# Rapid Visual Flow: How Fast Is Too Fast?

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## Abstract

It is becoming increasingly common for user interfaces to use zooming visual effects that automatically adapt to user actions. The MacOs X 'dock' icon panel, for instance, uses a fisheye distortion to assist users in targeting items. Another example is 'speed-dependent automatic zooming', which has been shown to improve scrolling by automatically varying zoom level with scroll speed—when scrolling fast the document is zoomed out, but when scrolling slowly the document is fully zoomed in. When implementing automatic zooming interfaces, designers must calibrate the behaviour of their zooming systems so that the visual effects allow rapid navigation without stressing the human visual system. At present, these calibrations are derived from trial and error. This paper describes an attempt to determine metrics of visual flow to answer the question "how fast is too fast"? Our main focus is on automatic zooming in document scrolling tasks. We performed an experiment to measure participants' preferred and maximum-tolerable scrolling speeds at two different magnifications. We found that magnification affected the length of time that data needed to remain on screen. We also used the data to provide estimations regarding the appropriate calibration of threshold values in speed-dependent automatic zooming systems.

*Keywords:* Visual flow, scrolling, zooming, magnification, speed.

## 1 Introduction

Scrolling is one of the most fundamental activities in computer use. In an analysis of five-hours of web use, Byrne, John, Wehrle & Crow (1999) observed that users spent 40 minutes scrolling. They commented that "An obvious case where widget design could make a difference is scrolling". Igarashi & Hinckley (2000) identified the problem that scrolling too fast results in the information blurring (see Figure 1). Motion blur can cause disorientation, and reduces the users ability to determine whether they have reached their target.

Igarashi & Hinckley proposed speed-dependent automatic zooming (SDAZ) as a solution to the problem of motion blur when scrolling rapidly. SDAZ automatically alters the zoom level, based on scrolling speed. The document is smoothly zoomed out when the user's scrolling speed exceeds a predefined threshold. The resulting lower magnification means that information need not be moved so rapidly across the screen to achieve the same comparative rate of navigation through the document, thereby reducing the motion blur. A video demonstrating several SDAZ systems is available at `www.cosc.canterbury.ac.nz/~andy/sdaz.mov`



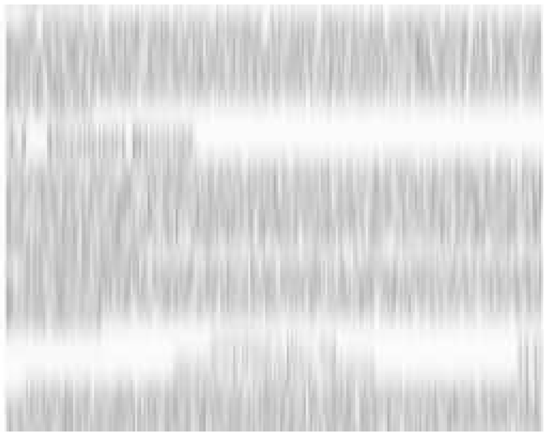


Figure 1: Scrolling too fast causes intolerable blurring. (Image generated artificially using *The Gimp.*)

In order to calibrate an SDAZ system, a value needs to be set for the threshold. Igarashi & Hinckley refer to this threshold value as one of several "predefined constants" used in their equations, but do not provide the values of these constants. Cockburn & Savage (2003) in their analysis of SDAZ also mention that they use a threshold, but similarly say nothing about the specific value used. Anecdotal evidence from the designers and implementers of SDAZ systems suggests that a large proportion of the implementation effort in constructing SDAZ systems is spent in fine-tuning the zooming behaviour through an informal look-and-feel approach.

The experiments reported in this paper aim to aid SDAZ designers and implementers by exploring the relationship between zoom level, rate of display movement, and user comfort. They also investigate the fundamental question of whether lowering magnification actually reduces motion blur.

The following section briefly describes some of the human-factors research on motion blur and uses these to derive theoretical estimates for the amount of time that scrolling data should be displayed while moving. The evaluation is described in Section 3, and the results are presented in Section 4 prior to a discussion of further work.

## 2 Document Scrolling

### 2.1 Human-Factors

Research into human visual perception has found that the human eye summates signals over a period of 120-125ms (Card, Moran & Newell (1987), Burr (1980)). Though the more recent signals are given more weight (Zagier 1997).

This might lead us to believe that we could predict the level of blurring by simply using the data's displacement in a 120ms time slot. Burr, however, found that observed blurring is significantly less than this model would predict. This is because the human visual system reduces blur by tracking moving objects with smooth-pursuit eye movement (Eckert & Buchsbaum 1993). Tracking moving targets with the eye reduces the relative velocity of the image across the retina. Smooth-pursuit eye movements cannot be induced voluntarily; instead, in the absence of an object to track, the eye moves in saccades which are very rapid eye movements of up to 900 degrees per second (Ware 2000).

Visual accuracy can usually tolerate an image retinal velocity of up to 3 degrees per second (Morgan & Benton 1989), with a comfortable velocity being around 2 deg/s (Kelly 1979). However, the introduction of smooth-pursuit eye movement allows movement in excess of 9 deg/s (Eckert & Buchsbaum 1993), perhaps even up to 100 deg/s (Blohm & Schreiber 2002), as the tracking of the target reduces the retinal image velocity to a manageable level.

### 2.2 A Theoretical Estimation

Let us assume that the user will use major headings and images as cues about where they are in the document when scrolling. A few informal calculations suggest that the tolerable scrolling velocities are somewhere around 20 deg/s. Hence, it will be necessary that the smooth-pursuit system activates to track the target. Thus, we can predict the time required as follows:

- The time taken to recognise a portion of the document as being an important landmark in the document will be ≈200ms according to Card et al.'s model, as it requires one cycle of both the visual system and the cognitive system.
- The time taken for the smooth-pursuit system to activate and reduce the retinal flow to an acceptable level will be ≈150ms according to Rashbass (1959).
- The time taken to identify an image is ≈100ms according to Spence. Alternatively, the time taken to read a three-word heading will be ≈ 200-600ms. This value is calculated from the normal reading rate which is approximately 280 words per minute (Kang & Muter 1989).

Therefore, a crude approximation would say that images need to be on-screen for about 450 milliseconds to be recognised properly, and headings for between 550 and 950 milliseconds to be read. However, we believe that when the user is familiar with the document that the pages themselves are treated as images—the shape of the layout of the text forms an image recognisable to the user.

### 2.3 Reflections on units of speed

The introduction of the idea of different levels of magnification (in such systems as SDAZ, for example) means that two distinct measurements of speed need to be separated.

Let us define *document speed* as the rate at which navigation through the information space is occurring. This will be measured primarily in units such as pages/second or lines/second. It is this value that it is desirable to maximise in order to acquire the target more rapidly.

Let us define *viewer speed* as the rate at which information moves across the display. We believe it is most convenient to measure this value in terms of *screen time*. That is, using units of seconds. Alternative units that might be used for this include cm/s, pixels/s and degrees/s. These alternative units can be calculated as functions of screen resolution, physical screen size, and viewer distance from the screen. Since, we are dealing with image velocities of significantly greater than 3 deg/s, the smooth-pursuit system is reducing the actual retinal image velocities to manageable levels, rendering the actual image velocity in deg/s somewhat irrelevant. The more generalisable unit therefore, should be *screen time*, which is in agreement with our theoretical analysis.

Given these definitions there will be a relationship between document speed and viewer speed as a function of magnification:

$$Viewerspeed = Magnification/Documentspeed$$

## 3 Evaluation

The objective of the experiment was to obtain empirical data on the rate of information flow that humans find comfortable and tolerable when scrolling rapidly. The experiment is also designed to reveal whether automatic zooming enables faster document navigation.

The participants' tasks involved setting 'comfortable' and 'maximum tolerable' scroll velocities for documents displayed at different zoom levels. The scrolling continued automatically; participants could only control the velocity at which the scrolling continued.

### 3.1 Participants

Twelve volunteer participants (ten male, two female) took part in the experiment. Eleven were Computer Science students and one was a Computer Science lecturer.

### 3.2 Apparatus

The system used for the evaluation was written in OpenGL/C, allowing us to exploit graphics hardware acceleration, which enables high frame rates ($> 300$ frames per second). The experiment was conducted on a 2.4 GHz Intel Pentium 4 computer with 512Mb RAM and a Geforce 4 MX Video card. The 19-inch display was set to 1280x1024 pixels, though the interface only took up 690x810 pixels. The software ran under Redhat Linux 8.

### 3.3 User interface

Initially the document was displayed stationary with page-one showing. Pressing pg-down caused the document to begin scrolling slowly towards the end. Further pressing pg-down increased the scrolling speed, while pressing pg-up reduced it. The up- and down-arrows could also be used to fine-tune the scrolling speed, with each arrow having only a tenth of the effect of the pg-buttons. The pg-buttons provided sufficiently fine adjustments (≈0.074 pages/s) that

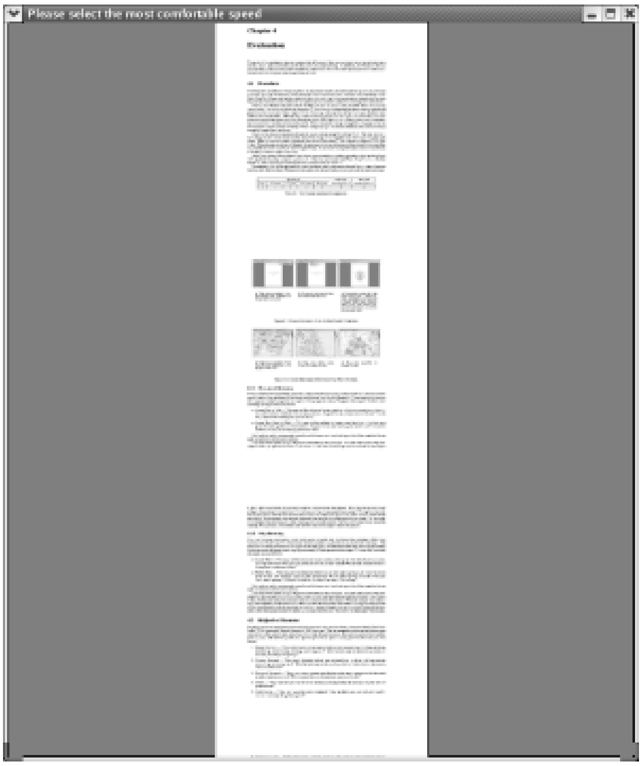


Figure 2: The user interface displaying a document at one-third magnification.

most participants found the use of the arrows largely unnecessary. When the end of the document was reached, the document started scrolling from the beginning again.

The document could be scrolled in one direction only (from top to bottom). Thus, continual pressing of pg-up or the up-arrow eventually reduced the scrolling to a halt, and further pressing of these keys had no effect.

Once an appropriate speed had been acquired, pressing the escape key recorded the speed and moved on to the next condition.

### 3.4 Experimental design

The experiment was a 2x2 repeated-measures design. The dependent measure was scrolling velocity. (This scrolling velocity will be reported in terms of both document speed and viewer speed.) The two factors were as follows:

- *Magnification.* The levels of this factor were full magnification (one document page on the screen at once) and one-third magnification (three pages on the screen at once).
- *Task Type.* The two levels of this factor were "most comfortable" and "maximum tolerable".

Participants were order-balanced in their exposure to the four conditions, using a Latin square, to avoid order effects.

The document used was a report (Savage 2002) with blank pages removed, which resulted in it being 28 pages (see Figure 2).

### 3.5 Procedure

An important part of the experiment lay in the participants' understanding of the meaning of the two different task types. Participants were advised to consider the task of scrolling through a familiar document with the goal of target acquisition in mind. They were instructed not to try and read the body text, but rather look for the locations of significant features such as pictures and section headings. They were asked to imagine they were scrolling through the document with the intention of navigating to a known heading or image.

The "most comfortable" speed was defined to be the speed at which they felt provided the optimal trade-off between acquiring the target quickly and maintaining an understanding of their location in the document. It was emphasised that this speed was to be the one at which they were most subjectively happy using to scroll through the document. They were advised to consider the question that "If this was your document and you were scrolling through it to get to another part of it, how fast would you go?"

The "maximum tolerable" speed was explained as the speed at which any faster was considered to be "too fast". Participants were told that this was the point at which they considered that if the document was scrolled any faster, they would no longer be able to see their target as it went by.

Each participant was questioned after the explanation of these two terms in order to ensure that they had fully understood the ideas behind them. (All participants had done so accurately.) By our understanding of the definition of these terms we expected that for any given participant, the "maximum tolerable" speed would be greater than the "most comfortable" speed. An analysis of the results showed that all participants had similarly understood the definitions.

Participants were strongly advised to rest their eyes regularly and were informed that there was no time limit. Most participants completed the four conditions in about five minutes. Three complained of eye strain, one commenting "my eyes hurt". Though another added, after expressing a similar complaint, "but if you look away for a bit, it's okay."

## 4 Results

We first present the results of the evaluation in terms of both viewer speed and document speed. We then discuss the practical applications of these results and their limitations.

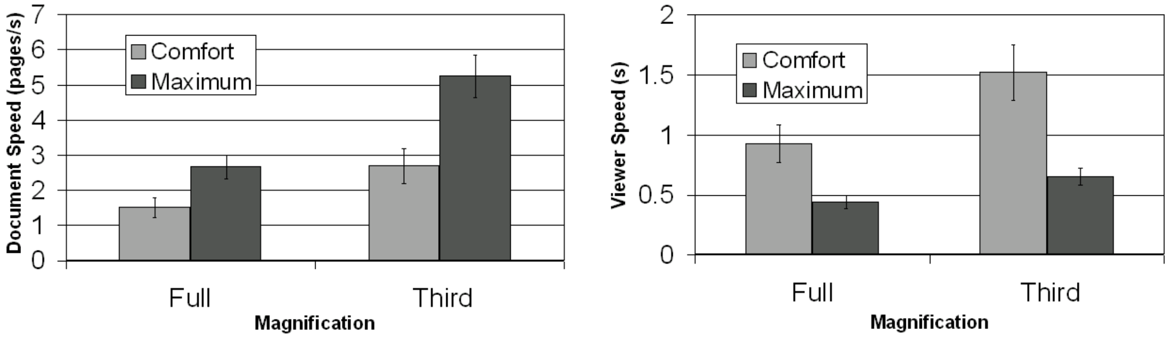
### 4.1 Document speed

A summary of the data obtained for document speed is given in Table 1 and shown in Figure 3(a).

An analysis of variance revealed a significant main effect for magnification ($F_{1,11} = 54.5, p < 0.001$). The effect of magnification on document speed is good news for SDAZ. It indicates (see Figure 3(a)) that reducing the magnification allows for much more rapid navigation through the document space while maintaining the same level of user comfort. Using the mean "most comfortable" speed, it would take 13.2 seconds to scroll 20 pages through a document at full

| Magnification | Task type | Mean | SD |
|---|---|---|---|
| full | max | 2.68 | 1.16 |
| full | comfort | 1.52 | 0.99 |
| third | max | 5.26 | 2.09 |
| third | comfort | 2.70 | 1.69 |

Table 1: Document Speed (pages/s).




(a) Mean Document Speed versus Magnification.

(b) Mean Viewer Speed versus Magnification.

Figure 3: Results.

magnification and 7.4 seconds to scroll the same distance at one-third magnification.

There was also a significant main effect for task-type ($F_{1,11} = 43.6, p < 0.001$) and a significant interaction ($F_{1,11} = 13.1, p < 0.005$). These will be discussed later.

### 4.2 Viewer speed

A summary of the data obtained for viewer speed is given in Table 2 and shown in Figure 3(b).

We had hoped there would be no main effect of magnification on viewer speed. This would have meant SDAZ systems could be implemented using the simple method used by Cockburn & Savage in which viewer speed is kept constant over all magnifications. However, we found a significant main effect for magnification ($F_{1,11} = 36.0, p < 0.001$), which implies a more complex relationship. We hypothesise two possible causes for this interrelationship:

- The reduced text size decreases reading rate, subsequently increasing the amount of time required to read the headings.
- The lower magnification results in more information being on the screen at once, which means the user is being presented with more data to process, thus requiring more time.

There was also a significant main effect for task type ($F_{1,11} = 24.4, p < 0.005$) and a significant interaction ($F_{1,11} = 8.7, p < 0.05$). These will be discussed in the next section.

## 5 Discussion

### 5.1 Task types

Our theoretical estimation suggested that 450–950ms would be an appropriate length of time for the information to remain on the screen. Our results at full

| Magnification | Task type | Mean | SD |
|---|---|---|---|
| full | max | 0.44 | 0.18 |
| full | comfort | 0.93 | 0.55 |
| third | max | 0.65 | 0.25 |
| third | comfort | 1.52 | 0.80 |

Table 2: Viewer Speed (screen time, in seconds).

magnification agreed strongly with this estimation. However, our results at one-third magnification did not.

In both result sets there was a significant main effect for magnification. This was contrary to our theoretical estimation which took no account of the magnification and thus predicted results independent of magnification.

The main effect for task type makes application of the results more difficult. It shows that viewer comfort begins to degrade prior to the point at which maximum performance is reached. Any calibration of a scrolling system will therefore have to consider the trade-offs being made between viewer comfort and performance.

The significant interactions measured also serve to reemphasise this point by showing that viewer comfort and maximum performance degrade differently with magnification. This makes the task of calibration difficult, because even if an optimal speed is found at one level of magnification, there is no easy way to determine the optimal speed at other magnifications.

The standard deviations obtained in our data were very large when compared to the means (see Tables 1 and 2). This indicates that the acceptable speeds varied significantly from user to user. The high variation suggests it may not necessarily be possible to find a speed that is acceptable to all users.

### 5.2 Practical values

We have already expressed concerned about the difficulty of recommending exact values for general use. However, concentrating on the application of SDAZ it should be possible to make some general suggestions.

In an SDAZ system it is desirable to zoom out sooner rather than later as the zoom out allows a higher document speed while maintaining the same level of user comfort. Also, if the zoom out does not trigger soon enough, then some users will find the visual flow too much. On the other hand, invoking the zoom out too soon could upset users who are only attempting to scroll short distances (one page, for example) and who do not want to trigger a zoom out. We therefore suggest that a zoom out should not be triggered until the viewer speed is in excess of the mean comfortable speed.

Since it is strongly desirable that it is not "too fast" for any users, we also suggest that the viewer speed exceed the maximum speed of, at most, 1% of

| Magnification | Mean comfort time | 1st percentile for maximum | Recommended screen time |
|---|---|---|---|
| full | 0.93 | 0.87 | 0.9 |
| third | 1.52 | 1.22 | 1.4 |

Table 3: Recommended calibration values (screen time in seconds).

users. That is, viewer speed should be less than what 99% of people indicated was their maximum tolerable speed. Note that this recommendation applies to interface mechanisms that provide constant document movement rather than very rapid 'burst' movements such as those produced when relocating a scrollbar thumb.

This data is displayed in Table 3, along with our recommended values which we obtained by selecting a value in the middle of the range given by the two suggestions.

### 5.3 Scope, generalisation and experimental concerns

There are several areas of concern in attempting to generalise from our results to guidelines for calibration of automatic zooming systems.

*Task type* Our experimental tasks were abstract ones in which the participants were asked to scroll at rates they felt were 'comfortable' and 'tolerable', independent of any actual search goal. There is a risk the resultant scrolling rates are not indicative of those the users would really use when executing their real tasks such as finding a known spatial location in a document, searching for a particular heading or picture, and so on.

We should note, however, that our on-going ecologically oriented evaluations, and our past evaluation (Cockburn & Savage 2003), are strongly focussed on realistic scrolling tasks. The purpose here, however, was to determine threshold values for SDAZ calibration.

*Participant demographics* All but one of the participants was in their early twenties, and all were experienced computer users. As such, they could be expected to be better at scrolling and more able to tolerate high rates of information flow than the general population. Furthermore, most of our participants regularly play computer games and may, therefore, have high tolerance for high visual flow rates.

*Scroll direction* Our experiment only involved document scrolling in one direction (top to bottom). Given that humans are used to reading from top to bottom it is entirely possible that different results would be obtained if we had examined scrolling in the other direction.

*Document type* We only used one document in the experiment. Perhaps if different documents were used (especially if they contained a different amount of graphics, different font sizes or different amounts of white-space) differing results might be obtained.

*Automatic versus manual scroll control* We asked participants to *imagine* they were scrolling through a document rather than having them perform the actual task of scrolling. It is possible that this caused a systematic error as participants may not have accurately estimated their scrolling speeds.

*Constant versus burst velocities* Our experiment involved constant velocities over a relatively long period. In real scrolling the velocities are only sustained for a relatively short period of time. It seems likely that people can tolerate a higher rate of visual flow if it is only sustained for a short period.

*Eye strain concerns* Several of our participants experienced eye strain despite our regular reminders to rest their eyes. It is possible that this fatigue meant participants were not able to tolerate flow rates that they might have otherwise found acceptable.

### 5.4 Other rapid display interfaces

Although our experiment focused strictly on document scrolling tasks, there are several interface types that would benefit for further work in the problems derived from motion blur. In particular, research into Rapid Serial Visual Presentation (RSVP) relies heavily on the human's ability to process information that is displayed for very brief periods. deBruijn & Spence (2000) describes RSVP as "the electronic equivalent of riffling a book in order to assess its content". Forster (1970) first used RSVP to explore the nature of human visual perception. He performed four similar experiments in which words were displayed in rapid succession and participants were then asked to record what they had seen. He found that syntactically simpler sentences require less time for participants to perceive them accurately. Increased informational content required an increase in the duration of exposure to the visual system, otherwise it resulted in decreased performance.

## 6 Conclusions

The task of scrolling involves a rapid movement through the information space. This movement can cause blurring if it occurs too rapidly. Igarashi & Hinckley proposed Speed-dependent Automatic Zooming as a solution to this, which invokes an automatic zoom out once information flow passes a predefined threshold. However, little work has been done to investigate an appropriate value for that threshold, neither is there conclusive evidence that a lower magnification actually allows a greater navigation rate.

We conducted an evaluation to determine an appropriate threshold value and whether magnification had an effect on the navigation rate. We found that magnification had a marked effect on the navigation rate and that zooming out allows a more rapid movement through the information space.

Our estimations of appropriate threshold values, based on our data, were that information should be on screen for 0.9 seconds at full magnification and for 1.4 seconds at one-third magnification. Our on-going work continues to validate and sure-up the empirical foundations for the design and calibration of SDAZ systems.

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