Glowworms and Fireflies: Ambient Light on Large Interactive Surfaces

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ABSTRACT

Ambient light is starting to be commercially used to enhance the viewing experience for watching TV. We believe that ambient light can add value in meeting and control rooms that use large vertical interactive surfaces. Therefore, we equipped a large interactive whiteboard with a peripheral ambient light display and explored its utility for different scenarios by conducting two controlled experiments. In the first experiment, we investigated how ambient light can be used for peripheral notifications, and how perception is influenced by the user's position and the type of work they are engaged in. The second experiment investigated the utility of ambient light for off-screen visualization. We condense our findings into several design recommendations that we then applied to application scenarios to show the versatility and usefulness of ambient light for large surfaces.

Author Keywords

Ambient light display; peripheral display; large interactive surfaces; interactive whiteboard; evaluations;

ACM Classification Keywords

H5.2 Information interfaces and presentation: User Interfaces

INTRODUCTION

Introduced by Philips, Ambilight (*ambient light*) is known as a lighting effect for TVs to illuminate the environment around the TV based on the predominant colors in the video image. This leads to enhanced visual comfort, less fatigue [10], and a subjective enlargement of the perceived screen size [7]. Early models provided only a static illumination to reduce eye-strain that occurs while watching TV in a dark room. Later versions aimed to adapt the illumination dynamically for providing a better and more immersive viewing experience [12]. Although Philips is offering the only commercial solution, several DIY-projects and open source projects (e.g. LiveLight Project[1], Atmolight[2]) aim to provide a similar experience by equipping screens with LED strips.

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All these efforts focus on enhancing the viewing experience while watching videos or playing games on TVs, where the ambient light depends on the content currently shown on screen. We believe that ambient light can enhance how people work with *large interactive surfaces.* It can extend the screen-space and provide a peripheral information space (see Figure 1) across multiple applications and scenarios. Ambient light can ameliorate the resolution limitations of current large interactive surfaces, such as wall projections, by preserving valuable display space, as notifications can be displayed in the periphery.

Figure 1: Using ambient light to support work on large interactive surfaces via peripheral information display.

In this paper, we are mainly interested in establishing an understanding of how best to use ambient light to display information and support work on large interactive surfaces within a productive environment, such as in discussion or control rooms. For this, we firstly equipped a digital whiteboard with an ambient lighting system. Drawing upon related work and our own insights, we formulate a number of hypotheses and conduct a series of two user studies using our setup to explore the design space provided by peripheral LEDs. The first experiment deals with the issue of different tasks, different user positions, and the limits of peripheral perception. The second experiment examines the utility of ambient light visualizations for off-screen object visualization by comparing it to the well-established techniques Halo [6] and Wedge [14]. Based on the results of the studies, we present a number of design recommendations for how best to use ambient light to display information and enhance how people work with large interactive surfaces. Finally, we present a number of different usage scenarios to highlight the design principles.

[1] http://www.livelightproject.com/

[2] http://www.vdr-wiki.de/wiki/index.php/Atmo-plugin

RELATED WORK

According to the definitions of Pousman and Stasko [35] our setup, which extends a large interactive surface with ambient light, is a peripheral display. Therefore, after discussing various related projects that use *ambient light*, we present insights on *peripheral vision*, and provide examples of systems that apply these principles. Finally, we also provide a brief overview on *territoriality* in the context of large surfaces as well as *off-screen visualizations,* as these topics are relevant for our experiments.

The taxonomy for ambient information systems by Pousman and Stasko [35] includes the following four design dimensions: *information capacity*, *notification level*, *representation fidelity,* and *aesthetical emphasis*. In this paper, we focus on exploring the information capacity and notification level of ambient light. A peripheral display can also oftentimes be understood as a notification system. Matthews et al. [30] distinguish between five types of notifications: *ignore*, *change blind*, *make aware*, *interrupt*, and *demand action*. In the context of this paper, we are especially interested in the third type, classified as *make aware*.

Ambient Light

While there are many ambient light displays that use only light as a source of output [1,18,26,34], there are only a few examples where ambient light is used in combination with high-resolution displays [32,33]. AmbiX [31] provides valuable insights on how to use ambient light displays to provide visual cues in an unobtrusive manner. Löcken et al. [27] explored the design space of ambient light displays by simulating various ambient light properties, such as the optimal LED arrangement in software, before actually building an entire hardware setup. Their tool was used to create Sparkle [33] an ambient light display for dynamic off-screen points of interest. From a technical perspective our setup has many similarities with Ambilight by Philips, with the previously mentioned DIY projects, and with the Ambient Timer [32].

Peripheral Vision

While the perception of color is lacking in the periphery [45], the human vision system is exceptionally capable of perceiving movement and brightness in the peripheral area [43]. Therefore, Bartram et al. [4] suggest using movement to increase perception in the periphery, which we also investigate in one of our studies by observing blinking notifications. Ball and North [3] investigated why visualization tasks benefit from large-scale displays. They conclude that the major factor is physical navigation, but also found that the effect is amplified by peripheral vision. Bezerianos et al. [8] studied the perception of visualizations on wall-sized displays. Their findings suggest that perception accuracy is negatively impacted when users are close to the wall. Therefore, they suggest that users stand further away when examining data.

Peripheral Displays

There are various examples for ambient displays that demand the use of peripheral vision. ambientRoom [22] is an early project of utilizing an entire room for providing information in an ambient way. IllumiRoom [23] also follows the idea of focus and context [5]. It casts a projection on the wall around the TV to extend the screen and provide a more immersive gaming experience. Perifoveal Display [20], a large visualization display for a desktop workstation, was designed for observing large amounts of data. Kimura [28] and the Peripheral-Vision Display presented by Birnholtz [9] are examples of using a peripheral display to support background activities within an office context. We observe peripheral perception of ambient light and on-screen notifications in our first study.

Territoriality in the Context of Large Vertical Displays

Various work deals with territoriality in the context of public ambient displays [41] and large vertical displays [2]. Range [24] and Hello.wall [36] use proximity sensing to provide a smooth transition between different modes of interaction. Based on this, we study three scenarios that utilize different interaction zones in front of large interactive displays.

Off-screen Visualizations

Two well-known examples of off-screen visualization methods are Halo [6] and Wedge [14]. Although both were initially designed for small devices, they are also used as reference strategies on larger surfaces [21], since there are few alternatives. Another popular way to help users to find off-screen visualizations are minimaps [37]. Folding metaphors like in Melange [12] or Canyon [21] require high-res screen space to be available outside of the main working area.

DESIGN SPACE OF AMBIENT LIGHT

At first glance, it may seem that ambient light has a very limited set of properties that can be used to convey information. However, light offers quite a large number of different parameters to encode information [31]. The most obvious parameter is *color*, which contains three subcomponents: *hue*, *brightness*, *saturation*. These single parameters can also be found in the enumeration of Visual Variables by Mackinlay, who referred to them as *Color Hue*, *Color Saturation* and *Density* (*Brightness*) [29]. While hue is a very good parameter to encode nominal data, brightness and saturation are more suitable to encode ordinal or quantitative data. We assume this kind of encoding transfers to ambient light. Besides color, *duration* and *frequency of changes* (*=animation*) [25,31] can also be used. In addition, the specific physical setting along the rim of a large surface also provides the *position* and the *size* of the luminous area as useful properties.

Besides these properties, another important factor that has to be considered is the *user's position* [31]. When watching TV, the position and the view of the user are well defined. In contrast, the situation in front of a large interactive wall is fundamentally different. Dependent on the task, users may be standing directly in front of the board, moving around, discussing the content with others, standing a couple of meters away, or sitting at the back of the room. This variety of possible user positions and visual perspectives requires a closer look at the dependencies of position, focus and perception of peripheral visual stimuli.

DECODING WORKING STYLES AND DISTANCE

Interactive surfaces are designed to support a wide variety of tasks and working styles [15,38,44]. A very common use case for these systems is to support people in gaining an overview of large amounts of data [44]. They can also be used for focused work, where users either work directly on the surface [15], or use it in an ambient manner while performing primary tasks on other devices [28,39]. Based on these insights, we classified the work on interactive whiteboards into two dimensions: *distance* and the *type of work*, which yields four scenarios:

The ***Close-Focused*** scenario for an interactive wall setup comprises a large degree of user involvement. Users are typically very close to the wall and have a limited field of view.

In the ***Close-Overview*** scenario specific UI elements, such as mini-maps are used to provide overview on a small area.

The ***Distant-Overview*** scenario involves discussion or taking in a lot of content. People try to gain an overview, rearrange, and structure content. To gain such an overview, users often step back from the wall to widen their field of view.

The ***Distant-Focused*** scenario involves focused tasks performed on a different, personal or stationary device. The interactive wall is then used as a peripheral or ambient display where public information is updated and visible to others.

We acknowledge techniques such as mini-maps or similar approaches that provide an overview through additional UI elements. However, on very large display surfaces these can easily be too far away to be useful. Moreover, people naturally take a step back from the board to get an overview. Thus, *Close-Overview* does not present a typical working style to us and we focus on the other three scenarios here: *Close-Focused, Distant-Overview, and Distant-Focused* (see Figure 2).

Related work suggests that the perception of ambient information is closely related to the user position [31]. We also expect that the type of *Distant-Focused* work has a considerable effect on the perception. Therefore, in our first experiment we explored these notions regarding perception of ambient light notifications within these three scenarios.

EVALUATION

Two empirical studies were conducted to explore the benefits and limitations of the ambient light equipped whiteboard. All experiments were carried out with the same apparatus.

Apparatus

The studies were conducted in a quiet white room with a large interactive whiteboard, equipped with an ambient light display system. For the ambient light we used multiple Adafruit NeoPixel LED strips with 680 LEDs in total, driven by an Arduino Leonardo and external power supplies. The whiteboard had a resolution of 3840 × 1080 pixels and was operated by two Vivitek D795WT short-throw projectors, with input through Anoto digital pens (ADP 601). The bottom edge of the whiteboard was mounted at 90cm. During

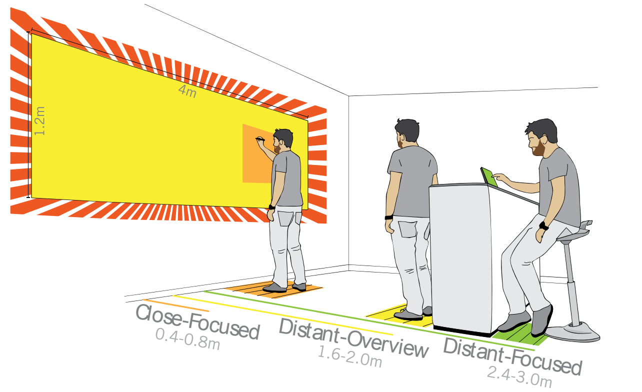

Figure 2: The three scenarios evaluated in experiment 1: *Close-Focused* on the whiteboard (orange), *Distant-Overview* (yellow), and *Distant-Focused* on an external device (green). The red striped area highlights the notification area.

the study we aimed to create realistic and reproducible lighting conditions. We used artificial light sources to provide an average brightness of 600 lx in the back where the participants worked in the *Distant-Focused* scenario and 300 lx next to the interactive wall. These values fulfill the lighting and energy standard defined in ISO 8995-1 – CIE S008/E.

EXPERIMENT 1: PERCEPTION OF NOTIFICATIONS

In the first experiment, *Ambient Light* was compared to *On-Screen* notifications in the three scenarios, *Close-Focused*, *Distant-Overview*, and *Distant-Focused* as described earlier. A blinking animation effect was also explored as a means of improving peripheral perception.

Hypothesis

The experiment was designed and conducted with the following hypotheses in mind.

Hypothesis 1.1: *Ambient Light vs. On-screen Notifications.* Due to their brighter appearance on the non-cluttered wall, Ambient Light notifications will be spotted more frequently than *On-Screen* notifications in the *Distant-Overview* and the Distant-Focused scenario. There will be no big difference in the Close-Focused scenario, due to steep visual angles.

Hypothesis 1.2: *Impact of Scenarios on Visual Perception.* The perception of stimuli for the *Close-Focused* scenario will be low compared to the *Distant-Overview* and *Distant-Focused* scenarios, as both types of notifications are outside of the peripheral view.

Hypothesis 1.3: *Blinking vs. Static Notifications.* People's perceptional system is trained to notice changes. Therefore, blinking notifications will increase people's ability to perceive the notifications regardless of the scenarios and whether *On-Screen* or *Ambient Light* visualizations are used.

Design

We conducted a controlled experiment, where we assigned three different primary tasks to the participants that were designed to engage them in focused work on the board (*Close-Focused*), a task that required them to get an instant overview (*Distant-Overview*), and focused work on an external device within the room (*Distant-Focused*). We asked participants to work on the right side of the board (see Figure 2), as users usually do not work at the border between two projections. While the participants were executing the primary task, we triggered Ambient Light and On-Screen notifications and asked participants to identify the position of the notification when it was perceived. This way we calculated the percentage of perceived notification, which we used as the main metric in this experiment. In addition, we also added the *blinking* and *static* conditions; we assumed that blinking would increase the perception of notifications dramatically.

A within-subject design was used. The 3 scenarios × 2 (ambient light vs. on-screen) × 2 (blink vs. no blink) conditions were counterbalanced using a Latin square design. For each *position* (*left*, *right*, *top*, *bottom*, *top left*, *bottom left*, *top right*, *bottom right*) a total of two *trials* had to be completed. Summarizing, each participant completed a total of 192 trials (3 scenarios × 4 conditions × 8 positions × 2 trials). After each condition, participants were asked to rate the different techniques. The whole test, including instruction, training sessions, questionnaires, and a final interview lasted for approximately 80 minutes for each participant.

Tasks

Primary Tasks

For both the *Close-Focused* and *Distant-Focused* scenarios, we initially implemented a square click task [40], where participants have to click on a black square that randomly changes position every second. As our pilots revealed, participants still had enough time to actively search for notifications during performing this task. Thus, we decided to increase the task difficulty. Inspired by Hausen et al. [19], we provided four squares of different color. A colored border indicated the color of the square that had to be selected.

In the *Distant-Focused* scenario the colored square click task was performed full-screen on a 10.6" screen (MS Surface Pro) using touch for input (see Figure 3, *right)*.

In the *Close-Focused* scenario, an adapted version of the colored square task was executed directly on the whiteboard using a digital pen (see Figure 3, *left)*. To simulate focused work, the interaction area was limited to an area of 50 cm × 50 cm; moreover, the height was adjusted to suit the height of each participant.

As the *Distant-Overview* scenario does not involve continuous interaction, we had to search for a scenario that required gaining an overview of a large amount of data displayed on the board, but which also was mentally demanding so that participants would focus on it. Therefore, we used a word-search task (see Figure 3, *middle*) and asked participants to find as many words as possible and to strike them out once found on the board, and to step back for the next search.

Secondary Task

All participants were told to focus on the primary tasks while notifications appeared on the edges of the board. We asked

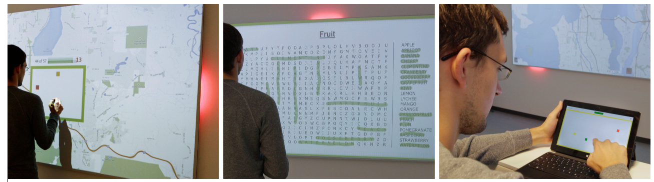

Figure 3: The primary tasks for the Close-Focused scenario (left), the Distant-Overview scenario (middle), and the Distant-Focused scenario (right).

the participants to name the position of the notification once they have been recognized. As shown in Figure 4, both *Ambient Light* as well as *On-screen Notifications* were colored red as we considered it as being an attention-demanding color. Both notification designs had the same length, 200px (~24cm). *On-Screen Notifications* were 25px high, as this size can fit text labels, which are comfortable to read up to a 4m distance, as humans mainly react to change. Additionally, the *On-screen Notifications* were given a white border and a drop shadow to stand out. Presented next to each other in Figure 4, Ambient Light undoubtedly stands out more. Due to the use of different technology, its visual footprint is larger. However, we decided not to mimic the visual footprint of the ambient light in the *On-Screen Notifications* as notifications of this size would be hardly used in a real world application where it is important and common practice to conserve limited display space. Moreover, our pilots revealed that sudden change is much more important than notification size. Therefore, *Static Notifications*, while they stayed for 3s, were faded in and out for 0.5s to minimize the 'one-time' blinking effect. In contrast, in the *Blinking Notifications*, alternated between on and off every 0.5s without any fading effect.

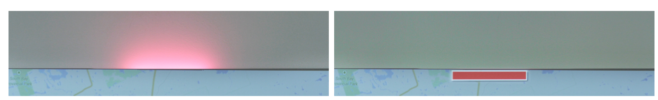

Figure 4: Notifications were shown as Ambient Light (*left*) as well as in an On-Screen condition (*right*).

Participants

We recruited 12 participants (4 female) from various computer science research labs at our university. Their ages ranged from 22 to 38 and their height ranged from 160 to 185 cm. Two of the participants were left-handed and four of them wore glasses. None of them were color-blind.

Results

In all analyses reported here, the assumption of sphericity was not violated, so no corrections were necessary. We used repeated measures ANOVA ($\alpha = .05$) and pairwise tests with Bonferroni corrections for post-hoc analysis.

Hypothesis 1.1: Ambient Light vs. On-Screen Notifications

A three-way ANOVA showed a significant interaction between the factors ($F_{2,11} = 9.02$, $p < .001$) with power = .972.The post-hoc tests showed that in the *Distant-Overview* scenario as well in the *Distant-Focused* scenario, the percentage of perceived notifications with *Ambient Light* was higher than for *On-Screen Notifications*. A repeated

Figure 5: Perception of notifications in different spots. The green part of the circles shows the recognition rates for Ambient Light, the blue part the rates for on-screen notifications.

measures ANOVA unveiled an overall highly significant difference between *Ambient Light* and *On-Screen* Notifications ($F_{1,11}$ = 298.82, p < .001) with power = 1. Post-hoc tests showed that there was no significant difference in the *Close-Focused* scenario. However, there was a highly significant difference in the *Distant-Overview Static* scenario ($F_{1,11}$ = 75.94, p < .001) with power = 1 as well as in the *Distant-Focused Static* scenario ($F_{1,11}$ = 166.26, p < .001) with power = 1. Thus, *Hypothesis 1.1* is confirmed. For the *Static* condition (*Distant-Overview* and *Distant-Focused* scenarios), there was a vast difference between *Ambient Light* and *On-Screen Notifications* (see Figure 5). For the *Blinking* condition, the difference was significant for the *Distant-Overview* scenario ($F_{1,11}$ = 9.0, p < .05) with power .78, and for the *Distant-Focused* scenario ($F_{1,11}$ = 11.0, p < .01) with power .86.

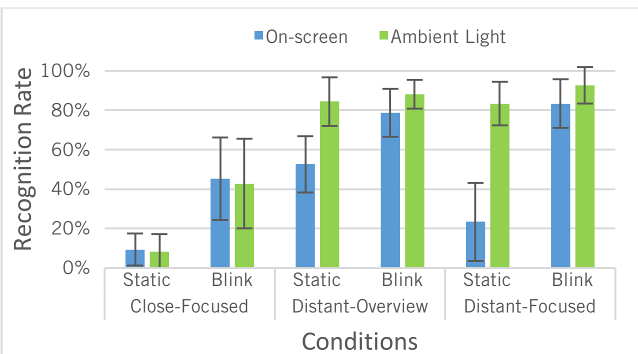

Figure 6: Results *Ambient Light* vs. *On-Screen* Notifications. The error bars indicate the range of two standard errors of the mean (above and below the mean).

Hypothesis 1.2: Impact of Scenarios on Visual Perception

Generally, notifications were difficult to perceive in the *Close-Focused* scenario. However, the percentage of perceived notifications was much higher with 75.9% (*Distant-Overview*) and 70.7% (*Distant-Focused*) respectively. Thus, the collected data confirms *Hypothesis 1.2*. Examining Figure 6 more closely, we see that the percentages given above differ, particularly because the proportion of *Static On-Screen* Notifications that was noticed in the *Distant-Focused* scenario was low. Another interesting observation was that more *Blinking Ambient Lights* were perceived in the *Distant-Focused* scenario than in the *Distant-Overview* scenario, which had lower temporal demand and gave participants more time to look around.

Hypothesis 1.3: Blinking vs. Static Notifications

As humans are good in perceiving changes within their peripheral vision [4], it is not surprising that blinking improves the visual perception of notifications in all conditions and scenarios. The analysis showed a highly significant difference between *Static* and *Blinking* overall ($F_{1,11}$ = 78.28, p < .001) with power = 1. A highly significant difference between *Static* and *Blinking* was found in the *Close-Focused Ambient Light* scenario ($F_{1,11}$ = 25.76, p < .001) with power = .99, where the percentage of identified notifications increased from 8.3% (*Static*) to 42.7% (*Blinking*), as shown in Figure 6. There was also a significant difference for the *Distant-Focused* scenario, ($F_{1,11}$ = 6.6, p < .05) with power = .65. This demonstrates that blinking has the highest impact when users are engaged in focused work and rely on their peripheral vision for monitoring notifications.

Further Insights

Perceived Positions

Figure 5 shows how well notifications were perceived in each location. Note that the participants worked at the right side of the board. Unsurprisingly, notifications were perceived less likely the further they were away from the participant. Although the perception rates were quite low in the *Close-Focused* scenario overall, blinking notifications close to the user could be perceived relatively well. Also in the *Distant-Overview* and the *Distant-Focused* scenario, the distance and consequently the viewing angle of the notifications had a considerable effect.

Task Performance Comparison

We used two different primary tasks, which was a potential source of bias when comparing results. However, there was no statistically significant difference in the performance of the primary task for participants, regardless of which secondary task conditions were applied. Results from a NASA TLX questionnaire confirm this observation.

Qualitative Results

Semi-structured interviews and a post-study questionnaire revealed additional insights. Existing literature suggests blinking could be irritating [31]. The responses we collected did not reflect that, but, such feedback might be different with other blinking patterns or frequencies. Some participants reported that they actively searched for notifications at some times, but ultimately felt that this did not help their performance for the secondary task. Furthermore, participants' subjective perception of their performance using *Ambient Light* in each scenario did not match their actual performance; they rated their performance in the *Distant-Overview* scenario highest, but performed best in *Distant-Focused*.

Discussion

In general, focused tasks as investigated in the *Close-Focused* and *Distant-Focused* scenarios relied more on peripheral perception than in the *Distant-Overview* scenario. As a blinking animation effect supports visual perception in the periphery, it is highly recommended for capturing the attention of users who are engaged in focused work. However, this effect might not work as well if other parts of the UI also blink. The results show that Ambient Light notifications could be very useful in multi-user scenarios (e.g. in control rooms), where users working directly at the board should not be disturbed, while people in the background need to be alarmed if a status change happens. In such a scenario it is beneficial to use a technology that prevents clutter on the screen by moving notifications off-screen.

THE RIGHT 'GAMMA' – CORRECTING THE BRIGHTNESS

When altering the intensity value of the Ambient Light display it becomes apparent that the value sent to the LED strips and the perceived brightness do not match well. The task of transforming a linearly growing value that is not perceived in a linear way by humans is traditionally solved using Gamma correction [13,42].

The Adafruit NeoPixel strips and other addressable LEDs use *pulse-width modulation.* This means in order to display different intensity levels the LEDs quickly toggle on and off [11]. The ratio between the on and off state defines the intensity level. However, to our perceptional system the perceived brightness is close to 100%, even if the LEDs are only on for 50% of the time. To compensate for humans' non-linear perception, it is thus necessary to perform gamma correction. The gamma values suggested for the LED strips we used are around 2.8 [11]. We ended up using a gamma-factor of 3.0, as we achieved the best results with this value.

The blue line in Figure 7 maps the perceived brightness levels to the displayed ambient light levels. As our LED strips cannot represent the small differences in brightness that could be perceived at lower levels, we compromised by taking the smallest available steps for these low levels (see Figure 7, dashed red line).

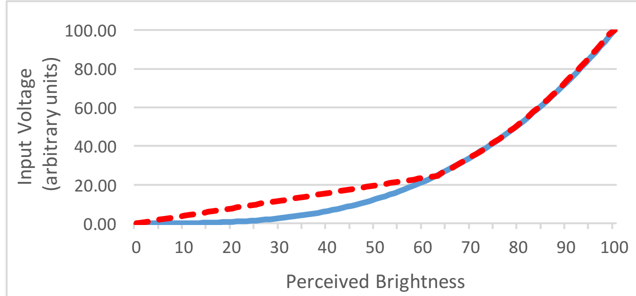

Figure 7: The blue line shows the ideal brightness mapping when using gamma correction (γ=3.0). The red dashed line shows the actual brightness mapping due to the limitations of our LEDs.

EXPERIMENT 2: COMPARISON TO OTHER OFF-SCREEN VISUALIZATIONS (HALOS AND WEDGES)

As an array of controllable lights around the periphery of the whiteboard, ambient light can show off-screen information. In this experiment we aim to examine this use-case and explore the advantages and disadvantages of different types of visualizations to gain insights on how to use some of the different properties of ambient light discussed earlier. Specifically, we use *color* to distinguish between different sets of notes, *brightness* and *size* to encode distance of off-screen objects, and *position* to indicate direction.

We developed two different variations of ambient light visualizations and compared them to the well-established off-screen visualization methods Halo [6] and Wedge [14]. This is because unlike other techniques, they work in the periphery of the screen. In comparison to these on-screen visualizations, ambient light has a much smaller design-space. It provides only a single line of LEDs and therefore cannot use geometric shapes to provide a hint of the off-screens objects position. Thus, we used the size of notifications in one and the brightness in another condition. As Halo and Wedge were mainly designed for small screens, we carefully adapted them for use on large surfaces without changing their main principles. Moreover, they were initially not designed to supply color information and required adaption.

Halo

We re-implemented Halo (see Figure 8, *left*) as described in the paper [6]. As we felt that in contrast to ambient light the small ring segments were quite difficult to spot, we filled the circles. In a pilot study we compared the filled with the non-filled version. We kept the filled version as it performed better. As in the original paper, close circles are stacked, and the visible part of the circle is divided, with displaying the color of a smaller circle (closer object) in the middle.

Wedge

Similar to Halo, we re-implemented Wedge (see Figure 8, *middle-left*) as described in the paper [14]. We also tested a filled version against an outline version in a pilot study, with a similar result. Therefore, we used filled Wedges in our final experiment. Corners are challenging, as a large amount of off-screen space needs to be represented in a small area [5,9]. Due to the large number of off-screen notes in our study and the limited space in corners, overlaps could not always be resolved. For these cases we ensured that at least all wedges are visible by moving smaller indicators to the front so that none is fully hidden.

Ambient Light – Glowworm

Glowworm (see Figure 8, *middle-right*) is an ambient light implementation that uses *brightness*. Starting with the closest objects, it displays all off-screen objects. Distant objects do not overwrite closer ones but are shifted to a nearby free spot. The accuracy of the displayed position decreases in this situation. The brightness indicates the 'rank' of the represented note in contrast to other notes of the same color. This means that the closest yellow note is the brightest, while the furthest is the dimmest.

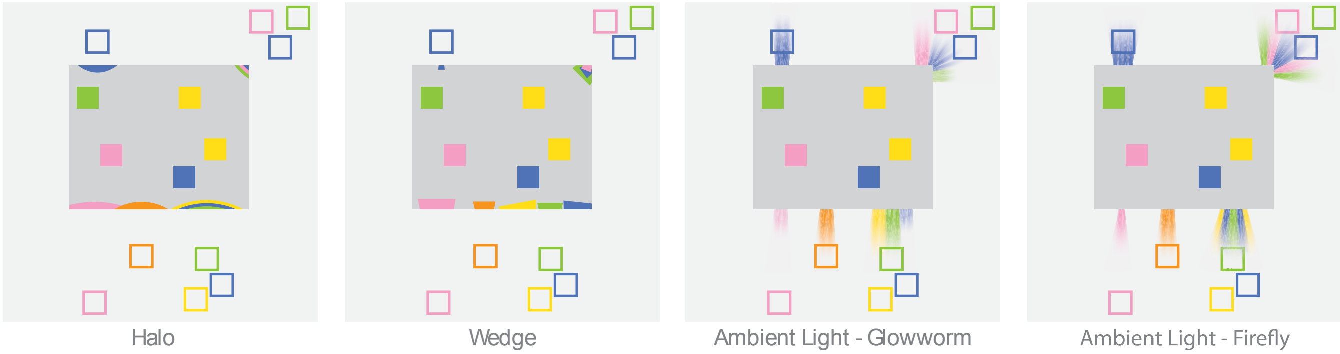

Figure 8: The four conditions that were compared in experiment 2. Please note that figures are not to scale.

Ambient Light – Firefly
Firefly (see Figure 8, *right*) maps the distance of the off-screen object to the *size* of the spot. Starting with a size of 200px the notification gets smaller as the object moves away. There is no change in brightness. If two indications are overlapping they get stacked. In this case the closer note is placed inside and the furthest outside. The size of the stack is calculated by using the size of the closest element as a basis. For each added note to the stack, the size of the combined notification is increased by 20%.

Hypothesis

Hypothesis 2.1: Performance: Ambient light will not be significantly slower than Halos or Wedges from a performance perspective. On-screen solutions can show more complex information about the note location than ambient light. Nevertheless, the ambient light techniques can compete with the on-screen solutions, due their bigger visual footprint which does not require valuable screen space.

Hypothesis 2.2: Preference: Ambient Light will be preferred. Ambient light benefits from a clear visual separation to the screen, resulting in less clutter on the screen. Users will prefer ambient light over on-screen solutions.

Design

In this controlled experiment we compared the four mentioned notification conditions. In addition, we also ran a baseline condition without any visualization of off-screen objects, which resulted in a total number of five conditions. The conditions were tested in a repeated-measures, Latin Square study design, balanced for first-order carry-over effects. In our first experiment we learned that the ambient light works best at a certain distance from the board. We applied this knowledge in this comparison in a setting similar to the Distant-Focused condition from experiment 1 (see Figure 9). The participants sat facing the whiteboard on a height adjustable chair, in front of a small height adjustable table. A wireless computer mouse was used as the input device.

We provided participants with a virtual canvas of 6 × 6 screens (11.520 × 6480 pixels). As the whiteboard is a two projector setup, they could see a section of two of these 36 screens side by side at once (3860 × 1080 pixels). On the whole canvas 30 sticky notes of different color (10 yellow, 8 pink, 6 blue, 4 green, 2 orange) and with different content were placed pseudo-randomly. Participants were presented with an image of a sticky note on a small screen on their desk. Their task was then to find this particular note on the virtual canvas, using the off-screen visualizations to make their search more efficient. Each condition consisted of three blocks of 10 notes with the option to pause in between. Each block was carried out on a different data set (different placement of notes) to avoid location memory effects.

Figure 9: Setup in experiment two: On the tablet the target note is shown. Glowworm refers to the chains of colored lights.

The study started with a demographic questionnaire. No training was done. Between the different conditions we asked the participants to rate the task load using a NASA TLX [17] test. The study was concluded with another short questionnaire and a semi-structured interview, lasting approximately 50 minutes overall for each participant.

Apparatus Adaption

When performing the first pilots for this experiment we soon noticed that the lower resolution of ambient light was a considerable disadvantage for this condition in comparison to the on-screen solutions. Especially the natural additive mixing of colors was a problem, as close off-screen objects of different color blended into a white spot and could not be distinguished (see Figure 10, *left*). Therefore, we decided to alter our hardware setup. We installed small separators (35×40 mm white cardboard) between the individual LEDs around the whiteboard, which keep the lights separated and enhance visibility (see Figure 10, *right*). This installation decreases the general possible brightness of the ambient light installation. Overall this effect is only minor and can be diminished further by using a reflective material for the separators (e.g. mirror cardboard), as initial tests have shown. In all other regards the installation and the light conditions in the room was similar to first experiment.

Figure 10: Comparison between ambient light with and without separators. *Left*: The light blends and different colors can hardly be distinguished. Middle: The separators prevent the blending of colors to make identification easier. *Right*: The separators in the whiteboard context.

Participants

We recruited 10 participants (3 female) with an age range between 22 and 53 from various computer science research labs and administration staff at our university. Six wore glasses and nobody was color-blind. All were regular computer users, but only five had experience with interactive whiteboards.

Results

The quantitative results show only small deviations between the different conditions.

Hypothesis 2.1: Performance

For the performance analysis we measured the task execution time of the individual trials. Trials with times greater than average + three time SD were considered as outliers and eliminated for further analysis (1.3% of the data). Execution time was analyzed by a repeated-measures ANOVA (α = .05). The assumption of sphericity was violated, so the Greenhouse Geisser corrected values are reported. It showed that the Baseline (M = 17.35s, SD = 4.75) was significantly slower than all the other conditions ($F_{2.28,9}$ = 10.339, $p < .005$) with power = .982. Our test confirmed the measures in [14]. Post-hoc tests showed that although Wedge was the fastest technique (M = 12.61s, SD = 4.42) tightly followed by Firefly (M = 12.68s, SD = 2.86), it was not significantly faster than both of the ambient light conditions. Thus *Hypothesis 2.1* is confirmed.

Hypothesis 2.2: Preference

All of the participants preferred using ambient light visualizations (6 participants Firefly, 4 participants Glowworm) over On-Screen solutions. From an aesthetic point of view, seven participants preferred Firefly, and two Glowworm. One person liked Halo best from an aesthetic point of view.

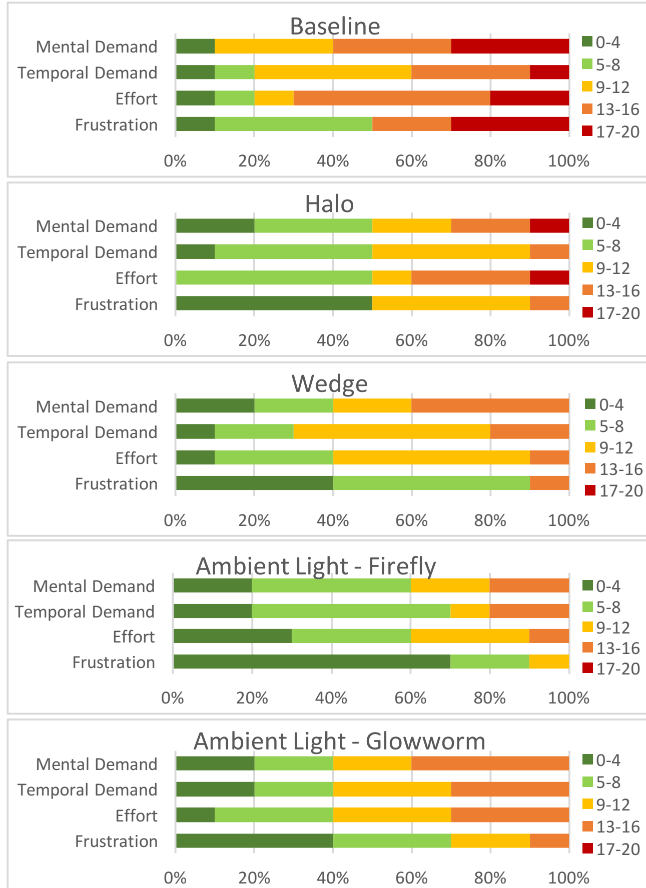

Figure 11: NASA-TLX results of the second experiment.

The NASA-TLX ratings (see Figure 11) show the lowest task load for the Firefly condition. A Friedman test indicated significant results for the overall task load ($\chi^2(4)$ = 15.82, p = .003) and Frustration ($\chi^2(4)$=15.94, p = .003). In depth analysis by performing a Wilcoxon Signed Rank test showed that the overall task load for Firefly was significantly lower than for Wedge (Z = -2.193, $p < .05$) and Halo (Z = -2.654, $p < .01$). Further investigations unveiled that this was mainly due to a significantly lower *frustration* level compared to Wedge (Z = -2.059, $p < .05$) and Halo (Z = -2.657, $p < .01$). Firefly also has a low load of *Effort* and *Mental Demand* (see Figure 11). In contrast, we measured a higher task load for Glowworm, which indicates that the better performance caused also higher overall task load, effort, and frustration. All participants stated a preference for one of the ambient light solutions. Due to this and the significantly lower task-load and frustration level for Firefly, we can confirm *Hypotheses 2.2*.

Additional Insights

The way how distance is mapped in the different conditions is quite diverse. We were interested in how intuitive the different mappings were to the participants. In the post-experiment interviews six participants stated that they had problems interpreting Wedge in the right way. P2 stated: *"I understand it from a logical point of view but it is unintuitive that they (the visualizations) are bigger when they are fur-*

Figure 12: Example applications. ***Left*****: Off-Screen content visualization in a virtual 2D workspace;** ***Middle*****: Visualizing notifications;** ***Right*****: Indicating the position of a remote user – the colored silhouettes are not part of the actual visualization.**

ther away". Seven participants considered the mapping of close objects to a bigger visualization as used in Firefly as "*intuitive*" and "*right*", confirming insights in [33]. Obviously the different mapping are a source of potential bias. However, we implemented Wedge and Halo close to the original techniques to provide maximum comparability to existing state-of-the-art-work. We still implemented the best possible ambient light technique.

Regarding Glowworm the opinions were divided. While some of the more technologically-literate participants could use the different cues well and also performed quite well, novice users had a hard time with this condition. We are hesitant to draw strong conclusions, due to our small sample size. However, we assume this difference is due to the fact that brightness is not used to indicate the absolute distance, but a ranking between the different off-screen notes of similar color. We observed that this worked particularly well for participants whose strategy was to identify the closest note and move there. Others, who tried to gain an overview of the note positioning had a harder time. As P8 put it: *"Firefly gives a better understanding of the whole picture"*.

Discussion

The experiment showed that ambient light is not significantly inferior to state-of-the-art off-screen visualizations, despite its smaller design space, and was even preferred by users. While ambient light requires some additional hardware, it does not require any screen-space. The natural separation between on-screen objects and off-screen visualization helps to reduce clutter and reduces users' workload. This is reflected in the analyses of the overall task load and frustration, which were significantly reduced when using Firefly.

DESIGN RECOMMENDATIONS

Based on our two experiments that created new insights and confirmed existing knowledge, we present the following design implications that designers should consider when using ambient light to enhance large interactive surfaces. Drawing on the existing literature, we suggest to apply the concept of Visual Variables [29] for encoding parameters.

D1: Accommodating User Positions: Standing close to the whiteboard decreases one's ability to perceive ambient light notifications. Hence, they are best suited to support scenarios that involve distant interaction or observation. For scenarios where the user is standing close to the board visibility can be increased by using animation.

D2: Using Animation for Notifications: The animation of ambient light notifications increases its perceptibility in all scenarios, confirming insights of related work [4,43]. Use blinking or animated ambient light for high priority notification to ensure that it is perceived.

D3: Enhance Brightness Perception: We recommend to apply gamma correction to make better use of the available and perceivable brightness levels (c.f. [13,42]). If the user position is static, one can accommodate for different viewing angles, increasing intensity when the viewing angle is flatter.

D4: Size is Interpreted Faster than Brightness: Most users are quicker to detect size than brightness. While it is not too difficult to distinguish different brightness levels, most users seem faster in interpreting the meaning of different sizes.

D5: If Resolution is Important, Add Light Separators: Separators are a great way to prevent light blending. This enables the system designer to show notifications of different colors close to each other. Moreover, the separators aid in the perception of changes in notification size.

APPLICATION SCENARIOS

Based on the design recommendations we showcase a variety of applications, which highlight the benefits of using ambient light to enhance work on large interactive surfaces. While the Virtual 2D Workspace and Emergency Response scenario build directly on the performed studies, the others suggest different domains where ambient light could be beneficial.

Virtual 2D Workspace (see Figure 12, *left*): Having spatial awareness of off-screen objects in a virtual 2D workspace is often crucial, yet challenging to sustain. As shown in experiment 2 using ambient light is very suitable for visualizing off-screen content. It also showed that using the property of size to encode for distance, such as in Firefly, is easier for users to interpret than brightness in the Glowworm visualization (*D4*). However, if brightness is used for encoding, gamma correction is of great benefit to account for human perception (*D3*). For spatially close notifications, separators are a great help to enhance light visibility (*D5*). Finally, considering the user position is also important in this scenario. Ambient light has the advantage of not disturbing users who work close to the board. However, when stepping back to gain overview it can help to enhance understanding of the relation to off-screen content. In this case the use of ambient light for off-screen visualizations is beneficial (*D1*).

Emergency Response (see Figure 12, *middle*): Ambient light is very well suited for emergency response applications where operators work in collaboration with each other. Firstly, the flexibility to determine the position of ambient light notifications means that spatial data can be conveyed to operators working independently at the back of the room, while users close to the board are hardly affected (*D1*). Secondly, using animation can trigger attention more aggressively in an emergency situation (*D2*). Off-screen notifications are not any more disruptive than on-screen notifications for operators working close to the board, yet they help operators to understand the overall situation quicker. Thirdly, the ability to vary size or brightness levels allows for events to be portrayed in order of importance or priority (*D4*). Finally, the ability to increase the resolution might be helpful in this scenario to provide more sophisticated notifications that contain more information (*D5*).

Remote Activity (see Figure 12, *right*): Ambient lights can be used to facilitate remote collaboration. By showing the position of a remote person, ambient light enables users to perceive and avoid entering occupied working space. The approach is more abstract than, e.g., [46], but has the advantage of not occluding on-screen content. Notification size and brightness levels can be used to provide an estimate of the remote user's distance from the whiteboard (*D4*), while the position of the ambient light can indicate the viewing angle. As seen in Figure 12 (*right*), the light bars are shown at the bottom and top of the whiteboard to improve visual perception for users close to the board (*D1*).

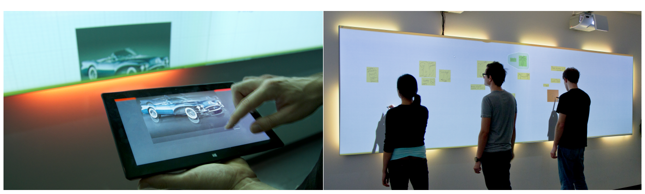

Figure 13: Additional applications: *Left*: A virtual border to an external device; *Right*: Visualization of a timed process.

Linking to Remote Devices (see Figure 13, *left*): Ambient light can be used to bridge real and virtual space. Using it in the context of remote device tracking, the position of the lights along the perimeter of the whiteboard can map directly to the real space occupied by a remote device. The light creates a border of virtual space that serves as a portal through which content can be transferred. Different colors identify different devices and while people working on external devices can easily detect the ambient light from the distance, users, standing close to the board, are hardly disturbed (*D1*).

Progress Indicators (see Figure 13, *right*): Peripheral ambient light can be used to convey information, such as the progression of time [32,34], without occluding valuable workspace, and without requiring users to explicitly switch their gaze and attention away from their primary tasks. To accommodate for various possible user locations close to the board (*D1*), we would suggest a design that provides progress indication at multiple spots, so that users can perceive changes close to them. Finally, blinking (*D2*) assures that every user is informed when the process ends.

LIMITATIONS

In this paper we summarize our insights in using ambient light on a large interactive surface, and more specifically, to augment an interactive whiteboard. We aimed to keep our insights transferable to similar and related setups and therefore reported variables such as the size of the board, distance of the users and lighting conditions. Nevertheless, when conducting the studies and pilots we learned that small changes can have considerable impact and that perception is ultimately a very personal issue that may differ between users. Nevertheless, we believe that ambient light has notable potential in the context of large interactive surfaces and that our experiments provide some valuable insights for others.

CONCLUSIONS & FUTURE WORK

In this paper, we considered how ambient light can be used for more than enhancing the TV viewing experience. We explored the applicability of ambient light for extending screen space and depicting peripheral information on large interactive surfaces. Based on the findings from two experiments, we developed design recommendations regarding how best to leverage ambient light for use in this context. These cover differences in the perception of notifications in three possible work scenarios, and insights on how to depict various types of information. Finally, we applied these design recommendations to five application scenarios to highlight the strengths of using ambient light in various situations.

We explored the influence of location and different working scenarios, concluding that ambient light is particularly suitable for giving notifications to people distant from the board. While we included a blinking animation effect in our first experiment, animations could potentially provide a much larger design space to communicate information [16], especially for peripheral use [4]. This would be an interesting topic for future work. We also examined the utility of ambient light as a tool for off-screen visualization. Our findings suggest that when making use of the property of size, ambient light lowers the task load and the frustration level. In the future, it would be interesting to see how ambient light performs in combination with interactive surfaces when used for longer periods of time in real-life scenarios.

Although there are topics to explore further, we believe that our studies and design recommendations provide helpful insights for designing applications that use ambient light. Moreover, the versatile scenarios we depict in this paper show that there is a general benefit in using ambient light to extend large interactive surfaces.

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