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Reading with screen magnification requires continuous horizontal scrolling to ensure that the magnified text of interest is within the screen viewport. We propose an algorithm that uses the reader's gaze to determine when to scroll the screen content, thus obviating the need for continuous mouse handling. Key to this approach is the determination at each time of whether the user is actively reading, in which case scrolling is activated. The scrolling speed is automatically adjusted to ensure that the gaze point lies within a certain region of the screen. To determine intervals of reading, the gaze track is first "compensated" to undo the effect of magnification and scrolling. This greatly simplifies gaze analysis, which can rely on standard fixation-saccade models of eye movement.

CCS Concepts: • **Human-centered computing** → **Accessibility**.

ACM Reference Format:
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1 Introduction

Screen magnification is a universally available tool that can be helpful for people with low visual acuity when accessing onscreen content, in particular, text. Full screen magnification uniformly expands the screen content around the center of magnification (CoM). As a result, areas that are far from the CoM may, after expansion, lie outside of the physical screen viewport. In order to see these areas, users need to move the CoM (using a mouse or trackpad) such that the content of interest is found within the screen viewport. For example, when reading a text line of a magnified document, users need to keep moving the mouse (and thus the CoM) to the right as they progress along the text line. When arrived at the end of the line, the mouse needs to be brought all the way to the left, moving the CoM to the beginning of the next line.

Manually scrolling the magnified content while reading can be cumbersome, especially for those with poor hand coordination, and can slow reading [Tang et al. 2023]. Arguably, removing the need for manual scrolling could simplify use of screen magnification, ultimately making reading more accessible to people with low vision. The simplest approach would be to simply let the content scroll right-to-left at constant speed. The technique (sometimes called *horizontal scrolling text* or HST), was shown in laboratory studies to enable reading of magnified text by people with simulated and real central vision loss [Akthar et al. 2021]. In practice, though, HST forces users to read at a pre-determined speed, which could make its use challenging (if the speed is too fast for the user) or inefficient (if too slow). In this contribution, we propose a new gaze-based method for automatic horizontal scrolling while reading text under screen magnification. Intuitively, this method could be seen as an "intelligent" version of HST, one that only scrolls the screen content when

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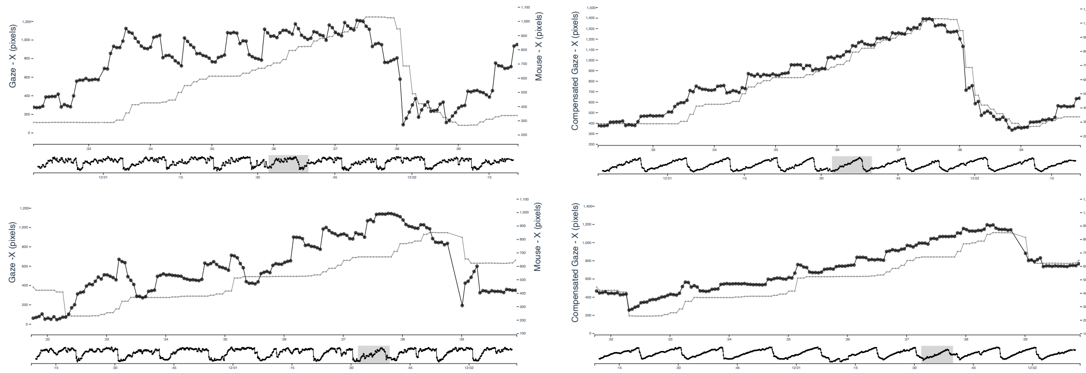

Fig. 1. Left panels: X coordinate of gaze data as a function of time (black line) recorded from two participants with low vision while operating a screen magnifier to read a text document, shown together with the location of the CoM (gray line). Data from the study described in [Tang et al. 2023]. Right panels: The X coordinate of the compensated gaze.

the user is actually reading, and adapts the scrolling speed to the user's own reading pace. Gaze is captured by an off-the-shelf gaze tracker; in our tests, we have used two different trackers (Tobii Pro Nano and Tobii Pro Fusion).

Key to our approach is its ability to robustly identify when the user is reading a text line, thus triggering scrolling right-to-left. In normal, un-magnified text reading, a reader's gaze point typically moves as a sequence of fixations and rightward saccades (rapid eye movements), with occasional leftward saccades [Reichle et al. 1998]. This dynamic behavior characterizes the act of reading, and simple mechanisms can be devised to differentiate between intervals of "reading" vs. "non-reading". For example, Sharmin et al. [Sharmin et al. 2013] detect pairs of consecutive fixations, then determine whether or not the user was reading based on order, distance, and intermediate saccade angle. Unfortunately, when reading with magnified text that is made to scroll right-to-left, the gaze track looks rather dissimilar from the "canonical" fixation-saccade sequence. As already noted in [Akthar et al. 2021], in these situations the gaze dynamic is better represented by a sequence of leftward smooth pursuit, alternating with rightwards saccades. This can be seen in Fig. 1 (left panels), which shows gaze tracks recorded from low vision readers using a screen magnifier, along with the CoM location [Tang et al. 2023]. What happens is that, when the text is scrolling right-to-left, the reader follows with their gaze a text point, before jumping to the next location in the text line. These smooth pursuit eye movements can thus be seen as "equivalent fixations", in the sense that the reader fixates on a moving text point. A detailed statistical analysis of eye movements under this modality can be found in [Heo et al. 2024].

Identifying intervals of active reading while using screen magnification from gaze tracks such as those shown in Fig. 1. may appear challenging. Thankfully, as shown in [Heo et al. 2024], it is possible to transform (*compensate*) these gaze tracks into something that faithfully resembles canonical fixation-saccade sequences. This compensation operations uses knowledge of the magnification factor and of the CoM location at each time (which corresponds to the location of the pointer on the screen, and thus is easily measurable).

In this contribution, we introduce an algorithm for the detection of intervals of active reading on magnified screen from data recorded by a gaze tracker, along with the application of this algorithm to an automatic right-to-left scrolling controller, which ensures that the portion of text to be read next in a line is located within the screen viewport, and regulates the scroll velocity based on the user's reading speed.

While we focus on full screen magnification in this contribution, we should observe that other magnification techniques are available. For example, “lens" magnification only expands the screen content in a small area around the pointer, and still requires the user to move the “lens" with the mouse. The need to move the CoM with the mouse can be obviated through other, “typographic" techniques, such as increasing the font of text in a Word file, or through Responsive Web Design (RWD), which re-wraps the text content to ensure that, after magnification, it does not exceed a certain horizontal extent. RWD is widely implemented in modern web sites, however, it may complicate navigation [Rathore and Singhal 2024], and is not available for documents that cannot be reformatted (e.g., PDF documents).

2 Prior Work

Although screen magnifiers are most commonly navigated using a mouse or trackpad, researchers have explored a range of alternative control techniques, including using a joystick [Kurniawan et al. 2002], or leveraging video saliency models to automatically detect, follow, and enlarge regions of interest within dynamic content [Aydin et al. 2020]. MagPro [Lee et al. 2020] extends this line of work in a different direction by augmenting office productivity software, enabling more efficient access to key commands when magnification is enabled. More recently, attention has shifted toward gaze-driven interaction, where the user’s eye movements determine the magnification focus instead of conventional pointing devices. Most of these approaches have considered the *lens* magnification paradigm, with the lens (magnification window) center being controlled directly by gaze [Aguilar and Castet 2017; Maus et al. 2020; Pölzer et al. 2018; Schwarz et al. 2020]. While this simple technique accomplishes the task of magnifying the text being gazed at, it may have the undesired effect of moving the lens as soon as one directs their gaze somewhere else, e.g. to quickly assess the layout of the screen content. To our knowledge, only one prior article focused on gaze-contingent automatic magnification control for *full screen* magnification. Specifically, [Manduchi and Chung 2022] considered two methods: *Dead Zone*, wherein constant speed right-to-left scrolling is activated when the user’s gaze lies in a vertical band at the right edge of the screen; and *Integrative*, which adjusts the scrolling speed according to the distance of the gaze point to the screen center. Neither of these control methods considered whether or not the user is actively reading text on the screen when deciding when to activate scrolling.

3 The Method

3.1 Preliminaries: Compensated Gaze

Gaze compensation, originally introduced in [Heo et al. 2024], maps the location of gaze point on the screen when reading magnified content, to the location being gazed at in the original, non-magnified content. A point (x, y) in the non-magnified content maps to a screen pixel (x_S, y_S), with $x_S = f_X(x, x_M, MF)$ and $y_S = f_Y(y, y_M, MF)$ after magnification, where (x_M, y_M) are the coordinates of the pointer in the screen, and MF is the magnification factor. The form of the mapping functions depends on the magnification system. For example, using the MacOS option that moves zoomed images to keep pointer centered, and denoting by W the screen width (in pixels), the function f_X takes on the following form:[1]

[1]Note that with this option, the magnified screen content is moved such that the CoM is at the center of the screen, except when $m_x < W/(2 \cdot MF)$ or $m_x > W - W/(2 \cdot MF)$, in which case it is moved to the left or to the right to ensure that only the magnified content is seen through the viewport.

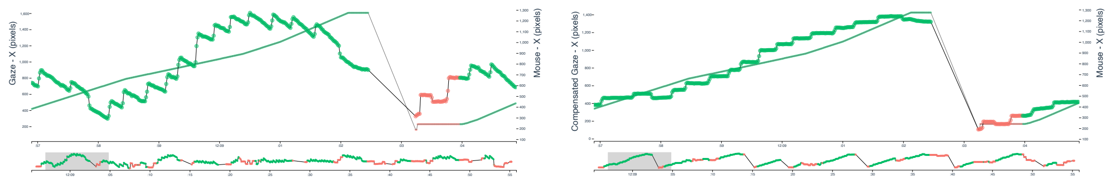

Fig. 2. Left panels: X coordinate of gaze data as a function of time (colored line) recorded while reading a text document under automatic scrolling control ($x_S(t)$), shown together with the location of the CoM. Right panels: The X coordinate of the compensated gaze ($x(t)$). Green points have been identified as "reading"; red points as "not reading".

$$f_X(x, x_M, MF) = \begin{cases} x \cdot MF & \text{if } x_M < W/(2 \cdot MF) \\ x \cdot MF + W(MF-1) & \text{if } x_M > W - W/(2 \cdot MF) \\ MF(x - x_M) + W/2 & \text{otherwise} \end{cases} \tag{1}$$

An identical form is obtained for f_Y, where the screen height H substitutes for W.

Given the gaze point location (x_S, y_S), the compensated gaze point x, y is obtained from (x_S, y_S), (x_m, y_m), and MF by trivially inverting f_X and f_Y. Tracking the compensated gaze allows one, for example, to determine progression while reading a text line on a magnified document. Compensation also conveniently transforms the graph of the function of the X coordinate of gaze point when reading magnified text from a sawtooth shape (Fig. 1, left panel) to the familiar staircase (Fig. 1, right panel) representing a sequence of alternating fixations and saccades.

3.2 Active Reading Detection

Our approach for the detection of reading intervals when using magnified screen relies on the observation that the X coordinate of the *compensated* gaze point, $x(t)$, grows approximately linearly in time (minus the "staircase" effect) when reading a horizontal text line (Fig. 2). Note that this would **not** be the case for the recorded, *uncompensated* gaze point $x_S(t)$, shown in the left panel of the aforementioned figure. Thus, the compensated gaze $x(t)$ during active reading should support a linear approximation with small residual. Accordingly, we compute a linear regression over the past 1.5 seconds of $x(t)$, and set an empirically determined threshold on the standard deviation of the residual. Note that in the study with low vision subjects reading with magnified screen reported in [Tang et al. 2023], the average values for fixation time and saccade where found to be 331 ms and 31 ms, respectively [Heo et al. 2024]. Hence, in the period considered for linear regression, we expect approximately four fixation-saccade pairs for these readers.

Additionally, we set a minimum threshold for the slope of the interpolated segment: if the segment is horizontal, the reader is not progressing along the line, and therefore there is no need to scroll the magnified content. When the screen is not being scrolled, a flat compensated gaze profile means that the reader is fixating a text character for a relative long time; if right-to-left scrolling is active, the user is following a character with their gaze through the extent of the screen. Examples of reading to non-reading transition are shown in Fig. 3. Note that an occasional backward saccade may sometime cause the system to believe that the user temporarily stopped reading (as it perturbs the otherwise monotonic progression of $x(t)$). Although this may cause scrolling to momentarily slow down, we did not find this to be a problem in practice.

We implemented two additional criteria that must be satisfied during active reading intervals. The first criterion regards the Y coordinate of compensated gaze, $y(t)$. Since text lines are horizontal, we expect $y(t)$ to be approximately

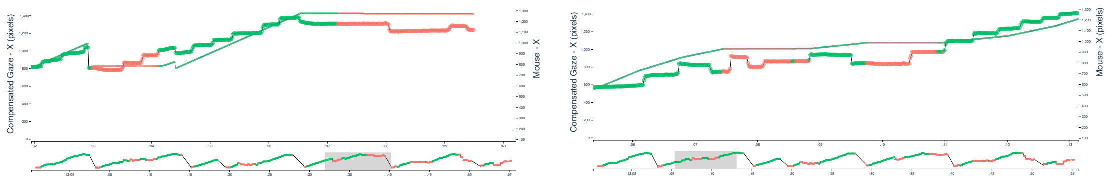

Fig. 3. Two different situations in which a "not reading" event was detected. X coordinate of compensated gaze as a function of time ($x(t)$, colored line) recorded while reading a text document under automatic scrolling control, shown together with the location of the CoM. Green points have been identified as "reading"; red points as "not reading".

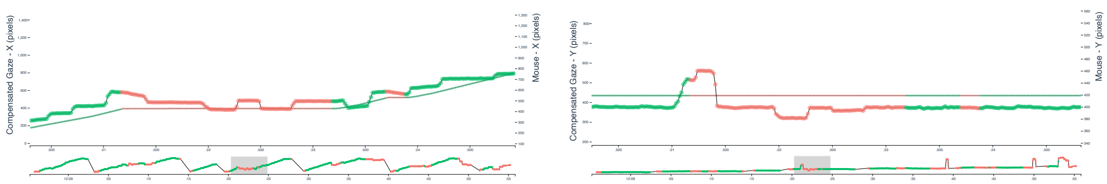

Fig. 4. Left panel: X coordinate of compensated gaze as a function of time ($x(t)$, colored line) recorded while reading a text document under automatic scrolling control, shown together with the location of the CoM. Right panel: Y coordinate of compensated gaze ($y(t)$). Green points have been identified as "reading"; red points as "not reading".

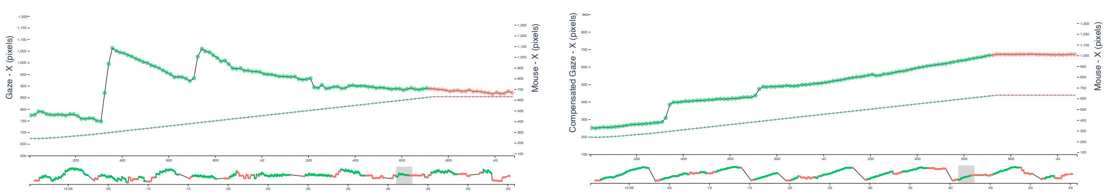

Fig. 5. Left panels: X coordinate of (uncompensated) gaze data as a function of time ($x_S(t)$, colored line) recorded while reading a text document under automatic scrolling control, shown together with the location of the CoM. Right panels: The X coordinate of the compensated gaze ($x(t)$). Green points have been identified as "reading"; red points as "not reading". The right third of the plots shows a situation in which the reader gazed at a fixed point on the screen while the content was scrolled right-to-left, generating a linear ramp of the compensated gaze. Once that was detected as a "non reading" situation, scrolling stopped.

constant along a text line, as indicated by its variance (also measured over the past 1.5 s). Fig. 4 shows an example with the reader jumping to a different line momentarily, triggering scrolling to stop.

The second criterion was inspired by a situation that we encountered a few times during our pilot tests. Occasionally, when the text is scrolling right-to-left, a reader may find themselves confused or overwhelmed (e.g., if magnified text is scrolling too fast), and "freeze", with their gaze fixating on a fixed point on the screen. Due to scrolling, the *compensated* gaze in these cases resembles a perfect ramp (see Fig. 5) – passing the linear regression test with flying colors, and thus leading the system to keep scrolling. To account for these potentially catastrophic situations, we implemented a simple test on the *uncompensated* gaze $x_S(t)$, by setting a minimum threshold on its variance, computed over a short period of time (0.5 s).

3.3 Automatic Scrolling Control

Right-to-left scrolling is activated when the system determines that the user is actively reading a line of text. An exponential filter is applied to the scrolling function, which is particularly useful to smooth out abrupt reading/not reading transitions. For what concerns the speed of scrolling, we designed a simple controller based on the following observation. If the scrolling speed is too low, readers may "outdo" it and find themselves at the right edge of the screen, waiting for more magnified content to appear. On the other hand, if the scrolling speed is too fast, the reader may find themselves trying to catch up with it, with their gaze progressing towards the left end of the screen (in the direction of scrolling). Accordingly, the controller has as its target to ensure that *uncompensated* gaze point (x_S) of the reader is approximately situated in the center of the screen width, by increasing or decreasing the scrolling velocity by an amount that is proportional to the horizontal distance of gaze to the screen width center.

We also borrowed a page from the "Dead Zone" algorithm [Manduchi and Chung 2022], and activate scrolling (at the appropriate speed) when the user's gaze is within a region at the right edge of the screen (we set this region width to be 1/10 of the screen width). This can be considered as a fail-safe measure, in case our reading detection malfunctions.

For what concerns *retracing* (moving the center of magnification to the beginning of the next line when the user is done reading the current line), we decided to let the user activate it by pressing the bar key, prompting a full screen left-to-right scroll. We also implemented a simple algorithm to scroll the magnified content upwards after retracing by an appropriate amount, computed based on the average vertical coordinate y_S of the *uncompensated* gaze point measured while reading the previous text line (with the goal to ensure that the magnified text line lies within the top half of the screen).

4 Conclusions and Future Work

We have presented a simple system for determining active reading intervals for readers of magnified onscreen text, and for the automatic control of right-to-left scrolling during reading. Our algorithm analyzes the progression in time of the X coordinate of compensated gaze (i.e., the equivalent gaze point on the un-magnified screen content), and identifies interval during which it grows approximately linearly in time. Additional tests involve uncompensated gaze (to identify situations when the user fixates a point on the screen) as well as the vertical coordinated of compensated gaze, which is expected to be relatively constant while reading an horizontal text line. Our scrolling speed control algorithm ensures that the gaze point, while reading scrolling magnified text, is approximately located in the center of the screen width. This algorithm has worked well in pilot tests, and we are planning for a user study that will involve participants with low vision, who will be tasked with reading different types of documents using our the proposed gaze-contingent magnification control system.

Our algorithm was motivated by the analysis of eye movements during reading, and informed by the data recorded in a prior user study by Tang et al. [Tang et al. 2023]. A natural evolution of this work would be to implement a machine learning-based controller that does away with the hand-tailored parameters, which were set empirically in this work. This system would need to be trained on reading vs. not reading labeled gaze data, recorded in a magnified screen reading context, such as the data set used in recent work by Heo & Manduchi [Heo and Manduchi 2025].

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