A Study of Emotion-triggered Adaptation Methods for Interactive Visualization

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Abstract. As the size and complexity of datasets increases, both visualization systems and their users are put under more pressure to offer quick and thorough insights about patterns hidden in this ocean of data. While novel visualization techniques are being developed to better cope with the various data contexts, users find themselves increasingly often under mental bottlenecks that can induce a variety of emotions. In this paper, we execute a study to investigate the effectiveness of various emotion-triggered adaptation methods for visualization systems. The emotions considered are boredom and frustration, and are measured by means of brain-computer interface technology. Our findings suggest that less intrusive adaptive methods perform better at supporting users in overcoming emotional states with low valence or arousal, while more intrusive ones tend to be misinterpreted or perceived as irritating.

Keywords: Adaptive affective visualization, emotion-based adaptation, adaptive methods, human factors.

1 Introduction

Massive datasets are being generated on many different occasions, e.g., in genome or climate research, huge software systems, or economy. At the same time, our dependency on a good understanding of data and effective analyses increases because of the need to discover, for example, new drugs, correlations in social networks, or bugs in complex software systems. As such, analyzing and gaining insight into these large multivariate datasets through visualization is one of the major challenges of our days [15]. However, the complexity of the data and the task can exercise pressure and influence the user in a negative way, inducing various emotional states: some of discomfort or frustration, and others of boredom or the feeling of being overwhelmed. At the same time, most computer systems are currently designed to execute the same operations "regardless of whether you are sitting forward eagerly in your seat, or have begun to emit loud snoring sounds" [18].

This has never been more true than in the case of visualizations that have the potential to closely interact with users and adapt to their needs, e.g. mental models, cognitive processes and affective states, in order to improve performance and increase user satisfaction [14, 21]. Still, visualization systems are mostly oblivious of user emotions and needs, thus limiting the adaptability of the representation and the overall impact of visualization effectiveness. In this paper we will focus on investigating the efficiency and intrusiveness of a set of emotion-triggered adaptation techniques for visualizations. This is achieved through a study in which participants are interacting with a visualization tool while wearing brain-computer interface (BCI) devices capable of interpreting electrical signals generated by their brains as user emotions.

In the following sections, we shortly highlight related work in the field of affective visualization, adaptive approaches and BCI-based emotion detection. Next, we describe the design of our study and WebComets [7], the visualization tool used by the participants. We finally highlight our findings and open questions, as well as expose our conclusions.

2 Emotion and Visualization Tailoring

In order to employ user emotions as a driving feature behind visualization tailoring, one must first consider how these emotional states could be detected. While there are various approaches involving speech, facial expressions and eye movement [4], one of the real-time approaches that has gained popularity in the recent years is represented by EEG measurements executed with lightweight neuroheadsets [5, 6, 12, 17]. Moving towards aspects of emotions in Information Visualization, such wireless non-intrusive BCIs have been used in evaluating the cognitive workload induced to the user by different visualization techniques [2]. At the same time, lightweight passive BCIs have been used to detect emotional states that can be indicative of moments of insight during the exploration of visualization systems [5]. Related to our study task, the work [9] highlights possible correlations of webpage complexity with emotional valence.

On the other side, adaptive systems have been investigated in the context of user emotion mostly in affective computing and emotion-based adaptive interfaces [3, 13, 16, 20]. Narrowing the view down to the field of visualization, user-adaptive representations have considered multiple human characteristics, e.g., shaping visualizations based on user behavior [11], visualization context [10] and user models [1]. However, emotion—a powerful inner force that influences humans in all their activities—remains widely unexplored as a user attribute employed for adaptive visualization.

3 Study on Emotion-Triggered Adaptive Visualization

The following study focuses on estimating the effectiveness of various emotion-triggered adaptation techniques applied on an information visualization system.

In order to allow a visualization to adapt to the user emotions, we need to support the real-time detection of these emotions. In our study, this is achieved through the Emotiv EPOC headset, a wireless, non-intrusive EEG device that is capable of capturing EEG signals from the brain and interpreting them as a set of user emotions through a software framework. The accuracy of the emotion detection achieved with this BCI device and its framework has been previously investigated showing promising results [5, 6] and therefore is not the focus of our current study. Although capable of detecting a wider range of emotions through the included software framework (detailed in [5]), our attention went towards a subset of available emotions, namely *boredom* and *frustration*. These two emotions have been selected as they can influence the user experience negatively, but also due to their negative positioning on the arousal (boredom) and valence (frustration) axes of Russell's circumplex model of affect [19]. Furthermore, non-basic emotions like frustration and boredom have been recently reconfirmed as highly relevant in affective computing [8].

Our study involved 5 participants (2 female, 3 male) with an average age of 23 years. The majority of these participants had some experience with visualizations and have participated in previous BCI-based studies. In order to explore the potential of emotion-triggered adaptation of visualization, we decided to use a visualization system that enabled—through a wider range of supported functionality and interaction—the implementation of multiple adaptation approaches: WebComets [7] is an interactive visualization tool for multi-session, multi-user parallel browsing histories. The information displayed in the visualization corresponds to the websites that one or multiple users have accessed during their online navigation. The accessed websites are represented as circles (called nodes), and positioned on horizontal lines encoding the individual tabs that were employed to load the page, see Fig. 1 (top). Horizontal lines can be interconnected vertically, suggesting that one browser tab has branched off from another one when a user clicked on a hyperlink, thus generating a deep tree-like browsing structure. The temporal dimension flows from left to right.

For the purpose of our study, the WebComets visualization has been adapted to react to the emotional readings detected by the EPOC headset. More precisely, when the headset signals the detection of boredom or frustration, the visualization tries to support the user and make some changes to the system in order to influence the user's state. Note that in order to avoid triggering the visualization adaptations too often, the emotion triggers are only activated if the boredom and frustration readings are 75% above the individual baseline for a period of over 3 seconds. The baselines for both emotions have been individually established prior to the study, while each participant executed mundane tasks that did not influence the emotional readings from the BCI and during which the participants themselves reported a balanced emotional state.

The participants received a set of tasks of identifying particular node sequences (i.e., browsing patterns). Furthermore, they were given an introduction of the visualization, by covering theoretical background, functionality and sample tasks until the point were every user felt confident using the system. They

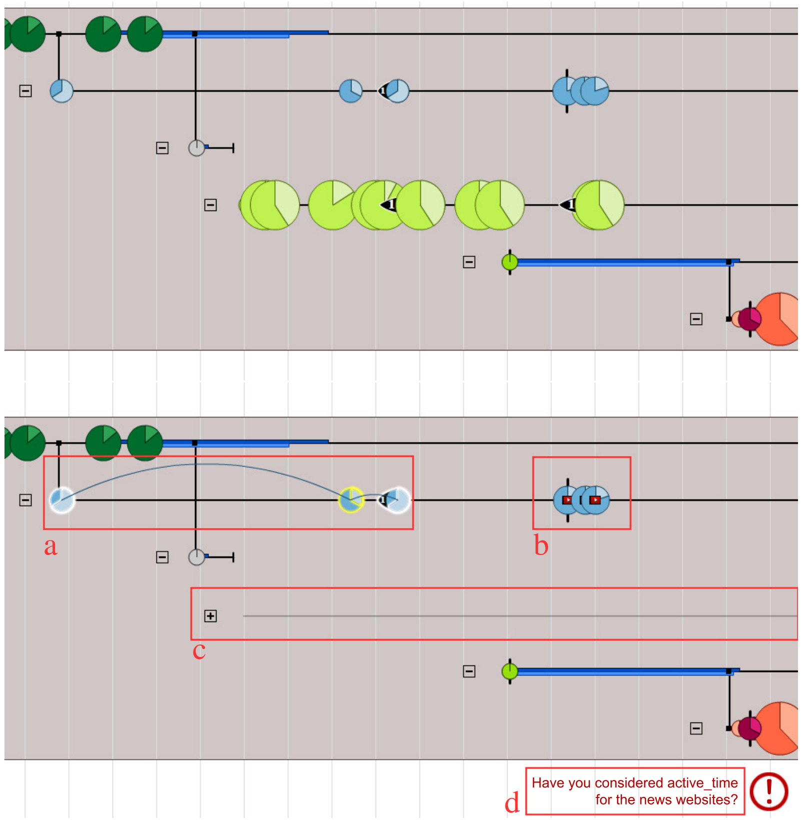
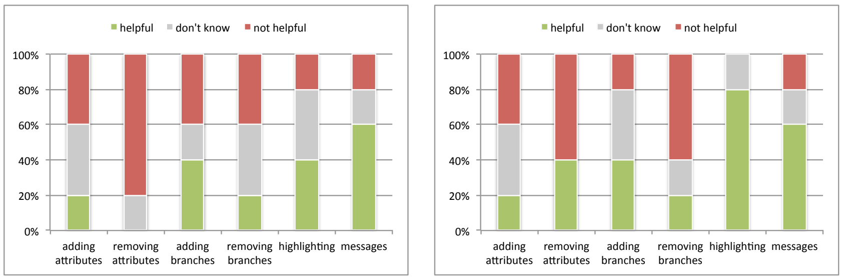


Fig. 1. A snapshot of the WebComets visualization (top). The set of considered adaptation techniques (bottom): (a) highlighting visualization elements (e.g., nodes), (b) adding or removing details through the control of displayed attributes (e.g., website icons), (c) adding or removing width information through the control of branching, and (d) showing custom hint messages.

were also informed of the fact that the visualization will make automatic changes based on their subjective states, and that these changes will involve either showing/highlighting relevant information or hiding irrelevant one. The detection of boredom and frustration were considered in two distinct sessions for all participants. In terms of adaptation, the following techniques have been considered:

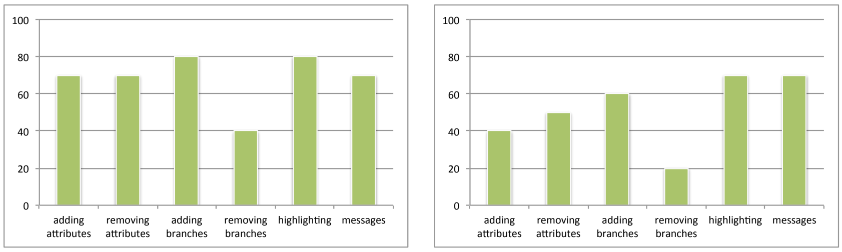
- adding or removing details (through the control of attributes for multidimensional data, as each website is a multivariate node with over ten dimensions),
- adding or removing width information (through the control of branching),
- highlighting visualization elements (e.g., nodes or connections), and
- showing custom hint messages.

Fig. 1 highlights each of the six approaches (adding and removing were considered separately in both cases). In order to support a smooth transition and the



(a) user boredom (b) user frustration

Fig. 2. User rating of the automated adaptation triggered by the visualization system.



(a) user boredom (b) user frustration

Fig. 3. BCI measurements after each system adaptation capturing the ratio of significant drops in boredom and frustration measured in a time period of one minute after an adaptation was executed.

users' contextual awareness, changes were animated or faded in over a period of three seconds. Additionally, whenever a change that has been induced by the adaptive mechanism was executed, an exclamation sign would be displayed in the corner of the system (Fig. 1 (bottom)) to improve user awareness.

The hint messages were generated based on the different keywords present in the task statement. The various adaptation techniques were used in a random order, such that each user would see each adaptation twice. Also, tasks as well as the datasets had varying complexity, ranging from simple tasks to difficult ones, and from small datasets to complex ones. The increasing difficulty ensured that users would experience both boredom and frustration in a relatively short amount of time, as neither session exceeded 30 minutes for any of the participants.

4 Results

After having experienced all six adaptation approaches, the users were inquired about their usefulness and intrusiveness. Specifically, the participants were asked about each technique if they found that it was useful for influencing their emotional state positively. Their answers are highlighted in Fig. 2. It seems that in the case of user boredom, the adaptation techniques perceived the most helpful were element and connection highlighting, hint messages, and adding width information. Removing attributes seems to be least helpful when trying to overcome boredom. In the case of user frustration, element and connection highlighting as well as hints have again been perceived as most helpful, while hiding attributes and width information less so.

While participant feedback is vital, we also wanted to inspect the effects that the various adaptation methods had on the user emotional states. Therefore, we considered the emotional states for each user for a period of one minute after an adaptation technique has been triggered, in order to see if a significant drop in boredom, respectively frustration, could be detected. We defined a significant drop as emotional readings that were less than a 25% increase from the individual baseline for longer than half of the one minute period. The findings are captured in Fig. 3. Note that the drops in boredom or frustration may have multiple reasons. However, our results capture interesting differences. The drop in boredom is mostly consistent for all adaptation methods, except for the hiding of width information, after which a larger number of participants still experienced the same emotional state. This same pattern is visible for frustration, where removing width information did not seem to positively influence the frustration levels of many users. At the same time, hints and highlighting seem to be coupled to higher rates of frustration reduction.

When correlating the user rating with our measurements, we notice that participants tended to perceive the adaptation techniques more negatively or without any noticeable effects compared to our BCI readings. One possible reason for this could be the fact that four participants had difficulties accepting that the system would sometimes control which information would be added and which considered irrelevant and hidden. Thus, it seems that in terms of both effectiveness and intrusiveness, hint messages and element highlighting are the most reliable adaptive methods triggered to counteract boredom and frustration. Further research is required in order to investigate how visualizations could be adapted dynamically based on user emotions as well as how various emotions influence the performance of visualization users.

5 Conclusion

The current study focuses on the effectiveness of a set of adaptation techniques applied on an interactive visualization to influence user boredom and frustration. Our results show that approaches involving less intrusive methods like highlighting and help messages offer better results in guiding the user towards a more positive and aroused emotional state, and implicitly, towards a more focused interaction with the visualization tool. Further, we plan to extend this study to a larger set of emotions involving multiple participants as well as inspect the importance of emotional self-awareness in visualization.

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