Machine Translation

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Language Technology I
WS 2008/9

Machine Translation: Overview

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- Relevance of MT, typical applications and requirements
- History of MT
- Basic approaches to MT
  - Rule/grammar based
  - **Statistical**
  - Example-based
  - **Hybrid, multi-engine**
- Evaluation techniques

Sources for Information

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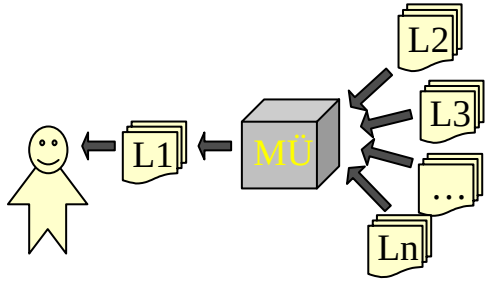
- MT in general, history:
  - http://www.MT-Archive.info: Electronic repository and bibliography of articles, books and papers on topics in machine translation and computer-based translation tools, regularly updated, contains over 3300 items
  - Hutchins, Somers: An introduction to machine translation. Academic Press, 1992, available under http://www.hutchinsweb.me.uk/IntroMT-TOC.htm
- MT systems:

  Compendium of Translation Software, see http://www.hutchinsweb.me.uk/Compendium.htm
- Statistical Machine Translation:

  See www.statmt.org

Use cases and requirements for MT

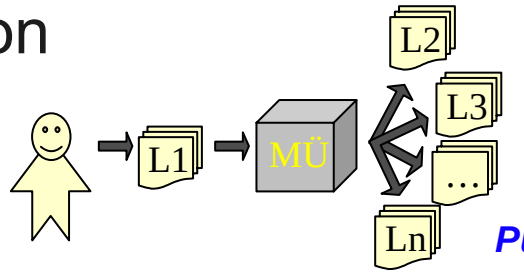
a) MT for assimilation
„inbound“



Robustness
Coverage

Daily throughput of online-MT-Systems > 500 M Words

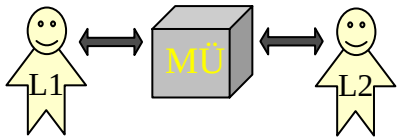
b) MT for dissemination
„outbound“



Textual quality

Publishable quality can only be authored by humans; Translation Memories & CAT-Tools mandatory for professional translators

c) MT for direct communication



Speech recognition, context dependence

Topic of many running and completed research projects (VerbMobil, TC Star, TransTac, …)
US-Military uses systems for spoken MT

On the Risks of Outbound MT

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Some recent examples

'I am not in the office at the moment. Please send any work to be translated'

History of Machine Translation

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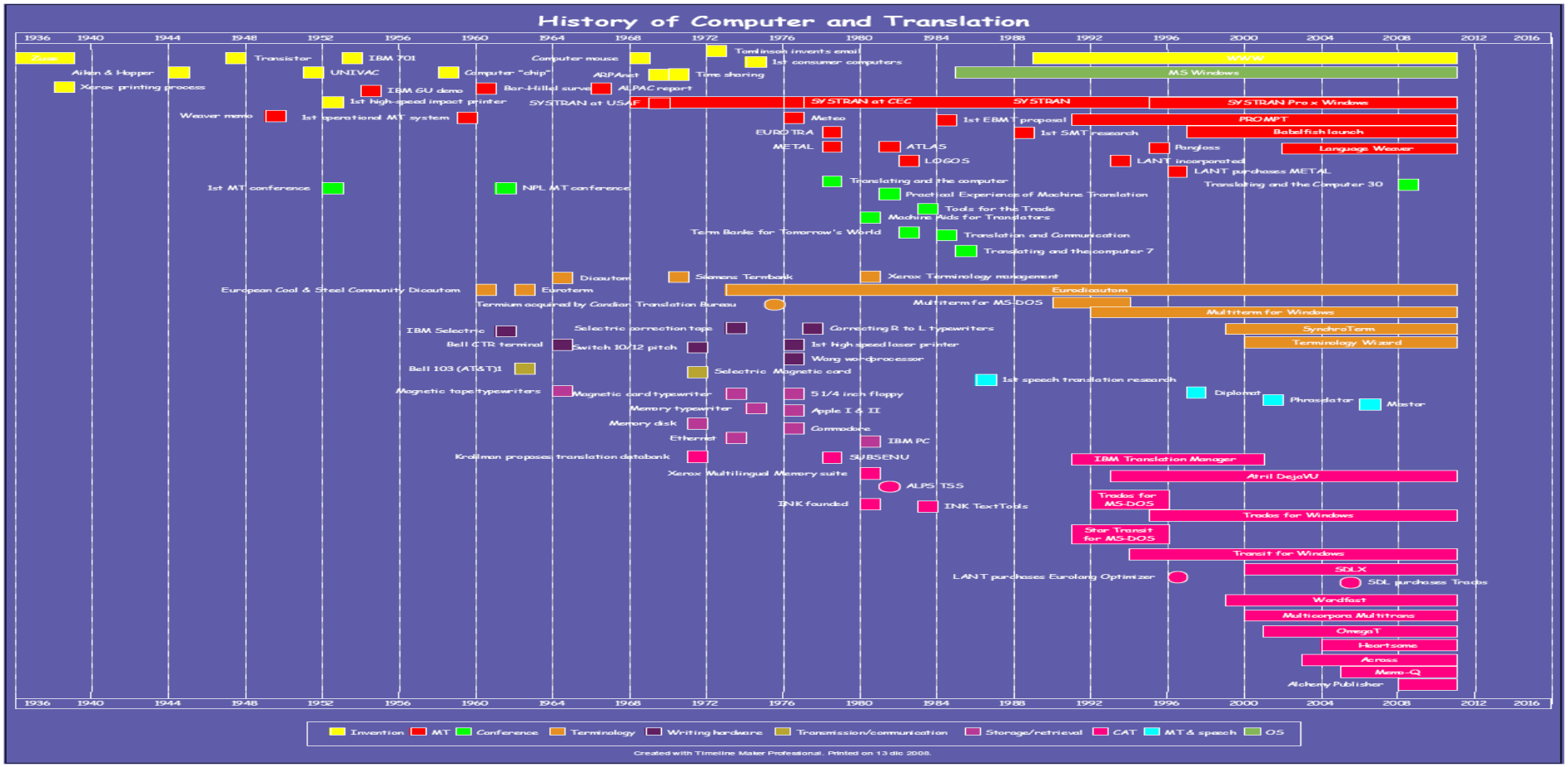
- Slides by John Hutchins:
  http://www.hutchinsweb.me.uk/SUSU-2007-1-ppt.pdf



Existing MT systems for EU languages

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Situation in early 2005, almost all systems are rule-based

From Hutchins: Compendium of Translation Software, 2005

	Engl.	Germ.	Fren.	Span.	Ital.	Port.	Dutch	Poli.	Latv.	Greek	Czech	Hung.	Swed.	Finn.	Slova.	Roma.	Dani.	Bulg.	Slove.	Malt.	Lith.	Irish	Esto.
English		47	41	44	30	30	10	8	2	4	1	4	1	-	1	1	-	2	-	-	-	-	-
German	48		24	8	10	4	2	3	1	-	1	2	1	1	1	-	1	-	-	-	-	-	-
French	40	23		11	13	8	4	1	1	3	1	-	-	-	-	-	-	-	-	-	-	-	-
Spanish	41	7	11		9	8	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Italian	29	10	13	9		4	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Portuguese	29	5	7	8	4		1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dutch	10	2	4	1	1	1		-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polish	7	2	1	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Latvian	2	1	1	1	1	1	1	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Greek	3	-	3	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-
Czech	1	1	1	-	1	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-
Hungarian	2	2	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-
Swedish	2	1	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Finnish	2	1	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-
Slovak	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
Romanian	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
Danish	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-
Bulgarian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-
Slovene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-
Maltese	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-
Lithuanian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-
Irish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-
Estonian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

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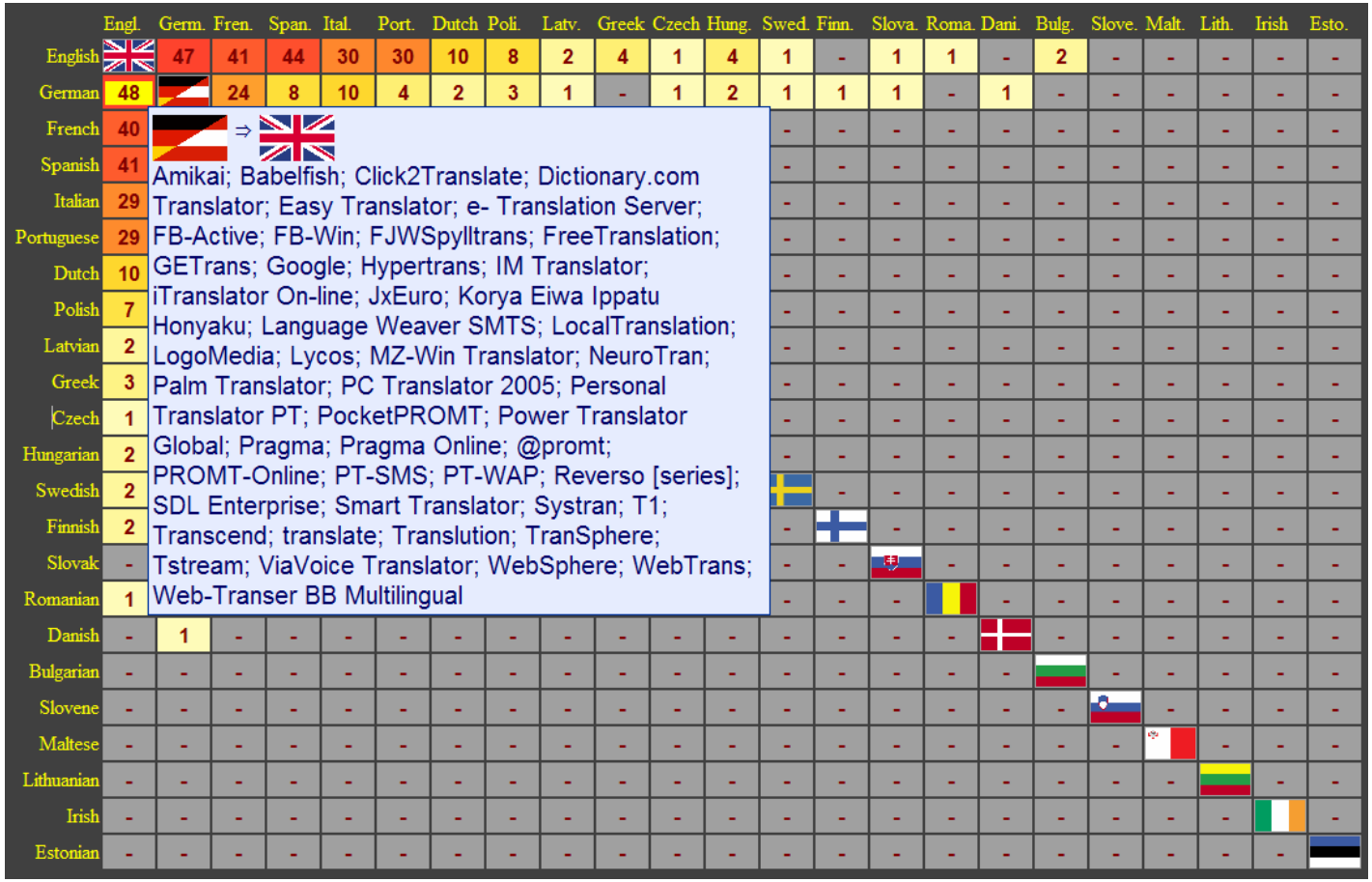

Motivation for rule-based MT

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- Good translation requires knowledge of linguistic rules
  - …for understandig the source text
  - …for generating well-formed target text
- Rule-based accounts for certain linguistic levels exist and should be used, especially for
  - Morphology
  - Syntax
- Writing one rule is better than finding hundreds of examples, as the rule will apply for new, unseen cases

Possible (rule-base) MT architectures

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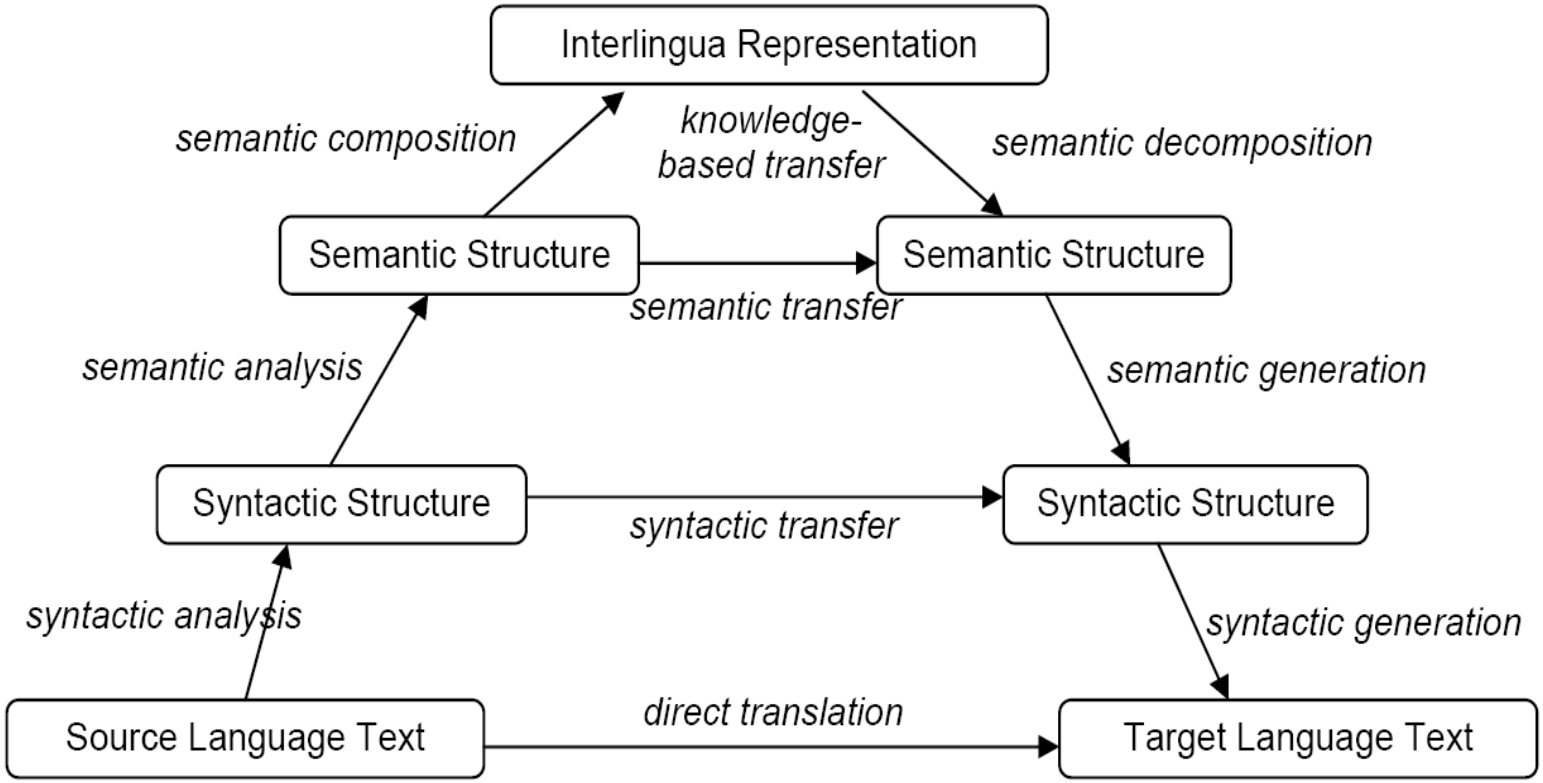
The „Vauquois Triangle“



Motivation for statistical MT

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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 of SMT and Important Players I

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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)
- Early 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

History of SMT and Important Players II

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- 1999 Johns Hopkins workshop: open source re-implementation of IBM's SMT methods (GIZA)
- since 2001: DARPA/NIST evaluation campaign (XYZ -> English), uses BLEU score for automatic evaluation
- Various companies start marketing/exploring SMT:
  language weaver, aixplain GmbH, Linear B Ltd., esteam, Google Labs
- 2002: Philipp Koehn (ISI) makes EuroParl corpus available
- 2003: Koehn, Och & Marcu propose *Statistical Phrase-Based MT*
- 2004: ISI publishes Philipp Koehn's SMT decoder *Pharaoh*
- 2005: First SMT workshop with shared task
- 2006: Johns Hopkins workshop on OS factored SMT decoder Moses, Start of EuroMatrix project for MT between all EU languages, Acquis Communautaire (EU laws in 20+ languages) made available
- 2007: Google abandons Systran and switches to own SMT technology
- 2009: Start of EuroMatrix Plus *"bringing MT to the user"*

Statistical Machine Translation

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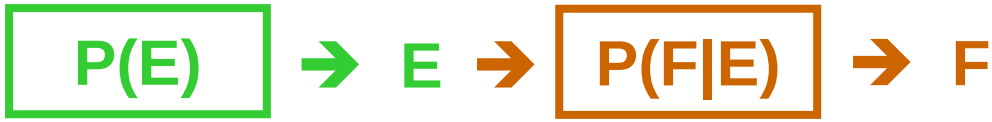
- Based on „*distorted channel*“ Paradigm (successful for pattern- and speech recognition)



- Decoding: Given observation **F**, find most likely cause **E***

$$E^* = \text{argmax}_E\ P(E|F) = \text{argmax}_E\ P(E,F) = \text{argmax}_E\ P(E) * P(F|E)$$

➔ Three subproblems
Model of **P(E)**
Model of **P(F|E)**
Search for **E***

each has approximative solutions
nGram-Models $P(e_1 \ldots e_n) = \Pi P(e_i|e_{i-2}\ e_{i-1})$
Transfer of „phrases“ $P(F|E) = \Pi P(\mathbf{f}_i|\mathbf{e}_i)*P(d_i)$
Heuristic *(beam)* search

- Models are trained with (parallel) corpora, correspondences (alignments) between languages are estimated via EM-Algorithm (GIZA++, F.J.Och)

Statistical Machine Translation

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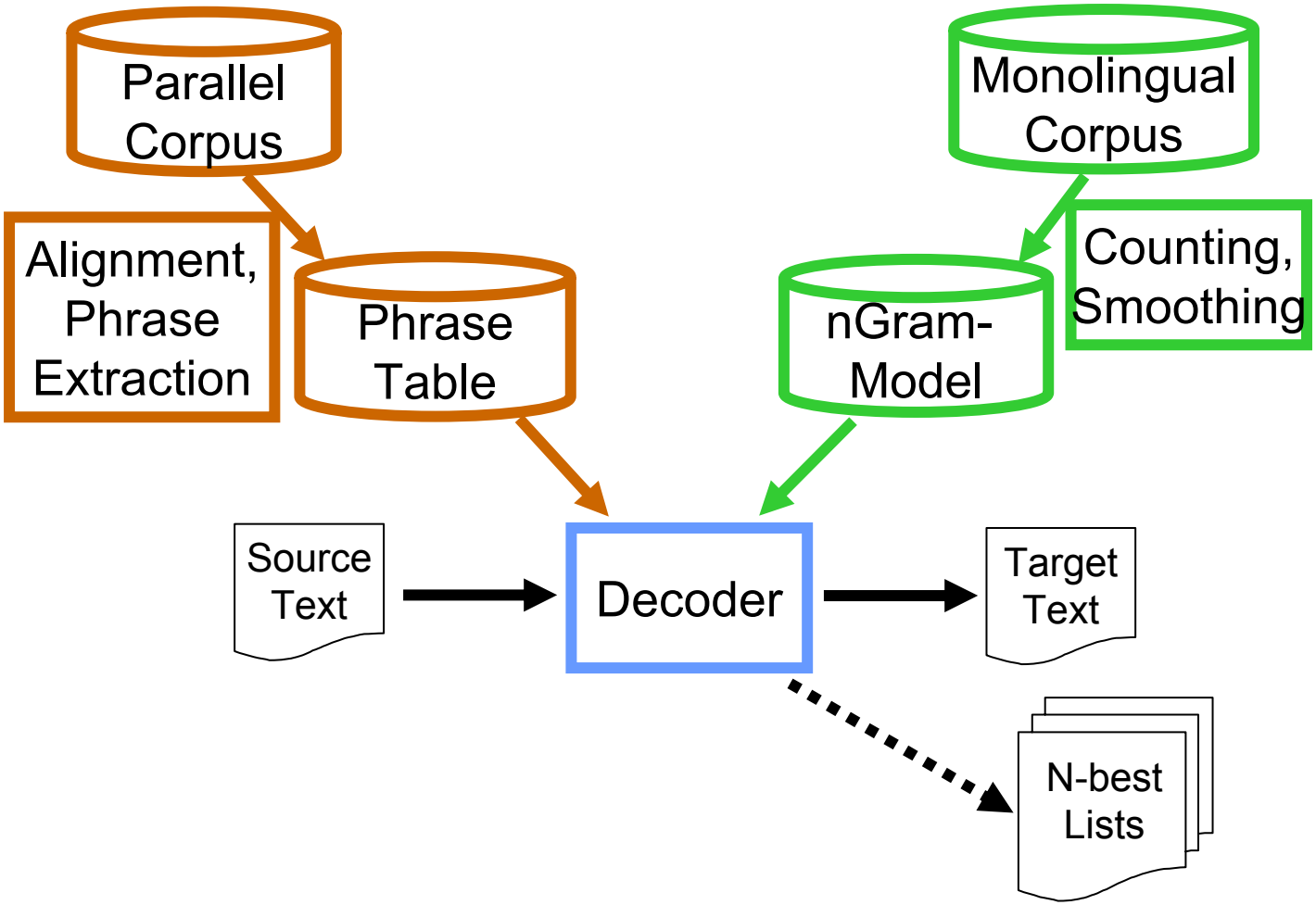
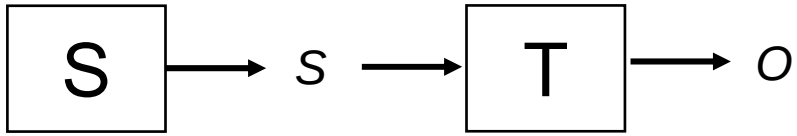
schematic architecture



"Distorted Channel" Paradigm in General

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
- Models that take linguistic structure into account will be better in the long run, require more effort to be built & used

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	.	*	.	.	.	.	.	.	.	.	.	.	.
,	.	.	*	.	.	.	.	.	.	.	.	.	.
are	.	.	.	*	.	.	.	.	.	.	.	.	.
you	.	.	.	.	*	.	.	.	.	.	.	.	.
sure	.	.	.	.	.	.	*	.	.	.	.	.	.
your	.	.	.	.	.	.	.	.	.	.	.	.	.
point	.	.	.	.	.	.	.	.	*	.	.	.	.
of	.	.	.	.	.	.	.	.	.	.	.	.	.
order	.	.	.	.	.	.	.	.	.	.	.	.	.
is	.	.	.	.	.	.	.	.	.	.	.	.	.
related	.	.	.	.	.	.	.	.	.	.	.	.	.
to	.	.	.	.	.	.	.	.	.	.	.	.	.
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

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- 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

SMT: A Walkthrough

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- Parallel text
- Sentence segmentation and tokenization
- Sentence alignment
- Make sure you will have unseen test data
- Word alignment
- Phrase-table construction
- More text from target language
- Stochastic (target) language model
- Decoding
- Inspect/evaluate results

Parallel text

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De-facto standard: EUROPARL corpus

- "Successor" of Canadian Hansards used by IBM
- Free, no legal constraints
- 11 languages -> 110 directed language pairs
- includes some "important" languages
- somewhat representative for EU publications
- future versions will have 20++ languages

But:

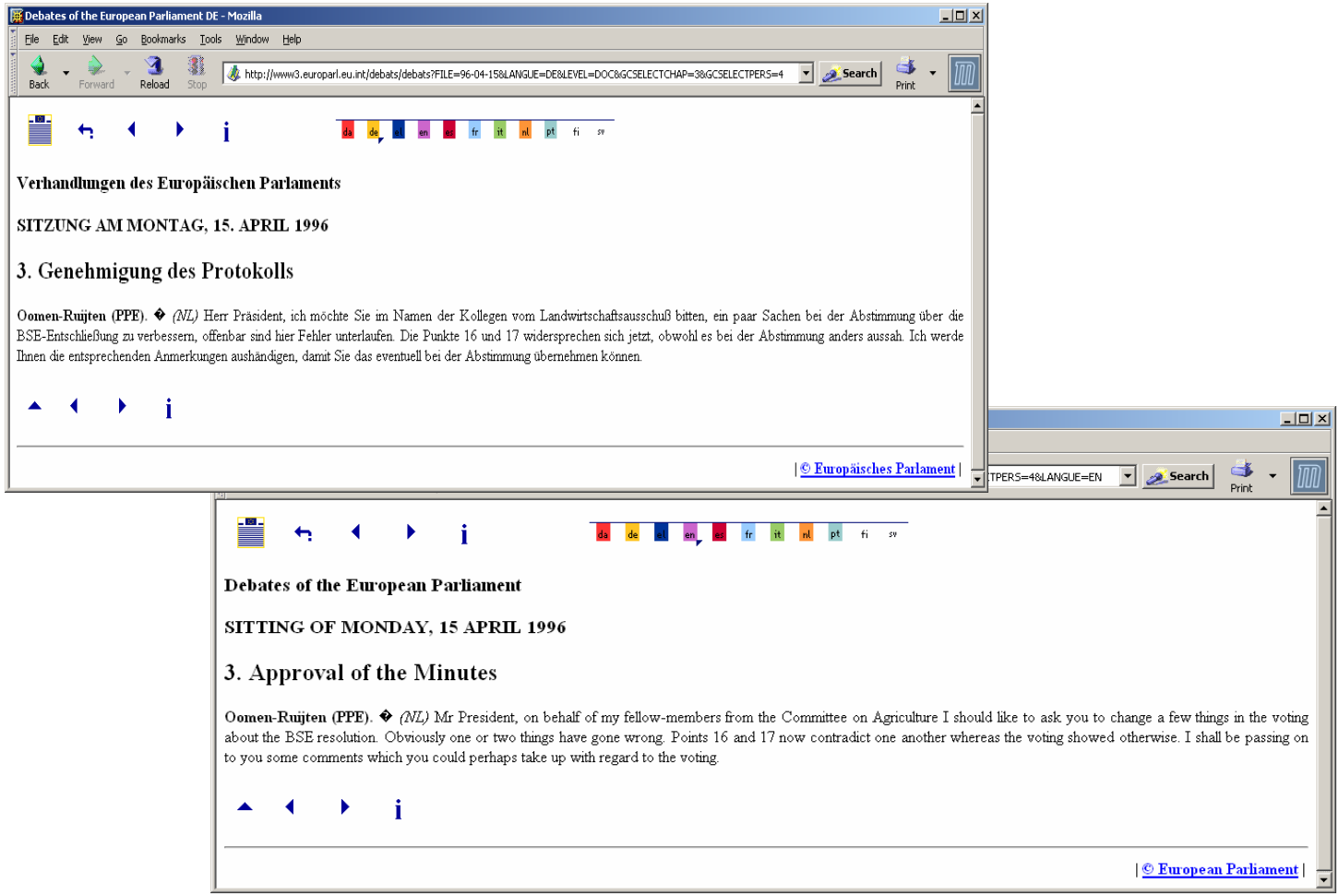
- does not cover the most difficult/interesting languages (Chinese, Arabic, Japanese, Walpiri, Inuktitut, …)
- not very technical
- not overly interesting from stylistic point of view
- dependencies on context as in typical written text

In the meantime:

EU has been extended to 25 states with 20 official languages (more to come), official law has been translated to all these languages

(= "**Acquis Communautaire**" Corpus)

Parallel text: EUROPARL



Parallel text: EUROPARL

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- non-trivial to find texts in a form that facilitates processing (PDFs are quite inconvenient)
- millions of words distributed over 10000s of URLs
- some translations are missing
- the hard work of crawling the site has already been done for us (thanks to Philipp Koehn)
- results available from **http://www.statmt.org/europarl/**

Tokenization and sentence segmentation

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- Both can be tricky if you want to get all the details right
  - "That is not true!" he said…→ 1 or 2 sentences?
  - doesn't → doesn + ' + t **vs.** does + n't ?
- Distinguishing end-of-sentence marks from sentence-internal punctuation requires recognition of abbreviations, which isn't quite trivial to do in 11 languages
- We may not always like Philipp Koehn's decisions, but they are good enough to get a system up and running

Sentence alignment

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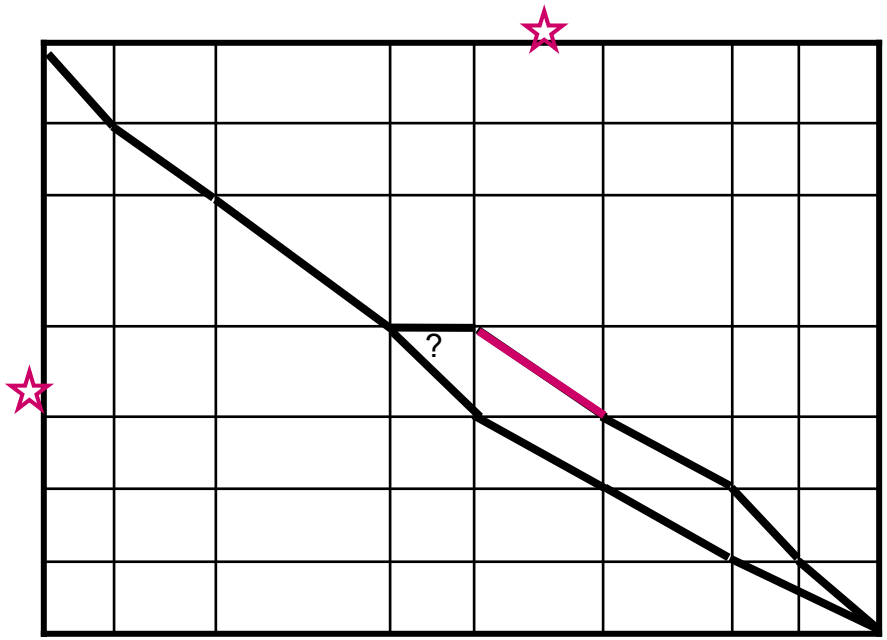
- Problem: During translation, sentences may have been split, merged, dropped or re-ordered.
- This does not look hard until you have enough data (Europarl:11*1.3M sentences)
- If data is clean and some errors are acceptable: Simple length-based heuristic does the job
- Task can be seen as finding an optimal path through rectangular grid (see next slide)
- Europarl v.1: 10 sentence alignments XY ⇔ EN
- Europarl v.2: sentences + generic alignment tool

Sentence alignment

- Can be solved by dynamic programming



- Complexity is O(n*m)
- Additional evidence (e.g. from invariant or cognate words) can be helpful

Word alignment

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- Words may (dis-)appear during translation, they get reordered, words replace constructions …

→ almost impossible to reach full agreement on valid correspondences

- Simple stochastic models will automatically get the typical cases right, but will miss the tricky (=interesting) cases
- For SMT, the typical cases are most important; we may have to live with 10% error rate

Word alignment

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- Typical approach: use IBM models as implemented in GIZA++ system
- Apply it in both directions
- Take intersection of results (increasing precision at the cost of recall)
- Extend using various heuristics
- Partial word alignments for 4 language pairs DE/ES/FI/FR⇔EN available from
  `http://www.statmt.org/wpt05/mt-shared-task/`

Word alignment

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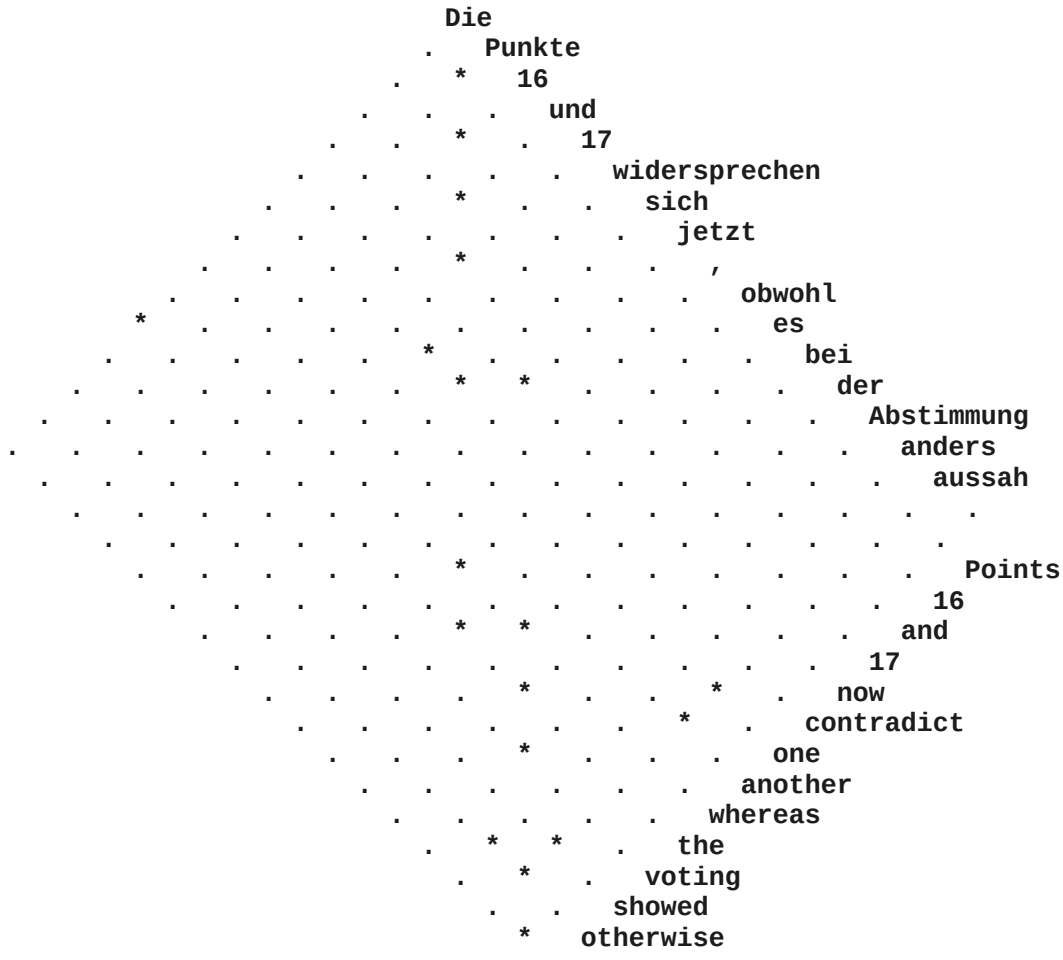
Sample from the DE⇔EN alignment:

```
Die Punkte 16 und 17 widersprechen sich jetzt , obwohl es bei der Abstimmung anders aussah .
Points 16 and 17 now contradict one another whereas the voting showed otherwise .
0-9 1-0 2-1 3-2 4-3 5-5 6-5 7-4 9-8 10-9 11-8 12-9 13-10 14-12 15-6 15-7 15-11 15-12 16-13
```

Word alignment

Same sample represented graphically:



Phrase-table construction

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Idea: collect pairs of substrings that are compatible with word alignment

Incorporating linguistic constraints at this level has (so far) deteriorated outcomes

→ more and coarser is better

Phrase table are annotated with scores that will be used during decoding

Phrase-table construction

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```
widersprechen ||| contradict ||| 0.5 0.174039 0.227273 0.119306 2.718
widersprechen , ||| to contradict ||| 0.333333 0.046708 0.2 0.0134216 2.718
Kommissar Bolkestein ausdrücklich widersprechen ||| expressly contradict Commissioner Bolkestein ||| 1
    0.0417032 1 0.0147184 2.718
widersprechen ||| contravening ||| 0.333333 0.0320171 0.0113636 0.0032612 2.718
nicht widersprechen ||| not contradictory ||| 0.125 0.0291049 0.111111 0.017083 2.718
nicht widersprechen ||| does not contravene ||| 0.5 0.0288053 0.111111 0.000371669 2.718
widersprechen oder ||| contradictory or ||| 0.333333 0.0251621 1 0.0207105 2.718
widersprechen ||| run counter ||| 0.4 0.017062 0.0681818 0.00114863 2.718
widersprechen ||| disagree ||| 0.0106383 0.0167791 0.0113636 0.0714746 2.718
Wir widersprechen ||| We disagree ||| 0.0666667 0.00997179 1 0.0503599 2.718
teilweise widersprechen ||| partly contradictory ||| 1 0.00637625 1 0.00291665 2.718
widersprechen ||| inconsistent ||| 0.0169492 0.00598197 0.0113636 0.0032612 2.718
widersprechen uns ||| contradicts us ||| 1 0.00561145 1 0.00174914 2.718
nur dann widersprechen ||| only overrule ||| 1 0.00216227 1 0.000444817 2.718
auch der Konferenz der Präsidenten widersprechen ||| contradict both the Conference of Presidents ||| 1
    0.001813 1 5.17342e-05 2.718
Herr Bolkestein widersprechen ||| Mr Bolkestein disagrees with ||| 1 0.00175593 1 0.00041956 2.718
könnte dem widersprechen ||| could gainsay that ||| 1 0.00174458 1 4.90747e-06 2.718
widersprechen muß ||| have to contradict ||| 0.333333 0.00163608 0.5 0.000911924 2.718
widersprechen , wird ||| contradictory , is ||| 1 0.00161673 1 0.00362608 2.718
Änderungsanträge widersprechen dem ||| amendments contravene the ||| 1 0.00160169 1 0.0101469 2.718
17 widersprechen sich jetzt ||| 17 now contradict ||| 1 0.00143452 1 0.0283876 2.718
und 17 widersprechen sich jetzt ||| and 17 now contradict ||| 1 0.00120543 1 0.0256701 2.718
widersprechen zu müssen ||| to have to contradict ||| 1 0.00111525 0.333333 0.00167714 2.718
Herrn Brinkhorst nicht widersprechen ||| not disagree with Mr Brinkhorst ||| 1 0.00103174 1 0.00613701 2.718
einander widersprechen ||| contradict ||| 0.025 0.00101814 1 0.0609116 2.718
sich nicht widersprechen ||| are not contradictory ||| 0.25 0.000998935 1 0.00137116 2.718
widersprechen ||| any case contrary ||| 1 0.000890016 0.0113636 4.16211e-07 2.718
16 und 17 widersprechen sich jetzt ||| 16 and 17 now contradict ||| 1 0.000830368 1 0.0236414 2.718
widersprechen ||| conflict with ||| 0.0465116 0.000750812 0.0454545 0.00236106 2.718
James Elles widersprechen ||| what James Elles said ||| 1 0.00071772 1 0.00011574 2.718
nicht widersprechen ||| not conflict with ||| 0.4 0.00060168 0.222222 0.00164904 2.718
Rassismus , Fremdenfeindlichkeit und Antisemitismus widersprechen ||| racism , xenophobia and antisemitism
    are completely incompatible with ||| 1 0.00055052 1 1.87174e-08 2.718
```

Stochastic language model

Motivation:

Translations should satisfy 2 requirements:

- → equivalence with source sentence P(f|e)
- → well-formedness P(e)

So far, we have only dealt with equivalence

Well-formedness can be approximated via even simpler stochastic models, based on n-gram probabilities.

We know (since Chomsky '57…) that n-gram models cannot capture essential long-distance effects, but in practice, 3-grams seem to be good enough…

Stochastic language model

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Toolkits for counting word co-occurrences and estimating sentence probabilities have been developed for speech recognition.

Some are freely available:

SRILM (Stolcke)

CMU/Cambridge (Clarkson&Rosenfeld)

Philipp Koehn's Pharaoh decoder uses the SRILM format, Koehn even distributed an English LM trained on Europarl

Dilemma: More text of slightly different type may help or hurt, one needs to try it out

Decoding

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The decoder…

- takes source sentence *f*, phrase table to estimate *P(e|f)*, SLM to estimate *P(e)*
- searches for target sentence *e* that maximizes *P(e)*P(f|e)*
- uses beam-search approximation, as complete search for optimal solution is not feasible
- has some additional bells and whistles (factored models) that will improve the quality

Rule-based vs. statistical translation (1)

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(RBMÜ:translate pro ⟷ SMÜ:Koehn 2005, examples from EuroParl)

EN: ***I wish the negotiators continued success with their work in this important area.***

RBMÜ: ***Ich wünsche, dass die Unterhändler Erfolg mit ihrer Arbeit in diesem wichtigen Bereich fortsetzten.***

continued: Verb instead of adjective

SMÜ: ***Ich wünsche der Verhandlungsführer fortgesetzte Erfolg bei ihrer Arbeit in diesem wichtigen Bereich.***

three wrong inflectional endings

Rule-based vs. statistical translation (2)

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Englisch	RMBÜ: translate pro	SMÜ: Koehn 2005
We seem sometimes to have lost sight of this fact.	*Wir scheinen manchmal Anblick dieser Tatsache verloren zu haben.*	*Manchmal scheinen wir aus den Augen verloren haben, diese Tatsache.*
The leaders of Europe have not formulated a clear vision.	*Die Leiter von Europa haben keine klare Vision formuliert.*	*Die Führung Europas nicht formuliert eine klare Vision.*
I would like to close with a procedural motion.	*Ich möchte mit einer verfahrenstechnischen Bewegung schließen.*	*Ich möchte abschließend eine Frage zur Geschäftsordnung.*

Motivation for hybrid MT (1)

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In the early 90s, SMT and RBMT were seen in sharp contrast.

But advantages and disadvantages are complementary.

➔ Search for integrated methods is now seen as natural extension for both approaches

	RBMT	SMT
Syntax	++	--
Structural Semantics	+	--
Lexical Semantics	-	+
Lexical Adaptivity	--	+

Motivation for hybrid MT (2)

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- Statistical and rule-based approaches address different types of knowledge:
  - Rule-based approaches focus on linguistic knowledge
  - Statistical approaches provide a holistic, integrated model that also incorporates (some) implicit knowledge of the world
- All available types of knowledge are urgently required, as the task is too difficult to ignore important aspects
- Research on a deep integration of statistical and linguistic approaches is required but this will take some time
- In the meantime, we can try to tinker with existing MT engines

Exercises

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- Participate in on-line evaluation of the results of the WMT09 shared task via http://www.statmt.org/wmt09/judge
- Investigate two on-line MT engines by sending sentences through both of them and comparing the results

  Use http://www.google.com/language_tools as a typical SMT system and compare with http://babelfish.altavista.com/ (based on Systran)
- Try to find typical errors of both systems. Try variations of input sentences to find out whether the systems „understand“ what they translate
- Send us the most interesting/funny errors you encounter, so that we all can learn & have fun