






Glyph-Based Visualization of Affective States

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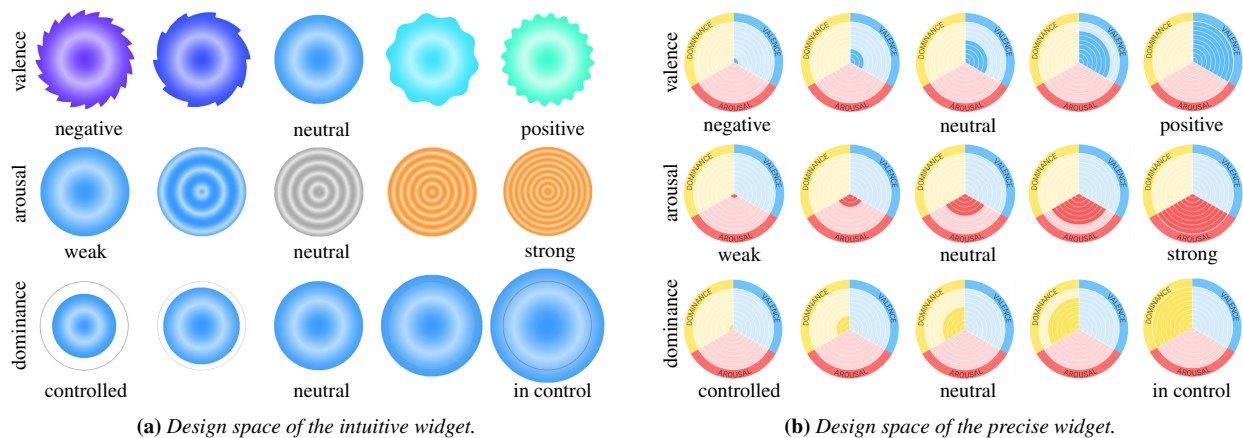


Figure 1: Affective states are often measured in terms of valence, arousal, and dominance to conceptualize emotions and mood. We developed two graphical user interface widgets that visualize affective states to users. Our first widget in (a) focuses on the intuitiveness of understanding different combinations of valence and arousal. Therefore, they are mapped to color. Our second widget in (b) focuses on the precise representation of the levels of the three dimensions using radial bar charts.

Abstract

Decades of research in psychology on the formal measurement of emotions led to the concept of affective states. Visualizing the measured affective state can be useful in education, as it allows teachers to adapt lessons based on the affective state of students. In the entertainment industry, game mechanics can be adapted based on the boredom and frustration levels of a player. Visualizing the affective state can also increase emotional self-awareness of the user whose state is being measured, which can have an impact on well-being. However, graphical user interfaces seldom visualize the user's affective state, but rather focus on the purely objective interaction between the system and the user. This paper proposes two graphical user interface widgets that visualize the user's affective state, ensuring a compact and unobtrusive visualization. In a user study with 644 participants, the widgets were evaluated in relation to a baseline widget and were tested on intuitiveness and understandability. Particularly in terms of understandability, the baseline was outperformed by our two widgets.

CCS Concepts

• **Human-centered computing** → Empirical studies in visualization; User studies; **Information visualization**;

1. Introduction

Affective states describe emotions (short-term) and moods (long-term) [Ekk12, LE16, Sch05]. Measuring the affective state of a user can be useful in education and gaming. Teachers having access to the visualizations of the affective states of their students can provide feedback to the students based on the affective information,

which can increase the learning experience [GMH⁺15]. In gaming, the user's affective state can be used to automatically adapt game elements if the player gets bored or overstrained. Such an adaptation can enhance the player's experience [NMS14]. The affective information can also be useful to the users themselves. Information about one's affective state can improve emotional self-awareness, which can have an impact on the user's well-being [LML⁺11]. Further-

more, it may allow the user to foster self-regulation, detect potential stress causes, and adjust daily routines based on the extracted information. Despite the variety of benefits, graphical user interfaces (GUIs) often focus on the purely objective interaction with the user and do not visualize affective states [CWEK13].

In this paper, we visualize the affective states by extending existing approaches and optimizing them for intuitiveness and precision. To achieve this objective, we developed two application-specific GUI widgets, which visualize the user's affective state with glyph-based methods [BKC*13] in two different ways. The first widget, called the intuitive widget, focuses on users that need an assessment of the current affective state at first sight, e.g., teachers monitoring the widgets of their students. The second widget, called the precise widget, focuses on users that want to track the individual dimensions of the affective states over time to enable a more detailed analysis of affective states. The design space of the glyphs can be seen in Figure 1. The widgets were compared to a baseline visualization in a user study with 644 participants for testing them on understandability and intuitiveness. The study showed that, particularly in terms of understandability, our widgets were able to outperform the baseline significantly. Furthermore, the intuitive widget was intuitive and understandable without further explanation of the meaning of the visualization. Our main contribution is threefold. To the best of our knowledge, we propose the first glyph-based visualization of affective states optimized for precision and intuitiveness. Further, we devise the first visualization of valence, arousal, and dominance. Finally, we conducted the first large-scale field study evaluating the visualization of affective states.

2. Background and Related Work

2.1. Classification of Affective States

Affective states are often represented along the valence, arousal, and dominance dimensions [Wun97, Osg52, OST57]. Valence indicates how pleasant a stimulus is conceived, arousal indicates the perceived intensity of a stimulus, and dominance indicates the degree of control the subject has over the situation. In practice, affective states are measured using different modalities, e.g., heart rate and skin conductance [WKS*19] and facial expressions [CKC08]. The measurements result in quantitative attributes that vary over time. Therefore, their depiction becomes a multi-variate time series visualization problem [BCB*07].

2.2. Visualization of Affective States

To measure the three dimensions of an affective state, the Self-Assessment Manikin [BL94] was proposed, which uses glyph-based visualizations [BKC*13]. Each dimension is assessed on a 9-point scale where the different levels of each dimension are denoted by glyphs. This makes the approach widely applicable because it relies on a universal and language-independent representation.

Cernea et al. [CWEK13] developed a visualization of valence and arousal for user interface components such as buttons. The affective states are visualized by displaying a color bar per dimension conveying different affective information by adjusting the color and saturation of the bar. Valence is displayed using a divergent

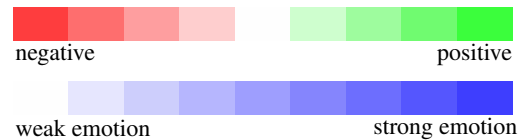


Figure 2: Example visualization of valence (top) and arousal (middle) based on work by Cernea et al. [CWEK13]. Saturation and color of each bar denote the level of the corresponding dimension.

color map, and arousal is displayed using a sequential color map, see Figure 2. The bars allow multiple states to be displayed at the same time. The bar is divided vertically into multiple parts, each of which corresponds to an affective state at a certain time, i.e., time is mapped to the horizontal axis. This visualization allows a comparison among user interface components because each component has multiple affective states assigned to it. However, it impedes an exact evaluation of the current level because levels are mapped to color saturation. Furthermore, the valence bar uses red and green, which is problematic for color vision deficiencies.

In a later work, Cernea et al. [CWEK15] combined the visualizations of valence and arousal. They placed a closed curve around the user interface component under consideration. The outline exhibits waves or spikes depending on how high or low valence is. The higher the arousal, the higher the pulsation frequency of the curve. While this visualization impedes a visualization of affective states over time, it allows for a more intuitive and compact reading of the affective state. However, the visualization of valence may not be suitable if the visualization is too small, because differences between spikes and curves become hard to see.

3. Method

3.1. Requirements

The requirements for the visualization are application-dependent. In our work, we consider two possible use cases. First, we focus on users that are mainly interested in a fast assessment of the current affective state, e.g., teachers that are monitoring the affective states of their students. Such users may want to have an overview of the affective states at first sight. Second, we focus on users that are interested in precise measurements over time, e.g., a user that is interested in adjusting daily routines based on potential stress causes. Such a user may want a more detailed analysis of the affective dimensions over time in order to draw useful conclusions. From those two use cases, we derive the following requirements.

R1. We aim for a fast assessment of the current affective state. The state should be identifiable at first sight (i.e., intuitive and preattentive [War20]). Past affective states are less important.

R2. To track current trends over time, we aim for exact values and an intuitive reading of time. Furthermore, the visualization should keep the dimensions easily separable for clarity.

R3. In both use cases, a core requirement is a small space consumption. Further, the glyphs should be orientation-independent, compact, and transparent, such that users can place the widget wherever it interferes least with other activities on the screen. A circular shape meets these requirements and is therefore used for both widgets.

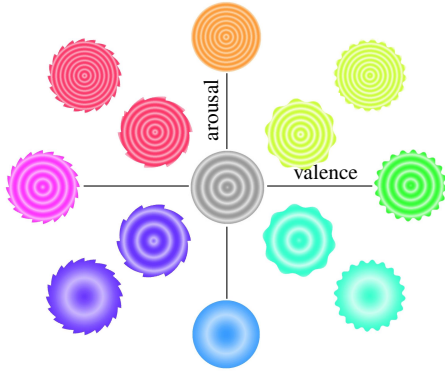


Figure 3: As in the literature [SSH05], valence and arousal are mapped to color. Valence increases from left to right, arousal increases from bottom to top.

3.2. The Intuitive Widget

The widget that focuses on the first use case from Section 3.1 should meet R1 and R3. Since it is more self-explanatory than the second widget, we call it the intuitive widget. For its design, we extended the idea by Cernea et al. [CWEK15] and improved the visualization for the use on small screens, see Figure 3 for an overview.

Valence. Because of the similarity of spikes and waves for small widget sizes, we replaced the spikes by a curve that resembles a saw blade because it maintains a sharp appearance that is better distinguishable from the waves, see Figure 1a.

Dominance. Dominance is incorporated by smoothly adapting the radius of the base circle proportional to the change in dominance. In addition, a thin gray reference circle denoting medium dominance is constantly displayed, see Figure 1a.

Arousal. Since pulsation affects the widget size—which would interfere with dominance—we used concentric waves flowing with constant speed from the widget center to the border, see Figure 1a. The number of waves increases with increasing arousal.

Color. The widget is color-coded to enable affective state identification even at peripheral vision. The color is determined by the level of valence and arousal based on a unification [SSH05] of Itten’s color wheel [Itt70] and Russell’s Circumplex Model of Affect [Rus80]. A measurement of valence and arousal can be seen as a two-dimensional point living in the discrete space $\{1, \dots, 9\} \times \{1, \dots, 9\}$. Given a certain level of valence v and arousal a , we map the corresponding point to its polar angle $\phi = \text{atan2}(a, v)$. The angle is then mapped to hue in HSV color space, similar to Ståhl et al. [SSH05]. For the neutral point ($v = 5, a = 5$) the color is mapped to gray. Thereby, saturation and value are set to 1, see Figure 4. For colors like yellow or green, we adapt the saturation to enhance contrast.

3.3. The Precise Widget

The precise widget focuses on the second use case from Section 3.1. It should meet R2 and R3. A simple bar chart fulfills R2. For R3, we visualize the bar chart as a circle such that three sectors are formed, each of which corresponds to one affective dimension, see Figure 1b. Thus, all dimensions are adjacent, which enables direct comparability among dimensions. The number of filled parts per

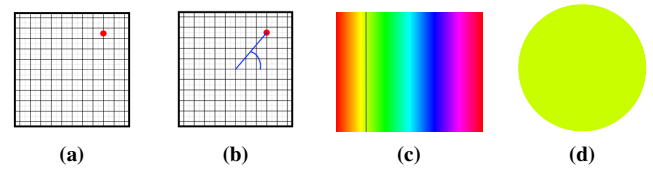


Figure 4: Color mapping example. The affective space is centered around the origin and is normalized (a). Then, the polar angle of the current point of interest (red dot) is calculated (b). From the polar angle, the hue is extracted (c). The base circle is filled using the color having this hue, setting the saturation and the value to 1 in HSV color format (d).

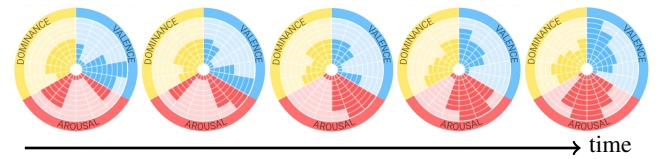


Figure 5: The precise widget shown in five consecutive time steps from left to right. The new affective state is put in the first segment in clockwise direction, and all other affective states are shifted in this direction whereby the oldest one is not shown anymore.

segment denotes the current level of the corresponding affective dimension. This representation is unambiguous and lossless with respect to the underlying space of valence, arousal, and dominance since each affective state is displayed precisely. However, this is less intuitive and demands more time for interpretation because the user has to parse first which affective state is represented by combining the dimensions. The time dimension is incorporated by dividing each sector into equal pieces, see Figure 5. The pieces in a sector show the development of a dimension over the last few affective states. This allows the user to track current trends in each dimension.

4. User Study

4.1. Study Setup

The user study was carried out using an online survey platform. We recruited 644 participants between the ages of 18 and 52 (mean = 23.8, standard deviation SD = 4.2), mostly undergraduate students. The study was split into three parts. The first part assessed the intuitiveness of the first widget, while the other two parts compared our two widgets to the baseline. As baseline, we used the visualization by Cernea et al. [CWEK13], cf. Section 2.2. Since their approach does not include dominance, we extended it by a third bar using a different sequential color map (ochre). The last part focused on demographical questions and subjective ratings of understandability. We enclosed the experimental setup in the supplemental material.

Task Design. In Part 1 and Part 2, we presented six images and six short sentences. Each image showed a person, expressing a specific affective state. Alternatively, each sentence consisted of a statement about a person and contained one affective keyword. For each image and each sentence, the participants were shown three different visualizations of each widget visualizing different affective states. The participants were asked to choose the correct one. For the sentences, the keywords were mapped to valence, arousal, and

dominance using the lexicon by Mohammad [Moh18]. While there are databases for images such as the International Affective Picture System [LBC08] that trigger certain affective states, there is no database for images that expresses affective states analogously to the lexicon used for the sentences. Thus, we mapped affective keywords to the images instead, and then tested and improved the choice of images as well as sentences in a pilot study ($n = 10$). To obtain affective states, the keywords were mapped to valence, arousal, and dominance using the same lexicon as used for the sentences.

4.2. Intuitiveness of Widget 1

Hypotheses. Since the color mapping was shown to be intuitive [SSH05], we expect that the design of our widget is intuitive.

Experimental Setup. The participants were shown the images described above, and three different states of the intuitive widget. For this part, no explanation about the widget nor any background information about affective states was provided to the participants.

Results. 54.9% of the responses were correct, which is above random level (33%). Furthermore, the state of the widget, which differed the most from the correct state in terms of valence, was often ruled out by the participants. A more detailed analysis of the results showed that in 82.9% of the cases either the correct version or the most similar version in terms of valence was chosen. Hence, the visualization of valence seems self-explanatory (64.0% for arousal, 65.9% for dominance).

4.3. Baseline Comparison

Research Question. How do our two widgets compare to the baseline in terms of performance in the tasks presented above?

Experimental Setup. In this part, background information about affective states and a detailed explanation about the widgets were provided. Afterwards, both images and sentences were presented to the participants. In order to ensure comparability, the three states shown per widget always encoded the same affective state across the widgets. The order of the appearance of the widgets and the order of the states was randomized.

Results. In the sentence-based part the average number of correct answers was 86.6% (SD = 18%) for the intuitive widget, 83.5% (SD = 19%) for the precise widget, and 82.8% (SD = 20%) for the baseline. For the image-based part, the average number of correct answers was 71% (SD = 18%) for the intuitive widget, 76.2% (SD = 18%) for the precise widget, and 70.6% (SD = 17%) for the baseline. Our widgets provide a small but statistically not significant improvement over the baseline.

4.4. Questionnaire

In the last part of the study, the participants were asked to rate the understandability of the widgets on a 5-point scale. The average ratings were 3.6 (SD = 1.0) for the intuitive widget, 4.05 (SD = 1.0) for the precise widget, and 2.45 (SD = 1.25) for the baseline. An independent Welch's t-test showed that the differences of the

means are pairwise significant ($t = -7.8, p = 1.62 \cdot 10^{-14}$ for our two widgets, $t = 17.86, p = 8.09 \cdot 10^{-64}$ for the intuitive widget and the baseline). Hence, the precise widget is the most understandable, followed by the intuitive widget and the baseline. In addition, the participants were asked to indicate on a 5-point scale how important each dimension was when solving the tasks. The results showed a mean score of 4.5 (SD = 0.7) for valence, 3.95 (SD = 0.9) for arousal, and 2.9 (SD = 1.15) for dominance. An independent Welch's t-test showed a statistically significant difference of the means ($t = 12.74, p = 5.1 \cdot 10^{-35}$ for valence and arousal, $t = 18.13, p = 3.0 \cdot 10^{-65}$ for arousal and dominance).

4.5. Discussion

At the end of the study, participants had the opportunity to leave comments. It was repeatedly pointed out that two images were ambiguous, and that the participants struggled in guessing the affective state of the person in the image. For one of those two images the number of correct answers was in fact random. Hence, in a future study, the images could be selected better to avoid ambiguities.

5. Conclusions

Measuring the affective state of users and visualizing it to the users themselves can have various benefits such as increasing the learning experience [GMH*15] or improving the user's well-being [LML*11]. However, GUIs seldom make use of those benefits. We developed two application-dependent GUI widgets that provide affective feedback. The intuitive widget focuses on an intuitive and fast assessment of the current affective state. The precise widget concentrates on an exact, clear, and time-dependent visualization. We tested the widgets on intuitiveness and understandability, and compared them with a baseline in a user study with 644 participants. The results showed that the intuitive widget is indeed self-explanatory, especially the valence dimension. In terms of subjective understandability ratings, both widgets outperformed the baseline widget. The widgets were designed to be compact and transparent such that they interfere as little as possible with other activities on the user's screen.

In this paper, we focused on the visualization of affective states rather than on their measurement. Next, we would like to combine our widgets with real-time affective state measurements. For example, Wampfler et al. [WKS*19] created a machine learning model that predicts the user's affective state based on biosensor and handwriting data of users solving tablet-based math tasks. With such a model, one could test how the self-assessment of affective states changes when using our widgets. Also, a next step is to investigate the cognitive processing time for both widgets, as well as the cognitive processing stages when translating from sentences and images to visualizations. Furthermore, the precise widget can be improved in two ways. The different levels of the radial bar chart show varying prominence, which could be solved by using varying thickness of the rings. Also, the medium level could be highlighted such that the sign of the dimension is identifiable. One could investigate other choices than a radial bar chart for the precise widget. A final step would consist of testing the widgets on different devices such as smartwatches and using a perceptually normalized hue for the color mapping of the intuitive widget to eradicate contrast issues.

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