Inversion Transduction Grammars

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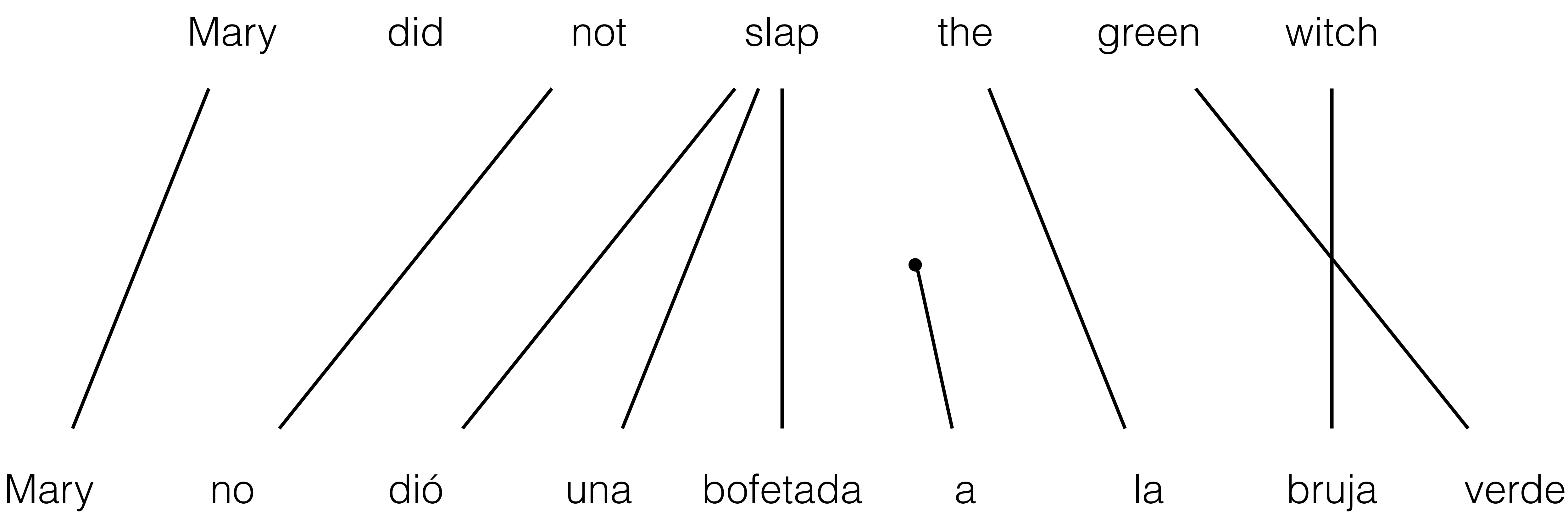
12/4/16

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

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Estimation

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

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Generation

- NP-completeness!

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NP-complete problem

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- Generalised TSP [Knight, 1999; Zaslavskiy et al, 2009]

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- Perfect matching [DeNero and Klein, 2008]

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

$S \rightarrow A_{123}$

$A_{123} \rightarrow a_1\ A_{23}\ |\ a_2\ A_{13}\ |\ a_3\ A_{12}$

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

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

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

$A_1 \rightarrow a_1$

$A_2 \rightarrow a_2$

$A_3 \rightarrow a_3$

"IBM constraint"

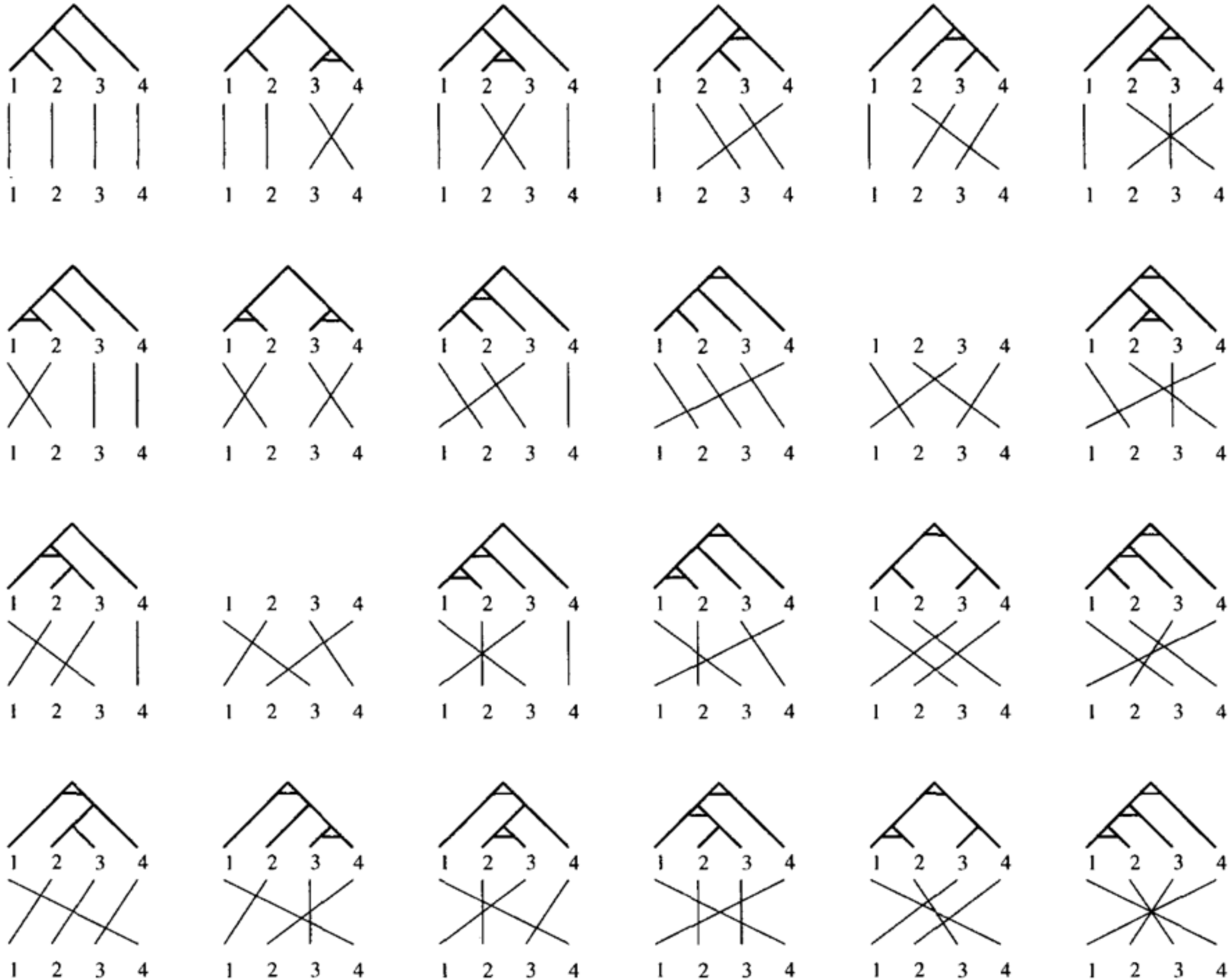
Distortion limit in **generation** but not in **estimation**

- 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

ITG

English	French

ITG

	English	French	
S →	X	X	copy

ITG

	English	French	
S →	X	X	copy
X →	X_1 X_2	X_1 X_2	copy

ITG

	English	French	
$S \rightarrow$	X	X	copy
$X \rightarrow$	$X_1\ X_2$	$X_1\ X_2$	copy
		$X_2\ X_1$	invert

ITG

	English	French	
$S \rightarrow$	X	X	copy
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$X \rightarrow$	e	f	transduce

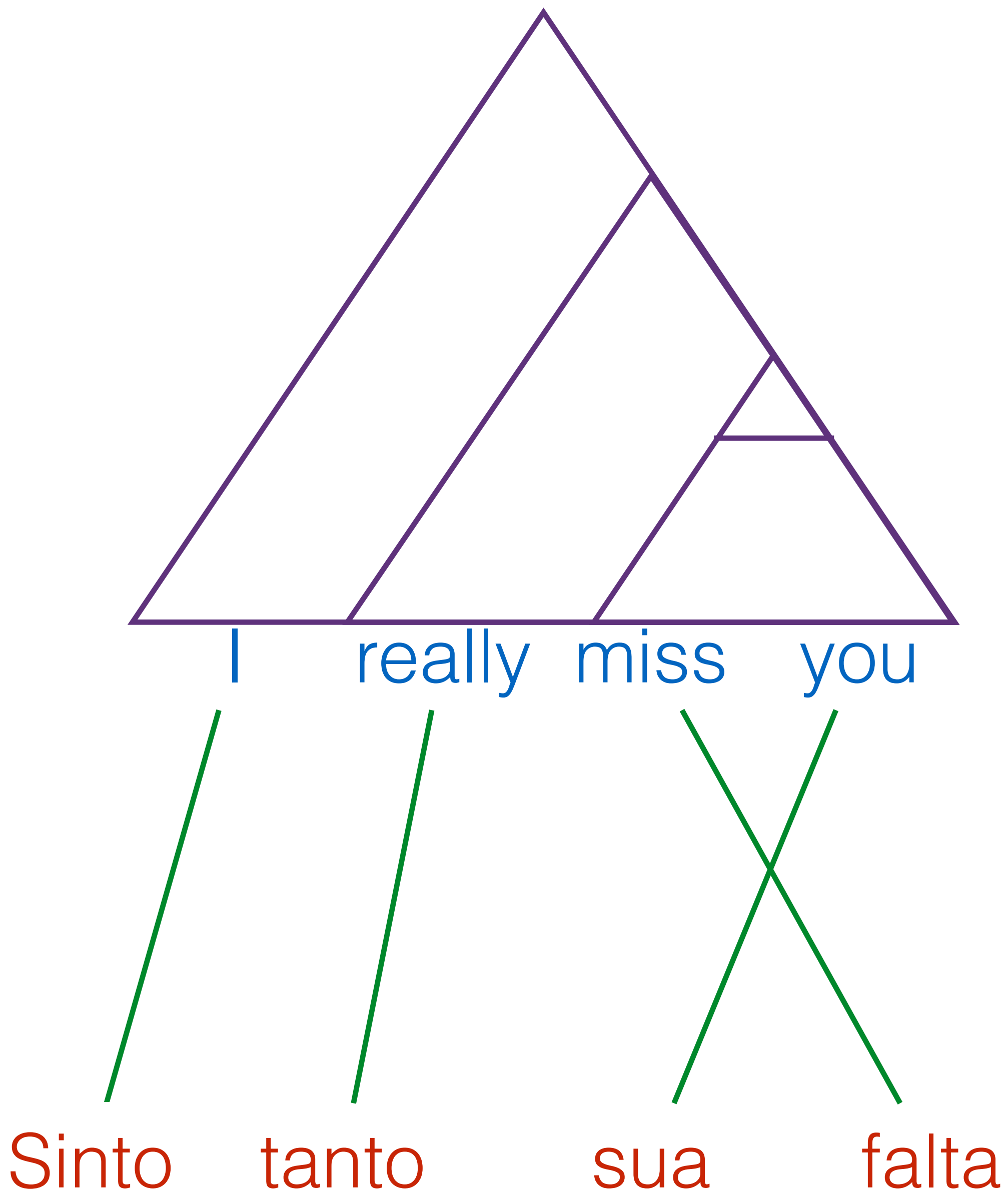
ITG

	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

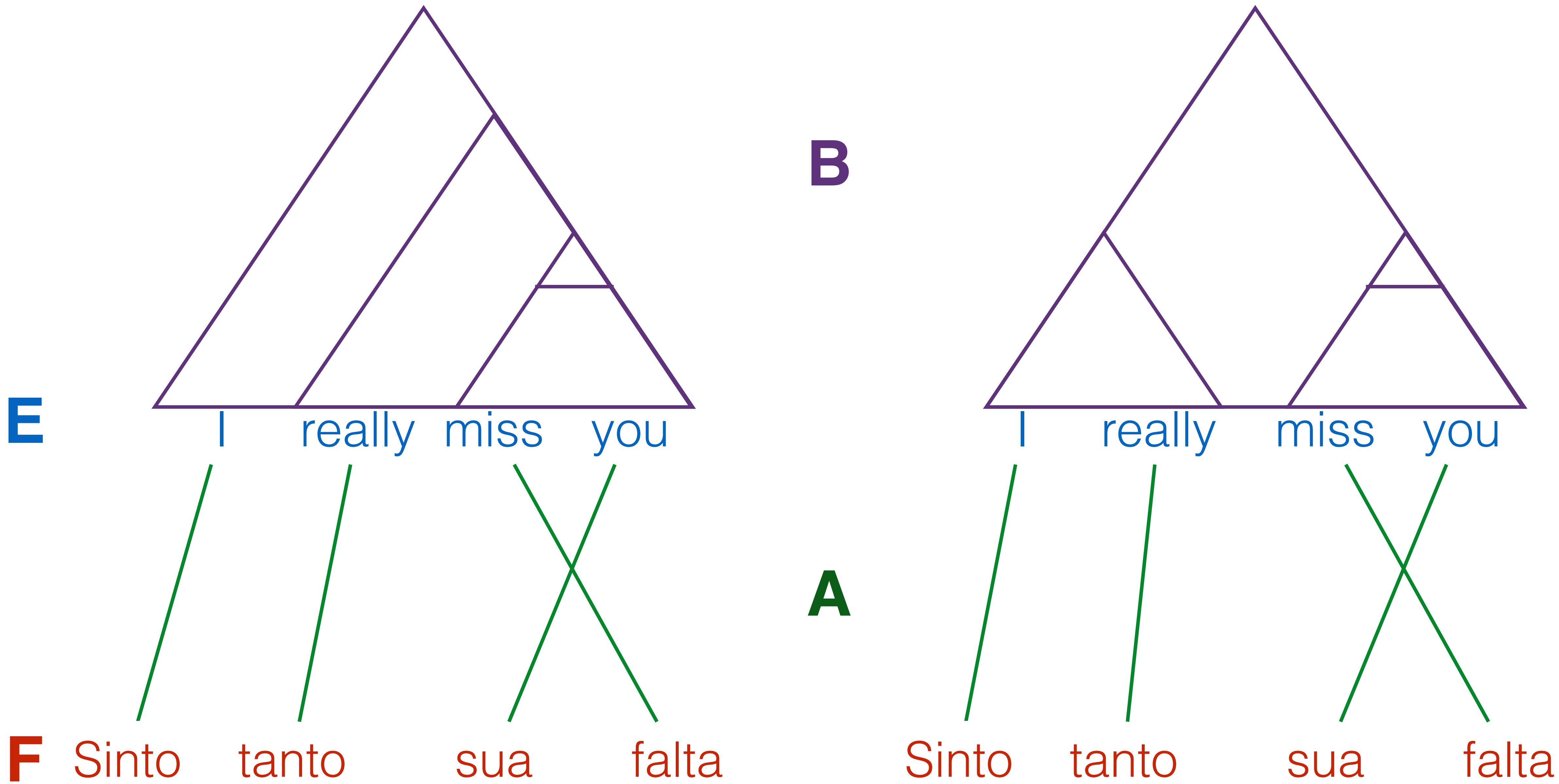
ITG

	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

ITG Trees


B
E
I
really
miss
you
I
really
miss
you
A
F
Sinto
tanto
sua
falta
Sinto
tanto
sua
falta

Model

Joint probability model P(T) = P(A, B, E, F)

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

$$
\begin{aligned}
P(T = t) &= P(A = a, B = b, E = e, F = f) \\
&= \prod_{i=1}^{N} \theta_{r_i}
\end{aligned}
$$

Parametrisation

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Multinomial: one parameter per rule

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- $\theta_{e/\varepsilon}$ one parameter per deleted **English** word

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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

$$\theta_{X \to \alpha} = \frac{\langle n(X \to \alpha) \rangle_{P(A,B|F,E)}}{\sum_{\alpha'} \langle n(X \to \alpha') \rangle_{P(A,B|F,E)}}$$

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]

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

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