# Hierarchical Machine Translation

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# Content

# Recap

- Noisy Channel
  $P(E|F) = \frac{P(E)P(F|E)}{P(F)}$

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- Noisy Channel
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- Most likely translation
  $\underset{e}{\mathrm{argmax}} P(E|F) = \underset{e}{\mathrm{argmax}} P(E)P(F|E)$
  (1) the chance that someone would say **E** first place
  (2) if say **E**, the chance that someone else would translate it into **F**.
  (3) $P(F|E)$ will ensure that a good **E** will have words that generally translate to words in **F**.
  (4) $P(E)$ language model.

# Recap

- Noisy Channel
  $P(E|F) = \frac{P(E)P(F|E)}{P(F)}$
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  (1) the chance that someone would say **E** first place
  (2) if say **E**, the chance that someone else would translate it into **F**.
  (3) $P(F|E)$ will ensure that a good **E** will have words that generally translate to words in **F**.
  (4) $P(E)$ language model.
- Linear Model

$$S_\theta(e, d, f) = \theta^T \sum_i^n h_i(d_i|e, f)$$

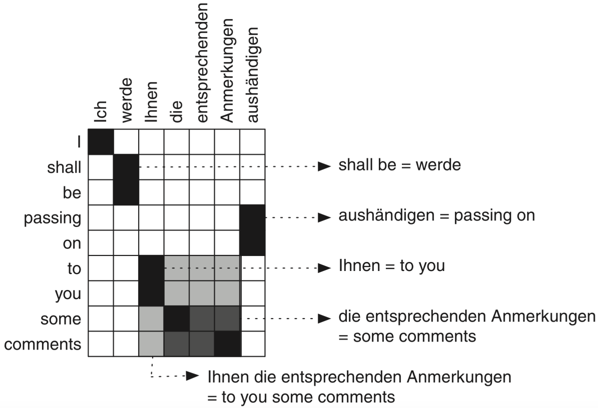


Figure: Koehn [2010]

werde $X$ aushändigen | shall be passing on $X$

# Why hierarchical structure?

Better generalisation

- compositionality
- reordering

# Why is reordering important?

Monotone translation is unrealistic

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# Why is reordering important?

Monotone translation is unrealistic

- languages differ wrt word-order
  e.g. different syntactic structure
  e.g. rich morphology

Reordering is arguably one of the hardest problems in MT

- part of the model of translational equivalences
  *the part that determines the space of translations*

# Key aspects

Expressiveness

- how much can two languages differ wrt word order?

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- how much can two languages differ wrt word order?

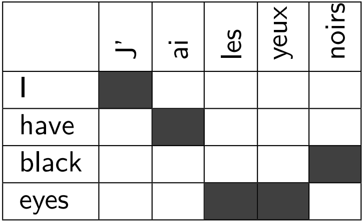
Modelling

- how many parameters do we have to estimate?

# Content

# Hierarchical phrase-based - Motivation

Local Reordering



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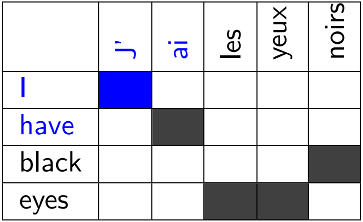
Local Reordering




- Monotone
  J'$_1$ ai$_2$ $\rightarrow$ I$_1$ have$_2$

# Hierarchical phrase-based - Motivation

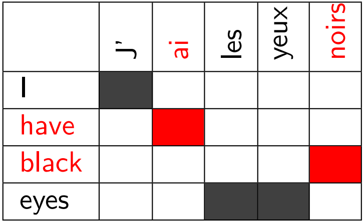
Local Reordering

| | J' | ai | les | yeux | noirs |
|---|---|---|---|---|---|
| I | | | | | |
| have | | | | | |
| black | | | | | |
| eyes | | | | | |

- Swap
  les yeux$_4$ noirs$_5$ $\rightarrow$ black$_3$ eyes$_4$

# Hierarchical phrase-based - Motivation

Local Reordering




- Discontinuous
  ai$_2$ $X_{3-4}$ noirs$_5$ $\rightarrow$ have$_2$ black$_3$ $X_4$

# Hierarchical phrase-based - Motivation

Discontiguous Phrases

| | Je | ne | vais | pas |
|---|---|---|---|---|
| I | | | | |
| do | | | | |
| not | | | | |
| go | | | | |

# Hierarchical phrase-based - Motivation

Discontiguous Phrases

| | Je | ne | vais | pas |
|---|---|---|---|---|
| I | | | | |
| do | | | | |
| not | | | | |
| go | | | | |

- Gappy phrase
  ne vais pas $\rightarrow$ do not go
  ne $X_{vais}$ pas $\rightarrow$ do not $X_{go}$

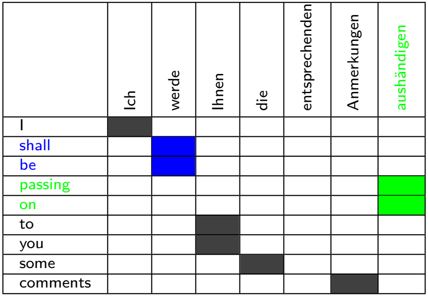
# Hierarchical phrase-based - Motivation

## Long Distance Reordering

| | Ich | werde | Ihnen | die | entsprechenden | Anmerkungen | aushändigen |
|---|---|---|---|---|---|---|---|
| I | ■ | | | | | | |
| shall | | ■ | | | | | |
| be | | ■ | | | | | |
| passing | | | | | | | ■ |
| on | | | | | | | ■ |
| to | | | ■ | | | | |
| you | | | ■ | | | | |
| some | | | | ■ | | | |
| comments | | | | | | ■ | |

# Hierarchical phrase-based - Motivation

## Long Distance Reordering




- How can we extract a biphrase for **shall be passing on**?

# Hierarchical phrase-based - Motivation

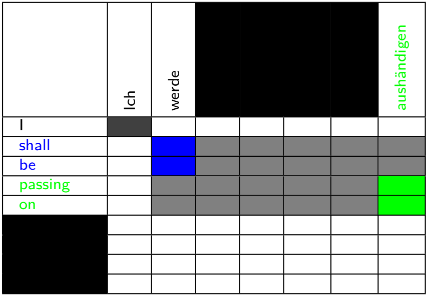
## Long Distance Reordering

| | Ich | werde | Ihnen | die | entsprechenden | Anmerkungen | aushändigen |
|---|---|---|---|---|---|---|---|
| I | | | | | | | |
| shall | | | | | | | |
| be | | | | | | | |
| passing | | | | | | | |
| on | | | | | | | |
| to | | | X | | | | |
| you | | | X | | | | |
| some | | | | X | | | |
| comments | | | | | | X | |

- How can we extract a biphrase for **shall be passing on**?
- We cannot, we need to extract **to you some comments** along

# Hierarchical phrase-based - Motivation

## Long Distance Reordering




- How can we extract a biphrase for **shall be passing on**?
- We cannot, we need to extract **to you some comments** along
- Unless we replace all those words by a variable

# Hierarchical phrase-based - Motivation

Long Distance Reordering

shall be passing on to you some comments

$\updownarrow$

werde Ihnen die entsprechenden Anmerkungen aushändigen

# Hierarchical phrase-based - Motivation

Long Distance Reordering

shall be passing on ~~to you some comments~~

↕

werde ~~Ihnen die entsprechenden Anmerkungen~~ aushändigen

# Hierarchical phrase-based - Motivation

Long Distance Reordering

shall be passing on $X$

$\updownarrow$

werde $X$ aushändigen

# Hiero

Extends phrase-based MT with hierarchical rules [Chiang, 2005]

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# Hiero

Extends phrase-based MT with hierarchical rules [Chiang, 2005]

- conditions on word alignment
- heuristic rule extraction
- heuristic scoring by relative frequency counting
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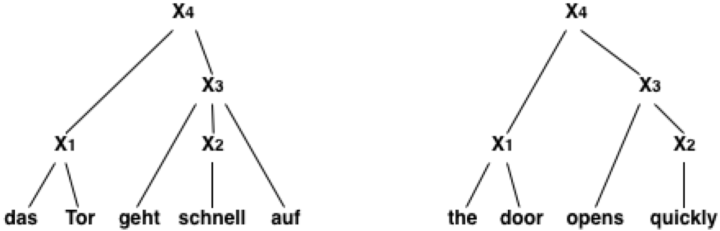
- SCFG decoding

Motivation

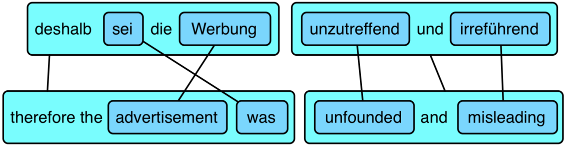
- long-distance reordering
- lexicalised reordering

# Hiero

PBSMT, one level of hierarchy.
HPBSMT, any kind of tree depth.



# Hiero




Rules with two non-terminals:

$$\mathrm{X} \rightarrow \textit{deshalb}\ \mathrm{X}_1\ \textit{die}\ \mathrm{X}_2 \mid \textit{therefore the}\ \mathrm{X}_2\ \mathrm{X}_1$$

$$\mathrm{X} \rightarrow \mathrm{X}_1\ \textit{und}\ \mathrm{X}_2 \mid \mathrm{X}_1\ \textit{and}\ \mathrm{X}_2$$

# Heuristic rule extraction

Initial phrase pairs created with same heuristic as PBSMT.

shall be passing on to you some comments

$\updownarrow$

werde Ihnen die entsprechenden Anmerkungen aushändigen

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Initial phrase pairs created with same heuristic as PBSMT.

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# Heuristic rule extraction

Initial phrase pairs created with same heuristic as PBSMT.

shall be passing on $X_1$ some comments

$\updownarrow$

werde $X_1$ die entsprechenden Anmerkungen aushändigen

# Heuristic rule extraction

Initial phrase pairs created with same heuristic as PBSMT.

shall be passing on $X_1$ ~~some comments~~

$\updownarrow$

werde $X_1$ ~~die entsprechenden Anmerkungen~~ aushändigen

# Heuristic rule extraction

Initial phrase pairs created with same heuristic as PBSMT.

shall be passing on $X_1$ $X_2$

$\updownarrow$

werde $X_1$ $X_2$ aushändigen

# Heuristic rule extraction

Initial phrase pairs created with same heuristic as PBSMT.

$[X] \rightarrow$ shall be passing on $X_1$ $X_2$ | werde $X_1$ $X_2$ aushändigen

$[X] \rightarrow$ shall be passing on $X_3$ | werde $X_3$ aushändigen

$[X] \rightarrow$ to you | Ihnen

$[X] \rightarrow$ some comments | die entsprechenden Anmerkungen

$[X] \rightarrow$ to you some comments | Ihnen die entsprechenden Anmerkungen

# Hiero - Scoring

Relative frequency: assume all fragments have been "observed"
Give a count of one to phrase pair occurrence, then distribute its weight equally among the obtained rules.

- Joint rule probatility: $p(LHS, RHS_{source}, RHS_{target})$

$$p(X, \text{la maison } X_1, \text{the } X_1 \text{ house})$$

- Rule application probability: $p(RHS_{source}, RHS_{target}|LHS)$

$$p(\text{la maison } X_1, \text{the } X_1 \text{ house}|X)$$

- Direct translation probability: $p(RHS_{target}|RHS_{source}, LHS)$

$$p(\text{the } X_1 \text{ house}|\text{la maison } X_1, X)$$

- Noisy-channel translation probability: $p(RHS_{source}|RHS_{target}, LHS)$

$$p(\text{la maison } X_1|\text{the } X_1 \text{ house}, X)$$

- Lexical translation probability

$$\prod_{t_i \in RHS_{target}} p(t_i|RHS_{source}, a) \qquad \prod_{s_i \in RHS_{source}} p(s_i|RHS_{target}, a)$$

# Hiero - Model

Log-linear combination of features

# Hiero - Model

Log-linear combination of features Linear model

$$S_\theta(e,d,f) = \theta^T \sum_{r_{s,t} \epsilon d} h_i(r_{s,t}|e,f)$$

where $s$ is a span over F,
$t$ is a span over E
and $r$ is a rule.
Weighted synchronous CFG.
LM.

# Content

# Decoding

Phrase-based

Tree-based

# Decoding

Phrase-based

- Left-to-Right

Tree-based

- Bottom-Up

# Decoding

Phrase-based

- Left-to-Right
- Beam Search

Tree-based

- Bottom-Up
- Chart Parsing

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Phrase-based

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- Beam Search
- Formally intersection:

Tree-based

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# Decoding

Phrase-based

- Left-to-Right
- Beam Search
- Formally intersection:
- FST (TM) $\times$ FSA (LM)

Tree-based

- Bottom-Up
- Chart Parsing
- Formally intersection:
- SCFG (TM) $\times$ FSA (LM)

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# Discriminative Model

- model consists of features.

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- model consists of features.
- each feature has a weight.
- supervised learning: tune feature weights wrt. an evaluation metric on development data
- Which objective?
  Bilingual Evaluation Understudy metric BLEU

# Tuning

**Task**: find weights so that the model ranks best translations first.

- Translate development corpus using model with current feature weights,
  N -best list of translations (N = 100, 1000, . . .)

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# Tuning

**Task**: find weights so that the model ranks best translations first.

- Translate development corpus using model with current feature weights,
  N -best list of translations (N = 100, 1000, . . .)
- Evaluate translations with the objective
- Adjust feature weights to increase the gain
- Iterate translation, evaluation, and adjustment of feature weights

# MERT

Minimum error rate training (MERT)

- coordinate ascent, where the search updates a feature weight which appears most likely to offer improvements.

# MERT

Minimum error rate training (MERT)

- coordinate ascent, where the search updates a feature weight which appears most likely to offer improvements.
- Highest point in a hilly city with a grid of streets, like San Francisco. [Koehn, 2008]
  We start along a certain street.
  Find its highest point and continue along the cross-street.
  Also in this cross-street we find the highest point.

# MERT

- Line search for best feature weights
  given: sentences with n-best lists of translations

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- iterate n times
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- Line search for best feature weights
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  for each feature
  - find best feature weight

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- iterate n times
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  for each feature
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    - update if different from current

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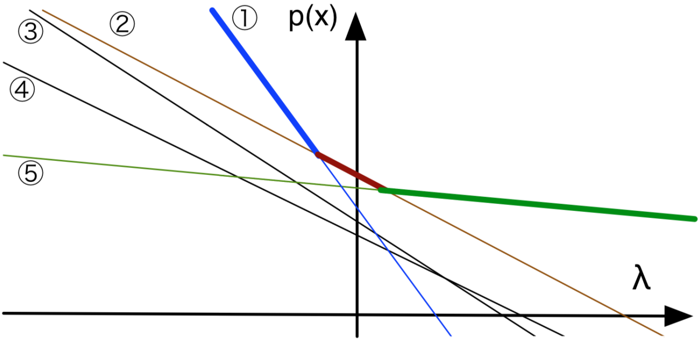
- Line search for best feature weights
  given: sentences with n-best lists of translations
- iterate n times
  randomize starting feature weights
  for each feature
  - find best feature weight
  - update if different from current
- return best feature weights found in any iteration

# MERT



# Homework

- Deep Learning, NLP, and Representations
  http://colah.github.io/posts/2014-07-NLP-RNNs-Representations/
- Understanding LSTM Networks
  http://colah.github.io/posts/2015-08-Understanding-LSTMs/

# Questions?

# References I

David Chiang. A hierarchical phrase-based model for statistical machine translation. In *Proceedings of the 43rd Annual Meeting of the Association for Computational Linguistics (ACL'05)*, pages 263–270, Ann Arbor, Michigan, June 2005. Association for Computational Linguistics. doi: 10.3115/1219840.1219873. URL `http://www.aclweb.org/anthology/P05-1033`.

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