Inclusive Interaction Design: Bridging the gap between Information Visualization Perception and Color Vision Deficiency Users

Project-Thesis

Mestrado em Design de Interação

Cristina Kohlhoff Feijó Relvas

Supervisors: Professor Carlos Rosa and Professor Lara Reis

2018

Jury

President

Doctor Professor Maria Emília Capucho Duarte

Arguer

Doctor Professor Carlos Miguel Lopes Rosa

Vowel

Doctor Professor Ana Filomena Curralo Gonçalves

Project-Thesis Model

The investigation followed a project-thesis model, where part of the research was theoretical and the other half practical. This type of model allowed a deep research about the subject which was later on applied on a practical experiment, involving data analysis and the emergence of real conclusions. The study benefited from this hybrid approach, since the design methodology applied also followed this structure.

Acknowledgments

Firstly, I would like to state that without the help of all the people mentioned in the following paragraph this project would never be possible.

I'd like to give a special thank you to my three friends Carlos Silva, Manuel Costa Reis and Mauro Silva who dedicated themselves entirely to the development of this project and made the whole experiment possible. Thank you for all the patience and re-coding, never did they complain about iterations that needed to be made, even contributed with creative and solution thinking.

Secondly, I'd like to thank my grandparents, Emílio and Clementina, for all the support and motivation not only in this project, but through my whole academic life. Although, my grandmother isn't present anymore to witness the conclusion of this life chapter, I'm sure she would be very proud and happy to know her effort is being reflected on today.

I'd also like to give a very special thank you to my mother Cristina, who has always supported me to achieve my goals and has been one of my main counselors academically and, above all, in life.

Additionally, I'd like to thank my partner and best friend António, for always making me see the bright side when things got harder, for having my back and not hesitating for a moment.

Of course, I need to thank my thesis advisors for all the support and work put into this project, their guidance was indispensable.

Also, I want to give a special thank you to the professor Joaquim Casaca, who supported me through the whole data analysis and was always available and present.

At last, I wanted to dedicate a little piece of this moment to give a big thank you to the Landing.jobs team for giving me the tools and knowledge to design a better project and, above all, always making me aim for more!

A sincere thank you to you all.

Keywords

Interaction Design; Information Visualization; Color Vision Deficiency; Color Saturation;

Abstract

It’s becoming increasingly important to design for Inclusivity, meaning building products that are accessible to all type of users, namely color vision deficiency (CVD) deuteranope users. Along with that, we can say that Information Visualization plays a big role in the understanding of how our world functions, since the amount of produced data (2.5 exabytes) is increasing every day. In this way, this project aims to bridge the gap between Information Visualization perception and color vision deficiency users, by exploring the effects that saturation as a variable, applied through an interaction design methodology approach, has on human visual perception. An interactive system was designed in order to explore the effects saturation had in both user’s perception. To perform the experiment, 12 trichromatic male participants were recruited and the selected graph’s colours were simulated into colours a CVD user would normally perceive. This experiment enabled to reach a range in which both trichromatic and CVD users perceive the information of a specific graph in an optimal way. Serving as a first assessment in potentially reaching a range that ensures the optimal visual perception of all types of Information Visualizations for both CVD and trichromatic users, this project intends to be used as a reference in future investigations, in order to improve the quality of life of users affected by this visual constraint.

Index

List of Figures

List of Tables

List of Graphs

Introduction

This project is divided into 4 different main parts. The first part focuses on explaining the significance of Interaction Design and defines a possible methodology when solving user experience issues. It begins with understanding some possible design approaches for problem solving, guiding the reader step by step through the different phases needed to build a solid product. The product in question is Information Visualization graphs, since in our contemporaneity they've become tools that make some hidden realities visible and even comprehendible.

Also, a big emphasis is given to Inclusive Design, meaning how to build products that are accessible to all possible users, including disabled users, taking specifically Colour Vision Deficiency (CVD) users into consideration. The next step involves the understanding of the Human Visual Perception which is linked to the Gestalt Principles, demonstrating how our vision is one of our main perception and cognitive tools.
The second part focuses on the project's Design and development and how the previous explained methodology was applied. The main goal of the project was to understand if vision becomes damaged, like in the CVD users case, how can Design aid those users to perceive products still correctly independently of their incapacities. An attempt to solve this concern was made by designing a project that after intensive data analysis provided a common saturation value which would make the Information Visualization graph in question perceptible for trichromatic and CVD users simultaneously. Future objectives are that with additional testing of different graphs and data gathering it could be possible achieving a saturation value that indicates from and to which point graphs are both perceptible to CVD and trichromatic users even when disregarding specific selection.
The third part converges into the showing of the findings made and interprets the investigation hypothesis. Wrapping it up, the final and fourth part indicates which

conclusions and future observations were made in order to continue de investigation and reach further outcomes.

1. Chapter 1: Literature Review

1.1 The significance of Interaction Design

Let's start with the first big question that is most probably popping into your mind: What is Interaction Design (IxD) and why should we see it as something meaningful and important? This is a very much valid question, as its answer is what drives interaction designers to perform and perfect their everyday work. As a matter of fact, it's the key point for any kind of designer handling a product and its users.

Think about all the products you use in your everyday life and how usable they are: a computer, a watch, a TV, a Nintendo controller, a router, a fitness app, an alarm clock, the list is infinite. Are they all easy and intuitive to use or did they ever lead you to frustration, even to an extreme anger outburst? The answer is probably "Yes, at least once or twice". This happens because many of those products were not produced thinking on the final user, their needs and, most importantly, their expectations. Managing the users' expectations is something many times underestimated, leading quickly to their discontentment. Users always have a certain expectation towards their products, if this expectation is not fulfilled the product has failed to perform their goal: to satisfy their customer and solve a specific issue they're facing. If this is the case, I'm sorry to break it to you, but the designer has failed likewise, as it is their job to anticipate behaviours and understand their targeted users.

In this way, Interaction Design helps building products that are easy and efficient to use, according to Preece "*A central concern of interaction design is to develop interactive products that are usable. By this is generally meant easy to learn, effective to use, and provide an enjoyable user experience*" (Preece, Rogers, & Sharp, 2002, p.2). Above all, we can state that it is a discipline in which its main focus is on the study of product behaviour, in their digital or physical state. "*While interaction design has an interest in form (similar to other design fields), its main* *area of interest rests on behaviour. Rather than analysing how things are, interaction design synthesizes and imagines things as they could be."*

Hence IxD exists to serve and support their users, to match their activities and extend their performance. One could accomplish this by guessing and hoping for the best, or one could be smarter and make decisions by understanding their users and rely on their actual pains and needs. For this to happen, some steps have to be taken into consideration, namely:

- *taking into account what people are good and bad at;*
- *considering what might help people with the way they currently do things thinking through what might provide quality user experiences;*
- *listening to what people want and getting them involved in the design using "tried and tested" user-based techniques during the design process;*

In this way, we can state that IxD surfaces as one of the most multidisciplinary areas as its extension doesn't limit itself to one dimension. More than a specialization, IxD can be seen as an area that is in constant change and mutation, which stimulates the collaboration of various other fields: sociology, psychology, engineering, computing science, ergonomics, graphic design, user experience, usability, among others.

To achieve results an interaction designer might have to dig a bit through areas which aren't that familiar and seek knowledge about subjects which, at first glance, seem to have nothing to do with the final product. It's not wisdom and know-how that characterizes the greatest designers, it's their openness and truthful honesty of admitting their lack of knowledge on some subjects, but still having the determination and discipline for wanting to learn and, more importantly, sharing and discussing this knowledge with others.

Interaction designers aim to "*design interactive products that support people in their everyday and working lives. In particular, it is about creating user experiences that enhance and extend the way people work, communicate and interact.*" (Preece et al., 2002, p.6) Making this happen in an efficient and agile way, requires designers to have a good and strong communication with software engineers, which can be difficult as the preoccupations of a developer aren't, most times, the same as the experience designer. In agreement with Preece (2002), this objective contrasts with software engineering, which primary focus relies on functionality and "getting things done", as many might say "it's better done than perfect". This is where and why many designers clash with development teams. Although both teams are working towards the same outcome, their way of getting there and prioritization is very different. Preece (2002) compares interaction design to software engineering in the same way as architecture is related to civil engineering "*A simple analogy to another profession, concerned with creating buildings, may clarify this distinction. In his account of interaction design, Terry Winograd asks how architects and civil engineers differ when faced with the problem of building a house. Architects are concerned with the people and their interactions with each other and within the house being built. For example, is there the right mix of family and private spaces? Are the spaces for cooking and eating in close proximity? Will people live in the space being designed in the way it was intended to be used? In contrast, engineers are interested in issues to do with realizing the project. These include practical concerns like cost, durability, structural aspects, environmental aspects, fire regulations, and construction methods. Just as there is a difference between designing and building a house, so too, is there a distinction between interaction design and software engineering*" (Preece et al., 2002, p.6).

1.1.1 Optimization through Agile Software Development

Agile Software Development processes have started to shift this reality by adopting methodologies that anticipate and manage the need for flexibility and reinforcing the need for constant communication between teams. Agile allows product teams to deliver individual pieces and smaller parts of the project, instead of the whole application at once. (Rouse, 2017)

Agile has replaced the Waterfall methodology[1], since in 2001 seventeen software developers created the Agile Manifesto, including 12 principles that build Agiles' core values. These values support the idea that everyone on the team, including business development and developers, are synched, informed and involved in the process. In this way, communication turns out to be as important as technology (Rouse, 2011).

IxD designers benefit a lot from this kind of new working methodology, as developers are integrated in the product cycle much sooner in the process, possible technical challenges are anticipated and handled. The communication between the two teams becomes more efficient, optimizing the whole process. Change becomes something natural to both parties, requiring a strategy that enables the breaking of big features in smaller ones for a continuous delivery. This step can sometimes turn out to be tricky, as "*both engineers and designers need to strive for efficiency, but also need to come to terms with a certain level of waste to reach product effectiveness for users*" (Calleia, 2014).

---

[1] The Waterfall methodology employs a sequential (or linear) design process. It is sometimes referred to as the cookbook approach. This means that, as each of the eight stages (project preparation, analysis, planning, design, construction, testing, implementation, and maintenance) are completed, the team moves on to the next step. As this process is sequential, once a step has been completed, the team can't go back to a previous step—not without scratching the whole project and starting from the beginning. There's simply no room for change or error, so a project outcome and an extensive plan must be set in the beginning and then followed very carefully. (Babich, 2016)

At the end of the day, it's important to note that designers and developers are both working for the same purpose, having both important roles in the process. "*Designers collect data to understand users and how these users will both use and benefit from the product, they then think strategically and creatively about how to solve problems. Is that really any different from how an engineer approaches a problem? Not really. Design and engineering are both creative professions, they have more similarities than many think — emphasize these similarities*" (Calleia, 2014).

The connection and communication between these two teams is very important, as they're dependent on each other´s knowledge. This project was only possible because there was a strong and constant relationship between both designers and engineers, in which both understood the project's requirements and constraints, thereby enabling a balance between both functionality and aesthetics elements.

1.1.2 Design Approaches for Problem Solving

Most of the products surface because of a pre-existing problem, the role of the designer is to understand the problem and then solve it. According to Saffer (2006) there are four different design approaches to finding a solution for a problem:

1. *The User-Centered Design*

The logic behind user-centered design is very simple: users are what moves designers to make decisions and build products in a specific way. Designers shouldn't guess what their users desire, need or aim; users themselves share these insights. Their constant participation is something very relevant in every stage of the process, modelling the product to their behaviors through the whole creative process. Some practitioners even see users as co-creators. "*Simply put, throughout the project, user data is the determining factor in making design decisions. When a question arises as to how something should be done, the users' wants and needs* *determine the response*" (Saffer, 2006, p. 89). One point the user-centered approach solves in a very efficient way is to remove the designers preconceived bias and personal preferences, focusing the problem in the users perspective turns out to be much easier.

2. *Activity-centered Design*

Instead of focusing on the user, activity-centered Design aims to design a product which drive is to understand which activities make sense to incorporate in the product. As Saffer (2006) states, activities can be loosely defined as a cluster of actions and decisions that are done for a purpose, although a purpose of an activity isn't necessarily a goal. Purposes are normally more specific and tangible, goals expand further in time and are seen as something more abstract and generic. For example, a user can have the purpose of bookmarking an article, but his goal is to interpret the article and get a good grade in the final exam. This kind of approach enables the designer to target specific actions/activities the user needs to perform, activities override user preferences. Although activity-centered design seems to be very appealing, it suffers from a very dangerous concern, by focusing on specific tasks the users need to fulfil, designers might lose the overview of the whole picture and create solutions that don't manage to answer the users' needs entirely.

3. *Systems Design*

Systems Design reveals itself to be a holistic way to approach the problem, through deemphasizing the user, more importance is put on the context, focusing on the project as a whole piece and not giving relevance to smaller features. Functionality comes before the users perspective/preferences.

According to Nirosh's (2013) technique the first step of designing systems is by asking a few questions:

1. *What are the Input(s) of the system?*
2. *What are the Processes of the system?*
3. *What are the Output(s) of the system?*

(Nirosh, 2013)

By gathering answers to these three questions you'll be able to understand the system and create more questions which will lead you to leaf level functions (sub-levels) of your system. It also helps to discover uncovered actors of the system. This process of trying to answer questions and understanding requirements continues until there are no more questions to be asked and all the leaf levels are discovered and planned.

4. *Genius Design*

In this type of methodology the designers instinct and experience are what defines the solution. Designers rely on their best judgement and experience from previous mistakes to come up with the best result. Users only get involved at the end of the process to verify that the designers' previous way of thinking was correct. This method can be critical, as our instincts can be very wrong.

Most designers choose one design approach and stick to it, but the best designers alternate between methods and follow approaches according to different projects and their requirements. In this way, the IxD creative process is very flexible in the way solutions are thought of and implemented.

Although designers might adopt different postures facing their challenges, essentially, the process of IxD involves four basic steps:

1. *Identifying needs and establishing requirements.*
2. *Developing alternative designs that meet those requirements.*
3. *Building interactive versions of the designs so that they can be communicated and assessed.*
4. *Evaluating what is being built throughout the process* (Preece et al., 2002, p.12).

The project's methodology followed these four steps and made use of various approaches to get to the final design. There was a lot of user-centered design thinking, involving the elaboration of proto personas (see the next paragraph), but also a Systems Design was needed in order to establish the task analysis.

1.1.3 Creating Proto Personas

The first step when approaching a new project, with unknown users, is to identify their needs and to establish requirements that the product should have in order to fulfil them. Hence, one of the most important phases is the research, where the macro product requirements are defined, and proto personas are built. In a short, "*A persona is a representation of a user, typically based off user research and incorporating user goals, needs, and interests*" (Ilama, 2015).

The purpose of determining personas is to create realistic representations of our targeted users, understand their habits, needs, everyday activities they perform, behaviors, even dreams and desires. The more personas are created realistically, the best our product can be designed, suited to their users. It's just like the difference of having a stuffed puppet or an animated cartoon character. The puppet might even look real and fluffy, but you'll never know what it feels, desires or what his story really is. An animated cartoon can tell you his story, where it wants to go, what his goals and pains are. The more details your persona has, the more you can relate and actually design something appropriate and thought through.

Benefits of investing time and effort in realistic personas are: having the chance to let leaders and stakeholders evaluate new features; interaction designers develop informed wireframes, interface behaviors and labelling; system engineers/developers decide which approaches are best to used based on user behaviors; and appropriate content can be written to the appropriate audiences (Affairs, 2013).

Quoting Affairs "*it is better to paint with a broad brush and meet the needs of the larger populations than try to meet the needs of everyone*" (Affairs, 2013). It's important to focus on larger populations and audiences who use the product, creating three or four personas is ideal. To make sure these personas are accurate representations, you need to make sure that:

1. *The user research was properly made: understand their behaviors, assumptions and expectations;*
2. *The research is condensed: Investigate only specific and relevant themes to the universal of the system.*
3. *Brainstorming was done: organize your researched elements into groups and name/classify that group (they'll be your personas);*
4. *Personas are combined and prioritized, dividing them into primary, secondary and complementary groups; (3-4 primary personas maximum)*
5. *Personas are realistic: Think about each persona as an unique individual with a background, motivation and expectations* (Affairs, 2013).

This project worked with two different proto personas, which were created based on user research and brainstorming (see chapter two). Each one of them had their specific behaviors and life story, making them realistic and, most importantly, relatable.

1.1.4 Mapping your User Story

The next step after defining the personas is to understand which activities the user will need to perform and in which order, so they can achieve their goals. For this to take place, writing a User Story might be very helpful. There are other methodologies that can be used to define the User Story and how the tasks will be performed, normally this approach is used by designers because of its flexibility, it was created to support constant project changes, as in the beginning of a project it's very common that strategies aren't yet well defined, the User Story itself grows as the project gets more robust.

There are two steps in producing a User Story, the first is to have several conversations about the desired functionalities and to sum them up in an established template (Cohn, n.d.):

As a < type of user >, I want < some goal > so that < some reason >.

The second part of building a solid user story is to map that story, which according to Patton (2014) you can do in six simple steps:

1. *Frame the problem: Who is it for, and why are we building it?*
2. *Map the big picture: Focus on breadth, not depth. Go a mile wide and an inch deep (or a kilometer wide and a centimeter deep, for my friends in the rest of the world). If you don't have a clear solution in mind, or even if you think you do, try mapping the world as it is today, including pains and joys your users have.*

3. *Explore: Go deep and talk about other types of users and people, how else they might do things, and the kinds of things that can (and likely will) go wrong. For extra credit, sketch, prototype, test, and refine solution ideas—changing and refining the map as you go.*

4. *Slice out a release strategy: Remember: there's always too much to build. Focus on what you're trying to achieve for your business, and on the people your product will serve. Slice away what's not needed to reveal minimum solutions that both delight people and help your organization reach its goals.*

5. *Slice out a learning strategy: You may have identified what you think is a minimum viable solution, but remember that it's a hypothesis until you prove otherwise. Use the map and discussion to help you find your biggest risks. Slice the map into even smaller minimum viable product experiments that you can place in front of a subset of your users to learn what's really valuable to them.*

6. *Slice out a development strategy: If you've sliced away everything you don't need to deliver, you'll be left with what you do need. Now slice your minimum viable solution into the parts you'd like to build earlier and later. Focus on building things early that help you learn to spot technical issues and development risks sooner* (Patton, 2014, p.83).

At the end of the day you should be able to have a clear picture of your project and every single step needed to build a full blown product.

Your user story mapping wall should look something similar to this:

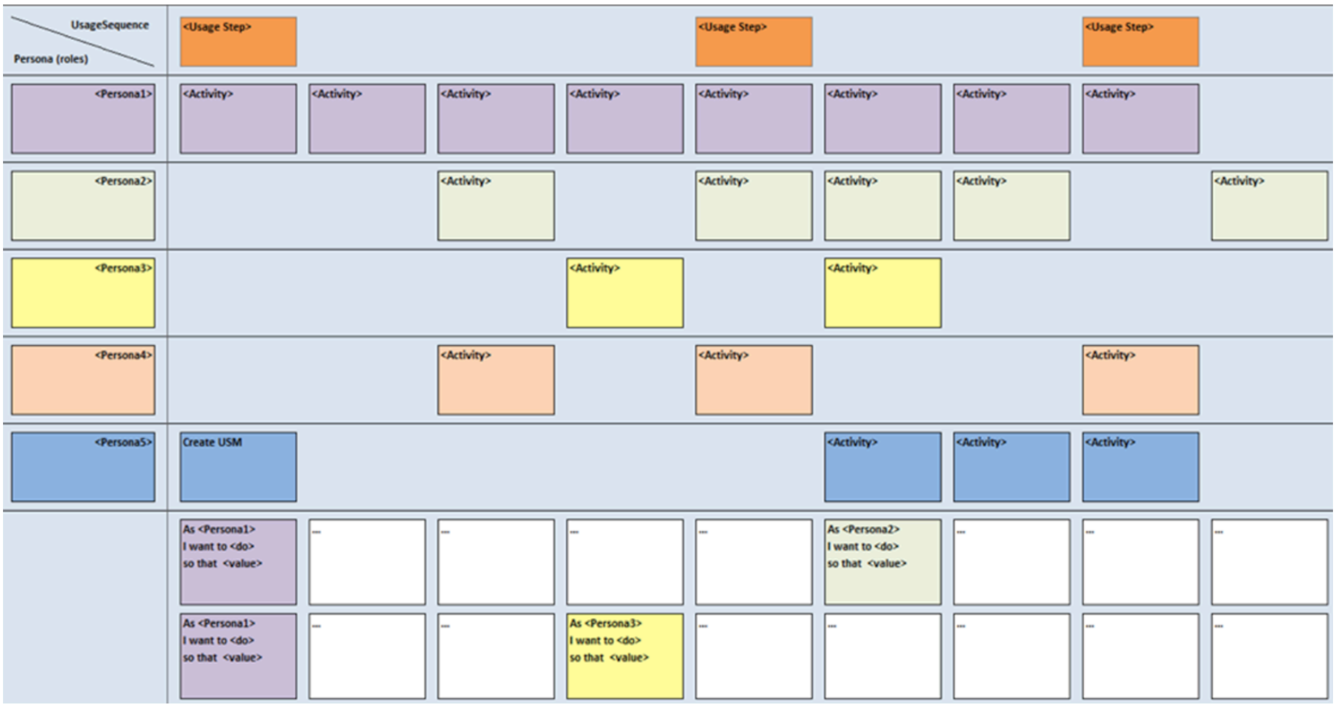


Figure 1 User Story Mapping Template (Patton, 2014)

Of course, this layout can change from project to project, according to its scale, requirements and stage, therefore, the User Story is something that is in constant change, it can be transformed and adapted as the project evolves.

The first User Story created for this project had the following structure, of course some iterations were made and activities adapted as the projects necessities changed over time:

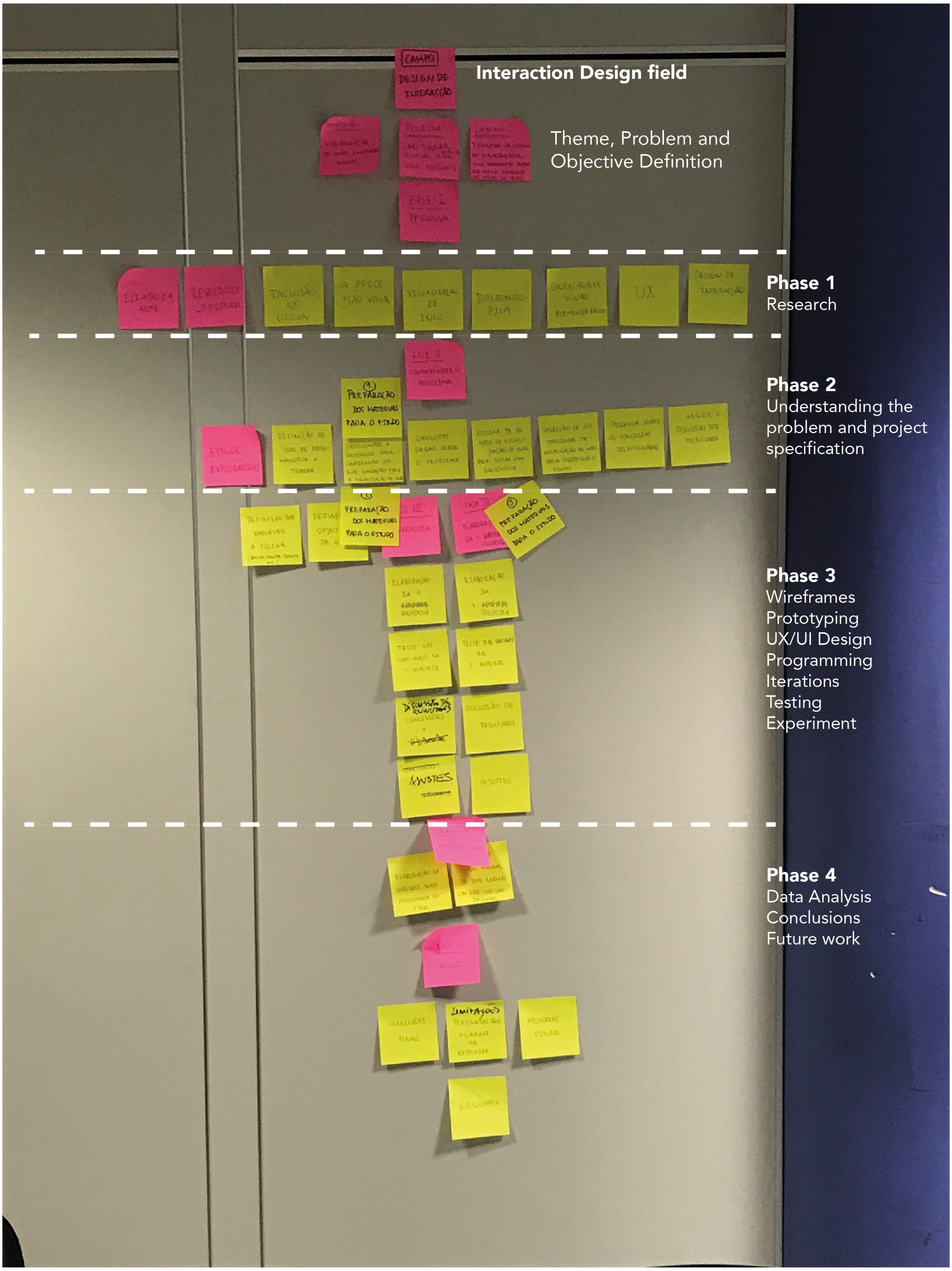


Figure 2 High level User Story Mapping of the project

2.1.5 Creating a Task Analysis

After building the User Story it's important to create a task analysis, where all the tasks the user will be able to perform are listed down. "This list of tasks can be assembled from several places: from business requirements ("Users need to be able to contact customer service"), design research ("Everyone we spoke to said that a self-destruct button was essential"), existing products ("Every mobile phone needs to be able to make phone calls"), and especially from brainstorming and scenarios ("What if we gave users the ability to customize that display?") (Saffer, 2006).

After collecting these tasks, it's important to connect them. How is this done? By implementing task flows. According to Saffer (2006), task flows will display, in a visual and logical way, how features appear to the user and how he'll make sense of them. Through this organization the affordance[2] of elements becomes visible and tangible.

The visual representation in a diagram of the hierarchical organization of these tasks and flows is commonly referred to as Information Architecture. Such a diagram helps designers to perceive how the system will globally work, between pages and task connections.

The task analysis was very important for the development of this project; it helped to define the activities the user needed to perform on the interface and how they were connected.

[2] Gibson (2002) defines affordance as the relationship between man and the things that surround him. Trough experience or innately we perceive objects according to their properties and actions we can have over them. The cognitive interpretations helps us understand the uses we can benefit from that object and how it'll help us achieve certain goals.

1.1.6 Wireframing

The next step, after defining the Information Architecture, is to design wireframes. As Saffer (2006) mentions, wireframes are the rough representation of a product; it's where functionalities, content and the means to navigate those two conditions are established.

Wireframing enables the preview of what the product will turn into and gives room for iterative quick improvements. It's similar to an architect´s blueprint; it helps in the organization of the information and in predicting user behaviors. By settling hierarchies, different states of the product, content, copy and defining where each block of information should be placed, we have more than half of the design process covered. Also, this strategy allows designers to be focused on functionality and not get distracted by aesthetics. Stakeholders and developers (engineering team) are involved in this phase, preventing for technical restrictions and avoiding miss communications.

An essential step before starting with the User Interface (UI) is to make sure all the interactions and features in the product make sense as a whole. To achieve this designers use prototypes. *"Prototyping is where, finally, all the pieces of the design come together in a holistic unit. Indeed, many clients will have difficulty understanding a design until they see and use the prototype. Like all the other models and diagrams, it is a tool for communicating. Prototypes communicate the message "This is what it could be like"* (Saffer, 2006, p. 265). Many times it's necessary to build several prototypes, just to come to the conclusion that a hybrid of all the previous versions is what works best. This is an exploration phase which is part of the creative process, that leads to the best product the user could wish for.

Wireframing was considered to be one of the most useful parts of this project, as it facilitated the communication with the software engineers, and provided the means to show them drafts of how the overall system would, which then made it possible for them to start programming some basic functions and to structure the code without the final mockups. In sum, this saved the project's execution a lot of time and effort.

1.1.7 Mood Boards

When all functionalities, behaviors and connections are established, creating a mood board is the next challenge. "*Mood boards are a means for the designer to explore the emotional landscape of a product or service. Using images, words, colors, typography, and any other means available, the designer crafts a collage that attempts to convey what the final design will feel like*" (Saffer, 2006, p.255). Mood boards are tools of inspiration that aid the designer on establishing the emotional level of the product, having in mind what the final user will be. A product mood board will surely look very different from a 20-year-old persona to a five-year-old, as their contexts, way of thinking and cognition are also contrasting. This combination of elements will help later in the UI Design, choosing colors, typography, styles, etc.

This phase didn't apply to the type of project that was being developed, as it's core was the testing with real users the interface needed to be simple and intuitive without decorations or other aesthetic concerns. The Genius Design approach helped define the "look and feel" of the project, therefore, no further visual research was needed.

1.1.8 User Interface Design (UI)

The final step of a designers' creative process, and where all the previous work culminates, is the User Interface Design. Here's where the final look of the product will be defined. "*An interface is where the interaction designer's choices about how people can engage with a product and how that product should respond are* *realized. In other words, the interface is where the invisible functionality of a product is made visible and can be accessed and used*" (Saffer, 2006, p.277).

As Tidwell (2006) states in "*Designing Interfaces*", users normally associate a product's design to a genre that relates their expectations towards that product accordingly. For example, if a website presents itself as e-commerce, they'll be expecting to be able to buy goods. Genres are set up by multiple design principles that users are already familiar with, problem is "*as soon as you learn a "rule" for evoking an emotional reaction using a design principle, you can find a million exceptions*" (Tidewell, 2006, p.278).

In order to design a product that provides the user a good experience, as well as matches their expectations, a combination of multiple factors must be taken into consideration, namely attention to color, typography, spaciousness, angles and shapes, repeated visual motifs, texture, images, and cultural references.

When following the above mentioned steps, we can state that the product has to be well planned and thought through, in order to provide the user with a pleasurable experience that helps them to achieve their main goals. Consequently, in order to develop a product that will support people in their everyday lives, such a product should be:

- *Effective to use (effectiveness);*
- *efficient to use (efficiency);*
- *safe to use (safety);*
- *have good utility (utility);*
- *easy to learn (learnability);*
- *easy to remember how to use (memorability)* (Preece et al., 2002, p.14) ;

These steps were taken into consideration when analyzing the UI Design, after developing the wireframes and organizing the content. In the end, the UI turned out to be very simple, as all the requirements, activities and functions were planned and thought through.

1.2 Information Visualization

Information Visualization was the core issue of this project, more specifically, the perception of graphs, by regular and CVD users. Therefore, it became necessary to carry out a complete research on the matter.

According to Cairo (2013), every phenomenon that can be perceived or measured can be described as information, in this way Information Visualization (IV) has become one of the main tools in our contemporaneity. With the amount of produced data, to be precise, 2.5 exabytes per day, equivalent to 530,000,000 music tracks, data structure becomes almost mandatory (Khoso, 2016). IV makes some hidden realities visible and provides a better understanding of some subjects, for example web flow information networks, information segmentation by different consumers, which if not structured, would stay unexplored and lost in the data overload.

According to Alberto Cairo (2013), the goal of any kind of graphic representation is to be used as a tool, which is directly connected to our brain and makes it possible to interpret what is out of our natural visual reach. As human beings we have the instinct to organize non-structured information into a natural order, establishing hierarchies between the various elements. The main intention of IV is to assist on the establishing of these same hierarchies before our brain does so.

Also, IV exists to help us avoid, what Wurman (2000) calls Information Anxiety, "the black hole between data and knowledge". As Wurman states "*Information anxiety is produced by the ever-widening gap between what we understand and what we* *think we should understand. (…) It happens when information doesn't tell us what we want to know*" (Wurman, 2000, p.14).

IV tries to fight this condition, as in the current world it becomes more important than ever to gain control over the bit. As Hurst interprets "*Information anxiety is more important today than ever, thanks*
to the arrival of the bit. The tiniest one-or-zero-pulse of digital data, the bit will affect our lives as much as the atom. Ten years ago, Americans may have felt some anxiety over the magazines and newspapers piling up at home, but today the anxiety is increasing as bits appear in all areas of our lives. Email, Web sites, e-newsletters, chat rooms, email, instant messages, and more email — all of these streams of bits can interrupt us, and keep us engaged, anywhere and anytime. Devices made to hold these bits are springing up, too: PDAs and cell phones bring us the bits when we're away from our PC" (as cited in Wurman, 2000, p.6).

The solution to this problem is what Hurst calls "bit literacy", being aware of the information overload, how it affects our lives and understand how we can control it. As Bawden & Robinson (2009) state, taking control of one's information environment is the first step to avoid some of the information pathologies, avoid the feeling of powerlessness. To achieve this power one must be disciplined through time management, desk management, critical thinking, information presentation, better information organization and a continuous personal information management style.

Designers too can play a big part in triggering this awareness; if designers present information to their readers in a way that they can correctly perceive and interpret it, their trust is earned and the users will label and consider that information as valuable and important.

The diagram below (Figure 3) shows how we process information and make sense of it, it's based on various DIKW models (Data, Information, Knowledge, Wisdom.

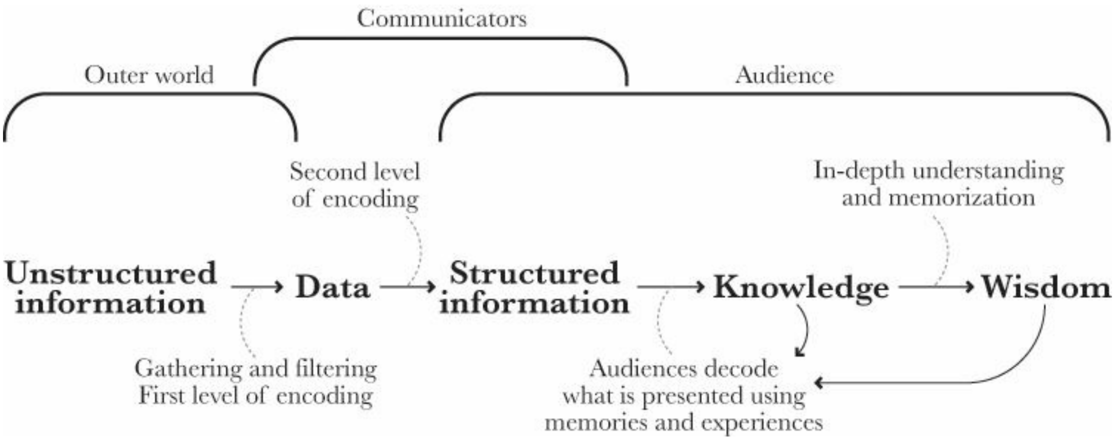


Figure 3 From reality to peoples' brains (Cairo, 2013, p.54)

The unstructured information represents our reality, data in its natural form and complexity. The first step of encoding the information is by gathering and filtering the information turning it into data. Structuring the data and making it perceptible for the audience is the second level of encoding, here's where the designers challenge relies, finding a way that'll visually show users what that data really means in a way they can make sense of it and relate. After the graph is perceived by the audience, it's interpreted by comparing and analyzing the information to previous memories and experiences. "*We reach wisdom when we achieve a deep understanding of acquired knowledge, when we not only "get it", but when new information blends with prior experience so completely that it makes us better at knowing what to do in other situations, even if they are only loosely related to the information from which our original knowledge came*" (Cairo, 2013, pp.55-56).

Information Architects are responsible for preparing the information for efficiency and effectiveness purposes, they structure and organize the data into structured information. As we can see in Figure 3, Information Architecture works as a big umbrella that wraps Information Design and Visualization Information Graphics.

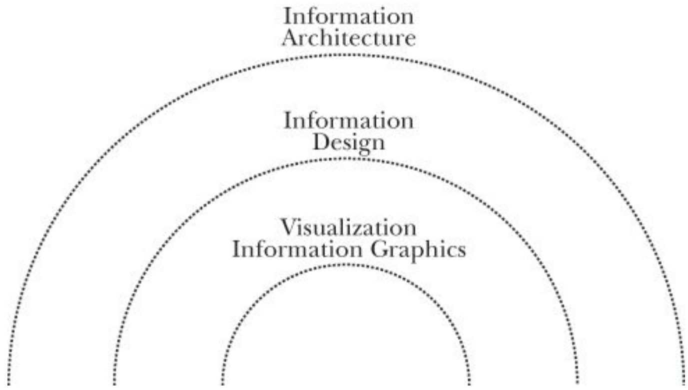


Figure 4 Information graphics is a form of information design. Information design branches from information architecture (Cairo, 2013, p.58)

1.2.1 Comparing Processes

We can say that IV helps its audience in the completion of some of their daily tasks. It's a functional art, where function constraints the form, in contrary of many other creative fields. For IV to help the user understand better the information it must:

1. *Present several variables, so that all the needed information is properly displayed;*
2. *It should allow the user to make comparisons between the information groups;*
3. *Based on the previous comparison, it should aid the user on information organization;*
4. *It should point out correlations and relationships between sets of information* (Cairo, 2013, p.68);

The form that information acquires is not always the same, data can be represented in multiple ways, though the question that must be always present when designing is if that graphical representation is answering our users questions in a direct and obvious way. "*What is really important is to remember that no matter how creative and innovative you wish to be in your graphics and visualizations, the first thing you must do, before you put a finger on the computer keyboard, is ask yourself what users are likely to try to do with your tool*" (Cairo, 2013, p.98).

In consonance with Cairo (2013), the form should be constrained by the function, the more the artefacts goals are defined the narrower variety of forms it can adopt. In Information Design (ID), we should always adopt a user-centered approach, so that we can be sure that our users will understand what we're trying to communicate.

When designing an information visualization project, being it an infographic, chart, graph, or any other kind, it's important to follow a methodology that ensures the IV projects optimal perception and interpretation. Cairo (2013) defined a 6-rule possible process:

1. Define the focus of the graphic, what story you want to tell, and the key points to be made. Have a clear idea of how the infographic will be useful to your readers, and what they will be able to accomplish with it.

2. Gather as much information as you can about the topic you are covering. Interview sources, look for datasets, and write or storyboard ideas in quick form.

3. Choose the best graphic form. What shapes should your data adopt? What kind of charts, maps, and diagrams will best fit the goals you set in the first step?

4. Complete your research. Flesh out your sketches and storyboards.

5. Think about the visual style. Choose typefaces, color palettes, etc.

6. If you've been sketching offline, move the design to the computer. Complete the graphic using the appropriate software tools (Cairo, 2013, pp. 265-266).

The method described above is very similar to the general interaction design process described before, even if not directly related to interactive products. IxD and IV have more in common than one might see at first glance, both fields have the same goal: to help their users in their daily tasks, providing simultaneously a good and pleasurable experience. The most striking difference between the two areas is that in IxD form results from previous user data collections and researches (if following a user centered approach) and in IV form comes from a specific topic you're covering.

It's possible to match the mentioned IV methodology steps to the IxD previous mentioned ones:

1.

IV: Define the focus of the graphic, what story you want to tell, and the key points to be made. Have a clear idea of how the infographic will be useful to your readers, and what they will be able to accomplish with it.

IxD: Define your target users, their needs, pains and expectations. What story do you want to tell, how will the product be useful for them, what tasks will they be able to accomplish with it.

2.

IV: Gather as much information as you can about the topic you are covering. Interview sources, look for datasets, and write or storyboard ideas in quick form.

IxD: Do research and interview your users, get as much information as you can from them. Prepare your architecture of information and elaborate the list of tasks your users would like to perform.

3.

IV: Choose the best graphic form. What shapes should your data adopt? What kind of charts, maps, and diagrams will best fit the goals you set in the first step?

IxD: Design your wireframes and define the visual structure of your product, organize the content.

4.

IV: Complete your research. Flesh out your sketches and storyboards.

IxD: Prototype your product and establish interaction patterns and user behaviours.

5.

IV: Think about the visual style. Choose typefaces, color palettes, etc.

IxD: Design your User Interface, define styles, color palettes, typographies, etc.

6.

IV: If you've been sketching offline, move the design to the computer. Complete the graphic using the appropriate software tools.

IxD: If you've been sketching offline, move the design to the computer. Complete the graphic using the appropriate software tools."

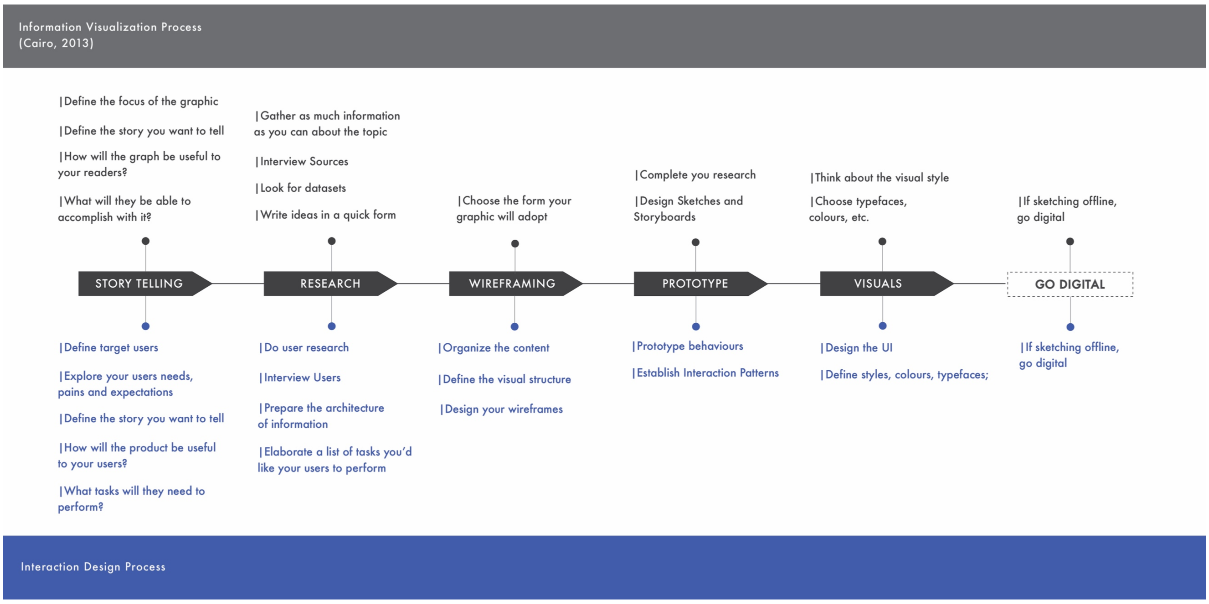


Figure 5 Comparing the Information Visualization and the Interaction Design Process Model

As we can see, the design process of information design is similar to other creative processes that have the goal to communicate with the user, such as Interaction Design, Service Design, Infographic Design, among others. These areas depend upon cognitive processes and visual perception for their creation (encoding) and use (decoding). The encoding process is the most relevant and critical one, understanding how the message should be communicated, in which form and what content should be displayed and how. If the encoding is not well resolved, the decoding will not be successful. Interaction designers have the responsibility of ensuring the artefacts encoding is being communicated effectively and produces a successful decoding, meaning the message is being interpreted in the right way by the user.

1.3 The Human Visual Perception

Vision is something we human beings take for granted, it appears to be very easy. It's what enables us to perceive the world as it is and identify possible threats and respond to certain stimulations. "*Vision isn't there merely to form a pretty picture of the world—it's there in order for us to be able to make sense of what is out there and to interact with it, and to actively seek information about the world*" (Snowden, Thompson, & Troscianko, 2012, p.6).

To understand how human visual perception works we have to first know how the eye functions, since it's the only organ that ensures visual perception.

As Snowden, Thompson and Troscianko (2012) explain, when analyzing the eye structure, the first thing to notice is the cornea, a transparent window through which light enters the eye. We can say that it's the main lens of the eye, just like a lens of a camera, since it's what focuses the light on to the retina.

Secondly, we have the iris, the colored part of the eye. The iris adapts itself to the light and lets it pass in less or more quantity. We can say that when our pupils constrict is where there is more light to be catched, our depth of focus increases.

Another important part of the eye is the lens, it ensures the focus of distant (lens is stretched into a skinnier shape) and close objects (lens relaxes into a fatter shape). The vitreous humor, the main cavity of the eye, behind the lens is filled with a gelatinous substance, it's task is to keep the eyeball in shape and the retina glued to the eye wall.

One of the most important part of the eye is the retina, a light sensitive layer located at the back of the eye. Here is where the real magic happens, the visual processing. When light approaches and passes through the photoreceptors, it reaches the outer segments of the receptors and the neural process begins. The receptors are connected to bipolar cells which send synapses to the ganglion cells, which are responsible to carry the visual information and define what from that information is important, from the eye towards the cortex (where all the cognition happens).

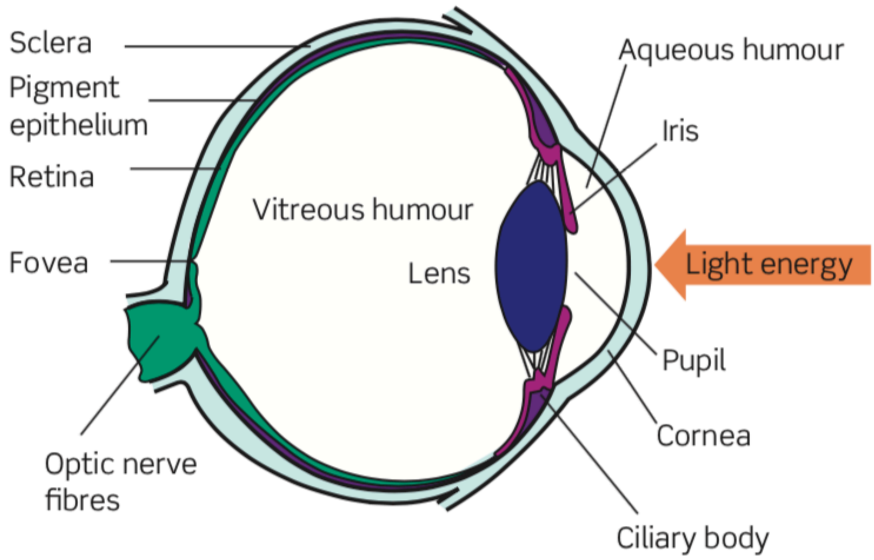


Figure 6 Horizontal cross-section through the human eye (Snowden et al., 2012, p.21)

Rewinding a bit back to the photoreceptors, which is something very important for color perception, there are two types of photoreceptors: rods and cones (named after their shape). Photoreceptors are responsible for transforming light energy into electrical activity, but both types do it differently. Rods are all equal and only respond until certain dim light, when full day light is the case they become completely obsolete, this is why all rods contain the same pigment called rhodopsin. Cones, on the other hand, come in three main categories: Red cones, Green cones and Blue cones.

The red cones incorporate a photo pigment that is most sensitive to long wavelengths of light; green cones are more sensitive to middle wavelengths of light and blue cones are most sensitive to shorter wavelengths. These are the three cones that give us the privilege to see the world colored.

Photoreceptors are not equally distributed through the retina, cones are concentrated in the center, in an area called the fovea.

But how do these cones receive certain wavelengths and not others? To answer that question the concept of light must be determined. Still following Snowden, Thompson and Troscianko (2012) thoughts, we can define light as little packets, called protons, these protons arrive in different quantities from the sun, the number of packages arriving simultaneously defines the intensity of the light, which consequently, defines its wavelength.

Light is a form of electromagnetic radiation, it’s a small piece that composes the electromagnetic spectrum, we call it the visible spectrum. According to Snowden, Thompson and Troscianko (2012), that definition is not very politically correct, as it’s called “visible light”, just because it’s visible to our species, ignoring others, like for example the sidewinder snake who senses infrared emissions, making us “specie-ists”.

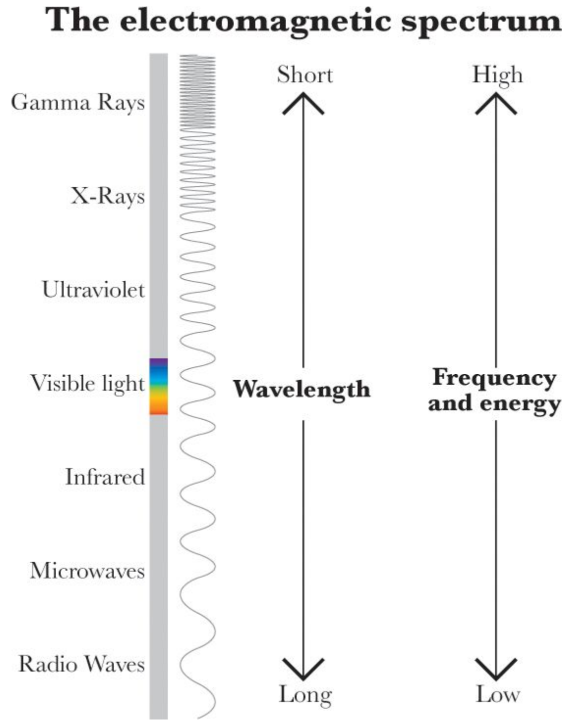


Figure 7 The electromagnetic spectrum of vision (Cairo, 2013)

The, so called, visible light or white light is composed by red, orange, yellow, green, blue, indigo and violet (ROYGBIV) colors. When it hits an object, its selectively absorbed, reflected or transmitted into specific light frequency. How the light relates to those objects depends on the frequency of that light and the nature of the atoms of the object.

Snowden, Thompson and Troscianko (2012) affirm that objects are composed by atoms and molecules which contain electrons, those electrons are set in motion when a light wave with the same natural frequency as the electron hits an atom. The electrons will absorb the energy of the light wave and transform it into vibrational motion. This leads that the light wave with the same frequency will never be again released in form of light. Consequently, the selective absorption of light takes place because the vibration frequency of the electrons is equal to the respective lights frequency. The frequency vibrations which weren't absorbed are then reflected. These reflected frequencies are captured by our eye and transmitted to the photoreceptors, depending on what frequency of light and wavelength it reflected, the respective photoreceptors sensitive to that lights frequency (red, green or blue) receive signals and transmit them through the optic nerve to the brain, where the cognition process begins.

1.3.1 Cognition

Cognition is part of the process of understanding IV. Sadly, it is known that vision is fast but reason is slow (Cairo, 2013). Imagine you're walking down the street and you see a high-speed object flying towards you, instinctively you try to protect yourself by holding your arms in front of your face, only when the object hits you, you realize it was a plastic cup. Your eyes saw the flying object and your brain perceived it as a threat, but only moments after you could identify and classify it as not being a real hazard. As follows seeing, perceiving, and knowing are different phenomena.

"*Scientists have proven that seeing is not exactly the same as perceiving, as people with severe brain damage reveal. For instance, V.S. Ramachandran in his illuminating The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human (2011) describes blindsight, a bizarre condition that leads you to see without knowing that you see. During experiments, a supposedly blind subject was seated in front of a source of light and asked to reach it with his hand. The man complained he couldn't do that because he was blind. But when he finally agreed to try, his hand grabbed the source with no hesitation. He was seeing, although his brain was not consciously aware of that sight*" (Cairo, 2013, pp. 197-198).

Some intellectuals, like Saussure, see the reading of symbols as something based upon social interaction, this means that a symbol is understood and interpreted based on its social convention. Diagrams are arbitrary and only effective if learned according to their social context, in this case the laws of perception become trivial.

"*Diagrams are made up of symbols, and symbols are based on social interaction. The meaning of a symbol is normally understood to be created by convention, which is established in the course of person-to-person communication. Diagrams are arbitrary and are effective in much the same way as the written words on this page are effective—we must learn the conventions of the language, and the better we learn them the clearer that language will be. Thus, one diagram may ultimately be as good as another; it is just a matter of learning the code, and the laws of perception are largely irrelevant*" (Ware, 2013, p.5).

According to Ware (2013), this assumption is strongly debatable, if realistic pictures and symbols don't embody a sensory language, visualizations can't be designed in a more perceptible way than others, every diagram and graph, even if poorly designed and structured, would have value and its perception would rest only in the users social conventions.

Many studies contradict Saussure's approach, saying that it is possible to interpret images and symbols without former training:

"*(…) Hochberg and Brooks (1962) raised their daughter nearly to the age of two in a house with no pictures. She was never read to from a picture book, and there were no pictures on the walls in the house. Although her parents could not completely block the child's exposure to pictures on trips outside the house, they were careful never to indicate a picture and tell the child that it was a representation of something. Thus, she had no social input telling her that pictures had any kind of meaning. When the child was finally tested she had a reasonably large vocabulary, and she was asked to identify objects in line drawings and in black-and-white photographs. Despite her lack of instruction in the interpretation of pictures, she was almost always correct in her answers, indicating that a basic understanding of pictures is not a learned skill*" (Ware, 2013, p.8).

As Ware (2013) explains, images and symbols understanding and perception are dependent on how well they're designed, if well matched to the first stages of neural processing the results are more likely to be effective across individuals, cultures and time. "A circle represents a bounded region for everyone. Conversely, arbitrary conventions derive their power from culture and are therefore dependent on the particular cultural milieu of an individual" (Ware, 2013, p.9).

This means that designing according to the laws of perception enhances our product, as well as leads us to build better and more recognizable information visualizations. It's something to take into consideration when designing the visuals, but also such behaviors should be anticipated in the wireframing and prototyping stages.

1.3.2 Preattentive Processing and ease of Search

The seeing process can be described as a series of cognitive acts with the following structure: make an eye movement, pick up some information, interpret that information and plan the next eye movement. First there's a cognitive construction of a simple pattern, then a visual search for that pattern takes place (Ware, 2013, p.142).

Following Wares' (2013) idea of perception, "preattentive processing" helps us with this visual search in determining which visual patterns deserve our attention first. Some visual patterns stand out more than others, their composition, colors and shape makes us instinctively assume them as more important, diminishing others. This phenomenon turns out to be very relevant for designing information visualization, when observing a graph (or other types of IV) we're able to see things "at a glance", that information will be the one first processed by our brain and will have a big impact on our data analysis.

Some visual characteristics are preattentively processed, as is the case of orientation, size, basic shape, convexity, concavity, color, contrast and border boxes (Figure 8).

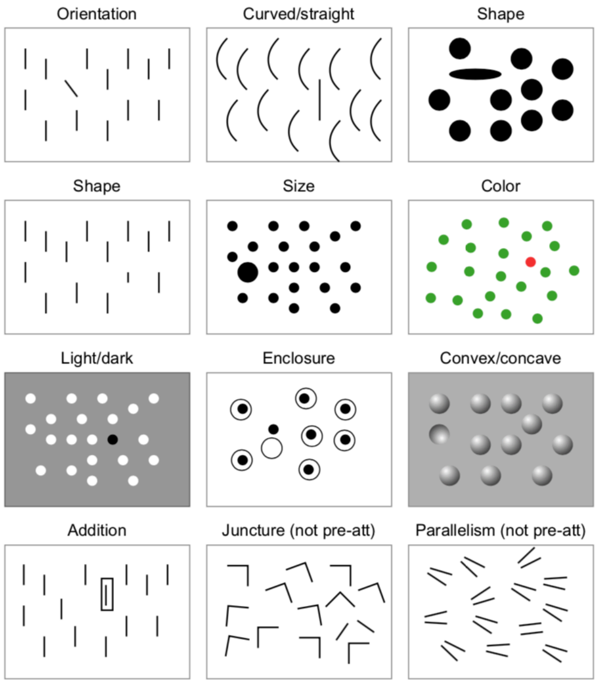


Figure 8 Most of the preattentive examples given here can be accounted for by the processing characteristics of neurons in the primary visual cortex (Ware, 2013)

According to Ware "The features that are preattentively processed can be organized into a number of categories based on form, color, motion, and spatial position.

- Line orientation
- Line length
- Line width
- Size
- Curvature
- Spatial grouping

- Blur
- Added marks
- Numbering (one, two, or three objects)
- Color
- Hue
    - Intensity
- Motion
    - Flicker
    - Direction of motion
- Spatial position
    - Two-dimensional position
    - Stereoscopic depth
- Convex/concave shape from shading" (Ware, 2013, pp. 154-155)

Not all preattentive effects have the same impact, there are differences based on color, orientation, size, contrast and motion or blinking. It's important as a designer to have these phenomenons in mind, as they're very useful when wanting to highlight certain parts of the IV and help the user understand the story flow of a graph.

When something is not easily findable, requiring a longer serial processing, it's called a "*conjunction*" search, normally it involves searching for more than one attribute, for example shape and color. *"The fact that conjunction searches are slow has broad implications. It means, among other things, that we cannot learn to rapidly find more complex patterns. Even though we may have hundreds or thousands of hours of experience with a particular symbol set, searching for conjunctions of properties is still slow, although a modest speedup is possible (Treisman et al., 1992)"* (Ware, 2013, p.160).

User-centered designers should make use of the preattentive search as much as possible, in order to avoid taxing the user, i.e., giving the observer the task to perform an exhausting conjunction search.

1.3.3 The Gestalt Principles

The Gestalt Principles were studies by Max Wertheimer (1920), who defined innate mental laws by which objects were perceived. As Mazza states (2009), Gestalt's most important principle is that the whole of an image is not perceived simply by the sum of its parts, but has a more important meaning than its elements put individually. This means that the human brain tends to process objects as a unit, organizing elements into groups.

According to Mazza (2009), there are some central principles which define the laws of gestalt and, consequently of image perception:

1. Figure and Ground Principle

This principle guides itself by the fact that our visual perception tends to separate an object from its background based on visual characteristics such as contrast, color and size. Such as in Figure 9 we identify the elements that compose the building as a whole and the black square behind them as its background.

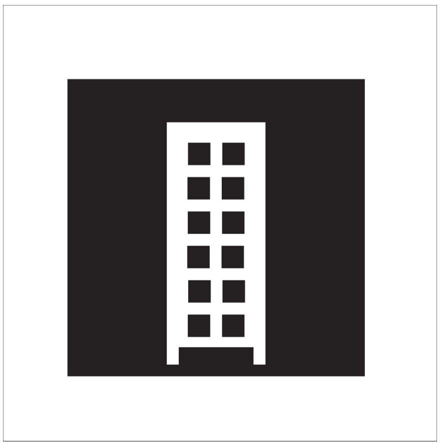


Figure 9 The Figure and Ground Principle Shapes

2. Proximity Principle

When elements are placed in proximity the human perception tends to recognize them as a group. In Figure 10 we automatically perceive the elements on the left and right images as groups, in contrast the elements in the center image are identified as separate.

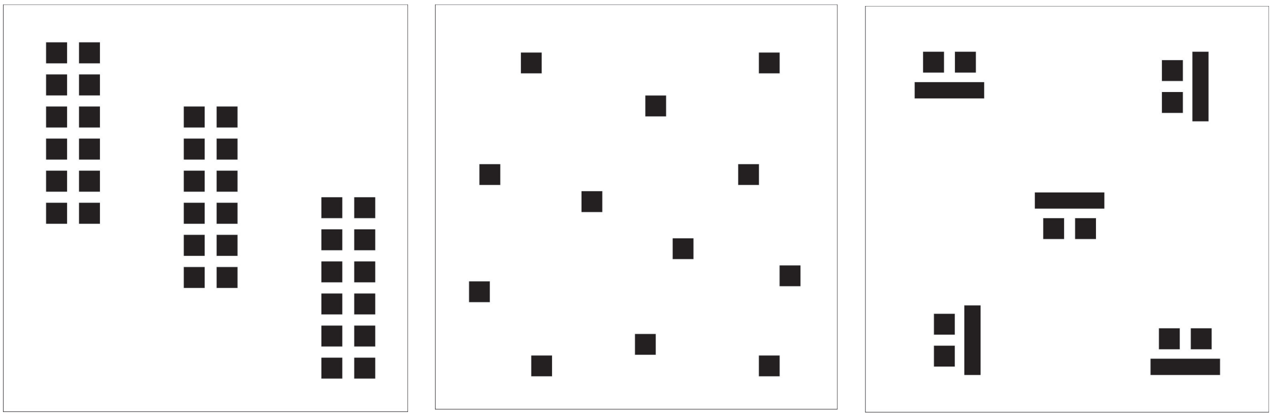


Figure 10 The Proximity Principle Shapes

3. Similarity Principle

This principle says that objects with similar attributes, such as color, orientation and texture are perceived as groups. In Figure 11 we aggregate the same textured visual elements as belonging together.

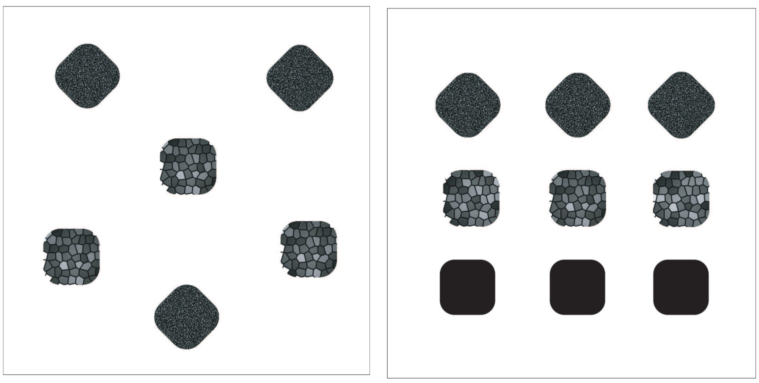


Figure 11 Similarity Principle Shapes

4. Closure Principle

When there are objects which aren't complete but are close enough to each other, they tend to be seen as a whole. Figure 12 shows this visual effect in two different possible image associations.

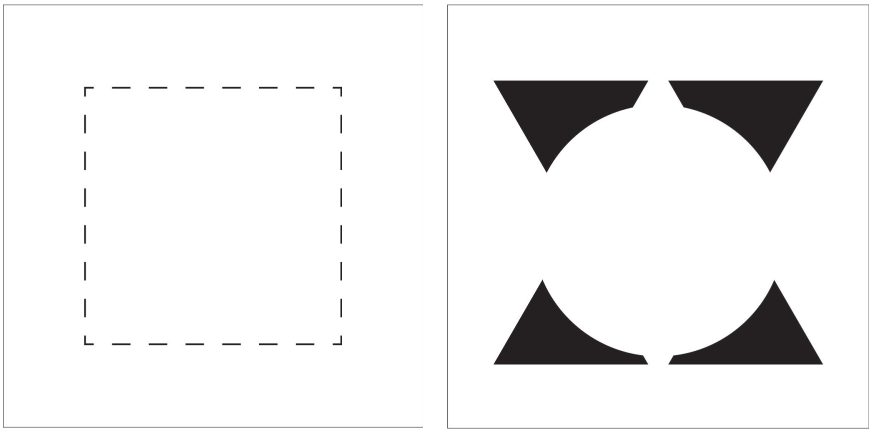


Figure 12 Closure Principle Shapes

5. Continuity Principle

If an object is placed in such a way that it appears to form a continuation to its nearest object, beyond the ending points, we perceive the various elements as a whole item. In Figure 13, on the left we perceive the X sign as one element and not two lines; on the right we perceive the two circles and the line uniting them as a joined object.

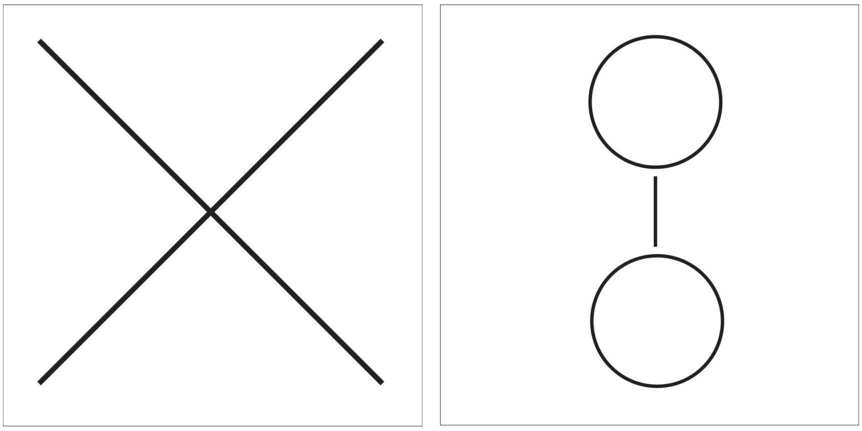


Figure 13 Continuity Principle

These are the five main principles of the Gestalt theory. As stated above, preattentive processes play a big role in the user's perception, but so do the Gestalt principles. When combining these two concepts and taking them into consideration in the design process, the IV can definitely be produced in a much more perceptible way, facilitating its reading and interpretation. *"(…) short-term memory and preattentive processing play an extremely important role in the design of effective visual representations, where the most important information can "pop out" from the surroundings through the mapping of data with preattentive attributes. Also, the designer of visual representations can take advantage of the basic Gestalt principles, as they can offer interesting insights into the design of groups of elements"* (Mazza, 2009, p.44).

The laws of perception, cognition and how visually displaying objects in a certain way helps human perception (Gestalt Principles), were themes that helped understand the constraints CVD users faced in their daily lives, but also to achieve a deeper knowledge on how we actually see the world and what practices can be adopted to aid in this process.

1.3.4 The RGB Model

The color scheme used in this project was the RGB Color model. It's important to understand how color is digitally generated in order to completely interpret how our human eye perceives it.

Essentially, according to Solomon & Breckon (2011), the RGB images are built of 3-D arrays which can be conceptually visualized in a 2-D plane, each plane corresponding to one color channel (R, G, B). These channels represent the three primary colors, which when mixed give origin to any digital color.

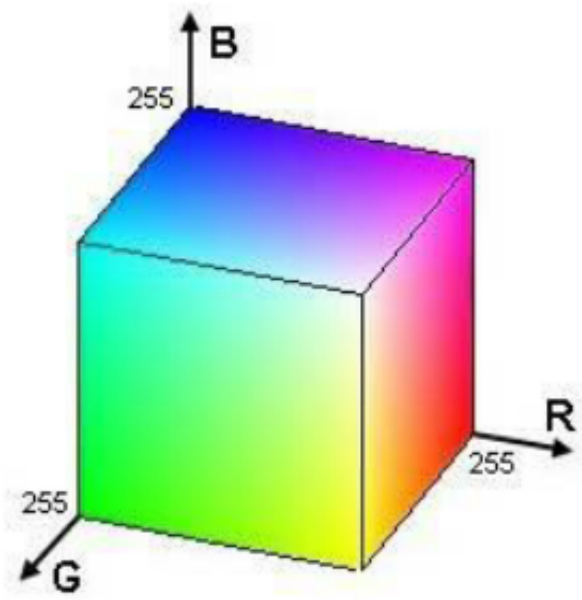


Figure 14 Representation of the RGB Model

Typically, all colors are a blend of these channels, although normally there's always a channel which is more ponderous. In the study and building of the interactive system, the same logic was followed, the color channel which had the most weight in the overall color model was the one which was susceptible to the color saturation manipulation.

Each axis of the 3-D color space (cube) has the same range, from 0-1, these values are normally scaled to 0-255 to achieve the regular 1 byte per color channel, which gives origin to the 24-bit representation. The same values are used in color manipulation softwares, such as Photoshop and Illustrator.

Still following Solomon & Breckon's (2011) thoughts, the RGB color space was defined based upon the electromagnetic spectrum visible to the human eye. As stated before, the eye has three different color receptors: the R, G and B. These receptors absorb different wavelengths which can be matched to the R, G and B color channels, making the digital color processing possible.

1.3.5 Saturation

According to Davis (2015), saturation (also named as intensity or chroma) can be described as the relative strength/purity of a color. This means that the more colors are saturated, the closest they are to their purest form.

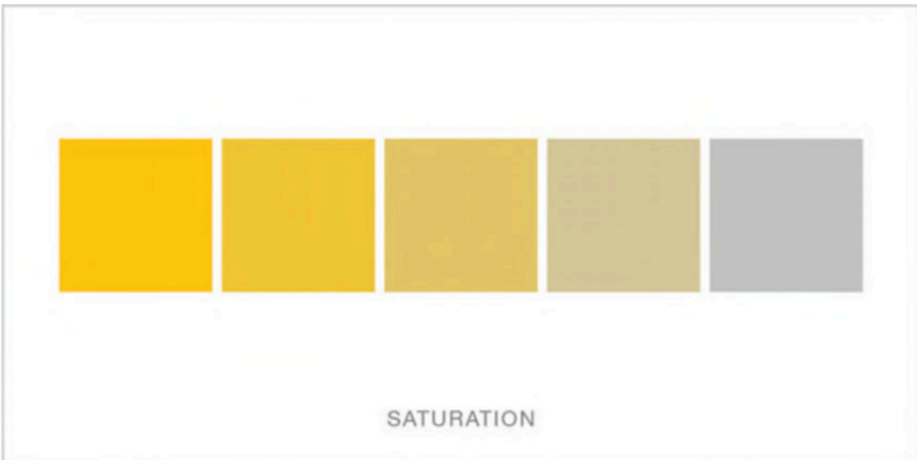


Figure 15 Saturation Model (Davis, 2015)

We can say that colors are chromatic when they achieve a considerable level of saturation, allowing the hue[3] to be perceptible. These colors correspond to the colors of the visible spectrum and don't contain white, black, or grey, making them the purest colors in the RGB color model. Davis also states that colors with moderate saturation are less assertive than colors at full saturation, something that could influence the users color perception when analyzing a graph or any type of image. In contrast to fully saturated colors, there are achromatic colors, which have no saturation and discernible hue. Black and white are an example of the achromatic color group.

In the study, the chromatic colors represented the maximum values of saturation and the achromatic the minimum.

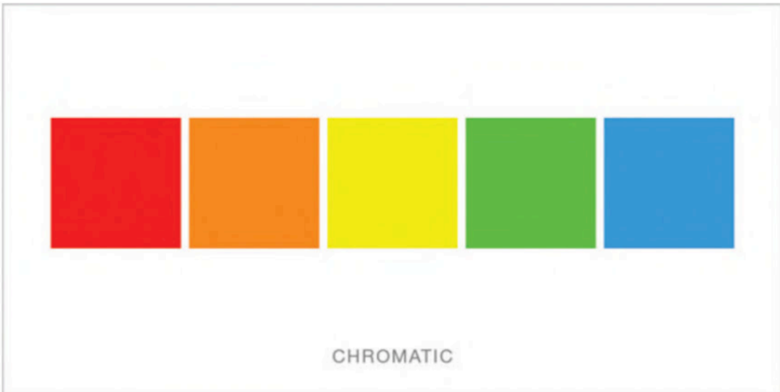


Figure 17 Chromatic colours model (Davis, 2015)

Figure 16 Achromatic colours model (Davis, 2015)

[3] In consonance with Solomon & Breckon (2011), hue is described as the dominant wavelength of the color, e.g. red, blue and green.

1.3.6 Colour Vision Deficiency

Designing for regular users is a task most designers are comfortable with, as they see what the users are seeing (or at least approximately), however, designing for users which have different concerns and needs is something else entirely. If designers cannot impersonate a user, they have to research and learn everything they can about that profile. If they don't, they'll never be able to design a product that completely suits the user's needs and/or exceeds their expectations.
We inhabit a planet with 7.6 billion people, where 10% of the male and 1% of the female population suffers from some kind of color vision deficiency (CVD), this means that 760.000.000 people struggle with this condition every day (Ware, 2013, p.98). This is a very big and relevant number that cannot be ignored. If following these numbers, and taking into consideration the number of internet users in the world (Miniwatts Marketing Group, 2018), we can conclude that from the 4.156.932.140 active internet users, 415.693.214 of them are very likely to suffer from CVD. These 415 million users won't perceive information correctly if not taken into consideration during the design process, one reason why designing for inclusivity is very important.

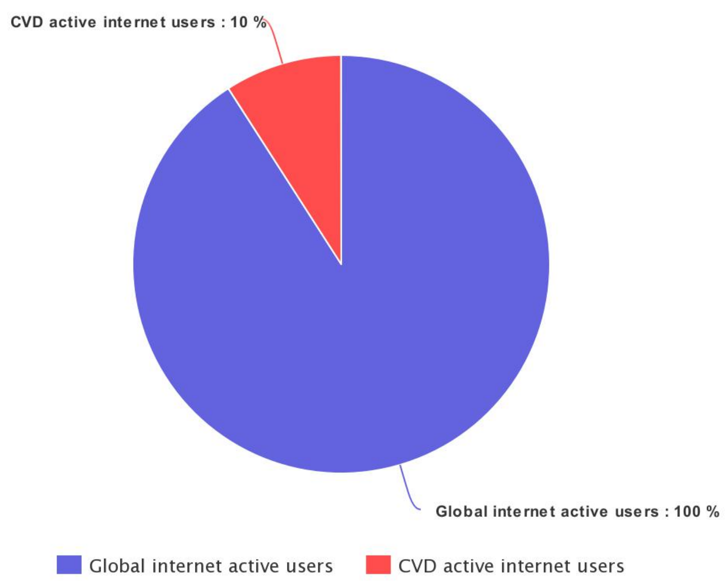


Figure 18 CVD and global internet active users

According to Ware (2013), the most common deficiencies are the lack of either the long-wavelength-sensitive cones (protanopia) or the medium-wavelength-sensitive cones (deuteranopia). These two conditions result in the inability to distinguish between red and green colors. Another characteristic of this condition is that everything the human being perceives as three dimensional, collapses into a two-dimensional space. As explained before, the rods and cones are responsible for our color vision, if they inherit a specific deficiency or are absent, CVD occurs. There are different levels of CVD effects, they can be mild, moderate or severe. If the condition was inherited and didn't evolve as a result of a long-standing disease, such as diabetes, then the level of severity will stay the same. Hence, the exact physical cause of CVD is still a complex theme for researches.

The most common CVD type is the deutan color vision deficiency. *"This subtype of red-green color blindness is found in about 6% of the male population, mostly in its mild form deuteranomaly"* (Colblindor, 2016). The colors which represent more difficulties for these individuals are the red and green, also some gray, purple and a greenish blue-green can't be distinguished very well. Figure 12 demonstrates an image viewed by a trichromatic individual and on the right, comparatively by a deuteranope individual.

Figure 19 Comparison between a trichromatic (left) and deuteranope (right) vision

Deutan color vision deficiency can be split in two different types:

"

1. *Dichromats:* ***Deuteranopia*** *(also called green-blind). In this case the medium wavelength sensitive cones (green) are missing at all. A deuteranope can only distinguish 2 to 3 different hues, whereas someone with normal vision sees 7 different hues.*
2. *Anomalous Trichromats:* ***Deuteranomaly*** *(green-weak). This can be everything between almost normal color vision and deuteranopia. The green sensitive cones are not missing in this case, but the peak of sensitivity is moved towards the red sensitive cones"* (Colblindor, 2016).

Since CVD is a congenital disease, the numbers don't oscillate much, as the condition is encoded on the X chromosome and men have only one they're therefore more often affected.

1.3.6.1 User Interface Good Practices

There are some principles which can be adopted to ensure that user interfaces are CVD friendly. Silver (2016) provides a 13-rule-guide that helps designers improve the experience for this type of users.

1. Text Readability

To assure that the text is readable to all audiences it should follow accessibility guidelines based on combination of text color, background color and text size. *"WCAG 2.0 level AA requires a contrast ratio of 4.5:1 for normal text and 3:1 for large text (14 point and bold or larger, or 18 point or larger)"* (Silver, 2016).

Figure 20 This illustrates how contrast is based on the combination of and size. (Silver, 2016)

2. Text overlaid on background images

For the text to be visible it's important to increase the background contrast by applying a darker overlay or highlighting the text with color or drop shadows as Figure 14 illustrates.

Figure 21 Good Practices: Text overlaid on an image with a mask (Silver, 2016)

3. Colour Filters, pickers and swatches

Whenever displaying a color on screen a descriptive text should be added so that it's possible to differentiate between colors, not depending on their pigments visual appearance.

Figure 22 Gap's Website with usage of colour filters (Silver, 2016)

4. Photographs without useful Descriptions

When displaying an item the label with the respective color should be added. For example instead of naming the product "Vintage T-shirt", you could label it "Grey Vintage T-shirt".

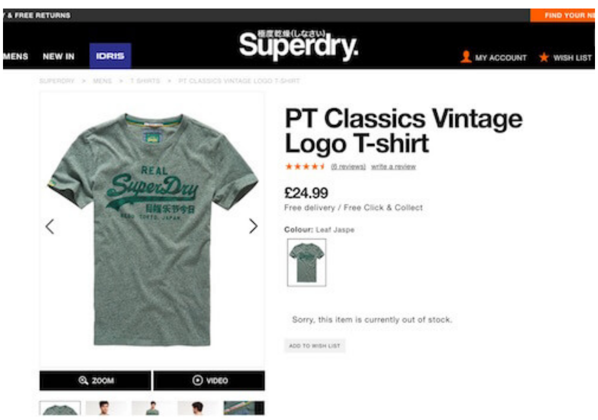


Figure 23 It's hard for colour-blind people to know what colour this SuperDry T-shirt is. (Silver, 2016)

5. Link Recognition

Links should be easy to spot without having to hover over them, as this is not possible on mobile. Underlining the content may be an option.

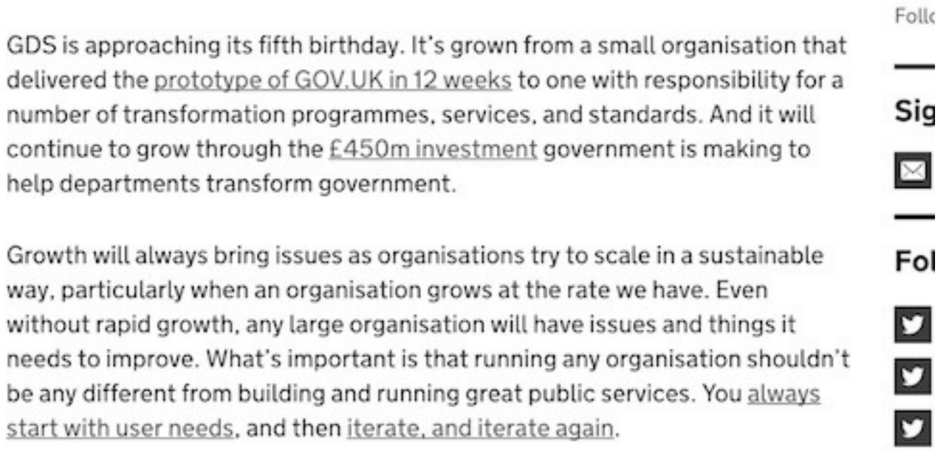


Figure 24 Underlined links are easy to see by someone with achromatopsia. (Silver, 2016)

6. Colour combinations

Some color combinations are especially difficult to distinguish between each other for CVD users (and regular users too), namely:

- green/red
- green/brown
- blue/purple
- green/blue
- light green/yellow
- blue/grey
- green/grey
- green/black

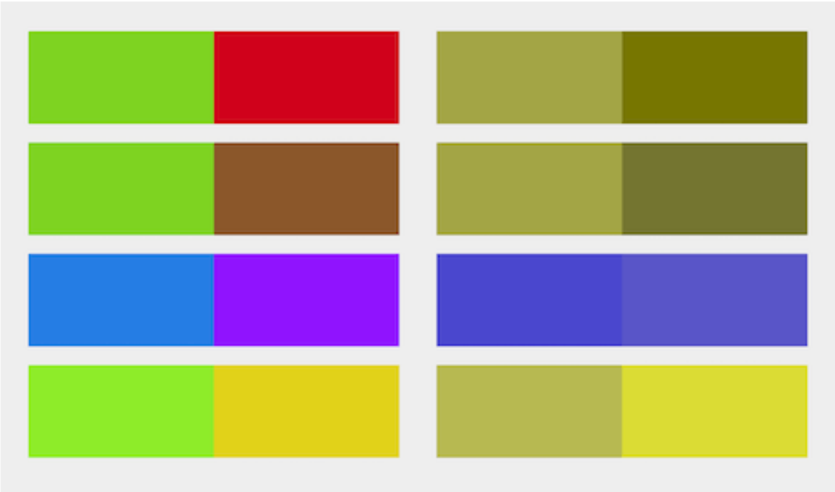


Figure 25 Combinations seen as a user with Protanopia (Silver, 2016)

7. Form placeholders

When using forms, a label text should be added in order to provide contrast and differentiate between placeholder and user input.

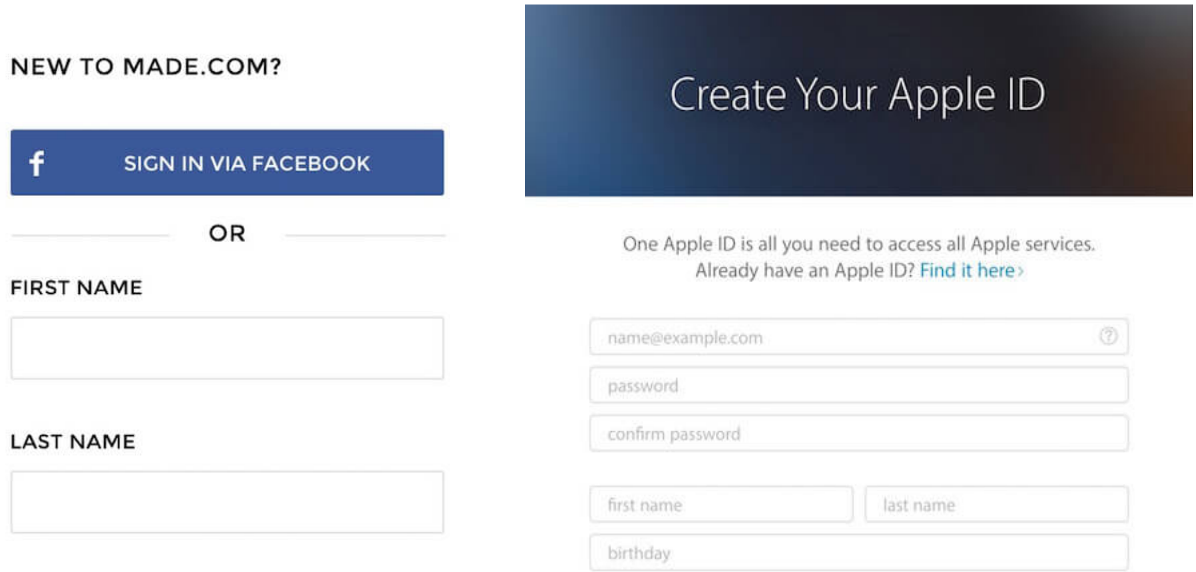


Figure 26 Apple Inputs use a placeholder without a label (left), Made.com uses labels with good contrast (right) (Silver, 2016)

8. Primary Buttons

Primary buttons should be highlighted through size, placement, boldness, contrast, borders and icons and not through color alone.

Figure 27 Kidly uses size, color and iconography to emphasize the primary button. (Silver, 2016)

9. Alert Messaging

It's common to use color success and error messages with green and red respectively, which makes it difficult to interpret for CVD users. Using a prefix or an icon helps with the rapid content recognition.

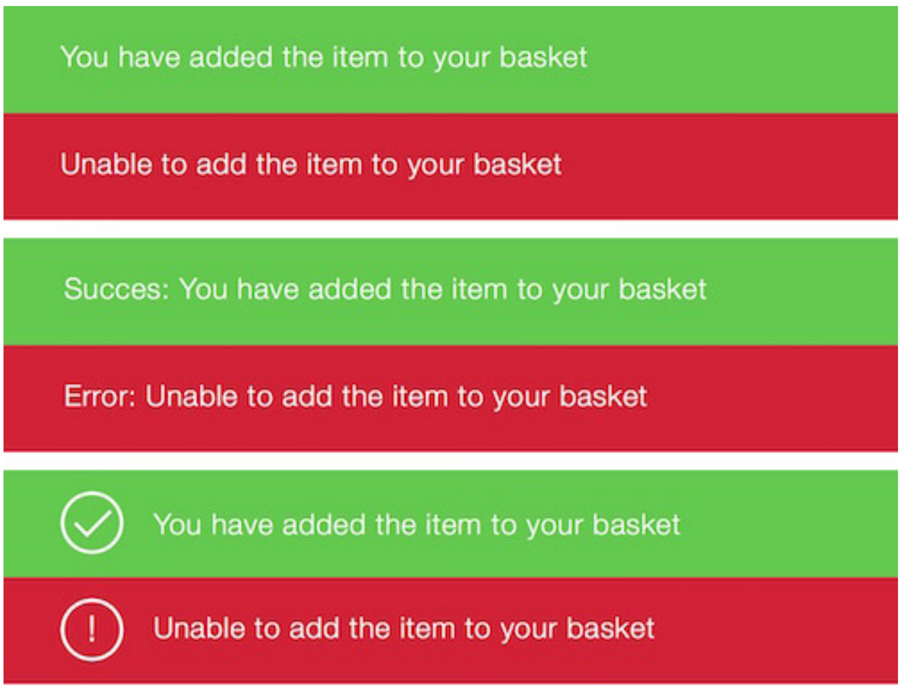


Figure 28 Alert messaging with text prefixes and icons

10. Required Form Fields

When a field is compulsory for a user to fill in, it should not be distinguished from other fields by its color, but by adding an asterisk or marking them as “required”.

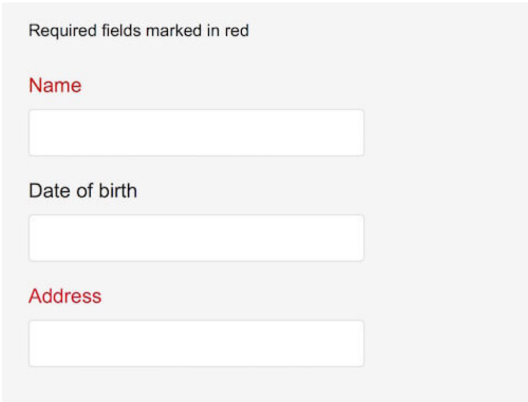


Figure 29 Denoting required fields (Silver, 2016)

11. Graphs

Color is one of the main elements in graphs, however, using patterns or placing text next to the graphs elements might help with perception.

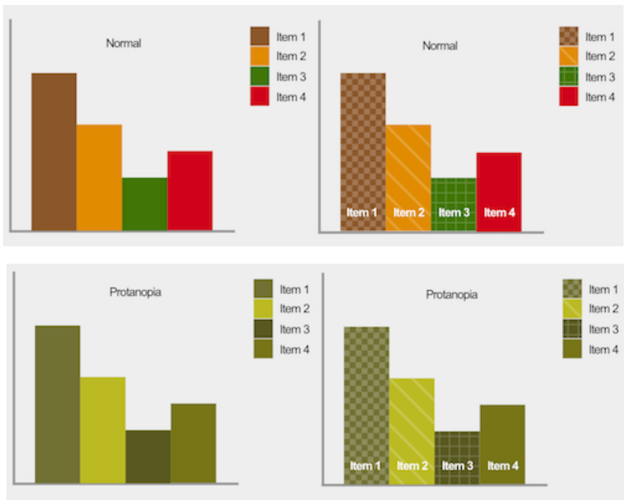


Figure 30 Graphs viewed with normal vision (top), Graphs viewed with protanopia (bottom)

12. Zoom

Zooming helps with text readability, however some sites which use the Viewport Meta Tag disable the zooming option.

13. Relative Font Size

It's possible to increase the text size (instead of the whole page) to support readability. Some browsers disable this functionality if the font-size is specified in absolute unite, like pixels for example. By using relative units font size zooming is guaranteed.

1.4 Designing for Inclusivity

As previously discussed, there is a big percentage of CVD users in which their perception is very different from regular users, including when perceiving web interfaces, meaning designers should create inclusive products that are accessible to anyone regardless of their needs.

Good designers do not promote exclusive products that are only directed to a single user in particular; good designers design inclusively, creating products that suit any type of user, with or without special needs. Inclusivity does not only bring advantages to users with special needs; common users also benefit from products that are more efficient to handle, as well as increase the overall user experience and satisfaction (Cassim, 2007).

According to Cassim (2007), people with a special condition shouldn't be labelled and included in the user group with special needs, they should be treated as any other type of user in the design methodology, and should always be introduced in the early stages of the process. "(...) people are not disabled by their own impairments, irrespective of the shortcomings of design, but included or excluded by social attitudes, and the quality of design, irrespective of their capabilities (DTI, 2000b; DTI, 2000c; DTI, 2002)" (Coleman, Clarkson, Dong, & Cassim, 2007, p.12).
In the second half of the 20th century, consumerism called for the necessity of producing a very large mass of affordable goods, this led to the concept of "one size fits all". Unfortunately, those who didn´t conform in the standard terms became vulnerable to exclusion, the needs which weren't qualified as "average" became secondary and, consequently, their users too.
According to Cassim (2007), with the appearance of Inclusive Design a shift of mentality took place, the consumer was no longer responsible for not being able to use the product, the responsibility relapsed on the Design.
Inclusive Design did not only improve the quality of life of disabled consumers, but brought also major advantages regarding other "able-bodied" users. We're all familiar with the famous potato peeler, which makes our kitchen duties much more effortless (Figure 31).

Figure 31 Good Grips potato peeler – second iteration (©OXO Inc.) (Coleman et al., 2007)

Good Grips potato peeler, was actually first designed and produced with the aim to support disabled people in their daily kitchen tasks. Sam Farber created "OXO Good Grips" in 1990, his wife Betsy suffered from severe arthritis and found cooking utensils increasingly difficult to manage. Sam saw this issue not as an impairment, but as a business opportunity, a gap in the market which could serve a higher purpose. He developed a set of user-friendly kitchen utensils, which would stand out, not because they were special need products, but because of their high design values. *"They realized that new utensils in a crowded, mature market had to work exceptionally well and offer distinctive features that were valued by customers. User research confirmed that the sharpest of blades were needed for the potato peeler, the first product in the range. The blades were eventually sourced from Japan which has a long history of superb sharp tools and swords. Next, they looked for the right material to enhance and cushion the grip to make the product more comfortable for those suffering from arthritis. Then they worked through hundreds of handle shapes before settling on one that worked well and looked good. Finally, they added unique 'fins' near the top of the handle which offered a natural resting place for a thumb, and created a talking point that* *communicated the functional benefits of the product. This patentable feature became a signature detail for the range."* (Coleman et al., 2007, p.34)

These products were never announced based on their inclusive and universal design, but promoted for their fitness for purpose, "the best, most convenient, comfortable and easy to use kitchen or garden tools available" (Coleman et al., 2007 p.35).

The Center for Universal Design at North Carolina State University defended the same principle, products should not only be accessible and produced for disabled users, but they should serve everyone's needs, ages and abilities, therefore they become more universal and inclusive. Story, Mueller and Mace (1998) established seven ethic conventions to assure accessibility of products:

"PRINCIPLE ONE: Equitable Use

The design is useful and marketable to people with diverse abilities.

Guidelines:

1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.

1 b. Avoid segregating or stigmatizing any users.

1c. Make provisions for privacy, security, and safety equally available to all users.

1d. Make the design appealing to all users.

PRINCIPLE TWO: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

Guidelines:

2a. Provide choice in methods of use.

2b. Accommodate right- or left-handed access and use.

2c. Facilitate the user's accuracy and precision.

2d. Provide adaptability to the user's pace.

PRINCIPLE THREE: Simple and Intuitive Use

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines:

3a. Eliminate unnecessary complexity.

3b. Be consistent with user expectations and intuition.

3c. Accommodate a wide range of literacy and language skills.

3d. Arrange information consistent with its importance.

3e. Provide effective prompting and feedback during and after task completion.

PRINCIPLE FOUR: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines:

4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.

4b. Maximize "legibility" of essential information.

4c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).

4d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

PRINCIPLE FIVE: Tolerance for Error

The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Guidelines:

5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.

5b. Provide warnings of hazards and errors.

5c. Provide fail safe features.

5d. Discourage unconscious action in tasks that require vigilance.

PRINCIPLE SIX: Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

Guidelines:

6a. Allow user to maintain a neutral body position.

6b. Use reasonable operating forces.

6c. Minimize repetitive actions.

6d. Minimize sustained physical effort.

PRINCIPLE SEVEN: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Guidelines:

7a. Provide a clear line of sight to important elements for any seated or standing user.

7b. Make reach to all components comfortable for any seated or standing user.

7c. Accommodate variations in hand and grip size.

7d. Provide adequate space for the use of assistive devices or personal assistance" (Story, Mueller, & Mace, 1998, p.44).

It's important for designers to fully understand their users' needs and impairments. As so, Patricia Moore, a young industrial designer in her twenties, decided that in order to completely design in a universal way, she'd had to literally incorporate the consumers' physical limitations. She disguised herself as an old woman, not only by changing her appearance with make-up, but also with artificial restrictions to her joints, hearing, vision, etc. Through her experiment she suffered various abuses and was subjected to discrimination, her Design approach was hugely influenced now that she had witnessed in first-hand how it felt to be disabled and, more importantly judged and marginalized. *"The discoveries she made were hugely influential on the growing universal design movement in America. The impact of her work, which pioneered an empathic research approach to user needs, was also felt in Japan, Australia and elsewhere. The fact that at the time she was employed in the New York office of Raymond Loewy, a high-profile contemporary of Henry Dreyfuss, added to the growing sense of unease about the human limitations of commercial US design practice"* (Coleman et al., 2007, p.25).

Figure 32 Patricia Moore in and out of disguise (Coleman et al., 2007, p.25)

Moore incorporated a life and impairments of an old-aged lady, but physical limitations aren't only present in elders, there are many other disabled conditions which affect individuals across all ages, CVD is one of them. It's important that by using a user-centered approach, designers can understand and predict solutions for these disabilities. This can be achieved via the adoption of various research methodologies, namely user panels, questionnaires, interviews, focus groups, observation, user mapping, exploration of specific case-studies, usability-testing, etc.

Consequently, the main goal of this project was to explore and understand the CVD users' special needs in the design methodology and graph representation.

1.5 Market and Technology Research: What's out there?

Although CVD affects a high percentage of the world's population, it's a topic which hasn't been very much explored. Maybe because it's not considered an illness, it's been classified under the term "condition". Hence, there are some projects and products which try to ease these individuals daily lives. These products served as inspiration and guide lines for the project, we can interpret them as a mixture of user research and a mood board.

1.5.1 Color Add (2010)

Color Add is a color code, created by the Portuguese designer Miguel Neiva, which gives people who suffer from CVD the possibility of identifying colors in various places, such as public transportations, hospitals, clothing, pencils, etc. Five simple symbols represent the primary colors – blue (cyan), yellow and red (magenta), plus black and white (Neiva, n.d.).

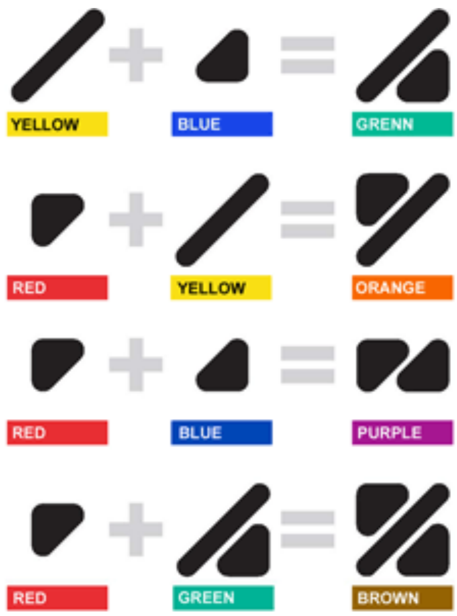


Figure 33 Color Add Scheme (Neiva, n.d.)

By adding two primary colors, a secondary color emerges – Green, Orange and Purple; mixing a primary and secondary color makes a new color take place and so on. Each color has its symbol and represents a unique mixture of colors. (Figure 34) If we aim to communicate grey, then we have two different options: light and dark grey. In this way, black and white are used to indicate the lighter and darker tone of colors. (Figure 34)

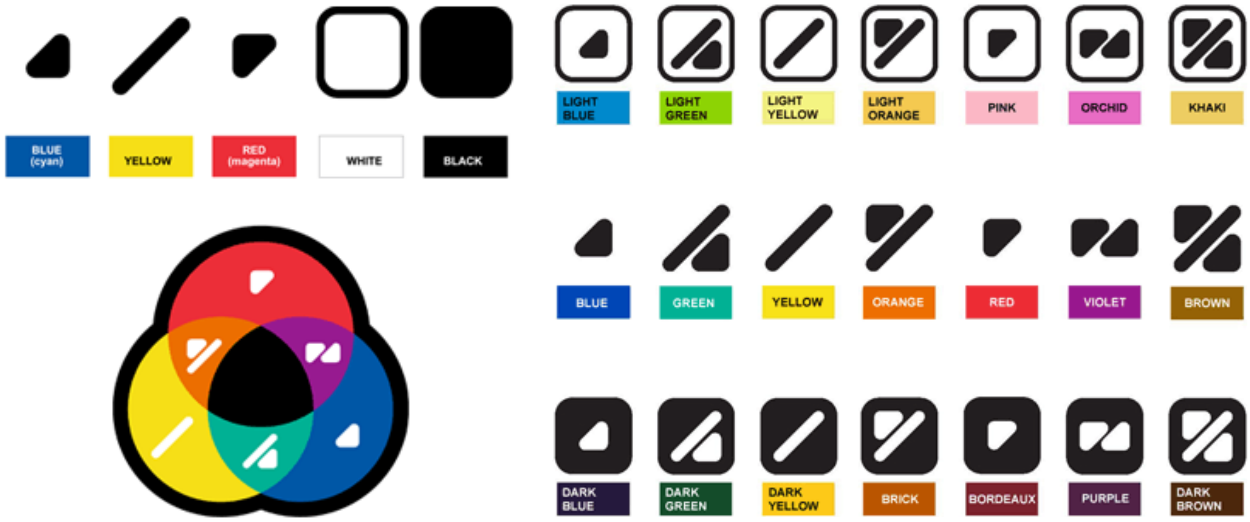


Figure 34 Color Add Color combinations (Neiva, n.d.) (left), Color Add Color Tones System Representation (Neiva, n.d.) (right)

1.5.2 EnChroma Glasses (2018)

These glasses alleviate red-green color blindness, enhancing colors. According to EnChroma Inc. (2018), the project started out as a computer simulation of CVD colors through using the latest research on genetics. Secondly, EnChroma developed a filter that targeted specific photopigments and cut sharp wavelengths of light to enhance other specific colors. The lenses separate red and green cones which helps people with red-green CVD type to differentiate colors.

Figure 35 EnChroma Glasses Models (EnChroma Inc., 2018)

1.5.3 Colour Blind Pal (2016)

Color Blind Pal (2016) is an App that helps the user identify with his phone camera which color he's targeting. The app is built with something similar to a color picker through the cam and a color spectrum at the bottom, where all colors are displayed. By targeting the pointer on to a specific color, the system will identify it, not only showing it on the color spectrum but also displaying its name.

You can also choose the type of naming you want to attribute to colors: common names, scientific names and colloquial naming. One of the features that best serves the app is the fact that you can see the colors' hue saturation, value and exact RGB color code. Even freeze the camera and inspect different colors across the image.

Additional features in the Color Filter include:

- Highlight a selected color
- Select a color by pressing it on the screen or by dragging the color spectrum slider
- Draw a stripe pattern over all reddish colors so you can tell what color everything is without changing the colors

- Freeze the camera and experiment with different filters to get an exact sense of what the image really looks like

- Hide all the buttons on the screen so your device becomes a portal through which you see the world in richer color.

Figure 36 Colour Blind Pal App for Desktop (left) and Mobile (right) (Fiorentini, 2016)

1.5.4 Removal of Colour Blindness using Image Segmentation

This project aims to extract images from websites and convert the content into CVD recognizable colors. "After saving these extracted images are passed through the color transformation process, by which unrecognized colors are transformed to recognizable colors to the color-blind person. This research focuses on the red-green color vision deficient. Transformation process result as red is transformed to yellow and green is transformed to blue and blue is remaining same" (Ranjani, 2015, p.202).

There are four different steps in the methodology adopted:

"**Image Simulation**

Find the LMS values of the RGB (red-green-blue) image using some conversion matrix. Then a conversion is made to delete the information associated with the loss of any of the cone type to get the modified LMS values L‶M‶S‶. Then, reverse transformation is done on the L‶M‶S‶ values to get the R‶G‶B‶ values. Now R‶G‶B‶ values represent that how the specific color RGB is perceived by a colour blind person. When this operation is done for all the pixels, the image is converted. This linear transformation can be achieved by a matrix multiplication.

Thresholding

Thresholding is the process of extracting all the pixels in an image that lie within a specific range of colors. Color information of each pixel in an image is typically represented as a point in a 3-dimensional space. In color images each pixel is characterized by the three RGB values. Then to construct a 3D histogram and the basic procedure is analogous to the method used for one variable. Histograms plotted for each of the color values and threshold points found.

Creating green mask

Using the threshold value, the green region of an image can be masked.

Modifying image

After the masking, the particular region of an image is converted to purple using matrix value" (Ranjani, 2015, p.202).

2. Chapter 2: Focusing the Problem

2.1 Methodology and Approach

As stated before, CVD is a condition that affects an elevated percentage of people in the world, namely 760.000.000 individuals (Ware, 2013, p.98). As follows, this project has the main objective to investigate how to decrease the social gap between CVD and trichromatic users, aiming for an inclusive design.

In this way, the investigation problem of this project focuses on understanding in which sense saturation as a color variable can influence the perception of CVD users over a specific graph, by using an interactive information visualization system. First, it's important to understand how color of complex information visualizations is perceived by trichromatic and CVD (deuteranope) users. Since these two different users perceive color in a very different way, the primary mission of this project was to understand if there was a common saturation range in which both types of users perceive the information correctly over a selected graph.

If color restriction is not taken into consideration when projecting information visualization projects, what saturation values can be applied to make color perception for CVD users still possible? Color saturation can be one of the variables which, when applied correctly, makes a difference in the graphs color perception and decoding.

Therefore, this research project seeks to evaluate to what extent the trichromatic and CVD users' color perception differ when visualizing a specific graph and applying different saturation values.

More specifically, it aims to measure the quantitative gap (i.e., from and to which chromatic saturation value) between both user groups' color perception in terms of color saturation. In order to carry out such an investigation, an interactive digital system was specifically designed for this purpose providing different color saturation visualization options, in which users were asked to manipulate a specific graph's ("History Flow" by Wattenberg (2003)) color saturation levels until they were satisfied with its overall contrast level.

By using this exploratory system, this study's main objectives are two-folded, namely: (1) to obtain and compare RGB values for both users groups; (2) to understand if it’s possible to indicate a common color saturation range that matches both groups' color perception.

As follows, we can state that the investigation problem translates into the following:
In which sense can saturation help deuteranope users better perceive a given graph by using an interactive information visualization system?

Following this approach, this research hypotheses are:

1. CVD users manipulating the graph have a more reduced saturation range than trichromatic users when perceiving the graph, leading to a higher overall difficulty in color perception;

2. Compared to trichromatic users, CVD users when manipulating the graph have a more reduced color perception range when measuring the RGB variables individually;

3. When analyzing the RGB variables clustered together, such values may vary when evaluated individually;

4. CVD users will select a higher minimum value of color saturation in order to perceive correctly the information compared to trichromatic users;
5. CVD users will select a lower maximum value of color saturation in order to perceive correctly the information compared to trichromatic users;

6. There is a common color saturation range value for both CVD and trichromatic users;

As an exploratory research, the project's sample included 12 male participants. Only males were considered as the inclusion criteria for this study due to the CVD condition affecting 10% the male population and only 1% of the female population. Ideally, such an experiment should have been conducted with male individuals who suffer from CVD, more precisely deuteranope users, however, unfortunately it wasn't possible to gather enough CVD users who were willing to participate in the project. The CVD laboratory in the University of Minho collaborated in reaching out to their regular CVD participants, coming up with 3 individuals. Since this number fell short for a pilot study, in order to carry out such a project, it was methodologically decided that for this study, the graph to be analyzed would have to be converted to CVD simulated colors in order to replicate the way CVD users envision colors, and then to conduct the experiment with trichromatic users only. This change isn't seen as very detrimental to the project, as stated before, it aims to better understand how color saturation influences CVD users' color perception and not provide final solutions.

2.2 An Exploratory Investigation

The research is considered to be an exploratory study which aims to analyze the research question mentioned above and its hypotheses. However, it doesn't offer a final and one-way solution to the problem, instead it intends to be a first approach to the previously mentioned problem. As CVD is a subject which hasn't been intensely approached in the research area, this project aims to explore the variable of color saturation, which could have an impact on the user's color perception. Also, according to different insights collected through the investigation, the research method had to be flexible so that the projects direction could change according to new developments and conclusions. It's intended to provide future researches a better understanding of the problem and not a conclusive solution, contrary to the conclusive research method whose outcome is to provide a final solution to a pre-existing problem.

As an exploratory research the projects sample size covers 12 male participants. It was opted for only males to make part of the experiment as the CVD condition affects in 10% the male population and only in 1% the female one.

Ideally the experiment would be conducted with male individuals who suffer from CVD, more precisely deuteranope users, unfortunately it wasn't possible to collect enough CVD users willing to participate in the project. The CVD laboratory in the University of Minho collaborated in reaching out to their regular CVD participants, coming up with 3 individuals. As this number was too reduced, a choice was made to simulate the colors to a CVD vision perception and conduct the experiment with trichromatic users only. This change isn't seen as very detrimental to the project, because as stated before it aims to better understand the problem in cause and not provide final solutions.

We can say that the investigation process adopted is mixed, meaning that the collected data varies between quantitative and qualitative results. The questionnaires conducted provided both qualitative and quantitative results; the experiment itself is more of a quantitative quality. According to Creswell (2014) the foundation of this mixed analysis is that combining these two approaches gives a more complete understanding over the problem, allowing the coexistence of different types of views. In this way, the investigation logic was mainly inductive, as the data analysis was built from a more specific and/particular topic of study to a more generalist and/universal theme.

2.3 Building the Interactive System

The interaction design process mentioned in the previous chapter (Chapter 1) was used to build the system that was adopted to perform the experiment. The Design approach was mixed and alternated according to different phases of the project. The phases needed to build the project were determined by the needs of the targeted users, but also based on the projects own requirements. As so, we can state that each phase had it's own design approach, depending on the type of effort involved.

2.3.1 Phase 1: Research

This phase involved the study of various subjects in order to understand the projects scope and context namely:

- *Interaction Design;*
- *User Experience;*
- *Information Visualization;*
- *The Human Visual Perception;*
- *The Gestalt Principles;*
- *Color Vision Deficiency;*
- *Inclusive Design;*

Building the User Story: Why are we doing this?

After having a close understanding of the project's research themes, a user story was created in order to understand the "Why" of the project and how it would be ultimately designed. The user story was designed according to the following steps:

1. Who is this for?

In a broad spectrum, this project is being developed for CVD users, i.e., to assist them in when visualizing a graph in which its decoding is based on color distinction.

2. What is the problem the user is facing?

CVD users have an elevated difficulty in perceiving and distinguishing colors in various graphs. Therefore, Information visualization, which should aid CVD users in data interpretation, becomes an unusable tool.

3. Why is it a problem?

This becomes a problem for these individuals as many of their decisions aren't made upon real data information. Their incapacity of analyzing graphs and other data representations makes them non-informed users in a distorted reality. We live in a society where users with special needs shouldn't be disregarded or treated as special, they should be included in the design process and seen as possible target users.

4. User type and specific goals

- *As a CVD user, I'd like to distinguish colours in graphs so that I can perceive the graph correctly and make informed decisions.*

5. "How might we questions…": questions to be answered while developing the solution

- *How might we develop a system that explores the perception of colours, namely colour saturation, for CVD and trichromatic users?*
- *How might that system help CVD users better distinguish between colours?*
- *How might we find a variable that influences colour distinction for CVD users?*

6. Quality Assurance: Describe failure scenarios and desired behavior

- *The user should be able to perceive differences in colour saturation when handling the different sliders;*
- *The user should be able to indicate the minimum and maximum value of colour saturation in each RGB channel while maintaining an optimal visual perception over the graph;*
- *The user should be aware of the current saturation value presented;*
- *The user should be able to perceive a graph in trichromatic colours and another one in CVD simulated colours;*
- *The failure scenarios involve the user not being able to discern any of the above tasks;*

Creating CVD Proto-Personas

Two proto-personas were designed to identify the users' needs and to establish basic requirements which were used to produce the task analysis in the subsequent phase.

Audrey Rivers

First impressions:

- *25 years old;*
- *Approachable;*
- *Sympathetic and joyful;*
- *Young and adventurous;*

Beliefs and Behaviors:

- *Works at an IT consultancy as an Account Manager;*

- *Goes to many client meetings;*
- *Usually goes out for some drinks with friends after work;*
- *Has a very organized apartment;*
- *Isn't very religious, but grew up with a religious education;*
- *Prefers public transportation instead of driving her own vehicle;*
- *Is very careful with her spending's;*
- *Although Audrey learned to live and cope with her condition, she feels many times embarrassed and frustrated when her perception isn´t aligned with the reality of others;*

Demography:

- *Is an only child;*
- *Lives far away from her parents;*
- *Suffers from CVD (deuteranopia);*
- *Has difficulties perceiving and interpreting some information (specially graphs) at work, which sometimes turns out to be frustrating;*
- *Established a process to aid her perceive colours in her daily chores, although sometimes still has difficulties in her daily-life;*
- *Goes regularly to her optometrist to check upon her condition;*

Goals and needs:

- *Needs to be very careful with some activities which appear to seem trivial, like for example, identifying the street lights not by colour but by the order they're in;*
- *Wishes to be able to see the world as the others do;*
- *Would like to be able to interpret information easily without colour restrictions so that she can make better informed decisions;*

- *Needs to be careful with some activities, like for example identifying if food is rotten or not;*
- *Has the goal of advancing in her career, although her condition sometimes seems to be a blocker;*

John Simons

First impressions:

- *40 years old;*
- *Grey beard;*
- *Looks tired;*
- *1,90cm;*
- *Wears glasses;*
- *Executive/formal dressing but with a wrinkled shirt;*

Beliefs and Behaviors:

- *Usually prepares breakfast for his family in the mornings;*
- *Works late almost every day;*
- *Would like to go more often to the gym;*
- *Because of the important position in his company, hasn't got a lot of time to spend with his friends;*
- *Is very dedicated to this family;*
- *Feels ashamed when his daughters want to play games which involve color distinction;*

Demography:

- *Has 2 daughters, Janine who is 6 years old and Ruby who is 6 months old;*
- *Suffers from severe CVD (protanopia);*

- *Additionally, needs to wear glasses to see at a distance;*
- *Is a CEO in a medium-large company in the banking business;*
- *Deals everyday with numbers and charts, which sometimes isn't an easy task;*
- *Has to make important decisions and manage other teams;*
- *Has a very high salary, about 7K/month;*
- *Lives in Sintra, but works in Lisbon, has to drive every day to the headquarters or other meetings;*
- *Completed his Bachelor and Masters in business development;*

Goals and needs:

- *Had to implement a process in his company in which graphs have to be reviewed and reported by a team in order for him to interpret them;*
- *Needs to have more independency at work when analysing data;*
- *Justifies his decisions a lot on his gut feeling and not data-driven decisions;*
- *At home, needs a lot of support from his wife to ensure he's doing some tasks correctly;*
- *Feels insecure sometimes when handling specific activities related to his children's well-being, for example making sure that they take the right vitamins at breakfast;*
- *Needs to go to the optometrist regularly, however this is many times put aside as his time is very limited;*

2.3.2 Phase 2: Task Analysis

A task list was created to ensure that the user was able to perform every necessary activity to complete the experiment. These tasks include:

- The user needs to be able to visualize the graph;
- The user needs to be able to change the saturation values in each RGB channel;
- The user needs to have a real-time response of the graph's colour alterations while changing the values;
- The user needs to be able to identify which value is being displayed in the graph;
- The user needs to understand which RGB colour value is being manipulated;
- The user needs to understand if the value being manipulated corresponds to the maximum/minimum value;

These tasks were represented in the following task flow (information architecture):

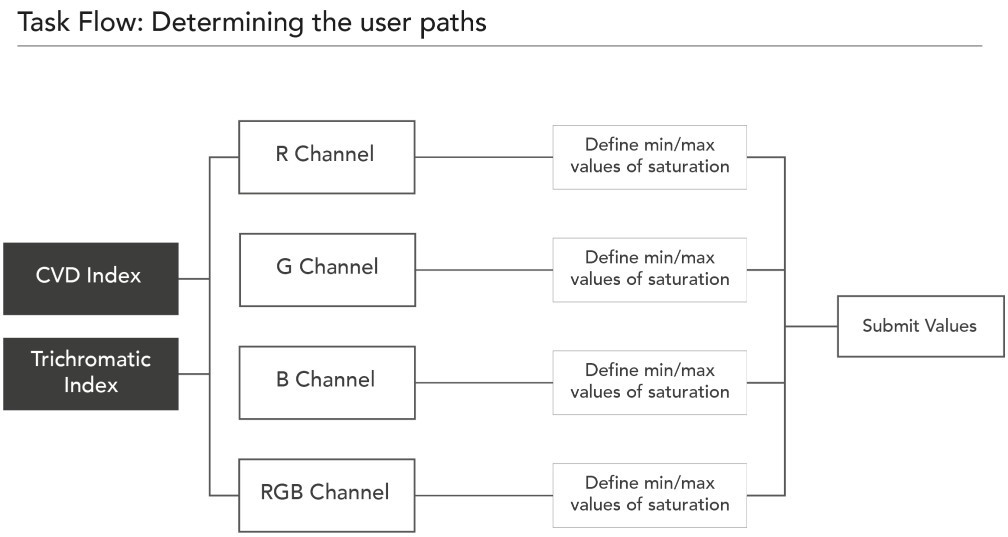


Figure 37 Task Flow: Determining the user paths

2.3.3 Phase 3: Determining the Graph

It was clear that the subject to be investigated was Information Visualization (IV), more precisely the visualization of graphs by individuals who suffered from CVD of the deuteranopia type. However, the variety of how to represent information into a visual graph is a very broad universe. To conduct this study it became necessary to narrow down the options and make an informed selection, Meirelles's (2013) book "Designing for Information" was used as a main reference. As Meirelles states in her introduction *"The selection criteria considered visualizations that are representative of relevant graphical methods and, most important, can serve as a platform for discussions on the histories, theories, and best practices in the field."* (Meirelles, 2013, p.7). Being this investigation related to the design field, it made complete sense to observe the IV in a more visual way.
Primarily, three different types of graphs were selected from the set of graphs discussed:

- **Chapter 1** | Hierarchical Structures: Trees (x1)
- **Chapter 2** | Relational Structures: Networks (x2)
- **Chapter 3** | Temporal Structures: Timelines and Flows (x1)

After concluding which type of graphs would be researched about, specific use cases were selected:

1. **Chapter 1** | Hierarchical Structures: Trees – *"The Rhythm of food: Analyzing food seasonality"* designed by Moritz Stefaner (Stefaner, n.d.)

This project aims to understand seasonal patterns in food searches in order to explain some food trends. In this case color is used to identify the year and the proximity of each segment to the center shows the relative search of interest. This way, it’s possible to identify both rhythms which repeat themselves on a yearly basis, but also year-over-year trends, such as the rise of avocado interest and the collapse of energy drinks. More than 130,000 data points on 200 topics are presented.

Figure 38 Screenshot of the Rhythm of Food project analysing when people search for grapefruit (right) and the graph in CVD simulated s (left) (Stefaner, n.d.)

2. **Chapter 2** | Relational Structures: Networks – *"Europe's migration crisis"* created by Reuters News (Reuteurs, 2016)

This graph analyses the flow of asylum seekers across Europe from January to August of 2015.

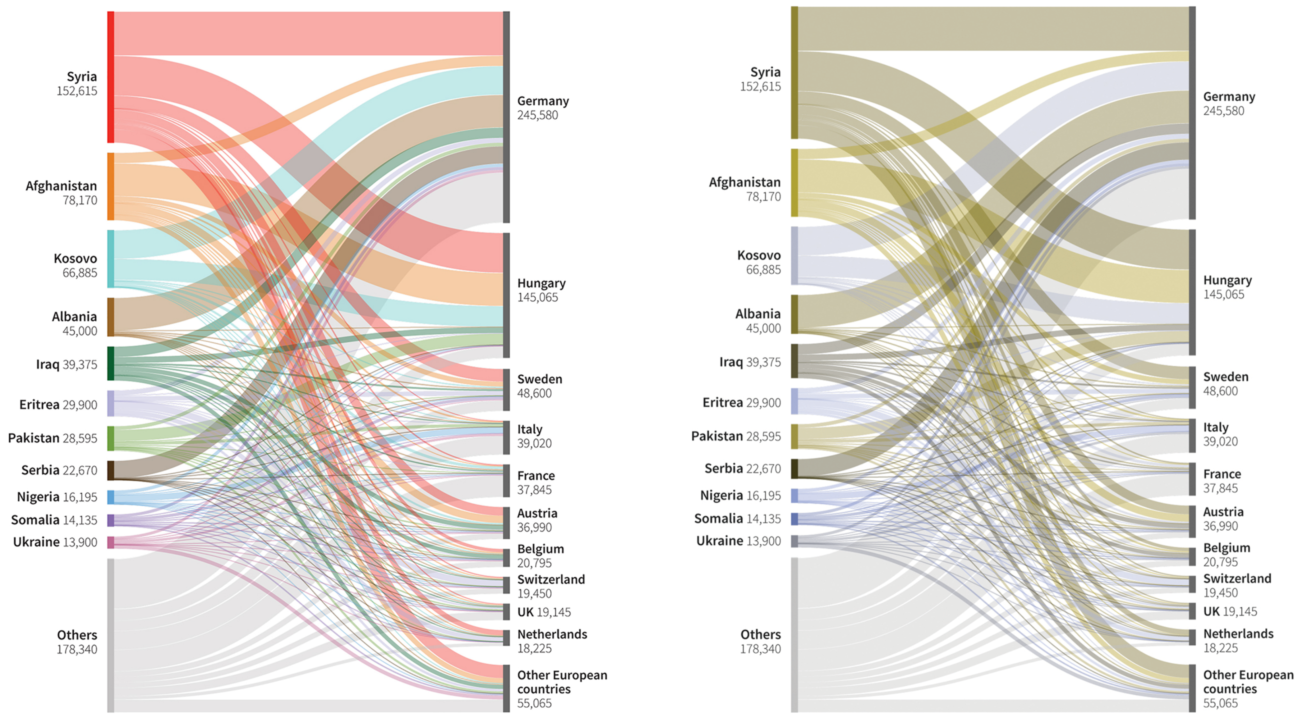


Figure 39 Screenshot of the graph available at Reuters Graphics (right) and the graph in CVD simulated s (left) (Reuteurs, 2016)

3. **Chapter 2** | Relational Structures: Networks – *"Global Carbon Emissions"* created by Stanford Kay (Kay, n.d.)

This graph shows the total of carbon emissions by nation, the sizes of the circles are relative to the carbon emission and the to the region.

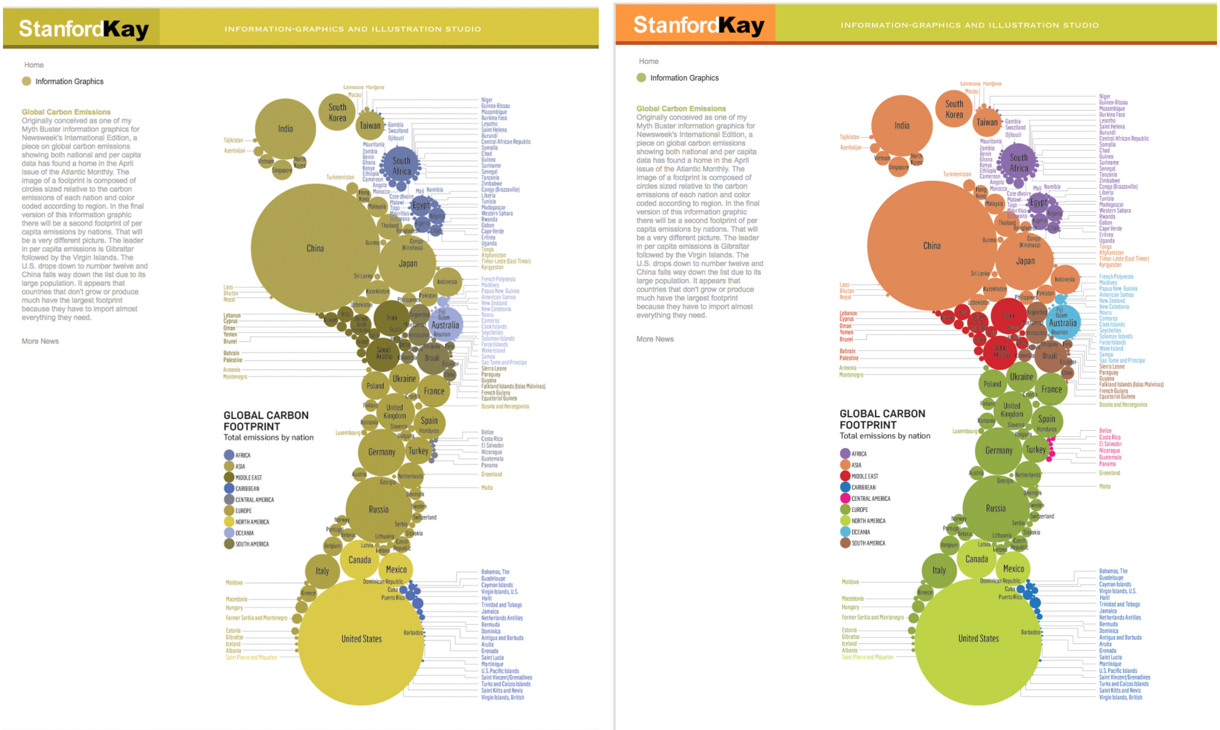


Figure 40 Screenshot taken from the Stanford Kay: information-graphics and illustration studio website (right) and the graph in CVD simulated s (left) (Kay, n.d.)

2. **Chapter 3** | Temporal Structures: Timelines and Flows – "History Flow" designed by Martin Wattenberg and Fernanda Viégas (2003)

This project investigates the dynamics behind editing in Wikipedia. It tries to understand the flow of information in time and at which moments vandalism is performed on Wikipedia articles. The findings were that although vandalism is performed pretty often its mean lifetime is measured in minutes, that's why we only face it very rarely.

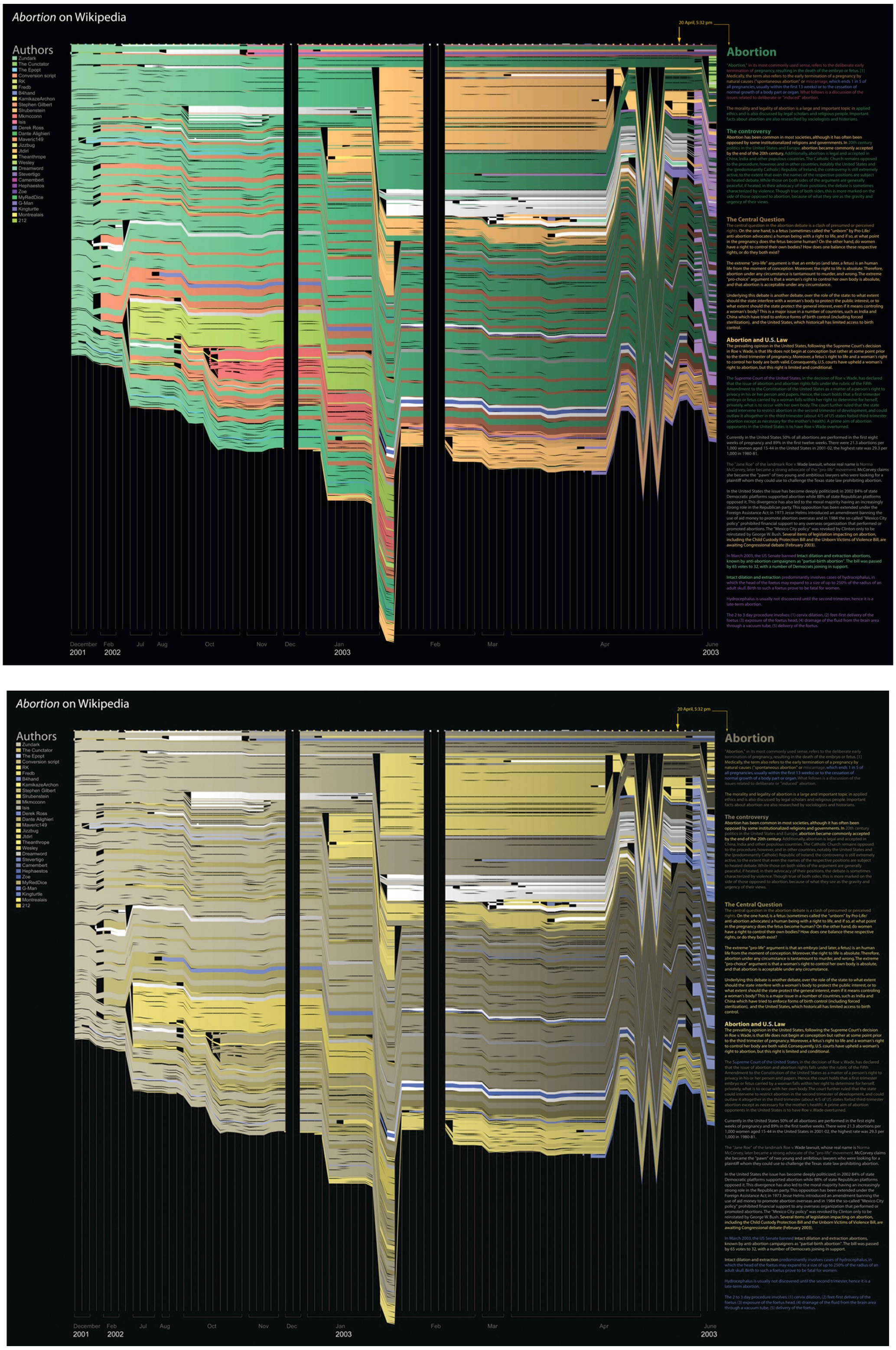


Figure 41 History Flow of the Visualization of the Wikipedia Entry on "Abortion" (image above) and the graph in CVD simulated s (image under) (Wattenberg & Viégas, 2003)

These four different projects were used to build a questionnaire[4] that inquired about which graph was the most difficult to perceive. The survey was set of 33 questions and the evaluation was based on 4 different criteria explored by Freitas et al in "Evaluating Usability of Information Visualization Techniques" (Freitas et al., n.d.), presenting the graph in CVD simulated colours:

1. **Cognitive Complexity**: Measured by data density, data dimension and relevance of the displayed information.

1.1 How much data density (quantity of displayed info) do you consider this graph to have?
1.2 Having in mind that this graph represents how many people search for grapefruit, do you consider the displayed information to be relevant?

2. **Spatial Organization**: Measured by identifying how easy it is to locate an information element in the graph.

2.1 Locate an element on the graph and interpret it. How easy is the graph to read?

3. **Information Decoding**: Measured by understanding if additional symbols or realistic characteristics would be used to aid in the graphs' perception.

3.1 In your opinion, in order to enhance the graph's perception, should other additional symbols and/or realistic characteristics be added?

4. **State Transition**: Measured by the user's memorability, i.e., observe if he/she can rebuild or retain information from the previous shown graph.

[4] For more details, check Attachment 5.

4.1 Without looking at the image above, can you describe what you visualized and interpreted from the graph?

Other questions regarding were asked to understand how effective the graph was regarding its colour perception and recognition.

- *When interpreting the graph, is it easy to distinguish between the colours from each other?*
- *In order to decode this graph, do you believe that it is important to be able to distinguish the different colours?*
- *When comparing Image 1 (CVD simulated s) and Image 2 (Trichromatic colours), which one of them is more difficult to perceive?*

These criteria were applied to all types of selected graphs, additionally it was asked for the participant to choose between all the previous presented graphs the one which he considered the most difficult to perceive when specially taking colour into consideration.

Analysing the collected data

After building the on-line questionnaire, 23 answers were collected, in which 60.9% were answered by females and 39.1% by male participants, ages between 21 and 54. None of the participants suffered from CVD, reason why the questionnaire was constructed based on CVD simulated images.

In order to analyse the questionnaire, two different approaches, a qualitative and a quantitative analysis were adopted.

Qualitative Analysis

First a qualitative scale was defined from “Very Bad” to “Very Good”, and such a scale was used to evaluate each graph's variables. Only the variables of image comparison and perception difficulty didn’t get a rating, since their answer wasn’t based upon a Likert scale. The points were then added, and the following results were obtained:

Qualitative Questionnare Analysis

Variables	Trees	Network Type 1	Timeline + Flow	Network Type 2
Readability	⊖	⊕	⊖⊖	⊕⊕
Color Distinction	⊕	⊕	⊖⊖	⊕⊕
Importance of Color Distinction for decoding	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Data Density	⊖⊖	⊖⊖	⊖⊖	⊖
Info Relevance	⊖⊖	⊕⊕	⊕⊕	⊕⊕
Additional symbols and/or realistic charcaters	⊕⊕	⊕	⊕⊕	⊕
Memorability	⊖	⊕⊕	⊖⊖	⊕⊕
Images Comparing	CVD Image	CVD Image	CVD Image	CVD Image
Perception difficulty	4.3%	13%	82.6%	N/A
Results	5 x ⊕ 6 x ⊖ = -1	9 x ⊕ 2 x ⊖ = 7	6 x ⊕ 8 x ⊖ = -2	11 x ⊕ 1 x ⊖ = 10

Qualitative Scale	
⊖⊖	Very bad
⊖	Bad
⊕	Good
⊕⊕	Very Good

Figure 42 Qualitative Table of Results Analysis

It was concluded that the graph of “Timeline + Flow” was the most difficult to perceive.

Quantitative Analysis

To confirm these results, a quantitative, more precise analysis was conducted. Each question was rated between 1 and 2, depending on the users' answers. If the answer was between 1-5, the rate would be 1, if between 6-10 the rate would be 2. These ratings were then added and divided by 100%, which resulted in a percentage value. All the percentages were added and divided by 23 (number of questions), resulting in an average rate of each type of graph. The graph with a higher value would be the one which was the most difficult to perceive. It was confirmed that the graph C, "History Flow" by Wattenberg (2003) was the one with a higher value (0,82), meaning it was the graph which was the most difficult, for the majority of the users, to perceive.

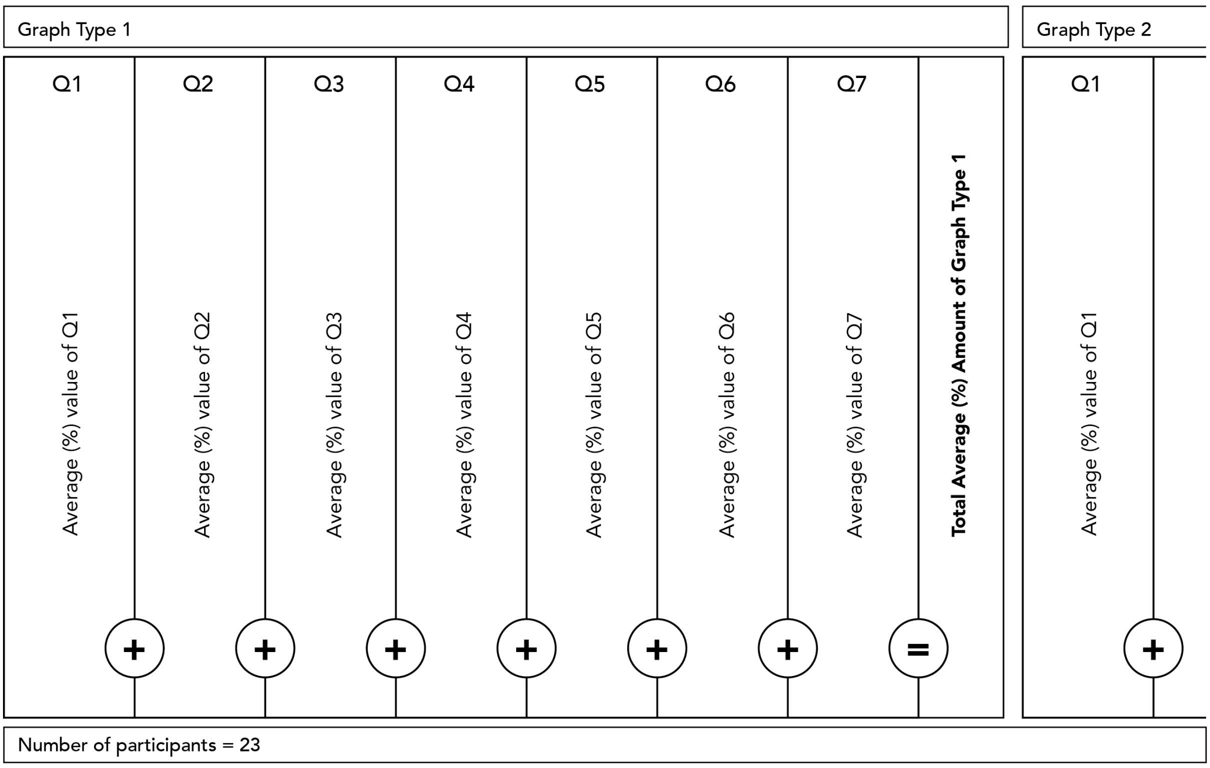


Figure 43 Quantitative Results Analysis Infographic

Due to this research and the out coming results, the graph to be used in the experiment was defined, leading to the next phase of the project: designing the wireframes.

2.3.4 Phase 4: Wireframes – Organizing the Content

In this phase, the graph was set, the tasks were listed down and the experiment's goal was defined; the only thing missing was the User Interface (UI). The first step to design the final visual appearance of the product was to organize the content and functionalities that needed to be present. The following wireframes[5] were elaborated in order to have a first notion about how the interface would be built. The sketches were very important not only to have a preview of the final design, but also to be able to communicate with software engineers and have some early conversations about the features that needed to be developed and some adjustments which would facilitate the programming. In this phase the screen size was established with the dimensions of 1366px of width, being the height of the page folder set to 768px.

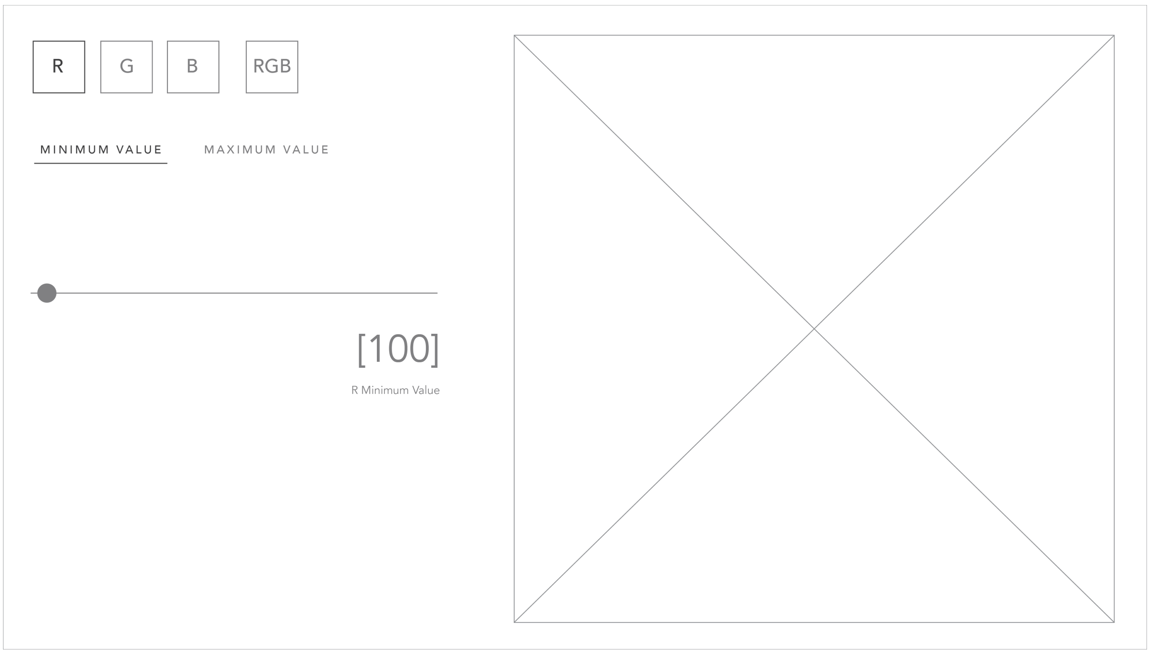


Figure 44 Wireframe R Minimum Value of interactive system

[5] For more details, check Attachment 2.

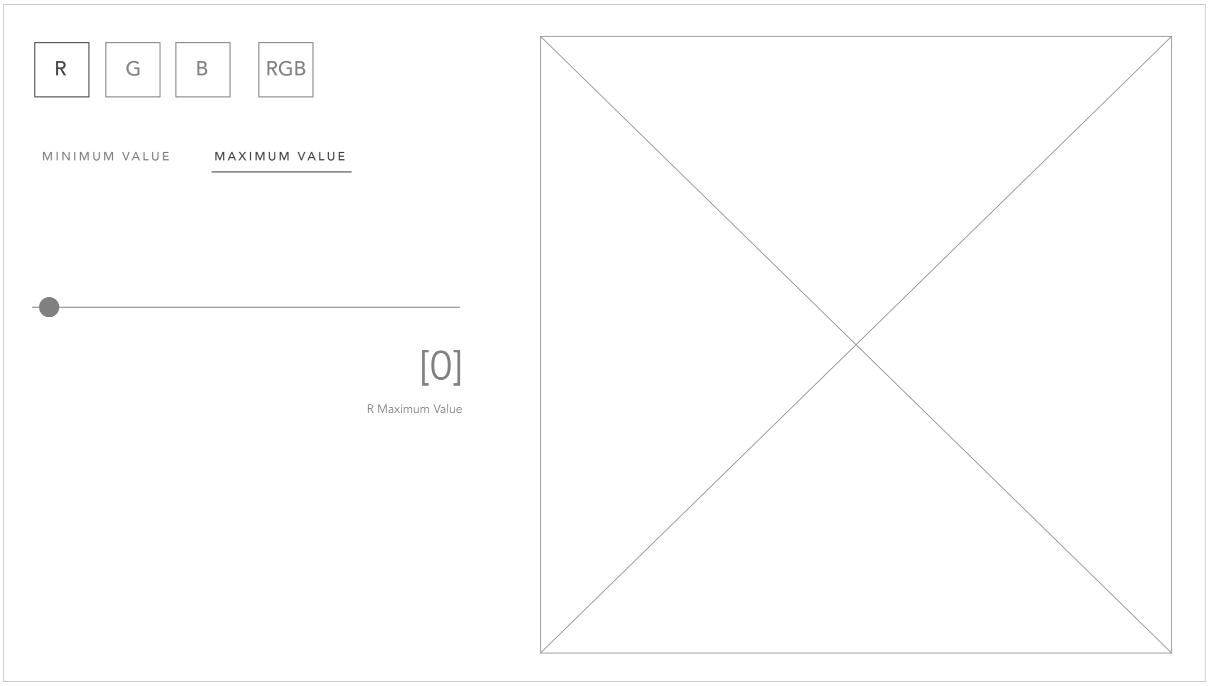


Figure 45 Wireframe R Maximum Value of interactive system

2.3.5 Phase 5: User Interface (UI) Design – The final Stage

After designing the wireframes and discussing it with the software engineers, the design of the actual interface was the next step. Some details had to be reviewed and adjusted, i.e. assets had to be exported in various formats, some design elements and interactions had to be simplified due to requiring a high technical effort and, most importantly, the G colour channel in the CVD simulated graph had to be disabled, since it didn't show significant differences when manipulating its colour saturation. Even so, the "skeleton" of the interactive system had been drawn. Colours were applied, the typography was chosen and the interactions were simulated. The background colours chosen was black due to the high contrast and readability it provided. The handlers, where the user defined the optimal saturation values, were designed in the most ergonomic and usable way so that the action the user was required to do was intuitive and easy to understand. Each handler had below the saturation value presented which the user was currently on, so that the saturation changes were perceptible not only through the graphs' visual changes, but also through the values decrease/increase. All the buttons were designed in a big format so that they were easy to click on and didn't require a high accuracy. All the visual elements were the most neutral possible, i.e. designed only with one colour (white) and sizable fonts.

It was interesting to see how the Design was transformed into something functional and interactive. Also, for that to happen it had to suffer some changes due to the technical issues mentioned above, in the development phase. Behaviours which when designing seem to make sense needed some adaptations. The RGB colour scale which normally comprehends values from 0 (minimum saturation) to 255 (maximum saturation), were proportionally transformed to a scale from 0 to 100. This equivalence was done so that the values were more familiar to the participants. In this way, 1 saturation value in the interactive system is equivalent to 2.5 in the common RGB values.

The final result, after implementation, ended up to be the following[6]:

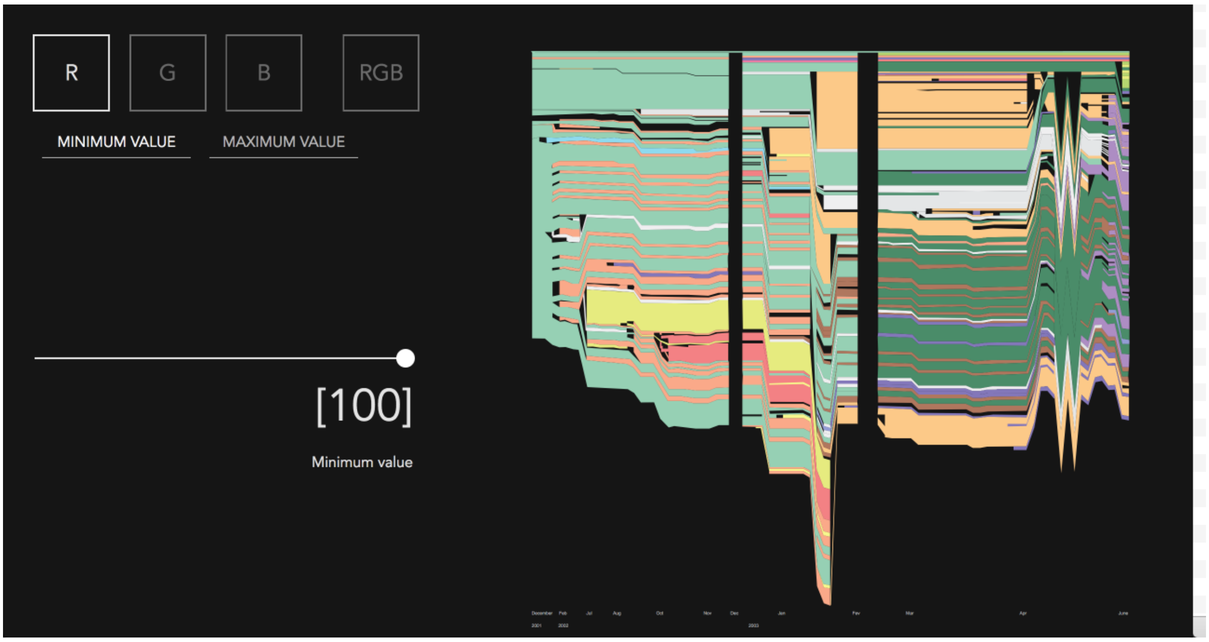


Figure 46 Interactive System for the Trichromatic user group

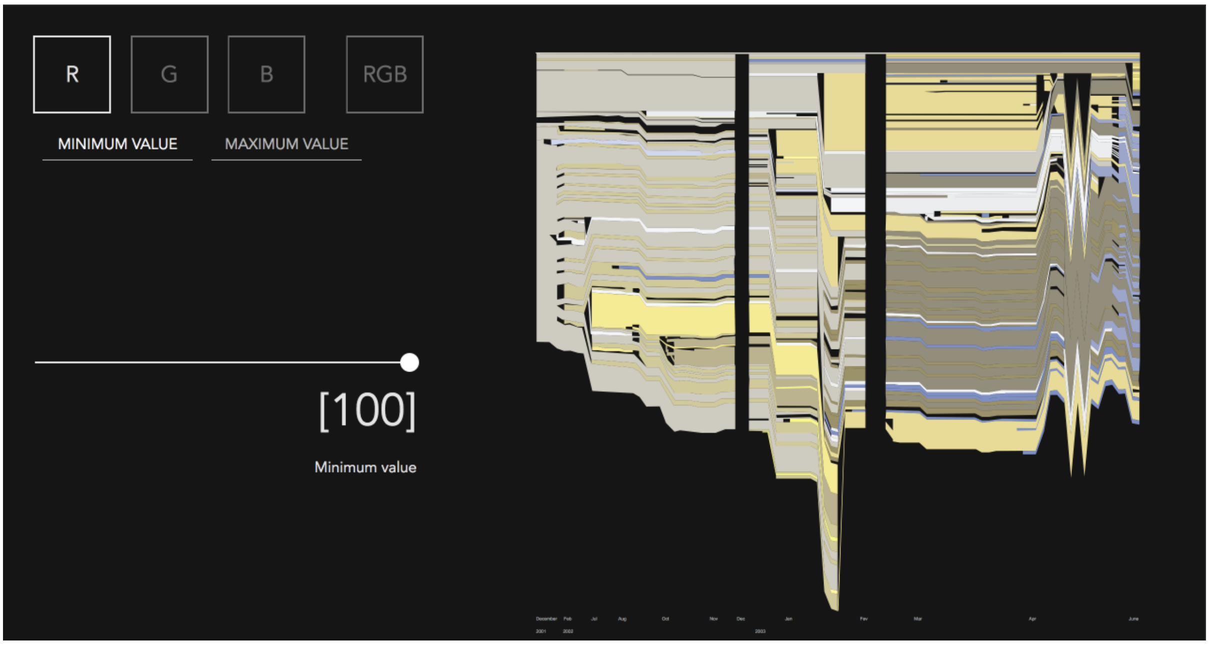


Figure 47 Interactive System for the CVD user group

[6] For more details, check attachment 3.

2.3.6 Phase 6: The Experiment – Getting the Hands dirty

The experiment involved one group of participants with two different tasks: evaluating a graph with its original trichromatic colours and a second version with simulated CVD colours, namely the colours deuteranopes would perceive.
The group was composed of 12 participants. Due to a reduced global percentage of female deuteranopes, only males were allowed to participate in the test.

Methodology

The experiment consisted in the evaluation of the participants' perception, when faced with a specific type of information visualization: a timeline and flow graph, named "History Flow" (Wattenberg & Viégas, 2003), which aimed to investigate the dynamics behind editing in Wikipedia. Because of the graph's high complexity, it was reproduced as trustworthy as possible to its reference image, although there might be some minor visual differences, such as slight variations in strokes and withdrawing of the subtitles, since the project only treated colour perception and not the interpretation of the graph. These differences aren't considered as relevant, once this project is only used as a reference and not as a specific case-study. However, it is worth mentioning that the interactive system, as well as this experiment, can be applied to other graphs that suffer from equal or similar colour perception issues.

The participants' colour perception, when visualizing the graph, was measured according to the general RGB code and its saturation in each parameter (R, G, B), both individually, as well as clustered (RGB). Therefore, this project comprised 4 main moments which had the goal of answering the following question:

"To what extent can you distinguish the colours of the graph and its details without causing visual confusion or requiring a high effort?"

Thereby, the concept of optimal perception was defined by 3 different characteristics:

- The colours had to be distinguishable;
- The graphs details had to be clear;
- No visual confusion should ocur or a high effort required in order to accomplish the above mentioned tasks;

The produce of the experiment was divided into 7 different moments: (1) The participants were welcomed and an explanation about how the experiment would be conducted was provided; (2) The participant and the investigator both signed the consent form[7]; (3) The first part of an UX/UI Usability questionnaire was conducted; (4) The experiment with the CVD graph was led; (5) The experiment with the trichromatic graph was led; (6) The second part of the UX/UI Usability questionnaire was undertaken; (7) Acknowledgments were delivered;

The sample tested the same graph twice, in which 6 users evaluated the graph in its original form, with trichromatic colours, and the remaining 6 participants assessed the second graph which simulated CVD vision. This study's main objectives were to obtain two different values (minimum and maximum), concerning each colour saturation variable (RS, GS, BS, RGBS), while the user still guaranteed an optimal perception over the graph. This allowed the analysing and comparing, not only of the values between groups, but also in the group itself.

Regarding the CVD simulated interface, while developing the G colour saturation functionalities, it was concluded that the variable didn't present any changes while

[7] For more details, check Attachment 1.

manipulating its saturation. In order to avoid user frustration as well as interference with data collection, this colour variable was disabled.

After completing the two different experiment phases the values were submitted and saved on a file for posterior analysis.

The short UX/Usability questionnaire encompassed two questions which turned to be relevant, a question which had the goal to assess which graph the user had more difficulty perceiving, the trichromatic graph or the CVD graph; and a Likert based question which compared the user tiredness level before and after the experiment.

Necessary materials and equipment

- MacBook Pro (Retina, 13-inch, Mid 2014) connected to power charge
- Maximum Brightness on Screen
- Online Questionnaire (Google Forms)
- Consent Form

The computer was placed always on the same table, with the same lightning conditions and surrounding objects. The room was the most neutral, i.e. containing only the necessary objects to perform the experiment, with no further decorations or colours which could distract the participant from the task, so that distractions didn´t take place. The screen's brightness was always set on its maximum. The experiment took place in the UX lab of IADE – Universidade Europeia.

3. Chapter 3: Data Analysis

The sample of the experiment comprehended 12 participants, since this study is exploratory and is seen as a primary exploration for further studies. The participants were all male, as the average of the population which suffers from CVD is 99% of that gender.

When analyzing the experiment, one of the first conclusions that could be done is that the channel "G", did not present significant alterations when being manipulated in the CVD simulated graph. In this way, the values of that variable in that group were set to 0 and have not been considered in the statistical analysis of the project.

The sample presented itself as tendentiously normally distributed. The Shapiro-Wilk test of normality was conducted, showing significant results in the "R_Min", "R_Máx", "B_Máx", "RGB_R_Min", "RGB_R_Máx" and "RGB_B_Min" variables. Additionally, to confirm normality, the skewness was observed confirming normality in all the variables. According to Marôco (2014), if the group sample is bigger than 5 and the skewness is not lower than 3 we can assume normality.

Table 1 Normality Tests to verify normality in the sample

Testes de Normalidade

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Estatística	gl	Sig.	Estatística	gl	Sig.
R_Min	.171	24	.069	.819	24	.001
G_Min	.265	24	.000	.664	24	.000
R_Máx	.179	24	.045	.879	24	.008
G_Máx	.353	24	.000	.727	24	.000
B_Min	.186	24	.031	.899	24	.020
B_Máx	.148	24	.189	.889	24	.013
RGB_R_Min	.161	24	.111	.934	24	.123
RGB_R_Máx	.120	24	.200*	.961	24	.453
RGB_G_Min	.261	24	.000	.697	24	.000
RGB_G_Máx	.356	24	.000	.704	24	.000
RGB_B_Min	.147	24	.197	.916	24	.049
RGB_B_Máx	.178	24	.047	.911	24	.037

*. Este é um limite inferior da significância verdadeira.

a. Correlação de Significância de Lilliefors

Table 4 Descriptive Statistics in order to understand ranges between groups

Statistics

	N Valid	N Missing	Mean	Median	Std. Deviation	Skewness
R_Min	24	0	26.54	19.50	21.585	1.871
R_Máx	24	0	85.21	88.00	13.151	-.575
G_Min	24	0	14.04	5.00	22.381	2.709
G_Máx	24	0	38.25	.00	43.288	.292
B_Min	24	0	20.33	17.00	12.085	.779
B_Máx	24	0	79.08	84.00	19.991	-.700
RGB_R_Min	24	0	28.42	23.50	17.508	.863
RGB_R_Máx	24	0	80.17	80.00	11.571	-.016
RGB_G_Min	24	0	15.58	2.50	24.327	2.243
RGB_G_Máx	24	0	34.63	.00	38.749	.229
RGB_B_Min	24	0	27.50	22.00	17.273	1.152
RGB_B_Máx	24	0	84.96	84.50	12.436	-.151
RGB_Min_Global	24	0	23.8333	21.1667	15.29327	1.174
RGB_Max_Global	24	0	66.5833	61.0000	15.11702	.090

Statistics

	Std. Error of Skewness	Kurtosis	Std. Error of Kurtosis	Range	Minimum	Maximum
R_Min	.472	4.462	.918	93	6	99
R_Máx	.472	-.954	.918	38	62	100
G_Min	.472	9.169	.918	100	0	100
G_Máx	.472	-1.944	.918	100	0	100
B_Min	.472	-.481	.918	39	6	45
B_Máx	.472	-.582	.918	63	37	100
RGB_R_Min	.472	.624	.918	70	5	75
RGB_R_Máx	.472	.253	.918	47	53	100
RGB_G_Min	.472	5.711	.918	100	0	100
RGB_G_Máx	.472	-2.053	.918	88	0	88
RGB_B_Min	.472	1.729	.918	72	5	77
RGB_B_Máx	.472	-1.139	.918	40	60	100
RGB_Min_Global	.472	1.535	.918	62.00	3.67	65.67
RGB_Max_Global	.472	-1.372	.918	51.00	40.33	91.33

Hypothesis 1:

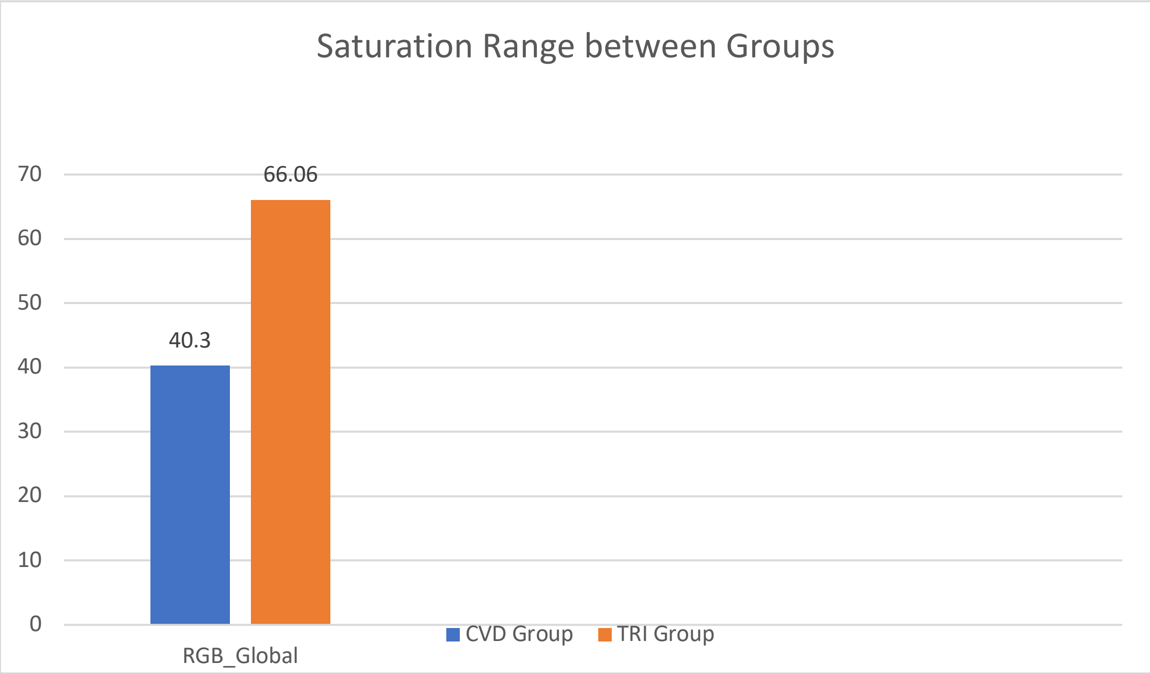
1. CVD users manipulating the graph have a more reduced colour saturation range than trichromatic users when perceiving the graph, leading to a higher overall difficulty in perception;

The confidence interval (CI) of the "RGB_Min_Global" and the "RGB_Max_Global" variable of both groups was measured, reaching the conclusion that the trichromatic group had a bigger scope in perceiving the graph than the CVD users group, assuming the CVD group had more difficulty in perceiving the information visualization. We can state that the CVD group had 25.76% more difficulty of perception due to having a more reduced range compared to trichromatic users.

Table 6 RGB_Global Values

Variable ID	Group	Lower IC	Upper IC	Amplitude of CI
RGB_Global	CVD	17.37	57.67	40.3
RGB_Global	TRI	18.90	84.96	66.06

Graph 2 Saturation Range between Groups



Plus, in the post-experiment questionnaire 75% of the users affirmed that the CVD graph was the most difficult to perceive.

Hypothesis 2:

Compared to trichromatic users, CVD users when manipulating the graph have a more reduced color perception range when measuring the RGB variables individually;

The second hypothesis was tested by executing an independent T-Student-Test and by measuring the confidence interval of each variable and its amplitude in each group.

The T-Student-Test was conducted to understand if the means in each variable were different between the CVD group and the trichromatic group. The hypothesis tested were the following:

Ho: There are no differences in the means between the CVD group and the trichromatic group.
H1: There are differences in the means between the CVD group and the trichromatic group.

Table 7 Independent T-Test 1

Teste de amostras independentes

		teste-t para Igualdade de Médias		
		Sig. (bilateral)	Diferença média	Erro padrão da diferença
R_Min	Variâncias iguais assumidas	.551	5.417	8.936
	Variâncias iguais não assumidas	.553	5.417	8.936
R_Máx	Variâncias iguais assumidas	.000	-16.917	4.139
	Variâncias iguais não assumidas	.001	-16.917	4.139
G_Min	Variâncias iguais assumidas	.001	-28.083	7.172
	Variâncias iguais não assumidas	.002	-28.083	7.172
G_Máx	Variâncias iguais assumidas	.000	-76.500	7.778
	Variâncias iguais não assumidas	.000	-76.500	7.778
B_Min	Variâncias iguais assumidas	.246	-5.833	4.889
	Variâncias iguais não assumidas	.246	-5.833	4.889
B_Máx	Variâncias iguais assumidas	.034	17.000	7.517
	Variâncias iguais não assumidas	.035	17.000	7.517
RGB_R_Min	Variâncias iguais assumidas	.511	-4.833	7.235
	Variâncias iguais não assumidas	.512	-4.833	7.235
RGB_R_Máx	Variâncias iguais assumidas	.025	-10.333	4.298
	Variâncias iguais não assumidas	.026	-10.333	4.298
RGB_G_Min	Variâncias iguais assumidas	.001	-31.167	7.679
	Variâncias iguais não assumidas	.002	-31.167	7.679
RGB_G_Máx	Variâncias iguais assumidas	.000	-69.250	6.606
	Variâncias iguais não assumidas	.000	-69.250	6.606
RGB_B_Min	Variâncias iguais assumidas	.714	-2.667	7.188
	Variâncias iguais não assumidas	.715	-2.667	7.188

Table 8 Independent T-Test 2

Teste de amostras independentes

		teste-t para Igualdade de Médias		
		Sig. (bilateral)	Diferença média	Erro padrão da diferença
RGB_B_Máx	Variâncias iguais assumidas	.691	2.083	5.172
	Variâncias iguais não assumidas	.691	2.083	5.172

After analyzing the p-value, it's observed that the following variables rejected the null hypothesis:

- R_Máx
- B_Máx
- RGB_R_Máx

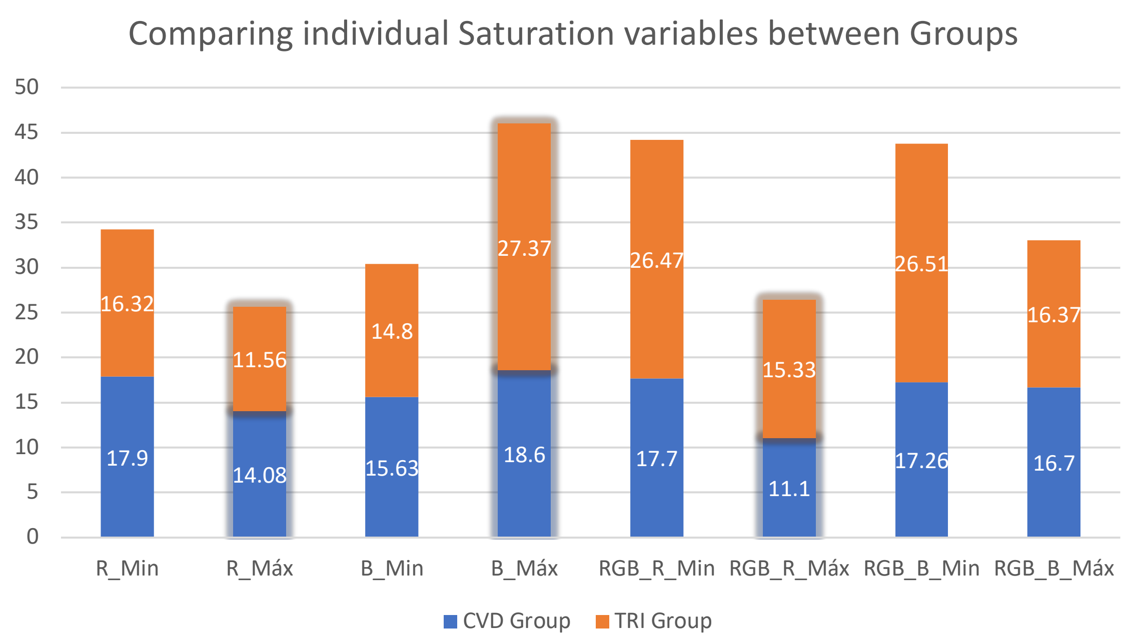
This leads us to the conclusion that only the "R_Máx", "B_Máx" and "RGB_R_Máx" present statistically different results when comparing means.

The intervals of confidence (CI) of each group were the following:

Table 9 CI individual Saturation Values between Groups

Variable ID	Group	Mean	Lower CI	Upper CI	Amplitude of CI
R_Min	CVD	29.25	11.35	47.15	17.9
	TRI	23.83	15.67	31.99	16.32
R_Máx	CVD	76.75	69.71	83.79	14.08
	TRI	93.67	87.89	99.45	11.56
B_Min	CVD	17.42	9.60	25.23	15.63
	TRI	23.25	15.85	30.65	14.8
B_Máx	CVD	87.58	78.28	96.88	18.6
	TRI	70.58	56.90	84.27	27.37
RGB_R_Min	CVD	26.00	17.15	34.85	17.7
	TRI	30.83	17.60	44.07	26.47
RGB_R_Máx	CVD	75.00	69.45	80.55	11.1
	TRI	85.33	77.67	93.00	15.33
RGB_B_Min	CVD	26.17	17.54	34.80	17.26
	TRI	28.83	15.58	42.09	26.51
RGB_B_Máx	CVD	86.00	77.65	94.35	16.7
	TRI	83.92	76.18	91.65	16.37

Graph 4 Comparing individual Saturation variables between Groups



Although there are always differences between groups regarding the amplitude of CI, the high lightened ones are considered statistically relevant. We can see that the colour perception range across the variables is tendentiously lower in the CVD group, meaning they have more reduced saturation spectrum of perceiving correctly.

Hypothesis 3:

When analysing the RGB variables clustered together, such values may vary when evaluated individually;

The third hypothesis was about understanding if the values changed when performing the experiment with the variables separately than when performing it clustered.

Table 10 CI Saturation Values with clustered variables

Variable ID	Group	Mean	Lower CI	Upper CI	Amplitude of CI
R_Global	CVD	53.00	42.56	63.43	20.87
RGB_R_Global	CVD	50.50	46.83	54.17	7.34
R_Global	TRI	58.75	54.26	63.43	9.17
RGB_R_Global	TRI	58.08	49.50	66.66	17.16
B_Global	CVD	52.50	47.57	57.42	9.85
RGB_B_Global	CVD	56.08	51.56	60.60	9.04
B_Global	TRI	52.50	47.57	57.42	9.85
RGB_B_Global	TRI	56.37	49.81	62.93	13.12

Graph 5 Saturation Variables clustered inside groups

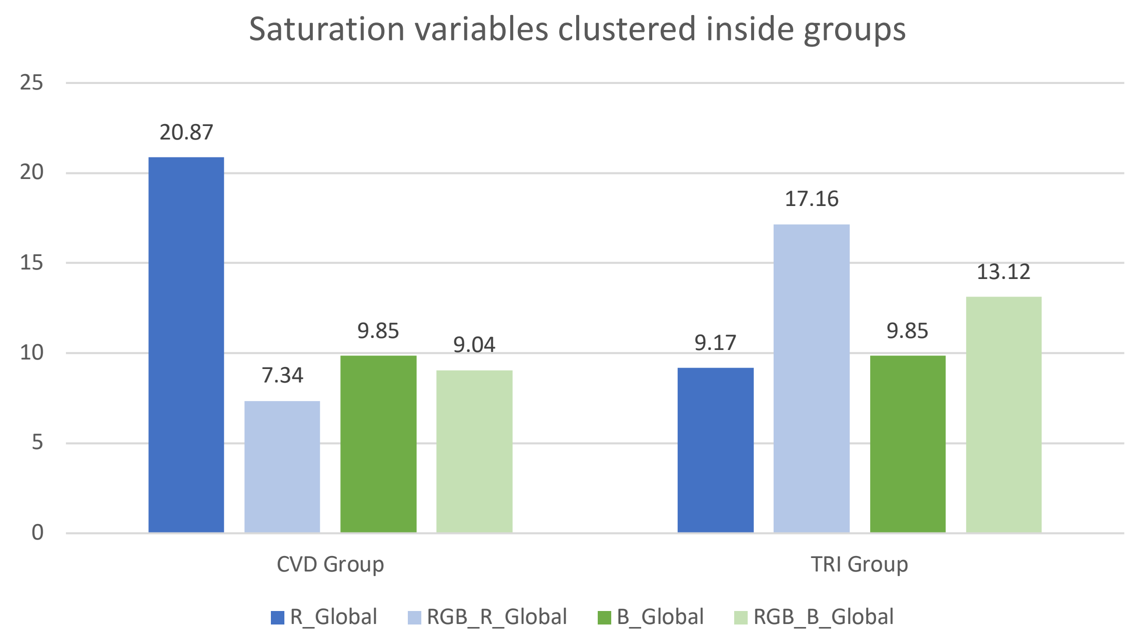
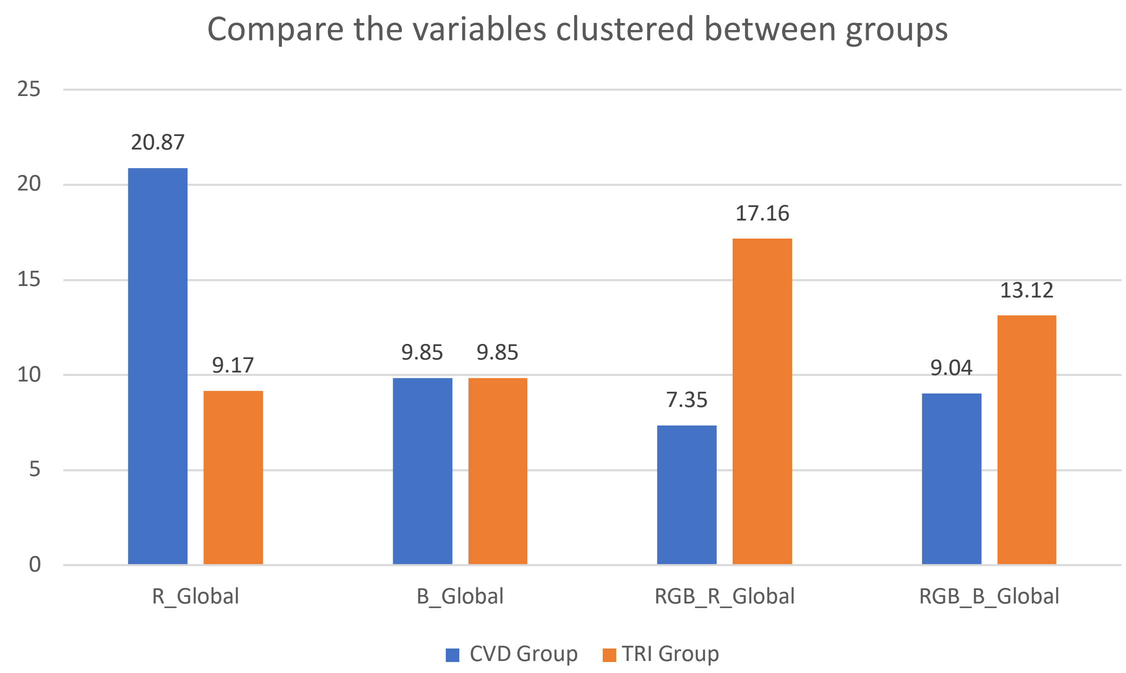


Table 11 Saturation Variables clustered between groups

Variable ID	Group	Mean	Lower CI	Upper CI	Amplitude of CI
R_Global	CVD	53.00	42.56	63.43	20.87
R_Global	TRI	58.75	54.26	63.43	9.17
B_Global	CVD	52.50	47.57	57.42	9.85
B_Global	TRI	52.50	47.57	57.42	9.85
RGB_R_Global	CVD	50.50	46.83	54.17	7.34
RGB_R_Global	TRI	58.08	49.50	66.66	17.16
RGB_B_Global	CVD	56.08	51.56	60.60	9.04
RGB_B_Global	TRI	56.37	49.81	62.93	13.12

Graph 6 Saturation Variables between groups



We can observe that only two groups didn't show significant differences, namely the "B" variable in the CVD group and the "B_Global" variable between groups. All the other variables presented relevant changes (high lightened rows).

Hypothesis 4:

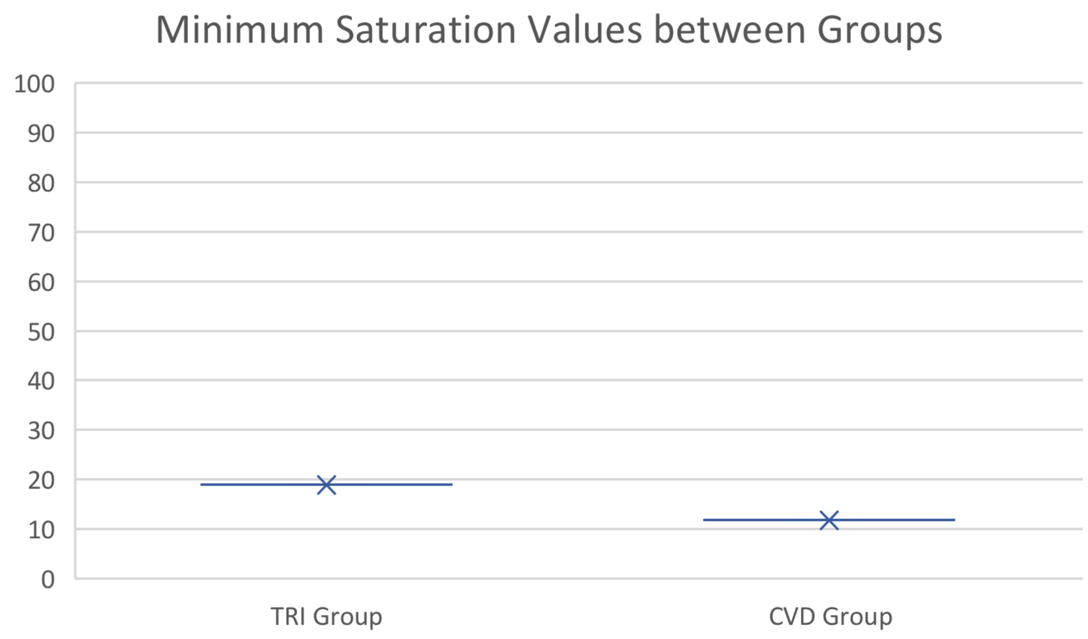
CVD users will select a higher minimum value of colour saturation in order to perceive correctly the information compared to trichromatic users;

Regarding the fourth, which states that the CVD users group needed a higher saturation value to perceive the graph correctly, being consequently their color minimum perception value higher than for the trichromatic users group, the lower CI's of the "RGB_Min_Global" variable where observed and compared between groups.

Table 12 RGB Global Saturation Values

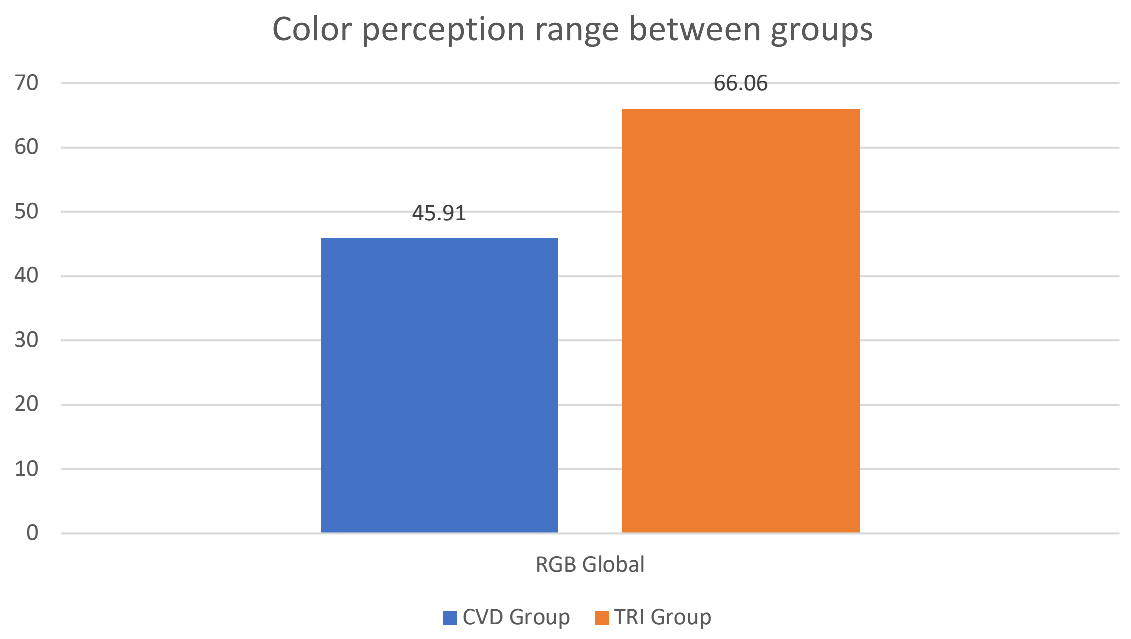
Variable ID	Group	Lower CI	Upper CI	Amplitude of CI
RGB_ Global	CVD	11.76	57.67	45.91
RGB_ Global	TRI	18.90	84.96	66.06

Graph 7 Minimum Saturation Values between Groups



We can conclude that the CVD group didn't need a higher color perception value to perceive the graph correctly (11.76), in fact the trichromatic group needed a higher minimum value (18.90) in order to have an optimal perception over the graph. Along with these findings it became visible that although the CVD users group didn't need a higher saturation value to perceive the information correctly, their color perception range was 69% (20.15 values) shorter than for the trichromatic users group.

Graph 8 Colour perception range between groups

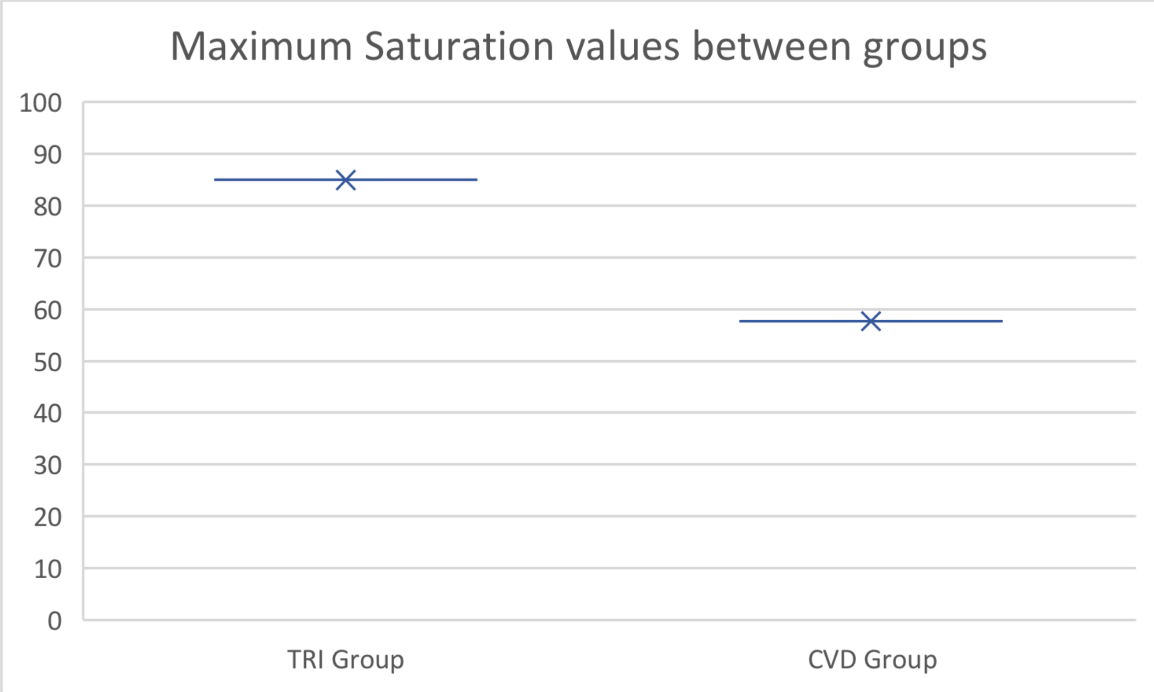


Hypothesis 5:

CVD users will select a lower maximum value of color saturation in order to perceive correctly the information compared to trichromatic users;

In the fifth hypothesis, it could be observed that the CVD users group had a significant lower maximum value (57.67) of saturation than the trichromatic group (84.96), meaning CVD users group needed 32.12% less saturation in order to perceive the information than the trichromatic users group.

Graph 9 Maximum Saturation values between groups

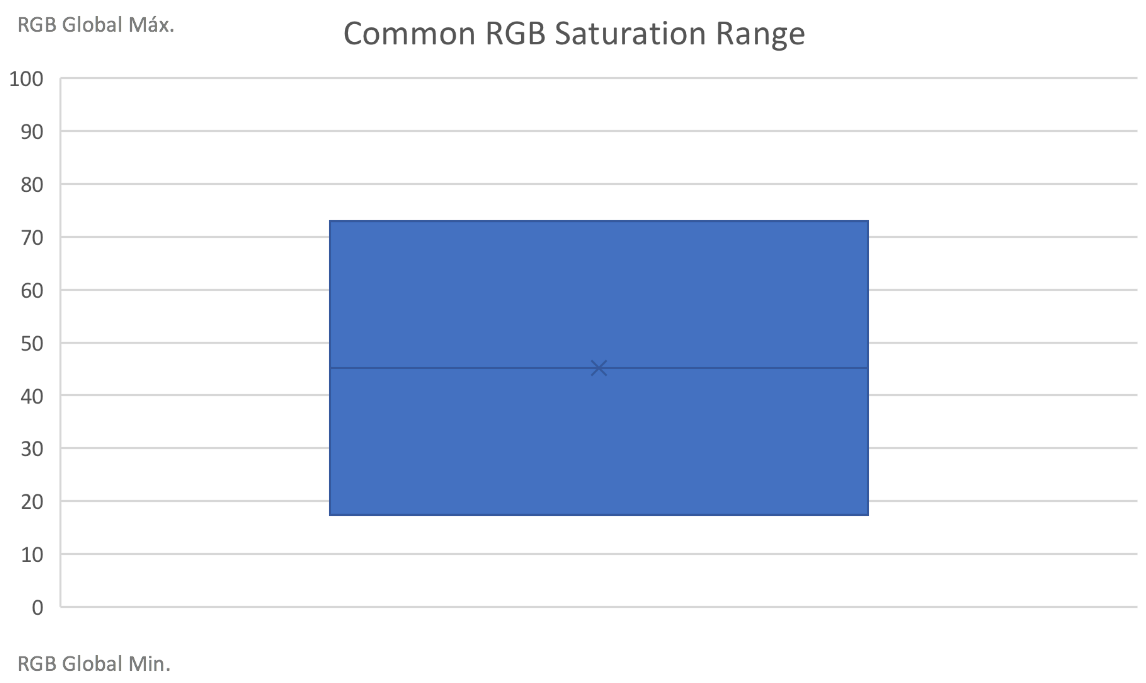


Hypothesis 6:

There is a common color saturation range value for both CVD and trichromatic users;

The last hypothesis assumed it was possible to create a common spectrum that would reflect the range in which both the CVD and trichromatic users group perceived the information correctly. By analyzing the lower CI of the "RGB_Min_Global" variable and the upper CI of the "RGB_Max_Global" variable, it became possible to reach that range. From 17.37 to 72.96 the optimal perception over the graph was guaranteed, meaning the amplitude of that range is 55.5, about 50% of the total scope.

Graph 10 Common RGB Saturation Range between CVD and TRI Group



According to the UX/Usability questionnaire, it could also be observed that the users showed to be tendentiously more tired after performing the experiment, due to the prolonged exposure to screen light.

4. Chapter 4: Conclusions, Reflections and Future Improvements

With this pilot study, it became possible to reach some very interesting conclusions about the perception of color saturation regarding a specific information visualization graph, between the CVD and trichromatic users group.

The first meaningful discovery was found in the preliminary phase of the project, when manipulating the saturation in the "G" variable of the CVD graph, no color alterations were perceived. This led to the conclusion that there were not enough color saturation alterations in that graph that would make a difference for the CVD group's color perception.

We also realized that the CVD users group had a more reduced color perception range than that of the trichromatic users group, consequently deteriorating their general color perception ability.

The CVD users group had tendentiously a more reduced perception range than the trichromatic users group when observing the RGB variables individually, meaning when executing the experiment with only one channel at a time, the CVD users group had a shorter colour perception range than the trichromatic users group. Some of these variables showed significant results, the "R_Máx", "B_Máx" and "RGB_R_Máx" were the variables with the highest differences between groups. We can assume that each of the group's perception, regarding such variables, were substantially different when compared to each other.

We could also conclude that there were significant changes of the values when observing the variables individually, then when clustered together. There where changes in the values when the users manipulated the RGB channels one at a time (i.e., observing only one change,), and when the users manipulated the three channels simultaneously. We can assume that using more than one channel in the graph's representation can influence perception.

An unexpected finding was that the trichromatic users group needed a higher minimum saturation value in order to perceive the graph correctly, although their perception range was 69% shorter than for the trichromatic users group. Also, when regarding the maximum saturation value, the CVD users group could only perceive the graph correctly with less 32.12% saturation than the other group.

The final, and most important discovery was that there's a common range between the CVD and trichromatic users group. A range where both groups could optimally perceive the information visualization graph. The scope of saturation comprehended values from 0 (minimum) to 100 (maximum), the results showed that the common range between the two groups was placed between 17.37 (minimum saturation) to 72.96 (maximum saturation). These values showed that only 50% of the total saturation scope was optimal. If converting these values back to the common RGB saturation values (from 0 – 255) the range extends from 44.5 to 187.05. We can speculate that if those values are applied by designers to graphs with similar characteristics (i.e. similar colours, graphs of the same typology and graphs with the same line strokes or higher) the optimal perception will be guaranteed for CVD users as much as for trichromatic ones. It's important for designers who deal with these types of graphical representations, such as complex timeline graphs, to take these saturation values into consideration so that colour blind users can be closer to its optimal perception.

When visualizing such graphs, we can presume that real CVD users would perceive the same colours as the CVD users group in this project did, but further tests would have to be conducted to confirm that their perception would be exactly the same. It's supposed that when, in future experiments, the test is applied to various graphs of different typologies and colours, and the mean of those saturation ranges are concluded, then a global saturation range can be defined in order to ensure that all types of graphs can be optimally visualized for both user groups.

Also, it would be interesting to test the saturation variable together with other variables which could have a visual impact, for example, stroke, form, hue, object overlapping, brightness, etc.

Of course this project had some limitations and constraints, being the most relevant one, the fact that it wasn't possible to test the interactive system with real CVD users, despite the effort. Ideally, by having real CVD users participate in the project, the insights gathered could have been much more of a qualitative analysis, aligning statistics with behavioural/contextual science.

In this way, after analysing the results and observing their impact on perception, we can state that this investigation, besides contributing to an initial study of colour blind users perception towards complex graphs, also reflects the importance of Interaction Design and it's methodologies applied to aid users overcome certain impairments. Without these research processes and problem identification systems users would have to settle for products less adaptable to their needs. Design is about creating interactive products that support people in their everyday and working lives. In particular, it is about creating user experiences that enhance and extend the way people work, communicate and interact.

Therefore, IxD, as a user-centered, collaborative and cross-functional domain, stimulates the social inclusion of every type of user and potentiates the design of better, more user-friendly products. In line with this mission, this research project aimed to serve as a starting point and inspiration for future investigations which have the goal to improve, if not solve, the daily lives of colour vision deficiency users, who struggle with everyday obstacles due to their impairments. As for IxD designers, this project aimed to provide them with knowledge about the perception of colour blind users and a methodology and tool with which they can use to test their designs of complex graphics to ensure an inclusive approach.[8]

[8] You can access the source code through this link: https://www.dropbox.com/sh/sg7ss28ld7pl759/AAC0_9tmqU5ohw-qwPFzddHta?dl=0

5. Bibliography

Affairs, A. S. for P. (2013). Personas. Retrieved from https://www.usability.gov/how-to-and-tools/methods/personas.html

Babich, N. (2016). Waterfall vs Agile. Retrieved April 6, 2018, from https://medium.com/@101/waterfall-vs-agile-9da25daf18e8

Cairo, A. (2013). *The Functional Art: An introduction to information graphics and visualization*. (N. E. McDonald, T. Croom, & C. Lane, Eds.). Berkeley: New Riders.

Calleia, M. (2014). Aligning Design and Engineering Teams. Retrieved January 28, 2018, from http://calleia.com/blog/aligning-design-and-engineering/

Cohn, M. (n.d.). User Stories and User Story Examples. Retrieved February 2, 2018, from https://www.mountaingoatsoftware.com/agile/user-stories

Colblindor. (2016). Deuteranopia – Red-Green Color Blindness | Colblindor. Retrieved February 26, 2018, from http://www.color-blindness.com/deuteranopia-red-green-color-blindness/

Coleman, R., Clarkson, J., Dong, H., & Cassim, J. (2007). *Design for Inclusivity: A Pratical Guide to Accessible Innovative and User-Centred Design*. Hampshire: Gower Publishing Limited.

Creswell, J. W. (2014). *Rsearch Design: Qualitative, Quantitative and Mixed Methods Approaches*. (V. Knight, K. Koscielak, B. Bauhaus, M. Markanich, & A. Hutchinson, Eds.) (4th Editio). Thousand Oaks: SAGE.

Davis, J. (2015). *Foundations of Color* (First Edit). Tempe Digital LLC.

Freitas, C. M. D. S., Luzzardi, P. R. G., Cava, R. A., Winckler, M. A. A., Pimenta, M. S., & Nedel, L. P. (n.d.). *Evaluating Usability of Information Visualization Techniques*. PPGC/Instituto de Informática – Univ. Federal do Rio Grande do Sul (UFRGS), Universidade Católica de Pelotas, LIHS Université Toulouse 1.

Gibson, E. J. (2002). *Perceiving the Affordances: A Portrait of two Psychologists*.

Book. Taylor & Francis. https://doi.org/10.1037/e520562012-343

Ilama, E. (2015). Creating Personas | UX Booth. Retrieved January 30, 2018, from http://www.uxbooth.com/articles/creating-personas/

Kay, S. (n.d.). Stanford Kay Information Graphics. Retrieved March 28, 2018, from http://stanfordkaystudio.com/

Khoso, M. (2016). How Much Data is Produced Every Day? Retrieved February 5, 2018, from http://www.northeastern.edu/levelblog/2016/05/13/how-much-data-produced-every-day/

Marôco, J. (2014). *Análise Estatística com o SPSS Statistics* (6th Editio). Report Number.

Mazza, R. (2009). *Introduction to Information Visualization*. London: Springer-Verlag. https://doi.org/10.1007/978-1-84800-219-7

Meirelles, I. (2013). *Design for Information*. Beverly: Rockport Publishers.

Miniwatts Marketing Group. (2018). World Internet Users Statistics and 2018 World Population Stats. Retrieved February 26, 2018, from https://www.internetworldstats.com/stats.htm

Neiva, M. (n.d.). ColorAdd - Color Identification System. Retrieved March 5, 2018, from http://www.coloradd.net/publications.asp

Nirosh, L. W. C. (2013). A Practical Approach to Computer Systems Design and Architecture. Sri Lanka. Retrieved from https://www.codeproject.com/Articles/16105/A-Practical-Approach-to-Computer-Systems-Design-an#The

Patton, J. (2014). *User Story Mapping. Discover the Whole Story, Build the Right Product*. (A. Treseler, Mary Jollymore, Ed.), *O'Reilly Media* (1st Editio). Sebastopol: O'Reilly Media, Inc. Retrieved from http://shop.oreilly.com/product/0636920033851.do

Preece, J., Rogers, Y., & Sharp, H. (2002). *Interaction Design: beyond human-computer interaction*. (G. Crockett & A. Melhorn, Eds.). New York: John Wiley

& Sons, Inc.

Ranjani, R. (2015). Removal of Color Blindness Using Image Segmentation. *International Journal of Advanced Research in Computer Science and Software Engineering*, *Volume 5*(Issue 3).

Reuteurs. (2016). Europe's migration crisis. Retrieved March 28, 2018, from http://graphics.thomsonreuters.com/15/migrants/index.html#section-asylum

Rouse, M. (2011). What is Agile Manifesto? Retrieved January 28, 2018, from http://searchcio.techtarget.com/definition/Agile-Manifesto

Rouse, M. (2017). What is Agile Software Development? Retrieved January 28, 2018, from http://searchsoftwarequality.techtarget.com/definition/agile-software-development

Saffer, D. (2006). Designing for Interaction: Creating Smart Applications and Clever Devices. Berkeley: New Riders.

Silver, A. (2016). Improving The Color Accessibility For Color-Blind Users — Smashing Magazine. Retrieved February 26, 2018, from https://www.smashingmagazine.com/2016/06/improving-color-accessibility-for-color-blind-users/

Snowden, R., Thompson, P., & Troscianko, T. (2012). *Basic Vision: An introduction to visual perception* (Revised Ed). Oxford: Oxford University Press.

Solomon, C., & Breckon, T. (2011). *Fundamentals of Digital Image Processing*. Wiley Blackwell.

Stefaner, M. (n.d.). Truth & Beauty - The Rhythm of Food. Retrieved March 27, 2018, from https://truth-and-beauty.net/projects/the-rhythm-of-food

Story, M. F., Mueller, J. L., & Mace, R. L. (1998). *The Universal Design File: Designing for People of All Ages and Abilities. Revised Edition.* Raleigh.

Tidewell, J. (2006). *Designing Interfaces*. (M. Odewahn, Andrew Obrien, Ed.) (1st Editio). Sebastopol: O'Reilly Media, Inc.

Ware, C. (2013). *Information Visualization: Perception for Design*. (M. Dunkerley &

H. Scherer, Eds.) (3rd Editio). Waltham: Elsevier.

Wattenberg, M., & Viégas, F. (2003). Martin Wattenberg: History Flow. Retrieved March 28, 2018, from http://www.bewitched.com/historyflow.html

Wurman, R. (2000). Information Anxiety 2. Indiana: Que.

Attachments

Note: Some attachments are written in Portuguese, due to the sample's linguistic preference.

Attachment 1: Consent form presented to the participants taking part in the experiment

Universidade Europeia
LAUREATE INTERNATIONAL UNIVERSITIES

Participante nº: _________
Data:____/____/_____ Hora:___________
Condição:___________________________

A sessão será dividida em 6 partes distintas:

(1) Breve explicação da experiência e as actividades nela envolvidas; (2) Preenchimento e assinatura do termo de consentimento; (3) Preenchimento de um questionário on-line antes da experiência; (4) Execução da Experiência; (5) Preenchimento de um questionário on-line pós-experiência; (5) Agradecimentos. O tempo total estimado para a sua participação é de, aproximadamente, 30min.

Riscos e desconforto

Não se preveem qualquer tipo de riscos nesta actividade. Poderá ocorrer algum desconforto e cansaço óptico devido à observação pormenorizada que é requerida em qualquer circunstância que envolva a observação prolongada para um ecrã de computador, devido ao seu brilho e luminosidade artificiais. Se durante a experiência sentir algum desconforto que possa ser agravador, indique de imediato à investigadora principal de forma a cessar a experiência.

Abandono da experiência sem qualquer penalização

A participação nesta investigação é voluntária, pelo que pode decidir interromper a experiência e abandonar o estudo a qualquer momento, sem qualquer consequência ou penalização.

Confidencialidade e finalidade dos dados

Citações directas do questionário poderão ser usadas em artigos ou comunicações científicas, mas nunca será dada informação de identificação.

Todos os dados recolhidos serão confidenciais, incluindo as suas respostas aos questionários, que serão anónimas. Para isso, os participantes serão identificados apenas com um número, que serve para a investigadora principal ter registo da sequência pela qual a experiência decorreu.

Universidade Europeia
LAUREATE INTERNATIONAL UNIVERSITIES

Participante nº: _________
Data:____/____/_____ Hora:___________
Condição:___________________________

Termo de Consentimento Informado, Livre e Esclarecido

Título do estudo:

Inclusividade no Design de Interação: Estabelecer a ponte entre a Percepção de Visualização de Informação e Utilizadores Daltónicos

Inclusive Interaction Design: Bridging the gap between Information Visualization Perception and Color Vision Deficiency Users

Investigadores: Cristina Feijó Relvas (investigadora principal), Carlos Rosa (orientador) e Lara Reis (orientadora)

Afiliação: IADE – Universidade Europeia

Informação geral

Foi convidado(a) a participar, como voluntário(a), num estudo, no âmbito de um trabalho de Mestrado, a decorrer na Faculdade do IADE – Universidade Europeia. A sua participação representa um importante contributo, não só para o estudo em curso, mas também para o desenvolvimento do conhecimento nas áreas do Daltonismo e do Design. Ao participar nesta experiência, terá a oportunidade de contribuir para o estudo e evolução da visualização de informação adaptada a qualquer tipo de utilizadores, destacando os utilizadores daltónicos como foco principal.

É importante que leia a informação seguinte, antes de concordar em participar neste estudo. Este texto descreve, de forma sucinta, os objectivos gerais do estudo e o que se espera da sua participação, incluindo a identificação dos procedimentos experimentais, dos riscos previstos, dos seus direitos, da confidencialidade e finalidade dos dados. Caso aceite fazer parte desta investigação, deverá assinar as duas vias deste documento, sendo que, uma delas ficará na sua posse e a outra com a investigadora principal.

Explicação do procedimento

Este estudo tem por objectivo avaliar a percepção visual do participante face a um gráfico, compreender em que ponto o participante deixa de conseguir distinguir os detalhes do gráfico.

Participante nº: _________
Data:____/____/_____ Hora:___________
Condição:___________________________

Contactos

Para esclarecimentos adicionais, ou questões relacionadas com este estudo, poderá contactar a investigadora principal para o telemóvel – 918 326 536, ou para o e-mail – cristina.feijo95@gmail.com

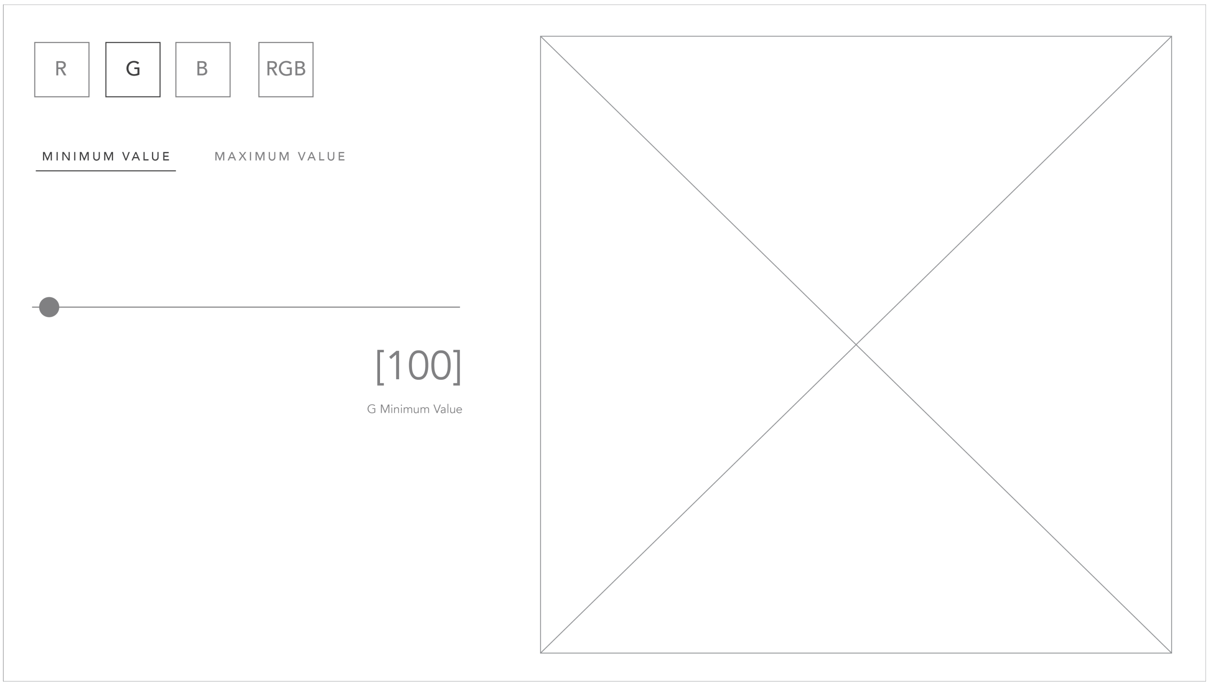
Consentimento

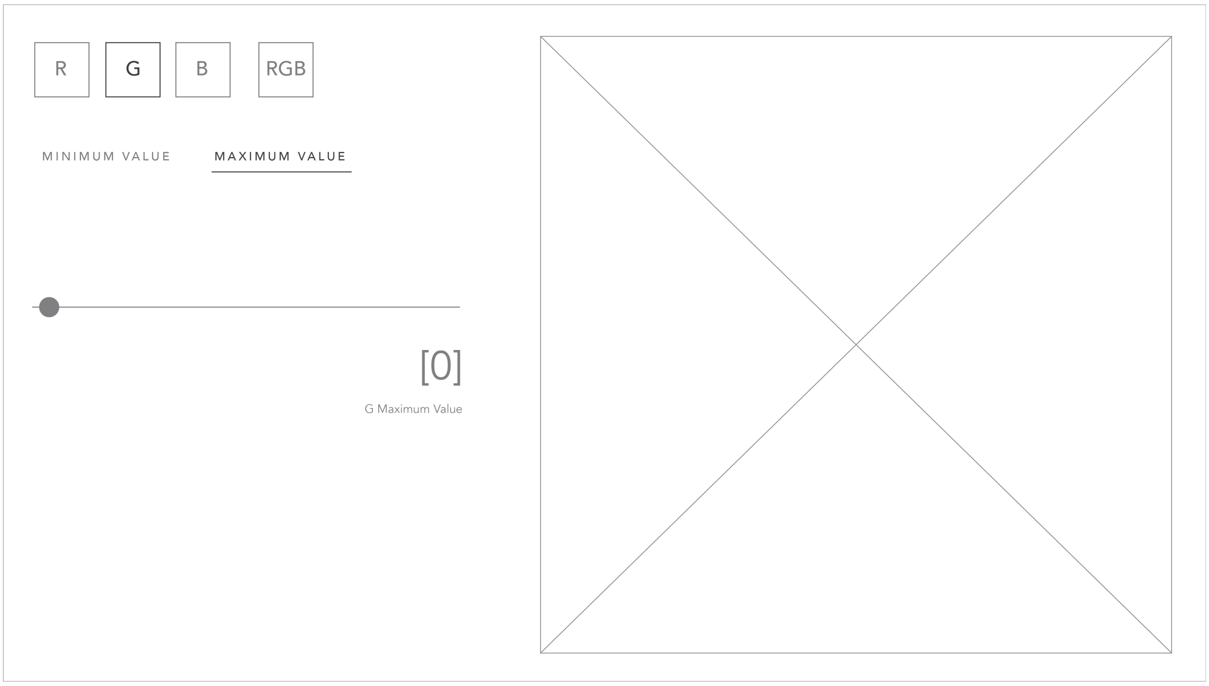
Ao assinar este documento está: (a) a declarar a sua vontade em participar neste estudo; (b) a confirmar que recebeu uma cópia deste documento; (c) a confirmar que tomou conhecimento das metodologias experimentais envolvidas neste estudo e que nada tem a opor; (d) a autorizar a recolha de dados para fins exclusivamente académicos; a declarar que vai manter o sigilo sobre o conteúdo deste trabalho, e não vai divulgar o seu objecto de estudo a outras pessoas, para não comprometer a sua participação no estudo (porque eles também poderão vir a ser convidados a participar); (e) garante que caso necessite de óculos ou lentes de contacto no seu dia-a-dia os vai utilizar no decorrer da experiência de forma a garantir uma percepção visual correcta.

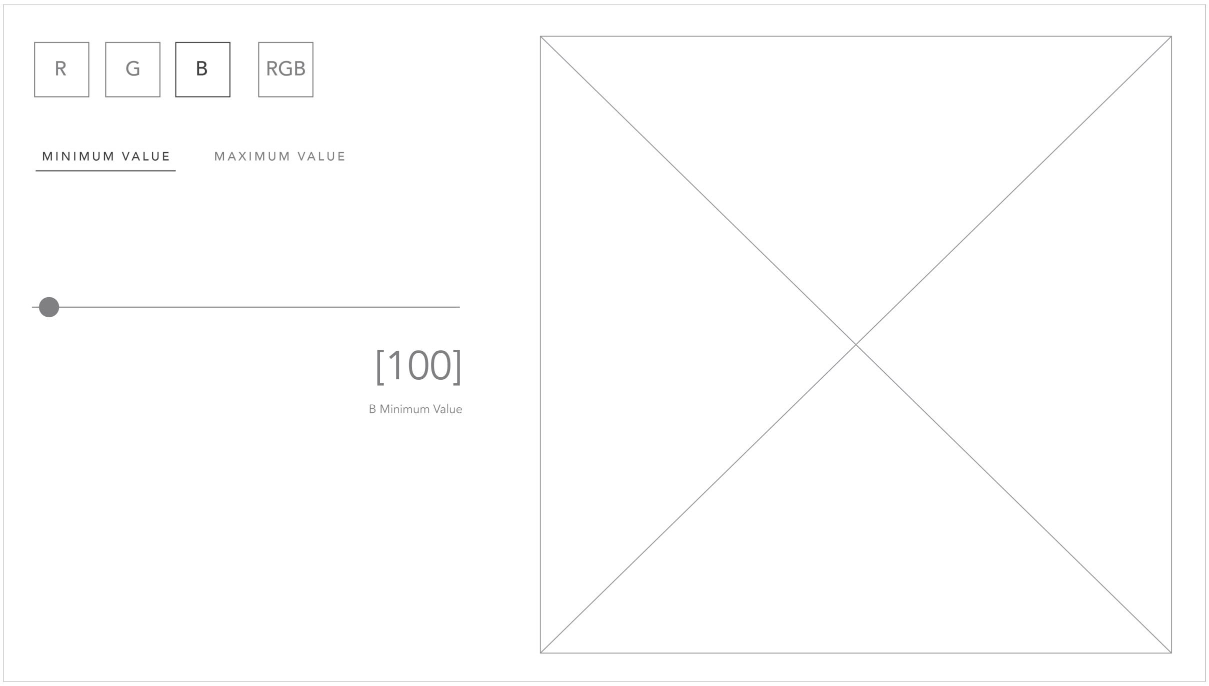
Assinatura /rúbrica do participante

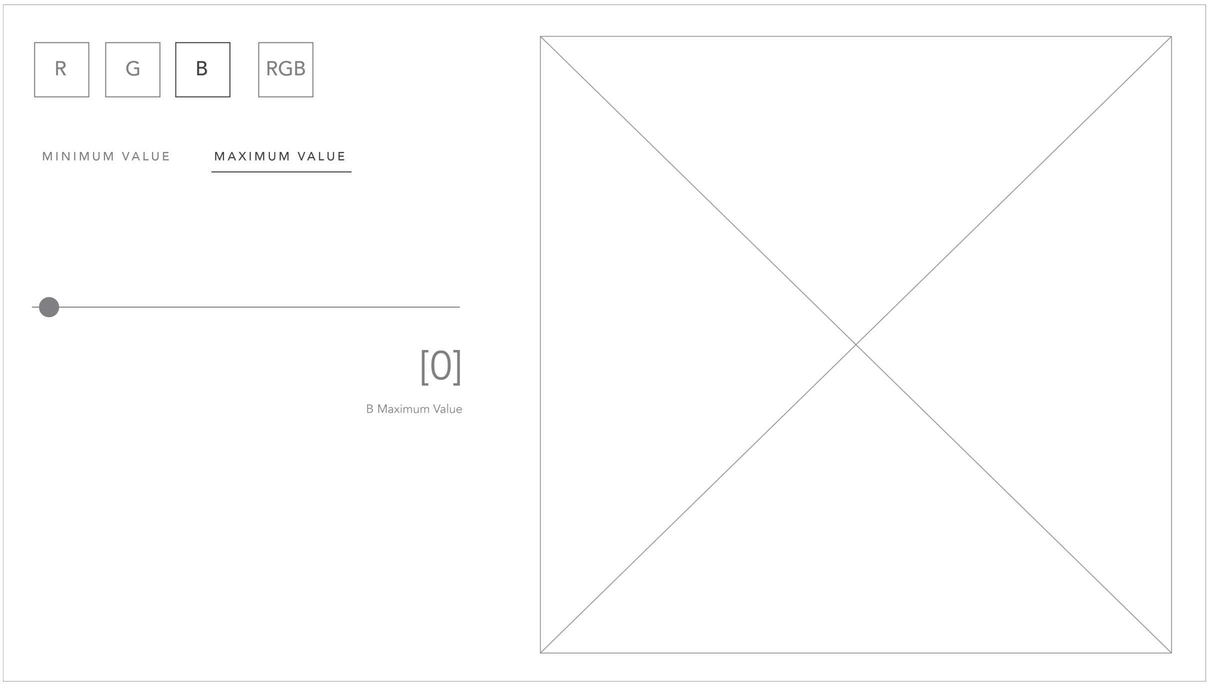
____ _______ / _______ / 2018
Assinatura da investigadora principal Data

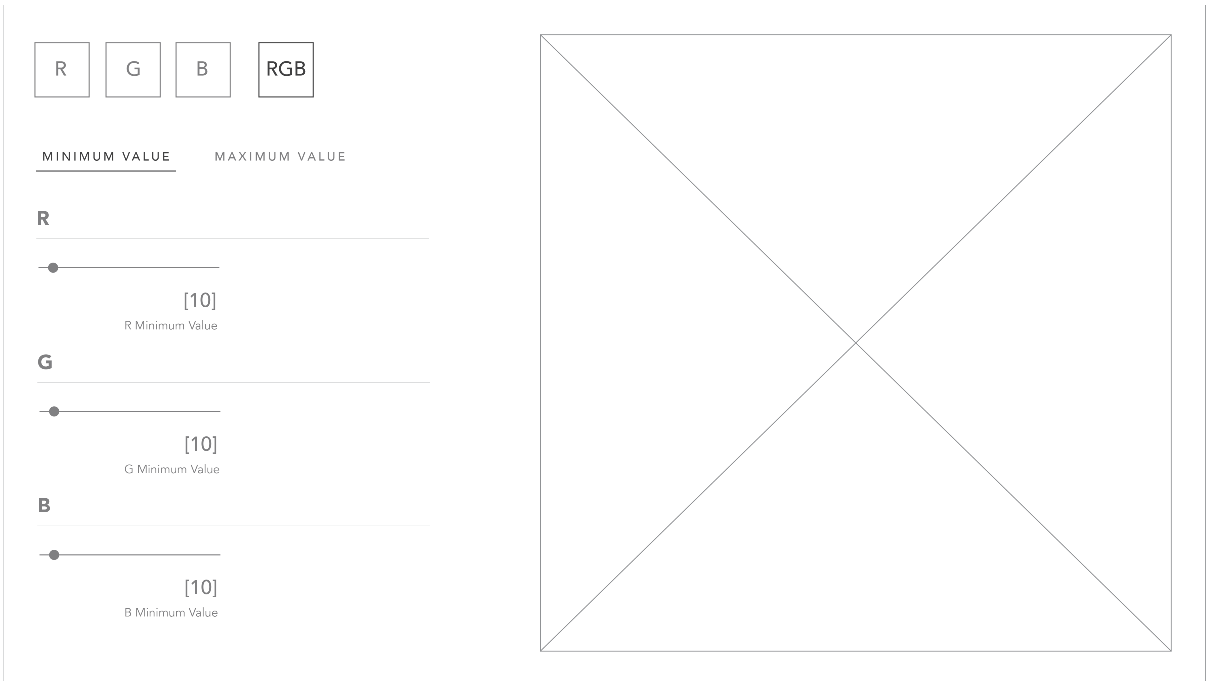
Attachment 2: Further Wireframes of the Interactive System

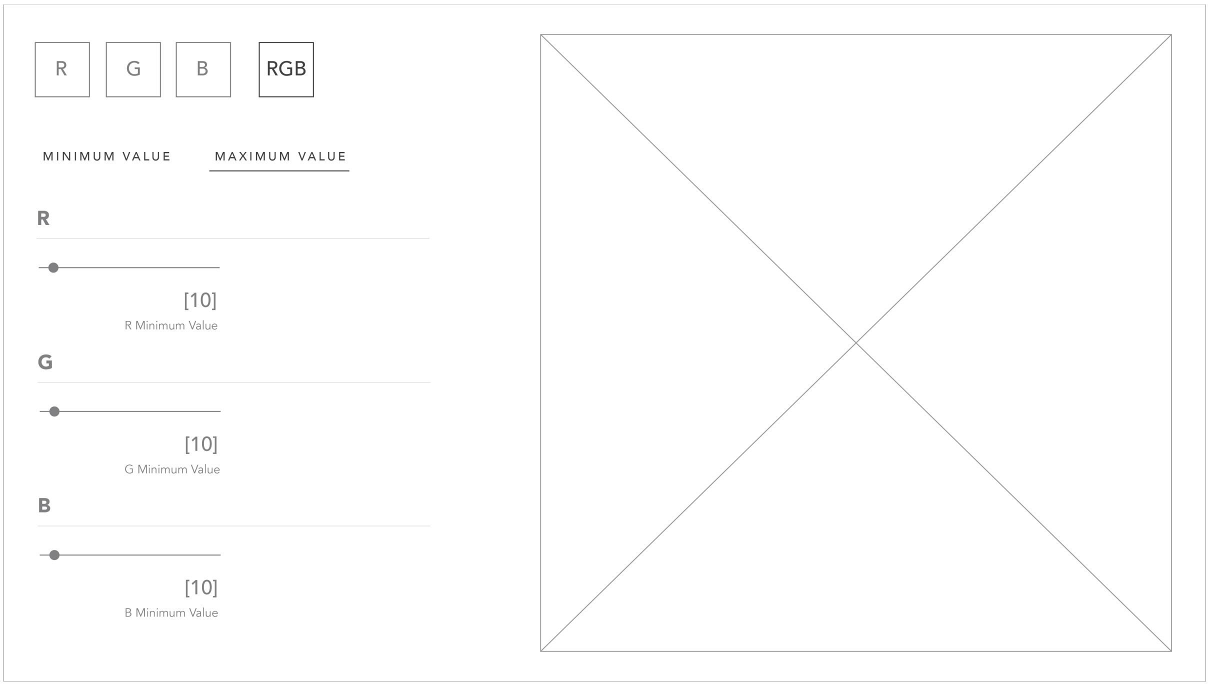




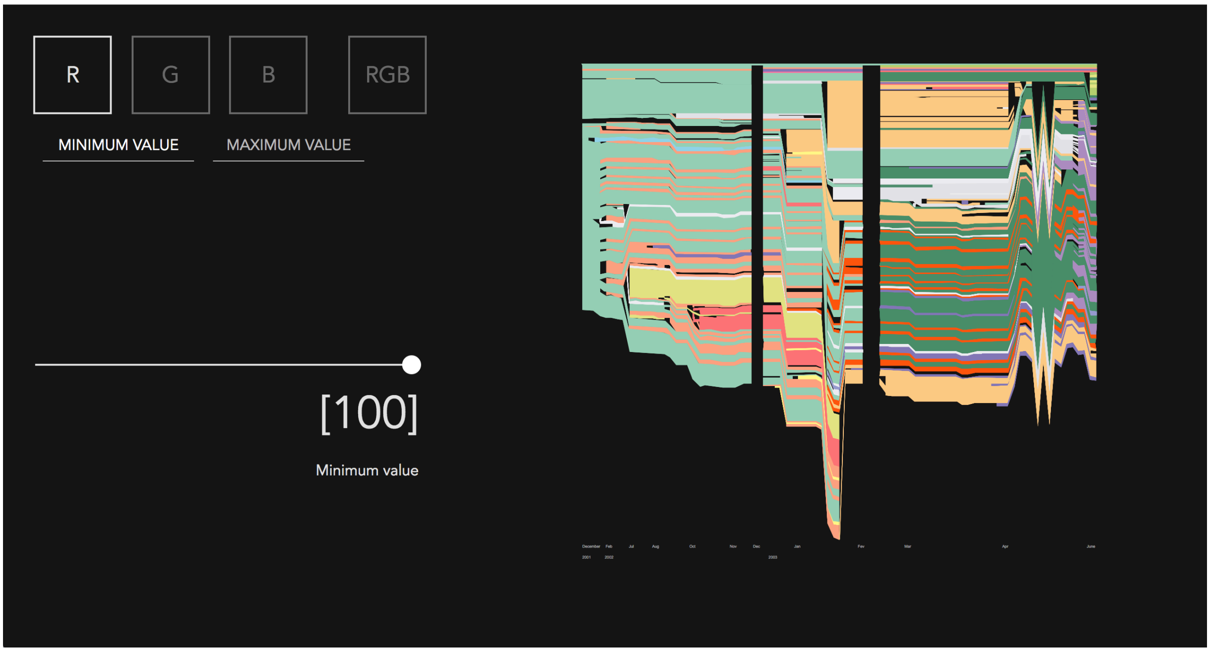

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[100]
B Minimum Value

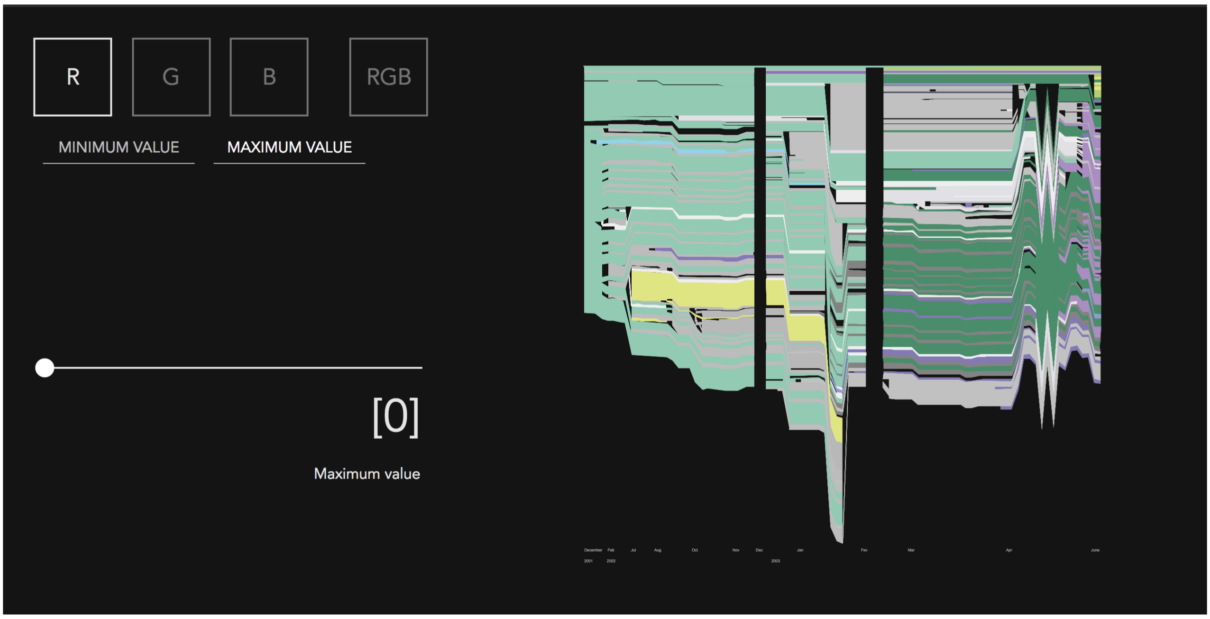

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[0]
B Maximum Value

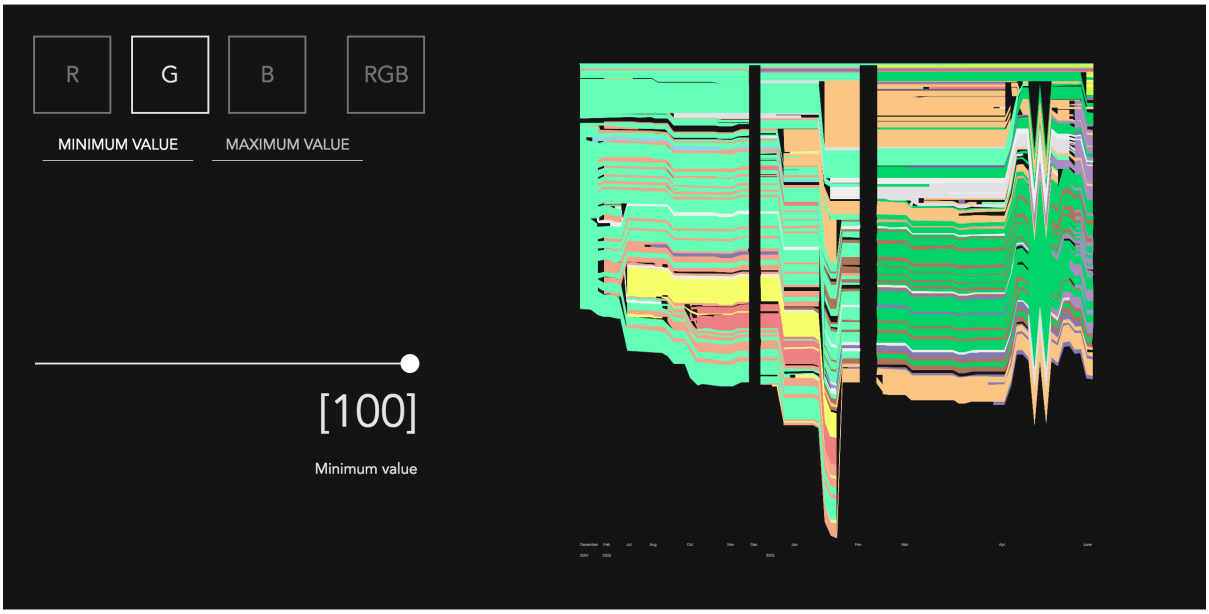

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[10]
R Minimum Value
G
[10]
G Minimum Value
B
[10]
B Minimum Value

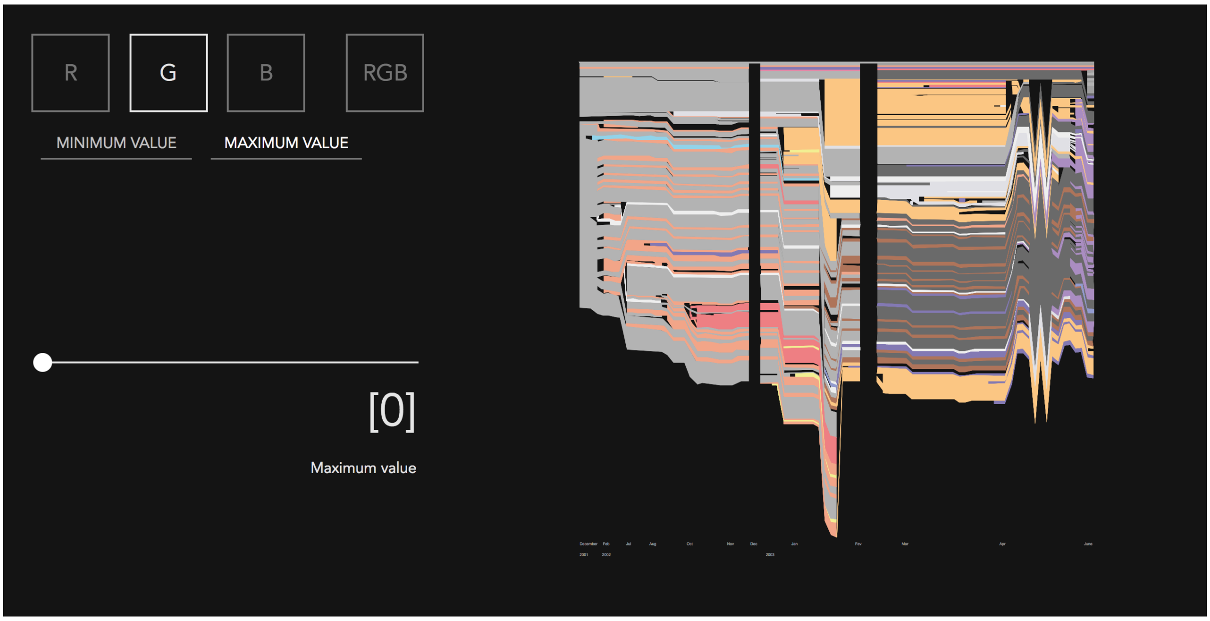

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[10]
R Minimum Value
G
[10]
G Minimum Value
B
[10]
B Minimum Value

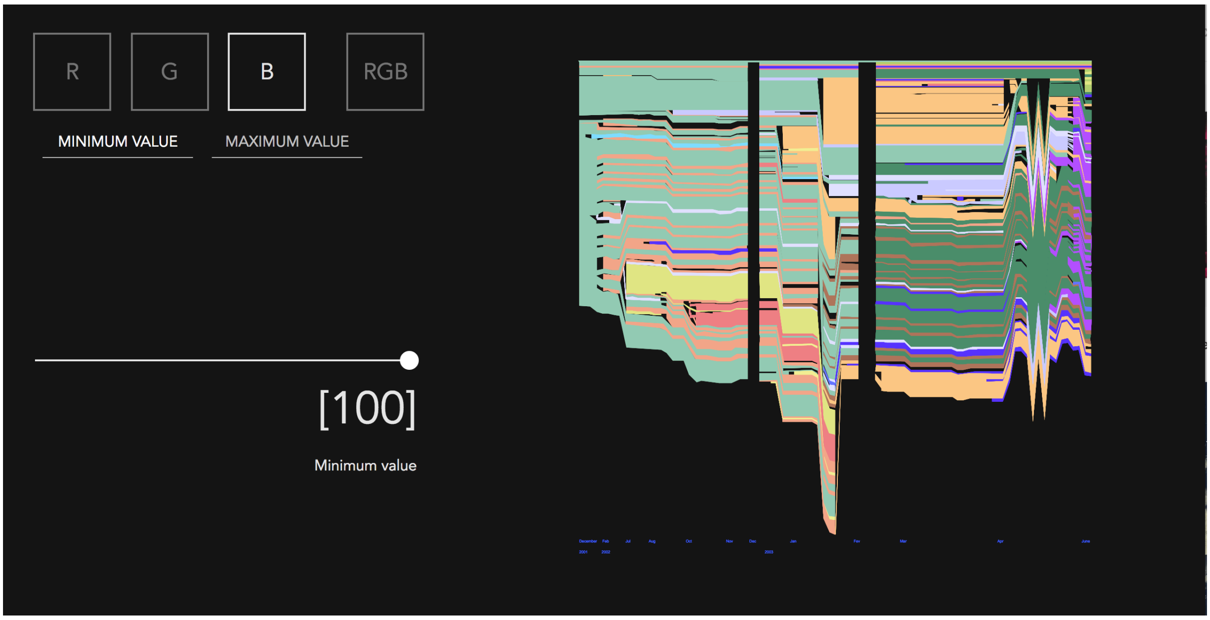
Attachment 3: Further UI Mockups of the (trichromatic) Interactive System

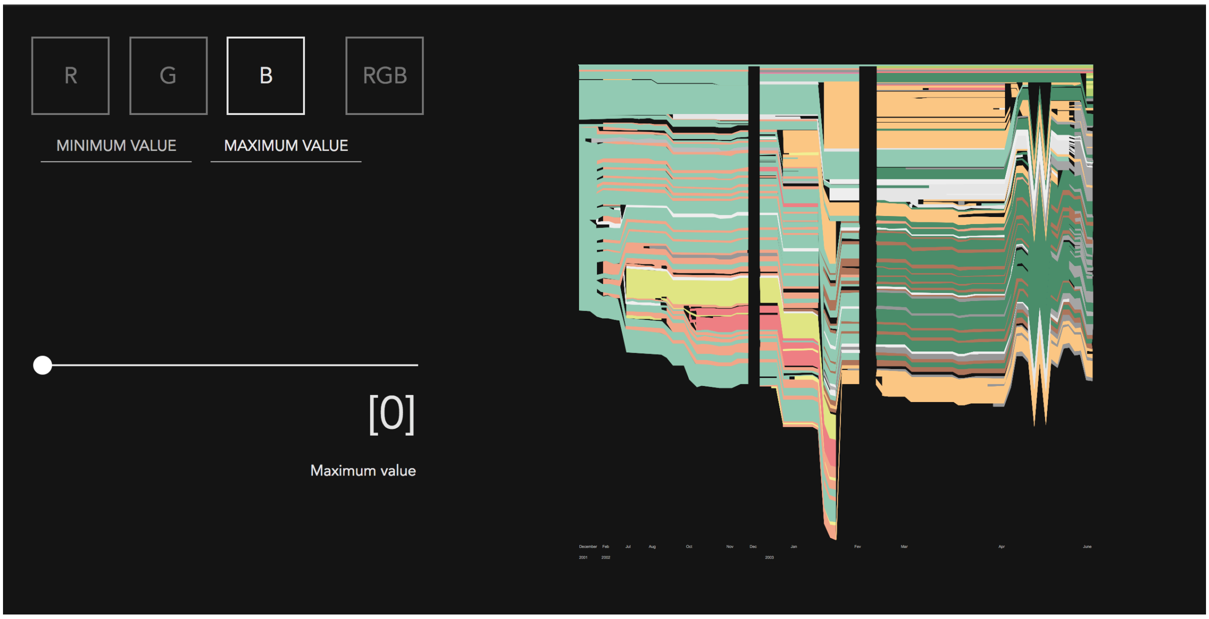


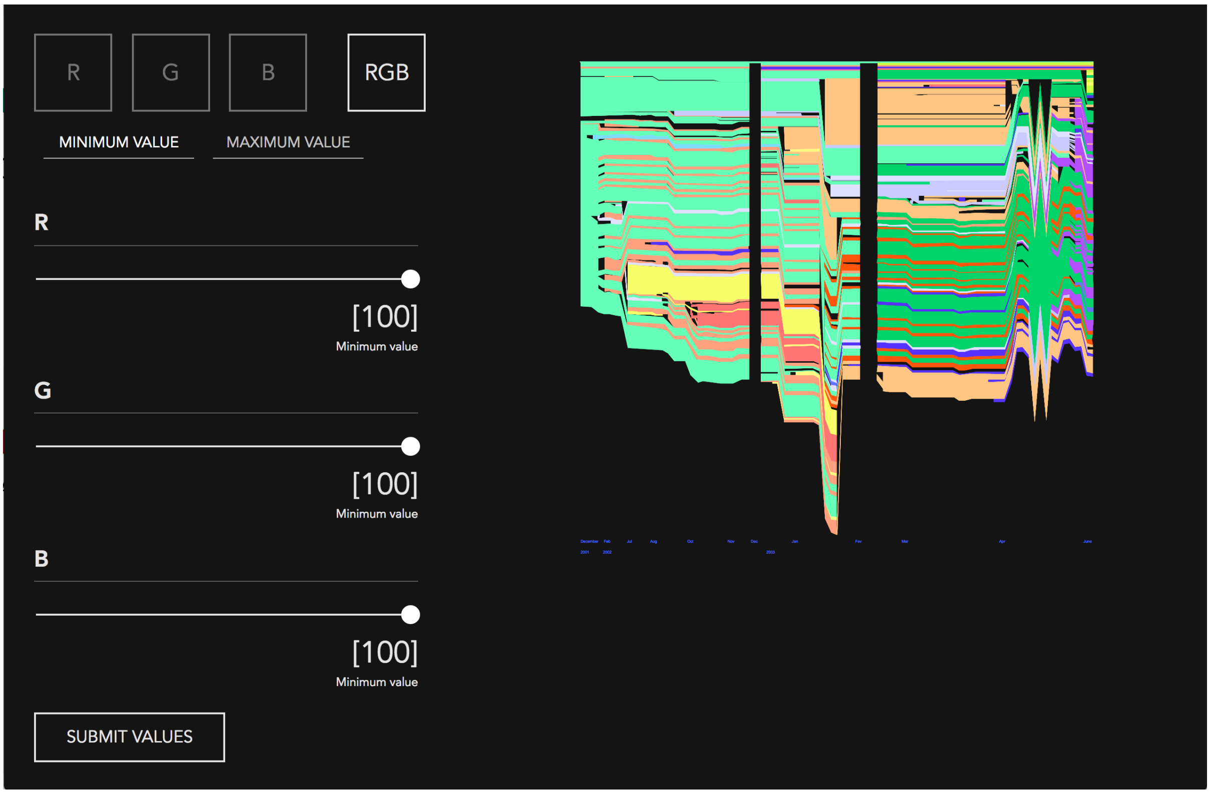


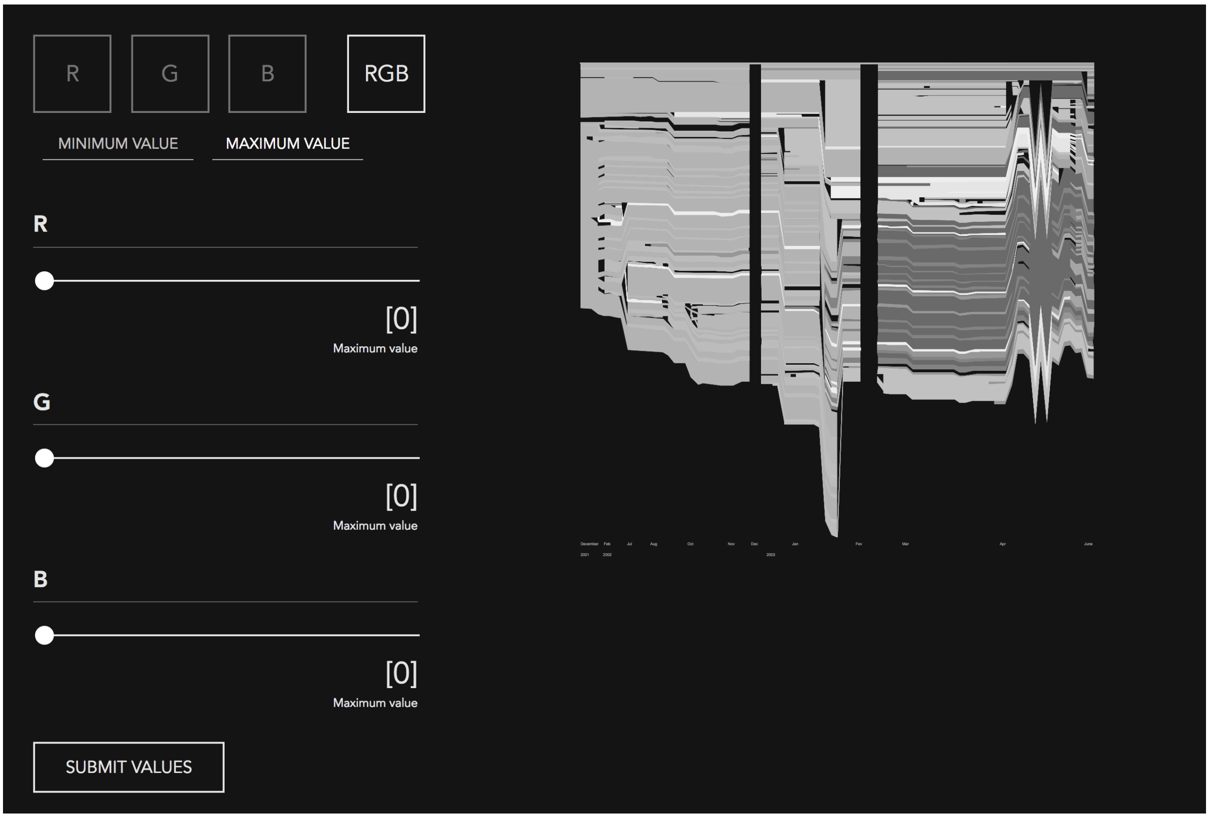

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[100]
Minimum value


R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[0]
Maximum value

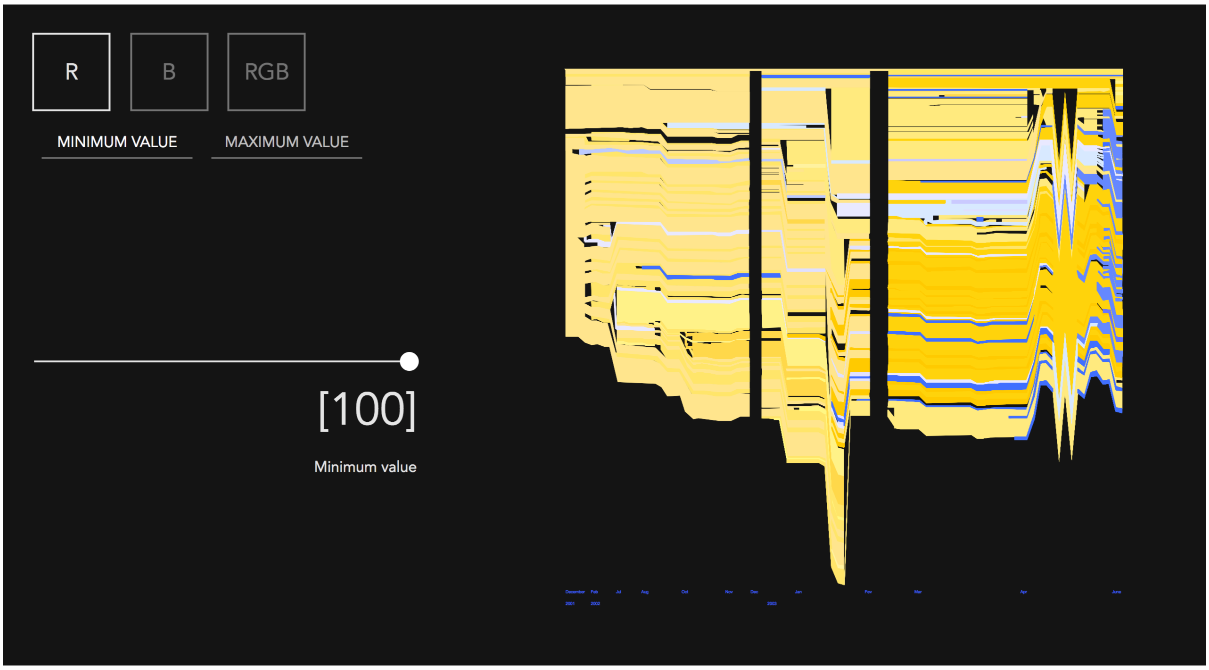

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[100]
Minimum value

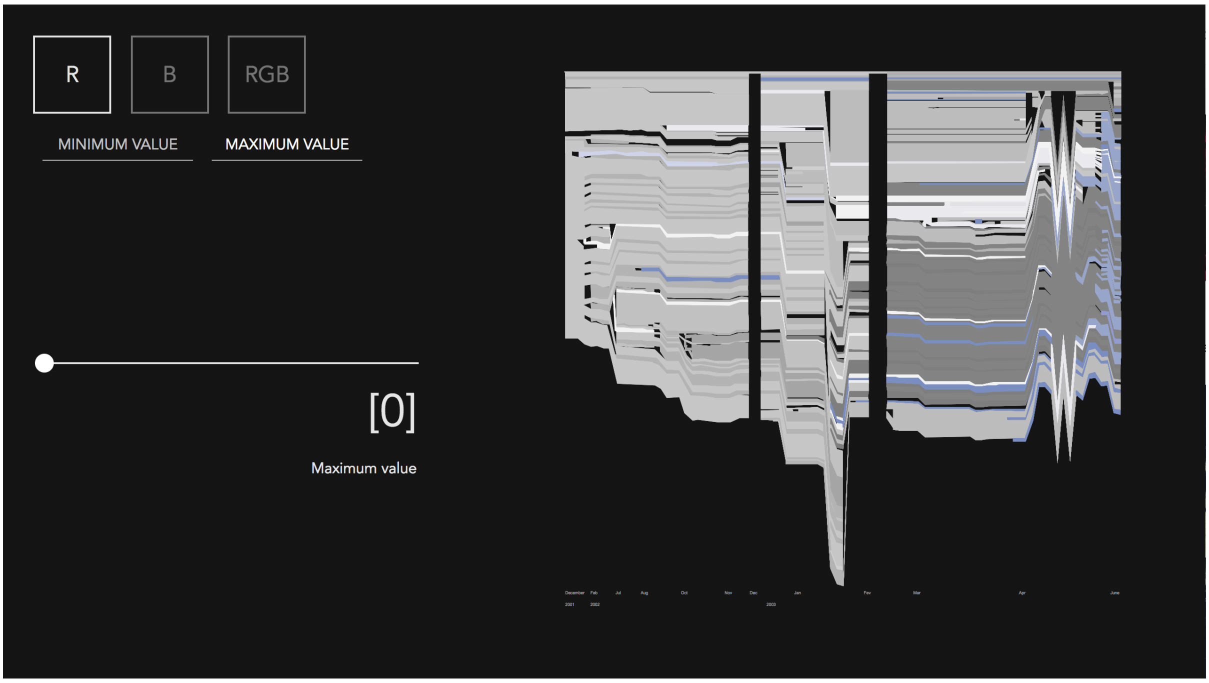

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[0]
Maximum value

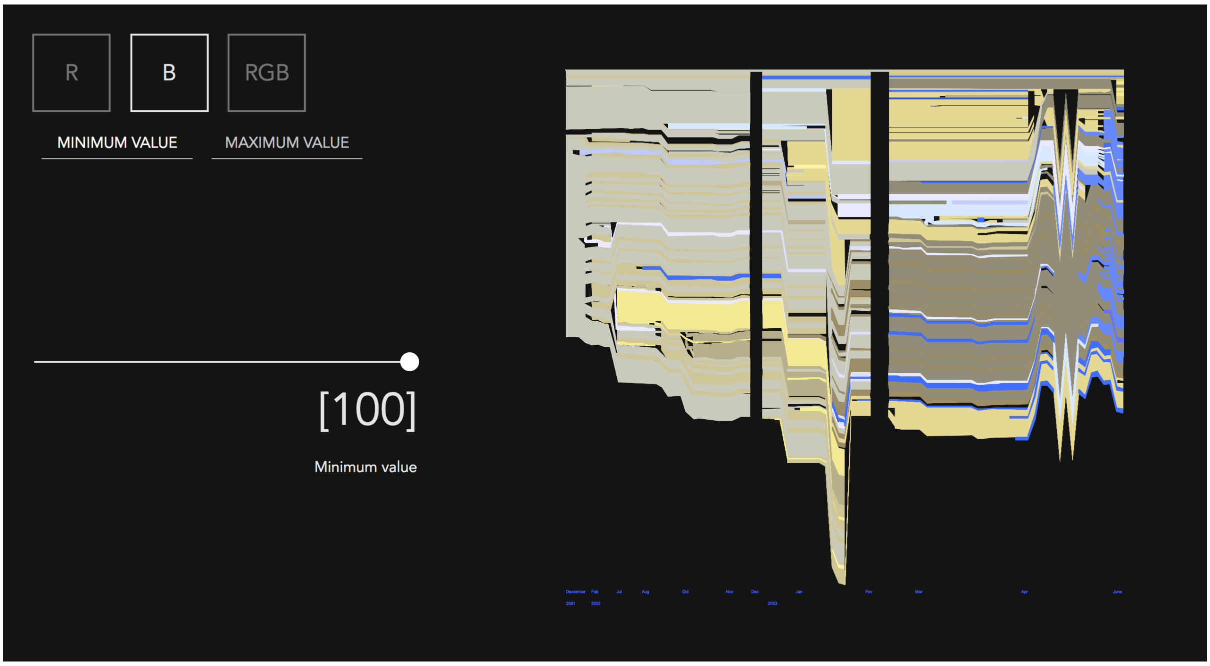

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[100]
Minimum value
G
[100]
Minimum value
B
[100]
Minimum value
SUBMIT VALUES

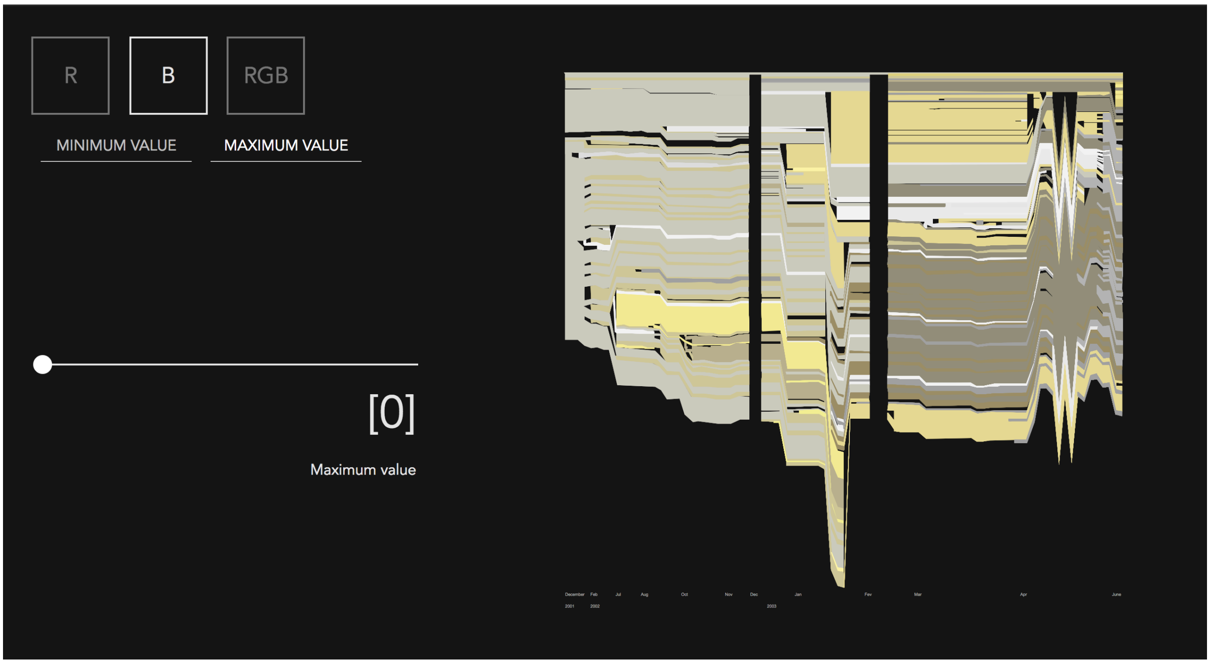

R
G
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[0]
Maximum value
G
[0]
Maximum value
B
[0]
Maximum value
SUBMIT VALUES

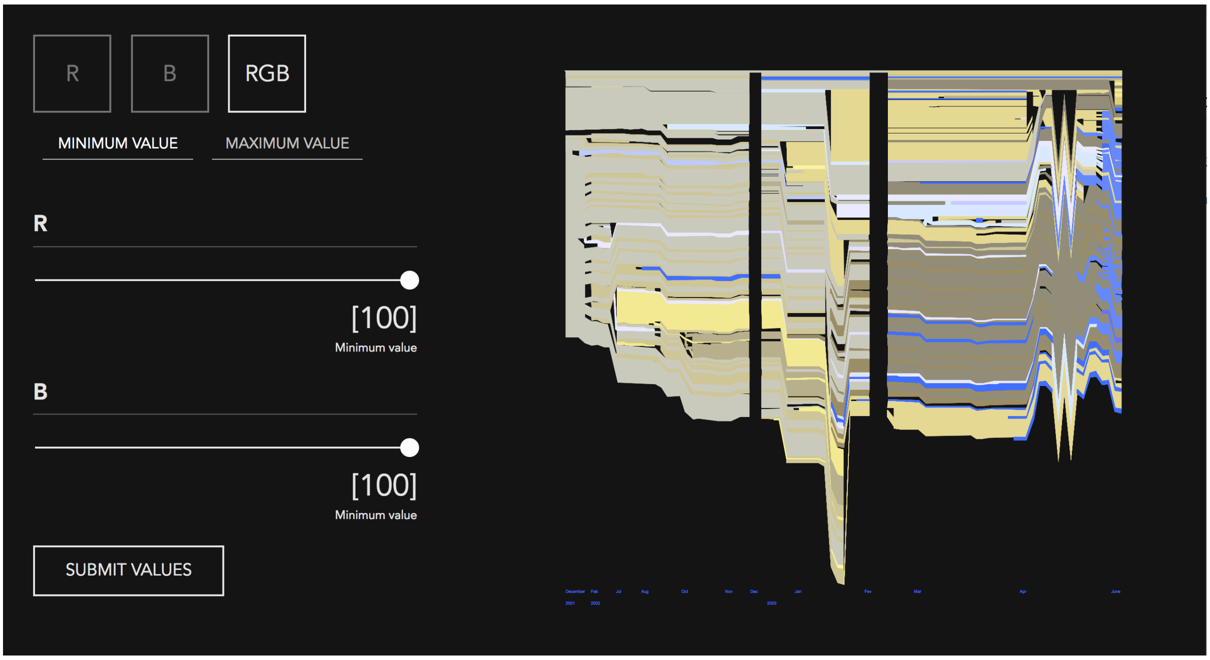
Attachment 4: Further UI Mockups of the (CVD) Interactive System



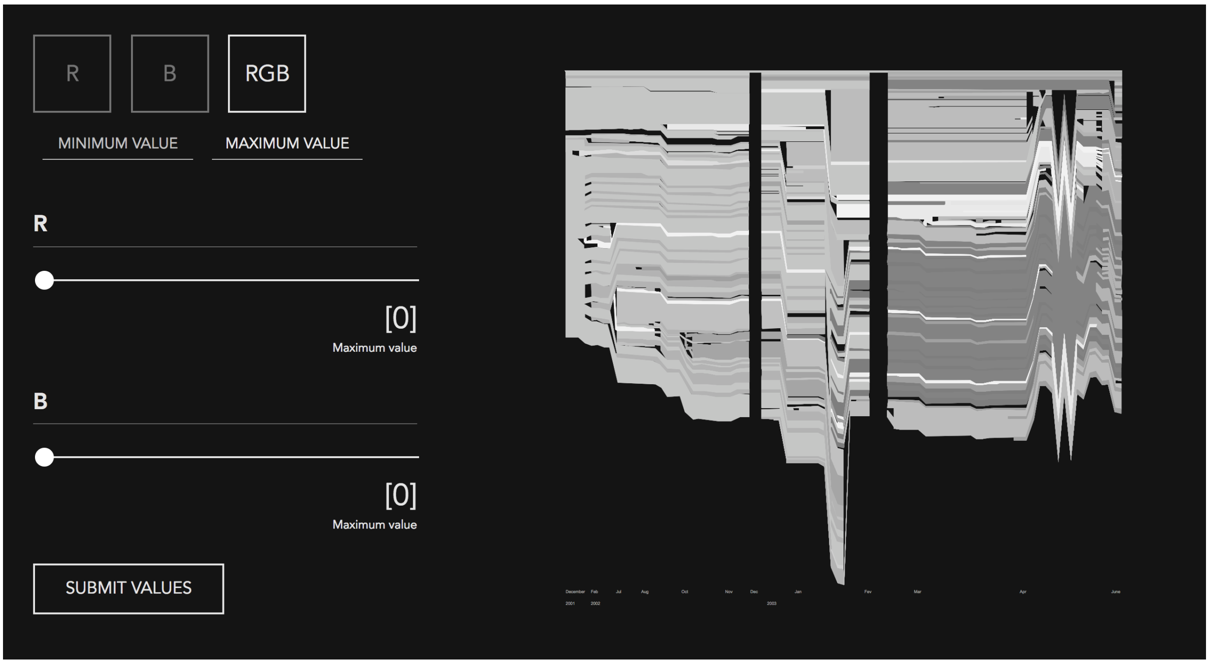



R
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[100]
Minimum value


R
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
[0]
Maximum value



R
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[100]
Minimum value
B
[100]
Minimum value
SUBMIT VALUES



R
B
RGB
MINIMUM VALUE
MAXIMUM VALUE
R
[0]
Maximum value
B
[0]
Maximum value
SUBMIT VALUES

Attachment 5: Online Questionnaire for the graphs' selection

Investigation on Information Visualization as a Color Blind User

This questionnaire´s goal is to evaluate which of the four types of information visualization is the most difficult for colour blind users to perceive. Therefore, the images in this questionnaire represent a simulation of how Red-Green Color Blind users see.

The estimated time to complete this questionnaire is 15-20min. All answers collected are confidential and will only be used for this masters study.

Thank you for your participation. Let's do this!

*Obrigatório

1. **Gender** *

   Marcar apenas uma oval.

   - Male
   - Female

2. **Age** *

3. **Qualifications** *

   Marcar apenas uma oval.

   - 6th Grade
   - 9th Grade
   - 12th Grade
   - Bachelor's Degree
   - Master's Degree
   - Doctorol Degree
   - None of the above

4. **Occupation** *

5. **Do you suffer from Color Vision Deficiency (CVD)?** *

   Marcar apenas uma oval.

   - Yes
   - No

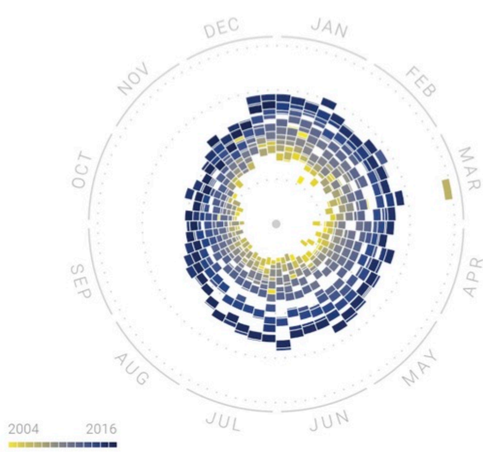
6. **If yes, what type of CVD do you suffer from?**
Marcar apenas uma oval.

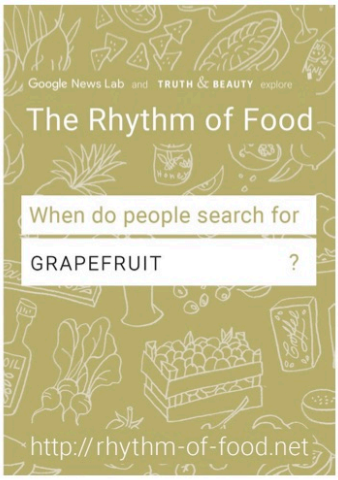
- Protanopia
- Deuteranopia
- Tritanopia
- Achromatopsia
- I'm not aware of my CVD type

A) Information Visualization: Trees

Please analyze the image below and answer the following questions.

The Rhythm of Food — Moritz Stefaner





7. **1. Locate an element on the graph and interpret it. How easy is the graph to read?** *
Marcar apenas uma oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very hard

8. **2. When interpreting the graph, it easy to distinguish between the colours from each other?** *
Marcar apenas uma oval.

- Yes
- No

9. **3. In order to decode this graph, do you believe that it is important to be able to distinguish the different colours?** *
Marcar apenas uma oval.

- Yes, I think it's fundamental.
- No, it's not relevant.

10. **4. How much data density (quantity of displayed info) do you consider this graph to have?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Little Data Density	⬭	⬭	⬭	⬭	⬭	A lot of Data Density

11. **5. Having in mind that this graph represents how many people search for grapefruit, do you consider the displayed information to be relevant?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Not at all.	⬭	⬭	⬭	⬭	⬭	Yes, very.

12. **6. In your opinion, in order to enhance the graph's perception, should other additional symbols and/or realistic characteristics be added?** *

Marcar apenas uma oval.

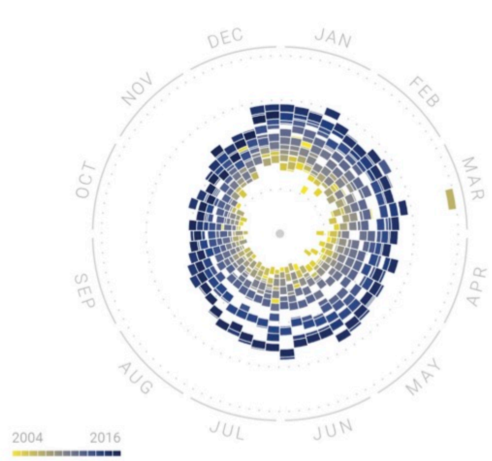
- ⬭ Yes, I think it would help with its perception.
- ⬭ No, I think the graph is fine this way.

A.1) Memorability

13. **7. Without looking at the image above, can you describe what you visualized and interpreted from the graph ?** *

A.2) Comparing Images

Image 1



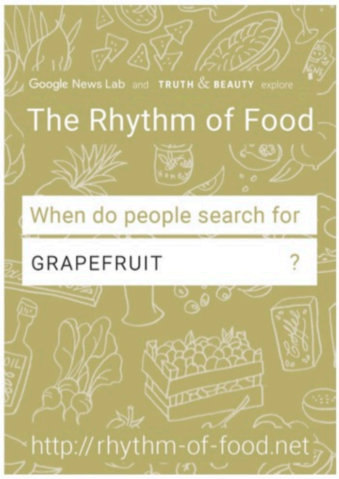
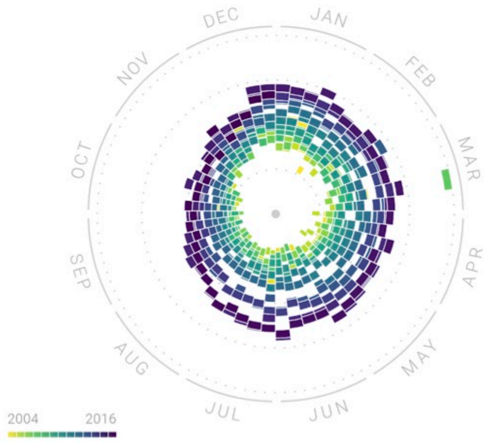
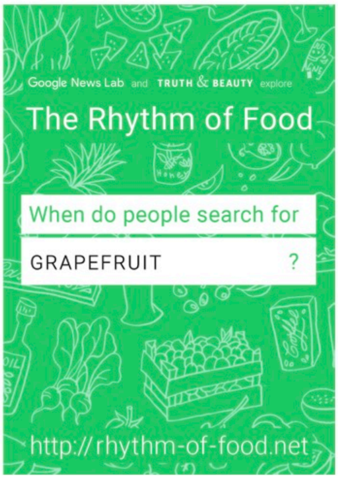


Image 2





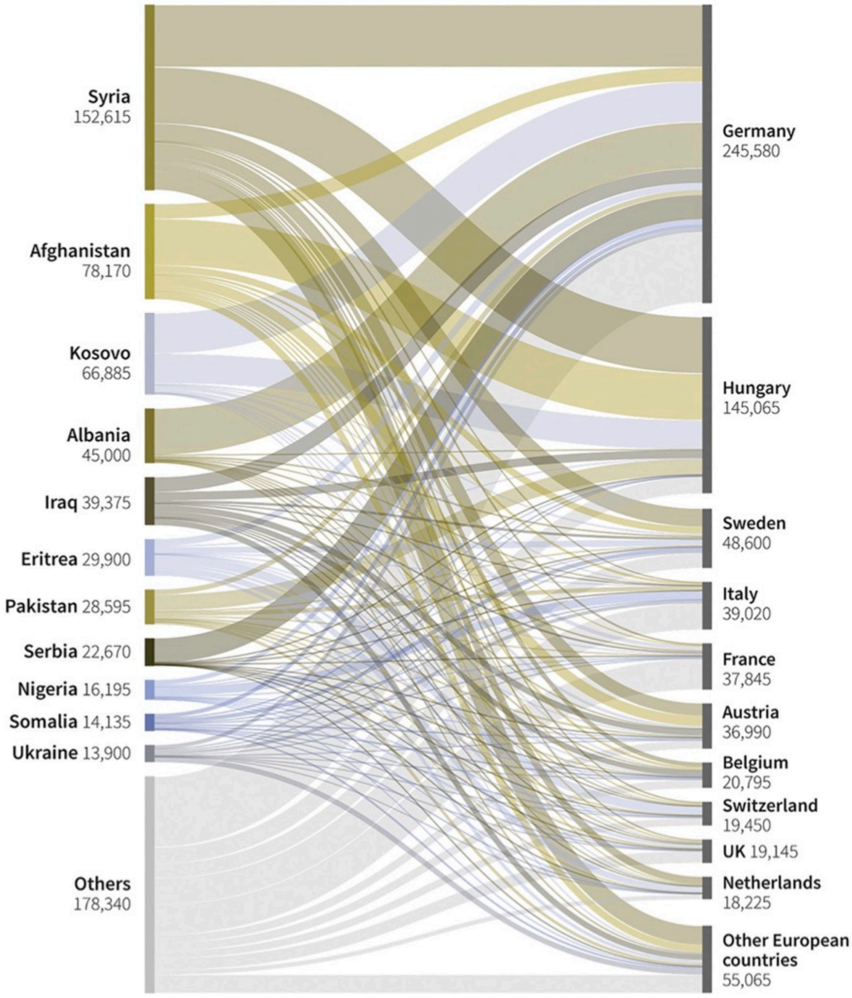
14. **8. When comparing Image 1 and Image 2, which one of them is more difficult to perceive?** *
Marcar apenas uma oval.

- Image 1 is more difficult to perceive.
- Image 2 is more difficult to perceive.

B) Information Visualisation: Network

Please analyze the image below and answer the following questions.

Europe's migration crisis: Asylum seekers in Europe



15. **9. Locate an element on the graph and interpret it. How easy is the graph to read?** *
Marcar apenas uma oval.

	1	2	3	4	5	
Very easy	⬭	⬭	⬭	⬭	⬭	Very hard

16. **10. When interpreting the graph, it easy to distinguish between the colours from each other?** *
Marcar apenas uma oval.

⬭ Yes
⬭ No

17. **11. In order to decode this graph, do you believe that it is important to be able to distinguish the different colours?** *

Marcar apenas uma oval.

- Yes, I think it's fundamental.
- No, it's not relevant.

18. **12. How much data density (quantity of information displayed) do you consider this graph to have?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Little Data Density						A lot of Data Density

19. **13. Having in mind that this graph represents the Europe's migration flow, do you consider the displayed information to be relevant?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Not at all.						Yes, very.

20. **14. In your opinion, in order to enhance the graph's perception, should other additional symbols and/or realistic characteristics be added?** *

Marcar apenas uma oval.

- Yes, I think it would help with its perception.
- No, I think the graph is fine this way.

B.1) Memorability

21. **15. Without looking at the image above, can you describe what you visualized and interpreted from the graph ?** *

B.2) Comparing Images

Image 3

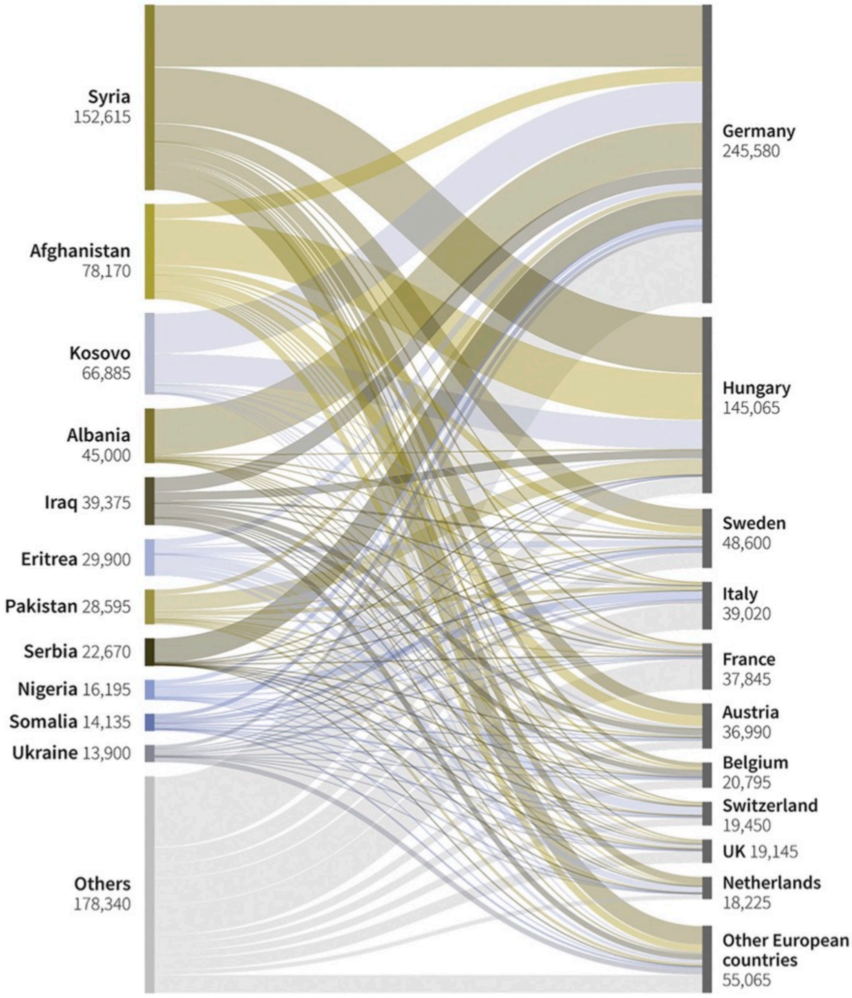
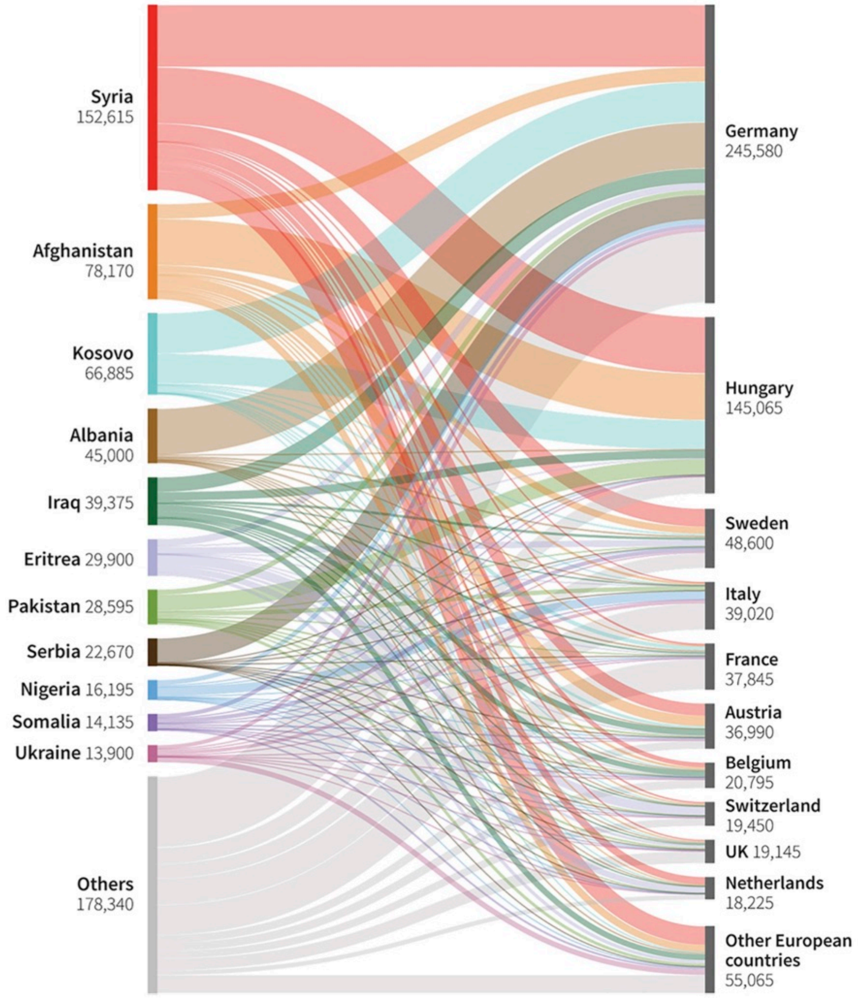

Syria
152,615
Afghanistan
78,170
Kosovo
66,885
Albania
45,000
Iraq 39,375
Eritrea 29,900
Pakistan 28,595
Serbia 22,670
Nigeria 16,195
Somalia 14,135
Ukraine 13,900
Others
178,340
Germany
245,580
Hungary
145,065
Sweden
48,600
Italy
39,020
France
37,845
Austria
36,990
Belgium
20,795
Switzerland
19,450
UK 19,145
Netherlands
18,225
Other European countries
55,065

Image 4



22. **16. When comparing Image 3 and Image 4 which one of them is more difficult to perceive?** *

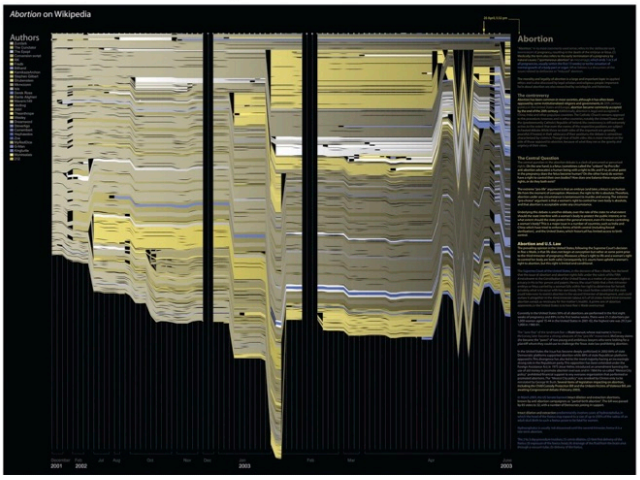
Marcar apenas uma oval.

- Image 3 is more difficult to perceive.
- Image 4 is more difficult to perceive.

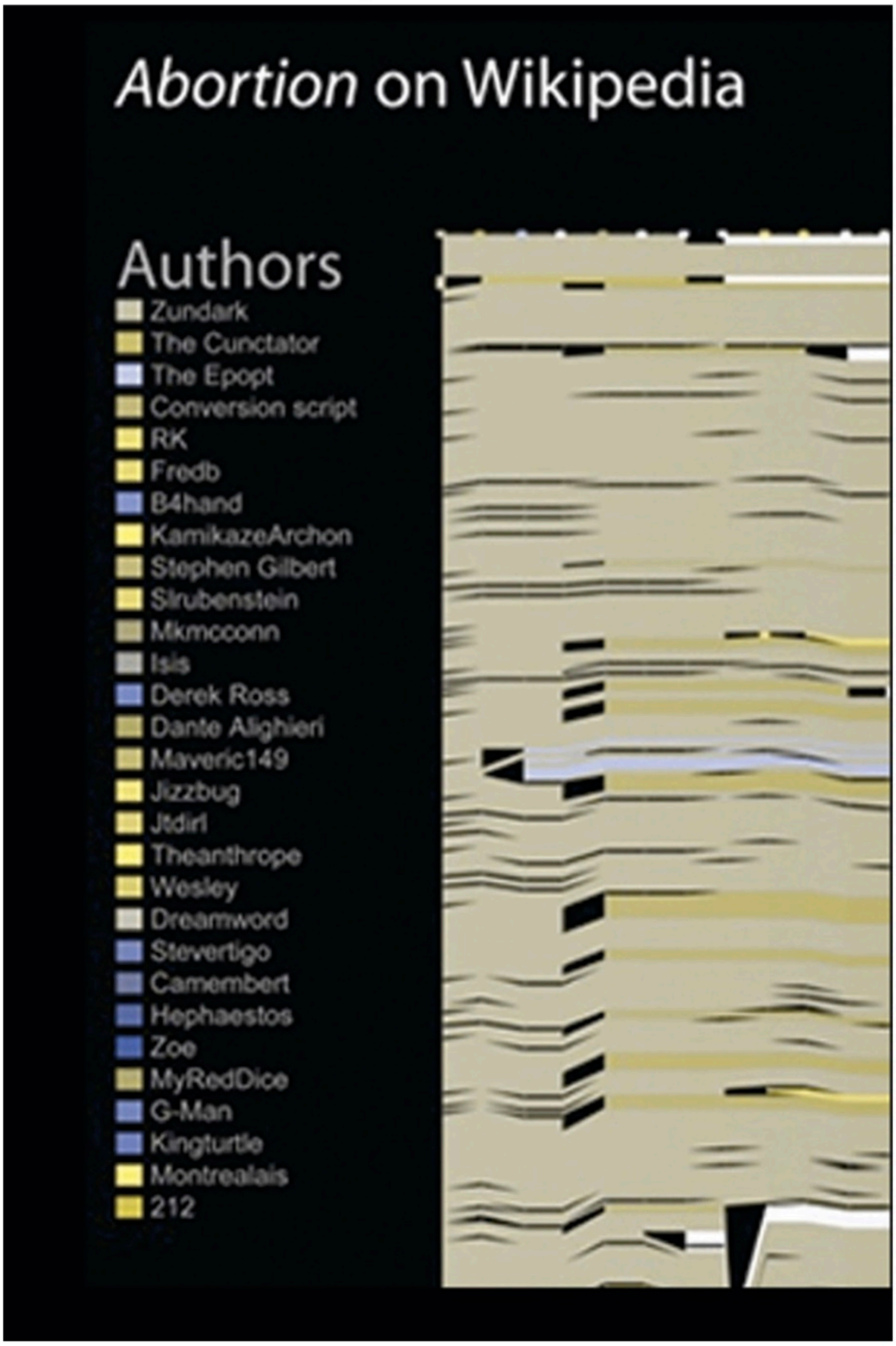
C) Information Visualization: Timeline and Flow

Please analyze the image below and answer the following questions.

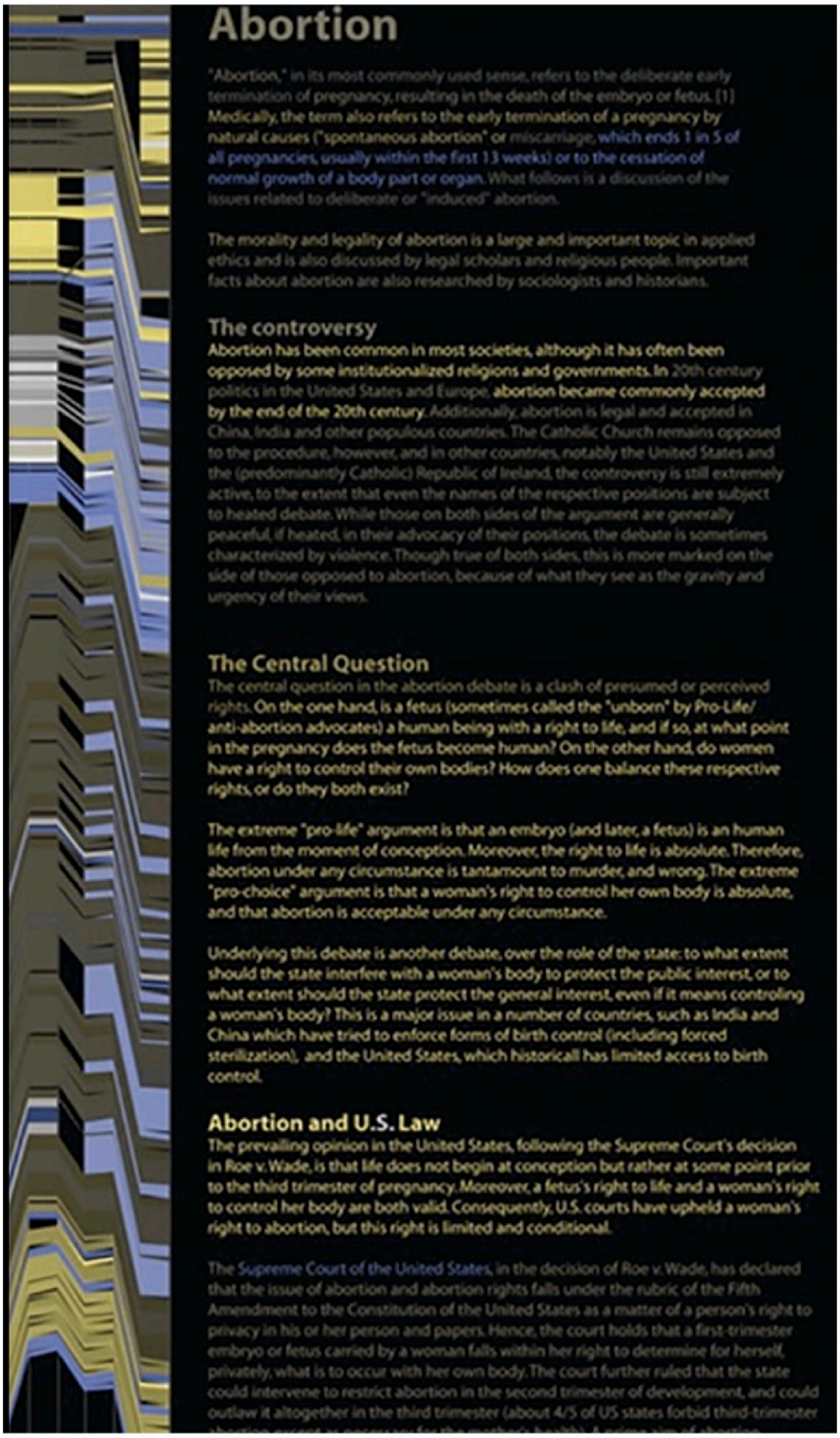
History Flow, 2003 — Martin Wattenberg

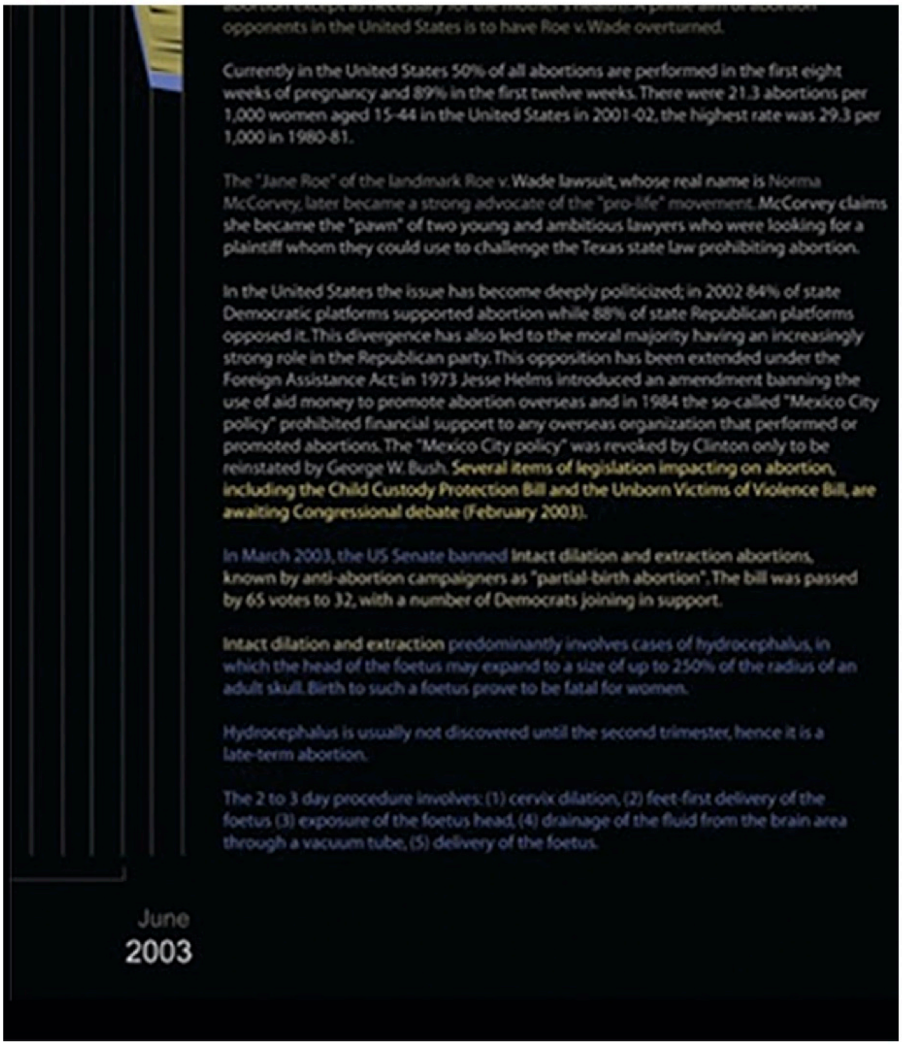


Authors which edited the articles



Abortion Article on Wikipedia


Abortion
"Abortion," in its most commonly used sense, refers to the deliberate early termination of pregnancy, resulting in the death of the embryo or fetus. [1] Medically, the term also refers to the early termination of a pregnancy by natural causes ("spontaneous abortion" or miscarriage, which ends 1 in 5 of all pregnancies, usually within the first 13 weeks) or to the cessation of normal growth of a body part or organ. What follows is a discussion of the issues related to deliberate or "induced" abortion.
The morality and legality of abortion is a large and important topic in applied ethics and is also discussed by legal scholars and religious people. Important facts about abortion are also researched by sociologists and historians.
The controversy
Abortion has been common in most societies, although it has often been opposed by some institutionalized religions and governments. In 20th century politics in the United States and Europe, abortion became commonly accepted by the end of the 20th century. Additionally, abortion is legal and accepted in China, India and other populous countries. The Catholic Church remains opposed to the procedure, however, and in other countries, notably the United States and the (predominantly Catholic) Republic of Ireland, the controversy is still extremely active, to the extent that even the names of the respective positions are subject to heated debate. While those on both sides of the argument are generally peaceful, if heated, in their advocacy of their positions, the debate is sometimes characterized by violence. Though true of both sides, this is more marked on the side of those opposed to abortion, because of what they see as the gravity and urgency of their views.
The Central Question
The central question in the abortion debate is a clash of presumed or perceived rights. On the one hand, is a fetus (sometimes called the "unborn" by Pro-Life/anti-abortion advocates) a human being with a right to life, and if so, at what point in the pregnancy does the fetus become human? On the other hand, do women have a right to control their own bodies? How does one balance these respective rights, or do they both exist?
The extreme "pro-life" argument is that an embryo (and later, a fetus) is an human life from the moment of conception. Moreover, the right to life is absolute. Therefore, abortion under any circumstance is tantamount to murder, and wrong. The extreme "pro-choice" argument is that a woman's right to control her own body is absolute, and that abortion is acceptable under any circumstance.
Underlying this debate is another debate, over the role of the state: to what extent should the state interfere with a woman's body to protect the public interest, or to what extent should the state protect the general interest, even if it means controling a woman's body? This is a major issue in a number of countries, such as India and China which have tried to enforce forms of birth control (including forced sterilization), and the United States, which historicall has limited access to birth control.
Abortion and U.S. Law
The prevailing opinion in the United States, following the Supreme Court's decision in Roe v. Wade, is that life does not begin at conception but rather at some point prior to the third trimester of pregnancy. Moreover, a fetus's right to life and a woman's right to control her body are both valid. Consequently, U.S. courts have upheld a woman's right to abortion, but this right is limited and conditional.
The Supreme Court of the United States, in the decision of Roe v. Wade, has declared that the issue of abortion and abortion rights falls under the rubric of the Fifth Amendment to the Constitution of the United States as a matter of a person's right to privacy in his or her person and papers. Hence, the court holds that a first-trimester embryo or fetus carried by a woman falls within her right to determine for herself, privately, what is to occur with her own body. The court further ruled that the state could intervene to restrict abortion in the second trimester of development, and could outlaw it altogether in the third trimester (about 4/5 of US states forbid third-trimester



23. **17. Locate an element on the graph and interpret it. How easy is the graph to read?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very hard

24. **18. When interpreting the graph, it easy to distinguish between the colours from each other?** *

Marcar apenas uma oval.

- ◯ Yes
- ◯ No

25. **19. In order to decode this graph, do you believe that it is important to be able to distinguish the different colours?** *

Marcar apenas uma oval.

- Yes, I think it's fundamental.
- No, it's not relevant.

26. **20. How much data density (quantity of information displayed) do you consider this graph to have?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Little Data Density						A lot of Data Density

27. **21. Having in mind that this graph represents the editing of articles about abortion on Wikipedia, do you classify the displayed info as relevant?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Not at all.						Yes, very.

28. **22. In your opinion, in order to enhance the graph's perception, should other additional symbols and/or realistic characteristics be added?** *

Marcar apenas uma oval.

- Yes, I think it would help with its perception.
- No, I think the graph is fine this way.

C.1) Memorability

29. **23. Without looking at the image above, can you describe what you visualized and interpreted from the graph ?** *

C.2) Comparing Images

Image 5

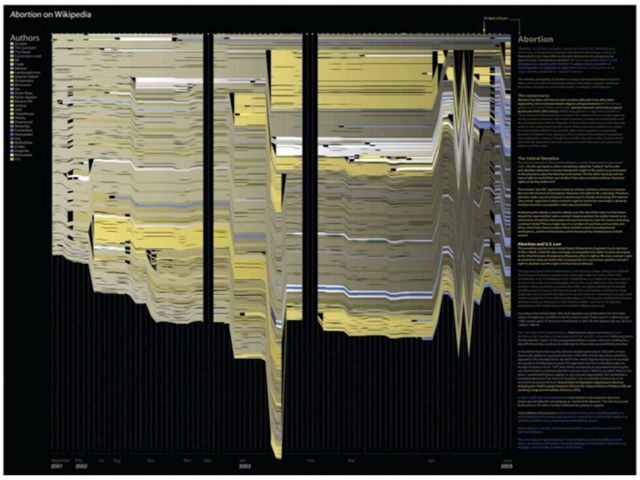
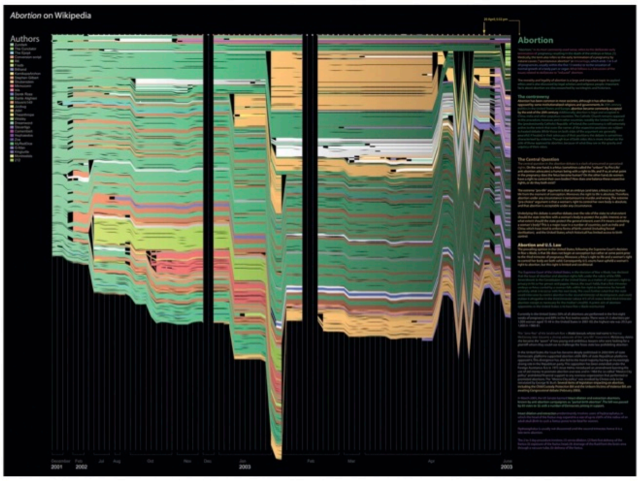


Image 6



30. **24. If comparing Image 5 and Image 6 which one of them is more difficult to perceive?** *

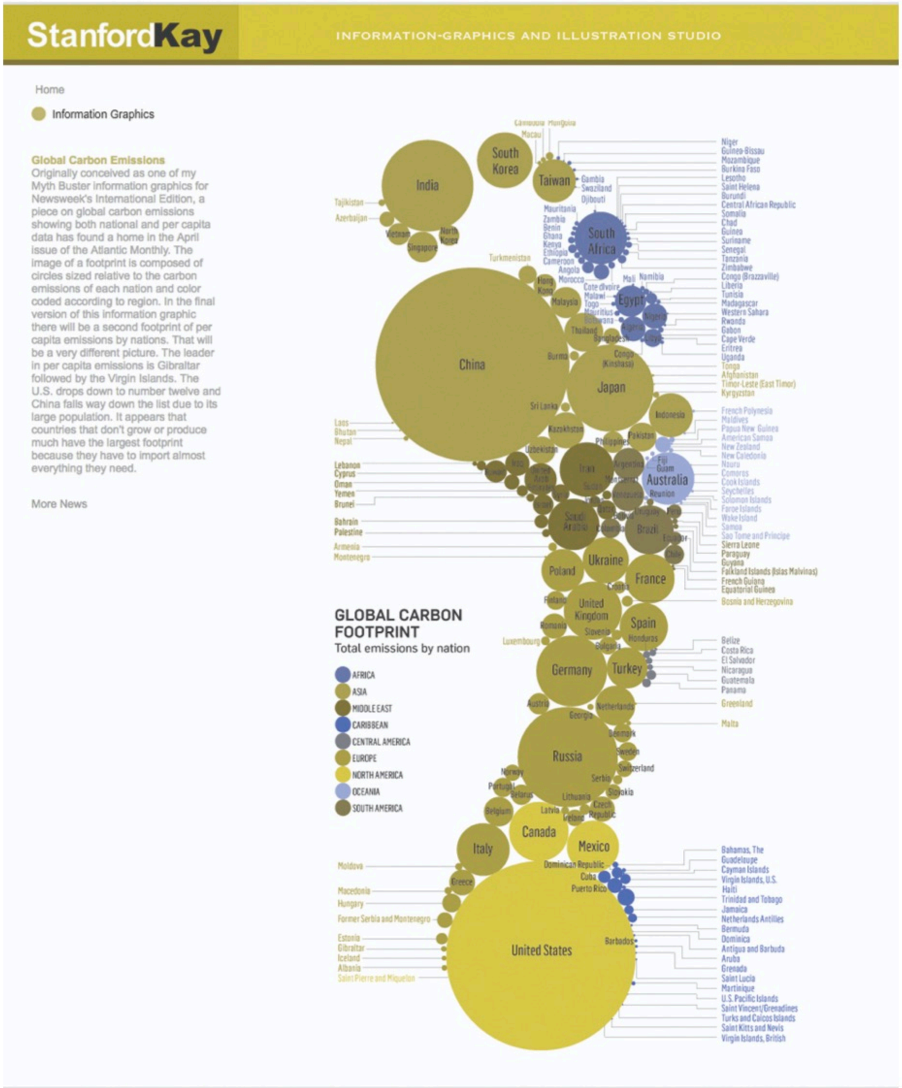
Marcar apenas uma oval.

- Image 5 is more difficult to perceive.
- Image 6 is more difficult to perceive.

D) Information Visualization: Networks

Please analyze the image below and answer the following questions.

Stanford Kay: Circle Packing



31. **25. Locate an element on the graph and interpret it. How easy is the graph to read?** *

Marcar apenas uma oval.

	1	2	3	4	5	
Very easy	◯	◯	◯	◯	◯	Very hard

32. **26. When interpreting the graph, is it easy to distinguish between the colours from each other?** *

Marcar apenas uma oval.

◯ Yes

◯ No

33. **27. In order to decode this graph, do you believe that it is important to be able to distinguish the different colours?** *
Marcar apenas uma oval.

- Yes, I think it's fundamental.
- No, it's not relevant.

34. **28. How much data density (quantity of information displayed) do you consider this graph to have?** *
Marcar apenas uma oval.

	1	2	3	4	5	
Little Data Density						A lot of Data Density

35. **29. Having in mind that this graph represents the global carbon footprint by nation/countries, do you consider the displayed information to be relevant?** *
Marcar apenas uma oval.

	1	2	3	4	5	
Not at all.						Yes, very.

36. **30. In your opinion, in order to enhance the graph's perception, should other additional symbols and/or realistic characteristics be added?** *
Marcar apenas uma oval.

- Yes, I think it would help with its perception.
- No, I think the graph is fine this way.

D.1) Memorability

37. **31. Without looking at the image above, can you describe what you visualized and interpreted from the graph ?** *

D.2) Comparing Images

Image 7

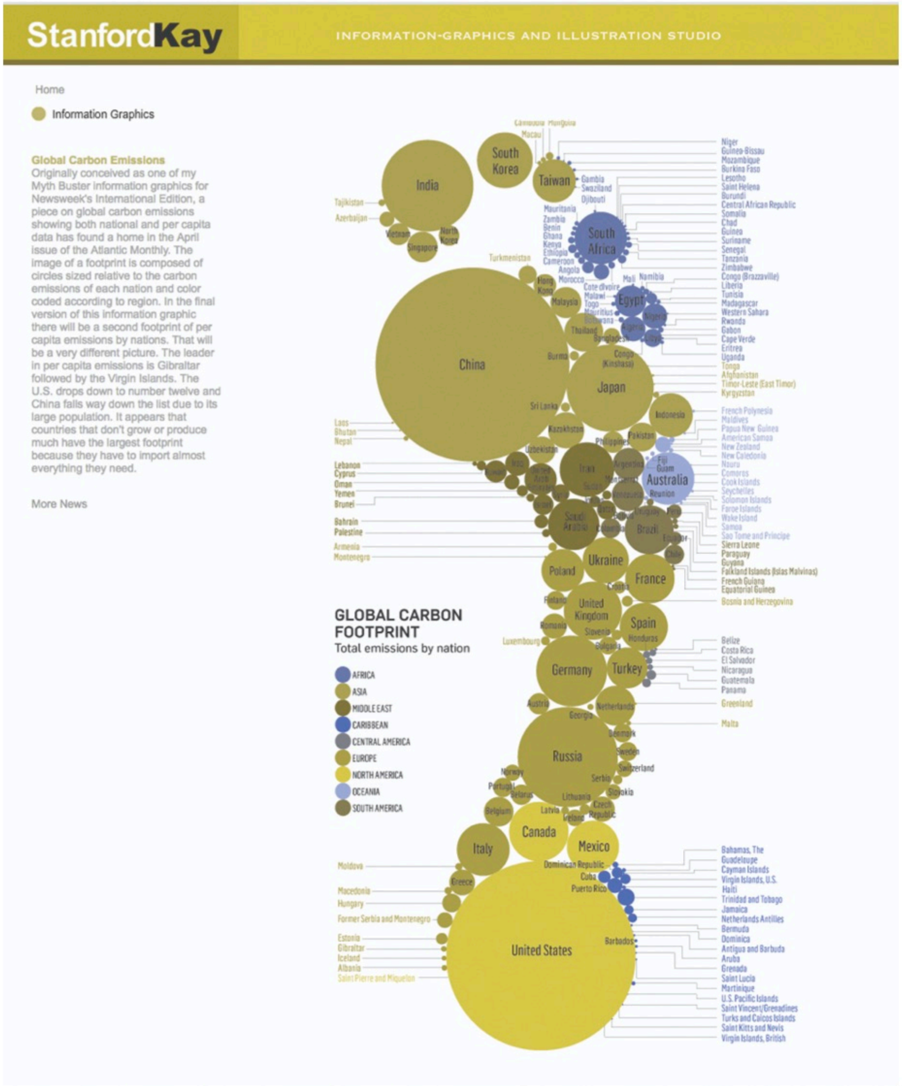
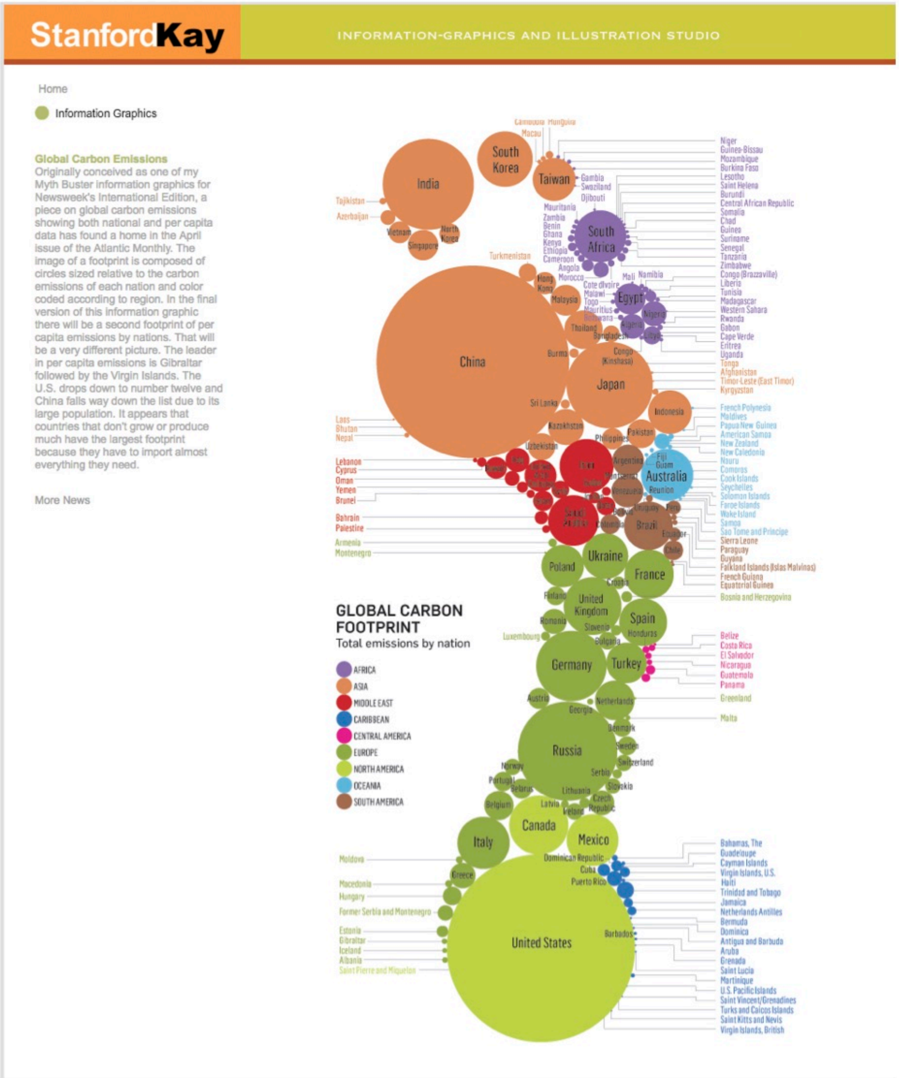

StanfordKay
INFORMATION-GRAPHICS AND ILLUSTRATION STUDIO
Home
Information Graphics
Global Carbon Emissions
Originally conceived as one of my Myth Buster information graphics for Newsweek's International Edition, a piece on global carbon emissions showing both national and per capita data has found a home in the April issue of the Atlantic Monthly. The image of a footprint is composed of circles sized relative to the carbon emissions of each nation and color coded according to region. In the final version of this information graphic there will be a second footprint of per capita emissions by nations. That will be a very different picture. The leader in per capita emissions is Gibraltar followed by the Virgin Islands. The U.S. drops down to number twelve and China falls way down the list due to its large population. It appears that countries that don't grow or produce much have the largest footprint because they have to import almost everything they need.
More News
GLOBAL CARBON FOOTPRINT
Total emissions by nation
AFRICA
ASIA
MIDDLE EAST
CARIBBEAN
CENTRAL AMERICA
EUROPE
NORTH AMERICA
OCEANIA
SOUTH AMERICA
India
South Korea
Taiwan
South Africa
China
Japan
Egypt
Australia
Ukraine
Poland
France
United Kingdom
Spain
Germany
Turkey
Russia
Italy
Canada
Mexico
United States

Image 8



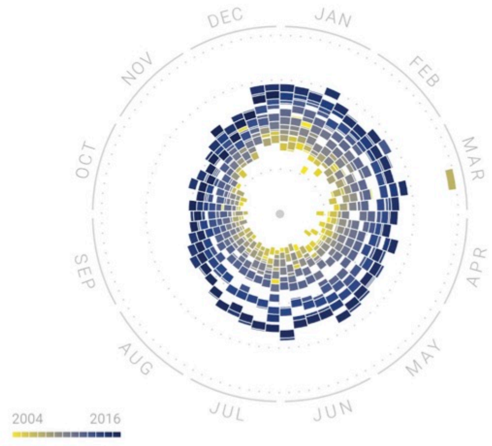
38. **32. If comparing Image 7 and Image 8 which one of them is more difficult to perceive?** *

Marcar apenas uma oval.

- Image 7 is more difficult to perceive.
- Image 8 is more difficult to perceive.

You're almost done! Just one more question!

Image 1


DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
2004
2016

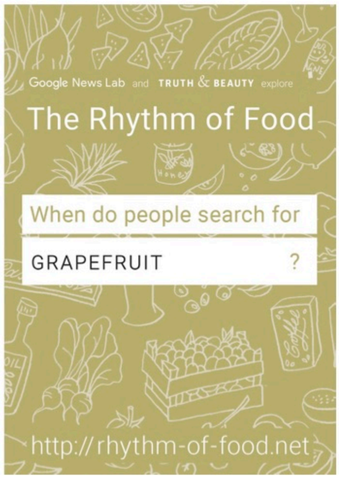

Google News Lab and TRUTH & BEAUTY explore
The Rhythm of Food
When do people search for
GRAPEFRUIT ?
http://rhythm-of-food.net

Image 2

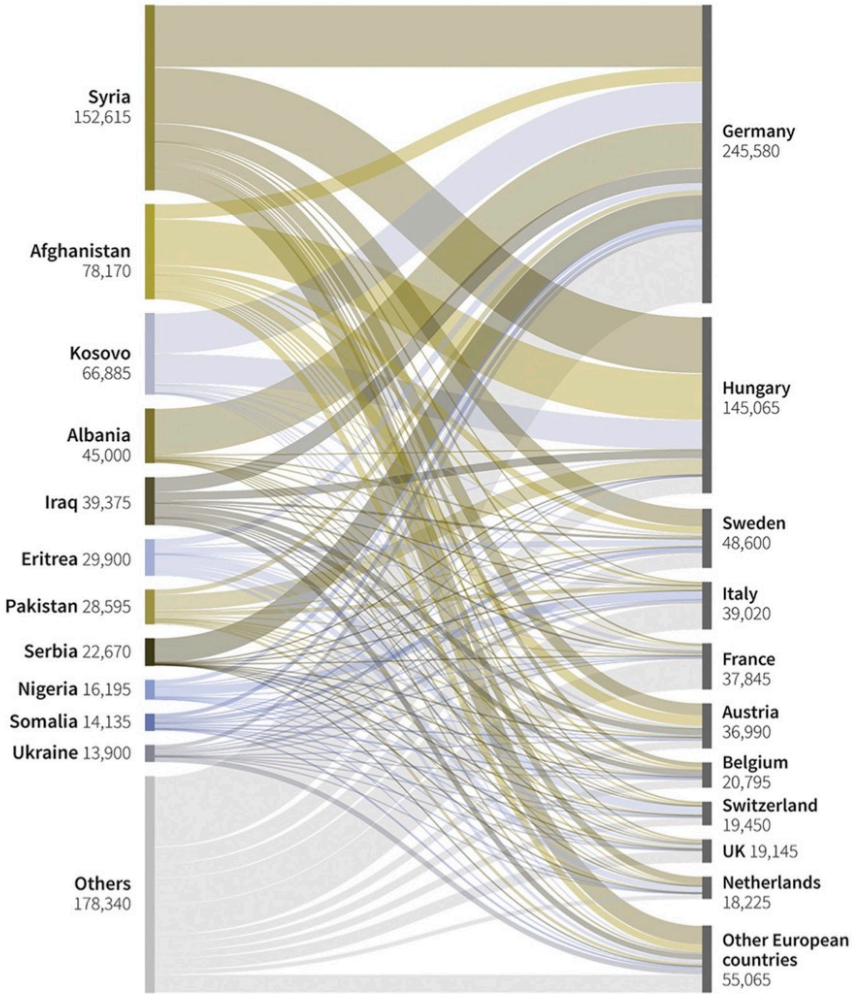

Syria 152,615
Afghanistan 78,170
Kosovo 66,885
Albania 45,000
Iraq 39,375
Eritrea 29,900
Pakistan 28,595
Serbia 22,670
Nigeria 16,195
Somalia 14,135
Ukraine 13,900
Others 178,340
Germany 245,580
Hungary 145,065
Sweden 48,600
Italy 39,020
France 37,845
Austria 36,990
Belgium 20,795
Switzerland 19,450
UK 19,145
Netherlands 18,225
Other European countries 55,065

Image 3

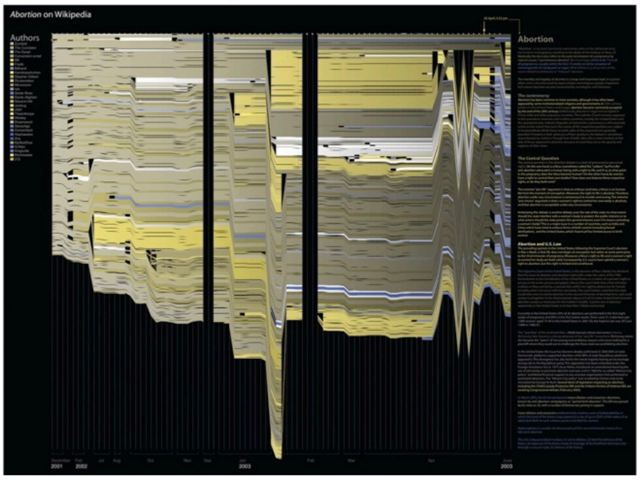
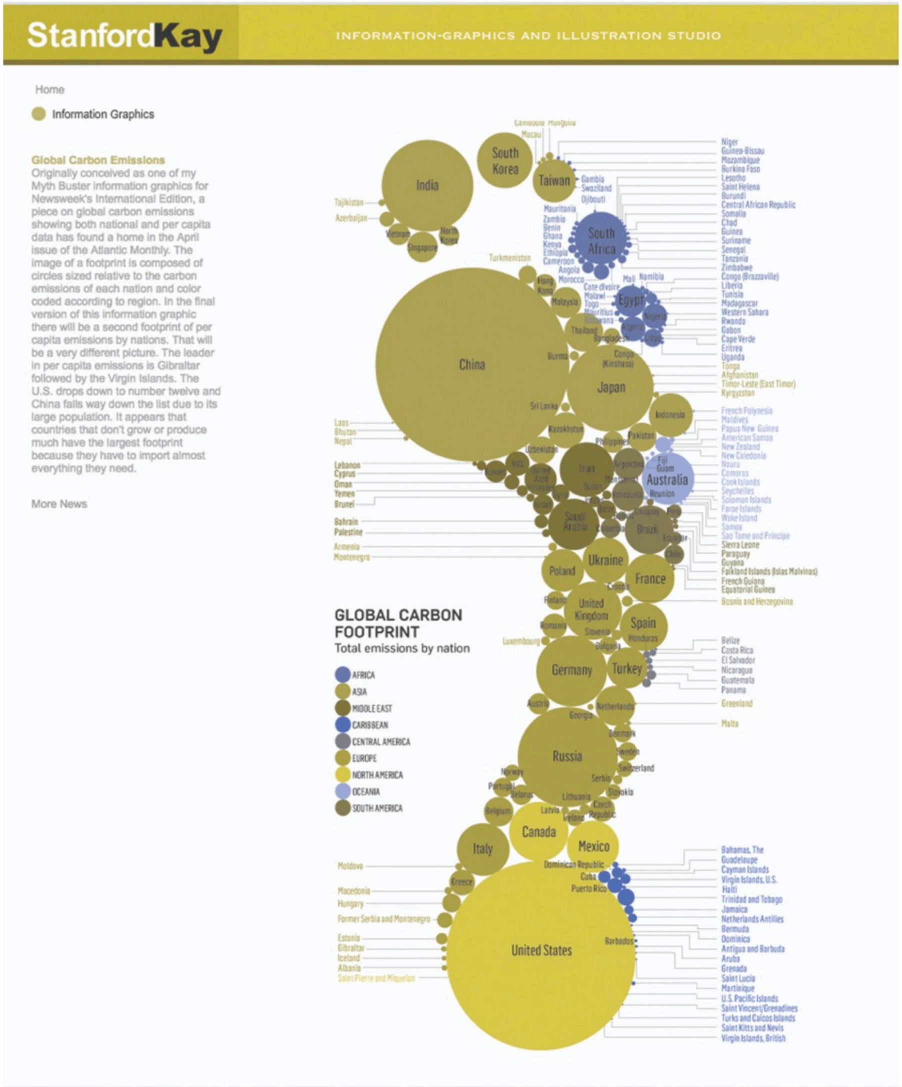


Image 4



39. **33. From all the previous shown images which one do you consider to be the most difficult to perceive when specially taking color into consideration?** *

Marcar apenas uma oval.

- Image 1
- Image 2
- Image 3
- Image 4

Com tecnologia Google Forms