VIZInteraction: Visualizing Psychophysiological Responses to Colors

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Abstract

It is difficult to imagine a day without looking at a screen. From the smaller to the bigger ones, we look at and interact with interfaces every day. Technologies has filled the lives of people changing and shaping it. From mobile applications and websites to smart TVs the world is surrounded by interfaces either simple or sometimes even very complex. Every screen has different aspects that go into the development of the interface, going from the shape and size of the components to color, but there is no real way of understanding what the user desires and what attracts the user to an interface, the data is complex, vast and difficult to read. Information visualization has been used more and more to analyze and explore data. Every dataset could be placed through a process of visualization to be easier and faster to take results. However, visualizing data must be a well thought process and depends on the data that would like to be seen in a visual form. As beings that react better to visual cues visualization can help to have a better understanding of the data and discover hidden patterns. In this project it was studied if by creating a visualization tool there was a better understanding of what the user prefers to see in an interface regarding color. The data that will be visualized is the psychophysiological responses to color and the emotions users say the same color transmits. This project visualizes valence and arousal collected from a user questionnaire and from brain wave signals, from twelve different colors, in an interface with a dashboard approach. An idiom study was made as well as two distant types of evaluation to ensure the usability and utility of the interface. Taking from the evaluations that visualization can in fact help understand this complex data.

Keywords: Colors, Emotions, Information Visualization, Psycophisiological Responses, Valence and Arousal

1. Introduction

Visualization of information is defined as the use of visual representations and interactions of data to amplify our acquisition of knowledge[4]. It is used not just as pictures or something pretty to look at on screen but, to gain a larger insight of data.

With an overload of data being produced every day, visualizing it would come as a natural next step to try and make sense of the millions of data running around the world and perhaps even find out new and unimaginable things.

This project is aiming to visualizing a specific dataset. The dataset at hand is the user perception and emootions of twelve different colors. Color can carry meaning and have an important influence on affect, cognition, behavior and even yield emotions, even though not always as easy to represent as a context-based response[5, 12]. These emotions are gathered using the psychophysiological values of valence (attractiveness or averseness of an event, object, or situation) and arousal (level of wakefulness) and comparing it to what the users think, acquiring these last emotions through a questionnaire. This project makes use of the dataset set provide by Inês Santos related to the Cognihue [12] work. The intention is to create an interface that gives the data new connections and displays it in an easy to access way and tries to make sense of such sensible and difficult to grasp data with the use the data driven tool of D3[1].

Cognihue[12] was a study made to create an emotion classifier based on neurophysiological responses to colors on an attempt to improve human-computer interaction regarding the use of color on interfaces, comparing the opinion of users and the feelings felt towards the colors taken from the neurophysiological stimulus. With the goal of achieving a more truthful and uninterpreted emotional color classification for interfaces.

The aim of this research is to **understand if**

[1] https://d3js.org/

by using techniques of information visualization it is possible to provide a better and efficient way to analyze user Psychophysiological responses and emotions to colors.

2. Background

This section is divided into three subsections that will be information visualization, what is it, why it is used and how it is used. A Psychophysiological signals section, which will explain how to get these signals and what is their meaning. And lastly the principles of evaluating interfaces and visualization

2.1. Neurophysiological signals and emotions

The neurophysiological signals used in this study are EEG(Electroencephalogram) and BVP(Blood Volume Pulse), typically the use of EDA signals is also used but in the works of Inês Santos[12] the EDA(Electrodermal Activity) values were discarded as they did not have a significance in the values for the calculus of arousal combining it with the BVP, so only these were used.

The signals were collected using a device called Bitalino[2] with the use of electrodes, which are small electric conductors use on nonmetallic surfaces in this case the skin of the users, to collect the waves.

From the EEG signals several waves are obtained when processing the raw data and separating it into different wave lengths. For this project *Alpha high* and *Alpha low* waves are the relevant ones which are associated with valence and stand between 8 to 14 Hz. Arousal is taken from the heart rate which is the BVP signals.

After collecting the raw data from Bitalino the files are then pre-processed and passed by a set of formulas, defined by the Bitalino, using the BioSPPy[3] library to separate the different wavelengths.

Emotions can be measured in terms of valence which is how positive or negative the emotion is, obtained by the *alpha* waves, and arousal, the BVP waves, which is how calming or exciting the emotion is. For example, the emotion "Angry" will have a negative valence and a high arousal as it is an emotion considered as bad and it is strongly felt by people.

3. Related Work

Visualizing emotions has been growing more and more for the past years since people have started to realize that both visualization and emotions is an interesting way to understand many different results that were not possible just by looking at tables with data. It allows researchers to find unexpected and relevant results in easier ways.

[2]https://bitalino.com/en/

[3]https://pypi.org/project/biosppy/

Emotions, valence and arousal do not seem to be represented in any specific way. Emotions are mainly represented in three main types of work. Emotion in social media, emotions represented by valence and arousal, and finally emotions represented with simpler emotion model.

For representing emotions in social media, even though there is no consensus regarding the what idioms to use in any types of work, timelines and small multiples seem to prevail when data comes from social media. Examples like Torkildson, Megan, Kate and Cecilia[13] and Misue, Kazuo, and Kiyohis[8] that use emotions as small multiples to show evolution and diferent types of emotion through time and location as seen on Figure 1 and Figure 2.

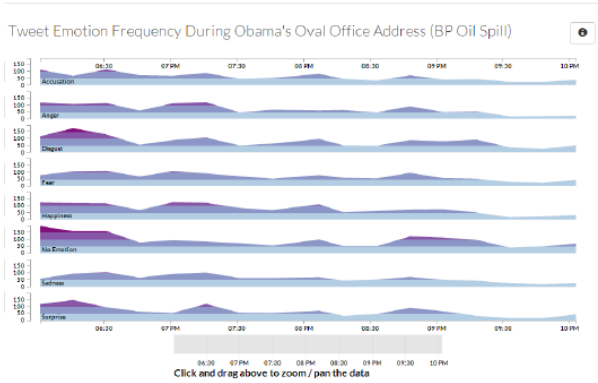

Figure 1: Stacked Area Chart interface for Crisis on Tweets [13]

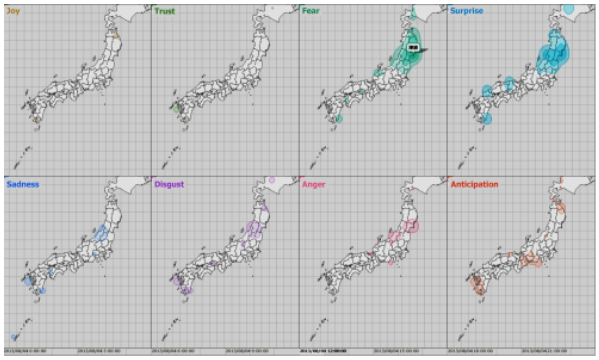

Figure 2: EmotionWeather Map's for different emotions [8]

Regarding simpler emotions and valence and arousal circular approaches are vastly used. Opinion Seer[15] and SentiCompass[14] make use of circular approaches and interactivity in colorful to show emotion. However, both works were cluttered and confusing to use as seen on Figure 3 and Figure 4.

Valence and arousal are very commonly represented as a two variable idiom visualizing both together at all times and expressing one in terms of the other, AffectAura[7] provides an interactive way to show, even if confusing to the user since each element was represented on the circle and the user

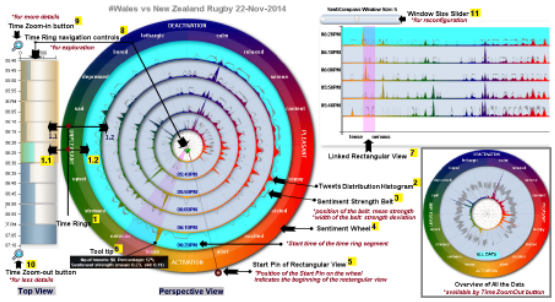

Figure 3: SentiCompass Visualizations [14]

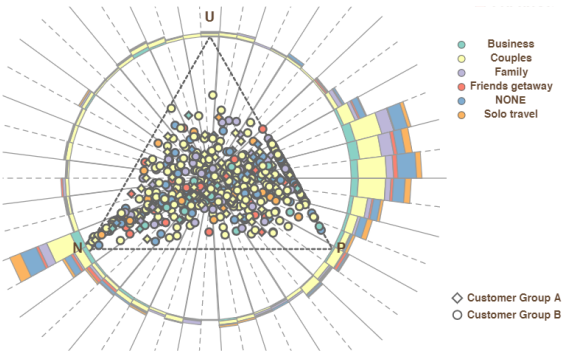

Figure 4: OpinionSeer sentiment triangle visualization [15]

did not understand exactly what was being shown, valence and arousal together and in real time.

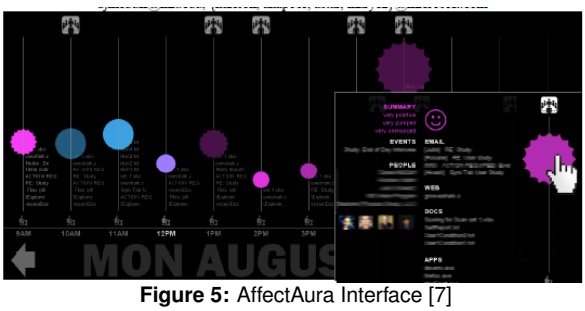

Figure 5: AffectAura Interface [7]

Although all these works showed emotions in interesting ways, most of them were lacking some of the basic visualization principles that are of the utmost importance when creating any visualization. The visualization should give the user the opportunity to explore the data without confusion and being able to take as much results as possible.

Concluding, there must be a special attention to meet the main visualization principles, being careful not to display large amount of information making use of filtering and zoom techniques to display data. A dashboard approach seems to make more sense when dealing with lots and different kinds of data and make use of interactivity. Regarding what types of idioms to use, since there does not seem to be a consensus an intensive study of the dataset and what the interface wants to accomplish must be made to determine the best graphs to use.

4. Methodology

The first step of any visualization must be to look at the objective and understand what can be done with the concept and what questions can and want to be answered by the visualization. So, for that a set of tasks and questions is created that gives a focus do the visualization and also has a play on what idioms to use in order to answer those questions.

The objective of Inês Santos CogniHue[12] was to create a classifier based on neurophysiological responses and associating them with what the user thought of a certain emotion, with the objective of understanding how people perceived colors on sceens and interfaces.

4.1. Tasks and Questions

to understand what is the purpose of this visualization and what types of tasks can be done with the data to show. Tasks can come in three main categories, which are analyze, search and query[9].

Task and Questions are also helpful to keep the focus and detail principle in check, guarantee that all the data is being used to the fullest and to understand the type of visualization that must be created.

To achieve that, the following tasks and the questions were created:

Tasks

1. Filter age/gender/education and compare how emotions changes. (Locate and Compare)
2. Compare valence and arousal between real and self-report emotions. (Compare)
3. Compare valence and arousal within colors. (Consume and Compare)
4. Agregate Valence/Arousal of colors. (Summarize and Present)
5. Compare Self-Report Valence/Arousal to Bitalino Valence/Arousal (Compare, Identify and Search)

Questions

- Is there a difference on emotions towards colors based on age and gender? (T1)
- What's the correlation between what we think of colors and what we feel? (T2)
- What's the color that causes the biggest emotions on people? (T3)
- How does Valence and Arousal distributes within several colors? (T3, T4)
- Do people with different education perceive color different? (T1)

- What colors cause similar emotions? (T3 and T2)
- How does Valence/Arousal compare from the Bitalino to the Self-Report? (T4)

4.2. Data processing

The data was collected using the device Bitalino[4] measuring Valence and Arousal of the users for twelve colors while answering a questionnaire using the Self-Assessment Manikin valence scale[2] to get the self-report values of the color shown on screen. A small survey was also done in the beginning of the tests to gather some general information like age, gender and education[12].

The Bitalino data was transported for a new dataset table, using Microsof Excel, and labeling it properly, having valence and arousal for all users per color and the median per color. The Arousal data was taken from the BVP signals and the Valence was calculated by averaging the *alpha low* and *alpha high* signals using Microsoft Excel, as well, to make this average.

For the self-report first the median per color was added to the new dataset, however the general information of the users and the answers of the self-report were in individual text files. The data from 31 files, corresponding to the 31 users of the study[12], was copied to an Excel file to be processed.

The general information and the self-report median for each color were placed in the dataset. The main problem encountered was that the colors were shown at random to the users, so simply adding this data to the dataset would not work. To solve this problem an Excel function was created to match the color with the specific self-report value. The colors were ordered in alphabetical order, so the valence for the self-report of the color black for User 1 would be: INDEX("Valences For User 1", MACTH("Colors For User 1, "Black", 0)").

After applying it to all colors and all users to get the Self-Report Data properly ordered it was added to the dataset.

To complete this process both Bitalino and self-report data were normalized to be on the same scale otherwise a comparison could not be made. Using the Plutchik model of emotion[10] to represent emotions the normalization is done in a range from -5 to 5.

The Bitalino data was normalized using the min-max feature scaling. So, for an arbitrary range [a,b], where for this work the range would be [-5,5], using the Formula 1.

$$x' = a + \frac{(x - min(x))(a - b)}{min(x) - max(x)} \tag{1}$$

[4]https://bitalino.com/en/

For the self-report data, the rescaling was made by subtracting 5 to the values because the values obtained in the tests were in a scale from 1 to 10.

The resulting emotion for every user from their respective valence and arousal for both the self-report data and the Bitalino data was additionally calculated as a derived measure.

To calculate the emotion some attention must be given to the Russel's 2D Valence/Arousal emotional space[11] as shown in Figure 6. Separating the wheel into quadrants and every quadrant into thirds the result is twelve parts of the circumference each one with a 30º angle representing the twelve emotions.

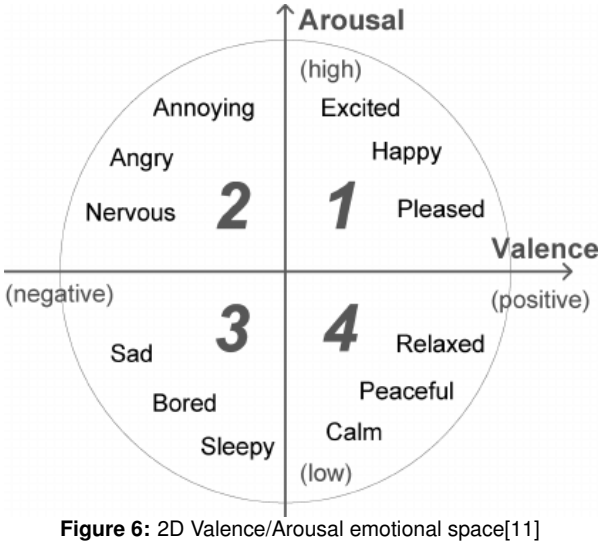

Figure 6: 2D Valence/Arousal emotional space[11]

To calculate the emotions every users' valence and arousal is used as coordinates and the emotion corresponding is the one where the coordinates land. A python script is used to calculate the angle of the two points using the Formula 2.

$$Degree = tan^{-1}\frac{Arousal}{Valence} \tag{2}$$

The script runs for every color for both Self-report and Bitalino and the resulting emotions were later placed in the overall dataset.

Finally, in order to show the exact color used in Santos' study[12] the corresponding RGB(Red, Blue, Green) color was added so when using the D3 tool the correct color could be used by simply calling it from the dataset. The result is the dataset shown in Table 1.

4.3. Visualizing Emotions Towards Color

Based on the related work and on the data, the proposed solution would be to create an interactive visualization to help and gather results to better understand the psychophysiological responses to colors by human beings.

Table 1: Visuzalization Dataset and Types

	User	Age	Gender	Education	Color	RGB	Valence Bitalino	Arousal Bitalino
Type	Categorical	Categorical	Categorical	Categorical	Categorical	Categorical	Quantitative	Quantitative
Ex.:	User 1	18 - 21 Anos	F	Graduate	Brown	rgb(82,38,0)	-1.35	-2.39

	Valence Self-Report	Arousal Self-Report	Median Valence BItalino	Median Arousal Bitalino	Median Valence Self-Report	Median Arousal Self-Report
Type	Quantitative	Quantitative	Quantitative	Quantitative	Quantitative	Quantitative
Ex.:	-2	-1	-1.96	0.40	-1	-1

	Emotion Bitalino	**Emotion Self-Report**
Type	Categorical	Categorical
Ex.:	Sleepy	Sad

The solution was a dashboard visualization to be able to showcase the most data possible and answer all the proposed questions. Following all the visualization principles, so the user does not get overwhelmed, being able to interact without problems with the interface and to take conclusions out of the data being visualized.

The biggest challenge would be to represent valence and arousal in the best way possible, since it is the most crucial part of the interface and the goal of this thesis, also how to accommodate the twelve colors for both the self-report and the bitalino data. After that the remaining data must also be taken in account like age, gender, education and emotions.

Valence and Arousal are normally represented as an axis based graphic so the idea was to compare valence and arousal of the twelve different colors and the two different types of data, for these the small multiples technique with heatmaps was a good candidate, small multiples are also used by Torkildson, Megan, Kate and Cecilia[13] and by Misue, Kazuo and Kiyohisa[8]. The heatmaps shows the distribution of valence and arousal with the use of color, the more saturated a color appears on the idiom the more users are situated within those numbers, the heatmmaps also interact with a side legend where all the colors are featured and having a tooltip element to display the emotion in each square. They are represented on the left side of the screen with a scrolling feature to be able to show all twelve colors, Figure 11.

Besides the small multiples, a scatterplot was made to be able to compare colors with each data and understand the distribution of all the collective colors better. Initially the intention was to showcase all the data, this was not a possibility as all the dots were on top of each other, so returning to the project done by Inês Santos[12] it was observed that the comparison between the colors was done by using the median, so the scatterplot was altered to display the median of each color and when each dot was pressed all 33 users for the pressed color will appear, giving opportunity to the user to see only the data of the color it desires. There is also a tooltip to display the emotion of the hovered dot, for both the individual user or the overall median dot This scatterplot is the main idiomof teh visualization being situaded in the middle-right of the interface, Figure 11.

It was also created an overall legend to all idioms consisting of the twelve colors studied in a circle form, creating a way to interactively link all idioms together. When selecting the colors all graphs will react and highlight the data for the selected color. In Figure 7 it can be seen both Red and Cyan selected and the highlight on the scatterplot and on the small multiples idiom.

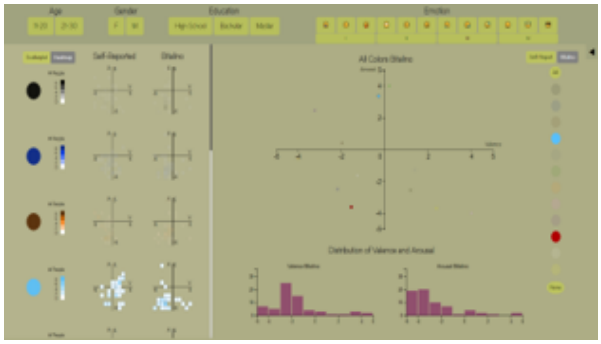

Figure 7: Color Red and Cyan Selected on the overall side legend

Valence and arousal can still individually give information about the nature of the users emotions towards color. Knowing this a histogram for valence and other for arousal was made, in that way both can be compared and there is an easy way to show the distribution of the components. They help give an estimate as to where values are concentrated, what the extremes are and whether there are any gaps or unusual values.

When selecting several colors on the side legend, the idea of creating a color blend of the selected colors for the histogram was appealing, however there are different ways to do blending algorithms using different color models.

The most commonly used color models for

blending are the HSL(Hue, Saturatio, Lightness) and the CMYK(Cyan, Magenta, Yellow, Black) models which are models supported by JavaScript. Both models have flaws and do not abide by the color theory rules[1] as the computer models do not directly correspond to how ink and color behaves, for example how watercolor would behave. In order to decide which model yo use a questionnaire was made to decide which blend was more natural for the user to see on screen.

Two questionnaires were made with 10 different blends each, one for the HSL model and the other for the CMYK model where each blend had a scale from one to five and two colors that equal a resultant one, the user must choose how accurate they think the resultant color is giving the colors that origin it. After performing each questionnaire to 15 users each, and the CMYK blending algorithm was the chosen one, in Figure 7 it can be seen the resultant color of Red and Cyan.

To compare all the components from both the Bitalino and Self-Report, all colors, and valence and arousal separately the idiom chosen was a parallel coordinates plot as it allows to compare many variables together and see the relationships between them. The graph displays four axis with the median valence and arousal for both the Bitalino and the self-report data with the twelve colors represented in the lines and the axis can change position so the user can compare any two variable directly next to each other as shown on Figure 8 the side legend was also connected to the parallel coordinate plot as seen in Figure 9.

This idiom was placed as an addition to the interface being placed in a slider that is only visible if the user presses an arrow displayed on the upper right side of the screen, this idiom is hidden not only because it mostly displays all the data from the other idioms in one but also to reduce clutter on screen.

The remaining data, which is only categorical, was made into a filter mechanisms that are connected with the idioms above to find patterns, tie all the idioms together and to make sure all the visualization principles are met. Giving origin to the final visualization before doing a formative evaluation as shown in Figure 10

A formative evaluation was made to fix mistakes before the final interface evaluation. Five people participated in this evaluation and answered five different questions in a random order, from there an extra idioms was taken out, the titles were enhanced so the user can better understand what data is being shown and a "Click Me" highlight was added to show the users there is a slider on the right side of the screen that can also be used, Figure 11.

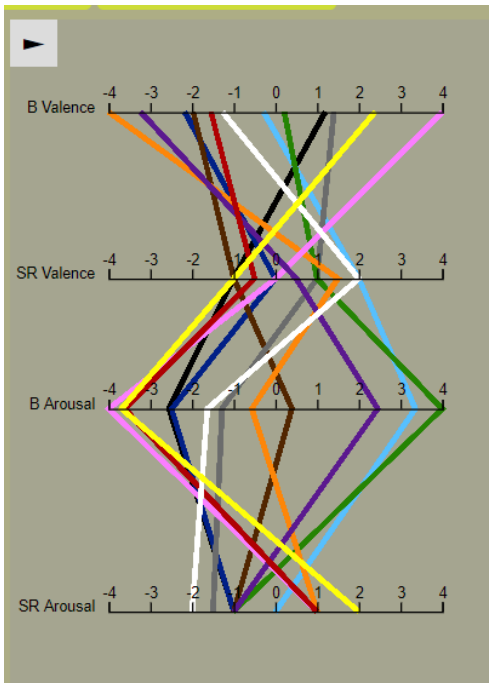

Figure 8: Parallel Coordinates Plot

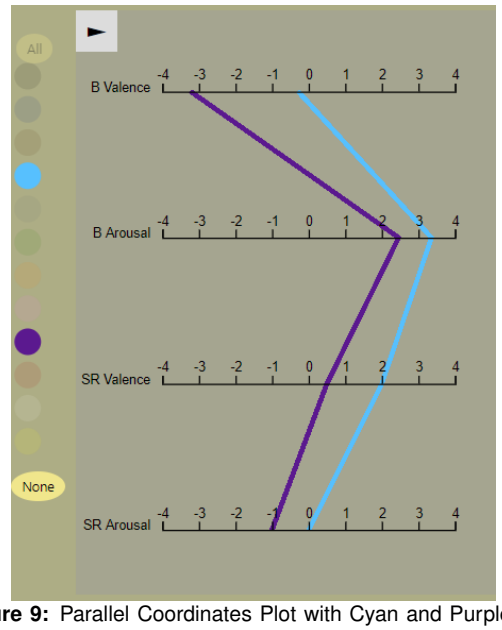

Figure 9: Parallel Coordinates Plot with Cyan and Purple selected

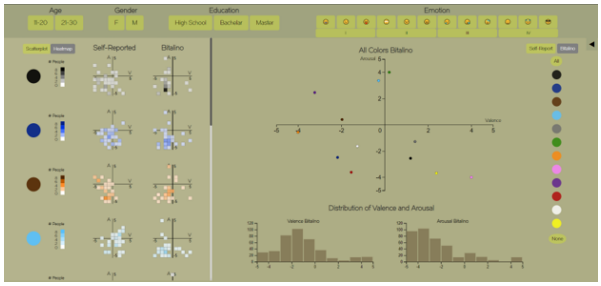

Figure 10: Complete visualization before formative evaluation

5. Results & discussion

To understand the objective of this works an evaluation was made in two parts with an usability eval-

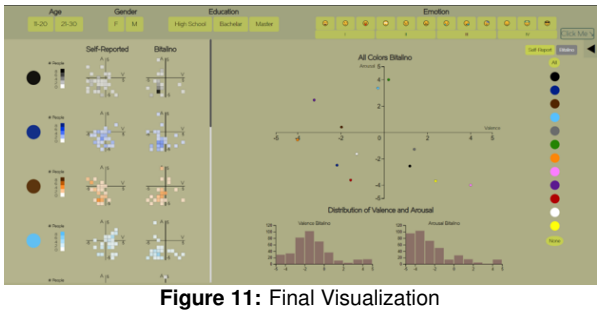

Figure 11: Final Visualization

uation and an utility evaluation being able to take results and conclusions from these evaluations regarding the objective of the project.

5.1. Summative Evaluation

In the section it will be presented the description of both evaluations, how they were made and what results were taken from them.

Summative evaluation can be made both in terms of usability and in terms of utility, where usability is how easy the interface is to use and utility corresponds to how relevant the visualization is to the users and to the goal of the project[6] to later measure efficiency, effectiveness and satisfaction.

For the usability evaluation, a series of tasks to perform is given to a minimal of 15 users. The tasks represent actions t

The utility evaluation differs from the usability because it is made with the target users of the interface and focused on the data, instead of being focused on how the interface is made, being more qualitative than quantitative. Case studies are made and time and errors are not relevant.hat an end user would typically carry out with the finished product.

5.1.1 Usability Evaluation

After this evaluation, no other changes were done to the visualization since this would be the last step of the process and any changes made in the middle of the evaluation would taint the results. With this evaluation, the main goal was to understand how the visualization behaved and if it was perceptible for the users.

Twenty users made this evaluation and were presented with five questions/tasks, in a random order to ensure that one question was not favoured because of the questions made before. The number of errors of each question, the number of clicks made to answer the given task, and the time to complete the task were recorded. The timer was started every time a question was presented and stopped when the user answered it.

After this process, a questionnaire called SUS[3] was presented to the user, using a Google Forms[5].

Two Excel files were created, one with the SUS answers taken from the Google Forms website, and the other with the number of clicks, errors and the time for each task for all users. All the calculations were made in the respective Excel Sheets.

The score can be calculated as $SUSScore = (Sum(EachOddQuestion - 1) + Sum(5 - EachEvenQuestion)) * 2.5$ and applying the formula for every user, afterwards an average SUS score can be done[3].

When applying the formula for the existing data, the SUS Score was 82.25 corresponding to an A grade meaning the users liked the system,considering it easy to use and would recommend the interface to friends.

Looking at the questions with low and high complexity on Table 2, the difference in number of clicks and errors it can be observed that the error average was almost the same in all task going from 1 error to 0.31 errors in average, so both high and low tasks were answered with equal difficulty by the users.

Looking individually to the questions, Table 2, task number 2 had the most significant difference from the expected to the real numbers. Users took two more clicks and twenty more seconds than the expected to answer given to the fact that two users did not understand the questions, so they clicked all the idioms searching for an answer and later giving the correct answer.

The question with the largest error number on average was the first one question. There was some confusion when the filters restarted after changing to Self-Report as it had happen in the formative evaluation however most users were not bothered by this problem. Furthermore, the question was answered correctly.

5.1.2 Utility Evaluation

The utility evaluation is made to understand if the visualization is useful and as a meaning to the focus users. The evaluation was done with the owner of the data and author of CogniHue[12].

The evaluation was conducted as a common dialogue while the user tested the interface and spoke aloud what were her thoughts. The interface was explained as the user used it, exploring it idiom by idiom and component by component.

The objective of these evaluation was also explained, and the questions proposed in Section 4 were kept close by to see if the visualization could answer them.

Starting with the scatterplot, since this idiom was the one used in the original work the user was al-

[5]https://www.google.com/forms/about/

Table 2: Visuzalization Dataset and Types

	Complexity	Clicks	Expected Clicks	Time	Expected Time	Errors
Task 1	High	3.15	3	0.46	0.4	1
Task 2	Low	3.35	1	0.55	0.34	0.55
Task 3	High	2.4	2	0.44	0.36	0.5
Task 4	High	3.65	3	0.4	0.3	0.5
Task 5	Low	1.9	2	0.35	0.5	0.31

ready very familiarized with it the only remark was that in case of two colors overlapping some information was being loss.

The histogram with the color blending feature was said to be a great addition to the interface as well as the parallel coordinate plot showed valence and arousal individually, something that is was not done before. When using the brushing in the parallel coordinate plot it was suggested that when selecting colors, it could also interact with the other idioms.

The heatmap was clear and appreciated as it separated well the data and was able to give a better insight to the users and to answer the questions proposed.

The main problem found was that when trying to filter on the scatterplot the median remained the same, since the filters are only implemented to filter the individual user data and not the overall median which is the default view when opening the interface. Making the data shown, even thought understood after it was explained, not perceptible or accurate to the filter being made.

With all the problems detected the last question asked was if the user would use this visualization to analyze the data and the response was positive.

5.2. Discussion

Regarding the findings in the usability tests and looking at the SUS Score, the score was **82.25**, which is equivalent to an A grade in the SUS evaluating system. The SUS Score is not only above average in this project, having the standard SUS average score to be 68, but it is also the highest grade possible, meaning the users considered the system usable.

When it comes to the metrics evaluated while performing the tasks, all questions were finished by all users and both highly complex tasks and low complex tasks were answered with similar number of errors not having users labelling any task as more complicated than the other, especially when comparing between the low and high tasks. Besides, the number of errors, the time to complete a task and, the number of clicks did not differentiate much from the expected values so no question was harder to complete than anticipated, all values can be found in Table 2.

So, from these values, it can be concluded that the system it is usable and efficient from the lack of differences between both high and low tasks and the expected values and satisfactory for the user as concluded from the SUS questionnaire.

Looking at the utility evaluation, even with the issues found during the evaluation the response to it was very positive. Having found good ways to show the data in ways that had not been explored before.

The interactivity was pleasant, and the user wanted more as to connect all the idioms since the filtering by color was very popular and enjoyed.

Regarding the proposed questions on Section 4 all questions were answered either directly or indirectly giving special attention to questions four and seven that make use of the histogram and parallel coordinates plot, respectively, that had a big impact on the user as this direct comparison was never done before.

Even with the issues found during the evaluation, specially regarding the filters, the visualization was found useful by the focus user.

In the end, the system was deemed overwhelmingly positive when it comes to usability. The evaluations were done with no unforseen problems and there was no problem for the users to understand the system even if the contents were not common knowledge. Doing a formative evaluation was the best step to do before the summative evaluation has it fixed problems that would not allow the users to answer the questions, for example by reforming some questions, presenting them in other ways, taking out irrelevant idioms, and fixing understandable idioms.

Taking the results from both evaluations they panned out with very good results being able to reach the objective. So, it is fair to say that the visualization did improve the way this data is analyzed, being useful and usable.

It can be acknowledged that visualizing this type of data might be very beneficial to assist clients that work with emotion and color related data. The chosen idioms proved to be adequate for the data and the initial requirements.

5.3. Demonstration of Potential

Information Visualization can be used to gather data and use it to amplify cognition on human beings[4]. So, this project would aid the focus users to analyze emotions and colors faster better way to take conclusions that were not achievable before. Taking what was concluded from the formative evaluation executed during the interface development, the users can now take conclusions from the individual components of valence and arousal, that was not able to do previously. The filters feature also allows to take meaning on emotions with different age groups, gender and education, something that was not remotely possible in the first analyses of this data since it only showcased the median of valence and arousal combined.

Besides, if the visualization becomes available publicly for everyone to use. Interested people could simply insert their own data into the visualization that have the same characteristic as the original data. So, everyone evaluating emotions, with valence and arousal, and colors can make use of the visualization to make their data analyses.

The visualization also allows for other colors to be tested since the dataset supports a RGB column, as shown on Table 1, where the user simply needs to introduce the colors tested and can now analyze emotion of any desired colors. For example, if the study was made using pastel certain pastel colors it could be made as showed in Figure 12.

Figure 12: Mock-up interface with pastel colors

6. Conclusions and Future Work

The goal of this dissertation was to try representing data regarding colors and emotion, represented by valence and arousal, and understand if by using information visualization techniques a new and better insight of this subject could be made.

From the related work it was observed that visualizing emotions is not a subject that has been made in abundance and that is fully explored. Conclusions varied and the way data was represented changed from work to work.

Looking at what was learned from the related work, tasks and questions, the data and data types a visualization was idilizated and each idiom was then selected to play differents and specific roles. A visualization was then implemented to answer the objective already described. For that the D3 - Data Driven Documents API was used and a prototype was created with 4 different idioms.

This project was evaluated in two different ways a formative evaluation and a summative evaluation. The formative evaluation was done before the summative evaluation, with the hopes of fixing usability issues that would give problems down the line. It proved to be the best option as it encountered problems that would cause usability problems when doing the final evaluations.

When it comes to the final evaluation, the summative evaluation, it was performed in two separate parts. A usability evaluation to understand how usable the visualization is. This evaluation was a success coming out with an A grade SUS Score. The users for the most part of the evaluation did not encounter any problem answering the required questions of the evaluation, considering it usable and efficient. The second evaluation was a utility evaluation, the users considered the visualization well executed and useful for their future works.

Being able to answer all the proposed questions and coming to the final conclusion from both evaluations that, it is possible to create a usable visualization from emotions, colors and their psychophysiological responses, but by doing this type of data treatment it becomes a good and efficient way to analyze this data.

In the future, since there were only thirty-three users the individual files were processed by hand using excel, however to process the text files a script could be implemented to quickly withdraw and rearrange the data. Still considering the data processing, when calculating the emotions based on the valence and arousal the current script does it for individual colors creating twelve files, it could be improved to have the script creating a single file and processing all the emotions at once.

During the sketch, creation of the interface and, the idioms that would make part of it, there was a lot of work put into to understand the best idioms to implement. It could benefit to have a longer sketch phase with maybe a heuristic evaluation to detect what was working or not before putting the ideas on code.

More evaluations could have also been made during the developing process to avoid carrying mistakes to the summative evaluation and cut irrelevant things on an earlier stage.

It would make the interface more put together and dynamic if the brushing on the parallel coordinate plot also filtered all the other idioms by the selected colors. As previously discussed, the filters when the median is being shown do not show the desired information instead they always show the

data of the thirty-three users, so when filtering and the only dot showing in the scatterplot is the median the dot appears to be in the wrong place, only being the correct information when expanding the dot on the scatterplot. This mechanism could be fixed by separating the filter to also work with both the median and the general user distribution.

References

[1] G. A. Agoston. *Color theory and its application in art and design*, volume 19. Springer, 2013.

[2] M. M. Bradley and P. J. Lang. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry*, 25(1):49–59, 1994.

[3] J. Brooke et al. Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7, 1996.

[4] M. Card. *Readings in information visualization: using vision to think*. Morgan Kaufmann, 1999.

[5] A. J. Elliot and M. A. Maier. Color psychology: Effects of perceiving color on psychological functioning in humans. *Annual review of psychology*, 65:95–120, 2014.

[6] M. J. Fonseca, P. Campos, and D. Gonçalves. *INTRODUÇÃO AO DESIGN DE INTERFACES*. FCA, 2012 edition, 2012.

[7] D. McDuff, A. Karlson, A. Kapoor, A. Roseway, and M. Czerwinski. Affectaura: an intelligent system for emotional memory. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 849–858. ACM, 2012.

[8] K. Misue and K. Taguchi. Development of emotion-weather maps. *Procedia Computer Science*, 60:292–301, 2015.

[9] T. Munzner. *Visualization Analysis and Design*. CRC Press, 2015.

[10] R. Plutchik. Emotions and psychotherapy: A psychoevolutionary perspective. In *Emotion, psychopathology, and psychotherapy*, pages 3–41. Elsevier, 1990.

[11] J. A. Russell. A circumplex model of affect. *Journal of personality and social psychology*, 39(6):1161, 1980.

[12] I. Santos, S. Gama, and D. Gonçalves. Cognihue-studying the cognitive effect of color in hci. *Instituto Superior Técnico*, 2017.

[13] M. K. Torkildson, K. Starbird, and C. Aragon. Analysis and visualization of sentiment and emotion on crisis tweets. In *International Conference on Cooperative Design, Visualization and Engineering*, pages 64–67. Springer, 2014.

[14] F. Y. Wang, A. Sallaberry, K. Klein, M. Takatsuka, and M. Roche. Senticompass: Interactive visualization for exploring and comparing the sentiments of time-varying twitter data. In *2015 IEEE Pacific Visualization Symposium (PacificVis)*, pages 129–133. IEEE, 2015.

[15] Y. Wu, F. Wei, S. Liu, N. Au, W. Cui, H. Zhou, and H. Qu. Opinionseer: interactive visualization of hotel customer feedback. *IEEE transactions on visualization and computer graphics*, 16(6):1109–1118, 2010.