

# Emotion-prints: Interaction-driven Emotion Visualization on Multi-touch Interfaces

Daniel Cernea<sup>a,b</sup>, Christopher Weber<sup>a</sup>, Achim Ebert<sup>a</sup>, and Andreas Kerren<sup>b</sup>

<sup>a</sup>University of Kaiserslautern, Computer Graphics and HCI Group  
P.O. Box 3049, D-67653 Kaiserslautern, Germany;

<sup>b</sup>Linnaeus University, Computer Science Department, ISOVIS Group  
Vejdes Plats 7, SE-35195 Växjö, Sweden

## ABSTRACT

Emotions are one of the unique aspects of human nature, and sadly at the same time one of the elements that our technological world is failing to capture and consider due to their subtlety and inherent complexity. But with the current dawn of new technologies that enable the interpretation of emotional states based on techniques involving facial expressions, speech and intonation, electrodermal response (EDS) and brain-computer interfaces (BCIs), we are finally able to access real-time user emotions in various system interfaces. In this paper we introduce *emotion-prints*, an approach for visualizing user emotional valence and arousal in the context of multi-touch systems. Our goal is to offer a standardized technique for representing user affective states in the moment when and at the location where the interaction occurs in order to increase affective self-awareness, support awareness in collaborative and competitive scenarios, and offer a framework for aiding the evaluation of touch applications through emotion visualization. We show that emotion-prints are not only independent of the shape of the graphical objects on the touch display, but also that they can be applied regardless of the acquisition technique used for detecting and interpreting user emotions. Moreover, our representation can encode any affective information that can be decomposed or reduced to Russell's two-dimensional space of valence and arousal. Our approach is enforced by a BCI-based user study and a follow-up discussion of advantages and limitations.

**Keywords:** Emotion visualization, emotion fingerprints, touch events, multi-touch interface, human-centered design, brain-computer interface

## 1. INTRODUCTION

Emotions are one of the omnipresent aspects of our lives: whatever we do, we are always accompanied, influenced and even defined by the emotional states that we experience. As such, it is not really surprising that scientists, technicians and developers are often seen as “cold” or rather emotionless, as informational systems are one of the few fields of our modern lives where feelings have gained minimal importance in the last years. This is partly due to the fact that IT systems are generally oriented towards information, speed and efficiency, but also because the interpretation of human emotions is as elusive and subtle as the emotional states themselves. Should this mean that software applications are doomed to contain only “dry”, quantitative information?

In recent years, different technologies have been developed that made it easier to capture and interpret the various emotions that users might experience based on facial expressions, speech and intonation, electrodermal response, brain signals, etc. While these techniques that can indicate the presence of certain emotions are slowly finding their way into software systems, most of the accent falls on affective applications<sup>1</sup> that are able to detect a set of user emotions and change their behavior based on these readings (i.e., emotional states as subconscious data input). Further examples for this include applications that react to emotions extracted from speech,<sup>2</sup> as well as systems that change the style of a painting based on the emotional state of the viewer.<sup>3</sup>

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Further author information: (send correspondence to D.C.)

D.C.: E-mail: cernea@cs.uni-kl.de; C.W.: E-mail: chweber@rhrk.uni-kl.de;

A.E.: E-mail: ebert@cs.uni-kl.de; A.K.: E-mail: andreas.kerren@lnu.se

In the following, we propose a visualization approach, called *emotion-prints*, for incorporating real-time information about user emotions in new or already designed multi-touch interfaces. Similar to fingerprints, where touching an object would leave a marker on the object uniquely identifying the person, emotion-prints aim at introducing a standardized visualization of emotions by marking the virtual object that a user touches with a representation of the user’s current emotional state. The power of this representation lies in the fact that it is applicable to any multi-touch screen and any interface element—regardless of its shape, size or color—as long as at least parts of its margins are inside the interface. Furthermore, our representation can encode and display a variety of emotions in terms of affective valence (pleasant or unpleasant) and arousal (excited or calm), while at the same time being entirely independent of the technique employed for acquiring the user’s affective states.

The goal of emotion-prints is to improve the user’s emotional self-awareness, the awareness of other users emotions in collaborative and competitive scenarios—be it games, visualization systems or any collaborative touch-based application—and support the evaluation of touch systems and user experience through the visualization of emotional involvement.

Awareness of and reflection on emotional states has proven particularly important in collaborative contexts, as “group self-awareness—of emotional states, strengths and weaknesses, modes of interaction, and task processes—is a critical part of group emotional intelligence that facilitates group efficacy”.<sup>4</sup> Furthermore, awareness of emotional states inside a group has been correlated with improved communication,<sup>5</sup> decision support and mitigation of group conflicts,<sup>6</sup> while offering an additional level of rich contextual information<sup>7</sup> and also supporting collaborative learning.<sup>8</sup> At the same time, lower values of emotional intelligence (EI) and negative emotion contagion inside groups have been linked to declining intra-group communication and collaboration,<sup>4,9</sup> suggesting the need for emotion awareness solutions.

In the next section we highlight relevant related work, followed by the design considerations that an emotion visualization for multi-touch interfaces would need to observe. Then, we describe the details of our approach, both in the context of real-time visualization of user emotions and their post-task analysis. The results we obtained with emotion-prints are presented in a user study, where user emotional states are acquired through wireless BCI headsets. Building on this, a discussion section addresses benefits as well as current limitations of emotion-prints. Finally, we present our conclusion and potential future improvements.

## 2. RELATED WORK

The visualization and perception of user emotions has been inspected in multiple contexts and from various angles over the last decades. In the work of Liu et al.,<sup>10</sup> an affect color bar reflects the emotional structure of loaded text documents, while Stahl et al.<sup>11</sup> focus on a creative tool for communicating emotional states through sub-symbolic expressions (colors, shapes, etc.) as an additional channel in text-based communication. In the area of emotion annotation, Ohene-Djan et al.<sup>12</sup> highlight a visualization tool that allows the user to express his current affective state in order to reflect his emotional perception about what s/he is currently watching or doing. Closer connected to our work, McDuff et al.<sup>13</sup> devise a visualization for supporting long-term emotional self-awareness, called AffectAura. This representation encodes valence, arousal and engagement levels through color, shape, size and opacity. However, AffectAura is a visualization system in itself, contrary to our approach that aims at offering a generalizable representation for enhancing touch interface elements.

Besides abstract representations, emotions have also been depicted in interfaces through avatars and affective icons,<sup>6,14,15</sup> as well as through custom interface widgets that would support user emotional awareness.<sup>6</sup> Further related to UI widgets, Cernea et al.<sup>16</sup> present an approach for fostering emotional awareness in the context of desktop computing. In terms of emotional awareness in a collaborative setting, Saari et al.<sup>17</sup> describe an emotion visualization system for mobile devices in order to address issues like emotional awareness within groups and the influence of emotion visualization on group performance.

Focusing further on group psychology, emotional awareness—be it on a personal or group level—has been shown to support the collaboration process by improving verbal and non-verbal communication,<sup>4,5</sup> support group decisions<sup>6,7</sup> and foster collaborative learning.<sup>8</sup> Research on emotion contagion further highlights the importance of emotional awareness in groups, as affective influences between group members can deeply impact the dynamic of the group, with positive emotional contagion resulting in increased efficiency and less conflicts, and vice versa.<sup>9</sup>

### 3. DESIGN CONSIDERATIONS

As a vital starting point, we have composed a list of requirements that a real-time visualization of user emotions on multi-touch interfaces would have to satisfy in order to offer an effective representation of affective states. The elements of the list are based both on related research and the previous research of the authors:

1. Less standardized than graphical user interfaces (GUIs) designed for desktop environments, graphical elements on a multi-touch device can have almost any shape. Accordingly, the representation has to be *generally applicable for any interface element* regardless of shape and size, and at the same time refrain from displacing or repositioning any of these interface objects.
2. The visualization of the emotions should be in the appropriate context, ideally *at the physical location of the touch event*. This would support easy identification of the operation-emotion couple as well as, in some cases, identify the corresponding user.
3. Human emotions are rarely precisely defined and complex in nature. A visualization that tries to convey emotional states or attributes should consider these inherent properties and offer representations for *hinting at the emotional state* of the user instead of trying to visualize exact values.
4. The representation needs to be as *intuitive* as possible and support *fast* processing. This is particularly important as users need to perceive and interpret the displayed emotions during the real-time touch-based interaction.
5. Various levels for emotional involvement have to be *distinguishable*. Also, users should have the possibility to compare the different emotions that are displayed at a point in time.
6. The representations should support the *real-time* nature of the interaction and also ensure that the interface does not succumb to visual clutter.

### 4. EMOTION-PRINTS

As highlighted previously, different sets of user emotions can nowadays be detected through a relatively wide range of techniques, including facial expressions, speech,<sup>19,20</sup> electrodermal response or galvanic skin response (EDS or GRS),<sup>21,22</sup> and brain-computer interfaces (BCI).<sup>15,23,24</sup> The importance of detecting and classifying these emotions increases as one considers that user emotional states are usually generated by *stimulus events*,<sup>25</sup> events which in our context can be related to the applications the users interact with. As a result, emotions might be closely connected to the visual systems users interact with (e.g., frustration about an unintuitive representation), to the task they have to execute (e.g., excitement after having an insight), or even to the other users they collaborate with (e.g., group tensions).

In this paper, we aim at creating an emotion representation that is independent of the emotion acquisition technique and is thus combinable with any approach that can interpret affective states in real-time. In order to demonstrate and evaluate our concept, our implementation and corresponding study employs emotion reports obtained through BCI readings. Details about the emotion acquisition process are highlighted in the User Study section.

Once the emotional states are established, the design considerations could be addressed in order to generate the most fitting visualization. To satisfy the first two requirements, we decided to employ a metaphor based on the actual fingerprints people leave when interacting with touch displays. More precisely, virtual objects that would be touched and acted upon by users would receive a colored halo that would closely follow their outline. Thus, the emotion-prints would be included in the representation spatially right at the position where the touch event took place and without influencing the previous distribution of elements on the interface.

To model the halo effect around the objects we had to generate an offset-curve following the underlying shape (Figure 2). These halos would extend the outline of the virtual objects by a constant distance  $a$ , computed along the normal to the object's outline. At the object's edges, the halos would be rounded in order to offer a smoother contour capable of sustaining an additional layer of information: outline texture. With this approach, colored

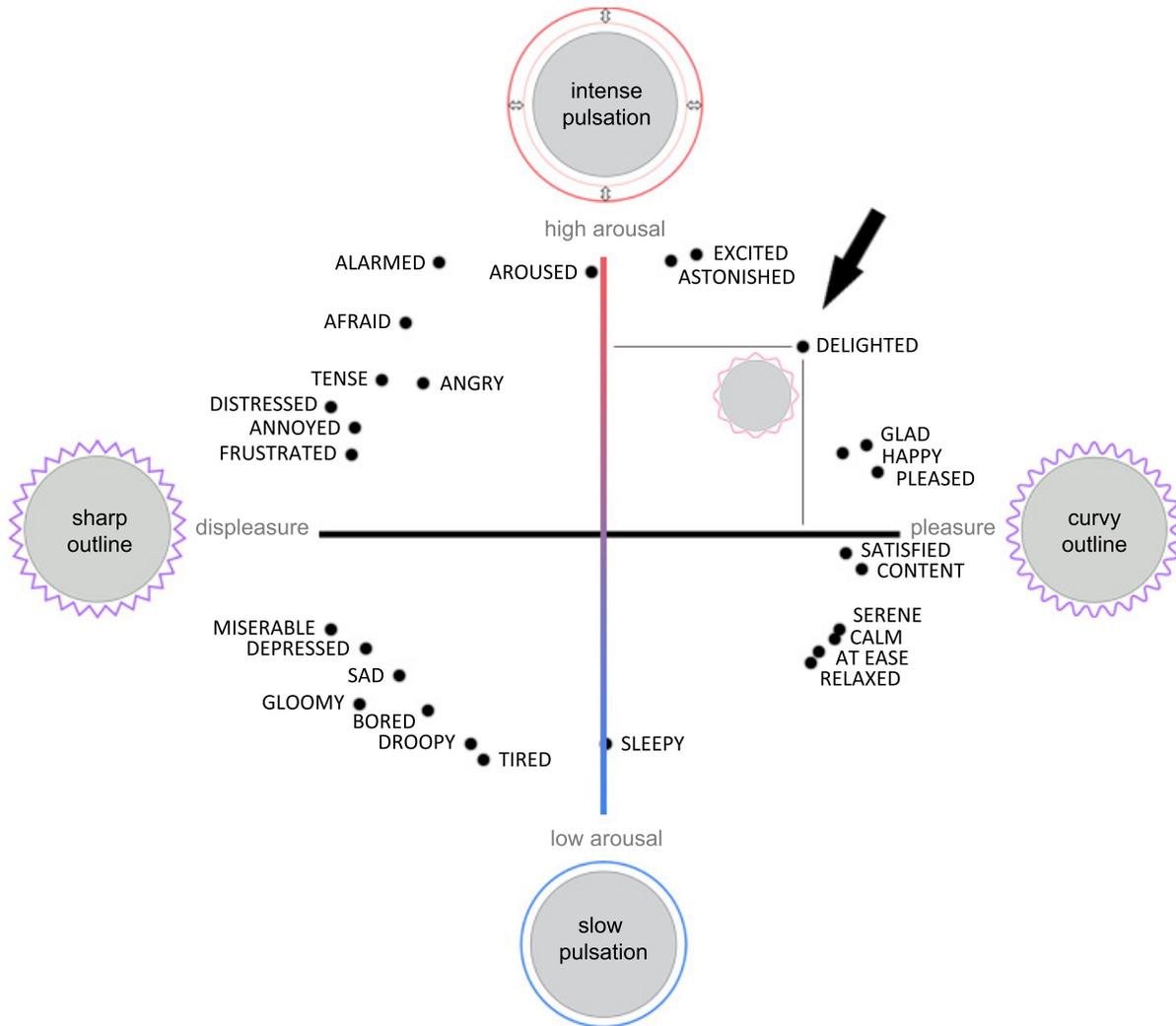


Figure 1. Russell's circumplex model of affect<sup>18</sup> extended by the visual metaphors employed by emotion-prints. On the horizontal axis of valence, positive and negative emotions are encoded by outline texture. Positive emotions are represented by halos with an increasing number of wavy, round shapes, while negative ones have halos with jagged, angular outlines. The intensity of each emotion—positive or negative—increases with the number of shapes that define the outline of the halo, e.g., see arrow pointing at the state of *delight* and its corresponding emotion-print. On the vertical axis, high arousal is encoded by intense red color and a fast pulsation of the halo, while low arousal is encoded by a blue halo and almost no pulsation at all.

halos could be displayed for virtually any object on the display, regardless of shape and size. Note that the developers of multi-touch applications can control which of the virtual objects will be able to represent an emotion-print around their outline by adding the ID of those objects to a list of *touch\_items*. Through this, developers have the option of defining a subset of virtual objects that can display the emotion halos, as not all interface elements might be relevant for enhancing user awareness or evaluating the interface and user experience.

Considering the inherent complexity and imprecision of emotions, we addressed the third design consideration by employing Russell's circumplex model of affect (Figure 1), a two-dimensional space that positions a set of affective states in terms of emotional arousal (excited or calm) and valence (pleasant or unpleasant). The model follows the dimensional theory of emotions that states that different emotions can be considered as dissimilar only in terms of one or more distinct dimensions.<sup>26</sup> Widely accepted in the literature of affective systems,<sup>18,27</sup> Russell's model thus allows us to take any emotion included in this domain and convert it to a valence-arousal

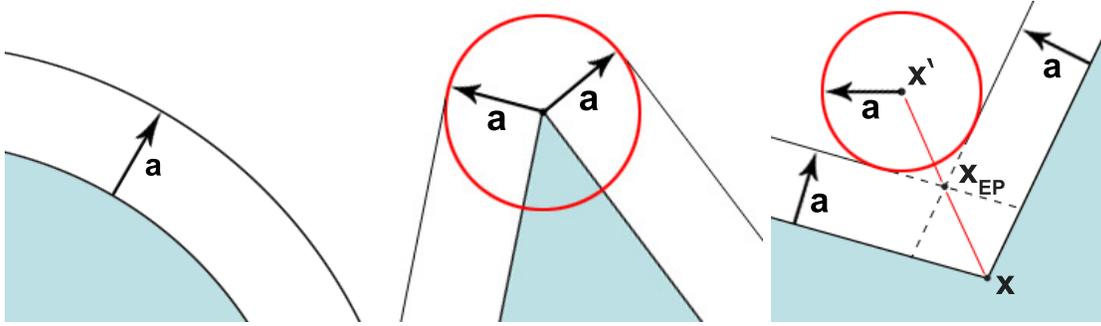


Figure 2. Computing the outline of the emotion-prints halo: (left) the basic shape of the halo is computed by extending the outline of the touched object by a length  $a$  along the normal of the object shape; (center) in the case of convex edges, the edge of the halo is rounded, following the outline of a circle with the center in the edge of the object and a radius of  $a$ ; (right) for concave edges, the edge of the halo is again rounded by drawing a circle with the center  $X'$  and radius  $a$ .  $X'$  is computed as the point that is on the line defined by the object edge  $X$  and the virtual edge of the halo  $X_{EP}$  and positioned such that the following segments are equal:  $\overline{X'X_{EP}} = \overline{XX_{EP}}$ .

pair, which can function as the core data for our representation. Visually encoding valence and arousal instead of specific user emotions enables the use of a wider range of techniques for detecting user affective states. As long as these emotions would be part of the model, they could be visualized in terms of valence-arousal pairs. Note also that the valence-arousal emotional space has been used previously for increasing awareness in communications scenarios, where participants have rated the encoding as understandable and useful.<sup>28</sup>

The visual representation of emotion-prints is inspired by the interface of the eMoto mobile application,<sup>11</sup> that focuses on emotion expressivity and communication by using color, shapes and animation to encode the two-dimensional emotional space defined by Russell’s model. Similarly to this approach, emotion-prints employ color, shapes and motion to represent various levels of valence and arousal (Figure 1). However, in contrast to eMoto, where the color attribute changes over the entire Russell model, our solution is intended as a simpler visualization, where users should be able to more easily and quickly distinguish the different levels of arousal and valence.

For the vertical axis of our representation model, arousal is double encoded through color and motion. As arousal increases from boredom towards excitement, the halos start to pulsate increasingly fast, in a manner that is meant to mimic the human heart rate in terms of frequency. At the same time, the color of the halos changes from blue to red as the perceived arousal levels increase. This is consistent also with Ryberg’s theory,<sup>29</sup> that suggests that emotional energy can be represented as increasing from blue to red. The two attributes of color and pulsation are meant to combine their effects on the human perception in order to transmit the metaphor of thawing and becoming excited or calming down and freezing, depending on the extremity of the axis.

On the other hand, the horizontal line of valence is encoded in the emotion-prints representation through a variation of the halos’ outline. More exactly, positive emotions are captured through an increasing number of waves forming on the outline of the halo, while negative emotions are displayed as halos with increasingly many jagged, sharp corners. Figure 1 highlights this representation of emotion-prints for the valence-arousal space.

By employing different attributes for each of the two dimensions, as well as by using separable dimensions like color, curvature and motion,<sup>30,31</sup> we addressed the fourth design consideration by supporting the intuitive processing of the emotion-prints. Furthermore, the attributes allow users to clearly distinguish between multiple levels of valence and arousal, thus also tackling the fifth design requirement. While it is clear that color and motion do not allow for a very fine-grained classification, our study has shown that users are capable of clearly distinguishing at least three distinct levels of arousal: blue for low arousal, violet for medium arousal and red for high arousal.

Finally, in order to address the last design consideration and support the real-time character of the visualization, all emotion-prints slowly dissipate in a preset time interval after the touch event occurred (Figure 3). Additionally, one can set an upper limit for the number of fingerprints that can be displayed simultaneously.

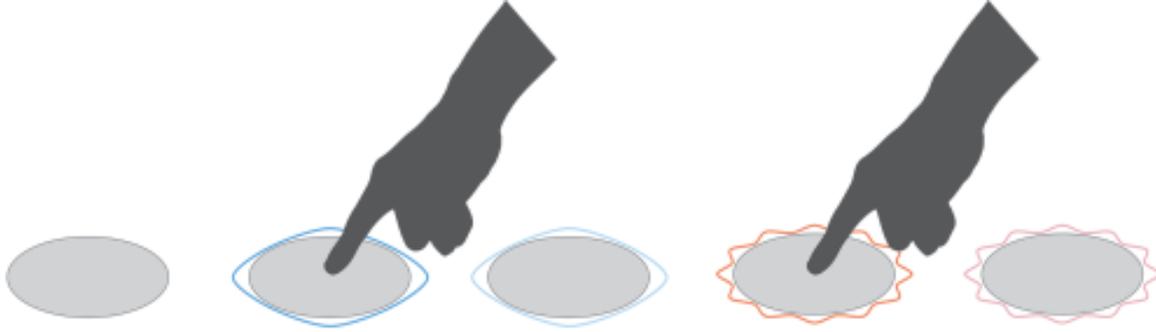


Figure 3. Example of emotion-prints dissipating and being overwritten. The first touch of the user generates a halo that suggests low arousal and a slightly positive valence. This emotion-print starts to dissipate over time by increasing the alpha channel of the halo. Before it can become completely transparent, the user touches the same object again and the old emotion-print gets overwritten. This time, the emotional readings suggest high levels of arousal and an increased positive valence. Finally, the new halo starts to dissipate again.

These two features—dissipation and maximum number of displayed halos—ensure that emotion-prints can be customized for the particular needs of any multi-touch application, such that the visual clutter introduced by this additional layer of affective information is minimal.

## 5. POST-TASK ANALYSIS OF EMOTION-PRINTS

As stated in the beginning of this paper, one of the goals of our visualization is supporting the evaluation of touch-enabled applications by offering visual feedback about the affective states of the interacting users. However, as previously described, emotion-prints are aimed mainly as a real-time emotion visualization approach that requires the representations to dissipate shortly after each touch event of the user in order to reduce display clutter and maintain the visualization up-to-date. Thus, to further support evaluation and post-task analysis of user interactions and corresponding emotions, we extended the concept behind emotion-prints to incorporate an additional visualization that allows users to inspect the temporal and spatial distribution of the touch-emotion couples.

After a session in which one or multiple users have interacted with an application on a touch interface, the emotion-prints histogram can be displayed, as shown in Figure 4. The histogram offers a temporal overview of the touch events of a user and the corresponding valence-arousal pair for each such instance. To establish this correspondence, our current implementation is able to track the hands and arms of multiple users around the tabletop based on the infrared image captured by its camera and the orientation of the users' arms over the table. At the same time, a down-facing camera tracks the motion of the tabletop users around the display for the entire length of the session, ensuring the correct user identification based on their location and arm movement.

While the initial design conventions have been considered also for the histogram, there are a couple of differences in the way emotion is encoded. In order to better differentiate between emotional states with positive and negative valence but also due to the inherent design of histograms, the valence corresponding to each touch is encoded by the orientation and height of the vertical bars. The two sides of the histogram—positive and negative—are indicated by a circle and a triangle that make the connection to the round and sharp edges of the emotion-prints, as highlighted in the previous section. Moreover, touching one of these two glyphs will hide the corresponding half of the histogram, allowing user, for example, to display and more easily compare only the touch instances that represented a positive valence. In terms of arousal, the color of each bar encodes the arousal levels for the touch instance, following the same color mapping from Figure 1. Again, the selected attributes for encoding the two-dimensional emotion data are some of the more separable ones.<sup>31</sup>

As sometimes multiple touch events can be executed by a user in a very short period of time (e.g., fast tapping in a game), we decided to discretize the temporal axis and convolute all emotional readings for time intervals smaller than a second. For example, if a user executed three touch events in a one second interval, the valence and arousal values for these three instances would be averaged and only one bar would be displayed in

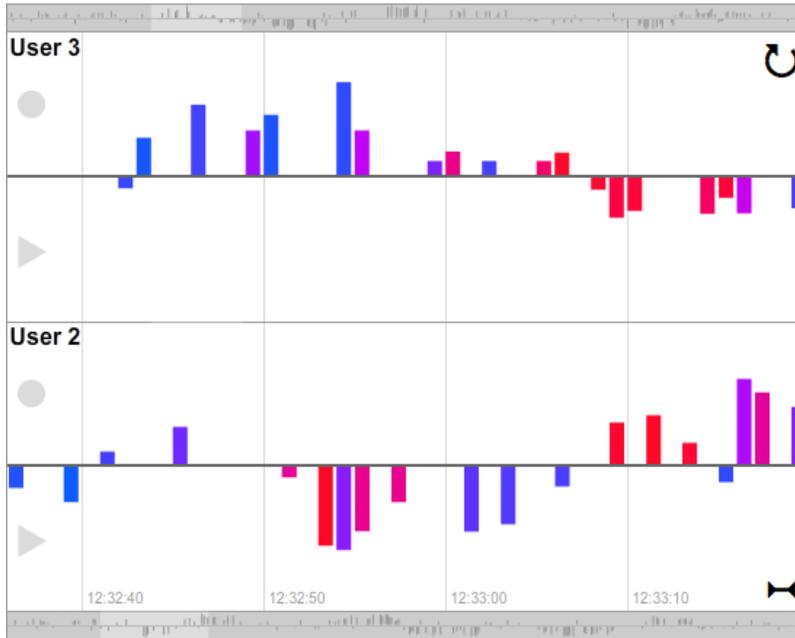


Figure 4. Histogram representation of touch events and their associated arousal-valence values for two users. Users can inspect their own temporal distribution of emotion-prints and compare it to other users by snapping together two views, like in this figure. The bars are positioned along the temporal axis, and their orientation and size encode the valence and its intensity. At the same time, the color of a bar encodes the arousal level experienced at that point in time, during that interaction.

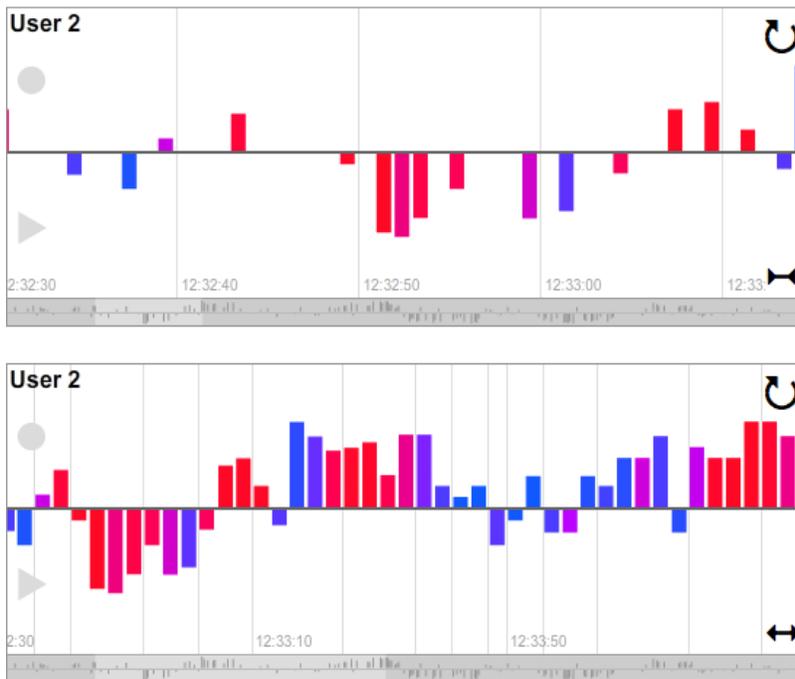


Figure 5. Emotion-prints histogram can be displayed with constant time intervals (top) or can be compressed to eliminate time intervals where the user did not execute any touch events (bottom). Switching between these two representations is done through the double-ended arrow at the right-bottom corner of the histogram. The curved arrow at the right-top corner allows users to resize and reposition the view.



Figure 6. Screenshot of the eSoccer multi-touch game supporting up to four users. The background of the field is covered by a blue-violet-red heatmap that encodes the arousal level of a user during the last gaming session. An emotion-prints histogram is displayed for the same user. By selecting a bar in the histogram, the system displays the quasi-simultaneous locations where the user has executed the corresponding touch operations on the screen. Besides location information, the histogram instance further correlates with the user ID, the ID of the touched object and the executed operation (e.g., tap, drag or resize).

the histogram (see Figure 6 where one histogram bar corresponds to two touch events). This allows us to reduce clutter, especially as emotional signals do not fluctuate with such a high frequency.

In terms of interaction, the histograms have a custom scrollbar attached, that allows users to both move to a certain location in the history and to see an overview of a user's valence during an entire session. As presented in Figure 4, two histograms can also be coupled in order to facilitate comparison. More precisely, when a histogram is positioned next to another one, the one that is being moved resizes to the same dimension as its counterpart and snaps into place next to it. Additionally, if there are common periods of interaction for the two histograms, the time axes align automatically.

Sometimes the density of touch events fluctuates heavily during a session. To allow for a more comprehensive exploration of tendencies and patterns, emotion-prints histograms can be compressed to discard the temporal segments where the user did not interact with the interface (Figure 5, bottom). To maintain a frame of reference, the vertical interval lines are shifted such that areas where the lines are closer together suggest periods of time when the touch events were more sparse, and vice versa.

While the histogram encodes the temporal distribution of touch-emotion events for a selected user, it gives no information about what areas of the display or what objects have been interacted with. In order to achieve this, the individual bars of a histogram can be selected highlighting the spacial distribution of the corresponding touch instances (Figure 6). This means that for each valence-arousal pair displayed in a histogram, one can inspect the ID of the issuing user, the location on the screen where the touch event/s took place and the operation that the user executed (e.g., touch, drag, resize).

Further, to obtain an overview of the spatial distribution of emotion-prints during an entire session, a heatmap can be displayed over the area of the application. Again, this heatmap employs the same color mapping from



Figure 7. Two players interacting with the eSoccer game on a tabletop while their emotional cues are being interpreted via BCI and represented through emotion-prints, all in real-time.

Figure 1, and combined with the histogram visualization offers a comprehensive solution for user post-task analysis and evaluation support. However, one drawback of the heatmap representation is that it can only use colors to convey information. As such, one can only show the spatial distribution of either arousal or valence at a certain moment.

## 6. USER STUDY

When working with concepts like affective states, it is difficult to devise a study that can quantitatively inspect the merits of a visualization. In such a context, the issue of “correct” and efficient representation can be defined only vaguely, as it seems more important to evaluate whether the emotion-prints were perceived by the users as intended in the design considerations, and if the representation had an impact in terms of emotion awareness and user experience analysis.

In order to validate our visualization, we incorporated emotion-prints in two tabletop applications: a soccer game supporting up to four players (Figure 7) and a collaborative semi-hierarchical history visualization (Figure 8). In the soccer game, the only objects that users could manipulate were virtual soccer players, which were then registered as *touch\_items*. Similarly in the history visualization, the nodes of the graph were tagged as *touch\_items* on which emotion-prints could be displayed. The two applications were selected in order to investigate how emotion-prints are perceived in a competitive and a collaborative scenario.

One difference between the two applications in terms of emotion visualization was that for the collaborative scenario, touches corresponding to a negative valence would not be displayed. The motivation for this is given by the fact that reinforcement and feedback on positive emotions has been shown to foster the collaboration process as well as contribute to the development of positive group affective tone.<sup>32,33</sup> Note that the group affective tone is defined as a consistent emotional state throughout the members of a group. More importantly, the presence of a (positive) group affective tone can also influence the effectiveness of said group. This has also been addressed by Saari et al.,<sup>17</sup> who state that in a group, negative emotions can lead to withdrawal, while positive emotions can foster the interaction and collaboration of the team members.



Figure 8. User interacting with the browser history visualization on a tabletop. Emotion-prints are being displayed each time a user touches a rectangular segment, corresponding to the nodes of the history that represent the websites that have been accessed.

In both applications, whenever the user would interact with a virtual object, his current levels for arousal and valence would be determined based on brain signals obtained from an electroencephalograph (EEG) device, transmitted to the tabletop computer and represented through an emotion-print around the corresponding UI object (Figure 9). In order to detect the two dimensions of the Russell's emotional space, we employed the Emotiv EPOC BCI system\* to ensure real-time detection of emotions and a high level of mobility for the work around the tabletop. The Emotiv EPOC is a wireless EEG-based headset that enables the detection of electrical brain signals on the surface of the scalp. These electrical signals are recorded through 14 electrodes positioned at key locations on the head of the user.<sup>24</sup>

The headset is accompanied by a software framework that can interpret the raw EEG signals and classify them in terms of a predefined set of facial expressions, emotional states and mental commands (Figure 10). Note that the BCI-based detection of user emotional states is beyond the scope of this paper, and that the Emotiv technology and its corresponding framework have been previously evaluated in the context of emotion reporting.<sup>16,24</sup> Also, the EPOC headset and similar BCI systems have been used successfully in various subjectivity and state-based evaluations, including some in the field of visualization.<sup>23,34</sup> In our study, coupling both the facial expression readings and the classification of affective states generated by the EPOC framework supplied us with values for the emotions that are closest to the extremes of the arousal-valence axes in Russell's circumplex model, and which can be employed to cover the entire corresponding 2D space.

Twelve subjects took part in our study, all of which had some level of experience with multi-touch devices or tabletops. The participants were split into six pairs, where each pair was asked to play a game of virtual soccer against each other and to collaboratively find a node with a particular set of attribute values in the history

\*<http://www.emotiv.com>

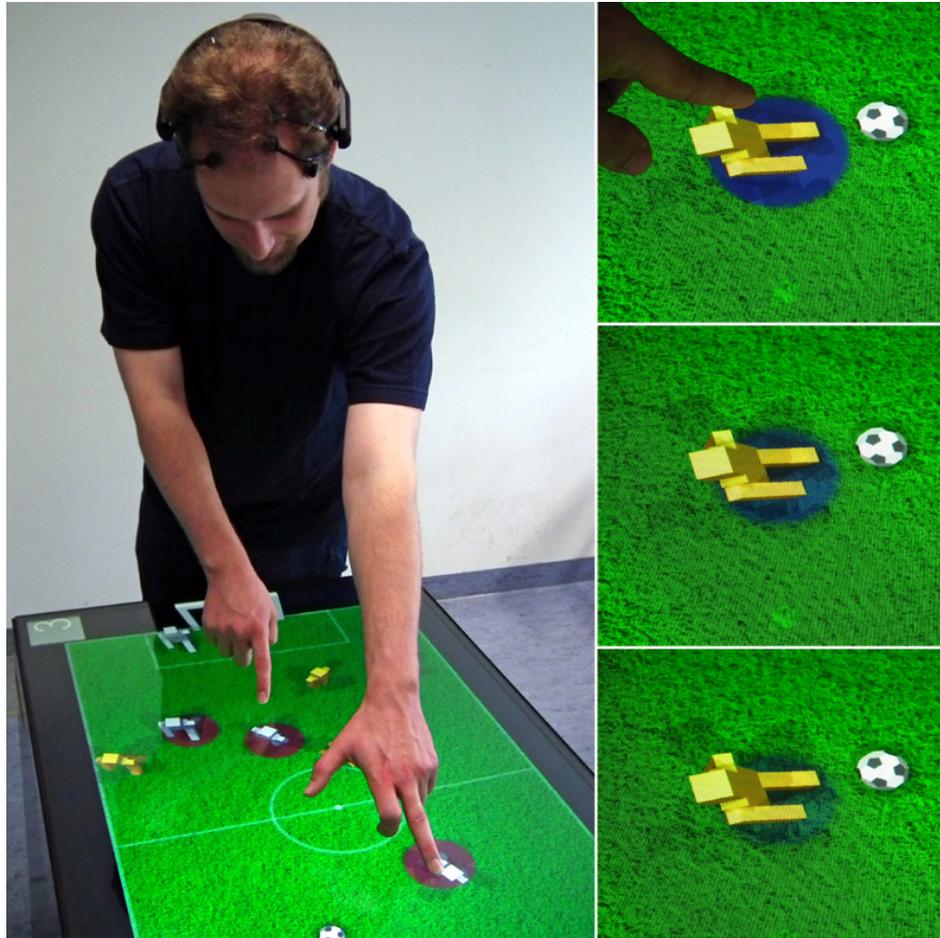


Figure 9. User playing on a tabletop while wearing the BCI headset. Each time the user touches the multi-touch surface, his EEG signals are read and interpreted as affective states. Subsequently, emotion-prints are displayed on the tabletop around the object that the user touched. The images on the right highlight—from top to bottom—how the emotion-prints dissipate in time.

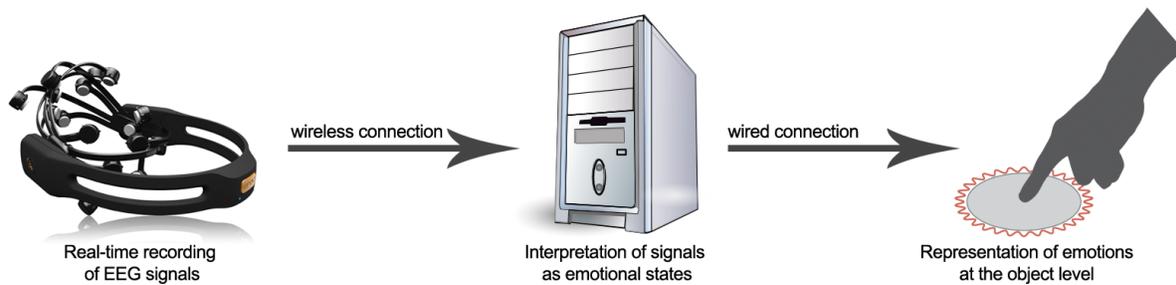


Figure 10. Computing the emotion-prints representations: (left) gathering data that can encode information about user affective states (e.g., EEG signals, facial expressions, galvanic skin response); (center) interpreting this data as affective states that can be decomposed into valence and arousal; (right) representing the valence and arousal information on the multi-touch surface as emotion-prints.

visualization. Before the tasks commenced, each team got introduced to the functionality of the two applications until they felt confident to use them. All participants were equipped with an Emotiv EPOC headset, but only after the abilities and limitations of this system has been highlighted to them, and they agreed to share the readings and interpretations of the device.

In order to compare the impact of emotion-prints, the six groups were divided in two, where three groups would complete the two tasks enhanced by the emotion representation obtained through the users BCI readings, and three groups that could employ the same two applications without emotion-prints representations. However, the members of the groups that did not have the benefit of emotion representations did still wear the BCI headsets. This allowed us to inspect and compare user behavior in cases where similar valence-arousal readings would be reported. The members of the pairs that would work with emotion-prints were given a thorough presentation of its design and functionality. Furthermore, all users were encouraged to express themselves freely during the tasks.

During the study, almost all participants engaged in verbal communication, allowing us to analyze their interaction relatively to the emotion-prints. In the context of the soccer game, there were multiple instances where the groups that had the emotion visualization at their disposal managed to use this information, in some cases even gaining an advantage. For example, a player that was leading 4 to 3 after being down 1 to 3 saw that his opponent's emotion-prints were very edgy and red, thus making the following statement: "Wow, you must be really annoyed". He later was able to extend his lead also by directly addressing the frustration of his opponent. On the other side, in the collaborative history visualization, users that had access to viewing the emotion-prints would often notice the positive excitement of their colleague, suggested by phrases like "Did you find something?" and "You think it's in this area?". In contrast, in the pairs that did not have access to the emotion representation, the awareness of affective attributes was minimal. This is also supported by the fact that although users in these three groups experienced similar emotional configurations, there were almost no discussions addressing real-time user experiences.

After the two tasks, the participants that worked with emotion-prints were asked to fill out a questionnaire about their design and utility. The subjects considered that the design was intuitive and distinguishable. However, some would have liked to adjust the time interval in which the prints would dissipate. All participants considered the opportunity of enriching the interface of multi-touch systems with emotional states a good idea. The most powerful feedback was related to the impact on collaborative work and competitive gaming on multi-touch devices ("I really want to see this in some of my iPad games"). At the same time, the collaborative aspect brought up issues like privacy and property of the represented emotions. These are further discussed in the following section.

Furthermore, all 12 participants had the opportunity to inspect and analyze their emotional readings in the emotion-prints histograms and heatmaps. Their verbal iterations during the analysis process suggested that most participants managed to gather valuable insights about their emotional states, increasing the overall awareness of their own and their colleagues experience (e.g., "I really got frustrated after that, didn't I?", "What did you see there?"). When inquired directly, all participants felt that *emotion-prints* increased their affective awareness in the two tasks. More precisely, users considered themselves aware especially of the opponents emotions in the soccer game, while in the history visualization the focus was more equally distributed between emotional self-awareness and emotional awareness of their collaborators. At the same time, the heatmaps gave them insights both about the areas that they most interaction one and their emotional experience during those touch events. For example, one user preferred executing his attacks on the side of the field in the soccer game, and was mostly successful in this approach. Thus, the heatmap for this case presented more intense coverage and positive valence in those areas of the field.

## 7. DISCUSSION

As briefly mentioned in the previous section, the participants of our study have addressed the issue of emotional privacy. Perhaps similarly to social media and other approaches to digital sharing, emotion visualization both in single-user and collaborative context has to commence by informing and empowering the user. Irrespective of how user emotions are interpreted and represented, users need to first be informed about the particularities

and capabilities of the acquisition technique, be it emotion recognition through facial expressions, BCI, or physiological responses. Only through this, users will be able to take a pre-task informed decision whether they want to share this data and to what extent. This is the reason why applications that are enhanced with emotion-prints should inform the user about the interpreted emotional states and require them to agree with those terms, as in any virtual sharing activity that involves private data. More precisely, users should be made aware that the visualization approach does not inform other participants about concrete affective states, but rather converts this information to the space of valence and arousal. This conversion has also implications in terms of resolution, as two distinct discrete emotions will be encoded similarly in the valence-arousal representation (e.g. sad and bored in Figure 1). As such, this limitation needs to be considered when applying emotion-prints to a particular scenario or task where only a certain set of emotional readings is relevant. Furthermore, as in the collaborative history visualization, Russell’s two-dimensional space can be further restricted to filter out a set of values. Note that the visual representations introduced by emotion-prints are consistent for any emotion detection or signal interpretation technique that outputs either directly user valence and arousal levels, or reports the presence of one or more emotions included in Russell’s circumplex model of affect and that can be decomposed to the two-dimensional encoding.

Other concerns that have been raised include display clutter and a corresponding increased cognitive workload. To address this, the last design consideration has been added to our concept. Limiting the period of time that an emotion-print stays visible has multiple advantages: the presented emotional information is never outdated, the display objects can quickly revert to their original form in order to minimize clutter, and the identity of the user that generated the print can be better recalled compared to an emotion-print that has been displayed for a longer period of time.

## 8. CONCLUSION

In this paper we introduce the emotion-prints, a visualization framework for representing affective states in new or existing multi-touch system. In the past, emotions have been considered mostly in affective systems that try to react to the users emotions. Still, to our knowledge, no research has been undertaken on correlating user emotions with the touch interface elements the user acts on and visualizing these states in real-time on the corresponding objects.

The aim of emotion-prints is to aid user emotional self-awareness and the awareness of other users’ emotions in collaborative and competitive touch-enabled applications, like games or collaborative visualization. User awareness in collaborative scenarios is of particular importance, as awareness of and reflection on emotional states has been linked to improved group communication and efficiency. Additionally, we have highlighted how our approach can support the evaluation of user experience and multi-touch applications. Our user study suggests that the selected representation can capture and convey user emotional valence and arousal. At the same time, emotion-prints are independent of the technique through which user emotions are reported, as well as generally applicable irrespective of the shape of the virtual object.

Even if most emotion detection techniques are not fully mature yet and our current work only addresses the two-dimensional space defined by valence and arousal, we believe it is crucial to pave the way in fields like visualization for the day when a large set of emotional states will be more easily and more precisely detectable by dedicated systems.

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