Noticeable or Distractive? A Design Space for Gaze-Contingent User Interface Notifications

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Abstract
Users are interrupted by an ever-increasing number of notifications, ranging from error messages, over new email or chat alerts, to advertisement pop-ups. We explore *gaze-contingent user interfaces notifications* that are shown depending on users' current gaze location. Specifically, we evaluate how different design properties influence notification noticeability and distractiveness. We measure noticeability quantitatively by analyzing participants' performance in confirming notifications and distractiveness using a questionnaire. Based on a 12-participant user study on a public display, we show that each of these properties affects noticeability and distractiveness differently and that the properties, in turn, allow for fine-grained optimization of notification display. These findings inform the design of future attentive user interfaces that could optimize the trade-off between, for example, the notification importance and the cost of interruption.

Author Keywords
Interruptions; Attentive User Interfaces; Eye Tracking; Public Display; Peripheral Display

ACM Classification Keywords
H.5.m. [Information Interfaces and Presentation (e.g. HCI)]: Miscellaneous

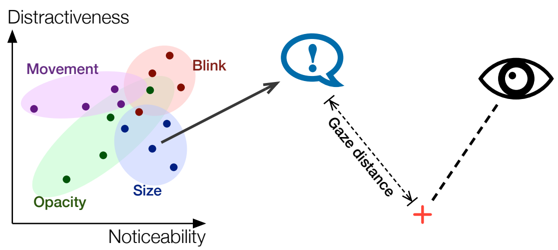


Figure 1: We explore gaze-contingent user interfaces notifications that are shown at a certain distance away from users' current gaze location (red cross) and evaluate their key properties in the 2-dimensional noticeability/distractiveness space.

Introduction

With digital communication having become a dominant part of our everyday life, we are overloaded by an ever-increasing number of notifications from different sources, such as mail user agents, chat clients, or social networking apps [7, 11]. Unimportant notifications interrupt users, thereby reducing user experience [16], while important or urgent information can be missed [14]. The development of attentive user interfaces that actively manage notification display to reduce interruptions has therefore emerged as an important research challenge in HCI [3, 9, 20].

Peripheral displays were proposed as a potential solution to this problem. The key idea is to take the users' visual field of view into account and selectively display information in the foveal area or the periphery [12, 13]. These displays can be generalized to *gaze-contingent displays* in which information is shown at different distances away from users' current on-screen gaze position [6]. By adaptively controlling this *gaze distance* as a function of, for example, the importance of the information to be delivered or current user engagement, unnecessary interruptions of the user could be avoided. Previous works also investigated gaze-aware interfaces, such as to indicate display changes [5] or to implement gaze-aware user interface components [8].

Some prior work on peripheral displays such as [2] discussed appearance properties of notifications in addition to the gaze distance reflecting the fact that appearance plays an at least equally important role in human visual perception. While foveal vision is particularly sensitive to color [22], peripheral vision is sensitive to motion [17]. Changing the appearance of notifications in addition to the gaze distance therefore promises further possibilities to exploit perceptual properties for notification management.

In terms of user experience, there are two closely related yet complementary concepts in notification perception: *noticeability* and *distractiveness*. While noticeability describes how easily a notification can be noticed by the user, distractiveness describes how much the notification keep the user away from his primary task. The goal of this work is to investigate a design space for gaze-contingent user interface notifications based on these definitions of noticeability and distractiveness (see Figure 1). The goal of notification is not always as simple as maximizing the noticeability. While urgent notifications can have larger distractivenesses, minor information should be displayed with the lowest possible distractiveness and the minimally required noticeability. By understanding how different visual properties affect users' perception in the 2-dimensional noticeability/distractiveness space, designers can have more control on notification management.

In this work, we provide an analysis on how different appearance properties impact noticeability and distractiveness of notifications, and how these properties interplay with the distance between the current on-screen gaze location and the notification. We measure noticeability quantitatively by analyzing participants' performance in confirming notifi-

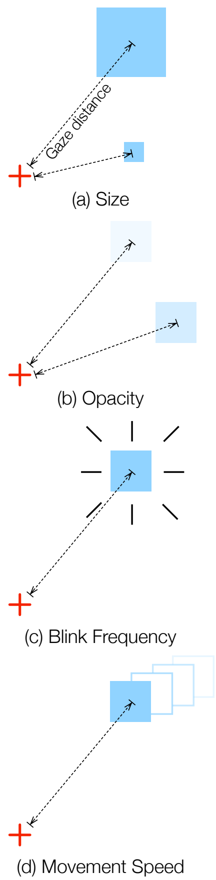


Figure 2: Design properties used in our study. In addition to the *gaze distance* from the user's gaze position (red cross), we consider (a) size, (b) opacity, (c) blink frequency and (d) movement speed of the notifications.

cations and distractiveness using a questionnaire. A key difference to prior work is that we propose and study this design space in a principled manner and jointly with gaze distance, and that we treat gaze distance as a continuous free parameter. Based on a 12-participant user study on a public display, we show that each of these properties affects noticeability and distractiveness differently and that the properties, in turn, allow for fine-grained optimization of notification display. These findings demonstrate the significant potential of gaze-contingent notifications, and promise new attentive user interfaces.

Gaze-Contingent Interface Notifications

To study the concept of gaze-contingent user interface notifications, we implemented a prototype notification system that exploits different characteristics of the human visual system. For better coverage of these characteristics and to gain flexibility in notification design, we opted to study notification designs that leverage variable gaze distances and different appearance properties.

Previously used visual designs exploit both stationary and dynamic notification properties [15]. While dynamic designs can increase noticeability, it has been also reported that dynamic notifications are perceived to be more distractive than stationary ones [23]. Another study reported that smooth motion can be perceived as less distractive [1]. It has been also pointed out that humans easily identify exceptions in color, shape and size in the peripheral view [21], and subtle animations such as fading have lower noticeability [12]. It is also important to note that notification perception depends on the task performed by the user [4, 18].

Appearance Properties

In our study we evaluated four commonly-used properties controlling notification appearance (see Figure 2): *size*, *opacity*, *blink frequency* and *moving speed*. Each of these properties was combined with the gaze distance, which is defined as the angular distance (d degrees) from the user's current on-screen gaze position. Three discrete values were used for the gaze distance (d=10, 25, 40) so that each can represent foveal (d=10) and peripheral (40) views from the user and the middle point (25) between them. In addition, three levels were considered for each appearance properties as discussed below.

Size One straightforward approach to change notification appearance is by their size (s=0.5, 1.0, 2.0 degrees) [21]. Size was defined in degrees with respect to the user's visual field. In the following, the medium size ($s = 1.0$) was used as the base size for other properties.

Opacity Opacity is another important property to control notification appearance [23]. We used an opacity of (o = 90%, 50%, 0%) ranging from near-transparent (90%) to fully visible (0%).

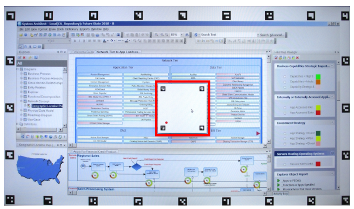
Blink Frequency Blinking is one of the most common dynamic appearance properties [2, 16]. We used a blink frequency of (b=1, 7, 12 Hz).

Movement Speed We finally used movement speed of notifications [23, 18, 4, 12]. Notifications started moving from a location 30 cm horizontally away with a constant speed (m = 2.25, 4.5, 36 cm per second).

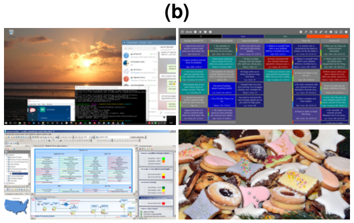
User Study

We conducted a user study to evaluate noticeability and distractiveness of gaze-contingent user interface notifications. As shown in Figure 3a, the study was conducted on a 56-inch public display with WUXGA resolution. The system was implemented using the PsychoPy framework [19],

(a)



(b)



(c)

Figure 3: The study was conducted on a public display with participants wearing a head-mounted eye tracker (a). The primary task window was shown at the center of the display (marked in red), and gaze-contingent notifications were shown in the background (b), with random background images (c).

and we used a state-of-the-art Pupil Pro head-mounted eye tracker [10] for obtaining real-time gaze positions. Twelve university students (four female) aged between 21 and 26 years participated in the study. Most participants had previous experience with eye tracking studies; none was color-blind and all had normal or corrected-to-normal vision. To evaluate noticeability and distractiveness under a realistic cognitive load, we asked participants to perform a dummy primary task on the public display. The task involved following a dot randomly moving at different speeds and colors in a primary task window with a mouse pointer (see Figure 3b, primary task window marked in red).

Procedure
Upon arrival in the lab, participants were first informed about the study and asked to sign a consent form. Afterwards the eye tracker was calibrated for each participant using a standard 9-point calibration routine. Participants were standing 60cm away from the display, and the primary task window (the small white window shown at the center of Figure 3b) was shown at the center of the display to cover the foveal area ($\sim 15°$) of the participants. Gaze-contingent notifications were shown in the background of the primary task window. The participants were instructed to focus on the primary task, and to press a button of a wireless presenter every time they recognize a notification. To remove false positive reactions, we counted button presses only in a small time span after a notification appeared. The noticeability was measured as the percentage of displayed notifications recognized by the participants.

As discussed above, each of the four appearance properties had three levels and all of them were combined with three different gaze distances. During the study, each of the $4 \times 3 \times 3$ design combinations was shown six times. The notifications were always light blue squares as illustrated in Figure 2, and did not contain any textual information. These notifications were shown in randomized order, for 2.5 seconds with a random interval of 2 ± 1.5 seconds. There was also a break every 15 minutes for participants to relax and to re-calibrate the eye tracker.

Since noticeability of the notifications highly depends on the background, random background images were shown behind the primary task window. The background images consisted of four real screenshots of ordinary desktop environments and two colorful photos (see Figure 3c for some examples). We ensured that each notification design was shown on all of the background images. Finally, we again showed all design combinations to the participants one by one and asked them to provide distractiveness ratings for each of them using a five-point Likert scale.

Results and Discussion
Figure 4 summarizes the results of the user study, illustrating the influence of the different appearance properties on noticeability and subjective distractiveness. Each of the 12 graphs in the figure corresponds to one combination of an appearance property and gaze distance. From top to bottom, each row corresponds to one of four appearance properties (size, opacity, blink frequency, and movement speed, respectively), while the three columns correspond to different gaze distances (10, 25, 40° from left to right). In each graph, the line plot shows noticeability (the percentage of notifications confirmed by participants) with respect to appearance properties. Three bar plots show histograms of subjective distractiveness score, where red and blue regions correspond to higher and lower distractiveness, respectively. Three levels of property values are ordered from the weakest (smallest, slowest, . . .) to the strongest (largest, fastest, . . .).

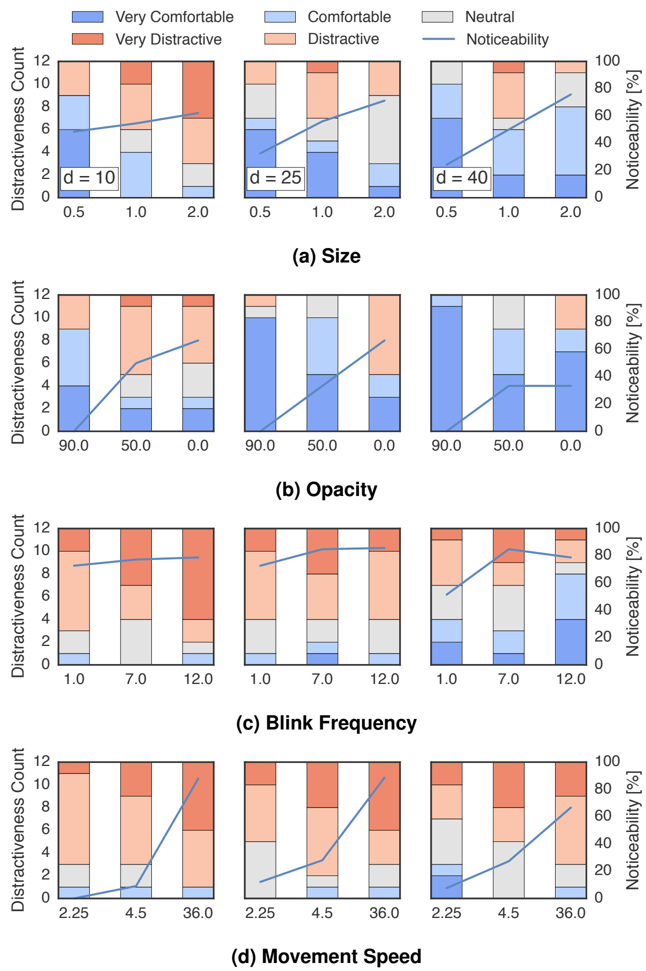
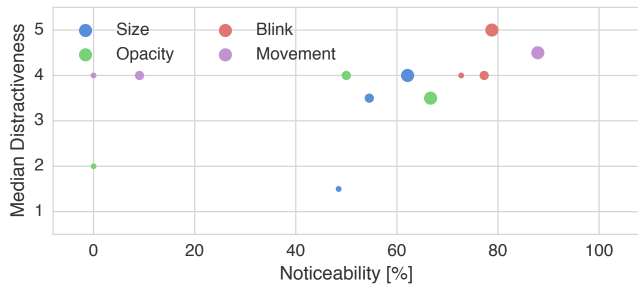


Figure 4: User study results with rows corresponding to the different appearance properties (size, opacity, blink frequency, movement speed) and columns to the gaze distances (10, 25, 40). The line plots show noticeability while the bar plots show histograms of subjective distractiveness scores.

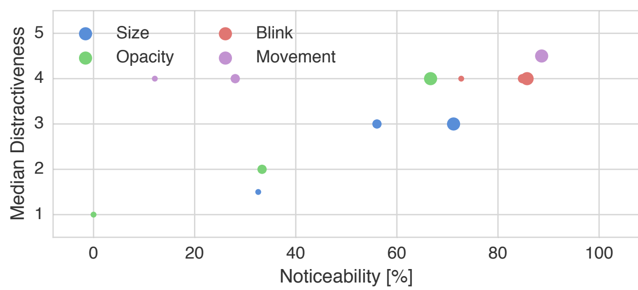
As can be seen from Figure 4c and Figure 4d, in general, dynamic appearance properties, such as blinking and movement, result in higher noticeability and distractiveness. However, slower moving notifications (2.25, 4.5 in Figure 4d) only increase distractiveness while their noticeability is significantly lower than for other properties. In contrast, static appearance properties, size and opacity, show lower distractiveness (see Figure 4a and Figure 4b). It can be seen in Figure 4b that increasing opacity is the most efficient way to reduce distractiveness among all properties.

Furthermore, while noticeability and distractiveness are both higher at close distances, they both behave differently at far distances. To further analyze the relationship between gaze distance, appearance, noticeability and distractiveness, Figure 5 shows overview plots of each appearance property in the noticeability/distractiveness space. The horizontal axis shows noticeability as in Figure 4, and the vertical axis shows median distractiveness scores among all participants. Each color indicates each appearance property, and the size of the marker shows the strength of the appearance property; the larger the marker, the higher the property value. Figure 5a, Figure 5b, and Figure 5c correspond to the three gaze distances 10, 25, 40, respectively.

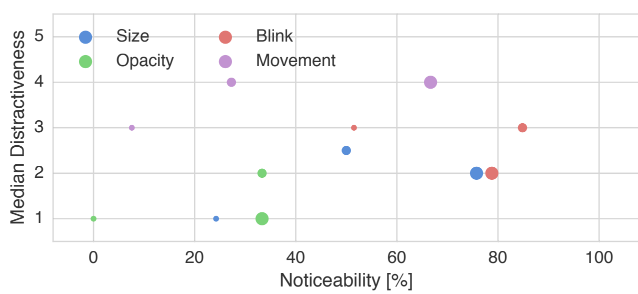
At the closest gaze distance (see Figure 5a), most notifications have both high noticeability and distractiveness. It is interesting to note, though, that the smallest size (smallest blue marker) results in lower distractiveness even for the closest gaze distance (paired t-test: $p = 0.02$ for $s = 0.5°$, M = 48.5, SD = 21.9 vs. 1.0°, M = 54.5, SD = 19.2, $d = 10°$). In contrast, at the furthest gaze distance, different appearance properties are covering different areas in the 2-dimensional noticeability/distractiveness space (Figure 5c). With larger size, notifications can be more noticeable (paired t-test: $p < 0.01$ for $s = 1.0°$, M = 50.0 , SD



(a) Gaze distance: 10



(b) Gaze distance: 25



(c) Gaze distance: 40

Figure 5: Noticeability (horizontal axis) and subjective distractiveness (vertical axis) for different notification appearance properties. Color indicates the type and the marker size the level of each appearance property.

= 21.3 vs. 2.0°, M = 75.8, SD = 28.3, $d = 40°$) while distractiveness remains lower. The similar tendency is also observable for blink frequency (paired t-test: $p = 0.01$ for $b = 1.0$ Hz, M = 51.5, SD = 9.8 vs. 7.0 Hz, M = 78.8, SD = 20.3, $d = 40°$). Opaque notifications can achieve lower distractiveness with mid-level noticeability, while fast moving notifications can still achieve higher noticeability. Taken together, these findings illustrate the significant potential of gaze-contingent user interface notifications and show that the different appearance properties offer flexibility to control distractiveness and noticeability.

Conclusion

In this work we proposed the concept of gaze-contingent user interface notifications and investigated how the distance to the current gaze position and different appearance properties affect noticeability and subjective distractiveness of user interface notifications. We demonstrated that by combining distance and appearance appropriately we can nearly fully cover the 2-dimensional noticeability/distractiveness space. We found that opacity is most promising to make notifications subtle while movement and blinking can increase noticeability even at large gaze distances, and that changing notification size depending on gaze distance provides flexible control of noticeability. These findings inform the design of future gaze-contingent notification systems and pave the way for a new generation of systems that optimize notification display depending on, for example, the importance of the information.

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