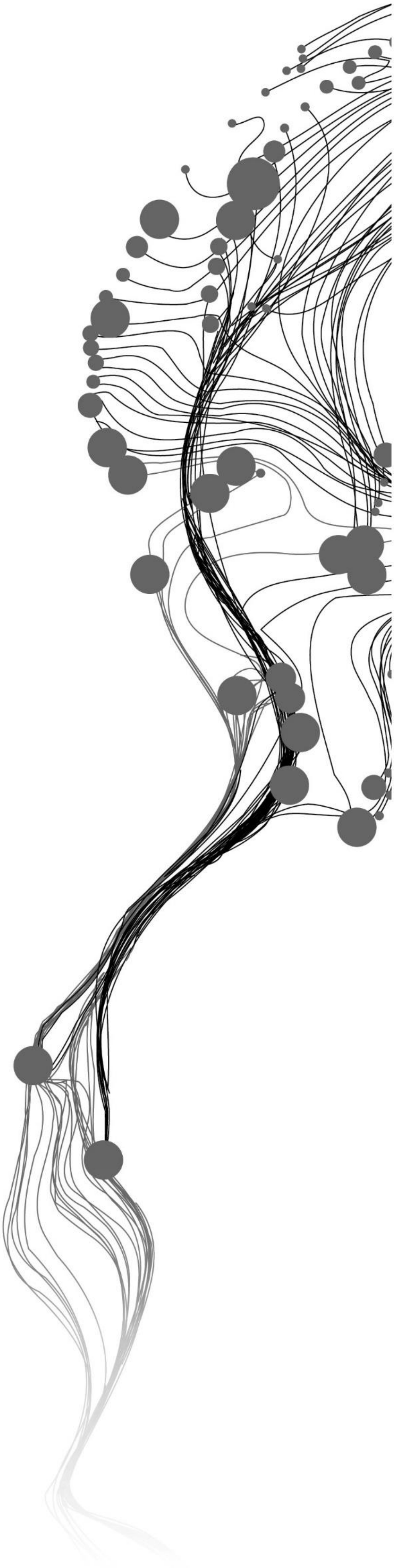

Animated Transitions in Statistical Maps

VALERIIA SHURUPINA

Enschede, The Netherlands, October 2020

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the joint Master of Science in Cartography

SUPERVISOR:

Drs. Barend Köbben

THESIS ASSESSMENT BOARD:

Prof. Dr. M.-J. Kraak (Chair)
Drs. B. Köbben (Advisor)
M.Sc. M. Zahtila (Reviewer, TU Dresden)
Dr. P. Raposo (Local Coordinator)

Cartography M.Sc.

Master thesis

Animated Transitions in Statistical Maps

VALERIIA SHURUPINA

Technical University of Munich
TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology
TECHNISCHE UNIVERSITÄT DRESDEN
ITC UNIVERSITY OF TWENTE.

2020

Abstract

Statistical data is often communicated through data graphics, such as maps and charts. They complement each other in helping to visualize, explore, and analyze statistical data by representing different aspects. With the advent of animation, these graphics became motional, simplifying data analysis and emptying screen space. However, there is no research on animations between spatial and non-spatial statistical graphics. Thus, this study develops possible transitions between maps and charts and determines how they affect user perception. There were two experiments conducted testing the effects on the syntactic and semantic levels of analysis. The results revealed a positive influence of animation on identifying objects with the highest or the lowest value and no effects for tasks in which participants were required to determine trends. An object tracking test showed that tweening is a more effective technique than staging.

Keywords: animated transitions, statistical data, graphics, maps, charts, cartography

Acknowledgements

First of all, I would like to express my gratitude to my supervisor Drs. Barend Köbben for his continuous guidance, help, and patience throughout this thesis. Gratitude also goes to Dr. Paulo Raposo and Dr. Yuri von Engelhardt, I truly appreciate the time you took to talk with me and help with ideas in developing my research.

I cannot thank the Cartography MSc consortium and Erasmus + enough for accepting me to the programme and awarding an Erasmus Mundus scholarship, allowing me to study abroad. I am also thankful for all the people I met for the last two years within and outside the programme and for all the skills and knowledge I gained here.

I am greatly thankful to Juliane Cron for the best coordination and support, especially valuable in challenging pandemic times.

I am grateful to my entire family, especially Mom and Dad, for their unconditional care, love, and support. I am extremely thankful to my brother Stanislav for putting his faith in me and encouraging me to work towards my dreams.

Last but not least, gratitude goes to all my friends and any other person who directly or indirectly helped and supported me.

Contents

List of Figures

Chapter 1

Introduction

This Chapter describes the context of this research. In the beginning, the Chapter explains the motivation and states the main problem. Then, it defines the primary objective of the study and lists its sub-objectives. Further, it addresses the main research questions and identifies innovation. The last Section contains an outline of the research, describing its structure and brief contents of each Chapter.

1.1 Motivation and problem statement

Cartography has always been closely allied with statistics (Clark, 1937). They both aim to compress complex quantitative data into a shape understandable by human eyes and minds, and both try to reach design efficiency (Kruskal, 1975). As the disciplines are intertwined, statistical data might often be communicated by several statistical data graphics at once.

In cartography, statistical maps alone "tend to be inefficient and inaccurate sources of data" because they are "symbolized generalizations of the information contained in a table" (Jenks, 1976). For this reason, quantitative statistical maps are often supported by other graphics, such as charts and graphs. On the other hand, non-spatial data graphics hugely simplify the complexity of statistics and data (Dent et al., 2009). Thus, these graphical techniques complement each other in exploring, visualizing, and analyzing statistical data by displaying different aspects when combined.

With the advent of animation, statistical graphics became motional, displaying variable changes in temporal and non-temporal contexts. Animation simplified detection of patterns, trends, and relationships (DiBiase et al., 1992; Dorling & Openshaw, 1992; Harrower, 2004; M.-J. Kraak, 2007; MacEachren et al., 1998), and helped emptying a screen space by leaving fewer animated single-view statistical graphics instead of tens of multiple static maps (map series), charts or graphs (Griffin et al., 2006). However, even these "reduced" multi-component visualizations seem to be difficult to integrate into a clear cognitive image (Opach et al., 2014), and being animated, they also leave questions on the human ability to pay attention to two or more juxtaposed dynamic views (Blok et al., 1999; Javed & Elmqvist, 2012). Therefore, this research will focus on analyzing perception changes when transitioning between spatial and non-spatial graphics with shared statistical data. This may help to avoid dividing the map reader's attention (Opach et al., 2014), improve cognition (Bederson & Boltman, 1999) and decision-making (Gonzalez, 1996), and increase levels of engagement (Tversky et al., 2002).

As an animated map can be a viable alternative to multiple static maps (Dent et al., 2009; Griffin et al., 2006), animated transitioning between maps and diagrams can also become an alternative to juxtaposed views. However, it is not clear what kind of animated transitions are possible between maps and diagrams and how they might affect user perception.

1.2 Research objectives and questions

The current study's main objective is **to determine how animated transitions from statistical maps to charts and vice versa change user perception**. To accomplish this, the study has the following sub-objectives:

1. To describe possible animated transitions between statistical maps and charts;
2. To develop working examples of the suggested transition types;
3. To test and analyze if and how the animated transitions affect user perception.

The results of the suggested research can contribute to the area of data visualization, specifically quantitative thematic cartography and statistical data graphics. This study could be valuable to cartographers, data graphics and user interface designers, statisticians, storytellers, and journalists to find more efficient ways to explore, analyze, and design statistical data representations.

To meet the aforementioned objectives, the following research questions need to be addressed:

- Q1 What are the possible ways to transition between statistical maps and charts?
- Q2 How do animated transitions affect the map reader's perception?
- Q3 Does the change in perception improve the understanding of patterns, trends, or relationships in statistical data?

1.3 Innovation aimed at

There has been much research dedicated to animation, in particular, in statistical data graphics. Along with it, many studies worked on how animation affects the perception, cognition, and decision-making of users. However, there was no research working on finding and describing possible transitions between spatial and non-spatial data graphics and their helpfulness in exploring and analyzing statistical data. Therefore, the current research aimed to fill the gap in the theory and started from animated transitions between maps and charts.

Moreover, due to the relatively recent advent of simple and accessible tools for cast-based animation design, not many studies in thematic cartography investigated this technique. Thus, the suggested research could serve as an addition to the limited number of studies using cast-based techniques.

1.4 Outline of the thesis

The First Chapter explains the research's motivation and problem statement and determines research objectives, questions, and innovation. The Second Chapter introduces the basics of visual encoding principles and graphic components, and gives an overview of statistical maps and animated transitions in related studies. The Third Chapter designs possible animated transitions between statistical maps and charts answering Q1. The Fourth Chapter describes the methodology of the research, the process of designing selected animated transitions and conducting the experiments, used data, tools, and results. The Fifth Chapter interprets the experiment results and answers to Q2 and Q3. The closing Sixth Chapter summarizes all the work and gives recommendations for further research.

Chapter 2

Background and Related Work

This Chapter describes components of graphical representations that serve as the main elements involved in transitions. To justify the choice of selected charts and maps for transitions design, it explains visual encoding principles and types of information that statistical graphics use. Section 2.2 gives a definition of statistical maps and seeks for a broad classification, covering most of their types, to find the most common and diverse ones and use them for further animated transitions design. The concluding Section 2.3 gives an overview of ways to characterize animated transitions in related studies and describes some of the techniques affecting animation efficiency.

2.1 Graphic components, visual encoding principles, and data types

Data visualization is a graphical representation of data ”expressing meaning by way of graphic relationships between graphic components” (Engelhardt & Richards, 2018). Graphic components may be shapes, lines, symbols, pictures, or words.

Representing graphic relationships between graphic components, data visualization helps to see and understand trends, outliers, and patterns in data. Richards and Engelhardt distinguish 16 general types of visual components (Richards & Engelhardt, 2020). The most important for the current study are:

- **Bands** function as ’path indicators’ connecting two other visual components and use width representing different quantities. They can also point directions using arrows.
- **Bars** are rectangular components with heights or length proportional to the values that they represent.

- **Partitions** are the result of proportional partitioning. For example, the segments of a pie chart.

- **Surface locators** are indicated locations of surfaces within an area of visualization that is structured by picturing, mapping, or positioning within some other coordinate system. For instance, administrative divisions on a map.

- **Symbols** are basic visual components to which none of the above applies.

Visual components can depict graphic relationships ”by their respective spatial positions, by having the same color or different sizes, by being connected by lines, etc.” (Engelhardt & Richards, 2018). They can represent several different relationships at the same time, making use of several visual encoding principles. Among the basic principle types are depicting, scaling, ordering, grouping, and linking (figure 2.1).

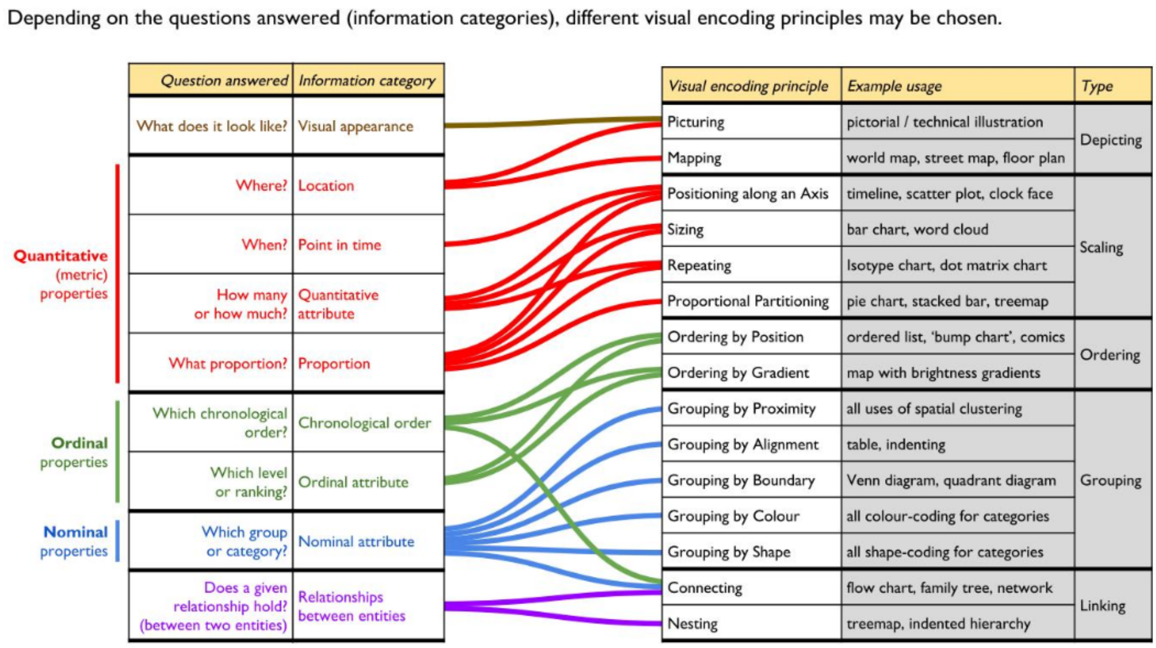

Figure 2.1: Interdependencies between types of information and the visual encoding principles (Engelhardt & Richards, 2018)

All the basic visual elements of data visualization, such as maps, charts, or graphs, are based on the same visual encoding principles. Thus, by combining them, it is possible to describe a vast design space of visualizations. Examples of visual representations for some of the visual encoding principles are shown in figures 2.2 and 2.3. For instance, most of the charts and graphs refer to the scaling principles based on positioning along an axis, sizing, repeating, or proportional partitioning. Maps generally belong to the mapping visual encoding principle, and being combined with other visual principles, may represent even more types of information and data.

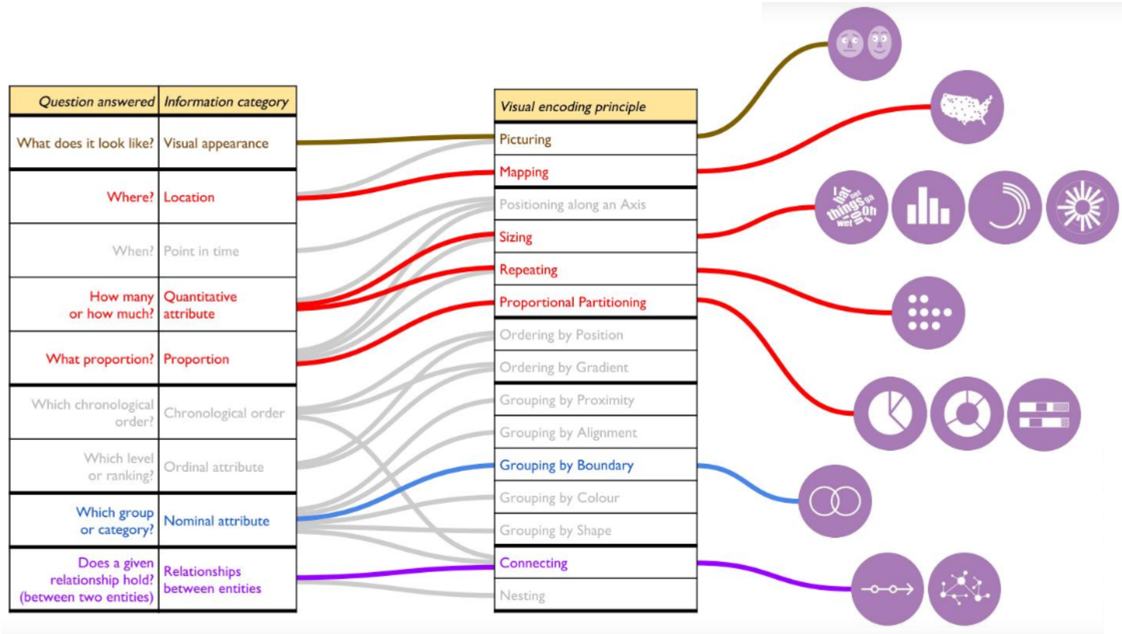

Figure 2.2: Usage examples of visual representations for some of the encoding principles (Engelhardt & Richards, 2018)

Among the main data types used in graphical representations are nominal, ordinal, interval, and ratio. *Nominal* data distinguishes qualitative features based on their textual or descriptive attributes such as male or female, green or red, etc. *Ordinal* defines feature categories based on a rank according to quantitative measure. Both interval and ratio types represent only quantitative numeric data. *Interval* scales rank features showing the exact value differences between categories. Similarly to the interval, *ratio* scales order categories, showing the differences between their values and calculating them along with an absolute zero, which simplifies work with statistical data. Figure 2.1 shows interdependencies between data types and the visual encoding principles that can be used to represent them.

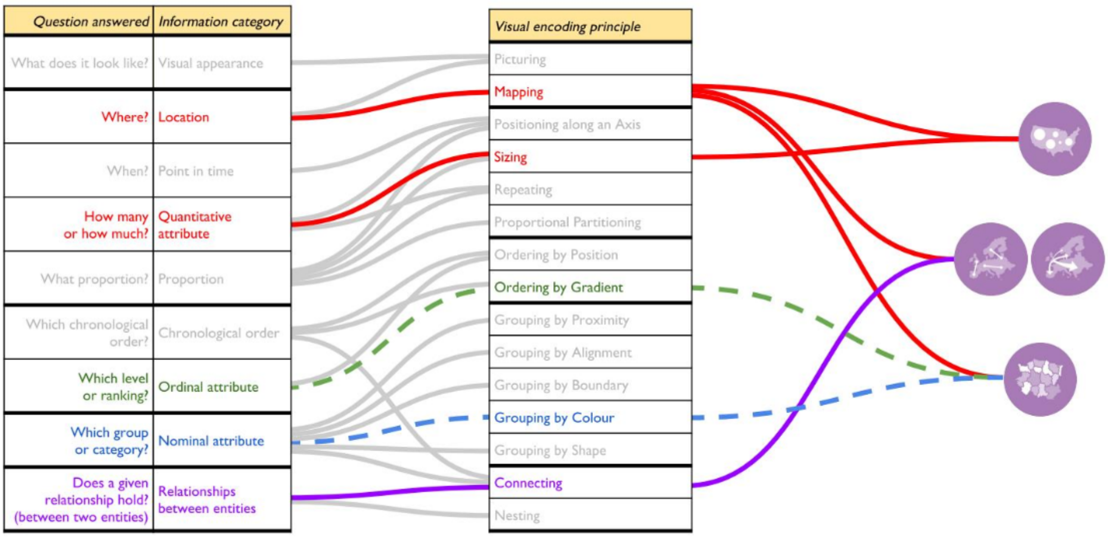

Figure 2.3: "Mapping" in combination with other encoding principles (Engelhardt & Richards, 2018)

2.2 Statistical maps and their visual encoding principles

A statistical map, or a quantitative thematic map, is a type of map showing the spatial attributes of quantitative geographic phenomena (Dent et al., 2009). The map's primary purpose is to characterize the level or degree at which phenomena change from place to place.

There are various types of statistical maps. Most are well covered with Kraak and Ormeling's classification shown in figure 2.4. It subdivides map types based on the measurement scale, corresponding graphical variables, and (dis)continuity of the data at the same time (M. Kraak & Ormeling, 2013).

The measurement scales are traditionally divided into nominal, ordinal, interval, and ratio scales and were already described above (M. Kraak & Ormeling, 2013).

Graphical or visual variables are symbols applied to a map in order to communicate information to the map reader (Dent et al., 2009). These include variables of location, size, shape, orientation, texture, saturation, and value.

(Dis)continuous data is a type of data change that can be smooth or abrupt (M. Kraak & Ormeling, 2013). The smoothness of the change describes the continuous or discrete distribution. *Continuous* data can technically have an infinite number of steps, which form a continuum, while *discrete* data has finite values (Sauro & Lewis, 2012).

All statistical maps can be described with the visual encoding principles mentioned above. Two visual encoding types work with spatial and statistical data: depicting

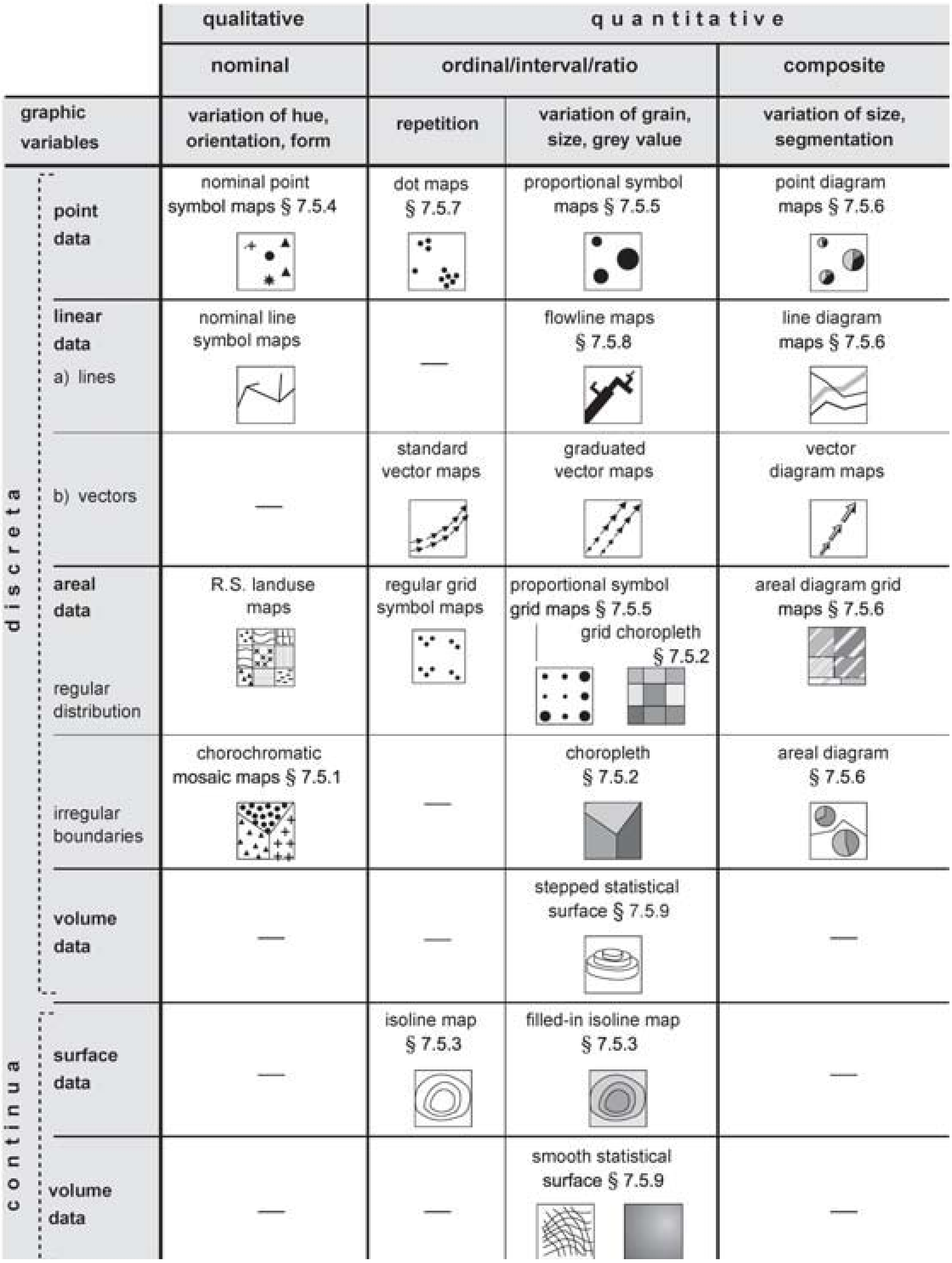

Figure 2.4: Classification of map types based on the measurement scale, corresponding graphical variables and (dis)continuity of the data (M. Kraak & Ormeling, 2013)

and scaling. Depicting can represent the visual appearance and/or spatial location, and scaling shows quantitative attributes of entities or percentage of total (Engelhardt & Richards, 2018). Among their encoding principles are:

- **Mapping** displays a two-dimensional layout of physical configurations (spatial location).
- **Positioning along an axis** describes all the data graphics that use a line(s) with a predefined scale, along which all the graphical components arranged. It can be a horizontal/vertical line with rectangular coordinates or a radial line with polar coordinates. Among the examples are timelines, clock faces, line charts, and scatter plots.
- **Sizing** changes the graphical components' size in accordance with the quantitative attributes or percentage of the total. It is widely used in bar charts and word clouds.
- **Repeating** arranges graphical components into arrays of proportional size. It works with quantitative attributes or percentage of total and applies to isotype and dot-matrix charts.
- **Proportional partitioning** shows the percentage of total by dividing a given surface area into proportional segments. This encoding principle is a key in pie charts, stacked bars, and treemaps.

Figure 2.3 demonstrates examples of combining mapping with other visual encoding principles. For instance, a proportional symbol map is a combination of mapping and sizing, (in)directed flow maps can consist of mapping and connecting, and choropleth is a mix of mapping, ordering by gradient, and grouping by color encoding principles.

2.3 Characteristics and the use of animated transitions

Animated transitions are responsible for the visual connection of two or more visualization states. They help to follow changes and keep users oriented during an animation (Tversky et al., 2002). The most common examples in cartography are panning and zooming or animated map series at different time spans. However, the vast majority of cartographic studies consider transitions only within a map representation and do not discuss their potential usage along with other graphical representations (Battersby & Goldsberry, 2010; Karl, 1992). The current research seeks for the possible animated transitions from statistical maps to charts and vice versa.

There are different approaches to describing animated transitions in related studies. Chalbi characterizes dynamic changes in information visualization based on the four following dimensions: when, who, what, and how (Chalbi, 2018). *When* defines the duration of a dynamic change answering between which time steps or across which time steps a given change happened. *Who* describes the scope, specifying which entity in the visualization was affected by a dynamic change. *What* defines the type of the change, in other words, what happens to a visual item and what changes. *How* determines the manner of a dynamic change: the direction of the change, the value of the change, shape of the change, rate of the change, and cardinality of the change.

Heer and Robertson (2007) describe transitions between data graphics in the context of dynamic statistical visualizations. They identified transitions "by considering the syntactic or semantic operators one might apply to a data graphic" (Heer & Robertson, 2007). This means that the focus is aimed at the actual visual marks, their composition (syntax), and the meaning of the graphic (semantic). The latter defines how the visual marks represent data values and relations among them. There is also a third pragmatic level that focuses on how meaningful symbols convey information above or beyond the direct semantic interpretation, but it is not included in their study.

In other words, semantics are responsible for displaying the data dimensions and values, and syntax - for the description of the visual elements with position, size, shape, transparency, color hue, and value. Therefore, transitions between graphics can be modeled as dimension changes resulting in the description changes of visual elements (Heer & Robertson, 2007). By considering these levels, the authors categorized seven types of transitions:

- *View Transformation*

  Change of a viewpoint such as panning or zooming. It is a syntactic operator, which means that schemas (dimensions) and visual encodings remain untouched.

- *Substrate Transformation*

  Change of a spatial substrate, for example, axis rescaling or log transforms.

- *Filtering*

  Specifies which elements stay visible and which not by adding or removing them from a display.

- *Ordering*

  Spatial rearranging of ordinal data dimensions.

- *Timestep*

  Makes transitions based on temporal data values. The common example is a transition between values of the current and previous years.

- *Visualization Change*

  Change of visual mappings applied to the data, such as switching between data representation in a bar chart and a pie chart.

- *Data Schema Change*

  Change of data dimensions being visualized. For example, adding a new data column to visualization might result in several possible bivariate graphs.

Each of the types describes an action that is applied to the initial visualization state: change of a viewpoint, of visual mappings, or data dimensions. However, the manner of transiting between the start and end visualization states can be modeled in different ways (sharp, abrupt, etc.), influencing efficiency, and users' perception. Tweening and staging are the most common techniques for that.

Tweening (morphing) is an interpolation technique combining starting and ending visualization states. Several software libraries support interpolated transitions of numbers, colors, and geometries. For instance, one of them is D3.js library (Bostock et al., 2011).

Staging, in visualization, refers to the decomposition of animation into steps (Chalbi, 2018). It helps to reduce cognitive and perceptual load when tracking or understanding complex animated visualizations.

These and similar techniques can also use additional tools to improve animations such as timing or staggering (Dragicevic et al., 2011). Timing describes the aspects of animated transitions related to their duration. The animation can be designed at a constant rate having fixed speed throughout its duration; with slow-in/slow-out temporal distortion causing a motion to speed up gradually and then slow down; using fast-in/fast-out effect accelerating the middle of the animation; or an adaptive rate slowing down the animation endpoints (Dragicevic et al., 2011). Staggering works with delays of individual graphic elements to prevent occlusions of moving graphic components (Kim & Heer, 2020).

2.4 Conclusions

There are certain basic graphic components that all the graphical representations consist of. They can serve as the main building elements for animated transitions design between spatial and non-spatial graphics.

Visual encoding principles make use of visual components to represent different types of data. Combinations of the principles can describe the vast majority of graphics with spatial and non-spatial data. The current research used these basics to select the most common but diverse types of graphics.

To find the most common statistical maps, this study used the classification proposed by M. Kraak and Ormeling (2013). It is based on the measurement scale, corresponding graphical variables, and (dis)continuity of the data covering most statistical maps.

To design the manner and the type of transitions, the Chapter reviewed related studies. They characterize animated transitions in many ways, such as *when, who, what, and how* dimensions or with syntactic and semantic operators (Chalbi, 2018; Heer & Robertson, 2007). Based on the categorization of transition types proposed by Heer and Robertson (2007), transitions between maps and charts within a single view can be best described with *visualization change*. To enhance animation efficiency, the designing part can apply additional techniques and parameters such as tweening, staging, timing, or staggering.

Chapter 3

Transitions between statistical maps and charts

This Chapter selects statistical graphics based on their graphic components and visual encoding principles, data types and (dis)continuity to design meaningful transitions. In the second part, it designs and describes possible animated transitions between spatial and non-spatial statistical data representations answering to Research Question 1.

3.1 Selection of maps and charts

For this study, three standard charts and three map types were considered for designing transitions between them. Each represents quantitative statistical data at discrete enumeration units and can demonstrate a visual change of those entities during transitions.

Referring to the paper of Engelhardt and Richards (2018), the research selects one chart type for each visual encoding principle consisting of different graphical components (figure 3.1). They are:

- **Scatter plot** (chart) is a graphical representation displaying numerical values at discrete entities (similarly to the bar chart) with the use of dots. It corresponds to positioning along with an axis visual principle and uses symbols as graphic components.
- **Bar chart** is a chart presenting quantitative data with rectangular bars with heights or lengths proportional to the values that they represent. It is described with the sizing encoding principle and uses bars as graphic components.

- **Pie chart** is a statistical graphic represented as a circle divided into sectors to illustrate numerical proportion. This type of chart belongs to the proportional partitioning encoding principle and uses partitions (sectors) as graphic components.

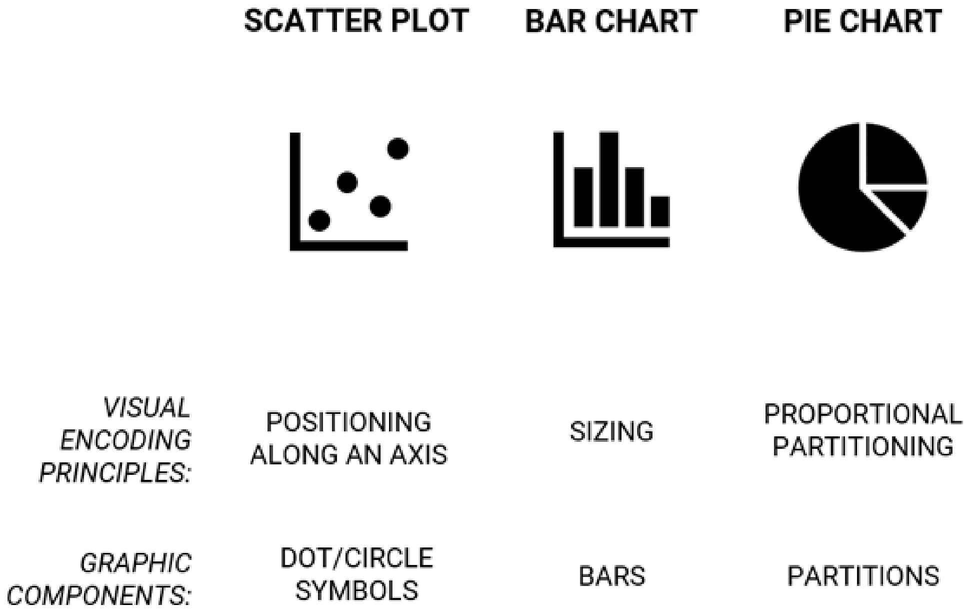

Figure 3.1: Selected charts

The current research omitted the repeating encoding principle because it uses multiple graphic components to represent an entity. The transition of such an entity is challenging to design and analyze.

The choice of the most common map types was based on Kraak and Ormeling's classification (figure 2.4). Each of the selected types uses different basic spatial elements, combinations of visual encoding principles, and graphic components. Thus, the following types of statistical maps are selected (figure 3.2):

- **Proportional symbol map** makes use of symbol forms graduated across the area in proportion to the value (Dent et al., 2009). Symbol forms may be pictorial, literal, and, the most popular, geometric. The proportional symbol map is often used with raw (totals) or standardized (percentages, ratios) data aggregated at points or within areas.

  This map represents a combination of mapping and sizing visual encoding principles.

- **Flow map** depicts movements between places (Dent et al., 2009). In statistical mapping, the technique uses line widths in proportion to quantities, thus representing how much data migrated, or in other words, it uses bands as graphic

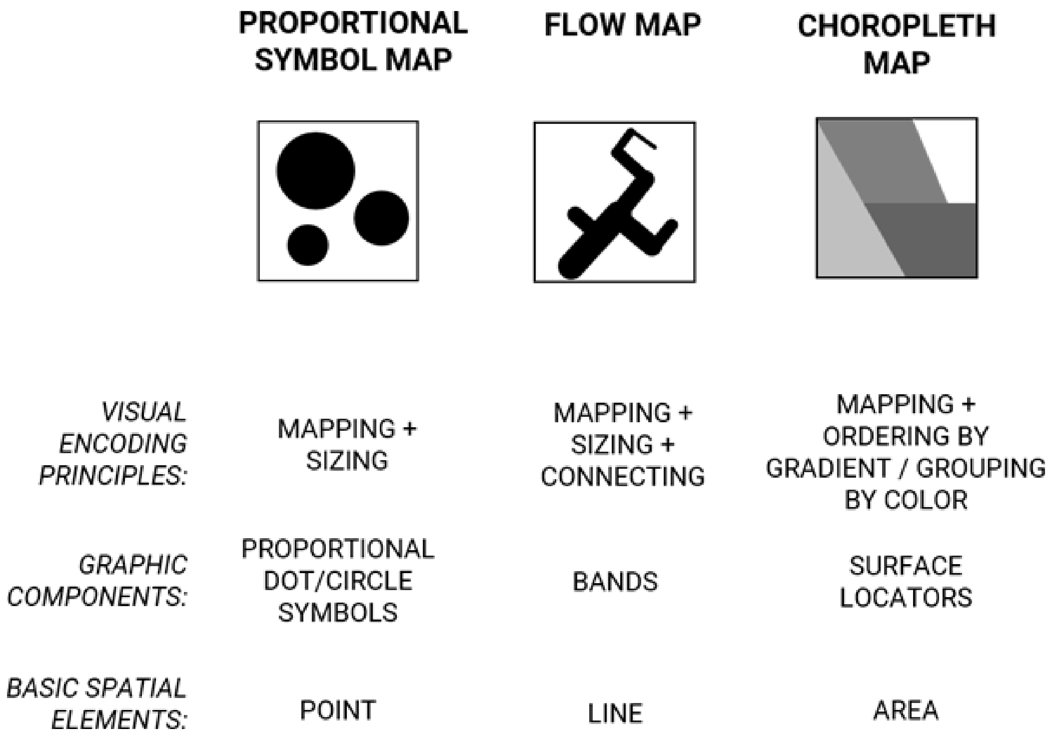

Figure 3.2: Selected maps

components. There are two main types based on direction presence: directed/vector and undirected/flow maps. They perfectly work with any data displaying movement between places in totals, proportions, or ratios. In most cases, data is usually grouped into categories so that individual values cannot be read or recovered with the original value.

Flow maps belong to the mapping, sizing, and connecting encoding principles.

- **Choropleth map** uses a shaded or colored areal symbol to display aggregated data over predefined enumeration units (Robinson, 1995). In statistical mapping, enumeration units are often represented as administrative divisions, and their attribute data is either raw or standardized.

  Choropleth maps are based on mapping, ordering by gradient, or grouping by color visual encoding principles. Their essential graphic components are surface locators.

There are several reasons why among selected map types, only three options were taken. Firstly, the qualitative types from the Kraak and Ormeling's taxonomy are not taken into account because this research works only with quantitative statistical data.

Secondly, maps with composite, continuous, and volume data might be too difficult to work with when transiting between data graphics. Composite maps are complex representations of data that contain maps and diagrams simultaneously so that it would be either meaningless or not needed to transit to another type of graphics. Maps containing continuous or volume data are not taken at this stage either because they represent a continuum that needs to be quantized. Moreover, transitioning from a map, enumeration units lose their meaning in a statistical chart.

Thirdly, maps with repetitions that ordinarily show only one fact or attribute and do not provide any absolute figures that could be mapped on a chart are not included (Robinson, 1995). Among them are dot, standard vector, and regular grid symbol maps.

Similarly to continuous and volume maps, proportional symbol grid and grid choropleth maps are not based on statistical map areal enumeration units such as districts, provinces, or countries. The map displays statistical data across grid cells, which makes transitioning from selected maps to charts meaningless.

Another type of map whose transition effectiveness would be hard to evaluate is a value-by-area cartogram. It represents enumeration units distorting their shape and size so that it would need an extra transition to a recognizable state. Thus, during the experiment, it will be difficult to distinguish which transition exactly and how it changes the user perception. The same is true for indirect transitions via other types of maps, such as Dorling's or Demer's cartograms.

3.2 Design of transitions

Referring to Heer and Robertson (2007), the design of transitions between maps and charts would be best described with *visualization change* when graphic components change their position and shape. Thus, nine basic pairs of transitions between maps and charts were designed and presented in figure 3.3. Among them:

1. **Scatter plot - Proportional symbol map**

   Symbols of a scatter plot transform to proportional symbols on a map, changing their size and location.

2. **Scatter plot - Flow map**

   A scatter plot's symbols transform to the bands (lines) of a flow map changing shape, size, and location.

3. **Scatter plot - Choropleth map**

   A scatter plot's symbols transform to the surface locators (areas) of a choropleth, changing shape, size, and location. Since choropleth uses colors for grouping or ordering values, the scatter plot symbols can also be colored.

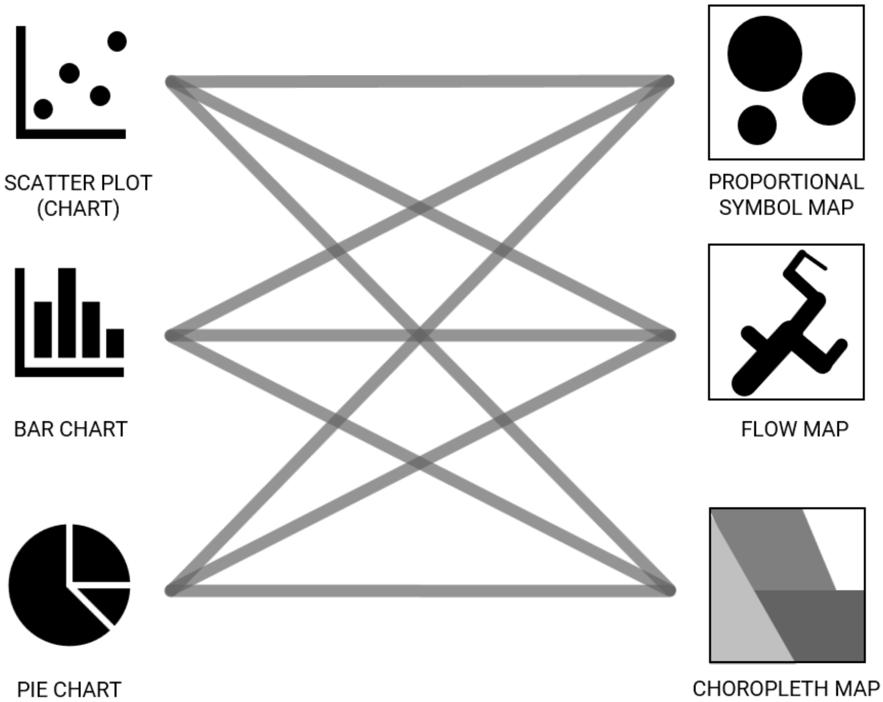

Figure 3.3: Possible transitions between maps and charts

4. **Bar chart - Proportional symbol map**

   Bars transform to proportional symbols on a map changing shape, size, and position.

5. **Bar chart - Flow map**

   Bars transform to the bands (lines) of a flow map changing shape, size, and position.

6. **Bar chart - Choropleth map**

   Bars transform to the surface locators (areas) of a choropleth map, changing shape, size, and positions. Since choropleth uses colors for grouping or ordering values, the bars can also be colored.

7. **Pie chart - Proportional symbol map**

   Partitions transform to the proportional symbols on a map changing shape, size, and position.

8. **Pie chart - Flow map**

   Partitions transform to the bands (lines) on a flow map changing shape, size, and position.

9. **Pie chart - Choropleth map**

Partitions transform to the surface locators (areas) on a map changing shape, size, and position. Since choropleth uses colors for grouping or ordering values, the partitions can also be colored.

All of the transitions are possible in both directions: from charts to maps and from maps to charts. They can consist of the various numbers of graphic components and use different techniques and parameters described in Section 2.3 to make this animated visualization change more efficient.

3.3 Conclusions

For this research, three standard charts and three map types were considered for designing transitions between them. Among them are scatter plot (chart), bar chart, pie chart, proportional symbol map, flow map, and choropleth map. Each represents quantitative statistical data at discrete enumeration units and can demonstrate a visual change of their graphic components during transitions.

Thus, nine basic pairs of transitions between selected maps and charts were designed. Each can apply additional transition techniques described in 2.3 in order to enhance the animation ability to represent and communicate statistical data. Following up on this, the fourth Chapter develops designed transitions and tests their effects on a map reader's perception with experiments.

Chapter 4

Research Methodology

It is uncertain if and how transitions designed in Chapter 3 affect a map reader's perception (Research Question 2) and understanding of patterns, trends, or relationships in statistical data (Research Question 3). Therefore, this research conducted experiments to test this. This Chapter describes the methodology and general workflow of transitions development, data and task preparation, and experiment conduction.

4.1 Workflow

To answer how transitions affect map reader's perception (Research Question 2), the research analyzes perception change in animated graphics at the syntactic and semantic levels. The syntactic test reveals the effects of transitions on recognizing and locating transforming objects in shape, size, and position. The semantic analysis seeks if animated graphics improve understanding of statistical data, thus answering Research Question 3. To test these two levels, two experiments were prepared.

The first experiment sets an object tracking test considering transitions and map types, the order of transitions, and the number of animated graphic components. The second experiment is narrowed down to identifying map trends and objects with the highest/lowest values. The evaluation of results is based on answers' accuracy, time spent on completing each task, and subjective preferences.

Due to complexity and time-consuming development, only one type of chart and two types of maps were selected: bar chart, proportional symbol, and choropleth maps. Thus, the experiments examine only two examples of designed animated transitions from Chapter 3.

The workflow of the experimental part was comprised of the following steps:

1. Selection of several designed animations and data preparation;
2. Animated transitions and experiment tasks development;
3. Survey implementation and results based on the:
    - Correctness of the answers;
    - Time of completing each task.
4. The analysis and interpretation of the results (described in the following Chapter 5) considering:
    - The participants' qualitative responses.

4.2 Data

The experiment tasks do not have to contain real statistical data. Therefore, numerical data is designed in accordance with the task needs. For instance, if it is a task with trend determination, it has increasing values in one cardinal direction.

Geometry is used depicting the municipalities of the Netherlands, districts of Germany, and Austria. Administrative borders of Germany and the Netherlands in GeoJSON format in different quality levels were taken from GitHub repositories (https://github.com/isellsoap/deutschlandGeoJSON, https://github.com/cartomap/nl). Austrian municipal boundaries were downloaded from the website of the Institute for Strategy Analysis (ISA) (https://wahlen.strategieanalysen.at/geojson/).

Using QGIS, statistical data was manually added to the geometry layer. It was then exported as GeoJSON and, using the MapShaper tool, converted into TopoJSON and simplified, reducing the files' size for better computer performance and animation smoothness.

4.3 Development of animated transitions

JavaScript is a scripting language enabling the design of dynamic and interactive content and working closely with Hypertext Markup Language (HTML) and Cascading Style Sheets (CSS). It was chosen as the main tool to develop animated transitions and experiment tasks.

D3.js is a JavaScript library that "binds arbitrary data to a Document Object Model (DOM), and then applies data-driven transformations to the document" (Bostock et al., 2011). Within this research, it brings functions such as d3.geoMercator() to map spatial geometry data and d3.geoPath() to project geographic coordinates into Scalable Vector Graphics (SVG) path data. It also helps with incorporating transitions into the visualization, particularly for fading in and fading out of the axes, labels, and background graphic components.

To ease the working process with interpolating shapes, sizes, and positions between bars and map graphic components, this research used KUTE.js. This is another library working with "complex animations, with properties or elements that cannot be animated with CSS transitions or other animation engines, or attributes that are not even drafted in the specification yet" (KUTE.js Documentation, 2020). Its component *SVG Morph* was used to design smooth and abrupt interpolated transitions using coordinates of the SVG path data and control animation duration.

To test if there is a difference in user perception between tweening at a fixed rate and staging animation techniques, both were included in the survey. Additionally, the staged animation was split into 2 versions with a sharp and smooth (tweened) change of shape, resulting in 3 categories:

I Graphic components *sharply* change their shape, then smoothly interpolate their size and position (staged);

II Graphic components *smoothly* change their shape, then smoothly interpolate their size and position (staged);

III Graphic components simultaneously tween (smoothly interpolate) their shape, size, and position.

Finally, 24 animated tasks were developed for the first experiment. They combined 3 different transitions, 2 types of maps, 2 transition orders, and 2 levels of complexity containing a different number of graphic components (5 and 8).

For the second experiment, 6 animated tasks were developed (not including 2 static tasks). Each of them used 3 types of transitions in combination with 2 types of maps.

All the tasks were created as independent HTML components, published on the GitHub repository (storage space for projects), and hosted through GitHub Pages to be used in the online survey tool (https://valeriiashur.github.io/maps2charts/index.html).

4.4 Survey implementation and results

To cover a greater number of participants, the experiments were launched online using a service SoSci Survey (https://www.soscisurvey.de). It is a tool for creating online surveys and hosting them on the service server. It helps design questions with selections and multiple choices, require participants to fill in the answer and not leave a field blank, record time of completing each task and export the results in various formats. Another reason to chose this service is the possibility to insert HTML code containing links to third-party websites, which was used to place designed tasks from GitHub.

Two experiments were launched separately since going through both in a row could have taken too long, affecting the results due to subjects losing interest and focus. Participants were also free to go through only one or both surveys; therefore, the number of participants in the experiments differs. The invitation to take part was posted and distributed through Facebook, LinkedIn, and email, mentioning that users should use a standard PC.

4.4.1 Experiment 1: Object Tracking

The first experiment was designed similarly to that described by Heer and Robertson (2007). It tests the effects of animated transitions at the syntactic level of analysis and can support the assumption that transitions improve the graphical perception of recognizing and locating transforming objects.

At the start, subjects were given an experiment description, instructions, and general questions about gender, age, and familiarity with static and animated statistical data graphics. Then, the main part containing 24 animated tasks (described in Section 4.3) asked to look at the initial graphic and find two required objects, click on a button to start the animation, track the objects (not using a mouse cursor), find their location in the final graphic, and choose the right answer. The tasks with both correctly defined end positions were considered correct, with 1 correct and 1 wrong answer - half-correct, and with no correct matches - wrong. The animation button was limited to only one click to prevent multiple attempts to solve the same task.

Participants were not asked about their familiarity with the areas since the tasks use fake statistical data, and it is not obvious in which direction graphic components would move. Therefore, it should not affect the experiments' results.

To ensure that users do not rely on labels, object names in initial graphics fade out during transition, and simple numbers fade in the final graphics.

In the end, 5 questions were aimed to ascertain subjective preferences on the helpfulness of the animation. If they found some more helpful than others, they had to rank transitions from the least to the most helpful. Three other questions asked about the effects of transition types, animation order, and level of complexity on participants' visual perception. In total, there were 9 qualitative questions with selections and text input options prepared.

The number of people who participated in the experiment was 53 (22 female, 31 male). Their ages ranged from 22 to 65 (*M* = 33.5, *SD* = 10.9). All of them had previous experience with *static* statistical data graphics and only 39 had experience with *animated* statistical representations.

The calculation of percentage among correct, half-correct, and wrong answers highlighted animated transitions with the lowest and the highest number of correct answers (figure 4.1). The highest number of correct answers was given using a smooth interpolated transition (III) and amounted to 87%. Both staged animations with sharp (I) and smooth changes (II) of shape had similar results - 73% and 74% accordingly.

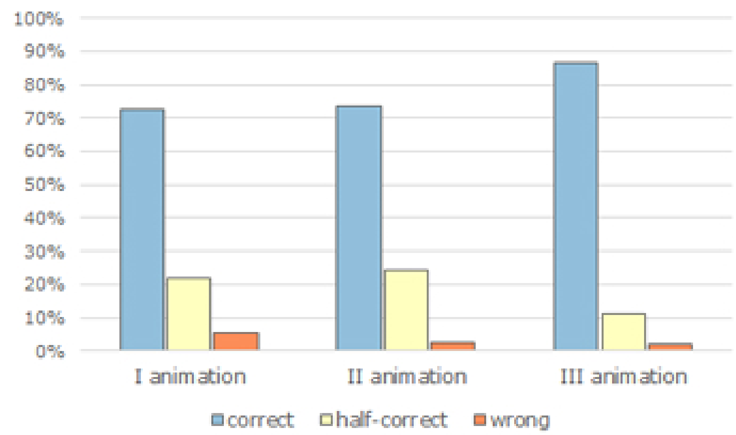

Figure 4.1: Experiment 1: percentage of correct and wrong answers in object tracking among different transitions

The results slightly differed when using different types of maps (figure 4.2). Graphics based on proportional symbol maps represented a higher number of correct answers: animation I was 74%, animation II was 77%, and animation III was 89%. In choropleth transitions: animation I gained 72% correct answers, animation II - 70%, and animation III - 84%.

The average time of completion the tasks with different animations is presented in figure 4.3. The mean value of animation II was 64 sec (*SD* = 912), animation I - 26 sec (*SD* = 30), and animation III - 17 sec (*SD* = 12).

Additionally, the tasks tested the impact of transition order and the number of animated graphic components. The result is displayed in figure 4.4. Overall, graphics transiting from charts to maps tended to have more accurate results. Transiting from maps to charts, animation I had 67%, animation II - 71%, and animation III - 83% correct answers. Transiting from charts to maps, animation I gained 79%, animation II - 76%, and animation III - 91% correct answers.

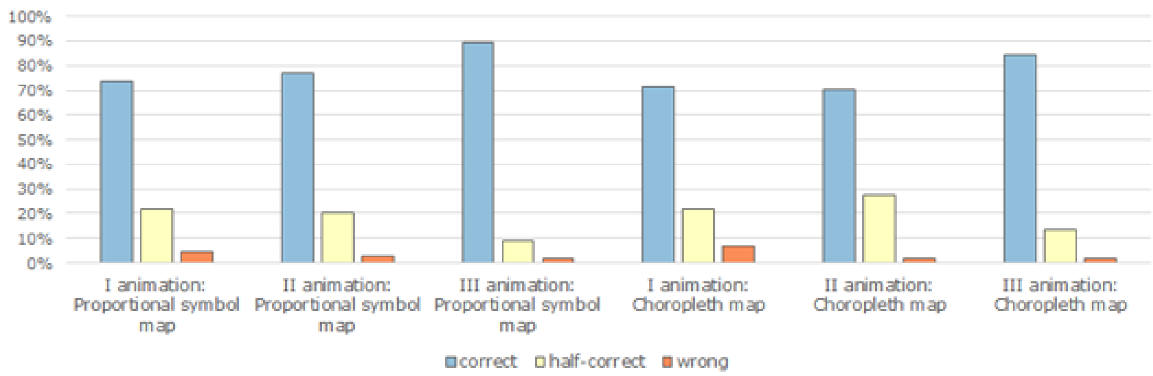

Figure 4.2: Experiment 1: percentage of correct and wrong answers in object tracking among different transitions and types of maps

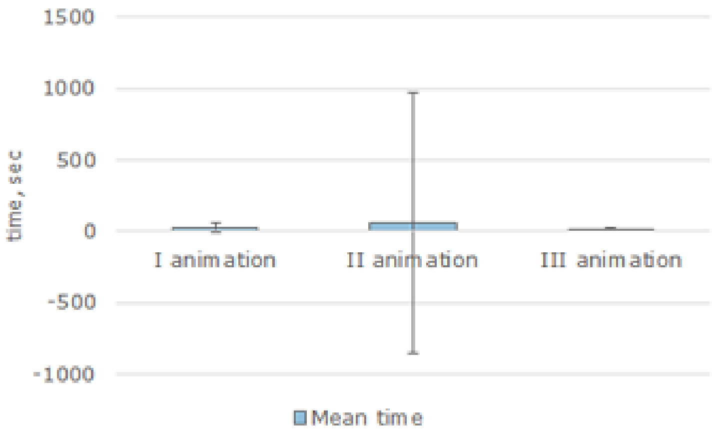

Figure 4.3: Experiment 1: time of completing the tasks in object tracking

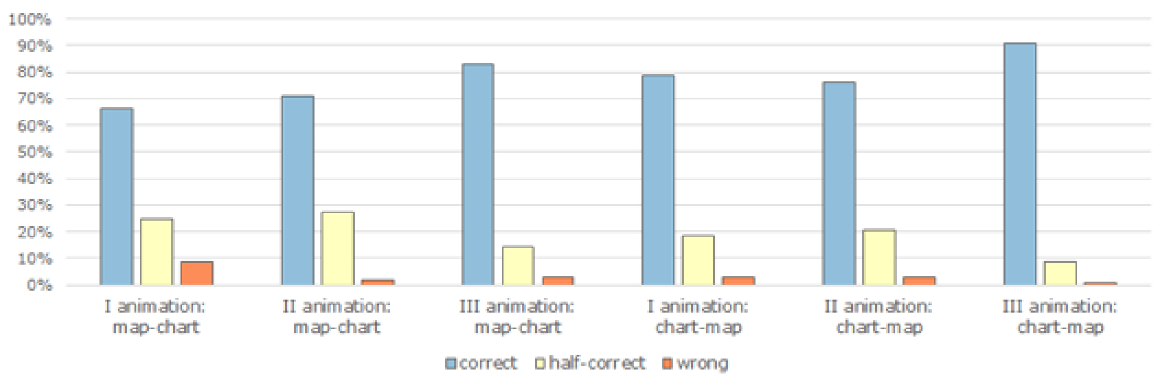

Figure 4.4: Experiment 1: percentage of correct and wrong answers in object tracking among different transitions with different transition order

The variations in results between 5 and 8 animated graphic components are shown in figure 4.5. Generally, tasks with 5 components had a higher number of correct answers: animation I - 85%, animation II - 83%, and animation III - 95%. Among tasks with 8 components, animation I had 60%, animation II - 65%, and animation III - 80%.

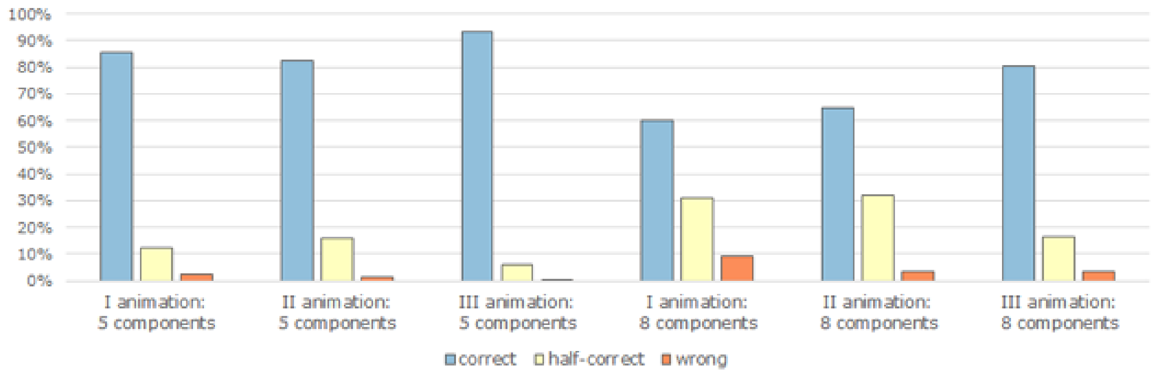

Figure 4.5: Experiment 1: percentage of correct and wrong answers in object tracking among different transitions with different number of animated graphic components

4.4.2 Experiment 2: Underlying Data Understanding

The second experiment tested whether animation facilitates the graphical perception of underlying data understanding by comparing tasks with the three mentioned above animated transitions and static juxtaposed graphics. It is focused on the semantic level of analysis, revealing its efficiency in defining trends and determining values.

At the start, participants read the description, instructions and answered general questions about gender, age, familiarity with static and animated statistical data graphics. Then, there were 2 types of tasks on defining trends and determining an object with the highest or the lowest value. They used 6 examples of animated transitions developed in Section 4.3. Each transition example was used twice in both types of tasks, resulting in 12 tasks with animated graphics. 2 static juxtaposed graphics (with two map types) were also prepared for each type of task. Overall, the main part contained 16 tasks.

In animated tasks, subjects could use the button to start the animation and click it as many times as needed or not use it at all. The only condition is to track objects visually, not using a mouse cursor. In static examples, participants did not need to click anything, just choose the right answer.

All the object names were labeled in both maps and charts, and there was a legend added to estimate object values.

After completing the main part with tasks, participants were given a list of questions asking about their preferences on animated or static graphics, helpfulness of animation, types of transitions, and which of them seemed more useful. Two other questions aimed to determine how often users used the animation button and if and how map types affected their perception. Finally, there were 16 tasks with or without animation and 11 additional questions.

The number of participants was 24 (15 female, 9 male). Their ages ranged from 22 to 65 (M = 33.5, SD = 10.9). Among the subjects, 23 worked with *static* statistical data graphics before, and 17 used *animated* statistical data graphics.

Determining trends

Figure 4.6 displays the percentage of correct and wrong answers for I, II, and III transitions, and also for static tasks. Staged (I, II) and static graphics had equally good results (for each - 88% correct). Animation III resulted in only 69% of correct answers.

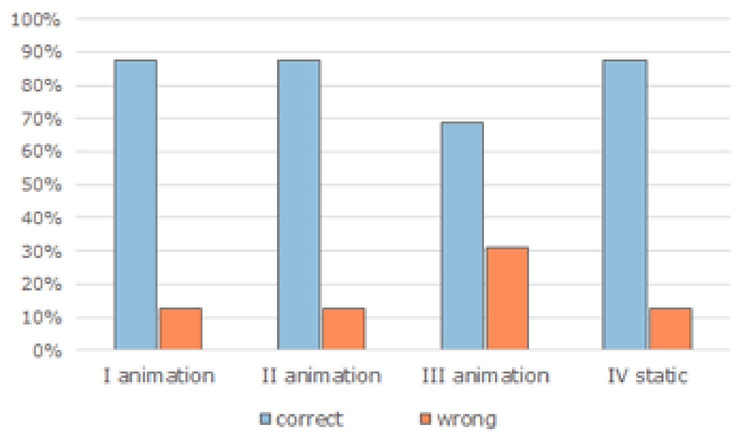

Figure 4.6: Experiment 2: percentage of correct and wrong answers in determining trends among different transitions

The types of maps also played an important role (figure 4.7). Choropleth maps with sharp and smooth staged animations (I, II) showed the highest percentage of correct answers - 96% and 92% accordingly. Both static choropleth and static proportional symbol maps gave 88% correct answers, and proportional symbol map with the smooth staged transition (II) - 83%. The majority of mistakes appeared with tweened transitions (III) in both proportional symbol and choropleth maps, having only 71% and 67% correct answers accordingly.

Figure 4.8 represents the mean time spent on each task. Smooth staged transition II and static graphics had the quickest performance completing the tasks in 16 (SD = 11) and 17 secs (SD = 9) accordingly. Tasks with animation III were performed for 26

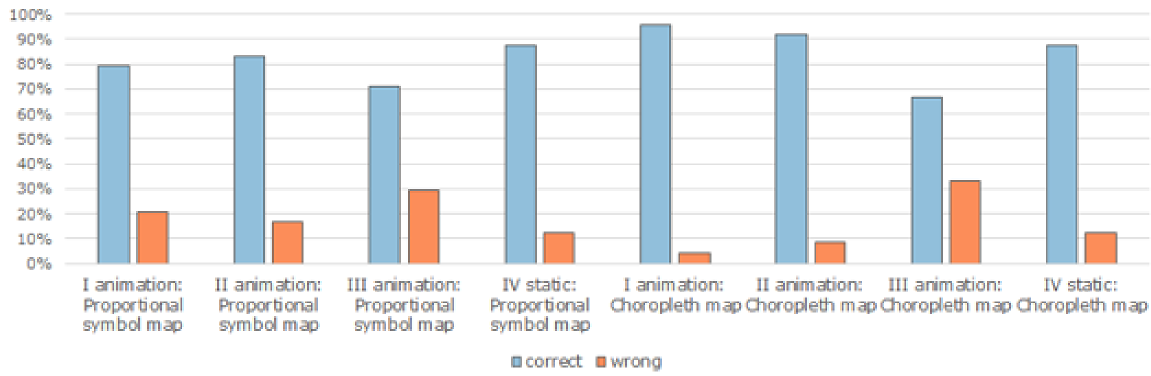

Figure 4.7: Experiment 2: percentage of correct and wrong answers in determining trends among different transitions and types of maps

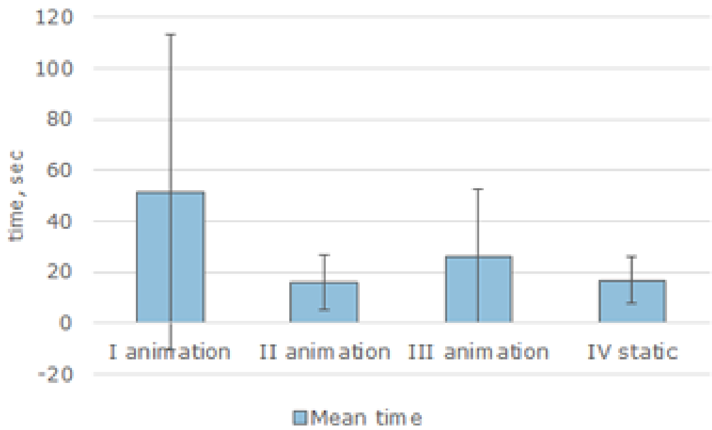

Figure 4.8: Experiment 2: time of completing the tasks in determining trends

secs (*SD* = 26). The longest amount of time was in tasks with animation I taking on average about 51 sec (*SD* = 62).

Subjects were also asked whether they used the animation button in every task: 50% did not use it at all, 42% only in some tasks, and 8% always clicked it to start the animation.

Identifying objects with the lowest or the highest value

The results of answering accuracy among animated and static graphics are presented in figure 4.9. I and III transitions were equally 100% correctly solved, while animation II and the juxtaposed graphics gained only 90% and 81% correct answers accordingly.

There was also a difference in accuracy in tasks with proportional symbol and choropleth maps. Figure 4.10 represents the percentage of correct answers between two types of maps using three different transitions. Tasks with the proportional symbol

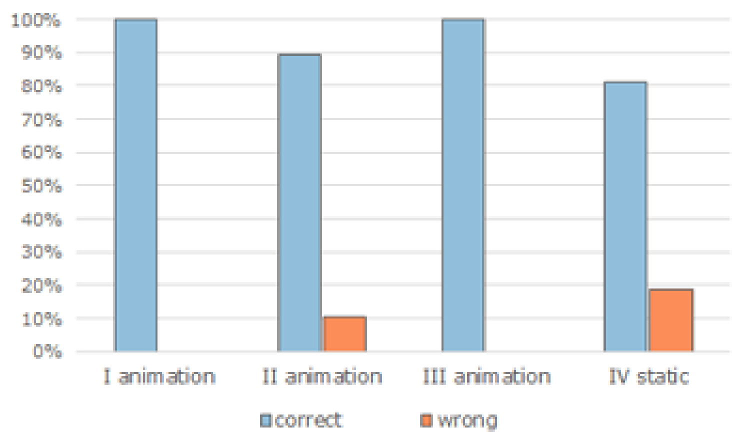

Figure 4.9: Experiment 2: percentage of correct and wrong answers in identifying values among different transitions

and choropleth maps showed slightly worse results combined with smooth staged animation II and static graphics IV.

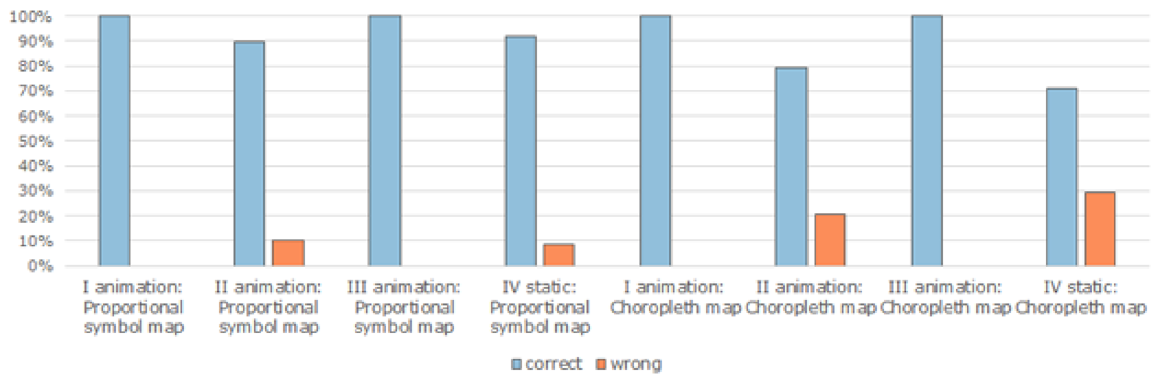

Figure 4.10: Experiment 2: percentage of correct and wrong answers in identifying values among different transitions and types of maps

Figure 4.11 depicts the mean time spent on completing static and animated tasks. Tweened animation III had the best time performance having only 2 secs (*SD* = 0). Smooth staged animation II took second place showing 6 sec (*SD* = 2), static graphics IV were solved in 10 sec (*SD* = 7), and sharp staged animation I in 38 sec (*SD* = 131).

Answering how often the transition button was used, 33% said that they did not use it at all, 21% only in some tasks, and 46% clicked the button in each task.

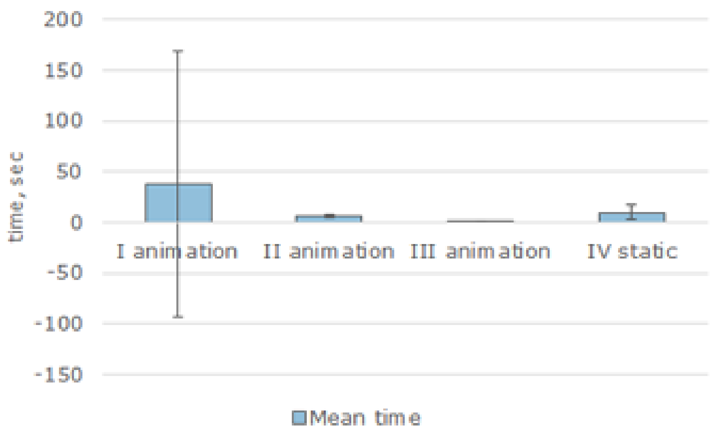

Figure 4.11: Experiment 2: time of completing the tasks in identifying values

4.5 Conclusions

The object tracking experiment results showed the advantages of tweening over staged animations in completing the tasks more accurately and faster. They also demonstrated the better results achieved with proportional maps as compared to choropleths. Participants tended to be more successful in completing the tasks starting from charts than from maps. A fewer number of graphic components also positively affected the answer's accuracy.

Determination of trends did not reveal any discernible influence of animation either in accuracy nor in timing; both static and animated tasks had equally good results. In animated tasks, it showed the benefits of staging over tweening in answers' accuracy. Generally, choropleth maps had a higher number of correct results than proportional symbol maps when animated. When animated, results highlighted a better performance of smooth staged animation (II) for transitions with proportional symbol maps; and better results of sharp staged animation (II) in combination with choropleth maps.

Identification of objects with the highest/lowest value displayed a greater number of correct answers in animated tasks than static ones. Among transitions, smooth staged animation performed slightly worse in accuracy than sharp staged and tweened ones. However, a comparison of the mean time spent on solving revealed a better performance of tweening. "The slowest" transition was smooth staged animation. Additionally, there was no significant difference revealed in accuracy between proportional symbol and choropleth maps when animated. In static examples, proportional symbol maps had a greater number of correct answers than choropleth.

Chapter 5

Interpretation of Results

This Chapter interprets the outcome described in Chapter 4 and explains how animated transitions affect map readers' perceptions (Research Question 2) and whether the change in perception improves the understanding of underlying data (Research Question 3). It additionally describes and uses subjective preferences to support the results of the main experiment parts.

Since Research Question 2 includes Research Question 3 as part of the answer, the current Chapter begins by answering the latter.

5.1 The effects of transitions on the underlying data understanding

Experiments with transitions between non-spatial statistical graphics show that animations have a significantly lower error rate when estimating changing values (Heer & Robertson, 2007). This implies that animations improve the graphical perception of underlying data understanding. However, experiments with transitions between spatial and non-spatial statistical data graphics gave two opposite results within this research.

On the one hand, the results did not reveal any major differences between static and animated tasks when determining trends. On the other hand, the answers to animated graphics were more accurate and solved faster when identifying object values. It basically showed that transitions do not affect graphical perception in trend identification but might improve value estimation.

Perhaps, the reason for no animation influence is that the determination of trends is mostly based on spatial graphics and does not always require switching to a chart.

On the contrary, one can say that tasks with estimating values do not require a map view either and that the animation button could be used to switch to a chart (animated tasks always started from a map, and it was necessary to use the animation button to switch to a bar).

This assumption is supported by the frequency of using the animation button. The results showed that less participants used it determining trends and much more clicked it estimating values. Subjects also reasonably noticed that *"yes [I used the button], but only to see the bar chart rather than the map. The animation didn't really bring something"*. Participants that used the animation button always or sometimes explained it by the need to support their guess.

Thus, both task results and subjective preferences showed that the determination of trends does not require the animation or at least has no strong effect on graphical perception. The transitions possibly can be refined to outperform static graphics, but this is discussed further in Section 5.3. Better results of animated tasks on value estimation were not supported by subjective opinion. Even though animated graphics were solved more accurately and faster, participants still indicated that they prefer juxtaposed views.

Among the participants, 79% proffered static over animated graphics to define trends and 67% to evaluate object values. With trends, participants did not see any advantages in animations because they cause delays in reading the data and require extra clicks:

"Having an animation in between them just impedes the work by adding a delay"

"No need to click if bars are next to the map"

"The animation does not give me any advantage, so static is just fine"

Additionally, 63% did not find animated graphics helpful in working with trends and 71% determining object values. Those 17% left in the first and 29% in the second type of task preferred animated graphics over static ones. Graphics with animated transitions were found more eye-catching, keeping attention, and helping to follow objects.

Another discrepancy between these two types of tasks is that accuracy and time performance in trend determination were affected by the map type. This was supported by 79% of subjective responses. The majority thought that choropleth maps provide much more help in completing the tasks.

Object value estimation was not affected by the map type, and the percentage of subjects thinking that they were influenced by it was reasonably less, gaining only 58%.

"They made no difference for different reasons. With color, it is not possible to

distinguish multiple elements of the same category. With proportional, it is difficult to differentiate 2 elements with similar sizes. The bar chart was nearly always needed to answer correctly."

The type of task can easily explain the influence of map types. Trend determination results vary depending on the map type, while object value estimation is mostly based on charts and influenced by the map type much less.

However, according to the relatively high percentage of people not using the animation button at all when estimating values, subjects often tried to find the object with the highest or the lowest value only based on a map view. Even though charts contain a better overview of values, participants commented:

"In proportional, it is easier to determine the highest/lowest value and I used transitions to make sure I was selecting the correct choice. However, in choropleth it was a necessity because map doesn't give enough information."

"In proportional it is easier to determine the highest/lowest value and i used transition to make sure i was selecting the correct choice. However, in choropleth it was a necessity because map doesn't give enough information."

All of the above-mentioned does not support the positive effects of transitions but proves that two graphics serve two different purposes, and subjects still prefer having them as juxtaposed static graphics. Trend determination was not affected by the animation but mostly by the type of map. Value estimation was not strongly affected by the map type. However, animated graphics still gave a better result in estimating object values (both in time and accuracy). Is it because static graphics bring more confusion with two juxtaposed views, catch less attention and focus, and have a higher cognitive load? Or is the main reason for better results still in the animation influence?

The analysis of tasks with object value evaluation showed the best accuracy and time performance using tweened transitions. Staged animation with abrupt shape change had the same 100% accuracy but took the longest time to complete one task. Another staged animation with an interpolated shape generally performed better than static but lost to other transitions in accuracy.

Generally, this result was supported by subjective responses. Subjects were asked if they noticed three different transitions: 25% noticed, 29% noticed only some tasks, and 46% did not notice them at all. Those 54% who noticed were additionally asked if they found any of the designed transitions more helpful than others. Among them, 33% said yes, and 21% said no. After, those 33% were given an additional question to rank transitions from the least to the most helpful. The result showed that directly tweened animation was the most helpful (17%), staged animation with sharp shape change took second place (13%), and another staged animation with tweened shape change was considered as the least helpful (4%).

Thus, the fact that tweening facilitates the graphical perception of identifying object values more than staging is supported by both the results of the main experiment tasks and by subjective opinion.

5.2 The effects of transitions on a map reader's perception

The analysis of underlying data understanding in the previous Subsection revealed the advantages of animated graphics over static ones at the semantic level of analysis, specifically, in tasks identifying the object values. Additionally, it showed that the tweening transition technique outperforms staging. Nevertheless, the analysis did not find any animation influence on determining map trends.

Referring to Heer and Robertson (2007), transitions can also positively affect graphical perception in non-spatial statistical graphics at the semantic level of analysis (object tracking). The first experiment results can help find the least and the most helpful transitions between spatial and non-spatial representations in object tracking tasks. The evaluation was based on the accuracy of given answers, time performance, and subjective responses.

The results of animated tasks determined tweened transitions as the most effective in object tracking. Directly interpolated transitions showed better results than other transitions, independent of the map type, the order of transition, and the number of animated graphic components. Both staged animations lost to the interpolated one in answer's accuracy and timing. Staged sharp and smooth transitions had similar results with a slight outperforming of the latter.

Subjective preferences entirely supported this ranking: 74% of participants found that some of the transitions seem to be more helpful than others and were given a ranking task. 51% considered interpolated transitions as the most helpful among others, 13% chose smooth staged transitions, and 9% abrupt staged animation.

Subjects did not specify why tweened transitions were the most helpful to work with, but some of them described the advantages of staged transitions, saying that it felt easier solving tasks with staged transitions *"when the shape morphing happened first in place and only afterwards the position animation started"*. Among the staged animations, people considered smooth shape change (II) easier than the sudden one (I) because *"sudden shape changes cause a huge amount of confusion"*.

Besides animations, there was another factor affecting results. Tasks with proportional symbol maps demonstrated a higher rate of accurate answers than choropleth. This might be related to different visual variables used to represent values. Proportional symbol maps use size, while choropleth use color hues.

The percentage of respondents who agreed that the type of map affected their graphical perception was 74%. However, only a smaller part of them preferred proportional symbol maps *"as the symbol colours were uniform"*, *"the morphing was the same for each symbol"*, and they did not have a large area of overlapping when animated.

The vast majority of subjects commented that tasks with choropleth are easier to solve for two reasons. Firstly, the colors of the bars and map enumeration units match, making it easier to track and compare the objects, and secondly, *"color hues were easier to sort, focus, and follow"*. On the other hand, they also noticed that choropleth maps were harder when transiting *"from charts to maps, since the elements overlap through each other and similar colors can be deceiving"*. The choropleth can also confuse when having the same color for several enumeration units or having a low color contrast between neighboring classes.

Analyzing staged transitions, the animation's performance with a smooth change of shape was slightly higher than the sharp one in tasks with proportional symbol maps. Conversely, the sharp animation outperformed a smooth one in choropleth maps.

Participants also noticed that some transitions were more helpful in combination with some types of maps. However, they argued that the abrupt change of shape in choropleth can be visually difficult to perceive because the elements do not move on the same line and it is *"really hard to remember which one was which"*. They also mentioned that the proportional symbol map *"was easier to follow when shape changed first and then the elements transitioned, but choropleth was easier to follow when they were happening at the same time"*.

The results' interpretation includes two other task conditions that affected the accuracy and time of completing besides the animation and map types. Some transitions started the animation from a map view, while others began from a chart. Tasks contained 5 or 8 animated graphic components.

Tasks starting from charts generally had better results. The percentage of participants agreed that the order of transitions affected their perception was 60%, but almost half (28% from those who commented) found transitions from maps to charts much easier. The reason is that map units had more distinctive object shapes, normally expanding animation, and less overlapping between objects. Some of the subjects said:

> *"Shapes of provinces are much more distinctive to start with, with following them*

instead of bar charts.”

”Easier from map to bar charts as the object, i was tracking, generally got bigger, so it was easier to track.”

”It was easier to track the shapes shrinking to bars, since there was less overlap between parts of the same color.”

However, fewer participants still preferred starting from charts to maps. 40% were not affected or found no difference in the order of transitions.

The task to follow two objects does not seem difficult and does not seem to be affected by the number of moving graphic components since all the focus is aimed at those necessary two. However, the results revealed that tasks with 5 animated components show a higher accuracy rate than tasks with 8 components.

The percentage of subjects who agreed that the number of moving elements affected their perception was 83%. Most supported the results saying *”less elements means less perturbations to ignore”* and *”more elements made it much harder to follow which [object] transformed into which”*. The greater number of animated components added more confusion by having more ending positions and brought more doubts, especially when they shared neighboring positions.

5.3 Additional remarks

Even though the trends determination experiment did not reveal any advantages of animated graphics, transitions can still be analyzed and compared. This is the only type of task where staging techniques showed better results than tweening. The analysis of time displayed that smooth staged animation was solved the quickest way, tweening was in the middle, and the sharp staged transition was the longest. It supports that at least smooth staging outperforms tweening animation techniques in this type of task. Perhaps, it might be refined in a way that gives better results than static graphics.

5.4 Conclusions

The experiment results revealed the positive effects of animated transitions on graphical perception at the semantic level. Animations helped give more accurate answers and solve tasks faster when identifying objects with the highest or the lowest value. Tests on syntax showed that tweening techniques are more efficient than staging for object tracking.

The tasks with the identification of object values showed better results when animated. As they are not affected by the map type, this might have been caused by two possible reasons: either by transition types or by the absence of a map in a single chart view. In other words, static graphics have juxtaposed maps and charts generating cognitive load. However, tasks with tweened and smooth staged animations showed a better time performance, which argues for the animation impact. In any case, this can speak for the improvement of underlying data understanding.

There was no influence of animation found in tasks with trends determination, perhaps, because trends determination is mostly based on spatial graphics and does not always require switching to the chart.

Another effect of transitions was tested with object tracking. The analysis revealed that the most effective transitions for this kind of task use the tweening animation technique. Tweened transitions were affected neither by the map type, nor by transition order, nor by the number of moving graphic components. Subjective preferences also supported its effectiveness. However, the animation was not the only factor affecting results. Tasks with proportional symbol maps demonstrated a higher rate of accuracy in comparison with choropleth. The reason can be a similar way of shape change and uniform colors for each moving object. This might cause less confusion.

Additionally, object tracking tasks were affected by transition order and the number of animated graphic components. Transitions starting from charts had generally better results but were less preferred by the subjects.

A lower number of animated graphic components positively affected the results of the object tracking experiment. More moving elements are the source of more perturbations to ignore, more overlapping objects during transitions, and more possible endpoints for guessing a correct answer.

Chapter 6

Discussion

The Chapter summarizes all the work and answers the main research question. It also discusses the current study limitations and gives recommendations for further research.

6.1 Conclusions

In this thesis, the main objective was **to determine how animated transitions from statistical maps to charts and vice versa change user perception**. To accomplish this, there were three sub-objectives:

1. To describe possible animated transitions between statistical maps and charts;
2. To develop working examples of the suggested transition types;
3. To test and analyze if and how the animated transitions affect user perception.

In order to meet the objectives, the following research questions were addressed:

- Q1 What are the possible ways to transition between dimensions of statistical maps and charts?
- Q2 How do animated transitions affect the map reader's perception?
- Q3 Does the change in perception improve the understanding of patterns, trends, or relationships in statistical data?

The research selected three statistical charts and three map types and described nine pairs of possible transitions between them. Among the chosen graphics are scatter plot, bar chart, pie chart, proportional symbol map, flow map, and choropleth map. Each represents quantitative data at discrete enumeration units and consists of different visual components used to create a meaningful visualization change between them.

Then, there were two pairs of possible transitions developed in order to test and analyze their effects on user graphical perception.

Two online experiments revealed the advantages of animation at the semantic level of analysis when identifying objects with the highest or the lowest value. On the other hand, they did not display any effects of transitions when determining trends. Subjective opinion showed that participants generally prefer static graphics over animated ones.

Since the trends are determined mostly based on maps, the subjects were affected by the map type and not by the animation. In contrast, the object value identification is based on charts and therefore was not influenced by the map type; but was affected by the animation.

The tweening animation technique showed higher efficiency in comparison with staging in tasks estimating object values. Subjective preferences also supported this.

There were also animation effects on perception in terms of graphical syntax. The object tracking experiment determined that tweened transitions were more effective than staged ones. The results were also affected by the map type, transition order, and the number of moving graphic components. The proportional symbol map outperformed choropleth in the accuracy of answers but was less preferred by participants. Subjective preference also claimed that transitions starting from maps were easier, while the result analysis displayed otherwise. The experiment revealed that tasks with less number of components show a higher accuracy rate.

In conclusion, we hope that this thesis's results contribute to the field of data visualization and provide practical findings on the design and effects of animated transitions between spatial and non-spatial statistical data graphics.

6.2 Study limitations

Two experiments were conducted separately to make each one shorter in time and avoid loss of focus and attention. Therefore, the first experiment had 53, and the second had only 24 participants. There is no assurance that the results could be the same having bigger groups.

This research did not control the experiments. Subjects used their own PCs with a different pixel resolution and monitor size. It is not certain if they used browser zoom and how far they sat from the screen. Due to SoSci service specifications, it was still possible to go through the survey several times or reload some pages to start the animation again, even though the animation button was limited to only one click. Moreover, participants could omit the instructions and still track moving objects with a mouse cursor unintentionally.

6.3 Outlook

The experimental part developed and analyzed only 2 designed transitions from Section 3.2. The other 7 transitions use other graphical components and encoding principles; consequently, visualization change happens and looks differently. Therefore, the effects on user graphical perception might differ from the tested ones.

The Research Question 3 was narrowed down to determining map trends and identifying objects with the highest or the lowest value. However, it did not test how animations affect the understanding of patterns and relationships in statistical data. The effectiveness of animation for them might differ in the same manner as that which occurred between trends and value determination. Perhaps, the tasks on semantics can display various results depending on the type of task.

It will be also interesting to see if the results would be different between the tasks asking to define the objects with the highest or the lowest value and the tasks asking to estimate the exact numerical value.

Trends' determination did not show significant variations between static and animated graphics. However, it might be possible to refine transitions in order to outperform static graphics. Tasks with identification of object values were based mostly on charts and did not require the animation to switch to a map but still showed better performance when animated. The same might also work for tasks with trends.

In further research, it will be interesting to see whether and how the implementation of other animation techniques and parameters might change the conducted experiments' results. Perhaps, the use of timing, staggering, exaggeration, or other techniques can improve animated graphics' efficiency.

This research selected only three common maps and three charts, leaving a variety of graphics outside of the examination. There might be possible ways to transition between graphics with composite, continuous, or volume data. Graphics with repetitions and grids can also be reconsidered. A broad research area could be animations between cartograms and non-spatial data graphics because it would require an extra transition to a recognizable map state.

Another question is whether transitions between spatial and non-spatial statistical graphics should be designed differently compared to those designed only between non-spatial representations. Map graphic components might have complex geometry affecting the perception of the visualization change.

Interactive static graphics can also be analyzed and compared with animated representations since they have reduced cognitive load. They might perform even better than animated graphics.

References

Battersby, S. E., & Goldsberry, K. P. (2010). Considerations in Design of Transition Behaviors for Dynamic Thematic Maps. *Cartographic Perspectives*(65), 16–32. Retrieved 2020-03-31, from https://doi.org/10.14714/CP65.127 (Number: 65)

Bederson, B. B., & Boltman, A. (1999). Does Animation Help Users Build Mental Maps of Spatial Information? In *Proceedings of Information Visualization Symposium (InfoVis99)* (pp. 28–35). New York: IEEE. Retrieved 2020-04-14, from https://doi.org/10.1109/INFVIS.1999.801854

Blok, C., Köbben, B., Cheng, T., & Kuterema, A. (1999). Visualization of Relationships Between Spatial Patterns in Time by Cartographic Animation. *Cartography and Geographic Information Science*, *26*(2), 139–151. Retrieved 2020-03-31, from https://doi.org/10.1559/152304099782330716

Bostock, M., Ogievetsky, V., & Heer, J. (2011). D³ Data-Driven Documents. *IEEE Transactions on Visualization and Computer Graphics*, *17*(12), 2301-2309.

Chalbi, A. (2018). *Understanding and Designing Animations in the User Interfaces* (PhD Thesis). Retrieved from https://hal.archives-ouvertes.fr/tel-01881889

Clark, S. G. N. (1937). *Science and social welfare in the age of newton*. New York: Oxford University Press.

Dent, B., Torguson, J., & Hodler, T. (2009). *Cartography: Thematic Map Design* (6th ed.). New York: McGraw-Hill.

DiBiase, D., MacEachren, A. M., Krygier, J. B., & Reeves, C. (1992). Animation and the Role of Map Design in Scientific Visualization. *Cartography and Geographic Information Systems*, *19*(4), 201–214. Retrieved 2020-04-10, from https://doi.org/10.1559/152304092783721295

Dorling, D., & Openshaw, S. (1992). Using Computer Animation to Visualize Space-Time Patterns. *Environment and Planning B: Planning and Design*, *19*(6), 639–650. Retrieved 2020-04-09, from https://doi.org/10.1068/b190639

Dragicevic, P., Bezerianos, A., Javed, W., Elmqvist, N., & Fekete, J.-D. (2011). Temporal Distortion for Animated Transitions. In *Proceedings of the Conference on Human Factors in Computing Systems* (p. 2009). Vancouver: Association for Computing Machinery. Retrieved 2020-04-03, from https://doi.org/10.1145/

1978942.1979233

Engelhardt, Y., & Richards, C. (2018). A framework for analyzing and designing diagrams and graphics. In P. Chapman, G. Stapleton, A. Moktefi, S. Perez-Kriz, & F. Bellucci (Eds.), *Diagrammatic representation and inference* (pp. 201–209). Cham: Springer International Publishing.

Gonzalez, C. (1996). Does Animation in User Interfaces Improve Decision Making? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 27–34). New York: Association for Computing Machinery. Retrieved 2020-04-14, from https://doi.org/10.1145/238386.238396

Griffin, A. L., MacEachren, A. M., Hardisty, F., Steiner, E., & Li, B. (2006). A Comparison of Animated Maps with Static Small-Multiple Maps for Visually Identifying Space-Time Clusters. *Annals of the Association of American Geographers*, *96*(4), 740–753. Retrieved 2020-04-10, from https://doi.org/10.1111/j.1467-8306.2006.00514.x

Harrower, M. (2004). A Look at the History and Future of Animated Maps. *Cartogr.: Int. J. Geogr. Inf. Geovisualization*, *39*, 33–42. Retrieved 2020-04-09, from https://doi.org/10.3138/7MN7-5132-1MW6-4V62

Heer, J., & Robertson, G. (2007). Animated Transitions in Statistical Data Graphics. *IEEE Transactions on Visualization and Computer Graphics*, *13*(6), 1240–1247. Retrieved 2020-03-26, from https://doi.org/10.1109/TVCG.2007.70539

Javed, W., & Elmqvist, N. (2012). Exploring the Design Space of Composite Visualization. In *Proceedings of the 2012 IEEE Pacific Visualization Symposium* (pp. 1–8). Songdo, South Korea: IEEE Computer Society. Retrieved 2020-04-13, from https://doi.org/10.1109/PacificVis.2012.6183556

Jenks, G. F. (1976). Contemporary Statistical Maps—Evidence of Spatial and Graphic Ignorance. *The American Cartographer*, *3*(1), 11–19. Retrieved 2020-04-08, from https://doi.org/10.1559/152304076784080258

Karl, D. (1992). Cartographic Animation: Potential and Research Issues. *Cartographic Perspectives*, *13*, 3–9. Retrieved 2020-03-30, from https://doi.org/10.14714/CP13.999

Kim, Y., & Heer, J. (2020). *Gemini: A Grammar and Recommender System for Animated Transitions in Statistical Graphics.*

Kraak, M., & Ormeling, F. (2013). *Cartography: Visualization of spatial data* (3rd ed.). USA: CRC Press.

Kraak, M.-J. (2007). Cartography and the Use of Animation. In W. Cartwright, M. P. Peterson, & G. Gartner (Eds.), *Multimedia Cartography* (pp. 317–326). Springer Berlin Heidelberg. Retrieved 2020-04-06, from https://doi.org/10.1007/978-3-540-36651-5_22

Kruskal, W. (1975). Visions of Maps and Graphs. In *Proceedings of the Interna-*

tional Symposium on Computer-Assisted Cartography: Auto-Carto II (pp. 27–36). Washington, DC: U.S. Bureau of the Census and Americal Congress on Survey and Mapping. Retrieved 2020-04-07, from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.526.702

KUTE.js Documentation. (2020). *KUTE.js JavaScript library.* Retrieved 2020-11-10, from https://thednp.github.io/kute.js/

MacEachren, A. M., Boscoe, F. P., Haug, D., & Pickle, L. W. (1998). Geographic Visualization: Designing Manipulable Maps for Exploring Temporally Varying Georeferenced Statistics. In *Proceedings IEEE Symposium on Information Visualization* (pp. 87–94). IEEE. Retrieved 2020-03-31, from https://doi.org/10.1109/INFVIS.1998.729563

Opach, T., Gołębiowska, I., & Fabrikant, S. I. (2014). How Do People View Multi-Component Animated Maps? *The Cartographic Journal*, *51*(4), 330–342. Retrieved 2020-04-10, from https://doi.org/10.1179/1743277413Y.0000000049

Richards, C., & Engelhardt, Y. (2020). Excerpt from Richards and Engelhardt, in preparation.

Robinson, A. H. (1995). *Elements of Cartography* (6th ed.). Michigan: Wiley.

Sauro, J., & Lewis, J. (2012). *Quantifying the User Experience: Practical Statistics for User Research*. Elsevier Science. Retrieved from https://books.google.nl/books?id=QncH02-bvjoC

Tversky, B., Morrison, J., & Bétrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*, 247–262. Retrieved 2020-04-14, from https://doi.org/10.1006/ijhc.2002.1017

Appendix A

Experiments structure

A.1 Experiment 1

Introduction	1. Description; 2. Consent form;
General questions	3. Gender; 4. Age; 5. Experience with statistical graphics; 6. Experience with animated statistical graphics;
The main part with tasks	7-30. 24 animated graphics;
Subjective preferences	31. Effects of the order; 32. Effects of the number of animated components; 33. Effects of the map type; 34. Helpfulness of transitions types; 35. Ranking of transitions according to their helpfulness.

A.2 Experiment 2

Introduction	1. Description; 2. Consent form;
General questions	3. Gender; 4. Age; 5. Experience with statistical graphics; 6. Experience with animated statistical graphics;
The main part with tasks	7-10. Trends determination: - 3 animated tasks; - 1 static tasks; 11-14. Identification of an objects with the highest or the lowest value: - 3 animated tasks; - 1 static tasks;
Subjective preferences	15-18. Determining trends: - Preferences between animated and static graphics; - Animation helpfulness; - Transitions usage; - Effects of the map type; 19-22. Identifying object values: - Preferences between animated and static graphics; - Animation helpfulness; - Transitions usage; - Effects of the map type; 23. Three transition types; 24. Helpfulness of transition types; 25. Ranking of transitions according to their helpfulness.

Appendix B

Screenshots of each page of the online survey

Find them attached in https://kartoweb.itc.nl/students/msc-carto/shurupina_2020/

B.1 Experiment 1

B.2 Experiment 2

Appendix C

Results of the first experiment

Find them attached in https://kartoweb.itc.nl/students/msc-carto/shurupina_2020/

C.1 Response data

C.2 Response Code Listing

Appendix D

Results of the second experiment

Find them attached in https://kartoweb.itc.nl/students/msc-carto/shurupina_2020/

D.1 Response data

D.2 Response Code Listing