Visual Guidance with Unnoticed Blur Effect

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ABSTRACT

In information media such as TV programs, digital signage, or web pages, information content providers often want to guide viewers' attention to a particular location of the display. However, "active" methods, such as flashing displays, using animation, or changing colors, often interrupt viewers' concentration and makes viewers feel annoyed. This paper proposes a method for guiding viewers' attention without viewers noticing. By focusing on a characteristic of the human visual system, we propose a dynamic blur control method. Our method gradually blurs the image on the display to the threshold at which viewers are aware of the modulation of the display, while the region where viewers' attention should be guided remains unblurred. Two subjective experiments were conducted to show the effectiveness of our method. In the first, viewers' attention was guided to the unblurred region using blur control. In the second, a threshold was found at which viewers were aware of the modulation, and viewers' gaze is guided below this threshold. This means that the viewers' attention can be guided without them noticing.

CCS Concepts

•**Human-centered computing** → *Interaction techniques; Visualization;* •**Computing methodologies** → *Computer vision;*

Keywords

Attentive user interfaces, gaze direction, visual saliency, dynamic blur control.

1. INTRODUCTION

In information media such as TV programs, digital signage, or web pages, information content providers often want to guide viewers' attention to a particular location of the display. For example, in digital signage, the content providers want people to look at the products rather than people on the display. On web pages, they want to guide people's attention to banner advertisements. In electronic markets, people's attention should be guided to today's campaign products. Such requirements for visual guidance are not limited to advertisements. For example, when people are searching for a particular place using a map application, it would be helpful to guide their focus to the place they want to go. In information visualization applications, it would be nice to guide users' attention to a particular element in huge and complex visualization [11].

There have been some approaches that guide people's attention to a particular location of the display. These approaches include changing the color of objects, flashing the objects, vibrating the objects, and so on to draw people's attention. Such "active" methods, however, are not widely appreciated. For example, flashing or animation can interrupt people's concentration on their main task. The web sites using such visual effects risk becoming unpopular.

On the other hand, there are some methods to guide people's attention without modifying the display much. Some of them can even move people's focus without them recognizing the modification by focusing on the characteristics of humans' visual perception. Most of these approaches focus on the difference between foveal vision, which has higher spatial resolution, and peripheral vision, which has lower spatial resolution but is more sensitive to moving objects. Recent work uses the saliency map developed by Itti et al. [9]. However, these approaches often change the color and intensity of a particular object in the image, and therefore the modified image often looks unnatural.

This paper proposes a method to guide people's visual attention to the intended location without them noticing by using unnoticed blur effect. The rest of this paper is as follows. First, we describe related work. Then we propose a simple but novel method for visual guidance using unnoticed blur effect. Next, we describe the first user experiment to show the ability of visual guidance by blurring the display and the second user experiment to find out the threshold at which the people become aware of the blur. We explain the relationship we found between the blur strength and the fixation time. We also discuss some scenarios in which our method can be used. Finally, we present our conclusions.

2. RELATED WORK

Users' gazes and intentions have been widely studied in psychology [7, 13, 20]. Spillmann [15] reported that the human visual system is very sensitive to luminance changes. Dodge [3] described saccadic masking. These psychophysical studies have explained the mechanism and cause of eye movement. On the basis of such psychophysical studies, we describe the work most closely related to this paper below.

2.1 Visual Guidance

To guide people's visual attention, "active" methods are often used. Such methods include highlighting, flashing, vibrating the object, or changing its color. Sometimes animated characters or

AVI '16, June 07-10, 2016, Bari, Italy

© 2016 ACM. ISBN 978-1-4503-4131-8/16/06. . . $15.00

DOI: http://dx.doi.org/10.1145/2909132.2909254

Figure 1: Visual guidance of users' attention using blur control. (Left) The house at the center is unblurred while other areas are blurred. (Right) The house on the left is unblurred while other areas are blurred.

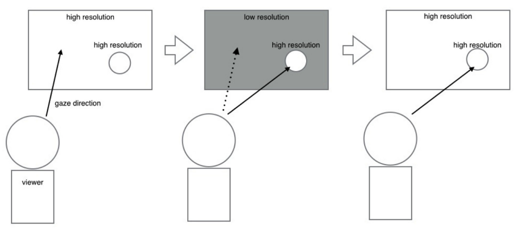


Figure 2: Basic concept of guiding users' attention using blur control.

agents appear on the screen to draw people's attention. However, these methods are generally not appreciated by people since they interrupt their concentration when they want to focus on something else.

Bailey et al. [2] proposed an approach that focuses on the difference between foveal vision and peripheral vision. As is well known, humans' foveal vision has higher resolution than their peripheral vision. On the other hand, peripheral vision is more sensitive to moving objects than foveal vision. Bailey et al.'s method, used with eye tracking, makes a flash at a particular position outside the user's foveal vision. When the user recognizes the flash and begins to move his/her gaze in its direction, the flash stops. As a result, the user recognizes the flash but does not identify where it was. This approach is interesting because it effectively utilizes the difference between foveal vision and peripheral vision. One issue with their approach is that it cannot be applied to multiple-user environments. Some users might have the flash in their foveal vision, and recognize the trick. Another issue is that viewers might feel annoyed if they notice the flash and it interrupts their concentration.

On the other hand, there are some "passive" approaches that do not drastically or dynamically change the display. These approaches often focus on the visual saliency of the object. The visual saliency is divided into two categories: top-down and bottom-up. The top-down saliency is driven by humans' memory. For example, in an image, a human's face has higher saliency than other objects. The bottom-up saliency is driven only by external stimuli. For example, a red circle within many green circles has higher saliency. The related work described below and our work are based on the bottom-up saliency.

Itti et al. [9] proposed a saliency map model that calculates the visual saliency of the image. The saliency map is calculated as a linear combination of the visual salience of the primitive elements such as colors, intensity, and orientations. Hagiwara et al. [5] used the saliency map to increase the saliency of the target object. The obtained image, however, has less natural color than the original image. Veas et al. [17] also used the saliency map to modulate the image frame of video sequences. They conducted user studies to show a threshold at which the users are aware of the image frame being modulated. Also, they showed the effectiveness of their approach by using an eye tracker. Their motivation to develop a visual guidance method that is not recognized by the users is similar to ours. However, since their approach is to change colors of a certain object, the obtained image is somewhat unnatural. In contrast, our method does not modify colors or intensity of the image. Moreover, as we describe below, our method modifies the image dynamically.

Okatani et al. [14] proposed an image display system that enhances a person's depth perception by using depth-of-field blur. Their system tracks users' eyes and changes the blur of each object in the scene on the basis of the gaze direction. Their focus was on providing more realistic depth images to the user. On the other hand, our method is focusing on guiding users' gaze just by using the blur.

3. VISUAL GUIDANCE WITH UNNOTICED BLUR EFFECT

3.1 Basic idea

Figure 1 illustrates a basic idea of guiding users' attention with blur. When we see the image such as Figure 1(a), our attention tends to go to the house at the center. On the other hand, in the case of Figure 1(b), our attention tends to go to the house at the left.

Such visual effects are often seen in TV programs or movies. For example, when the director of the movie wants its viewers to look at an actor, by adjusting depth-of-field of the camera, the camera focuses on the actor and other areas are blurred. Next, when the director wants to the guide viewers' attention to the object behind the actor, the camera moves its focus to the object and the actor is blurred.

As mentioned above, the human visual system has foveal vision and peripheral vision. Foveal vision has higher spatial resolution and lower temporal resolution, and peripheral vision has lower spatial resolution and higher temporal resolution. Also, when a person sees any scene, his/her eyes do not stay at one point and are always moving.

The human visual system is always searching for something in the real world. When it finds something interesting, it stays on the

(a)$\sigma = 0$(original) (b)$\sigma = 1$ (c)$\sigma = 2$

(d)$\sigma = 3$ (e)$\sigma = 4$ (f)$\sigma = 5$

Figure 3: Blurred images with different σ.

object a little longer (i.e. fixation) and then moves on to the next thing. When the image is blurred, although it depends on the blur strength, the human visual system cannot obtain much information and moves its focus to other objects. However, if it finds an object with high resolution, the visual system stays on the object.

Our attention control mechanism uses these characteristics of the human visual system. The whole image is blurred while the region to which we want to guide people's gaze remains unblurred. On the basis of the previous discussion on the human visual system, we hypothesize that people's focus will be moved to the unblurred region.

The mechanism by which people's focus moves to the unblurred region can be explained on the basis of the studies in psychology. When resolution of the image becomes lower, the visual saliency of edges also becomes lower according to the saliency model of Itti et al. [9]. On the other hand, the visual saliency of the high resolution area remains the same. Therefore, people's focus is guided to the unblurred region. This was also reported by Abrams et al. [1] and Gobell and Carrasco [4].

By using this approach, we could move people's focus to our intended position. One problem with the approach, however, is that people easily recognize the blur when it is strong.

Our solution to this problem is that first to show the original unblurred image to the people. Then the image is gradually blurred weakly enough that they do not notice. When the people's gaze is guided, the image gradually becomes unblurred to return it to its original state. This process is illustrated in Figure 2 .

3.2 Blurring with a smoothing filter

In our experiments, a smoothing filter was used to control the image resolution. Although there are many smoothing filters such as a median filter, Gaussian filters, a bilateral filter, etc., Gaussian filters were used in our study. The Gaussian filter is calculated with the following expression.

$$f(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1}$$

There are three parameters in the Gaussian filter: x, y, and σ. x and y are called kernel sizes. We used $x = y = 13$ as the kernel size. The strength of the blur is decided by one parameter σ. Moreover, unlike a median filter or a bilateral filter, there is no edge between a filtered region and an unfiltered region. Figure 3 shows images when we apply the Gaussian filter with a parameter σ from 0 (unblurred) to 5.

To confirm the effectiveness of our approach, the following questions must be answered.

- Can people's attention be moved by using blur control?
- Is there any threshold in blur level at which people are aware of the blur?

In the following sections, we describe two experiments conducted to answer the above questions.

4. EXPERIMENT 1

In this experiment, our focus is on whether or not the attention control is possible using the dynamic blur control. If it is, we wanted to clarify that the relationship between the blur strength and the effect of the attention control.

Figure 4 shows the set up of this experiment. A 23-inch LCD display (1920 ×1080 pixel) with a Tobii TX300 eye tracker is on the table. The Tobii TX300 can track the gaze direction without the user wearing any device such as eye glasses. Its sampling rate is 300Hz, and the latency is under 10ms. To measure accurate gaze direction, a chin rest was used. The distance between the subjects' eyes and the display was 60 cm. We recruited 15 subjects (12 males, 3 females, 22–28 years). They wore their own contact lenses or eye glasses if necessary.

After the eye tracker was calibrated, the experiments started. When the experiment started, a black screen with a small white cross cursor at the center of the display was shown. Each subject was required to look at the cursor in order to move his/her gaze to the center of the screen. After 5 seconds, the image was displayed for 10 seconds, and the subject was allowed to see the image freely. Then the initial black screen was shown again for 5 seconds. This process was repeated 60 times as illustrated in Figure 5.

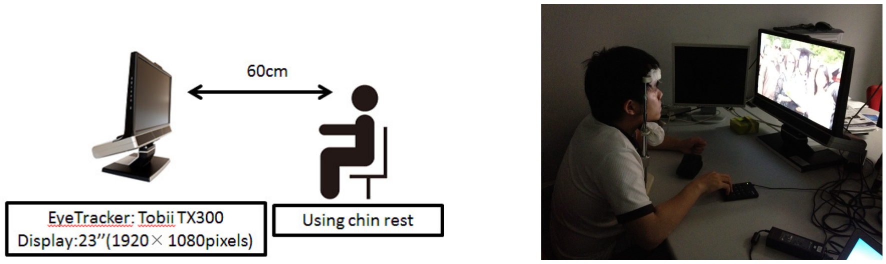


Figure 4: Setup of experiments.

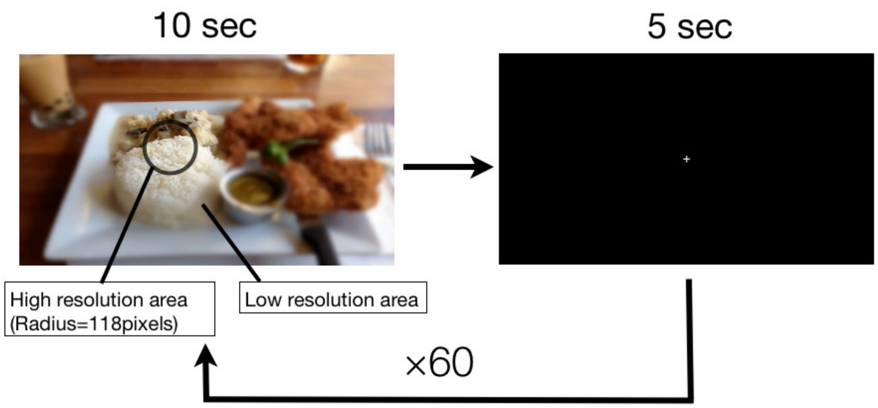


Figure 5: Process of experiment 1.

Table 1: Tukey' test for time until gaze moves to unblurred region.

	1	2	3	4	5
1					
2	6.698				
3	6.490	0.2089			
4	6.162	0.5376	0.3286		
5	6.051	0.6481	0.4392	0.1105	

Table 2: Tukey's test for number of saccades.

	1	2	3	4	5
1					
2	5.924				
3	6.326	0.4021			
4	6.433	0.5089	0.1068		
5	5.472	0.4514	0.8536	0.9604	

The following are instructions given to subjects. We did not mention anything about blur.

> *"You will see a black screen for 5 seconds and a picture for 10 seconds. This process will be repeated 60 times. When the black screen appears, rest your eyes and move your gaze to the white cross cursor at the center of the screen. When the picture appears, look at it freely without fixing your gaze on a particular position. "*

For the displayed image, we used 10 images collected from Flickr, a photo sharing website. We applied different levels of the Gaussian blur (σ = 0 (unblurred) to 5) to each image. Thus, each user saw 60 images (i.e. 10 images $\times$ 6 different levels) in random order.

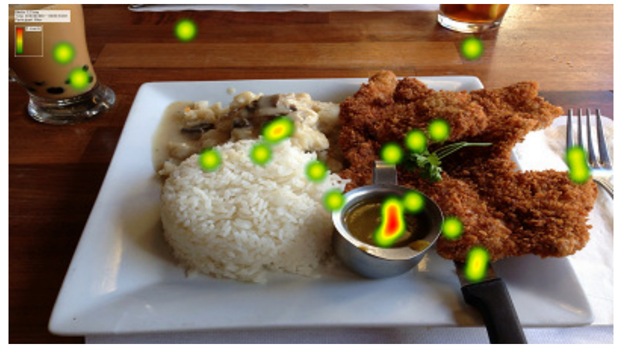
Then we put an unblurred circle region with a 118-pixel radius at the position over 300 pixels from the center. The radius of the unblurred circle was calculated on the basis of the size of a human's foveal vision ($\simeq 1.5°$) and the distance to the screen (60 cm). The distance of 300 pixels was decided so that the unblurred region was outside of foveal vision. The unblurred region and the blurred region were smoothly connected by gradation using 80 pixels.

Figures 6, 7, and 8 show the results of the experiment. Figure 6 and 7 show the images used in the experiment and their heat maps. The heat map shows the gaze direction and its fixation time using colors from blue (short) to red (long). Figure 6(a) is an image with $\sigma = 0$ (i.e. unblurred) shown to the subjects, and Figure 6(b) is a heat map when the subjects saw the image. On the other hand, Figure 6(c) is an image with $\sigma = 5$ (i.e. most blurred) shown to the subjects, and Figure 6(d) is a heat map when the subjects saw the image. In Figure 6(d), a white circle that indicates the unblurred region was added after the experiments. The subjects did not see the circle during the experiments. Figure 7 shows the different images and their heat maps.

While looking at the heat maps, understandably users' gazes were statistically guided to the unblurred region. We did not tell the subjects before the experiment that there were blurred and unblurred regions in the image. When the experiments finished, the subjects were asked if they recognized that there were blurred and unblurred regions. They, however, answered that they did not recognize them.

In this experiment, we measured (1) the time, (2) the number of

(a) Presented image when $\sigma = 0$.



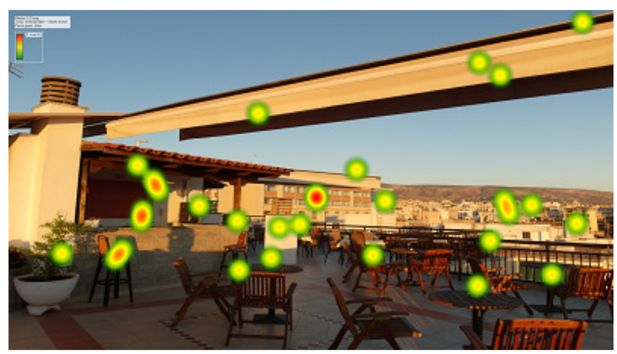
(b) Heat map when $\sigma = 0$.

(c) Blurred image when $\sigma = 5$.

(d) Heat map when $\sigma = 5$. White circle indicates unblurred region.

Figure 6: Images used in experiment 1 and their heat maps.

(a) Presented image when $\sigma = 0$.

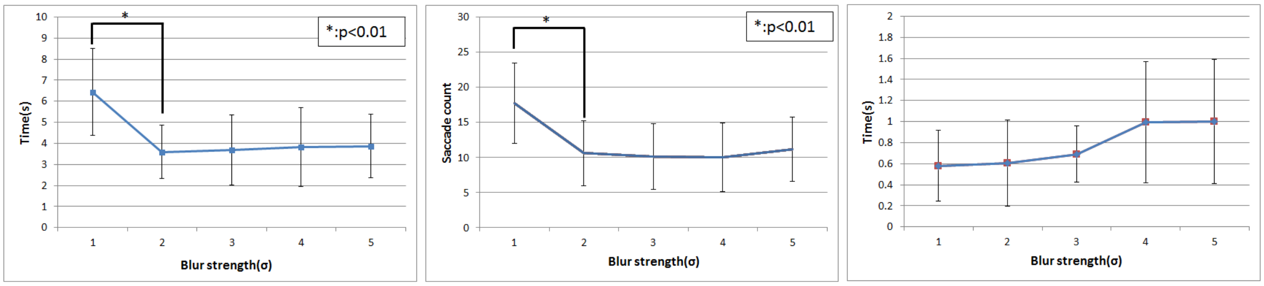


(b) Heat map when $\sigma = 0$.

(c) Blurred image with $\sigma = 5$.

(d) Heat map when $\sigma = 5$. White circle indicates unblurred region.

Figure 7: Other images used in experiment 1 and their heat maps.



(a) (b) (c)

Figure 8: Results of experiment 1. (a) Relationship between blur strength and time of fixation. (b) Relationship between blur strength and saccade count. (c) Relationship between blur strength and fixation time.

Figure 9: Images with heat map that failed to guide attention. White circle indicates unblurred region.

saccades until a subject's gaze entered the unblurred region, and (3) the time of fixation in the unblurred region. (1) and (2) are expected to decrease and (3) is expected to increase.

Figure 8(a) shows the relationship between the blur strength (σ) and the time until a subject's gaze enters the unblurred region. The horizontal axis shows the blur strength, and the vertical axis shows the time. Figure 8(b) show the relationship between the blur strength and the number of saccades. Figure 8(c) shows the relationship between the blur strength and the time of fixation in the unblurred region. In each graph, blue dots show average values.

Since the saccades number more than $100°/sec$ according to Henderson et al. [6], we identified the saccade count when a subject's gaze moved more than 30 pixels.

We performed ANOVA in each case. In (1) and (2), $F(4, 36) = 2.51304$, $p < .05$ and $F(4, 36) = 2.51304$, $p < .01$, respectively, which were statistically significant. On the other hand, $F(4, 36) = 2.51304$, $p > .05$ in (3), which was not statistically significant. We also performed Tukey's test to find out which σs significantly differ. The results are shown in Tables 1 and 2. In both cases, there is significance between $\sigma = 1$ and $\sigma = 2$.

These experimental results confirmed that, if the strength of blur becomes higher, the time until the subject's gaze moves to the high resolution area becomes shorter and the number of saccades becomes smaller. This effect was obtained when $\sigma < 2$. It was, however, not confirmed whether the time of fixation in the unblurred region becomes longer.

On the other hand, the visual guidance failed in some cases. Figure 9 shows the images and the heat maps when the guidance failed. In the case in Figure 9(a), the guidance failed because the unblurred region was set where there was less texture. In the case in Figure 9(b), some objects (i.e. face) have higher visual saliency.

5. EXPERIMENT 2

The purpose of this experiment is to investigate when people become aware of the guidance. In other words, we want to know the σ at which people become aware of the blur control. If that $\sigma > 2$, it is said that we can guide people's gaze without them noticing.

We used the same hardware setup for experiment 2 as experiment 1. The same subjects in experiment 1 took part in experiment 2. They rested for an hour between experiments. In experiment 1, it was important that the subjects did not know we applied blur to the image. On the other hand, the subjects were told the existence of blur in experiment 2. Therefore, their participation in experiment 1 does not affect the results of experiment 2.

First, the black screen with a white cross cursor was shown for 5 seconds. Then the image was shown on the display and was gradually blurred from $\sigma = 0$ to $\sigma = 5$ within different transition times (3–15 sec). Subjects were asked to click the mouse when they recognized the blur. When they clicked the mouse, the black screen with a white cross cursor appeared again and the subjects moved their eyes back to the center (Figure 10). The following are instructions given to subjects.

> *"You will see a black screen and a picture in turn. When the black screen appears, rest your eyes and move your gaze to the white cross cursor at the center of the screen. While you are looking at the picture, it will become blurred. When you notice the blur, please click the mouse button."*

Five images (1920×1080 pixel) were used in the experiment. Since we used 13 different transition time from 3 to 15 sec, we had 65 (= 5 images × 13 transition time) combinations to show. Although the order of the image and the transition time were random, each combination appeared only once. The same image did not appear in succession. The unblurred area was a circle region with a 118-pixel radius and appeared further than 300 pixels from the center of the image.

Figure 11 shows the results of the experiment. This graph shows the relationship between the time until complete blur ($\sigma = 5$) and the blur strength when the subjects clicked the mouse button. For example, when it took 15 sec from $\sigma = 0$ to 5 (the slowest transition), the subjects clicked the mouse button when $\sigma = 2.31$ on average. When the transition time was 3 sec, the subjects clicked the mouse button when $\sigma = 3.84$ on average. Blue dots indicate average values, and the blue dotted line is a simple fitted line. It is, however, reported that a user takes 300 ms to click the mouse after recognizing a stimulus [19]. The red dotted line is the fitted line when such latency is taken into account.

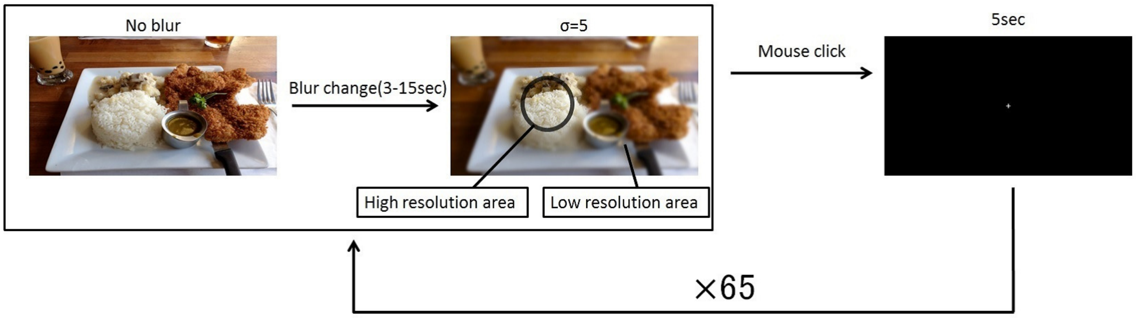


Figure 10: Process of experiment 2.

In this graph, average σ values are always more than 2. These σ values are more than the σ values ($\sigma < 2$) when the subjects' gaze can be moved.

We performed ANOVA in each blur level when significance level is 1 %. As a result, $F(12, 48) = 1.82$ and $p < .05$, which were statistically significant.

The graph shows that the subjects recognized the blur more easily when the transition time was long and more difficultly when the transition time was short. This is because when the transition time is long, the subjects have enough time to find the area in which the blur is easier to recognize.

When we consider only visual sensory memory, people recognize the blur when the scene changes fast. People react faster when recognizing in visual sensory memory than when recognizing in other factors [8]. The results of our experiment, however, contradict this. Subjects did not seem to recognize in visual sensory memory when the transition time was over 3 sec. The reason subjects recognize the blur faster when the transition time is longer may be explained by visual attention and visual memory. In the case of visual attention, people change their attention to the object whose edges are easy to recognize. Henderson et al. [6], however, reported that the average time of fixation is 354 msec. According to Julesz [10] and Wolfe [18], the time to recognize one edge is 20 msec. In our experiment, subjects could see the original image for 2-5 sec. The visual attention might not be a cause.

From the viewpoint of visual memory, subjects seem to have compared the original image in their visual memory and the current image. They also seem to have easily recognized the blur since they fixed their gaze longer. This matches the results obtained by Hollingworth and Henderson [8]. Therefore, visual memory is concluded to be the most related to the recognition of the blur.

6. DISCUSSION

6.1 Usage scenarios

Our method can be used in many scenarios. For example, Figure 12 (top) shows a scenario of applying it to an electronic market. When the user is browsing the market, the resolution of all items but today's campaign item would be decreased below the threshold at which the user can recognize the modification. Statistically this item would have more chance of selling.

Figure 12(bottom) shows another scenario of applying it to a map application. When the user is searching the map, the resolution of the target location remains as its original, while other areas are blurred. This would help the user to find the target location. The user can also see the surrounding neighborhood area. This scenario shows that our method can be used to see the target location in more detail while other areas can be seen more abstractly. This is regarded as a kind of focus-and-context view.

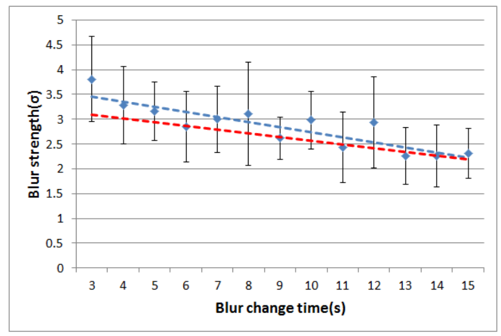


Figure 11: Relationship between time to be completely blurred and blur strength when subjects clicked mouse button.

6.2 Multiple users

One of the advantages of our approach is that it can be used in multiple-user environments. Bailey et al.'s approach tracks one person's gaze and makes a flash while he/she is not looking at the intended position. In a multiple-user environment, someone may see the flash. On the other hand, our approach can be applied to multiple-user environments. The resolution is controlled below a threshold at which people can recognize the blur. Even if multiple users see the different locations simultaneously, the blur is hard to recognize.

6.3 Limitations

Our method has limitations. First, as we showed in the first experiment, it does not work well when the image contains high saliency objects such as faces. When the image contains high saliency objects, the user's gaze moves to the objects. Second, our method may not be effective for people who have poor eyesight because they may not recognize the blur on which our method depends. Third, whether or not our method can be used in videos is not known. As we described in section 2, the depth-of-view approach has been used in TV programs and movies. However, this blur effect is recognizable to the viewers. The subtle blur used in our method might not work with videos, in which successive frames can greatly differ.

6.4 Relationship with subliminal stimuli

Subliminal stimuli [12, 16] are stimuli below the threshold for

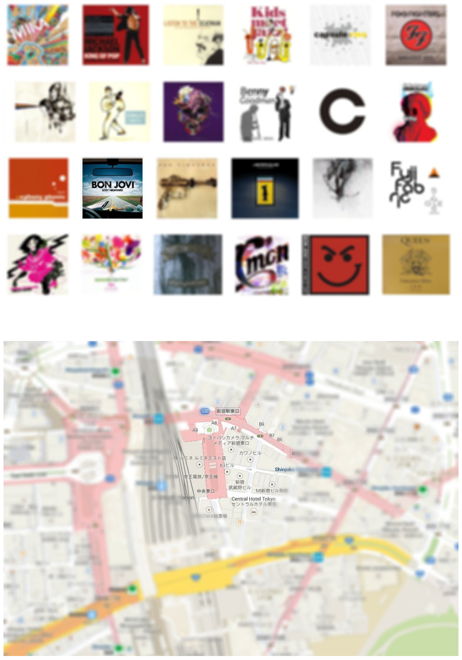


Figure 12: Usage scenarios. (top) Application to electronic market. (bottom) Application to map system.

conscious perception. Their effectiveness has long been discussed in cognitive studies. However, since there is a concern that they may be able to embed information on people's brains without them noticing, subliminal stimuli have not been allowed to be used on TV or in movies. Since our method guides people's attention without them noticing, there might be the similar concern that our method is a kind of subliminal messaging. The main issue of subliminal messaging is that it tries to send information that the user cannot recognize. On the other hand, our approach does not hide any information even though it guides people's attention without them realizing. At this point, our approach is essentially different from subliminal stimuli.

7. CONCLUSION

This paper proposed an attention control method with unnoticed blur effect. Our focus is on guiding people's attention without them noticing. We conducted two experiments. One was to investigate whether or not people's focus was guided when we used the blur control. The other was to investigate when people became aware that the image was blurred. Through the experiments, we showed that people's attention is guided to the unblurred region and they are not aware of the blur below a certain threshold.

We are currently applying the method to interactive applications, such as a digital signage system. Since the digital signage system is used in a public environment, eye tracking of one person is useless. Even though the eye tracking is not used, however, the method can be used to guide multiple people's attention simultaneously.

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