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Reimagining Design: Exploring the Potential of the Infinite Canvas for Collaborative Interactive Articles

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Vienna, 1st September, 2023

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Philipp Klein, BSc.

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Wien, 1. September 2023

Philipp Klein

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Kurzfassung

Mit der fortschreitenden Digitalisierung, welche Kommunikation und Konsum von Inhalten verändert, sind Kollaboration und kollektive Ideenfindung zu grundlegenden Elementen moderner Webtechnologien geworden. Während interaktive Artikel darauf abzielen, die aktive Erkundung von Informationen zu fördern, bleibt die Integration von Kollaboration und Anwendungen wie der unendlichen Leinwand in diesem Kontext noch weitgehend unerforscht.

Diese Arbeit erforscht die Chancen und Grenzen dieses Bereichs. Sie präsentiert die unendliche Leinwand und untersucht ihre Stärken und Schwächen für kollaborative interaktive Artikel. Dafür wurde eine Anwendung in Miro, einer webbasierten unendlichen Leinwand für kreative Zusammenarbeit, gestaltet, wodurch Design und Implementierung einer solchen Anwendung untersucht wurde. In einer Thinking-Aloud User Studie wird diese Anwendung und ihre Integration in einer unendlichen Leinwand erprobt.

Dadurch wurde verdeutlicht, dass die unendliche Leinwand einen immersiven virtuellen Raum bietet, während das kollaborative Design von Artefakten neue Herausforderungen mit sich bringt. Die Unterscheidung zwischen gemeinsam genutzten und individuellen Artefakten unterstreicht die Bedeutung der räumlichen Einbettung des kollaborativen Artefakts.

Zusätzlich identifiziert diese Arbeit zwei unterschiedliche Benutzerrollen für das Design kollaborativer interaktiver Artikel: Moderator:innen, die Gruppenaktivitäten leiten, und Teilnehmer:innen, die Erkenntnisse suchen. Dafür wird das Konzept "Gamestorming" als Rahmen für zielgerichtete Zusammenarbeit verwendet, um ansprechende Gruppenaktivitäten anzubieten. In Verbindung mit semantischen Informationen auf einer unendlichen Leinwand ergeben sich dadurch neue Anwendungsmöglichkeiten.

Darüber hinaus erlauben Methoden aus der Informationsvisualisierung die Erstellung ansprechender und interaktiver Artefakte. Im Kontext von Visual Analytics dient die unendliche Leinwand als dynamische visuelle Datenbank, die eine direkte Interaktion mit Datenentitäten und -beziehungen erlaubt. Infolgedessen können Informationsvisualisierungen eine Übersicht und die Erkundung der Inhalte einer unendlichen Leinwand ermöglichen.

Letztendlich zeigt diese Arbeit, wie das Potenzial von interaktiven Artikeln und Visualisierungen auf der unendlichen Leinwand genutzt werden kann.

Abstract

As digital technology continues to reshape communication and content consumption, collaboration and collective ideation have become fundamental to modern web technologies. Interactive articles aim to encourage active information exploration to foster knowledge creation. However, the integration of collaboration and tools like the infinite canvas remains unexplored in this context.

This thesis investigates the opportunities and limitations of this area. It presents a exploration of the infinite canvas and examines its strengths and challenges for collaborative interactive articles. Through the design and implementation of an application built for Miro, a web-based platform utilizing the infinite canvas for creative collaboration, it investigates the design process for the infinite canvas. In a thinking-aloud user study, this thesis evaluates this application and its integration in this environment.

This revealed that the infinite canvas offers an immersive virtual space, though collaborative artifact design introduces unique challenges. The distinction between shared and individual artifacts underscores the importance of considering the collaborative artifact space. Providing a clear user experience proved to be crucial, especially for inexperienced users. Tasks and input methods for end-users need to be kept simple.

This thesis identifies two distinct user roles for the design of collaborative interactive articles: facilitators who guide group activities and participants who seek insights. It adopts the idea of Gamestorming as a framework for goal-driven collaboration to facilitate group work and provide engaging activities. Combined with semantic information present on an infinite canvas, this opens up further use cases.

Moreover, information visualization techniques highlight possibilities to create engaging and interactive artifacts on the infinite canvas. In the context of visual analytics, the infinite canvas acts as a dynamic visual database, enabling direct interaction with data entities and relationships. Consequently, information visualizations can provide an overview of the infinite canvas and enhance the exploration of content.

In the end, this thesis contributes to the collaborative and interactive potential of the infinite canvas, offering insights for the design of interactive articles and explorable visualizations.

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CHAPTER 1

Introduction

With the integration of computer technology into our daily lives, digital tools have fundamentally changed the way we interact with information and with each other. This created a sheer endless pool of possibilities, and today, most people use some form of technology on a daily basis. Over the last decade, the internet has allowed us to become more interconnected and has shaped the world we live in. It not only allows us to communicate with people on the other side of the globe but also gives us fast and easy access to books, movies, songs, articles, and much more. Nowadays, it seems that most of the information is just one click away.

This not only affected the way we consume information and media, but also how it is represented. In many cases, content is no longer desired in a static form but people rather demand dynamic interactions that allow them to interact with the information in their own way. Additionally, the time we spend with digital media is increasing each year, as a report by the GlobalWebIndex shows [WPB19]. This constant occupation with digital interfaces made people highly skilled at naturally interacting with such systems and interactivity is considered a crucial part in modern computer technology. As a result, an increasing amount of teachers, educators, journalists, and designers started to make use of the benefits that digital tools provide in their respective field. For example, interactivity in education can support students learning experience by enhancing their motivation and engagement [HS12, HBM07, DD18, Bau03]. Today, the integration of interactive elements and information visualization has found its way into digital articles, a relatively new research area within computer science that aims to incorporate interactivity to convey information effectively.

"Interactive Articles" or "Explorable Explanations" have emerged as a communication approach that leverages interactive elements to enhance the reading experience [HCHC20]. These articles aim to go beyond traditional static content and provide readers with a more engaging and enjoyable way to explore information. By incorporating various interaction techniques into a cohesive digital narrative, interactive articles create a dynamic and immersive experience for users. Although this concept has been utilized by newspapers, educators, and designers in the past, the creation of interactive articles is still a relatively new fields of research.

In interactive articles, information visualization is a common element to show data through visual representations and graphical illustrations. Modern computer technology has drastically shaped this field of research, as it allows for much more sophisticated ways to show and interact with data. While traditional information visualizations are usually static data representations, modern computer technology allows us to integrate complex interactivity methods as a communication method. Today, information visualization combines many areas such as human-computer interaction, visual design, cognitive science, and interaction design and is widely used in education, information communication, journalism, and other fields of application. Information visualizations allow consumers to draw insights from abstract data that would be incomprehensible otherwise.

Over time, digital applications have fundamentally changed the way we access information, communicate, and collaborate. However, Hohman et al. argue that while "the technology to distribute our ideas has grown in leaps and bounds, the interfaces have remained largely the same" [HCHC20]. Thus, they highlight the importance of exploring new forms of communication and data representation that digital technologies provides.

One of these new concept to show information is the "Infinite Canvas". This highly interactive environment is based on the idea of physical whiteboards. Thus, they are also referred to as "Infinite Whiteboards" and "Infinite Boards". As the name suggests, their main distinction from physical whiteboards is their possibility to embed information on an infinitely expandable canvas, something that is not possible in the physical world. On these digital canvases editors can often add objects, like shapes, text, notes, videos, images, etc. The concept of the infinite canvas was originally introduces by Scott McCloud in his book "Reinventing Comics" for the creation of webcomics [McC00]. However, this idea of an endless digital space gained a lot of popularity in other areas as well and over time, multiple applications emerged that applied it for a more general use. Today, the infinite canvas is applied in many application areas, becoming a popular tool for all forms of content creation and presentation. However, its opportunities and limitations in the fields of collaborative and interactive information visualization are complex and have not been fully explored so far.

The concept of the infinite canvas aligns with the idea of providing more engaging content through the use of information visualization concepts, emphasizing interactivity and collaboration. Interactivity, in its broadest sense, involves the exchange of information between two or more entities, with feedback being an integral part of the process [Kio02]. Similarly, collaboration entails multiple entities working together to achieve a common goal or complete a task. In the realm of computer technology, collaboration is often realized through digital systems that allow multiple individuals to collaborate on the same content. The dynamic capabilities of the modern web have opened up a wide range of applications for designers, educators, writers, publishers, and researchers to create interactive and collaborative systems.

However, relatively little research has been conducted on the possibilities that information visualization can add to the design of interactive articles in infinite canvas environments. As mentioned earlier, the current trend towards digital information presentation allows for the integration of more sophisticated interactivity and collaboration in information presentations. In the past, traditional articles mainly relied on static content, a concept rooted in more traditional communication theories. However, modern data representations must leverage the full potential that digital technology provides. The rapid changes in our education and communication environments have been noted by many scientists. For example, as early as 2001, Prensky argued that, in the context of education, “today’s students are no longer the people our educational system was designed to teach” [Pre01, p 1].

Given this context, it becomes essential to examine the possibilities and discuss the integration of collaborative information visualization activities in interactive articles. By investigating information visualization in interactive articles and exploring their potential use on an infinite canvas, we can demonstrate how collaborative and interactive content can be applied in these innovative design spaces.

The main aim of this thesis is to explore the possibilities of collaborative and interactive activities on an infinite canvas and to provide directions on how more dynamic information communication can be applied in these environments. To achieve this goal, this thesis provides an insight into the state of the art in these research areas and describes the design and implementation of an application for the infinite canvas. It presents the opportunities and limitations of the infinite canvas and how it can be leveraged to enhance user experience through collaboration and interactivity. Through this exploration the aim is to contribute to the advancement of interactive and collaborative digital communication, paving the way for innovative approaches to information presentation and understanding.

1.1 Motivation and Problem Description

Most traditional content is build from materials like images, text, animations, and videos. These are often considered as static content, since such media does not include interactivity as a form of communication. However, these static presentation methods do not take full advantage of the possibilities that modern computer technologies provide. Therefore, they are often enhanced with interactive communication methods, as Hohman and Bret argue [HCHC20, Bre11]. Interactive articles, and other forms of interactive communication, try to address these limitations by integrating interaction techniques such as details-on-demand, play, simulations, visualizations, and self-reflection. The main goals of such interactive content is to support active exploration and to boost learning, understanding, and engagement [HCHC20, Bre11].

Research on interactive content highlights its benefits that we can leverage in various application areas. One of the main reasons to use interactivity is its close connection to engagement and learning motivation [DD18]. Interaction and engagement closely correlate with each other, and interactivity is often needed to build engaging products.

However, there is no widely agreed-upon definition of engagement as it is a relatively complex area that is influenced by the context and various other factors [DD18, O'B16]. But most research define engagement as something that draws us in and holds our attention.

The motivation of this thesis is to explore the possibilities of the infinite canvas to create such engaging content through the use of interactive and collaborative content. For this, it explores the concepts of interactive articles and the infinite canvas and how information visualization is applied in them. A main focus was to explore how infinite canvas environments can integrate collaborative interactive content and information visualizations and how we can apply the core ideas of interactive articles. Although, interactive articles and the infinite canvas are established concepts, they are still in their early research and especially the interplay between them can provide new insights and opportunities for future applications.

1.2 Aim of the Work

The aim of this work is to explore the potential of the infinite canvas as a platform for designing interactive and explorable information visualizations. The infinite canvas not only offers an unlimited design space but also incorporates possibilities for collaboration, innovative interactions, and information presentation.

While the concept of the infinite canvas is well established, its integration with information visualization techniques remains relatively unexplored. This thesis takes inspiration from the ideas of explorable explanations and interactive articles, which emphasize interactivity and active reader engagement. The goal is to encourage readers to ask questions, reflect on content, and allow them to draw their own conclusions through various forms of information visualizations.

This thesis aims to investigate the opportunities and challenges involved in designing interactive and explorable information visualizations on the infinite canvas. It explores how the infinite canvas integrates collaboration and interactivity and how this can be harnessed to create more engaging and interactive content. Additionally, the work explores potential application areas for visualizations and identifies its limitations.

The research questions of this thesis are:

RQ1: What possibilities does an infinite canvas provide for the design of interactive articles?

RQ2: What visualization and interaction techniques can facilitate communication, engagement, creativity, and collaboration on an infinite canvas?

RQ3: How to design for collaboration in interactive articles on an infinite canvas (i.e., through group activities)?

By addressing these research questions, this thesis seeks to advance our understanding of how interactive articles can be effectively integrated on the infinite canvas.

1.3 Methodological Approach

To address the research questions, this thesis adopted a design study approach following the methodology proposed by Sedlmair et al. [SMM12]. This problem-solving process emphasizes a human-centered perspective, placing users' needs and interactions at the forefront of the design process. The design study approach allowed this work to iteratively explore the possibilities of interactive articles on the infinite canvas. Through the lens of human-centered design, the aim was to create engaging and collaborative experiences that resonate with users and effectively communicate information.

The thesis followed a iterative methodological approach, which also serves as the overall structure of the work. The methodology is divided into the following key steps:

1. **Literature Review**
   In the beginning, a review of related literature has been conducted. At this stage interactive articles and explorable explanations have been investigated. Explorable information visualization, a closely related research area, and its use of storytelling and visual communication has been reviewed. Furthermore, the use of collaboration in digital technology, especially in exploratory environments, has been examined.

2. **Exploration of the Infinite Canvas**
   After the literature review has been conduced, the infinite canvas environment has been explored. In this phase of the thesis the infinite canvas, as well as its opportunities and limitations have been analyzed thoroughly. The fundamental ideas of the infinite canvas as well as its approach to represent information have been researched. Furthermore, existing applications that use the infinite canvas as a method to show content have been reviewed. In this stage Miro has been chosen as the infinite canvas environment for a prototype implementation.

3. **Problem Characterization and Target Domain**
   After a deeper understanding of relevant research areas and the infinite canvas has been achieved, application areas were investigated. Here, the fields of communication, education, design, and research have been analyzed and how the infinite canvas can be used in those situations. A special focus was placed on how the infinite canvas can support creativity and the generation of ideas.

4. **Application Design and Prototyping**
   In this phase, the possibilities and limitations of Miro as an infinite canvas platform for creative collaboration have been investigated. Here, the suitability and technical feasibility of Miro as an infinite canvas to create and use interactive content were investigated. This first part of the design and prototyping phase has shown possible

directions for the development of an application for the infinite canvas. To get further insights into the actual use of the infinite canvas to gather and extract information, a first prototype that supports facilitators such as teachers, researchers, designers, and other moderators to identify patterns on the infinite canvas has been developed afterwards. This allowed us to further explore the input and output capabilities of the infinite canvas.

5. **Evaluation of Prototype**
   As mentioned, the main objective of the prototype has been to look for opportunities and limitations on how facilitators can be supported when using the infinite canvas. As part of this thesis, the prototype has been evaluated in a user study with a field-like environment. In it, a thinking-aloud approach and semi-structured interviews were used to investigate the prototype and the participants perception of the infinite canvas. In the study, participants had to perform tasks with the prototype while explaining their thoughts. This was used to gain insights into their perception of the prototype and the infinite canvas.

6. **Design Concept for a Refined Prototype**
   The development and the evaluation of the first prototype has highlighted its capabilities and limitations. As part of this thesis, a concept of a second, more sophisticated prototype has been designed. Advanced interaction methods as well as better utilization of the infinite canvas' collaboration features allowed the design of a more engaging refined prototype. The insights form the design, implementation, and evaluation of the first prototype were used to better support the creative process of groups by using computer supported semantic analysis on an infinite canvas.

CHAPTER 2

Related Work

This chapter discusses related work and gives an overview on its relevance to this thesis. It begins by exploring the concept and application areas of interactive articles. Afterwards, it introduces explorable information visualization and their connection to interactive articles, analyzing their strengths and weaknesses for the creation of explorable interactive stories. Lastly, this chapter investigates collaboration and how it is utilized in interactive articles and explorable information visualizations as well as the challenges it introduces.

2.1 Interactive Articles

Digital technologies have found their way into almost all areas of our everyday life, one being the way we consume and communicate with information. However, Hohman et al. argue that this digital integration in the communication process does not fully utilize the opportunities our increasingly digital world provides [HCHC20]. They write that although "the technology to distribute our ideas has grown in leaps and bounds, the interfaces have remained largely the same" [HCHC20]. Today, an active form of consuming information is considered as an approach for more engaging content [HCHC20, Bre11, OCA+20]. In the end, the major goal of these information representations is to provide a reading and learning experience that allows humans to actively explore information on their own terms rather than passively consuming it.

Today, digital applications in various areas use some form of interactivity when presenting information. In this context, the focal point revolves around the integration of interactivity as a core component to present and engage with information. Artifacts such as explorable explanations [Bre11], exploranation [YLT18], interactive non-fiction [SZ11], explorable visualizations [GLG+16, NBX14], and interactive paper [SN10] emerged and highlighted the importance to let readers actively engage with information. Due to the absence of a singular term encompassing all these elements, Hohman et al. coined the phrase

Interactive Articles (IA) as a comprehensive term to describe these diverse artifacts that emphasize interactivity in showcasing and engaging with information [HCHC20].

In their work, Hohman et al. analyzed over sixty different IA from areas such as journalism, education, policy making, and science communication. They argue that, even though all related concepts differ in their technical approach, they fundamentally employ interactivity, introduced with modern digital [HCHC20]. In the end, Hohman et al. define five affordances that we can use to identify an interactive article:

1. Connecting People and Data
2. Making Systems Playful
3. Prompting Self-Reflection
4. Personalizing Reading
5. Reducing Cognitive Load

Hohman et al. show that, while these affordances are necessary to make an artifact an IA, not all of them need to be present in the artifact and incorporate them to the same extent. Figure 2.1 for example, illustrates an interactive component that Hohman et al. used to demonstrate how interactive articles can contribute to the reduction of readers cognitive load [HCHC20]. Here, we can also see how the visual information seeking mantra "overview first, zoom and filter, then details on demand" from Sheiderman [Shn96] can be applied in an interactive article. A multi-modal visualization using details-on-demand can either act as a component of the interactive article or as the interactive article itself. Figure 2.1 shows an component where readers can select a point on the map and listen to a birdsong recorded at that location. In this case, this interactive map is embedded in an bigger text and thus acts as a single component within a larger interactive article.

Another IA Hohman et al. [HCHC20] discuss, is the so called "Uber Game" [KBH+17]. Figure 2.2 shows the start screen and premise of the game. *The Uber Game* aims to tell the workday of an Uber drivers more interactively through a game and therefore provide a more engaging journalistic story. In general, gamified interactive articles often integrate game dynamics like rewards, competition, and self-expression to create interactive articles on the web. Sicart introduced the term *Newsgames* for such approaches that use computer games as news media [Sic08].

Especially interactive articles, that aim to make systems more playful are closely related to serious games and gamification [DKND11, Sic08, SWL18]. The use of game dynamics and elements are popular mechanisms to enhance engagement and motivation [DKND11, DDKN11, SWL18, ZSHC20], foster creativity [Cop15, ZSHC20], explain information [Sic08], and improve learning performance [ZSHC20]. Suh et al. describe that game elements such as points, levels, and leaderboards, can induce dynamics which lead to more user engagement [SWL18]. Thus, an IA that integrates game elements can leverage this

Figure 2.1: An example of an interactive component integrated in an interactive article. Hohman et al. use this component to illustrate how multimodal details-on-demand can be used as a from of interactivity in interactive articles [HCHC20]. From [HCHC20]

effect and address the affordances of *Personalize Reading* and *Making Systems Playful* in particular.

Furthermore, interactive articles are a way to condense information into a more dense form. IA aim to use effective information representations to reduce the cognitive load of readers [HCHC20]. Thus, they address the phenomena of Information Overload (IO) that can occur if an individual's perception has no longer the capacity to absorb the perceived information [MP77, RWT14]. Rachfall et al. argue that there is a connection between information type and IO [RWT14]. Johnson also addresses this problem in his work as he argues that much of the text in apps and websites is unnecessary [Joh21]. In his opinion, user interfaces should only feature the minimum required prose text [Joh21].

Today, text is one of the most commonly used forms to convey information and we are exposed to written words in physical and digital form alike. However, in contrast to speaking, humans are not wired to reading [Joh21]. According to Johnson, reading revolves around the identification of visual patterns and features, such as lines, contours,

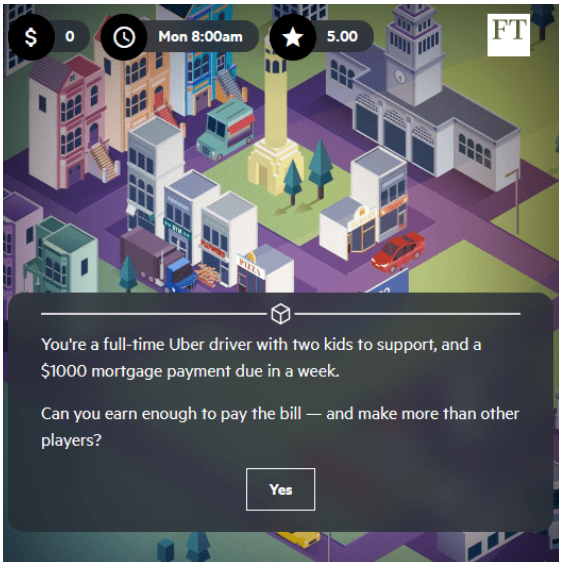


Figure 2.2: Start screen of an interactive news articles in form of a game. It tells a news story from a Uber drivers workday through a gamified interactive article. From [KBH+17]

and shapes [Joh21]. Thus, the act of reading is not as intuitive as we may think, but rather an active process that involves various cognitive and perceptual mechanisms [Joh21]. IA build on this premise as they advocate an active form of information consumption that emphasizes supporting static content through interactive visual elements to allow critical engagement [HCHC20, Bre11]. Especially activities that aim for readers to learn and understand new knowledge, need to be mentally involving for the reader [Dri02]. "Traditional" static texts often lack this possibility [HCHC20, Bre11]. In interactive articles, readers no longer passively absorb information presented by the author. Instead, they harness the power of interactivity that digital technology introduces to allow readers to actively construct their own insights, fostering an engaging and personalized experience. This active reading approach is closely related to a constructivistic approach of information representation. Constructivism sees learning and perception as an active process in which people construct new knowledge by their own personal experiences [Bau03, RMR07].

2.1.1 Application Areas

As previously stated, IA lack a precise definition and can manifest in diverse forms across various application areas. They exhibit a wide spectrum of characteristics, with some leaning towards a playful approach (see Figure 2.2 from [KBH+17]), while others concentrate on enhancing textual content with interactive features (see Figure 2.1). Additionally, certain IA endeavor to replace traditional text entirely with interactive elements. Consequently, IA can be observed in a multitude of forms and applied across various domains, showcasing their versatility and adaptability.

Although, IA provide numerous benefits to readers, they are still sparely found across the web. The creation of an IA is a time-consuming and technical demanding process and requires fundamental skills in areas such as human perception, interaction design, writing, and editing [HCHC20, CH18, LG20, LRIC15]. To support authors, tools like Idyll [CH18], Data Theater [LG20] and Observable [BM] have emerged. However, Hohman et al. argue that these tools lack clear guidance and support for authors without programming skills [HCHC20].

On today's web, IA are often found in areas such as research and science communication, education, and journalism. For example, web-based journals, like *The Parametric Press* [CHSS] and *Distill* [dis] provide a platform, where researchers and other contributors can publish IA in a digital magazine. However, as these platforms are still in their early stages, they mainly target authors with technical knowledge (i.e. programming skills) and time resources [HCHC20].

IA are a possibility for researchers to bring science to a broader audience and to communicate scientific discoveries and methods in exploratory as well as explanatory way [DJS$^+$19, YLT18]. But IA also found their way into journalism where authors use them to break down complex topics into more understandable content [HCHC20, VHLG17, SZ11]. For example, *The New York Times* publishes numerous interactive articles on their website, as their yearly wrap up of previously created interactive news articles shows [Tim20, Tim21, Tim22].

However, a recurring theme in all IA is their use of exploration and information visualization, which we will discuss in the following section of this chapter.

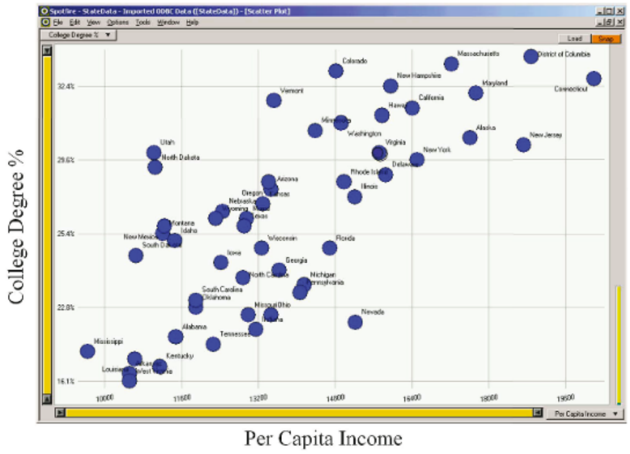
2.2 Explorable Information Visualizations

At the heart of IA lies a fundamental question: How can information be presented in an interactive and captivating manner using digital technology? In this regard, IA and Information Visualization (InfoVis) are intricately linked, as both fields aim to establish meaningful connections between humans and information [HCHC20, Dix13, FVWSN08]. Particularly, the area of interactive information exploration using visualizations shares a close affinity with IA, as both concepts emphasize the importance of interaction and narration as tools to generate insights [YLT18, CMS99, HCT$^+$14].

In general, the field of visualization has a rich historical background, but it was the advent of digital computer technology that revolutionized and shaped its current application. Different approaches to visualize information have been developed, each tailored to its own application domain and target audience [Dix13]. Card et al. formulated one of the most widely accepted descriptions of InfoVis that define visualization as "the use of computer-supported, interactive visual representations of data to amplify cognition" [CMS99]. Dix argues that in the end, visualization is about "making data easier to understand using direct sensory experience" [Dix13, p 2]. Thus, pure textual descriptions do not qualify as visualizations as they do not address our direct sensory experience.

State	College Degree %	Per Capita Income
Alabama	20.6%	11486
Alaska	30.3%	17610
Arizona	27.1%	13461
Arkansas	17.0%	10520
California	31.3%	16409
Colorado	33.9%	14821
Connecticut	33.8%	20189
Delaware	27.9%	15854
District of Columbia	36.4%	18881
Florida	24.9%	14698
Georgia	24.3%	13631
Hawaii	31.2%	15770
Idaho	25.2%	11457
Illinois	26.8%	15201
Indiana	20.9%	13149
Iowa	24.5%	12422
Kansas	26.5%	13300
Kentucky	17.7%	11153
Louisiana	19.4%	10635
Maine	25.7%	12957
Maryland	31.7%	17730
Massachusetts	34.5%	17224
Michigan	24.1%	14154
Minnesota	30.4%	14389
Mississippi	19.9%	9648
Missouri	22.3%	12989
Montana	25.4%	11213
Nebraska	26.0%	12452
Nevada	21.5%	15214
New Hampshire	32.4%	15959
New Jersey	30.1%	18714
New Mexico	25.5%	11246
New York	29.6%	16501
North Carolina	24.2%	12885
North Dakota	28.1%	11051
Ohio	22.3%	13461
Oklahoma	22.8%	11893
Oregon	27.5%	13418
Pennsylvania	23.2%	14068
Rhode Island	27.5%	14981
South Carolina	23.0%	11897
South Dakota	24.6%	10661
Tennessee	20.1%	12255
Texas	25.5%	12904
Utah	30.0%	11029
Vermont	31.5%	13527
Virginia	30.0%	15713
Washington	30.9%	14923
West Virginia	16.1%	10520
Wisconsin	24.9%	13276
Wyoming	25.7%	12311

(a) Spreadsheet of data



(b) Visualization of data

Figure 2.3: Illustration for the expression "A picture is worth a thousand words". From [FVWSN08]

Reading words always requires linguistic and logic processing and therefore text alone does not allow us to get an immediate "feel" for the data [Dix13, War20, Joh21].

This argument is supported by Ware, who claims that reading is unintuitive, and that representations that use visual patterns allow us to solve problems with our natural cognition and perception [War20]. Fekete et al. also see the support of our cognitive system to solve real-world problems as the most beneficial value of InfoVis [FVWSN08]. In their opinion, InfoVis is most useful when "a person simply does not know what questions to ask about the data or when the person wants to ask better, more meaningful questions" [FVWSN08, p 2]. Thus, they argue that the expression "A picture is worth a thousand words" is especially valid and prominent in the visualization of data. Figure 2.3 illustrates this idea. It shows the percentage of the population from US states who earned a college degree along with their income. While the spreadsheet representation on the left allows us to quickly answer simple questions such as "How many people have a college degree in Alabama?", the scatterplot representation enables us to find and answer more complex questions and explore the data in a more meaningful way. For example, we can immediately see that there seems to a be a correlation between the two dimensions, income and education.

The introduction of interactivity in InfoVis has also significantly enhanced the possibilities to explore data. With the advent of digital technology, advanced interactive methods have been incorporated into InfoVis [Dix13]. Shneiderman's information seeking mantra "Overview first, zoom and filter, then details-on-demand" summarizes these methods and their sequential application [Shn96]. However, it's important to note that modern computer technology enables us to support these interaction methods in a more dynamic and flexible manner [War20]. Today, the mantra serves more as a guiding principle, since the evolution of technology allows us to seamlessly integrate and adapt more complex interactive techniques to suit specific visualization requirements and user needs.

Ware argues that the ultimate goal of interaction in visualizations is to help us perform cognitive work more efficiently [War20]. Consequently, interaction in InfoVis allows us to get insights into information through visual encodings [War20, YKSJ07, FVWSN08]. This thesis, refers to this interconnection between interactivity, exploration, and InfoVis as *Explorable Information Visualization*.

2.2.1 Storytelling through Interactive Exploration

As discussed, explorable InfoVis is closely connected to IA through their focus on exploration and narration. Both highlight the importance of using interaction and visual representations to communicate with people [HCHC20, YLT18].

In the present day, InfoVis evolved into various forms and found application in a wide array of fields. The rise of InfoVis for casual audiences has introduced distinct requirements compared to traditional visualizations designed for experts [PSM07]. However, the use of interactivity in this context is not without controversy, as it can sometimes lead to unintuitive and complex visualizations that fail to fully leverage the potential of interactive InfoVis [Ais17, FVWSN08, Fig14].

The popularity of InfoVis for casual audiences has given rise to new considerations in terms of design, usability, and user experience. Visualizations meant for non-experts often require a more intuitive and user-friendly approach to effectively communicate information and facilitate understanding [FVWSN08, Fig14]. The intersection of IA and explorable InfoVis offers an approach to build more engaging visualizations for such general audiences. Interaction becomes a tool in visualizations enhancing trust, engagement, and insights by providing data transparency [Ais17, Maz09].

Essentially, there are two approaches to enable consumers of InfoVis to derive insights from data [YLT18, HDR+13]. Exploratory visualizations enable users to effectively analyze data for (scientific) discovery. These visualizations provide interactive capabilities for users to delve into the data, uncover patterns, and make discoveries. Explanatory or communicative visualizations, on the other hand, aim to explain and communicate with visualizations. They are designed to convey a specific message or narrative, guiding the audience towards understanding complex concepts or relationships.

Section 2.1 describes how visual exploration and explanation are not mutually exclusive; in fact, an overlap between the two is encouraged in IA. This overlap enables non-experts to actively engage with the data while following a structured narrative [CKH19].

Figure 2.4: Interactive information visualizations in public spaces can engage the audience to explore artifacts. For example, children in a museum can interact with a visualization to learn about Egyptian mummies. From [YLT18]

Interactive exploration of visualizations can harness people's fascination about a subject by allowing them to discover a subject on their own [MP21, YLT18, PK02]. Humans are visual creatures, which means that aesthetically pleasing images and illustrations play a large role for attraction and engagement [MP21, LRB16, CKH19]. For example, in their work on visualizing invisible parts of plants, McGaley and Paszkowski, address the importance of visual representations to present microscopic organisms to the lay-audience [MP21]. They argue that visually engaging with otherwise invisible parts of nature can alleviate to form an individuals mental model which motivates people towards a more environmental-friendly behavior. Thus, the exploration of information can support a narrative, i.e. how hidden parts of plants look like. This empowers individuals to forge meaningful connections between the data and their personal experiences, fostering a profound engagement with the narrative.

Ynnerman et al. argue that in interactive InfoVis "it is the story and how it is told that make the difference" [YLT18, p 18]. Figure 2.4, for example, illustrates how a broad audience can immerse themselves in a InfoVis to learn about artifacts in a museum, such as Egyptian mummies.

However, content that is central to a narrative visualizations should never be hidden behind interactions [Ais17, CKH19]. A clear structure and guidelines in interactive and narrative elements should always be present in InfoVis [HDR+13]. Integrating clear sequences and interactions in explorable InfoVis can support people's curiosity and enhance their desire to explore [HDR+13].

In this context, Willet et al. introduced the analogy of interactivity as superpowers that visualization designers can equip people with [WAC+22]. They argue that using the language of comics and other superhero stories can encourage researcher and other visualization designers to think about interaction in a more creative way. In contrast to

Figure 2.5: Scatterplot to show the correlation of climate change responsibility of individual countries along with their readiness and vulnerability of its consequences. From [Wen22]

the previously mentioned techniques, this idea of combining interaction and narration in visualizations is aimed towards creators of InfoVis in particular. Thus, a lens of fictional superpowers provides a new way of examining existing visualizations and suggest directions for new innovations of interactions [WAC+22].

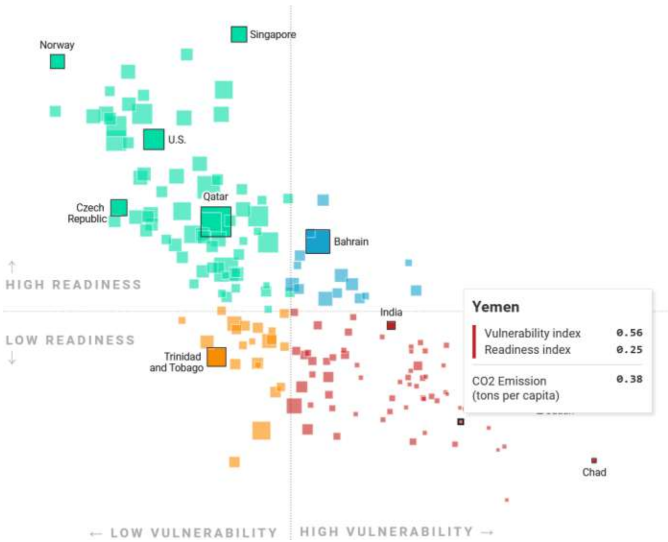


Figure 2.6: Scatterplot to show the correlation of climate change responsibility of individual countries along with their readiness and vulnerability of its consequences. A details-on-demand tooltip is shown when hovering over a country. From [Wen22]

As mentioned, interaction design has become a fundamental part of tools for InfoVis creation such as Tableau [tab], Datawrapper [dat], or D3 [d3]. Figures 2.5, 2.6, and 2.7 for example, show how we can use interactivity for the exploration of data on countries vulnerability of climate change and their CO2 emissions [Wen22]. In essence, it tells the story that countries with the highest vulnerability make the lowest contribution to it. To do so, it uses a two-dimensional scatterplot to show the relationship between multiple variables. Figure 2.5 shows the initial visualization that is presented to the audience. The countries are sorted by their vulnerability and readiness to climate change and are colored accordingly. The size of the squares shows the CO2 emission per person in that country.

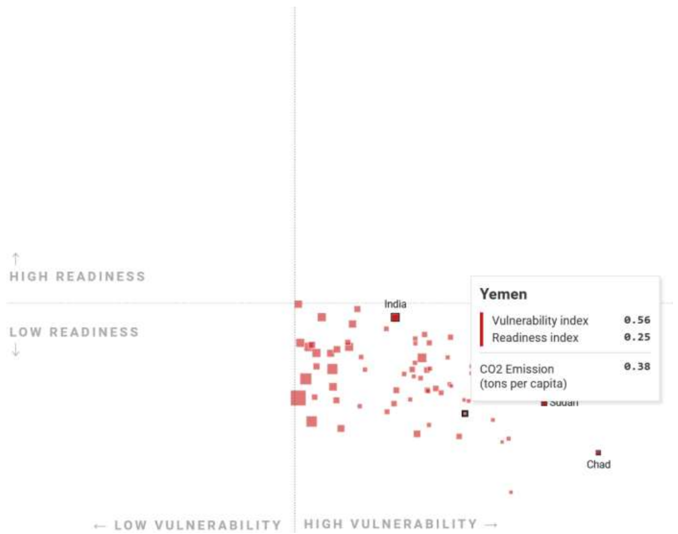


Figure 2.7: Scatterplot to show the correlation of climate change responsibility of individual countries along with their readiness and vulnerability of its consequences. A filter of countries in the same category is applied when hovering on a country for long enough. From [Wen22]

Readers can explore the visualization by hovering over elements which reveals more information about a countries variables. Figure 2.6 shows the effect of such a mouse-over action for the country of Yemen. Readers can immediately observe the consequences of an interaction with additional information about this data point.

If readers continue hovering on this data point, they can also filter for other countries in this category. Figure 2.7 shows how the visualization looks like after applying such a filter. Here visually highlighting the number of countries in each category through color allows for more exploration. For example, hovering long enough over the country of Yemen hides all other categories which allows readers to see patterns in the data of the highly vulnerable and lowly ready countries more easily.

2.3 Collaboration in Interactive Articles and Information Visualizations

In the digital age, collaboration has emerged as a ubiquitous feature of modern web applications. The power of the web enables us to seamlessly work together, share insights, and collectively make sense of data. Collaborative platforms like GitHub [1], GoogleDocs [2], ownCloud [3], and Zoom [4] have become essential components of digital workspaces and education. Technology to enable human collaboration is now a fundamental aspect of human computer interaction and is becoming more and more commonplace [IES+11, Cla11]. Online workspaces, for example, enable real-time collaborative document editing and seamless communication, transcending the limitations of physical distance [onl22].

In order to fully understand collaboration, it is crucial to also consider competition, often seen as its counterpart. Interactive game elements, such as points, badges, and leaderboards, have been shown to enhance student motivation and engagement in educational settings [KM22, HH15]. The term "Gamification" describes the use of such game elements in non-game contexts [DDKN11]. These game dynamics award participants digital points and artifacts, based on their individual behaviors and performance. Top performers are often awarded more points or badges for exhibiting "correct" behavior, fueling their competitive drive.

But in the context of IA and explorable InfoVis, no objective correct behavior that can be evaluated is present. Participants can navigate freely and interact with the content in their own distinct way. These environments allow individuals to actively explore the presented information in order to generate insights and understanding [DJS+19]. There is no predetermined path or predefined objective to be achieved. While collaboration has gained popularity in modern web applications for building artifacts and gaining insights, its integration within exploratory settings is still in its early stages. The exploration of information is often seen as an individual endeavor, as individuals explore and derive insights based on their own curiosity and perspectives [HVHC+08, MCE02].

Sections 2.1 and 2.2 have emphasized the significance of active interaction with information in exploratory environments. While research on cognitive processes, such as creativity, has traditionally focused on an individual perspective, collaboration in these environments opens up new possibilities for more engaging and dynamic content [MCE02].

Interactive and explorable InfoVis enables users to find meaning in data by identifying patterns, clusters, trends, gaps, and outliers [Shn09]. Environments and interfaces that support such exploration can enhance creativity of individuals and groups by facilitating dialogue and the sharing of insights [LRB16, MCE02, Shn09]. Especially in settings that require thinking and creative problem solving, collaboration can be a powerful tool

[1] `https://github.com/` (accessed 2023-07-12)
[2] `https://docs.google.com` (accessed 2023-07-12)
[3] `https://owncloud.com/` (accessed 2023-07-12)
[4] `https://zoom.us/` (accessed 2023-07-12)

[MCE02]. The "Partnership Model" by Mamykina et al. highlights that mutual benefits while maintaining ownership of individual achievements is fundamental for collaborative creativity [MCE02]. Thus, in contrast to competition, collaboration allows people to work together towards a common shared goal while also allowing individuals to engage with interactive content on their own.

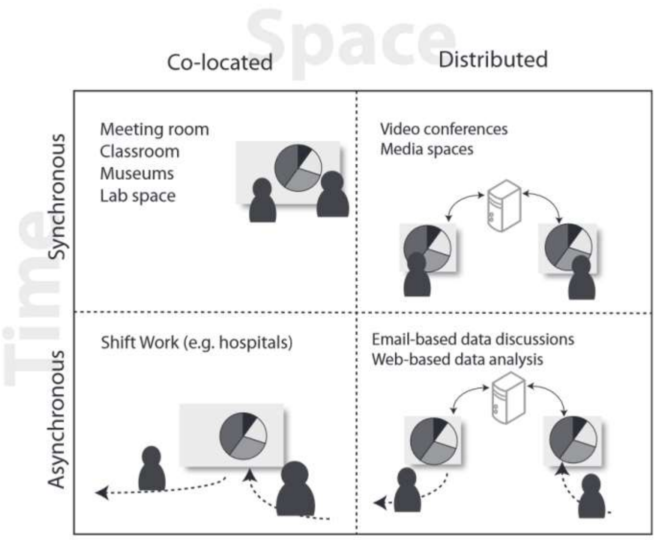


Figure 2.8: Collaboration can take on different forms based on the specific usage scenario, particularly regarding space and time. From [IES+11]

Collaboration in digital environments can manifest in various forms, depending on the specific usage scenario [IES+11]. Figure 2.8 shows the four dimensions of collaboration regarding space and time [IES+11]:

Synchronous collaboration enables real-time and simultaneous activities and interactions of individuals.

Asynchronous collaboration takes place over an extended period of time, without the need for immediate real-time interaction between individuals.

Co-located collaboration occurs when individuals are physically present in the same space, facilitating real-time interactions and immediate communication.

Distributed collaboration uses digital tools to allow individuals to work together from geographically dispersed locations.

However, Isenberg et al. argue that by creating new design spaces and expanding the view on collaboration in visualizations, we can also explore new contexts such as hybrid scenarios (e.g., using both, synchronous and asynchronous collaboration in the same space) [IES+11].

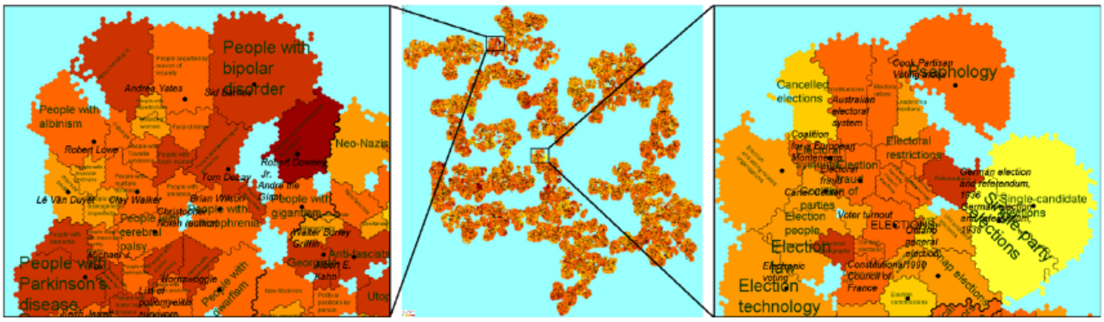


Figure 2.9: Visualization of collaboration in Wikipedia. From [BAPS14]

Collaboration in visualizations can take on different forms, whether it involves visualizing collaboration itself or incorporating collaboration as a component within visualizations. Biuk-Aghai et al., for example, visualized the collaboration among co-authors in Wikipedia to gain insights into the distribution of collaboration in large-scale collaborative environments (see Figure 2.9) [BAPS14].

While this approach allows researchers and users to better understand the dynamics of collaboration, directly integrating collaboration as a component allows multiple users to interact with each other and the data. For example, in ManyEyes users can individually explore and analyze data, gaining insights and generating observations [VWVH+07]. ManyEyes allows users to share their findings and perspectives through visualizations, fostering collaboration and encouraging a collective sensemaking process.

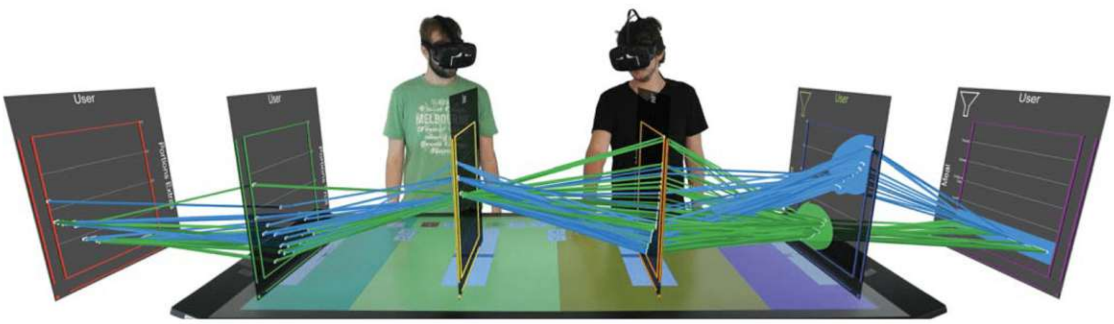


Figure 2.10: Using Augmented Reality or Virtual Reality can facilitate collaborative exploration and analysis of data. From [BHM+18]

Additionally, immersive technologies such as augmented reality allow users to collaboratively analyze data in a digital, shared space [BHM+18]. In contrast to ManyEyes, collaborators are able to directly interact with each other in the same design space which allows them to create the visualizations together. Figure 2.10 shows an example of such a virtual reality, which facilitates immersion in the data and helps collaborators to investigate data together.

2.3.1 Challenges of Collaboration

When using interaction techniques in IA and explorable InfoVis we interact with data and change the visualization accordingly [YKSJ07]. Especially, exploration enables us to examine data by interacting with a subset of the data [YKSJ07]. However, this introduces numerous design and implementation challenges. Frameworks like the visualization pipeline, illustrated in Figure 2.11, address this concept of interacting with visualizations [CMS99]. But introducing collaboration in these interactions introduces complex and challenging questions for the design of IA and explorable InfoVis [IES+11]. Digital information accessed by multiple people to view together, share information, analyze, or form decisions has to deal effectively with extensive and dynamic content, while simultaneously preserving interactivity for all participants [IES+11].

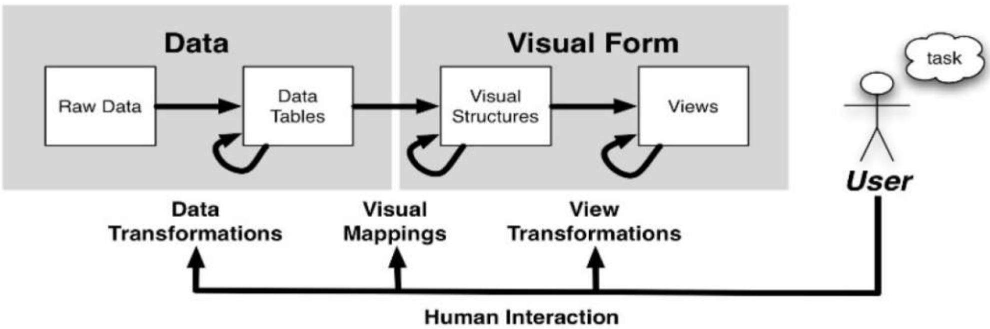


Figure 2.11: Information visualization reference model. From [CMS99]

Furthermore, collaboration requires collaborators to define a common vocabulary to discuss goals, motivations, and outcomes [LRB16]. This constant flow of dialogue, insights, and interactions needs to be represented by a visualization accordingly [LRB16]. Especially when collaborators are synchronously working on the same visualization, interaction rules are necessary to avoid conflicts [MSRdSM+16].

CHAPTER 3

The Infinite Canvas

A main focus of this thesis is the exploration of the infinite canvas and its possibilities for the design of collaborative interactive articles and explorable information visualizations. This chapter introduces the concept of the infinite canvas through its evolution towards today's digital applications. It describes how the infinite canvas integrates interactivity and collaboration in group activities and how it represents content and information. Additionally, it discusses the infinite canvas as a new form to show information as part of highly interactive and collaborative environments.

3.1 History of the Infinite Canvas

With the introduction of modern computer technology, graphical user interfaces also became increasingly important. One of the earliest applications for computer-aided design is the so-called "Sketchpad", created by Ivan Sutherland in 1963 [Sut63, Inf]. For the first time, a digital software allowed users to create accurate drawings using a pen and a computer display. In contrast to other software and physical paper, users were able to edit, change, and move parts or whole illustrations made with the Sketchpad. To do so, it featured one of the earliest applications of the infinite canvas.

Over the next decades, the popularization of digital technology and the web allowed for more sophisticated interfaces and graphical representations. Scott McCloud first introduced the term "Infinite Canvas" in his book "Reinventing Comics" in 2000 as a reference to the possibilities of these new environments [McC00]. Back then, digital tools were becoming more ubiquitous and people were excited to experiment with the possibilities the web and technology provided. Webcomics, for example, became more and more popular and McCloud realized that this created many new opportunities to overcome the physical limitations of paper. He saw that an infinite canvas allows for new forms of structuring and organizing webcomics to enhance storytelling in digital environments.

Beyond comics, the concept of the infinite canvas found applications in various other fields, including presentations, mind mapping, brainstorming, and collaborative tools. These platforms adopted the idea of an infinitely expandable space where users could freely explore and organize their ideas, information, and visual content. Sketch [1], for example, became one of the earliest adapters of the infinite canvas for design and idea generation. The aim of this application was to allow designers to use vector graphics for creating visual artifacts, such as icons or user interface designs. Around the same time Miro (initially launched as RealtimeBoard) [2] became a tool that allowed distributed teams to collaborate on a digital whiteboard. Now, Miro has become one of the leading applications that enables people to collaborate in a virtual design space [Inf].

Today, many of the ideas, the infinite canvas introduced, are still popular for webcomic artists. But the idea of the infinite canvas spread out into a wide range of other consumer-oriented platforms. In many cases, these allow us to creatively collaborate by using the possibilities of digital web applications. Overall, the ideas behind an infinitely expandable space allow us to creatively collaborate with endless and flexible possibilities. Or as McCloud put it:

> "The "infinite canvas" is a challenge to think big; a series of design strategies based on treating the screen as a window rather than a page." [McC09]

3.2 Modern Application Areas

The introduction of the infinite canvas has always been tightly connected to the evolution of digital technology and the web. In the beginning these systems featured only simple interaction possibilities and basic representations of information. With technological advancements, such as increased display resolution, bandwidth, and new input methods, the infinite canvas has manifested in various forms and application areas. Today, sophisticated interactions, collaboration, and visualization techniques allow us to interact with each other and information by using an infinite canvas in new and innovative ways.

In the early days of the infinite canvas, it was seen as a possibility to add innovative and interactive storytelling techniques to comics on the web. These digital graphical stories are commonly known as webcomics. While some of McClouds ideas have been controversially discussed, they are still used as a storytelling technique in various webcomics. For example, in Munroes "Click and Drag" [3] the reader can interactively explore the world of an infinite comic panel [Mun]. The story of this comic is told through visual exploration by the reader. An infinite explorable digital space allows readers to create their own personal reading experience.

Fundamentally, this active exploration of such an infinitely expandable space as a storytelling approach can personalize a reading experience, which is also one of the

[1] `https://www.sketch.com/` (accessed 2023-07-15)
[2] `https://miro.com/` (accessed 2023-07-15)
[3] `https://xkcd.com/1110/` (accessed 2023-07-15)

fundamental affordances of an infinite article. Thus, a possible connection of unrestricted exploration of content and a personalized reading experience becomes evident on an infinite canvas.

Today, the basic concept of the infinite canvas can be found in many applications. However, the research of its use as a personal storytelling tool is relatively thin. Thus, it opens up an exciting area, as the combination of interactive articles and the infinite canvas can harness the collaborative and creative powers of the infinite canvas by using the concepts of exploration, central to interactive articles.

As mentioned, the application area of the infinite canvas is extensive and a broad field of purposes and target audiences exist. Code Canvas, for example, provides an infinitely zoomable environment for software development [DR10]. By zooming in users can edit single documents organized in separate windows. These windows can be arranged on an canvas which allows users to get an overview and therefore exploit spatial memory and structuring to get an overview of items. Figure 3.1 shows how this concept of an infinitely expandable and zoomable space is implemented in Code Canvas where windows represent individual code fragments.

Similar to paper sheets on a desk, these windows are spatially arranged on an canvas. However, the digital environment allows developers to use size as an additional structuring and organization method of information. Differently sized windows with smaller or bigger information enables them to exploit size as a third dimension which they can access by zooming in and out. This brings in new opportunities for spatial content arrangement and positioning by using differently sized windows with smaller information.

Today, we can also observe many of the fundamental ideas of the infinite canvas in information visualization. While the term “infinite canvas” is not common in these contexts many overlapping areas exist. In information visualization the term “zoomable” or “zooming” interface is a common approach to refer to the generation of an overview and to seek out smaller patterns in the data. Ware for example, argues that zoom in information visualization allows the exploration and comparison of “patterns that are isolated small islands of information in a large geographical space” [War20, p 400].

An example of an application that fosters exploration in an infinite and zoomable information visualization is the OneZoom project [WR22]. Wong and Rosindell created an interactive tree of life that allows readers to explore species and the connections between them. Figure 3.2 illustrates their visualization approach. They argue that this zoomable tree layout can also provide a new form of research, teaching, and science communication. The OneZoom project is available at `https://www.onezoom.org/` (accessed 2023-07-15).

3.2.1 Creative Collaborative Applications

As mentioned, there are many applications that use the infinite canvas in different ways and areas. A popular usage is the area of content creation. A collection of such applications

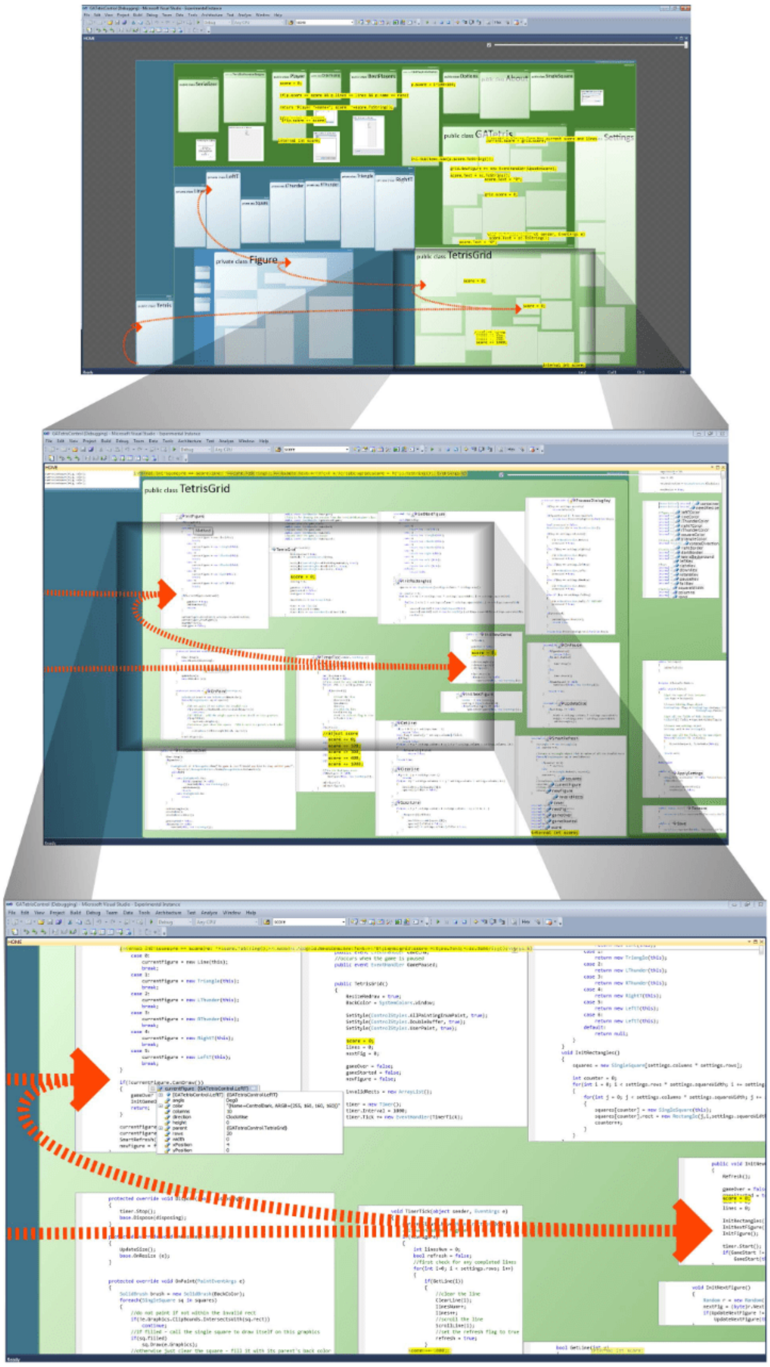


Figure 3.1: Code Canvas uses windows to represent code fragments. Together these "islands of information"[War20] make up the world. Zooming into a window creates a more detailed view of a single window. Zooming out allows to get an overview of the structure of the whole application by spatial arrangement of windows. From [DR10]

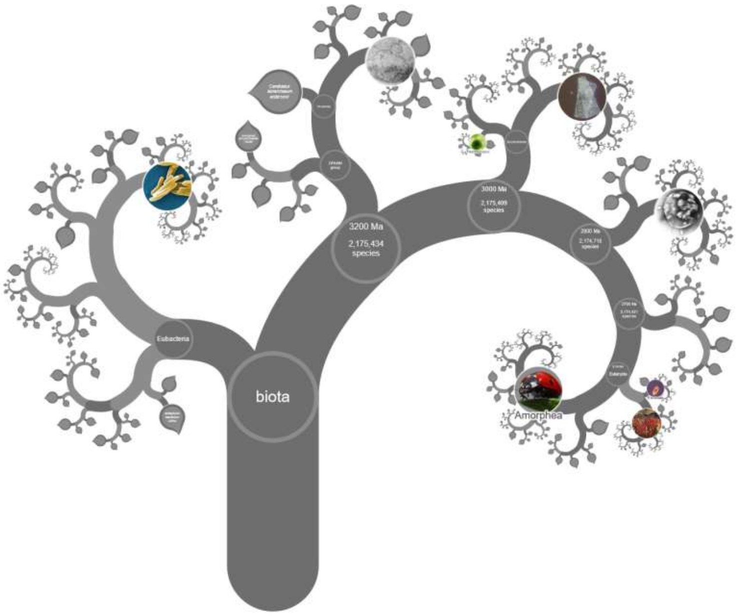


Figure 3.2: The OneZoom project lets readers explore the tree of life [WR22]. Zooming in and out of branches fosters active exploration of species and their connections with each other. Screenshot from `https://www.onezoom.org/life.html` (accessed 2023-07-15)

is listed at `https://infinitecanvas.tools/gallery/` (accessed 2023-07-15). In many applications drawing on an infinite canvas is a fundamental part, e.g., Concepts [4], DoodleBoard [5], and Endless Paper [6].

A focus of this thesis to investigate the creative powers that an infinite canvas provides, especially for collaborative information design and insight generation. Interactive infinite canvas environments allow us to use an endless space to build digital artifacts; individually and in teams. These tools for creative collaboration are also referred to as digital (infinite) whiteboards. Higgins et al. argue that, in the context of teaching and and learning, these interactive whiteboards provide significant changes and opportunities for the generation of insights and knowledge [HBM07].

Miro was already mentioned in Section 3.1 as one of the earliest platforms that emerged in this application area. It allows people to creatively collaborate on an infinite canvas. ClickUp [7], Mural [8], FigJam [9], and the Zoom Whiteboard [10] are other applications with

[4] `https://concepts.app` (accessed 2023-07-15)
[5] `https://www.doodleboard.pro/` (accessed 2023-07-15)
[6] `https://www.endlesspaper.app/` (accessed 2023-07-15)
[7] `https://clickup.com/` (accessed 2023-07-15)
[8] `https://www.mural.co/` (accessed 2023-07-15)
[9] `https://www.figma.com/figjam/` (accessed 2023-07-15)
[10] `https://explore.zoom.us/en/products/online-whiteboard/` (accessed 2023-07-15)

a similar focus. They also aims to make teamwork more collaborative by using an infinite canvas as a collaborative digital whiteboard for teams and individuals.

In our increasingly digitized workspaces and everyday life such applications are becoming more and more popular and today there is a wide range of available tools using an endless digital space. They allow us to leverage the collaborative potential of the infinite canvas that we can harness for creative collaboration. Here, we can overcome the constraints of physical and temporal location by creating a digital space with technology.

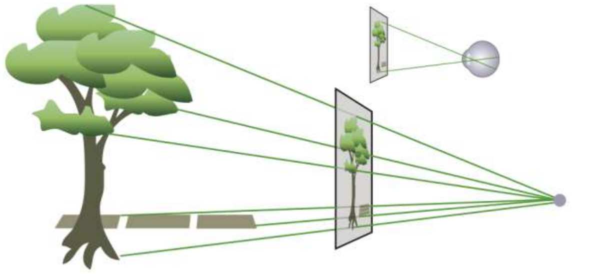
3.3 Fundamentals of the Infinite Canvas

Most of the mentioned digital whiteboard environments argue that an infinite canvas represents a more "natural" way of structuring and organizing content by supporting spatial thinking. According to them, an infinite canvas allows people to navigate freely in a digital space and expand it whenever it is necessary. This navigation and organization of content in an endless space is the main distinctions to "traditional" digital information representations, such as a digital text document. In contrast to an infinite canvas, these documents are only expandable in one dimension, namely length. For example, in a text editor we can add new content at the end, the beginning or in between existing content. But all of these actions only increase the length of a document. On an infinite canvas it is possible to add new information to existing elements through various approaches without changing the original content itself.

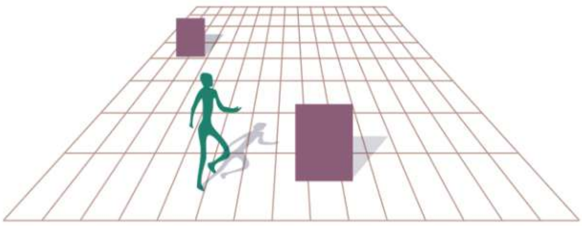
3.3.1 Representation and Organization of Content

While the content on an infinite canvas usually depends on its target purpose, two main properties for every piece of information are necessary, namely its size and its position. Zooming in and out lets users see specific parts of the visualizations, as some things get bigger and therefore more prominent. Thus, the way the infinite canvas presents information is closely related to our perception of space and distance in the real world. Ware argues that these perception principles are fundamental to our real three-dimensional world and their integration in digital representations opens up opportunities to enhance information visualizations [War20].

On the infinite canvas we can observe an abstracted version of this perception of a three-dimensional space described by Ware. Visual information in the real world relies on linear perspective and perception of distance for depth cues. Figure 3.3 show these concepts by illustrating linear perspective and perception of distance for three-dimensional representations. In digital applications, such as the infinite canvas, the understanding of both allows us to represent information for an observers viewpoint where objects that are further away appear smaller than closer ones. On the screen we can then use this three-dimensional position of items to use the size of items as an additional information representation, for example to highlight their importance and relationships between elements.



(a) A linear perspective allows to represent a three-dimensional space onto a two-dimensional plane. An observers viewpoint allows to determine distance by visual distortions. From [War20]



(b) Through the perception of distance we can determine the geometry of objects. Objects that are further away appear smaller than close ones. From [War20]

Figure 3.3: Linear perspective and perception of distance are prominent features of an infinite canvas. They provide depth cues which allow us to determine the size and position of elements. From [War20]

But the design space of an infinite canvas also proves to be more challenging than “traditional” two-dimensional design spaces. The introduction of an additional dimension, adds more complexity to represent information. However, it also allows us to show information in a richer way as new possibilities regarding size and positioning of elements emerge which we can use to highlight relationships, hierarchies, and the importance of elements.

As mentioned, different applications domains and target audiences for infinite canvas applications exist. This also makes the type of content on an infinite canvas quite diverse since it is usually adapted to its application domain and target audience. However, the basic structures on an infinite canvas are closely related to the Gestalt laws which are also recurring topic in information visualization [War20].

In general, the Gestalt laws build on the idea that the whole is different from the sum of its parts. These principles provide a description of the way we perceive patterns in visual data which is especially important on an infinite canvas. While new Gestalt laws have been identified and added over time, we discuss six principles described by Rock and Palmer here [RP90].

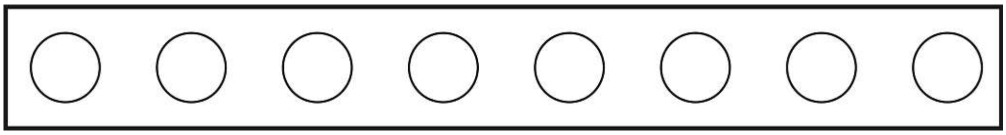


Figure 3.4: Content without any Gestalt laws

Figure 3.4 shows an illustration of content without any Gestalt laws applied. Here, no connections or relationships among individual items is present and every item is equally important. Thus, they are perceived independent from each other and each item stands on its own. On an infinite canvas such items would have no connection with other in term of Gestalt laws. However, we may mentally perceive neighbors as having some connection with each other.

As argued in Section 2.1, reading is rather something we have to learn than being engraved in our perceptual system. Thus, content without any explicit visual pattern can be perceived differently by different people. For example, the reading and writing direction of our mother tongue might affect if we perceive the most left or most right as the first or last element.

On an infinite canvas other explicit visual connections are implemented through the application of the Gestalt laws. They allow us to represent the structures of information through visual patterns. These visual encodings are ubiquitously present in the world around us and therefore unambiguous to everyone.

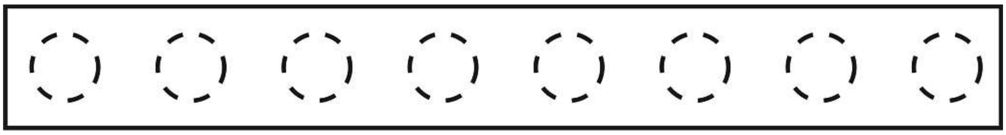


Figure 3.5: Gestalt law of closure

The Gestalt principle of closure argues that we perceive objects with a closed contour as one individual object. However, when these contours have gaps in them, we tend to close these gaps in our mind. Figure 3.5 illustrates this principle through dashed lines. Although there is no circle present in this illustration, we still see eight objects and not a random collection of lines.

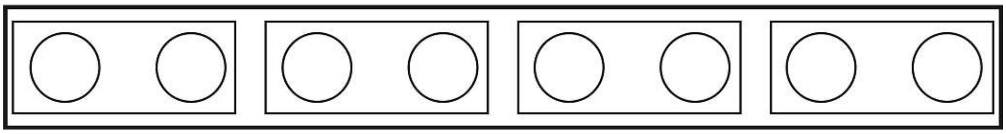


Figure 3.6: Gestalt law of common region

The Gestalt law of common region builds on a similar foundation as the law of closure. It argues that a region enclosed by a contour becomes connected and a “common region”.

In Figure 3.6 we can see how the eight circles are grouped by organizing them in four regions. Each of the four rectangles encloses two circles that makes us perceive them as having some form of relationship with each other. The Gestalt law of common region is often used on an infinite canvas to show a hierarchy and relationship between individual items.

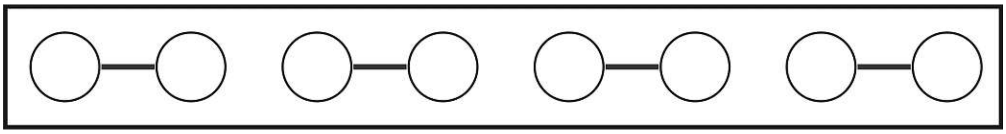


Figure 3.7: Gestalt law of connectedness

An common Gestalt law on the infinite canvas is the law of connectedness. This principle implies that two or more items that are connected through a line or any other visual element, have a shared relationship with each other. Figure 3.7 shows how this law can be applied to visually highlight the circles connections. On the infinite canvas this is often used to show relationships between elements through lines. For example, in brainstorming, lines can show what ideas have been deducted from others and how a train of thought has been formed.

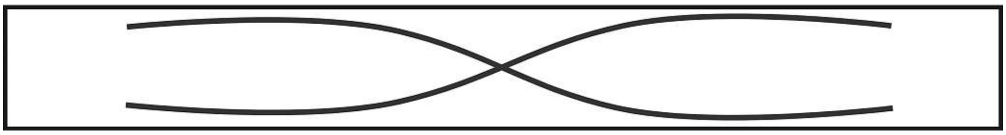


Figure 3.8: Gestalt law of good continuation

The Gestalt law of good continuation or continuity implies that we tend to perceive a smooth and continuous line instead of abrupt interruptions and direction changes. In Figure 3.8 we can see how two lines form two separate object, with one line going from the upper left to the lower right and the other from the lower left to the upper left part of the image. This allows us to make paths between nodes clear and easier to identify.

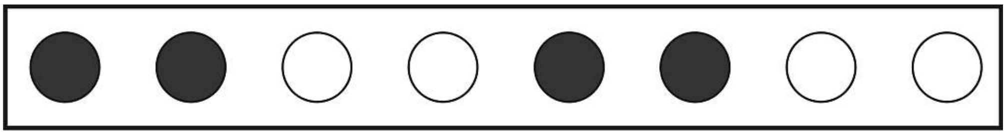


Figure 3.9: Gestalt law of similarity

With our visual system we perceive elements that share similar patterns as something that belongs together. Their shape, color, size, texture, or item type allows us to visually group them and separate one group from the other. Figure 3.9 illustrates this by filling four circles black, while the other four remain white. This makes us perceive them as two groups of items that share some attribute with each other.

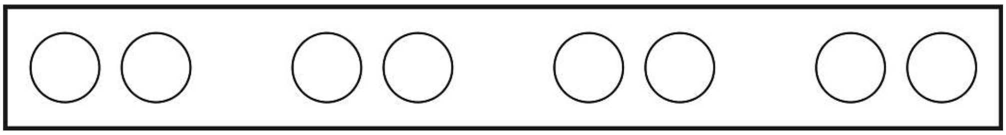


Figure 3.10: Gestalt law of proximity

The Gestalt law of proximity is one of the most prominent principles of an infinite canvas. It allows us to perceive spatial properties of items to group close ones together. Thus, on an infinite canvas, items that represent related information should be placed together to make them visually connected through space. Figure 3.10 illustrated this principle by moving the circles closer together so we perceive them as forming four groups with two items each.

Regarding proximity in visual storytelling, McCloud [McC00] and Sousanis [Sou15] argue that the arragement of items can also be a powerful tool to incorporate time. They argue that in a visual story items that are farther apart, also imply a slower pace while close items suggest that lot of things happen in a brief amount of time.

Figure 3.13 from Sousanis' graphic novel "Unflattening" illustrates how multiple Gestalt principles can be applied in visual storytelling. He argues that individual items are stitched together by the reader which forms a story in their head through static images. This connection of individual lets a "meaningful whole" emerge which is also the fundamental argument of the Gestalt principles.

Additionally, the research area of information visualization often refers to these Gestalt principles, as they are a common approach to describe visual relationships of information [FVWSN08, War20]. However, different visualizations focus on different principles [FVWSN08]. A treemap, for example, uses the closure principle to structure content while a network designed to find related nodes adheres to the proximity and connectedness principles.

Figure 3.11 shows an example of an information visualization that incorporates many of these principles. In their approach Rufiange et al. use various visualization techniques to show the hierarchical information of compound graphs [RMF12]. Each node in these graphs features hierarchical clustering that can be explored by interactively collapsing and expanding subtrees.

The TreeMatrix from Figure 3.11 also highlights the possibility of integrating attributes in the visual representation of elements. Figure 3.12 shows how such attributes can be integrated into single arrow glyph. Ware argues that this allows us to enhance elements by representing more information with the same content [War20]. The non-integrated glyphs from Figure 3.12 represent three properties through three separate objects (i.e. orientation by an arrow, temperature by the color of a circle, and air pressure by the height of a rectangle) whereas the integrated glyphs apply all three attributes to the same object.

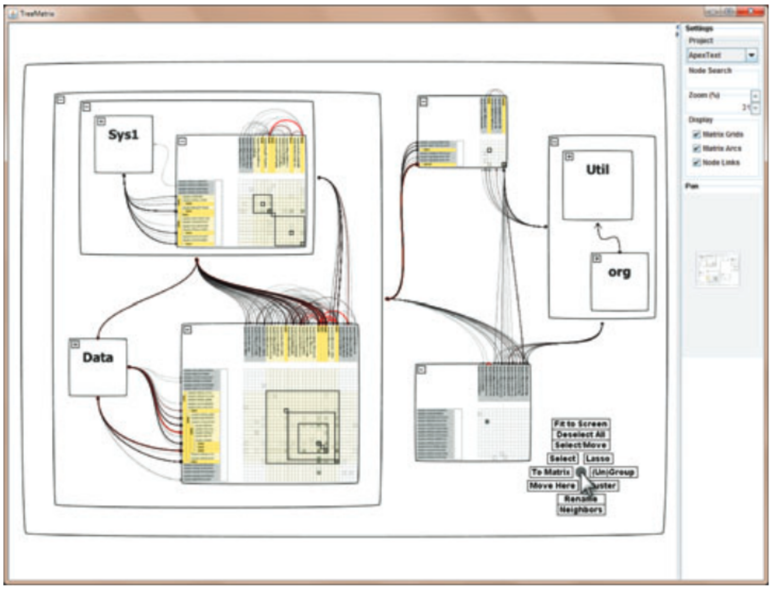


Figure 3.11: The TreeMatrix from Rufiange et al. incorporates various Gestalt laws when showing compound graphs. These graphs feature hierarchical clustering on the nodes which the user can explore by interactively collapsing and expanding subtrees. We can, for example, identify the laws of common region, connectedness, and proximity. From [RMF12]

Especially, in creative collaborative design spaces that use the infinite canvas, such as Miro, these integrated attributes are common. For example, the mentioned Gestalt law of connectedness is often implemented through lines. Here, we are able to change various parameters of these lines to embed further information in them.

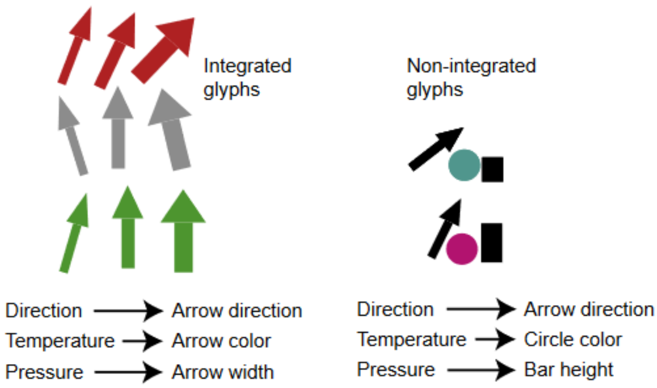


Figure 3.12: Integrated attributes in visual representations. From [War20]

However, on an infinite canvas these information integration methods are not limited to lines as we can also change properties of various other visual elements to integrate attributes. For example, we can change the background color of rectangles to make them stand out and highlight the importance of elements. But overall, the prominence of the Gestalt laws suggest that the infinite canvas and the area of information visualization share a close connection with each other.

3.3.2 Navigation

As already discussed, an infinite canvas requires a different approach to structure and organize content in a digital design space. Therefore, it also requires a more complex navigation techniques compared to "traditional" web environments. McCloud argues that an infinite canvas enables us to explore content more freely but he highlights that this also needs new interaction techniques as an alternative to scrolling [McC09]. In these environments, navigation of information can become a challenge as an endless space can make exploring information unclear and confusing. The already introduced Gestalt laws, provide some principles how participants can perceive and therefore guide the navigation of content on an infinite canvas.

However, different implementations of an endless space feature different navigation techniques. This thesis investigates the navigation of content in creative collaborative environments, particularly Miro. In these environments we can navigate freely in a horizontal and vertical direction by panning left, right, up or down, as Figure 3.14 illustrates. But we can also move across another dimension by zooming in and out of the application which allows us to use the size of elements additionally.

In general, this free navigation across multiple dimensions allows us to fully immerse ourselves in an information visualization. In combination with a intuitive information design this immersion stimulates our urge for exploration of the content on an infinite space. Figure 3.15 illustrates an analogy of the design space of an infinite canvas. We navigate through a three-dimensional space, which we can explore and find relationships of elements. Depth cues such as size and occlusions are used to visually represent a third dimension.

3.3.3 Creative Collaboration in an Infinite Spaces

Collaboration has become a major element of creative environments that incorporate the concept of an infinite canvas. As already discussed in Section 2.3, we can distinguish between synchronous and asynchronous, as well as co-located and distributed collaboration. Depending on its usage area, an infinite canvas can focus on one or multiple of these areas. However, one of the major advantages of creative collaborative applications is their possibility to persistently save collaborative artifacts which allows collaborators to work across all four dimensions.

In general, collaboration is a widespread concept in various application areas. For example, in the context of education, students and a teacher interact with each other to transfer and gain knowledge. But collaboration can also be a powerful tool in design, where teams work together to overcome a problem.

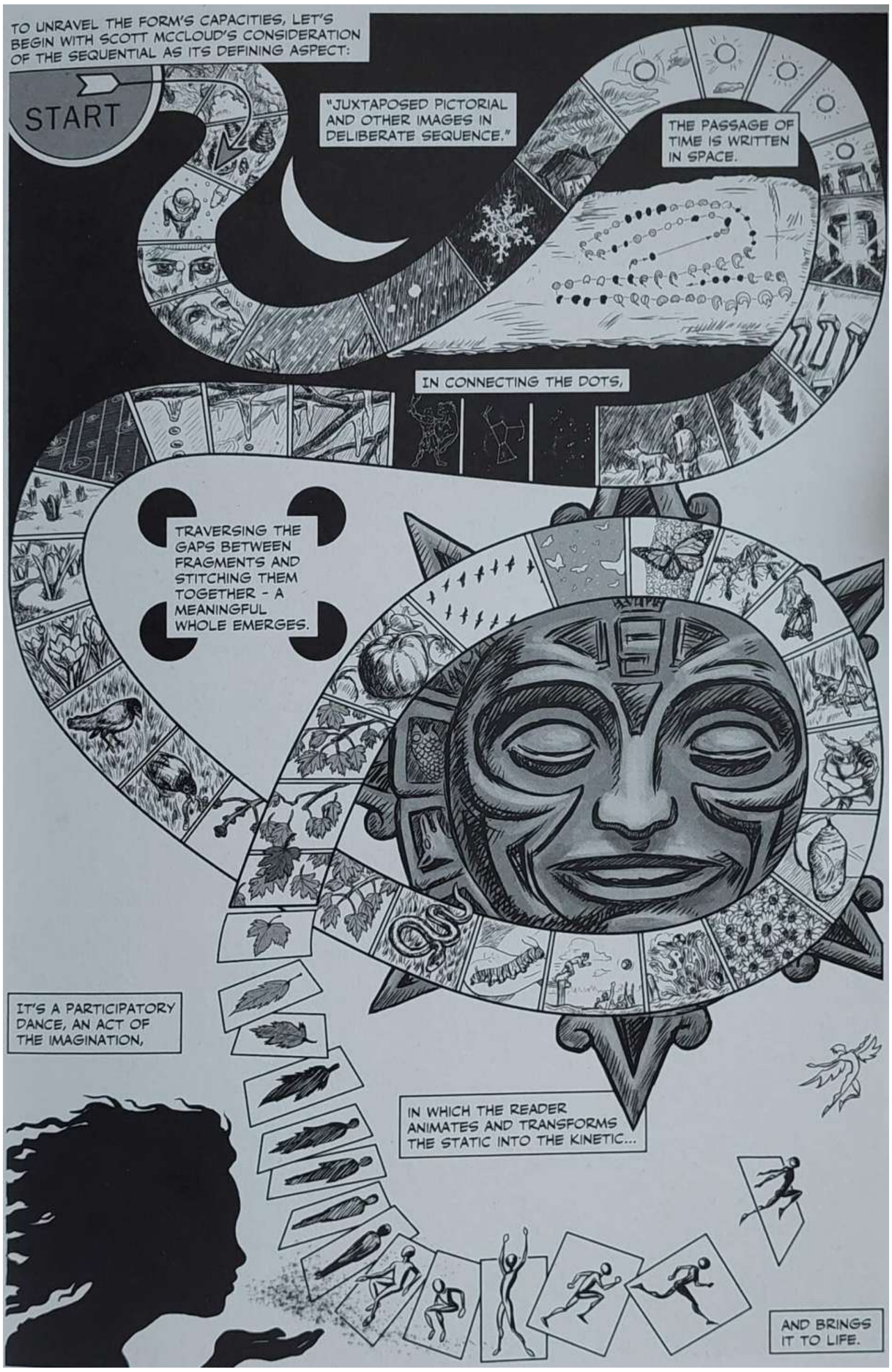


Figure 3.13: The Gestalt laws are a powerful mechanism in visual storytelling. Sousanis argues that they let a whole emerge that allows us to form a story in our head. In such stories, spatial properties of elements can give us cues about the sequence of events and also the passage of time [Sou15]. From [Sou15]

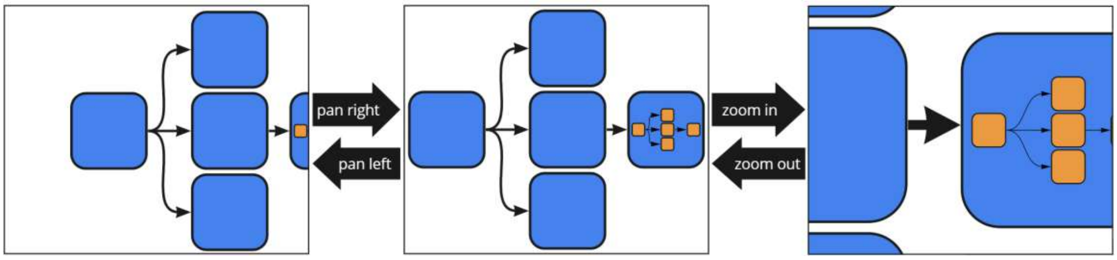


Figure 3.14: Navigation through horizontal pan and zoom on an infinite canvas. On an infinite canvas the reader can move the viewpoint and thus items in and out of the window.

Since creative collaborative applications do not restrict the collaborators towards one of the collaboration dimensions, they allow us to collaborate synchronous or asynchronous as well as distributed and co-located on the same canvas. Figure 3.16, for example, shows how Miro represents multiple collaborators in their application. Each pointer represents one collaborator which highlights where an individual is and what they are currently doing.

Richer et al. argue that, especially in information visualization, collaboration needs to be scalable to allow individuals to contribute to existing data [RPA+22]. The infinite canvas can provide an intuitive platform and approach to address this requirement. Here, one of the fundamental principles of collaboration is, that all collaborators immediately see the impact of their and others actions. This allows us to build collaborative applications for these environments that leverage the opportunities of the infinite canvas to support both principles.

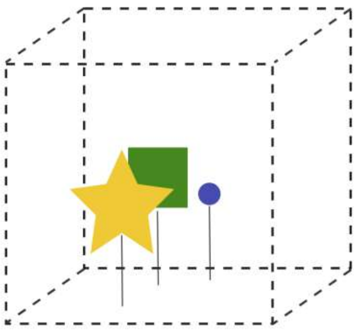


Figure 3.15: On an infinite canvas we navigate in a multidimensional space with content. Occlusions of content are used to suggest a order of items along a distance dimensions. Navigation of this space allows us to immerse ourselves into a visualization of information.

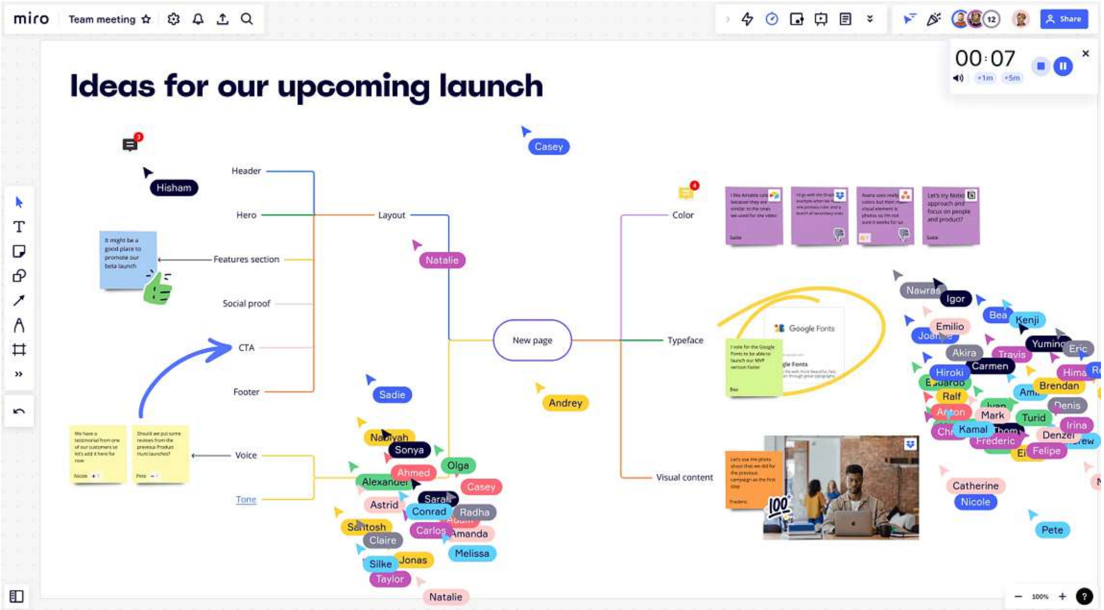


Figure 3.16: In Miro each collaborator is represented by a pointer that shows where they are on the infinite canvas and the elements they are currently interacting with. From `https://miro.com/` (accessed 2023-07-17)

3.4 Prototyping Environment: Miro

As part of this thesis, an application for the infinite canvas environment was developed. As already mentioned, a focus was placed on creative collaborative applications since they allow us to use the potential of the infinite canvas for idea generation and knowledge abstraction.

Miro is one of the most popular applications in this area and fulfills the requirements set for this thesis. It allows us to use both, real-time and asynchronous collaboration, which makes it possible to explore both areas for a prototype design. In Miro multiple users can work on the same canvas at the same time, but also use the canvas for asynchronous content creation. Furthermore, we can store information persistently across multiple sessions.

Miro is also very open towards and actively supports application development in their platform. It features and provides many resources for developers [11], a good documentation [12], and has an active developer community on Discord and in a developer forum [13]. Furthermore, tutorials and frameworks provided by the company allow quick prototyping while example application can give us guidance and inspiration for our own applications.

[11] `https://developers.miro.com/` (accessed 2023-07-17)
[12] `https://developers.miro.com/docs` (accessed 2023-07-17)
[13] `https://developers.miro.com/page/community` (accessed 2023-07-17)

CHAPTER 4

Target Domain

This chapter sets the context of this thesis in order to clearly articulate answers to the research questions. To do so, it identifies group activities in design that focus on insight generation and the formation of new ideas as our target domain. It describes how we generate wisdom from data and how a collaborative visualization to facilitate communication, engagement, creativity, and collaboration can be implemented in this process.

4.1 The Generation of Insight

The mental process from perception of data to the generation of insight is far from a straightforward process. It requires us to make complex connections between new and existing knowledge and experiences. Tools for creative collaboration often claim that they help us build better ideas, but we have still not harnessed the full potential of integrating information visualization in this process. However, the generation of insight is a well studied area in the context of information visualization.

Figure 4.1 illustrates Mazzas interpretation of Shedroff's "Continuum of Understanding" [Maz09]. In information visualization this process argues that we first perceive data, which we transform into information by giving it meaning. Afterwards, we use our previous experiences in combination with the information to form knowledge. In the end, we achieve wisdom, the highest level of comprehension, which allows us to express qualified judgments about the initial data.

But the integration of collaboration in this process adds complexity that requires further understanding. Dörk et al. created a framework for collaboration to connect people that use a visualization with the visualization itself [DMS+20]. They argue that co-design in information visualization needs to consider the "set of stakeholders as actors, the entire

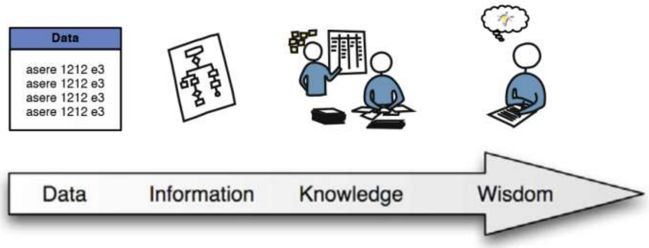


Figure 4.1: Shedroff's "Continuum of understanding". From [Maz09]

design process as a connected series of activities, of which each involves the joint creation and critique of artifacts" [DMS+20, p 221]. Figure 4.2 illustrates this framework.

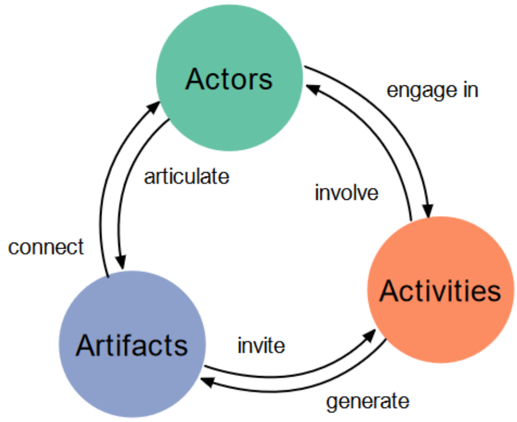


Figure 4.2: Framework for co-design in visualizations. From [DMS+20]

4.1.1 How Does Collective Creativity Work?

Interactive articles and explorable information visualizations integrate this process of insight generation through active exploration of content. They aim to communicate complex topics to readers by using engaging and interactive representations of data. This approach highlights that existing knowledge allows readers to immerse themselves in an setting that fosters the creation of new insights. Although the possibilities that digital technology introduced in this context are vast, the use of collaboration in these environments is still in its early days.

In general, the process of collaborative idea formation and insight generation is closely connected to activities that support both, the groups and the individuals creativity. However, as already discussed, these two concepts require two different approaches. While our creativity as individuals builds on previous experiences and knowledge, collective creativity builds on the sum of all of our individual ideas. Chae et al. argue that such an increased level of knowledge sharing among individuals allows collaborators to create more and better ideas [CSL15]. It allows team members to obtain new knowledge and to learn about different approaches though the experiences and perspectives of others. Thus, knowledge sharing and providing an overview of collaborators perspectives should be a main focus of creative collaborative activities.

A digital system for creative work, such as Miro, allows individuals to create, edit, and share information through an infinite canvas. However, we can also leverage the collaborative possibilities of these platforms to facilitate creative group activities. Through the interactions with content and the collaboration with others, we can facilitate communication, engagement, creativity, and collaboration.

4.2 Collaborative Creativity in Design

An area that focuses on harnessing this creative powers of collective activities is Design Thinking. This problem-solving approach emphasizes the understanding of user needs and their involvement throughout the design process. Today, design thinking is a popular methodology that allows teams to creatively approach a problem and a wide range of similar frameworks emerged that aim to describe this process [MvT16, MdSAMSDCFdA19, VBUB12]. However, Brown and Wyatt argue that the "design thinking process is best thought of as a system of overlapping spaces rather than a sequence of orderly steps" [BW10, p 33].

In its core, design thinking is an approach to find a creative solution to a problem through using innovative activities with a human-centered design approach. For this Brown and Wyatt introduce the the following three spaces in a design thinking process [BW10]:

Inspiration is the starting point of this process and allows the exploration of the problem and to find opportunities for solutions. Here we discover people's needs and build understanding about the design context.

Ideation is the space to generate, develop, and test ideas. The generation of as many solution approaches as possible allows the identification of the most innovative and valuable one. In the end, this solution provides a new way to solve the initial problem.

Implementation is the thirds space of design thinking where the final solution is implemented and launched into the market or applied to the problem at hand.

While design thinking is more of a conceptual way to approach and solve problems and can therefore span weeks or months, Design Sprints try condense the idea of design thinking into a fixed and condensed time frame, usually five days [desb]. Similar to design thinking it describes an approach to support the generation of innovative ideas and to provide creative solutions to problems. Design sprints were popularized by Google Ventures as an agile and flexible framework that to quickly solve and test design problems.

Figure 4.3 illustrates the steps of a design sprint as proposed by Google Ventures [desa]:

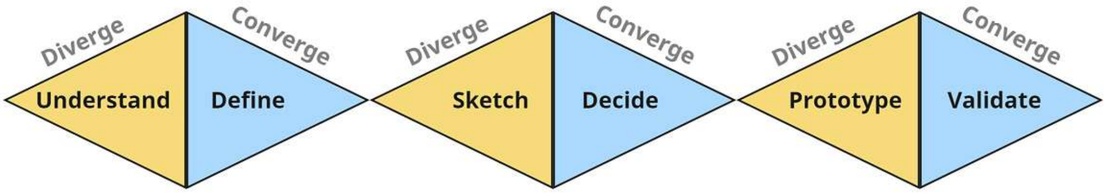


Figure 4.3: Design Sprint methodology. Adapted from [desa]

1. **Understand**: In the first stage, the team gains a deep understanding of the problem they aim to solve. They review relevant data, insights, and any existing solutions to create a common knowledge base.

2. **Define**: The second stage the team evaluates the results of the first stage and define the key strategy and focus of the sprint.

3. **Sketch**: In this stage the individuals generate a broad range of ideas. This allows the team to have an extensive collection of possible solution strategies for further exploration.

4. **Decide**: Now the team narrows down the list to the most promising solutions and decides which solution(s) to prototype.

5. **Prototype**: This phase focuses on the creation of a prototype of your concept. However, a prototype in a design sprint can take various forms, and range from paper sketches to interactive digital mockups, depending on the nature of the challenge. The goal of this phase is to make the prototype real enough to be able to generate meaningful feedback in the final stage.

6. **Validate**: In the final stage, end-user evaluate and give feedback to the previously created prototypes. This step helps identify potential flaws or improvements and validates the chosen solution of the sprint.

Although differences between design thinking and design sprints exist, at the core both approaches incorporate the idea that creative and innovative solutions arise from diverging and converging thinking. This is often referred to as the double-diamond flow. Figure 4.3 also illustrates this process in the design sprint process. It show how we first open up our way of thinking about a problem and try to find as many solutions as possible. When converging we identify a solution as the most valuable one and explore it further. However, the use of information visualization in this collaborative design process, has not gained much traction and remains a promising area for insight generation and creativity [DJD+13, DJ14].

CHAPTER 5

Application Design and Implementation

This chapter discusses the design and development of an application for the infinite canvas. It describes Miro in more detail and shows what opportunities and limitations for designing and developing applications emerge. To do so, it discusses how Miro incorporates visual information design and what possibilities this opens up for visual analytics and collaborative interactive article.

As a next step, this chapter introduces an application for the infinite canvas and describes its design and implementation to show how the concepts of the infinite canvas can be leveraged for visual collaboration. Here, it first discusses how information can be clustered based on the Gestalt laws from Chapter 3. This highlights approaches to design intuitive and innovate applications for the infinite canvas. Afterwards, this chapter presents a prototype application for Miro that uses spatial positioning content to generate a holistic overview.

In the end, this chapter gives a possible usage scenario of the developed prototype.

5.1 Miro: Designing on a Collaborative Infinite Canvas

As already discussed in Chapter 3, Miro is one of the most popular applications that uses the infinite canvas for creative collaboration. It allows us to explore various ideas and gives us the opportunity to conduct a comprehensive analysis of the powers of collaboration on the infinite canvas. Thus, we identified Miro as the prototyping environment of this thesis. This section outlines the core concepts of Miro and gives a brief introduction to its approach towards application development.

In terms of collaboration, Section 2.3 already investigated a two-dimensional framework that describes how teams can works together in time and space. Content in Miro is stored persistently on so-called boards, which allows the exploration of both concepts.

In general, the platform Miro [1] is used for private, business, and education. It is a highly flexible system where the integration of an infinite canvas on a digital whiteboard lets you generate new and work with existing ideas. Furthermore, according to Miro's website, it can facilitate communication and allows teams to expand ideas together.

5.1.1 Board

As mentioned, the central part of Miro is the so-called board, its implementation of the infinite canvas. On a board users can directly interact with so-called board items that people can add, modify, or remove. This board is a surface that allows users to work with tools such as applications and templates to exchange information with featured items.

In general, the board is the collaborative space where people can work and build artifacts together. Figure 5.1 shows an example of a Miro board with a mindmap template.

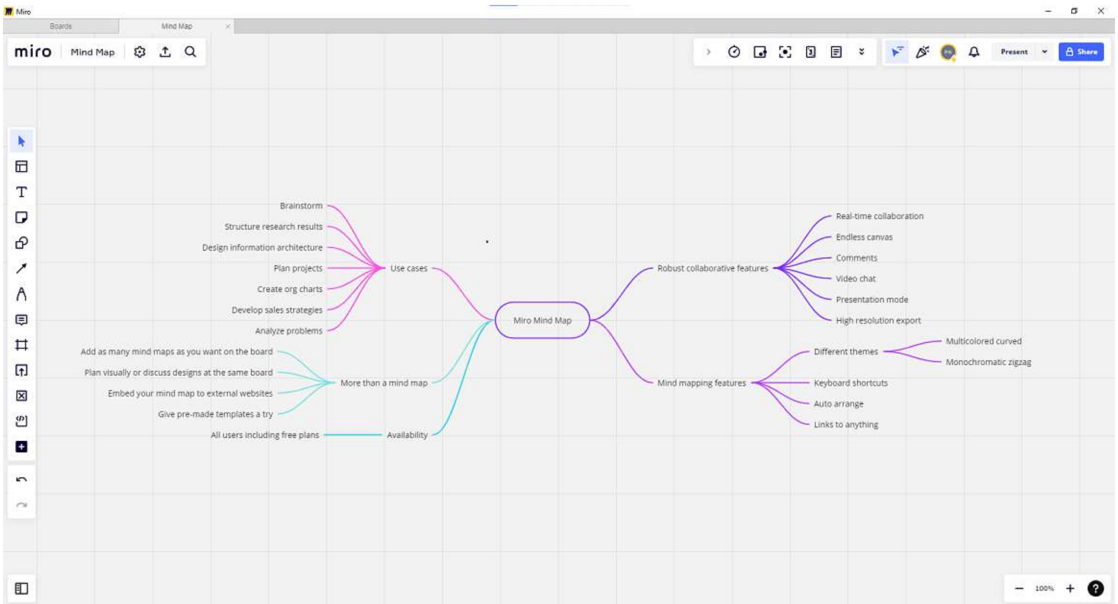
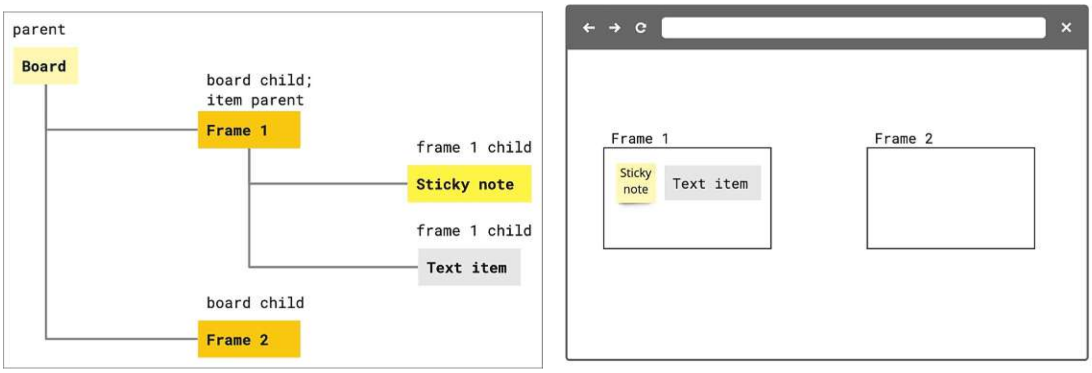


Figure 5.1: A board is the implementation of the infinite canvas in Miro. It is a collaborative space where people can work and build artifacts together. This figure shows a board with a mindmap template.

The overall structure and organization of a board follows a hierarchical approach where the board is the root of a tree structure. A board can hold multiple board items such as frames, images, and text which are embedded in this structure. Frames have a special

[1] `https://miro.com/` (accessed 2023-07-20)

purpose on a board, as they can also act as a parent for other items and thus contain children themselves. Figure 5.2 illustrates how this board hierarchy is implemented in Miro.



(a) Hierarchical tree structure of elements on a Miro board.

(b) Representation of the hierarchical structure on the board from Figure 5.2a

Figure 5.2: The overall structure and organization of a board follows a hierarchical approach where the board is the root of a tree structure. A board can hold multiple board items that can also be nested through frames. From `https://developers.miro.com/docs/boards` (accessed 2023-07-20)

Chapter 3 discussed the basic idea of an infinite canvas, specifically how it provides an endless space in three dimensions. Users can zoom in and out and move horizontally and vertically. This also enables users to freely place items anywhere on a board. Thus, the actual position of content can be described by its size, x, and y position. When a shape on a board with the position `x:10` and `y:40` is moved up by 20 points and to the left by 10, its new position is `x:0` and `y:20`.

5.1.2 Board Items

Miro defines board items as "visual representations of the information that users share on the board" [mir]. They can be a piece of text, a sticky note, a link, an image, a geometric shape, a video, and more. Figure 5.3 shows a collection of board items. These items allow users to interact with digital tokens on the board and therefore to construct visual artifacts on an infinite canvas.

Although Miro incorporates a wide range of items, we briefly discuss the following Miro items here as these are the most common and intuitive ones:

Sticky note In the real world sticky notes are a central part of collaborative design and allow people to express their thoughts and ideas [Cla11]. In Miro sticky notes are one of the simplest and most intuitive ways users can add their perspective to the board. They provide a quick way to create new inputs and to let people see and build on others ideas.

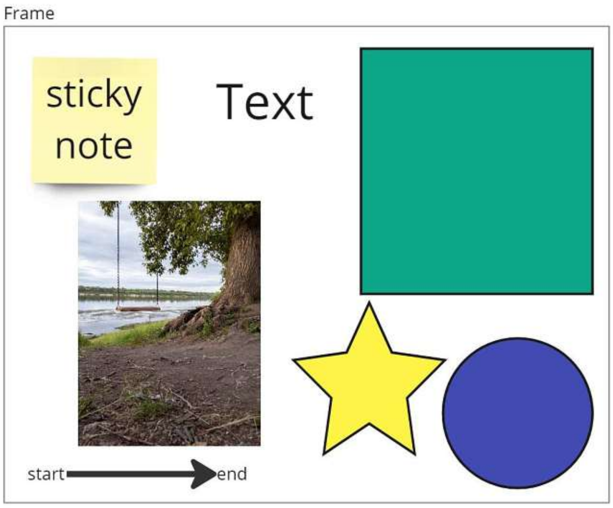


Figure 5.3: Miro features various items that can be placed on a board. These are referred to as board items. This figure shows the most common items, i.e. sticky notes, text, images and connectors. It also shows three different shapes, a rectangle, a star, and a circle. Connectors usually feature a start and end item, in this case a text.

Text Similar to sticky notes, users can add text to a board. However, text items provide more functionality for styling and are more suitable for longer paragraphs, whereas sticky notes target quick and brief expressions of ideas.

Shape These board items add geometric shapes to a board, such as rectangles, circles, stars, triangles, arrows, and so on. Thus, they allow us to style the board visually, for example, by changing their background or border color.

Connector Connectors are lines that connect two items on a board. Thus, they can incorporate other board items as their start and end point. They also come in various shapes and styles. Similar to shapes, connectors allow us to enhance boards visually. However, their true power lies in their ability to allow users to create a "flow of information" between board items by connecting them.

Image As the name suggests, this item is simply a image that is placed on a board. Like a printed picture on a whiteboard, this board item allows us to add digital images to a Miro board.

Frames These items are used to structure and organize other board items. They enclose items and build a child-parent relationship where the frame acts as the enclosed items parent. Frames are a core concept in Miro and allow boards to organize content in defined spatial arrangements.

Listing 5.1 shows an abbreviated extract of the board items in a JSON format from Figure 5.3. This data of each board item can be obtained through the Miro Web SDK or the Miro Rest API. The item type is defined by the `type` property, for example `sticky_note`, `text`, `image`, `shape`, or `connector`. However, depending on the item type, the data includes different properties.

Furthermore, some properties can only be read and not modified or customized. For example, the type of items is defined as a `Readonly` property by Miro. Additionally, the type of an item also determines other `Readonly` properties. Therefore, the type is crucial on how they can be used when developing an application. The Miro developer documentation [2] gives a detailed description on board items and how developers can use their corresponding properties.

Listing 5.1: This listing shows an abbreviated extract of the board items from Figure 5.3 in JSON format. By using the Miro Web SDK, a comprehensive collection of data about the board items can be obtained, which can subsequently be used for the development of applications.

```
[
    {
        "type": "sticky_note",
        "content": "<p>sticky note</p>",
        "style": {...},
        ...
    },
    {
        "type": "text",
        "content": "<p>Text</p>",
        "style": {...},
        ...
    },
    {
        "type": "image",
        "title": "",
        "url": "https://...",
        ...
    },
    {
        "type": "shape",
        "content": "",
        "shape": "rectangle",
        "style": {...},
        ...
    },
    {
        "type": "connector",
        "start": {"item": "3458764557023"},
        "end": {"item": "3458764557023"},
        "style": {...},
```

[2] https://developers.miro.com/docs/board-items (accessed 2023-08-23)

```
        ...
    },
    {
        "type": "frame",
        "title": "Frame",
        "childrenIds": ["3458764557023", "3458764557023", ...],
        "style": {...},
        "showContent": true,
        ...
    }
]
```

Further properties that all board items include are shown in Listing 5.2. Due to its length, this Listing only shows an excerpt in addition to the properties from Listing 5.1. The `id` is one of the most important ones, as it identifies the item on the board. Furthermore, the `x` and `y` determine the position of the item on the board while the `width` and `height` determine its size. The `parentId` reveals a relationship of the item with a frame item. This relationship is also present in the frame data through its `childrenIds` property where the ids of the frames child items are listed (see Listing 5.1).

Listings 5.3 and 5.4 show an example of the style property of a connector and a shape item.

Listing 5.2: All board items usually include the additional properties from this Listing. All items include the id to identify the item on the board. The x and y properties determine the position of the item on the board while the width and height determine its size.

```
{
    "id": "3458764557024203174",
    "parentId": "3458764557023780097",
    "origin": "center",
    "relativeTo": "parent_top_left",
    "createdAt": "2023-06-13T21:10:16.974Z",
    "createdBy": "3074457365770466845",
    "modifiedAt": "2023-06-13T21:11:11.879Z",
    "modifiedBy": "3074457365770466845",
    "x": 159.38769902085733,
    "y": 270.84168792988567,
    "width": 148.2653450979249,
    "height": 198.3735404319458,
}
```

Listing 5.3: As connectors play a special role for the flow of information in Miro they feature different styling options compared to other items. This listing shows the style attribute of the connector item from Figure 5.3 in JSON format.

```
{
    "startStrokeCap": "none",
    "endStrokeCap": "rounded_stealth",
    "strokeStyle": "normal",
    "strokeWidth": 5,
    "strokeColor": "#333333",
    "textOrientation": "horizontal"
}
```

Listing 5.4: This listing shows the style attribute of the shape item from Figure 5.3 in JSON format.

```
{
    "fillColor": "#0ca789",
    "fontFamily": "open_sans",
    "fontSize": 10,
    "textAlign": "center",
    "textAlignVertical": "middle",
    "borderStyle": "normal",
    "borderOpacity": 1,
    "borderColor": "#1a1a1a",
    "borderWidth": 2,
    "fillOpacity": 1,
    "color": "#1a1a1a"
},
```

5.1.3 Roles

As shown in Listing 5.2, Miro saves all interactions with board items in the `createdBy` and `modifiedBy` properties. On a Miro board every user is identified by unique number, for example `3658432978520043388`. This numbers is then saved in the corresponding fields.

In general, Miro users can be categorized in two categories *board owners* and *editors*. A board owner is the person that created the board, and editors are people that interact with the board, but have some restriction. For example, editors can not delete a board they are working on.

However, it is only possible to get the users id but not their role or permission level. Although the id of the user and their role would allow us to build one application for both user groups, the board owners id has been recently removed from the board metadata.

In the beginning of this thesis, the idea of creating a application for both user groups has been explored. The motivation was to show a different view, depending if the person interacting with the application is the board owner or an editor. Using this information would allow an application to show different views which could create more engaging applications and address user needs according to their tasks and involvement on the board. This would enable us to design an application, where the board owner has more rights than editors or visitors. For example, teachers in education have other needs than students when generating insights on an infinite canvas. A different view could allow them to see and do different things.

After an update of the Web SDK version, different solution strategies for this problem were evaluated. However, they were either not feasible or too complicated. For example, one idea was that board owners need to manually identify themselves on the board or in the application (e.g., by clicking a button). Afterwards the board owners unique id can be saved accordingly. In the end, all strategies turned out to be unstable and overly complicated. Since Miro does not incorporate this functionality at the moment, this idea was discarded for this thesis.

5.2 Application Development in Miro

As already outlined, the development of an application for collaborative and creative insight generation introduces some major challenges for the representation of information. The infinite canvas is a way to address these challenges but also introduces some restrictions and requirements. In such a setting, the generation of new insights requires a shared space where each opinion is equally considered. Thus, participants need to be able to input data in form of elements that feature their ideas and perspectives. On an infinite canvas for creative collaboration, every participant has to have some basic control over their own created elements, while also being able to interact and analyze the existing data on an infinite canvas.

As already argued in Sections 2.3 and 3.3.3, the design and development of an collaborative information visualization requires a different approach than "traditional" information visualizations. However, the following procedure to create visual representations of abstract data from Mazza can still give us guidance on how to tackle the design of such an visualization [Maz09]:

1. Define the problem
2. Examine the nature of the data to represent
3. Identify the number of dimensions of the data
4. Get to know the data structures
5. Define the interactions of the visualization

While other infinite canvas applications only provide limited or no support for custom application development, Miro encourages its users to create applications on their own. They provide a developer platform [3] and actively help their development community in

[3] `https://developers.miro.com/docs` (accessed 2023-07-20)

Categories	Use Case
Productivity & shortcuts	Ideation & brainstorming
Projects & tasks	Agile workflows
Documents & notes	Strategy & planning
Design tools	Mapping & diagramming
Import to Miro	
Presentations	
Visual assets	
Facilitation	
Research & insights	
Embed Miro	
Communication	
Admin, security, user management	

Table 5.1: Categories and use cases of applications available on the Miro marketplace.

multiple communication channels. Miro itself is under constant development and engages with application developers to continuously enhance their product. This allowed us to submit various ideas on how to enhance the development possibilities in Miro through various channels. Furthermore, during the prototyping phase of this thesis, an employee of Miro conducted an interview with Philipp Klein, the author of this thesis, about his experience with developing an application for Miro. Miro also published a major update to their developer platform during the prototyping phase of this thesis.

In the Miro environment, an application allows developers to extend the board functionality and to integrate custom actions on the board or with its items. This makes a board more flexible and enables developers to integrate and create additional features for end-users that would otherwise not be available on a board. In general, Miro integrates two different approaches to build applications, the Miro Web SDK and the Miro REST APIs.

The Miro Web SDK is directly embedded on a Miro board and shows information through the use of panels and modals. These are iframes that run on the board and help to structure and show information of an application. An application is launched by the board user through the *App toolbar* on the left side of the board windows. The Web SDK allows developers to access board items and gives end-users the possibility to directly use the functionality of an application for live interactions with the content on the board.

The REST APIs on the other hand do not allow live interactions from end-users and targets users that want to integrate Miro in a third-party tool. Thus, the REST APIs allows developers to enhance the functionality of third-party tools, such as GitHub, by integrating a Miro board in this setting.

However, as the Miro Web SDK and the Miro REST API offer different functionlity they complement each other to enable producing apps that offer a set of methods to create,

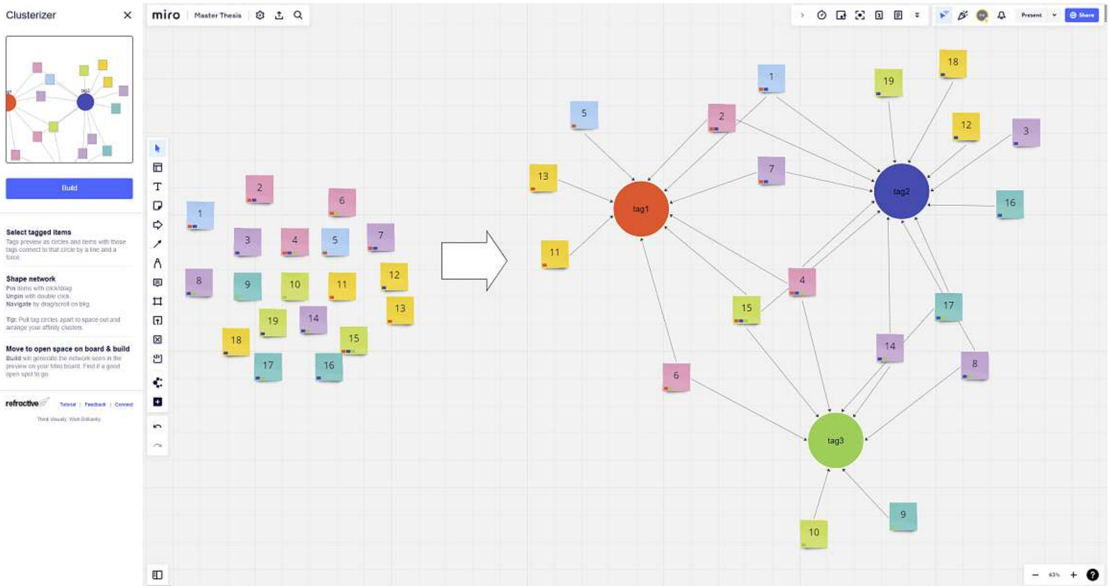


Figure 5.4: Clusterizer is an application for a Miro board, published on the Miro marketplace. It uses tags on sticky notes to create a graph on a board. It duplicates the sticky notes and analyzes the tags to connect the new sticky notes with the corresponding tags, represented by circles.

update, and remove board items, control panels and modals, and interact with the user's viewport. Over the course of this thesis the Web SDK and the REST API became more interwoven and options on how to use both simultaneously became available.

Miro also offers a collection of example applications that developers can use as starting points and inspiration for their own applications. These applications are published under `https://github.com/miroapp/app-examples` (accessed 2023-07-20) and include, for example, an applications that lets users create a calendar made with shapes and text for a given month and year. Furthermore, Mirotone [4] is a CSS library that provides pre-built components for developers to make the applications in Miro consistent and allow developers to quickly build applications.

5.2.1 Example Applications

As mentioned, Miro has an extensive collection of examples to inspire and support developers to create their applications. On their Marketplace [5], Miro divides the available applications into twelve categories and four use cases (see Table 5.1).

Clusterizer [6], for example, is an application for Miro that uses tags on sticky notes to create a visual representation of the notes with a graph. This allows users to get insights

[4] `https://www.mirotone.xyz/css` (accessed 2023-07-20)
[5] `https://miro.com/marketplace/` (accessed 2023-07-19)
[6] `https://miro.com/marketplace/clusterizer/` (accessed 2023-07-19)

into overlapping and recurring topics. Figure 5.4 illustrates how Clusterizer can build a graph out of tagged sticky notes. It allows users to analyze information embedded in sticky notes and create a graph to highlight areas of interest.

5.3 Visual Analytics in Miro

We already outlined the visualization powers of the infinite canvas and Miro in previous parts of this thesis. This section examines the data present on a Miro board, the structures of this data, and the definition of interactions for the end-users in more detail.

In general, Miro offers three different views for the user, the board, the panel, and the modal. We already discussed the board in Section 5.1. Additionally, Miro provides so-called panels and modals [7]. These are windows, embedded in the Miro system, that are only visible when using an application and therefore only to the user of an application.

Panels are small windows on the side of a board that can feature logic to carry out additional actions while the application is open. These windows typically add functionality to Miro while the rest of the board is still visible to the user. Modals on the other hand, often span the entire viewport and therefore hide the board for the user of an application. However, this allows to add more complex workflows and representations of data since they also feature a bigger frame. For example, we can use a modal to add functionality such as the integration of visualizations of the board items. However, when a user closes a panel or a modal, the code of this window stops and all related actions are aborted. Panels and modals typically start as a result of a user interaction. For example, we can open a modal when a user clicks on a button in the panel of the application.

By looking at the infinite canvas and Miro through the lens of Visual Analytics (VA) systems, we can treat the infinite canvas (i.e. a Miro board) as a database where the data entities and their relationships are visually present for the users. In general, entities are individual objects, items, or elements within a dataset that hold distinct information. In the context of Miro, board items such as sticky notes, shapes, or texts represent such entities. In Miro we can also visually add relationships between these entities. These relationships describe how entities are connected or associated with each other. For example, on a board connectors show how different entities (i.e. board items) are related by connecting two items with each other. Thus, these board items describe the relationships of individual entities in our board dataset.

Figure 5.5 shows this connection of the Miro board with its items (i.e. the database) and the modal or panel as our VA system. Furthermore, the figure also illustrates how the metadata in Miro can be used as an additional storage of data. This gives us the possibility to add further metadata to individual board items or to the application. This metadata is stored persistently on a Miro board although it is only accessible by the corresponding application and is not visible on the Miro board. Thus, it is not available to a board user without the corresponding application. However, metadata in Miro

[7] `https://developers.miro.com/docs/app-panels-and-modals` (accessed 2023-08-23)

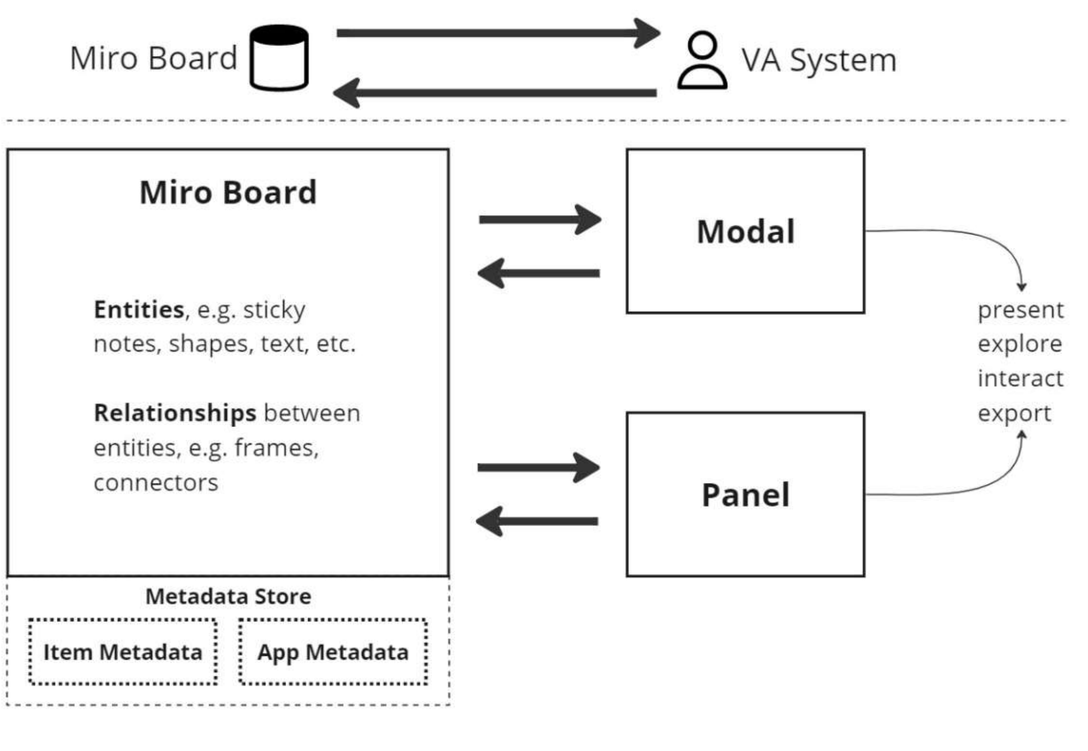


Figure 5.5: In the context of a visual analytics systems, a Miro board can be seen as a database where the user can directly and visually interact with its entities and relationships between entities. A board stores information in a visual format and its included board items, such as sticky notes, shapes, and text, function as entities of this database. Items such as frames and connectors add relationships to these entities. Through the modal's and the panel's iframe functionality we can use web libraries such as D3 to present, explore, interact and export the dataset. Furthermore, we can use the metadata of Miro to enhance data present on a board. Since the modals and panels run inside Miro, the flow of data is bi-directional and we can modify and add entities and relationships from our visual analytics system.

currently only offers very limited storage capacity which may cause unwanted side effects for applications.

One of the biggest opportunities for VA in this context, is the possibility to add and use visualization libraries, such as D3, in Miro's panel and modal windows. These windows consist of iframes which gives us the possibility to create dynamic web visualization of a boards content in Miro. Here we can add visual analytics systems directly in Miro and therefore analyze the content on the infinite canvas. Furthermore, we can interact with the content on a Miro board inside panel and a modal windows which creates a bi-directional flow of information with the board and the visual analytics system. Figure 5.5 illustrates this process.

Miro also gives us the possibility to track the activity on a board through its *Board Activity list*. This history can be accessed by eligible editors to track and evaluate the input that every board participant made. However, this functionality is only available on the board and cannot be accessed by an application. But the use of this log data would add additional possibilities for visual analytics, especially regarding the visualization of collaboration and user activity, as mentioned in Section 2.3. Future work might be able to investigate this feature for more insights into the collaboration of participants on an infinite canvas.

5.3.1 Clusters of Information on an Infinite Canvas

One step of the design process was to identify how the Gestalt laws described in Chapter 3 are applied in Miro. This allows us to gain deeper understanding on how we can use the relationships and elements present on a board in a prototype and what forms of visual representations are best suited for collaborative activities.

Overall, the connection and relationship of board items with each other is a fundamental part of any Miro board. This means that the idea of clusters, embedded as properties in our dataset, allows us to find ways how we can analyze board items regarding their relationships through similarity, proximity, and connectedness. In the end, the description of information clusters that are present on a board, allow us to explore data and use it as a knowledge-extraction method [NBX14].

On a Miro board such clusters (i.e. relationships of items) come in the form of connections between items and are present through various properties. To describe these clusters, we may think of them as "islands of information" introduced by Ware [War20]. This emphasizes that clusters on an infinite canvas are artifacts in space in which the individual elements are united by a connection in form of a shared property. The shared property of these islands of information can be visually present on the board or hidden in the items properties.

Based on the Gestalt laws from Chapter 3, Figures 5.6, 5.7, 5.8, 5.9, and 5.10 show common clusters of information found on a Miro board.

As Miro, also integrates more properties for board items, that are often not visible to board editors, developers can also find clusters in the entities through various other shared connections. For example, Figures 5.11, 5.12, 5.13, 5.14, 5.15, and 5.16 illustrate how clusters of information can also be found by an items creator or updater, the creation and update timestamp, the content (e.g., text) of the item, the size of an item, and tags that are present on this item. However, here much more possibilities are possible to identify and use clusters on a Miro board.

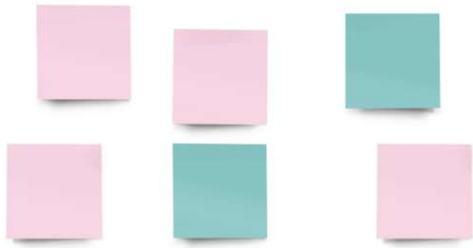


Figure 5.6: A simple approach to cluster items is their similarity to each other, e.g., the color of sticky notes. However, this idea of similarity is quite broad in Miro as Figure 5.14 shows. The use of different board item types can also be considered as the identification of clusters based on the Gestalt law of similarity.

Figure 5.7: Similar to the Gestalt law of proximity the spatial position of board items can determine how items are connected. As discussed in Section 3.3.1, clustering based on proximity is one of the most intuitive and easiest to understand representations of a relationship between items on an infinite canvas.

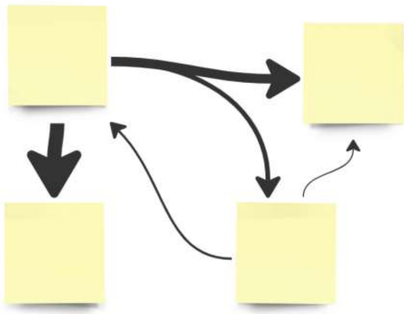


Figure 5.8: As already discussed, connectors allow board editors to show connections between two board items. They allow us to see how content on a board is forming groups of elements and to see their relationship with each other. Connectors in Miro can, for example, also indicate the strength of the relationship between items through the line thickness.

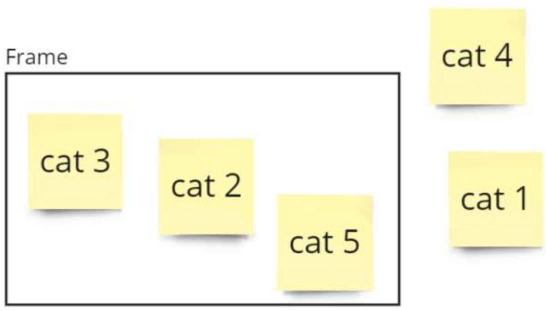


Figure 5.9: Frames are a way to structure and organize board items and build a parent-child relationship between the frame and the enclosed items. This feature is closely related to the Gestalt law of common region as it allows to build a hierarchy on the board.

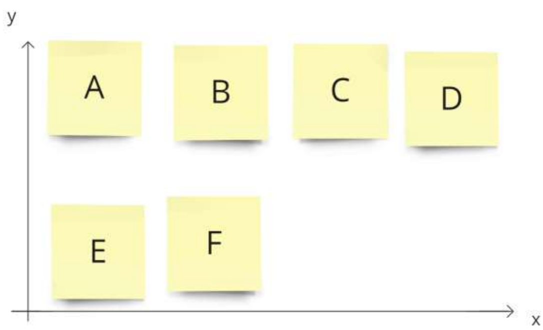


Figure 5.10: Although a board is a three-dimensional space, we can also identify clusters of items by their continuity on an axis. For example, if the sticky notes above were clustered by their position on the y-axis the two groups could be `[A,B,C,D]` and `[E,F]`.

Figure 5.11: Every board item in Miro features the properties `createdBy` and `modifiedBy`. This information can be used to build clusters on the collaborators activity on the board.

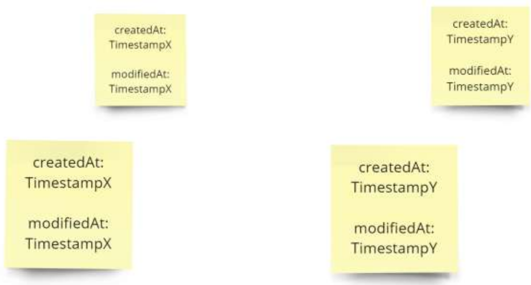


Figure 5.12: Similar to the creator or updator cluster, the item properties `createdAt` and `modifiedAt` allow us to build clusters based on the timestamp of these actions.

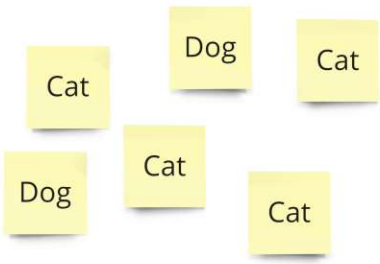


Figure 5.13: Although not all Miro board items allow to build content clusters as some item types do not include this property (e.g., images), we can also build clusters based on the content of an item. For example, we can use the text on a sticky note. In this figure we can identify two clusters, “Dog” and “Cat”. As of July 2023, this clustering based on content of sticky notes was added in a first beta version of *Miro AI*. It allows board owner to find keywords across sticky notes and also to summarize a collection of notes.

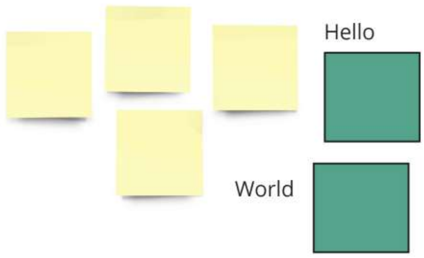


Figure 5.14: As a Miro board can hold various items of different types, we can also describe clusters based on the type of elements. For example, this figure shows how we can identify one cluster with sticky notes, one with text, and one with shapes. In general, this approach to identify clusters is related to the Gestalt law of similarity.

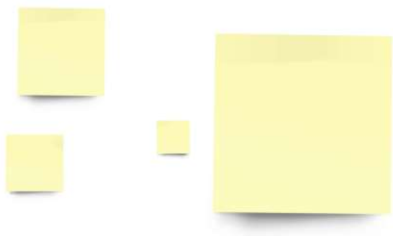


Figure 5.15: The size of the item can also be seen as its closeness to the user in the viewport. For example, it is possible that an item has the same x and y coordinates but has a different size. However, we identified that this form of clustering can be very unintuitive and difficult to comprehend and should therefore be used carefully.

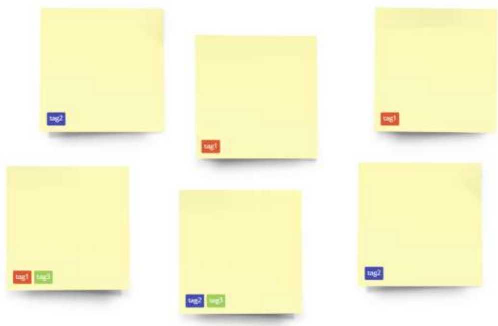


Figure 5.16: We already discussed clustering with tags with the Clusterizer application as shown in Figure 5.4. Tags allow us to add further information to sticky note items and categorize them accordingly.

5.4 Prototype Design and Implementation

As mentioned, is is possible to develop an application for a Miro board by using the Miro Web SDK, the Miro REST APIs, or by combining both. The prototype of this thesis uses the Miro Web SDK since one of the design requirements, identified in Chapter 4, was to enable direct interactions with content on an infinite canvas. Furthermore, the Web SDK allows us to directly embed the application in an infinite canvas through the use of panels and modals on a Miro board.

5.4.1 Motivation and Problem Analysis

After the analysis of design elements that we can use and how they we can arrange and groupe items on a Miro board, a prototype application has been developed. The main motivation of this prototype was to analyze how participants can contribute to the design of a collaborative interactive articles and how the infinite canvas can support them to express their thoughts. It integrates spatial positioning of board items, since words alone often do not have the power to accurately describe our perspectives, thoughts, and ideas to others. To do so, the prototype focuses on a set of simple interactions with the board, as the integration of complex navigation and interaction techniques can be overwhelming for people that have only limited or no experience with an infinite canvas or Miro.

Another goal of the prototype is to investigate how the collaboratively created information can be analyzed and visualized to generate insight into peoples collective knowledge. Here, a information visualization allows users to get a quick holistic overview of the content on a board.

On a Miro board users can have one of two distinct roles, the board owner or the editor. In the domain of creative collaboration and design sprints a sprint master is common and functions as a leader that guides the team through the process [mir17]. In the following sections this person is referred to as the *facilitator*. In contrast to the facilitator, *participants* are individuals that contribute their knowledge on an infinite canvas.

In the prototype this facilitator is the person that guides participants through an activity and is able to generate insights into the overall perspectives and ides of the team in the end. The prototype allows them to analyze participants input and to quickly create a summary of the key findings. Participants are invited to share their ideas on sticky notes, as these items provide a simple and fast functionality to produce a ground truth of the individuals perspective on the Miro board. In the end, the facilitator can analyze this ground truth of individually produced data and gain insights into the groups dynamic. Figure 5.17 illustrates this process.

To produce this ground truth, the prototype focused on the possibilities of spatial clusters of information on the board. The data input by participants is based on a research project by the co-advisor of this thesis, Victor Schetinger [SDBEA+23]. Here, Schetinger et al. conducted a study that followed a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis to better understand the role that generative models might play in

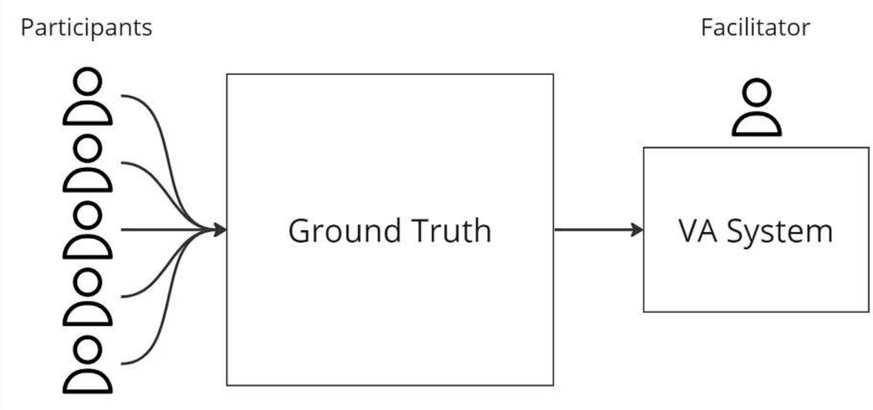


Figure 5.17: Flow of information in prototype from participants to the facilitator. The participants produce a ground truth which is analyzed by the facilitator with a visual analytics system.

visualization. They used Miro in semi-structured interviews where interviewees can place their thoughts and perspectives on a two-dimensional plane.

In general, the use of spatial information as a feedback mechanism is a common approach to gather participants perspectives. Miro, also features the Likert scale template that attempts to measure participants knowledge, ideas, and opinions. It allows participants to freely position elements along a line where they can express themselves with a greater degree of nuance. Figure 5.18 illustrates how sticky notes, not only allow participants to position an answer a question, but also allow them to add their thoughts through the content of these notes. However, in this template there is currently no possibility to get insights into the answers and to get an overview of the overall perspectives of individuals. The Likert scale template and the approach by Schetinger et al., required a manual analysis of the data on the board which can become a tedious and time consuming task.

In the end, the prototype aims to investigate how the idea generation of participants can be supported by using two-dimensional spacial input that builds on the SWOT analysis method. It furthermore, aims to analyze how the input of participants on an infinite canvas can be used as a mechanism for insight generation into a collective perspective. To do so, a facilitator guides participants, prepares the board, and sets up a two-dimensional plane where the input of participants is collected. Afterwards, the facilitator is able to use the positioning of participants notes in an output in form of an information visualization.

5.4.2 Views

As mentioned, there are two user groups in Miro, the participants and the facilitator. The participants interact with the board by using the default Miro functionality. This means that they do not directly engage with the application, but rather input data for the analysis and further investigation of the board content. This investigation is performed

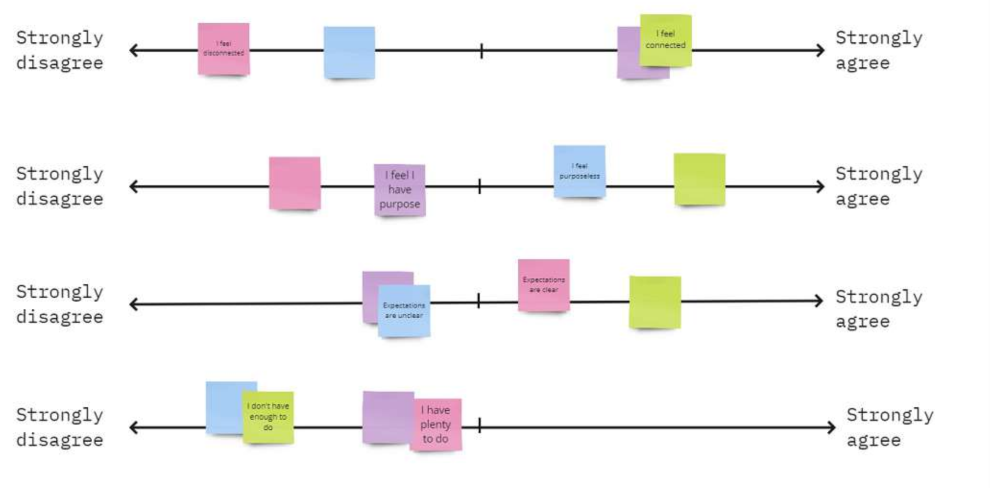


Figure 5.18: The Likert scale of Miro offers a template to answer questions along one dimension. However, it is not possible to analyze the answers automatically.

by the facilitator that installs the application with their Miro account and uses it to gain deeper insights into the collective information the participants provided.

Thus, the two approaches to use the prototype are:

- Participants only interact with the input plane, which serves as the collaborative space for participants.
- Facilitators interact with the board through the application and the application itself. The application is implemented through the panel and modal windows in Miro.

Input Plane

The input plane is a two-dimensional structure on the Miro board. It functions as the input field for participants where they add their thoughts on sticky notes and produce the data for the facilitator to evaluate. This approach lets us harness the potential of an infinite canvas, empowering participants and teams to express themselves in an explorative way. It gives people the freedom to articulate their individual perspectives using a two-axis plane that challenges conventional thinking. This approach encourages participants to express themselves by spatial positioning of sticky notes notes. It also helps individuals and groups to find and visualize ideas, opinions, and perspectives with the infinite canvas.

Figure 5.19 shows an example of such an input plane. As illustrated, an input plane offers the ability for participants to create notes and visualize their spatial relationships on the plane, facilitating a deeper engagement with their own thoughts. This creates a dynamic and immersive way to explore different perspectives. An example of the corresponding data of Figure 5.19 is shown in Table 5.2. Here the data of the sticky notes are distributed along the two axis (TOP-BOTTOM and LEFT-RIGHT) along a scale from -1 to 1.

An input plane consists of a parent frame with the two-dimensional input area for participants as its children. Additionally, a textual description can be used to give participants more information on their task, e.g., a question or a task description. Each axis of the input area consists of two text items that are connected through a connector item. This allows us to create a two-dimensional coordinate system as visual guidance for participants. For example, the two text items “Left” and “Right” represent one input dimension. In combination with the second dimension, participants are able to place their sticky notes on a two dimensional plane. However, to be able to correctly analyze the content for the prototype, all board items need to be on a input plane and therefore children of its frame. Miro automatically creates this parent-child-relationship whenever board items are placed inside the frame.

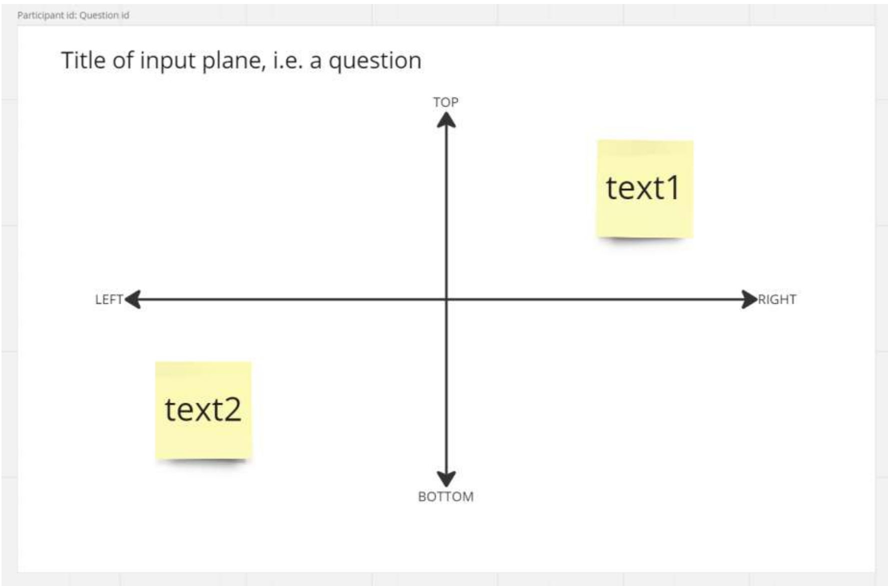


Figure 5.19: Example of an input plane of the prototype. It features an frame as its parent, a text field as its title and two axis as the answering dimensions. Additionally, two example answers (text1 and text2) are present on the input plane.

The prototype allows participants to express their perspectives, thoughts, and ideas by using spatial articulation on an infinite canvas, resulting in an interactive and engaging activity. The task of participants is to brainstorm by creating and positioning sticky notes on an input plane. The interaction with the infinite canvas for participants is as simple as possible, since they may not be familiar with Miro or such an input format.

Facilitator have to set up the input planes and guide the participants through the brainstorming process if necessary. It is also possible to add other Miro items to the

Item	TOP-BOTTOM [1;-1]	LEFT-RIGHT [1;-1]
text1	0.6	-0.7
text2	-0.6	0.7

Table 5.2: Example data of the sticky notes from the example input plane from Figure 5.19. To make this example simpler, the sticky notes are distributed along an exemplary [1;-1] scale.

input plane, such as rectangles, images, etc. to customize the input area and allow for more sophisticated use cases. These items will be ignored and not included in the data analysis. But sticky notes are restricted to participants and should only be used to gather participants thoughts, ideas, and perspectives.

Figure 5.20 shows an example use case where six participants had to answer two questions each by placing sticky notes on the input planes. The application in the panel on the left side of the Miro board is only visible to the facilitator.

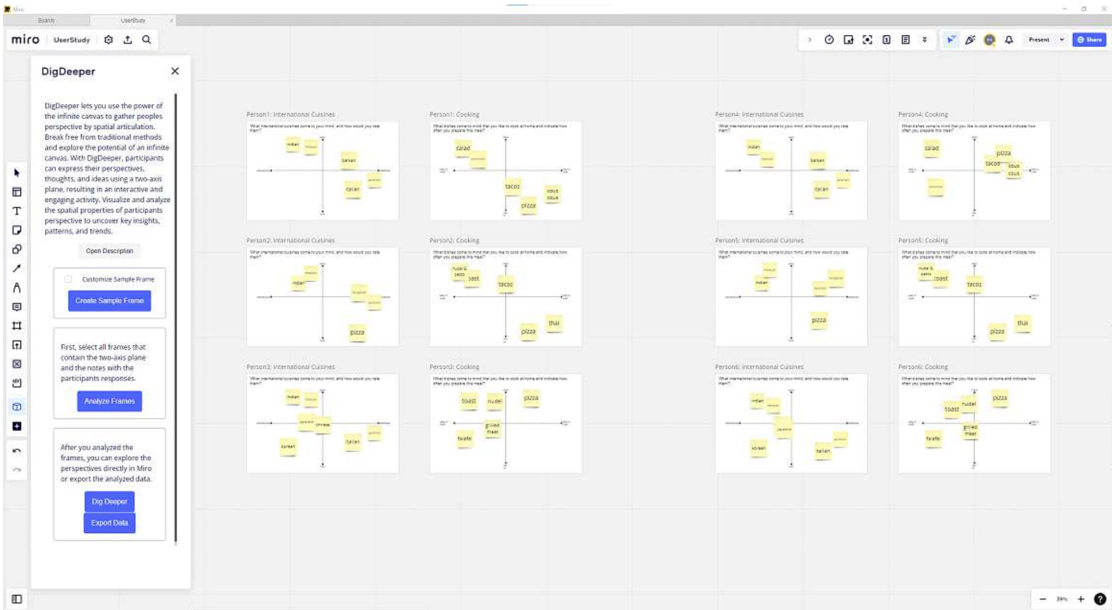


Figure 5.20: Example of input planes in Miro for six participants with two questions each. Each question is featured as an input plane which is the place for participants to provide sticky notes as their answers. In this example, the participants already provided answers to the questions on the input planes.

To analyze the answers provided by participants on the input planes in Figure 5.20 using the Miro application prototype, it's necessary to transform them into JSON format. Subsequently, this data can be further explored and visualized using web libraries like D3.

Listing 5.5 provides a snippet illustrating how the prototype converts the board data into a JSON format. This excerpt demonstrates the identification of each participant based on the input plane's title. Consequently, the prototype processes the questions and answers for each participant. In this particular example dataset, there are six participants (Person1 - Person6), each with an associated questions array.

Listing 5.5: Abbreviated excerpt of the dataset from Figure 5.20. It shows the structure of data of the six participants and illustrates how it can be further analyzed. Listing 5.6 shows the question dataset in more detail.

```
[
  {
    "participant": "Person1",
    "questions": [
      {...},
      {...}
    ]
  },
  {
    "participant": "Person2",
    "questions": [
      {...},
      {...}
    ]
  },
  {
    "participant": "Person3",
    "questions": [
      {...},
      {...}
    ]
  },
  {
    "participant": "Person4",
    "questions": [
      {...},
      {...}
    ]
  },
  {
    "participant": "Person5",
    "questions": [
      {...},
      {...}
    ]
  },
  {
    "participant": "Person6",
    "questions": [
```

```
        {...},
        {...}
      ]
    }
]
```

Listing 5.6 presents an illustrative example of the structure of a question array for a single participant. The array encompasses the question's title, drawn from the input plane's (i.e., the frames) title, as well as the responses, labels, and axis positions. The `answers` array contains the content and position of a participant's answers to a given question. By combining this information with the maximum and minimum positions of the x and y axes, the participant's viewpoint regarding individual answers can be deduced. As child items within a frame in Miro are positioned relative to the frame's top-left corner, the values of `xMaxPosition`, `xMinPosition`, `yMaxPosition`, and `yMinPosition` are the same in this instance. However, if the facilitator alters the minimum and maximum axis values, the participant's perspective can still be inferred from the answer's position based on its relationship to these extremes.

Listing 5.6: Listing showing the answers to the questions from Figure 5.20 and Listing 5.5 from participant "Person1". It shows the position of answers and labels of the axes. This allows us to calulate the position of the answers along the axes and therefore visualize the perspective of the participant.

```
"questions": [
      {
        "title": "Cooking",
        "answers": [
          { "value": "pizza", "x": 578.5202184352711, "y":
             499.58582256360387 },
          { "value": "tacos", "x": 485.22999999999956, "y":
             390.4629240102513 },
          { "value": "salad", "x": 196.16882553608957, "y":
             165.55999999999767 }
        ],
        "xLabelMax": "hard to cook",
        "xLabelMin": "easy to cook",
        "yLabelMax": "often",
        "yLabelMin": "never",
        "xMaxPosition": 814,
        "xMinPosition": 99,
        "yMaxPosition": 96,
        "yMinPosition": 544
      },
      {
        "title": "International Cuisines",
        "answers": [
          { "value": "mexican", "x": 376.5196929138692, "y":
             157.23810502710694 },
```

```
        { "value": "indian", "x": 270.79066018336016, "y":
            141.23810502710694 },
        { "value": "austrian", "x": 747.1163024847265, "y":
            351.23810502710694 },
        { "value": "italian", "x": 620.7481929941096, "y":
            405.78955566282093 },
      ],
      "xLabelMax": "traditional",
      "xLabelMin": "adventurous",
      "yLabelMax": "spicy",
      "yLabelMin": "mild",
      "xMaxPosition": 814,
      "xMinPosition": 99,
      "yMaxPosition": 96,
      "yMinPosition": 544
    }
  ]
```


Visualization Approach Using Miro's Panel and Modal

While the input planes represent the space where participants create and position sticky notes and therefore create the data, the user interface of the application is shown in the panel and modal windows inside Miro. This allows developers to use web technology such as React, Typescript, and visualization libraries.

The facilitators view with the opened application is shown in Figure 5.20. The panel is visible on the left side of the board and features four main parts:

1. A brief introduction to the application along with a button that opens a more detailed description. This part only has an informative value for the facilitator as it describes the intended use of the application. Clicking on the button “Open Description” opens a modal where facilitators can get a more detailed explanation of the application and instructions on how to use it.

2. The “Setup” part allows facilitators to quickly build input panels for participants. It allows them to create a sample frame that they can customize directly on the board with the built-in Miro functionalities. However, application users can also customize this sample frame in the application by activating the checkbox “Customize Sample Frame”. This expands an area above the “Create Sample Frame” button where they can customize the input plane. Here they can change the person ID, input plane ID, plane description, x-axis left, x-axis right, y-axis top, and y-axis bottom.

3. The “Analysis” section includes the functionality to analyze the content of the input planes with the prototype. Here, the user is instructed to first select all input planes with the participants notes. After selecting the input planes and clicking the “Analyze Frames” button, the fourth section unlocks. Now, the facilitator can start

the analysis of the data. The prototype also offers basic guidance through Miro notifications. When the user successfully implements analyses the input planes, a notification confirms its successful completion. Conversely, if any errors arise during the analysis, the corresponding error message is displayed, accompanied by suggestions for its resolution. For instance, if the selected frames are in an incorrect format, the error message guides the user with the instruction: "Detected wrong format in selection. Select frames with the correct format."

4. In the final part, the facilitator can further explore the input from participants on a modal with a heatmap or export the selected and processed data in a JSON format (see Listings 5.5 and 5.6). This allows the facilitator to investigate the data in their favorite tool outside Miro.

As mentioned, the prototype incorporates a modal where facilitators can further explore the dataset present on the Miro board with an information visualization. For this, a heatmap has been implemented to give facilitators an overview of participants input. A heatmap is a graphical representation of data where values are depicted with colors on a two-dimensional grid. Heatmaps are commonly used to make it easier to identify patterns and analyze complex information. In a heatmap, a data point is represented as a colored cell or pixel, and the color intensity corresponds to the value of the data point. Heatmaps offer an intuitive way to explore and interpret data, which enables facilitators to gain valuable insights from the participants inputs. Furthermore, heatmaps can be valuable to determine if and how clusters are present in the data [MV15]. As the target group of this prototype is the broad audience, meaning that they are not visualization experts, but rather want to get a quick overview of the participants notes, the interface is kept very simple. Furthermore, this prototype serves as a proof of concept, thus only basic functionality has been integrated.

Figure, 5.21 illustrates how the modal looks like. At the top of the modal, a short text explains the overall purpose of the visualization and how to interact with it. It describes how users can create the heatmap and what insights they can gain from the heatmap.

The heatmaps are created by dividing the two-dimensional input plane into a coordinate system where the two two dimensions are divided into equally spaced steps. Users can specify the number of steps with the "Granularity" input which allows them to visualize and explore the spatial properties of participants perspective with more or less details. This enables facilitator to uncover key insights, patterns, and trends in the collective perspective of participants. The subfigures in Figure 5.22 illustrate how data can be explored by changing the granularity input.

Overall, the prototype helps facilitators to set up a collaborative environment where participants are able to use spatial relationships to encode their thoughts, ideas, and perspectives on so-called input planes. The applications allows facilitators to analyze and investigate the answers from participants on these planes to quickly pinpoint the most crucial aspects. To do so, it enables facilitators to explore the data directly in Miro with a heatmap visualization or to export a JSON data file to use in other tools.

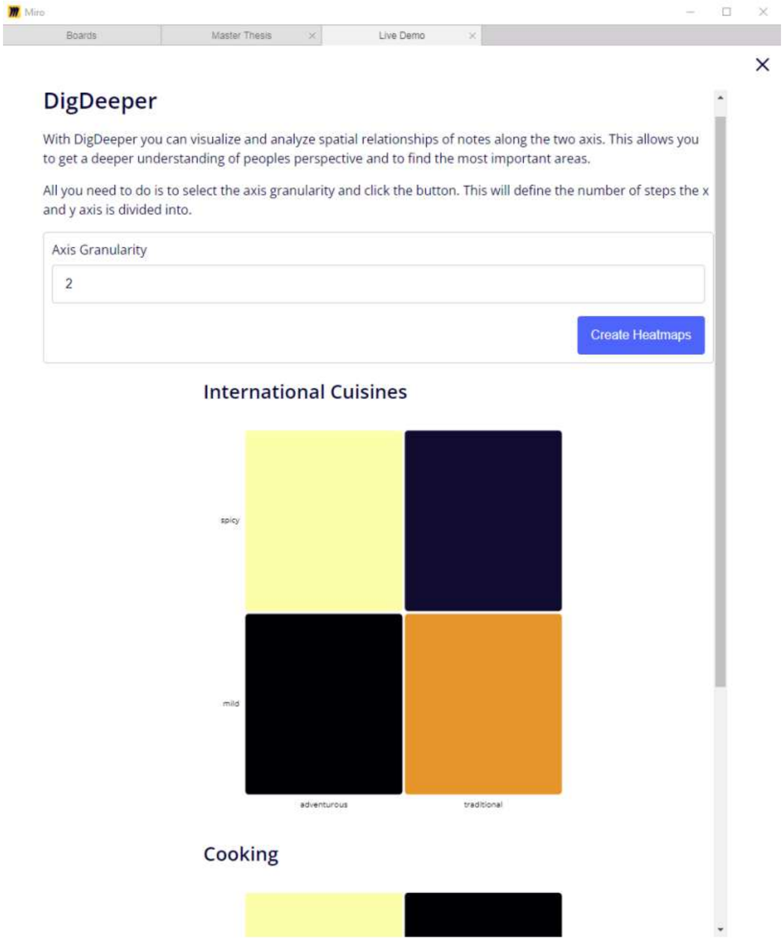
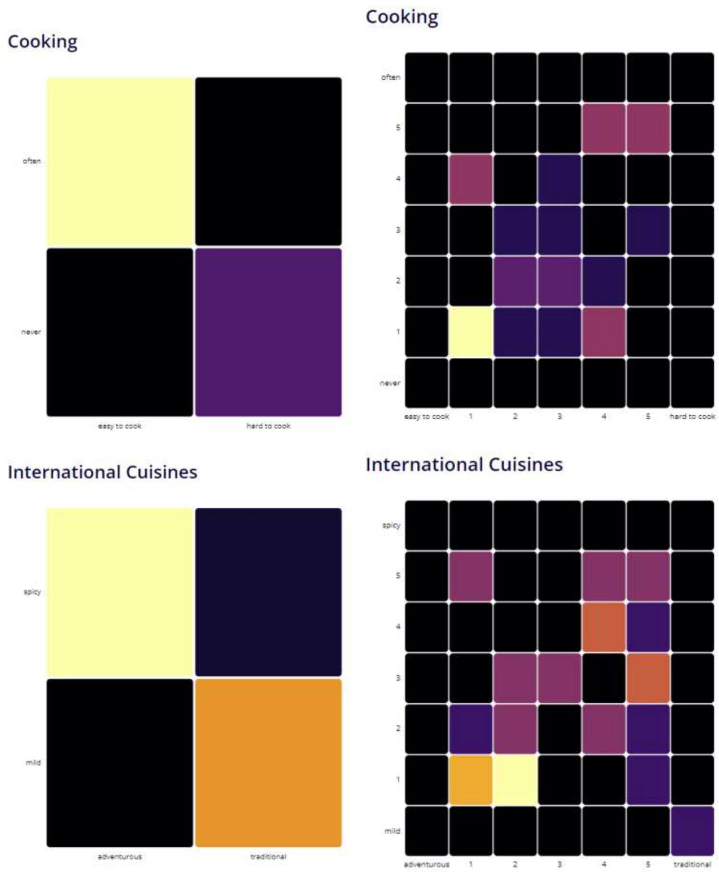


Figure 5.21: A modal in Miro which visualizes participants answers on sticky notes from the Miro board. The data from the board is analyzed and facilitators can investigate it with a heatmap visualization.



(a) Heatmaps divided into 2 steps

(b) Heatmaps divided into 7 steps

Figure 5.22: Heatmap visualizations generated with a granularity of 2 (Figure 5.22a) and 7 (Figure 5.22b)

5.4.3 Technology Stack

In general, application development in Miro is highly flexible and allows developers to choose from a range of tools and frameworks. However, most of the example applications and the developer community use React in combination with TypeScript to build their applications with the Web SDK. Thus, the prototype implementation uses React and Typescript as well. Furthermore, React allows us to use the D3 library to easily build and integrate information visualizations.

React

React [8] is a popular open-source JavaScript library that allows developers to build web applications. At its core, React offers a component-based structure, which means that reusable, self-contained components enable developers efficient code organization for maintenance and scalability. This allows to build a parent-child relationship of components where a child component can be embedded within multiple parent components. Here, data follows a unidirectional flow in React where it is passed down from parent components to child components.

React has gained significant importance in the development of modern web applications. Especially, its component-based structuring of content and unidirectional data flow, offers an extensive toolset for creating dynamic, interactive, and scalable applications.

Typescript

TypeScript [9] is a superset of JavaScript that adds static typing and other advanced features to enhance the development experience. It introduces type annotations, allowing developers to specify types for variables, function parameters, and return values. These type annotations provide early detection of potential errors and improved code reliability. TypeScript also supports features such as interfaces, classes, generics, and modules, bringing object-oriented programming concepts to JavaScript.

When it comes to React, TypeScript complements and enhances the development process by highlighting common mistakes within components.

D3

D3 [10], short for Data-Driven Documents, is a JavaScript library that provides a set of tools for creating dynamic and interactive data visualizations on the web. Developed by Mike Bostock and a team of contributors, D3 allows developers to bind data to the Document Object Model (DOM) and apply transformations to create visual representations of data. With D3, developers have fine-grained control over every aspect of a visualization, from data manipulation to rendering. D3 allows developers to build complex and interactive visualizations that can respond to user input and dynamic data updates.

Since its introduction, D3 has gained widespread adoption among data visualization professionals and developers due to its versatility, flexibility, and robustness. Today, its developer community provides a wide range of resources and examples for quick prototyping.

[8] `https://react.dev/` (accessed 2023-07-20)
[9] `https://www.typescriptlang.org/` (accessed 2023-07-20)
[10] `https://d3js.org/` (accessed 2023-07-20)

5.4.4 Data Extraction

In term of data extraction from a Miro board, multiple approaches can be employed based on specific use cases. However, all approaches require a crucial step: the specification of items on the board that will be analyzed by an application. This specification can be achieved either through code implementation within the application (such as extracting all data on the board) or by granting the user of the application the power to make selections (like handpicking specific items on the board). Figure 5.23 illustrates this process. We can use the items selected by the user on the board or specify the board items in the code, for example all items with the same type or a single item by its id.

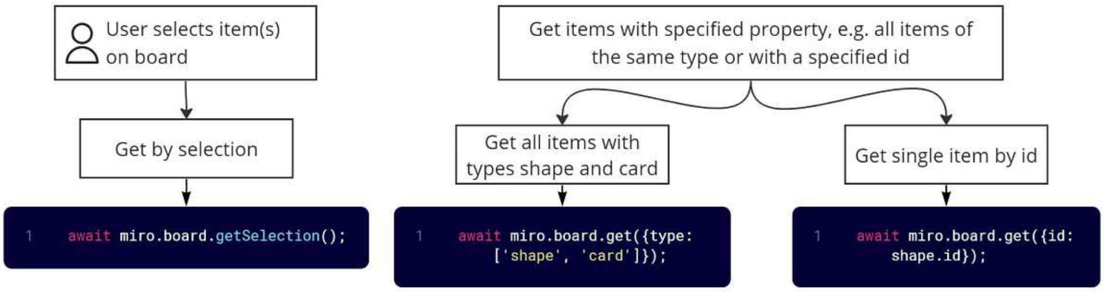


Figure 5.23: After an item has been added to the board, we can retrieve its data with the Miro Web SDK in two ways. We can use the items selected by the user on the board or specify the board items in the code, for example all items with the same type or a single item by its id.

In the context of this particular prototype, the user has to select all frames that serve as input frames. This design choice empowers the user with greater flexibility when it comes to data extraction and the subsequent analysis of input planes. By placing control in the user's hands, the prototype enables a more dynamic exploration of data, enhancing the overall experience and usability of the application.

As already mentioned, each input plane serves as a designated area for data collection for a single participant. An input plane is also intended to capture responses for one specific question. To obtain a collective perspective from all participants and questions, the prototype must allow the creation and analysis of multiple input planes, each contributed by various participants.

Achieving this functionality is made possible through the utilization of Miro frames that enclose the respective input areas. In Miro, each frame comes with a title. This title serves as the identifier for the participant and the question they are addressing. It is crucial for the prototype to organize and distinguish the data of individual participants and planes accurately. Therefore, the setup of the frame titles by facilitator plays a pivotal role.

To ensure consistency and proper identification, the title of each frame must adhere to a specific format: it should commence with the participant identifier, followed by a colon and the plane identifier. In this way, the prototype can effectively correlate responses to the appropriate participants and their respective questions. Thus, the correct format for the frame's title should be in the form of `<ParticipantId>: <PlaneId>`. By adhering to this prescribed format, the prototype will be equipped to manage and analyze the collected data efficiently.

Figure 5.19 provides a visual representation of the structure of an input plane and the essential board items it should encompass. Typically, an input plane is comprised of specified components, namely a frame, two axes (each consisting of two text items connected with a connector), and the participants' sticky notes.

While Miro board items can possess a diverse array of properties that can be set and read with the Web SDK, the prototype focuses on extracting and utilizing specific data for the analysis of the input planes. The following data is extracted from the board to facilitate this analysis:

Frames

- *title*: Short header text for the frame. Must be `<ParticipantId>: <PlaneId>`.
- *childrenIds*: An array of Ids of the frames children.

Sticky Notes

- *id*: Unique ID of the item
- Position of the sticky note inside the frame.
  - x
  - y

Connectors

- *id*: Unique ID of the item
- *start*: Id of board item that the start point of the connector attaches at.
- *end*: Id of board item that the end point of the connector attaches at.

A JSON representation of this data is shown in Listings 5.5 and 5.6.

In the context of the prototype, the connectors' "start" and "end" properties are associated with text items, which can be located using their respective IDs. This enables us to extract the labels, as well as the positions of the minimum and maximum values of the axes. Consequently, knowing the the minimum and maximum values enables us to calculate and interpret the scale and distribution of data points on the input plane, i.e. the sticky notes, along the axes.

With this extracted information, the prototype can then process and analyze the input planes, offering valuable insights and facilitating the understanding of participants' responses.

5.4.5 Data Processing and Visualization

In the Miro environment, panels and modals serve as spaces where the application code is loaded within iframes. These iframes provide developers the capability to construct applications using HTML, CSS, and JavaScript. This functionality offers an opportunity to explore the potential of an infinite canvas for information visualization by integrating well-established visualization frameworks.

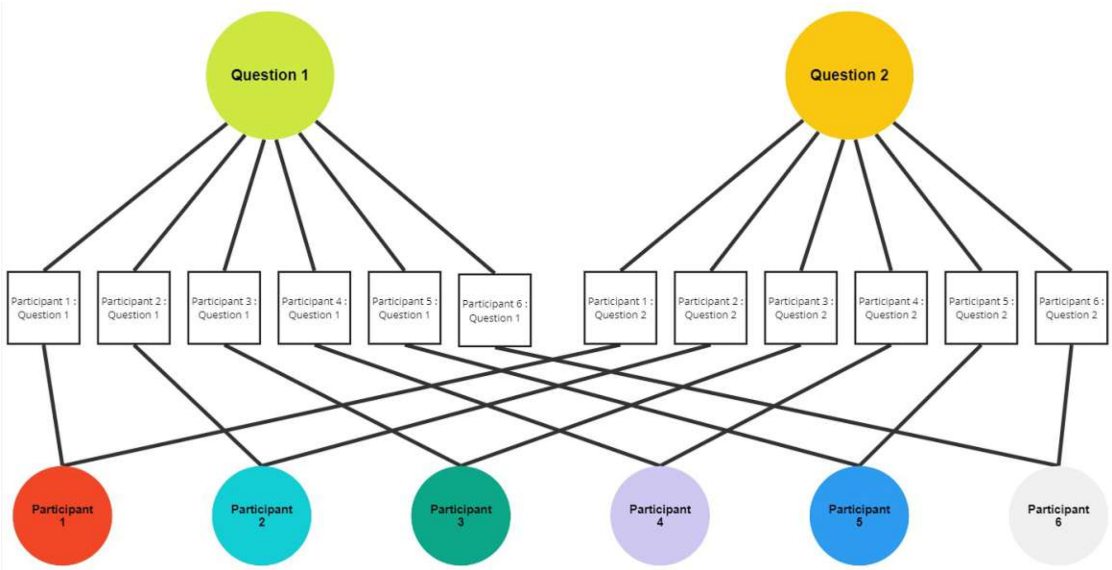


Figure 5.24: Connection between participants, questions, and input planes as shown in Figure 5.20. The rectangles in the center represent the input planes that are connected to questions and to individual participants through their frame title.

Figure 5.24 showcases the connection between questions and participants through the title of frames and therefore input planes. Each participant is connected to each question through exactly one frame. For example, the title `Participant 1: Question 2` connects the Participant 1 with the Question 2.

By leveraging this capability, the prototype connects individual input planes and processes the data to generate a simple heatmap visualization. For quicker prototyping and a proof-of-concept, the implementation of the heatmap is based on examples provided by the D3 community [11] [12].

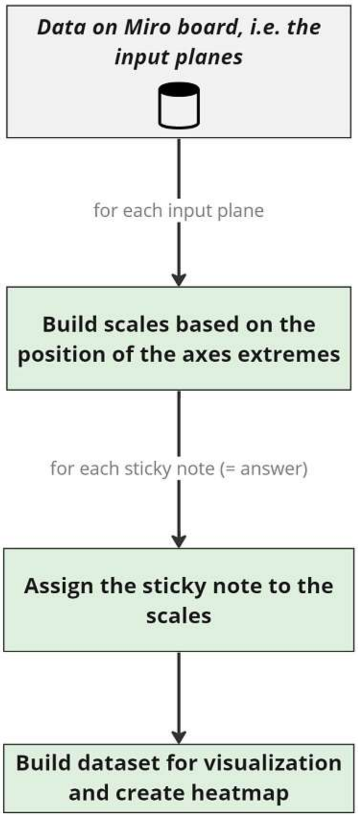


Figure 5.25: Flow of data from board items to the heatmap visualization. First, the data for each input plane gets analyzed and the scales are build. Then, we assign the position of each sticky note to the scales. In the end, we can use this information to build our final dataset and consequently the heatmap visualization.

With the extracted data from a Miro board, we can process and prepare the data for the heatmap visualization within the modal. Figure 5.25 illustrates this process which involves the following steps:

1. Building scales for both axes with equally distributed containers. The scales are based on the position of the connector labels and the value chosen by the user in the granularity input. These scales are then used to determine the corresponding position of the sticky notes in the heatmap data.

[11] https://d3-graph-gallery.com/graph/heatmap_style.html (accessed 2023-07-21)
[12] https://www.react-graph-gallery.com/heatmap (accessed 2023-07-21)

2. Assigning the sticky notes from the participants to the scales, determining the position of each sticky note relative to each scale. This step enables us to calculate the position of each sticky note along each scale and place them into the corresponding range.

3. Based on the position of the sticky notes we can now build the dataset for the heatmap. Here, each data point has an x and y position along with the number of sticky notes in that data point.

In the end, the heatmap visualization provides an overview of the content on the board, enabling users to quickly gain insights into the positions of the sticky notes within the Miro environment.

5.5 Final Prototype: Use Case Scenario

When a facilitator starts the application in Miro, a panel view with the application is opened on the board. As mentioned, this application focuses on an facilitator that wants to get insights into the collective perspective of participants. In this scenario, we describe a fictional interview where a facilitator acts as an interviewer that wants to get the perspective from three participants (= interviewees) on international cuisines.

First, the facilitator needs to set up the input frames for the participants. To do so, they open the application on their Miro board and create the input planes for the participants. In this case the question for input plane is “What cuisines come to your mind, and how would you rate them?”. The interviewees need to create sticky note with a response to this question and place the notes in the two-dimensional plane with the scales “spicy” to “mild” and “adventurous” to “traditional”. Figure 5.26 shows how such a finished setup might look like for one participant.

After facilitator set up the input planes, the participants have to create and position sticky notes as a response the question. They position them in the plane. For example, an interviewee might think that *Indian* is a relatively adventurous and spicy cuisine, while *Austrian* is rather traditional and mild. *Mexican* would be more traditional and but not as spicy as *Indian*. Figure 5.27 illustrates this interviewees responses on their input plane.

After all interviewees finished their input, the facilitator can get insights into the answers of the interview. To do so, they select the frames with the question planes and analyze them. Afterwards the facilitator can use the heatmap visualization to explore the participants answers and get an overview of the groups perspectives. Furthermore, the granularity can be changed by the facilitator to allow a more nuanced evaluation of the interviewees answers. This allows them to explore the answers in different graduation. For example, a granularity of two might tell an interviewer that, regarding international cuisines, interviewees associate adventurous cuisines as rather spicy. Figure 5.28 shows such an analysis.

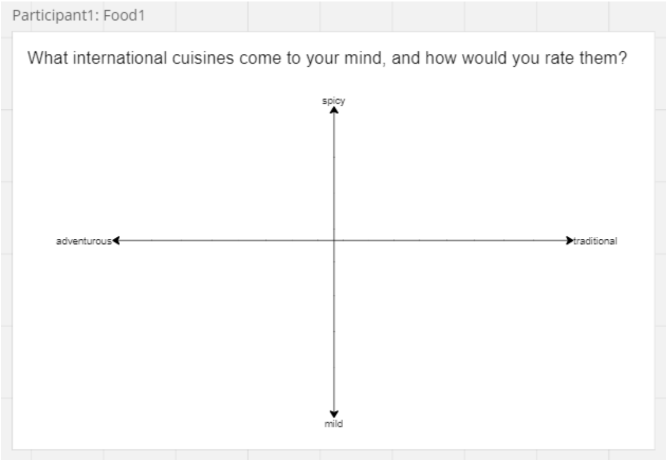


Figure 5.26: Finished input plane of fictional interview with the question "What cuisines come to your mind, and how would you rate them?" and the scales "spicy" to "mild" and "adventurous" to "traditional".

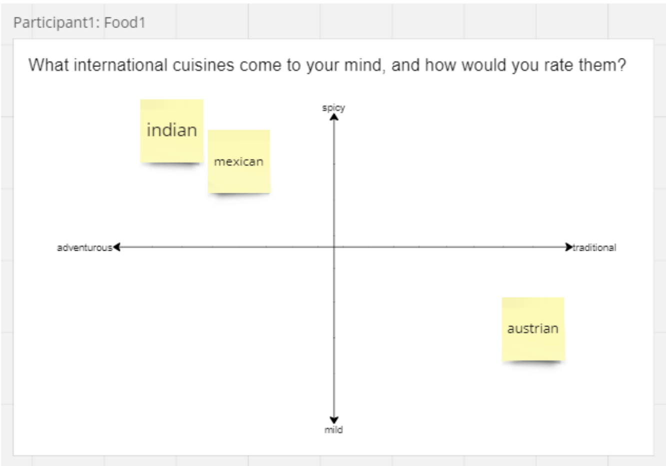


Figure 5.27: Completed interview from participant with sticky notes as answers on input plane from Figure 5.26. The interviewee created the sticky notes, i.e. answers, *indian*, *mexican*, and *austrian*.

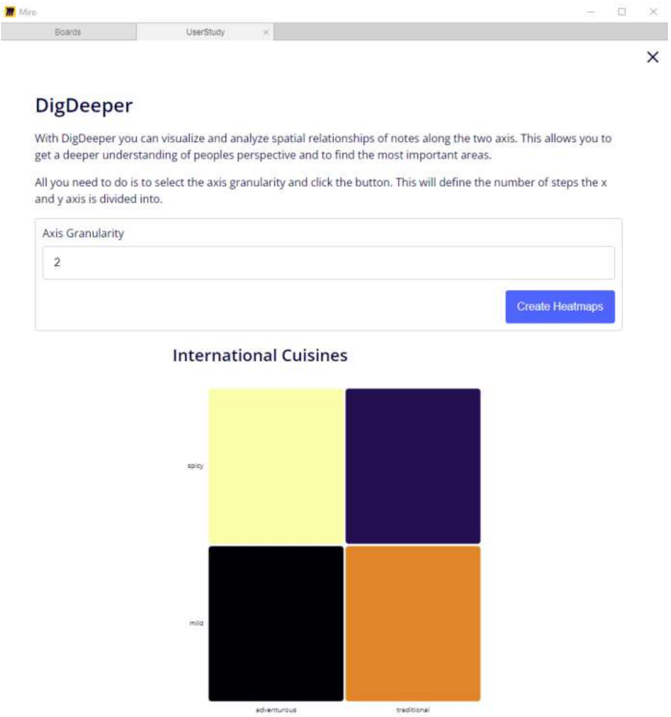


Figure 5.28: Heatmap visualization of the interviewees answers on the input plane. The granularity is set to “3”.

CHAPTER 6

Evaluation

This chapter describes the evaluation process, which involved conducting a user study with the prototype to observe participants' behavior on the infinite canvas. It begins by outlining the study setup, including the selection of participants and the specific tasks assigned to them during the study.

Following the study setup, this chapter proceeds to describe the study process itself. It presents what participants engaged in during the study and their interactions with the infinite canvas. Participants' feedback, insights, and thoughts on the infinite canvas were examined, which offers valuable perspectives on usability, user experience, and overall impressions of the prototype.

Finally, this chapter presents the results of the user study, its key findings, and conclusions drawn from the collected data. It synthesizes the results, highlighting the strengths and weaknesses of the prototype and the infinite canvas in general. The implications of the study findings are discussed for prototype improvements and the development of future applications for Miro.

6.1 User Study

The primary objective of the user study was to evaluate the infinite canvas as a collaborative platform for idea collection and collaboration. To accomplish this, the study employed the application introduced in Chapter 5 as the evaluation tool. Participants engaged with this application on a Miro board, which served as the designated design space for the study.

By utilizing Miro as the canvas for the study, we had the opportunity to explore and analyze the potential, possibilities, and constraints of the infinite canvas for both inputting and outputting information. The study focused on understanding how participants interacted with the prototype and the infinite canvas, how they utilized its features, and how they navigated on an infinite canvas.

During the study, participants' behavior was observed to gain insights into their approach towards collaboration and idea collection on the infinite canvas. Their interactions, thought processes, and responses to the application provided critical feedback on the effectiveness and usability of the prototype.

By investigating the participants' experiences within the context of the infinite canvas, the user study aimed to contribute a deeper understanding of its role as a collaborative tool. The findings of the study allowed us to identify the infinite canvas' strengths, limitations, and potential for supporting effective teamwork and creative idea generation.

6.1.1 Study Setup

The user study employed a fictional usage setting to create a simulated real-life experience for participants. This approach was chosen to emulate field-like conditions, as advocated by Sedlmair et al. [SMM12]. According to them, field studies with observations from real-life situations often yield more meaningful and authentic findings in design studies.

In the study, we selected and implemented task-driven thinking-aloud as the overall approach. This methodology, based on Ericsson and Simon [ES98], allowed us to gain valuable insights into participants' thought processes and decision-making while interacting with the infinite canvas. The thinking-aloud technique enabled a comprehensive investigation of how users utilized and engaged with the prototype and the infinite canvas during their tasks.

To further enhance the understanding of participants' perspectives and experiences, semi-structured interviews were conducted after a brief questionnaire. The aim of the questionnaire was to kick-start the semi-structured interviews and to strengthen possible claims made by participants or to put their feedback into perspective. This complementary approach provided a deeper level of insight into the users' feedback, impressions, and subjective experiences in the study. By combining thinking-aloud studies with interviews and questionnaires, we aimed to gather comprehensive insights into participants' usage patterns, interactions, and overall perceptions. The use of simulated real-life conditions and multiple data collection techniques added rigor to the study, contributing to a robust evaluation of the infinite canvas and the prototype.

The study is conducted with a small number of test subjects (n = 8). Participants were recruited by word of mouth and had a diverse background which allowed us to collect feedback from a wide range of perspectives. The backgrounds of participants were marketing and communication (1 participant), health and fitness (2 participants), education (2 participants), computer science (2 participants), and urban planning (1 participant). Considering their experience with an infinite canvas, four participants had prior exposure to Miro as a collaborative tool, with two of them using it regularly for work or education. This mix of participants with varying backgrounds and familiarity with creative infinite canvases provided a broad foundation to gather perspectives and insights for the study.

6.1.2 Participant Roles

According to the prototype described in Chapter 5, we created a study setting where we investigated the perspective of both user groups of the prototype. To do so, we created a fictional interview setting which allowed us to investigate the perspective of the collaborators in the prototype as well as the facilitator. As discussed in Section 5.4, the prototype's facilitator interact with the application and prepare the input planes for participants who provide the input for a collective insight generation.

Before the user study, the study participants were divided into these two user groups. For clarity and a consistent description in this chapter, the study participants in the respective groups are referred to as questioners and respondents. The questioners task was to set up and evaluate a fictional interview session and therefore are the facilitator user group of the prototype. The respondents had to create responses to predefined questions which makes them the participants or collaborators in the prototype. The goal of this approach is to gather feedback from both perspectives, the facilitator and the collaborators of the prototype. One session with a respondent lasted for 30-45 minutes and one session with a questioner for about 60 minutes.

Questioners The tasks of the questioners focused on the prototype itself and their experience with using an application on an infinite canvas to gain insights into the collective answers of a fictional interview situation. Questioners had to use the the prototype and therefore needed access to a Miro board where the application was preinstalled along with prepared test data.

Respondents While questioners had to interact with the prototype application, the respondents had to create sticky notes on input planes. This means they had to answer predefined questions with spatial arrangement which provides the data for the prototype. The tasks of this role are limited to basic interactions on the infinite canvas as they only need to create sticky notes and place them on a grid.

6.1.3 Tasks of Study Participants

The following fictional setting was chosen for questioners and respondents:

Questioners

Participants in this group had to set up a fictional interview where they wanted to gather insight from interviewees on a topic. To do so, questioners had to create two interview questions represented by input planes of the prototype. Each of the questions need to be answered for three participants. The topic of the interview could be created by the participants themselves or chosen from two suggestions. The use of pre-defined settings

Category	Question	Scales
Food	What international cuisines come to your mind, and how would you rate them?	spicy-mild; adventurous-traditional
Food	What dishes come to mind that you like to cook at home and indicate how often you prepare this meal?	easy to cook-hard to cook; often-never
Music	What music genres or artists do you enjoy listening to, and how would you rate them?	energetic-relaxing; mainstream-niche
Music	Where do you listen to music during your day?	rarely-frequently; digital-physical

Table 6.1: Suggested questions for questioners in the user study

allowed questioners to focus on the tool itself, rather than stress them by forcing them to come up with a suitable topic. Table 6.1 shows the suggested questions for the questioners along with the suggested scales.

After creating the input planes with the interview questions, questioners had to analyze the frames and create a heatmap from the results. Here, they had to interact with the visualization and describe what insights they can get with this visualization.

Respondents

The respondents are the participants that provided the data for a collaborative insight generation with the prototype. They created sticky notes as responses to a question which allowed them to explain their perspectives and preferences using spatial positioning on an infinite canvas. Here the suggested questions for questioners from Table 6.1 were used, and respondents could choose either category as their setting. To get more reliable insights of respondents behavior, they had to create responses to both questions of the chosen category. While answering, the respondents had to do the following tasks:

1. Create sticky notes in Miro and fill them with their response to the presented question.
2. Place the sticky notes on the input plane according to the prototype design.

The answers and behavior of respondents aimed to provide insights into their approach to interact with content on an infinite canvas in the context of the prototype. This allowed us to observe their thinking processes when answering questions with a two-dimensional input method.

6.1.4 Study Process

The user study itself consisted of the following steps:

1. Onboarding
2. Completion of tasks with thinking-aloud protocol
3. Debriefing interviews

Before the start of the user study, we also conducted a pilot study with one participant in a remote setting where the participant communicated with us by a Discord call. The goal was to identify problems with the study environment and the study setup [KHI+04]. This participant had first to do the tasks of the questioner, and then to do the tasks of the respondent afterwards. However, at the beginning of the study the Miro board of the participant had struggles to open the application. This was caused since the prototype application was still in development mode and not published on the Miro marketplace. Thus, it became evident that it is necessary to conduct the user study of the questioners in person as the installation of an application in development mode proved to be too challenging for end-users.

After the initial struggles of the pilot study, the study participant continued with the tasks of the respondent. Here, the participant had to use the built-in functionalities of Miro and no problems occurred. They were able to do all tasks without any problems and therefore we are able to include the results of this participant as a respondent in the results of the user study.

Onboarding

If necessary, the study participants were given a basic introduction to Miro and how they can interact with the platform. Although the study only required fundamental interaction techniques with Miro, i.e. selection, drag-and-drop, changing text, and resizing, a brief introduction to the infinite canvas and the interactions with Miro was requested by most participants. However, three out of four participants in the questioner group had some experience with Miro, thus no or only a short introduction was necessary. The respondents were less experienced as only one participants had worked with Miro before. Since the respondents also required less knowledge about Miro, the explanation of Miro and the infinite canvas only covered interactions necessary to fulfill their tasks.

Task Completion

The tasks of participants were conducted with two approaches. Overall, three participants had a remote session where they verbally communicated through Discord or other technology. Remote study participant were sent a link to a Miro board where they interacted with Miro. Here, the participants behavior was constantly watched, as Miro allows us to observe the actions of collaborators on a board in real-time.

The other five participants had a live session where they were physically present next to the researcher. As mentioned, it was necessary to conduct in-person study sessions for the questioner group, as the installation of the prototype proved to be too challenging for participants without extensive knowledge about Miro. Here, we equipped the questioners with a Laptop with an opened and empty Miro board. On this board, the prototype was already installed and ready to be used.

As a first step of the questioners study, participants were invited to explore the prototype before fulfilling their tasks. This allowed them to get a better understanding on the setting of the user study and an overall usage scenario of the prototype. If any questions occurred they were answered by the researcher.

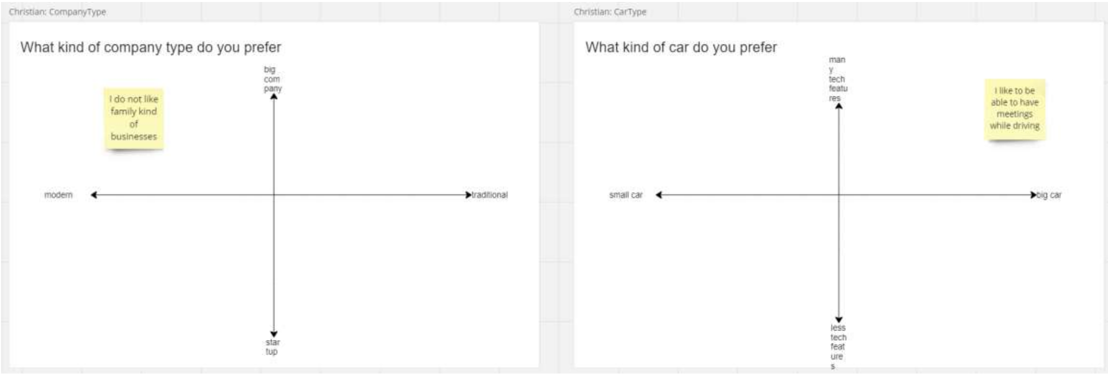


Figure 6.1: A custom interview setting created by a Questioner 4 of the user study. They created two input planes with their own questions and axes. Furthermore, they created sticky notes as answers to see if their mental model of the question would work out.

Afterwards, the interaction with the prototype as described in Section 6.1.3 started. First, questioners had to set up the questions. Here, three participants tried to come up with their own topic first, but two discarded this approach and continued to use one of the suggested interview settings. Figure 6.1 shows the custom interview setting that the remaining participant created. The first question they chose was "What kind of company type to do you prefer" with the scales "'modern - traditional" and "big company - start-up". The second question was "What kind of car do you prefer" with the scaled "small car - big car" and "many feature - less tech features".

In the setup phase of the prototype, participants were successfully guided, since all were able to create the necessary input planes. However, the option to customize a sample frame to create input planes with the prototype was not perceived by two participants. Instead of using this option they created a sample frame first and manually changed it afterwards directly on the board. Furthermore, the participants struggled with the naming of the frames that the prototype uses to identify the question and the interviewer. Only two participants named the frames correctly, the other two did not change the title of the frames after creating them.

The second task of the questioners was to evaluate the creation of a visualization in the prototype. For this, data of a completed fictional interview was provided. Here, they were given access to a prepared interview with answers from fictional respondents. They had to use the prototype to analyze this interview and create the heatmap visualization from the content on the board. Here, all participants were immediately able to create the visualization but struggled with the usage of the granularity option in the beginning. However, after some time all participants were able to correctly identify the purpose and usage of the granularity input and complete this task as well.

The respondents task did not directly involve the prototype but rather focused on the use the input planes of the prototype. Here, we observed the participants behavior when answering the questions on the prototypes input planes. As a first step respondents had to choose the topic of their interview. Three participants chose the topic "Food" and one participant chose "Music". Afterwards, they were instructed to use sticky notes to answer the questions and to express their thoughts when creating answers and positioning them. A special focus was placed on the respondents behavior regarding their approach to position items on the input planes and how they found answers to the question.

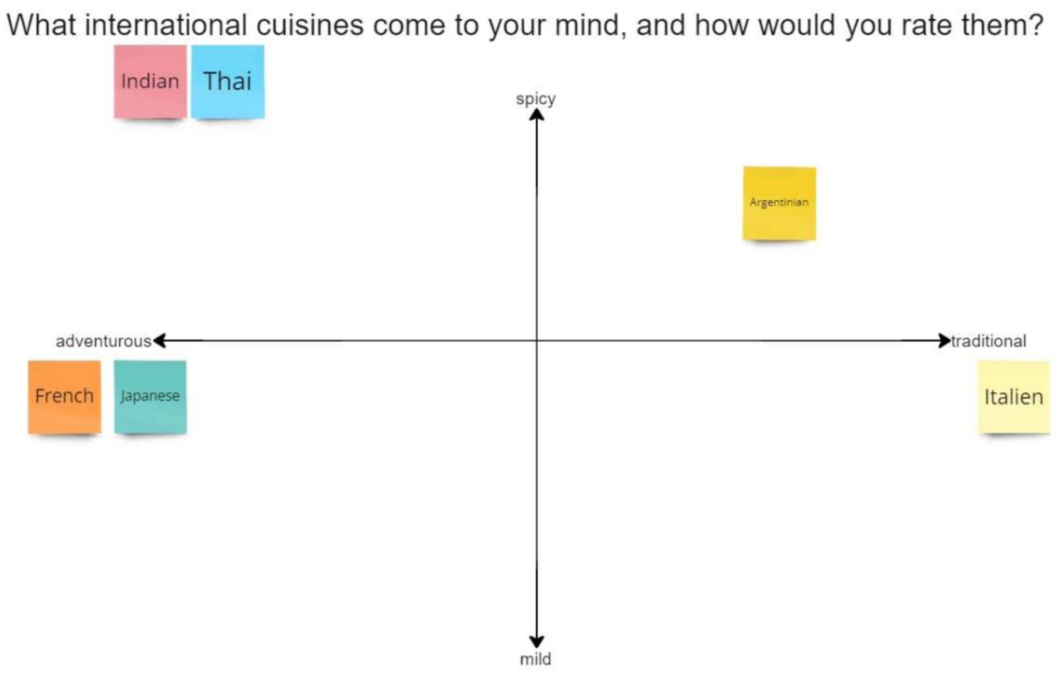


Figure 6.2: An input plane for the first question of the food category with answers on sticky notes, created by Respondent 3 in the user study.

Figures 6.2 and 6.3 show two artifacts created be the participants of the user study. In general, the participants were able to complete their tasks without any problems and were able to provide valuable insights into the approach to use positioning as input on an infinite canvas. Respondent 3 chose to customize the sticky notes with color, although they reported to have never used such an environment before. This suggests that the respondents were engaged in this answering process which allowed them to add a "personal touch" to the answers (see Figure 6.2). The respondents also mentioned that

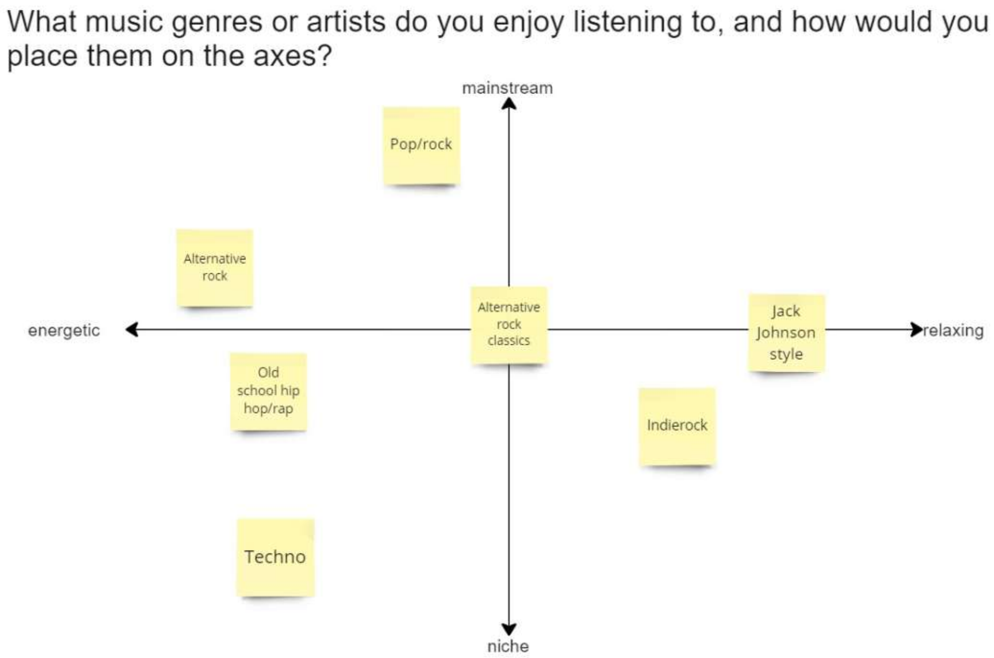


Figure 6.3: An input plane for the first question of the music category with answers on sticky notes, created by Respondent 2 in the user study.

the input plane inspired them to think about a question differently which allowed them to engage with the answering process more substantially and create more answers than they would have otherwise.

Overall, respondents argued that spatially positioning answers allows them to give more nuanced and detailed answers which they found engaging. However, the extent of inspiration coming from the two-dimensional input plane can vary between individuals as two different approaches to answer questions have been identified. One respondent (Respondent 3) created answers to the question first which they then positioned on the input plane. This might have resulted in a focus on the extremes of the scales, as Figure 6.2 suggests. The others, used the two-dimensional input plane as inspiration for their answers and created a more equally distributed set of answers. This was also highlight by Respondents 2 final sticky note (see Figure 6.3), where they added the answer “Alternative rock classics” in the middle of their input plane as they mentioned that they “felt like something is missing in the middle”.

6.2 Results

The evaluation of the prototype demonstrated the potential of the infinite canvas as a versatile and effective tool for collaborative ideation and information visualization. The results highlighted its ability to foster creativity, facilitate interactions, and gain insights from collective data. Participants, including those without prior experience with an infinite canvas, found it easy to work within the environment. Thus, the implementation of the infinite canvas in Miro provided an intuitive and easy-to-understand platform, enabling users to set up and provide input to artifacts effortlessly.

The user-friendly nature of Miro and its interactive positioning approach received positive feedback from participants. The possibilities of flexible positioning of responses allowed for diverse and nuanced input of participants. However, careful design considerations are necessary to maintain coherence and usability in collaborative applications. Insights from the User Experience (UX) and User Interface (UI) evaluation of the prototype showed the importance of clarity, visibility of customization options, and error handling.

The feedback on semantic information in answer notes highlighted an interesting direction for the design of interactive articles and explorable information visualizations. Furthermore, participants expressed interest in more sophisticated information visualizations, enabling deeper exploration of content.

The following sections provide a more detailed insight into the final evaluation process of the user study. By categorizing the study participants feedback into “Using the Infinite Canvas for Input and Output of Information”, “User Behavior and Interactions with the Infinite Canvas”, “UX and UI of the Prototype”, and “Other Insights” we were able to gather a comprehensive understanding.

6.2.1 Using the Infinite Canvas for Information Input and Output

The prototype’s evaluation revealed that the infinite canvas offers a valuable and clear platform for both inputting and outputting information within interactive information visualizations and collaborative interactive articles. Participants appreciated the freedom to create and input information as it facilitates a sense of ownership, e.g., coloring of sticky notes. This makes creating content more fun and engaging for users. Moreover, positioning of elements on the canvas prompted participants to contemplate their responses more thoughtfully.

During the study, two distinct approaches to answer questions emerged. The first involved answering based on textual responses and positioning them accordingly on the canvas. In the second approach, participants created their responses with the help of the two-dimensional input plane, especially the labels of axes, which showed that the representation of information of input areas on the infinite canvas can have an influence on the input behavior of users.

The “flow of information” on the infinite canvas was understandable in collective activities, where items on the canvas were analyzed and used to generate output. An overview of respondents’ answers and the positioning of sticky notes emerged as a powerful tool for insight generation and comprehension. Here, participants recognized potential in integrating information visualizations to analyze and gain deeper insights into the content on the infinite canvas.

Notably, the content displayed on the infinite canvas, such as the labels of axes on input planes, sparked inspiration and motivation among users to add more input. However, selecting labels for axes needs to be considered carefully, as they can influence participants' responses.

6.2.2 User Behavior and Interaction with the Infinite Canvas

The evaluation highlighted the ease of use of sticky notes and their integration within Miro, making them an ideal choice for collaborative interactive articles, particularly when working with inexperienced users. Participants found the positioning of sticky notes on the infinite canvas to be an exciting and engaging method of interaction.

The use of a two-dimensional plane for positioning answers also allowed participants greater flexibility in their responses. This freedom empowered them to express their thoughts and ideas more dynamically and adapt their answers based on their unique perspectives. However, in the context of the user study, some participants still prefer conventional forms to give answers in this setting.

While the flexibility offered by the infinite canvas was well-received, it also posed challenges for application design. The endless space allowed for multiple ways to accomplish simple tasks, which could lead to varied data encodings. Thus, this aspect requires careful consideration to ensure consistency and coherence in data representation for data analysis within collaborative interactive articles.

6.2.3 UX and UI of the Prototype

In the evaluation of the prototype's UX and UI, participants acknowledged the value of the heatmap visualizations. However, they also suggested areas for improvement. Some explanations and labels were not perceived as clear by participants, indicating a need for better clarity in the presentation of information.

While the setup of the input planes was generally mentioned as clear by participants, observations during the study suggested otherwise. First, not all of them perceived the option to customize these planes. This suggests the need for improved visibility and intuitive controls for customization features.

Furthermore, participants frequently encountered issues with the setup of question planes, such as incorrect naming of frames. To address this, error-checking mechanisms should be implemented, and the application should provide clearer instructions for setting up question planes.

6.2.4 Other Insights

During the evaluation, participants highlighted the lack of using the semantic information in answer notes. Incorporating semantic information would enhance the understanding and interpretation of responses, providing more context and meaning to the data.

Participants also expressed a desire for additional and more sophisticated information visualizations. Incorporating diverse visualization options would allow them to explore the content more deeply, facilitating deeper insights and a more comprehensive understanding of the data.

The questioning format used on the infinite canvas allowed for more detailed insights into respondents' perspectives and responses. Participants appreciated the possibilities of this format as it enabled them to add more depth to information and their thoughts. The flexibility in answering questions provided users with the freedom to respond in a nuanced manner, fostering a more engaging and enjoyable experience. Participants appreciated the interactive nature of the infinite canvas.

6.2.5 Identified Prototype Improvements

The feedback from participants indicated that they generally found the tasks with the prototype clear and understandable. However, two main aspects proved to be difficult for users. Firstly, the correct setup of input planes and secondly, the implemented heatmap visualization.

Regarding the visualization, some participants expressed concerns about certain aspects of the heatmap visualization. While the visualization was deemed helpful for obtaining a quick overview of input planes and respondents' answers, three questioners mentioned certain elements, such as colors and tooltips in the hover effect as unintuitive. Participants suggested different labels, the addition of a color legend, or the use of a different color scale to improve the visualization's clarity. Furthermore, they argued for more exploration possibilities when analyzing interview data on the infinite canvas, emphasizing the potential of information visualizations in this context.

Additionally, some questioners encountered issues with incorrectly setting up input planes, which could lead to inaccurate data analysis. This highlights the need for clearer explanations and additional error checks in the application to ensure proper data processing and accurate results.

In conclusion, designing applications for the infinite canvas requires thinking outside the box, as it presents unique challenges not present in conventional design spaces. The participants' ability to approach tasks in their own way can create difficulties in designing for all possible decisions they may make. Providing clear guidance for usage and a well-explained setup process is crucial to ensure a user-friendly experience.

CHAPTER 7

Refined Miro Application

Previous chapters explored the potential and limitations of the infinite canvas as a collaborative platform for ideation and information visualization. Through a user study, valuable insights were gathered, shedding light on the strengths and areas of improvement in the prototype.

This chapter presents the design of a refined prototype that seeks to leverage semantic information on the board. The refined prototype aims to provide users with a more informative and intuitive environment, enabling deeper exploration and analysis of data in the context of interactive articles on an infinite canvas.

While the first prototype only allowed for indirect and asynchronous collaboration between participants, the refined prototype focused on a synchronous activity that also fosters more communication between individuals. Despite the progress made in the design of this refined prototype, there are still challenges to overcome, and further iterations will be needed for its completion.

7.1 Motivation and Improvements of First Prototype

After the implementation and evaluation of the prototype it became evident that, when using collaboration on an infinite canvas, the personalized reading experience of individuals needs to be restricted. Whenever multiple people collaborate in the same design space, they can either work on the one shared artifact or work on separate multiple artifacts.

When using a shared artifact where multiple users collaborate at the same time, clear instructions and guidance becomes crucial, as individuals can easily become overwhelmed if new and existing elements are created, edited, or moved by others.

For the refined prototype we aim to create create a more interactive and collaborator-centered approach to gain insights. This allows us to integrate a more active form of

	First Prototype	**Refined Prototype**
Collaboration	Asynchronous with individual artifacts	Synchronous with shared artifacts
Communication	No direct communication between collaborators	Direct communication between collaborators
Information visualization	Visualization focused on a facilitator	Usage of visualization techniques for group on the infinite canvas
Interaction with infinite canvas	Creation and positioning of sticky notes by participants	Creation and positioning of sticky notes by participants. Exploration of information on the infinite canvas by participants
Input of information	Sticky notes with thoughts, ideas, and perspectives on two-dimensional input plane	Sticky notes with thoughts, ideas, and perspectives regarding images

Table 7.1: Differences between first and refined prototype

communication and collaboration while leveraging the opportunities of Miro even more. Table 7.1 gives an overview of the main differences between the two prototypes.

7.2 Gamestorming: Introducing Guidance for Creative Collaboration

As mentioned, guiding principles are crucial for ideation or the generation of insights in collaborative and creative settings. Guidance in collaboration allows us to work towards a shared goal within a clearly outlined framework. One approach to introduce such principles and rules is trough the use of games and gamification [GBM10].

Gray et al. argue that games can help people overcome challenges, generate insight, enable new perspectives, and find ideas in collaboration with others. Thus, they introduce "Gamestorming" as a method to reach these fuzzy goals [GBM10]. In general, gamestorming is about creating game worlds for collaborators where they can work on fuzzy goals, a fundamental concept in knowledge work. Gamestorming allows us to explore new ideas and find new and creative possibilities to overcome challenges.

While gamestorming builds on a collaborative idea of introducing games in design session, competitive game activities also found their way into group work. We already discussed the difference between collaboration and competition in Chapter 2. There we argued, that competition in team work where people want to reach a shared goal can be difficult as it needs the introduction of "correct" behavior. However, in creative settings where people generate ideas, no correct or incorrect behavior is present.

An example, of a gamified competitive environment that uses digital web technology in learning settings is Kahoot! [1]. It allows teachers and educators to create interactive quizzes, surveys, and discussions that can be accessed by students or participants on their own devices, such as smartphones, tablets, or computers. Kahoot! creates a game-like experience where points are awarded for correct and fast responses, adding a competitive element to the learning process of individuals within a group.

A more collaborative approach is implemented in Mentimeter [2]. Similiar to Kahoot! it provides polls and quizzes, but also collaborative activities such as the generation of word clouds for brainstorming. However, in contrast to Kahoot!, Mentimeter is not only built for education but also targets areas such as presentations, workshops, meetings, and other more collaborative settings. In Mentimeter, presenters can create interactive elements and display them while presenting, which allows them to interact with their audience in real-time. But many activities do not necessarily require collaboration between individuals of a group and often lack an engaging element in form of gameified activities.

Although, originally introduced for collaboration in physical design spaces, gamestorming provides a framework to combine interactive articles, information visualization, and the infinite canvas. In its core, gamestorming is about creating game worlds that use tangible, portable, and physical objects that hold information. Such a game word is created by a moderator that guides the team or players through a session.

To do so, gamestorming emphasizes the idea that, in order to create a tangible outcome, also referred to as the target state, we need to know what the initial state looks like. In between those two states, conducting many consecutive games allows us to collaboratively find ideas, explore them, and, in the end, identify the most valuable one. Figure 7.1 shows the gamestorming framework from Gray et al. [GBM10].

In it, the target state "B" and the initial state "A" are connected through three stages, the opening stage, the exploring stage, and the closing stage. In each of these stages, games have a different purpose and include a different set of games. In the opening stage games are about the creation of as many ideas as possible. Here, the goal is to open up people's minds and allow them to generate a new perspective. Ideas gathered in this stage are not judged, as they should be as diverse as possible.

The second stage is about exploring the ideas developed in the first stage. Here, seeing and investigating the ideas from the opening stage in more detail is the core concept. This stage is about emerging ideas and finding unexpected patterns in them.

The closing stage is about converging ideas. As we want to move towards conclusions, we need to assess the ideas by looking at them critically. Games from this stage allow us to collaboratively make decisions that result in tangible artifacts.

[1] `https://kahoot.com/` (accessed 2023-07-22)
[2] `https://www.mentimeter.com/` (accessed 2023-07-22)

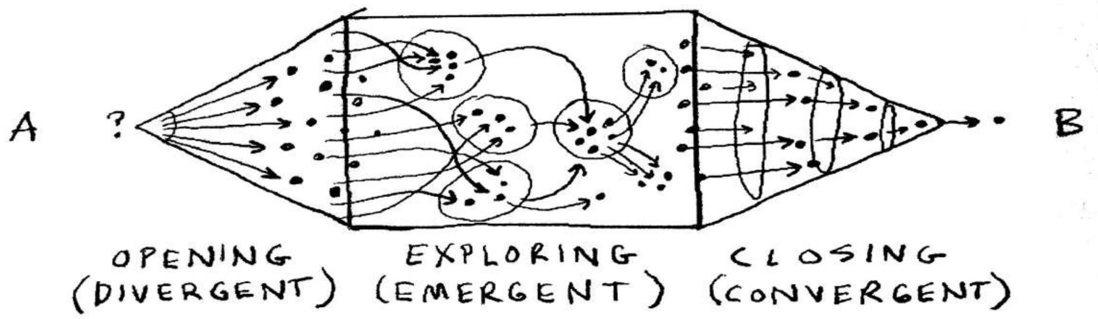


Figure 7.1: In the Gamestorming framework a target state "B" and the initial state "A" are connected through three stages, the opening stage, the exploring stage, and the closing stage. In each stage multiple games can be carried out to support divergent, emergent, and convergent thinking. From [GBM10]

However, gamestorming is not a rigid framework. It emphasizes the use of a series of games to generate more knowledge in each of these areas. Additionally, it also allows us to freely move ideas and concepts from one stage to the other whenever we feel like we reached a dead end. Thus, we can string various games together to get to the desired target state.

7.3 How to Use the Semantic Information on the Board?

In the course of developing and evaluating the prototype, a significant insight emerged in the form of semantic information on sticky notes. The textual content in the artifacts created by participants were identified as a promising area for further investigation. Thus, a pivotal question in refining the prototype became: How can we effectively utilize the semantic information present on the board to foster collaborative insight generation? To address this question, we turn to the concept of gamestorming as a framework to create an engaging environment for input generation, where participants can collaboratively contribute and explore semantic information on a Miro board.

To explore this semantic information created by participants we introduce the GloVe unsupervised learning algorithm as our tool for this task. The GloVe model offers pretrained vector datasets that enable us to obtain vector representations for a word [PSM14]. With these vectors, we construct a semantic space that allows us to calculate the distance between words based on their semantic similarity. This semantic space holds enormous potential for digital design tools, as it opens up a direction for the creation of collaborative interactive articles that fosters communication and collaboration. By harnessing the infinite canvas as a creative design space, we can use digital technology to build a semantic space that enables further exploration of participants' perspectives in the ideation process.

The concept of a semantic space can be imagined as an n-dimensional construct, where each

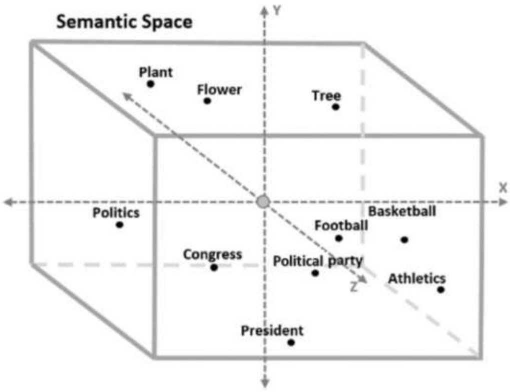


Figure 7.2: Representation of a 3-dimensional semantic space. It shows how we can use semantic measurements of words to calculate their distance to each other. From [JOL18]

vector determines the coordinates of a word and its position within that space [JOL18]. For instance, in a GloVe model, a word vector may feature 300 dimensions, resulting in a 300-dimensional semantic space. Figure 7.2 illustrates a simplified representation of such a semantic space in three dimensions.

The strength of a vector representation of words in a semantic space lies in its mathematical capabilities. We can perform calculations using word vectors, allowing us to measure the semantic distance between words. For example, the Euclidean distance or cosine similarity between two words in the space can be calculated to evaluate their semantic similarity [PSM14, JOL18]. The Euclidean distance between two vectors $\mathbf{v}_1$ and $\mathbf{v}_2$ of dimension n is given by:

$$\text{Euclidean Distance}(\mathbf{v}_1, \mathbf{v}_2) = \sqrt{\sum_{i=1}^{n} (v_{1i} - v_{2i})^2} \tag{7.1}$$

where v_{1i} and v_{2i} are the elements at index i of $\mathbf{v}_1$ and $\mathbf{v}_2$ respectively.

This approach enables us to assess the proximity of words based on their semantic meanings, as shown in Figure 7.3, where the words “leaf” and “tree” are closer to each other than “tree” and “window” in a two-dimensional semantic space.

By utilizing the Euclidean distance or other metrics in a semantic space, we gain the ability to perform powerful calculations, such as finding the nearest semantic neighbors to a given word [PSM14]. This capability allows for extensive exploration and analysis of semantic information in collaborative environments.

With these insights, this chapter focuses on the design of a refined prototype for a Miro board, leveraging the computational powers of the infinite canvas. Through the use of pre-trained word vectors with 50-dimensional vector representations for 400,000 words

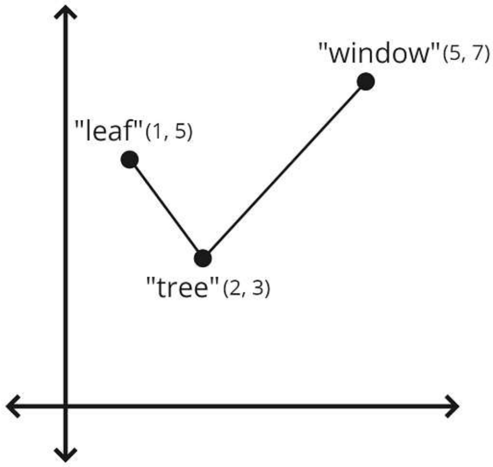


Figure 7.3: Example of the Euclidean distance in two dimensions of the words “tree”, “leaf”, and “window”. The words “leaf” and “tree” are closer to each other than “tree” and “window” in a two-dimensional semantic space.

from `https://nlp.stanford.edu/projects/glove/` (accessed 2023-07-22), we explore the potential of this semantic space in Miro. Initial tests applying k-means clustering on words based on semantic similarity show promising results, enabling the creation of word clusters that facilitate the exploration of collaborative perspectives on a problem through individual input.

In the following section, we present the first version of a refined prototype, which aims to harness the potential of semantic information in collaborative insight generation and ideation.

7.4 Concept for Refined Prototype

In this section, we present a first draft of a refined prototype that uses the semantic space of participants’ input, unlocking new possibilities for engaging and insightful exploration activities on an infinite canvas. Building upon the concepts of gamestorming and the semantic space, we aim to create an interactive investigation tool that leverages the computational powers of infinite canvas environments.

This prototype introduces two key roles: the “Moderator” and the “Players”, as defined by gamestorming. The moderator sets up the game world on the infinite canvas, overseeing and guiding the players through the game. Players actively engage with the prototype to contribute their input, seeking to gain new insights and perspectives by reaching the target state of the gamestorming session.

In the core of this prototype lies the concept of an “Affinity Map”, inspired by the work of Gray et al. [GBM10, p 146]. An affinity map aims to discover embedded patterns in language-based information by finding and sorting artifacts based on their relationships with each other. For example, players can organize physical sticky notes on a whiteboard into categories based on their textual content.

In addition, the use of images in the ideation process allows us to build on a richer dataset to investigate; compared to the two-dimensional input planes from the first prototype. This can create a more engaging environment for players which can result in a more dynamic and interactive insight generation process. Here, the possibilities of the infinite canvas can synthesize the individual perspectives on images into a collective holistic view.

To play the game, the moderator sets up the game world by organizing images into frames and posing a clear question. To do so, they drag images to a Miro board where the application organizes each image in a grid and encloses it with a frame. It is important that the moderator also has a clear question in mind that they want to investigate with the images in order to spark players curiosity and allow them to generate enough information per image.

Afterwards players individually add their thoughts, ideas, and perspectives as a response to the question to each of the images. Figure 7.4 shows a finished game setup where four images are organized into frames. Additionally, players contributed their sticky notes to the images. This intertwines the sticky notes of players with the image which provides the necessary information for the next step.

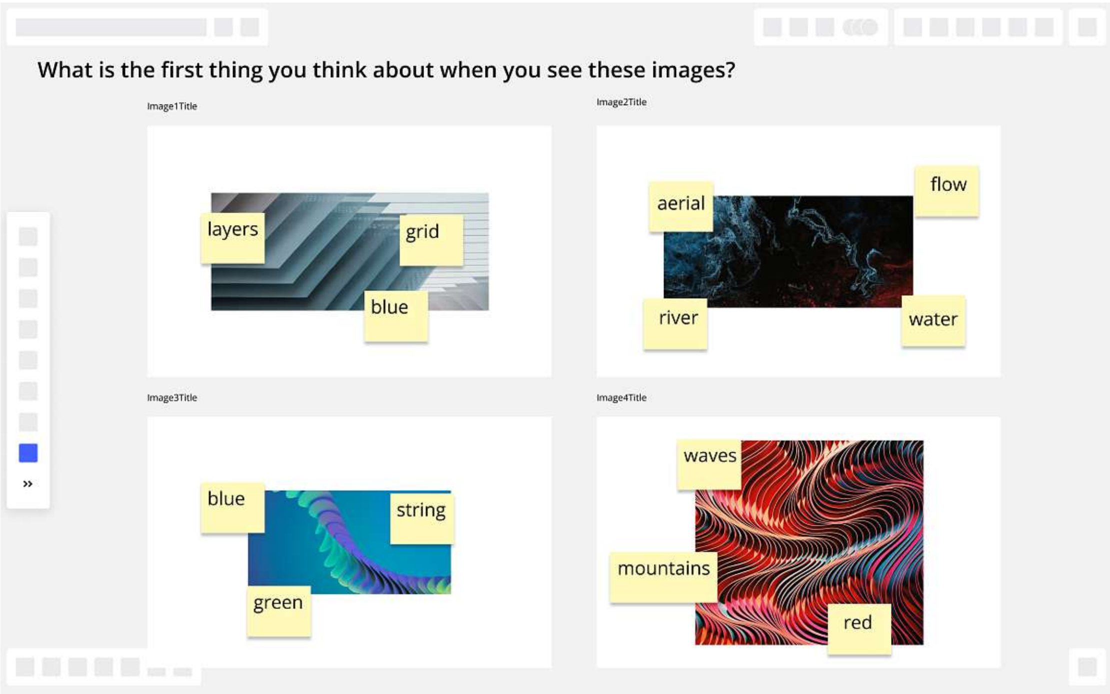


Figure 7.4: Example of frames with images where players also added sticky notes to each image. This creates a dataset where each image features a collection of associated keywords provided by players.

The corresponding JSON data of Figure 7.4 now contains a collection of images with their associated keywords by players. Listing 7.1 illustrates how this data looks like.

Listing 7.1: Dataset for the images with their corresponding keywords from Figure 7.4.

```
{
  "data": [
    {
      "title": "image1Title",
      "keywords": [ "layers", "grid", "blue" ]
    },
    {
      "title": "image2Title",
      "keywords": [ "aerial", "flow", "river", "water" ]
    },
    {
      "title": "image3Title",
      "keywords": [ "blue", "string", "green" ]
    },
    {
      "title": "image4Title",
      "keywords": [ "waves", "mountains", "red" ]
    }
  ]
}
```

Once all players have completed their input, the moderator uses the application to analyze the sticky notes. The GloVe algorithm enables the creation of image clusters based on the semantic information found in the player sticky notes. Each image is associated with an `imageVector` property, representing the average vector derived from all the words it is annotated with. As a result, each image now possesses a unique vector, which serves as the basis for uncovering hidden relationships and patterns between images, offering valuable insights into the players' perspectives. Listing 7.2 illustrates the result of this process.

Listing 7.2: Example of the calculated average image vectors based on the annotations from Figure 7.4 and Listing 7.1. The GloVe dataset has been used to calculate the average semantic vector for each image.

```
{
  "data": [
    {
      "title": "image1Title",
      "keywords": [ "layers", "grid", "blue" ],
      "imageVector": [ 0.4123, 0.2424, 0.1232, 0.4214, ... ]
    },
    {
      "title": "image2Title",
      "keywords": [ "aerial", "flow", "river", "water" ],
```

```
      "imageVector": [ 0.1023, 0.2314, 0.4012, 0.1204, ... ]
    },
    {
      "title": "image3Title",
      "keywords": [ "blue", "string", "green" ],
      "imageVector": [ 0.3213, 0.2314, 0.2122, 0.0994, ... ]
    },
    {
      "title": "image4Title",
      "keywords": [ "waves", "mountains", "red" ],
      "imageVector": [ 0.2303, 0.3414, 0.1014, 0.2314, ... ]
    }
  ]
}
```

Figure 7.5 depicts the next step in the game. After the images are analyzed and the average vector calculated, clusters based on the semantic similarity of images can be built. Now the images are duplicated on the Miro board and enclosed by colored borders. Players are now tasked with identifying the clusters of images by arranging them on the infinite canvas. To do so, they interactively drag and drop the images, seeking to correctly group them into their clusters based on their semantic similarity. The color of the duplicated images signifies their connections to neighboring images. A yellow frame indicates that the image is near other images, it shares semantic similarities with and therefore within its correct cluster. In contrast, a blue frame indicates that the image stands out from its neighbors.

The clustering process in the refined prototype encourages active collaboration among players. As they work together to organize the images into meaningful clusters, communication becomes an essential part of the insight generation process. Through discussion and exchange of ideas, players gain new perspectives and collectively uncover hidden structures and patterns in the semantic space embedded in the images.

Once the clustering is completed, the refined prototype leverages the GloVe word vectors to automatically find labels for the image clusters based on their centroid vectors. These labels provide descriptions of the underlying semantic information, creating a deeper understanding of the relationships between images.

Figure 7.6 illustrates the end state of the game. Each image is surrounded by a yellow border which signifies its proximity to related images within the same cluster. Additionally, labels have been added to the clusters, providing categories of the underlying semantic information of the clustered images.

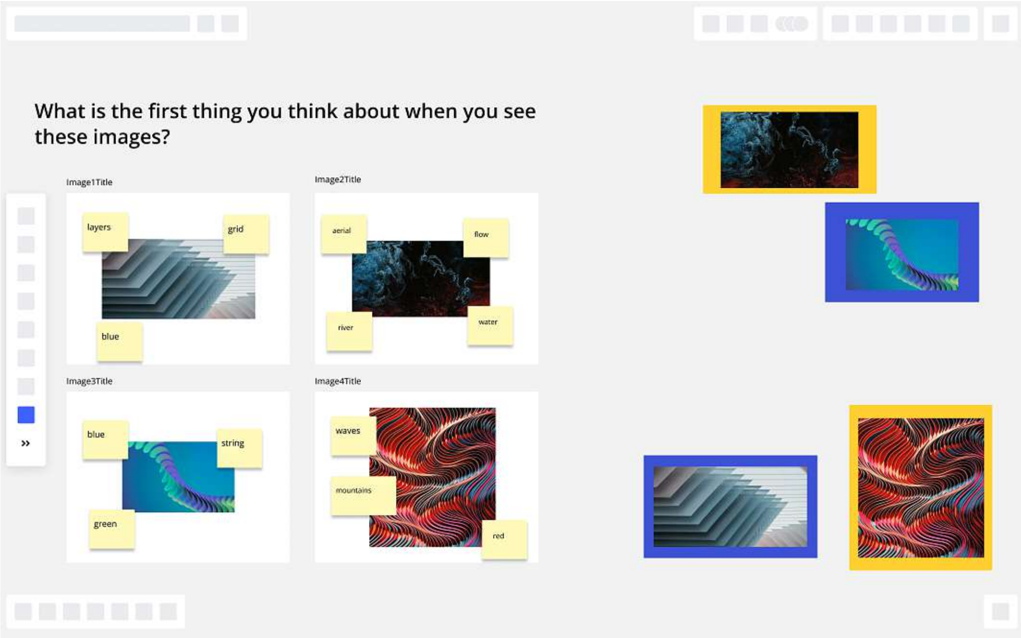


Figure 7.5: Example of duplicated images with embedded clustering information based on players associations. The average vector for each image is used to determine the classification into clusters

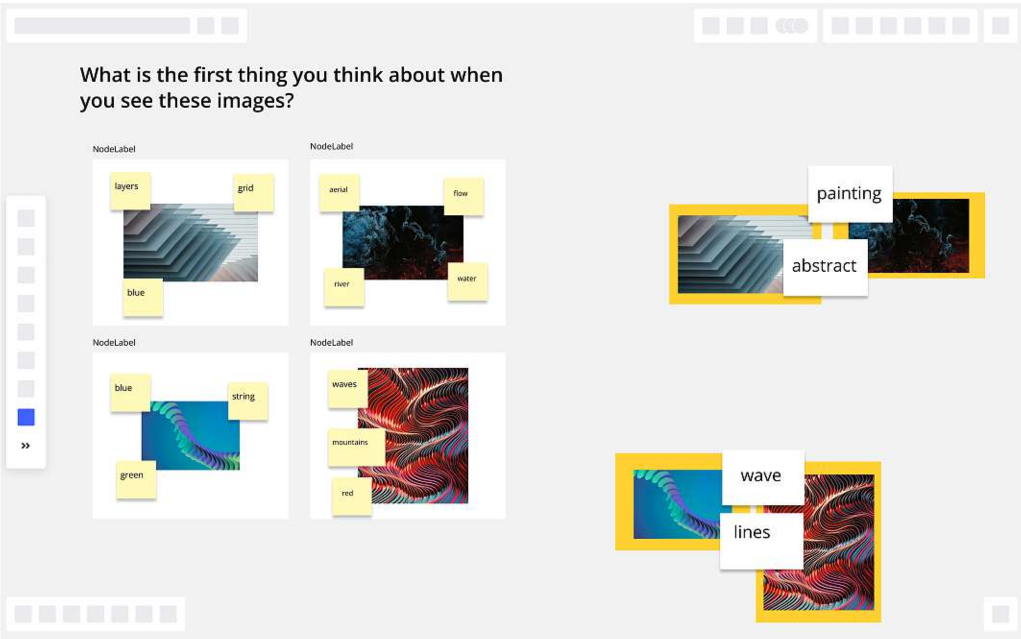


Figure 7.6: When the clusters of all images have been successfully found by players the game is over. It is also possible to use GloVe word vectors to find labels for the image clusters based on their centroid vectors.

CHAPTER 8

Summary and Conclusion

Since the introduction of the web, interactivity has become a fundamental part of how we present and consume information through digital technology. To further research this area, this thesis adopts the concept of interactive articles as a novel framework to promote active communication with readers of digital information.

Interactive articles seek to create systems that enable people to acquire new knowledge by allowing readers to actively explore the information created by an author. Authors of interactive articles integrate interactivity in order to create an engaging and immersive reading environment for readers. Here the areas interactive articles and explorable information visualizations overlap as both highlight the importance of creating an engaging story and emphasize interactive and explorative information analysis to gain novel insights. Nonetheless, the integration of collaboration in these systems is still in its infancy and group activities, like brainstorming, can be valuable tools to explore new perspectives and discover innovative ideas.

We investigated the infinite canvas as a creative environment for integrating collaborative activities into interactive articles. The infinite canvas proves to be a promising research area for designing such explorable content, where individuals can provide and gain insights and knowledge. As a result, this work presents potential future directions and challenges in this exciting research domain.

In conclusion we provide the following answers to the research questions:

RQ1: What possibilities does an infinite canvas provide for the design of interactive articles?

Since its first implementations, the infinite canvas has gained popularity as a versatile tool for information presentation. Today, infinite canvas applications enable individuals and groups to create innovative interfaces for various usage domains.

Interactive articles can harness the potential of the infinite canvas due to its inherent flexibility, offering intuitive navigation and a sense of freedom to users. The infinite canvas allows for a more natural use of space and fosters engaging interactions.

From a designer's perspective, creative and collaborative infinite canvas environments like Miro hold great promise for crafting interactive articles. Participants can fully immerse themselves in the design space, becoming direct contributors to the article's content. This fosters a sense of connection with the data and aligns with the active communication approach of interactive articles.

However, as infinite canvases are relatively new and diverge significantly from traditional platforms, they may be less intuitive for some users, designers, and developers alike. The concept of infinite space and free navigation across multiple dimensions should be implemented carefully, especially for inexperienced users. Tasks and inputs of end-users should be kept simple and address existing knowledge, like the use of sticky notes.

Ultimately, interactive articles can leverage the possibilities of computer-supported information representations to provide content in engaging ways by using interaction to allow readers to actively interact with information. The infinite canvas, and especially Miro, offers a design space where users can actively work with data to let them fully immerse themselves in the creation of information.

RQ2: What visualization and interaction techniques can facilitate communication, engagement, creativity, and collaboration on an infinite canvas?

The consideration of visualization and interaction techniques on the infinite canvas is essential for facilitating effective communication, engagement, creativity, and collaboration. By adhering to universally applicable Gestalt laws, content can be intuitively organized, making it easier for users to navigate and understand the information.

However, the integration of active exploration and collaboration can become a challenging task on an infinite canvas and the understandably of content needs to considered carefully. Leveraging techniques from information visualization, such as visual storytelling and interactive information exploration, enables the creation of visually appealing and engaging artifacts on the infinite canvas. Additionally, the research area of information visualization can provide guiding frameworks that allow us to build visually appealing and interactive artifacts on the infinite canvas that are intuitive to the user.

Moreover, the dynamic nature of the infinite canvas itself fosters active exploration, allowing participants to interact with the content and create their own narratives. Techniques like collaborative annotations and spatial organization further enhance the collaborative and creative aspects, enabling groups to work together, share insights, and generate new knowledge.

The concept of the infinite canvas as a visualization environment to show information and tell stories through visual encodings using space allows participants to engage with the content more deeply. It allows individuals and groups to create their own story with digital design elements. In the context of visual analytics, the infinite canvas can be considered as a visual database where users can directly interact with the data entities and the relationships between them. On a Miro board, this data can consequently be used for information visualizations which provide deeper insights into the content of an infinite canvas.

As a result, the infinite canvas becomes a comprehensive tool for building interactive articles that promote engagement and encourage collaboration. By focusing on exploration and storytelling, interactive articles can harness the potential of the infinite canvas, creating meaningful and immersive experiences for users. Incorporating playful interactions, personalization, and reducing cognitive load further can enhance interactive articles on the infinite canvas. Furthermore, the data on an infinite canvas can be seen as a resource for visualizations where users can visually and collaboratively work with the initial dataset.

RQ3: How to design for collaboration in interactive articles on an infinite canvas (i.e., through group activities)?

In design situations where individuals collaborate to generate ideas together, decisions go beyond determining the time and physical space of collaboration. In these situations, we also need to consider the space of the artifact. When designing for collaborative group activities two different approaches regarding artifact space are possible. Participants can either work on one shared artifact or on multiple separate artifacts.

Through a collaborative artifact space, we gain the ability to create collective and explorable interactive articles that allow us to generate new insights as a collective. This approach allows individuals to contribute their unique perspectives, knowledge, and creativity which fosters a exchange of ideas and collective problem-solving.

By engaging in collaborative design on an infinite canvas, teams can collectively construct artifacts that enable innovation, exploration, and self-reflection. However, the integration of collaboration is a complex and difficult task. Here, many pitfalls and challenges emerge and creative infinite canvas platforms, such as Miro can become difficult to navigate when done carelessly.

Thus, we identified the importance of two user groups when designing for collaborative activities in interactive articles on an infinite canvas. Facilitators set up the collaborative tasks and guide the group through the activities. If necessary, they give an introduction to the design space and provide support during the group activities. Facilitators need to be somewhat familiar with the infinite canvas as they are the first contact should problems arise. Participants or collaborators, on the other hand, are individuals that are part of a group that wants to gain new knowledge and insights. They share a common goal with other participants and bring their individual ideas and perspectives into the group. In the context of collaborative interactive articles, participants interact with the elements of the artifact and provide the input for the interactive article. As already mentioned, simple and intuitive interactions should be the focus to accommodate inexperienced participants' contributions.

However, to truly harness the potential of collective thinking, we need a structured framework that can effectively organize and synthesize the generated ideas. We identified the concepts of "Gamestorming" as a promising area that allows us to facilitate group work and provide engaging activities. Such structured approaches can help maintain focus on a shared goal, encourage active participation, and, in the end, ensure that the collaboration follows a clear and understandable structure.

Collaborative infinite canvas environments, like Miro, present exciting opportunities for designing interactive articles. They provide a platform for designers to facilitate group creativity and idea generation through interactive and collaborative features. By integrating collaboration and interaction into the design, the resulting interactive articles can foster creativity and facilitate the generation of new insights in a collaborative way. However, it is essential to address the challenges of navigating the flexible space of the infinite canvas and provide adequate support for both facilitators and participants to maximize the benefits of collaborative design on the infinite canvas.

8.1 Possible Future Directions

Throughout this thesis, we have identified several areas that could become interesting directions for future research in interactive articles and explorable visualizations. The infinite canvas offers a wealth of possibilities, and here are potential directions to explore further:

Spatial Information The spatial encodings on the infinite canvas, such as the location and size of elements, equip users with an intuitive way to position and interact with content. Further research could investigate how spatial information can enhance the interactive experience and communication of ideas.

Semantic Information The semantic information present on the infinite canvas, expressed through words and annotations, could be a valuable source for generating insights and supporting collaborative activities. Exploring ways to extract and utilize this semantic information could lead to novel applications.

Volume Visualization The infinite canvas allows for multidimensional exploration of content, overlapping with the field of volume visualization. Exploring how to leverage this area could lead to innovative ways to present and interact with complex data.

Information Visualization for an Overview Perspective Integrating "traditional" information visualization libraries within the Miro ecosystem could provide a quick overview of the content, which could lead to a better understanding of participants' behaviors and perspectives. The infinite canvas can be considered as a visual database where users can directly interact with data entities and relationships between them.

Gamestorming and Gameified Activities Collaborative group work often requires a shared goal and a clear framework. Integrating gamestorming techniques or gameified activities on the infinite canvas can provide structure and encourage active participation.

Collaborative Storytelling The creation and integration of shared stories and the use of storytelling techniques can be integrated into interactive articles to create compelling narratives and engaging experiences for participants.

By exploring these and other directions, we can harness the potential of the infinite canvas as a collaborative creative environment and further advance the field of interactive articles and explorable visualizations. As the field is only beginning to evolve, it is essential to keep exploring new possibilities and challenges to create engaging and insightful experiences for participants on the infinite canvas.

In general, the overall aim of this thesis was to investigate the possibilities of the infinite canvas for the design of interactive articles and to open doors for possible future directions. We were able to identify some interesting areas for future applications that can leverage the creative and collaborative powers of the infinite canvas and give inspiration for the design of future applications.

8.2 Limitations and Future Work

The evaluation of the first prototype revealed some limitations regarding the prototypes user experience and user interface design. Especially, the difficulties for facilitators to set up the design space on the infinite canvas became evident. Here, improvements are necessary to provide an intuitive and understandable interface for the prototype and clear instructions how to set up the infinite canvas as a input space for collaborators.

Although, the overall idea of the second prototype is in an advanced state, fine tuning is still required. Early tests show promising results for the exploration of the collective semantic space. We were able to analyze and build clusters with the semantic information present on the Miro board. Here, we still need to answer technological considerations, e.g., how the clustering of semantic information can be effectively implemented in Miro and represented on the Miro board accordingly.

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Acronyms

IA Interactive Articles. 8–11, 13, 17, 20

InfoVis Information Visualization. 11–17, 20

IO Information Overload. 9

SWOT Strengths-Weaknesses-Opportunities-Threats. 58, 59

UI User Interface. 85, 86

UX User Experience. 85, 86

VA Visual Analytics. 51, 53

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Appendix

Interviews

The following questions were asked to participants of the user study in the post thinking-aloud questionnaire and semi-structured interviews. The questions for the two groups, questioners and respondents, were chosen so they provide deeper insights into the respective perspective of the group.

Questioner

Questionnaire for questioners:

- Background
  - How often do you use Miro or similar applications?
  - How often do you take part in an idea finding process in a group setting?
  - How familiar are you with brainstorming, mind map, SWOT analysis, or other creativity techniques?
- Application in General
  - On a scale from 1-10, how would you rate the overall appearance of the application?
  - On a scale from 1-10, how do you like the navigation within the application?
  - On a scale from 1-10, how would you rate the difficulty to set up the question planes?
  - On a scale from 1-10, how would you rate the clarity of the explanation texts?
- Interface and User Experience
  - On a scale from 1-10, how would you rate the clarity of creating answers on the two-axis plane?
  - On a scale from 1-10, how would you rate your experience while creating answers on the plane?

  - On a scale from 1-10, how would you rate the clarity of your task during the creation of notes?
- Visualization and Data Insights
  - On a scale from 1-10, how would you rate the clarity of the granularity input?
  - On a scale from 1-10, how would you rate the clarity of information visualization?

After the questionnaire open questions were asked. Depending on the thoughts and responses during the thinking-aloud process different questions were included. However, the guiding questions all questioners had to answer were:

- How did you like the application? Were you lost at some point?
- Do you think DigDeeper allows you to get insights into the responses of participants that would have been hidden otherwise?
- Do you have any ideas or suggestions to improve the tool?

Respondent

Questionnaire for respondents:

- Background
  - How often do you use Miro or similar applications?
  - How often do you take part in an idea finding process in a group setting?
  - How familiar are you with brainstorming, mind map, SWOT analysis, or other creativity techniques?
- Application in General
  - On a scale from 1-10, how would you rate the overall appearance of the application?
  - On a scale from 1-10, how do you like the navigation within the application?
  - On a scale from 1-10, how would you rate the clarity of the question planes?
- Interface and User Experience
  - On a scale from 1-10, how would you rate the clarity of creating answers on the two-axis plane?
  - On a scale from 1-10, how would you rate your experience while creating answers on the plane?

– On a scale from 1-10, how would you rate the clarity of your task during the creation of notes?

Similar to the questioners, guiding questions were pre-defined for the respondents. If necessary a respondents thoughts during the the thinking-aloud process was investigated further in the post-study interview. However, the guiding questions were:

- Did you enjoy this form of giving responses to questions? Were you lost at some point?
- Did this format change your way to response and express yourself? (e.g., more freedom, felt restricted, ...)
- Do you have any ideas or suggestions to improve the tool?

Feedback from Participants

The key insights and arguments made by study participants were collected in a Miro board within a table. Here, the categories "Approach to answer the question", "Placement of answers", and "Other feedback: Respondents perspective" were used to analyze the key arguments for respondents. Arguments by questioners were organized into the topics "Understandability of the application", "Interactions with the application tasks", "Flow of information on the infinite canvas", "Heatmap visualization", and "Other feedback: questioner view". If a participant made a comment or expressed a thought that was more suitable to a category outside their corresponding group it was categorized accordingly.

Afterwards the feedback in these categories were summarized and abstracted in the key arguments of Chapter 6.

Topic	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Questioner 1	Questioner 2	Questioner 3	Questioner 4	Summary
Approach to answer the question	• Participant uses axis as inspiration to find answers to question, although in the beginning they tried to answer the question without using the scales.	• This participant heavily used the axes to answer the questions. They went along both axis and tried to find answers that fit on the axis. For example, on the calm-energetic music scale, they thought about music genres with this scale in their head. They even said that "it is not easy to find something in this category". • In the post-study interview this participant mentioned that the minimalistic design of the question plane and the labels of the axis inspired them to think about the question differently and create more valuable answers.	• Although this participant has no experience with the infinite canvas, they also changed the answers of the sticky notes, as it "made answering even more fun". • This participant was not influenced by the axes labels at all. Although they mentioned them in the beginning of the study, they focused on answering the question first. Only after they created an answer to the question on the sticky note, they thought about position the item on the plane.	• Participant gets inspiration from axes and argues they perceive them as "part of the question" • Thinks about position of answers during the creation of sticky notes					• Two approaches to answer question: a. Create answer based on textual question and position it b. Create answer based on axes labels • Axes gives inspiration and motivation to add more answers. • Be careful about labels of axes as it can influence the responses from players.
Placement of answers	• In the beginning the participant creates answers and then places them on the plane. • After creating a few answers they switch to a different approach and try to find answers based on empty areas on the plane. • Does not focus on extremes but reorders existing answers position when adding new sticky notes.	• This participant also thought more deeply about placing the items. They argue that the placement "is often not as easy". • However, the placement along the axis allowed them to "fine-tune" their answers.	• When placing the answers this participant went for the extremes, and did not focus too much on the two axes. • Similar to participant 1 this participant also started to think about previous answers and their placement along the axes. As they added new answers, they started to reposition existing ones as they "did not belong there anymore".	• Argues that answers can be hard to place at one exact location as answers can rather span a larger area					• Positioning of answers on the infinite canvas was considered as an interesting way to give responses. • Using positioning of answers on a two-dimensional plane allowed participants to be more flexible in their responses. • Positioning makes people reflect on their response. • HOWEVER, some people might still prefer a traditional answering format because it can also be more difficult and less understandable how they should position their answers.
Other feedback: Respondent perspective	• Does not like this approach to answer questions as it is "more difficult and less understandable" than a traditional questionnaire. • However, they also mention that this way of thinking about questions promotes a new perspective. They argue that it inspired them to create more and different answers.	• This participant commented that they really liked the spatial arrangement of answers as it is a "more realistic way to answer questions" compared to traditional scales, e.g., a Liker-Scale. • When confronted with the application and how it helps to analyze players responses this participant was mentioning different use cases how this approach to gather responses could be valuable in their work (e.g., by creating engaging questionnaires as "nobody really likes boring questionnaires")	• This participant mentioned that they really liked this form of giving feedback, as it is "much more accurate "and they "feel more flexible" when giving responses. This resulted in interacting with a "fun" type of giving responses. • They argue that the plane influenced their answers as it gave them the possibility to add another dimension to the answer. • This participant said that once they were stuck and could not think about new answers the axes labels gave them "new ideas of answers they could add".	• This approach of answering questions was perceived as intuitive and allowed them to fine-tune their answers • Can see huge potential for this application in a brainstorming setting. e.g. in school they had to set the focus of classes. Here they wanted to get the perspective of all students and a quick overview can be brought to the other teachers to discuss about the implications and directions					• Possibilities of the infinite canvas made answering more fun (e.g., changing colors of sticky notes) • This form of answering was described as more interesting compared to traditional scales. • Infinite canvas gave more flexibility to answering questions and also allows a more nuanced form of giving answers.

Topic	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Questioner 1	Questioner 2	Questioner 3	Questioner 4	Summary
Understandability of application UX and UI (texts, inputs, buttons, …)				• some labels and names were confusing, e.g. question planes	• This participant did not use the possibility to customize the question plane directly in the application, but rather changed the items directly in Miro. • This participant did not correctly set up the question planes. They did not change the title of the frame at all after using the "Create sample frame" button.	• This participant did not use the possibility to customize the question plane directly in the application, but rather changed the items directly in Miro. • During this process the participant did not connect the text labels correctly with the connectors. Thus the application would have had troubles to analyze the data. • This participant did not correctly set up the question planes. They did not correctly set the title of the frame as they did not change the title to the right format. The only changed the title of the first plane and duplicated this frame. Afterwards, the titles of the other frames were not changed accordingly. • They duplicated the first frame and adapted the question and axes labels. Afterwards these two frames were duplicated three times for the other participants according to the participants tasks.	• Some explanations were unclear, especially the explanation how the frame title should be composed. They were not sure how the title should be composed. • This shows in the finished frames that this participant set up. • This participant used the possibility to customize the sample frame.	• This participant immediatle used the possibility to customize the sample frame. • They also created their own interview topic and found their own question along with the corresponding scale. • Afterwards they wanted to try how participants would answer their questions as they wanted to see if their questions work.	• UI and UX of application was considered clean by participants. • Explanation texts were not clearly formulated, especially for people without much knowledge about Miro. • Some participants mentioned that they think that more is possible regarding the heatmap.
Interactions with application tasks, i.e.: • **setup of input planes** • **analysis of planes**					• They duplicated the first frame and adapted the question and axes labels. Afterwards these two frames were duplicated three times for the other participants according to the participants tasks.	• This participant tried to come up with their own question first. As a food science and microbiology master student this person created their question around the premise of healthy food. However, after the question has been created they realized that they could not come up with understandable two dimensional axes on the fly and used the suggested questions instead. • They especially mentioned that "formulating the question right is not as easy as they thought". They then argued that the questions need to be "rather specific" to get the desired responses from players.	• The participant first created a uncustomized sample frame. They then deleted this frame and created a new one with the customize input fields. They did the same thing for the second question. • However, they did not correctly set the persons id in the title and ended up using two different person ids for the same person (i.e., A1:QA and B1:QB instead of A1:QA and A1:QB). When they were made aware of this mistake they immediately understood their error. • This participant then duplicated both question planes and renamed the other planes also wrong (A2:QA & B2:QB).	• They argued that they were able to set up the input planes so quickly because of their technological background.	• The creation of question planes is clear to participants. • However, the option to customize the automatic creation in the application has not been found by all participants. • Set up of question planes often wrong. (i.e., the name of the frame). This needs to be error checked and made more clear to the user in the application. • Participants did use Miro to change default question plane.

Topic	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Questioner 1	Questioner 2	Questioner 3	Questioner 4	Summary
Flow of Information, i.e. from participants sticky notes on input plane to the heatmap					• Although the flow of information was not immediately clear to this participant, after some experimentation it became clear to them.	• This participant immediately understood the flow of information after they hovered over the heatmap.	• First this participant was not too sure where the data of the heatmap was coming from. However, after some investigation (i.e., through hovering over the heatmap to show the tooltips) it became clear to them.	• After the setup of the custom questions, this participant expected that the answers from respondents would be analyzed with a more individual-centered approach, e.g. what is the perspective of Jacob, what is the perspective of Christian	• The usage of the infinite canvas as a medium for input and output medium was understandable and working. • Interactions and usage area needs to be more clear as some expectations led to wrong mental models of the prototype.
Heatmap Visualization	• interesting to see how the players answered in general • provides a quick overview of huge set of interviews	• valuable to quickly see patterns • get a quick overview of responses			• Although the heatmap was understandable. They then mentioned that after some initial time, the labels of the tooltip were not as clear for this participant. Especially, the label "Value" was confusing in the beginning. • Commented on missing semantic information of responses but they understood why. • Granularity was confusing in the beginning but after some experimentation with the heatmap generation they understood as they mentioned that "granularity gives me an idea about the finesse of the heatmap and the density of responses in the corresponding areas. • They argue that the granularity value of 4 makes the most sense to them as it "allowed them to see some details without getting lost in the data".	• This participant immediately understood the heatmap and explored the data in much detail. They tried multiple different granularities to find the most suitable one for their purpose. During this they commented that "a granularity of 100 is not helpful at all because it it way too detailed". • Although they understood the meaning and purpose of the granularity input they argued that the label "Granularity" was a bit confusing to them. • They especially liked the heatmap visualization as it is very helpful for a visual overview of data. • However, they commented that they feel like that "there is much more possible regarding visualizations".	• Similar to the other participants the granularity input was confusing in the beginning. But after some experimentation with the heatmap generation they understood. However, they mentioned that the wording is very confusing as it does not tell them what changing this value would do. • Furthermore, the label "value" was not clear to them as it became not immediately evident that this describes the number of notes in this area. • This participant liked the heatmap as it allowed them to "find extreme answers relatively quickly" and that it allows them to "see an overall pictures".	• They suggested to see the question in the modal, • Furthermore, they suggested that the number of answers should be more prominent, e.g. directly in the heatmap without the need to hover over cells. • The granularity was confusing to this participant as well when first creating the heatmap. But this became more clear to them afterwards. • In general, they were not satisfied with the heatmap visualization as they expected something else (to get an idea about individual respondents answers and not the group) • But overall, they see the possibility to get a quick overview about answers from multiple participants.	• Valuable to get quick overview of players answers. • However, some parts of the heatmap were criticized. Especially, the labels for the "Granularity" and the tooltip of the visualization could be improved. • Furthermore, the general coloring was critisized as it was considered "too dark" and also
Other feedback: Questioner perspective					• Verbal answers are missing in the data output, but "it would be very interesting to know what people wrote on their notes".	• This participant argued that this application may give them a lot of opportunities to analyze questions and to allow people to give answers according to their perspective. • It also gives people the opportunity to answer questions more accurately.	• This participant commented that they see the value of this application, however they think that it can mostly be helpful for a large group since "it is easy to see this for a few people on the go". • The participant commented on the missing written information of the notes in the data output. They would be interested to "see what people wrote"	• In general, they see two potential approaches to extract information in this prototype. Either to get insights into a groups answers or to get more insights into individuals. • As a final remark they argued that in brainstorming in groups they especially value "Kritzeln" (doodeling) in the idea finding process.	• Missing semantic information of answer notes was pointed out multiple times. • Further possibilities of adding different and more sophisticated visualizations was pointed out. • More detailed insights into players perspective/response s possible with such a questioning format. • Ability to freely create and input information important to both, respondents and questioners.