6.881: Natural Language Processing

Machine Translation I

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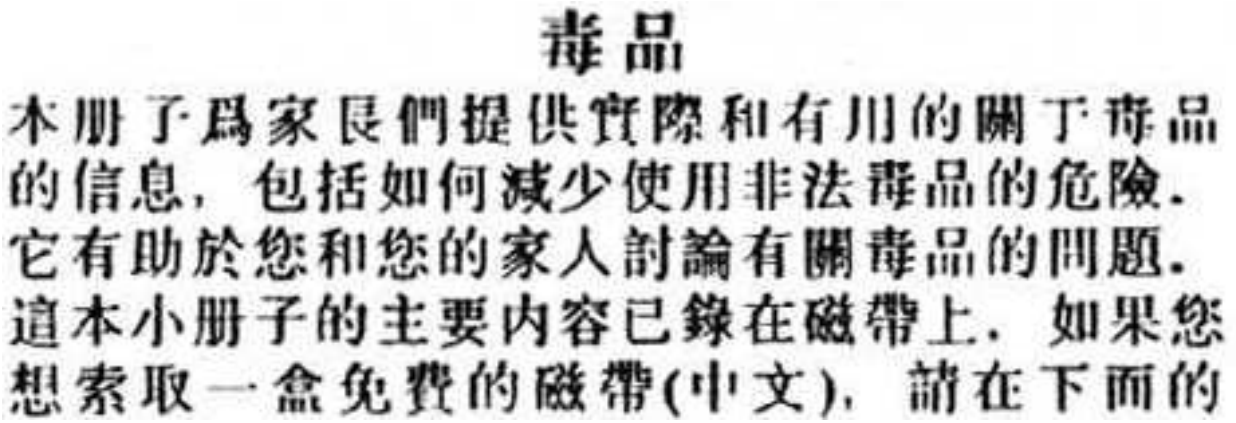
Outline

- Lecture I
  - Introduction to Machine Translation
  - Principles of Statistical MT
  - Word-Based Models
  - Phrase-Based Models
- Lecture II
  - Beam Search Decoding
  - Discriminative Training
  - The Challenge of Syntax

Machine Translation

- Task: Make sense of foreign text like



毒品

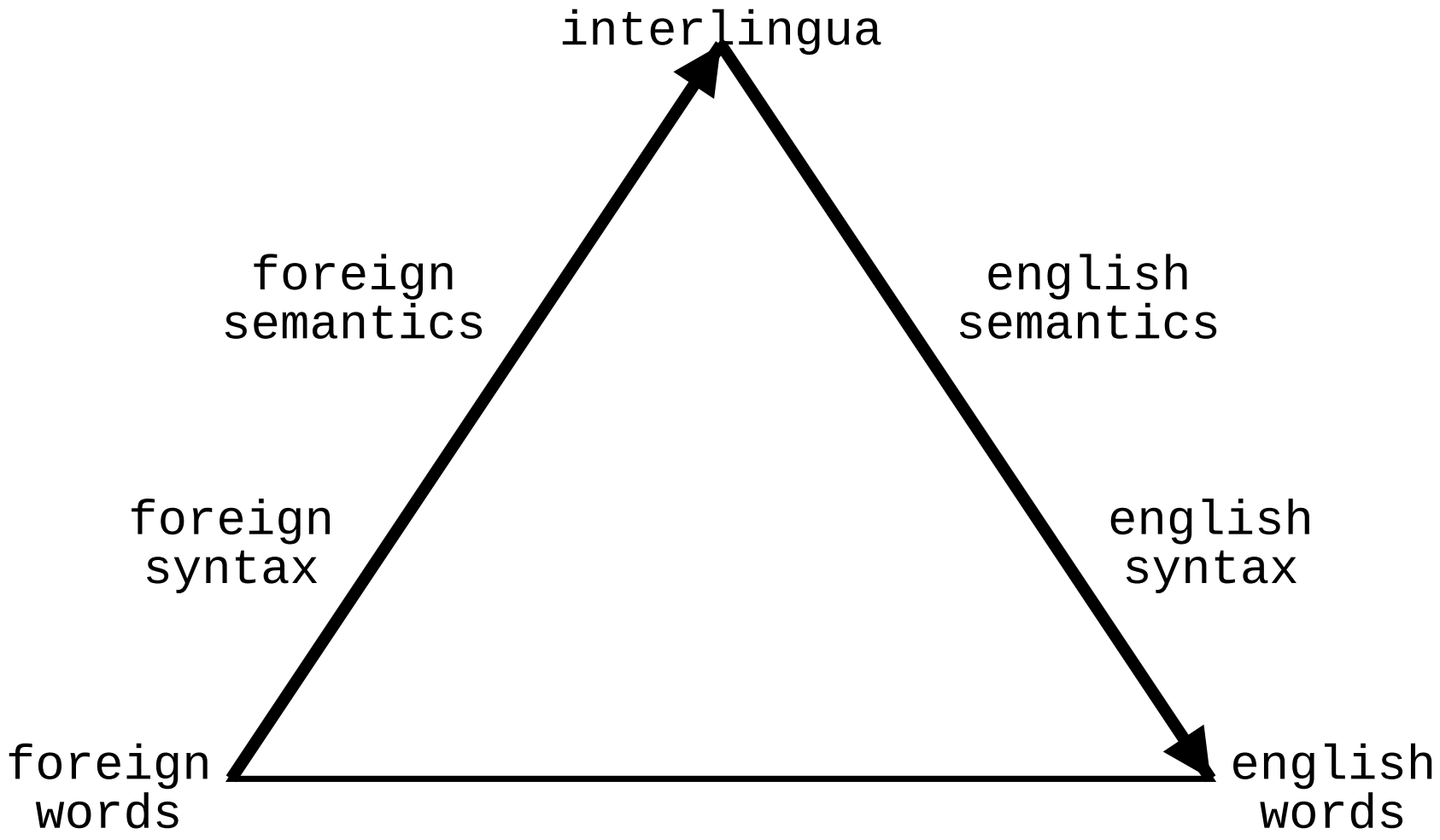
本册子爲家長們提供實際和有用的關于毒品
的信息，包括如何減少使用非法毒品的危險。
它有助於您和您的家人討論有關毒品的問題。
這本小册子的主要内容已錄在磁帶上。如果您
想索取一盒免費的磁帶(中文)，請在下面的

- One of the oldest problems in Artificial Intelligence
- AI-hard: reasoning and world knowledge required

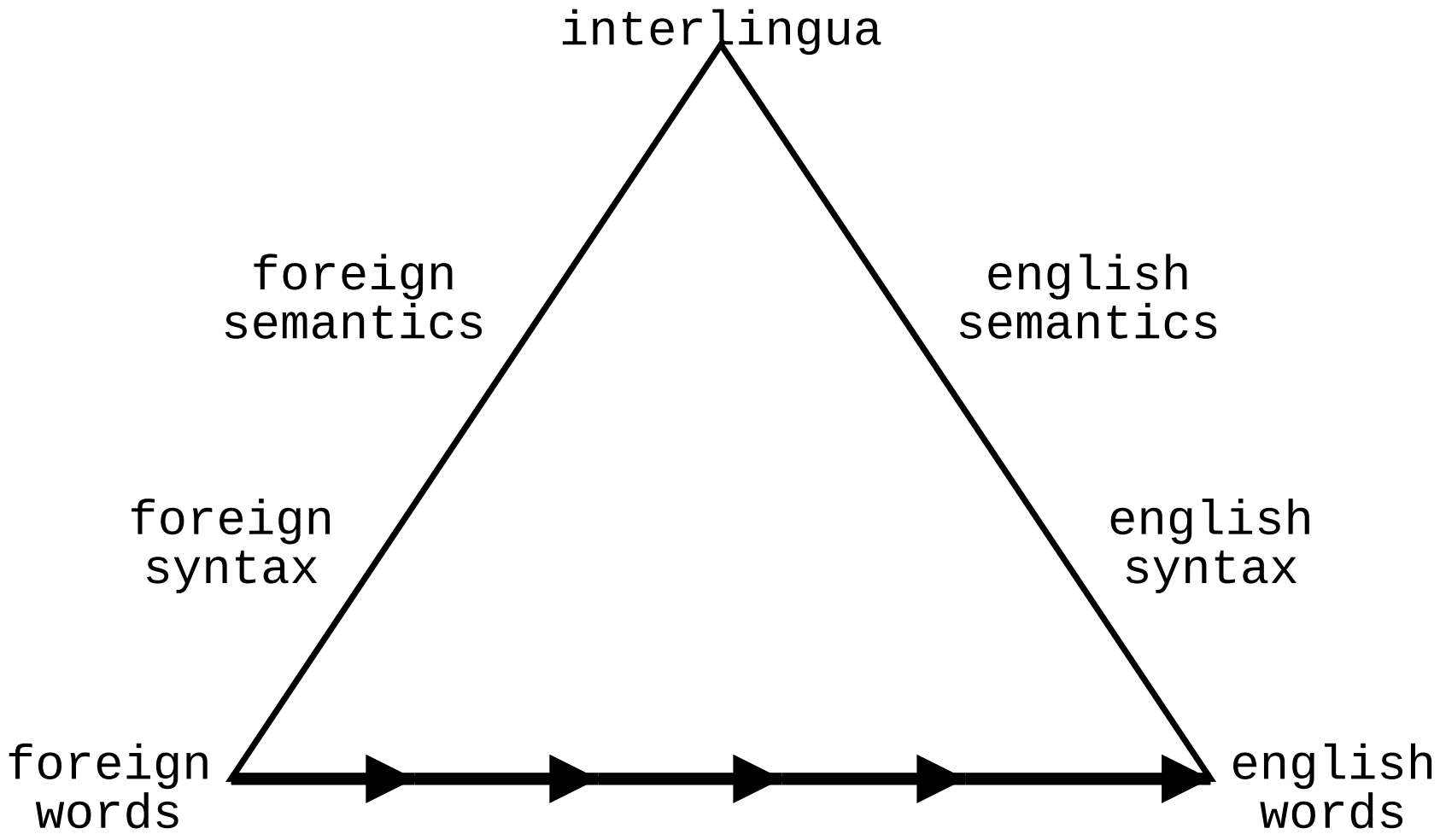
A Brief History

- 1950s: success in code breaking $\rightarrow$ investment in MT
- 1964: ALPAC report killed MT research funding
- Late 1970s: Transformer MT
- 1980s: commercial companies like Systran founded
- 1980s: Example-Based MT, Linguistic Knowledge MT
- 1990s: Statistical MT
- 2000s: Commercial companies sell statistical MT systems (Language Weaver, IBM)

The Machine Translation Pyramid



The Machine Translation Pyramid

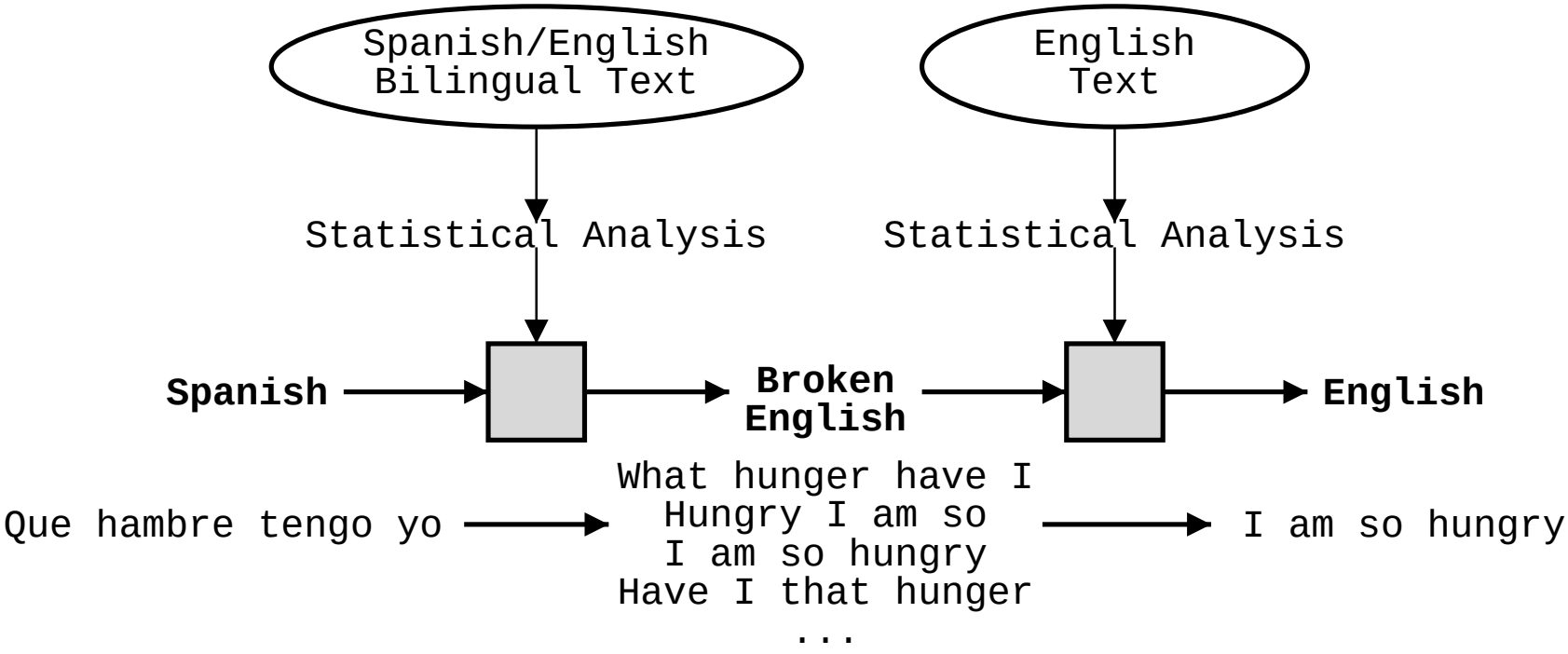


However, the currently best performing statistical machine translation systems are still crawling at the bottom.

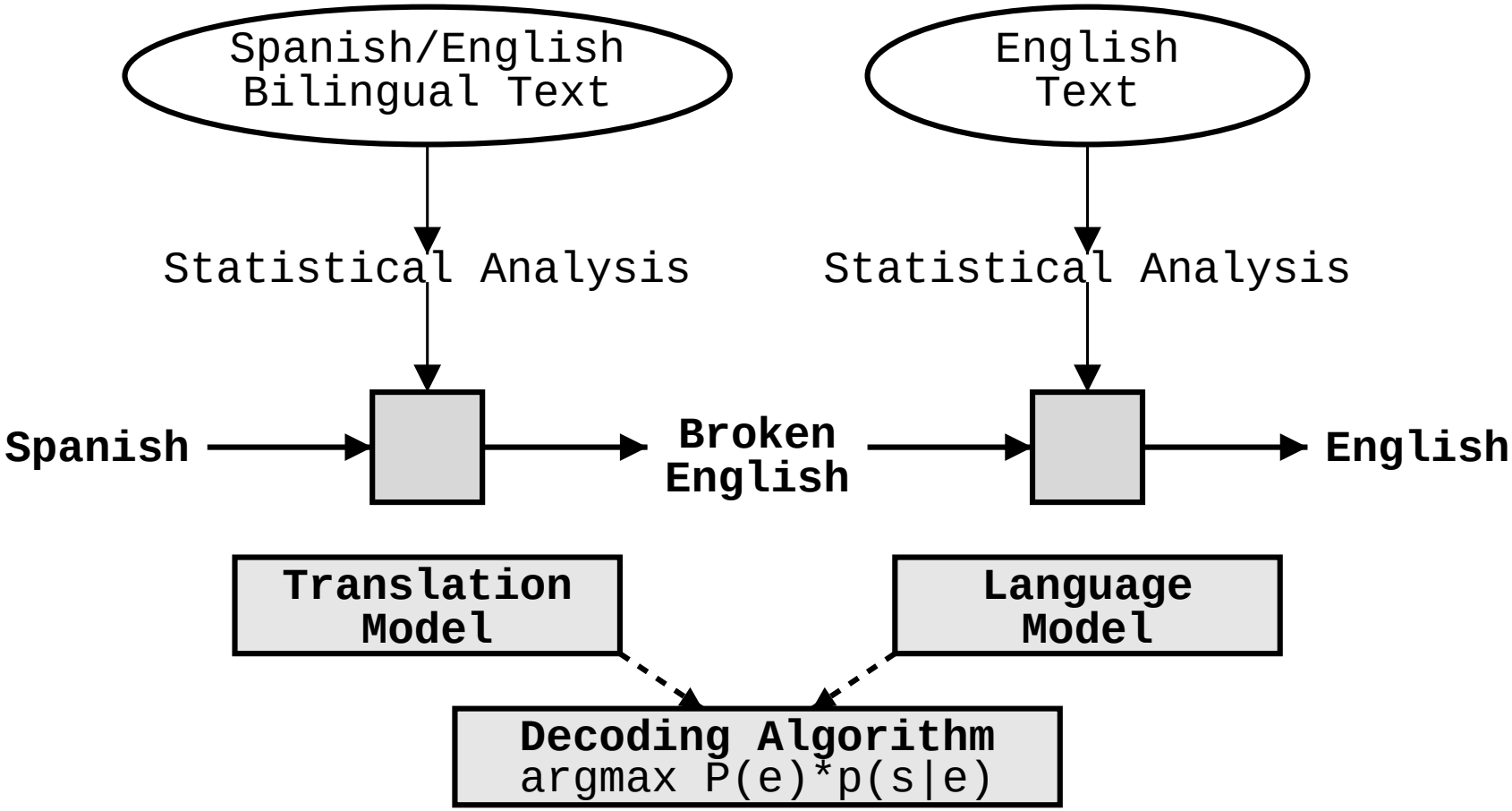
Data for Statistical MT: Parallel Corpora

- French-English: 180 million words
  - UN, Canadian Hansards, European Parliament
- Chinese-English: 130 million words
  - UN, Xinhua news corpora
- Arabic-English: 100 million words
  - UN, news corpora
- German-English: 30 million words
  - European Parliament

Statistical MT Systems



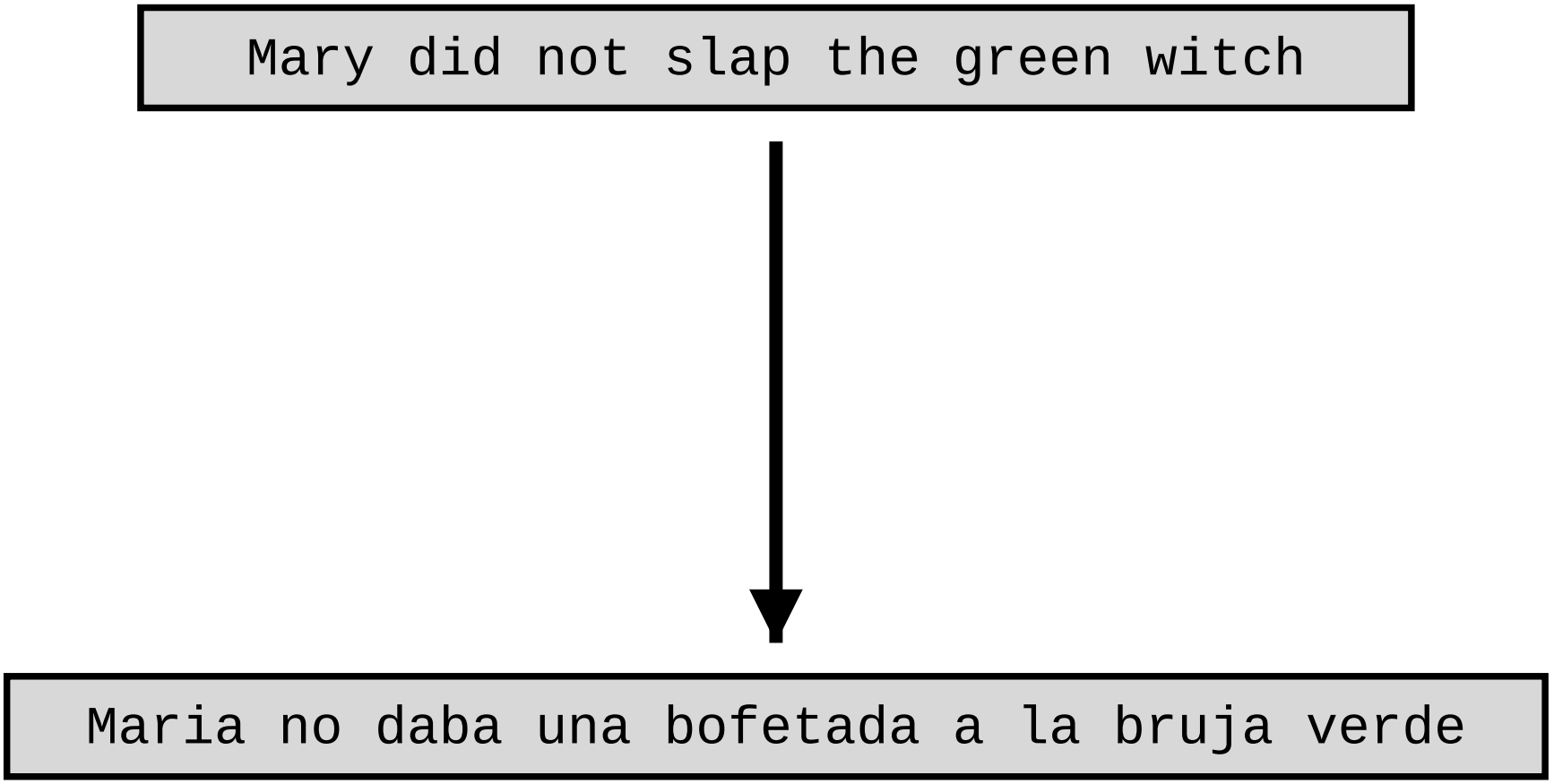
Statistical MT Systems (2)



Three Problems in Statistical MT

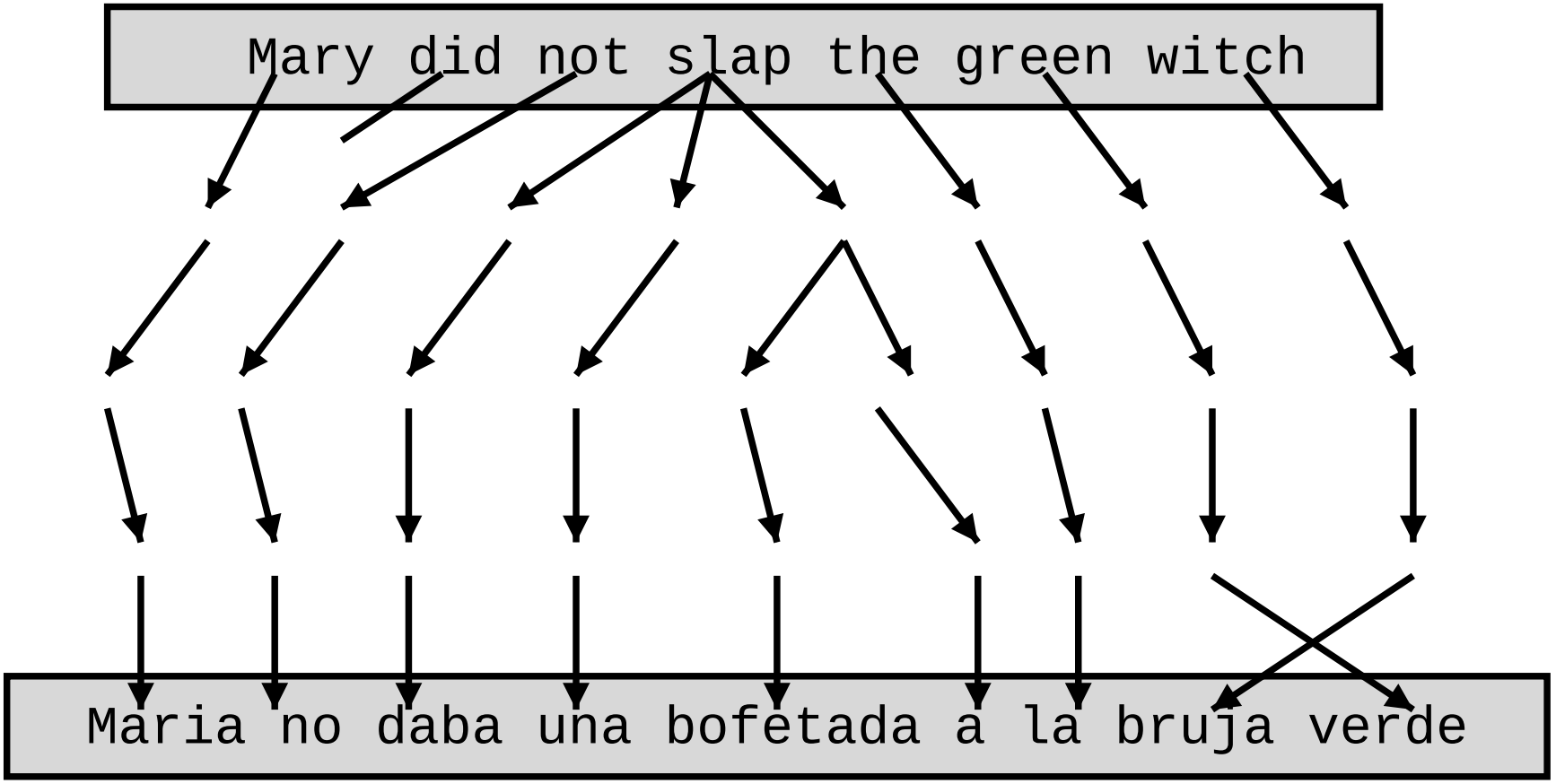
- Translation Model
  - given a pair of strings $< f, e >$, assigns $P(f|e)$ by formula
  - $< f, e >$ look like translations $\Rightarrow$ high $P(f|e)$
  - $< f, e >$ don't look like translations $\Rightarrow$ low $P(f|e)$
- Language Model
  - given an English string e, assigns $P(e)$ by formula
  - good English string $\Rightarrow$ high $P(e)$
  - bad English string $\Rightarrow$ low $P(e)$
- Decoding Algorithm
  - given a language model, a translation model and a new sentence f, find translation e maximizing $P(e) \times P(f|e)$

Statistical Modeling



- Learn $P(f|e)$ from a parallel corpus
- Not sufficient data to estimate $P(f|e)$ directly

Statistical Modeling (2)



- Break the process into smaller steps

Statistical Modeling (3)

- Probabilities for smaller steps can be learned

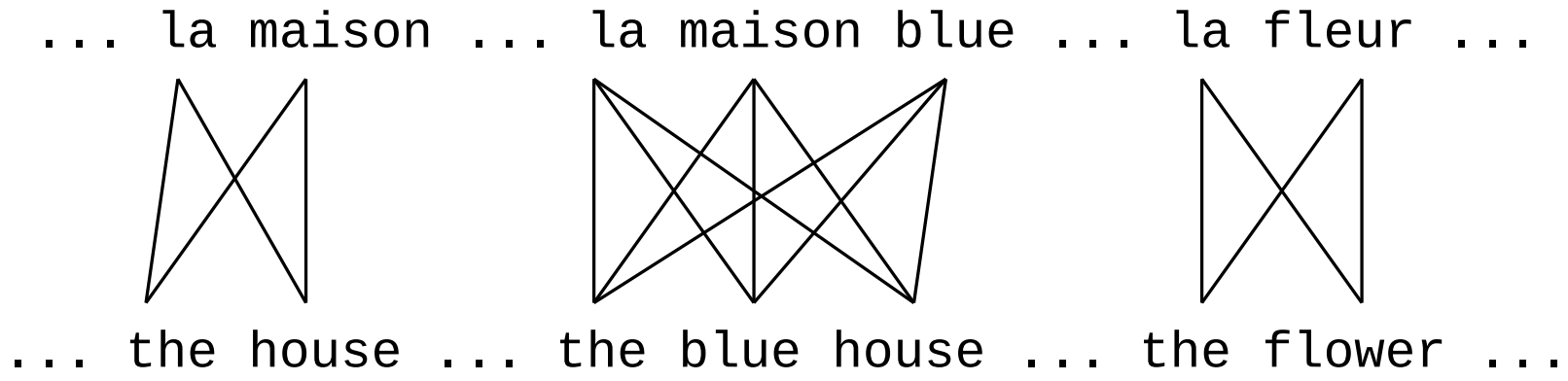
Statistical Modeling (4)

- Generate a story how an English string e gets to be a foreign string f
  - Choices in story are decided by reference to parameters
  - e.g., $p(\text{bruja}|\text{witch})$
- Formula for $P(f|e)$ in terms of parameters
  - usually long and hairy, but mechanical to extract from the story
- Training to obtain parameter estimates from possibly incomplete data
  - off-the-shelf EM

IBM Model 4

- Fertility
  - `n(3|slap)` number of words generated
  - `n(0|do)` dropped words
- NULL Word
  - parameter p_0
  - allows generation of additional words
- Translation
  - `t(la|the)` lexical translation
- Distortion
  - `d(-1|...)` reordering

Learning the Parameters

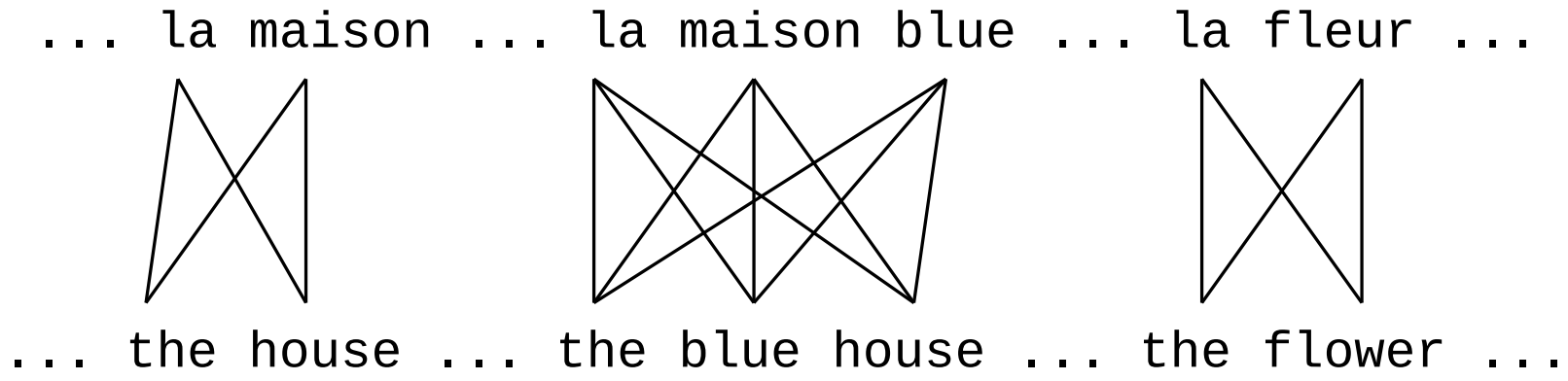


- Incomplete Data
  - English and foreign words, but no connections between them
- Chicken and egg problem
  - if we had the connections, we could estimate the parameters of our generative story
  - if we had the parameters, we could estimate the connections

EM Algorithm

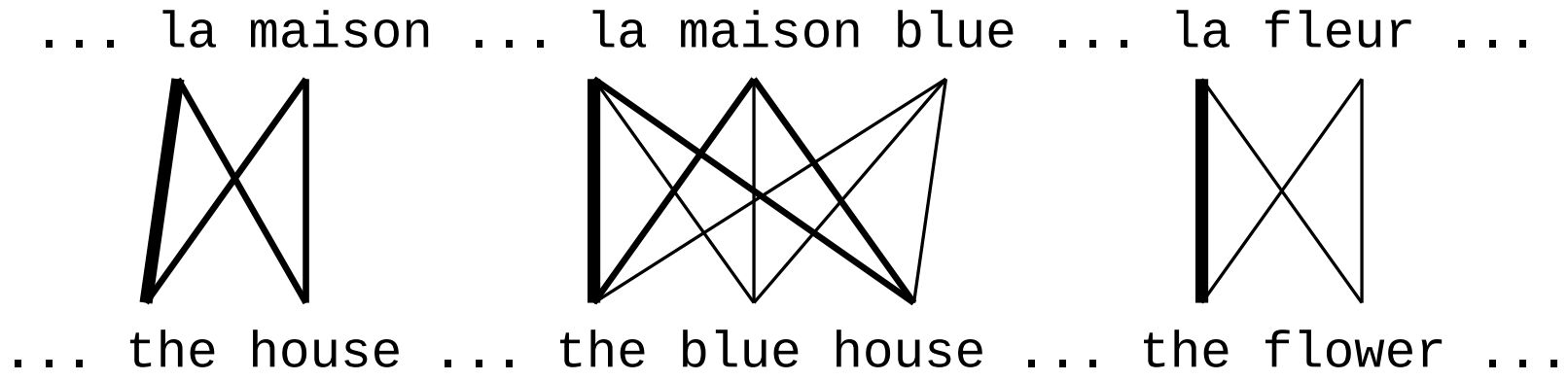
- Incomplete data
  - if we had complete data, would could estimate model
  - if we had model, we could fill in the gaps in the data
- EM in a nutshell
  - initialize model parameters (e.g. uniform)
  - assign probabilities to the missing data
  - estimate model parameters from completed data
  - iterate

EM Algorithm (2)



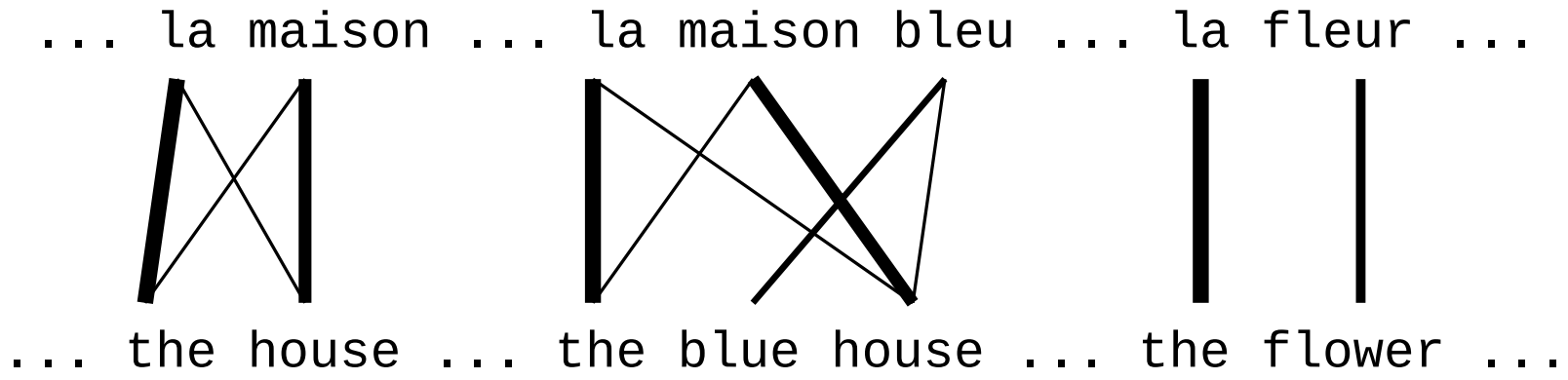
- Initial step: all connections equally likely
- Model learns that, e.g., la is often connected with the

EM Algorithm (3)



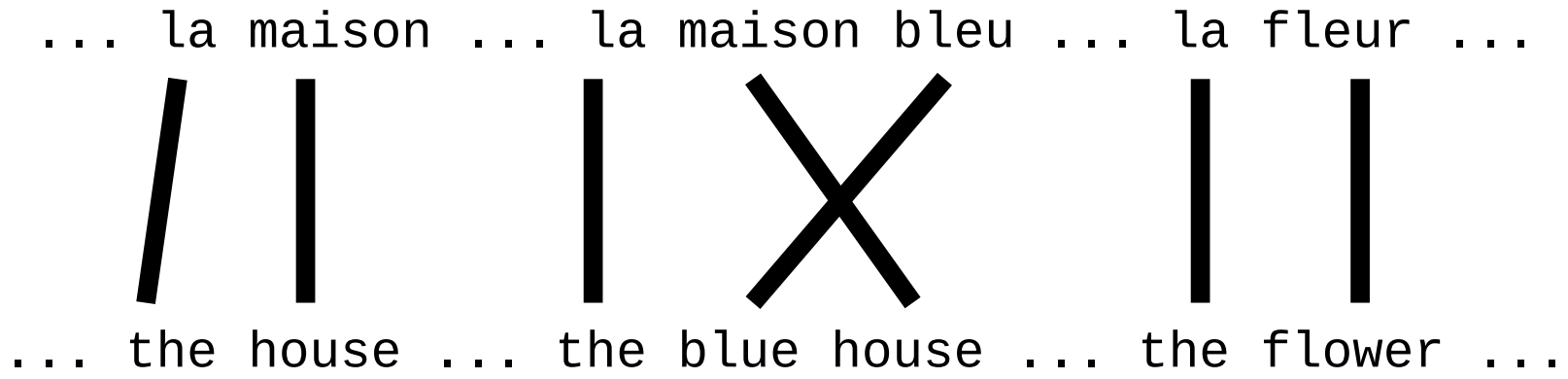
- After one iteration
- Connections, e.g., between la and the are more likely

EM Algorithm (4)



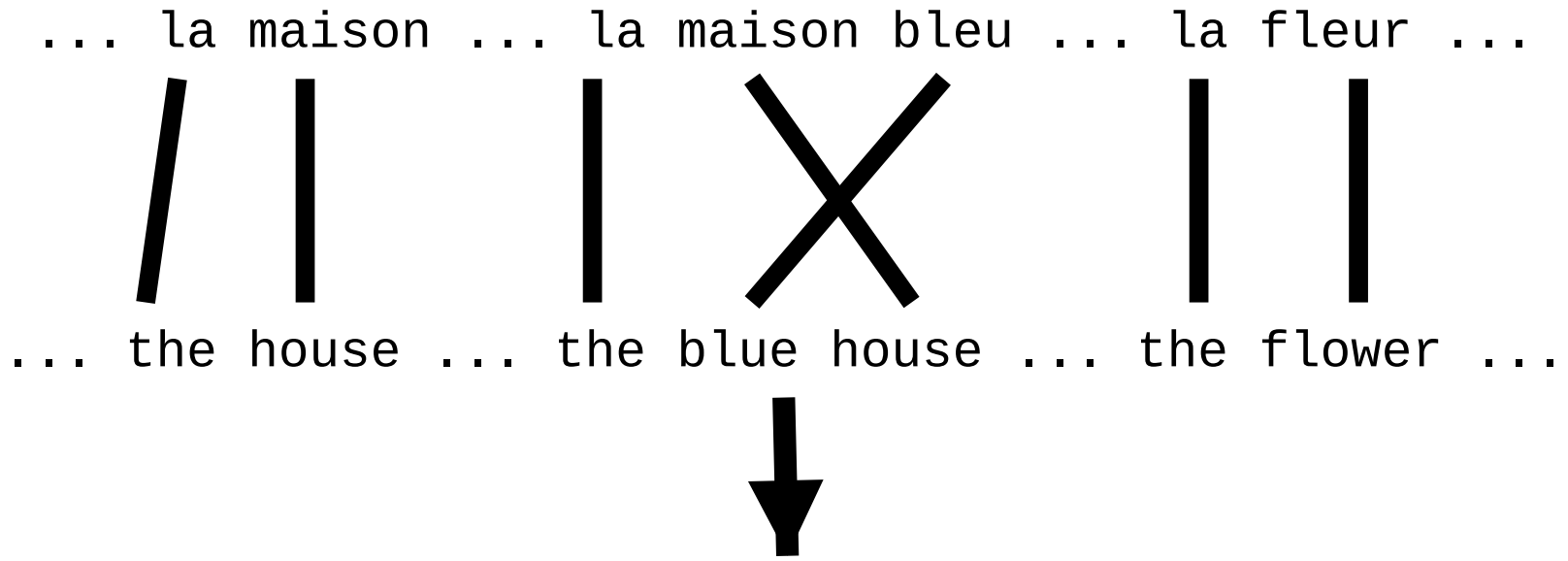
- After another iteration
- It becomes apparent that connections, e.g., between fleur and flower are more likely (pigeon hole principle)

EM Algorithm (5)



- Convergence
- Inherent hidden structure revealed by EM

EM Algorithm (6)



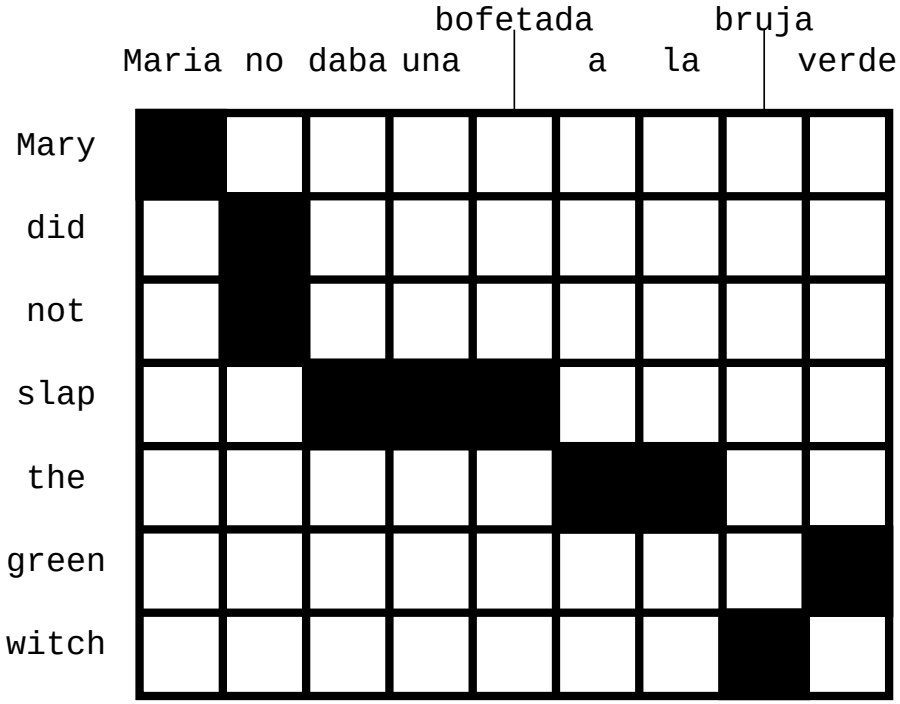
- Parameter estimation from the connected corpus

More detail on the IBM Models

- “A Statistical MT Tutorial Workbook” (Knight, 1999)
- “The Mathematics of Statistical Machine Translation” (Brown et al., 1993)
- Downloadable software: Giza++, ReWrite decoder

Word Alignment

- Notion of word alignments valuable
- Trained humans can achieve high agreement
- Shared task at data-driven MT workshop at NAACL/HLT



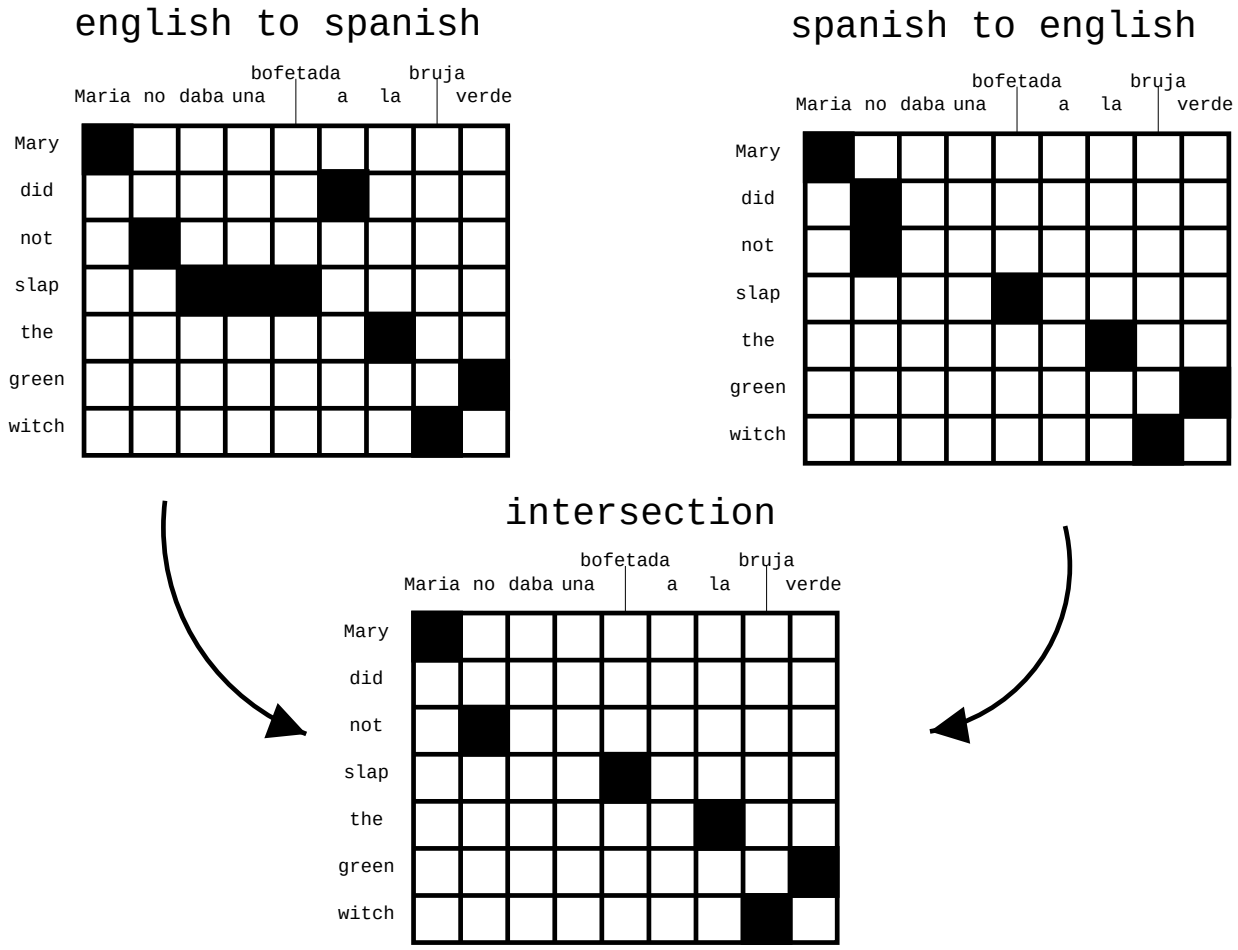
Improved Word Alignments

- Improving IBM Model word alignments with heuristics [Och and Ney, 2000, Koehn et al., 2003]
  - one-to-many problem of IBM Models
  - bidirectionally aligned corpora $e \rightarrow f$, $f \rightarrow e$
  - take intersection of alignment points

    (high precision, low recall)
  - grow additional alignment points

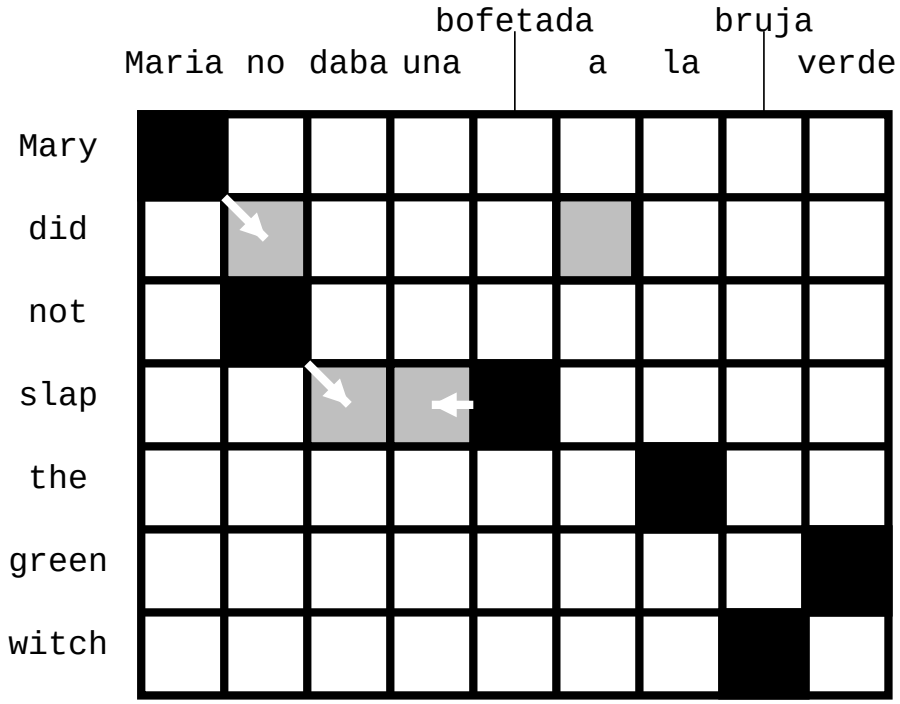
    (increase recall while preserving precision)

Improved Word Alignments (2)



- Intersection of bidirectional alignments

Improved Word Alignments (3)



- Grow additional alignment points

Other Methods for Word Alignment

- Comparison of various methods in journal “Computation Linguistics”, March 2003 [Och and Ney, 2003]
- Shared task at data-driven MT workshop HLT/NAACL 2003

Flaws of Word-Based MT

- Multiple English words for one German word

German:	Zeitmangel	erschwert	das	Problem	.
Gloss:	LACK OF TIME	MAKES MORE DIFFICULT	THE	PROBLEM	.

Correct translation: Lack of time makes the problem more diffi cult.

MT output: `Time makes the problem .`

- Phrasal translation

German:	Eine	Diskussion	erübrigt	sich	demnach	
Gloss:	A	DISCUSSION	IS MADE UNNECESSARY	ITSELF	THEREFORE	

Correct translation: Therefore, there is no point in a discussion.

MT output: `A debate turned therefore .`

Flaws of Word-Based MT (2)

- Syntactic transformations

German:	Das	ist	der	Sache	nicht	angemessen	.
Gloss:	THAT	IS	THE	MATTER	NOT	APPROPRIATE	.

Correct translation: That is not appropriate for this matter .

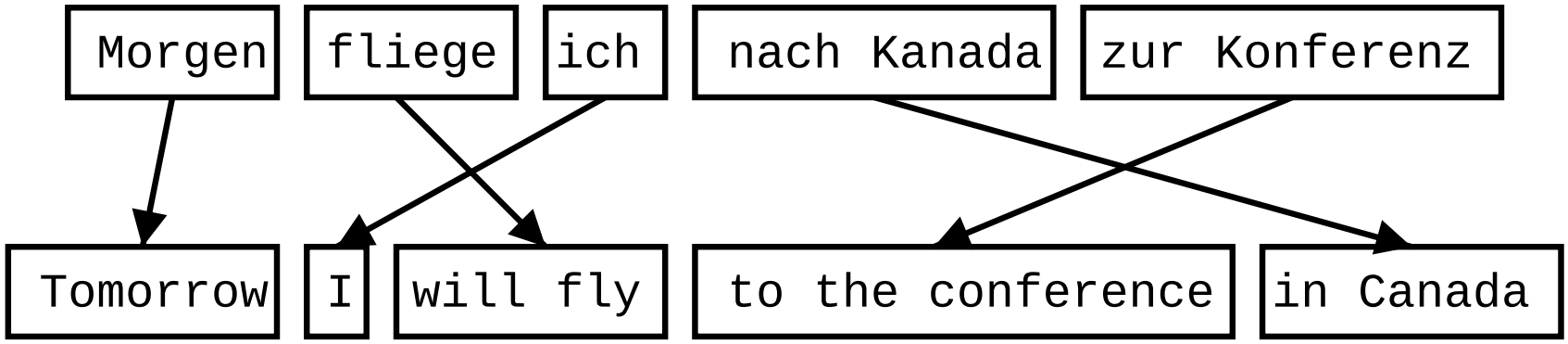
MT output: That is the thing is not appropriate .

German:	Den	Vorschlag	lehnt	die	Kommission	ab	.
Gloss:	THE	PROPOSAL	REJECTS	THE	COMMISSION	OFF	.

Correct translation: The commission rejects the proposal .

MT output: The proposal rejects the commission .

Phrase-Based Translation



- Foreign input is segmented in phrases
  - any sequence of words, not necessarily linguistically motivated
- Each phrase is translated into English
- Phrases are reordered

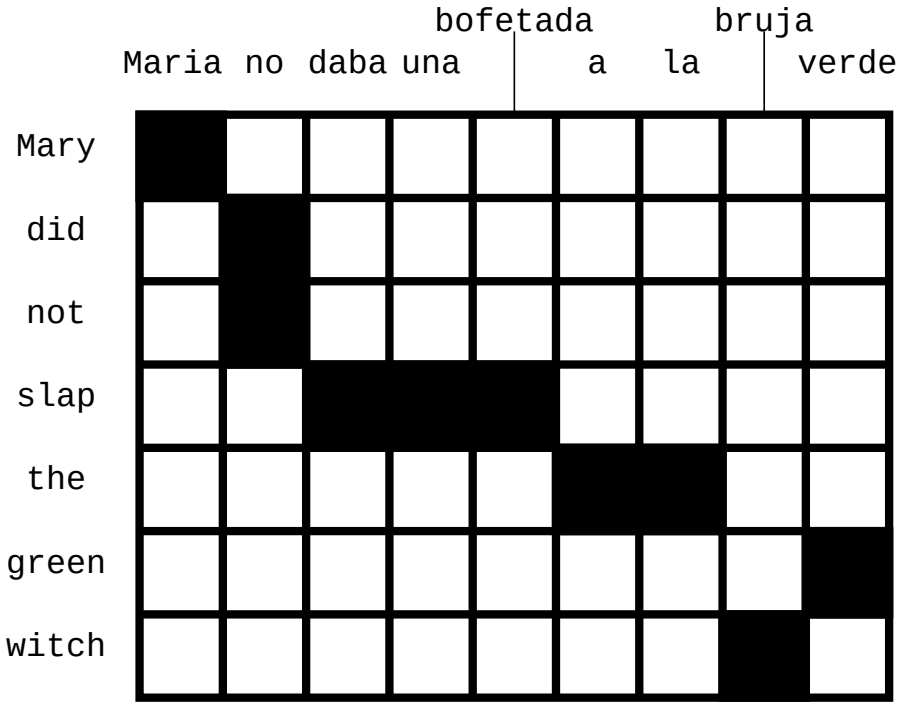
Advantages of Phrase-Based Translation

- Many-to-many Translation
- Use of local context in translation
- Allows translation of non-compositional phrases
- The more data, the longer phrases can be learned

Three Phrase-Based Translation Models

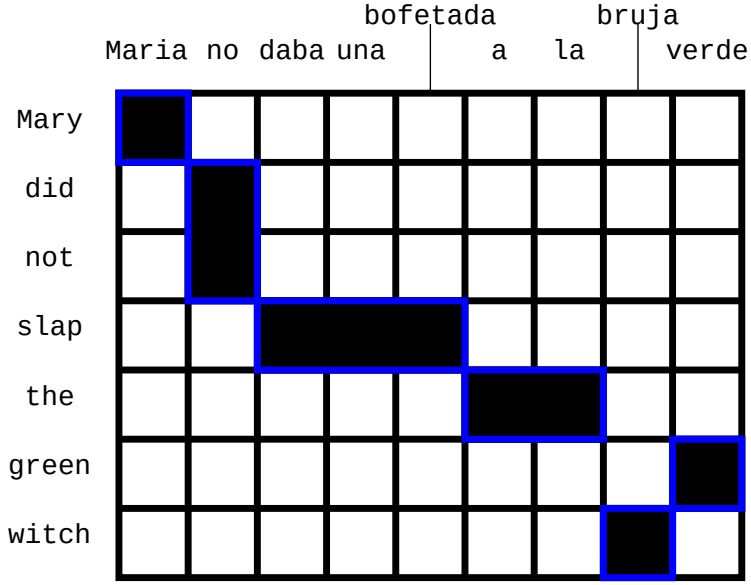
- Word alignment induced phrase model [Koehn et al., 2003]
- Alignment templates [Och et al., 1999]
- Joint phrase model [Marcu and Wong, 2002]

Word Alignment Induced Phrases



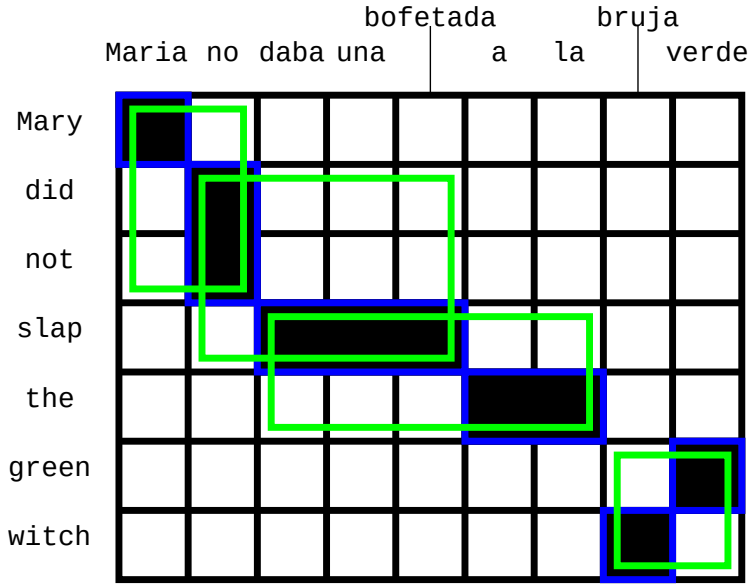
- Collect all phrase pairs that are consistent with the word alignment
  - a phrase alignment has to contain all alignment points for all words it covers

Word Alignment Induced Phrases (2)



(Maria, Mary), (no, did not), (slap, daba una bofetada), (a la, the), (bruja, witch), (verde, green)

Word Alignment Induced Phrases (3)



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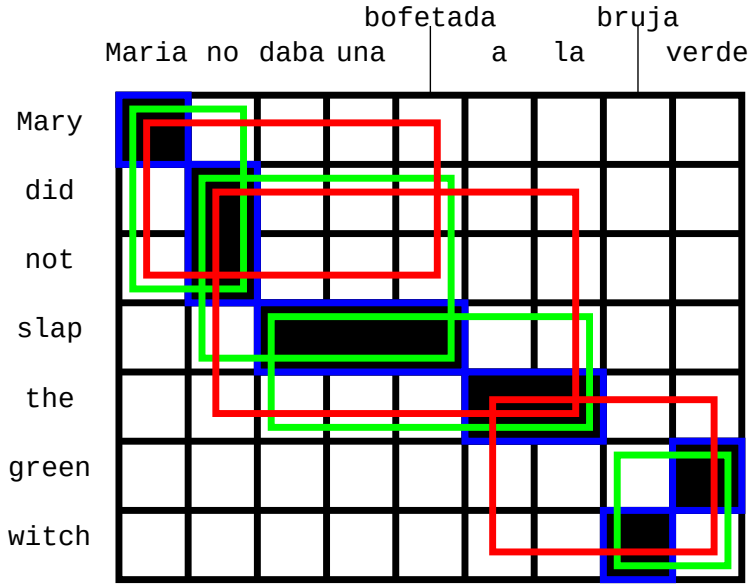
Word Alignment Induced Phrases (4)



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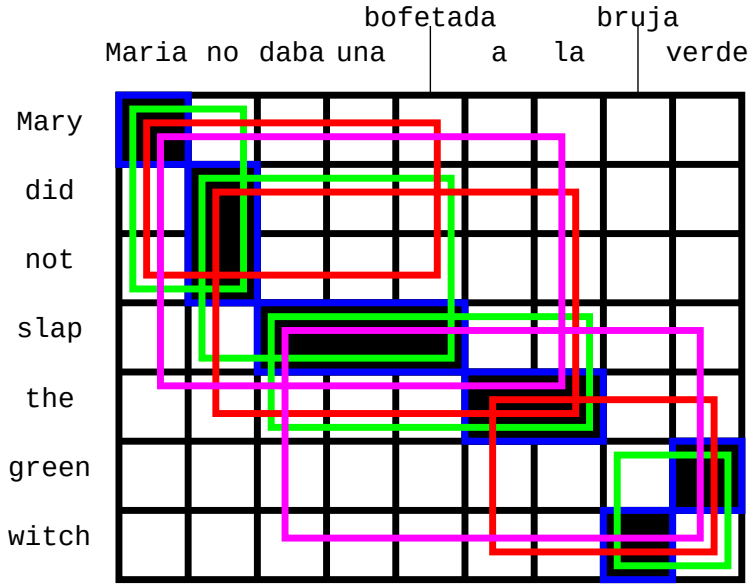
Word Alignment Induced Phrases (5)



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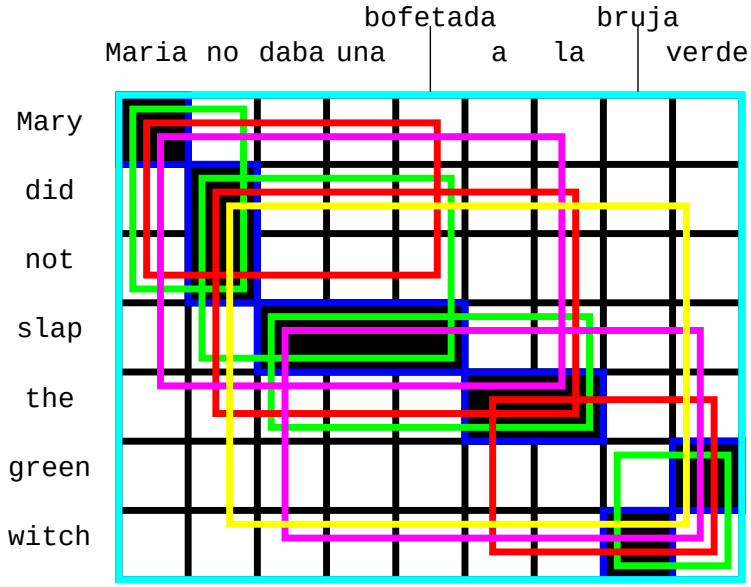

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Word Alignment Induced Phrases (7)

- Given the collected phrase pairs,

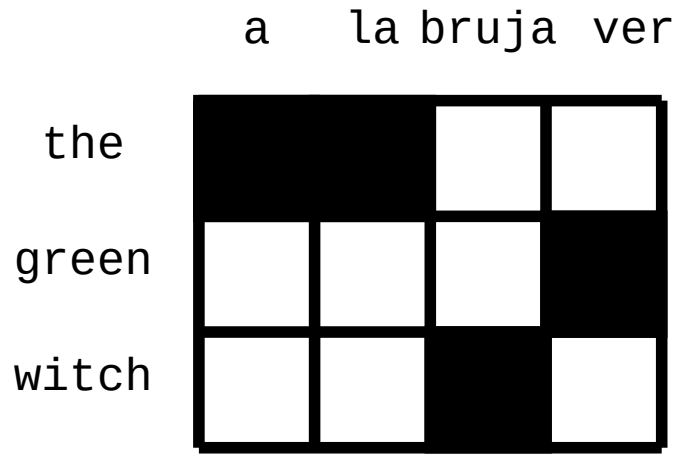
  estimate the phrase translation probability distribution

  by relative frequency:

$$\phi(\bar{f}|\bar{e}) = \frac{\text{count}(\bar{f},\bar{e})}{\sum_{\bar{f}} \text{count}(\bar{f},\bar{e})}$$

- No smoothing is performed

Word Alignment Induced Phrases (8)



- Lexical weighting:

$$p_w(\bar{f}|\bar{e},a) = \prod_{i=1}^{n} \frac{1}{|\{j|(i,j)\in a\}|} \sum_{\forall(i,j)\in a} w(f_i|e_j)$$

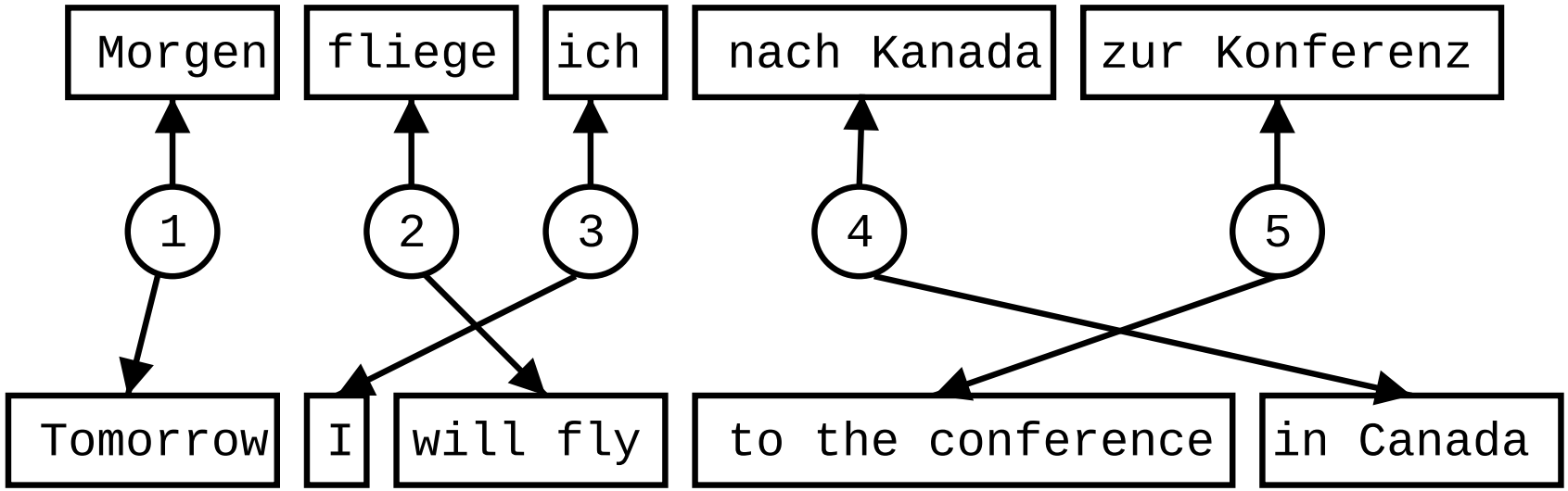
$p_w(\text{a la bruja verde}|\text{the green witch}) =$

$w(\text{a}|\text{the}) \times w(\text{la}|\text{the}) \times$

$w(\text{verde}|\text{green}) \times$

$w(\text{bruja}|\text{witch})$

Joint Phrase Model



- Direct phrase alignment of parallel corpus

  [Marcu and Wong, 2002]

- Generative story
  - a number of concepts are created
  - each concept generates a foreign and English phrase
  - the English phrases are reordered

Limits of Phrase Models

- Non-contiguous phrases
  - German: *Ich habe das Auto gekauft*
  - English: *I bought the car*
  - good phrase pair: *habe ... gekauft == bought*
- Syntactic transformations
  - German: *Den Antrag verabschiedet das Parlament*
  - English gloss: *The draft approves the Parliament*
  - case marking that indicates that “the draft” is object is lost during translation

Phrase-Based MT: Do it yourself

- Phrase-based MT has currently best performance
- Corpora available at LDC, ISI, other places
  - e.g., Europarl `http://www.isi.edu/~koehn/europarl/`
- Giza++ toolkit available at RWTH Aachen

  `http://www-i6.informatik.rwth-aachen.de/web/Software/GIZA++.html`
- Language model available at SRI
  - `http://www.speech.sri.com/projects/srilm/`
- Pharaoh decoder available at ISI
  - `http://www.isi.edu/licensed-sw/pharaoh/`

Output of Chinese-English System

In the First Two Months Guangdong's Export of High-Tech Products 3.76 Billion US Dollars

Xinhua News Agency, Guangzhou, March 16 (Reporter Chen Jizhong) - The latest statistics show that between January and February this year, Guangdong's export of high-tech products 3.76 billion US dollars, with a growth of 34.8% and accounted for the province's total export value of 25.5%. The export of high-tech products bright spots frequently now, the Guangdong provincial foreign trade and economic growth has made important contributions. Last year, Guangdong's export of high-tech products 22.294 billion US dollars, with a growth of 31 percent, an increase higher than the province's total export growth rate of 27.2 percent; exports of high-tech products net increase 5.270 billion us dollars, up for the traditional labor-intensive products as a result of prices to drop from the value of domestic exports decreased.

In the Suicide explosion in Jerusalem

Xinhua News Agency, Jerusalem, March 17 (Reporter bell tsui fbwer nie Xiaoyang) - A man on the afternoon of 17 in Jerusalem in the northern part of the residents of rammed a bus near ignition of carry bomb, the wrongdoers in red-handed was killed and another nine people were slightly injured and sent to hospital for medical treatment.

MIT statistical MT system [Koehn, 2004], NIST Eval 2002 test set, about 100 million words training data

Partially Excellent Translations

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Partially excellent translations

Mangled Grammar

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