
Computer Aided Translation

Philipp Koehn

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Why Machine Translation?



Assimilation — reader initiates translation, wants to know content

- user is tolerant of inferior quality
- focus of majority of research■

Communication — participants don't speak same language, rely on translation

- users can ask questions, when something is unclear
- chat room translations, hand-held devices
- often combined with speech recognition■

Dissemination — publisher wants to make content available in other languages

- high demands for quality
- currently almost exclusively done by human translators

Why Machine Translation?



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Goal: Helping Human Translators



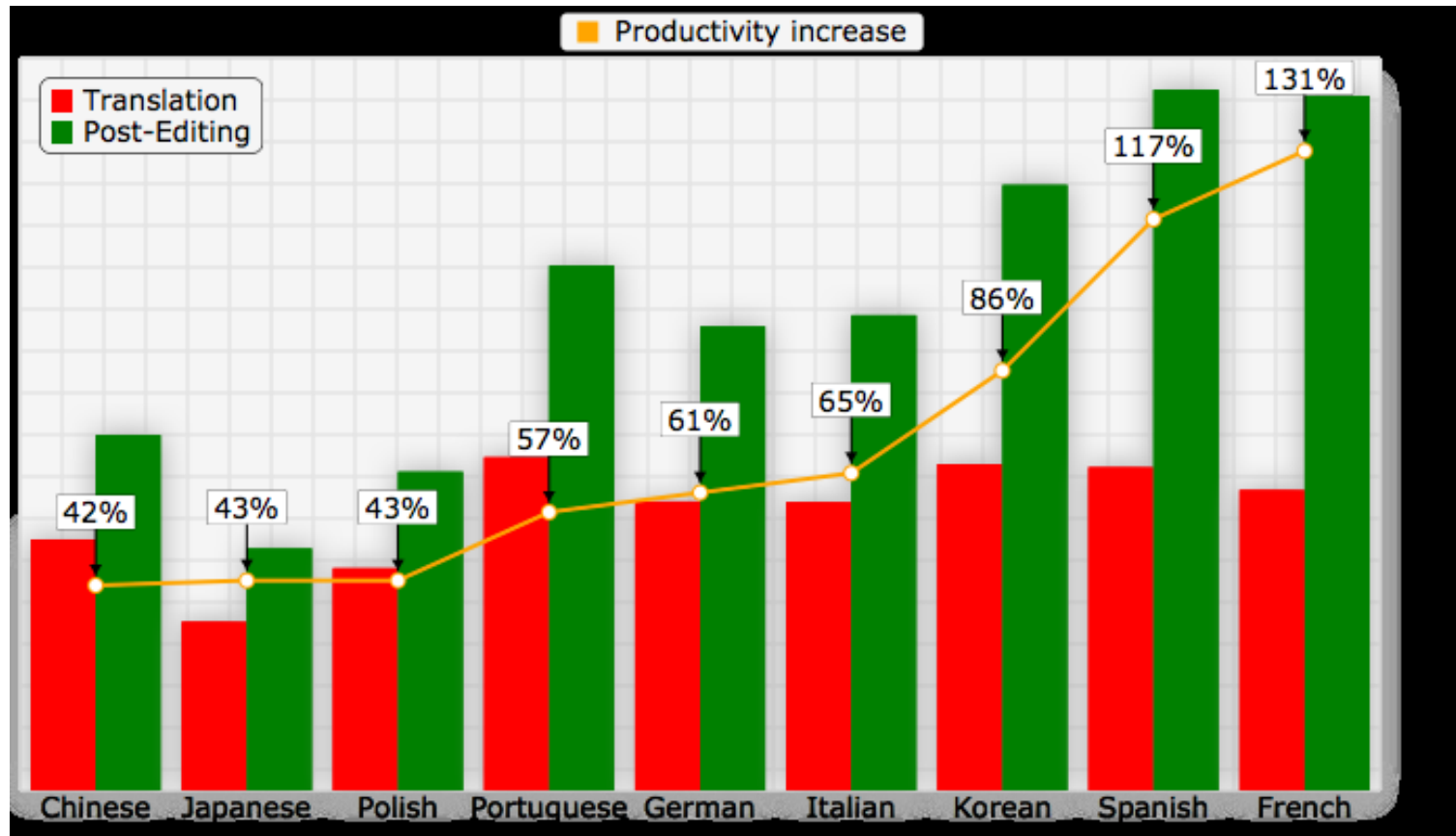
If you can't beat them, join them.■

→ How can machine translation help human translators?

Post-Editing Machine Translation



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(source: Autodesk)

MT Quality and Productivity

System	BLEU	Training Sentences	Training Words (English)
MT1	30.37	14,700k	385m
MT2	30.08	7,350k	192m
MT3	29.60	3,675k	96m
MT4	29.16	1,837k	48m
MT5	28.61	918k	24m
MT6	27.89	459k	12m
MT7	26.93	230k	6.0m
MT8	26.14	115k	3.0m
MT9	24.85	57k	1.5m

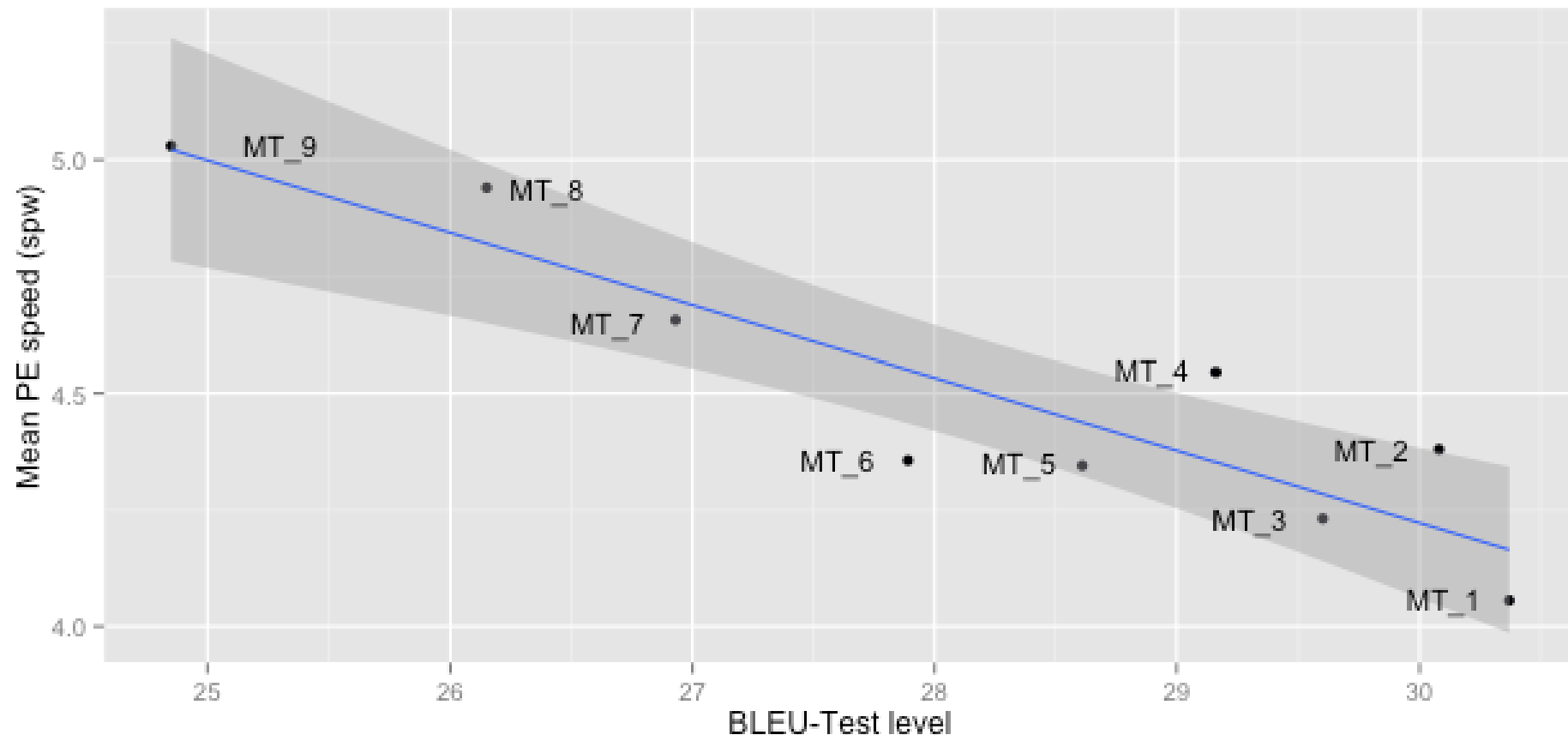
- Same type of system (Spanish–English, phrase-based, Moses)
- Trained on varying amounts of data [Sanchez-Torron and Koehn, AMTA 2016]

MT Quality and Productivity

System	BLEU	Training Sentences	Training Words (English)	Post-Editing Speed
MT1	30.37	14,700k	385m	4.06 sec/word
MT2	30.08	7,350k	192m	4.38 sec/word
MT3	29.60	3,675k	96m	4.23 sec/word
MT4	29.16	1,837k	48m	4.54 sec/word
MT5	28.61	918k	24m	4.35 sec/word
MT6	27.89	459k	12m	4.36 sec/word
MT7	26.93	230k	6.0m	4.66 sec/word
MT8	26.14	115k	3.0m	4.94 sec/word
MT9	24.85	57k	1.5m	5.03 sec/word

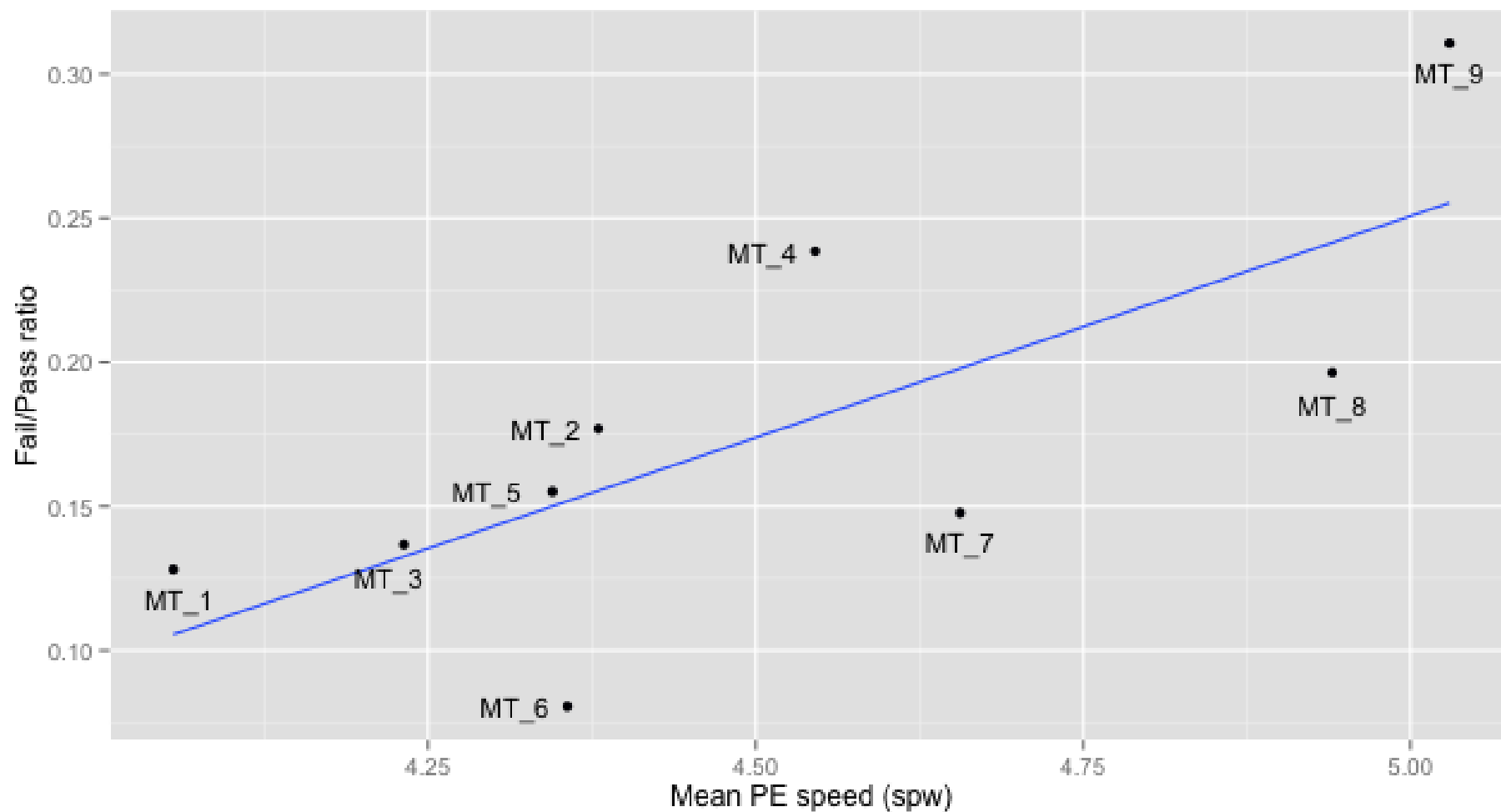
- User study with professional translators
- Correlation between BLEU and post-editing speed?

MT Quality and Productivity



BLEU against PE speed and regression line with 95% confidence bounds
+1 BLEU \leftrightarrow decrease in PE time of ~ 0.16 sec/word, or 3-4% speed-up

MT Quality and PE Quality



better MT \leftrightarrow fewer post-editing errors

Translator Variability



	HTER	Edit Rate	PE speed (spw)	MQM Score	Fail	Pass
TR1	44.79	2.29	4.57	98.65	10	124
TR2	42.76	3.33	4.14	97.13	23	102
TR3	34.18	2.05	3.25	96.50	26	106
TR4	49.90	3.52	2.98	98.10	17	120
TR5	54.28	4.72	4.68	97.45	17	119
TR6	37.14	2.78	2.86	97.43	24	113
TR7	39.18	2.23	6.36	97.92	18	112
TR8	50.77	7.63	6.29	97.20	19	117
TR9	39.21	2.81	5.45	96.48	22	113

- Higher variability between translators than between MT systems

- **Interactivity**
- Choices
- User Studies
- Confidence
- Adaptation

- Traditional professional translation approaches
 - translation from scratch
 - post-editing translation memory match
 - post-editing machine translation output
- More interactive collaboration between machine and professional?

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

|

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

| He

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He | has

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He has | for months

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He planned |

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He planned | for months

- Show n next words

Olvidarlo. Es demasiado | **arriesgado.** Estoy haciendo

- Show rest of sentence

Spence Green's Lilt System

- Show alternate translation predictions

C Les étudiants eux-mêmes n'ont pas les moyens de se rendre à des cours, nous essayons de les aider de cette manière.

The students themselves cannot be required to attend courses, we are trying to help themselves cannot

D Dans le cadre de l'Institut Jedlička, nous transférerons ce projet dans un nouveau bâtiment.

themselves could not
themselves do not
themselves cannot afford

E

- Show alternate translations predictions with probabilities

To equip students with training, we have reduced mobility and Institute Jedlička, we will transfer this project to a new building.

■ routinely
■ steadily
■ regular
■ regularly

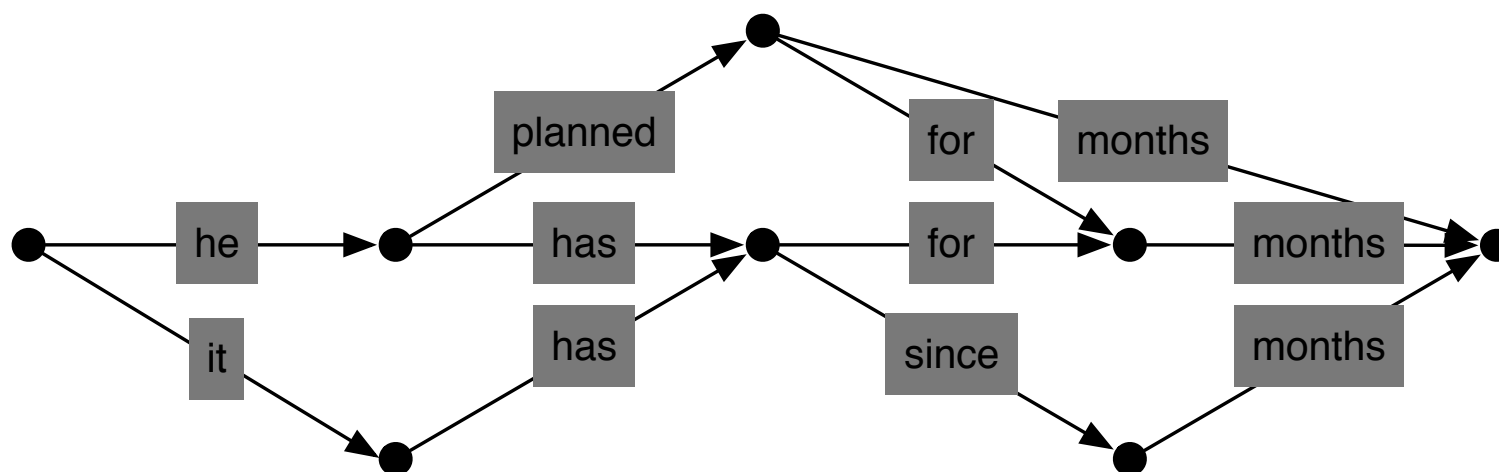
Des enseignants se rendent régulièrement auprès d'eux et proposent des activités qui les intéressent et les aident.

Teachers regularly visit Jedlička and propose activities for them and help them.

Les étudiants eux-mêmes n'ont pas les moyens de se rendre à des cours, nous essayons de les aider de cette manière.

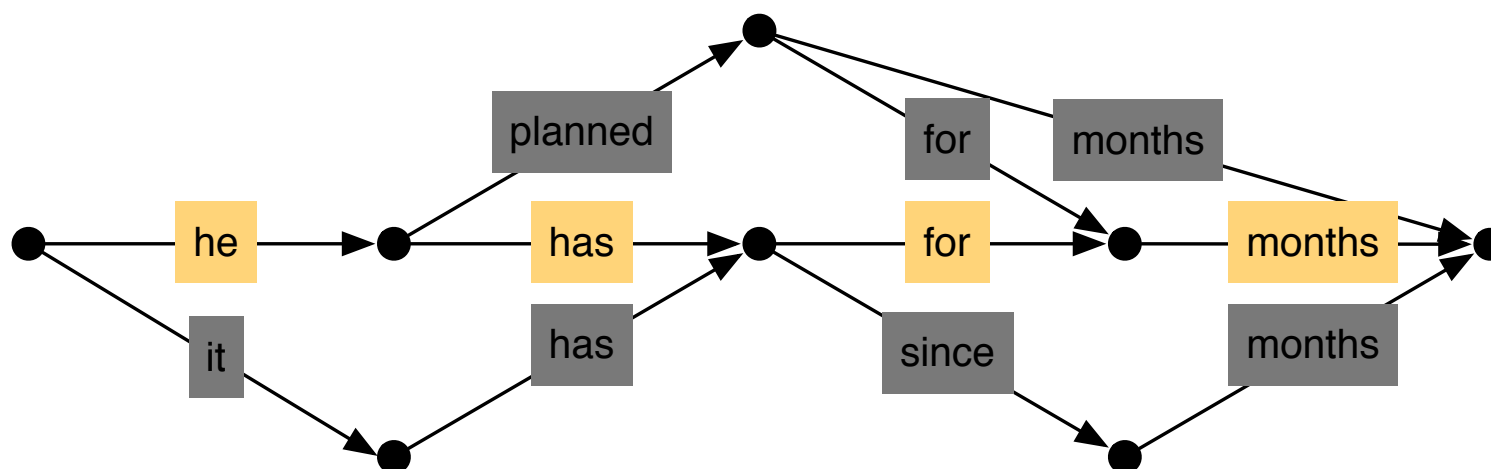
make regular
are regularly

Prediction from Search Graph



Search for best translation creates a graph of possible translations

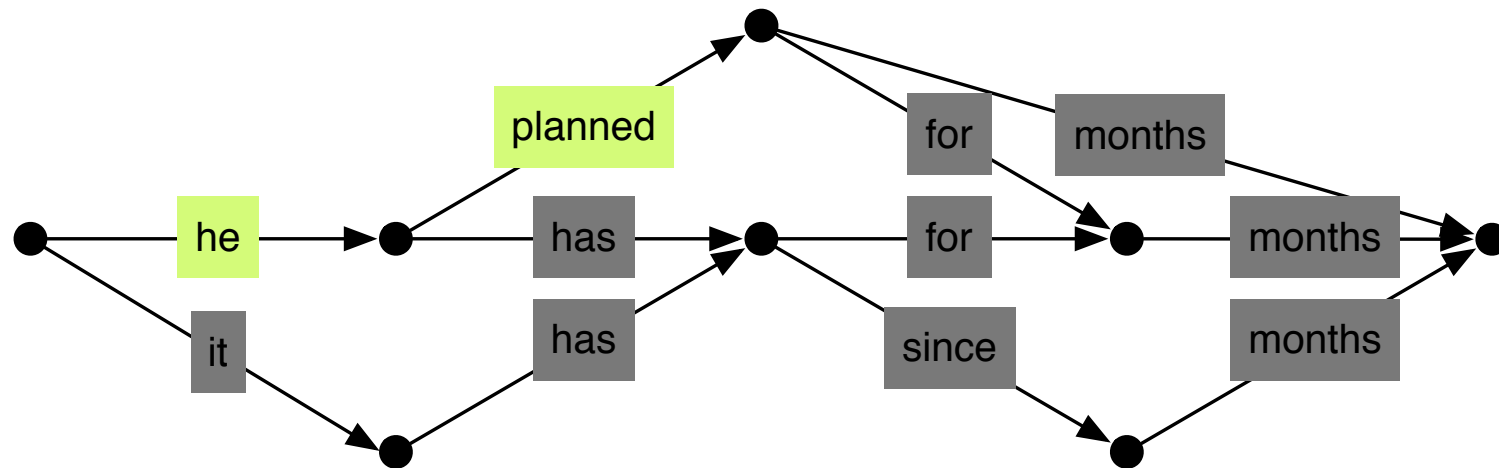
Prediction from Search Graph



One path in the graph is the best (according to the model)

This path is suggested to the user

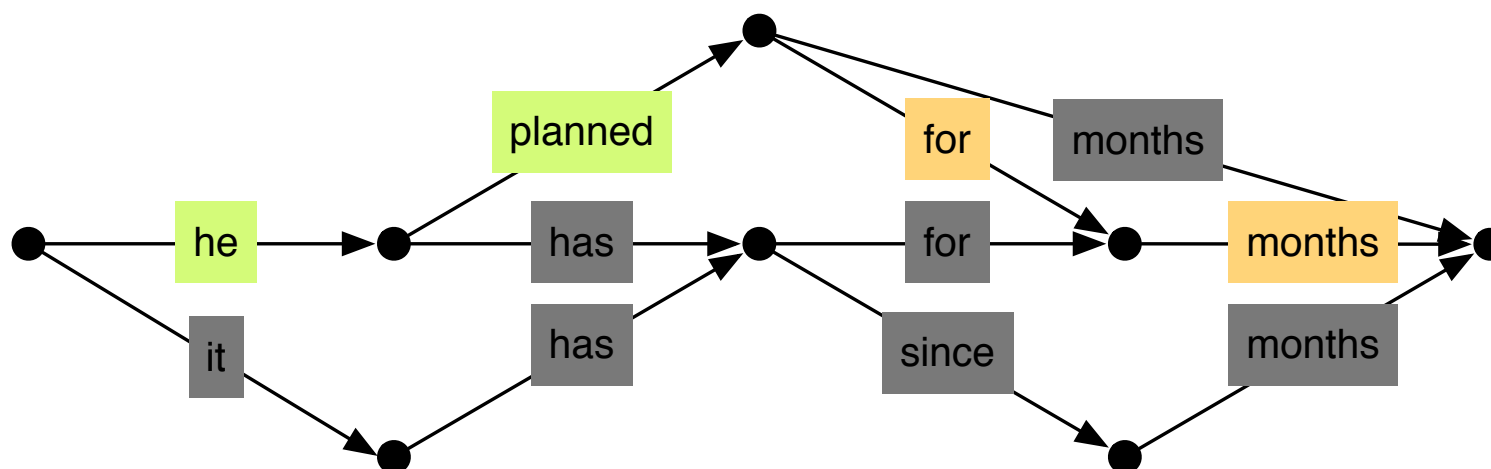
Prediction from Search Graph



The user may enter a different translation for the first words

We have to find it in the graph

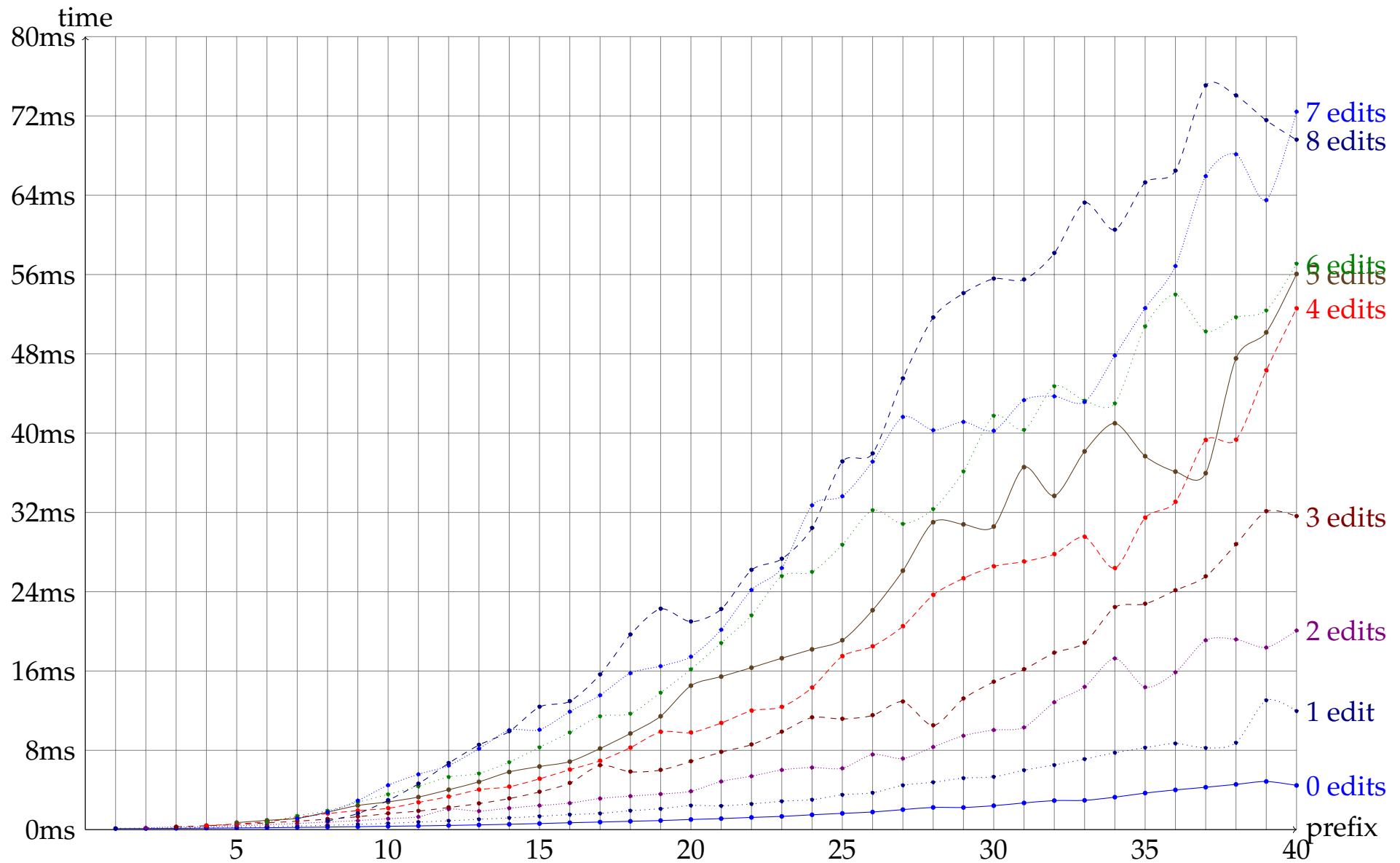
Prediction from Search Graph



We can predict the optimal completion (according to the model)

Run Time

24



Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He planned for months to give a lecture in Baltimore | in

Input Sentence

Er hat seit Monaten geplant, **im** November einen Vortrag in Baltimore zu halten.

Professional Translator

He planned for months to give a lecture in Baltimore | **in**

Shading off Translated Material

Input Sentence

Er hat seit Monaten geplant, **im** November einen Vortrag in Baltimore zu halten .

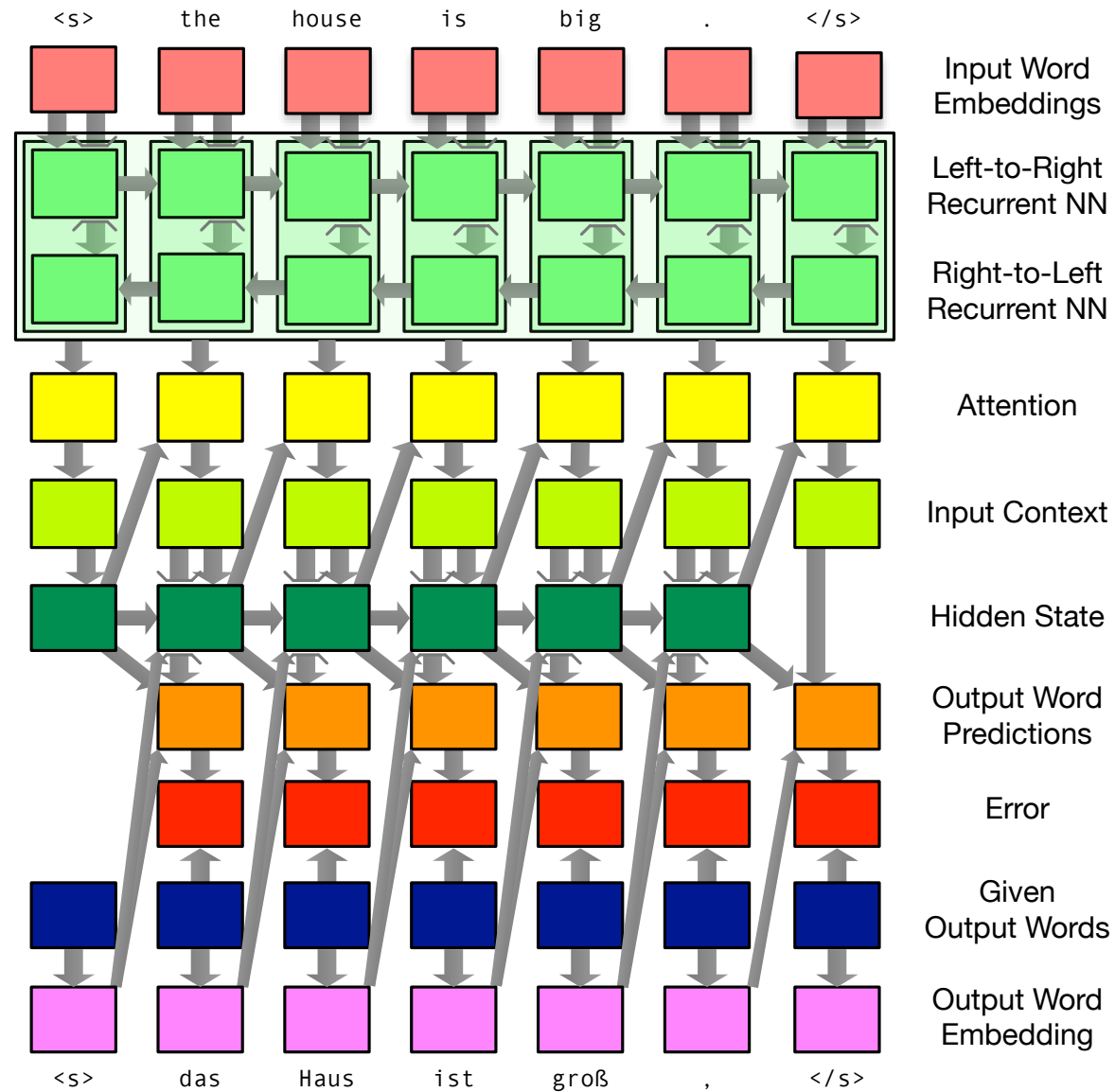
Professional Translator

He planned for months to give a lecture in Baltimore | **in**

- How can we do this?
 - word alignments by-product of matching against search graph
 - automatic word alignments (as used in training)
- User feedback
 - users like interactive machine translation
 - ... but they may be slower than with post-editing machine translation
 - user like mouse-over word alignment highlighting
 - user do not like at-cursor word alignment highlighting

Neural Interactive Translation Prediction

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- The model produces words in sequence

$$p(\text{output}_t | \{\text{output}_1, \dots, \text{output}_{t-1}\}, \vec{\text{input}}) = g(\hat{\text{output}}_{t-1}, \text{context}_t, \text{hidden}_t)$$

- Translation prediction: feed in user prefix

Example

Input: *Das Unternehmen sagte, dass es in diesem Monat mit Bewerbungsgesprächen beginnen wird und die Mitarbeiterzahl von Oktober bis Dezember steigt.*

	Correct	Prediction	Prediction probability distribution
✓	the	the	the (99.2%)
✓	company	company	company (90.9%) , firm (7.6%)
✓	said	said	said (98.9%)
✓	it	it	it (42.6%) , this (14.0%), that (13.1%), job (2.0%), the (1.7%), ...
✓	will	will	will (77.5%) , is (4.5%), started (2.5%), 's (2.0%), starts (1.8%), ...
✓	start	start	start (49.6%) , begin (46.7%)
	inter@@	job	job (16.1%), application (6.1%), en@@ (5.2%), out (4.8%), ...
✗	viewing	state	state (32.4%), related (5.8%), viewing (3.4%) , min@@ (2.0%), ...
✗	applicants	talks	talks (61.6%), interviews (6.4%), discussions (6.2%), ...
✓	this	this	this (88.1%) , so (1.9%), later (1.8%), that (1.1%)
✓	month	month	month (99.4%)
✗	,	and	and (90.8%), , (7.7%)
✗	with	and	and (42.6%), increasing (24.5%), rising (6.3%), with (5.1%) , ...
✓	staff	staff	staff (22.8%) , the (19.5%), employees (6.3%), employee (5.0%), ...
✗	levels	numbers	numbers (69.0%), levels (3.3%) , increasing (3.2%), ...
✗	rising	increasing	increasing (40.1%), rising (35.3%) , climbing (4.4%), rise (3.4%), ...
✓	from	from	from (97.4%)
✓	October	October	October (81.3%) , Oc@@ (12.8%), oc@@ (2.9%), Oct (1.2%)
✗	through	to	to (73.2%), through (15.6%) , until (8.7%)
✓	December	December	December (85.6%) , Dec (8.0%), to (5.1%)
✓	.	.	. (97.5%)

- Better prediction accuracy, even when systems have same BLEU score (state-of-the-art German-English systems, compared to search graph matching)

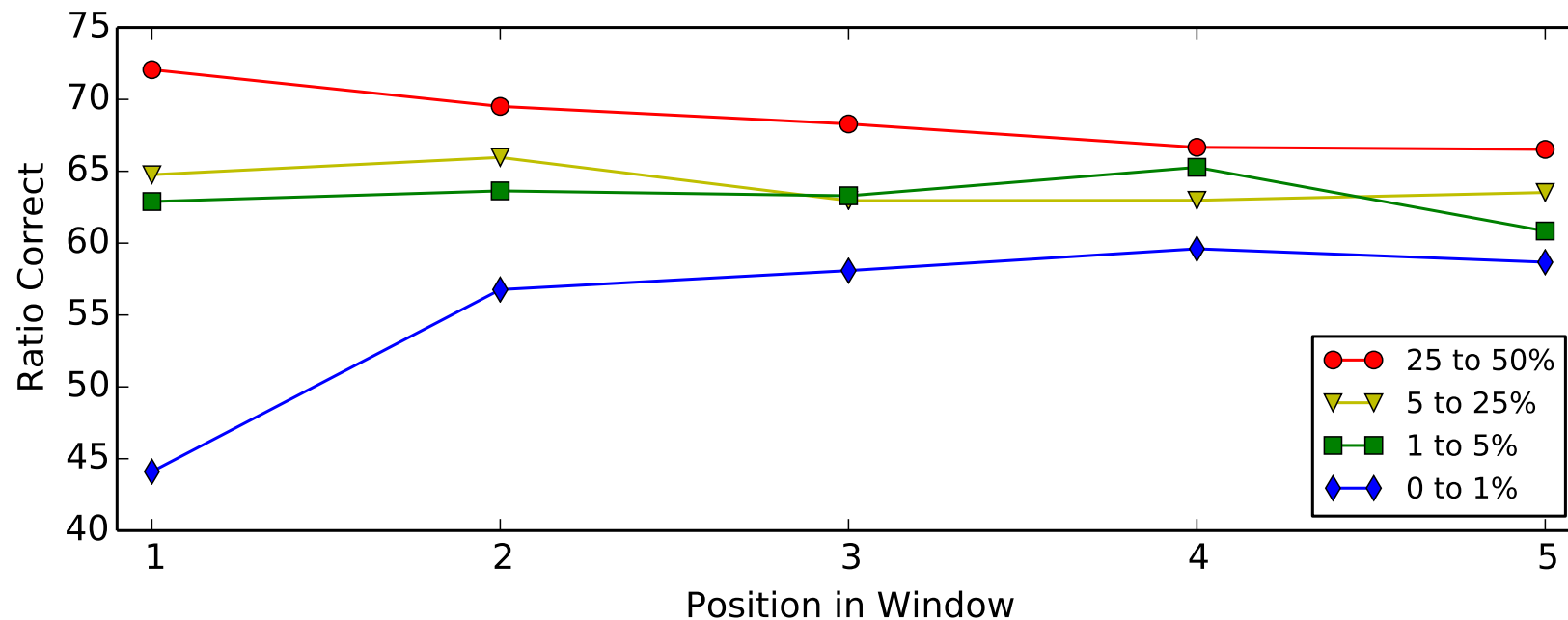
System	Configuration	BLEU	Word Prediction Accuracy	Letter Prediction Accuracy
Neural	no beam search	34.5	61.6%	86.8%
	beam size 12	36.2	63.6%	87.4%
Phrase-based	-	34.5	43.3%	72.8%

Recovery from Failure

- Ratio of words correct after first failure

System	Configuration	1	2	3	4	5
Neural	no beam search	55.9%	61.8%	61.3%	62.2%	61.1%
	beam size 12	58.0%	62.9%	62.8%	64.0%	61.5%
Phrase-based	-	28.6%	45.5%	46.9%	47.4%	48.4%

- Depending on probability of user word (neural, no beam)



Patching Translations

- Decoding speeds
 - translation speed with CPU: 100 ms/word
 - translation speed with GPU: 7ms/word
- To stay within 100ms speed limit
 - predict only a few words ahead (say, 5, in $5 \times 7\text{ms} = 35\text{ms}$)
 - patch new partial prediction with old full sentence prediction
 - uses KL divergence to find best patch point in ± 2 word window
- May compute new full sentence prediction in background, return as update
- Only doing quick response reduces word prediction accuracy 61.6% \rightarrow 56.4%

- Interactivity
- **Choices**
- User Studies
- Confidence
- Adaptation

- Trigger the passive vocabulary
- Display multiple translations for words and phrases

er	hat	seit	Monaten	geplant	,	im	März	einen	Vortrag	...
he has		for months		the plan		in March		a lecture		...
it has		for months now		planned	,	in	March	a presentation		...
he was		for several months		planned to		in the March		a speech		...
he has made		since	months	the pipeline		in March of		a statement		...
he did		for many months		scheduled		the March		a general		...

- Rank and color-highlight by probability of each translation
- Prefer diversity

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Professional Translator

He planned for months to **give a lecture** in Baltimore in November.

give a presentation
present his work
give a speech
speak

User requests alternative translations for parts of sentence.



entre autres(560/1554)

...d and made recommendations , " **inter alia** " , with respect to the follow...
 ...on (EC) No 1995 / 2000 imposing , **inter alia** , a definitive anti @-@ dumping dut...
 ...ervices . this increase , arising , **inter alia** , as a result of economic growth , ...
 ...of paragraph 1 the Commission may , **inter alia** , bring forward :
 ... of stocks of obsolete pesticides , **inter alia** , by supporting projects aimed at s...
 ...wn rules of procedure which shall , **inter alia** , contain provisions for convening ...
 ...uch specific agreements may cover , **inter alia** , financing provisions , assignment...
 ...he internal market and concerning , **inter alia** , health and environmental protecti...
 ...e product concerned) originating , **inter alia** , in Belarus and Russia (the count...
 ...e product concerned) originating , **inter alia** , in India .

... des recommandations concernant , **entre autres** , les questions spécifiques suiva...
 ...995 / 2000 du Conseil instituant , **entre autres** , un droit antidumping définitif ...
 ...nsports . cette augmentation , due **entre autres** facteurs à la croissance économi...
 ...aragraphe 1 , la Commission peut , **entre autres** , présenter :
 ...r les stocks de vieux pesticides , **entre autres** en soutenant des projets à cet ef...
 ...lement intérieur , qui contient , **entre autres** dispositions , les modalités de c...
 ...ords spécifiques peuvent porter , **entre autres** , sur les mécanismes financiers s...
 ...hé intérieur et qui concernent , **entre autres** , la santé et la protection de l&...
 ...it concerné ") originaire , **entre autres** , du Belarus et de Russie (ci @-@ ...
 ...t concerné ") originaires , **entre autres** , de l ' Inde .

notamment(447/1554)

... the EU budget by addressing " **inter alia** " the problems of accountabili...
 ...ates , the Commission has adopted , **inter alia** , Decision 2003 / 526 / EC (3) wh...
 ...d equitable development involving , **inter alia** , access to productive resources , ...
 ...ertain products which could be used **inter alia** , as equipment on board ships but w...
 ...nexes , taking into consideration , **inter alia** , available scientific , technical ...
 ...w that it is absolutely necessary , **inter alia** , because of enlargement , to find ...
 ...paragraphs 1 and 2 as appropriate , **inter alia** , by conducting studies and compili...
 ...liability and efficiency , caused , **inter alia** , by insufficient technical and adm...
 ...in the Programme shall be pursued , **inter alia** , by the following means :

...get de l' Union , ce qui passe **notamment** par la résolution du problème de r...
 ...es États membres , la Commission a **notamment** arrêté la décision 2003 / 526 / C...
 ... durable et équitable , impliquant **notamment** l' accès aux ressources produc...
 ...usceptibles d' être utilisés **notamment** comme équipements mis à bord , mai...
 ...ion et à ses annexes , compte tenu **notamment** des informations scientifiques , tec...
 ...os ; il est absolument nécessaire , **notamment** en raison de l' élargissement ...
 ...ragraphes 1 et 2 le cas échéant , **notamment** en menant des études et en compilan...
 ... et d' efficacité en raison , **notamment** , d' une interopérabilité tec...
 ...nis dans le programme , il convient **notamment** de mettre en oeuvre les moyens ci @-...

- Interactivity
- Choices
- **User Studies**
- Confidence
- Adaptation

- Different types of events are saved in the logging.
 - configuration and statistics
 - start and stop session
 - segment opened and closed
 - text, key strokes, and mouse events
 - scroll and resize
 - search and replace
 - suggestions loaded and suggestion chosen
 - interactive translation prediction
 - gaze and fixation from eye tracker

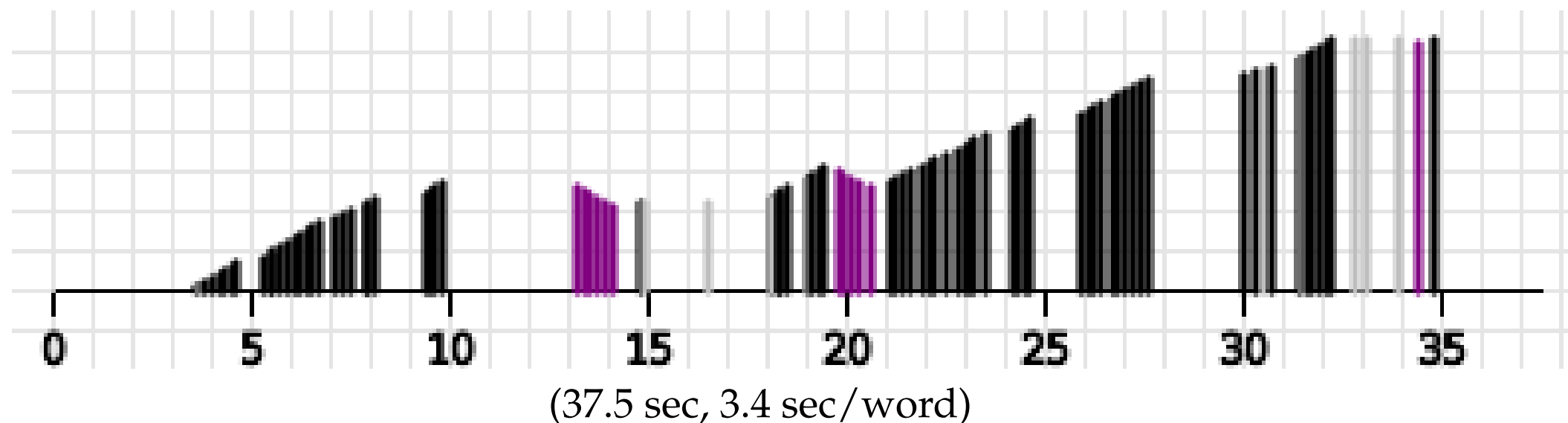
- In every event we save:
 - Type
 - In which element was produced
 - Time
- Special attributes are kept for some types of events
 - Diff of a text change
 - Current cursor position
 - Character looked at
 - Clicked UI element
 - Selected text

⇒ Full replay of user session is possible

Keystroke Log

Input: Au premier semestre, l'avionneur a livré 97 avions.

Output: The manufacturer has delivered 97 planes during the first half.



black: keystroke, purple: deletion, grey: cursor move
height: length of sentence

Example of Quality Judgments

Src. Sans se démonter, il s'est montré concis et précis.

MT Without dismantle, it has been concise and accurate.

1/3 Without fail, he has been concise and accurate. *(Prediction+Options, L2a)*

4/0 Without getting flustered, he showed himself to be concise and precise.
(Unassisted, L2b)

4/0 Without falling apart, he has shown himself to be concise and accurate. *(Postedit, L2c)*

1/3 Unswayable, he has shown himself to be concise and to the point. *(Options, L2d)*

0/4 Without showing off, he showed himself to be concise and precise. *(Prediction, L2e)*

1/3 Without dismantling himself, he presented himself consistent and precise.
(Prediction+Options, L1a)

2/2 He showed himself concise and precise. *(Unassisted, L1b)*

3/1 Nothing daunted, he has been concise and accurate. *(Postedit, L1c)*

3/1 Without losing face, he remained focused and specific. *(Options, L1d)*

3/1 Without becoming flustered, he showed himself concise and precise. *(Prediction, L1e)*

Main Measure: Productivity

Assistance	Speed	Quality
Unassisted	4.4s/word	47% correct
Postedit	2.7s (-1.7s)	55% (+8%)
Options	3.7s (-0.7s)	51% (+4%)
Prediction	3.2s (-1.2s)	54% (+7%)
Prediction+Options	3.3s (-1.1s)	53% (+6%)

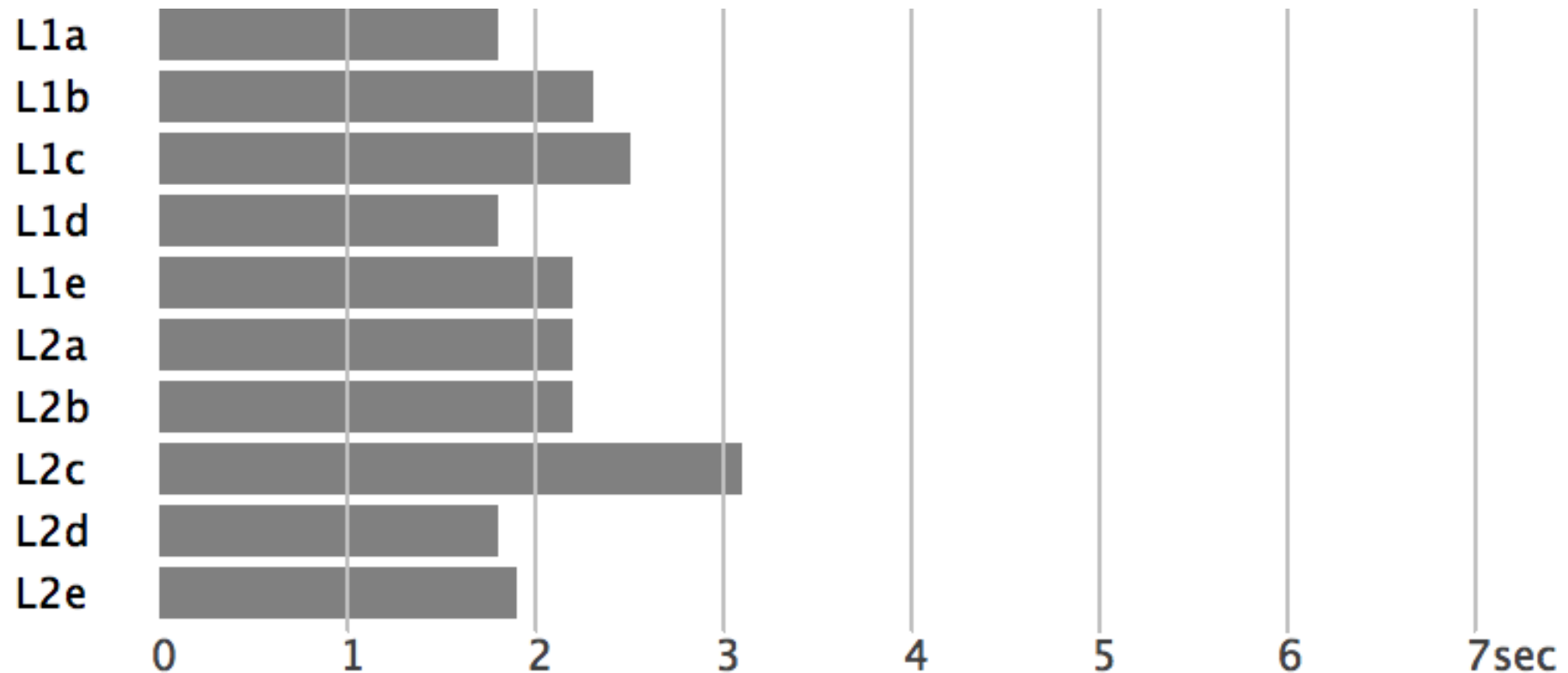
Faster and Better, Mostly

45



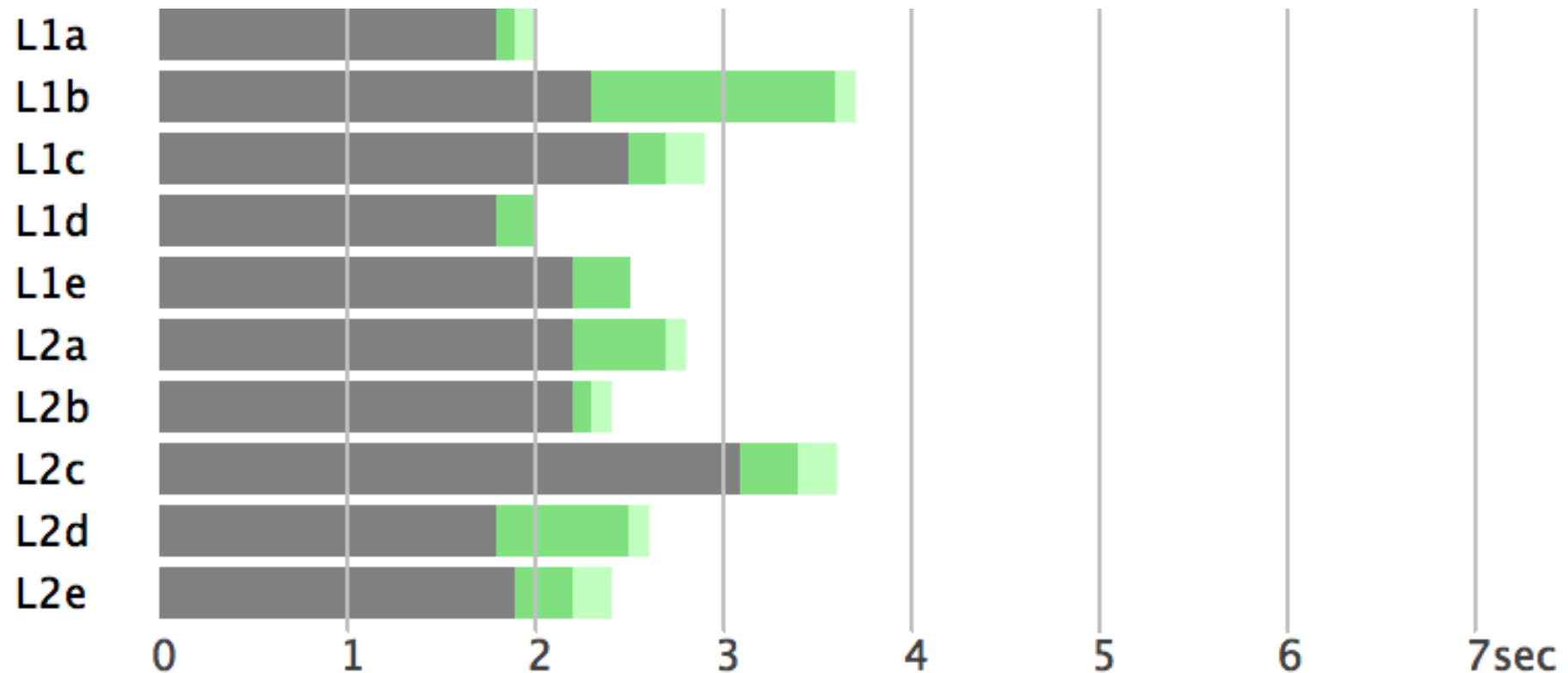
User	Unassisted	Postedit		Options		Prediction		Prediction+Options	
L1a	3.3sec/word 23% correct	1.2s 39%	-2.2s +16%)	2.3s 45%	-1.0s +22%	1.1s 30%	-2.2s +7%)	2.4s 44%	-0.9s +21%
L1b	7.7sec/word 35% correct	4.5s 48%	-3.2s) +13%	4.5s 55%	-3.3s +20%	2.7s 61%	-5.1s +26%	4.8s 41%	-3.0s +6%
L1c	3.9sec/word 50% correct	1.9s 61%	-2.0s +11%	3.8s 54%	-0.1s +4%	3.1s 64%	-0.8s +14%	2.5s 61%	-1.4s +11%
L1d	2.8sec/word 38% correct	2.0s 46%	-0.7s +8%	2.9s 59%	(+0.1s) (+21%)	2.4s 37%	(-0.4s) (-1%)	1.8s 45%	-1.0s +7%
L1e	5.2sec/word 58% correct	3.9s 64%	-1.3s +6%	4.9s 56%	(-0.2s) (-2%)	3.5s 62%	-1.7s +4%	4.6s 56%	(-0.5s) (-2%)
L2a	5.7sec/word 16% correct	1.8s 50%	-3.9s +34%	2.5s 34%	-3.2s +18%	2.7s 40%	-3.0s +24%	2.8s 50%	-2.9s +34%
L2b	3.2sec/word 64% correct	2.8s 56%	(-0.4s) (-8%)	3.5s 60%	+0.3s -4%	6.0s 61%	+2.8s -3%	4.6s 57%	+1.4s -7%
L2c	5.8sec/word 52% correct	2.9s 53%	-3.0s +1%	4.6s 37%	(-1.2s) (-15%)	4.1s 59%	-1.7s +7%	2.7s 53%	-3.1s +1%
L2d	3.4sec/word 49% correct	3.1s 49%	(-0.3s) (+0%)	4.3s 51%	(+0.9s) (+2%)	3.8s 53%	(+0.4s) (+4%)	3.7s 58%	(+0.3s) (+9%)
L2e	2.8sec/word 68% correct	2.6s 79%	-0.2s +11%	3.5s 59%	+0.7s -9%	2.8s 64%	(-0.0s) (-4%)	3.0s 66%	+0.2s -2%
avg.	4.4sec/word 47% correct	2.7s 55%	-1.7s +8%	3.7s 51%	-0.7s +4%	3.2s 54%	-1.2s +7%	3.3s 53%	-1.1s +6%

Unassisted Novice Translators



L1 = native French, L2 = native English, average time per input word
only typing

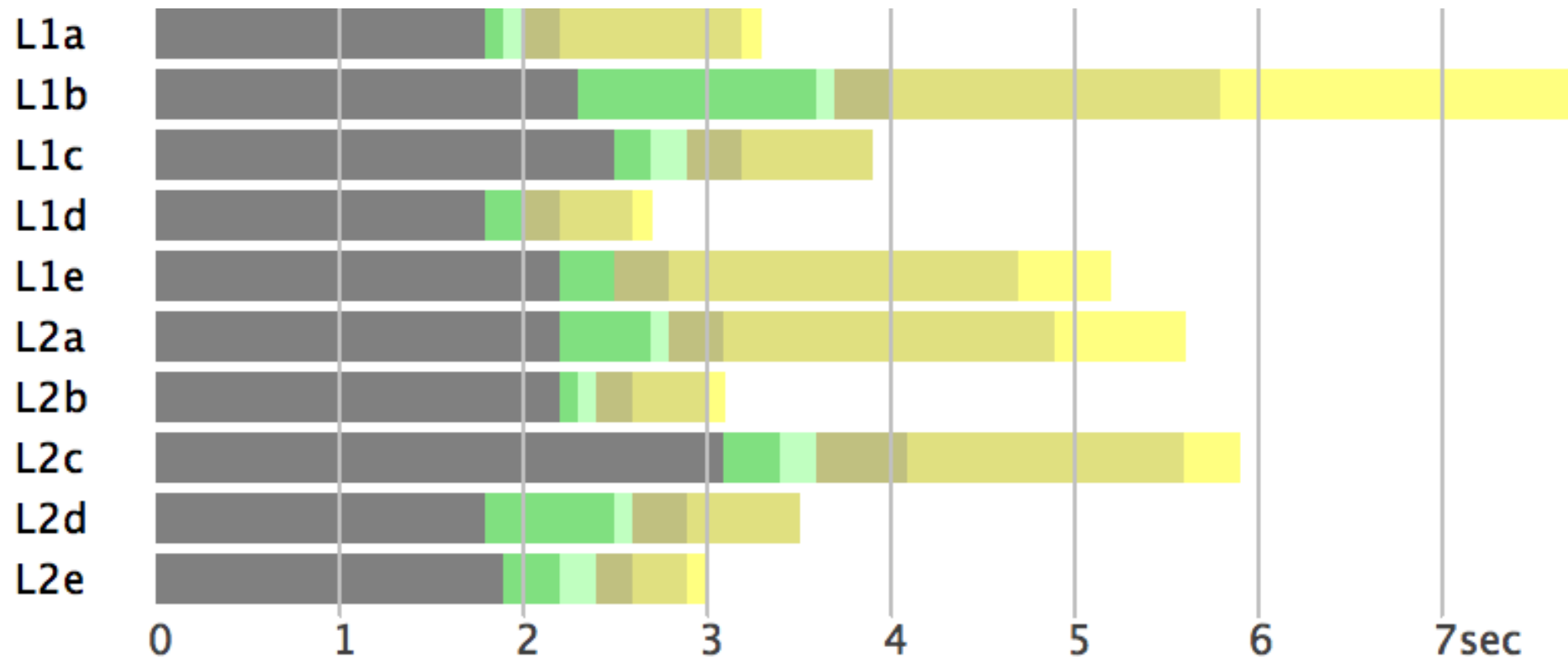
Unassisted Novice Translators



L1 = native French, L2 = native English, average time per input word

typing, initial and final pauses

Unassisted Novice Translators



L1 = native French, L2 = native English, average time per input word

typing, **initial and final pauses**, **short, medium, and long pauses**
most time difference on intermediate pauses

Activities: Native French User L1b

User: L1b	total	init-p	end-p	short-p	mid-p	big-p	key	click	tab
Unassisted	7.7s	1.3s	0.1s	0.3s	1.8s	1.9s	2.3s	-	-
Postedit	4.5s	1.5s	0.4s	0.1s	1.0s	0.4s	1.1s	-	-
Options	4.5s	0.6s	0.1s	0.4s	0.9s	0.7s	1.5s	0.4s	-
Prediction	2.7s	0.3s	0.3s	0.2s	0.7s	0.1s	0.6s	-	0.4s
Prediction+Options	4.8s	0.6s	0.4s	0.4s	1.3s	0.5s	0.9s	0.5s	0.2s

Activities: Native French User L1b

User: L1b	total	init-p	end-p	short-p	mid-p	big-p	key	click	tab
Unassisted	7.7s	1.3s	0.1s	0.3s	1.8s	1.9s	2.3s	-	-
Postedit	4.5s	1.5s	0.4s	0.1s	1.0s	0.4s	1.1s	-	-
Options	4.5s	0.6s	0.1s	0.4s	0.9s	0.7s	1.5s	0.4s	-
Prediction	2.7s	0.3s	0.3s	0.2s	0.7s	0.1s	0.6s	-	0.4s
Prediction+Options	4.8s	0.6s	0.4s	0.4s	1.3s	0.5s	0.9s	0.5s	0.2s

Slightly
less time
spent on
typing

Activities: Native French User L1b

User: L1b	total	init-p	end-p	short-p	mid-p	big-p	key	click	tab
Unassisted	7.7s	1.3s	0.1s	0.3s	1.8s	1.9s	2.3s	-	-
Postedit	4.5s	1.5s	0.4s	0.1s	1.0s	0.4s	1.1s	-	-
Options	4.5s	0.6s	0.1s	0.4s	0.9s	0.7s	1.5s	0.4s	-
Prediction	2.7s	0.3s	0.3s	0.2s	0.7s	0.1s	0.6s	-	0.4s
Prediction+Options	4.8s	0.6s	0.4s	0.4s	1.3s	0.5s	0.9s	0.5s	0.2s

Less
pausing

Slightly
less time
spent on
typing

Activities: Native French User L1b

User: L1b	total	init-p	end-p	short-p	mid-p	big-p	key	click	tab
Unassisted	7.7s	1.3s	0.1s	0.3s	1.8s	1.9s	2.3s	-	-
Postedit	4.5s	1.5s	0.4s	0.1s	1.0s	0.4s	1.1s	-	-
Options	4.5s	0.6s	0.1s	0.4s	0.9s	0.7s	1.5s	0.4s	-
Prediction	2.7s	0.3s	0.3s	0.2s	0.7s	0.1s	0.6s	-	0.4s
Prediction+Options	4.8s	0.6s	0.4s	0.4s	1.3s	0.5s	0.9s	0.5s	0.2s

Less
pausing

Especially
less time
in big
pauses

Slightly
less time
spent on
typing

- Interactivity
- Choices
- User Studies
- **Confidence**
- Adaptation

- Machine translation engine indicates where it is likely wrong (also known as quality estimation — Lucia Specia)■
- Different Levels of granularity
 - document-level (SDL's "TrustScore")
 - sentence-level
 - word-level■
- What are we predicting?
 - how useful is the translation — on a scale of (say) 1–5
 - indication if post-editing is worthwhile
 - estimation of post-editing effort
 - pin-pointing errors

- Translators are used to “Fuzzy Match Score”
 - used in translation memory systems
 - roughly: ratio of words that are the same between input and TM source
 - if less than 70%, then not useful for post-editing
- We would like to have a similar score for machine translation
- Even better
 - estimation of post-editing time
 - estimation of from-scratch translation time
 - can also be used for pricing
- Active research question, see also shared task at WMT 2013

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Machine Translation

He has for months planned in November give a lecture in Baltimore.

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

Machine Translation

He has for months planned in November give a lecture in Baltimore.

Note: different color for wrong words and reordered words
(inserted words? missing words?)

- Can we identify errors in human translations?
 - missing / added information
 - inconsistent use of terminology

Input Sentence

Er hat seit Monaten geplant, im November einen Vortrag in Baltimore zu halten.

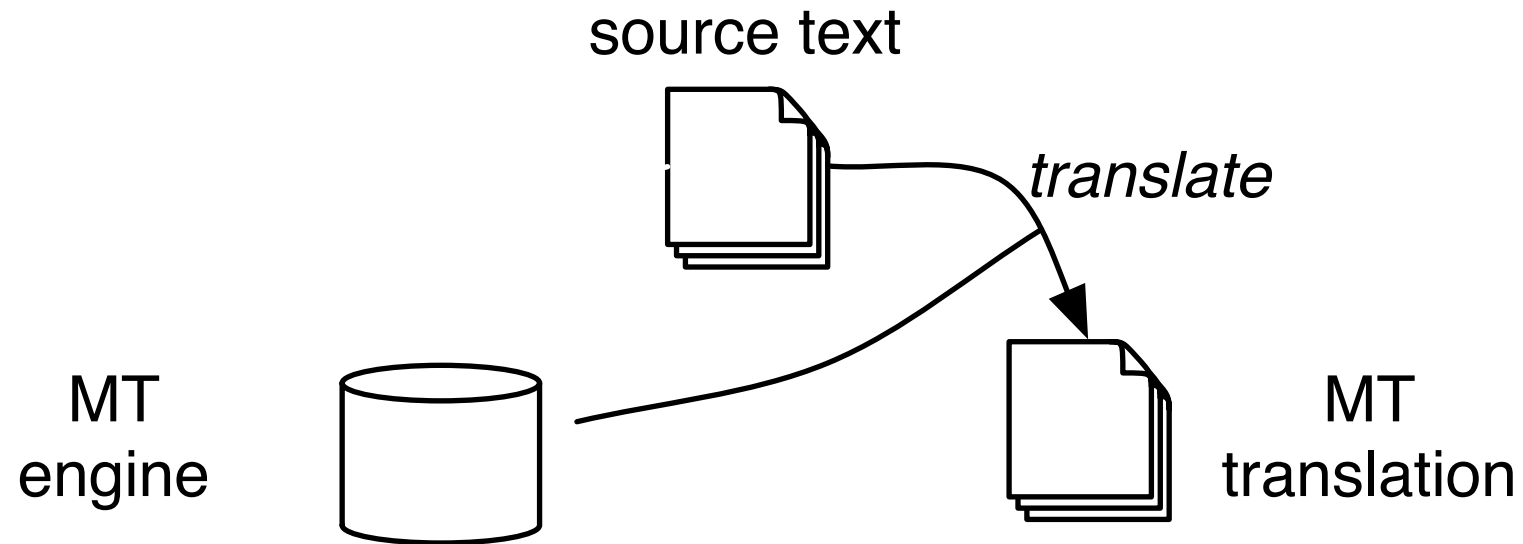
Human Translation

Moreover, he planned for months to give a lecture in Baltimore.

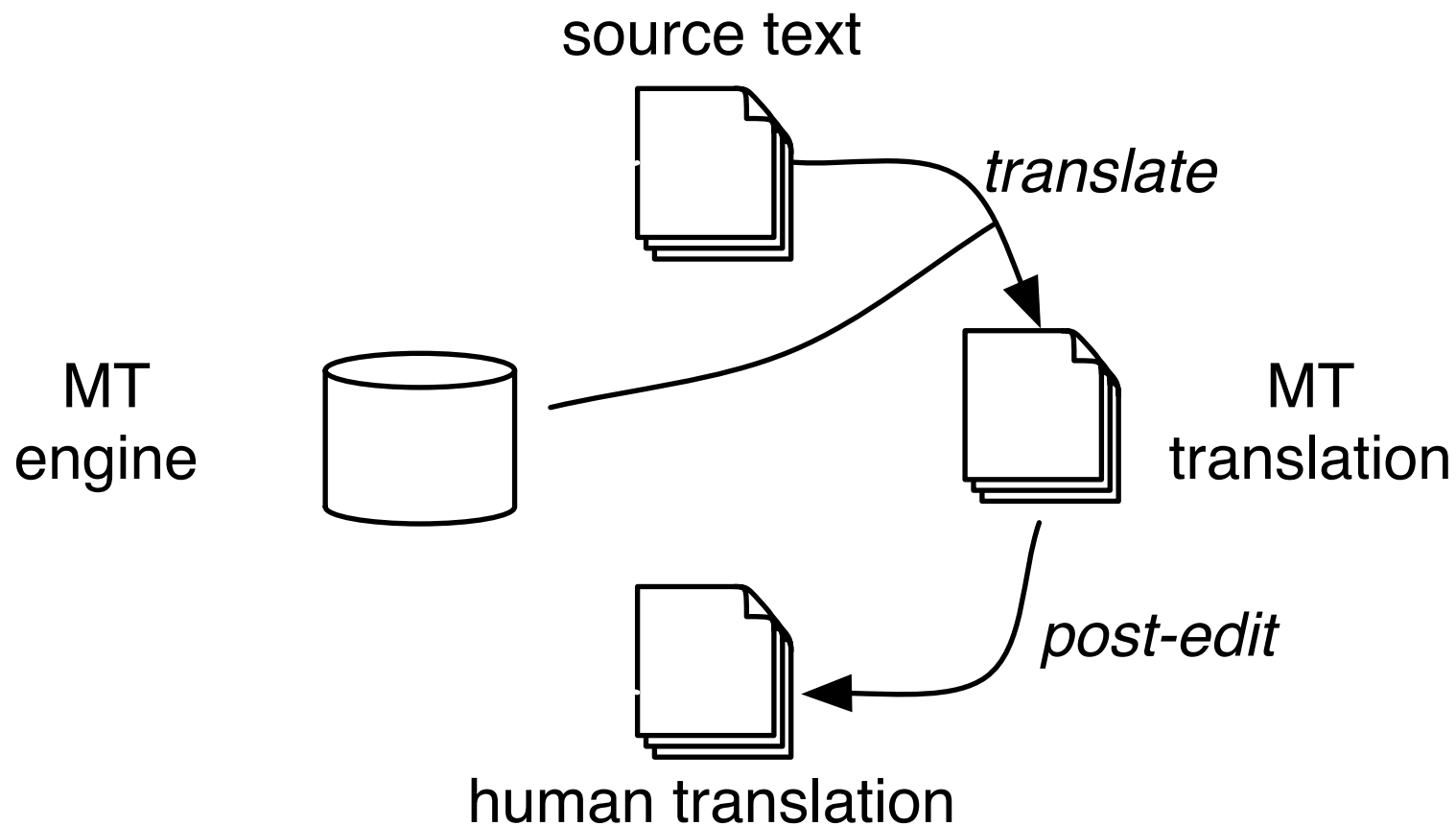
- Interactivity
- Choices
- User Studies
- Confidence
- **Adaptation**

- Machine translation works best if optimized for domain
- Typically, large amounts of out-of-domain data available
 - European Parliament, United Nations
 - unspecified data crawled from the web
- Little in-domain data (maybe 1% of total)
 - information technology data
 - more specific: IBM's user manuals
 - even more specific: IBM's user manual for same product line from last year
 - and even more specific: sentence pairs from current project
- Various domain adaptation techniques researched and used

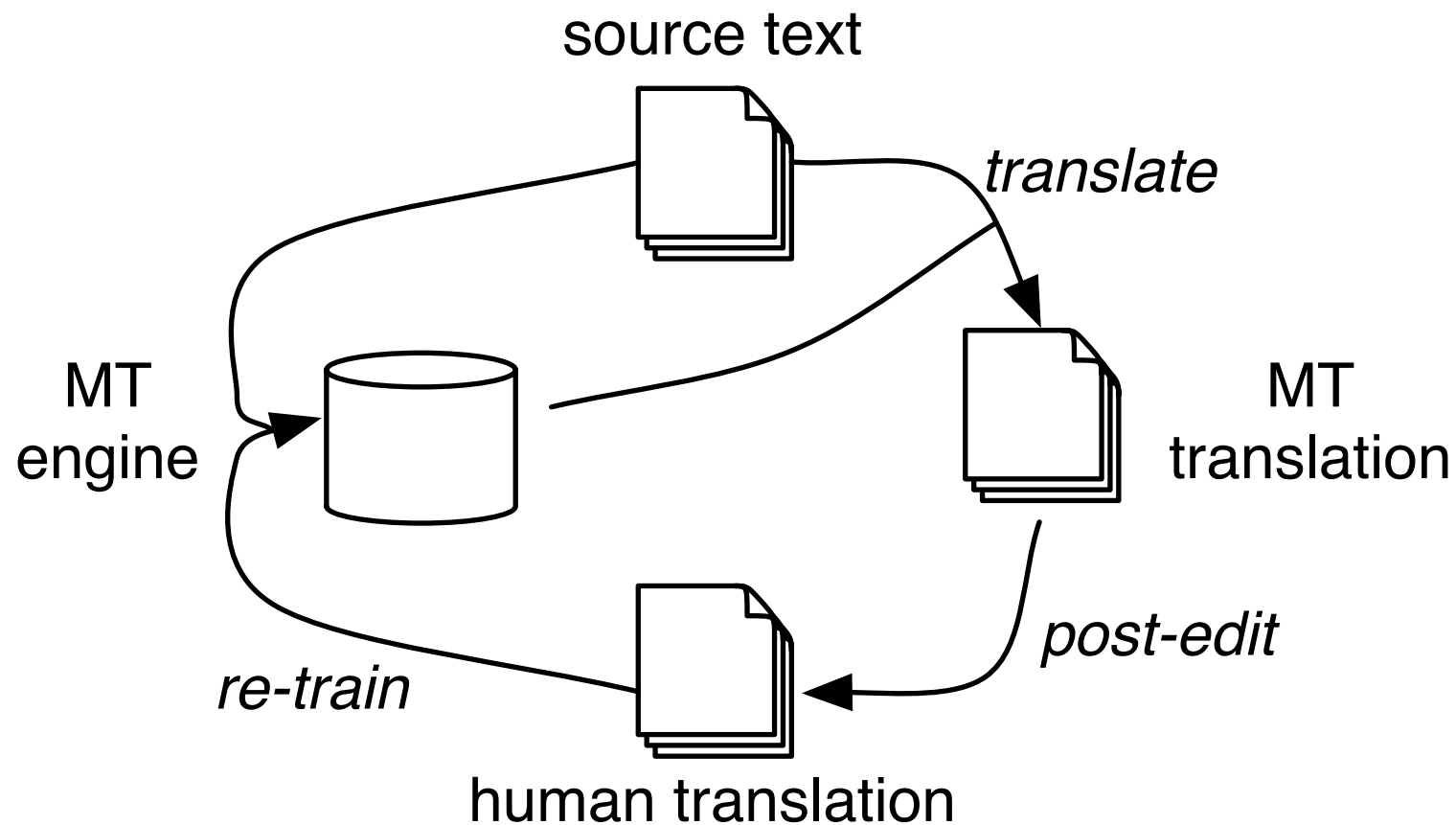
Incremental Updating



Incremental Updating



Incremental Updating



Updatable Translation Table

- Required: quickly add a sentence pair to the translation table
 - word alignment
 - phrase extraction
 - phrase table building
- Online word alignment
 - use existing model to align new sentence pair
- Online phrase table building
 - Store parallel corpus in memory
 - Index corpus with suffix array
 - Extract phrases on the fly
- This can be done in less than 1 second

Suffixes

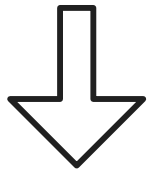
1 government of the people , by the people , for the people
2 of the people , by the people , for the people
3 the people , by the people , for the people
4 people , by the people , for the people
5 , by the people , for the people
6 by the people , for the people
7 the people , for the people
8 people , for the people
9 , for the people
10 for the people
11 the people
12 people

Sorted Suffixes

5 , by the people , for the people
9 , for the people
6 by the people , for the people
10 for the people
1 government of the people , by the people , for the people
2 of the people , by the people , for the people
12 people
4 people , by the people , for the people
8 people , for the people
11 the people
3 the people , by the people , for the people
7 the people , for the people

Suffix Array

5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people



suffix array: sorted index of corpus positions

Querying the Suffix Array

5

, by the people , for the people

9

, for the people

6

by the people , for the people

10

for the people

1

government of the people , by the people , for the people

2

of the people , by the people , for the people

12

people

4

people , by the people , for the people

8

people , for the people

11

the people

3

the people , by the people , for the people

7

the people , for the people

Query: people

Querying the Suffix Array

5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people

Query: people

Binary search: start in the middle

Querying the Suffix Array

5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	→ of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people

Query: people

Binary search: discard upper half

Querying the Suffix Array

5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people

Query: people

Binary search: middle of remaining space

Querying the Suffix Array

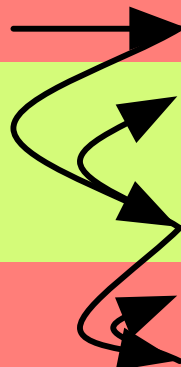
5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people

Query: people

Binary search: match

Querying the Suffix Array

5	, by the people , for the people
9	, for the people
6	by the people , for the people
10	for the people
1	government of the people , by the people , for the people
2	of the people , by the people , for the people
12	people
4	people , by the people , for the people
8	people , for the people
11	the people
3	the people , by the people , for the people
7	the people , for the people



Query: people

Finding matching range with additional binary searches for start and end

- Phrase translation probability

$$p(\bar{e}|\bar{f}) = \frac{\text{count}(\bar{e}, \bar{f})}{\text{count}(\bar{f})}$$

- Suffix array allows quick estimation of $\text{count}(\bar{f})$
- By looping through the \bar{f} , the $\text{count}(\bar{e}, \bar{f})$ can be collected as well
- If there are too many \bar{f} , we can resort to sampling

Summary

- Use of machine translation in translation industry becomes standard
- Interaction between machine and human open problem
- Not very much research in this area
- Open source toolkit: CASKAT