of the manual evaluation, Cohen's $\kappa = 0.338$

Notion of Alignment Capacity

Same as in previous related work

- A **translation unit** (TU) is a maximally connected subgraph of a given alignment structure.
- Alignment structure is divided into disjoint TUs.



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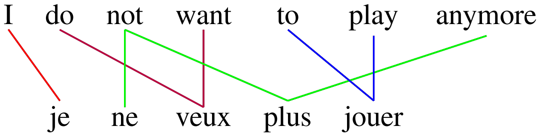
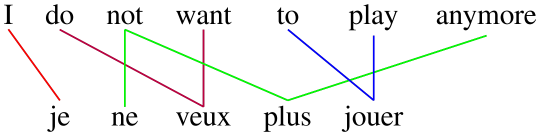


Notion of Alignment Capacity

Same as in previous related work

- A **translation unit** (TU) is a maximally connected subgraph of a given alignment structure.
- Alignment structure is divided into disjoint TUs.
- Synchronously recognized or generated terminals are aligned $\rightarrow$ TU



LCFRS (1)

(Vijay-Shanker et al., 1987; Weir, 1988)

A tuple $G = (N, T, V, P, S)$ where

- N: a finite set of non-terminals with a function dim: $N \to \mathbb{N}$ determining the **fan-out** of each $A \in N$;
- T and V: disjoint finite sets of terminals and variables;
- $S \in N$: start symbol with $dim(S) = 1$;
- P: a finite set of rewriting rules

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- T and V: disjoint finite sets of terminals and variables;
- $S \in N$: start symbol with $dim(S) = 1$;
- P: a finite set of rewriting rules

$$A(\alpha_1, \ldots, \alpha_{dim(A)}) \rightarrow A_1(X_1^{(1)}, \ldots, X_{dim(A_1)}^{(1)}) \cdots A_m(X_1^{(m)}, \ldots, X_{dim(A_m)}^{(m)})$$

where

- $A, A_1, \ldots, A_m \in N$, $X_j^{(i)} \in V$ for $1 \leq i \leq m$, $1 \leq j \leq dim(A_i)$, and
- $\alpha_i \in (T \cup V)^*$ for $1 \leq i \leq dim(A)$, for a **rank** $m \geq 0$.

LCFRS (2)

$$A(\alpha_1, \dots, \alpha_{dim(A)}) \rightarrow A_1(X_1^{(1)}, \dots, X_{dim(A_1)}^{(1)}) \cdots A_m(X_1^{(m)}, \dots, X_{dim(A_m)}^{(m)})$$

- Every variable X in $r \in P$ occurs exactly once in the LHS and exactly once in the RHS of r.
- r describes how the yield of the LHS non-terminal is computed from the yields of the RHS non-terminals.
- The yield of S is the language of the grammar.
- Rank u of G: the maximal rank of any of its rules
- Fan-out v of G: the maximal fan-out of any of its non-terminals.

Normal Form

Conditions:

1. $u_G \leq 2$
2. For all $r \in P$ it holds that that the LHS arguments of r_s and r_t contain either terminals or variables but not mixture of both.

NF-ITG $\leftrightarrow$ $(2, 2_{1|1})$-SLCFRS in normal form
ITG of rank 2 $\leftrightarrow$ $(2, 2_{1|1})$-SLCFRS

Different alignment capacity of normal form and full class

Bitext Parsing Complexity

SLCFRS in normal form with fan-out v

$\mathcal{O}(n^{3v})$

(assuming that $n_s \approx n_t$)

Bitext Parsing Complexity

SLCFRS in normal form with fan-out v

$\mathcal{O}(n^{3v})$

(assuming that $n_s \approx n_t$)

Which fan-out v is required to cover the alignment configurations that occur in manually aligned data?

Data & Results

Graça	en-fr
	en-pt
	en-es
	pt-fr
	pt-es
	es-fr
Martin	en-ro
	en-hi
	en-iu
Pado	en-de
Mihal.	en-fr
CDT	da-en
	da-de
	da-es
	da-it
Holmqv.	en-sv
Schoen.	en-de
Lambert	en-es
Macken	en-nl

Data & Results

		NF $v = 2_{1\|1}$ = NF-ITG	$u = 2$
Graça	en-fr	73.00	
	en-pt	76.00	
	en-es	82.00	
	pt-fr	73.00	
	pt-es	90.00	
	es-fr	74.00	
Martin	en-ro	45.07	
	en-hi	82.73	
	en-iu	40.66	
Pado	en-de	73.74	
Mihal.	en-fr	67.56	
CDT	da-en	72.90	
	da-de	64.87	
	da-es	66.61	
	da-it	69.01	
Holmqv.	en-sv	82.83	
Schoen.	en-de	29.15	
Lambert	en-es	47.15	
Macken	en-nl	57.14	

Data & Results

		NF	$u = 2$
		$v = 2_{1\|1}$ = NF-ITG	$v = 2_{1\|1}$ = ITG
Graça	en-fr	73.00	95.00
	en-pt	76.00	98.00
	en-es	82.00	96.00
	pt-fr	73.00	92.00
	pt-es	90.00	99.00
	es-fr	74.00	91.00
Martin	en-ro	45.07	95.07
	en-hi	82.73	96.36
	en-iu	40.66	100.00
Pado	en-de	73.74	94.41
Mihal.	en-fr	67.56	95.30
CDT	da-en	72.90	97.80
	da-de	64.87	94.94
	da-es	66.61	97.50
	da-it	69.01	97.95
Holmqv.	en-sv	82.83	95.60
Schoen.	en-de	29.15	76.11
Lambert	en-es	47.15	94.85
Macken	en-nl	57.14	94.86

Data & Results

		NF	$u=2$	Søgaard (2010)	
		$v=2_{1\|1}$ = NF-ITG	$v=2_{1\|1}$ = ITG	NF-ITG	ITG
Graça	en-fr	73.00	95.00	65.00	68.00
	en-pt	76.00	98.00	65.00	67.00
	en-es	82.00	96.00	73.00	74.00
	pt-fr	73.00	92.00	63.00	63.00
	pt-es	90.00	99.00	80.00	81.00
	es-fr	74.00	91.00	68.00	68.00
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	en-hi	82.73	96.36		
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Pado	en-de	73.74	94.41		
Mihal.	en-fr	67.56	95.30		
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	da-de	64.87	94.94		
	da-es	66.61	97.50		
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Lambert	en-es	47.15	94.85		
Macken	en-nl	57.14	94.86		

Data & Results

		NF		$u=2$	Søgaard (2010)	
		$v=2_{1\|1}$ = NF-ITG	$v=4_{2\|2}$	$v=2_{1\|1}$ = ITG	NF-ITG	ITG
Graça	en-fr	73.00	**100.00**	95.00	65.00	68.00
	en-pt	76.00	**100.00**	98.00	65.00	67.00
	en-es	82.00	**100.00**	96.00	73.00	74.00
	pt-fr	73.00	**97.00**	92.00	63.00	63.00
	pt-es	90.00	**99.00**	99.00	80.00	81.00
	es-fr	74.00	**100.00**	91.00	68.00	68.00
Martin	en-ro	45.07	**97.85**	95.07		
	en-hi	82.73	**100.00**	96.36		
	en-iu	40.66	**95.60**	100.00		
Pado	en-de	73.74	**100.00**	94.41		
Mihal.	en-fr	67.56	**98.88**	95.30		
CDT	da-en	72.90	**98.93**	97.80		
	da-de	64.87	**98.42**	94.94		
	da-es	66.61	**97.68**	97.50		
	da-it	69.01	**97.65**	97.95		
Holmqv.	en-sv	82.83	**99.78**	95.60		
Schoen.	en-de	29.15	**94.74**	76.11		
Lambert	en-es	47.15	**97.83**	94.85		
Macken	en-nl	57.14	**98.86**	94.86		

Data & Results

		NF		$u = 2$	Søgaard (2010)	
		$v = 2_{1\|1}$ = NF-ITG	$v = 4_{2\|2}$	$v = 2_{1\|1}$ = ITG	NF-ITG	ITG
Graça	en-fr	73.00	**100.00**	95.00	65.00	68.00
	en-pt	76.00	**100.00**	98.00	65.00	67.00
	en-es	82.00	**100.00**	96.00	73.00	74.00
	pt-fr	73.00	**97.00**	92.00	63.00	63.00
	pt-es	90.00	**99.00**	99.00	80.00	81.00
	es-fr	74.00	**100.00**	91.00	68.00	68.00
Martin	en-ro	45.07	**97.85**	95.07		
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Data & Results

		NF		$u = 2$		Søgaard (2010)	
		$v = 2_{1\|1}$ $= \text{NF-ITG}$	$v = 4_{2\|2}$	$v = 2_{1\|1}$ $= \text{ITG}$	$v = 4_{2\|2}$	NF-ITG	ITG
Graça	en-fr	73.00	**100.00**	95.00	**100.00**	65.00	68.00
	en-pt	76.00	**100.00**	98.00	**100.00**	65.00	67.00
	en-es	82.00	**100.00**	96.00	**100.00**	73.00	74.00
	pt-fr	73.00	**97.00**	92.00	**100.00**	63.00	63.00
	pt-es	90.00	**99.00**	99.00	**100.00**	80.00	81.00
	es-fr	74.00	**100.00**	91.00	**100.00**	68.00	68.00
Martin	en-ro	45.07	**97.85**	95.07	**100.00**		
	en-hi	82.73	**100.00**	96.36	**100.00**		
	en-iu	40.66	**95.60**	100.00	**100.00**		
Pado	en-de	73.74	**100.00**	94.41	**100.00**		
Mihal.	en-fr	67.56	**98.88**	95.30	**100.00**		
CDT	da-en	72.90	**98.93**	97.80	**100.00**		
	da-de	64.87	**98.42**	94.94	**100.00**		
	da-es	66.61	**97.68**	97.50	**100.00**		
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Holmqv.	en-sv	82.83	**99.78**	95.60	**100.00**		
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		NF		$u = 2$		Søgaard (2010)	
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