

A Simple Movement Time Model for Scrolling

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ABSTRACT

A model for movement time for scrolling is developed and verified experimentally. It is hypothesized that the maximum scroll speed is a constant at which the target can be perceived when scrolling over the screen. In an experiment where distance to target and target width were varied, it was found that movement time did not follow Fitts' law. Rather, it was linearly dependent on the distance to the target, suggesting a constant maximum scrolling speed. We hypothesize that the same relationship between movement time and target distance apply to other computer interaction tasks where the position of the target is not known ahead of time, and the data in which the target is sought is not ordered.

Author Keywords

Scrolling, movement time model, Fitts' law.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation: User interfaces.

INTRODUCTION

The design of the computer desktop is among other things guided by quantitative models of movement time. "Laws of action" have been discovered that accurately describes the average movement time in a number of interaction situations, such as pointing and steering [2]. Scrolling is another widely used interaction technique [13], but a satisfactory and widely accepted model has yet been developed that accounts for the time used in the general case of scrolling. Scrolling is important to both the classical desktop WIMP interfaces, but also as computing moves to new areas such as mobile computing, where display size is limited. An example is the PDA that today offer applications for people on the move, but with significant less screen real estate.

A model predicting movement time is especially relevant in the design and evaluation of input techniques for scrolling. With a model that adequately accounts for the time spend in scrolling, it is possible to compare techniques across varying experimental conditions, which otherwise would not have been possible.

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Scrolling experiments to date have been focused on target acquisition [13, 5], effectively turning scrolling into an aimed movement paradigm just like pointing. This paradigm focuses on only the last part of the scrolling process. In practice the process of controlling scrolling for the purpose of finding the target in motion could be just as important an aspect as capturing the target upon finding it.

Hinckley and colleagues [5] have shown that certain scrolling patterns can be modeled by Fitts' law. In this paper we build on their work by investigating movement time when the target position is not known ahead of time. We question the applicability of Fitts' law in the general task of scrolling and other tasks. Fitts' law is developed for "aimed" movement whose velocity profile is typical a bell curve (accelerate and decelerate) with no speed plateau [1]. We believe that scrolling in unsorted data where the target position is not known, is not only dependent on the time it takes to physically move a pointer or other means of control as Fitts' law predicts, but is also limited by human perception, specifically visual scanning. Visual scanning limits the maximum speed beyond which one can keep track of the visual content for scrolling purpose, and thus we expect to observe a speed plateau in the velocity profile of scrolling.

Our initial exploration includes studies of the following factors: distance to target, target width and control/display ratio. An experiment is presented where the movement time is observed for the common task of scrolling in text documents. Distance to target and target width was varied, and the results were evaluated using quantitative data analysis.

SCROLLING IN ONE DIMENSION

To develop a movement time model, we study the simplest case of scrolling, scrolling in one dimension, to establish a base relationship. Scrolling in one dimension is most commonly done in text, but also scrolling in the time dimension of audio and video is increasingly common for both desktop and mobile users. In the work presented here we focus on scrolling in text.

Scrolling techniques and devices

Techniques for scrolling in one dimension can be classified by the type of mapping used. Most common is position based mappings, such as the mouse wheel and the scroll bar. Alternative to position based mappings are mappings that

employ a higher order transfer function. An example of such a mapping is used in the Scrollpoint [13], where a small isometric joystick controls the rate at which the document is moved. The advantage with direct control of the rate is that the user has the ability to scroll very fast, and at the same time the precision needed to reach an exact point regardless of document length. Recently, several novel techniques has been proposed using circular motion [9, 10].

In practice the aforementioned techniques are often combined into a single pointing device, making the device *multi-stream* [13], such as the wheel mouse or Scrollpoint mouse.

Human motor capacity

Interaction techniques such as pointing and scrolling have been evaluated and modeled using Fitts' law of aimed movement. Fitts' law predicts the movement time T to a target with distance D , also called the amplitude of movement, and target width W in one dimension. In HCI it is often formulated as [8]:

$$T = a + b \log_2(D/W + 1) \quad (\text{Equation 1})$$

where a and b are empirically determined constants. The logarithmic part of Equation 1 is often defined as Index of Difficulty (ID). In Fitts' original experiment on aimed movement, movement time was measured between tapping two visible targets with a pen. The task was performed in succession over a time duration, and the average movement time was used in evaluating the human motor capacity. A similar setup was used to evaluate movement time in scrolling by Hinckley et al. [5]. In that experiment participants repeatedly scrolled up and down between two target lines as fast as possible. The participants knew the target position, and thus they did not have to rely solely on visual feedback to find the target. What Hinckley effectively measured was the performance of the input device used in scrolling, minimizing possible effects caused by the feedback during scrolling. In studying the applicability of Fitts' law in HCI, MacKenzie [8] notes that Fitts' law is likely to be usable only in situations with negligible or known preparation time. However, in many tasks it is not only the mental effort used in preparing the task, but also during the task that can limit the applicability of Fitts' law. An interaction technique can be limited by the human motor capacity, but also by perception and cognition.

Another issue is the effect of control movement scale on input. Control movement scale was formally studied in the steering law [2] where it was found that performance for tasks with same ID but different movement scales did result in different completion time, but the difference was relatively small compared to the impact of ID change. In the preliminary exploration phase of this work a number of experiments was carried out with few participants where control-display ratio was varied, using either a relative or absolute mapping. We did not observe any significant effect on movement time. This result is in agreement with [2] since the effect is relatively small compared to varying the ID.

Feedback

When scrolling text, the primary form of feedback is visual. The feedback can appear as a smooth scroll when scrolling at lower speed, or as smeared or blurred when scrolling at high speed.

To avoid blurring when scrolling at high speed, Igarashi et al. [6] devised a technique that continuously adapted the zoom factor during scrolling, depending on the speed of scrolling. At high speed, the text was zoomed out, so that the scrolling speed remained constant. The technique makes it possible to maintain overall orientation in the document when scrolling at high speed, but reading the text or other means of perceiving the content at a higher level of detail is not possible. The technique was in the study evaluated to be equally effective when compared to traditional scrolling, but the participants liked the new technique better.

Other examples of helping to maintain perception of position in the document has successfully been applied using additional visual feedback [12, 7].

Visual scanning of static data (non moving) is either done attentively or pre-attentively. When scanning for words or sentences that do not have outstanding typographic features the scanning will be attentive and depend linearly on the number of distractors [11]. For moving text, the visual scanning time is likely to be the limiting factor in movement time. If the features that are sought can be scanned pre-attentively, such as a line with a different color than the rest of the text, the scanning time is independent of the number of distractors. However, in scrolling only a portion of the whole document is shown at a time and thus the speed at which the document can be moved and the target line seen is likely to be a limiting factor here too.

A simple model

We propose a linear model for movement time T in scrolling:

$$T = a + b D \quad (\text{Equation 2})$$

where a and b are empirically determined constants, and D is distance to target. T is limited by the maximum rate at which the target can be perceived when scrolling over the screen. The constants a and b accounts for the maximum scrolling rate and will depend on factors such as input device, control-display ratio, display size and type of target.

EXPERIMENT

In the experiment we use a setup similar to that used by Hinckley et al. [5], but with an important difference. The user has to scroll until a target line is reached, but the position of the target line is unknown at the beginning of the trial. When the target line becomes visible the user will adjust the target position to be within the required range and press a button.

Design

We ran the experiment on a computer sufficiently fast to avoid latency and non-smooth scrolling. We used a 21 inch CRT screen, with a text window 847 pixels wide, and 600

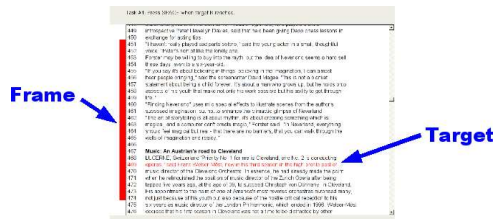


Figure 1. Screenshot of running experiment.

pixels high. Each line was 21 pixels high, and the length of the document used was 1200 lines. The smallest possible movement of the scroll bar corresponds to exact 2 lines in the text. Figure 1 shows a screenshot.

An optical mouse was used as input technique directly mapped to the handle of the scrollbar. The mouse cursor was not displayed, and the user did not have to click the handle before moving the mouse. This mapping was chosen to avoid the delay needed for users to point and click the scroll bar handle, and to avoid the users interacting with the scrollbar in other ways. We chose to use an ordinary optical mouse with a scroll bar and ordinary text display as input technique, because this is a commonly used technique for scrolling documents and because the focus of this paper is not on device/technique comparison.

The text document used was a collection of newspaper articles from the culture section of International Herald Tribune. To the left of each line was displayed a line number. The articles were marked with an empty new line and the heading displayed in Bold. The target line was marked by red text. To ensure a certain uniformity of the target lines, all target lines were at least as long as the average line length used in the document and no target line was a heading, i.e. marked in bold.

The goal was to find the target line, and position it within the range specified by the frame, a red vertical bar on the left of the text display. The tolerance defined by the frame is called target width.

The choice of marking the target with red, was partly because it is identical to the method used in [5], partly because it is a method that can be expected to interfere less with reading speed and higher order cognitive processes compared to searching for a specific word or sentence. The red line was relatively easy to identify when scrolling through the document, but still could be missed. The marking of the target is artificial in the sense that it is not a common task to search for red lines in a document. The result we obtain from the experiment is highly dependent on the type of target we use. However, since our hypothesis is that the scrolling speed is dependent on the maximum perceivable rate of the target, the relationship is not changed by the type of target, only the maximum scrolling speed.

In choosing a target more close to a natural task, such as finding a specific sentence or description, we might however observe other interactions. For example the scrolling direction is likely to influence the maximum

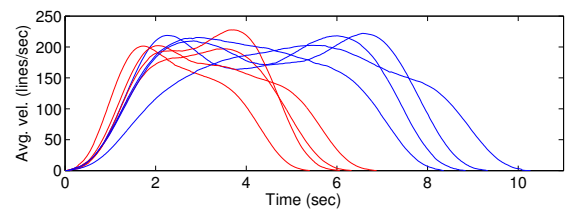


Figure 2. Average velocity as a function of time plotted for 1 subject in 8 trials using two target distances. $D=673$ lines (red), $D=1109$ (blue).

scrolling speed, because it can be expected that people read faster forward than backwards.

Procedure

A fully-crossed, within-subjects factorial design with repeated measures was used. Twelve subjects participated in the experiment. Independent variables were the target distance (amplitude of movement, $D=16, 235, 454, 673, 892, 1109$ lines), width ($W=4, 12$ and 24 lines), and starting point (top or bottom). In the condition with a target width of 4 lines, there were only two valid positions for the target line to reach the target. A target of 24 lines, is close the the screen length of 28.6 lines. Each condition was repeated twice. Starting point was varied by alternating the starting point to be at the top or the bottom of the document. Target distance and width was ensured to be repeated twice in each start position; otherwise the presentation order of these two variables was chosen randomly.

Analysis and Results

The dependent variables we used were movement time and error. In Figure 2 example velocity profiles are shown for two target distances. It can be seen that the speed does not follow a bell curve, but it reaches a plateau as predicted.

Figure 3 shows a correlation of movement time as a function of target distance. A linear fit is done for all data points, with a correlation of 0.97 ($a=4573.6$ msec, $b=9.6$ msec/line). This suggests that indeed there exist a tight linear relationship between target distance and average movement time. In comparison the correlation between the data and linear regression of movement time as a function of ID is 0.72 (Figure 4). A significant difference in movement time was observed for target distance ($F_{5,55}=13.90, p<0.001$), and for target width ($F_{2,22}=8.13, p=0.002$). Pairwise comparison showed significant difference between target width of 4 lines and the two other width conditions ($p<=0.021$), but no other significant differences. The mean movement time for each width condition is shown in figure 5. No significant differences in movement time across start position ($F_{1,11}=3.641, p=0.083$) was observed. There were no significant difference in number of errors across target distance ($F_{5,55}=0.53, p=0.756$), width ($F_{2,22}=2.10, p=0.146$) or start position ($F_{1,11}=0.044, p=0.838$).

Target width only slightly affected the results of the experiment but is likely to play a role in scrolling, as shown by Hinckley. The total scrolling time can be formulated as bound by at least two factors: the time used in visual

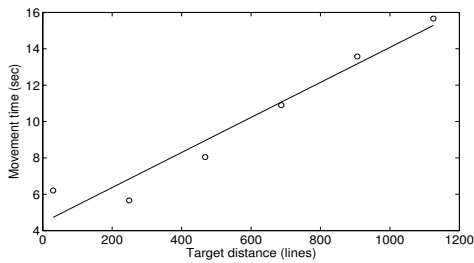


Figure 3. Linear regression of target distance against movement time.

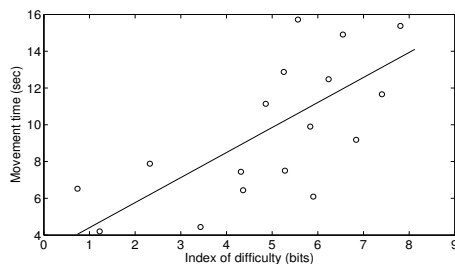


Figure 4. Linear regression of ID against movement time.

scanning and the time used to perform aimed movements. In the beginning and ending phases of a scrolling action, the movement time is likely to be bound by human motor performance, i.e. in the task of speeding up and slowing down to reach the right point. Between the starting and ending phases of the scrolling, the visual scanning seems to be the limiting factor rather than the motor performance as measured through an input device. Given a different search task where the target cannot be found by pre-attentive scanning, we might expect the movement time to be significantly higher than what is observed in this experiment, caused by the limit in scanning speed rather than motor performance. Exact how much time is used in each phase, and how movement time can be described in the starting and ending phases of the scrolling movement should be a subject of further investigation.

CONCLUSION

We have examined the relationship between movement time and scrolling in a text document. We found that for a task that more closely resembles scrolling than what Hinckley and other have presented, we find a tight linear relationship between movement time and distance to target, with a correlation coefficient of 0.97. In comparison the correlation coefficient between observed data and a regression based on Fitts' law is only 0.72.

Applying this to the design of scrolling techniques is especially important. Evaluating scrolling techniques using an experimental setup similar to the one used here, ensures that not only the input device is evaluated but also the type of feedback, which is an equal important part of scrolling. The proposed model is likely to apply to other interaction tasks where the target position is not known ahead of time, and the data in which the target is sought is not ordered.

Looking at input devices in isolation, the relationship between movement time and target distance is in favor of

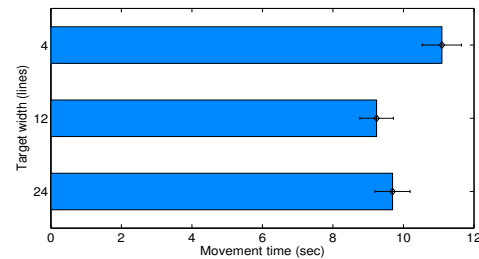


Figure 5. Mean movement time for different target width.

rate based scrolling techniques, where an optimal scroll rate can be held constant without any limb movement as opposed to position based devices that requires continuous adjustment to maintain a constant rate.

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REFERENCES

1. Abend, W., Bizzi, E., & Morasso, P. Human arm trajectory formation. *Brain*, 105 (1982), 331-348.
2. Acott, J. and Zhai, S. Beyond Fitts' law: Models for Trajectory-Based HCI Tasks. In *Proc. CHI 1997*, ACM Press, 295-302.
3. Acott, J. and Zhai, S. Scale Effects in Steering Law Tasks. In *Proc. CHI 2001*, ACM Press, 295-302.
4. Fitts, P.M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, 47 (1954), 381-391.
5. Hinckley, K., Cutrell, E., Bathiche, S. and Muss, T. Quantitative Analysis of Scrolling Techniques. In *Proc. UIST 2002*, ACM Press, 65-72.
6. Igarashi, T. and Hinckley, K. Speed-dependent Automatic Zooming for Browsing Large Documents. In *Proc. UIST 2000*, ACM Press, 139-148.
7. Kaptelinin, V., Mäntylä, T. and Åström, J. Transient Visual Cues for Scrolling: An empirical Study. In *Ajunct Proc. CHI 2002*, ACM Press, 620-621.
8. MacKenzie, I. S. Movement time prediction in human-computer interfaces. In *Proc. Graphics Interface 1992*, Canadian Inf. Proc. Society, 140-150.
9. Moscovich, T., Hughes, J. F. Navigating Documents with the Virtual Scroll Ring. In *Proc. UIST 2004*, 57-60.
10. Smith, G.M. The Radial Scroll Tool: Scrolling support for... In *Proc. Of UIST 2004*, ACM Press, 53-56.
11. Ware, C. Information Visualization. (2000). Morgan Kaufmann Publishers.
12. Wirth, M. and Zhai, S. Visual scrolling feedback and method of achieving the same. 2000. US patent 6,476,83.
13. Zhai, S., Smith, B.A. and Selker, T. Improving Browsing Performance: A Study of Four Input Devices. In *Proc. INTERACT 1997*, 286-292