Combining Rules and Statistics in the German-to-English MT System METIS-II

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IAI

Overview:

METIS-II

- Polemic 1: statistics of language & grammatical pattern
- Polemic 2: understanding & statistical MT
- Integration of Rules and Statistics in METIS-II
- Detailed Description of METIS-II:
  - Source language analysis
  - Dictionary matching and lookup
  - Target language adjustment
  - Translation ranking and selection
  - Target language token generation

Polemic 1:

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- „In fact, there is little reason to believe that there is any interesting relation between the statistics of language use and the grammatical pattern."

  Chomsky (1957)

- Data ==> statistics of language
- Rules ==> grammatical pattern

Chomskys argument

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These sentences have never occurred in English:

(1) Colorless green ideas sleep furiously (Grammatical)
(2) Furiously sleep ideas green colorless (Ungrammatical)

In any statistical model ... these sentences will be ruled out on identical grounds as equally remote from English. Yet (1), though nonsensical, is grammatical, while (2) is not.

Compositional Computation of Sentence Probabilities

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- Probabilities of *n*-grams:
  - decompose (representative) texts into *n*-grams (*n*=1,2,3,4 ...)

    (colorless) (green) (ideas) (sleep) (furiously)
    (colorless green) (green ideas) (ideas sleep) (sleep furiously)
    (colorless green ideas) (green ideas sleep) ...
  - compute relative frequency of *n*-gram occurrences in text

- Probability of a sentence is the product of its relative *n*-gram frequencies

Falsification of Chomsky's argument
Pereira (2000)

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- Sentence (1) ist 200.000 times more probable than sentence (2)
- Stochastic grammars can be learned with positive examples
- Hidden variables can be learned inductively

Polemic 2:

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- "A statistical translation model (TM) is a mathematical model in which the process of human language translation is statistically modeled."

  K. Yamada and K. Knight (2001)

- " ... the broad statistical MT program is aimed at a wider goal than the conventional rule-based program - it seeks to understand and explain human translation data, and automatically learn from it."

  M. Galley et al. (2005)

Fragmentation of derivation trees

M. Galley et al. (2004)

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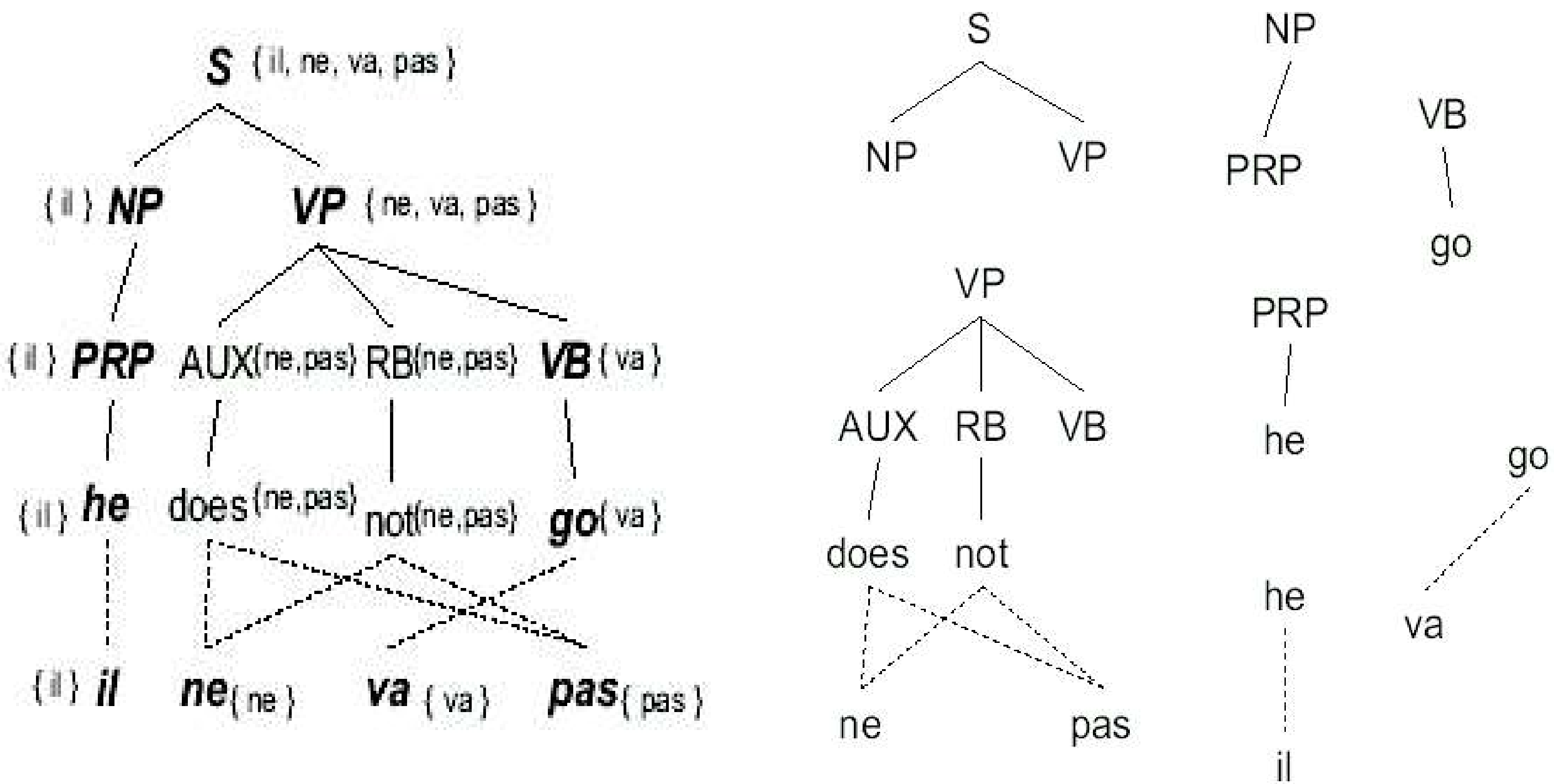

'Understanding' translation data
according to Galley et al. (2004)

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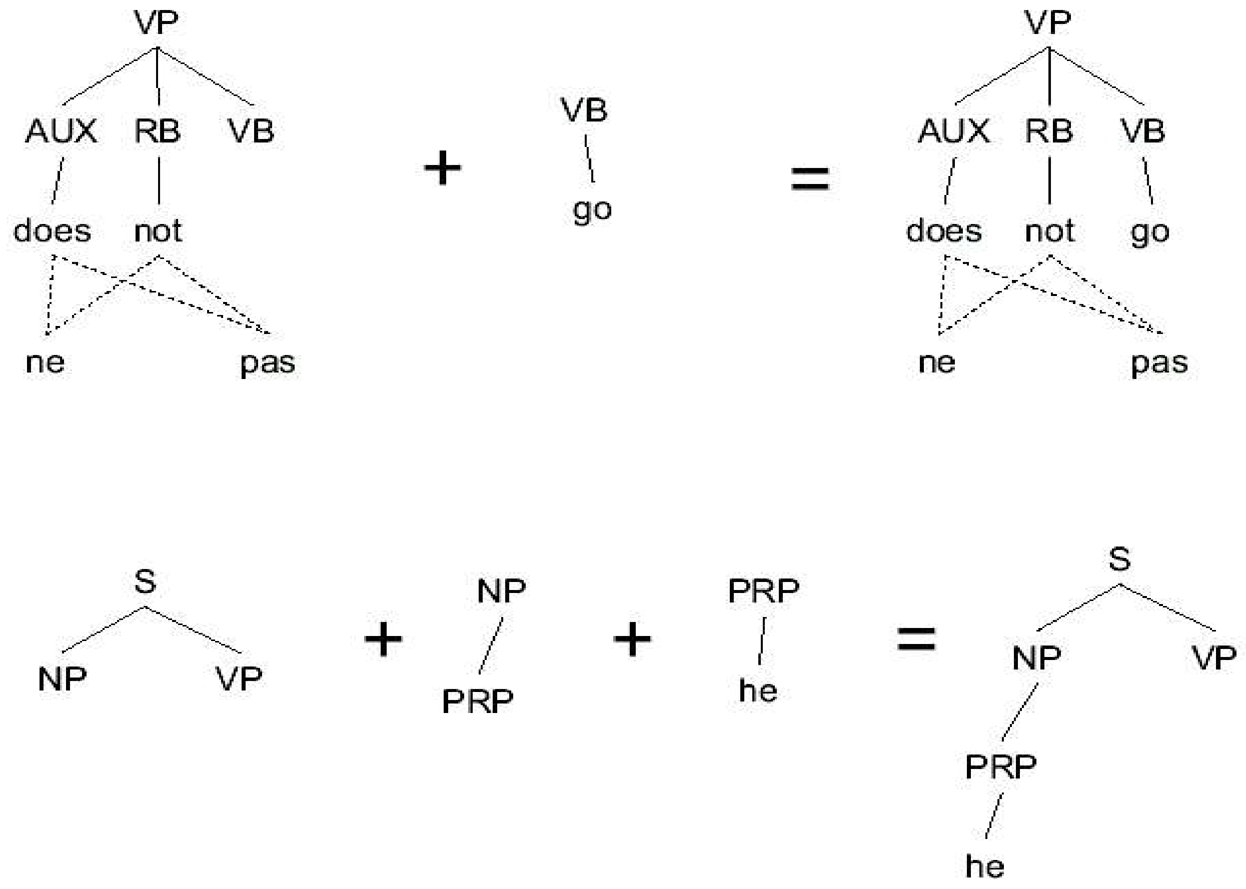

Problemes of (S)MT

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Combination of Fertility, Distortion and Ambiguity:

Zeitmangel erschwert das Problem.

Lack of time makes the problem more difficult.

Das ist der Sache nicht angemessen.

That is not appropriate for this matter.

Den Vorschlag lehnt die Kommission ab.

The Commission rejects the proposal.

Translation Divergencies

B. Dorr (1994)

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- Thematic divergence: I like Mary <--> Maria me gusta a mi
- Promotional divergence: John usually goes home <--> Juan suele ir a casa
- Demotional divergence: I like eating <--> Ich esse gerne
- Structural divergence: John entered the house <--> Juan entra en la casa
- Conflational divergence: I stabbed John <--> Yo le di punaladas a Juan
- Categorial divergence: I am hungry <--> Ich habe Hunger
- Lexical divergence: John broke into the room <--> Juan forzo la entrada al cuarto

'Understanding' human translators
according to Nida (1964)

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1) Reading over the entire document
2) Obtaining background information
3) Comparing existing translations of the text [if they exist]
4) Making a first draft of sufficiently comprehensible units
5) Revising the first draft after a short lapse of time
6) Reading aloud for style and rhythm
7) Studying the reactions of receptors by the reading of the text by another person [omissible]
8) Submitting a translation to the scrutiny of other competent translators [omissible]
9) Revising the text for publication

Goals of MT
Hutchins & Somers (1992)

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- Produce translations which are useful in certain situations:
  - No Shakespeare, Goethe, Tolstoy

- Main problems: linguistic modelling, not computational
  - differences in vocabular
  - elliptic and ungrammatical sentences
  - incomplete knowledge

- Linguistics: is being modelled by means of rules !!

Constitutive und regulative rules Searle (1995)

- Constitutive rules:
  - Tightly linked with or produce the behaviour which is described
  - e.g. playing soccer: emerges only through soccer rules
- Regulative rules:
  - Describe a behaviour which exists independent from the rules
  - e.g. Table manners: eating exists without table manners
- Traditional rule-based MT: constitutive rules
- Data-oriented MT: regulative rules

Rules and Data

- linguistic events are generated through a set of ‘basic configurations' whose distribution follows probabilities associated with a likelihood constraint
  (Harris, 1988)

- rule-based approaches are suited to generate hypotheses, while probabilistic approaches are concerned with evaluation and the selection of the best hypotheses
  (Flach and Kakas, 1997)

Rules & Data in METIS-II

METIS-II

- Generate partial translation hypotheses
- Store hypotheses in an AND/OR graph
- Rank best combination of partial translation hypotheses
- Resources needed:
  - Bilingual German to English Dictionary
  - Basic 'linguistic' tools: SL and TL tagger, chunker
  - Permutation/reordering rules
  - Monolingual TL Corpus: BNC (10^8 words, 10^6 sentences)
- Parallel Corpora (SMT/EBMT) **not** required
  - avoid data-acquisition bottleneck

Overview of the System

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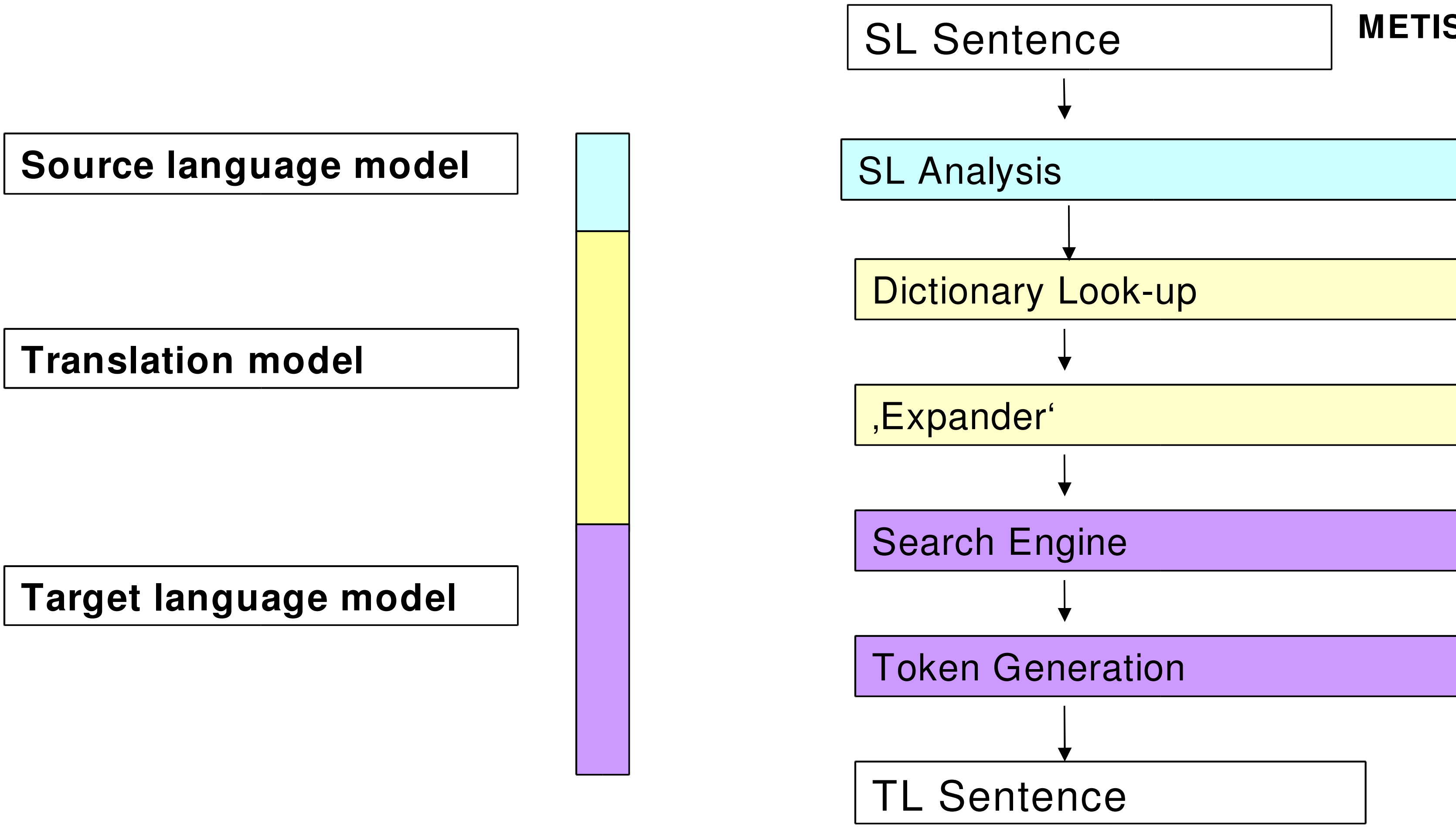

SL Model: German Analysis

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- MPRO:
  - lemmatization
  - morphological analyser
- KURD / FRED (shallow syntax analysis):
  - grammar is basis for:
    - Duden Korrektor (German grammar checker)
    - CLAT (Controlled language technology)
    - text indexation
    - pattern-based formalism to detect and mark phrases, clauses, topological fields

German Grammar

- Recognised Constituents (flat representation):
  - NPs, PPs, Verbal groups
  - clauses
  - topological fields
  - does not detect/mark relation between constituents
- Method:
  - originates in requirements for grammar correction
  - iterative process:
    - mark 'secure' patterns
    - disambiguate the pattern

Input/Output of German Analyser

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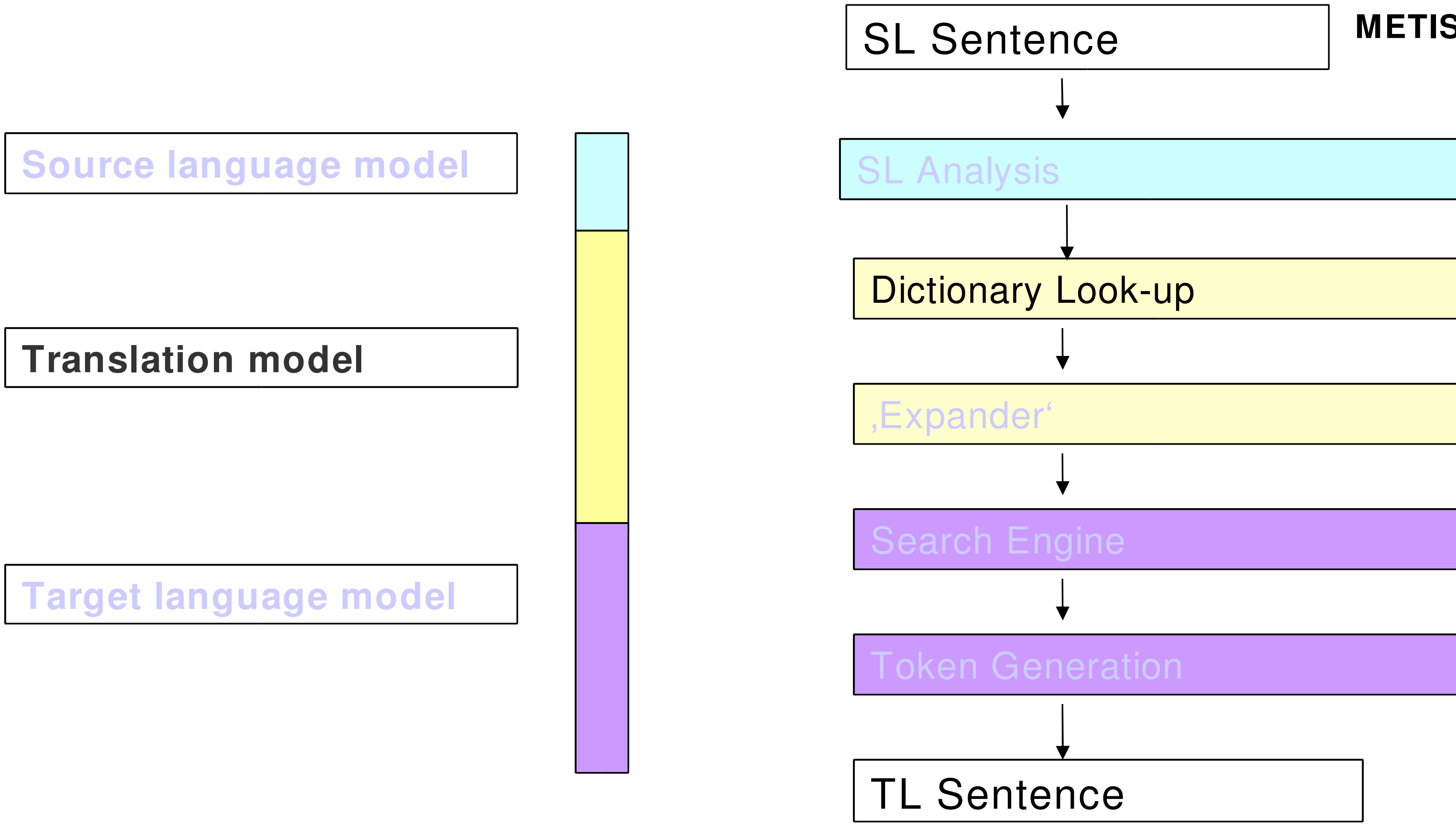
- Das Haus wurde von Hans gekauft
  The house was from Hans bought

Lemma	wnr	PoS	phrase	clause/field
{lu=das,	wnr=1,	c=w,sc=art,	phr=np;subjF,	cl=hs;vf} ,
{lu=haus,	wnr=2,	c=noun,	phr=np;subj,	cl=hs;vf},
{lu=werden,	wnr=3,	c=verb,vt=fiv,	phr=vg fiv,	cl=hs;lk},
{lu=von,	wnr=4,	c=w,sc=p,	phr=np;nosubjF,	cl=hs;mf},
{lu=Hans,	wnr=5,	c=noun,	phr=np;nosubj,	cl=hs;mf},
{lu=kaufen,	wnr=6,	c=verb,vt=ptc2,	phr=vg ptc,	cl=hs;rk}

.

Translation Model: Dictionary Look-up

METIS-II



German-to-English Dictionary

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- > 600.000 Entries
- Independent tag sets in SL and TL
- Single- and multi word units, phrase translations
- Represented as flat trees:
  - leaves contain lexical information
  - mother node contains meta information

Goals of Dictionary Look-up

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- Discontinuous Entries:
  - separable prefix — lehnt ... ab <--> reject
  - reflexive verbes — sich ... beeilen <--> hurry up
  - support verbes — in Gefahr bringen <--> endanger
  - idioms — vom Mund ablesen <--> lip-read
- Lexical Overgeneration:
  - lex.-sem. ambiguities — Bank <--> bank;bench
  - main/aux.verb — werden <--> will;be;become
  - negation — nicht <--> do not;not
  - magniers/intensifers — stark <--> strong;good;heavy ...
  - prepositions — auf <--> on;in;up;onto ...

Types of Discontinuous Verbal Realisations

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- Dictionary entry:
  - **Anweisung ausführen** <--> *execute statement*

- Realisation in a subordinate clause (en bloc):
  - dass er sofort die **Anweisungen ausführt** …
    *that he immediately the **statements executes** …*
- Realisation in a main clause (left Klammer & Mittelfeld) :
  - Er **führt** die **Anweisung** sofort **aus** …
    *He **executes** the **statement** immediately **VPREF …***
- Realisation in a modal main clause (Mittelfeld & right Klammer):
  - Er will die **Anweisung** sofort **ausführen.**
    *He will the **statement** immediately **execute.***

Dictionary Maintainance and Look-up

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- Structure and Maintenance of the dictionary:
  - lemmatisation and morphological analysis of entries
  - consistency of entries
  - generation of variants
  - indexation of morphemes
- Dictionary look-up:
  - retrieve entries and filter 'best' matches
    - lexical similarity
    - contextual consolidation

Structure of Dictionary Entry

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{de=einsperren,mde={c=verb}, en=lock_<so.>_away,men={c=verb}}.

{de=ausführen, mde={c=verb}, en=execute,men={c=verb}}.

- Structure of dictionary entries:
  - represented as flat trees
  - contain lexical information and meta information
  - leaves follow canonical representation
- Problem:
  - inflexion, derivation, variation
    ==> lemmatization, analyse morphological structure

Canonical Forms of Dictionary Entries (German side)

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- c=verb: last word of entry is infinite verb
  e.g. “tanzen gehen” *(dancing go)*
- c=noun: last word of entry is noun/sing/nominative
  e.g. “dritte Welt“ *(third world)*
- c=adj: last word of entry is adjective:
  e.g. “hell grün“ *(light green)*
- c=p: last word of entry is preposition
  e.g. “in Bezug auf“ *(with respect to)*

Morphological Analysis of German Entries

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{de=ausführen, mde={c=verb},en=execute,men={c=verb}}.

“ausführen” has morphological structure: “ls=aus_$führen“

and several morphological analyses:

{lu=ausführen,c=noun,ehead={nb=sg,case=acc;dat;nom,g=n}};

{lu=ausführen,c=verb,vtyp=fiv,nb=plu,per=1;3,tns=pres};

{lu=ausführen,c=verb,vtyp=inf}.

Disambiguated entry (according to canonical form):

{c=verb}@{lu=ausführen,ls=aus_$führen,c=verb}.

Lexical Variation

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- Abfertigung des Gepäcks --> Gepäckabfertigung
  check-in of the luggage --> luggage check-in

- Anzahl der Mitarbeiter --> Mitarbeiteranzahl
  number of worker --> *worker number*

  {c=noun}@{c=noun,ls=anzahl},{c=art,ls=art},{c=noun,ls=mit_$arbeiten}.
  -->
  {c=noun}@{c=noun,ls=mit_$arbeiten#anzahl}.

- ausführen --> führen … aus

  {c=verb,type=ns}@{c=verb,ls=aus_$führen}.
  -->
  {c=verb,type=hs}@{c=verb,ls=führen},{c=vpref,ls=aus}.

Dictionary-lookup: Retrieval and filtering

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- Retrieve entries which share morphological structure
- Filter best candidates:
  - consolidate word order
    - dictionary entry and match in same word-order
  - compute lexical delta
    - find most 'similar' word form
  - contextual consolidation
    - check 'internal' and external context of match

Some Surface Realisations of „aus_$führen“

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Word	Lemma	PoS	Derivation	Feature Info
Ausführbarkeit	ausführbarkeit	noun	~bar~heit	nb=sg
Ausführer	ausführer	noun	~er	nb=sg
Ausführung	ausführung	noun	~ung	nb=sg
ausführen	ausführen	verb	---	per=1;3, tns=pres
ausführbar	ausführbar	adv	~bar	deg=base
ausführbarer	ausführbar	adv;adj	~bar	deg=comp
ausgeführten	ausgeführt	adj	ptc2	deg=base
ausgeführteren	ausgeführt	adj	ptc2	deg=comp
ausgeführt	ausführen	adj;verb	ptc2	
Ausführender	ausführend	adj	ptc1	deg=base
ausführend	ausführend	adv	ptc1	

Lexical delta for Morph. Structure: aus_$führen

METIS-II

- Dictionary entries:
  - ausführen <--> export (verb)
    {lu=ausführen,c=verb,nb=plu,per=1;3,tns=pres}
  - ausgeführt <--> executed (participle)
    {lu=ausgeführt,c=adj,ptc=2,deg=base}
- Inflected German forms in sentence:
  - ausführst (inflected verb)
    {lu=ausführen,c=verb,nb=sg,per=2,tns=pres}
    --> match: ausführen <--> export
  - ausführende (present participle)
    {lu=ausführend,c=adj,ptc=1,deg=base}
    --> match: ausgeführt <--> executed

Contextual Consolidation of 'verbal' Entries (1)

METIS-II

- **Anweisung** ausführen **<-->** execute **statement**

  main clause:

  - If ((verbal part of entry is left Klammer) and
    (**nominal part** of entry is in Mittelfeld)) then
    consolidate match
    end

  - Er führt die **Anweisung** sofort **aus**
    *He executes the **statement** immediately VPREF ...*

Contextual Consolidation of 'verbal' Entries (2)

METIS-II

- ***Anweisung*** *ausführen* <--> *execute* ***statement***

  modal main clause:

  – If ((verbal part of entry is right Klammer) and
  (**nominal part** of entry is in Mittelfeld)) then
  consolidate match
  end

  – Er will die **Anweisung** sofort **ausführen**.
  *He will the **statement** immediately execute.*

Contextual Consolidation of nominal Entries

METIS-II

- *Abbau der Ozonschicht <--> depletion of ozone*

  within a noun phrase (np):

  – *Only additional adjectives may modify the entry:*

    Abbau der arktischen Ozonschicht
    depletion of arctic ozone

Output of Dictionary Look-up

METIS-II

```
{lu=das,wnrr=1,c=w,sc=art, ... }
    @{c=art,n=146471}@{lu=the,c=AT0}. .
,{lu=Haus,wnrr=2,c=noun, ...}
    @{c=noun,n=268244}@{lu=company,c=NN1}.
     , {c=noun,n=268246}@{lu=home,c=NN1}.
     , {c=noun,n=268247}@{lu=house,c=NN1}.
     , {c=noun,n=268249}@{lu=site,c=NN1}. .
,{lu=werden,wnrr=3,c=verb,vtyp=fiv, ...}
    @{c=verb,n=604071}@{lu=be,c=VBD} .
     , {c=verb,n=604076}@{lu=will,c=VM0} . .
...
```

Discontinuous Match

METIS-II

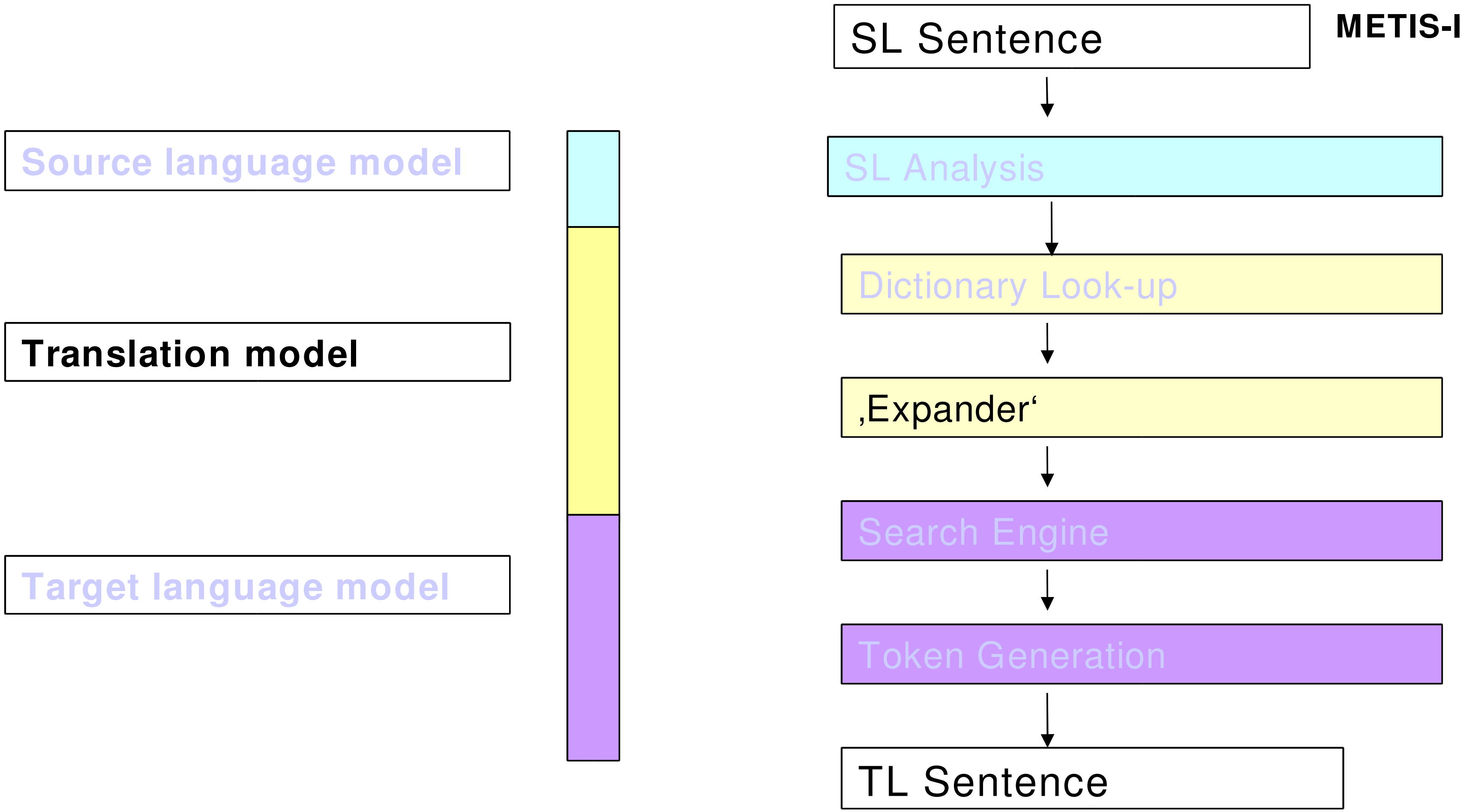
Das **geht**, solange es Frauen gibt, nie **vor die Hunde**.

vor die Hunde gehen <---> go to the dogs | be buggered

,{lu=gehen|...|vor|der|hund,wnrr=2;10;11;12,c=verb,markcl=hs}
@{c=verb,n=13}@{lu=go,c=VVB;VVD;VVI;VVN;VVZ}
, {lu=to,c=TO0;PRP}
, {lu=the,c=AT0}
, {lu=dog,c=NN2;NN1} .
, {c=verb,n=14}@{lu=be,c=VBB;VBD;VBI;VBN;VBZ}
, {lu=bugger,c=VVN;VVD} . .

...

Translation Model: Expander



Expander

METIS-II

- Rule-based device to adjust word order
- insert/delete/permute/modify translation hypotheses in AND/OR graph:
- insert article — Hans ist Lehrer --> Hans is **a** teacher
- verbal group — Das Haus **wurde** von Hans **gekauft** --> The house **was bought** by Hans.
- add hypotheses — Die Milch trinkt die Katze.

--> (The cat drinks the milk. | The milk drinks the cat.)
Peters Auto --> (Peters' car | the car of Peter)

Example of an Expander Rule

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Hans **hat** das Haus **gekauft**. --> Hans **hat gekauft** das Haus.
*Hans **has** the house **bought**. --> Hans **has bought** the house.*

V *N P --> V P *N

```
ReorderFinVerb_hs =
       Ve{mark=hs}e{mark=vg_fiv},
      *Ne{mark=hs}a{mark~=vg_ptc;vg_inf},
       Pe{mark=hs}e{mark=vg_ptc}
   :     p(move=V->VPN).
```

Negation

METIS-II

- Negation

  Hans kommt **nicht.** **-->** Hans **does not** come.

  Hans comes ***not.***

- Dictionary: nicht --> not | do not
- Expander Rule:

```
Negation_hs2 =
   Ae{mark=hs,mark=vg_fiv},
  *Be{mark=hs,lu~=nicht},
   Ne{mark=hs,lu=nicht}
 :   p(move=A->ANB).
```

AND/OR Graph for
Hans kommt nicht

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- {lu=Hans,c=noun, wnr=1}
  @{c=noun}@{lu=hans,c=NP0}. .
  ,{lu=nicht,c=adv,wnr=3}
  @{c=verb}@{lu=do,c=VDZ},{lu=not,c=XX0}.
  , {c=adv}@{lu=not,c=XX0}..
  ,{lu=kommen,c=verb,wnr=2}
  @{c=verb}@{lu=come,c=VVB}.
  , {c=verb}@{lu=come,c=VVB},{lu=along,c=AVP}.
  , {c=verb}@{lu=come,c=VVB},{lu=off,c=AVP}.
  , {c=verb}@{lu=come,c=VVB},{lu=up,c=AVP}..
  .

TL Model: Search Engine

METIS-II

Source language model

Translation model

Target language model

SL Sentence

SL Analysis

Dictionary Look-up

‚Expander'

Search Engine

Token Generation

TL Sentence

Search Engine: Scoring n-best Translations

METIS-II

- Beam-search algorithm (breadth first)
- Traverses AND/OR graph to score *n*-best Translations
- Heuristic Function :

$$\hat{e} = \operatorname{argmax} \sum_{m}^{M} w_m h_m(\cdot)$$

- h_i Feature Funktion
- w_i weigting
- Log-linear Combination of feature functions

Heuristic Function

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- trained on BNC (10^8 words, 10^6 sentences)
- $LM(lem)$ Lemma Language Model (3-gram, 4-gram)
- $LM(tag)$ Tag Language Model (5-gram to 7-gram)
- $w(lem, tag)$ Lemma/tag co-ocurrence modell

$$\hat{e} = \text{argmax} \ \{w_1 * LM(tag) + w_2 * LM(lem) + w_3 * w(lem, tag)\}$$

lemma	tag	#	w(lem; tag)
tape-recorder	AJ0	3	1.003
tape-recorder	NN1	87	22.080
tape-recorder	NN2	13	3.512
tape-recorder	<*>	0	0.250

Search Engine Output

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lemma,	tag,	#dictionary,	expander rule:
<s id=3-0 lp="-9.227912">			
the	AT0	146471	
company	NN1	268244	
is	VBD	604071	PermFinVerb_hs
buy	VVN	307263	PermFinVerb_hs
by	PRP	587268	PermFinVerb_hs
hans	NP0	265524	PermFinVerb_hs
.	PUN	367491	
</s>			

TL Model: Token Generation

METIS-II

Source language model

Translation model

Target language model

SL Sentence

↓

SL Analysis

↓

Dictionary Look-up

↓

‚Expander'

↓

Search Engine

↓

Token Generation

↓

TL Sentence

Reversible Lemmatiser and Token Generator

METIS-II

- Token Generator (for English):
  Lemma + Tag --> Token
  trained on reversible Lemmatiser:
  Token + Tag --> Lemma

- Reversible lemmatizer:
  - based on BNC Lemmatiser (10^8 words)
    - inflection rules are regular-expressions
  - augmented with additional tags (for reversibility)
    - 10 types of inflection rules for ADJ, NN2, VVG ...
    - ca 200 rules and ca. 1500 lexical exceptions

Reversible Lemmatiser

METIS-II

- Token + Tag <---> Lemma+Tag+O+IR

  Setting VVG <---> set VVG_f_4

- Lemma: normalised lemma
- Tag: BNC /CLAWS5 tag set
- O: orthographic properties of token
- IR: inflexion rule

- 100% reversibel: no loss of information
  --> but O and IR are not known when generating

Lemmatisation and Token Generation Rules

METIS-II

Lemmatisation: knowing token + tag:

- apply first matching rule

#	Tag	token suffix	lem. Suffix		Example token --> lemma
1	VVG	ffing	-->	ff	stuffing --> stuff
2	VVG	^(.{1,3}ll)ing	-->	$1	selling --> sell
3	VVG	ssing	-->	ss	kissing --> kiss

....

Token generation: knowing lemma + tag:

- guess lemmatisation rule
- apply inverse lemmatisation rule

Token Generation

METIS-II

- Generation while guessing inflexion rule:

  abort VVG ---> aborting VVG

- Method: guess inflexion rule from suffix of lemma.
  - Collect 27.000 suffixes from lemmatised BNC

Tag + suffix	# inflection rules	
VVG	28	unknown lemma suffix
VVG + t	5	
VVG + rt	2	
VVG + ort	2	
VVG + bort	1	deterministic token generation

- The longer the known lemma suffix the better the guess

Evaluation of Reversible Lemmatiser

METIS-II

- Lemmatiser:
  - 96,18% correct lemmas
  - incorrect mostly for closed class words (he, the, a, ...)

- Token Generator:
  - 99.5% correct reproduction of original token tested on 244,500 different wordforms
  - incorrect for writing variants:
    burned / burnt VVN --> burn VVN
    BNC british English: burned more likely

Conclusion

METIS-II

METIS-II German-to-English Basic Idea:

- First: use 'secure' symbolic resources:
  - generate partial translation hypotheses
  - store hypotheses in an AND/OR graph
- Then: use statistical resources:
  - rank best combination of partial translation hypotheses
  - integrate various global resources with feature functions

Main Components

METIS-II

- Lexicon:
  – basic translation equivalences
  – match phrases and discontinuous entries
  – overgeneration
- Expander:
  – structural adjustment
  – permute, insert, delete translation units
- Search engine:
  – rank translation hypotheses
  – use target language knowledge

Distribution of Information

METIS-II

- Search Engine vs. Lexicon

  stark <--> heavy,strong,large,big …

  Raucher <--> smoker

  or

  starker Raucher < ✇ heavy smoker

- Expander vs. Lexicon

  guerra <--> war

  civil <--> civil

  española <--> spanish

  or

  guerra civil española <--> spanish civil war

Evaluation

METIS-II

- Evaluation depends on:
  - Dictionary and performance of matching algorithm
  - Expander rules
  - Number and weights of feature functions

- Impact of modifications on BLEU score:
  - Changing weights of feature functions: BLEU scores from 1.6 to 1.8
  - Modifying expander rules: BLEU scores from 1.6 to 2.2

- Test set of 200 German sentences:

NIST	BLEU	lemma LM	tag LM
5.4801	0.1861	6M-n3	100K-n4
5.3004	0.2030	5M-n3	5M-n7

Future prospectives

METIS-II

- Enhancement of components:
  – Dictionary lookup (maintainance & matching)
  – Generation of discontinuous English fragments e.g. *give <sth> away,* *make <sth> easy*
  – *Testing more feature functions (lexical weight)*

- Dynamic Adaption to user needs:
  – explore automatised weighing strategies for:
    - Dictionary entries
    - Expander rules

THANK YOU