Statistical Machine Translation
Part I - Introduction

Alexander Fraser

Institute for Natural Language Processing (IMS)

Universität Stuttgart

2012.09.10   Seminar: Statistical MT

NSSNLP, University of Kathmandu

About the course

- This is a course on statistical machine translation, but from three perspectives
  - First perspective: basic statistical machine translation (as explained in Koehn textbook)
  - Second perspective: how to integrate linguistic information into basic statistical MT
    - Statistical MT for many languages cannot work without such linguistic processing!
  - Third perspective: resources required for Nepali, Pashto, Punjabi, Sinhala, Tamil, Urdu
    - Others?

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About the instructor

- ## Dr. Alexander "Alex" Fraser

  – Dissertation in computer science on statistical machine translation at University of Southern California, Information Sciences Institute

  – Developed first commercial statistical machine translation system: Language Weaver Arabic/English

  – Cross-language retrieval and resource construction at BBN Technologies

  – Senior researcher, leading research group at Stuttgart: Morphosyntactic Modeling for Statistical Machine Translation (located inside Hinrich Schuetze's department)

  – Also interested in statistical parsing, terminology

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PhD students
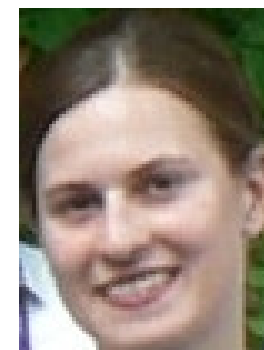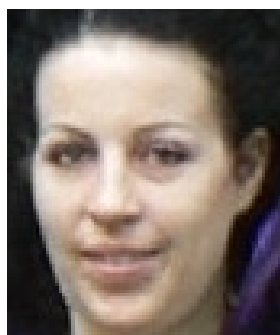
Fabienne Braune: Tree-based models for Statistic Machine Translation
(Also works with **Andreas Maletti** on Tree Transducers for SMT)
Fabienne Cap: Compound words and derivational morphology for SMT
Nadir Durrani*: New statistical models for SMT
Anita Ramm (no picture): Word reordering in translation and verbal phenomena
Hassan Sajjad*: Transliteration mining and modeling
Marion Weller: Inflectional morphology and lexical semantics for SMT
(Primary advisor: **Sabine Schulte im Walde**, lexical semantics)
*: jointly supervised w/ **Helmut Schmid**;   Masters with **Prof. Sarmad Hussain**

Outline

- Part 1: introduction, resources, machine translation evaluation

- Part 2: word alignment

- Part 3: basic phrase-based model, decoding

- Part 4: discriminative phrase-based modeling

- Part 5: basic ideas for integrating linguistic knowledge, including syntactic models and morphology

- Part 6: utilizing linguistic resources: case study on German

- Comments:
    - Parts 2 and 4 have lots of math
    - Part 3 includes a complex search algorithm
    - I will separate into **main ideas** (easily accessible to everyone) and **details** (CS/math background helpful, important to study Koehn book)

- Slides will be on the course web page

- Other resources: Philipp Koehn's book ->

- Kevin Knight's tutorial on word alignment is long, but it is good!

Statistical Machine Translation

Philipp Koehn

CAMBRIDGE
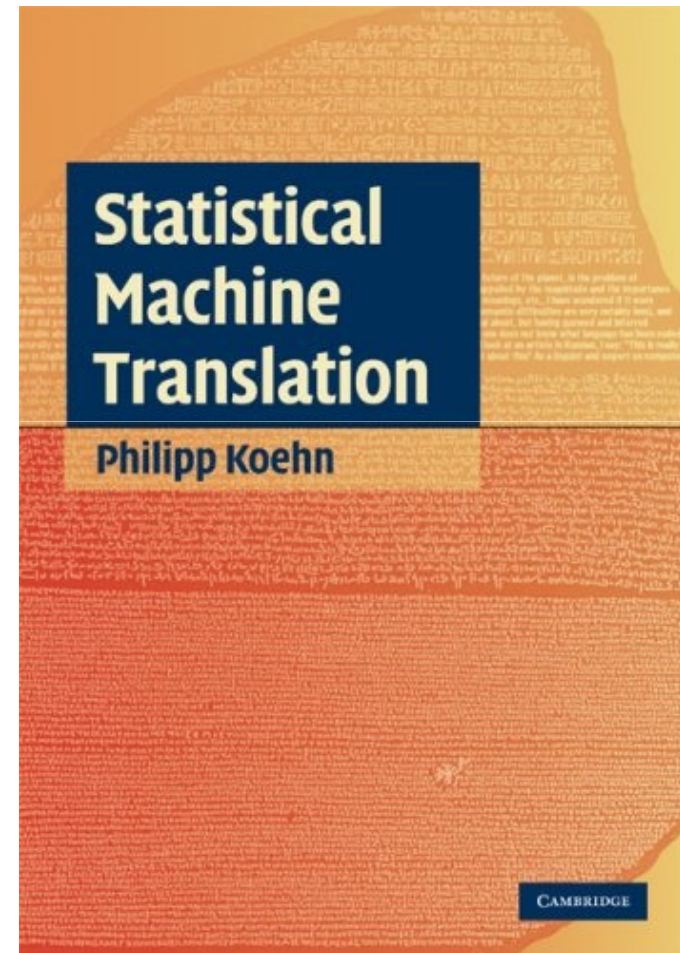
Assignments

- There will be three assignments
- First assignment will involve using Google Translate
  - If there is anyone who does not know the basics of any language other than English supported by Google Translate, **please talk to me after class today**

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- Any basic questions before we start?

Lecture 1 – Introduction + Eval

- Machine translation
- Data driven machine translation
  - Parallel corpora
  - Sentence alignment
  - Overview of statistical machine translation
- Evaluation of machine translation

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A brief history

- Machine translation was one of the first applications envisioned for computers

- Warren Weaver (1949): "I have a text in front of me which is written in Russian but I am going to pretend that it is really written in English and that it has been coded in some strange symbols. All I need to do is strip off the code in order to retrieve the information contained in the text."

- First demonstrated by IBM in 1954 with a basic word-for-word translation system

Modified from Callison-Burch, Koehn

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Interest in machine translation

- Commercial interest:
  - U.S. has invested in machine translation (MT) for intelligence purposes
  - MT is popular on the web—it is the most used of Google's special features
  - EU spends more than $1 billion on translation costs each year.
  - (Semi-)automated translation could lead to huge savings

Modified from Callison-Burch, Koehn

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Interest in machine translation

- Academic interest:

  – One of the most challenging problems in NLP research

  – Requires knowledge from many NLP sub-areas, e.g., lexical semantics, syntactic parsing, morphological analysis, statistical modeling,…

  – Being able to establish links between two languages allows for transferring resources from one language to another

Modified from Dorr, Monz

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Machine translation

- Goals of machine translation (MT) are varied, everything from *gisting* to rough draft

- Largest known application of MT: Microsoft knowledge base

  - Documents (web pages) that would not otherwise be translated at all

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Language Weaver Arabic to English

Description of the Iraqi President George Bush American elections-which will follow in the current month of the thirty-that they constitute a historic moment, recognizing that the organization of elections in current circumstances difficult issue.

It was considered bush in the press that the pronouncements of the possible organization of elections in most regions of the Iraqi punctually wish that the turnout where high. He added that "Iraqi 14 appear in the relative calm 18الـ governorates".

v.2.0 – October 2003

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Iraqi troops had become a target always Iraqi gunmen (French)

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v.3.0 - February 2005

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Document versus sentence

- MT problem: generate high quality translations of **documents**

- However, all current MT systems work only at **sentence** level!

- Translation of independent sentences is a difficult problem that is worth solving

- But remember that important discourse phenomena are ignored!
  - Example: How to translate English *it* to French (choice of feminine vs masculine *it*) or German (feminine/masculine/neuter *it*) if object referred to is in another sentence?

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Machine Translation Approaches

- ## Grammar-based
  - Interlingua-based
  - Transfer-based

- ## Direct
  - Example-based
  - Statistical

Interlingua

IL
-based

Transfer-
based

Direct

Source Language

Target Language
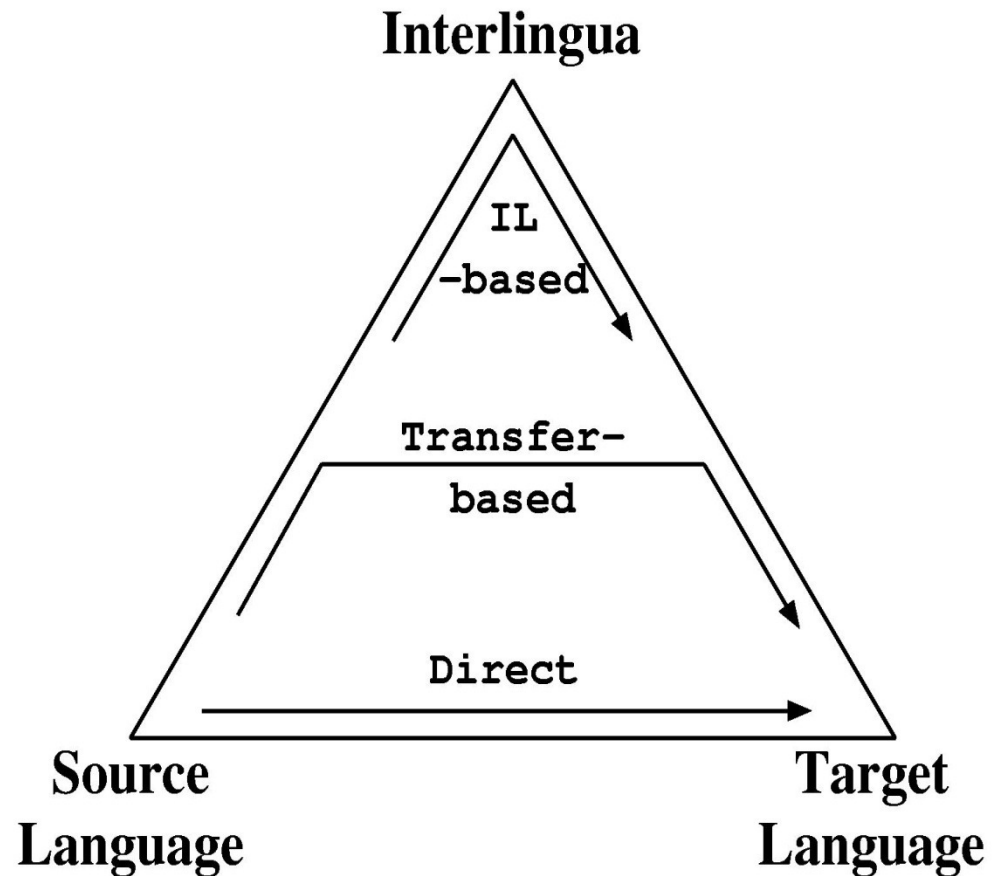
Statistical versus Grammar-Based

- Often statistical and grammar-based MT are seen as alternatives, even opposing approaches – wrong !!!

- Dichotomies are:
  - Use probabilities – everything is equally likely (in between: heuristics)
  - Rich (deep) structure – no or only flat structure

- Both dimensions are continuous

- Examples
  - EBMT: flat structure and heuristics
  - SMT: flat structure and probabilities
  - XFER: deep(er) structure and heuristics

	No Probs	Probs
Flat Structure	EBMT	SMT
Deep Structure	XFER, Interlingua	Holy Grail

- Goal: structurally rich probabilistic models

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Modified from Vogel

Statistical Approach

- Using statistical models
  - Create many alternatives, called hypotheses
  - Give a score to each hypothesis
  - Select the best -> search

- Advantages
  - Avoid hard decisions
  - Speed can be traded with quality, no all-or-nothing
  - Works better in the presence of unexpected input

- Disadvantages
  - Difficulties handling structurally rich models, mathematically and computationally
  - Need data to train the model parameters
  - Difficult to understand decision process made by system

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Modified from Vogel

Outline

- *Machine translation*

- Data-driven machine translation

  - Parallel corpora

  - Sentence alignment

  - Overview of statistical machine translation

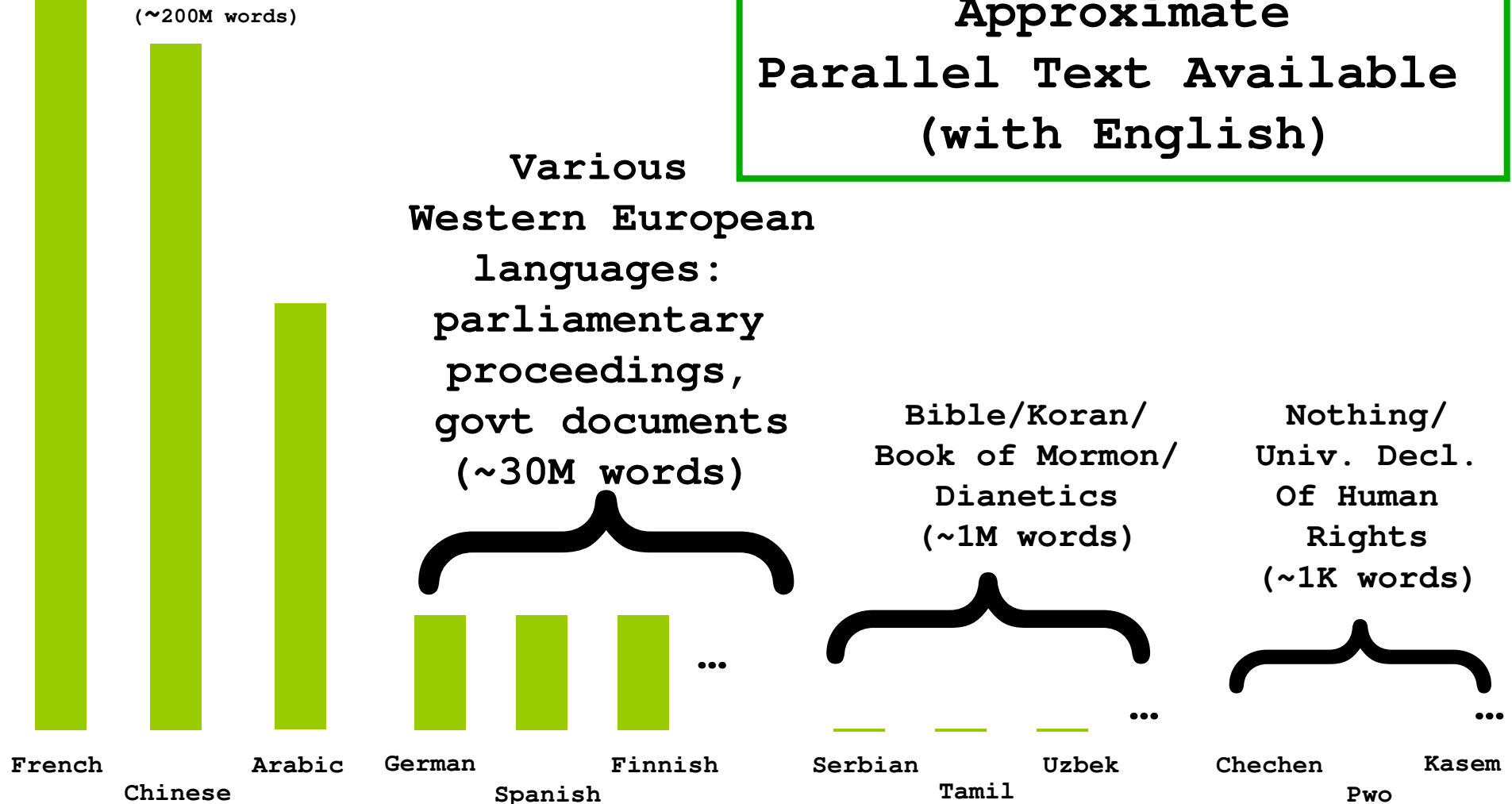- Evaluation of machine translation

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Parallel corpus

- Example from DE-News (8/1/1996)

English	German
Diverging opinions about planned tax reform	Unterschiedliche Meinungen zur geplanten Steuerreform
The discussion around the envisaged major tax reform continues .	Die Diskussion um die vorgesehene grosse Steuerreform dauert an .
The FDP economics expert , Graf Lambsdorff , today came out in favor of advancing the enactment of significant parts of the overhaul , currently planned for 1999 .	Der FDP - Wirtschaftsexperte Graf Lambsdorff sprach sich heute dafuer aus , wesentliche Teile der fuer 1999 geplanten Reform vorzuziehen .

Modified from Dorr, Monz

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Most statistical machine translation research has focused on a few high-resource languages (European, Chinese, Japanese, Arabic).

Approximate Parallel Text Available (with English)

(~200M words)

Various Western European languages: parliamentary proceedings, govt documents (~30M words)

Bible/Koran/ Book of Mormon/ Dianetics (~1M words)

Nothing/ Univ. Decl. Of Human Rights (~1K words)

French
Chinese
Arabic
German
Spanish
Finnish
Serbian
Tamil
Uzbek
Chechen
Pwo
Kasem

Modified from Schafer&Smith

How to Build an SMT System

- Start with a large parallel corpus
  - Consists of document pairs (document and its translation)
- Sentence alignment: in each document pair automatically find those sentences which are translations of one another
  - Results in sentence pairs (sentence and its translation)
- Word alignment: in each sentence pair automatically annotate those words which are translations of one another
  - Results in word-aligned sentence pairs
- Automatically estimate a statistical model from the word-aligned sentence pairs
  - Results in model parameters
- Given new text to translate, apply model to get most probable translation

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Sentence alignment

- If document D_e is translation of document D_f how do we find the translation for each sentence?

- The *n*-th sentence in D_e is not necessarily the translation of the *n*-th sentence in document D_f

- In addition to 1:1 alignments, there are also 1:0, 0:1, 1:n, and n:1 alignments

- In European Parliament proceedings, approximately 90% of the sentence alignments are 1:1

Modified from Dorr, Monz

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Sentence alignment

- There are several sentence alignment algorithms:
  - Align (Gale & Church): Aligns sentences based on their character length (shorter sentences tend to have shorter translations then longer sentences). Works well
  - Char-align: (Church): Aligns based on shared character sequences. Works fine for similar languages or technical domains
  - K-Vec (Fung & Church): Induces a translation lexicon from the parallel texts based on the distribution of foreign-English word pairs
  - Cognates (Melamed): Use positions of cognates (including punctuation)
  - Length + Lexicon (Moore; Braune and Fraser): Two passes, high accuracy, freely available

Word alignments

- Given a parallel sentence pair we can link (align) words or phrases that are translations of each other:

Diverging opinions about the planned tax reform

Unterschiedliche Meinungen zur geplanten Steuerreform

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How to Build an SMT System

- Construct a function g which, given a sentence in the source language and a hypothesized translation into the target language, assigns a goodness score

  – g(die Waschmaschine läuft , the washing machine is running) = high number

  – g(die Waschmaschine läuft , the car drove) = low number

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Using the SMT System

- Implement a search algorithm which, given a source language sentence, finds the target language sentence which maximizes g

- To use our SMT system to translate a new, unseen sentence, call the search algorithm

  – Returns its determination of the best target language sentence

- To see if your SMT system works well, do this for a large number of **unseen** sentences and evaluate the results

SMT modeling

- We wish to build a machine translation system which given a Foreign sentence "f" produces its English translation "e"

  – We build a model of P(e | f), the probability of the sentence "e" given the sentence "f"

  – To translate a Foreign text "f", choose the English text "e" which maximizes P(e | f)

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Noisy Channel: Decomposing P(e|f)

$$\text{argmax}_e \; P(\,e\mid f\,) \;=\; \text{argmax}_e \; P(\,f\mid e\,)\; P(\,e\,)$$

- P(e) is referred to as the "language model"
  - P (e) can be modeled using standard models (N-grams, etc)
  - Parameters of P (e) can be estimated using large amounts of monolingual text (English)
- P(f | e) is referred to as the "translation model"

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SMT Terminology

- Parameterized Model: the form of the function g which is used to determine the goodness of a translation

  g(die Waschmaschine läuft, the washing machine is running)
  = P(e | f)

  P(the washing machine is running|die Waschmaschine läuft)=

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SMT Terminology

- Parameterized Model: the form of the function g which is used to determine the goodness of a translation

  g(die Waschmaschine läuft, the washing machine is running)
  $= P(e \mid f)$

  P(the washing machine is running|die Waschmaschine läuft)=
  What??

  Unless we have seen exactly the input sentence in our training data, we can't GENERALIZE.

  So we will decompose this translation into parts, so that we can generalize to new sentences.

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SMT Terminology

- Parameterized Model: the form of the function g which is used to determine the goodness of a translation

  g(die Waschmaschine läuft, the washing machine is running)
  = P(e | f)

  P(the washing machine is running|die Waschmaschine läuft)=

  Suppose we translate:

  "die" to "the"

  "Waschmaschine" to "washing machine"

  "läuft" to "is running"

  (and further suppose we don't worry about word order…)

SMT Terminology

- Parameterized Model: the form of the function g which is used to determine the goodness of a translation

  g(die Waschmaschine läuft, the washing machine is running)
  = P(e | f)

  P(the washing machine is running|die Waschmaschine läuft)=

  - n(1 | die) t(the | die)
  - n(2 | Waschmaschine) t(washing | Waschmaschine)
    - t(machine | Waschmaschine)
  - n(2 | läuft) t(is | läuft) t(running | läuft)
  - l(the | START) l(washing | the) l(machine | washing) l(is | machine)
    l(running | is)

SMT Terminology

- Parameters: lookup tables used in function g

  P(the washing machine is running|die Waschmaschine läuft) =

  n(1 | die) t(the | die)

  n(2 | Waschmaschine) t(washing | Waschmaschine)

                  t(machine | Waschmaschine)

  n(2 | läuft) t(is | läuft) t(running | läuft)

  l(the | START) l(washing | the) l(machine | washing) l(is | machine)
      l(running | is)

  0.1 x 0.1
  x 0.5 x 0.8
  x 0.7
  x 0.1 x 0.1 x 0.1
  x 0.0000001

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SMT Terminology

- Parameters: lookup tables used in function g

  P(the washing machine is running|die Waschmaschine läuft) =

  n(1 | die) t(the | die)

  n(2 | Waschmaschine) t(washing | Waschmaschine)

  t(machine | Waschmaschine)

  n(2 | läuft) t(is | läuft) t(running | läuft)

  l(the | START) l(washing | the) l(machine | washing) l(is | machine)
  l(running | is)

	Change "washing machine" to "car"
0.1 x 0.1	0.1 x 0.1
x 0.5 x 0.8	x 0.1 x 0.0001 n(1 | Waschmaschine)
x 0.7	t(car | Waschmaschine)
x 0.1 x 0.1 x 0.1	x 0.1 x 0.1 x 0.1
x 0.0000001	x also different

SMT Terminology

- Training: automatically building the lookup tables used in g, using parallel sentences

- One way to determine t(the|die)
  - Generate a word alignment for each sentence pair
  - Look through the word-aligned sentence pairs
  - Count the number of times „die" is translated as „the"
  - Divide by the number of times „die" is translated.
  - If this is 10% of the time, we set t(the|die) = 0.1

SMT Last Words

- – Translating is usually referred to as decoding (Warren Weaver)
- – SMT was invented by automatic speech recognition (ASR) researchers. In ASR:
  - P(e) = language model
  - P(f|e) = acoustic model
  - However, SMT must deal with word reordering!

Outline

- *Machine translation*

- *Data-driven machine translation*

  - *Parallel corpora*

  - *Sentence alignment*

  - *Overview of statistical machine translation*

- **Evaluation of machine translation**

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Evaluation driven development

- Lessons learned from automatic speech recognition (ASR)
  - Reduce evaluation to a single number
    - For ASR we simply compare the hypothesized output from the recognizer with a transcript
    - Calculate similarity score of hypothesized output to transcript
    - Try to modify the recognizer to maximize similarity
  - Shared tasks – everyone uses same data
    - May the best model win!

- These lessons widely adopted in NLP and Information Retrieval

Evaluation of machine translation

- We can evaluate machine translation at corpus, document, sentence or word level

  – Remember that in MT the unit of translation is the sentence

- Human evaluation of machine translation quality is difficult

- We are trying to get at the abstract usefulness of the output for different tasks

  – Everything from gisting to rough draft translation

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Sentence Adequacy/Fluency

- Consider German/English translation

- **Adequacy**: is the meaning of the German sentence conveyed by the English?

- **Fluency**: is the sentence grammatical English?

- These are rated on a scale of 1 to 5

Modified from Dorr, Monz

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Human Evaluation

INPUT: Ich bin müde.   **(OR INPUT: Je suis fatigué.)**

	Adequacy	Fluency
Tired is I.	5	2
Cookies taste good!	1	5
I am tired.	5	5

Modified from Schafer, Smith

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Further slides on manual evaluation

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Automatic evaluation

- Evaluation metric: method for assigning a numeric score to a hypothesized translation
- Automatic evaluation metrics often rely on comparison with previously completed human translations

Word Error Rate (WER)

- **WER**: edit distance to reference translation (insertion, deletion, substitution)

- Captures fluency well

- Captures adequacy less well

- Too rigid in matching

      Hypothesis = „he saw a man and a woman"

      Reference = „he saw a woman and a man"

      WER gives no credit for „woman" or „man" !

Position-Independent Word Error Rate (PER)

- PER: captures lack of overlap in *bag of words*

- Captures adequacy at single word (unigram) level

- Does not capture fluency

- Too flexible in matching

  Hypothesis 1 = „he saw a man"

  Hypothesis 2 = „a man saw he"

  Reference = „he saw a man"

  Hypothesis 1 and Hypothesis 2 get same PER score!

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BLEU

- ## Combine WER and PER
  - Trade off between rigid matching of WER and flexible matching of PER

- ## BLEU compares the 1,2,3,4-gram overlap with one or more reference translations
  - BLEU penalizes generating short strings with the brevity penalty, precision for short strings is very high
  - References are usually 1 or 4 translations (done by humans!)

- ## BLEU correlates well with average of fluency and adequacy at corpus level
  - But not at sentence level!

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BLEU discussion

- BLEU works well for comparing two similar MT systems
  - Particularly: SMT system built on fixed training data vs. Improved SMT system built on same training data
  - Other metrics such as METEOR extend these ideas and work even better – ongoing research!

- BLEU does not work well for comparing dissimilar MT systems

- There is no good automatic metric at sentence level

- There is no automatic metric that returns a meaningful measure of **absolute** quality

Language Weaver Arabic to English

Description of the Iraqi President George Bush American elections— which will follow in the current month of the thirty–that they constitute a historic moment, recognizing that the organization of elections in current circumstances difficult issue.

It was considered bush in the press that the pronouncements of the possible organization of elections in most regions of the Iraqi punctually wish that the turnout where high. He added that "Iraqi 14 appear in the relative calm 18 الـ governorates".

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v.3.0 - February 2005

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- Next time we will look at word alignment models
  - Next lecture will be more mathematical
  - If you are highly motivated, take a look at Kevin Knight's excellent tutorial (not required!)

- Thank you for your attention!

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