Developing a Timeline Visualization for Spatio-temporal Data - Revealing Patterns of Derived Change Rates

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Abstract

Timelines are often used as the basis for temporal data visualizations due to their intuitive nature of displaying time in a linear way. Many types of data can be visualized with a timeline. One particular option beyond plotting a fluctuating variable is plotting its rate of change. Looking at the change rate of a dataset instead of the absolute rate can potentially reveal patterns within the data that would otherwise have been less clear. In this research, a visualization method is developed with the goal of revealing patterns, by plotting rates of change and combining a timeline with other graph types. The prototype of the visualization developed here consists of a timeline combined with a line graph, representing the change rate, and a circle graph, representing the absolute rates. The prototype is developed in a 5-stage design framework, which consists of a cyclical process containing defining, prototyping and testing elements. The testing of the prototype is performed in the form of usability testing. Ten testing sessions are performed using questionnaires and the think-aloud method. The tests consist of participants completing a number of assignments. The outcomes of the tests are processed through two coding schemes. The tested prototype is effective in revealing three types of patterns in the data: stability, instability, and the difference between a rising positive change and a rising negative change. The prototype does require certain improvements as determined from the coded transcripts of the test sessions and the results of the questionnaire. A few of the suggested improvement are the following: the option to enlarge graphs for better viewing, a change to one of the interactive tools in order to read specific change rate values, and the addition of multiple legends. Suggested future research include a follow-up study that cycles back through the design thinking stages, implementing the suggested improvements.

Table of contents

1 Introduction

1.1 Context

Data-driven Decision Making (DDDM) is becoming increasingly more important. The term refers to making decisions based on analysis of data rather than purely on intuition (Provost and Fawcett, 2013). While the corporate sector has already widely adopted this kind of decision making and proved its value, governmental organizations are starting to embrace it as well. However, as decision makers themselves do not have the time to analyze large sets of data, it is often the case that analysis is done for them. This includes the exploration of datasets in search for potential meaningful patterns which can form the basis for decisions or policy. Translating these abstract data into useful information can be done in part via visualization. Information visualization (InfoVis) and scientific visualization (SciVis) are the scientific disciplines that research and develop the visualization of data. Effective visualization of data is of large importance, as impactful decisions can be reliant on it. Besides, research has shown that visualized statistical information is more preferred than articles and numerical tables (Lonsdale and Lonsdale, 2019).

As the name reveals, the case of visualizing spatio-temporal data is concerned with time. This parameter is often visualized by using a timeline. Timelines are easily interpreted and widely used as the base for temporal data visualization. However, their potential could be extended by combining them with other graph types. A wide variety of graphs can be incorporated in a timeline visualization, offering a presentation that can reveal patterns within the data effectively. Another element that could potentially reveal otherwise hidden patterns in data, is calculating a change rate. The change rate is mathematically the first derivative of a dataset, and represents the change within the data over a certain time. Both these elements—a timeline combination and a change rate derivative—hold the potential to reveal patterns within data. Especially in the day and age of digital visualization, an interactive combination of timelines with other graph types could be very useful in exploratory data analysis, as the field of information visualization demonstrates.

1.2 Research Objective

The goal of the research is to develop a visualization using rates of change, based on a timeline combined with other types of graphs, that effectively reveals patterns in data. This new synthesis of graphs will reveal patterns of change more effectively than timelines in isolation.

The main objective of this thesis can be formulated as follows:

> Develop a novel visualization, based on a timeline combined with other graphs, that will effectively reveal patterns of derived change rates in spatio-temporal data.

This objective contains multiple elements of interest. The first notable element is *novel graph.* This means that a visual graph will be developed that is somewhat unique. This project attempts to accomplish this by taking the most intuitive element of temporal data visualizations, a timeline, as a basis, and expand on this by incorporating other visual elements. This is the second notable part of the objective. Thirdly, *patterns of derived change rates* is of interest. This refers to the main objective of the developed graph: it should be able to reveal certain patterns in datasets. It should visually show rates of change in the data, leading to better understanding of the subject at hand. As indicated, the graph is intended to be used for derived data, meaning that it should be suitable for any sort of derivative of datasets. The last notable element refers to *spatio-temporal data,* meaning that the visualization will be intended for data regarding spatial subjects, like environmental data or any type of subject related to space. As a result, the graph will be suited for use by policy makers in the field of any spatial matter, like spatial planning, environmental planning, urban/rural policy makers, etc.

1.3 Sub-questions

In order to accomplish the objective of this thesis, a clear understanding of the implications of its elements is needed. Therefore the main objective is supported by the following sub-questions:

1. Which design principles and visual variables can be applied to a timeline based graph to ensure usability?
2. To what extent can users recognize patterns in data by exploring a visualized derivative change rate?

Sub-question 1 relates to the first of two major elements within the main research objective, how the design of the combination of graph types can ensure the usability of the visualization. 'Design principles' is a broad concept, which is consciously chosen so it can be reflected on in many ways. While the theoretical background provided in section 2 may offer some insights in effective visualization, this broad definition offers for the research to be open for other principles than may be taken from the presented theories. The concept of visible variables however is less open for interpretation, as literature provides a proper background on this concept. The last notable element of this question is usability, which is a concept that will be discussed in the theory chapter, and offers a fitting structure for testing the visualization.

The second sub-question should result in a better understanding of why visualizing the derived change rate of a dataset can potentially show patterns in the data more clearly than the looking at absolute rates, before calculating a certain derivative. Although the overarching objective of this research regards the revelation of patterns in change rates, visualizing the absolute rates may be of interest as well during exploratory data analysis. Besides, absolute rates may function in a supportive role, confirming certain hypotheses based on the calculated change rate. The tested prototype is designed in such a way that the potential effect of the derivative as well as the absolute rates of a dataset can be demonstrated.

1.4 User Identification

In order to evaluate the usability of a visualization method, it is required to know what determines whether or not a visualization is successful. This can be done by specifying the potential users of the visualization product and their needs. A user identification offers the possibility of listing these user needs, which can later be translated into product features. Based on these needs and features, an evaluation can be performed, testing the effectiveness of these features.

Identifying users can be done in various ways. In the case of known users, their wishes, goals and needs can simply be asked and can thus be regarded as known. For these cases a fitting visualization method can be chosen that has the right characteristics for achieving the tasks of the user.

However, in the case of unknown users, their needs can be distilled by determining the tasks a certain visualization method is created for. In these cases, the visualization methods are known, including their capabilities, or 'tasks they are able to perform.' These goals or tasks can be found in literature. Based on these capabilities of a visualization, the type of user can be determined by comparing their goals to these capabilities. This way, the user and visualization method can be identified based on the characteristics of each other.

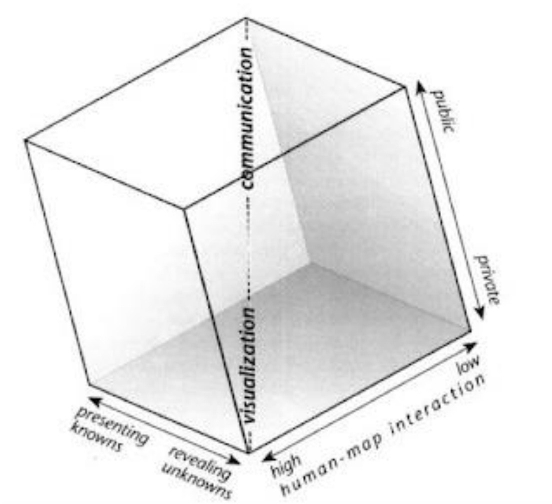


Figure 1.1 – Cartography cube (Maceachren, 1994)

Identifying the type of user of a visualization can be done with reference to the Cartography cube as introduced by MacEachren (1995), which can be seen in Figure 1.1. As explained in section 2.3, maps and visualizations can be categorized using this Cartography cube by looking at the three axes and comparing these characteristics with the project at hand. For this case, which deals with the bottom-left corner of the cube, this means the following (in bold are the characteristics corresponding to this project):

- Axis 1: presenting knows vs **revealing unknowns:** exploratory data visualization deals with the revelation of patterns within the data. As there is not yet a known message, the goal of the visualization is to find this. The visualization should be able to reveal structure within the data.

  Implications for user: users want to be able to effectively reveal structure within the data.

- Axis 2: Human-map interaction: **high** vs low: as exploratory data analysis often takes place in the early stages of data analysis, the user often requires a hands-on approach for dealing with the data. When trying to find structure in data, a high level of interactivity with the configuration of the visualization is needed to deeply explore the dataset. Especially options regarding additional viewing interfaces can be helpful in getting proper insight.

  Implications for the user: the users want highly interactive interfaces, with extra viewing options in order to get as much insight as possible into the data. While visualizations for the public sphere tend to be static and straightforward because they are meant for laymen, cases like this—exploratory visualization in private sphere—may be extensive in terms of options, as they are meant to be used by professionals in geo/GIS/data visualization.

- Axis 3: audience: public vs **private:** the audience of a visualization ranges from public, relating to a wide non-specific audience, to private, meaning that the audience is specific and often in a professional sphere with specialized training and expertise. Visualizations for a private specific audience are likely to stay private, as they are used for discovering new information. They are not meant to be an end product because the wider public cannot effectively interpret them.

  Implications for the user: for a private audience, a visualization does not need to be overly attractive in terms of appearance. Whereas public maps and visualizations also rely on aesthetics in order to be effective, a private visualization rather has a functional goal: discovering structure in the data. This means that aesthetics have a low priority in the user's needs. Note that this does not mean that proper application of visual variables can be ignored. On the contrary: they should be taken into account seriously for the visualization to be as effective and clear as possible.

The above mentioned implications translate into the following user requirements as summarized in Table 1.1.

Table 1.1 – User requirements

Requirement	**Explanation**
Effective pattern revelation as main goal	The visualization should have the main objective of being able to reveal patterns as clear as possible. This is the main goal, so as little compromises as possible should be made
Interactivity to support pattern finding	In order to find patterns, interactive elements should be incorporated in the visualization. Elements like a pop-up of a specific part of the graph can improve readability and thus effectiveness of the visualization. Besides, configuring the visualization to personal needs can accelerate the exploratory process.
No need to be simplistic in terms of configuration options	As this type of geovisualization is meant for professionals in the field of geo-information, there is no need for compromises that sacrifice user options for the goal of simplicity. The visualization is not made for laymen.
Function over form	The visualization is aimed to be functional, so aesthetics have a secondary priority.

1.5 Demonstration Dataset

In order to demonstrate the developed visualization, an exemplar dataset is required. The used dataset is from the recently started global COVID-19 pandemic, and consists of the daily death count caused by the virus. The dataset is further discussed in section 3.4

2 Theoretical background

2.1 Time-geography

Arguably the most notable contributor to time-geography has been Torsten Hägerstrand. The essence of time-geography comes down to a model Hägerstrand (1970) proposed to represent the movement trajectories of a person, in space, through time. This is often represented in a diagram containing an axis for space, usually a flat map with x and y coordinates, and an axis for time, having z coordinates, thus being a 3D diagram. In this diagram, the movement trajectory of a person through this time-space is represented as a line (see Figure 2.1). Using this as a basis, the model can be used to represent possible unknown movement trajectories with a given time frame.

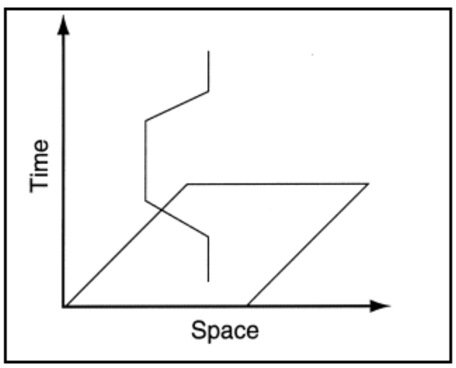


Figure 2.1 – Time geography model (Gren, 2003)

As can be seen in Figure 2.2, using a time budget T and a travel velocity v, the potential path space of an actor in time and space is represented by the prism in the graph. The actor has to be within that space given the time and velocity and the fact that the known trajectory is picked up again, which is represented by the most upper line piece in the top of the graph.

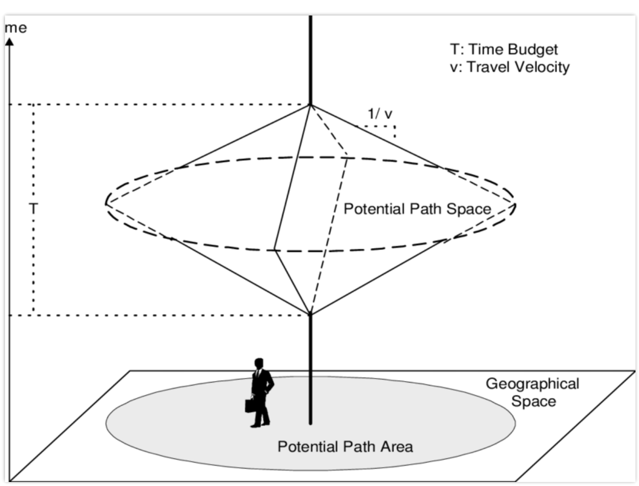


Figure 2.2 – Potential path space (Wu and Miller, 2001)

This can be expanded by adding a stationary activity to the person's trajectory. This means that a known activity is added to the person's day, which has a given duration and is known to be stationary. This results in the graph shown in Figure 2.3. This volumetric space is referred to as the space-time prism. It represents the areal and temporal bounds of an activity.

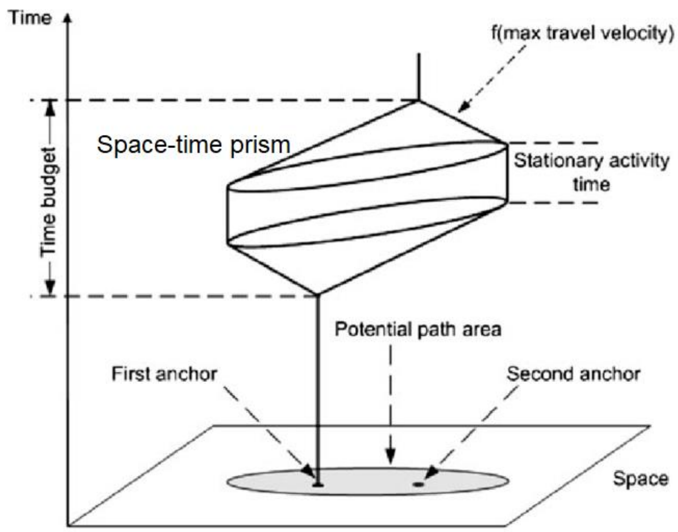


Figure 2.3 – Space-time prism (Kobayashi et al., 2011)

After its introduction, time-geography was criticized for various reasons (Hallin, 1991). Giddens (1984) criticizes Hägerstrand's perspective on humans as being an object rather than an acting subject that has intentions and feelings. Besides, he argues, not enough attention is paid to the nature and origin of the actions of human agents. Sui (2012) summarizes the criticism in three categories. The first being that time-geography is inherently reductionist due to Hägerstrand feeling the need to simplify human travelling paths to basic lines, neglecting underlying reasoning and emotional components. As a result, the reduction of humans as agents travelling via paths is critiqued to be simply a graphical exercise. Secondly, time-geography was very data heavy, especially during the time it was introduced. As data-intensive individual movement trajectories have to be recorded, the scale tended to be very local, resulting in a small scale analysis. The third point of criticism revolves around a structure-agency debate, in which time-geography is either found to be too dependent on structure or on agency.

Nevertheless, as Lenntorp (1999) states, since the 1970s the thoughts of Hägerstrand are reflected in the works of others time-geography related studies. Yet, while time-geography has been used as a framework for various topics concerning the time and space in peoples lives, Kwan (2004) argues that its actual methods were not widely implemented until the 1990s. Reasons for this could be found in the difficulties caused by the complexity and lack of data on individual-level movement trajectories, and interacting dimensions. It was, in short, difficult to analyze these patterns simultaneously. However, as Kwan (2004) argues, the rapid development of hard- and software enabled digital analysis possibilities using geographical information systems (GIS). Thanks to a massive increase in computational power, large amounts of data can be analyzed very easily. This demonstrates that the ideas and models introduced by Hägerstrand are still very relevant. For example, Hägerstrand's space-time prism (1970) can be used in analyses using GIS, like Miller (1991) demonstrates. As Millers work dates from the early nineties, one can imagine that the growth of information and communication technologies (ICT) has massively increased the possibilities of applying time-geography methods using GIS. Even extensions to the classic concepts have been done, like Shaw and Yu demonstrated (Shaw and Yu, 2009) by including virtual activities in a hybrid physical-virtual space-time model. Studies like these react to the classic space-time model by arguing that ICT developments have removed certain spatial constraints, as increasingly more activities can be done through digital devices, e.g. meeting people through video-calling and ordering products online. As these activities are performed via internet, temporal constraints are removed as well.

Another development building on space-time geography is set in motion by Winter (2009) and Winter & Yin (2011), suggesting the possibility of probabilistic space-time models, representing the possible future location of a mobile agent. Winter argues for a model that includes a priori knowledge of the behavior of an agent to more accurately predict its location within the space-time prism (see Hägerstrand, 1970). This direction of research is further studied by Song and Miller (2014) by identifying the limitations in the work of Winter & Yin (2011) and using two simulation methods to more effectively predict future agent locations.

Works like these show that the influence of Hägerstrand reaches far in time, offering a foundation for various studies concerning human interaction with space. While the goal of Hägerstrand was to offer a framework, it can be argued that he succeeded in the sense that other scholars have widely built upon his work and adopted his models. He has gained a great deal of followers that expand on his work, but also received criticism, evoking discussions though multiple decades. According to Sui (2012), Hägerstrand himself has never made an attempt to really update the classic time-geography. Yet he left various fragments on how time-geography could be expanded. Sui gathers these fragments that contain Hägerstrands shifting views through time and attempts to reconceptualize time-geography. The result is a multitude of perspectives on time-geography, based on the classic Greek views of space and time, also taking into account criticism and developments that it has received throughout the decades (see Figure 2.4). When combining these different conceptualizations (see Sui (2012) for in depth explanation) of space time and agency, many variants can be made (e.g. Chronos-Choros, Chronos-Topos, Kairos-Choros, etc). The implication of the reconceptualization of these concepts is that it opens up many doors in terms of research possibilities. As Sui himself states, it offers for development of time geography in a broader and interdisciplinary way for the years ahead.

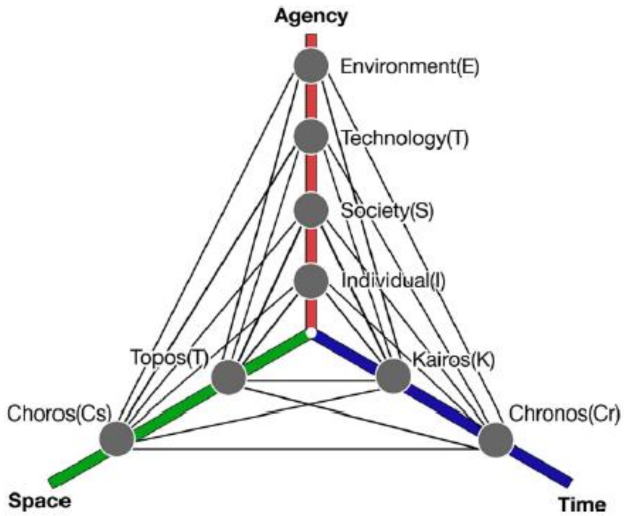


Figure 2.4 – Alternative conceptualizations of space, time and agency for time-geography (Sui, 2012)

2.2 Representation of Temporal Data

During the rise of time-geography, especially since it started to be implemented in GIS, scholars were searching for a way to represent temporal data (Miller, 1991). In order to have a representation that is suitable for a specific application, one should be aware of the problem that is being dealt with. Peuquet (1999) proposes two questions that are at the foundation of most space-time related problems: "1) World state; what was/is/will be the spatial distribution of a given phenomenon at a given time? 2) Change; which elements changed/are changing/will change during a given time span?" She then presents three perspectives on how change related spatio-temporal data can be represented: location, entity and time. Most presented representations include only one of these three aspects as the main perspectives. For example, time oriented representations are mostly built around a timeline of some sort (e.g. Peuquet and Duan's Event-based Spatiotemporal Data Model (ESTDM) (1995)). Timeline approaches can contain specifics like dates and times but can also ignore those, and be strictly ordinal of nature. For example Frank (1994) proposes a ordinal definition of time, including an algebraic notation. This ordinal definition of time deals with relations of events as 'before' and 'after' each other. Frank argues that using ordinal time, combined with an algebraic notation, can in fact be very useful, as it is often used in disciplines like archeology and urban development, and should be incorporated in GIS. His approach offers possibilities for branching time, making alternative parallel sequences possible instead of relying on a linear timeline. Concepts like these can be the solution for a problem that Andrienko et al. (2010) propose years later. They argue that GI and GIS still struggle while dealing with temporal aspects of geographic data. They state the following: "Time is routinely modelled as a high-level linear characteristic of spatial entities; maps and other analyses simply compare a limited number of particular moments or intervals rather than take advantage of the full structure of time". They argue that there is a strong need for advanced techniques that are able to visualize these specific time characteristics and refer to the research field of visual analytics as being suitable for these challenges. Visual analytics includes the capabilities of humans to recognize patterns as an essential part of interactive visual representations.

While a single perspective in representations has been used widely, Peuquet argues that trends at that time showed that combinations of these perspectives were attempted as well. Peuquet herself presented a dual model (1988), which combined the perspective of location and object. Some years later she proposes an approach that builds upon concepts from perceptual psychology, artificial intelligence and related fields (1994) that expands on the dual model and introduces time. The proposed approach consists of a triad that represents object, location and time and forms a conceptual basis for the development of database representations that are flexible and efficient while at the same time being interpretable for humans.

2.3 Visualization of Temporal Data

Multiple researchers have attempted to structurally list techniques or methods for visualization of temporal data. However, as that is a broad category, a distinction can be made based on the perspective or goal of the visualization. This can be done by taking the Cartography[3] cube introduced by MacEachren (1994) as a basis. When exploring data, trying to reveal patterns or unknown information, one deals with the bottom corner of the visualization-communication line (see Figure 1.1). In this case there is a high level of interaction between the user and the map. For these cases, Andrienko et al. (2003) present a catalogue of visualization techniques, which will be further elaborated on in section 2.4.

Table 2.1 and Table 2.2 list techniques sorted by their source and expands on the type of data it is suited for, and the exploratory tasks it is able to perform. In the cases where a map should present a known message, the top corner of the line in Figure 1.1 is at hand. In these instances, there is a low level of interaction with the map. These maps are often used in a public sphere, meaning that mostly 'non-professionals' will use them. The goal of these visualizations is often the communication of a message. These visualizations will from now on be referred to as 'communication visualization'. Techniques and methods for these kinds of visualizations are listed by Vasiliev (1996).

2.4 Exploratory Visualization

Exploratory visualization refers to the process of getting the first insights from an acquired set of data with the goal of stimulating thought, revealing patterns and relationships (Blok, 2000). For cases of exploratory data visualization, corresponding to the lower left corner of the Cartography cube, the intended audience is deemed 'private.' This implies that the use will most likely take place in analytical sphere by professionals. This does not inherently mean that exploration is only possible with the required skills, like knowing a querying language. Methods that use effective visual presentation for exploring data are being developed, like Compieta et al. (2007). They present an approach that exploits existing and well-known software (Google Earth) to more effectively show data-mining results. It includes the data mining process itself, which can be regarded as an exploratory data analysis for very large spatial datasets. However the emphasis of their work is directed towards the effective visualization and interpretation of the mining results, as this is often the critical requirement for extraction of information from a large dataset. For this, two tools are presented: one for domain experts, who do not necessarily have technical knowledge in the field of data mining, and one for users that do have expertise in the mining process. Each tool has it advantages for the specific user. Specifically the first presented tool is of interest, that uses Google Earth as a basis can combined with several data layers to present the outcomes of the data mining process in an interactive user environment. It offers easy comparison possibilities for geographical areas or thematic attributes. Examples like this offer great benefits for easier decision making without having technical knowledge.

For exploratory visualization, there are many options in terms of techniques and tools that can be applied. Naturally, each technique has its own specific requirements in terms of the type of data it is suitable for, and which type of tasks it can perform. Andrienko et al. (2003) present an overview of techniques that can be used in exploratory visualization. They use a classification scheme that categorizes the data based on the kind of changes that the data shows. Besides the techniques that are suitable for all kinds of data, it uses the three following classes introduces by Blok (2000):

> *"1. Existential changes, i.e. appearance and disappearance.*
>
> *2. Changes of spatial properties: location, shape or/and size, orientation, altitude, height, gradient and volume.*
>
> *3. Changes of thematic properties expressed through values of attributes: qualitative changes and changes of ordinal or numeric characteristics (increase and decrease).*

Table 2.1 gives an overview of the techniques that are categorized based on the type of data they are suited for.

Table 2.1 – Summary of visualization techniques, classification based on type of data, based on Andrienko et al. (2003)

Technique	Type of data	Description
Querying	All types of data	Look-up – providing requested information – and filtering – removing data that does not satisfy the query constraints
Map animation	All types of spatio-temporal data	Updating the content, showing changes in data by changing the display
Map iteration	All types of spatio-temporal data	Juxtaposition of maps, showing state of a phenomenon at different points in time
Time labels	Existential changes	Representation of age by color. Example software: SpaTemp
Aggregation of data	Existential changes	Summarized data of spatially aggregated events: proportionally sized symbols. Temporally aggregated events: bar charts
Space-time cube	Existential changes, locational changes	Time is treated as the vertical dimension. Earliest events are shown on the bottom and latest events on the top. 3D viewing is used for better detection of spatial and thus temporal clusters.
Conventional cartographic methods	Location changes	Lines connecting object positions at different time points. Arrows showing direction of change. Points showing trajectory of change at time intervals.
Animation methods	Location changes	Snapshot in time: successive maps only showing location of object at a specific time. Movement history: map shows routes of movement trajectory until present time. Time window: shows fragments of routes for specified time intervals.
Change map	Attribute changes (numeric)	Shows for each area or location the absolute or relative amount of change for a given time interval. Uses color: choropleths, colors indicating increase or decrease, degrees of darkness representing magnitude of change.
Time-series graph	Attribute changes (numeric)	Timeline-based graph that shows the change of numeric attribute on the Y-axis. Offers possibilities in combination with interactive map by highlighting areas or objects when hovering over lines or points in the graph. Also see Hochheiser and Shneiderman (2001) for an example of such an interactive time-graph.
Aggregation	Attributes changes (numeric)	Aggregation of spatio-temporal data per location for user-selected time periods. Calculation of statistics for these periods. Visualization by so called "time bar", showing segments of the aggregated periods which can be assigned colors according to chosen values.

Techniques are also categorized based on tasks. Tasks can be best understood as having two components: a target and constraints. The target is the information that is looked for, and the constraints describe the conditions that this information needs to fulfil. For the classification of tasks, Andrienko et al. (2003) offer a typology that is based on work of several authors: It includes the classification scheme of Bertin (1983), who identifies two notions about the structure of the data: "question types" and "reading levels," referring respectively to the questions one can ask about a dataset. For example: a dataset containing two component, time and gas prices can rise two types of questions: 1) "what is the gas price for time x?", and 2) "at what time was the gas price y?". For these questions, one can also identify different reading levels. These levels refer to the specificity of the asked question, ranging from elementary – meaning that the question is about a single data element, like one point in time – towards overall – referring to all the phenomena in the dataset as a whole. Andrienko et al. (2003) have adopted and slightly changed these reading levels into "searching levels", as there is being dealt with exploration of data.

Added to this classification are elements from the previously introduced work of Peuquet (1994) on the triad of object, location and time. When applied to the questions of Bertin, these three components result in the following questions that can be asked about a dataset (Andrienko et al., 2003):

- "when + where → what: Describe the objects or set of objects that are present at a given location or set of locations at a given time or set of times.
- when + what → where: Describe the location or set of locations occupied by a given object or set of objects at a given time or set of times.
- where + what → when: Describe the times or set of times that a given object or set of objects occupied a given location or set of locations."

The third element that is added to the classification scheme are the two types of cognitive operations that can be performed as exploratory tasks in datasets as introduces by Blok (2000): "identification," referring to monitoring temporal changes and finding trends, and "comparison," referring to finding similarities and differences, but also to the detection of (cause-effect) relationships.

As a result, the classification scheme as can be seen in Figure 2.5 is introduced. Table 2.2 below gives an example of one of the summaries of the techniques, categorized based on the classification of tasks they are to perform. It can be imagined that for each of the combinations in Figure 2.5 a list of techniques can be generated. These can be found in the work by Andrienko et al. (2003).

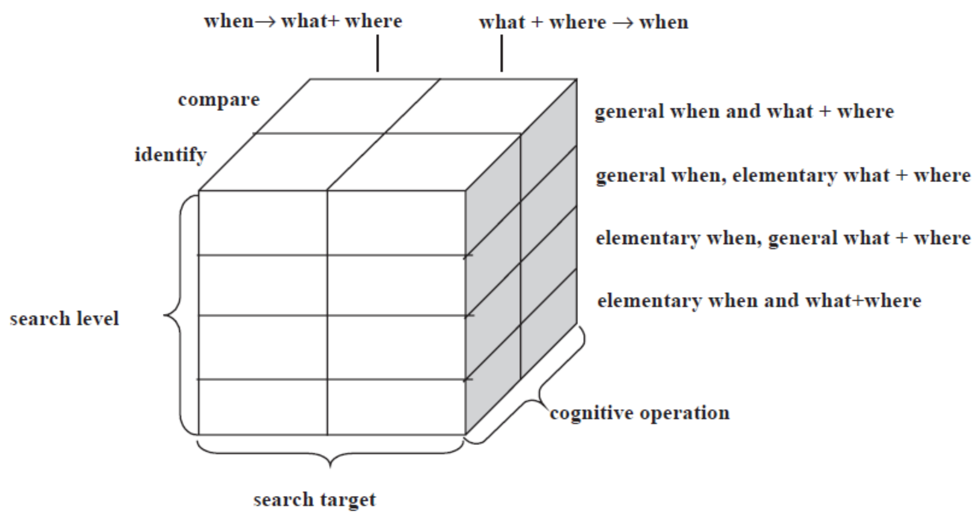


Figure 2.5 – Operational task typology for the review of visualization techniques for spatio-temporal data (Andrienko et al., 2003)

Table 2.2 – Summary of techniques for when → what + where on the elementary level with respect to time

Cognitive operation	**Search level:** **Elementary**	**General**
Identify	Cartographic representation methods supporting the elementary search level, e.g. chart maps	Summary for a territory or object set in whole: data aggregation
	Direct lookup	Spatial distribution: Cartographic representation methods supporting the general search level, e.g. choropleth maps or dot maps.
	Dynamic link between maps and other displays ("brushing")	
Compare Objects (locations)	See above	Juxtaposition of maps representing different phenomena or different territories at the same time moment
		Overlaying different phenomena in the same map
Time moments	Map iteration	Map iteration
Detect change	Map overlaying	Change map (with numeric attributes)

		Fading	
		Change map (with numeric attributes)	
	Measure change	Map overlaying	Map iteration; data aggregation by parts of territory
		Moving objects: static trajectory representation like lines, arrows or traces. May be combined with filtering	Change map (with numeric attributes)
		Change map combined with direct lookup	Data aggregation for whole territory

2.5 Information Visualization versus Scientific Visualization

The general topic of visualizing data can be divided into two subfields: Information visualization (InfoVis) and scientific visualization (SciVis).

Information visualization is concerned with visualization of data which has not a given (spatial) structure. The data is abstract. A visualization form for this abstract data can therefore be chosen and structure can be found. An example is provided in Figure 2.6, showing temperatures for a city throughout the year.

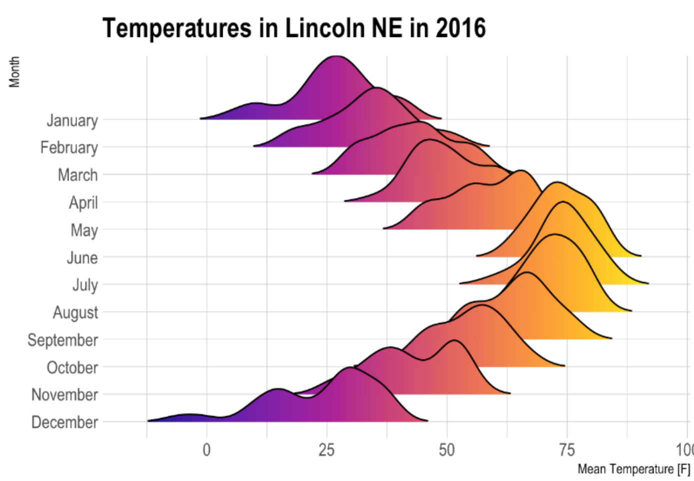


Figure 2.6 – Example of information visualization (Holtz, 2018)

Scientific visualization is concerned with the visualization of data which has a inherent given structure, which can be spatial. Visualizations follow naturally from this. An example can be seen in Figure 2.7.

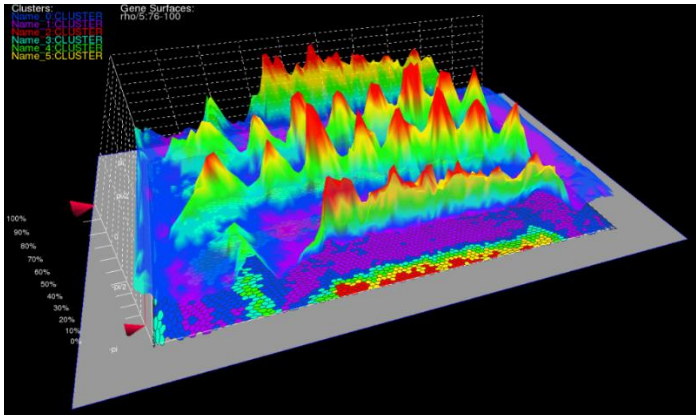


Figure 2.7 – Example of scientific visualization (OmniSci, 2019)

This project is concerned with information visualization as it is attempted to develop a general visualization method for abstract spatio-temporal data. Within the subfield of information visualization, it is possible to specify the context of this project even further. Gaviria (Gaviria, 2008) makes the distinction between functional information visualization and aesthetic information visualization. The former being mostly concerned with being neutrally informative and the latter with effectively telling a subjective story:

> "… functional information visualizations aim to convey a message or delineate patterns hidden in the represented data through metaphors that users can quickly understand, while aesthetic information visualizations are more concerned with presenting a subjective impression of a data set by eliciting a visceral or emotive response from the user" (Gaviria, 2008).

This project deals mostly with functional information visualization. Gaviria argues that the visual form of representation in functional InfoVis matters in the sense that it speeds up communicating the message of the data. In other words, it is of importance that thought goes into the visual design of InfoVis.

2.6 Visual Variables

At the core of visualization of geographic information lie visual variables. In cartographic design, visual variables are visualization techniques that are used to create visual hierarchy. The concept was introduced and developed by Bertin in his book Semiologie Graphique from 1967. Bertin identified seven variables that can be controlled in the symbology of maps. These are position, size, shape, orientation, color, texture and value. Figure 2.8 gives an overview of these variables and should give a rough idea of how these variables can vary, and thereby create hierarchy in cartographic design. The variation within these variables make it possible to compare objects within a map or visualization.

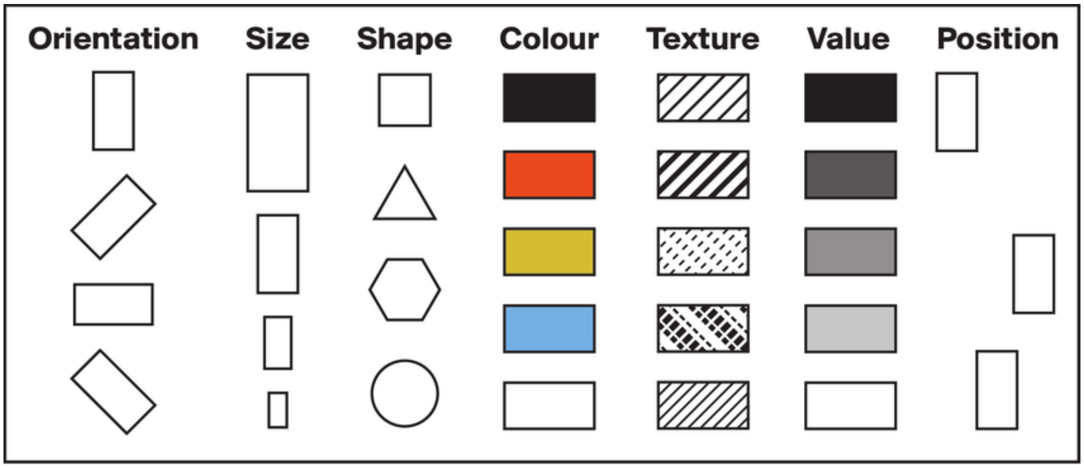


Figure 2.8 – Visual variables as identified by Bertin. Image source: (Kilchör, 2014)

To further organize this system, these visual variables have different levels of organization, linked to their perceptual properties: *associative*, *selective*, *ordered* and *quantitative*. Andrienko and Andrienko (2006) interpret these properties of Bertin as follows: variables are *associative* when it permits immediate grouping of objects. For example: square shaped objects of the same color and size can be regarded as the same sign. Variables are *selective* if objects can be isolated if they belong to the same category of this variable. For example: all blue objects belong to the same family and all red objects to the same family. *Ordered* variables show a visual ranking or classing which immediately places the object in hierarchy. For example: the color grey is perceived as intermediate between white and black. Finally, with *quantitative* variables, the visual distance between two categories can be expressed as a numerical ratio, like the length of an object can be twice as long as another object. The visual variables each have their own perceptual properties they are able to achieve, which are summarized in . Planar dimensions relates to the spatial dimensions of the plane on which objects are situated. These properties also relate to the type of data that is being dealt with. Associative and selective properties are suitable for nominal data, ordered for ordinal data an quantitative for ratio (numerical) data.

Table 2.3 – Perceptual properties of visual variables (Bertin, 1983), summarized by Andrienko and Andrienko (2006)

	Associative	**Selective**	**Ordered**	**Quantitative**
Planar dimensions	yes	yes	yes	yes
Size		yes	yes	yes
Value		yes	yes	
Texture	yes	yes	yes	
Color (hue)	yes	yes		
Orientation	yes	yes		
Shape	yes			

Green (1998) has taken the concepts of Bertin and criticized some, while expanded upon others. For example, Green argues that the variable of color (hue) can in fact be ordered. While taking two colors and gradually move from one to the other. For example a gradient from yellow to green does in fact contain order. Another addition of Green to the ideas of Bertin is the distinction of the variables being shown on printed paper or being viewed on a computer monitor. Computer monitors offer for three additional variables that expand the original model of Bertin:

- *Motion*: with sub-variables *velocity* and *direction* of the movement
- *Flicker*: with sub-variables *frequency* and *phase*
- *Binocular disparity*, meaning that computer screens offer viewing options for showing each eye of a user another view of the visualization, making possible the perception of depth

Table 2.4 shows an overview of the additional variables as introduced by Green (1998) with their corresponding perceptual properties.

Table 2.4 – Perceptual properties of additional visual variables (Green, 1998)

	Associative	**Selective**	**Ordered**	**Quantitative**
Motion: velocity		yes	yes	yes, if scaled
Motion: direction		yes		
Flicker: frequency		yes	yes	yes, if scaled
Flicker: phase		yes		
Bin. disparity		yes	yes	

Another example of additions to the traditional list of variables is suggested by MacEachern (1995), who argues for the inclusion of cartographic uncertainty into visual variables. He does this by introducing the variables *crispness*, *resolution* and *transparency*.

For an even more complete overview of all variables discussed above, see Halik (2012, p. 21).

2.7 Towards Geovisualization

In the day and age of digital visualizations, the ideas of Bertin may be limited since they are static and do not take advantage of digital possibilities a computer screen has to offer. As shown above, researchers like Green recognize this and expand on the traditional variables of Bertin with their own ideas. While Bertin himself argued that digital additions like animations would completely change the playing field, because that would "… make us pass from the graphic system … into film, whose laws are very different" (Bertin, 1983), other researches like DiBiase et al. (1992) argue that the variables do still apply to animated maps. On top of that, they introduce new so called dynamic variables that apply in the case of animated maps: duration, order, rate of change. All these above mentioned changing definitions, slight nuances and additions of variables show that the framework introduced by Bertin still is an ongoing construct (Blok, 2005).

Kraak and Ormeling (2010) argue that the trends in the few past decades in terms of increasing interactivity in cartography, together with approaches from scientific visualization and developments in geographic information systems have resulted in the field of geovisualization, which provides theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data. According to MacEachren (2001), all these additions related to animation and dynamic visualizations show that geovisualization distinguishes itself from traditional cartography in the sense that it uses highly interactive displays. This is also stated by Kraak and Ormeling (2010) who argue that these kinds of dynamic geovisualizations need high interactivity. They call for interactive legends that offer users the possibility to manipulate the flow of animations. One could think of sliders (when dealing with linear time) or dials (in the case of cyclical time) as demonstrated in Kraak et al. (1997). In his 2001 essay, MacEarchren attempts to set the agenda for the next decade by addressing challenges that will be at hand according to him. One of these includes the need for the development of a topology of interactive georepresentation operations. These operations refer to user initiated actions that cause something in the visualization or map to change.

2.8 Effective Visualization

In order to develop a successful visualization, it is wise to be aware of certain principles that influence the effectiveness of a visualization. Lonsdale and Lonsdale (2019) present a body of guidelines for visualization of information. They base these guidelines on principles that they extracted from extensive literature review. These underlying descriptive theories include theory on cognition and visual perception, since psychology and perception lie at the basis of effective visualization. Built upon these principles are presented sections on infographics and on data visualization. Especially the latter is of interest for this project, as presents best practices for presenting "data in a visualized and objective form." It should be noted that the presented guidelines should not be regarded as rules, but being open to interpretation.

Guidelines on effective visualization focus on multiple elements. Some of the elements that are addressed by Lonsdale and Lonsdale (2019) include: general guidelines, text/typography, color, graphics/visual elements, layout and structure and 'chartjunk.' Of each of these elements, best and worst practices are presented.

While for most of these elements clearness is often advocated for, 'chartjunk' is a topic of discussion in literature. Chartjunk, as introduced by Edward Tufte (1990), refers to unwanted extraneous elements in the design of graphs of abstract quantitative information. The reasoning behind keeping visualizations as clean as possible – reducing the amount of decorative elements to a bare minimum, only saving the 'ink' for the actual data visualization – lies in the optimization of information processing. When a graph is kept simple and clean, less cognitive capacity is needed to process the information. Instead, the processing is taken over by the perceptual system, which is capable of naturally identifying patterns in the information (Hullman et al., 2011). This is in accordance with the *image theory* introduced by Bertin (1983), which states that a visualization is good if it immediately offers the extraction of the information that is being portrayed. The viewer must be able to get the message in a single glace. However, multiple studies like Bateman et al. (2011) have demonstrated that decorated graphs containing attractive elements can outperform simple graphs in terms of memorability. This may lead to consciously introducing difficulties into visualizations with the goal of increasing memorability. Hullman et al. (2011) conclude this in their work. However, as they state, effective visualization should rather be regarded as a compromise between efficient processing and desirable visual difficulties that stimulate learning. For the project at hand this means that the goal of the visualization developed here should be carefully described. While memorability can be a valuable characteristic of a visualization, efficient processing of the presented information will most likely be more desirable in the case of pattern revelation.

2.9 Usability Testing

Testing the usability of a product originates from the field of human factors and ergonomics, which revolves around the usability of any designed object or tool. This field originates back to the industrial age, and was centered around physical objects. During the information age, ergonomics were introduced into computers and other electronical consumer products. This research focusses on this digital context of ergonomics, which is the field of Human-Computer Interaction (HCI).

Even though geovisualization methods are developed with the intention to work, if they do not actually enhance science, decision making or education outside the laboratory where they are created, they are of little use. So argue Slocum et al. (2001), also stating that traditional usability testing in cartography does not apply well enough to geovisualization. This opinion is shared by MacEachren and Kraak (2001, p. 6), who state that there was a "lack of established paradigms for conducting cognitive and usability research applied to highly interactive environments" at the time of publishing, 2001. Traditional map-use studies meant for cartography are not fully applicable in the context of new highly interactive geovisualizations, including advanced user interfaces (Koua et al., 2006).

However, during the decade of the 2000's, User Centered Design (UCD) has found its way into cartographic application design. The philosophy of UCD stems from research on HCI (Schobesberger, 2011). In the beginning, usability was developed as a term to indicate how easy it was for users to accomplish their tasks. It tested the ease of use of user interfaces. Other aspects that it dealt with were the speed at which a piece of software could be learned, and how easy it was to remember. However, according to Kraak and Ormeling (2010), usability has moved beyond the computer interface and now also indicates the effectiveness and efficiency a user is able to reach a specific conclusion in a specific map use environment.

Van Elzakker (2005) distinguishes two categories of research: holistic functional map use research, and perceptual and cognitive research. Functional map use research is based upon the assumption that the purpose of the map is known and that it is useful to test whether and to what extent the map achieves to fulfil that purpose. This type of testing is holistic, meaning that the map and its contents, including the interpretation and cognitive processing is treated as a whole. Besides, functional map use research also requires knowledge of the needs of the users. The goal is often to improve the effectiveness of map products (van Elzakker and Wealands, 2007).

Perceptual and cognitive map use research is more often from the perspective of an individual. Perception map use research looks at the user's initial reaction on map symbols, and cognition takes also earlier experience and memory into account. The latter researches why maps and certain symbology work. According to Van Elzakker and Wealands (2007) there has been a shift from perceptual towards cognitive map use research due to technological advancements. They state that there is a recent growing interest in cognitive processes, deriving meaning from maps as a whole and the role of maps in knowledge construction. This is also placed in the context of the new map use goals, that later evolved into the concept of geovisualization. However, according to Ellis and Dix (2006), only 20% of 65 papers introducing new visualizations included any user testing. Because of this, Lloyd et al. (2007) researched which methods of human-computer interaction (HCI) can be applied to the characteristics of geovisualization. The results showed that human-centred techniques that specifically included the user during the application creation stage shows benefits. This is also in accordance with the notions of MacEachren and Kraak (2001) who state that user involvement should be considered well before the beginning of software design.

User studies in GIS can include multiple methods. Schobesberger (2011) mentions focus groups, participatory and non-participatory observations of users diary keeping and talking-aloud as established methods to discover usability problems in GIS. Talking-aloud and thinking-aloud are two comparable methods during which the participant explains what they are doing. In thinking-aloud, the participant also expresses what they think, feel, or look at. Talking-aloud only describes the actions of the participant, and can be regarded as a more objective method. Thinking-aloud is considered one of the most popular methods in HCI, and offers insight in the cognitive processes of participants during engagement with computers (Nielsen and Yssing, 2002).

According to Faulkner (2000), usability is often measured in three aspects as set by the ISO standard 9241-11 (International Organization for Standardization, 2018):

- “Effectiveness: accuracy and completeness with which users achieve specified goals;
- Efficiency: resources used in relation to the results achieved. Typical resources include time, human effort, costs and materials;
- Satisfaction: extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user’s needs and expectations.”

These aspects can be measured by using a questionnaire. An example of a questionnaire can be found in the System Usability Scale (SUS) test, developed by Brooke (1996). The questionnaire includes questions that cover the three mentioned aspects of usability, offering a useful method for conducting a usability study.

3 Methods

This section will explain which methods are used to develop the visualization. First, an explanation is given on the chosen research approach. This includes an introduction in design thinking, containing a design thinking process framework of 5 stages. After this, an overview will be given of the steps taken in this project. The steps will be explained and a conceptual overview will be provided. These design steps will then be related to the 5-stage framework of design thinking. The methods also include a part on the testing of the visualization method and the dataset that is used.

3.1 Design Process

The process undertaken in this thesis is rather a design process than a research process, although research is still being performed in the form of literature research and usability research. The design process ranges from the early stages of inspiration and rough ideas towards the finalization of a prototype and the testing of that prototype.

A way of dealing with a design process is found in design thinking. Design thinking refers to the way designers handle their problem solving by going through an often iterative or cyclical process. While design thinking is often placed in a professional context in which designers are hired by companies to solve problems using design centered approaches, practices and knowledge, its methods can offer guidance in a small scale design process like this project. Design thinkers are associated with a human-centered approach, instead of having a technology- or organizational-centered approach (Kimbell, 2011). This can be recognized during stages in a design process that include concepts like empathic design, referring to design also fulfilling psychological and emotional needs. Also the emphasis on understanding the user's needs in the beginning of the process stands out. This focus on the user has a strong relation to UCD, as described in section 2.9 (Schobesberger, 2011).

A 5-stage design thinking framework (see Figure 3.1) is taken as the basis for the design process for this project. It contains the following stages (Dam and Teo, 2019):

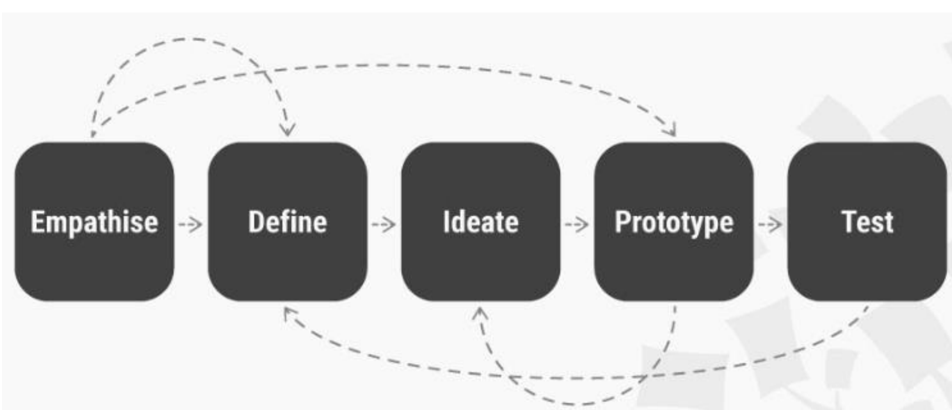


Figure 3.1 – The 5-stage design thinking process (Interaction Design Foundation, 2019)

- Empathize: this stage entails gaining understanding of the problem. During this stage, information is gathered about the area of concern. This can be done by observing, engaging and empathizing with people to understand their motivations and experiences. This stage provides the input for the next stage.
- Define: all information from the Empathize stage is put together into a problem definition. This definition should be human-centered instead of technology centered. In the case of a geovisualization, this means that the problem definition should address the tasks and goals the user should accomplish by using the visualization. During this stage, features and functions can be defined that should be included in the design.
- Ideate: the ideation stage is about coming up with ideas on how to solve the problems stated during the define stage. All kinds of brainstorming methods can be applied here, resulting in ideally as many ideas as possible.
- Prototype: during this experimental stage, the first products will be created. These can be scaled down versions of the product, or specific features of the product that are developed in isolation to see what works. Prototypes can be tested within the development team. At the end of this phase, the designer will have a good understanding of the product and it's features, including its constraints.
- Test: during this 'last' stage of the process, the product is tested. By evaluating the features and the product as a whole, the problem can be redefined, going back to the define stage. This way the process is rather a cycle during which a deep understanding of the problem and solution is gained.

3.2 Design Steps

Based on the 5-stage design thinking framework, an overview of the steps involved in the design of the visualization can be found in Table 3.1. An extended explanation is provided below.

Table 3.1 – Overview of design steps in this thesis, based on 5-stage design thinking framework

Design Thinking Stage	**Design Steps**	**Products**
1. Empathize	• Gathering information about the needs of the users • Literature study on subject and context • User definition: relate to cartography cube (see Figure 1.1 and corresponding explanation in section 2.3)	• Literature review (section 0) • User identification (section 1.4)

2.	Define	• Write research objective • Define sub-questions	• Research objective (section 1.2) • Sub-questions (section 1.3)
3.	Ideate	• Get inspired by literature & internet research • Divergent & convergent thinking • Sketching ideas, digitize sketching	• Sketches (section 4.2.1) • Digitized sketches (section 4.2.2)
4.	Prototype	• Define features and functions • Translate different features into code, create product parts in isolation • Combine loose parts into a whole prototype	• Wishlist of features and definitions • Working loose features – python coded graphs & interactive elements • First prototype as a whole product
5.	Test	• Test loose features in isolation (functional testing) • Design usability test, including testing of the test • Test product as a whole: o User research, 10 participants o During test: think-aloud method o After test: questionnaire, based on SUS (Brooke, 1996) • Process test results: two coding rounds • Cycle back through definition, ideation and prototyping for improvement of features	• List of test results containing features that need improvement • Testing approach containing a setup design, questionnaire, plan for processing of results • Think-aloud transcripts • Questionnaire results

3.2.1 Stage 1: Empathize

Information is gathered about the subject and its scientific context, but also about the user – hence the word ‘empathize.’ The information about the subject is gathered by performing a literature study, resulting in chapter 2. By gaining a deep understanding of the scientific context of the subject, geovisualization, one can identify challenges that are discussed and take those into account while moving through the design process. One already relevant takeaway from the literature review is the concept of the cartography cube (see Figure 1.1) as introduced by MacEachren (1994), which is used to classify visualizations and map products. This cube can be used to identify the user type of a visualization, based on their goals. Data exploration and presenting unknowns as a goal will entail different users than presenting knowns and communicating a message. A identification of the user is done, which is found in section 1.4.

3.2.2 Stage 2: Define

After having created an understanding of the user and the context of the subject, the research objective itself can be defined. The input for this is taken from the results of the previous stage. Given the chapter containing the literature background and the user identification, the objective of the research is formalized (see section 1.2). Supporting this research objective are a few sub-questions. Answering these questions is helpful in reaching the main research objective. The sub-questions are listed in section 1.3.

3.2.3 Stage 3: Ideate

During the ideation stage, it is the goal to gather as many ideas as possible. This starts with finding inspiration for visualizations. Inspiration can be found anywhere, ranging from looking at exemplar visualizations in literature towards randomly coming up with a concept while riding your bicycle. The internet has a lot to offer on visualization of data, so browsing the web was very helpful. This part of the ideation stage can be defined as divergent thinking, referring to thinking as broad as possible. After having many ideas, it is time to narrow down. This can be called convergent thinking: taking some of the best ideas and try to refine these.

Part of the ideation stage is sketching ideas by hand and converting these sketches into digitized versions. Visually seeing an idea come to life can be helpful in coming up with alterations and improvements. This kind of visual thinking is embraced by the fields of information visualization and scientific visualization.

The outcomes of this stage are sketches and digital versions of some sketches and form the first half of the results section (chapter 4) together with the next stage, prototype.

3.2.4 Stage 4: Prototype

This stage is about transforming ideas into prototypes. This can be a mockup of a visualization method as a whole, but it can also be about defining and designing different features that are part of the design.

Creating a list of features that the end product should have is an essential part of this stage. The features are defined in terms of function and goal, which is necessary for the testing. The features are listed in the form of a wishlist and were developed apart from each other. This offered for the features to be functionally tested in isolation. This was mostly a process of trial and error, as the code was written from scratch. However, was made extensive use of online documentation and tutorials for guidance on the used Python packages.

After the individual features were created and tested (while cycling through the different stages of testing, redefining and designing), they were combined into a first prototype of the product as a whole. This entailed combining pieces of code, making sure that everything is in place and functional together.

The outcome of this stage is a working prototype that is ready for usability testing. This prototype is part of the first half of results (chapter 4), together with the sketches mentioned earlier.

3.2.4.1 Technical Specifications

The visualization was developed using the programming language Python. Table 3.2 provides an overview of the packages that were used, including the versions.

In order to host the visualization, which is needed for the testing participants to access the visualization online, a service called Heroku was used. Heroku offers a free plan for hosting code online, which also works for the developed visualization.

For coding the transcripts which will be discussed in section 3.3.4, an application called Taguette was used. Taguette is free software that offers tagging phrases of text with codes.

Table 3.2 – Used python packages

Package	Version
Pandas	1.0.3
Numpy	1.18.1
Geopandas	0.6.1
Jsonschema	3.2.0
Shapely	1.7.0
Bokeh	2.0.1

3.2.5 Stage 5: Test

For the fifth stage, a distinction can be made between functional testing and usability testing. Functional testing is about the testing of the individual technical features of the visualization. These features can be parts of a graph, like precisely positioning of graph elements or coding an interactive element like a slider or pop-up feature. This testing is done in the environment of development, as it only tests if these individual features work. While this process was placed in stage 5, it more or less already happened during the previous stage of prototyping, as blocks of code can immediately be tested as they are written. However, as this process is cyclical, it can be regarded as a constant cycle trough the stages of prototyping and testing.

Usability testing refers to the testing of the product as a whole and includes the testing done by other people than the developer, ideally being a potential user. For this project, a usability test is performed that includes a combination of the think-aloud method and a questionnaire. The product that was tested is the interactive timeline combination prototype that is developed in this thesis. The setup of the usability testing will be elaborately presented in section 3.3. The outcomes of the testing stage form the second half of the results, chapter 5.

3.3 Usability Testing

The prototype that was tested is the version of April 20th 2020. This version was developed during the months February 2020 – April 2020. The product was tested as a whole, meaning that all functionalities are tested concurrently.

3.3.1 Usability Testing Purpose

The main purpose of the usability testing phase was to gather feedback on the product that can be used to improve it. This feedback is gained by researching the experiences of test participants that conduct a hands on test with the product.

Testing of usability considers the three elements of usability as defined in the ISO standard 9241-11: effectiveness, efficiency and satisfaction:

- Effectiveness:

  Can participants successfully answer the asked questions accurately?

  This question relates to whether the product is able to do what it is intended for: can values actually be found? Does the product show the things it is intended to show? This goal is accomplished by measuring the success rate of the assignment that is given to each participant. If the participants can successfully answer each question, the product is able to achieve what it is functionally intended for. This goal does only consider the *if*, not the *how*.

- Efficiency:

  To what extent is the product efficient?

  This questions relates more to the way in which the answers can be found. How well does it work? Are the values easy to find? Can they be found where the user expects it? This is measured by researching the experiences of the participants: the think aloud method gains insight in the thought process of the participant while trying to figure out where to look. Immediate feedback on elements of the product can be found here. Furthermore, the questionnaire at the end will gain insight in what the participant thinks in hindsight of the different elements of the product, and the product as a whole. This also gives room for participants to offer recommendations and suggestions.

- Satisfaction:

  Does the prototype meet expectations in terms of response by the participant? This can be an emotional response, like enjoying the use of the prototype. This can also relate to elements of the prototype working as expected leading to a cognitive response. Satisfaction is also measured during the analysis of the think aloud method, and is included in the questionnaire.

3.3.2 Usability Testing Assignment

The assignment given to the participants simulates the intended real world use of the product. The product is meant to be used when trying to find patterns in data during exploratory data analysis. It is intended to provide insight in data patterns by looking at the derived change rate of the data. The assignment reflects this and is divided into different tasks. Most tasks contain questions that ask the participant to look up certain values, or which case shows the highest value at a certain time. Some questions are included that require the participant to have a basic understanding of the meaning of the derived change rate. Appendix A contains the assignment that is given to the participants. The assignments are handed to the participant in an online form. This offers the participants to perform the test online. The form is followed by the questionnaire, which is filled in after the participants have finished the testing. Figure 3.2 shows a snapshot of the assignment set up.

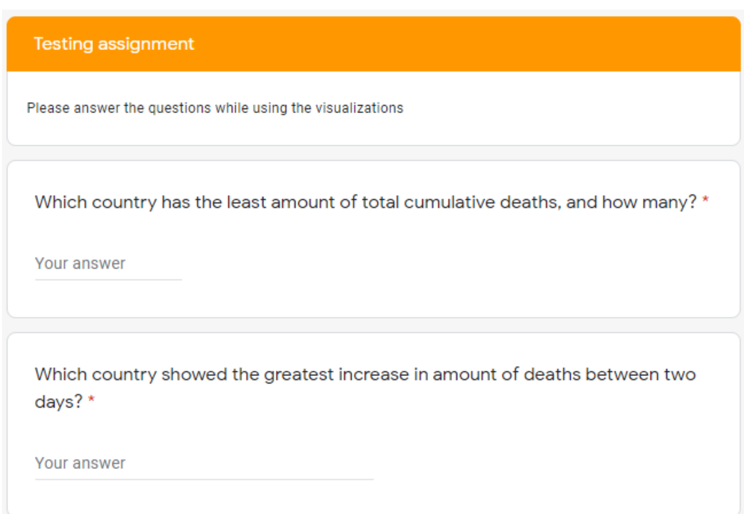


Figure 3.2 – Snapshot of testing assignment

3.3.3 Usability testing methods

Methods that are applied during the testing sessions are the think aloud method and a questionnaire.

3.3.3.1 Think Aloud Method

During the testing session, the think aloud method was applied. This means that participants were asked to speak oud their mind during their hands on with the product. They were asked to express what they were thinking and doing while trying to perform the given task. This way, insight is gained into the thought process of a first-time user of the product and the cognitive processes of the user can be captured. This is useful for gathering improvements on various elements of the product: how does the user initially respond to the interface? What draws their attention? How quickly does the user learn where to look for certain information? In case a participant fell quiet, some prompting questions were asked. For example: “which graph are you looking at now?” or “Have you tried using the map?”

This method is appropriate for this project as it captures a user’s experience with the project very closely. Despite users not directly being involved since the beginning of the design process as advocated for by researchers (Lloyd et al., 2007; MacEachren and Kraak, 2001), this method offers for their experiences and opinions to be taken into account during the cyclical design process.

Given the fact that the researcher of this thesis is of Dutch origin and all participants were Dutch as well, the think aloud method was performed in the Dutch language. This ensures participants to express their feelings as clear as possible.

3.3.3.2 Questionnaire

Participants were asked to answer a short questionnaire after finishing the test session. This questionnaire was be done via the same online form as the assignment. Appendix B gives an overview of the questionnaire questions. The questionnaire covered questions regarding the product as a whole, as well as the three different elements within the product. These elements are the 1) graphs on the left, 2) the map on the top-right, and 3) the graph on the bottom-right. The questions covered the elements of usability based on a 5-Likert scale. It was based on the Usability Scale as introduced by Brooke (1996). At the end, a question is dedicated for open feedback and recommendations for specific elements or the visualization as a whole.

3.3.4 Processing of Test Results

Each session results in the following data sources:

- Video recordings of the testing sessions;
- Transcripts of each recording of the testing sessions;
- Answers to the testing assignment;
- Answers to the questionnaire.

As mentioned earlier, testing was performed in Dutch, meaning that the transcripts are in Dutch as well. Further analysis—as will be discussed later—of the transcripts like coding was also performed in Dutch to stay as close as to the original data as possible, however all transcripts were fully translated into English.

3.3.4.1 Transcripts

All testing sessions were recorded, including video as well as audio of the participant as the researcher. For each session, the audio is transcribed. When there is referred to a certain element in the visualization that cannot be directly be tracked down, the video is looked at to review what the participant is meaning to refer to. This is then included in the transcript in brackets: []. For example, when the participant says the following: "now I click on this", the transcript will show the following: "now I click on this [the upper left graph]". This way the transcript will be clear about what is meant during these kinds of situations.

After the transcripts were finished, all documents are coded. Coding can be described as the act of highlighting certain sections or phrases of a transcript, and assigning a tag to that. Saldaña (2009) defines coding as the following:

> "A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data"

While this seems a little general for trying to distill meaning out of a dozen of transcripts, a tool that helps in doing so can be found in coding in multiple rounds, each time looking at the transcript with a different focus, called a 'filter'. These filters offer a way to have multiple versions of the transcript, each outcome highlighting something else (Saldaña, 2009). This method is applied to the transcripts of the testing sessions: two rounds of coding have been performed, each with a different filter.

The first round of coding looks purely at directly suggested improvements for the visualization, and will be referred to as the 'improvements filter.' These improvements are listed and counted, giving a summary of direct suggested improvements. This round of coding starts of with only one code, 'improvements.' After all phrases containing improvements are tagged, a sub code is given to the phrases to indicate which element is talked about (i.e. this can look like 'improvement – legend'). The results of this can be found in the results section, 5.1.1.

A second round is coding is performed to gather the more indirect feedback. This time there is a focus on how participants came to their answer. This coding round is referred to as the 'performance filter', because it is used to highlight how well participants can find the answers to the questions. Phrases that are coded in this round reflect the performance of the visualization to offer what it is made for. The coding scheme for this round of coding can be seen in

Table 3.3. This overview contains the codes, an explanation of when a phrase is tagged with a certain code, and the implication of the tags.

After the codes have been assigned, a round of sub-coding is done to indicate which element is meant by the code. This can look like the following: 'Expectation – wrong – cumulative graph'. This example shows a case of a wrong expectation at the element of the cumulative graph. By assigning these sub-codes, an overview is gained on which elements show certain performance. In the results section, these elements can then be highlighted. In order to see which codes reflect a good performance, a green color is assigned to them. These cases are likely to not require much change or improvements. Badly performing codes are assigned an orange color. These cases are likely to require improvements. The codes that have no color assigned are a somewhat neutral. While these elements are not necessarily performing well or less well, they are worth discussing and being taken into account in the result section. This way, the results for can be structured according to good or bad performance. The colors visually assist this.

3.3.4.2 Testing Assignment Answers

The answers of the testing assignment are checked, and error rates are calculated for each question. These error rates give an indication of which visualization elements are *effective,* meaning that they are able to functionally able to do what they are designed for. When certain elements contain multiple errors, these elements are taken into account for the final improvements list.

3.3.4.3 Questionnaire Answers

The results of the questionnaire answers are presented as descriptive statistics. These results give an indication on which visualization elements need most attention.

Table 3.3 – Coding scheme – Performance filter

Code	Explanation	Implication
Expectation – good	When participants speak out certain expectations, which turn out to be right. For example, when they say they think the answer can be found in a certain graph, which turns out right.	The elements referred to turn out to be at a place where participants expect them to be, indicating good performance.
Expectation – wrong	When participants speak out certain expectations (also see Expectation - good), which turn out to be wrong.	The elements referred to turn out not to be at a place where participants expect them to be, indicating bad performance.
Inventive use	When participants use graph elements in a certain inventive or creative way.	Creative or remarkable use of graph elements could be taken into account for the final improvements list.
Learning	Participants show a learning progress during the test session.	Elements referred have a learning curve to them, indicating that they are not necessarily performing bad, but take some time to get used to.
Performance – good	The answer is found in a quick and easy way.	These referred to elements perform well, meaning that they probably do not have to be changed drastically.
Performance – doubt	The participant is in doubt where to find the answer, but eventually finds it.	When participants are in doubt about certain elements, adding certain graphical or textual elements could clear things up about the use.
Performance – bad	The participant finds it difficult to find the answer.	Elements referred to do likely need to be changed, or at least need a clarifying addition. These cases are taken into account seriously in the final improvements list.

3.3.4.4 Outcomes

How all test results for each session are processed into different outcomes is summarized in Table 3.4. The table shows which results are gathered, what processing is involved, and what the final outcomes are. A total of four different outcomes are the result of the testing: the performance of the prototype based on the three aspects of usability—effectiveness, efficiency and satisfaction— and directly suggested improvements by testing participants. After this, a final outcome is generated in the form of a hierarchical improvements list.

The suggested improvements list are the results from the first round of coding (improvements filter) and the suggestions in the usability questionnaire.

The performance in terms of effectiveness is the outcome of the answers to the testing assignments. Error rates are calculated, indicating the performance of the different visualization elements.

Efficiency performance is the outcome of the second round of coding (performance filter) and the usability questionnaire. The coding is performed as is discussed in the previous section (3.3.4.1) and will be discussed in order of amount of occurrences for each of the positive and negative codes.

Satisfaction performance is also the outcome of the second round of coding (performance filter) and questions included in the questionnaire.

The final result is based on all test outcomes and consists of a hierarchical improvements list. This list will be a suggestion of improvements to include into a next prototype of the developed visualization.

Table 3.4 – Summary of processing and outcomes of test results

Test results	Processing	Outcomes	Final outcome
Transcripts	Improvement coding filter	Improvements list	Hierarchical improvements list
	Performance coding filter	Efficiency performance Satisfaction performance	
Assignment answers	Error rates calculation	Effectiveness performance	
Questionnaire answers	Usability questions	Efficiency performance Satisfaction performance	
	Last question on suggested improvements	Improvements list	

3.3.5 Usability Testing Practicalities

Due to the measures taken because of the Covid-19 pandemic during which this research was undertaken, user testing was conducted in an online environment. The visualization is hosted online on a global server, so participants can access the product online via their browser. Contact with the participants was held through a video call, using the online open-source software Jitsi (www.Jitsi.org). This enabled the researcher to keep in contact with the participant during the session. The researcher prepared a meeting room shortly before each session and send the link to that room via e-mail or other appropriate online messaging services. The Jitsi room were secured with a password to ensure privacy.

The sessions (video and audio) are recorded using screen recording software (OBS Studio). Before each session, consent for this is asked to each participant in two ways: vocally by the researcher, and by clicking 'I agree' at the first question of the questionnaire, that asks for consent.

The testing phase was conducted between April 27th 2020 and May 7th 2020. Nine full weekdays were dedicated for conducting testing sessions with participants. Each session with the participant was planned to take about 30 minutes from start to end, and fitted within a one hour block that is reserved for preparing and processing the sessions. A more detailed session schedule can be seen in Table 3.5. Each participant that was willing to help was contacted personally to schedule an online appointment. Within the first 5 minutes of that appointment, they received an e-mail containing the following:

- Link to online videocall room (Jitsi) with password
- Link to the online product environment
- Link to online questionnaire form and testing assignment

To simulate a real-world scenario, a target audience was recruited that most likely uses a product like this in their professional or educational career. In the context of data-driven decision making, this audience consists of geographers, urban planners and GIS professionals. Therefore the testing sessions was also be targeted at people with these backgrounds. The participants were recruited among colleagues and were contacted personally.

Table 3.5 – Overview of each testing block of one hour

Minute	**Content**	**Notes**
-15 - 0	Prepare links for new session Prepare software for new recording	New Jitsi meeting room New recording session
0-5	Sending videocall link Sending link to the online product Sending assignment & questionnaire link	Message including links is prepared on forehand, participants will be informed about receiving this e-mail within the first 5 minutes of the appointment
5-10	Ask consent for recording *Start recording* Introduction to product and instructions	Explain what the participant is looking at Explain they have to answer the questions Explain what to express during the think aloud
10-25	*Performing the assignment*	
25-30	Finishing up *Stop recording* Asking participant to answer questionnaire, which comes after the assignment task End videocall	Thanking the participant Asking them to answer the questionnaire
30-45	Process results	Put answers and recording files in the right folders

3.3.6 Privacy Measures

Because the testing is done with participants, it should be assured that their privacy is handled with care. In order to keep privacy as secure as possible, there is no place where the first or last name of the participants is stated.

Each participant was asked for consent two times, once vocally at the starting of the session, and once by clicking on the 'I agree' button at the start of the testing assignment form.

All anonymized datafiles containing the recordings of the sessions are stored securely on a separate external hard disk.

3.4 Data

As stated before, a dataset is needed for demonstration purposes. The chosen dataset is be used to calculate a derivative dataset, which will then be used to demonstrate the visualization method. This means that instead of the raw data rates, change rates will be calculated that represent the change of the raw data rates over a certain time. As sub-question 3 entails demonstrating the effect of using a derivative dataset, the non-transformed data is visualized as well in the tested prototype.

The dataset that is used has been selected based on a number of criteria:

- Some rate of change: to demonstrate the power of the visualization method, it is necessary that the dataset rates show at least some change. This way, the advantage that the visualization method will have, can be demonstrated. If a dataset just contains constant rates without any variation, demonstrating the advantages of the visualization method will not be as effective.
- Spatio-temporal: the datasets should be spatio-temporal, meaning that they contain a spatial and temporal element.
    - The spatial element is ideally some sort of distinction of different regions or countries/states which can be compared. Multiple regions are needed for comparison.
    - The temporal aspect refers to the data being of historic character, meaning that it should have plenty of time steps. Ideally the data should date back more than 10 time steps, but more is better. The more detailed the dataset is, the better it will be able to demonstrate the visualization method. Note: it does not matter if these time steps are days, weeks or months or years, as the dataset is only used for demonstrating the abilities of the visualization.

Ideally, the final script contains code that automates this, so the input for the visualization can be absolute rates. However, this will be challenging given the fact that the use of the visualization method can be different for every dataset applied to it. For example, like explained under dataset 1, the visualization could be used to compare regions to each other, or compare regions to the national rates.

In order to be used for the initial plots, some transformation has been applied to the downloaded data. If needed, the datasheets have been transposed so that the rows contain the temporal variable, like years and the columns contain the spatial variable, like regions. Furthermore, for the time being, unnecessary elements are deleted from the data sheets, like exploratory texts beneath the sheets.

3.4.1 Dataset

The first dataset that is used for the visualization consists of data on fatalities caused by the Corona virus, also known as Covid-19. The data is published by the European Centre for Disease Prevention and Control (ECDC). The dataset was updated daily during the time of the global pandemic in 2020, and was freely available via:

https://www.ecdc.europa.eu/en/publications-data/download-todays-data-geographic-distribution-covid-19-cases-worldwide(ECDC, 2020) First accessed on March 30 2020.

The dataset was subject to very little processing in the progress of this research. The following processing steps were performed on the dataset in order to prepare it for importing by the Python script:

Data was gathered for selected countries (China, USA, Italy, Spain, Germany and The Netherlands) and put in columns, each row representing a day. The data in the tested prototype ranged from January 1st 2020 until April 23th 2020. The dataset was saved as a .csv file in order to be imported in the script.

The dataset fulfills the two set requirements, meaning that it shows some rates of change. The outbreak and spread of the virus showed patterns of change in multiple countries, making it suitable for this project. The data is also of spatio-temporal nature, meaning that contains a spatial component (the countries) and a temporal component (the days).

The second used data is a spatial dataset, which is needed for plotting the map part of the visualization. The data consists of a shapefile of the world, containing each country.

https://www.naturalearthdata.com/downloads/110m-cultural-vectors/ (Natural Earth, 2018) First accessed April 7 2020

One step of processing has been performed on the world shapefile, namely the Douglas-Peucker algorithm to simplify the polygons in the shapefile in order to reduce file size and processing times. The shapefile is saved as .shp and imported into the script as such.

4 Results Prototype

4.1 Stages 1 and 2

These stages have resulted in the literature review, research objective and the sub-questions.

4.2 Stage 3: Ideate

As described in section 3.2.3, the ideation phase consists of the following design elements:

- Get inspired by literature & internet research
- Divergent & convergent thinking
- Sketching ideas, digitize sketching

These elements have resulted in a number of hand-drawn sketches of which a few have been digitized to get a feel for how such a graph would turn out. In this process the hand drawn sketched can be viewed as divergent thinking: there is aimed for quantity over quality in this step. A total of 13 drawings have been made.

After divergent thinking comes thinking in a convergent way, meaning the selection of the best idea and letting go of the other generated solutions. This entails making decisions on which of the generated sketches will be dropped and why. The convergent thinking has resulted in a few digitized versions of some of the sketches, which are discussed below.

The following section consists of an explanation of the ideas and design of the hand drawn sketches, which are included in the figures.

4.2.1 Hand Drawn Sketches

Sketch 1

This sketch consists of two elements: the upper part shows a timeline of the relative proportion of a phenomenon as a percentage of the whole group of phenomena. In this example that is the proportion of electric cars as part of all cars. The lower part shows a correlating factor on the same timeline. This combination of graphs is able to show the progression of both phenomena through time. While it may not be inherently true that there is a correlation between the two, this graph is intended for cases where there is a correlation. So a statistical test is required beforehand. When this is the case, this graph is able to portray the relationship between the factors clearly. However due to this known correlation, this is not an appropriate visualization for exploratory data analysis. Finally, it was chosen to not overplot the graphs on top of each other for two reasons: 1) less cluttering and 2) they might have different scales.

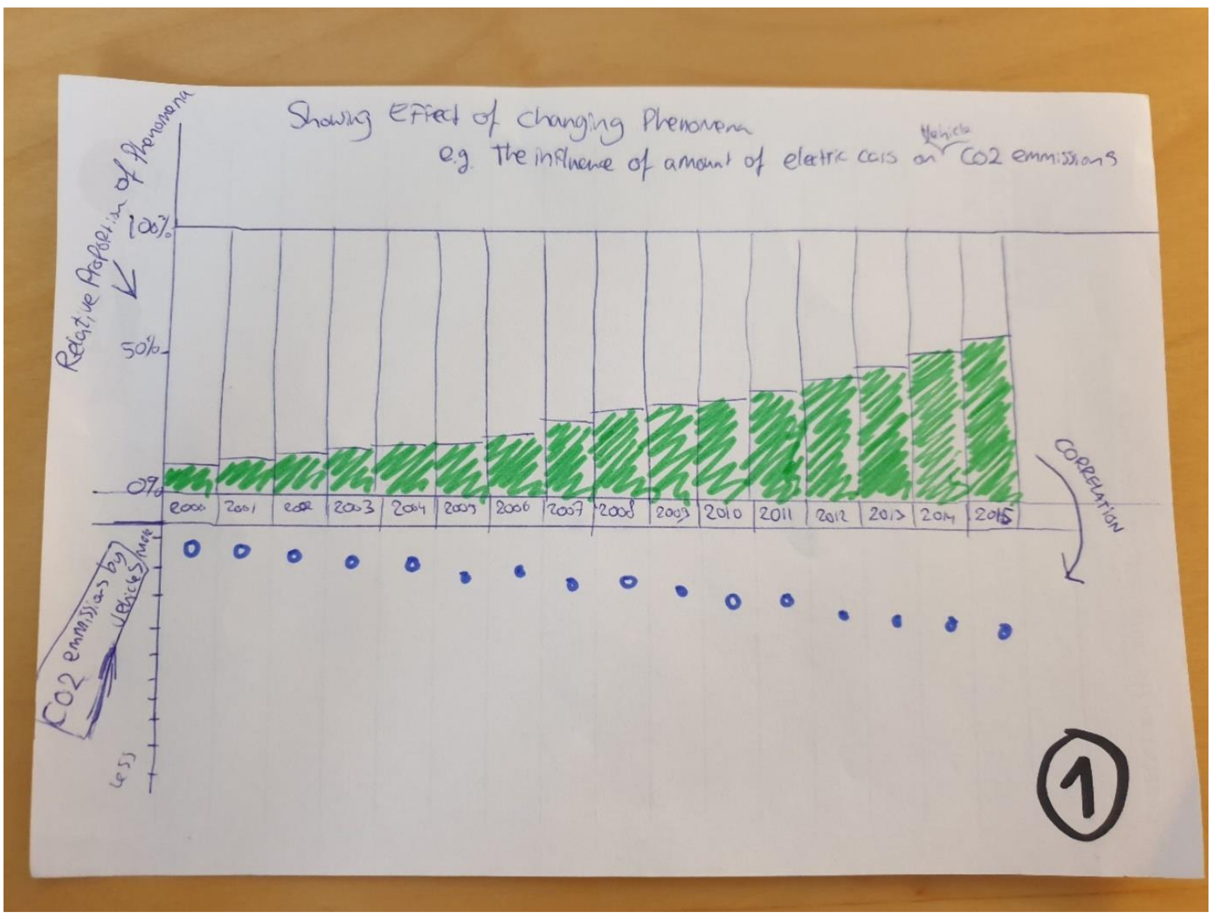


Figure 4.1 – Sketch 1

Sketch 2

Sketch 2 also shows two different factors that may have a correlation: Human Development Index (HDI) of a set of countries, and the ecological footprint per capita of those countries, combined with a third factor: the amount of citizens in those countries. This time, cases are plotted as circles with varying sizes, scaled to the amount of inhabitants. They are plotted across a two dimensional grid with the x axis representing HDI and the y axis ecological footprint. Then there is the last element of the slider (all the way on top) which offers the possibility to move through time, enabling the graph to show the change in all three factors. The idea of using sliders or dials was already mentioned in the '90s, for example by Kraak et al. (1997), as also discussed in section 2.7. A comparison with the ideas proposed by Kraak et al. is the clear distinction in the time slider between past (before the sign-vehicle), present (the location of the sign-vehicle) and the future (after the sign-vehicle). A difference can be found in the fact that the slider is not directly placed on the graph as suggested by Kraak et al., but rather next to (above) it. While Kraak et al. suggest that the slider should be placed "visually or sonically within the map", there is diverted from that idea with the notion in mind that users nowadays are far more used to digital and interactive displays than during the time of publication of said article (1997), and thus probably not as 'distracted' by two "competing views" as suggested.

This interactive element is the part that portrays the change within the data. However, the rate of change is hard to read in this type of graph. As one can imagine, it is difficult to compare a frame (a chosen year on the slider) with a next frame (next year on the slider), and even more so for all countries at once.

Sketch 3

The third graph is once again based on a timeline on the x axis. The y axis represents the worldwide amount of forests. Through time it can be seen that the size of that area decreases. The colors represent the continent that is responsible for the largest decrease. With this graph it was attempted to fit a story that contains much information in a single graph. If the colors representing the largest contributing continent were left out of this graph, that information could only be gained if there was a graph showing forest decreases for each continent. Implications for the development of this graph are that the data for all the continents is required in the background. With that data, graphs for each continent could be created as well. This graph would then be a summarizing synthesis.

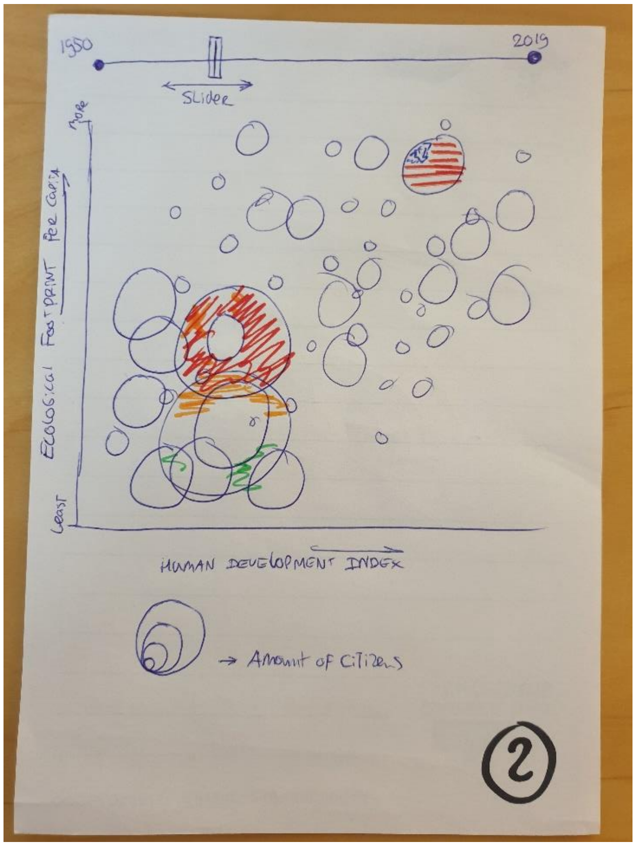


Figure 4.2 – Sketch 2

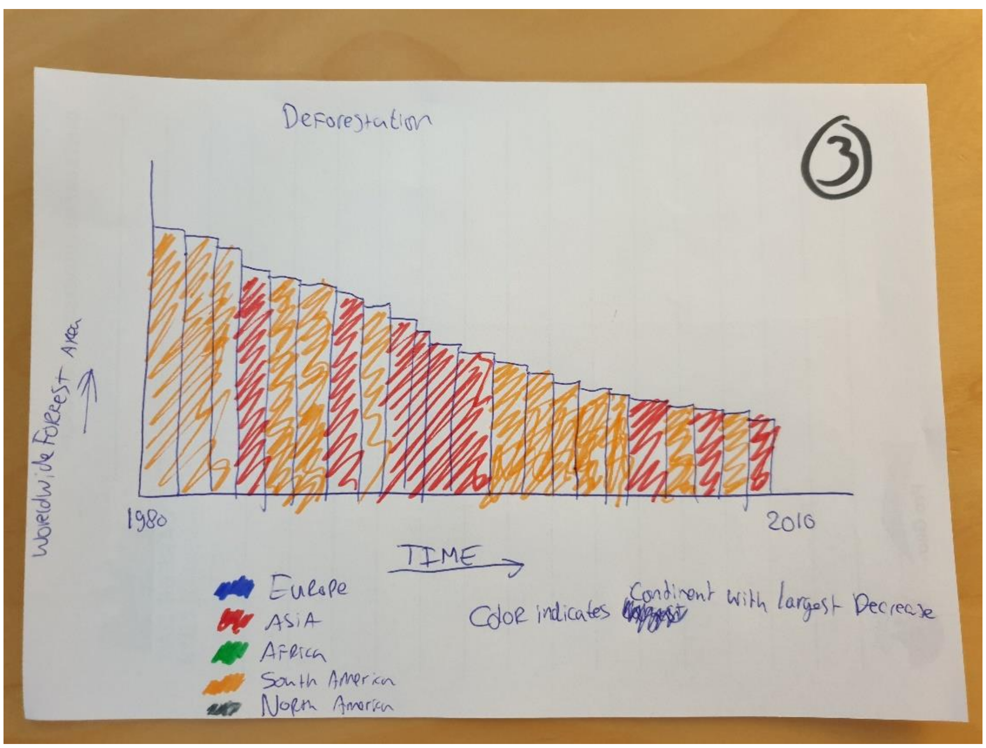


Figure 4.3 – Sketch 3

Sketch 4

Sketch 4 is also a combination of different graph types based on a timeline, represented by the x axis. The circles represent the size of the largest city of each continent (indicated by color), progressing through time. The line graph plotted on top of that shows the size of the total human population on earth. Combining these graphs gives the option to see how these factors change through time and progress together. Although there is a legend for the sizes of the largest cities, it can be hard to read exact sizes. However, this graph is intended to give a rough overview of the progression of these data.

The idea of combining circles of varying sizes with a line graph was taken for further development was a prototype, which will be discussed later.

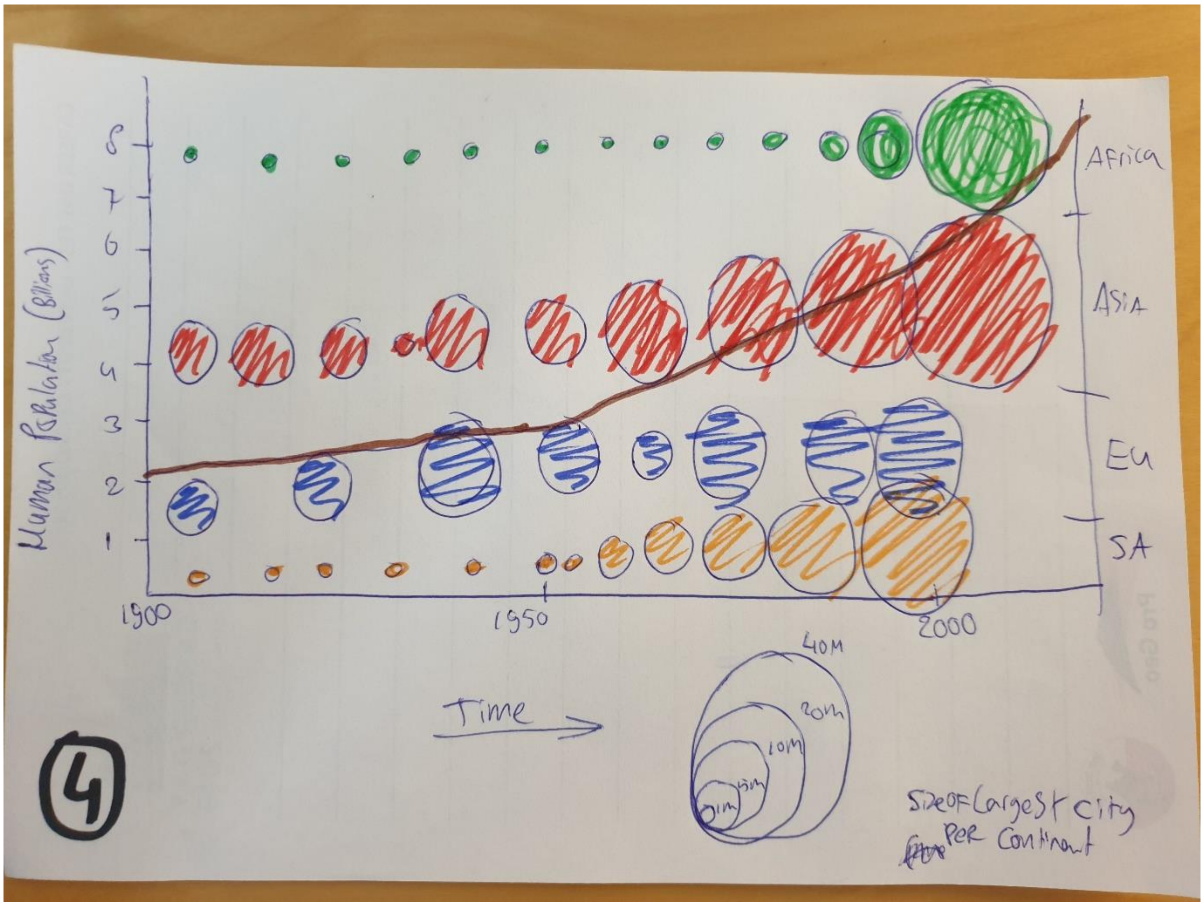


Figure 4.4 – Sketch 4

Sketch 5

This graph also shows the relationship of two factors. In this case sea level change on the y axis, and ocean heat change represented by color. This graph is once again based on a timeline on the x axis. This graph attempted to use color to represent change for once factor and the y axis to represent change for the other factor. However, this example may not be very useful as it does not show a decrease in either of the factors. This is thanks to the sea level that only rises. If this graph was demonstrated with more varying factors, the positive (or negative) correlation could have been more visible.

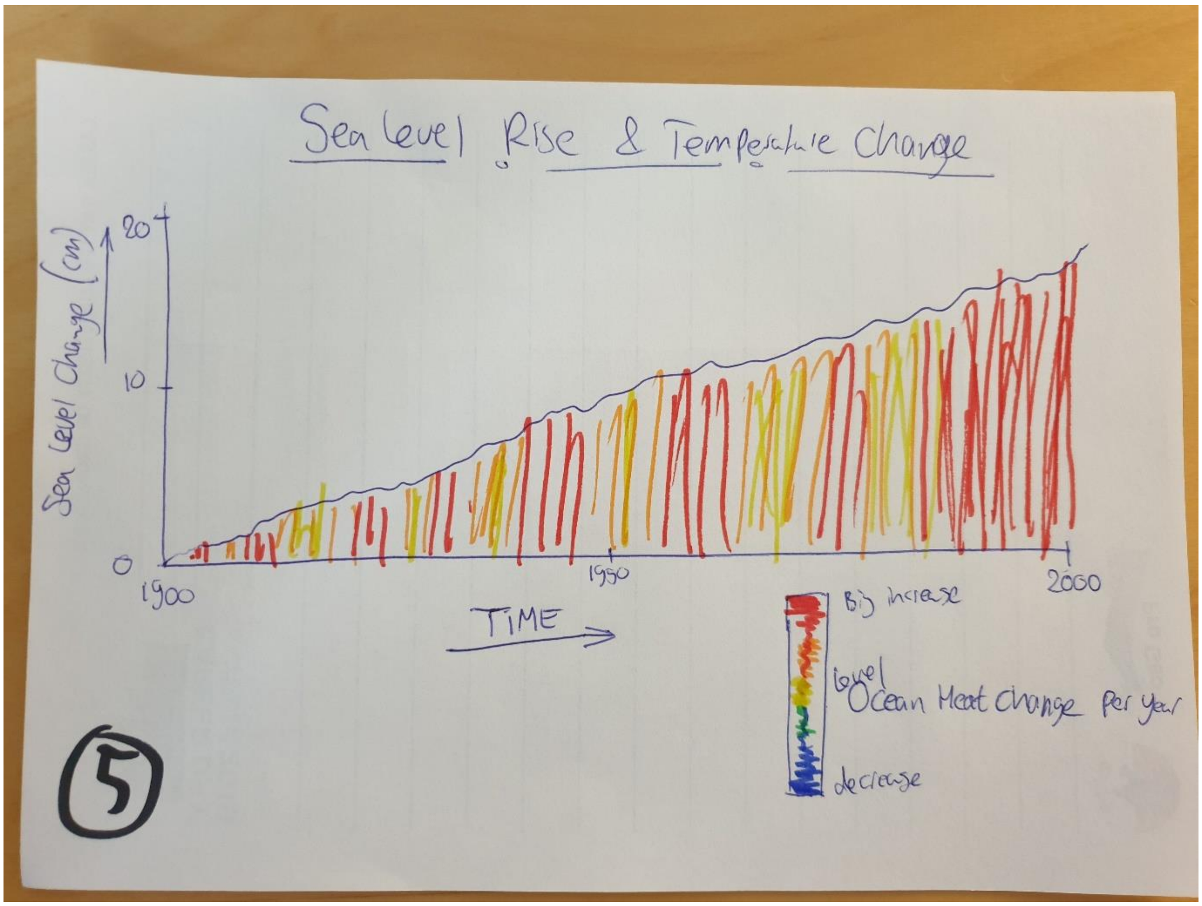


Figure 4.5 – Sketch 5

Sketch 6

Sketch 6 was developed with the idea of breaking through the habit of a linear horizontal timeline. A seasonal time-wheel was chosen instead, which is able to effectively portray cyclical data. The exemplar data in this case is a migration rate of a hypothetical country. When shown in a time-wheel, the cyclical effect really comes forward. The circle in the middle was added to show the outcome for the country: whether there are more immigrants than emigrants for the selected years or the other way around. As can be seen on the bottom part of the sketch, this makes comparing countries in once glance easy.

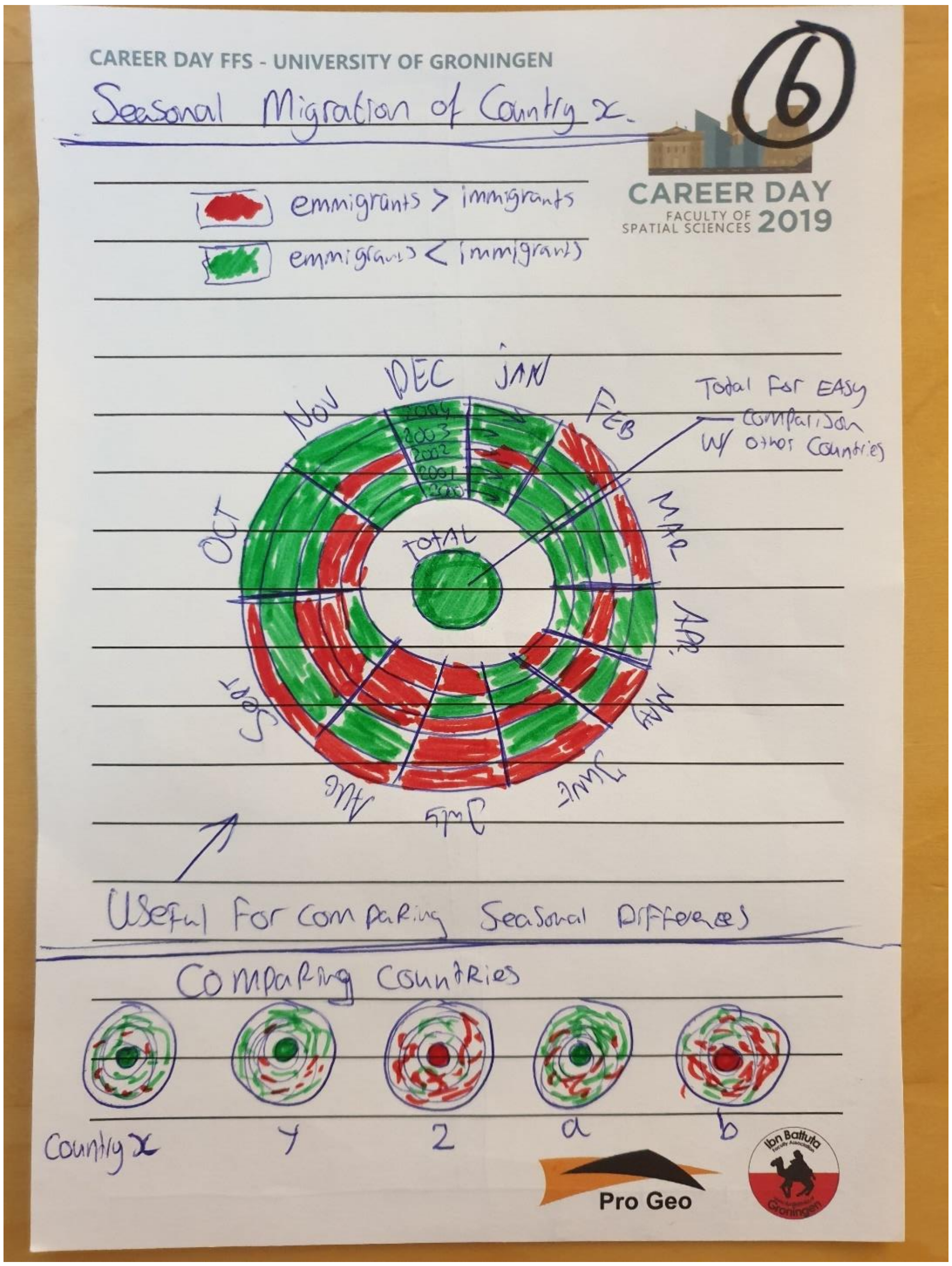


Figure 4.6 – Sketch 6

Sketch 7

Sketch 7 consists of four versions that were developed as a series, each time taking the original idea a bit further with new elements.

The base idea (sketch 7.1) is to show a timeline of proportional data, when two options form together a whole. The example uses election results in the US, where there are two options: Democrats and Republicans. The x axis is again a timeline. The election results are shows by the pie charts: the largest piece of the pie wins the elections. An extra added factor is the amount of voters that voted during the election, which is represented for each election by the size of the pie. This graph easily shows election results progression through the years, offering a summary of voting history in the US.

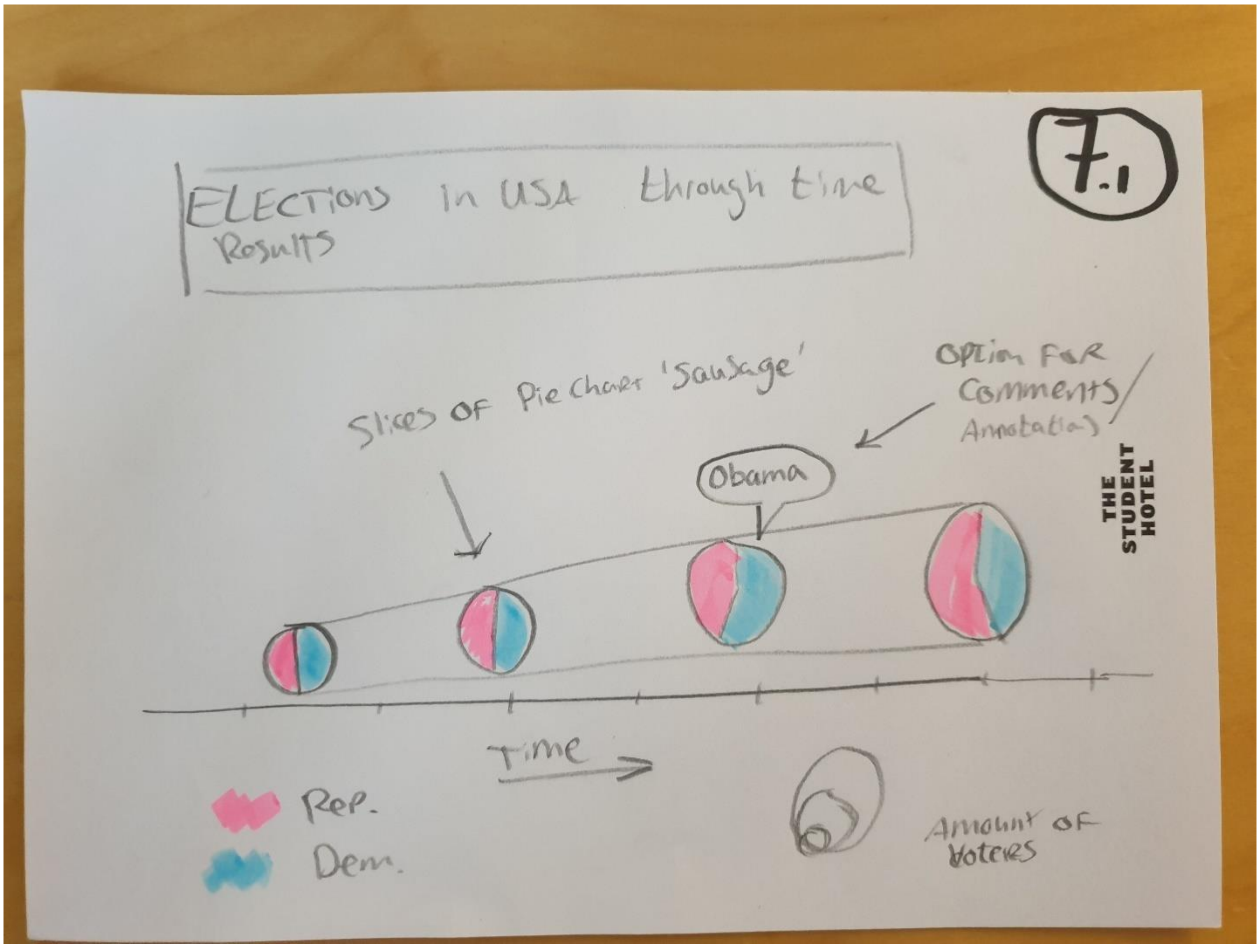


Figure 4.7 – Sketch 7.1

Sketch 7.2 takes this idea and adds an extra factor to it, by adding the y axis. This can be any factor that may have a correlation with the voting behavior of the people. For example: the y axis may represent the amount of controversial acts by one of the parties, which may show its effect in the voting results.

Sketch 7.3 shows the same as 7.2 but illustrates that this extra correlating factor may also result in varying voting results. This was named the spaghetti chart.

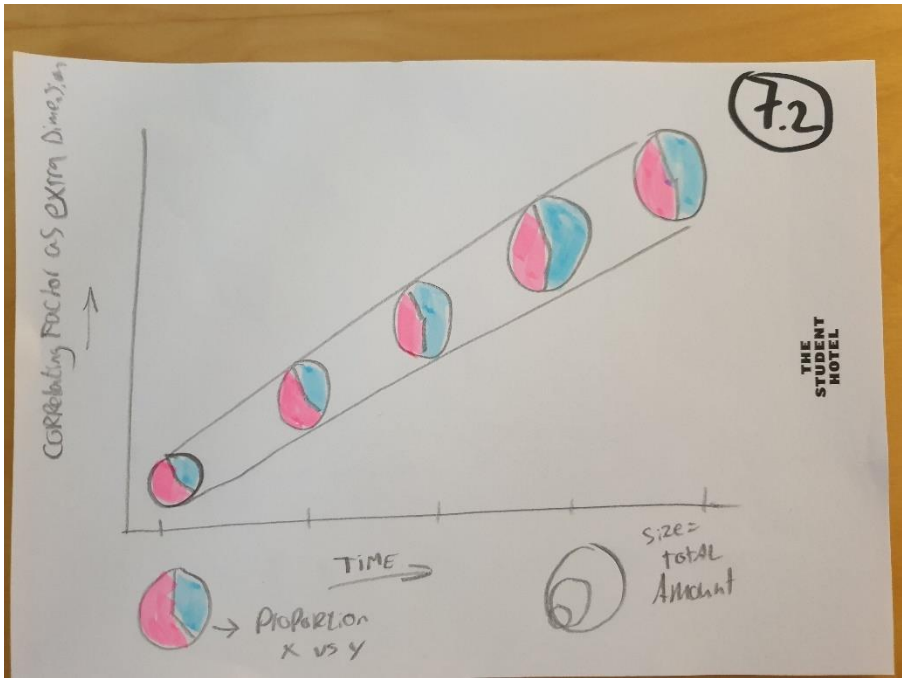


Figure 4.8 – Sketch 7.2

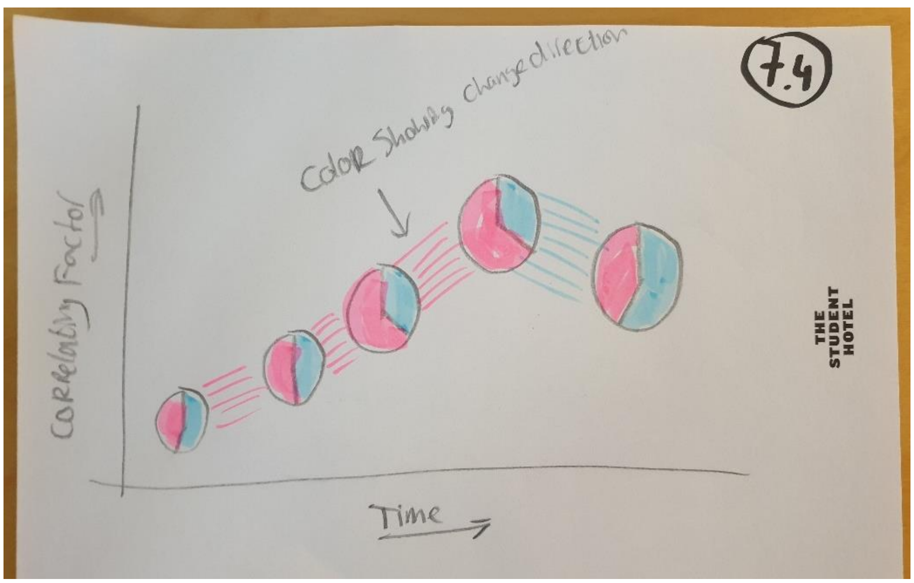


Figure 4.9 – Sketch 7.3

Sketch 7.4 adds one more thing to the graph: the direction of change within the voting results. This is portrayed by the colored swoosh effect between the election pie charts. In the case that, for example, the Republicans have gained the most votes compared to last elections, this swoosh will be colored pink.

While these ideas played around with showing change and direction of change, they are not suited for showing the rates of change. However, one can think of possibilities for including those rates, for example: varying sizes of the swoosh relative to the amount of change, or adding a number somewhere in the graph that represents the amount or percentage of change.

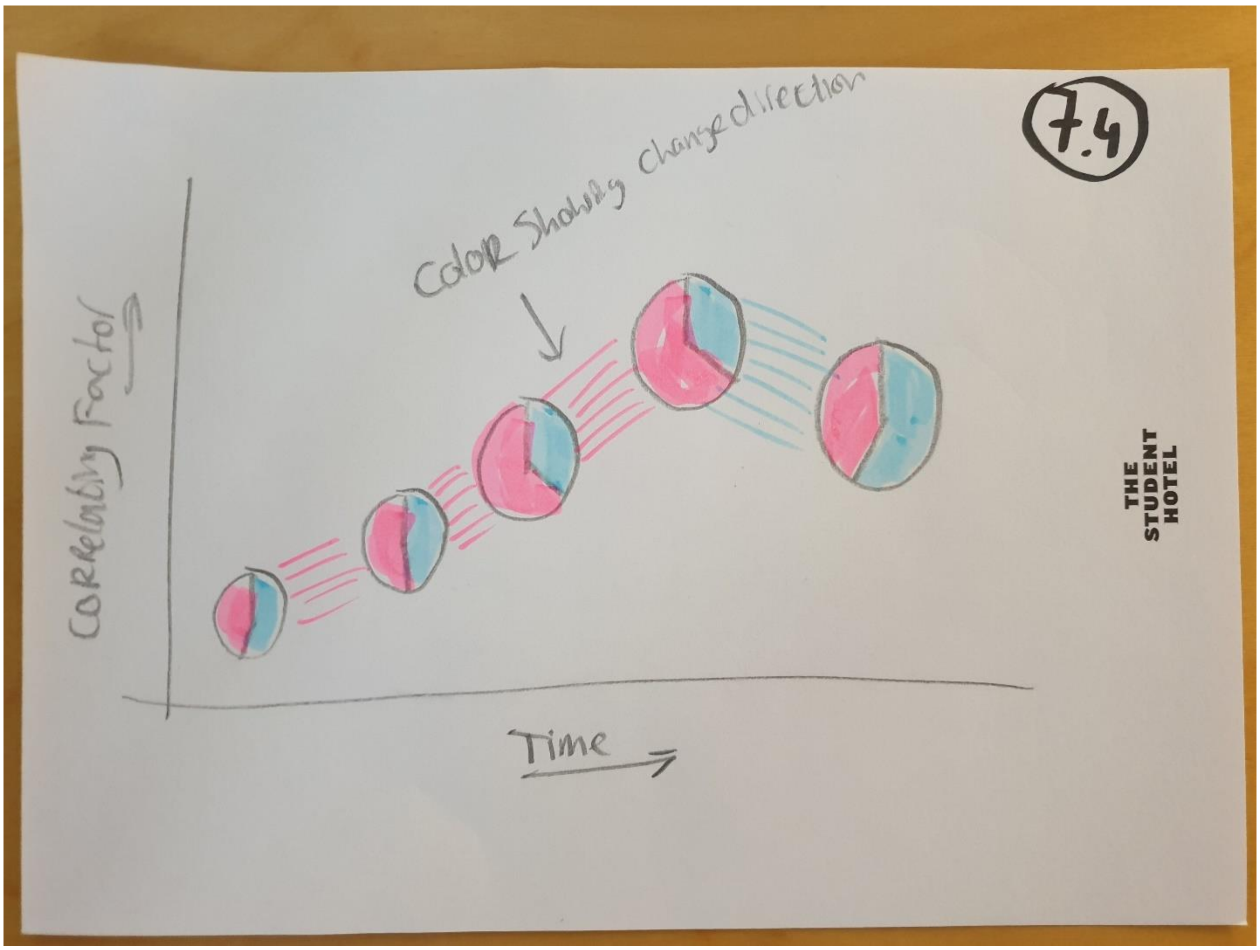


Figure 4.10 – Sketch 7.4

Sketch 8

Sketch 8 is very similar to the sketches explained at 7. However, this time it portrays continual data instead of discrete data (the elections). The absolute size of the phenomena is now represented by the width of the colored area at a point in time. The relative proportions of the parts are show within that absolute width. Another addition are the arrowheads, which show the direction of change of the extra added factor. On top of the graph represents a positive change and below represents a negative change.

A limitation lies in the fact that this looks a bit bulky. In case of data that has quick alterations of positive and negative change, the graph would probably be cluttered. Besides, the graph can look intimidating and confusing in general.

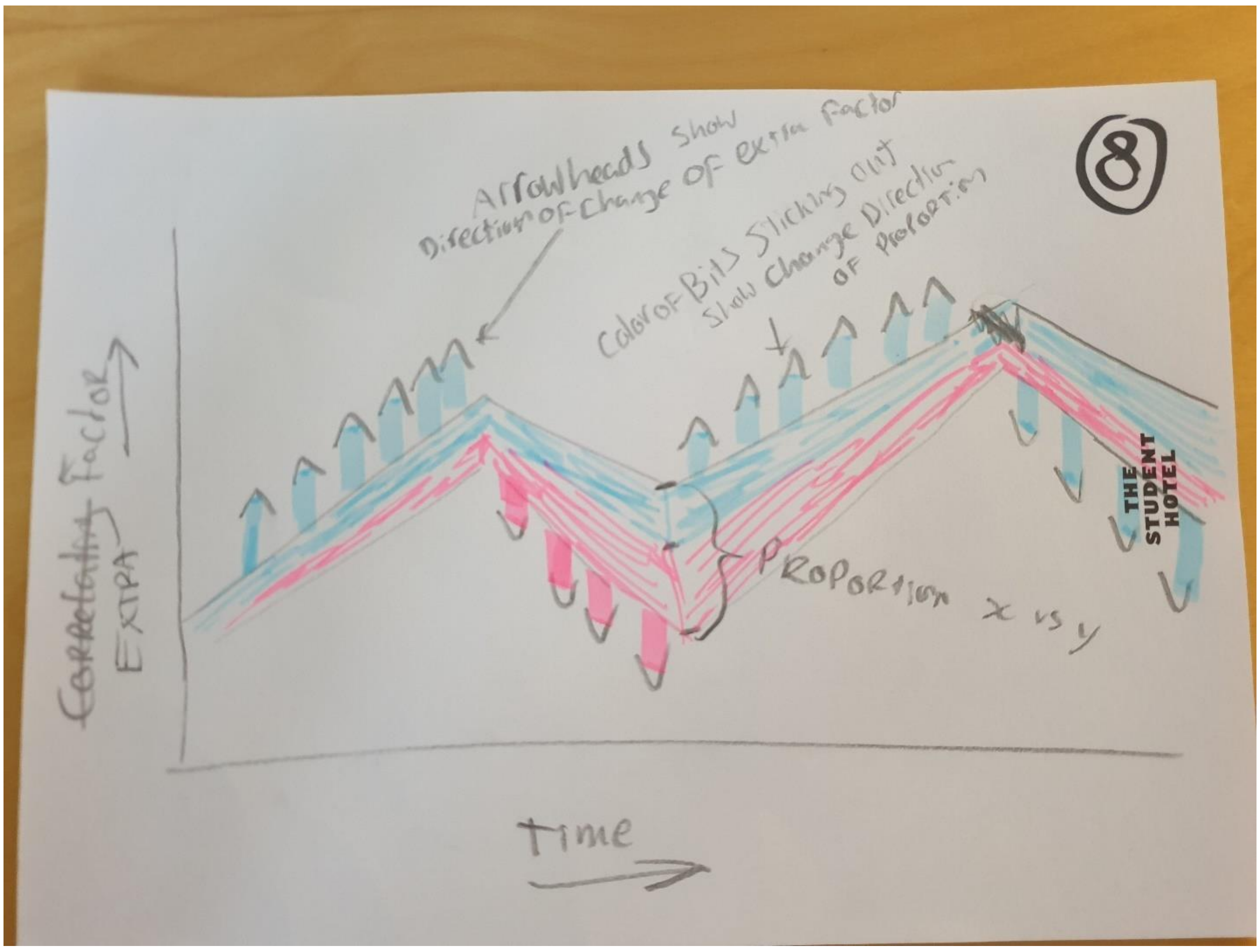


Figure 4.11 – Sketch 8

Sketch 9

This sketch is also based on a timeline, yet a less outspoken one. The x axis is hidden but still represents time, meaning that each bar to the right represents a step forward in time. The bars once again represent two parts that make up a whole. The relative proportions are represented by the colors within the bars. The circles above the bars show the change in proportional size relative to a timeframe earlier. So if a circle at time = T shows blue, blue has gained in size since T-1. This change can both be absolute or relative, but should be made clear so the user is aware of what they are looking at.

The idea in this sketch (and sketch 10) was a simplified overall picture with two goals: less elements to prevent cluttering, and aesthetics. The idea of less elements was drawn from the debate on chartjunk, as discussed in section 2.8. As Hullman (2011) explained, it is commonly regarded in the field of InfoVis that less elements can lead to a faster understanding of the provided information. This stems from the idea that the perceptual system of humans can take over cognitive processes in processing patterns. In the case of sketch 9 and 10, the idea was to use this natural pattern recognition ability. The idea is that it feels intuitive that a timeline ranges from left to right, making the addition of an x-axis unnecessary.

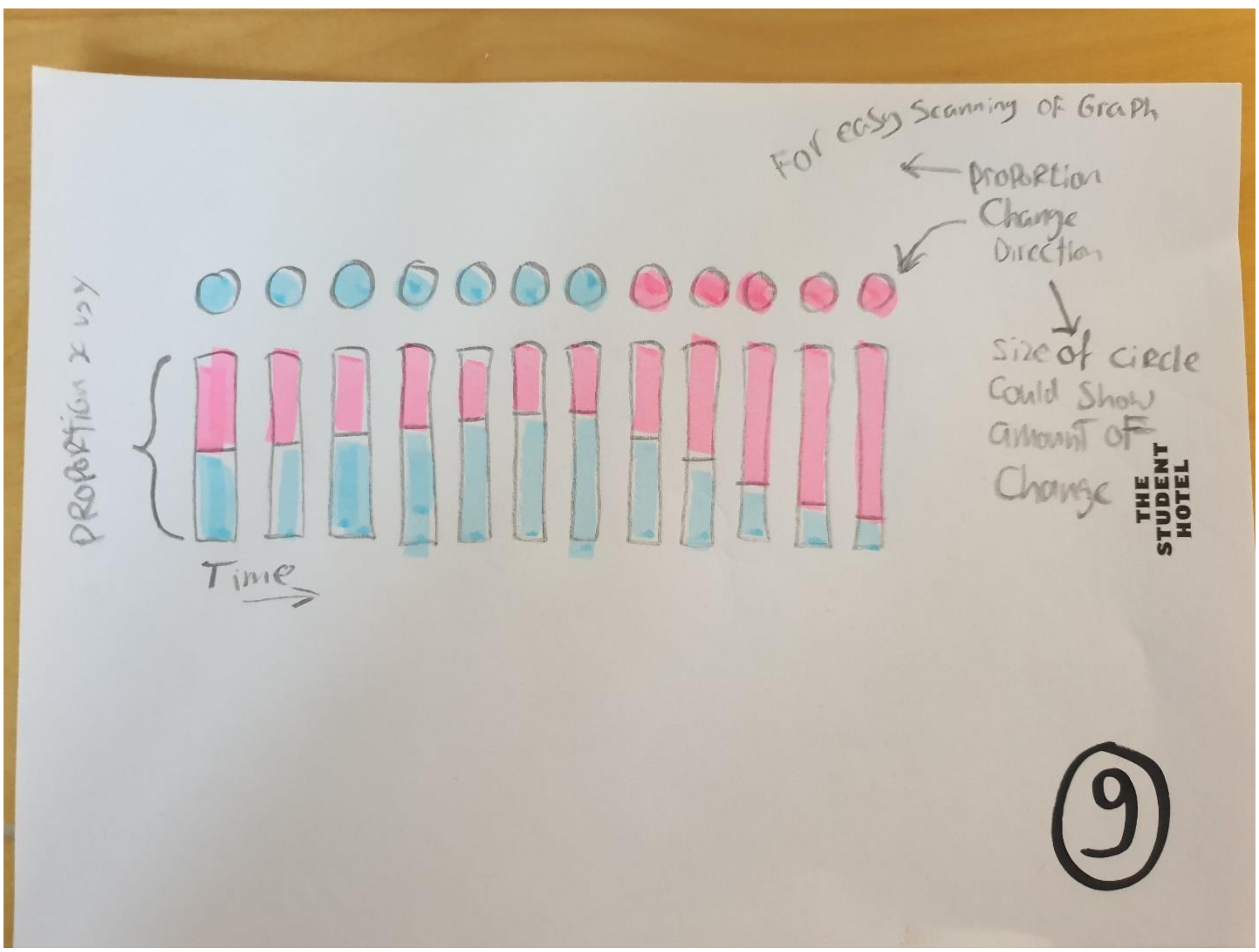


Figure 4.12 – Sketch 9

Sketch 10

Sketch 10 build upon sketch 9 in the sense that it is an even simpler version. However this time the proportions of the parts are not shown, but the focus is rather on the change that happens between the time steps, The colors of the circles show the direction of the proportional change between time steps. The size of the circles represent the amount of that change. Another addition in the case of a digital interactive version is the ability to hover over the circles with the cursor, to be able to see the exact numbers. As stated at sketch 9, this idea also stemmed from making a very simplified concept for reasons mentioned above.

Figure 4.13 – Sketch 10

While coming up with ideas for the sketches the overarching plan was to combine timelines with other types of graphs. This can be seen in all sketches, although some have diverged a little from that idea.

Most sketches have a clear timeline as the x-axis. Sketch 1, 3, 4, 5, all versions of 7, and 8 show this the most pure form: the x-axis represents time progressing towards the right. Sketch 2 diverges from this idea by having introduced interactivity into it, in the form of a time slider. Sketch 9 and 10 also show somewhat of a timeline but in a less outspoken form. In these concepts, the elements next to each other represent the chosen phenomenon at a different point in time, also progressing to the right.

The combined graph types vary from simply plotting two graph types on top or next to each other, to really trying to integrate different elements of graphs with each other. Examples of mere combinations are seen in graphs 1, 4 and 5. Real integrations of graphs can be seen in 2, 7 and 8.

4.2.2 Digitized Sketches

A few ideas of the hand drawn sketches were picked and digitized to get an idea of how these graphs might look when fully developed. It should be noted that this only gives a feel for the looks of the graphs. It does say very little about the use and implications of certain design elements for a hands on with the graphs.

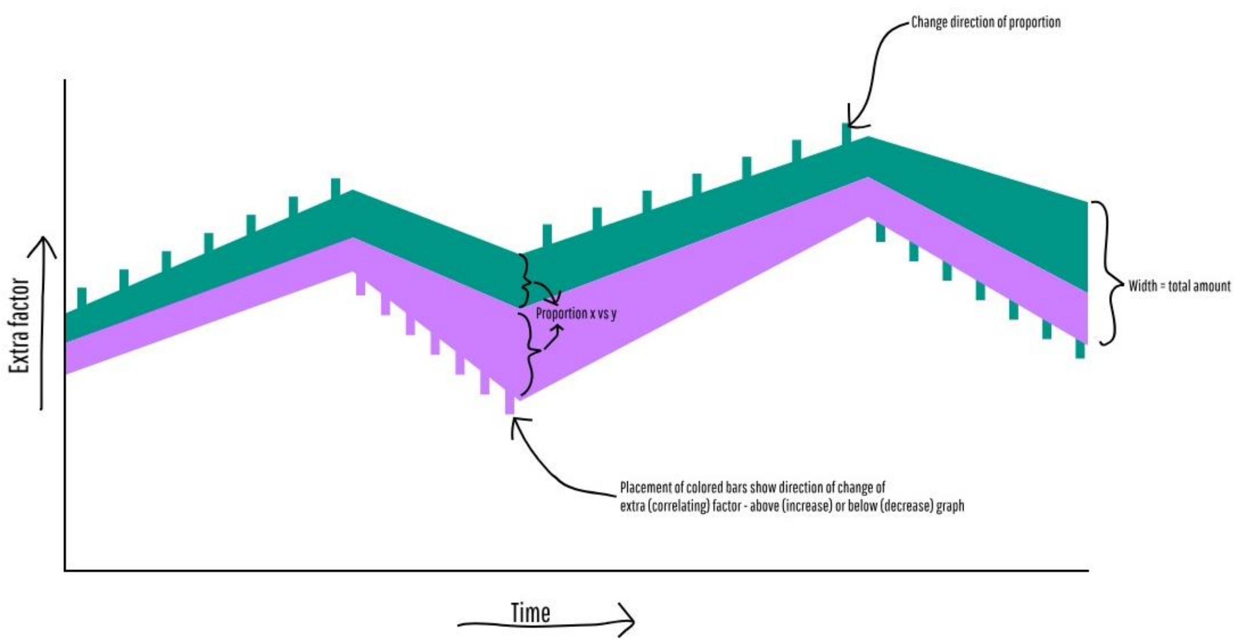


Figure 4.14 – Digitized version of sketch 8

Sketch 8 was the first graph that was digitized (see Figure 4.14). While it came out a little more clear than the hand drawn sketched version, it still turned out to be a little confusing. Without any explanation or legend, a user will likely have no idea what they are looking at. It lacks intuitiveness. However, as the initial idea of showing proportional changes together with absolute change and direction of change was something that felt inventive, an evolution of this graph was developed. This evolution in the form of a so called steam graph can be seen in Figure 4.15. This time, the confusing elements were dropped, like the little bars on top of the colored area showing the direction of change. Besides, the extra correlating factor was removed as well. This time, the y axis represents the absolute size of the whole phenomenon. The change in width of the colored area portrays progression through time of the absolute size of the whole group of parts. The relative size of parts are shown within that width, also enabling the user to see the change of the relative proportions of each part trough time. To make this more clear, an interactive function has been added to this design: while horizontally hovering with the cursor, a pop up shows a pie chart of the relative proportions of the parts, which changes through time. This pop up can also be a bar chart, see Figure 4.16. The only difference is that a bar chart would represent the different parts as absolute rates and the pie chart would show the parts as relative rates, with the whole pie being 100%, no matter the absolute size of the whole.

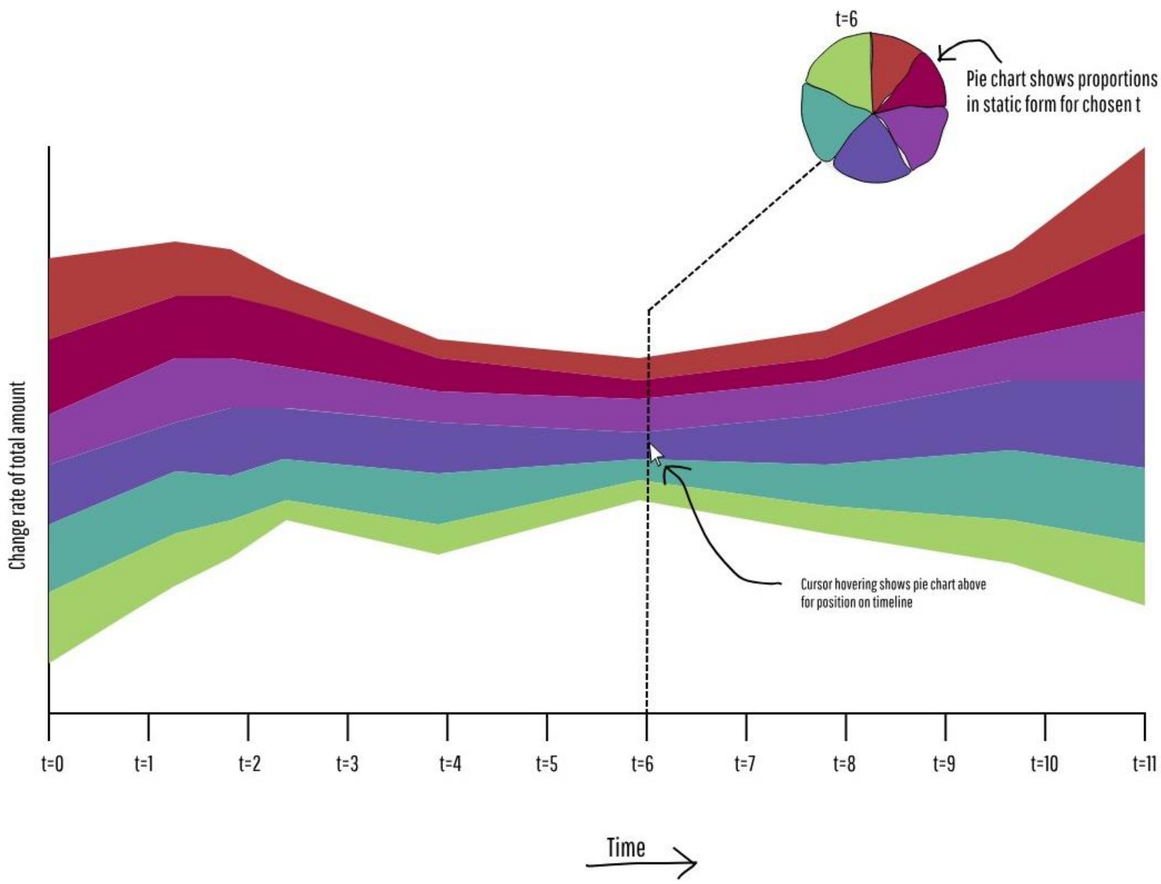


Figure 4.15 – Evolution of sketch 8

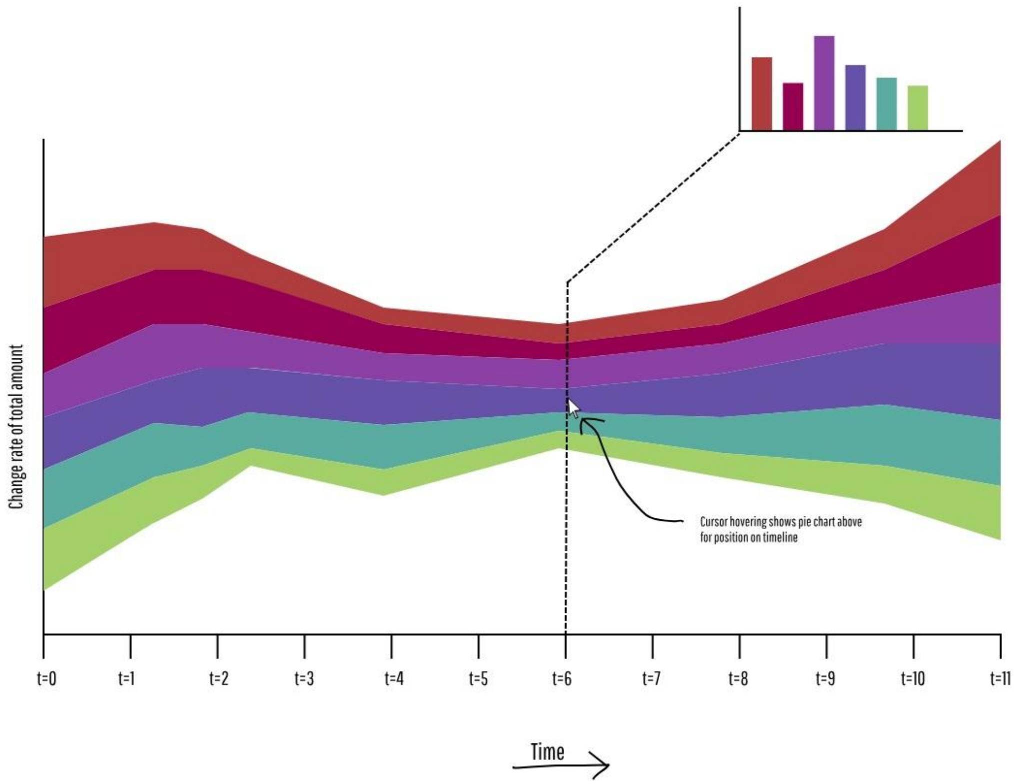


Figure 4.16 – Alternative version of evolution of sketch 8

An implication of the design of both these figures is that the time slider is somewhat integrated into the graph. By hovering left and right, the user can slide trough time for the proportional view. This is in accordance with the earlier mentioned suggestion by Kraak et al. (1997) of avoiding two competing views. However, one can argue that the pop ups could be competing with the stream graph, even though they technically show the same information.

Another implication is that stream graphs rely on clearly differentiated colors. As discussed in section 2.6 on the works of Bertin (1983), the visual variable of color can be associative and selective. In this case, the colors are mainly associative, meaning that color is used to distinguish cases for each other. However, this type of graph does offer the possibility of also using color in a selective way. This would mean that multiple parts (colors) would belong to a same group (like municipalities can belong to the same province). This can be portrayed by representing these parts in groups of colors. In the example of municipalities, that could mean that municipalities belonging to the same province could all be represented by a different shade of a certain color.

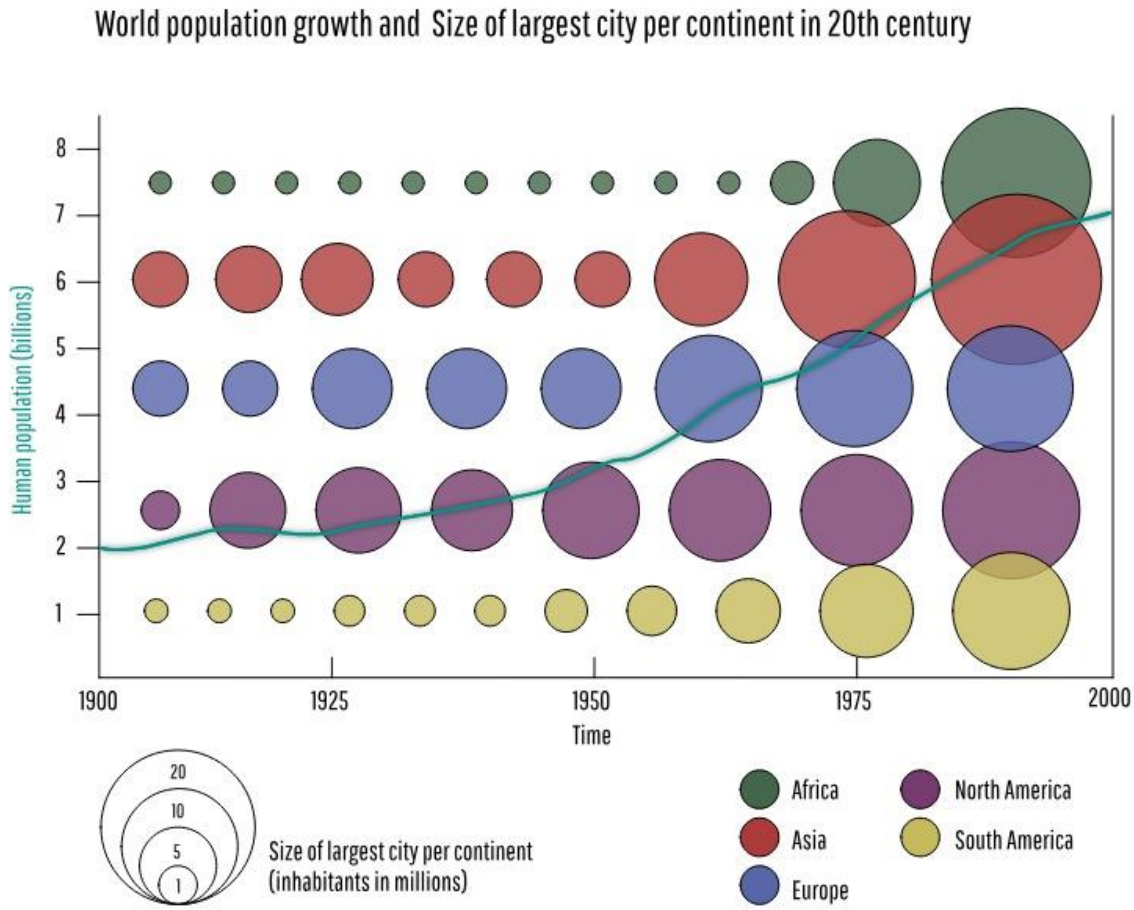


Figure 4.17 – Digitized version of sketch 4

Sketch 4 is the other sketch that has been digitized (see Figure 4.17). This version mainly shows that digitally generated visual variables like transparency or opacity offer great possibilities when space is limited. It also sparked the idea of making an interactive version of this graph that could potentially offer many benefits compared to a static graph. This graph also led to the imagination of incorporating change rates differently within a graph combination. The next section elaborates on how that was done.

4.3 Stage 4: Prototype

As described in section 3.2.4, the prototyping phase consists of the following:

- Define features and functions into wishlist
- Translate different features into code, create product parts in isolation
- Combine loose parts into a whole prototype

4.3.1 Wishlist

The first point can be regarded as a transition between the ideation phase and the prototype phase. While coming up with features that the product should have is indeed a process of ideating, it can also be regarded as a first conceptual prototype. The result of this process is a wishlist, containing elements and features that the end product should have and be able to do. The wishlist is included in the following section:

Features and definitions wishlist

Types of patterns

The goal of the visualization is for users to effectively reveal patterns in the data. This can be patterns of change (above a certain amount). These patterns are portrayed by a high values in their change rates, positive – meaning a large increase – or negative – meaning a large decrease. These high change rates can be the cause for policy or decision making in the sense that the studied phenomenon shows uncertainty: it changes a lot. Unless a pattern can be revealed that is repeated, like a cyclical pattern through the years.

Another 'pattern' that can be revealed, is a pattern of stability. If a certain phenomenon does only change a little, or not at all, this region shows stability. This is portrayed by low values in the change rate. This pattern of stability can also be useful in policy or decision making, in the sense that it can be substantiated that less attention (or resources/money/time/etc.) is needed for this region compared to other regions.

The graphs should be able to communicate if either of these patterns occur in the data.

Wishlist timeline graphs

One main graph, timeline style, combined with a second graph that adds effectiveness in accomplishing the user goal (user goal: recognizing patterns in the data). A second graph is included to add another perspective on the data. This can be useful in situations where the main graph is not clear enough, or the user wants another perspective to be certain. For example, next to the change rates in the main graph. showing the absolute data rates can offer different insights that can valuable.

Main graph

- Primarily meant for comparing regions to each other
- Can be used for studying the evolution of a single region but this is not the main goal
- In case the regions belong a communal larger region (like regions in a country): stream graph or stacked area graph (the accumulation of the regions can be of relevance)
  In case the regions are independent: line graph style, since the accumulated amounts (and thus stacking the graphs) do not mean anything
- Main graph shows the overview of the regions

- Main graph shows the rates of change of the chosen data

Second graph

- A second graph shows the proportions of the regions compared to each other as percentages (pie chart) or as absolute numbers (change rate) (bar chart) for a certain moment in time.
- Shows up next to or above the main graph. The graphs are linked, meaning that selecting an element on the main graph should also select the corresponding element on the second graph. This linking is based on the x axis, which is the timeline.

Interactive functions:

The interactive functions help the user in achieving their goal. It is not the interactivity itself that works, but certain functions that are interactive that are helpful.

- Option to only plot graph for certain conditions, like change rate above or below a certain amount.
  Above: this will only result in the regions that show much change – useful for finding regions that show patterns of change, or regions that show extremes.
  Below: shows regions with little or no change: stable regions.
- Linking with second graph. Selecting an element, like a certain point in time in the main graph, should also show that element in the second graph. This adds clarity and ease of use to the product as a whole.
- Zoom function to get a closer look at situations with small differences.
- Hovering with the mouse over the timeline in one graph highlights the corresponding moment in time in the other graph
- Option to choose the input for main and second graph: change rate and absolute rate, or other way around.

4.3.2 Prototypes

Based on the features wishlist and the sketching, the first prototypes were developed. Each prototype was built further upon the previous one, slowly developing in the final prototype that was tested. Below follows the progress of how the final prototype came together.

As described in section 3.4.1, the exemplar dataset that was chosen consists of data regarding fatalities caused by the corona virus, also knows as Covid-19. The product prototype visualizes this corona dataset and shows the absolute rates and change rates through time, starting from January 1st 2020.

Prototype 1

As can be seen in Figure 4.18, prototype 1 shows the data for corona fatalities for 6 different countries. The idea of plotting a circle graph with a varying size is drawn from sketch 4. The circles are sized according to how many deaths there are on that date. As can be seen, the sizes of the circles can become so large that they completely overlap the plots for other countries. Another thing that was noted during the development of this prototype, was the lack of a legend, or any way to indicate what the different sizes mean. This was taken into account for the development of the next version.

One thing that was already included into this version, was the ability to zoom in and pan through the view. An example of this is provided in Figure 4.19. This gave users the ability to zoom in on certain areas to view in higher detail.

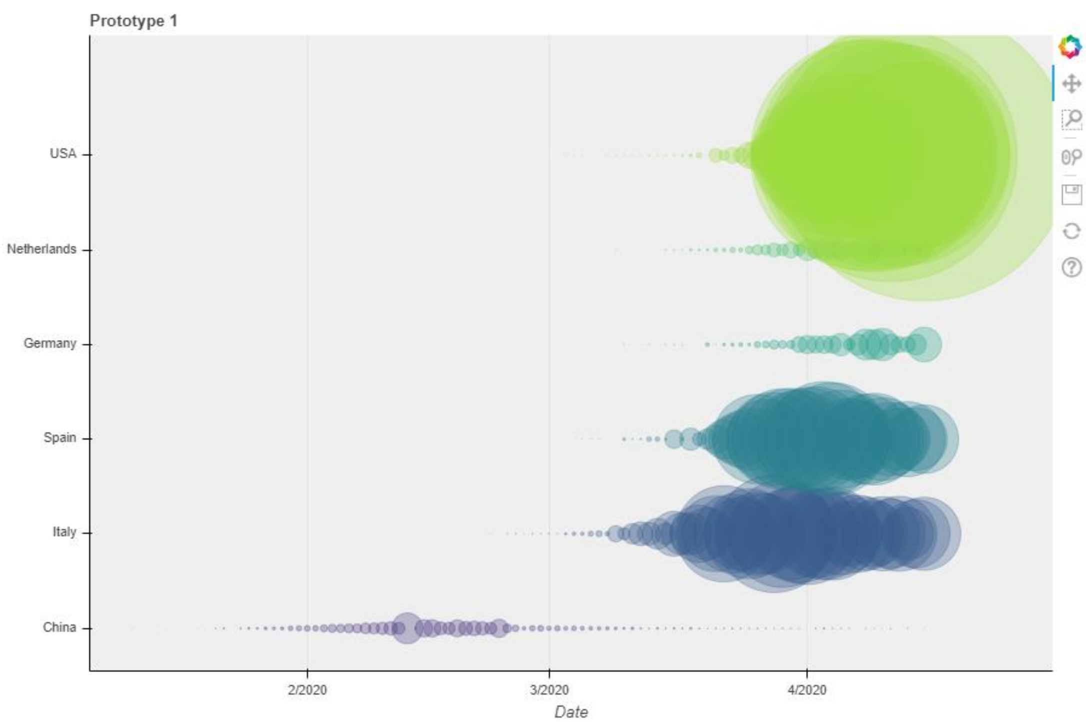


Figure 4.18 – Prototype 1

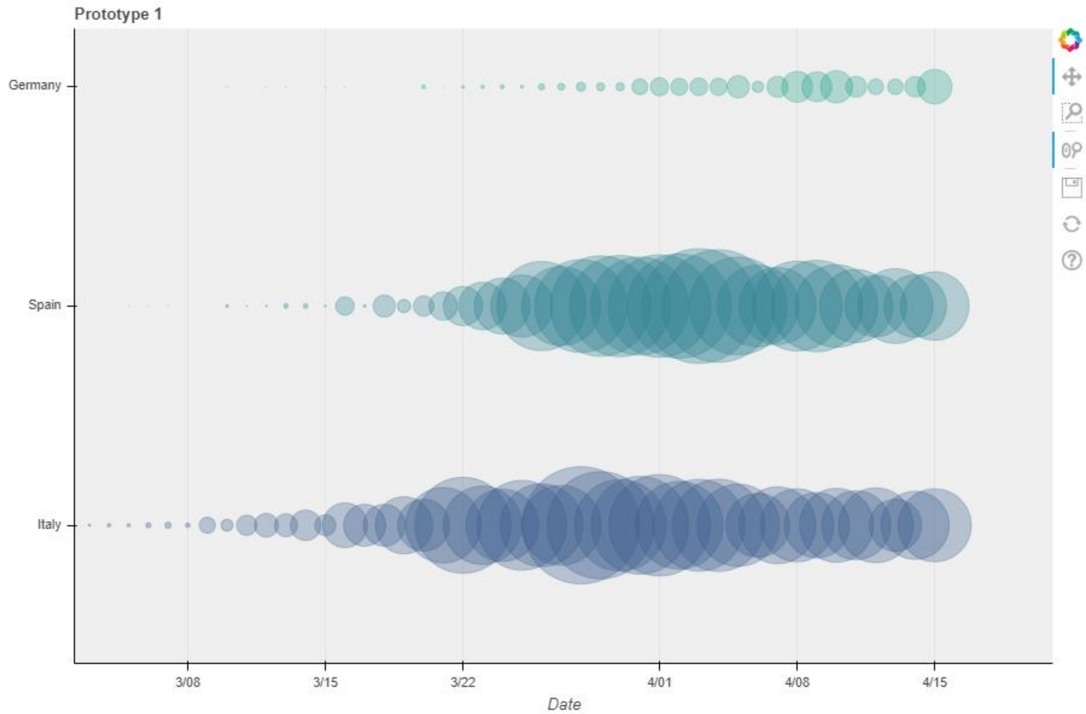


Figure 4.19 – Prototype 1 – zoom function

Prototype 2

The second prototype (see Figure 4.20) is built upon the first one and showed a major addition by adding a map viewer next to the graph section. This map shows the geographical location of the selected countries, and is able to show the change of the rates through time. In one version of this prototype the map showed the absolute rates – that is the amount of deaths on a certain date – and in another version the map showed the change rates for the selected date – that is the change in amount of deaths compared to the day before. The slider below the map lets the user select a certain day for the map to display.

Another feature that was included in this prototype is the addition of a hover tool. This hover gives the user the ability to hover over the circles and see a pop up with the rates. However, during this prototype it was not yet functional due to technical difficulties. However, the addition was promising because examples had been studies that showed a working pop up. Besides, as can be read in the wishlist in section 4.3.1, interactive features are some of the highly wanted additions to the visualization, as they can offer benefits that mere static graphs cannot.

By adding map, a slider and a hover tool, the goal of combining certain graph types was starting to be realized. However, this combination was still not based on the timeline. Although timelines are included in both the left and the right section, this prototype still missed an inventive part that would combine a timeline with other graph types. Also, the goal of revealing patterns by looking at change rates was far from reached in this version.

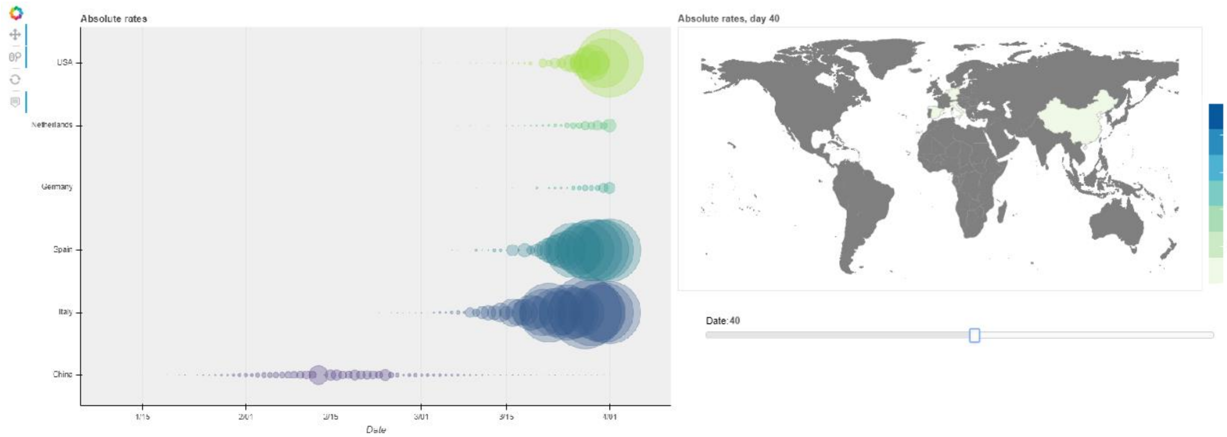


Figure 4.20 – Prototype 2

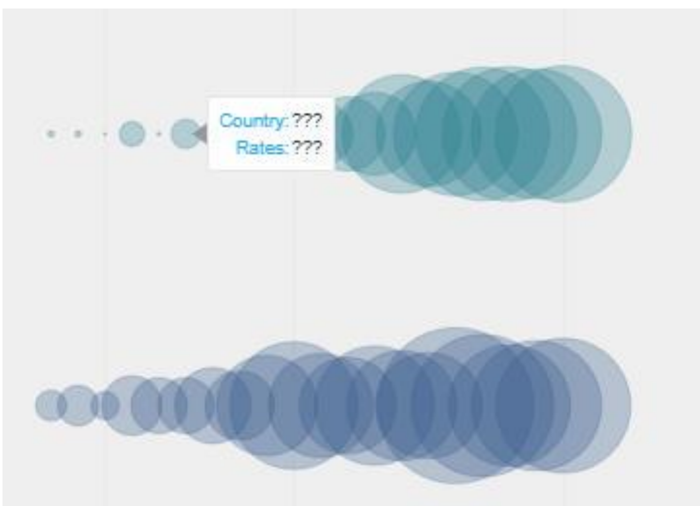


Figure 4.21 – Prototype 2 hover tool

Prototype 3

After the previous version, the idea emerged to separate the graphs of each country. The result of this can be seen in Figure 4.22. This version introduces multiple new features:

- Separate graphs for each country: each country has a circle graph and line graph. The circle graph represent the absolute rates, meaning the amount of deaths on that specific date. The line graph represents the change rate for each day, meaning the change in amount of deaths compared to the day before.

- The ranges of the graphs are linked. This means that zooming or panning in one graph will make the other graphs zoom and pan as well, keeping the x and y ranges of each graph the same.
- Better use of visual variables by choosing different colors for the countries. In the previous version, the colors were all in some shade or green or blue, which could suggest that they belonged in some sort of group (see section 2.6 on the selective perceptual property of color).
- The addition of a cumulative total graph. This graph shows the total amount of deaths, added up. While this does not contribute to the goal of revealing change rates, it does provide an overview of the total amount of deaths which could be a valuable piece of context for users.

One issue that was introduced came up while configuring the hover tool for the pop up. As can be seen in Figure 4.23, an extra plot in the graph means that two pop-ups show up when hovering over the graph. This seemingly minor issue causes the decision to be made on which of the two graphs – circle or line – necessarily needs the hover tool more than the other.

At this point in time, multiple points of the features wishlist have been accomplished in the design. The type prototyping moves on from general development to finetuning.

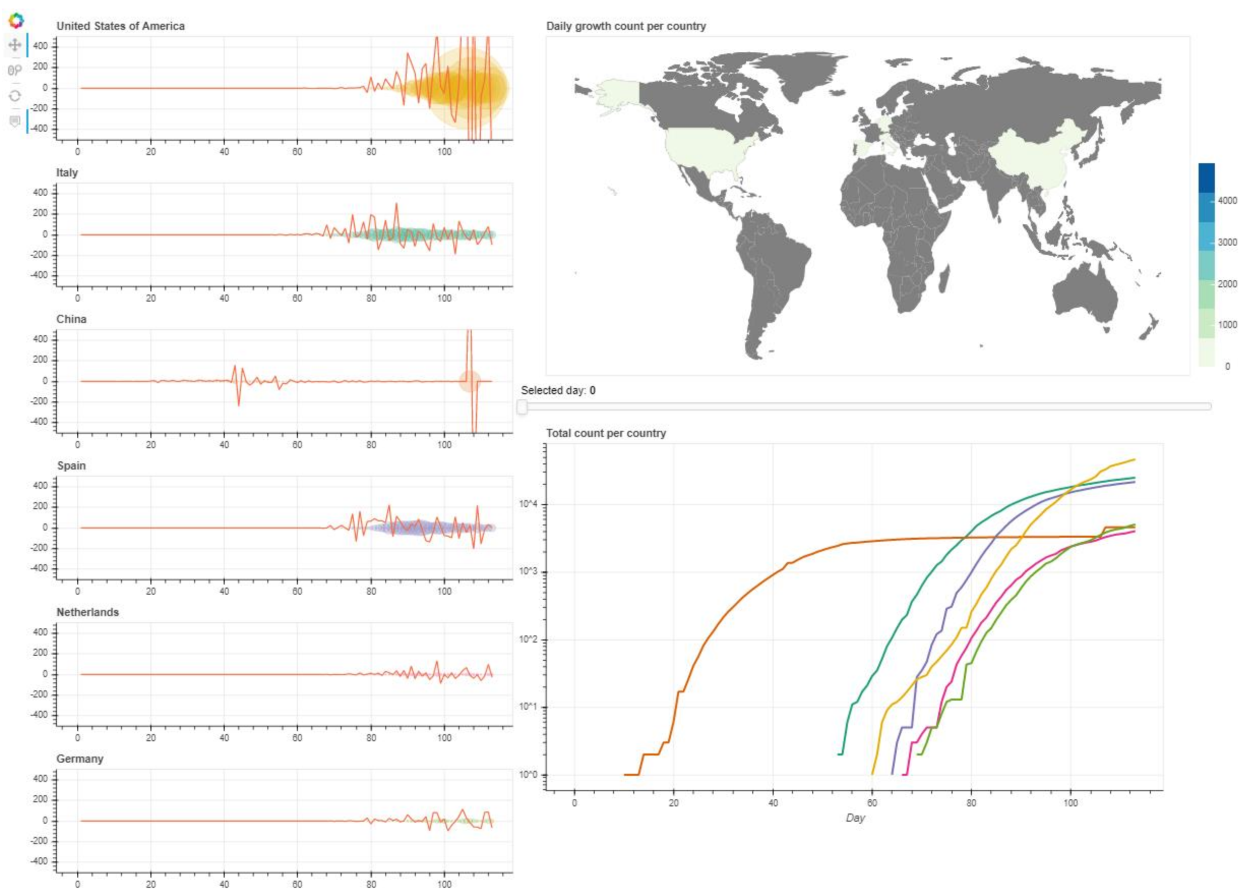


Figure 4.22 – Prototype 3

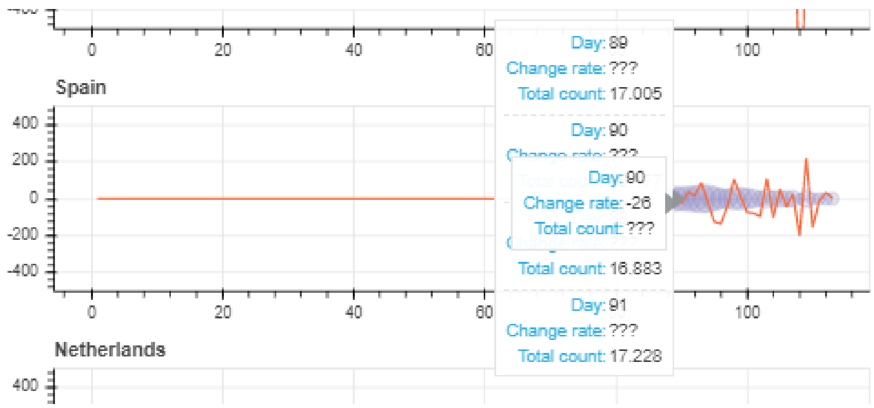


Figure 4.23 – Prototype 3 – hover issues

Final Prototype

This version is the last prototype, meaning that it is the version that is also tested during the usability testing. A snapshot of the prototype can be seen in Figure 4.24 .

The following additions have been made to this version:

- The color of each line graphs has been set according to the circle color of that country, as the previous color could be regarded as confusing.
- The map is no longer a choropleth but now uses graduating circles to represent the absolute death counts per country. This is more in line with correct cartographic practice, as choropleths should not be used for absolute rates.
- The spacing of the page as a whole has slightly been adjusted so it fits better on most monitors, as those are mostly widescreens nowadays
- A choice has been made for the hover tool to only work for the absolute rates (the circle graph for each country). The reason for this is that the line graph can be read using the y axis, while the circle graph cannot. So for the user to find exact values in the absolute rates, the hover tool can be used. A snapshot of how this hover pop up looks like can be seen in Figure 4.25.

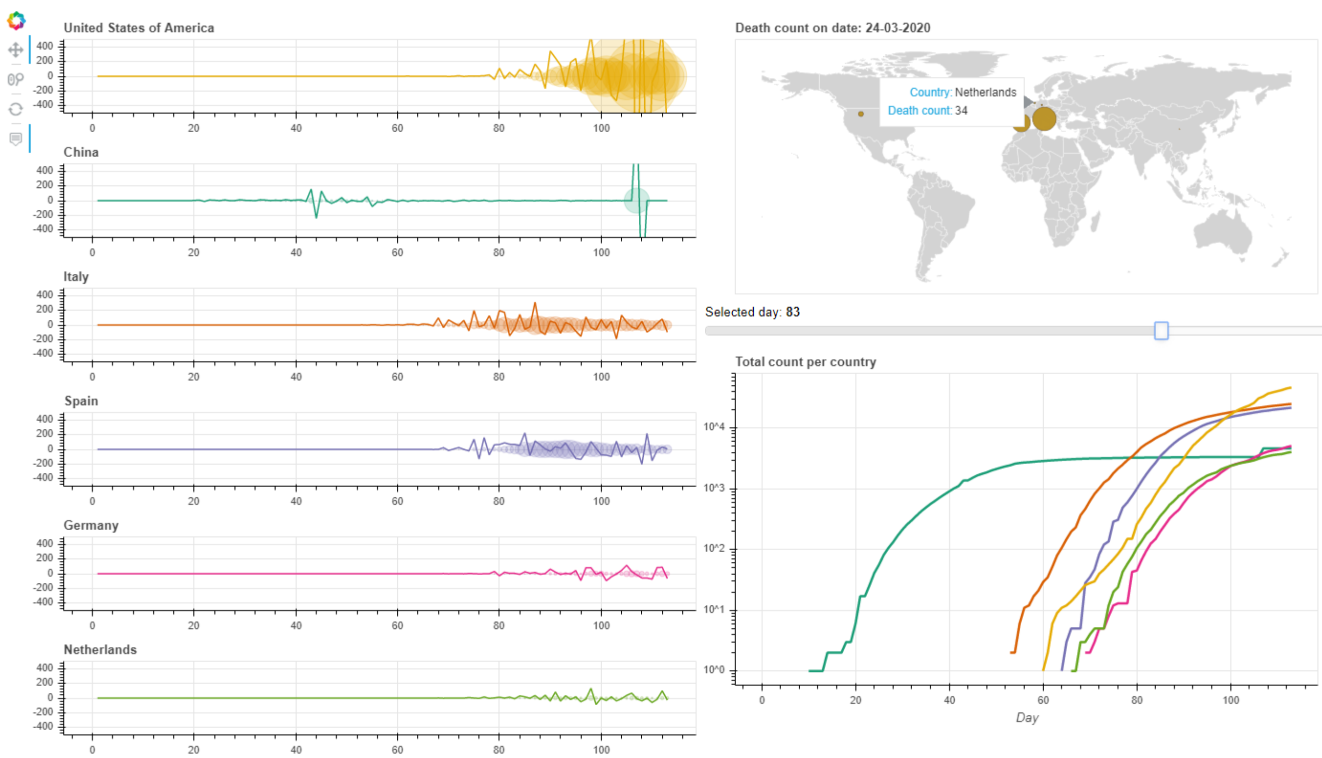


Figure 4.24 – Final Prototype

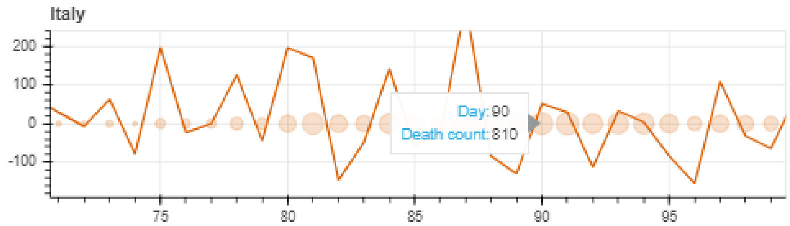


Figure 4.25 – Final Prototype – hover tool for absolute rates

5 Results usability testing

5.1 Stage 5: Test

The final stage of the 5-stage design thinking process consists of the testing stage. An overview of the test setup, methods and outcomes was described in section 3.3. The test results are divided into a few sections:

- Direct suggested improvements – this section is the result of two of the testing elements: 1) the first round of coding (see 3.3.4 for explanation on the coding of the transcript), based on the improvements filter, and 2) the answers of the testing participants to the last questionnaire question about suggested improvements.
- Effectiveness performance – this section is the result of the testing assignment. It consists of descriptive statistics on the performance of the participants for the tested elements. It indicates which prototype elements are able to functionally do what they are made for.
- Efficiency performance – this section is the result of two testing elements: 1) the second round of coding of the transcripts, using the performance filter, and 2) the answers to the usability questionnaire (see Appendix B for the questions).
- Satisfaction – this section is treated the same as efficiency performance and uses the same set of codes and phrases.

This chapter contains references to parts of the visualization. Figure 5.1 shows an overview of the different sections of the visualization to. Section 1 is often referred to as the left graphs or the change rate graphs. Section 2 contains the map with the slider and is referred to as such. Section 3 consists of the cumulative total graph which shows the added up total death count for each country.

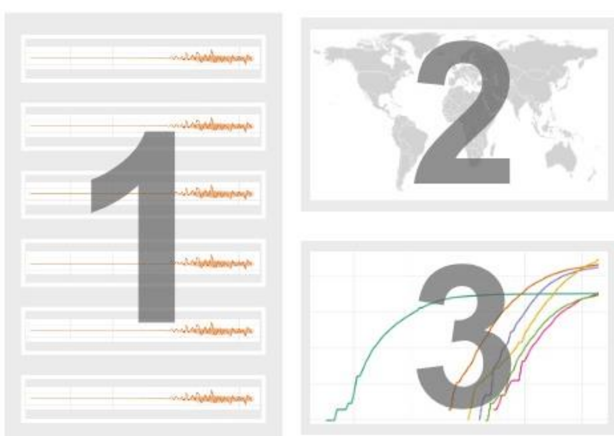


Figure 5.1 – Overview of sections in the visualization

5.1.1 Direct suggested improvements

5.1.1.1 Suggestions in Transcript (Improvements Filter)

During the first round of coding, using the improvements filter, a total of 12 phrased have been tagged that included directly suggested improvements. A summarizing sum-up of which improvements were directly suggested during the testing sessions can be seen in Table 5.1. As can be seen in that table, most suggestions consist of changing or adding elements in order to make things more clear. There were also a suggestion on the scale of the circle graphs, which is of more perceptive nature.

Table 5.1 – Summary of suggested improvements during test sessions

Number of times	Code	Suggested change
3	Improvements - Legend	Include legends for the graphs
3	Improvements - Enlarge graphs	Enlarge graphs
2	Improvements - Zero line	Make zero-line (y=0) more visible in left graphs
1	Improvements - Hover tool	Hover tool for lines instead of circles
1	Improvements - Scaling	Make circle scaling more intuitive
1	Improvements - Dates axis	Dates on x axis for graphs
1	Improvements - order of days	Fix order of days in hover pop up

The most suggested addition (3 times) is a legend for each of the graphs. This mostly regards a legend for the different graph types on the left, as is made clear by some of the tagged phrases with this code. An Example is as follows:

> "Describe what happens, and include the behavior of the line graph as well as the circle graph in your answer. […] Spain. 79 to 84. Uh… What were the circles again? I actually miss a legend now."

This participant was at the second-last question, and was wondering again what the circles meant. Although an instruction was given in the beginning on the different graphs and what they mean, it turned out that such information can be forgotten after a while, which for this participant led to them intuitively looking for a legend, containing information on the graph types.

The other most suggested addition (3 times) is the ability to make the graphs on the left larger. As the design of the visualization reflects one of the defined features, comparing regions, the choice was made to have graphs with a narrow height, offering for the graphs to be placed on top of each other for easy comparison. However, some of the testing assignments asked the participants to look up some specific values, which could be hard to read in a narrow graph. Some of the participants therefore suggested that the graphs would have an enlarge button, or pop-up option for it to display in a larger view. For example, one participant said the phrase below, suggesting the ability to double-click on a graph for it to open in full-screen:

> “There you want me to look very precisely? Then I'm going to do that. It is a pity that I cannot view the whole graph on its own. It would be nice if you double click that graph, and it would open on the whole screen.”

Other noteworthy suggestions include the following:

Making the zero line (y = 0) more visible in the change rate graphs (2 times). Participants suggested this to more clearly see the difference between a positive change (change rate line graph above zero) and a negative change (change rate line graph below zero). One participant said the following phrase:

> “To really have a clear zero line, that you also know that as soon as you are below that, then it is really below zero. [...] Then you have a division between increase and decrease, literally.”

Furthermore, suggestions were given about assigning the hover tool pop up to the line graph instead of the circle graph (1 time), making the scaling of the circles more intuitive (1 time), using the dates instead of the day number as the x axis on the left graphs (1 time), and fixing the order of days as displayed in the hover tool pop up for the circle graphs, which tends to be out of order in the case of hovering over multiple circles at once (1 time).

5.1.1.2 Suggestions in Questionnaire Answers

Table 5.2 provides an overview of all improvements that were given as answers in the final questionnaire question. A total of four participants answered this question with suggestions. One participant answered that their suggestions are stated in the recording and another participant answered that they sent some links to articles afterwards.

Table 5.2 – Overview of suggested improvements in questionnaire answers

Given Answers	Distilled Suggested Improvements
“1) For section 1: restrict usage of the x-axis to only positive values. 2) For section 3: add a vertical line that spans from the country line to the x-axis. Maybe add an indicator for the day to the hovertool.”	• Change rate graph: only positive values for the x axis, setting minimum x-range to 0 • Cumulative total graph: line indicating the day while hovering
“I think some added lines of text including a title would help”	• Adding text for clarity • Adding graph titles
“- putting in 6 graphs underneath each other sometimes made it harder to read the graph, but showcases the general information quite well and makes comparison easier (this is a thing you should balance I guess)	• Improve reading of graphs somehow while keeping the ability for easy comparison • Adding graph titles

- giving titles to the graphs makes it easier to understand what you're seeing"	
"The dates on the x line of the graphs in stead of the number of the day, the graphs in Section 1 are a bit chaotic for countries with high numbers (USA)"	• Dates as x axis for change rate graphs • Solve clearness issues due to high data values
"Stated in video"	
"I sent you some URLs for refinements. But for now, it is good."	

Some suggestions mentioned in the questionnaire answers show overlap with the suggestion in the transcripts of the sessions: suggesting to somehow fix clarity issues due to high data values (2 times) and the addition of dates as the x axis on the change rate graph (1 time). New suggestions include the addition of graph titles (2 times), the addition of text (1 time), setting the minimum range of 0 on the x axis for the change rate graph (1 time) and adding a line from the hover pop-up to the x axis on the cumulative total graph to indicate the day that is being hovered over (1 time).

5.1.2 Effectiveness Results

Indicating the effectiveness of the elements of the visualization is done by looking at error rates of the testing assignment questions. In cases where multiple errors can be attributed to a certain element of the visualization, that could be an indication that that part is not effective, meaning that the element does not do what it is supposed to. Table 5.3 below provides an overview of the error rates of each question, and shortly notes the implication of those errors for the improvement of the design. The questions can be found in Appendix A.

Table 5.3 – Testing assignment error rates

Question	Error rate	Tested element	Implication
1	1/10	Finding values (cumulative graph)	The wrong answer contained a value of the wrong day. This could be caused by the hover pop up not indicating the chosen date.
2	0/10	Pattern finding (peaks)	All participants could identify which country showed the greatest change in the change rate graph, however some participants based their answer on a wrong part of the data by misinterpreting the line graph.
3	2/10	Finding values (change rate)	Reading the right value seemed difficult at this question, mostly caused by the narrow graph and not having a hover tool for the line graph. Other mistakes

			were caused by misinterpreting the line graph: participants thought that the difference in Y value between two days was the change between those days, while in face the line graph itself already represents the change, meaning that the highest peak or lowest low could only be the correct answer.
4	0/10	Finding values based on specific date	All participants were able to find the right day for the asked date and found the right answer.
5	N/a		All participants used the map to find the highest value on a certain date.
6	0/10	Pattern finding (peaks)	All participants were able to identify the country with the highest change on the chosen date.
7	N/a		9/10 of the participants used the graphs on the left to find the answer to the previous question, 1/10 used the map.
8	0/10	Pattern finding (stable positive change rate)	All participants could recognize that a stable positive change rate graph means that the daily death count rises with about the same rate every day.
9	0/10	Pattern finding (unstable change rate)	All participants understood that a varying pattern of the change rate graph means that there are high differences between the days.
10	1/10	Pattern finding (rising negative change rate vs rising positive change rate)	1/10 of the participants misunderstood the change rate graph. The remaining 9/10 could identify the difference between a negative change rate and a positive change rate

Noteworthy implications that are the result of the assignment outcomes are the following:

- Multiple mistakes were made due to the line graph being hard to read. While peaks and lows could be identified (apart from being interpreted correctly), exact values seemed difficult to find. An improvement that could be distilled from this, is adding or changing the graph in such a way that there is more focus on the values of the line graph representing the change rate. While the focus now lies on the values of the absolute death count, by having made the decision that the hover tool only works for those values, that could be reversed so that the tool highlights the change rate values instead.
- The error rates for the last three questions are not that high, meaning that the tested elements in these questions (change rate graph) do perform well in the sense that participants were able to correctly recognize the patterns in the data. Question 8 and 9 tested the ability of participants to recognize patterns of stability and instability. Question 10 relied more on the right

interpretation of the graph. However, this result only means that the overall patterns could be recognized and does not say anything on the performance of finding specific values in these patterns.

5.1.3 Efficiency Performance

Assessing the efficiency of the elements in the visualization is done in two ways: 1) the second round of coding the test transcripts, using the performance filter, and 2) analyzing the outcomes of the usability questionnaire.

5.1.3.1 Efficiency Coding (Performance Filter) Results

During this round of coding of the transcripts, the focus is on *how* participants came to their answer to the testing assignments. It captures the process of the participants and looks at whether that progress was easy or hard, if expectations were met, and how participants used the prototype to find their answers. The codes that were used, including an explanation when something falls under that code, can be found in Table 3.3 in section 3.3.4.1.

A list summarizing the occurrence of the codes in the transcripts can be found in Table 5.4.

Table 5.4 – Occurrence of codes

Code	Number of times
Expectation – good	12
Expectation – wrong	3
Inventive use	5
Learning	8
Performance – good	28
Performance – doubt	18
Performance – bad	19

After the codes were assigned, sub-codes were assigned to indicate which elements are referred to in the phrase. First the positive cases are presented, then the negative codes, consisting of the elements requiring improvements. Finally the neutral cases are discussed. Each time a summarizing table will be shown, containing the sub-coded elements in order of amount of occurrences. After that, some returning subjects within the phrases are presented, which can be illustrated by quotes from the transcripts.

5.1.3.2 Positive Coding Results

The two codes that are used to tag phrases containing positive signs for certain visualizations are ‘expectation – good’, and ‘performance – good’. Note that there can be more sub-coded elements listed than in the summarizing list of Table 5.4. This is because certain phrases being tagged by a code (i.e. Performance – good) can be attributed to multiple elements (i.e. both the lefts graphs and the map).

Table 5.5 – Occurrences of positive codes and sub-codes

Code	Sub-coded element	Number of times
Performance – good	Left graphs	14
	Map	10
	Interactive tools	4
	Cumulative graph	2
Expectations – good	Left graphs	6
	Map	5
	Cumulative graph	2
	Interactive tools	1

Table 5.5 contains a summary of the sub-coded elements that occurred under the positive codes. As can be seen, most positive phrases are about the left graphs and the map.

Performance – Good

When looking at the tagged phrases with the code 'performance – good', a few things stand out.

- Left graphs: cases that include the left graphs often indicate the ease at which participants knew that they had to look for certain values in those graphs. Most of the phrases contain a statement of participants saying that they immediately looked at these graphs. This indicates that the graphs on the left perform well in the sense that people know what information they contain. Phrases that highlight this:

  "[…] Which country showed the greatest increase in amount of deaths between two days? Okay. I feel I have to look in the left row for that"

  "Then the difference in 1 day. Then I think you need that graph here, [left]"

- Map: good performance in combination with the map is often the case where participants emphasize the use of the slider beneath the map in order to find a certain date. Even though the slider and map do not contain a legend, it seemed that using the slider to go through the dates felt intuitive for some of the participants.

  "Which country faced the most deaths on 31 March 2020? Then we go to the slider."

"Which country faced the most deaths on 31 March 2020? Then I'm just going to put this nicely on that [slider], oh well, almost in one go."

- Interactive tools: the necessity of the interactive tools comes forward in the phrases that are tagged by this. One of the interactive features that participants specifically seemed to like is the linked panning and zooming. The panning and zooming was used by several participants to move the line graph in such a way that only the highest peak would stand out. These cases are also tagged with the 'inventive use' code. Phrases that highlight the use of these tools:

  "Researcher: "You did that in a great way, how you looked that up."
  Participant: "Nice that they are linked in that respect."

  "What was the amount of that increase? Oh that's handy. I'll just say… I'm zooming in on the height of that peak. I see that it is useful that it moves with it."

- Cumulative graph: the two cases tagged here both emphasize that participants immediately knew when to use this graph:

  "The least amount of total cumulative deaths. Then I look at the total count per country chart."

Expectations – Good

'Expectations – good' shows a large overlap with the previously discussed 'performance – good', mostly highlighting that certain elements are where participants expect them to be. The amount of occurrences of 'left graph', 'map' and 'cumulative graph' show that participants intuitively know that they had to look at these places for certain information:

"I want to know the biggest change in the number of deaths. Then I want this graph to the left, because it shows just that."

"[…] Then this is the most convenient, I think [cursor on map]. Because this represents the death count with the scale."

A final note on the positively coded phrases: it can be concluded from most of the highlighted points that the general layout of the visualization feels intuitive to the participants. They knew where to look for certain pieces of information. This was emphasized by participants that literally spoke out about that they knew where to look in advance. The good performance of the interactive tools like zooming and panning was highlighted as well, meaning that these functions definitely proved their use in the prototype.

5.1.3.3 Negative Coding Results

Table 5.6 contains a summary of the sub-coded elements that occurred under the negative codes. When only looking at the numbers, some things can be noted: all elements have at least one tag of the 'performance – bad' code, and the left graphs show a lot more tags with the code 'performance – doubt' than the other elements. Also, when comparing with the numbers of 'performance – good' as described in the previous section, the map occurs in more positive phrases than negative phrases.

Table 5.6 – Occurrences of negative codes and sub-codes

Code	Sub-coded element	Number of times
Performance – bad	Left graphs	11
	Interactive tools	5
	Hover tool	3
	Cumulative graph	1
	Map	1
Performance – doubt	Left graphs	17
	Map	3
	Cumulative graph	2
Expectations – wrong	Left graphs	3
	Interactive tools	1

Performance – Bad

The 'performance – bad' code is primarily used in cases where participants had trouble using the visualization. The following things stand out while looking at the phrases tagged with this code:

- Left graphs: a commonly heard frustration when using the left graphs was the limitations caused by the narrow height of the graphs. Due to the limited space for the Y axis, high peaks and low lows often fall out of the default Y range.

  "Participant: It is a bit unfortunate for the visualization that the data is so close together. It doesn't matter how far you zoom out, that it still comes out of its frame.
  Researcher: You mean that…
  Participant: The lines.
  Researcher: Yes correct.
  Participant: But that has more to do with the data peaks and lows."

Some participants suggested that the graphs should have an option to be viewed in a larger window. This is also included in one of the directly suggested improvements in section 5.1.1. Another participant said the following about that:

"Participant: […] Ah this is just a pity, can you also enlarge this graph [graph left of Spain]?
Researcher: What do you mean?
Participant: That you can click out the graph of Spain and that you get a bigger picture, because it is now very narrow."

Another returning piece of feedback on the left graphs is about the zero-line (y=0) in each graph. Multiple participants found that this line was not visible enough, causing troubles when trying to see whether the change rate graph was positive or negative at certain close points. This point was addressed during the last testing assignment question, where participants had to correctly interpret a change rate line going from below zero to above the zero line, which was a close call at one point. One phrase was already included in section 5.1.1. Another participant suggesting the exact same thing highlights the importance.

"[…] But that zero… It would have been clearer if that zero line was a bit more clear."

Other feedback on the left graphs included that the exact values of the change rate line graph are hard to read. A few reasons were given for this. One participant found the line graph hard to read in general, and simultaneously hints to the absence of a legend or explanatory title.

"Yes. It's hard to see I have to confess. Zoom in even further. Yes look, then more will happen. It is a pity that on the left side of those graphs… The line is the difference in the number of deaths, right?"

- Interactive tools and hover tool: this point mostly overlaps with the last point discussed for the left graphs, the notion that exact values are very hard to read on the graphs. Therefore multiple participants emphasized the that the hover tool should be enabled for the line graph instead of for the circle graphs:

"The hover tool only works for the circles and not for the line, which is a bit cumbersome."

"What will it be? I don't know if I can see it right here. No, not, because that hover tool does not work for the line"

"Day 90 is… But then you all see the absolute value. So that's not very useful."

Another piece of feedback on the interactive tools was the frustration that emerged when hovering over multiple circles at once. When doing this, the order of the days in the appearing pop-up seemed off. This was especially not useful during the test assignment where participants had to look up values for two successive days.

"Oh. When I look at America, and I hover over it with my mouse, I see day 106 and day 108, but not day 107."

"Oh wow. The order of the days that changes.[…] With one view, here it takes day 107, day 106, day 108, from top to bottom."

- Map and cumulative graph: these tagged phrases were both about how it may not immediately be clear what these elements consist of. For the cumulative graph a participant did not immediately understand that hovering over the plotted lines would say which country they were looking at.

  "Zoom in for a moment. China is still rising slightly, what is that green one?"

Performance – Doubt

The first notable fact that stands out is that the amount of 17 tags assigned to the left graphs element for this code, which is the highest of all codes and elements. The code 'performance – doubt' was primarily used for phrases that showed signs of the participants being confused, or doubting about the use of certain elements.

- Left graphs: one overarching theme in these tagged phrases is that participants were not immediately sure where to look for certain information. This is sometimes the case for doubting between two graphs, and sometimes caused by not knowing precisely enough the kind of information that certain graphs offer. That first case came forward a few times:

  "Now I'm thinking on one side, I want to go to that date very quickly, and I don't see an indication of the date [below the graphs] very quickly below, and I do know that it's been days since a certain day. That gives me the feeling that it might be easier to see in another way. Maybe the map too. But then it becomes mental arithmetic. So that does not seem to me like the solution. Then I will think for a moment."

  "This is a day, so this is a lot of hassle to add up. I don't think it's useful to use that. This is total count, which seems quite logical to use."

While these issues seem not very major, it should be prevented that people have a hard time even finding out where to look for certain data. The second mentioned problem also occurred for multiple participants. In these cases, participants did not certainly know what certain graph elements represented:

"The death count is the death count for that day?"

"Look at the change rate graph for Spain. That's the line graph right?"

Other issues that seemed to occur for multiple participants is that they thought they needed to calculate certain things, or add values up get to certain answers. For the case of this visualization, calculating manually should never have to be the solution so problems like that should be addressed by proper communication. Issues looked like the following:

"Yes, so you have to… Yes, how many days exactly can I calculate, but that may not be useful."

"Yes, and then you could count through, but here I can immediately see the specific day, instead of having to count through."

Expectations – Wrong

These show a few cases where participants thought that certain elements worked differently than they actually do. For example the hover tool:

"So I'm going to take a look. March 31, that's the end of the first quarter, so that's about 90 days. Hover, to see if I can see the date. It does not show."

Another example is when a participant expects that the y axis scale is also meant for reading the values of the circle graphs, while it is not:

"But you would say, within this graph you would not say that circle dot represents 266 deaths. Because it does not rise above the zero line. You automatically look a little at the y axis."

A final note on the negatively coded phrases: many of the phrases consist of moments where participants struggle with little design elements of the graph. Getting exact values out of the change rate line graphs is a reoccurring problem which is expressed in several different ways: some found the graphs too small, some missed the hover tool for the line graph to easily read the exact value, and some had issues with the zero line being too vague in situations where the line is close to zero.

Neutral Codes

Table 5.7 contains a summary of the sub-coded elements that occurred under the neutral codes.

Table 5.7 – Occurrences of neutral codes and sub-codes

Code	Sub-coded element	Number of times
Learning	Left graphs	5
	Interactive tools	3
	Map	1
Inventive use	Interactive tools	5

Learning

While the code 'learning' does not directly say something about the efficiency performance of certain elements, it does show that participants went through a short learning progress during the test assignments, which is regarded as a quality of the product as a whole. Some phrases indicate that:

> *"So if I zoom here ... yes yes yes, I get what you mean. I already understand how this will work. Then I'm going to be very precise ..."*

> *"There is a day, then it increases, and then there is a day when it decreases again, the increase. Then the increase decreases again, and then the increase increases again. Right, that's it. Now I have also understood the answer to the previous question. Not only given it, but I also understood it."*

> *"It is difficult to understand what such a relative graph does. You really have to let that sink in. Then a whole bag of coins falls."*

Inventive Use

Another code that not directly contributes to understanding about the efficiency but that is still worth including is the 'inventive use' code, which is used for phrases where participants came up with a creative way of solving a problem or finding a value. The phrases themselves may not say everything, but the actions of the participant at those specific moments showed inventive use.

The 5 cases of 'inventive use' all used the interactive tools. The first case is where participants separately from each other used the same technique for finding the highest peak of all countries. They panned the line graph down in such a way, that only the highest peak of all countries remained visible. This was made possible due to the graphs' ranges being linked.

> *"What was the amount of that increase? Oh that's handy. I'll just say… I'm zooming in on the height of that peak. I see that it is useful that it moves with it."*

The other clever solution that a participant used, was dragging a peak of the line graph towards to y axis in order to easily read the peak value:

> *"And how much is that? Then I have to drag that to the Y axis to see that."*

5.1.4 Satisfaction Performance

Just like the performance of efficiency as discussed above, satisfaction is tested by analyzing coded phrases. The same set of tagged phrases as discussed for the section of efficiency is used (see Table 5.5 and Table 5.6), however other phrases will be highlighted: in accordance with the definition of satisfaction as given in section 2.9, phrases that contain an emotional response to certain visualization element—positive or negative—are taken into account. Besides, phrases containing expectations are also taken into account.

Positive Phrases

A few phrases contain directly expressed positive notes on the prototype. One example shows that a participant is satisfied with the use of the interactive tools, which is confirmed by another participant expressing a similar emotional response to the zoom tool:

> *"Zoom out for a moment. And also zoom it out. I think it is very beautiful man. The more I work with it, the more I like what you can emphasize with it."*

> *"I can zoom in quite well actually"*

An expectation that turns out positive can also be regarded as satisfying the user needs. A few of these examples have already been discussed in the section on efficiency. One more example is given here, where a participant has certain expectations about the left graphs that are being met:

> *"Which country showed the greatest increase in amount of deaths between two days? Uhm. These guys [graphs on the left], This shows you the difference."*

Negative Phrases

A few negative phrases expressed by participants are both about the left graphs. The first example contains an expression that the left graphs are cumbersome in general. The second example shows that the graphs are difficult to read due to their small size. Some other negative examples about expectations that are not being met are already discussed during the section on efficiency.

> *"Okay, then I go here. [cumulative graph]. Okay I want to look at this, [top left graph] but actually that is very bad."*

> *"A little down… Yes. It's hard to see I have to confess."*

5.1.5 Usability Questionnaire Results

The results of the usability questionnaire are presented in this section. These results can be regarded as an extra assessment of the usability of the prototype and are mostly focused on the efficiency and satisfaction performance of the prototype. The results can show confirm certain findings from the previous results sections, but may also shed light on contradicting outcomes. The results are structured in the same way the questionnaire was structured, starting with general questions, followed by questions on the 3 different sections of the visualization. An overview of these sections can be seen in Figure 5.1.

General Questions

The results for the first question are varied. Although the participants range from a variety of backgrounds, a slight majority stated that they would use such a type of visualization

The results for the second question are varied. However, most of the participants did not find it too complex, despite the experienced difficulties as described in the previous sections. Although the visualization is meant for professionals in data visualization or geo-information as discussed in the user identification (section 1.4), this does not mean that the visualization has to be consciously made complex.

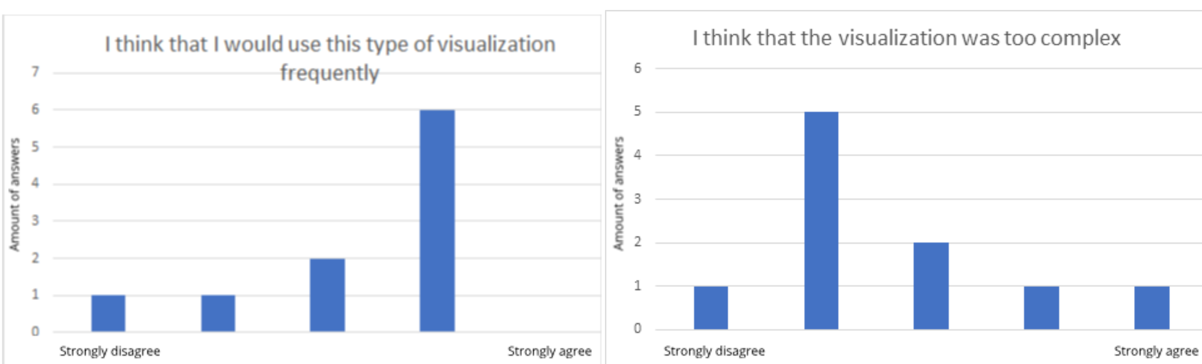


Figure 5.2 – Question 1 (left) and 2 (right)

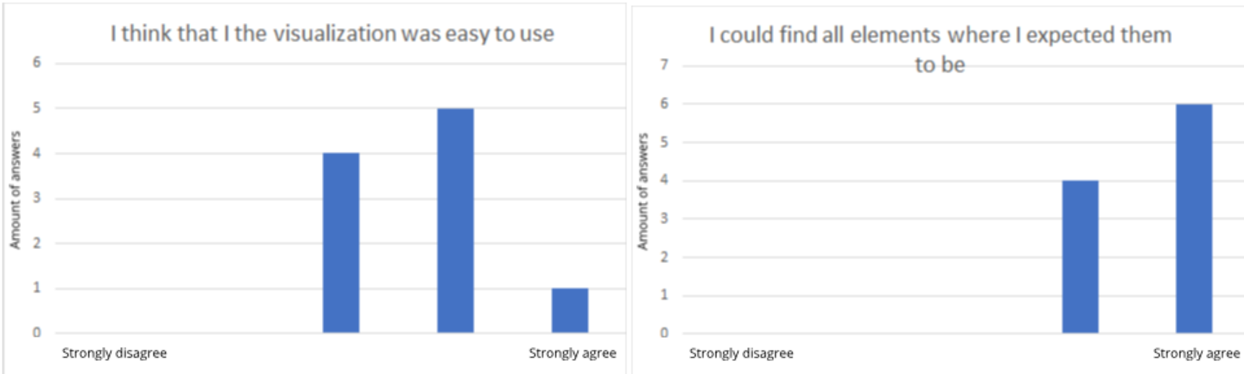


Figure 5.3 – Question 3 (left) and 4 (right)

The results for question 3 and 4 indicate that participants did not experience too many difficulties while using the visualization. Especially question 4 shows positive results for the participants expectations. This was also shown in the previous section at the results of the code 'expectations – good'.

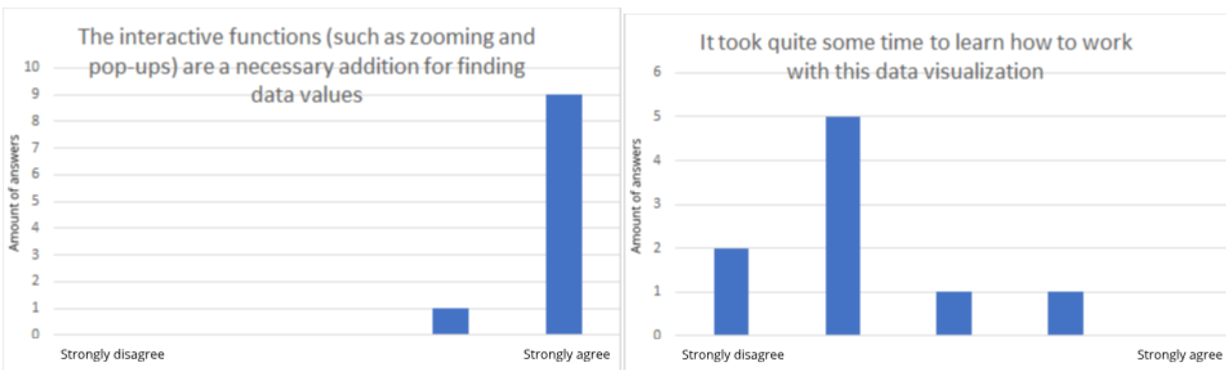


Figure 5.4 – Question 5 (left) and 6 (right)

Question 5 shows that participants really valued the addition of the interactive features. Multiple testing assignments questions relied on the use of these interactive tools for accurate value reading, which may have caused this result. This result is in accordance with many of the coded phrases on the interactive tools, which underline their value and necessity. The result of question 6 shows that a majority of the participants found that it took a while before they knew how to properly work with the visualization. This was also highlighted with some of the coded phrases under the code 'learning'.

Section 1 (Graphs on the Left)

The following results cover the questions asked for section 1 (see Figure 5.1)

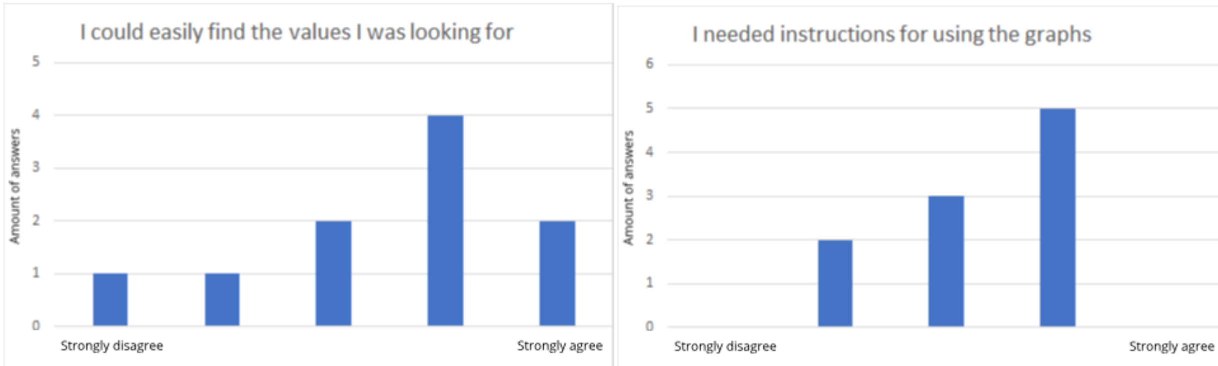


Figure 5.5 – Question 7 (left) and 8 (right)

Question 7 shows that a slight majority could easily find the values they were looking for. Yet there were also some participants that found it difficult. This result is also reflected in the variation of how easy participants the testing assignments found. Question 8 shows a rather neutral result, although a majority found that instructions were needed. This is most likely the case for the interactive tools, as the visualization has no included instructions on how to use these tools.

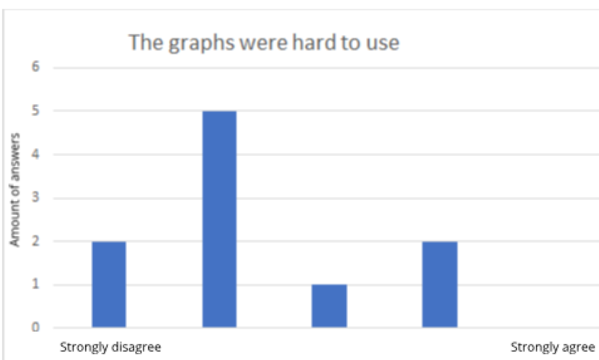


Figure 5.6 – Question 9

The results for question 9 are also varied, but a slight majority found that the graphs were not too hard to use. This does seem a bit contradicting with the previous question on needed instructions. It might be the case that participants found the graphs not hard to use as soon as they knew how they worked.

Section 2 (Map)

The following results cover the questions regarding the map (section 2, see Figure 5.1)

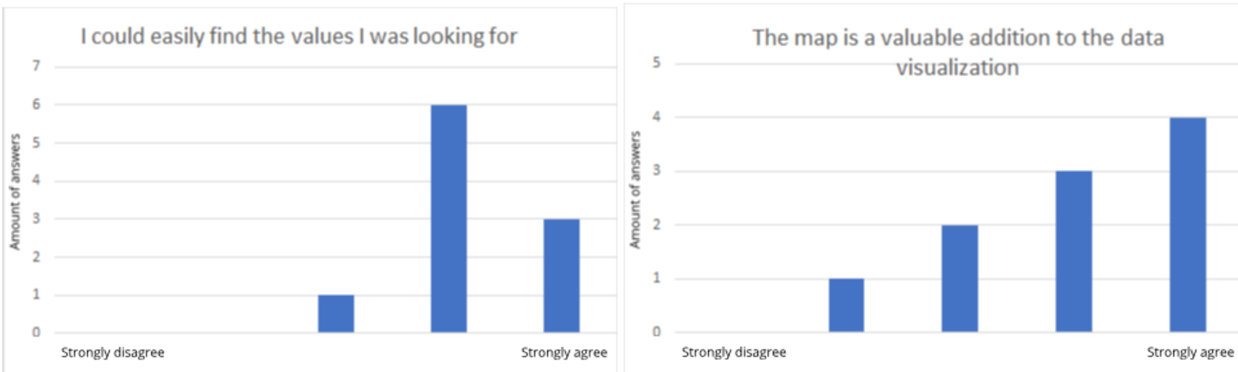


Figure 5.7 – Question 10 (left) and 11 (right)

Question 10 and 11 both show a tendency to the positive side. Participants could easily find the values they were looking for. About the map being a valuable addition: only one participant disagreed. Some were neutral, and the rest found the map valuable.

Figure 5.8 – Question 12 (left) and 13 (right)

Question 12 shows that most participants did not need any instructions for using the map. This may mean that the use of the map felt intuitive enough for the participants. The question 13 results show that the map use was satisfactory. This is also reflected in the results of the coded transcript: the division between positively coded phrases and negatively coded phrases for the map leans clearly to the positive side.

Section 3 (Cumulative Total Graph)

The following results cover the questions regarding section 3, the cumulative total graph (see Figure 5.1)

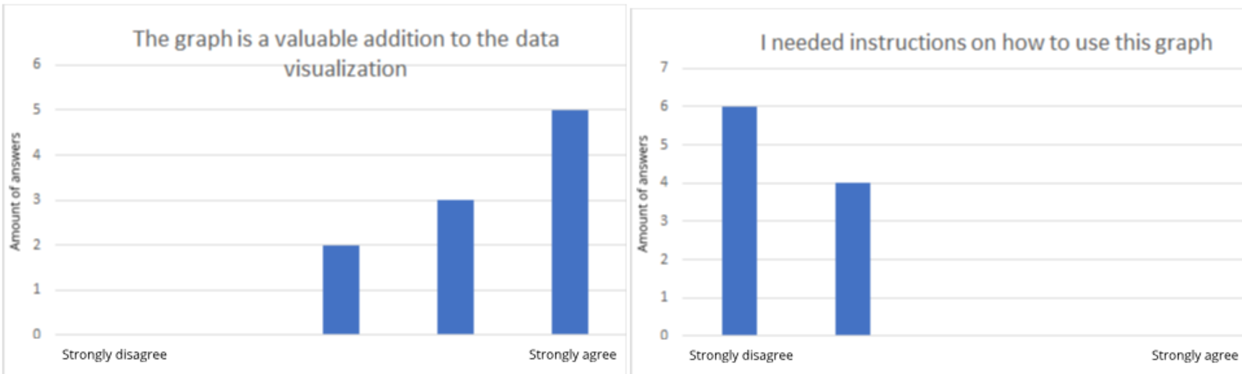


Figure 5.9 – Question 14 (left) and 15 (right)

Question 14 shows that participants valued the addition of the cumulative total graph. While the graph was not needed for most of the testing assignment questions, it did prove a contextual overview of the progression of the death rates for each country. Question 15 shows that participants could use the map without many instructions, even though the Y axis contained a logarithmic scale, which was specifically noted by some participants.

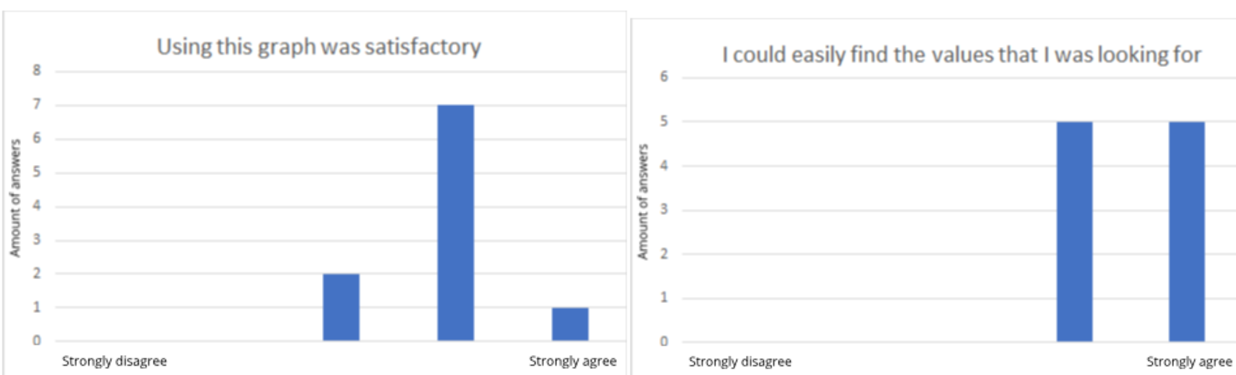


Figure 5.10 – Question 16 (left) and 17 (right)

The results of question 16 show that participants are moderately positive about the use of the cumulative total graph, although a high satisfaction performance is not reached. Question 17 shows that values could easily be found by all participants, emphasizing the easy use of the straightforward graph design, even though some participants specifically asked why there were no legends.

5.2 Suggested Improvements List

Based on all test results, this section contains an improvements list for the visualization. The listed improvements are distilled from all results sections and listed in hierarchical order, from most important to implement (1) to least important (3). The ordering is based on the appearance of certain problems in the transcripts results: directly suggested improvements (section 5.1.1) are taken, and solutions for problems that were presented in the results for the efficiency performance (section 5.1.3) are suggested. Lastly, the questionnaire results into account to put further emphasis on certain solutions if the underlying problems also came to light in these results.

First a summarizing list is presented in Table 5.8, followed by an explanation of each suggested improvement.

Table 5.8 – Summary of hierarchical improvements

Improvement	**Concrete changes**
1. More focus on change rate line graph	Hover tool pop up for line graph
	Clear zero-line
	Dates on x-axis
	Ability to toggle circle graphs on or off
2. The ability to enlarge graphs into larger view mode	Add a pop-up with larger
3. Clarifying text elements	Add graph titles
	Add legends
	Small instructions pop-up for interactive tools

1. More focus on change rate line graph:

For user to be able to find values in the change rate data more easily and correctly, the focus of the left graph section should be shifted more towards the line graph representing that change rate. As recognizing patterns of derived change rates is the main objective of the visualization, that should be reflected by the design as well. This entails the following changes to the design:

- The hover tool pop up showing the exact value at the hovered point should show for the line graph instead of the circle graph. This way users can easily look up exact values, preventing users from having to move their head very close to the screen in order to get a somewhat proper value.

- The zero-line within each graph should stand out a bit more. While this may seem a small change, the impact of mistakenly reading a wrong value due to this problem can be large. This is because a positive change rate means something very different than a negative change rate. The zero-line could be changed by making it a few pixels thicker, or assigning it a darker color like dark grey or black.
- The x axis should show dates instead of day numbers. This way users can more easily and intuitively scan through the timeline, making sure that they are looking at the correct days they are looking for. This would be more efficient than having to use the slider beneath the map to look up the specific date corresponding to the selected day.
- Users should have the ability to toggle the circle graphs on or off. The circle graphs represent the absolute death count per day, which is in itself useful data. However, as the main objective of the visualization is to recognize patterns in the change rates, the focus should be shifted towards the line graph instead. It is suggested that a toggle option is added instead of removing the circles at all, because during the testing assignment some participants used the circle graphs to verify certain made conclusions about the line graph, i.e. checking whether a stable line graph indeed means that the increase is rising at a constant rate.

2. The ability to enlarge graphs into a larger view mode:

While the choice was made to present the graphs of the countries on top of each other, this also comes with the disadvantage that each graph has a narrow height. The advantage of keeping the graphs placed in a top-down order is that the progression of the data through time for a certain country can be easily compared to the other countries in one glance. This comparison can be very useful when trying to categorize countries that show similar patterns through time. To maintain this advantage but solve the problem of the narrow height, the option should be offered to view each graph in a larger pop-up screen. In this larger view, the y-range would be significantly higher, enabling users to read values way more easily.

3. Clarifying text elements

Multiple participants had trouble with recalling what certain graphs represented, or what certain colors meant.

- By adding graph titles that include a short note on the type of data, users can find out what they are looking at without any instructions.
- Legends should be added to the graphs that need those. This is especially the case for the cumulative total graph, of which multiple participants wondered what it represents.

- A small instructions pop-up for the interactive tools should show up once the visualization is opened. This pop-up would indicate that there is a tool bar on the left top corner of the screen with the different interactive tools users can use. Right now, there is no intuitive way of finding this out. By adding this indicator at the start up of the visualization, the need for instructions for using the graphs and the map is further reduced, and the learning curve that some participants mentioned can be shortened.

6 Discussion

Apart from presenting the progress of the development of the prototype, the results section of interest consists primarily of the usability testing, which has three different outcomes: directly suggested improvements, effectiveness performance and efficiency performance. Each of these three will be discussed in terms of interpretation: what do the results mean and what don't they mean? Furthermore, the implications of the results are discussed as well: what are the results useful for? The results will also be put in a broader scientific context, referring to theoretical concepts as presented in chapter 0. Finally, limitations of this research will be discussed.

6.1 Directly Suggested Improvements

This part of the results consists of the improvements that were directly suggested by participants. The rationale for including these as an apart section is the following: when participants of the test sessions are able to recognize that certain elements or processes of the visualization do not work optimal, these limitations are either very obvious, or of such magnitude that participants took a moment to think of solutions themselves. A good example is the absence of legends for each of the visualization sections. During the development, this was not something that the researcher expected to cause any problems. However, the usability testing showed that it actually was somewhat of a problem, and in fact such an obvious one that multiple participants emphasized it. Apparently, the visualization was not designed in such a way that is was in accordance with the *image theory*, as introduced by Bertin (1983) and discussed in section 2.8. That theory states that a visualization is effective when it speaks for itself which kinds of information can be extracted from it. The implications of this is that it is suggested that multiple elements of the visualization need a clear title and a legend.

Generally, the directly suggested improvements are valued highly and are thus all taken into account while constructing the hierarchical improvements list as presented in section 5.2. However, as the suggested improvements come from the participants who do not know anything about the technical development of the prototype, the implementation of certain suggestions can be more difficult than expected, or even not possible regarding the limitations of the used software and packages. This will be further discussed in the research limitations, section 0.

6.2 Effectiveness Performance

Testing the effectiveness of certain elements of the visualization is done by looking at the error rates of the testing assignments. The assignment questions were all developed in such a way that they tested certain competences of the visualization. Examples are the ability of the visualization for the recognition of patterns, the reading of precise values, etc. (see section 5.1.2 for all tested elements). The error rates of the corresponding assignments reflect how well these elements perform, how effective they are. The results should be interpreted with care, as the rates only show whether or not the right answer has been found. It shows whether or not the tested elements do what they are supposed to do. This means that it should be acknowledged that these rates do not say anything about *how well* these elements perform. That kind of performance is measured in the next testing section, consisting of the efficiency performance. An implication of the effectiveness results is, when interpreted right, that the visualization is able to reveal multiple types of patterns within the change rate, as can be read in Table 5.3 (section 5.1.2), but the efficiency of that capability should be interpreted in the light of the corresponding efficiency performance results section.

6.3 Efficiency Performance

The efficiency performance is measured in two parts, 1) during the second round of coding of the transcripts, using the performance filter, and 2) by examining the questionnaire results.

The analysis of the transcripts using the performance filter resulted in a collection of phrases that are tagged with certain codes, reflecting the performance of elements of the visualization. These elements are also tagged as sub-codes in order to count the occurrences of the codes and sub-codes. While it may seem handy to simply conclude that the most tagged elements perform either the best (in cases of positively coded phrases) or the worst (in cases of negatively coded phrases, interpreting these results should be done with care. This is why the results section also included quotations of certain phrases, capturing the thought processes and actions of the participants and what the implications of these are. The phrases can somewhat reflect which elements perform well, thus needing no or little change, and elements that require improvements. During the construction of the hierarchal improvements list, reoccurring themes within the phrases are taken into account. Especially when a problem seemed to be of such magnitude that multiple participants ran into it, like the limited view of the narrow graphs.

The second part of this efficiency performance is measured by looking at how the participants answered the usability questionnaire. These outcomes can be regarded as giving a rough idea how the visualization elements perform, but should not be interpreted on their own, without studying their context and the other results. Besides, the sample size for the questionnaire is too small to run proper statistical tests that may offer conclusions with a little more certainty. The questionnaire answers can be interpreted as a confirmation of the other test results. In case that conflicting results occur, this could be a reason for further studies or another round of analysis of the transcripts.

6.4 Satisfaction Performance

Satisfaction of the prototype is measured in two parts, 1) during the second round of coding of the transcripts, using the performance filter, and 2) by examining the questionnaire results. Although the results for this aspect of usability show a large overlap with efficiency, something can be said about the use of the interactive tools within the visualization as this was the most prominent positively experienced feature according to the participants. Multiple participants expressed their positive emotional response to using the interactive tools such as the zooming and panning, and the slider beneath the map. Also, the linked view of the left graphs seemed to be a satisfying feature. Furthermore, the results for the code 'expectations – good' showed that certain elements met the expectations of the participants, indicating a positive satisfaction performance.

It was difficult to indicate which specific features of the visualization caused a feeling of dissatisfaction. One participant expressed negatively about the left graphs in general, but it was unclear why they felt that way. However, reasons may be found in the negatively coded phrases for the efficiency aspect, as visualizations that are not efficient may be regarded as dissatisfying as well. The results of the questionnaire indicate that most participants are satisfied with the map and the cumulative graph. Although this can be seen as a positive note for the visualization, it does only apply for these elements in general and should be interpreted as such.

6.5 Research Limitations

During the different phases of the research process, it came forward that the research is subject to several limitations. The most obvious ones are discussed in the list below:

- Chosen software & packages:

  During the early stages of research process, it was decided that the prototype of the visualization would be created using Python. Python is a programming language that fits very well for data science, as there are multiple packages created for data management and data visualization. However, this means that choices had to be made on which package seemed the most suitable for the project. The choice for using certain packages leads to certain abilities but also to certain limitations. For example, during the early development stage there was made use other packages than the final prototype was built with. Packages like Matplotlib and Altair have been explored for possible use, however it was decides that Bokeh was the choice for this project. The advantages of Bokeh are mostly its easy use for beginners and the rich interactive functions that it offers. However, certain functions of Bokeh also proved to be limiting factors, costing much time. Examples are the hover tool function, which caused major frustrations during development. In the grand scheme of things, every functionality in the tested prototype was only possible because Bokeh offered the functionality. Multiple of the improvements on the final hierarchical improvements list are not possible to build in Bokeh, like an expanding graph, offering for a larger view. This is why performing a similar study but with other packages or even languages is listed as one of the further research suggestions.

- Programming skill level vs conceptual ideas

Another limitation is caused by the large discrepancy between the conceptual ideas of the researcher and their programming capabilities. The programming skills of the researcher limit the research in such a way that the researcher is very aware of certain problems within the visualization, but is not able to fix them. While this has a bit of overlap with the previously mentioned limitation, it also means that choosing another language was not a realistic option.

If the research would have taken place in a team, together with others that do have advanced programming capabilities, this limitation could have been solved. A collaboration between the conceptual thinker and a practical implementer would have been an ideal duo for such a process.

- Testing limitations

The testing method in this research also contains certain limitations. The foremost is the testing audience. The audience for the usability testing was chosen with an aim to include participants that somewhat have a link with geodata visualization, but are no experts. This audience consisted of students in geography, spatial planning, GIS, and people working in GIS and psychology. In the light of data driven decision making, these participants do in fact fall under the category of people who might work with certain data and visualizations. However, the decision could also have been made to include a testing audience of professionals in data visualization. Participant with such a background would probably have provided different feedback, based on experience with similar data visualizations. Suggestions for improvements would probably have turned out way more extensive and useful, based on expertise. The only downside of picking such an expert testing audience could be that these people are developers rather than purely users of the product, causing them to look at the visualization from a developer's standpoint which might be too critical at small elements.

7 Conclusion

In this section, the research objective and research questions will be revisited. Each question will be answered, based on the results, keeping in mind the interpretation and implications as discussed in the discussion.

7.1 Research Objective

The main research objective is stated below, and will be decomposed to analyze to what extent each element has been achieved.

Develop a novel graph, based on a timeline combined with other graphs, that will effectively reveal patterns of derived change rates in spatio-temporal data.

Decomposed research objective:

Develop(1) a novel graph(2), based on a timeline(3) combined(4) with other graphs(5), that will effectively(6) reveal patterns(7) of derived change rates(8) in spatio-temporal data(9).

1) The prototype that has been tested was indeed *developed*, meaning that it has gone through an iterative process of development according to the 5-stage design thinking process as introduced by the Interactive Design Foundation (Dam and Teo, 2019).

2) The developed prototype is novel in the sense that this combination of graph types, line graphs combined with varying circle graphs, was conceptually created by the researcher. While the graphs may not be novel on their own, it is the combination that is unique.

3) The prototype is indeed based on a timeline, which comes forward in all design elements: the change rates graphs are all based on a timeline, the map uses a sliding timeline and the cumulative total graph is also based on a timeline on the x-axis.

4) There are multiple combinations to be found in the visualization. The foremost prominent one is the combination of the line graph, representing the change rate, and the circle graph, representing the absolute counts. Besides, the combination of other graph elements such as the map and the cumulative total graph can also be regarded as a combination in the visualization as a whole.

5) The tested prototype contained a combination of the line graph and circle graphs that are plotted over each other.

6) Effectiveness is a difficult quality to describe. One of the usability assessment methods tested the effectiveness of the prototype. Some of the tested elements regarded the recognition of patterns (7) (see Table 5.3) in the data, which the visualization was able to do. An addition to this, is the

assessment of the efficiency of the product. This is not stated in the original research objective, but is tested in the research. It can be concluded that the visualization is effective, and somewhat efficient, but requires certain improvements, which are listed in the hierarchical improvements list (section 5.2).

8) The prototype does indeed visualize the derived change rate of the dataset. This change rate is calculated in the script behind the visualization. The required input data only consists of the absolute death counts per day.

9) The used dataset is spatio-temporal, in the sense that it has a spatial component, being the different countries, and a temporal component, being that the data ranges through multiple months with each day as a time step.

7.2 Sub-questions

1) Which design principles and visual variables can be applied to a timeline based graph to ensure usability?

The prototype that was tested in this research contained the combined graph types of a line graph, and a graduated circle graph. These graph types were combined, together with a timeline on the x-axis. Based on the results it can be concluded that it was not the combination of these graphs that led a usable design. It can even be said that the combination, as it was tested, only led to confusion due to the overplotting of the graphs. This confusion was amplified by the wrong use of the hover tool pop-up. While this tool was useful in itself, by offering the reading of exact values, it was applied to the circle graphs showing the absolute count instead of the line graph showing the change rate.

Taking this into account and given the hierarchical improvements list, a design principle that has proven to improve usability is the addition of the interactive functions such as the linked view and zooming and panning options. Participants used these options to read exact values by dragging the view to their specific wanted X and Y range, offering them to identify peaks or lows. As can be seen in the results on efficiency and satisfaction, participants expressed their positive feelings about these features, resulting in enhanced usability.

A few visual variables have been applied to the visualization, each applying their perceptual properties:

Size – The circle graphs use size to represent the absolute death counts. The size linearly related to the absolute death count, only influenced by a scaling factor for the circles to fit in the graph. Given that there is no axis to read the scale for the circles, it seemed hard for some participants to intuitively interpret the value represented by a circle, based on it size. This means that perception of exact quantities is difficult. However, at least an ordered property can be perceived. This was demonstrated when participants used the 'growing of circles' to confirm their conclusions on the change rate, thereby positively influencing the effectivity of the prototype.

Color – Colors have been attributed to different countries, making use of the associative perceptual property of color. The colors of the countries in the left graphs were also used for the same countries in the cumulative total graph, offering for intuitive association. This association improved efficiency of the visualization, as users do not have to look which color corresponds to which country.

2) To what extent can users recognize patterns in data by exploring a visualized derivative change rate?

This sub-question was accounted for by visualizing both the absolute count and the change rates of the chosen dataset. The change rate was visualized by a line graph, the absolute count by circles of varying sizes. The recognition of patterns was tested in the three final testing assignment questions (see Appendix A for the questions). The patterns that could be recognized where a stable positive change rate, an unstable change rate and the difference between a rising negative change rate and a rising positive change rate. The results section on effectiveness (section 5.1.2) shows how these patterns correspond to the different assignment questions.

It can be concluded that the tested patterns could generally be recognized better when looking at the line graph than when looking at the circle graph. The stable positive pattern in the change rate corresponds to a constant grow in the absolute count, represented by growing circles. However, as proved earlier, due to the circles not being effective in showing exact quantities, this pattern is better portrayed by the change rate graph. The same goes for the unstable pattern. While the absolute count would show circles varying a little bit in size, the change rate graph would actually oscillate between positive and negative values, representing a varying increase in daily deaths. The pattern containing the difference between a rising negative change rate and a rising positive change rate could be seen when looking at both variations of the data: a shrinking circle shows the negative direction of change and a growing circle shows a positive direction of change. Participants used this perceptual property of size to confirm their interpretation of the change rate graph.

7.3 Further Research

Based on having performed this research and keeping in mind the limitations as presented in section 6.5, suggestion for further research include the following:

Follow-up study with processed feedback results. The usability testing of the prototype has resulted in rich outcomes, including a hierarchical improvements list. A continuation of this study could be done that implements the suggested improvements, and tests the next prototype with ideally the same participants. This way, the participants are really involved in the development process, as is also recommended in the literature in user centered design (section 2.9). This way, the 5-stage design thinking process can essentially be looped through again for as many times as wanted. An extension of this suggestion could be a follow-up study that uses different tools to build the visualization. This could be different packages, but also a different programming language or tool. By using different tools, limitations can be overcome.

8 References

Andrienko, G., Andrienko, N., Demsar, U., Dransch, D., Dykes, J., Fabrikant, S.I., Jern, M., Kraak, M.-J., Schumann, H., Tominski, C., 2010. Space, time and visual analytics. International Journal of Geographical Information Science 24, 1577–1600. https://doi.org/10.1080/13658816.2010.508043

Andrienko, N., Andrienko, G., 2006. Exploratory analysis of spatial and temporal data: a systematic approach. Springer, Berlin ; New York.

Andrienko, N., Andrienko, G., Gatalsky, P., 2003. Exploratory spatio-temporal visualization: an analytical review. Journal of Visual Languages & Computing, Visual Data Mining 14, 503–541. https://doi.org/10.1016/S1045-926X(03)00046-6

Bateman, S., McDine, D., Mandryk, R., Gutwin, C., Genest, A., Brooks, C., 2011. (PDF) Useful Junk? The effects of visual embellishment on comprehension and memorability of charts [WWW Document]. URL https://www.researchgate.net/publication/221517808_Useful_Junk_The_effects_of_visual_embellishment_on_comprehension_and_memorability_of_charts (accessed 10.8.19).

Bertin, J., 1983. Semiology of Graphics, Diagrams, Networks, Maps. The University of Wisconsin Press, Madison.

Blok, C., 2000. Monitoring Change: Characteristics of Dynamic Geo-spatial Phenomena for Visual Exploration, in: Freksa, C., Habel, C., Brauer, W., Wender, K.F. (Eds.), Spatial Cognition II: Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications, Lecture Notes in Computer Science. Springer, Berlin, Heidelberg, pp. 16–30. https://doi.org/10.1007/3-540-45460-8_2

Blok, C.A., 2005. Dynamic visualization variables in animation to support monitoring of spatial phenomena [WWW Document]. Netherlands Geographical Studies;328. URL http://dspace.library.uu.nl/handle/1874/2895 (accessed 1.5.20).

Brooke, J., 1996. SUS - A quick and dirty usability scale 7.

Compieta, P., Di Martino, S., Bertolotto, M., Ferrucci, F., Kechadi, T., 2007. Exploratory spatio-temporal data mining and visualization. Journal of Visual Languages & Computing, Visual Languages and Techniques for Human-GIS Interaction 18, 255–279. https://doi.org/10.1016/j.jvlc.2007.02.006

Dam, R.F., Teo, Y.S., 2019. 5 Stages in the Design Thinking Process [WWW Document]. The Interaction Design Foundation. URL https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process (accessed 1.6.20).

DiBiase, D., MacEachren, A.M., Krygier, J., Reeves, C., 1992. Animation and the Role of Map Design in Scientific Visualization. https://doi.org/10.1559/152304092783721295

ECDC, 2020. Homepage | European Centre for Disease Prevention and Control [WWW Document]. URL https://www.ecdc.europa.eu/en (accessed 5.25.20).

Ellis, G., Dix, A., 2006. An Explorative Analysis of User Evaluation Studies in Information Visualisation. pp. 1–7. https://doi.org/10.1145/1168149.1168152

Faulkner, X., 2000. Usability Engineering. Macmillan Education UK.

Frank, A.U., 1994. Qualitative Temporal Reasoning in GIS - Ordered Time Scales.

Gaviria, A.R., 2008. When Is Information Visualization Art? Determining the Critical Criteria. Leonardo 41, 479–450.

Giddens, A., 1984. The constitution of society: Outline of the theory of structuration.

Green, M., 1998. Toward a Perceptual Science of Multidimensional Data Visualization : Bertin and Beyond.

Hägerstrand, T., 1970. What about people in regional science. 1970.

Halik, Ł., 2012. The analysis of visual variables for use in the cartographic design of point symbols for mobile Augmented Reality applications. https://doi.org/10.2478/v10277-012-0019-4

Hallin, P.O., 1991. New Paths for Time-Geography? Geografiska Annaler. Series B, Human Geography 73, 199–207. https://doi.org/10.2307/490462

Hochheiser, H., Shneiderman, B., 2001. Visual Specification of Queries for Finding Patterns in Time-Series Data.

Holtz, Y., 2018. Ridgeline plot [WWW Document]. URL www.data-to-viz.com/caveat/ridgeline.html (accessed 6.1.20).

Hullman, J., Adar, E., Shah, P., 2011. Benefitting InfoVis with Visual Difficulties. IEEE Trans. Visual. Comput. Graphics 17, 2213–2222. https://doi.org/10.1109/TVCG.2011.175

International Organization for Standardization, 2018. ISO 9241-11:2018 [WWW Document]. ISO. URL https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/06/35/63500.html (accessed 6.3.20).

Kilchör, F., 2014. Visualizing Excavations Records by Means of Information Design Creating Knowledge Visualizations from Cultural Heritage Data.

Kimbell, L., 2011. Rethinking Design Thinking: Part I. Design and Culture 3, 285–306. https://doi.org/10.2752/175470811X13071166525216

Kobayashi, T., Miller, H., Othman, W., 2011. Analytical methods for error propagation in planar space-time prisms. Journal of Geographical Systems 13, 327–354. https://doi.org/10.1007/s10109-010-0139-z

Koua, E.L., Maceachren, A., Kraak, M.-J., 2006. Evaluating the usability of visualization methods in an exploratory geovisualization environment. International Journal of Geographical Information Science 20, 425–448. https://doi.org/10.1080/13658810600607550

Kraak, M.-J., Edsall, R., MacEachren, A.M., 1997. Cartographic animation and legends for temporal maps : exporation and or interaction.

Kraak, M.-J., Ormeling, F., 2010. Cartography - Visualization of Spatial Data, 3rd ed. Pearson Education Limited, Harlow.

Kwan, M., 2004. Gis methods in time-geographic research: geocomputation and geovisualization of human activity patterns. Geografiska Annaler: Series B, Human Geography 86, 267–280. https://doi.org/10.1111/j.0435-3684.2004.00167.x

Lenntorp, B., 1999. Time-geography - at the end of its beginning 5.

Lloyd, D., Dykes, J., Radburn, R., 2007. Understanding geovisualization users and their requirements–a user-centred approach.

Lonsdale, M., Lonsdale, D., 2019. Design2Inform: Information visualisation guidelines [Report 02].

MacEachren, A., 1995. How Maps Work: Representation, Visualization and Design. Guilford Press, New York.

MacEachren, A., Kraak, J.A., 2001. Research challenges in geovisualization. Cartography Geograph. Inf. Sci 28, 3–12.

MacEachren, A.M., 2001. An evolving cognitive-semiotic approach to geographic visualization and knowledge construction. https://doi.org/10.1075/idj.10.1.06mac

Maceachren, A.M., 1994. Chapter 1 - Visualization in Modern Cartography: Setting the Agenda, in: Maceachren, A.M., Taylor, D.R.F. (Eds.), Modern Cartography Series, Visualization in Modern Cartography. Academic Press, pp. 1–12. https://doi.org/10.1016/B978-0-08-042415-6.50008-9

Miller, H.J., 1991. Modelling accessibility using space-time prism concepts within geographical information systems. International Journal of Geographical Information Systems 5, 287–301. https://doi.org/10.1080/02693799108927856

Natural Earth, 2018. 110m-cultural-vectors | Natural Earth. URL https://www.naturalearthdata.com/downloads/110m-cultural-vectors/ (accessed 5.25.20).

Nielsen, J., Yssing, C., 2002. Getting access to what goes on in people's heads?: Reflections on the think-aloud technique. pp. 101–110. https://doi.org/10.1145/572020.572033

OmniSci, 2019. What is Scientific Visualization? Definition and FAQs | OmniSci [WWW Document]. URL https://www.omnisci.com/technical-glossary/scientific-visualization (accessed 6.1.20).

Peuquet, D.J., 1999. Time in GIS and geographical databases 14.

Peuquet, D.J., 1994. It's about Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems. Annals of the Association of American Geographers 84, 441–461.

Peuquet, D.J., 1988. Representations of Geographic Space: Toward a Conceptual Synthesis. Annals of the Association of American Geographers 78, 375–394.

Peuquet, D.J., Duan, N., 1995. An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. International journal of geographical information systems 9, 7–24. https://doi.org/10.1080/02693799508902022

Provost, F., Fawcett, T., 2013. Data Science and its Relationship to Big Data and Data-Driven Decision Making. Big Data 1, 51–59. https://doi.org/10.1089/big.2013.1508

Saldaña, J., 2009. Chapter 1: An introduction to codes and coding. The coding manual for qualitative researchers 3–21.

Schobesberger, D., 2011. A Meta-evaluation of User Studies on Web-delivered Cartographies. Presented at the International Cartographic Association.

Shaw, S.-L., Yu, H., 2009. A GIS-based time-geographic approach of studying individual activities and interactions in a hybrid physical–virtual space. Journal of Transport Geography, ICT and the Shaping of Access, Mobility and Everyday Life 17, 141–149. https://doi.org/10.1016/j.jtrangeo.2008.11.012

Slocum, T.A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D.R., Fuhrmann, S., Hedley, N.R., 2001. Cognitive and Usability Issues in Geovisualization. Cartography and Geographic Information Science 28, 61–75. https://doi.org/10.1559/152304001782173998

Song, Y., Miller, H., 2014. Simulating visit probability distributions within planar space-time prisms. International Journal of Geographical Information Science 28, 104–125. https://doi.org/10.1080/13658816.2013.830308

Sui, D., 2012. Looking through Hägerstrand's dual vistas: towards a unifying framework for time geography. Journal of Transport Geography, Special Issue on Time Geography 23, 5–16. https://doi.org/10.1016/j.jtrangeo.2012.03.020

Tufte, E.R., 1990. Envisioning information [WWW Document]. Infoscience. URL https://infoscience.epfl.ch/record/25556 (accessed 6.1.20).

Van Elzakker, C.P.J.M., 2005. From map use research to usability research in geo - information processing. ICC 2005 : Proceedings of the 22nd international cartographic conference : mapping approaches into a changing world, 9-16 July 2005, A Coruña, Spain.

van Elzakker, C.P.J.M., Wealands, K., 2007. Use and Users of Multimedia Cartography, in: Cartwright, W., Peterson, M.P., Gartner, G. (Eds.), Multimedia Cartography. Springer, Berlin, Heidelberg, pp. 487–504. https://doi.org/10.1007/978-3-540-36651-5_34

Vasiliev, I., 1997. Mapping time: An analysis of the cartographic problem of representing spatiotemporal information. Geography - Dissertations.

Winter, S., 2009. Towards a Probabilistic Time Geography, in: Proceedings of the 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, GIS '09. ACM, New York, NY, USA, pp. 528–531. https://doi.org/10.1145/1653771.1653861

Winter, S., Yin, Z.-C., 2011. The elements of probabilistic time geography. Geoinformatica 15, 417–434. https://doi.org/10.1007/s10707-010-0108-1

Wu, Y., Miller, H., 2001. Computational Tools for Measuring Space–Time Accessibility within Dynamic Flow Transportation Networks. Journal of Transportation and Statistics 4.

9 Appendix A - Usability Testing Assignments

1) Which country has the least amount of total cumulative deaths, and how many?

2) Which country showed the greatest increase in amount of deaths between two days?

3) What was the amount of that increase?
An error margin of +-10 is fine

4) Which country faced the most deaths on 31 march 2020?

5) Which visualization(s) did you use to find that out?

6) Which country showed the greatest change in amount of deaths on that date (31 march 2020)?

7) Which visualization(s) did you use to find that out?

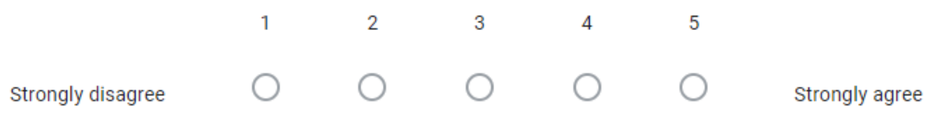
8) Look at the change rate graph for Spain between day 79 and 84. Describe what happens, and include the behavior of the line graph as well as the circle graph in your answer.

9) When looking at the USA data from +- day 90 onwards, what does the oscillation with the high amplitudes mean?

10) True of false: when looking at the data of Germany from day 101 – 105, the amount of daily deaths is rising every day

10 Appendix B – Usability Questionnaire

All questions use the following 5-Likert scale as answer options:



Questionnaire questions:

General:

I think that I would use this type of visualization frequently

I think that I the visualization was too complex

I think that I the visualization was easy to use

I could find all elements where I expected them to be

The interactive functions (such as zooming and pop-ups) are a necessary addition for finding data values

It took quite some time to learn how to work with this data visualization

Section 1:

I could easily find the values I was looking for

I needed instructions for using the graphs

The graphs were hard to use

Section 2:

The map is a valuable addition to the data visualization

I could easily find the values I was looking for

I needed instructions for using the map

Using the map was satisfactory

Section 3:

The graph is a valuable addition to the data visualization

I needed instructions on how to use this graph

I could easily find the values that I was looking for

Using this graph was satisfactory

Final Question:

Do you have any recommendations or tips on how to improve this visualization? This can be targeted at the page as a whole but also at a specific section (see images).