Edinburgh, April 17, 2007

Hybrid machine translation: Combining rule-based and statistical MT systems

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Joint work with Kamran Azam, Yu Chen, Christian Federmann, Greg Gulrajani, Eva Hasler, Michael Jellinghaus, Robert Neßelrath, Armin Schmidt, Silke Theison

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Structure of presentation

- Complementary advantages of rule-based and statistical MT
- Using a SMT decoder to merge outputs of multiple MT engines
- Feeding SMT lexicons into rule-based MT engines
- Thoughts on deeper integration

EuroMatrix: situation in early 2005

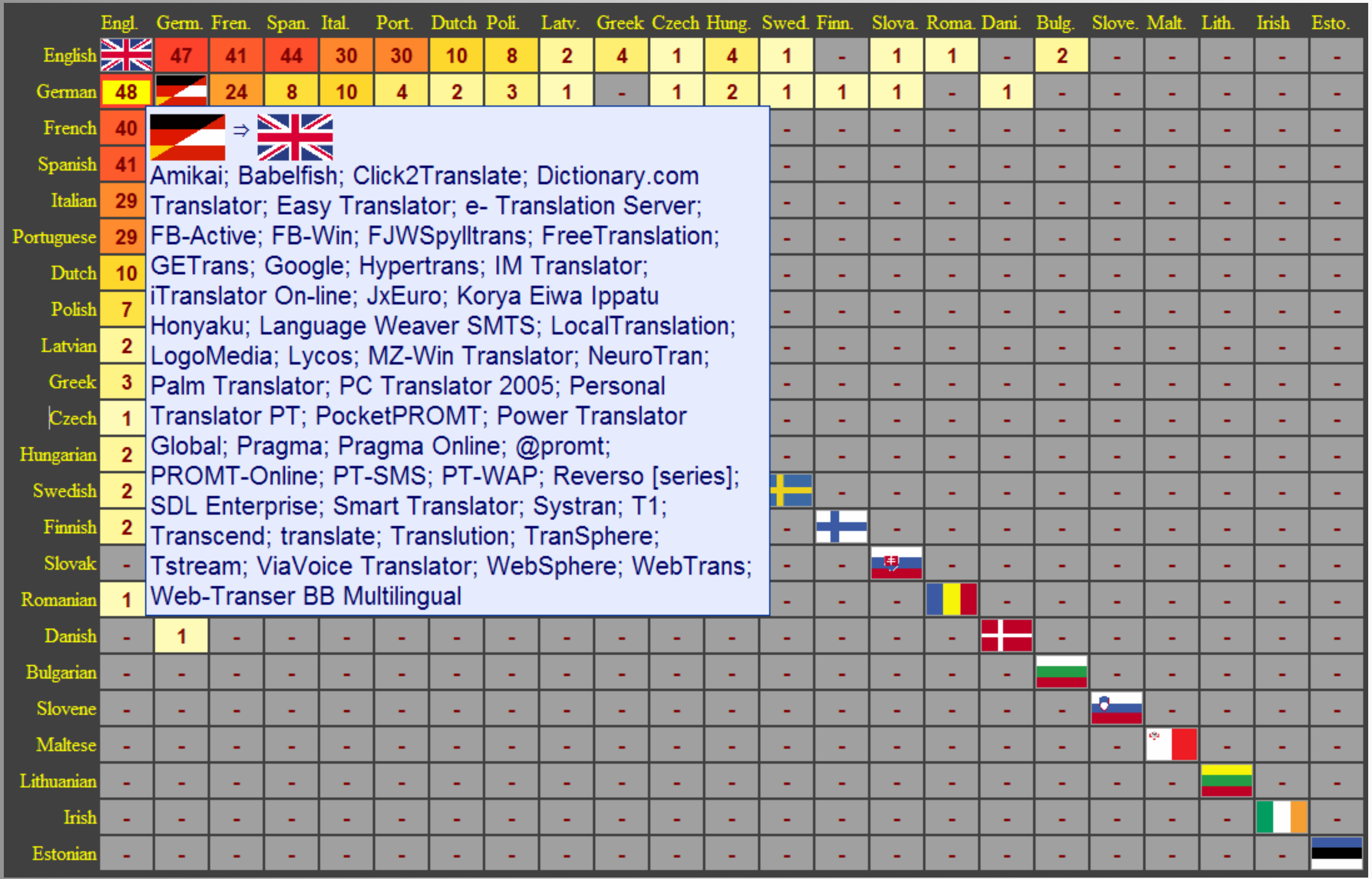
MT systems per language pair (data taken from J.Hutchins' Compendium of Translation Software, 12th Edition)

	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	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇪🇪

Most language pairs remain uncovered

EuroMatrix: situation in early 2005

MT systems per language pair (data taken from J.Hutchins' Compendium of Translation Software, 12th Edition)



	Engl.	Germ.	Fren.	Span.	Ital.	Port.	Dutch	Poli.	Latv.	Greek	Czech	Hung.	Swed.	Finn.	Slova.	Roma.	Dani.	Bulg.	Slove.	Malt.	Lith.	Irish	Esto.
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Italian	29												-	-	-	-	-	-	-	-	-	-	-
Portuguese	29												-	-	-	-	-	-	-	-	-	-	-
Dutch	10												-	-	-	-	-	-	-	-	-	-	-
Polish	7												-	-	-	-	-	-	-	-	-	-	-
Latvian	2												-	-	-	-	-	-	-	-	-	-	-
Greek	3												-	-	-	-	-	-	-	-	-	-	-
Czech	1												-	-	-	-	-	-	-	-	-	-	-
Hungarian	2												-	-	-	-	-	-	-	-	-	-	-
Swedish	2												🇸🇪	-	-	-	-	-	-	-	-	-	-
Finnish	2												-	🇫🇮	-	-	-	-	-	-	-	-	-
Slovak	-												-	-	🇸🇰	-	-	-	-	-	-	-	-
Romanian	1												-	-	-	🇷🇴	-	-	-	-	-	-	-
Danish	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇩🇰	-	-	-	-	-	-
Bulgarian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇧🇬	-	-	-	-	-
Slovene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇸🇮	-	-	-	-
Maltese	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇲🇹	-	-	-
Lithuanian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇱🇹	-	-
Irish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇮🇪	-
Estonian	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	🇪🇪

🇩🇪 ⇒ 🇬🇧

Amikai; Babelfish; Click2Translate; Dictionary.com Translator; Easy Translator; e- Translation Server; FB-Active; FB-Win; FJWSpylltrans; FreeTranslation; GETrans; Google; Hypertrans; IM Translator; iTranslator On-line; JxEuro; Korya Eiwa Ippatu Honyaku; Language Weaver SMTS; LocalTranslation; LogoMedia; Lycos; MZ-Win Translator; NeuroTran; Palm Translator; PC Translator 2005; Personal Translator PT; PocketPROMT; Power Translator Global; Pragma; Pragma Online; @promt; PROMT-Online; PT-SMS; PT-WAP; Reverso [series]; SDL Enterprise; Smart Translator; Systran; T1; Transcend; translate; Translution; TranSphere; Tstream; ViaVoice Translator; WebSphere; WebTrans; Web-Transer BB Multilingual

Most language pairs remain uncovered, but some are densely populated

Rule-based vs. statistical MT

Some examples (translate pro ←→ SMT Koehn 2005)

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

DE: Ich wünsche den Unterhändlern auch weiterhin viel Erfolg auf diesem wichtigen Gebiet.

RBMT: Ich wünsche, dass die Unterhändler Erfolg mit ihrer Arbeit in diesem wichtigen Bereich fortsetztzen.

continued: verb instead of adjective

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

three inflectional endings wrong

Rule-based vs. statistical MT

More examples

EN: We seem sometimes to have lost sight of this fact .

RBMT: Wir scheinen manchmal Anblick dieser Tatsache verloren zu haben.

idiomatic expression not known

SMT: Manchmal scheinen wir aus den Augen verloren haben, diese Tatsache.

wrong attachment of „diese Tatsache“

Rule-based vs. statistical MT

More examples

EN: I would like to close with a procedural motion .

DE: Mit einem Antrag zur Geschäftsordnung komme ich zum Schluss .

RBMT: Ich möchte mit einer verfahrenstechnischen Bewegung schließen.

wrong translation of procedural motion

SMT: Ich möchte abschließend eine Frage zur Geschäftsordnung.

verb is missing

Rule-based vs. statistical MT

More examples

EN: The leaders of Europe have not formulated a clear vision .

DE: Die Führung Europas hat keine klaren Visionen formuliert .

RBMT: Die Leiter von Europa haben keine klare Vision formuliert.

„Leiter von Europa“ sounds very odd

SMT: Die Führung Europas nicht formuliert eine klare Vision .

syntactically illformed

Motivation of Hybrid MT Approaches

In the early 90s, statistical and rule-based approaches were seen in strict contrast. But PROs and CONs are complementary:

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

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

Two Different Types of Hybridisation

- **Deep Integration**: Design a new setup that combines the advantages of two paradigms, e.g. by integrating some good features of Approach B into Approach A, such as
  - Making a rule-based system adaptive by adding a module for rule learning
  - Making a SMT system syntax-aware by adding syntactical constraints/rules

- **Shallow Integration**: Integrate two or more systems, following different approaches, into a larger system

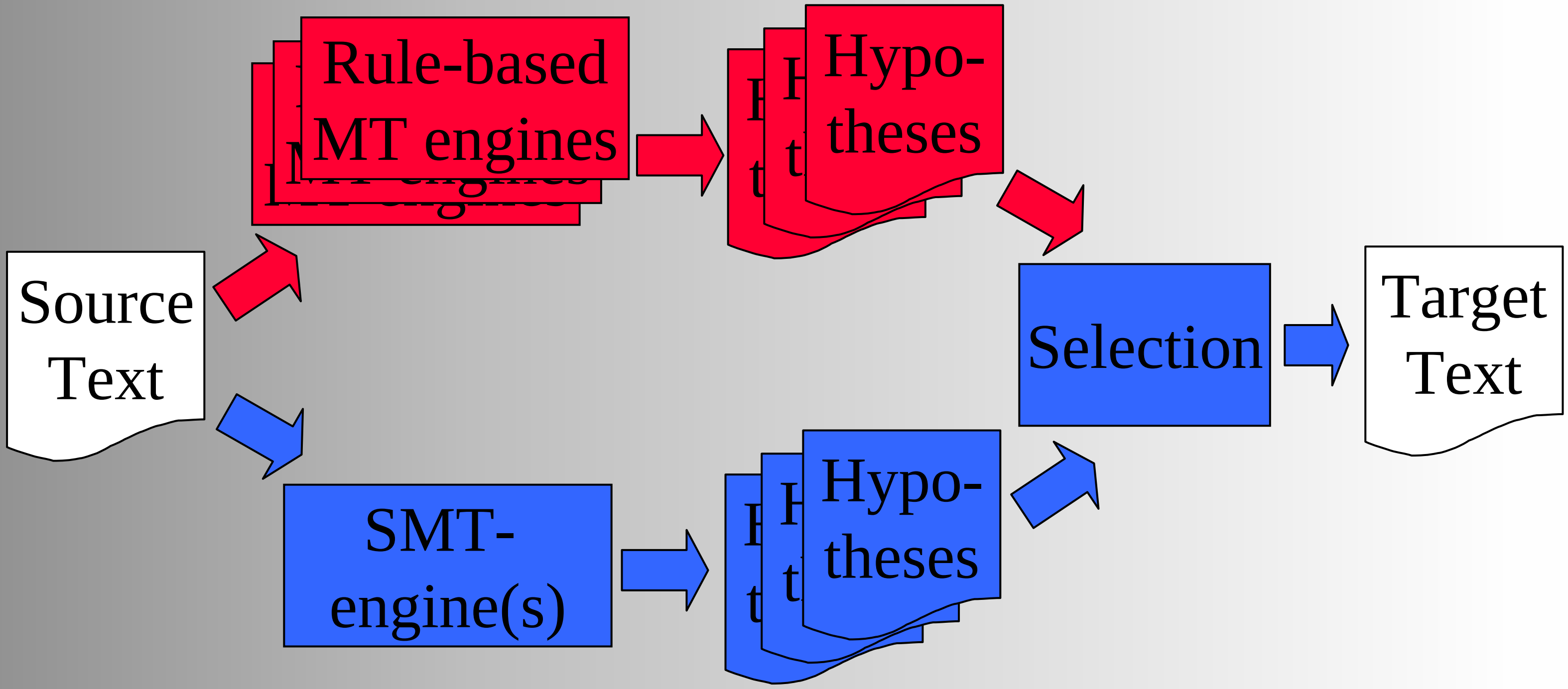
Deep integration is superior in the long run, but also much more challenging. WP2 (Richer models for statistical translation, U Edinburgh) and WP3 (Tree-Based Transfer Models, Charles U Prague) are steps towards deep integration

WP6 (Saarland U) will pursue the modest goal of shallow integration into a MEMT architecture, hopefully still giving insights into the relevant issues related to deep integration

Hybrid MT Architecture I

Multi-engine MT via black-box integration

(as done in VerbMobil and earlier)



Towards better hybrid MT Architectures

- Disadvantage of simple selection:
For longer sentences, no result will be perfect; we want to combine better parts of multiple outcomes.

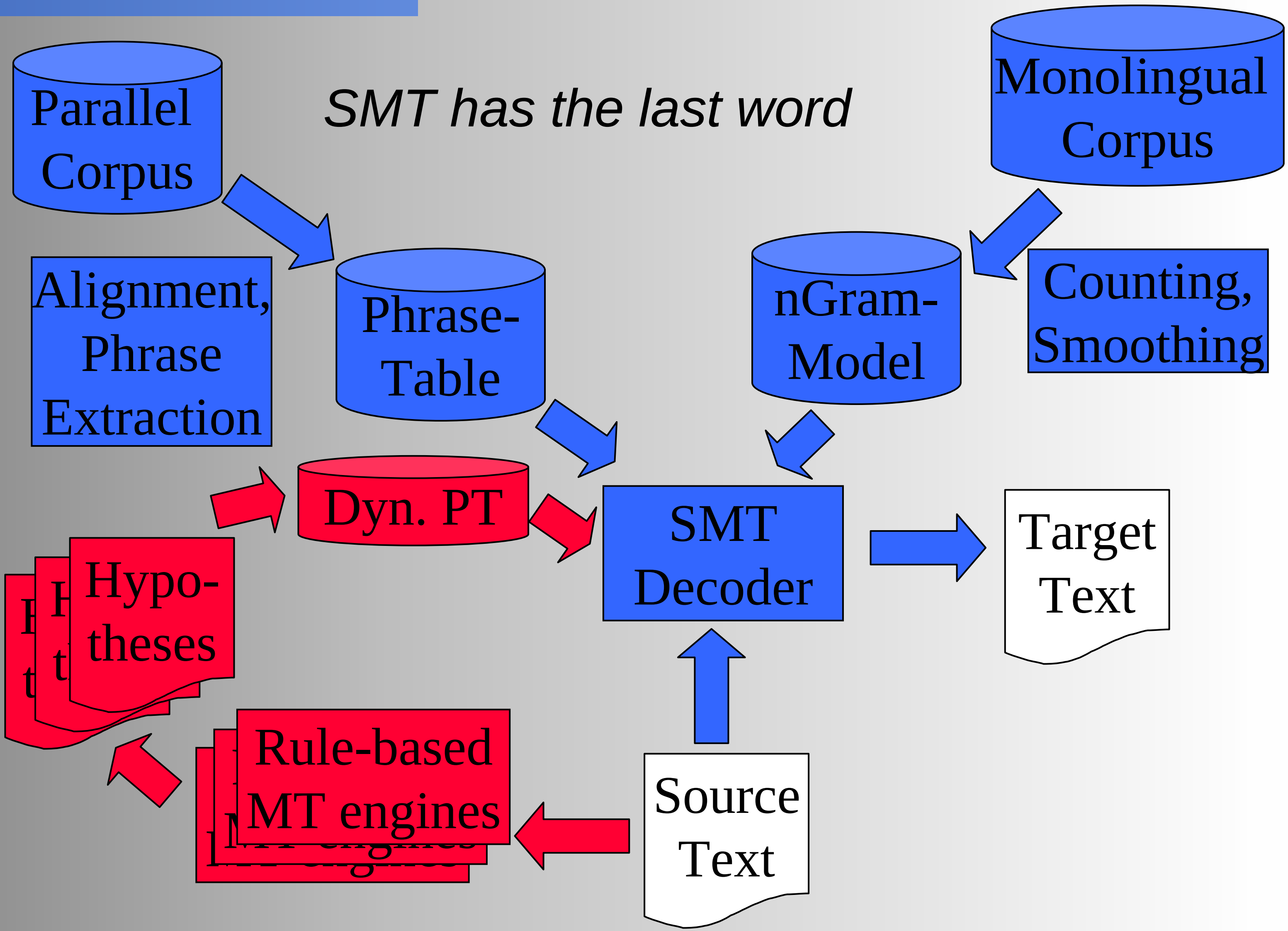
- But recombination can be fairly complex, as corresponding parts of alternative candidates are not obvious

- We need
  - alignment of MT results (needs to cope with MT errors)
  - search for best combination

- We can use existing SW modules for both purposes in first steps, error analysis may then suggest improvements

Hybrid MT Architecture II

SMT has the last word



Hybrid MT Architecture II

Key features:

- Source text is sent through many MT engines, including web-based and locally installed ones
- Alignment between MT output and source text is done via (modified) GIZA++
- Alignment quality is improved by using models trained on larger datasets
- Alignment waiting times are reduced by client-server setup

Hybrid MT Architecture II

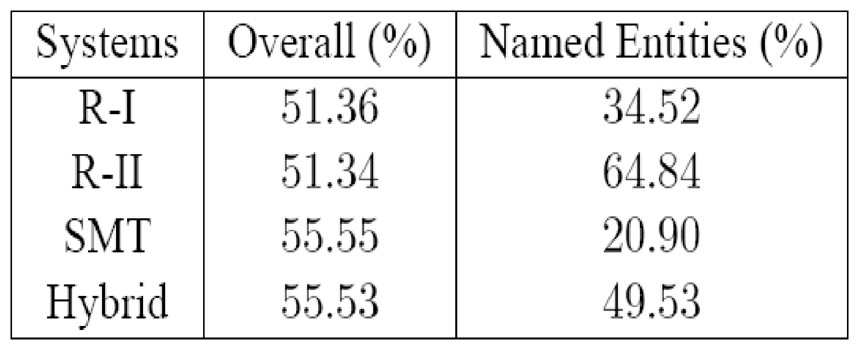
Current status:

- Using 6..7 engines: Systran, SDL, ProMT, OpenLogos, translate pro, L&H PTP, Lucy
- Each of the MT engines has its own peculiarities that require attention (encoding, tokenisation, …)
- Combined phrasetables slow down decoding, makes MERT more difficult
- Delays due to technical problems while preparing WMT07 submission
- Implementation essentially done, but current configuration does not yet beat baseline

Hybrid MT Architecture II

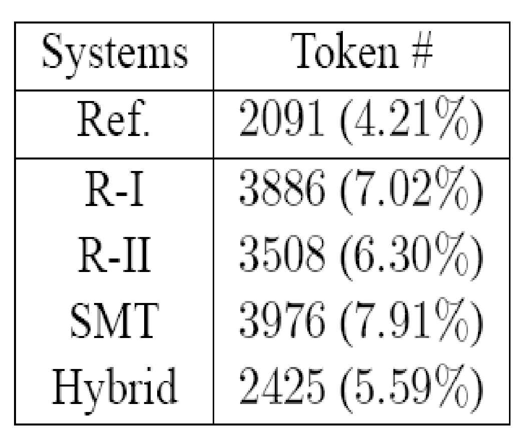
Indicative results

PoS-aware BLEU-1 score



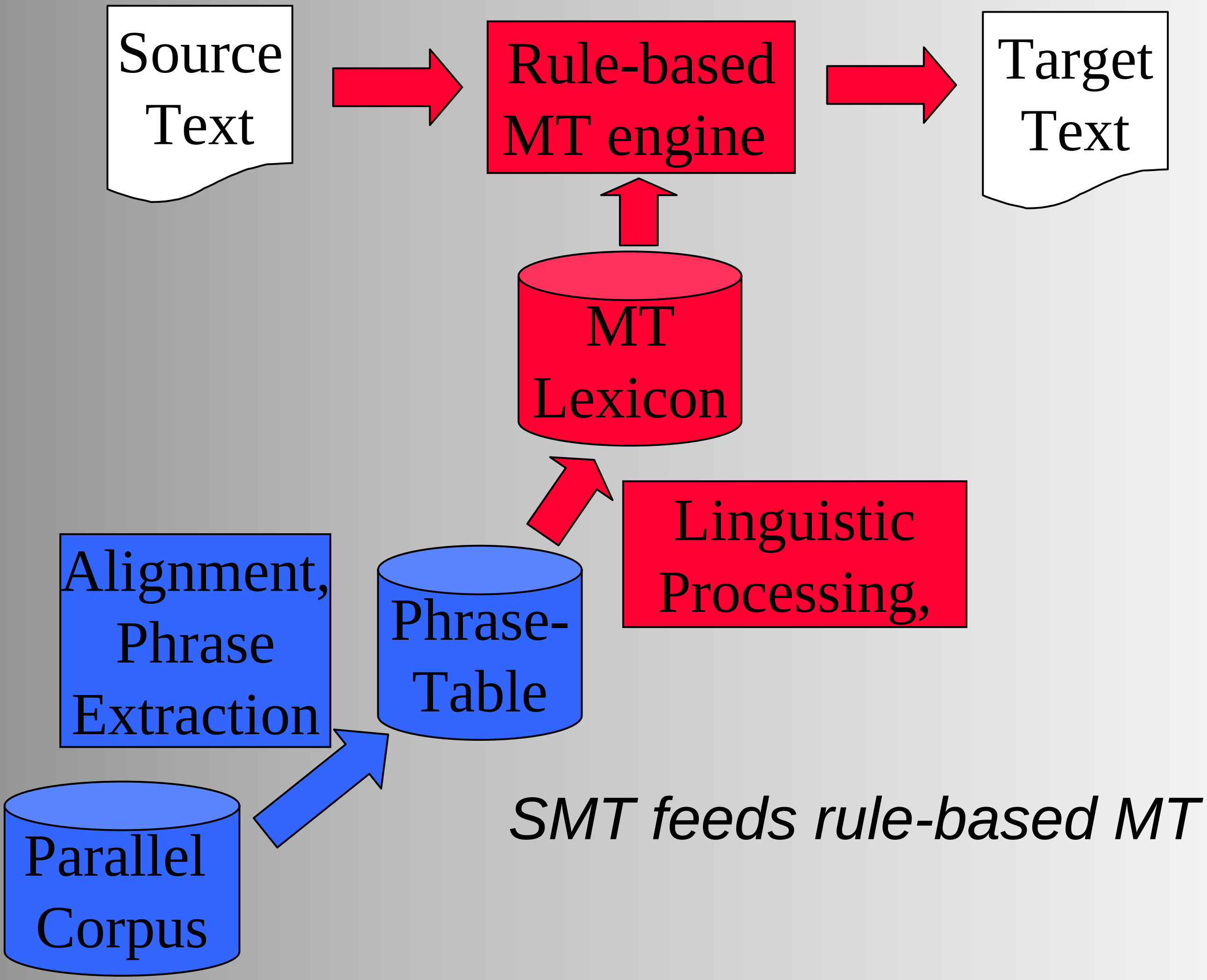
Systems	Overall (%)	Named Entities (%)
R-I	51.36	34.52
R-II	51.34	64.84
SMT	55.55	20.90
Hybrid	55.53	49.53

Ratio of untranslated tokens



Systems	Token #
Ref.	2091 (4.21%)
R-I	3886 (7.02%)
R-II	3508 (6.30%)
SMT	3976 (7.91%)
Hybrid	2425 (5.59%)

Hybrid MT Architecture III



SMT feeds rule-based MT

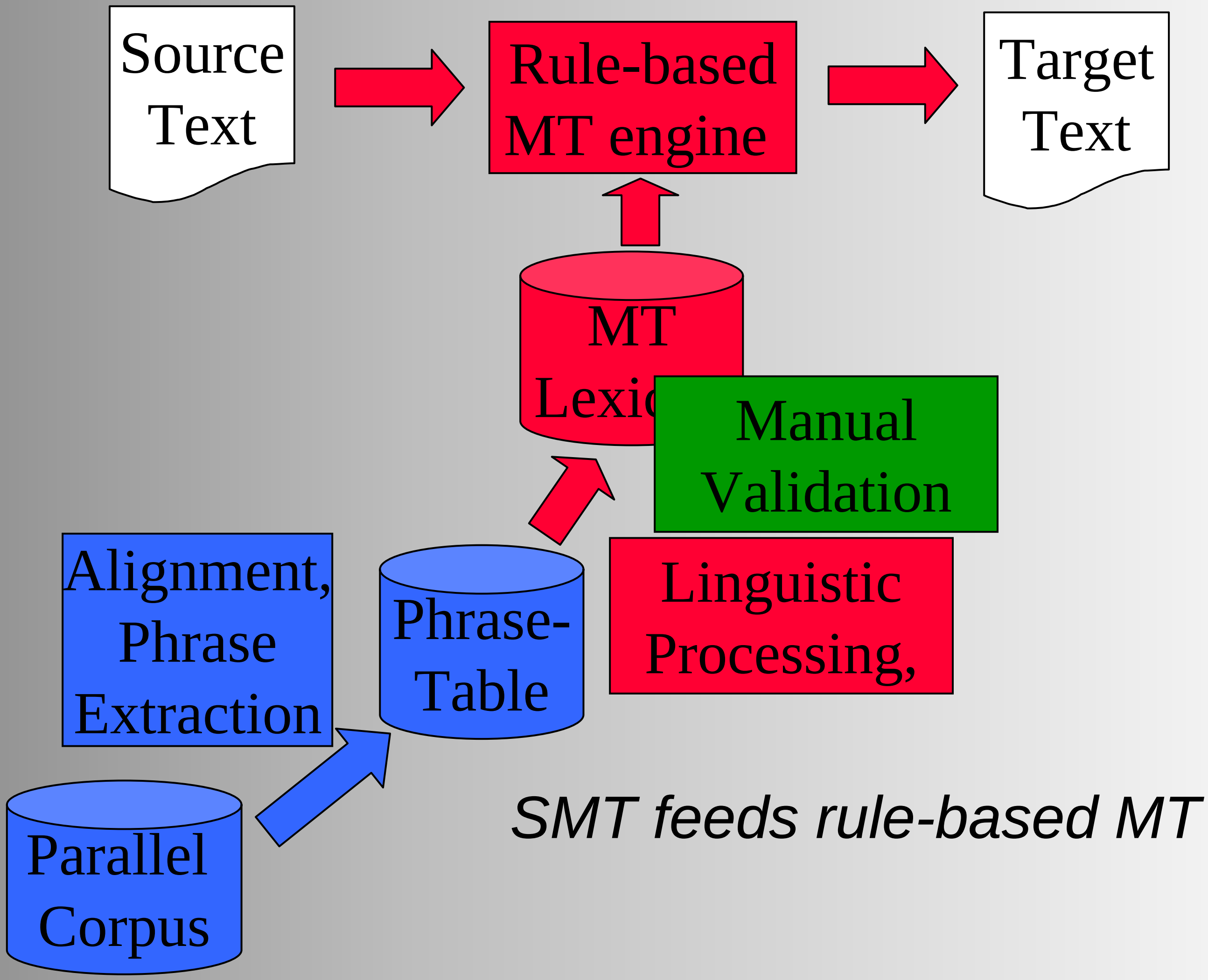
Hybrid MT Architecture III

Key issues:

- RBMT has no mechanism to disprefer implausible results → lexicon needs to be correct
- MT lexicon needs information not contained in parallel texts (lemma, gender, inflection, …)
- Current tools make fully automatic high-quality lexicon extraction rather difficult

Architecture requires manual effort → make it as simple and generic as possible, e.g. by using encoding standard for lexical data like OLIF

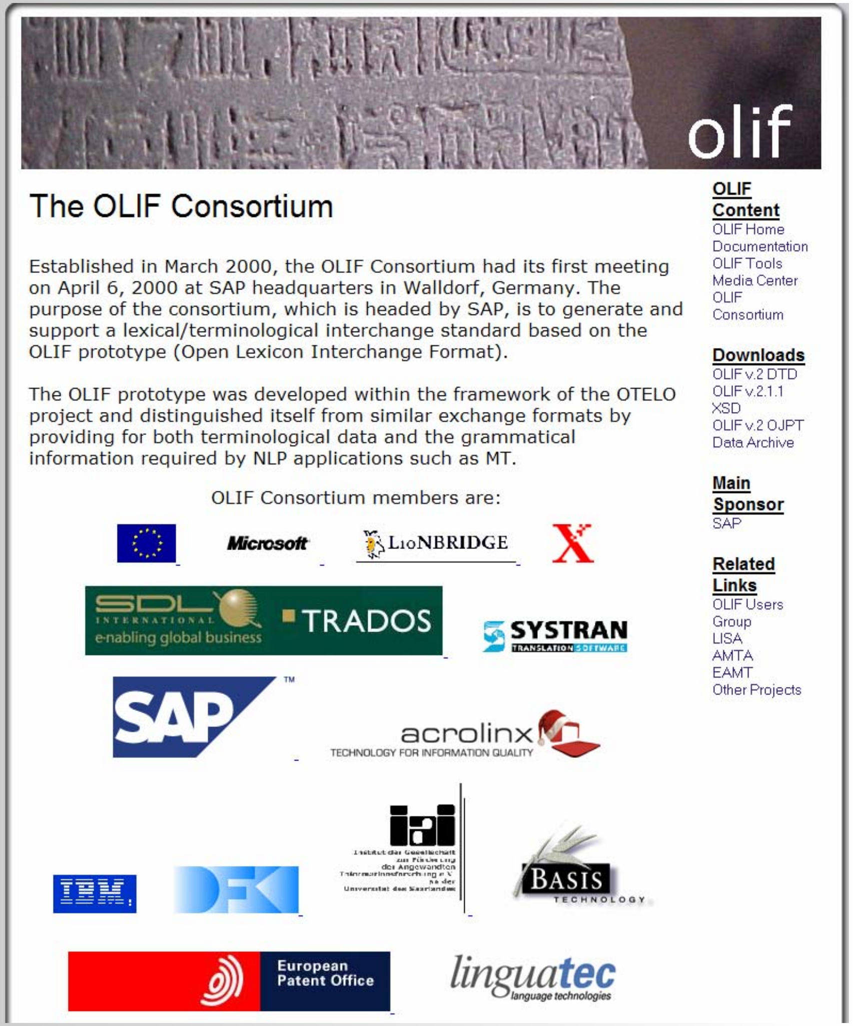
Hybrid MT Architecture III



SMT feeds rule-based MT

Hybrid MT Architecture III

- OLIF standard has been developed to facilitate exchange of multilingual lexical data.
- Contains encodings for part-of-speech and head, morphosyntactic features, and inflectional behaviour
- Current version 2.1 has focus on English, French, German, Portuguese, and Spanish
- See www.olif.net for details



The OLIF Consortium

Established in March 2000, the OLIF Consortium had its first meeting on April 6, 2000 at SAP headquarters in Walldorf, Germany. The purpose of the consortium, which is headed by SAP, is to generate and support a lexical/terminological interchange standard based on the OLIF prototype (Open Lexicon Interchange Format).

The OLIF prototype was developed within the framework of the OTELO project and distinguished itself from similar exchange formats by providing for both terminological data and the grammatical information required by NLP applications such as MT.

OLIF Consortium members are:

Terminology Extraction from Patents

Ongoing cooperation between DFKI and European Patent Office (EPO)

- Goal: Extract parallel terminologies for EN, DE, ES, FR from translated patent documents
- Motivation for EPO: Build up infrastructure for machine translation of patents, acquire relevant technical vocabulary
- Motivation for DFKI: Develop industrial applications of techniques from MT research, strengthen NLP tools

Terminology Extraction: Motivation

- **Technical documentation** makes up a **large share** of language industry's raw material, vocabulary is **commercially interesting**
- **Manual construction** of broad-coverage or unrestricted multilingual terminologies would be **prohibitively expensive**
- Translated documents exist in large volumes, as well as techniques for sentence/word/phrase alignment, these can be used to partially automate the task
- **IPC** (hierarchical system of about 70K classes) may help to relate extracted terms with **ontologies**
- Test-bed for **scalability** of tools and resources
  - How well do our tools cover technical texts?
  - Can we acquire new lexical information from data?
- First **step towards MT** for technical documents

Terminology Extraction from Patents

History and current status:

- Techniques were prototypically implemented in a feasibility study for WIPO (‘03, via acrolinx GmbH)
- Call for Tender by EPO in August ’05, bids and results on test data due in September
- From 14 bids, DFKI delivered best results for DE↔EN, ES↔EN and among the best for FR↔EN
- Test phase December ’05..July ’06: Term extraction from samples, feasibility study on validation
- Production phase (since August ’06): Work on 50 million sentence pairs (~ 2E9 running words), manual validation of specific subsets
- Continuation in 2007 may broaden scope to additional languages: PT, IT, RO, NL, SW

Terminology Extraction from Patents

The International Patent Classification (IPC)

- based on the Strasbourg Agreement (1971)
  used by >100 national authorities
- indispensable for finding prior art
- hierarchical structure, consisting of
  - eight sections (A..H)
  - 120 classes (A01 … H05)
  - 628 subclasses (A01B…H05K)
  - ≈69,000 subdivisions (e.g. A01B 1/02 or H05K 10/00)
- regularly updated (currently in force: 8th edition)
- officially released in EN and FR by WIPO, but translations to many languages are available from national authorities

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A: human necessities
B: performing operations; transporting
C: chemistry; metallurgy
D: textiles; paper
E: fixed constructions
F: mechanical engineering; lighting; heating;
G: physics [weapons; blasting
H: electricity

Terminology Extraction from Patents

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eating;
asting

A 01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING

A 01B SOIL WORKING IN AGRICULTURE OR FORESTRY; PARTS, DETAILS, OR ACCESSORIES OF AGRICULTURAL MACHINES OR IMPLEMENTS, IN GENERAL

A 01 B 1/00 Hand tools

A 01 B 1/02 spades, shovels

Terminology Extraction from Patents

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A 01 AGRICULTURE; FORESTRY; ANIMAL
H
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ing;
ing

H 05 ELECTRIC TECHNIQUES NOT OTHERWISE PROVIDED FOR

H 05 K PRINTED CIRCUITS; CASINGS OR CONSTRUCTIONAL DETAILS OF ELECTRIC APPARATUS; MANUFACTURE OF ASSEMBLAGES OF ELECTRICAL COMPONENTS

H 05 K 10/00 Arrangements for improving the operating reliability of electronic equipment, e.g. by providing a similar stand-by unit

Terminology Extraction from Patents

Research questions related to the IPC

- Automatic Classification

  Can IPC classes be identified automatically?

  (So far classification and search done by ~ 6500 experts)

- Ontology construction

  How does the IPC relate to the terminologies used in the various domains? Can we (semi-) automatically construct/extend these terminologies given the documents?

- Word sense disambiguation

  Can a given IPC class help to identify meaning/translation of a given term?

Terminology Extraction from Patents

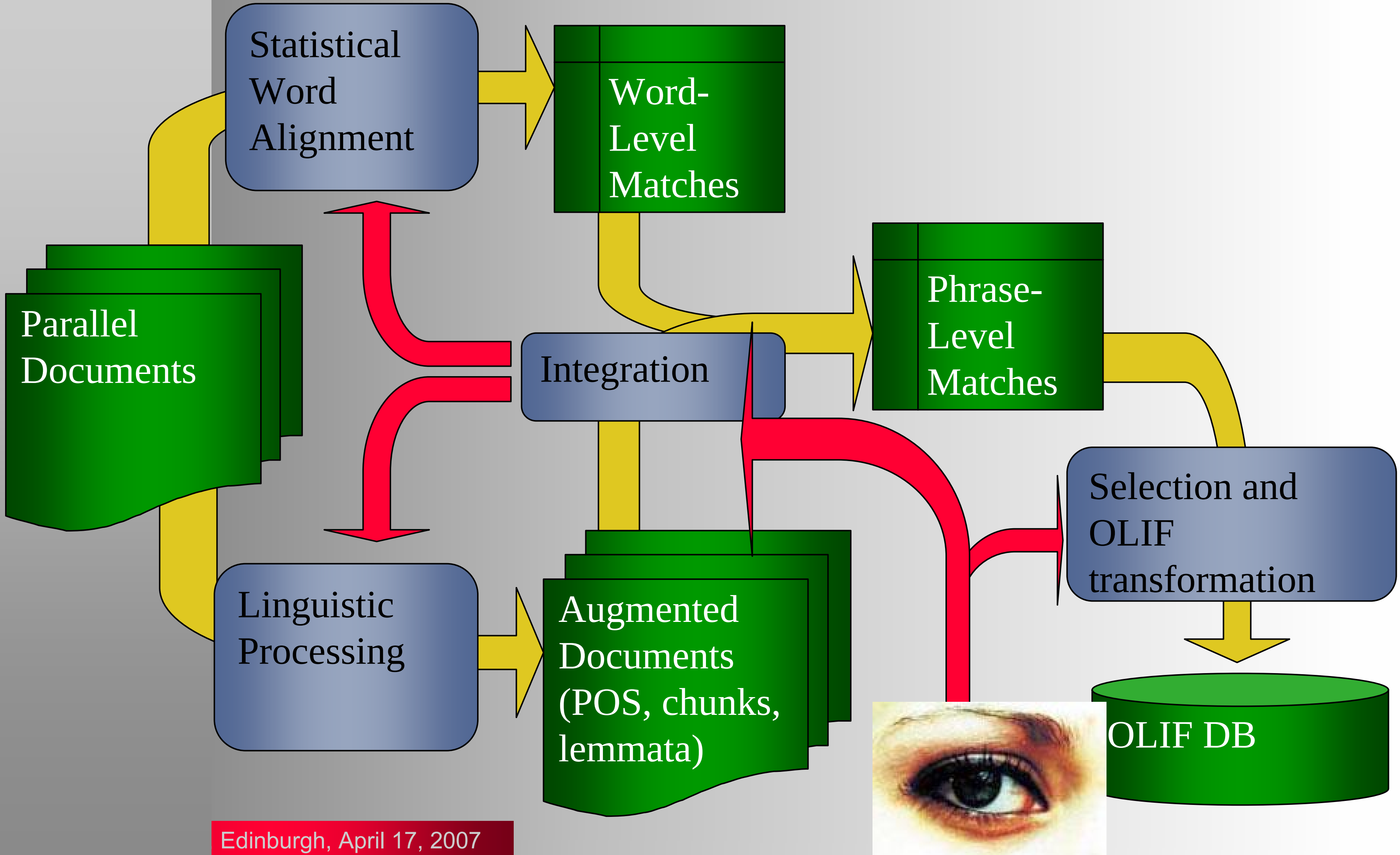
Technical setup:

- Use linguistic tools for corpus annotation
  - POS-tagging, phrase recognition, lemmatization
- Use statistical tools for alignment
  - GIZA++ from Franz Och
  - Own algorithms based on word similarities
- Integrate module outcomes, transform into OLIF entries

Improvement in 2nd phase:

- Feed-back of modifications to basic modules
- Infrastructure for manual validation
- Manual inspection and error analysis is used to improve algorithms as long as the project is ongoing

Terminology Extraction: Architecture


Statistical Word Alignment
Word-Level Matches
Parallel Documents
Integration
Phrase-Level Matches
Selection and OLIF transformation
Linguistic Processing
Augmented Documents (POS, chunks, lemmata)
OLIF DB

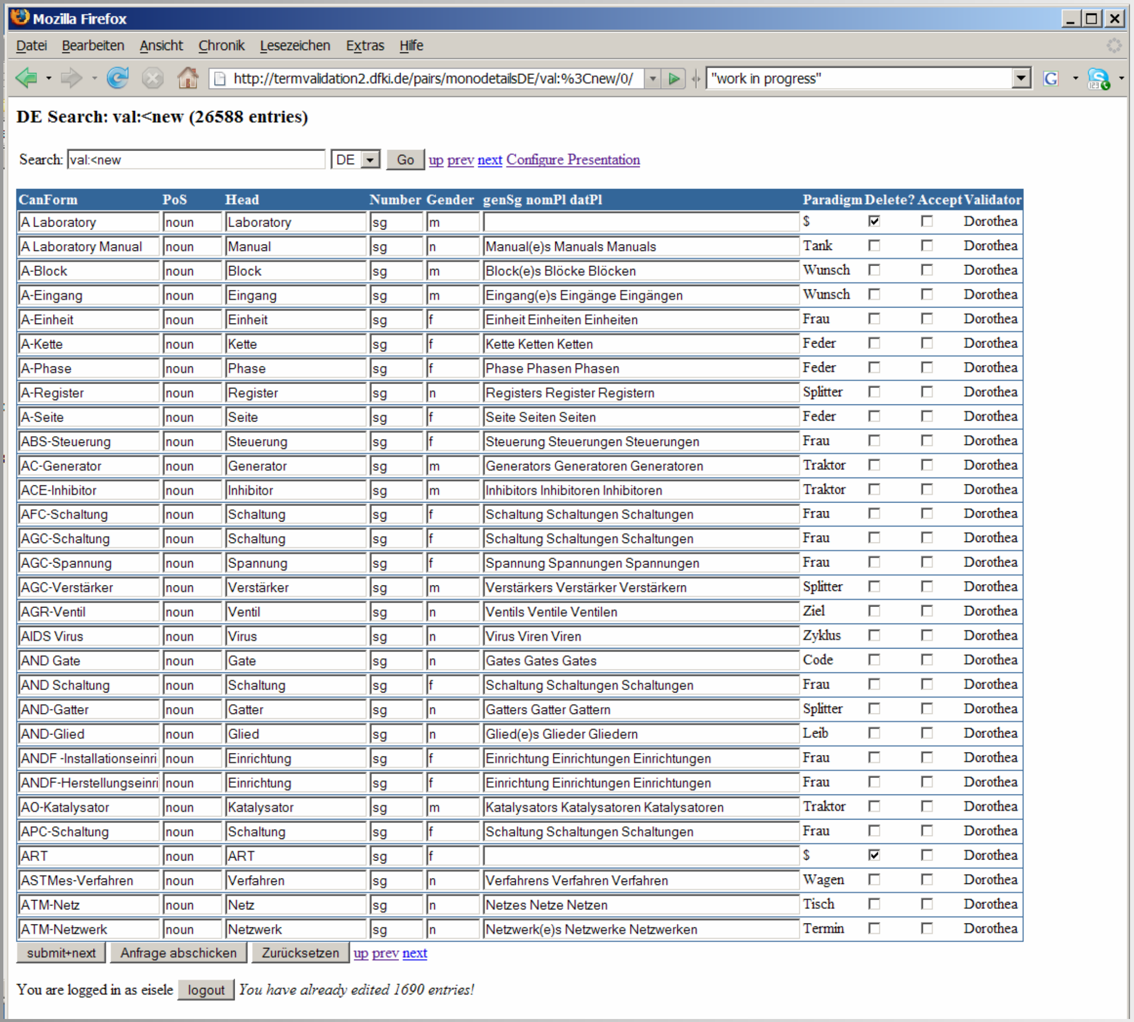
Examples for Patent Terminology

Postbestimmungsortinformationsspeichereinrichtung
= mail destination information memory means
Informationsdurchforstungssteuerungseinrichtung
= information browsing control means
Hypervideonachrichtversendungsverarbeitungseinrichtung
= hypervideo message posting processing means
Gasphasenverunreinigungsabsorptionsflüssigkeit
= gas phase contaminant absorbing liquid

Manual Validation of Terminology

- Original Plan:
  - Validation by (30..40) domain experts in national patent offices, but:
  - Linguistic validation not suitable for patent examiners
- New setup: Validation work is shared between
  - DFKI for linguistic validation and
  - patent offices for domain knowledge
- Validation workflow handled in a Web-based infrastructure for terminology maintenance
  - Prototype available since Fall ’06
  - Successfully used for first deliveries

Manual Validation of Terminology



DE Search: val:<new (26588 entries)

Search: val:<new DE Go up prev next Configure Presentation

CanForm	PoS	Head	Number	Gender	genSg nomPl datPl	Paradigm	Delete?	Accept	Validator
A Laboratory	noun	Laboratory	sg	m		$	☑	☐	Dorothea
A Laboratory Manual	noun	Manual	sg	n	Manual(e)s Manuals Manuals	Tank	☐	☐	Dorothea
A-Block	noun	Block	sg	m	Block(e)s Blöcke Blöcken	Wunsch	☐	☐	Dorothea
A-Eingang	noun	Eingang	sg	m	Eingang(e)s Eingänge Eingängen	Wunsch	☐	☐	Dorothea
A-Einheit	noun	Einheit	sg	f	Einheit Einheiten Einheiten	Frau	☐	☐	Dorothea
A-Kette	noun	Kette	sg	f	Kette Ketten Ketten	Feder	☐	☐	Dorothea
A-Phase	noun	Phase	sg	f	Phase Phasen Phasen	Feder	☐	☐	Dorothea
A-Register	noun	Register	sg	n	Registers Register Registern	Splitter	☐	☐	Dorothea
A-Seite	noun	Seite	sg	f	Seite Seiten Seiten	Feder	☐	☐	Dorothea
ABS-Steuerung	noun	Steuerung	sg	f	Steuerung Steuerungen Steuerungen	Frau	☐	☐	Dorothea
AC-Generator	noun	Generator	sg	m	Generators Generatoren Generatoren	Traktor	☐	☐	Dorothea
ACE-Inhibitor	noun	Inhibitor	sg	m	Inhibitors Inhibitoren Inhibitoren	Traktor	☐	☐	Dorothea
AFC-Schaltung	noun	Schaltung	sg	f	Schaltung Schaltungen Schaltungen	Frau	☐	☐	Dorothea
AGC-Schaltung	noun	Schaltung	sg	f	Schaltung Schaltungen Schaltungen	Frau	☐	☐	Dorothea
AGC-Spannung	noun	Spannung	sg	f	Spannung Spannungen Spannungen	Frau	☐	☐	Dorothea
AGC-Verstärker	noun	Verstärker	sg	m	Verstärkers Verstärker Verstärkern	Splitter	☐	☐	Dorothea
AGR-Ventil	noun	Ventil	sg	n	Ventils Ventile Ventilen	Ziel	☐	☐	Dorothea
AIDS Virus	noun	Virus	sg	n	Virus Viren Viren	Zyklus	☐	☐	Dorothea
AND Gate	noun	Gate	sg	n	Gates Gates Gates	Code	☐	☐	Dorothea
AND Schaltung	noun	Schaltung	sg	f	Schaltung Schaltungen Schaltungen	Frau	☐	☐	Dorothea
AND-Gatter	noun	Gatter	sg	n	Gatters Gatter Gattern	Splitter	☐	☐	Dorothea
AND-Glied	noun	Glied	sg	n	Glied(e)s Glieder Gliedern	Leib	☐	☐	Dorothea
ANDF -Installationseinri	noun	Einrichtung	sg	f	Einrichtung Einrichtungen Einrichtungen	Frau	☐	☐	Dorothea
ANDF-Herstellungseinri	noun	Einrichtung	sg	f	Einrichtung Einrichtungen Einrichtungen	Frau	☐	☐	Dorothea
AO-Katalysator	noun	Katalysator	sg	m	Katalysators Katalysatoren Katalysatoren	Traktor	☐	☐	Dorothea
APC-Schaltung	noun	Schaltung	sg	f	Schaltung Schaltungen Schaltungen	Frau	☐	☐	Dorothea
ART	noun	ART	sg	f		$	☑	☐	Dorothea
ASTMes-Verfahren	noun	Verfahren	sg	n	Verfahrens Verfahren Verfahren	Wagen	☐	☐	Dorothea
ATM-Netz	noun	Netz	sg	n	Netzes Netze Netzen	Tisch	☐	☐	Dorothea
ATM-Netzwerk	noun	Netzwerk	sg	n	Netzwerk(e)s Netzwerke Netzwerken	Termin	☐	☐	Dorothea

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Hybrid MT Architecture III

Next steps:

- Use existing infrastructure to feed various rule-based MT engines (OpenLogos, Lucy)
- Measure impact on results
- Decide on domain for which extended lexicons would be most useful

Conclusion

- We have presented two complementary architectures to combine rule-based and statistical MT engines
- Implementation is fairly advanced but fine-tuning still needs to be done
- These setups can themselves be combined into a MEMT system
- Truly deep integration using rule-based and statistical **knowledge sources** in well-balanced way will need more work

Thank You for Your Attention

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