

# **Chapter 5**

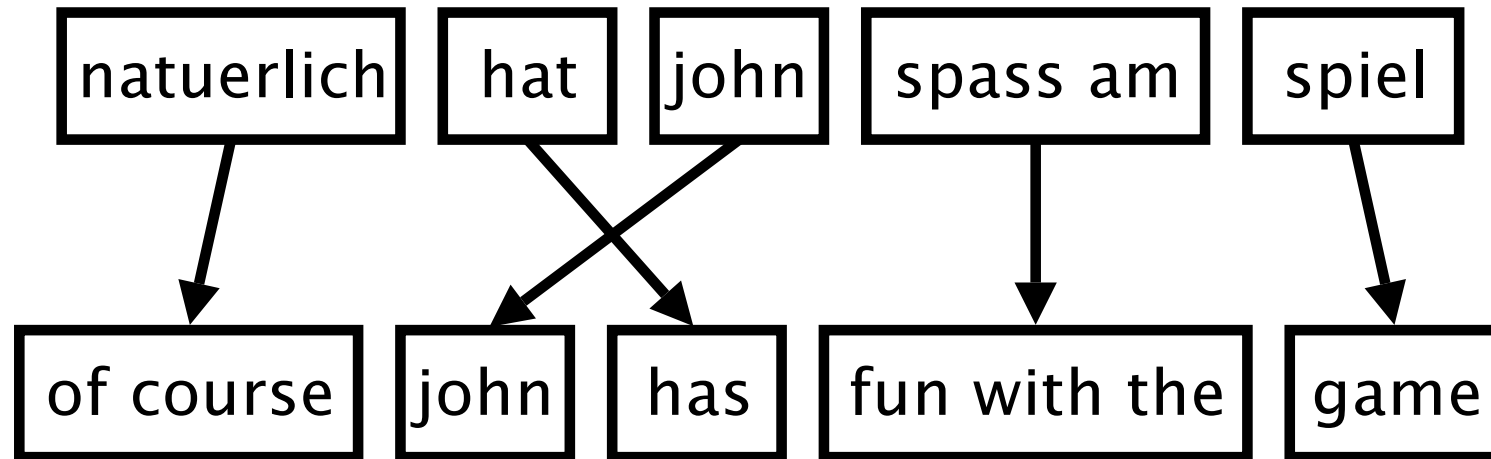
## **Phrase-based models**

Statistical Machine Translation

# Motivation

- Word-Based Models translate *words* as atomic units
- Phrase-Based Models translate *phrases* as atomic units
- Advantages:
  - many-to-many translation can handle non-compositional phrases
  - use of local context in translation
  - the more data, the longer phrases can be learned
- "Standard Model", used by Google Translate and others

# Phrase-Based Model



- Foreign input is segmented in phrases
- Each phrase is translated into English
- Phrases are reordered

# Phrase Translation Table

- Main knowledge source: table with phrase translations and their probabilities
- Example: phrase translations for [natuerlich](#)

Translation	Probability $\phi(\bar{e} f)$
<a href="#">of course</a>	0.5
<a href="#">naturally</a>	0.3
<a href="#">of course ,</a>	0.15
<a href="#">, of course ,</a>	0.05

# Real Example

- Phrase translations for *den Vorschlag* learned from the Europarl corpus:

English	$\phi(\bar{e} f)$	English	$\phi(\bar{e} f)$
the proposal	0.6227	the suggestions	0.0114
's proposal	0.1068	the proposed	0.0114
a proposal	0.0341	the motion	0.0091
the idea	0.0250	the idea of	0.0091
this proposal	0.0227	the proposal ,	0.0068
proposal	0.0205	its proposal	0.0068
of the proposal	0.0159	it	0.0068
the proposals	0.0159	...	...

- lexical variation (proposal vs suggestions)
- morphological variation (proposal vs proposals)
- included function words (the, a, ...)
- noise (it)

# Linguistic Phrases?

- Model is not limited to linguistic phrases  
(noun phrases, verb phrases, prepositional phrases, ...)
- Example non-linguistic phrase pair

spass am → fun with the

- Prior noun often helps with translation of preposition
- Experiments show that limitation to linguistic phrases hurts quality

# Probabilistic Model

- Bayes rule

$$\begin{aligned} \mathbf{e}_{\text{best}} &= \operatorname{argmax}_{\mathbf{e}} p(\mathbf{e}|\mathbf{f}) \\ &= \operatorname{argmax}_{\mathbf{e}} p(\mathbf{f}|\mathbf{e}) p_{\text{LM}}(\mathbf{e}) \end{aligned}$$

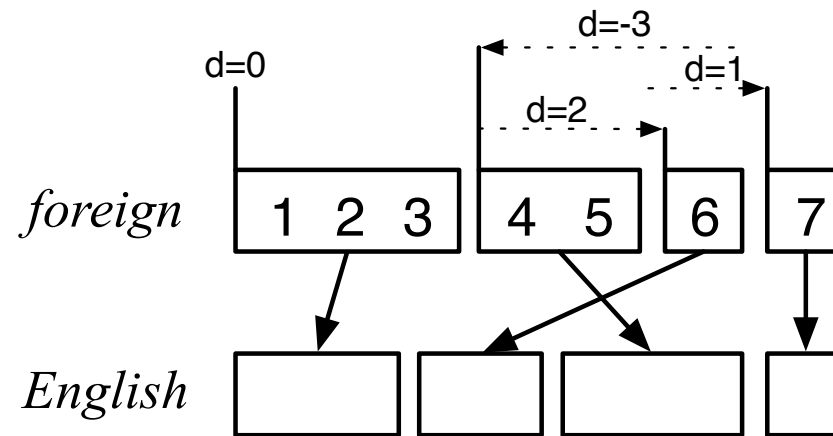
- translation model  $p(\mathbf{e}|\mathbf{f})$
- language model  $p_{\text{LM}}(\mathbf{e})$

- Decomposition of the translation model

$$p(\bar{f}_1^I | \bar{e}_1^I) = \prod_{i=1}^I \phi(\bar{f}_i | \bar{e}_i) d(\text{start}_i - \text{end}_{i-1} - 1)$$

- phrase translation probability  $\phi$
- reordering probability  $d$

# Distance-Based Reordering



phrase	translates	movement	distance
1	1-3	start at beginning	0
2	6	skip over 4-5	+2
3	4-5	move back over 4-6	-3
4	7	skip over 6	+1

Scoring function:  $d(x) = \alpha^{|x|}$  — exponential with distance



# Learning a Phrase Translation Table

- Task: learn the model from a parallel corpus
- Three stages:
  - word alignment: using IBM models or other method
  - extraction of phrase pairs
  - scoring phrase pairs

# Word Alignment

	michael	geht	davon	aus	,	dass	er	im	haus	bleibt
michael	■									
assumes		■	■	■						
that						■				
he							■			
will										■
stay										■
in								■		
the								■		
house									■	

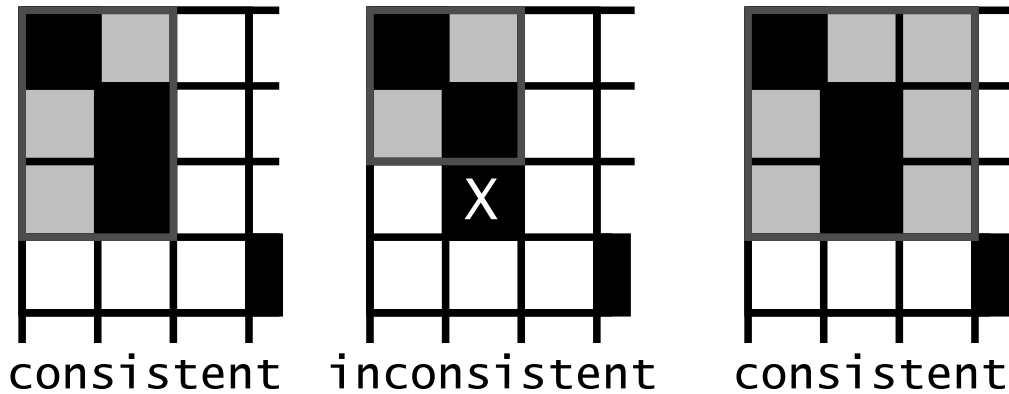
# Extracting Phrase Pairs

	michael	geht	davon	aus	,	dass	er	im	haus	bleibt
michael	■									
assumes		■	■	■	■	■				
that		■	■	■	■	■				
he							■			
will										■
stay										■
in								■		
the								■		
house									■	

extract phrase pair consistent with word alignment:

assumes that / geht davon aus , dass

# Consistent



**ok**

**violated**

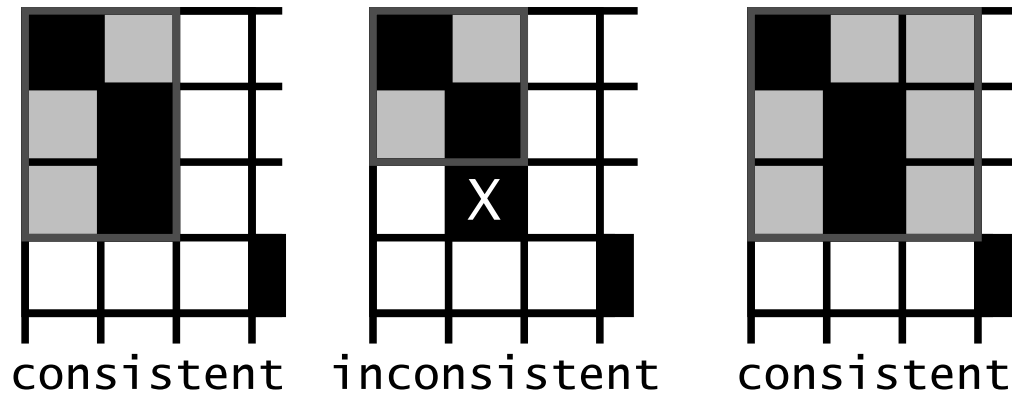
**ok**

one alignment  
point outside

unaligned  
word is fine

All words of the phrase pair have to align to each other.

# Consistent



Phrase pair  $(\bar{e}, \bar{f})$  consistent with an alignment  $A$ , if all words  $f_1, \dots, f_n$  in  $\bar{f}$  that have alignment points in  $A$  have these with words  $e_1, \dots, e_n$  in  $\bar{e}$  and vice versa:

$(\bar{e}, \bar{f})$  consistent with  $A \Leftrightarrow$

$$\begin{aligned} & \forall e_i \in \bar{e} : (e_i, f_j) \in A \rightarrow f_j \in \bar{f} \\ \text{AND } & \forall f_j \in \bar{f} : (e_i, f_j) \in A \rightarrow e_i \in \bar{e} \\ \text{AND } & \exists e_i \in \bar{e}, f_j \in \bar{f} : (e_i, f_j) \in A \end{aligned}$$

# Phrase Pair Extraction

	michael	geht	davon	aus	,	dass	er	im	haus	bleibt
michael	■									
assumes		■	■	■						
that					■					
he						■				
will										■
stay										■
in							■			
the							■			
house								■		

Smallest phrase pairs:

michael — michael  
 assumes — geht davon aus / geht davon aus ,  
 that — dass / , dass  
 he — er  
 will stay — bleibt  
 in the — im  
 house — haus

unaligned words (here: German comma) lead to multiple translations

# Larger Phrase Pairs

	michael	geht	davon	aus	,	dass	er	im	haus	bleibt
michael	█									
assumes		█	█	█						
that						█				
he							█			
will										█
stay										█
in								█		
the								█		
house									█	

michael assumes — michael geht davon aus / michael geht davon aus ,  
 assumes that — geht davon aus , dass ; assumes that he — geht davon aus , dass er  
 that he — dass er / , dass er ; in the house — im haus  
 michael assumes that — michael geht davon aus , dass  
 michael assumes that he — michael geht davon aus , dass er  
 michael assumes that he will stay in the house — michael geht davon aus , dass er im haus bleibt  
 assumes that he will stay in the house — geht davon aus , dass er im haus bleibt  
 that he will stay in the house — dass er im haus bleibt ; dass er im haus bleibt ,  
 he will stay in the house — er im haus bleibt ; will stay in the house — im haus bleibt

# Scoring Phrase Translations

- Phrase pair extraction: collect all phrase pairs from the data
- Phrase pair scoring: assign probabilities to phrase translations
- Score by relative frequency:

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



# Size of the Phrase Table

- Phrase translation table typically bigger than corpus  
... even with limits on phrase lengths (e.g., max 7 words)

→ Too big to store in memory?

- Solution for training
  - extract to disk, sort, construct for one source phrase at a time
- Solutions for decoding
  - on-disk data structures with index for quick look-ups
  - suffix arrays to create phrase pairs on demand

# Weighted Model

- Described standard model consists of three sub-models
  - phrase translation model  $\phi(\bar{f}|\bar{e})$
  - reordering model  $d$
  - language model  $p_{LM}(e)$

$$e_{\text{best}} = \operatorname{argmax}_e \prod_{i=1}^I \phi(\bar{f}_i|\bar{e}_i) d(\text{start}_i - \text{end}_{i-1} - 1) \prod_{i=1}^{|\mathbf{e}|} p_{LM}(e_i|e_1\dots e_{i-1})$$

- Some sub-models may be more important than others
- Add weights  $\lambda_\phi$ ,  $\lambda_d$ ,  $\lambda_{LM}$

$$e_{\text{best}} = \operatorname{argmax}_e \prod_{i=1}^I \phi(\bar{f}_i|\bar{e}_i)^{\lambda_\phi} d(\text{start}_i - \text{end}_{i-1} - 1)^{\lambda_d} \prod_{i=1}^{|\mathbf{e}|} p_{LM}(e_i|e_1\dots e_{i-1})^{\lambda_{LM}}$$

# Log-Linear Model

- Such a weighted model is a log-linear model:

$$p(x) = \exp \sum_{i=1}^n \lambda_i h_i(x)$$

- Our feature functions
  - number of feature function  $n = 3$
  - random variable  $x = (e, f, start, end)$
  - feature function  $h_1 = \log \phi$
  - feature function  $h_2 = \log d$
  - feature function  $h_3 = \log p_{LM}$

# Weighted Model as Log-Linear Model

$$p(e, a|f) = \exp(\lambda_\phi \sum_{i=1}^I \log \phi(\bar{f}_i|\bar{e}_i) + \lambda_d \sum_{i=1}^I \log d(a_i - b_{i-1} - 1) + \lambda_{LM} \sum_{i=1}^{|e|} \log p_{LM}(e_i|e_1\dots e_{i-1}))$$

# More Feature Functions

- Bidirectional alignment probabilities:  $\phi(\bar{e}|\bar{f})$  and  $\phi(\bar{f}|\bar{e})$
- Rare phrase pairs have unreliable phrase translation probability estimates  
 → lexical weighting with word translation probabilities

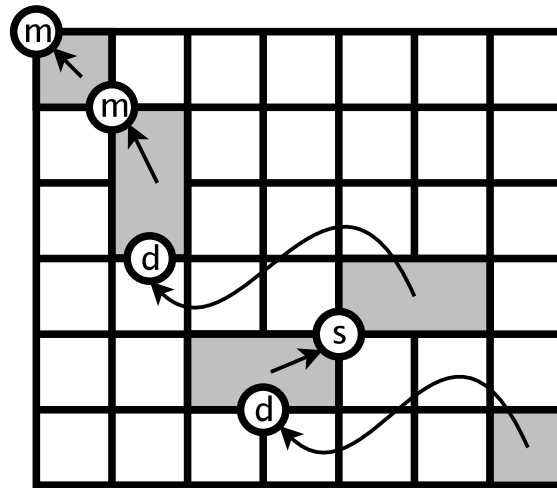
	geht	nicht	davon	aus	NULL
does					
not					
assume					

$$\text{lex}(\bar{e}|\bar{f}, a) = \prod_{i=1}^{\text{length}(\bar{e})} \frac{1}{|\{j | (i, j) \in a\}|} \sum_{\forall (i, j) \in a} w(e_i | f_j)$$

# More Feature Functions

- Language model has a bias towards short translations  
→ word count feature (word penalty)
- We may prefer finer or coarser segmentation  
→ phrase count
- Multiple language models
- Multiple translation models
- Other knowledge sources

# Lexicalized Reordering

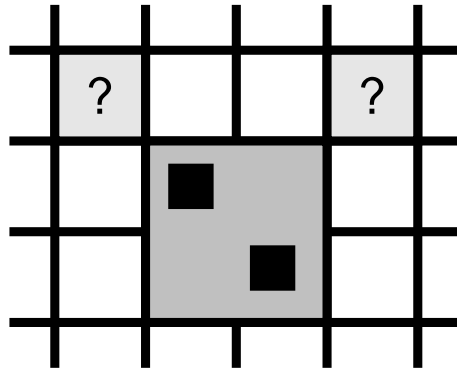


- Distance-based reordering model is weak  
→ learn reordering preference for each phrase pair
- Three orientations types: (m) monotone, (s) swap, (d) discontinuous

orientation  $\in \{m, s, d\}$

$p_o(\text{orientation} | \bar{f}, \bar{e})$

# Learning Lexicalized Reordering



- Collect orientation information during phrase pair extraction
  - if word alignment point to the top left exists → **monotone**
  - if a word alignment point to the top right exists → **swap**
  - if neither a word alignment point to top left nor to the top right exists → neither monotone nor swap → **discontinuous**



# Learning Lexicalized Reordering

- Estimation by relative frequency

$$p_o(\text{orientation}) = \frac{\sum_{\bar{f}} \sum_{\bar{e}} \text{count}(\text{orientation}, \bar{e}, \bar{f})}{\sum_o \sum_{\bar{f}} \sum_{\bar{e}} \text{count}(o, \bar{e}, \bar{f})}$$

- Smoothing with unlexicalized orientation model  $p(\text{orientation})$  to avoid zero probabilities for unseen orientations

$$p_o(\text{orientation} | \bar{f}, \bar{e}) = \frac{\sigma p(\text{orientation}) + \text{count}(\text{orientation}, \bar{e}, \bar{f})}{\sigma + \sum_o \text{count}(o, \bar{e}, \bar{f})}$$

# EM Training of the Phrase Model

- We presented a heuristic set-up to build phrase translation table (word alignment, phrase extraction, phrase scoring)
- Alternative: align phrase pairs directly with EM algorithm
  - initialization: uniform model, all  $\phi(\bar{e}, \bar{f})$  are the same
  - expectation step:
    - \* estimate likelihood of all possible phrase alignments for all sentence pairs
  - maximization step:
    - \* collect counts for phrase pairs  $(\bar{e}, \bar{f})$ , weighted by alignment probability
    - \* update phrase translation probabilities  $p(\bar{e}, \bar{f})$
- However: method easily overfits (learns very large phrase pairs, spanning entire sentences)

# Summary

- Phrase Model
- Training the model
  - word alignment
  - phrase pair extraction
  - phrase pair scoring
- Log linear model
  - sub-models as feature functions
  - lexical weighting
  - word and phrase count features
- Lexicalized reordering model
- EM training of the phrase model