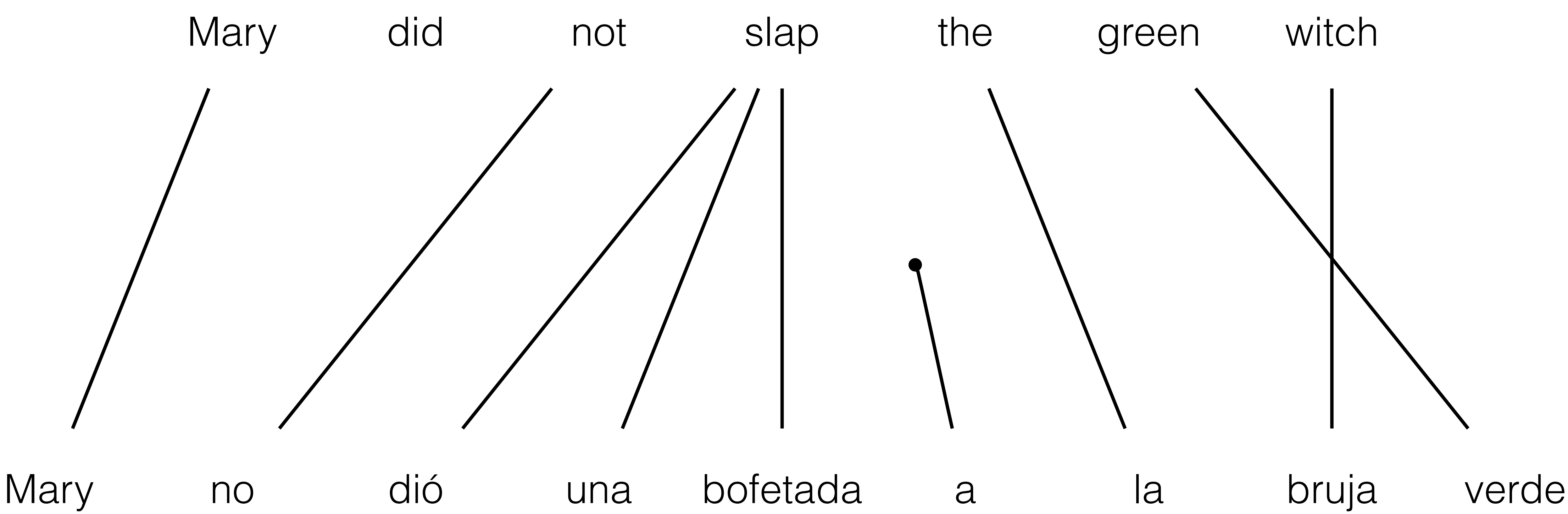
Inversion Transduction Grammars

Wilker Aziz

12/4/16

Word-based Translation



Every French word is generated by an English word (or null)

Generative Story IBM$_{\geq 3}$: Given E

Mary	did	not	slap		the	green	witch

Generative Story IBM$_{\geq 3}$: Fertility

Mary	did	not		slap			the	green	witch
Mary	~~did~~	not	slap	slap	slap		the	green	witch

Generative Story IBM$_{\geq 3}$: NULL insertion

Mary	did	not	slap				the	green	witch
Mary	~~did~~	not	slap	slap	slap		the	green	witch
						NULL			

Generative Story IBM$_{\geq 3}$: Translation

Mary	did	not	slap				the	green	witch
Mary	~~did~~	not	slap	slap	slap		the	green	witch
						NULL			
Mary		no	dió	una	bofetada	a	la	verde	bruja

Generative Story IBM$_{\geq 3}$: Distortion

Mary	did	not		slap			the	green	witch
Mary	~~did~~	not	slap	slap	slap		the	green	witch
						NULL			
Mary		no	dió	una	bofetada	a	la	verde	bruja
Mary		no	dió	una	bofetada	a	la	bruja	verde

Discussion

- IBM models do not constrain divergence with respect to word order
- Distortion step must consider

all the *m*! permutations

of *m* French words

All permutations: sensible or not?

If we do not impose structural constraints
(yet they do exist)

- the model will have to learn (rather *implicitly*) how not to violate them

- which ought to require more data

Practical consequences

Estimation

- modelling outcomes that even though possible are not plausible (unlikely to be observed)

Generation

- NP-completeness!

NP-completeness

NP-complete problem

- Generalised TSP [Knight, 1999; Zaslavskiy et al, 2009]
- Perfect matching [DeNero and Klein, 2008]
- All permutations [Asveld, 2006; 2008]

All permutations

Let $\Sigma_n = \{a_1, ..., a_n\}$

- $S \rightarrow A_{\Sigma_n}$
- $A_X \rightarrow a\ A_{X\text{-}\{a\}}$ for $X \subseteq \Sigma_n$, $\#X \geq 2$, $a \in X$
- $A_{\{a\}} \rightarrow a$

Regular grammar (there is an equivalent FSA)

Asveld (2006, 2008)

Complexity

Note that nonterminals are indexed by subsets of Σ_n

i.e. power set of $\boldsymbol{\Sigma}$

- 2^n nonterminals (states)
- $n \times 2^n$ productions (transitions)
- $n!$ strings (paths)

Example: 3 elements

$S \rightarrow A_{123}$

$A_{123} \rightarrow a_1\ A_{23} \mid a_2\ A_{13} \mid a_3\ A_{23}$

$A_{12} \rightarrow a_1\ A_2 \mid a_2\ A_1$

$A_{13} \rightarrow a_1\ A_3 \mid a_3\ A_1$

$A_{23} \rightarrow a_2\ A_3 \mid a_3\ A_2$

$A_1 \rightarrow a_1$

$A_2 \rightarrow a_2$

$A_3 \rightarrow a_3$

"IBM constraint"

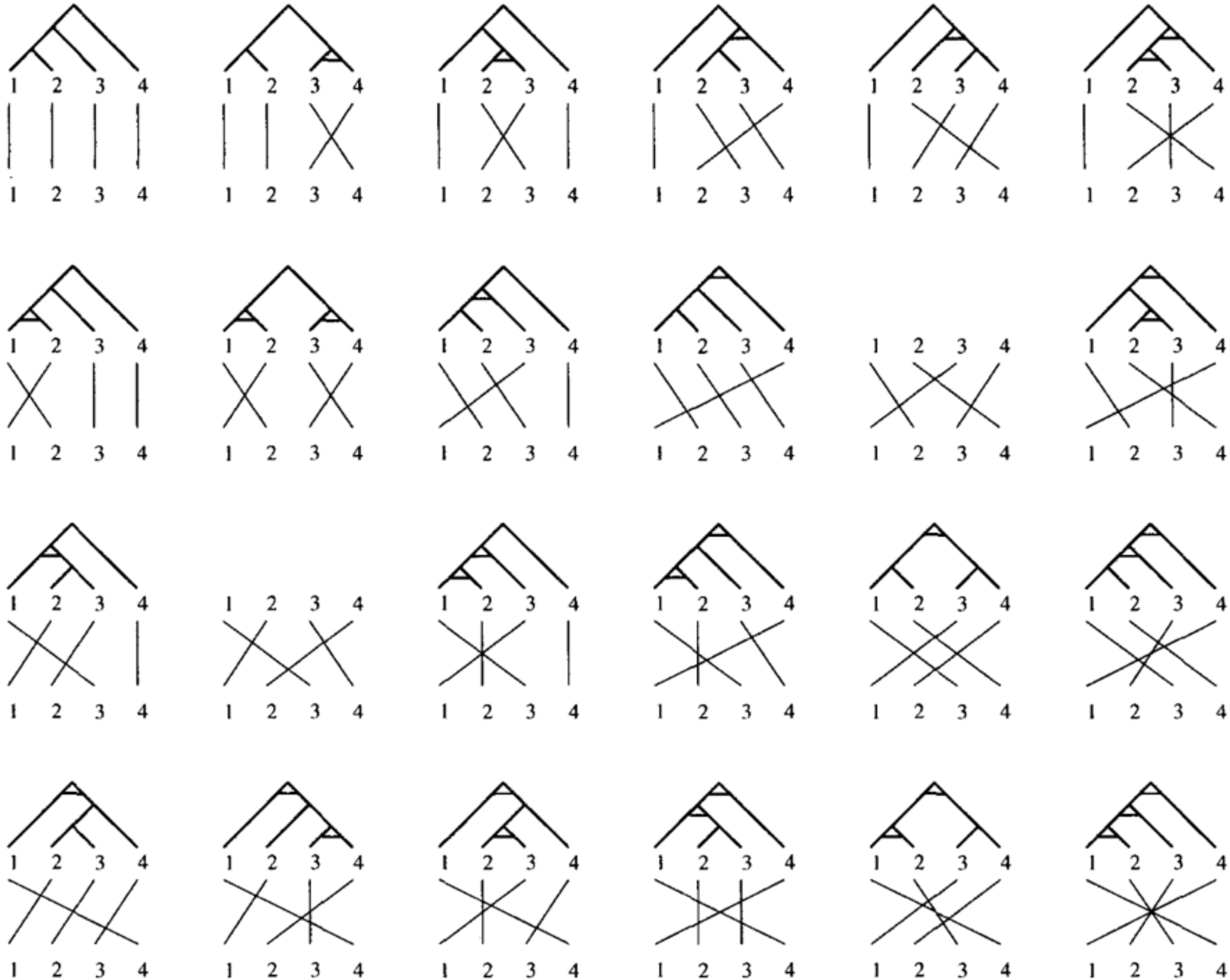
Distortion limit in **generation** but not in **estimation**

- any reasons why that may be unsatisfactory?

Constraining permutations without a distortion limit

Inversion Transduction Grammars (ITGs) [Wu, 1995; 1997]

- Binarizable permutations
  - two streams are simultaneously generated
  - context-free backbone



[Wu, 1997]

Number of Permutations

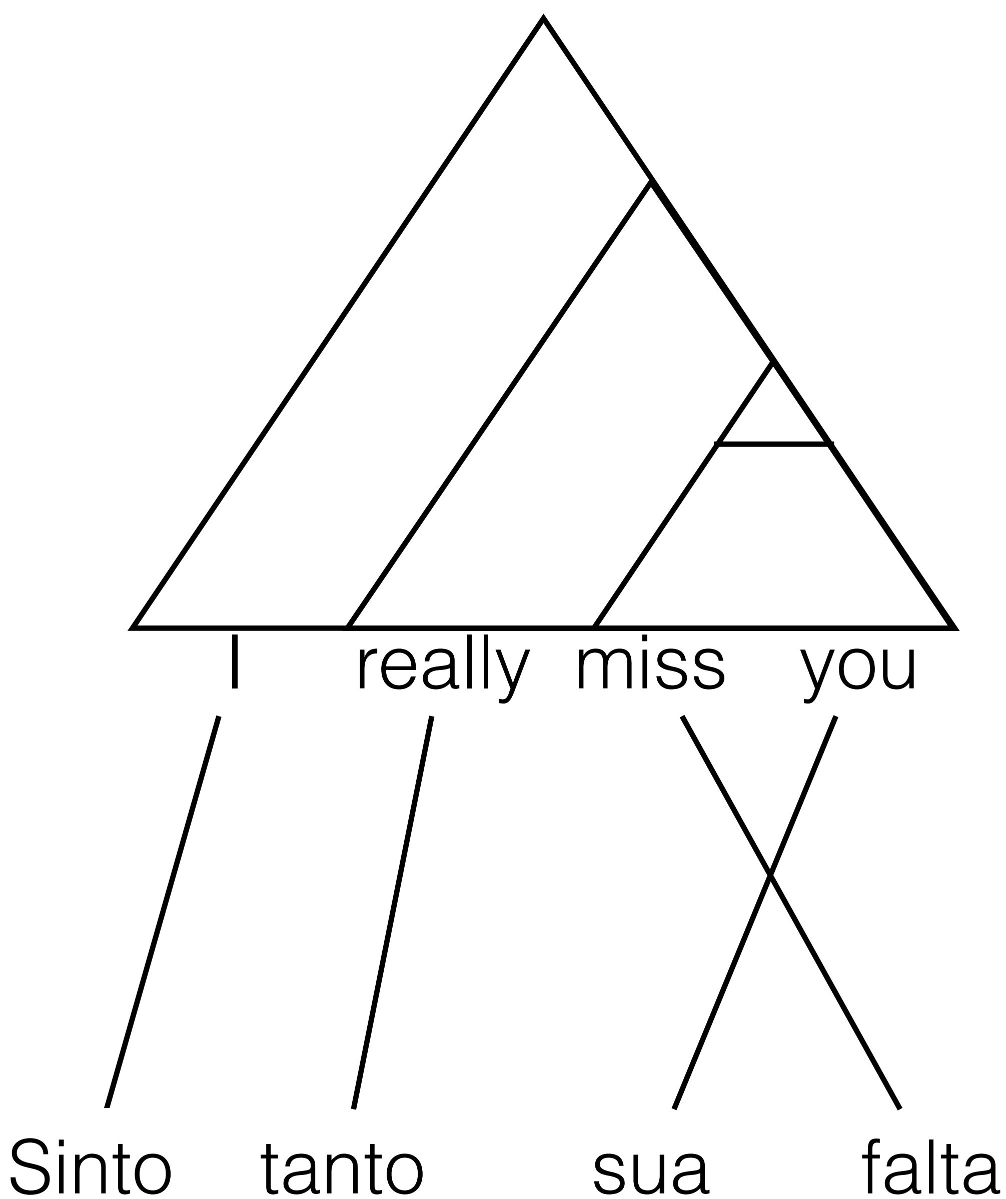
r	ITG	all matchings	ratio
0	1	1	1.000
1	1	1	1.000
2	2	2	1.000
3	6	6	1.000
4	22	24	0.917
5	90	120	0.750
6	394	720	0.547
7	1,806	5,040	0.358
8	8,558	40,320	0.212
9	41,586	362,880	0.115
10	206,098	3,628,800	0.057
11	1,037,718	39,916,800	0.026
12	5,293,446	479,001,600	0.011
13	27,297,738	6,227,020,800	0.004
14	142,078,746	87,178,291,200	0.002
15	745,387,038	1,307,674,368,000	0.001
16	3,937,603,038	20,922,789,888,000	0.000

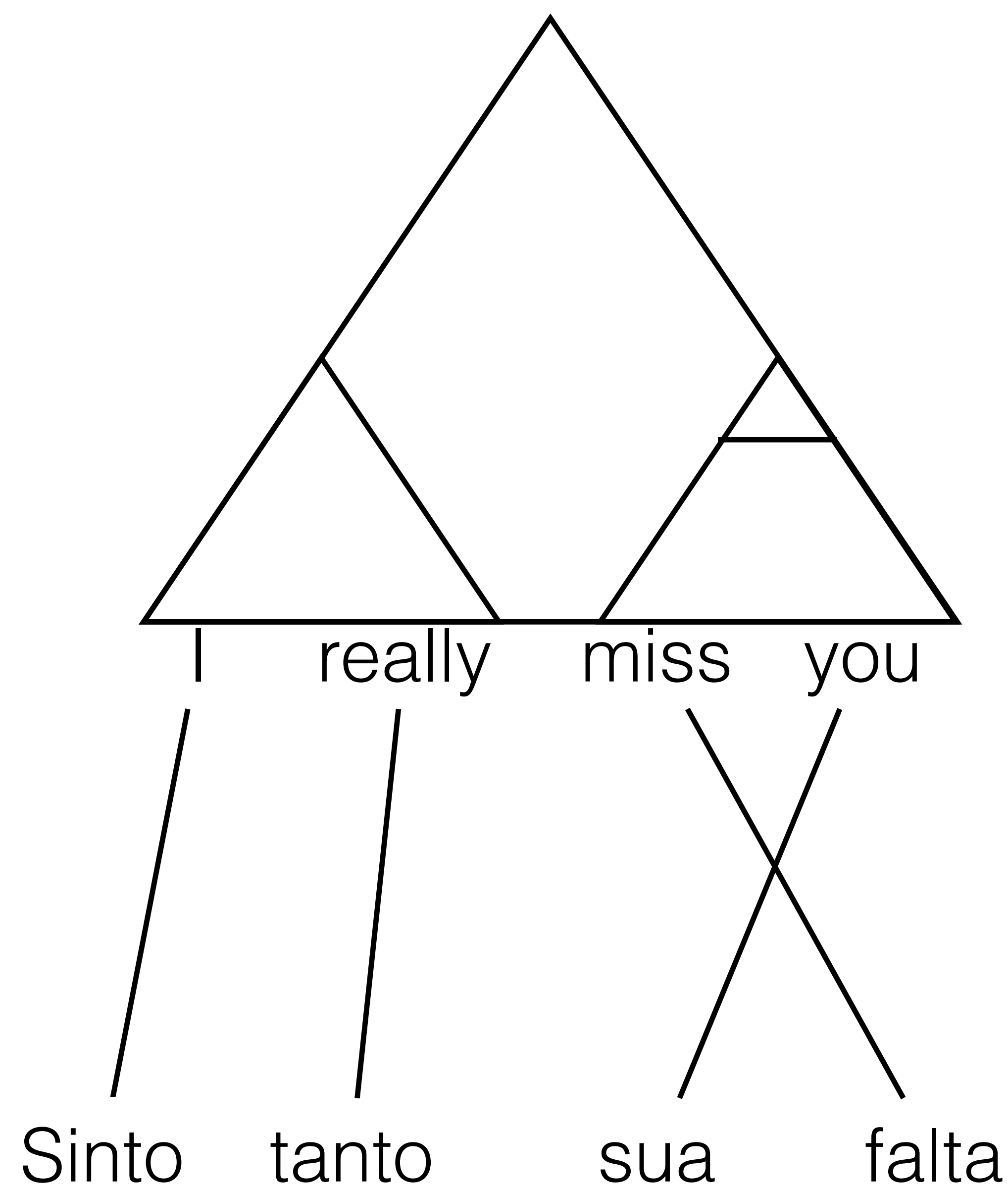
[Wu, 1997]

ITG

	English	French	
$S \rightarrow$	X	X	copy
$X \rightarrow$	$X_1\ X_2$	$X_1\ X_2$	copy
		$X_2\ X_1$	invert
$X \rightarrow$	e	f	transduce
$X \rightarrow$	e	ε	delete
$X \rightarrow$	ε	f	insert

ITG Trees


I
really
miss
you
Sinto
tanto
sua
falta


I
really
miss
you
Sinto
tanto
sua
falta

Model

Joint probability model P(T, E, F)

$$
\begin{aligned}
t &= \langle r_1, \ldots, r_n \rangle \\
e &= \mathrm{yield}_1(t) \\
f &= \mathrm{yield}_2(t)
\end{aligned}
$$

$$P(T = t, E = e, F = f) = \prod_{i=1}^{N} \theta_{r_i}$$

Parametrisation

Multinomial: one parameter per rule

- $\theta_{[]}$ one parameter for **monotone**
- $\theta_{<>}$ one parameter for **swap**
- $\theta_{e/f}$ one parameter per **word pair**
- $\theta_{e/\varepsilon}$ one parameter per deleted **English** word
- $\theta_{\varepsilon/f}$ one parameter per inserted **French** word

MLE

We do not typically construct treebanks of ITG trees

- **potential** counts instead of *observed* counts

$$\theta_{X \to \alpha} = \frac{\langle n(X \to \alpha) \rangle_{P(T|F,E)}}{\sum_{\alpha'} \langle n(X \to \alpha') \rangle_{P(T|F,E)}}$$

Expectations from parse forests

- Inside-Outside [Baker, 1979; Lari and Young, 1990; Goodman, 1999]

Typically initialised with IBM1

Difficulties

Inference: complexity $O(l^3m^3)$

Model: too few reordering parameters

Decisions: ambiguity

- Disambiguation problem is NP-complete [Sima'an, 1996]

$$\arg\max_A P(A|F,E) = \arg\max_A \sum_B P(A,B|F,E)$$
$$\approx \arg\max_{A,B} P(A,B|F,E)$$

Bibliography

- Knight, Kevin. 1999. Decoding complexity in word-replacement translation models. In *Computational Linguistics*. MIT Press.

- Zaslavskiy, Mikhail and Dymetman, Marc and Cancedda, Nicola. 2009. Phrase-based statistical machine translation as a traveling salesman problem. In *Proceedings of the Joint Conference of the 47th Annual Meeting of the ACL and the 4th International Joint Conference on Natural Language Processing of the AFNLP: Volume 1 - Volume 1.*

- DeNero, John and Klein, Dan. 2008. The Complexity of Phrase Alignment Problems. In *Proceedings of ACL-08: HLT*.

- Asveld, Peter R. J. 2006. Generating All Permutations by Context-free Grammars in Chomsky Normal Form. In *Theoretical Computer Science*. Elsevier Science Publishers Ltd.

- Asveld, Peter R. J. 2008. Generating All Permutations by Context-free Grammars in Greibach Normal Form. In *Theoretical Computer Science*. Elsevier Science Publishers Ltd.

- Wu, D. 1995. An Algorithm for Simultaneously Bracketing Parallel Texts by Aligning Words. In *Proceedings of the 33rd Annual Meeting of the Association for Computational Linguistics*. ACL.

Bibliography

- Wu, D. 1997. Stochastic Inversion Transduction Grammars and Bilingual Parsing of Parallel Corpora. In *Computational Linguistics*. MIT Press.
- James K. Baker. 1979. Trainable grammars for speech recognition. In *Proceedings of the Spring Conference of the Acoustical Society of America*.
- Karim Lari and Steve J. Young. 1990. The estimation of stochastic context-free grammars using the inside--outside algorithm. In *Computer Speech and Language*.
- Goodman, Joshua. 1999. Semiring parsing. In Computational Linguistics.
- Sima'an, Khalil. 1996. Computational complexity of probabilistic disambiguation by means of tree-grammars. In *Proceedings of the 16th conference on Computational linguistics - Volume 2*.