Information Visualization in Affective User Studies

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ABSTRACT

A typical affective study generates a great amount of data including physiological, performance, and demographic data. Visual representation of such data in compact form is challenging. Moreover, no visualization guidelines are available specific to this domain. Here we introduce a set of design principles for visualizing results of affective studies. Specifically, we propose an *inverted pyramid* approach, which communicates at a glance the causation links between the user's affective states and her/his performance. The proposed strategy has been evaluated on a case study focused on the role of students' affect in exam performance.

Index Terms: H.5.2 [Information interfaces and presentations]: User Interfaces—GUI D.2.11 [User Interfaces]: Software Architectures— [H.2.8]: Database Applications—Data mining

1 INTRODUCTION

With the advancement in the wearable sensor technology, real-life affective studies are becoming increasingly commonplace. A case in point is unobtrusive monitoring of surgeons' stress during training [1]. One challenge that such studies face is effective visualization of variables (e.g., physiological signs) that would otherwise require medical expertise to comprehend and derive meaningful conclusions. Another challenge is the variety of the data involved. Static data (e.g., demographic information) and dynamic data (e.g., physiological and kinetic data) have to be brought together and visualized at a glance. Moreover, many affective studies are longitudinal in nature and the visualization should present results from multiple subjects over a period of time. Finally, the visualization should effectively demonstrate causation links between the user's state and her/his performance, supporting qualitative understanding of their relationship.

In this work, we introduce a set of design principles to enable meaningful visual representation of affective study results. The remainder of the paper discusses these design principles using a student exam study as an illustrative example.

2 STUDENT EXAM STUDY

The student exam study aimed to understand the role of sympathetic arousal in challenging cognitive activities. These challenging cognitive activities were 5 exams taken by students enrolled in the Kinesiology course at the University of Houston. The study was approved by the university's institutional review board. In total, 23 students (10 M/13 F) participated in the study over the span of a full academic year (2012-2013). Sympathetic arousal was computed through psychometric questionnaires and wearable physiological sensors. Specifically, the State Anxiety Inventory (SAI) and Trait Anxiety Inventory (TAI) were the psychometric questionnaires used [2]. The BioHarness sensor from Zephyr Technology captured breathing and heart rate from the student's chest location. The Q sensor from Affectiva measured electrodermal activity (EDA) from the palm area of the student's non-dominant hand. The student's percentile grade for each exam and her/his GPA were the performance metrics used.

3 DESIGN PRINCIPLES

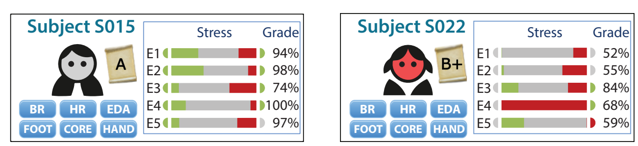
The proposed principles are based on an inverted pyramid design philosophy, where the most important information is communicated at the top view, while interesting details are hidden and can be accessed on demand.

Design Principle 1: Present demographic information at the top view

Gender and age are important covariates in an affective study. We can visualize the gender information via a male (see Figure 1 (a)) or female icon (see Figure 1 (b)) at the top level interface. The icon's appearance can also communicate the age group the user belongs to, which in the example study is youth ($\mu \pm \sigma = 23.0 \pm 5.6$ years).

Design Principle 2: Pair-up trait with demographic information at the top view

Personality traits are also important covariates in an affective study - they can condition the user's affective state vs. performance curve. Personality traits can be determined via appropriate psychometric inventories, such as TAI. We present this trait information on the participant's facial icon as gray (normal), green (relaxed), and red (anxious) - Figure 1. In other words, we cluster together information of permanent nature, either demographic or psychological profile.



(a) (b)

Figure 1: User Portrait of two students who participated in the study.

Design Principle 3: Detail affective physiology on demand - Abstract affective state at the top view

The user's affective states during a task can be estimated from the physiological data (i.e., heart rate, breathing rate, and emotional perspiration) or the kinetic data (e.g., hand motion, core body motion, and leg motion). These data are dynamic in nature, evolving over the course of the interaction. Therefore, it is necessary to preserve their temporal component. For this reason, we depict these data as evolving temporal signals on a separate interface. The analyst can access this dynamic information via the top level interface by pressing the appropriate button: BR for breathing, HR for heart rate, EDA for electrodermal activity, FOOT for leg motion, CORE for body motion, and HAND for hand motion (Figure 1).

Figure 2 shows a snapshot of the evolving breathing rate signal and the associated arousal state for student S015 in Exam 5. Specifically, the plot on the right side shows the breathing rate signal. The signal points are sampled every 10 s. The plot on the left side shows

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the Normal distribution model that is generated from the student's breathing data in all five exams. The model represents the full range of the student's affective states as indexed by the breathing indicator. Specifically, incoming signal values that are less than -1σ from the model's mean denote a relaxed state. By contrast, incoming signal values that are greater than $+1\sigma$ from the model's mean denote an aroused state. Incoming signal values between -1σ and $+1\sigma$ from the model's mean denote a neutral sympathetic state.

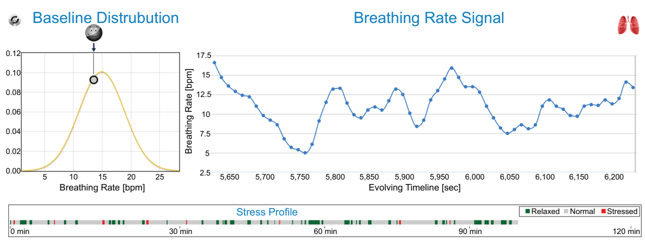

Figure 2: Snapshot of the evolving breathing rate and the associated arousal state for student S015 in Exam 5.

The instantaneous sympathetic state is identified with a circular marker, whose color and location on the Normal model is updated according to the value of the incoming signal point (far right). This state information is further reinforced with an appropriate face icon. Specifically, a red-colored circular marker with a frowning-face icon are used to indicate an aroused (stressful) state. A green-colored marker and a yawning-face are used to indicate a relaxed state. A gray-colored marker and a neutral-face icon indicate a normal state.

The horizontal bar that builds at the bottom of the visualization is the projection of the evolving sympathetic state on the Normal model. It represents a cumulative temporal abstraction of the user's state during the exam. The red, green, and gray segments on the bar depict aroused, relaxed, and normal states, respectively.

Similar visualizations take place for the two other physiological indicators, that is, heart rate and palm EDA. Then, the temporal sympathetic bars from each physiological sign are fused as follows: The percentage of the relaxed, aroused, and normal states are averaged, providing a mean sympathetic bar, where the temporal component has been lost. This new sympathetic bar is an abstraction of how much of the time during the exam the student was relaxed, aroused, and normal, taking into account all three physiological indicators. This abstraction is put on the top level, next to the student's performance score, in order to facilitate causal inferencing (Figure 1). For instance, Figure 1 reveals that the top student (GPA A) performed suboptimally when he experienced arousal for a significant amount of time during an exam (E3 for S015); an indication of challenge encounter. Suboptimal performance is also observed when the B+ student was not aroused at all during an exam (E5 for S022); an indication of disassociation from the task.

Typically, the physiological and kinetic information is difficult to capture outside the boundaries of each exam session. It is important, however, to know the emotional charge the user carries as s/he arrives for the exam session as well as when s/he leaves. This information can be obtained via psychometric inventories, such as SAI. We communicate this beginning/end sympathetic information using two semi-circular symbols on the left and right end of the exam's sympathetic bar, respectively (Figure 1). The semi-circular shape of the symbols denotes the rounding character of this information. These semi-circles are colored green, red, and gray to denote relaxed, aroused, and normal state, respectively, much like the case with the exam bar. The only difference between the two constructs is that the exam bar is physiologically determined, while the semi-circles are psychometrically determined.

Design Principle 4: Pair-up performance with affect Information at the top view

In affective studies, performance is measured at the task level and should be linked to the user's affect during that task; together, they form the information backbone of such studies. Therefore, performance and affective state per task should be displayed next to each other and in a prominent place. As shown in Figure 1, the percentile grade for each exam is shown besides a bar communicating the student's sympathetic arousal in that exam. The user's overall performance, as expressed by her/his GPA, is a more permanent quality and is placed close to the face icon, which communicates the student's other traits (Figure 1). In another case, such as a pilot performance study, this overall score would be the pilot's experience in terms of flying hours. This visualization scheme facilitates intra-subject and inter-subject observations.

4 Usability Study

A total of 7 participants (4 M / 3 F) evaluated the visualization interface. We asked each participant to review the interface and then complete an online survey. Special care was taken to ensure that the participants had correct understanding about each visualization component before they began rating. The participants evaluated each component on a Likert scale from 1 to 5 with 1 being poor design and 5 being excellent design.

Figure 3 illustrates the mean evaluation for each visualization component. The gender visualization scores the highest as it is the most intuitive visualization. The semi-circle for the beginning/end sympathetic state visualization scores the lowest, as it represents a more sophisticated concept, inadequately conveyed. Another interesting observation is that the participants scored very high the animated information. A case in point is the dynamic visualization of the user's affective state, with mean evaluation score 4.3. By comparison, the atemporal stress bars displayed at the top-level interface received a medium score (mean evaluation = 3.1), which suggests that this construct could be further improved. Overall, this pilot evaluation indicated that all the visualization constructs, except the semi-circles, scored above average. More information can be found at: http://www.cpl.uh.edu/projects/stress-studies/css/.

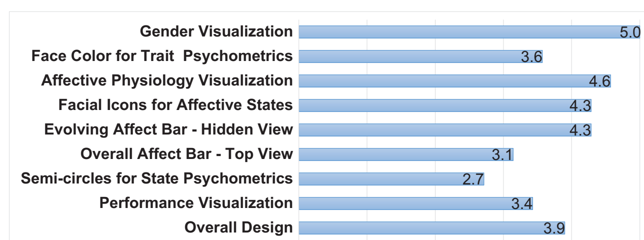

Figure 3: Mean evaluation of the visualization components. A total of $n = 7$ participants evaluated the interface.

5 Acknowledgemnts

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