A Computational Framework for a Cognitive Model of Human Translation Processes

Michael Carl

Center for Research and Innovation in Translation and Translation Technology
Dept. of International Languages Studies & Computational Linguistics
Copenhagen Business School, 2000-Frederiksberg, Denmark

Abstract. Human translation process research analyzes the translation behavior of translators such as, for instance, memory and search strategies to solve translation problems, types of units that translators focus on, etc. and determine the temporal (and/or contextual) structure of those activities or describe inter- and intra personal variation.
Various models have been developed that explain translator's behavior in terms of controlled and uncontrolled workspaces and with micro- and macro translation strategies. However, only few attempts have been made to ground and quantify translation process models in empirical user activity data. In order to close this gap, the paper elaborates a computational framework for a cognitive model of human translation. We investigate the structure of the translators keystroke and gaze data, discuss possibilities for their classification and visualization and elaborate how a translation model can be grounded and trained in the empirical data. The insights gained from such a computational translation model does not only enlarge our knowledge about human translation processes, but has also the potential to enhance the design of interactive MT systems and help interpret user activity data in human-MT system interaction.

1 Introduction

In the past years MT has become widely available, covering many language pairs. [1] Development for new language pairs are increasingly short [1] and the quality of the translation product increases based on the available resources and the similarity of the source and target languages.

However, to obtain high quality translations as e.g. for dissemination some kind of human intervention is necessary. In order to ensure the required translations quality and simultaneously increase translation production time, numerous technologies exist or are experimentally implemented that ease human-machine interaction. A Machine Translation (MT) system may either work in a batch process as is the case in MT

[1] At the time of writing this paper the google translation tool offers 58 source and target languages, which amounts to more than 3000 different language pairs.

post- or pre-editing (e.g. controlled language translation) or in an interactive modus. In the case of interactive *rule-based MT*, the user interfaces of some MT systems (e.g. Systran, ProMT) allow the translator to extend or modify the lexical databases of the system at translation time; other systems interactively ask for disambiguation information [2] which may be stored in a "companion" file for late reuse [3]. Recent implementations of interactive *data-driven MT systems* experiment with translation completion (TransType2, [4]) and translation options [5].

Whereas interactive rule-based MT systems ask for assistance to disambiguate the source text analyzes by providing linguistic knowledge of the SL, interactive data-driven MT systems ask the translator to provide or to disambiguate the TL, thereby putting the user into the center of the translation process [4]. However, non of the approaches has yet lead to all-satisfying approaches of human computer interaction.

In this paper we investigate the *human translator* who is supposed to work with the machine to produce a translation. Current models of human translation processes describe elements of human cognitive processes when they translate [6,7]. Those models aim at explaining and predicting translation behavior of novice and experienced translators, types of units that translators focus on, memory and search strategies to solve translation problems, etc. and how these strategies are acquired. However, up to date no attempts have been made to ground and quantify such models in empirical user activity data and to study these models in the light of interactive MT.

In this paper we argue that in-depth empirically grounded knowledge of human translation processes needs to be acquired and interpreted to understand in detail how humans translate. The insights from empirical translation process research could then be carried over to the design of interactive MT systems and help interpret the user activity data in a human-machine interaction. The long term aim of this work is to complement computational models of human translation processes with automated translation assistance, and to predict and validate human-computer interaction based on empirical translator activity data.

To study the human translation behavior, we have collected student and professional translator activity data, gaze and keyboard data, from 24 translations sessions. Each of the translations consist usually of three phases which different translators realize to a different degree: a skimming phase, where the translator gets familiar with the text and activates subsets of the mental dictionary; a drafting phase where sequences of words are read and translated in a loop process; and a revision phase, where the translated text is re-read and revised.

The paper focusses on formalizing and modelling the drafting phase: We fragment gaze and keyboard data into coherent units and analyze the amount of their overlap. Novice translators generally have a larger ST reading effort than experienced translators while experts show less fragmented typing behavior. Cognitive theories explain the reduced effort of expert performance by a higher degree of automatization of the mental processes, and the transformation of declarative knowledge into procedural knowledge. This transformation makes mental space for the experts' superior analytical, creative, and practical skills, which allows them to produce more fluent translations in shorter time and with lower effort, a lower number of production units and more instances of divided, or attention than novices do.

In section 2 we briefly outline current translation process theories and section 3 describes the User Activity Data which we collect from our translation experiments. We discuss the data structure of the user activity data, their segmentation, classification and visualization and link this with the available models of human translation processes. Section 4 gives an overview of cognitive architectures and section 5 elaborates elements of a computational framework for a cognitive model of human translation. Section 5 describes two approaches for a computational model of human translation processes, one based on ACT-R [8] and a statistical approach, both of which simulate an instance of expert performance.

Local translation operators and macro-strategies continuously intervene in the translation process and leave traces in the user activity data. Future work aims at a refined framework of translation operators and the quantification of their traces in the translation process data.

2 Models of Human Translation Processes

A distinction can be made between translation product research and translation process research. Whereas translation product research and comparative linguistics analyze the (differences between the) structure of the source text and their translation, translation process research investigates the cognitive processes of human translation activities.

Lörscher [9] was one of the first researcher to use thinking aloud, which according to him represents "a useful instrument to formulate hypotheses on mental processes in general and about translation processes in particular". Based on a number of translation experiments, he isolates five basic translator types and a number of complex types which differ with respect to how much the solution of a translation problem is automatized, whether the translator requires search, whether a translation problem is decomposed into smaller parts, and to what extent the translation problems can be verbalized. Lörscher finds that translators translating into their native mother tongue use more automatized and less complex linguistic strategies, while translators translating into their second language more likely fragment the translation problems into smaller pieces, using more complex translation strategies.

Lörscher [9] also shows that processing takes place at various levels simultaneously. Translators process largely in syntactic units at the word, phrase and clause level, but only very little at the sentence level. The higher the translation expertise, the more translators work in bigger units including the discourse level.

Höning [7] proposes a translation process model which makes the distinction between uncontrolled associative translation competence and a controlled translation workspace in which micro- and macro strategies are stored. The uncontrolled workspace is a necessary condition for the production of translations, which is more developed in expert translators and which is complemented by a controlled workspace. While the uncontrolled workspace activates frames and schemes from longterm memory and generates a number of translations options, the controlled workspace is acquired through extensive professional translation activities and serves to choose appropriate translation (sub)strategies. Göpferich [6] complements this model with translation competence comprising:

1. psychomotor competence: reading, writing, typing: require cognitive capacity
2. translation routine activation competence: recall and apply language-pairspecific transfer operations
3. tools and research competence: use translationspecific conventional and electronic tools
4. domain competence, such as terminological competence
5. communicative competence in the two languages: lexical, grammatical, pragmatic knowledge in the languages

Students and bilinguals process more at word level while expert translators process more at clause or at the discourse level (7%). Translators work retrospective-prospective creating a sense of context.

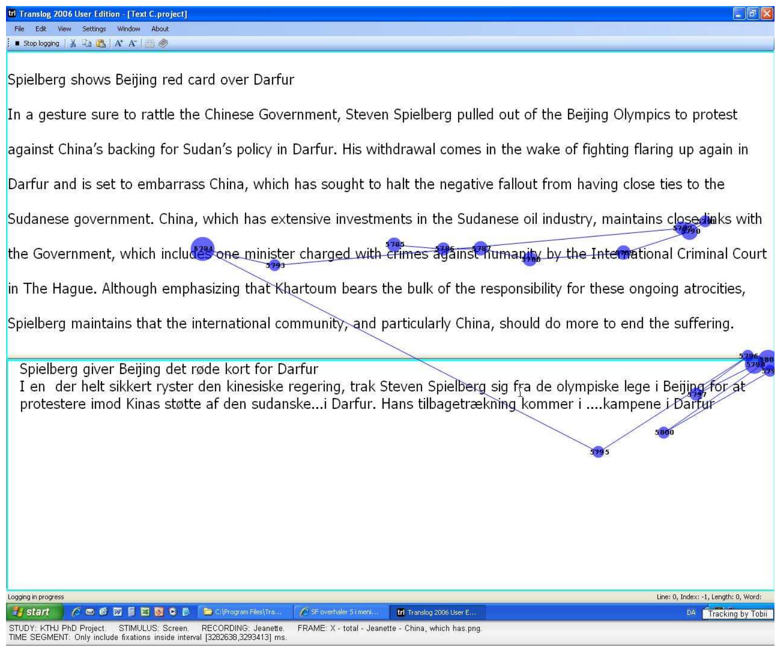

Fig. 1. The figure shows the number and durations of gaze fixation points accumulated during 10 seconds of translation pause when starting to read the third English sentence in the upper window. At this time the subject has already translated the beginning of the text into Danish in the lower window.

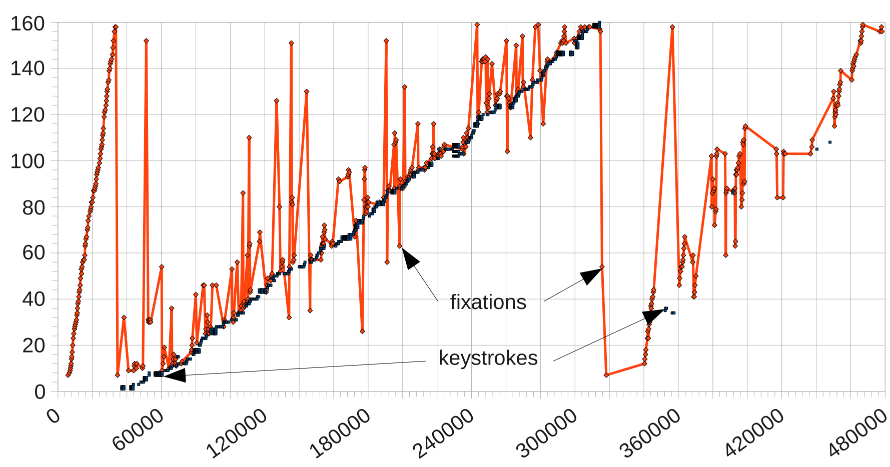

Fig. 2. The translation progression graph plots activity data, keystroke and gaze movements, in milli-seconds against word positions in the source text. The progression graph shows a separation into skimming, drafting, and revision phases.

3 Analysis of Translators Activity Data

Within the CRITT, we have developed a method and a data acquisition software, Translog[2], with which translators' activities (keystrokes and eye-movements) can be recorded. This tool is now the most widely used tool of its kind [10]. CRITT has also collected over the past years a substantial amount of translation process data from numerous translation sessions. The analysis of this data has given rise to more grounded translation models and a novel understanding of the underlying human translation processes [11].

As shown in figure 1, Translog separates the screen into two windows: the source text is shown in the upper window while subjects type a translation into the lower window. Figure 1 also shows the accumulations of fixation points (in blue) during the time span in which a translator reads a source language sentence ("Although empathizing that ...") and begins producing (i.e. typing in) its translation.

A translation session (or parts of it) can be represented in translation progression graphs as in figures 2, 3 and 4. The notion of *progression graph* was introduced by Perrin [12] to conceptualize and visualize writing progression. A *translation progression graph* represents the gaze and typing data in time. Translation progression graphs show where pauses and deletions occurred, and how keystrokes and gaze activities were distributed over time. It gives a general picture of how the translation developed, by relating each activity to the ST which is being translated.

Human translators are usually trained to proceed in three phases: *skimming*, *drafting* and *revision*. These phases are clearly visible in the translation progression graph in figure 2. In the skimming (or orientation) phase, the translator gets acquainted with the material, discovers the meaning of the source text, detects difficult terms, and may search for possible translations; in the drafting phase the actual translation is produced; and in the revision phase the draft is checked and revised. Depending on the size and type of the translation job, further revision cycles may be required, but one revision cycle tends to suffice in small-scale translations, as in the current experiment.

However, in practice, translators vary greatly with respect to how they produce translations [13]. While for every translation there is a drafting phase, large variances can be observed between translators even within the drafting phase. In this section, we shall look at two basic processing patterns in translation drafting.

[2] `www.translog.dk`

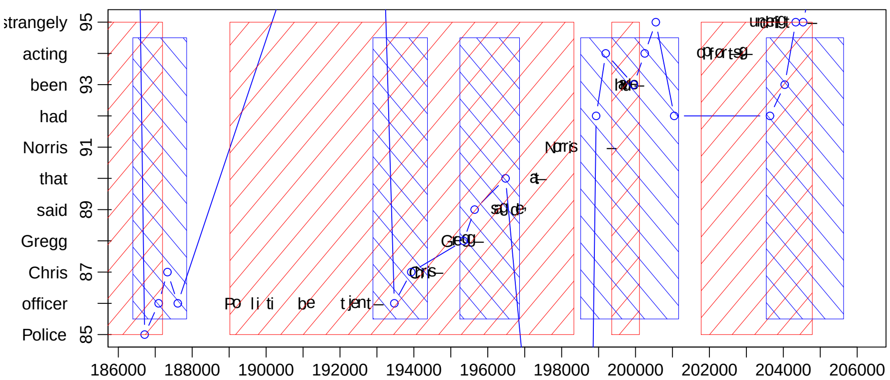

Fig. 3. Zooming into a translation progression graph: source text (vertical) and translation activities (horizontal). ST fixations connected dots (blue) and keystrokes in time. The graph plots translation activities of 20 seconds (ms. 186.000 206.000). It shows a long reading pattern at the onset of the sentence (sec. 186-189) followed by a number of parallel reading and typing activities. The larger hatched boxes represent production units, the smaller boxes are fixation units. Fixation units largely overlap with production units.

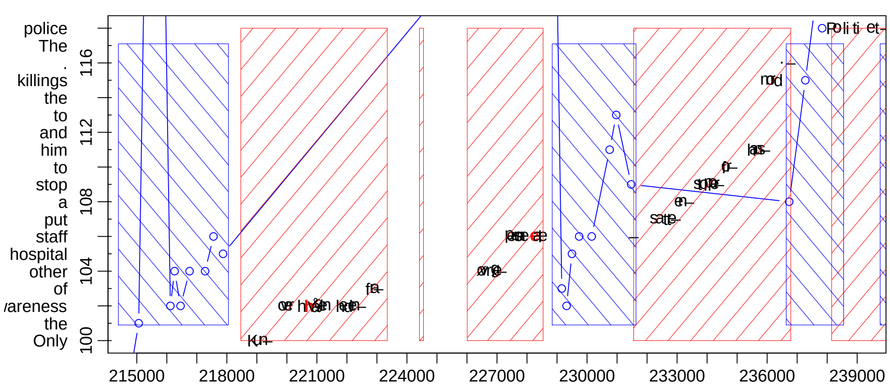

Fig. 4. This progression graph shows translation activities of 24 seconds, which are in the continuation of figure 3 for the same translator. Three reading pattern can be observed: one at the onset of the sentence (sec. ca. 214-218), one in the middle of the sentence (secs. 229-232) and a third before the beginning of the second sentence translation (sec. 237-238). This graph shows alternating (serial) fixation units (reading) and and production units (typing activities): a ST sequence is read and then typed.

Before a translation can be typed, a translator needs to read the according source text passage. As a basic translation behavior we can thus expect a loop in which a passage of the ST is first read and then the corresponding translation is produced. Figures 3 and 4 plot two fundamentally different realizations of this basic behavior, where production units (PUs) and fixation units (FUs) are either parallel (figure 3) or alternating figure 4.

A PU is a span of time in which one or more keystrokes occur and none of two successive keystrokes is separated by a pause longer than a given threshold [24]. That is, a new production unit starts after every pause in keystroke activities that is longer than the given threshold. In experimental investigations [13] and in line with other investigations [14,15] we assume this threshold to be around 800ms to 1000ms. That is, a lapse of time of more than 800-1000ms indicates a shift in the translators mind to another textual unit to be translated.

There is a strong correlation between the number of PUs and the overall translation time. Table 1 shows that student translators produce more and shorter PUs than professional translators, and that the translation time increases if more PUs are produced. In addition, table 1 shows that professional translators produce longer segments in time and in length, while the speed in which characters are typed is approximately identical for both groups, while figure 5 shows the relation between translation time and fragmentation of translation production.

	Professionals	Students
av. PU duration in ms	3113	2216
av. PU length in chars	17.61	12.54
av. (PU chars/PU dur.)	5.44	5.70
median (PU chars/PU dur.)	5.61	5.53

Table 1. Average PU duration, length and typing speed for professional and student translators.

In a similar fashion we fragment the stream of fixations into fixation units (FUs). A FU is a sequence of two or more ST[3] fixations where the time interval between the end of one fixation and the beginning of the

[3] Due to the fact that our software at the time of the experiments could not register fixations and word-mappings in the TT window, we only have fixations, and FUs in the ST.

next fixation does not exceed a given time threshold. Since reading is generally less linear than writing, and likely to skip e.g. function words [16], we also allow long saccades between non-adjacent words in the ST. A FU border occurs either if the translator's gaze leaves the the ST window, or if two successive fixations on the ST are separated by a long gap in time, which exceeds a predefined FU segmentation threshold.

FUs and PUs can either occur in parallel, at the same time (figure 3) if the translator writes a translation while reading a ST fragment, or sequentially, in an alternating fashion as in figure 4, where the translator either writes or reads.

A parallel segment is defined as a FU during which at least one keystroked is simultaneously typed, while an alternating segment is defined as a FU during which no keystrokes occur. [13] found that student and professional translators differ in their degree of parallel reading and writing activity. Figure 6 shows the correlation between translation time and the amount of alternating FUs: more alternating FUs go along with longer total translation time.

Table 2 shows that only a fraction of the overall gazing time is spent on the ST reading during translation, 20.3% 22.9% for Professionals and Students respectively. These results approximate the findings of [17], who measures 20% of gaze activities on the STC and [18], who finds that "far the most attention is devoted to the TT".

	Professionals	Students
#FU	652	634
ST reading time %	20.3	22.9
Parallel #FU	352	223
Parallel FU %	53.99	35.17
Parallel average dur.	1073	1428
Serial #FU	300	411
Serial FU %	46.01	64.83
Serial average dur.	1286	1588

Table 2. Parallel and serial translation (FU) for professional and student translators: while students and professionals have approximately the same overall number of FUs (first line), professionals show more parallel activities (352 FUs) and students work more in a serial manner (411 FUs). The average duration of serial FU is longer than the average duration of a parallel FU.

However, the average duration of the FUs differs with respect to their types (serial vs. parallel) and with respect to whether they are produced

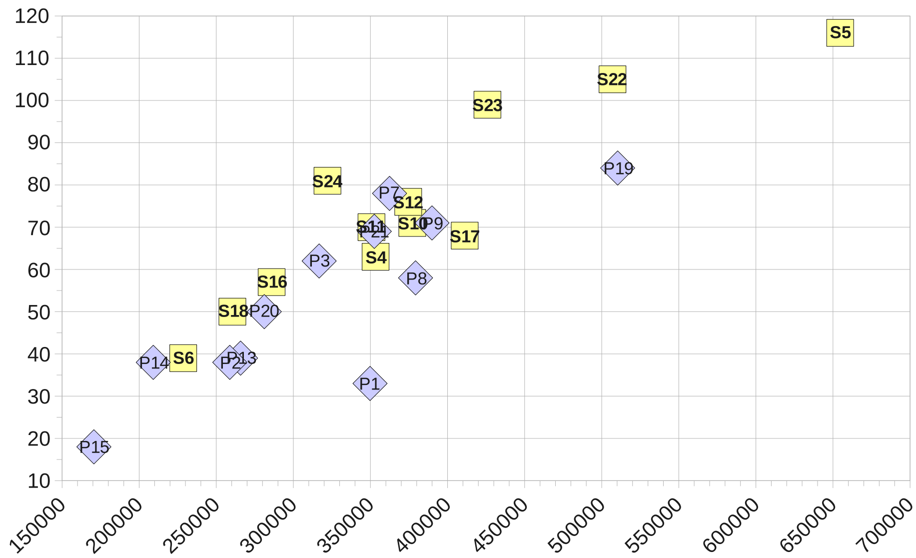

Fig. 5. The graph shows a strong correlation between the overall translation time (horizontal) and the number of PUs needed to produce the translation (vertical).

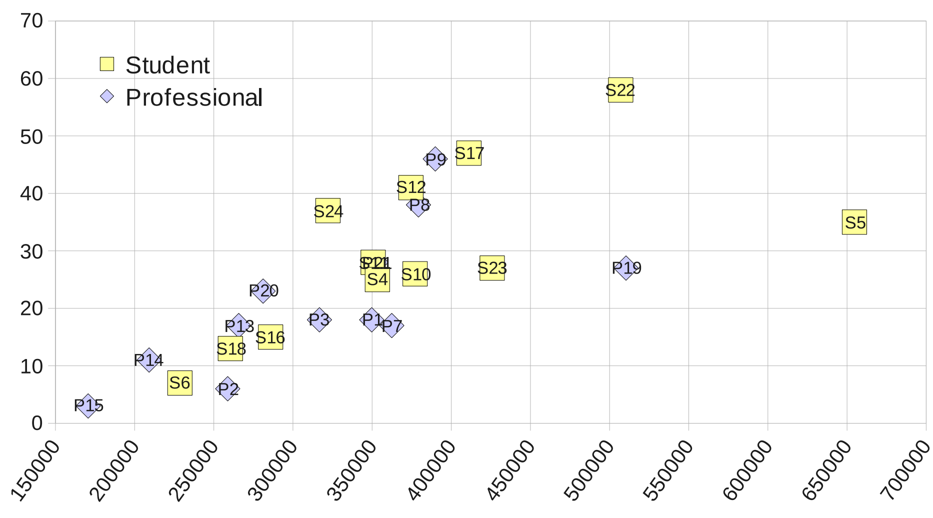

Fig. 6. Translation time (horizontal) and number of alternating FU (vertical) for students and professional translators. A strong correlation can be seen between the number of alternating gaze segments and translation time. Students tend to show more alternating segments than professionals

by students or by professional translators: Students have longer FUs than professionals (roughly 20%) and serial FUs are longer that parallel FUs.

Whereas for professional translators half of the FU overlap with text production (i.e. parallel production), this is only the case for roughly 1/3 of the student's gaze pattern. Notice also that the duration of serial FUs is slightly longer than the duration of parallel FU.

Since professionals need only 84% of the student's time to translate the texts, we suspect that the main factor that distinguishes student and professional translators is the latter's ability to better process in parallel. This is confirmed by the graphs in figures 5 and 6.

According to [19], students struggle more with ST comprehension than professional translators: in many instances, all attention is absorbed by reading and understanding the ST, and thus no TT production can take place at the same time. Skilled professional translators, in contrast, may already start typing the translation of a passage when still reading/understanding the end of that ST passage. Accordingly gaze patterns on the ST and typing activities of the TT may overlap and translation production time becomes shorter. Two types of behavior are thus to be distinguished for computational modeling:

1. most of the translation drafting is monotonous: translators look only a few words ahead into the ST position of what they are currently translating which leads to parallel activities. Much of the smaller translation problems, such as multi-word translations or local reordering may be may be solved during by this process. The degree of parallel activity depends on the typing skills of the translator. A touch typist would show behavior similar to the one in figure 3 while a translator with less developed motor skills would produce translation patterns as in figure 4.
2. at some points extensive reading behavior can be observed signaling more serious translation problems. For the experienced translator, this seems to be triggered by a TT production problem rather than a ST comprehension problem. That is, the ST is only understood to the degree required to produce a translation. If, for whatever reasons, the TT production fails with the given contents in the translator's working memory, the typing flow is interrupted, and the missing information need be sought. This can lead to a re-reading of a ST passage which needs to be verified or reinterpreted, or revision of the produced TT.

In the next sections we shall develop a computational model for the first type of behavior.

4 Computational Cognitive Architectures

While there are a large number of computational models to reproduce the translation product data (i.e. rule-based and statistical Machine Translation systems) there exists, to the author's knowledge no computational model of human translation processes. However, there are computational models of reading [20,21] and computational models of writing [22]. There exists also more generalized approaches to simulate the human mind in general, such as ACT-R [8] or ICARUS [23]. The ACT-R architecture adopts the view that cognition can be characterized as two distinct resources: a declarative resource that serves as a storage memory for factual knowledge and a procedural resource that integrates information and effects new behavior. In addition there are perceptual modules (motor, vision, auditory, speech) in ACT-R. Cognitive architectures have been applied to model and explain a number of human faculties, such as planning and problem solving, car driving etc.

More specialized models simulate certain aspects of human capacities. John [22] suggests an "engineering model" of typing texts which consists of three operators, a perceptual, a cognitive and a motor operator: the perceptual operator perceives a written words and encodes it into a an ordered list of letters, the cognitive operator initiates the characters in the list and the motor operator executes the typing activity.

> "The first three words are perceived with three perceptual operators; the spelling of the first word is retrieved from LTM with the cognitive operator; and the letters of the word, and the space following it, are initiated and executed in turn. " [22][p.105]

These operators can work simultaneously: while a portion of the text is perceived, another portion that is already encoded can be typed. However, for a word to be typed it first needs to be encoded and perceived, and there are no more than three words perceived ahead of the word which is currently being typed. Hence, as the typist looks only 3 words ahead in the text, no sentence understanding is required prior to typing - we shall assume the same model to be applicable for undisturbed, monotonous translation.

According to John, the perception of a word requires 340ms, the retrieval and encoding of that word takes 50ms and typing of each character is between 30 and 230ms, according to expertise of the typist. Whereas the duration of the perceptual and cognitive operators remain constant, practice in typing increases the typing speed, i.e. inter-keystroke time. As we will show below this cannot be verified for the translation scenario.

As for typing (copying), also for reading have been developed a number of computational models, most importantly the E-Z reader [20], and as an ACT-R implementation the EMMA model [21]. The E-Z Reader [20] provides a theoretical framework for understanding how word identification, visual processing, attention, and oculomotor control jointly determine when and where the eyes move during reading, while EMMA [21] is an implementation of E-Z Reader which is more general applicable than only to model reading.

EMMA predicts the observable movements of the eye that correspond to the unobservable shifts of visual attention. Visual attention begins with a command from the cognitive processor to move attention to a given visual object, whereas the visual system drives the eye movements and saccade planning. For instance, a visual-object with the value "3" represents a memory of the character "3" available via the eyes, not the semantic THREE used in arithmetic a declarative retrieval is necessary to make that mapping.

EMMA's control flow distinguishes four processes: cognition that drives shifts of attention, vision that shifts attention and encodes objects, eye-movement preparation that readies an eye movement, and eye-movement execution that includes both motor programming and execution. These processes run in parallel. Saccadic programming and eye-movement is, hence, decoupled from the shifts of attention.

As in E-Z Reader and in EMMA, also the vision module in ACT-R has two subsystems, a "where" system and a "what" system. The where system finds objects in the environment on the basis of spatial location and visual properties and the what system identifies and "attends" the object by placing a representation of it into a visual buffer, where "attention" refers to the process of integrating features that allows individual words to be identified. In the next section, we shall describe an ACT-R implementation

5 A Computational Model of Human Translation Processes

We have previously introduced a distinction between *translation processes models* and *translation product models*. While machine translation systems are computational models that simulate the relations between the source and the target texts, a computational model of human translation processes would seek to reproduce the sequence(s) of human translation activity for a given translation. In this section we discuss two translation process models, an ACT-R model and a statistical model.

The ACT-R model consists of 5 production rules (shown below) which run in a loop and which simulate unchallenged expert translation. The loop starts with searching for the location of the (next) word to fixate and executes a saccade to that word (the "where" system). The rule "locate-word" shifts then attention to the word looked at and recognizes the fixated visual object. Next a retrieval operation encodes the object and maps the form of the object to a (shallow) semantic representation. This is sufficient to retrieve in the next production rule an associated translation to the ST word. Whereas the rule "translate-word" retrieves the translation from memory, the rule "type-word" serializes the characters of the word and enters them into the keyboard.

- locate-word: find physical location on the screen
- attend-word: shift attention to word
- encode-word: retrieve word from mental dictionary
- translate-word: retrieve associated translation
- type-word: serialize spelling and type word

ACT-R allows to proceduralize the retrieval actions in the two rules "encode-word" and "translate-word" into one production rule by means of a process referred to as "production rule compilation" which would correspond to the behavior observed in expert translators. However, the modelling bottleneck in this ACT-R model are the motor activities and the keying of the characters: within ACT-R, it takes 250 ms to prepare the typing action, 50 ms to initiate the typing action, another 100 ms for the key to be struck, and finally it takes another 150 ms for the finger to return to the home row. In a ten finger model, each inter-key time may reduce to 200ms. A plot of the translation progression in a ten-finger model is shown in figure 7. While the ACT-R translation simulation in figure 7 is produced in exactly the same lapse of time (20sec.) as the human one in figure 1, all keystrokes are equi-distant in time and and there is exactly one fixation on each ST word immediately before the translation is produced.

However, in our data we observe that many successive keystrokes are separated by less than 200ms. Each keystroke-bigram seems to have their own temporal distribution. Figure 8 plots inter-key times for the six most frequent bigrams for Danish. For instance, the sequence "er" is most frequent in our Danish keystroke data and most of these bigrams are produced within a delay of around 60 to 80ms. That is, the delay between

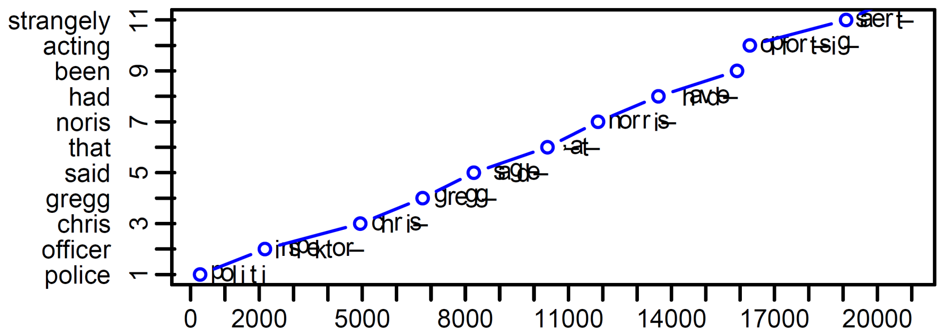

Fig. 7. The translation progression graph shows ACT-R simulation for the translation in figure 1.

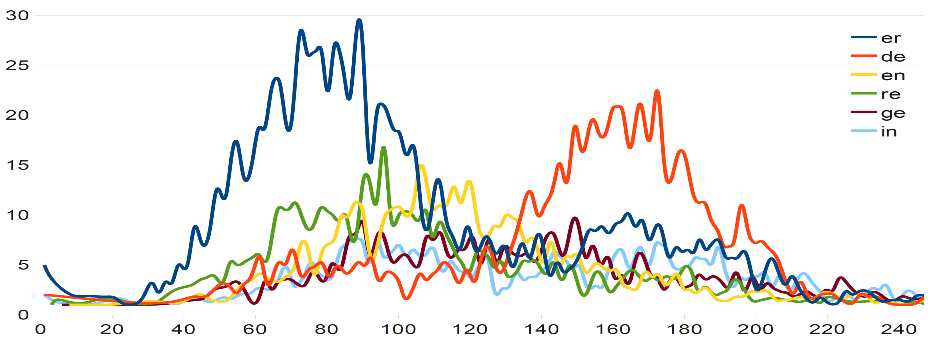

Fig. 8. Distribution of time intervals between the 6 most frequent successive keystrokes in Danish.

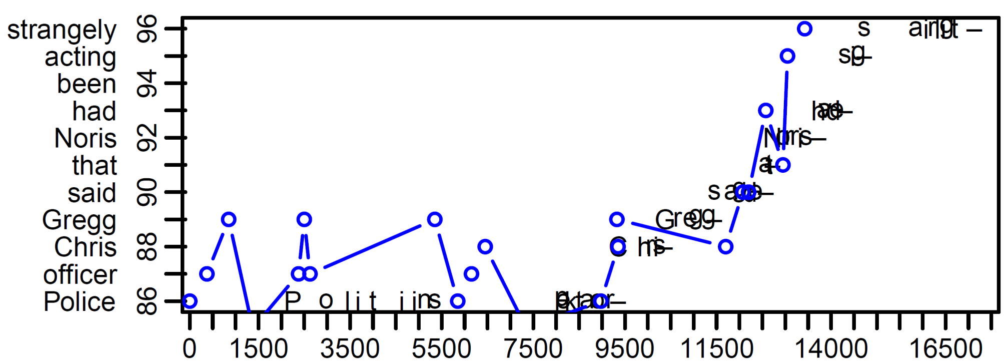

Fig. 9. This translation progression graph represents the same translation in figure 1 and figure 7 and is generated by means of the statistical model.

typing “e” and the following “r” keystroke is frequently around 60 to 80ms. The second most frequent keystroke bigram is “de” with a peak production time of around 160ms and also less frequent keystroke combinations (e.g. “rt”) have a peak around 190ms.

Since such statistical distributions are difficult to integrate into the ACT-R model, we have also experimented with a statistical translation process model. While a statistical model of the translation product (i.e. a statistical machine translation system) seeks to find the best (or most likely) translation T for given a source text S, a statistical model of translation processes would produce the (most likely) reading behavior R and writing behavior W for a given translation $S \longrightarrow T$. Thus, since the translation $S \longrightarrow T$ and hence the two texts S and T are known, the translation process model can be formulated as follows:

$$P(R, W|S, T) = P(W|R) * P(R)$$

where:

- R: $f_n \dots f_n$ fixations f on the source text S
- W: $k_1 \dots k_m$ keystrokes k producing translation T

We further decompose the complex writing behavior W into sequences of keystroke activities $w_1 \dots w_s$ where each sequences of keystrokes w_i consists of inter-key times for the typing activities of the translation for source word i, and where s is the number of words in S. The gaze activities R are decomposed into sets $r_1 \dots r_s$ where each r_i consists of the ST fixations which precede or occur simultaneously during the production of translation w_i. This decomposition of W and R leads to the following equation:

$$P(W|R) * P(R) = \prod_{i=1}^{t} P(w_i|r_i) * P(r_i)$$

Given the process data collected from 24 translators, we count for each ST word i the number of translation-producing keystrokes $C(w_i)$ and their associated ST fixations $C(r_i)$ and compute the translation process probabilities as follows: $P(w_i|r_i) = C(w_i, r_i)/C(r_i)$ and $P(r_i) = C(r_i)/\sum_{j=1}^{s} C(r_j)$. The most likely translation progression graph for the sentence given in figure 3 is shown in figure 9.

6 Discussion

We compare the three translation progression graphs in figures 3, 7 and 9. The human translation progression in figure 3 shows some reading activities before starting typing and towards the end of the sentence translation. There is less reading activity in the middle of the sentence where some of the ST words are looked at that are currently being translated.

In contrast to this, the ACT-R simulation in figure 7 has a very regular, static behavior: 200ms are needed for each inter-key time and there is exactly one fixation on every source word immediately before it is being translated. Even though the distribution of the keystroke events in the ACT-R simulation and in the human translation are quite different, the overall translation time is identical for both translations (20sec).

The statistical translation process simulation in figure 9 has a rhythmical keystroke distribution, with longer pauses during sentence initial typing of "Politiinspektor" and short inter key times towards the middle of the sentence, when translating the proper nouns. As in the human translation (figure 3), there are sentence initial and sentence final reading activities. This might be the reason why the statistical simulation appears closer to the human translation than the ACT-R simulation does, even though the overall translation time is 20% less.

Note, however, that these simulations only account for "undisturbed" translation. As in the E-Z reader, EMMA and for TYPIST, higher-order processes would only intervene when "something is wrong" and a signal would be sent to stop moving forward. As for the eye-movement behavior, we assume that cognition also drives translation and that typing movement needs to be initiated and interrupted by meta-processes.

As discussed in section 2, meta-processes [6,7] guide the human translation process and interve during translation production. Just like the E-Z reader [20] assumes word identification to be the forward "driving engine" in reading, we view the monotonous translation behavior, as outlined here, to be the default translation process by which chunks of words are knitted into larger target text units.

7 Conclusion and Outlook

In this paper we have described two models for human translation processes and defined production units in line with word boundaries. Source text fixation activities are allocated along with the word production segmentation.

Our data show that novice translators proceed in a more disrupted, alternating fashion (figure 3) than professional translators do (figure 4). However, in a previous study [24] we show that short sequences of keystrokes are typed at a similar speed by novice and by professional translators. This seem to indicates that keystroke are not individually prepared, initiated and struck, but rather that sequences of keystrokes are generated as small ‘programs’ where the preparation triggers an entire sequence of keystrokes, irrespectively of the translator’s expertise.

These small motor ‘programs’ could be interrupted through attentional shifts, for instance, if a spelling difficulty/uncertainty occurs, if a typo was detected, if a different wording comes to the translator’s mind, or if any other doubts occur. These typing programs can be quite long: our data shows sequences of up to 6 characters, such as “iserne”, “ntlige” or “ations” are typed in less than 600ms, with every inter-keystroke interval less than 100ms. The typing programs do not always co-incide with the spellings of words. More than 27% of the quickly typed sequences start and end in the middle of a word while only 33% start and end at a word boundary [24].

In future work we might seek to model production units which are in line with the typing programs to be the “driving engine” for translation where higher-order processes intervene in the target text production if translation problems occur. The model should then be able to explain and simulate regressions, revisions and corrections.

References

1. Lewis, W.D.: Haitian creole: How to build and ship an mt engine from scratch in 4 days, 17 hours, & 30 minutes. In: EAMT. Springer-Verlag (2010)
2. Boguslavsky, I.M., Iomdin, L.L., Lazursky, A.V., Mityushin, L.G., Sizov, V.G., Kreydlin, L.G., Berdichevsky, A.S.: Interactive resolution of intrinsic and translational ambiguity in a machine translation system. In: CICLing 2005. Springer-Verlag, Berlin Heidelberg (2005) 383 – 394
3. Choumane, A., Blanchon, H., Roisin, C.: Integrating translation services within a structured editor. In: DocEng ’05: Proceedings of the 2005 ACM symposium on Document engineering, New York, NY, USA, ACM (2005) 165–167
4. Macklovitch, E.: The contribution of end-users to the transtype2 project. In: Proceedings of the 6th Conference of the Association for Machine Translation in the Americas (AMTA-2004), Kyoto, Japan (2004) 197–207
5. Koehn, P., Haddow, B.: Interactive Assistance to Human Translators using Statistical Machine Translation Methods. In: MT Summit. (2009) `http://www.mt-archive.info/MTS-2009-TOC.htm`.
6. Göpferich, S.: Towards a Model of Translation Competence and its Acquisition: the Longitudinal Study TransComp. In: [25]. (2009) 11–37

7. Höning, H.G.: Translation Studies: The State of the Art, the first James Holmes Symposium on Translation Studies. In: Proceedings of the First James S Holmes Symposium on Translation Studies, Amsterdam (1991) 77–89
8. Anderson, J.: How Can the Human Mind Occur in the Physical Universe? Oxford Series on Cognitive Models and Architectures. University Press, Oxford (2007)
9. Lörscher, W.: Investigating the Translation Process . Meta **XXXVII** (1992) 426–439
10. Jakobsen, A.L.: Research methods in translation - Translog. In: [26]. (2006) 95–105
11. Mees, I.M., Göpferich, S., eds.: Methodology, Technology and Innovation in Translation Process Research. Volume 38. Copenhagen: Samfundslitteratur, Copenhagen, Denmark (2009)
12. Perrin, D.: Progression analysis (PA): investigating writing strategies at the workplace. Pragmatics **35** (2003) 907–921
13. Carl, M., Jakobsen, A.L.: Towards statistical modelling of translators activity data. International Journal of Speech Technology **12** (2010) `http://www.springerlink.com/content/3745875x22883306/`.
14. Alves, F., Vale, D.C.: Probing the Unit of Translationin time: aspects of the design and development of a web application for storing, annotating and querying translation process data. Across Language and Cultures **10** (2009) 251–273
15. Dragsted, B., Hansen, I.G.: Comprehension and production in translation: a pilot study on segmentation and the coordination of reading and writing processes. Copenhagen Studies in Language **36** (2008) 9–12
16. Radach, R., Kennedy, A., Rayner, K.: Eye movements and information processing during reading. Psychology Press, East Sussex (2004)
17. Dragsted, B.: Coordination of reading and writing processes in translation: an eye on uncharted territory. In: Translation and Cognition, Amsterdam/Philadelphia, Benjamins (2010) In press.
18. Jensen, K.T.: Distribution of attention between source text and target text during translation. In: IATIS. (2009)
19. Sharmin, S., Špakov, O., Räihä, K., Jakobsen, A.L.: Where on the screen do translation students look? Copenhagen Studies in Language **36** (2008) 30–51
20. Reichle, E.D., Rayner, K., Pollatsek, A.: The e-z reader model of eye movement control in reading: Comparisons to other models. Behavioral and Brain Sciences (2002) 1–102
21. Salvucci, D.: An integrated model of eye movements and visual encoding. Cognitive Systems Research **1** (2001) 201–220
22. John, B.E.: Typist: a theory of performance in skilled typing. Hum.-Comput. Interact. **11** (1996) 321–355
23. Langley, P., Laird, J., Rogers, S.: Cognitive Architectures: Research Issues and Challenges. Cognitive Systems Research **10** (2009) 141–160
24. Carl, M., Jakobsen, A.L.: Objectives for a query language for User-Activity Data. In: Natural Language Processing and Cognitive Science (NLPCS 2009), Milan, Italy (2009)
25. Göpferich, S., Jakobsen, A.L., Mees, I.M., eds.: Behind the Mind: Methods, Models and Results in Translation Process Research. Copenhagen: Samfundslitteratur, Copenhagen (2009)
26. Sullivan, K.P.H., Lindgren, E., eds.: Computer keystroke logging and writing: methods and applications. Volume 18. Elsevier, Oxford (2006)