Statistical Machine Translation

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Statistical Machine Translation (SMT)

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- Motivation
- History and Important Players
- Mathematical Basics
- IBM Models
- Transduction Grammars
- Template-Based Approaches
- Useful Resources
- Recent Developments

Exercise:

- Learn to Translate Between Unknown Languages

Motivation for SMT

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- Good translation requires knowledge and decisions on many levels
  - syntactic disambiguation (POS, attachments)
  - semantic disambiguation (collocations, scope, word sense)
  - reference resolution
  - lexical choice in target language
  - application-specific terminology, register, connotations, good style …
- Rule-based models of all these levels are very expensive to build, maintain, and adapt to new domains
- Statistical approaches have been quite successful in many areas of NLP, once data has been annotated
- Learning from existing translation will focus on distinctions that matter (not on the linguist's favorite subject)
- Translation corpora are available in rapidly growing amounts
- SMT *can* integrate rule-based modules (morphologies, lexicons)
- SMT *can* use feed-back for on-line adaptation to domain and user preferences

History and Important Players

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- 1949: Warren Weaver: *the translation problem can be largely solved by "statistical semantic studies"*
- 1950s..1970s: Predominance of rule-based approaches
- 1966: ALPAC report: general discouragement for MT (in the US)
- 1980s: example-based MT proposed in Japan (Nagao), statistical approaches to speech recognition (Jelinek e.a. at IBM)
- Late 80s: Statistical POS taggers, SMT models at IBM, work on translation alignment at Xerox (M. Kay)
- 90s: many statistical approaches to NLP in general, IBM's Candide claimed to be as good as Systran
- Late 90s: Statistical MT successful as a fallback approach within Verbmobil System (Ney, Och). Wide distribution of translation memory technology (Trados) indicates big commercial potential of SMT
- 1999 Johns Hopkins workshop: OS re-implementation of IBM methods
- since 2001: DARPA evaluation campaign (XYZ -> English)
- Various companies marketing/exploring SMT technologies:
  language weaver, aixplain GmbH, Linear B Ltd., esteam, Google Labs

Related Fields

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- Initially, statistical and knowledge-based approaches were seen in strict contrast.
- However, PROs and CONs are somewhat complementary:

	Syntax	Structural Semantics	Lexical Semantics	Adaptivity
Rule-based MT	++	+	-	--
Statistical MT	--	--	+	+
Example-based MT	-	--	-	++

➢ It is now more or less consensus to target integrated approaches

Hybrid Approaches

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In the beginning...

	SMT	EBMT	Transfer
Hypothesis probabilities	1		
Collocation bilexicons		1	
Transduction rules			1

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Hybrid Approaches

But then…

- SMT plants trees
  - got collocation bilexicons?
    - learning: Wu & Xia 1995, Smadja 1996, Och et al. 1999, Koehn et al. 2003
    - decoding: Wu 1996, Och et al. 1999, Koehn et al. 2003
- EBMT gets serious about template abstraction
  - got transduction rules?
- Transfer models string out
  - got collocation bilexicons?

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So then…

	SMT	EBMT	Transfer
Hypothesis probabilities	0.6		
Collocation bilexicons	0.4	0.6	0.4
Transduction rules		0.4	0.6

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And then…

- SMT plants trees
  - got collocation bilexicons?
    - learning: Wu & Xia 1995, Smadja 1996, Och et al. 1999, Koehn et al. 2003
    - decoding: Wu 1996, Och et al. 1999, Koehn et al. 2003
  - got 'real linguistic' transduction grammar rules?
    - eg: Wu & Wong 1998, Alshawi et al. 1998, Yamada & Knight 2001, Melamed 2003, Schafer & Yarowsky 2003
- EBMT gets real about scoring
  - got probabilities?
    - eg: Brown et al. 2003
- Transfer models soften up
  - got scores, backoff, stronger decoders?
    - eg: Lavie et al. 2003

Hybrid Approaches

So then...

	SMT	EBMT	Transfer
Hypothesis probabilities	0.5	0.2	0.2
Collocation bilexicons	0.3	0.5	0.3
Transduction rules	0.2	0.3	0.5

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Hybrid Approaches

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Convergence

	SMT	EBMT	Transfer
Hypothesis probabilities	0.33	0.33	0.33
Collocation bilexicons	0.33	0.33	0.33
Transduction rules	0.33	0.33	0.33

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But:

before integrating things, we need to know them in detail!

Mathematical Basics

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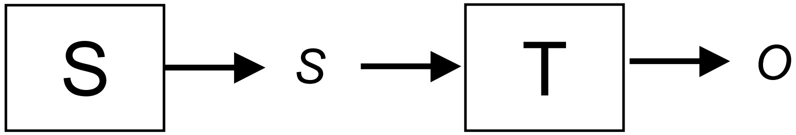
Assume the probabilities of English and French sentences e and f appearing as translations.

P(e): prior probability of e, w/o additional knowledge
P(f|e): conditional probability of f, given e
P(f,e) = P(e) * P(f|e): joint probability
P(f|e) = P(f) * P(e|f) / P(e): Bayes' Rule

Question: P(f,e) = P(f) * ??

"Distorted Channel" Paradigm

Assume a signal that has to be transmitted through a channel that may add distortion, noise, or other modifications:



Both the source of the signal and the transmission channel can be characterized as probability distributions:

P(s): propability that signal s is generated

P(o|s): probability that observation o is made, *given* s

P(o,s) = P(s) * P(o|s): probability that s is sent *and* o is observed

In typical applications, the most likely cause s' for a given observation o is sought, i.e.

$$s' = \text{argmax}_s\ P(s|o) = \text{argmax}_s\ P(s,o) = \text{argmax}_s\ P(s) * P(o|s)$$

Applications of Distorted Channel Paradigm

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Communications Engineering:

- S may be an input device, T a transmission line (modem line, audio/video transmission)

Speech recognition:

- S is the speaker's brain, generating a string of words
- T is the chain consisting of speakers articulatory device, sound transmission, microphone, signal processing up to morpheme hypotheses. The task is to reconstruct from a string of decoded sound events the intended chain of words.

Machine translation:

- S is text in one language, T is translation to another
- applying this model means to translate from the target language of the assumed "distortion" to the source, which can be confusing

Error correction

- S is the intended (correct) text, T is the modification by introducing typing, spelling and other errors

OCR, …

Important Properties of this Model

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- P(S) and P(O|S) can be modeled independently

- P(S) can be approximated using large amounts of monolingual text (e.g. using n-gram models)
- The same monolingual model P(S) can be useful for ASR, OCR, and SMT
- Models based on grammars and other knowledge sources are harder to build, but will be superior in the long run

- P(O|S) can be approximated from translated corpora, when correspondences between source and target language are known or can be estimated
- Again, models that take linguistic structure into account will be better in the long run, but require more effort to be built

IBM Translation Models

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- Brown e.a. 1993 propose 5 different ways to define P(f|e) and to train the parameters from a bilingual corpus
- There is a chicken-and-egg situation between translation models and alignments: given one, we can estimate the other. The standard approach to bootstrap reasonable models from partially hidden data is the Expectation-Maximization (EM-) Algorithm (as also used e.g. for HMMs)
- Model 1 assumes a one-to-one relation between individual words and a uniform distribution over all possible permutations
- Model 2 is similar, but prefers alignments that roughly preserve the original order

Word Alignment Example from Europarl

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	Frau	Ludford	,	möchten	Sie	auch	wirklich	eine	Anmerkung	zum	Protokoll	machen	?
NULL	.	.	.	.	.	*	.	*	.	.	.	*	.
Mrs	*	.	.	.	.	.	.	.	.	.	.	.	.
Ludford	.	*	.	.	.	.	.	.	.	.	.	.	.
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are	.	.	.	*	.	.	.	.	.	.	.	.	.
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the	.	.	.	.	.	.	.	.	.	*	.	.	.
Minutes	.	.	.	.	.	.	.	.	.	.	*	.	.
?	.	.	.	.	.	.	.	.	.	.	.	.	*

IBM Translation Models

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- Model 3 assumes that one English word can give rise to multiple French words by introducing "fertilities", i.e. distributions over the number of words in the translation of a given word. Exact calculation of EM-estimates becomes infeasible and is replaced with approximations restricted to plausible subsets of all possible alignments.
- Model 4 introduces a distinction between groups of words (derived from one source word) that tend to stay together (like: *implemented* → *mis en application*) and groups that tend to get separated (like: not → ne … pas).
- Model 5 is similar to Model 4, but avoids to distribute probability mass over impossible word sequences, e.g. sequences where words are missing or positions are simultaneously occupied with more than one word.
- Formulas in the CL'93 paper look heavy, but there are many tutorials and even an open-source implementation available.

IBM Translation Models

- Bootstrapping also works across models of increasing complexity (i.e. alignment from Model *i* is used to estimate parameters for Model *i+1*)
- Development of the IBM models was based on about 1.8 million sentence pairs from the Canadian parliament debates (Hansards)
- Decoding (i.e. search for argmax_s P(s) * P(o|s)) was computationally challenging for long sentences, hence various heuristics for sentence splitting were used
- The performance was evaluated in a ’94 ARPA test; Candide translations were judged as more fluent, but less adequate than those of Systran
- All models assume that correspondences are triggered by single words on the source level side, i.e. there is no support for phrase-to-phrase alignments

Inversion Transduction Grammars

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- Instead of a directed translation relation between input and output strings, transduction grammars [Wu 199x…] model the simultaneous stochastic generation of strings in two languages.
- Differences in word order can be explained by rules like

  NP → [Adj N]

  generating *Adj N* on one side and *N Adj* on the other
- Parsing sentence pairs using this type of grammars can be done by generalizing context-free parsing to two dimensions (~ squaring the computational complexity)
- Optimal decoding is possible in polynomial time, e.g. $O(n^7)$

Template-Based Approaches

- Models used by Ney/Och in Verbmobil and later at ISI are inspired by, but different from the IBM models
- They are based on the alignment of “phrases” in both languages (phrase = any sequence of words)
- Translation segments the input to phrases, translates each of the phrases, and re-orders the outcomes in the target language
- Search for best translation searches for optimal combined solution for all of these steps, including source language segmentation (= some very limited form of parsing)

Recent Developments

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- Since 2001: DARPA organizes a evaluation campaign for translation from Chinese, Arabic, and more languages to English. For some tests, the source language was known only a couple of weeks before the submission deadline. Practically all systems use SMT
- Philip Koehn (ISI, now MIT) collected and published a 11-language Corpus of European Parliament debates (20..30 MW/lang)
- OPUS project collected and aligned large number of texts (e.g. documentation of open-source software)
- Johns Hopkins Workshop 2003 explored “Syntax for Statistical Machine Translation” and reported some improvements via the inclusion of syntactic features
- Google Labs hired a group of world-class researchers (including Torsten Brants, Franz Och) to work on SMT

Some entry points…

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- Valuable Material (SW, corpora, papers) can be found at homepages of the following persons:
  - Franz Och (former homepage at Aachen)
  - Kevin Knight (ISI)
  - Philipp Koehn (MIT)
  - Andy Way (Dublin)

Centauri/Arcturan [Knight, 1997]

Your assignment, translate this to Arcturan: farok crrrok hihok yorok clok kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
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Your assignment, translate this to Arcturan: **farok** crrrok **hihok yorok clok** kantok ok-yurp

1a. ok-voon ororok sprok . 1b. at-voon bichat dat .	7a. lalok farok ororok lalok sprok izok enemok . 7b. wat jjat bichat wat dat vat eneat .
2a. ok-drubel ok-voon anok plok sprok . 2b. at-drubel at-voon pippat rrat dat .	8a. lalok brok anok plok nok . 8b. iat lat pippat rrat nnat .
3a. erok sprok izok hihok ghirok . 3b. totat dat arrat vat hilat .	9a. wiwok nok izok kantok ok-yurp . 9b. totat nnat quat oloat at-yurp .
4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat .
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .

process of elimination

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4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat . cognate?
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .

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Your assignment, put these words in order: **{ jjat, arrat, mat, bat, oloat, at-yurp }**

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4a. ok-voon anok drok brok jok . 4b. at-voon krat pippat sat lat .	10a. lalok mok nok yorok ghirok clok . 10b. wat nnat gat mat bat hilat .
5a. wiwok farok izok stok . 5b. totat jjat quat cat .	11a. lalok nok crrrok hihok yorok zanzanok . 11b. wat nnat arrat mat zanzanat . zero fertility
6a. lalok sprok izok jok stok . 6b. wat dat krat quat cat .	12a. lalok rarok nok izok hihok mok . 12b. wat nnat forat arrat vat gat .

It's Really Spanish/English

Clients do not sell pharmaceuticals in Europe => Clientes no venden medicinas en Europa

1a. Garcia and associates . 1b. Garcia y asociados .	7a. the clients and the associates are enemies . 7b. los clients y los asociados son enemigos .
2a. Carlos Garcia has three associates . 2b. Carlos Garcia tiene tres asociados .	8a. the company has three groups . 8b. la empresa tiene tres grupos .
3a. his associates are not strong . 3b. sus asociados no son fuertes .	9a. its groups are in Europe . 9b. sus grupos estan en Europa .
4a. Garcia has a company also . 4b. Garcia tambien tiene una empresa .	10a. the modern groups sell strong pharmaceuticals . 10b. los grupos modernos venden medicinas fuertes .
5a. its clients are angry . 5b. sus clientes estan enfadados .	11a. the groups do not sell zenzanine . 11b. los grupos no venden zanzanina .
6a. the associates are also angry . 6b. los asociados tambien estan enfadados .	12a. the small groups are not modern . 12b. los grupos pequenos no son modernos .