Cartography M.Sc.

Master thesis

Evaluating techniques and design gaps between static and animated flow maps

Zhiheng Jiao

Technical University of Munich

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

TECHNISCHE UNIVERSITÄT DRESDEN

UNIVERSITY OF TWENTE.

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Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

Evaluating techniques and design gaps between static and animated flow maps

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Shanghai, 23.08.2023 Zhiheng, Jiao

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I. Introduction

1.1 Background and motivation

Maps are powerful tools for conveying spatial information, but they have traditionally been limited to static depictions of the natural world. One approach that has been used for over a century to represent spatial movements is static flow maps, which use arrows to show the direction and magnitude of movement between points or areas (Tobler, 2003). However, in reality, everything is constantly changing, from the movement of ocean currents to the daily commutes of individuals. Therefore, while static flow maps are effective enough at displaying static data, there is no strong evidence that they are also effective for displaying dynamic or continuous data (Lobben, 2008; Narayanan & Hegarty, 2002). This presents a significant challenge for cartographers who need to find better ways to represent dynamic information and movements.

One promising approach is the use of animated visualization, which may better help people understand dynamic information and movements. As the field of computer science continues to evolve and develop, we are presented with new and innovative ways to acquire, analyze, and interpret data. With the advancements in technology, it has become easier than ever before to obtain large volumes of spatiotemporal data in real-time, enabling us to capture and visualize dynamic changes and movements that were previously impossible to display through static maps. This has led to the emergence of continuous visualization as a powerful tool for understanding and interpreting complex data sets. According to Griffin et al. (2006), animated visualizations might improve the efficiency and quality of readers' understanding of changing spatial patterns by comparing them to static visualizations (Tversky et al., 2002). Therefore, studying animated flow maps is becoming increasingly important in our dynamic world for cartographers.

Establishing design principles for animated flow maps that conform to human perception is a critical challenge in promoting their development. This challenge is especially important because cartography is not only about technology and science, but also art according to the International Cartographic Association (Tyner, 2017). Similarly, it has also been defined as the "production-including design, compilation, construction, projection, reproduction, use, and distribution of maps" (Thrower, 2008). Therefore, it is essential to conduct aesthetic research to guide the use and development of animated flow maps that meet the standards of cartographic representation.

However, due to the novelty and complexity of animated flow maps, there are few studies available on their design principles. While Tobler's pioneering work laid the foundation for designing flow maps, it focused mainly on static flow maps rather than animated flow maps (S. J. Rey et al., 2020). Furthermore, designing animated flow maps requires web front-end technology that determines the final outcome of the animated maps. Thus, to advance the field of cartographic visualization in the modern world, it is necessary to study the design principles of animated flow maps and the technology behind them. Moreover, displaying geospatial data volume is one of the main challenges for animated maps, as pointed out by Robinson et al. (2017). The challenge lies in ensuring that map viewers receive accurate information from multiple animated flows on a map.

Therefore, this thesis aims to explore design principles for animated flow maps by comparing with static maps, particularly by investigating the effects of visual attributes such as rate of change and duration effects on users' awareness of volume data. To ensure the authenticity and rationality of the design principles, a real user study will be conducted. The primary objective of this study is to improve the clarity and efficiency of map users' understanding of movement amounts and flow values for animated flow maps. Additionally, this research will also explore the related technology for creating animated flow maps, providing a foundation for future study in this field.

1.2 Research objective

The overall research objective (RO) is to evaluate techniques for creating animated flow maps and explore differences in design principles between animated and static flow maps. The study aims to summarize various approaches and techniques for making animated flow maps, highlighting their strengths and areas where they can be used. Additionally, it seeks to identify specific guidelines unique to animated flow maps, as well as those that can be adapted from static flow maps. This investigation aims to understand how the dynamic nature of animated flow maps affects the arrangement and representation of flow patterns, helping to optimize the visual communication of complex information in these maps. By following this objective, the research aims to provide valuable insights and practical recommendations for designing and implementing animated flow maps. This will ultimately promote their use in cartography for applications like transportation planning, urban mobility analysis, migration patterns, and other areas that require visualizing dynamic data. There are three sub-objectives that can be derived from the overall objective:

- To analyze and summarize various techniques used in existing animated map works for creating animated flow maps, with a focus on identifying their types and applicability.
- To design and develop web-based animated flow maps, incorporating diverse designs and visual variables to explore their visual representation and effectiveness (also used for user study).
- To conduct a user study that compares the effectiveness of static and animated flow maps, aiming to find out which methods are more efficient for displaying volumes of data on animated flow maps.

1.3 Research questions

In order to achieve the research objective stated above, the subsequent research questions (RQs) will be formulated below:
RQ-1. Which techniques can be used for making online animated flow maps and how they can be used?

RQ-2. Which design rules from static flow maps may not be suitable for animated flow maps?

RQ-3. Which design guidelines from static flow maps can be adapted, and what new design suggestions can be incorporated to create animated flow maps?

RQ-4. Which variables are the most efficient for showing the volume of flows on animated flow maps?

1.4 Thesis outline

The thesis outline provides an overview of the structure and organization of the research work. It outlines the main sections and chapters, which include six chapters:

Introduction

The introduction chapter serves as the opening of the thesis, setting the stage for the research by presenting the background information, problem statement, and research objectives (Cambridge Dictionary, 2023).

Literature Review

This chapter critically examines and synthesizes the existing body of knowledge and research related to the research topic. It involves an extensive review of academic articles, books, and other relevant sources to identify and analyze static and animated maps' key theories, concepts, and findings that inform the research area.

Methodology

This chapter details the research methods and procedures employed in the study. It outlines the overall approach taken to address the research questions in terms of techniques for creating animated maps and how the user study will be conducted.

Results

The results chapter presents the findings and outcomes of the user study. It involves the interpretation of the collected data from participants.

Discussion

The discussion chapter analyzes and interprets the results in the context of the techniques case studies and user study results.

Conclusion

The conclusion chapter summarizes the main findings, reaffirms the research objectives, and addresses the future study outlook.

II. Literature Review

2.1 Static visual variables

Visual variables are graphical elements that are used to represent geographical data on a map. The use of these visual variables significantly impacts whether the information can be conveyed to the map reader effectively or not (Battersby & Goldsberry, 2010). In other words, they ensure that maps are clear, accurate, and effective in communicating spatial information to users. The fundamental static visual variables, as proposed by Jacques Bertin (1967), include position, size, shape, value, texture etc. These visual variables have been further expanded upon by other researchers, such as Joel L. Morrison (1974) and Alan MacEachren (1995), who introduced more symbolization techniques that build upon Bertin's work. Each visual variable can be used selectively or in combination with other variables to represent different types of geographic data. MacEachren (1995) stated that understanding what roles visual variables play in cartography is essential for creating maps that are clear and informative for map users. Thus, I will provide an introduction of the key cartographic visual variables that are relevant to the fundamental guidelines and standards for the creation of maps.

2.1.1 Bertin's Visual Variables

The current Cartographic design principles have been developed by lots of outstanding cartographers over last decades. One of the greatest contributions is from Jacques Bertin's seminal work, *"Sémiologie Graphique"* (Semiology of Graphics), originally published in French in 1967 (Bertin, 2011). It is an influential and comprehensive analysis of visual communication in cartography. Bertin's work (1967) firstly defined the concept of '**visual variable**', established the foundation of modern cartography, and provided a theoretical framework for the design and interpretation of maps.

Bertin's (1967) primary contribution was the development of a systematic approach to cartographic design, based on the principles of visual perception. He argued that cartographers should consider the **semantic value** of map elements, the relationships between them, and the perceptual capabilities of the map reader. He proposed a set of (seven) visual variables, such as position, size, shape, lightness (value), hue, orientation and texture, which can be used to represent different types of data on a map.

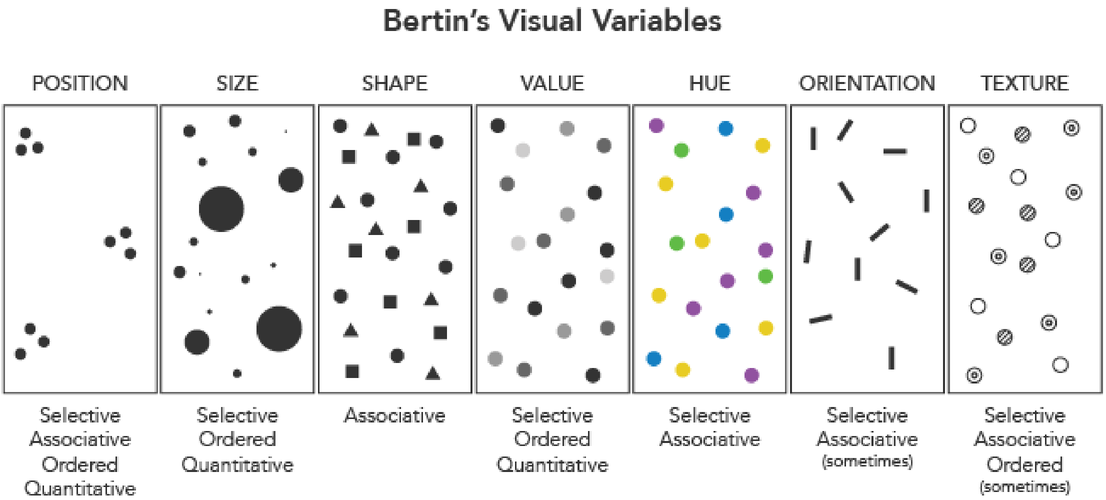

Figure 1. Adapted from Visual Variables, (Axis Maps, 2020)

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- **Position** is a limited visual variable when it comes to the necessity of preserving the actual position of the element being depicted, which restricts its application. As such, 'position' is not commonly employed in cartography (Roth, 2017).
- **Size** of a symbol indicates its dimensions and can be changed for point symbols and lines in terms of the size of point itself and the thickness of lines. It is rarely used for areal symbols, except when applied to the texture fill rather than the symbol itself (Roth, 2017).
- **Shapes** are often used for point data, visualizing a symbol with a specific shape. They are less used as linear symbols and areal symbols (Roth, 2017).
- **Value (Color lightness)** determines the lightness or darkness of a color, meaning that two colors with the same hue may have different values (Ibraheem et al., 2012).
- **Hue** typically refers to the name of a **color**, such as yellow, white, or red (Ibraheem et al., 2012).
- **Orientation** is typically employed for point symbols, except when they possess symmetrical features that hinder the identification of their orientation. In the case of areal symbols, orientation is applied to their texture (Roth, 2017).
- **Texture** is the pattern used to fill the symbol's body and is mostly applied to areal symbols. It is a fundamental graphics primitive with various applications and implications (Döllner et al., 2000).

Four Properties of Variables

Additionally, it is important to know, the visual variables are processed pre-attentively and perceived by the eye-brain system rather than understood cognitively (Griffin, 2017). According to Roth (2017), Bertin (1967) employed the term "retinal" to describe visual variables. Thus, apart from the description of visual variables, understanding the different levels of perception of visual variables can be significant in designing data visualizations that convey information to the audience. By selecting the appropriate visual variables for a given dataset, designers can create clear and informative visualizations that help viewers understand complex information at a glance.

Jacques Bertin (1967) introduced **levels** of **perception** for these variables, which have important implications for their application in map visualization. A variable can be associated with these four levels (Bertin, 1967):

1. The first level, called **selective**, refers to a visual variable that enables us to promptly distinguish a group of signs. According to Bertin (1967), shape is the only visual variable that he believed is always non-selective, along with orientation when utilized for representing area (such as polygons symbolized by differently angled stripe patterns).

   For instance, the use of color can create different categories of symbols, such as red and green for positive and negative values, respectively.

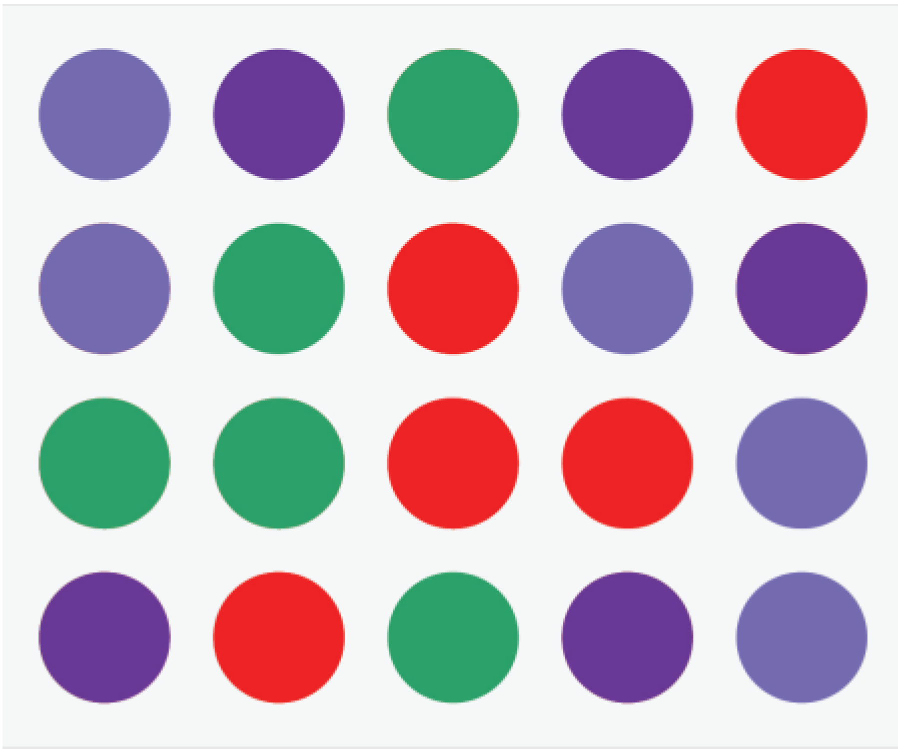


Figure 2. Color Hue - Selective (Roth, 2017)

2. The second level, **associative**, allows us to perceive symbols as a cohesive group even when there are variations in this particular variable. It is important to note that being an associative variable does not imply that it is not selective. Take color hue, for instance, which serves as both an associative and selective variable. While we can easily select symbols of the same color, a collection of symbols with different colors can still be perceived as a distinct group.

   On the other hand, quote Bertin's (1967) description on associative variable *"An associative variable does not cause the visibility of the signs to vary. A dissociative variable causes the visibility of the signs to vary."* ('size' and 'color value' are dissociative variables)

An example of an associative variable is shape, which can be used by modifying the shape of a symbol without changing its meaning.

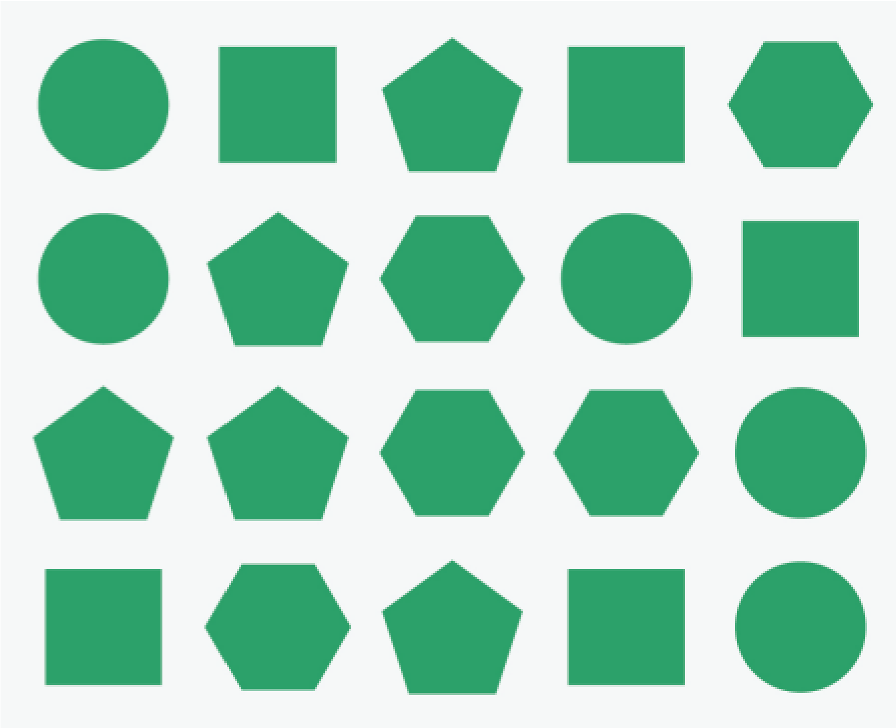


Figure 3. Shape - Associative (Roth, 2017)

3. The third level, **ordered**, is a visual variable that can be used to depict a specific ordering of symbols.

For example, value (color lightness) can be used to represent hierarchy or order, where darker symbols can be used to represent higher values or greater importance. E.G., in a map of population density, darker shades of a single color (e.g., blue) can be used to represent higher population densities

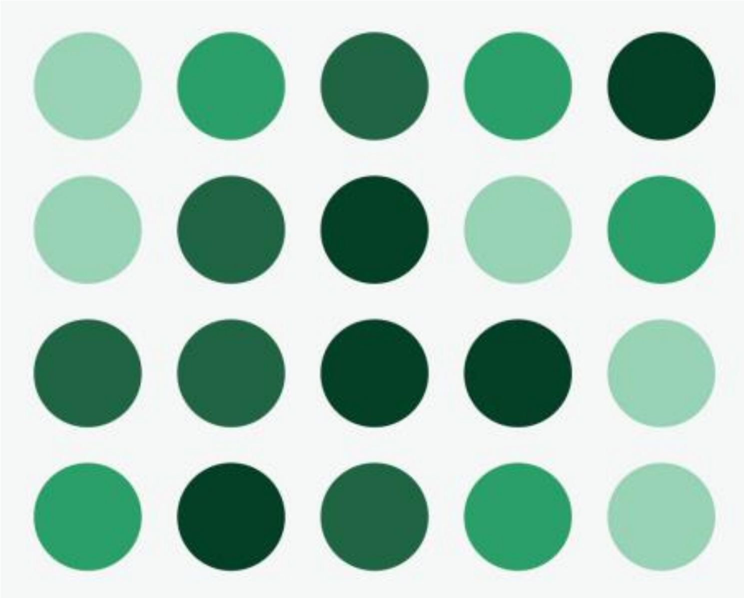


Figure 4. Value (Color lightness) - Ordered (Roth, 2017)

4. Finally, the fourth level, **quantitative**, is a visual variable that not only allows for ordering but can also **represent ratios.**

Examples of quantitative variables include size. It can be used to represent the magnitude of a value or quantity, making it easier for viewers to compare quantitative values across different symbols.

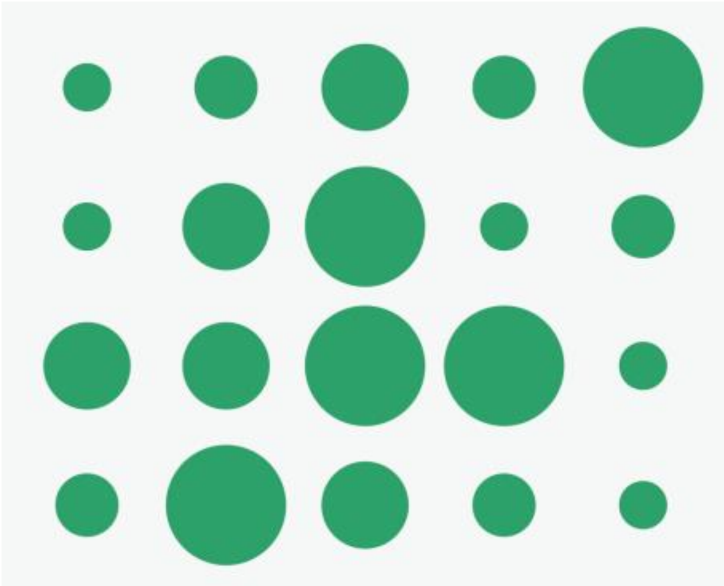


Figure 5. Size - Quantitative (Roth, 2017)

Bertin's (1967 & 2011) works formed the foundation for understanding the importance of visual variables in data visualization and the subsequent research conducted on this topic. Each variable fulfills specific functions based on the organization of information (Babwahsingh, Michael et al., 1999). Even after the passage of five decades, his publications have accumulated over 30,000 citations, attesting to the enduring influence of his ideas in the field of cartography (Harvey, 2019). In addition, his research on graphic semantics positioned him as one of the most notable semioticians of the 20th century (Eco, 1979).

2.1.2 Morrison's Visual Variables

Bertin's seven fundamental visual variables have been subsequently developed further by other researchers to enhance the effectiveness of data visualization. Among these researchers, Joel L. Morrison (1974), who innovative two additional approaches included the use of 1) Color saturation and 2) Arrangement to differentiate between categories. His work provided a richer range of tools for visualizing data and expanded the possibilities for effective communication in cartographic visual design (Morrison, 1974):

- **Color saturation** refers to the level of vividness or intensity of a color used in a map symbol. Saturation can be described as the concentration of a color's energy within a specific part of the visible spectrum. Bold and highly saturated colors emit or reflect energy in a concentrated band of the visible spectrum, while pastel or desaturated colors emit or reflect energy more evenly across the visible spectrum.

The level of saturation used in a map symbol can affect how it is perceived by the viewer. Bold and highly saturated symbols tend to be more noticeable and prominent, while pastel or desaturated symbols may appear less noticeable and blend more with the background.

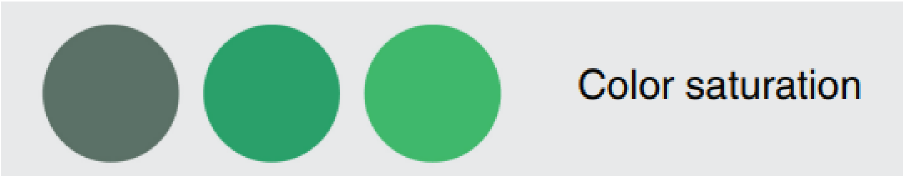


Figure 6. Color Saturation (Roth, 2017)

- **Arrangement** is the organization of the graphic marks that make up a map symbol. This visual variable ranges from regular, where the marks are aligned in a structured grid, to irregular, where the marks are randomly placed or form clusters.

Difference from 'Texture' visual variable

Arrangement shares some similarities with 'Texture' that belongs to Bertin's 7 visual variables mentioned above. However, it is important to understand the difference between arrangement and texture in cartographic symbolization. While arrangement refers to the layout of graphic marks and can varies from regular to irregular, texture refers to the pattern used to fill the body of a symbol and is always assumed to be arranged regularly (Roth, 2017).

Figure 7. Arrangement (Roth, 2017)

In short summary, Joel Morrison's (1974) contributions enriched the visual variables from 7 introduced by Bertin to 9 visual variables. Morrison's work on color saturation and arrangement has extended the scope of visual variables, providing cartographers with additional tools to represent data on maps. His research on color saturation highlights the importance of the spectral peakedness of a symbol and the impact that has on how the symbol is perceived. Meanwhile, Morrison emphasized that (1977) the outline of a syntactical structure for symbolization and a research framework for the pragmatics of map reading is crucial for eventually developing a comprehensive grammar for a cartographic language.

2.1.3 MacEachren's Visual Variables

Twenty years later, building upon the works of Bertin and Morrison, MacEachren's (1995) contribution to the field of visual variables came in 1995, when he identified three new variables to supplement the existing research. These additional variables further improved the cartographic visual variable syntax and they are all regarded as strongly ordered visual variables (Roth, 2017). The three variables introduced by

MacEachren (1995) were 1) Crispness, 2) Resolution, and 3) Transparency.

- **Crispness** is associated with the sharpness of a map symbol's boundary. In the context of information visualization, it is also known as "depth-of-field" or "fuzziness". The level of crispness in a map symbol can influence its perceived importance or salience, with symbols having a sharp or crisp boundary tending to be more prominent than symbols with a fuzzy boundary (Roth, 2017). MacEachren et al. (2012) did a user test and found that crispness is an visual variable in representing uncertainty when using point symbolization.

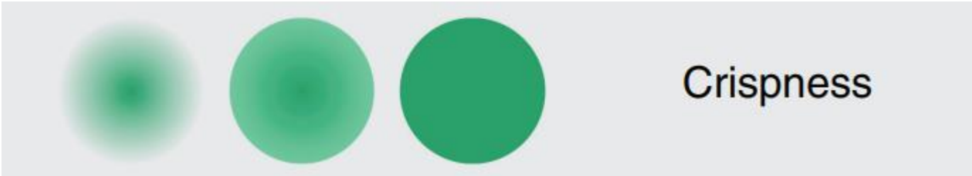


Figure 8. Crispness (Roth, 2017)

- **Resolution** is a visual variable that pertains to the degree of spatial precision in the depiction of a map symbol. This variable is closely tied to the concept of generalization in cartographic design, which involves selectively removing irrelevant details from the map while retaining important information (Roth, 2017). The level of detail in a map symbol can be adjusted to reflect the amount of information required at a specific scale. In raster maps, resolution is linked to the coarseness of the grid size, while in vector maps, it is determined by the number of nodes and edges used to represent the map symbol.

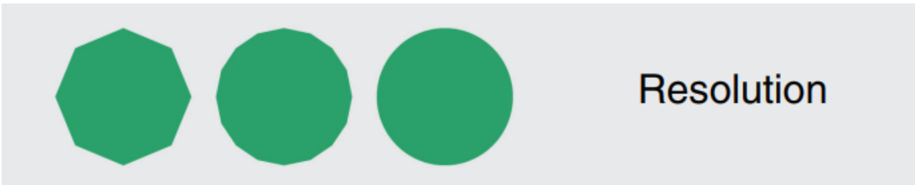


Figure 9. Resolution (Roth, 2017)

- **Transparency** represents the level of opacity or translucency of a map symbol in relation to the background or other map symbols. It determines the degree to which the underlying features are visible and can be used to create a sense of depth and layering within the map. High transparency means that the symbol is more see-through and the underlying features are more visible, whereas low transparency means that the symbol is more opaque and the underlying features are less visible. The use of transparency as a visual variable allows for the creation of complex and informative maps that convey a greater level of detail and context to the viewer (Roth, 2017).

Figure 10. Transparency (Roth, 2017)

These three MacEachren's visual variables complemented Bertin's original seven visual variables and Morrison's two additional ones. MacEachren's work helped cartographers better represent uncertainty and convey more information through the use of additional visual cues. Moreover, his contribution highlighted the importance of considering the technical aspects of map design, such as spatial precision and graphic blending, in addition to the perceptual aspects of visual variables.

2.1.4 Conclusion of static visual variables

In modern cartography design, visual communication is considered crucial, as maps are a powerful tool for conveying complex information quickly and accurately. Visual variables are used to highlight important information, create visual hierarchy, and help users navigate and understand the map's content effectively (Kent & Vujakovic, 2017).

Bertin's (1967) work, along with the contributions of Morrison and MacEachren (1977 & 1995), have had a significant impact on modern cartography design principles. These principles emphasize the importance of visual communication, the use of specific graphic elements and the semantics of visual variables. Their research established a fundamental scientific approach to cartographic design, essential for creating maps that are not only aesthetically pleasing but also in communicating complex information to users.

2.2 Dynamic visual variables

According to the last subchapter of Bertin, Morrison, and MacEachren (1967, 1977 & 1995), we have gained insights into the use of 12 static visual variables for understanding design foundations in flow maps. However, these studies focused on static maps, which might raise a challenge when it comes to effectively presenting animated flows (Han et al., 2017). Besides, Thrower argued much earlier in 1959 that cartographers should use methods in terms of audio-visual communication on maps. Therefore, exploring dynamic visual variables is worthwhile for studying dynamic cartographic representation. These variables provide alternative ways to visually represent animated flows, allowing for the understanding of animated map design patterns.

2.2.1 Six Dynamic Visual Variables

DiBiase et al., (1992) and MacEachren (1995) summarized six dynamic visual variables which are:

- **Moment (moment of display)** refers to the position of a state or change in the representation during display time. In other words, it refers to the time when a display change is initiated

- **Duration** refers to the length of time a state or change in the representation remains visible in the display. In simpler terms, it is the time interval between two identifiable states.
- **Frequency (rate of occurrence)** represents the repetition or the number of identical states or changes in the representation within a specific unit of display time. In simpler terms, it refers to the **count** of identifiable states per unit of time displayed.
- **Order** impacts chronological presentation of individual frames, therefore it is structured, such as being organized chronologically or based on specific attribute values. In the context of frames or scenes, order refers to the sequence in which they are arranged, with a scene representing a series of sequential frames with no changes.
- **Rate of change** is influenced by numerous factors, including the characteristics of the underlying data, design choices like the number of frames per second, and different user interactions (Blok, 2005). In simpler terms, it represents the difference in the magnitude of change per unit of time for each frame or scene in a sequence.
- **Synchronization (phase correspondence)** refers to the temporal alignment of two or more time series. In other words, it represents the correspondence of timing between different sets of data over time (Blok, 2005).

Blok (2000) created an illustration (see Figure 11) of these six dynamic visual variables, providing a visual aid to comprehend their definitions and to understand their differences.

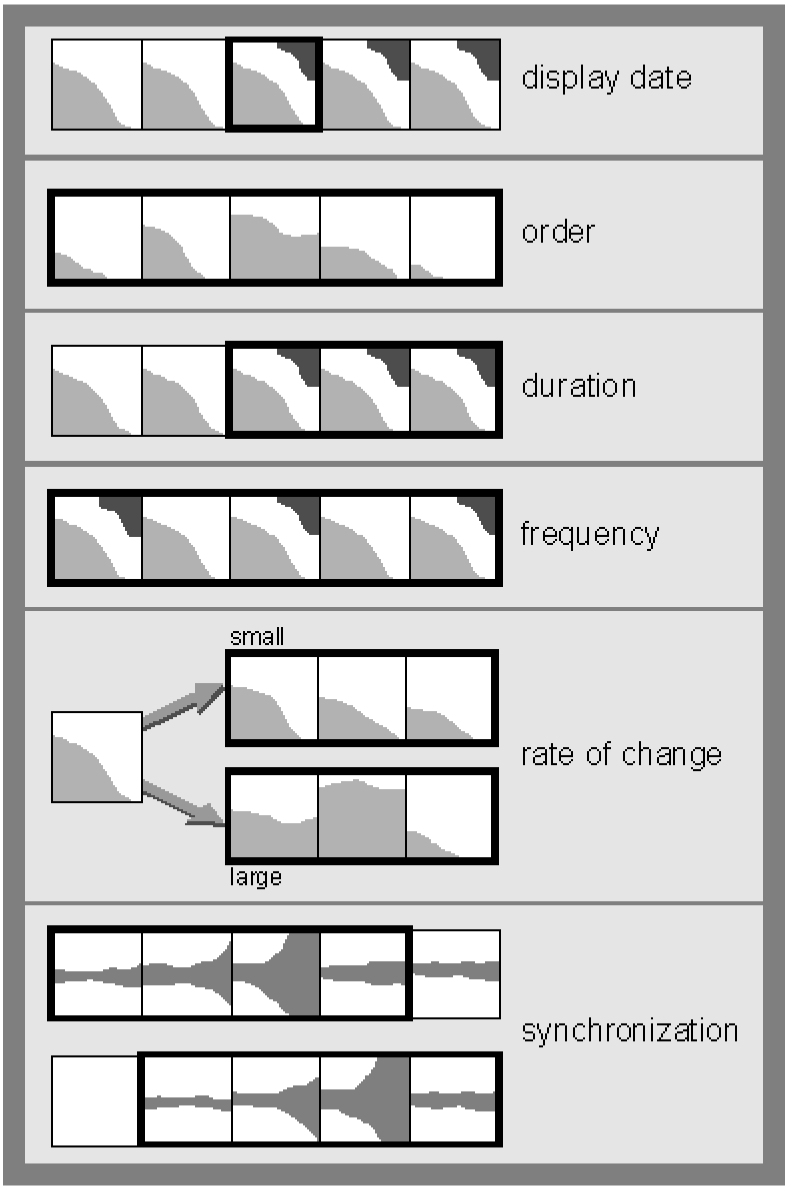


Figure 11. Illustration of the dynamic visualization variables (Blok, 2000)

2.2.2 Properties of Dynamic Visual Variables

As mentioned in section 2.1, we discussed the four properties of visual variables defined by Bertin (1967). Similarly, dynamic visual variables can also be analyzed in terms of these four perceptual properties. In this regard, Köbben & Yaman (1995) made contributions to the study of dynamic visual variables, exploring their perceptual properties and of how they can be utilized in visual representations. The result of the properties of dynamic visual variables from Köbben & Yaman (1995) were from the user test based on cartography professionals and students.

According to Table 1. below, all five visual variables, except for synchronization, have been analyzed with the four properties at three levels: weak, fair, and strong.

Dynamic visual variable	association	order	quantity	selection
Moment	weak			
Duration		strong	fair	
Frequency	fair	fair		weak
Order	fair	fair		weak
Rate of change		strong	weak	
synchronisation	*Not tested*			

Table 1. Perceptual properties of dynamic visual variables (Köbben & Yaman, 1995)

It is important to note that Köbben & Yaman (1995) conducted an examination to test whether the combination of dynamic visual variables and static visual variables could lead to an enhanced understanding of animated maps. This exploration aims to uncover the potential benefits that might arise from using both types of visual variables together. Their investigation revealed that using dynamic visual variables alone might not be easy for users to perceive information effectively. Therefore, their insights into utilizing a mixed approach represent an important contribution to the use of dynamic visual variables on maps.

2.3 Design Flow Maps

Flow maps are a valuable tool for visualizing the movement of various phenomena between geographic locations. They can represent diverse flows such as human migration, transportation of goods, water movement, and internet traffic. Flow maps are not a new type of map and have a long history in the world of cartography and they can usually be identified in four main types: origin-destination flow maps, trajectory-based flow maps, distributive flow maps and continuous flow maps (Slocum et al., 2022). The first three were mostly presented statically, whereas the last one, the continuous flow map, is dynamic. Flow maps can represent qualitative or quantitative data. Qualitative flow maps use different visual attributes, such as colors and line styles, to depict different features or types of flows (Boyandin et al., 2012). Quantitative flow maps represent numerical data, often using proportional symbols or varying line thickness to indicate the magnitude of the flow (Yang et al., 2017). Both unstandardized and standardized data can be used for flow maps. Unstandardized data, based on raw counts, is more common, but standardized data allows for meaningful comparisons between different regions or variables (Slocum et al., 2022).

2.3.1 Basic Types of static flow maps

1) Origin-destination flow maps

According to Koylu et al. (2022) description published in the Journal of Maps, origin-destination (OD) flow maps are used to depict flows between locations when the specific routes are not important. They show the total flow from one origin to another destination, often represented as straight or curved lines (Slocum et al., 2022). It is worth mentioning that many origin-destination flow maps do not consider the actual routes of flows (refer to Figure 12. below).

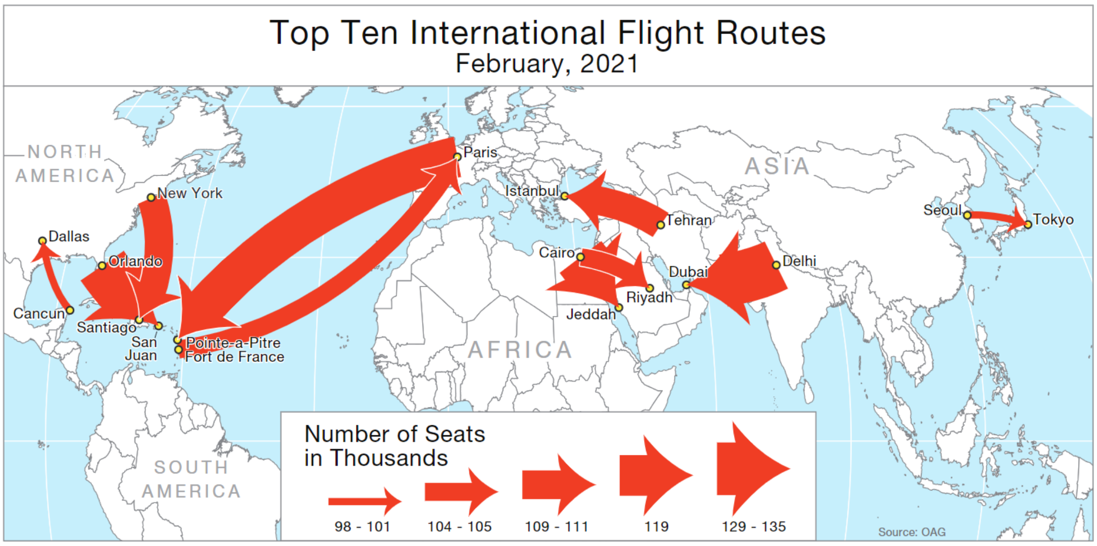


Figure 12. A flow map of International Flights (CNN, 2021)

(Data source: https://www.cnn.com/travel/article/world-busiest-air-routes-february-2021/index.html.)

2) Distributive flow maps

Distributive flow maps are a type of map that illustrates the distribution of phenomena between nodes in a geographic network. They differ from origin-destination maps in that the main flows can be split into different branches and amalgamated (i.e. merging and branching) (Steiner, 2019) . Additionally, flows on origin-destination maps do not need to strictly follow the actual routes, whereas flows on distributive flow maps usually reflect the real routes, such as exports from a country (Steiner, 2019)." One of the earliest known Distributive flow maps was created by Irish engineer Henry Drury Harness and published in 1838 as part of a report on the potential for railroad construction in Ireland (Griffith, & Harness, 1838). This flow map depicted the quantity of cargo traffic by road and canal (see 1.x). A. L. Robinson (1955) studied Harness's map and noted that it was "unusually ingenious" due to the proportional adjustment of the widths of each stream to correspond to the actual numbers.

Figure 13. The relative quantities of traffic in Ireland (Griffith, & Harness, 1838)

Available under the Open Database License [CC BY-NC-SA 4.0]()

Henry Drury Harness's map is a significant milestone in the history of flow maps. By using flow lines and proportional widths to represent quantities, he introduced a novel way of depicting movement phenomena on a map. His map not only provided a new approach to visualizing transportation networks but also became an inspiring example for later cartographers. The map's ingenious design, as noted by A. L. Robinson (1955), proved to be influential in the development of flow maps, as it set a precedent for accurately conveying quantitative information in a visually appealing manner.

3) Trajectory-based flow maps

The advancement of sensor, mobile GPS, and Internet of Things (IoT) technologies has made it possible to match real-world routes with map flows, thereby promoting the application of trajectory-based flow maps (Gong et al., 2018 & Kim et al., 2022). It is different from original-destination flow map, trajectory-based flow maps are employed when it is crucial to depict the actual routes of flow. Utilizing advanced location-aware technologies such as GPS data recorders and geotags, precise trajectory data can be collected (Slocum et al., 2022).

One example is from Grilli et al's (2017) study on the movements of 65 black and turkey vultures tagged in 5 regions of North and South America over 13 years. The map displays the migration routes over varying time periods. According to Miller et al. (2019)'s study, the development of Trajectory-based flow maps is made possible by advancements in location-aware technologies (LATs) for collecting data on moving objects (MOD). These technologies include Global Positioning System (GPS) data recorders, mobile phones, radiofrequency identification (RFID) chips, geotags, radiolocation devices, and georeferenced social media (Slocum et al., 2022).

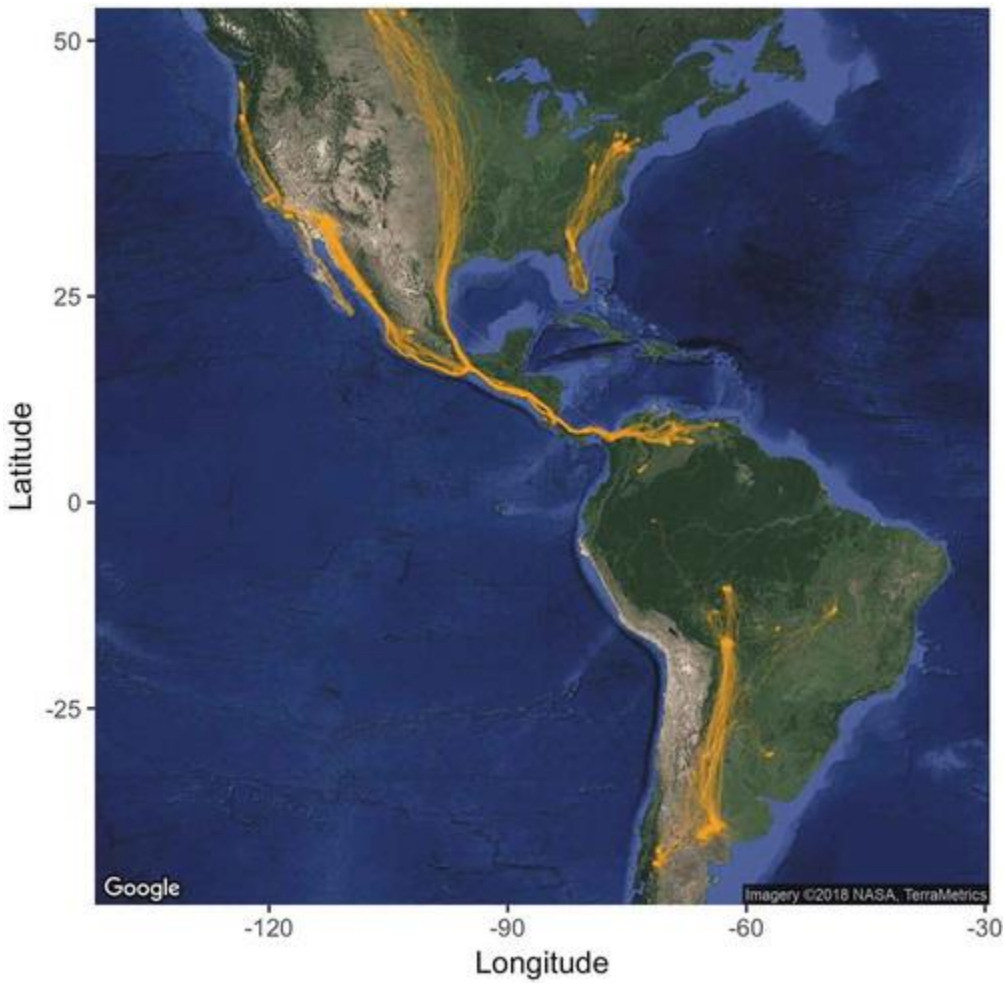


Figure 14. A trajectory-based flow map depicting the migration routes of turkey vultures *(Grilli et al., 2017).*
Data Source: (Bildstein et al., 2016)

2.3.2 Designing Static Flow Maps

Design principles play a pivotal role in the creation of effective flow maps, as they impact the understanding of these maps for their users. Borden Dent and colleagues (2009) have recognized the importance of design strategies and have provided a comprehensive summary of what can be referred to as **"13 essential design strategies"** for making flow maps:

1. Flow lines should be given the highest priority in terms of visual importance.
2. If smaller flow lines intersect or overlap with larger ones, they should be positioned on top.
3. Arrows are crucial when the direction of flow is critical for understanding the map.
4. When possible, the map designer should have control over line placement to achieve a balanced overall composition, avoiding top-heavy or bottom-heavy arrangements.
5. It is vital to establish contrasts between land and water areas, especially in maps that include both elements.
6. The choice of projection, its center, and aspect should guide readers' attention to the flow pattern that is significant to the map's purpose.
7. Simplicity is key, and all information, including flow line scaling, should be presented in a straightforward manner.
8. Legends should be clear, unambiguous, and incorporate necessary units of measurement.
9. Distributive flow lines where the widths of individual branches should add up to the width of the trunk.
10. When branching occurs, it is recommended to create separate lines for each origin-destination flow or aggregate segments to form a trunk line (see figure 15).

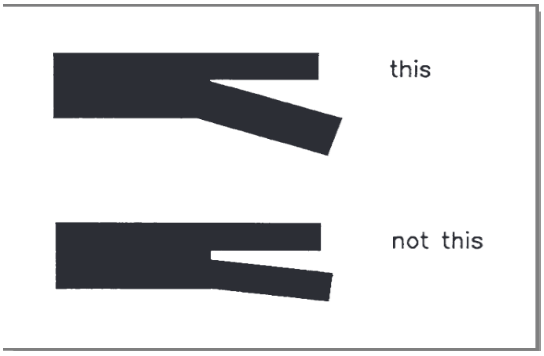


Figure 15. Symbolization of flow lines (Dent. et al, 2009)

11. Care should be taken to balance the placement of new lines and avoid visual imbalance.
12. Arrowheads, if used, should be clear and proportionally scaled to the lines, while smaller lines should appear on top of larger ones to avoid blending.

13. Techniques like shadows or borders can be employed to distinguish overlapping flows.

These strategies relate to line appearance, line placement, line intersection of flow maps (Slocum et al., 2022). However, the design rules are developed based on static maps (e.g., strategy 3 mentioned "arrows are crucial for direction of flows", which may not suitable for animated maps). Dent. et al (2009) mentioned when creating quantitative flow maps, line widths are typically scaled proportionally to represent the quantities they represent, taking into consideration the overall data range and avoiding symbols that appear too small or too large to be practical. Color can also be utilized to symbolize flow maps, with darker or more saturated hues indicating greater flow and lighter or less saturated hues indicating less flow (Dent. et al, 2009; Slocum et al., 2022) .

Dent. et al (2009) also argued that legends have not always been used on flow maps. It is generally advisable to include them for modern quantitative flow maps, providing precise information and facilitating interpretation. However, in some cases, the focus may be on visualizing the overall pattern without detailed labels, in which case accompanying written narrative becomes essential (see Figure 16) (Dent. et al, 2009; Slocum et al., 2022).

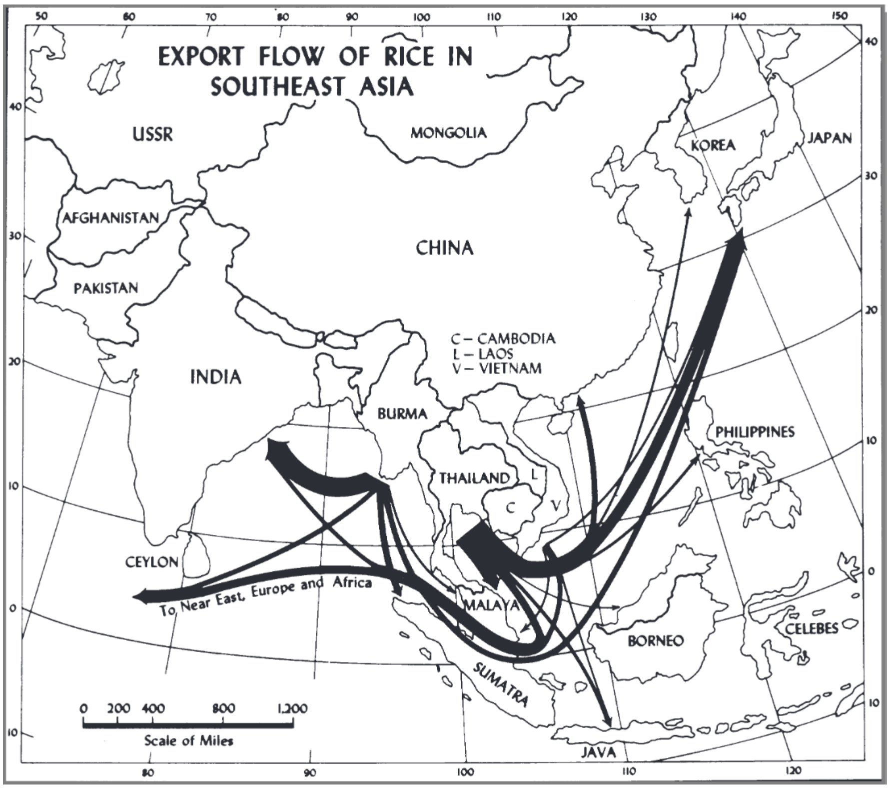


Figure 16. Exports flows in Southeast Asia (Dent. et al, 2009)

In addition to the Dent. et al's (2009) study, there are other design features of static flow maps that have been emphasized in recent decades. One example is the use of curved flows instead of straight lines. According to a study by Jenny et al. in (2016), curved flows are more effective in conveying information than straight lines. In the study, the researchers tested user error rates and response time when reading flow maps with different types of flow lines. They found that users had fewer errors and were faster to interpret maps with curved flows compared to those with straight lines. According to Jenny and his colleagues (2016) , this might be because curved lines more closely follow the natural paths of movement and are therefore more intuitive for users to follow.

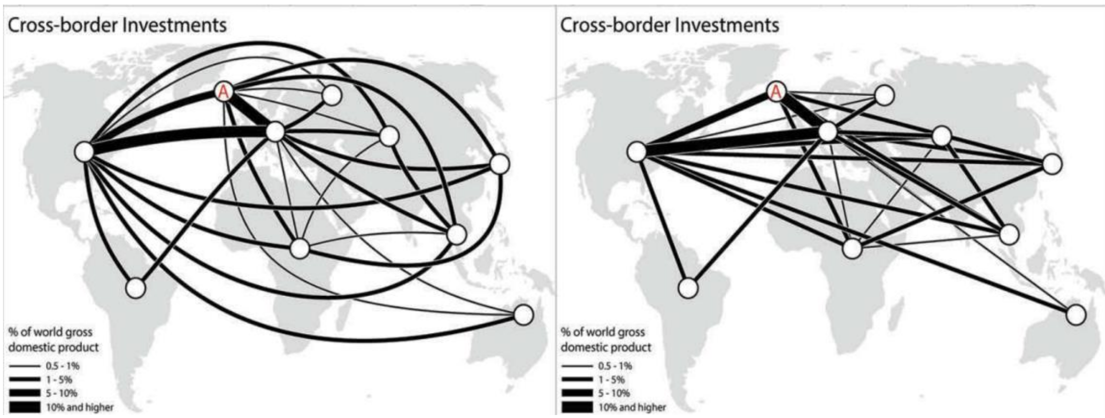


Figure 17. Maps with curved and straight flow lines for Cross-border Investment (Jenny et al., 2016)

In short summary, the previous studies have well developed a set of design rules for static flow maps in terms of proportional scaling of line widths, range grading, and color symbolization. It also mentions the treatment of symbols, such as the arrangement of distributive flow lines, handling branching, balancing line placement, using clear arrowheads, using curved lines and managing overlapping flows. The importance of legends and the inclusion of labels or written narratives for better understanding are also highlighted (Dent. et al, 2009; Slocum et al., 2022).

2.3.3 Deficiency of Static Maps

Based on the previous subchapter, static flow maps have already established lots of developed design principle systems. However, there are some limitations, particularly when it comes to using flow width as a representation of large data quantity on flow maps. In other words, when there is a need to depict a large number of flow lines on a single map, it becomes challenging to achieve an aesthetically pleasing representation using static maps (Han et al., 2017).

One typical example is demonstrated by the outgoing migration map from Colorado for the 1995-2000 period in Figure 18. While this approach is effective for maps with fewer starting nodes, it can result in **visual clutter** when there are too many flows on the map, which can negatively impact the user experience. In contrast, flow maps with a single starting node can be depicted using only the width variable. This highlights the importance of carefully considering the number of starting nodes when choosing the appropriate design principle for a flow map.

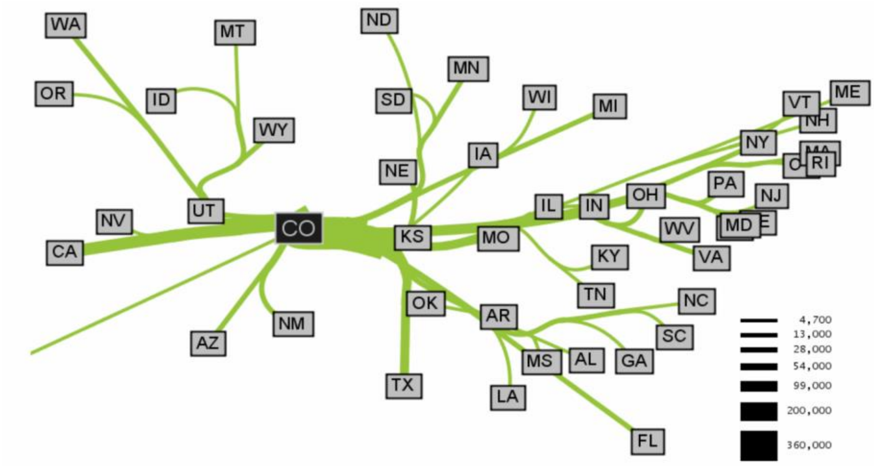


Figure 18. Outgoing migration map from Colorado (Doantam Phan et al., 2005)

Additionally, this issue is also evident in Tobler's work on digital mapping. Waldo Tobler, a renowned cartographer, has made significant contributions to flow maps. In his studies (1981 & 1987), Tobler explores the use of algorithmic methods to automate flow layout. However, visual clutter becomes more pronounced in Tobler's software when representing migration data using varying widths of flows.

For example, looking at the 1985-1990 Inter-Provincial Migration map (Figure 19.) produced using Tobler's (2003) flow mapper program, which displays the significant movement of people between different provinces in China. The challenge here is that nearly all provinces have their emigration area, resulting in a large number of flows on the map. While the flow lines of varying widths depict the relative quantity of migration between the provinces, the map becomes **visually crowded** and challenging to read, thus decreasing the efficiency of information communication.

Figure 19. Showing the majority of inter-provincial moves in China (Tobler, 2003)

This is evident in other maps from Tobler's mapping programme, Figures 20. to 21., which visually demonstrate the representation of migration and trade data using a large number of varying width flow lines.

Figure 20. Migration to and from California, 1965–1970. (W. R. Tobler, 1987)

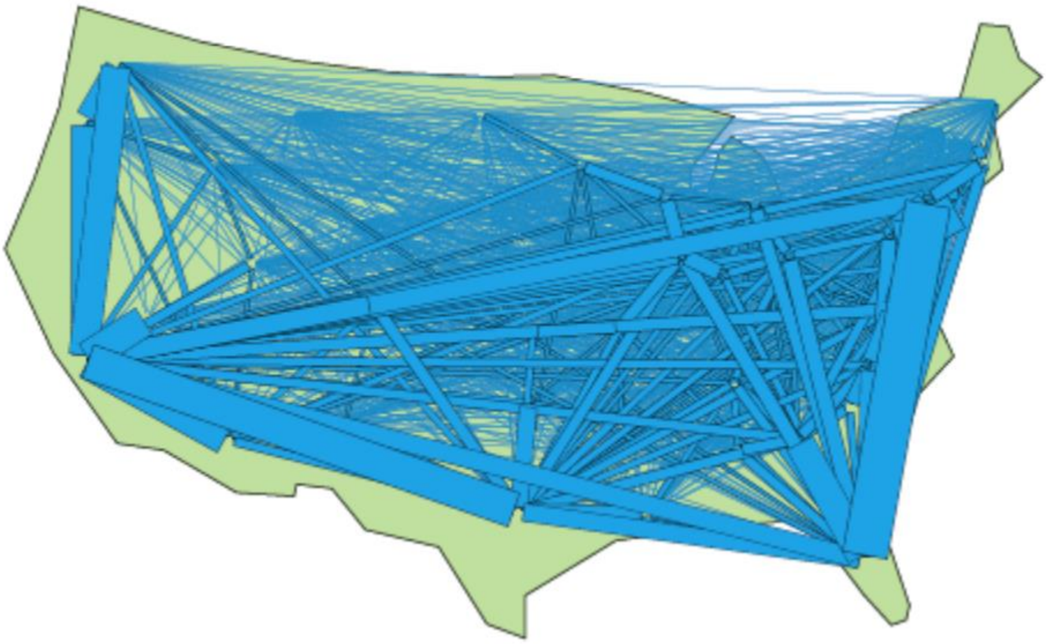


Figure 21. 1995-2000 Total Migration in the USA (Tobler, 2003)

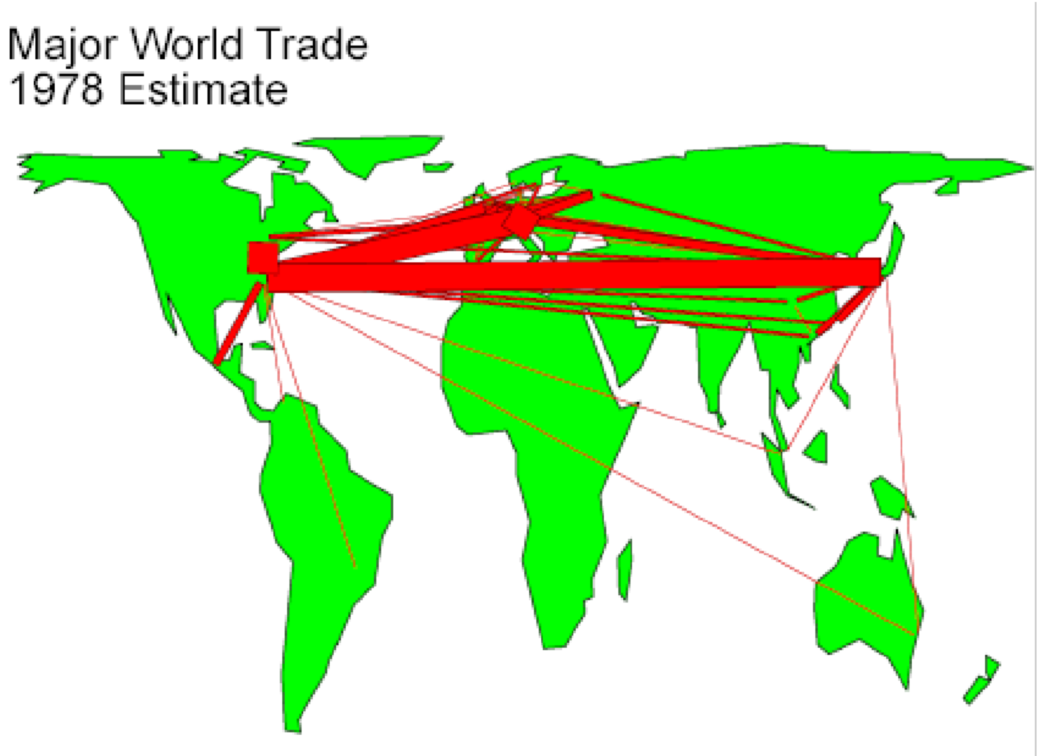


Figure 22. Major World Trade 1978 Estimate (Tobler, 2003)

Although there might be weakness of Tobler's flow mapping programme, it is worth mentioning that his study of digital mapping has also encompassed aspects of animated flow maps (Tobler, 1981). Furthermore, according to Slocum et al's (2022) research, the digital flow mapping tool demonstrates Tobler's engagement with Big Data before the term became popular.

Apart from visual clutter or visual crowding, Jobard and his colleagues (2012) found that the varying size of larger arrows can temporarily occlude the background in ocean currents maps. Therefore, the attention towards animated flow maps has been increasing in recent years. This is attributed not only to advances in technology but also to the limitations encountered by static flow maps when depicting a large number of flow lines in a single map, particularly when these flow lines vary based on different volume data (Guo, 2009; Wood et al., 2010; Buchin et al., 2011). Han et al. (2017) also argued that there is a challenge in static flow mapping that it is hard to represent a large number of connecting lines between origins and destinations without causing visual clutter. The conventional approach, employs varying line thicknesses and arrows to convey flow quantity and direction. Nevertheless, this technique can result in maps that are visually congested, particularly when there is a high concentration of flows or when the emphasis is on specific points, such as major cities. Consequently, the legibility and comprehensibility of these maps may be compromised, especially when dealing with extensive datasets.

In summary, the advancement of geographic information systems (GIS) and graphics software has greatly enhanced the automation of flow map creation (Goodchild, 2009). Additionally, Tobler's (1981) research emphasized the importance of animated maps in the context of flow maps, further emphasizing the need for their development.

2.3.4 Types of Animated Flow Maps

1) Animated Origin-Destination Flow Maps

In addition to the aforementioned static origin-destination flow maps, an animated origin-destination flow map example can be found from Reichelt's (2021) commuting map of individuals at Bremen, Germany. This map was made by incorporating animation and static flow lines. It captured the dynamic nature of commuting, enabling an understanding of the direction of commuting flow without the need for traditional "arrows" (see Figure 23). This animated representation not only highlights the origin and destination directions but also conveys the volume of commuting by varying width flows.

Figure 23. Commuters in Bremen (Reichelt, 2021)

2) Animated Trajectory-based Flow Maps

In the previous subchapter, I provided an explanation of static trajectory flow maps. The animated trajectory flow maps, on the other hand, differ from the static trajectory and involve animating flow lines (with animation software or programming technology). Considering that static trajectories primarily depict spatial information, it is suggested that animated trajectories have the ability to comprehensively convey both spatial and temporal information to the map reader (Schwalb-Willmann et al., 2020). This is due to the fact that animated trajectory-based flow maps illustrate the temporal changing of the spatial locations of tracked objects.(Dodge et al., 2008).

Movebank is a collaborative online platform that serves as a central repository for animal tracking data (Movebank, 2023). It is designed to facilitate the sharing, management, and analysis of animal movement data collected from various tracking technologies such as GPS, satellite telemetry, and radio tracking (Kranstauber et al., 2011). This database is suitable for creating animated trajectory-based flow maps, which are commonly used to visually represent animal movement patterns over time and space (Xavier & Dodge, 2014). An example of an animated trajectory-based flow map can be found on Movebank's website, displaying the movement paths of individual animals as lines within a specific area (see Figure 24).

Figure 24. Animal Trajectory-based Flow Map (Movebank, 2023)
Available at: https://www.movebank.org/cms/movebank-main

3) Animated Continuous Flow Maps

The third type of animated flow map is continuous flow maps, which are typically used to depict the movement of phenomena such as wind speed and ocean currents. It is important to note that static continuous flow maps were not mentioned in the 2.2.1 section, as these maps often use 'Areal' variables instead of 'Linear' variables to represent the movement of phenomena. Slocum and his colleagues (2022) used the term "fishnet map" to describe static continuous maps (see Figure 25).

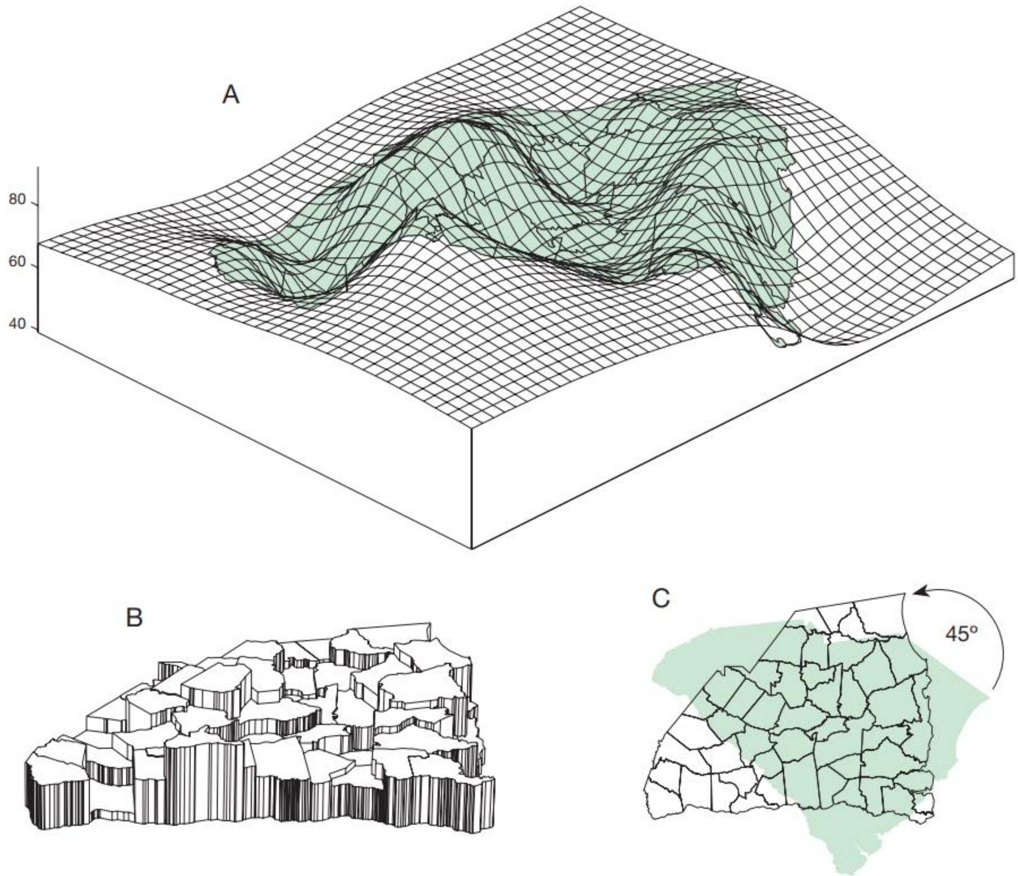


Figure 25. Approaches for mapping a data set of percentage of forest cover by county (South Carolina State Library, 1994)
Available at: https://dc.statelibrary.sc.gov/handle/10827/19485

Traditionally, limited point locations were used, but modern technologies like radar and weather forecasting models allow for more comprehensive data collection and visualization (Slocum et al., 2022). The development of continuous flow maps is attributed to advancements in computer science technology. With the increasing capabilities of computers and software, cartographers and researchers have been able to create animated and interactive visualizations of flow data (Slocum et al., 2022). A typical illustration of continuous flow maps is Cameron Beccario's (2023) animated depiction of global wind patterns, along with other weather conditions (refer to Figure 26.).

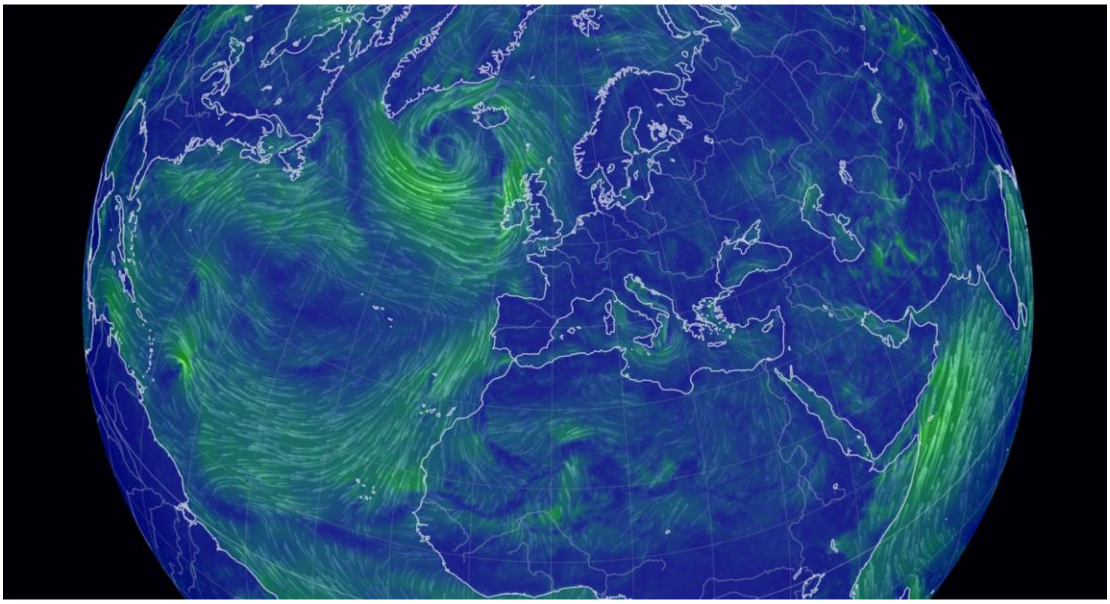


Figure 26. Animated Wind Map
Available at: https://earth.nullschool.net/

2.3.5 Designing Animated Flow Maps

Traditionally, static flow maps utilize varying line widths, often accompanied by arrows to indicate flow direction. However, the static design rules are primarily based on static maps according to Dent. et al, (2009) research. Some different visual variables, such as changing line speed and line lightness based on associated data values, have also been explored in recent years in animated maps.

In their study, Han et al. (2017) discussed the utilization of speed as a dynamic visual variable in animated flow maps. They (2017) proposed that adjusting the frame rate by repeatedly redrawing the flow lines can be an effective approach to indicate the volume values (see Figure 27). By varying the speed of the animated flow lines, viewers can perceive the varying volume of the different flows.

Figure 27. Flow of Twitter users from countries to Los Angeles (Han et al., 2017)

Furthermore, when comparing animated flow maps to static flow maps, it becomes apparent that certain guidelines from static maps may be less relevant or unnecessary in the context of animated maps. For instance, the use of arrows, which is considered crucial in static flow maps when the direction of flow is critical for understanding the map, is not commonly employed in animated flow maps. This is because the movement of flow lines itself can convey the direction information. Jobard et al. (2012) argued that arrows may not be a suitable choice for representing directions, particularly in maps depicting wind and ocean currents, as they can become misleading when the flow magnitude is low. A notable example of this can be observed in the widely recognized ocean and wind continuous flow map available on Beccario's (2020) wind surface map website (Figure 28. below).

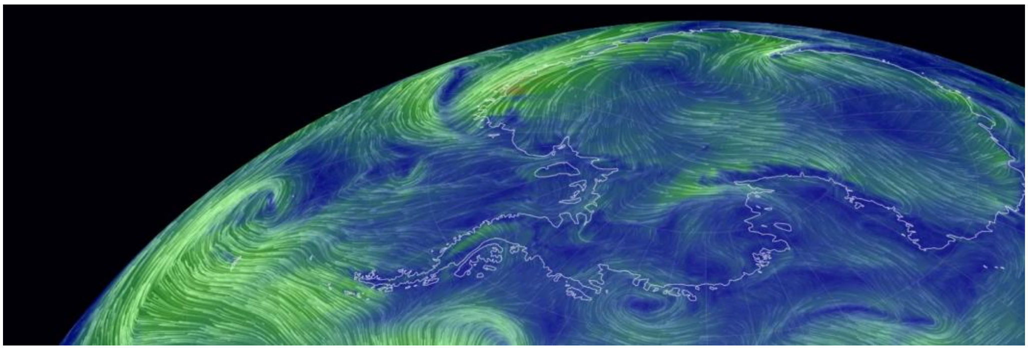


Figure 28. Animated Wind Map
Available at: https://earth.nullschool.net/

Similarly, another static map rule that might appear unsuitable for animated maps is the guideline stating that "if smaller flow lines intersect or overlap with larger ones, they should be positioned on top." This rule becomes challenging to apply in animated flow maps because the flow lines are continuously in motion, resulting in their positions constantly changing on the map. Determining which line is on top and which one is on the bottom becomes difficult, particularly when the lines incorporate varying tail lightness (i.e. when some flow lines have semi-transparent states, it becomes even more challenging to identify the hierarchy order or the stacking of flow lines in animated maps.) (see Figure 29).

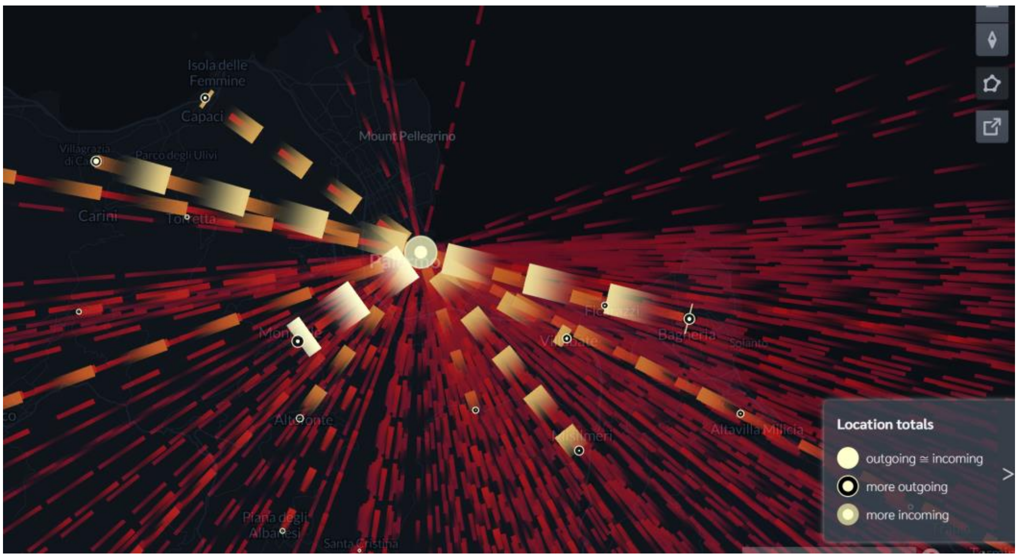


Figure 29. Commuters in Palermo, Italy (Created by: @gbvitrano, 2022)

Available at:

https://flowmap.blue/1gDrYiVk4jNhmqkBhFwKOYhBTHfOU_GNsjDUHV5vpuVE

Additionally, it is important to note that animated visual variables are not isolated from static visual variables but are used in conjunction with them. For example, in "The Migration of Plant Species in The Bridge of Beyond" map, Hannah (2021) employed both static variable size and animated variable tail length (see Figure 30). This demonstrates the integration of dynamic and static visual variables to represent the volume of migration.

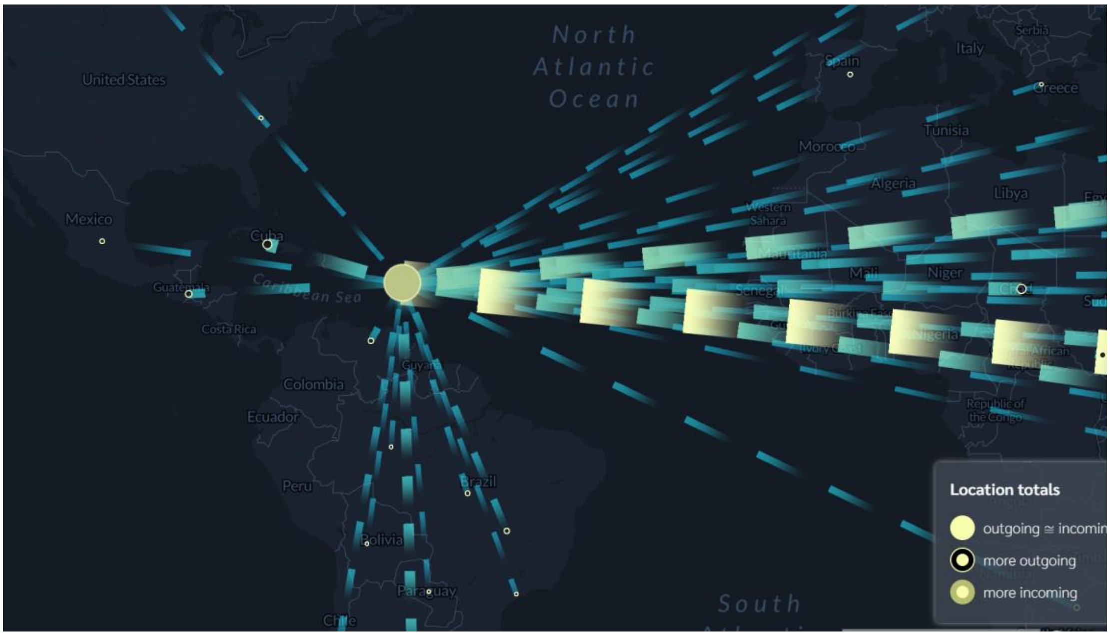


Figure 30. The Migration of Plant Species in The Bridge of Beyond (Hannah, 2021) Available at: https://flowmap.blue/1Hy6kV4O_qqcjNvNxmDkc-WA__8wcbAjUlBX5a0zcGWY

In conclusion, the application of static map design rules to animated flow maps is not without its challenges, as the visual methods and variables used in these two map types differ significantly. However, it is important to note that not all static map rules become irrelevant in the context of animated flow maps. Exploring how to integrate essential static map rules with new dynamic visual features to develop a set of animated flow map design strategies may represent an interesting direction for cartographers.

2.4 Techniques for making animated flow maps

In recent years, the ability to visually represent complex and animated data and convey information by using animated maps has become paramount ((Koussoulakou & Kraak, 1992; Han et al., 2017). These animated visualizations showcase the movement of data, entities, or phenomena across a map or network, enabling viewers to grasp patterns, trends, and interdependencies at a glance (Buchin et al., 2011). In this subchapter, we delve into the diverse methods and tools available for crafting animated flow maps.

The are many methods can be used such as 1) Animation Software, including Adobe After Effects, Blender, and Autodesk Maya; 2) Geographic Information System (GIS) software, such as ArcGIS and QGIS; and 3) Programming and Data Visualization Libraries, e.g., D3.js, matplotlib, Echarts, and Processing. While these methods can be used individually, they are often utilized collaboratively in practice. For instance, Jacobs (2018) conducted a study on Visualizing Bird Migration in the Americas, where a combination of After Effects, ArcGIS, and the D3 library was employed (Figure 31.). The techniques will be discussed based on the types of animated flow maps mentioned in chapter 2.2.1.

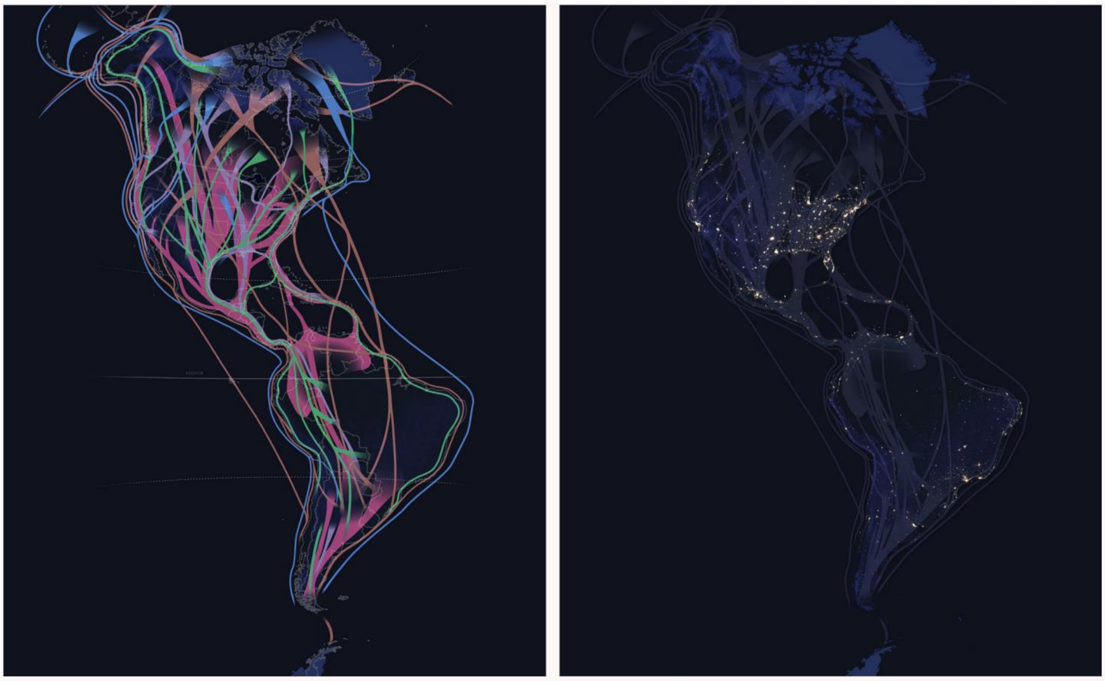


Figure 31. Converting different styles of maps (Jacobs, 2018)

- **Animation Software** utilize tools such as Adobe Illustrator & After Effects, Blender, or Autodesk Maya. These tools provide a wide range of features and capabilities for creating complex and visually appealing animated flow maps. I will introduce an example based on Adobe After Effects below.

- **Geographic Information System (GIS) Software** like ArcGIS or QGIS allows to create animated flow maps by combining geographical data with flow information. It is possible to visualize the movement of objects or data between different locations on a map, representing the flow using arrows, lines, or other graphical elements. These software packages often have built-in tools for creating animations.

- **Programming and Data Visualization Libraries** such as D3.js (JavaScript), matplotlib (Python), or Processing (Java) are also useful for creating animated flow maps. These libraries provide the flexibility to customize the animated flows based on specific data.

2.4.1 Techniques for Origin-destination Maps

Programming libraries that can be used for creating animated origin-destination flow maps include Leaflet.js and D3.js. Leaflet.js is a widely used JavaScript library for interactive maps and it provides a simple API for creating interactive maps with features like zooming, panning, and markers (Sudipto, 2023). Additionally, D3.js is a powerful library for creating dynamic data visualizations and both of them cover the basics of map projections, paths, and geojson data (Bacinger, 2014) . These libraries provide the necessary functions to work with geographic data, manipulate map elements, and animate the flow of objects between origin and destination points.

Method 1: Leaflet.Canvas-Flowmap-Layer

One of the useful example is from The Leaflet.Canvas-Flowmap-Layer that is a specialized plugin for LeafletJS that enables the visualization of object flow between origin and destination points using Bezier curves (Jwasilgeo, 2021). It utilizes GeoJSON point feature coordinates, converting them into pixel space for rendering on an HTMLCanvasElement. This allows for the accurate mapping of points and curves within the flow map.

The code below is an example of how to create a single GeoJSON point feature, representing the starting and ending points on a flow map.

```json
{
  "type": "Feature",
  "geometry": {
    "type": "Point",
    "coordinates":[109.6091129, 23.09653465]
  },
  "properties": {
    "origin_id": 238,
    "origin_city": "Hechi",
    "origin_country": "China",
    "origin_lon": 109.6091129,
    "origin_lat": 23.09653465,
    "destination_id": 1,
    "destination_city": "Sarh",
    "destination_country": "Chad",
    "destination_lon": 18.39002966,
    "destination_lat": 9.149969909
  }
}
```

This Leaflet.Canvas-Flowmap-Layer plugin supports various types of origin-to-destination relationships, including "One-to-many," "many-to-one," and "one-to-one." Figure 32. shows a simple demo of animated flows between points on a world map.

For more detailed information, you can refer to its Github page: https://github.com/jwasilgeo/Leaflet.Canvas-Flowmap-Layer.

Figure 32. Leaflet custom layer plugin for flow mapping (Jwasilgeo, 2021) Available at: https://jwasilgeo.github.io/Leaflet.Canvas-Flowmap-Layer/docs/comparison/

Method 2: FlowmapBlue - Flow map visualization tool.

Flowmap.blue is a freely available tool that facilitates the visualization of aggregated movement patterns between geographic locations through the use of flow maps. It serves as a powerful means to represent a wide range of real-world phenomena that involve pairs of locations (Slocum et al., 2022). These phenomena include but are not limited to urban mobility, commuting behavior, various modes of transportation such as buses, subways, and air travel, bicycle sharing systems, migration of both humans and birds, refugee flows, freight transportation, trade routes, supply chains, scientific collaborations, and more (Boyandin, 2019). Boyandin (2019) utilized several technologies such as deck.gl, flowmap.gl, mapbox, d3, blueprint, and CARTOColors.

With Flowmap.blue, users can input their data and generate interactive flow maps. The detailed tutorial and more information can be found on GitHub - FlowmapBlue/FlowmapBlue: Flow map visualization tool. https://github.com/FlowmapBlue/FlowmapBlue

Here is a quick tutorial for creating flow maps on Flowmap.blue (Boyandin, 2019):

1. Open the template spreadsheet
2. Make a copy of it (find “File” / “Make a copy…” in the menu)
3. Add data to the new spreadsheet. Read more…
4. Click the “Share” button, then change the selection from “Restricted” to “Anyone

with the link” in the drop-down under “Get link”. Read more…

5. Copy the link to your spreadsheet and paste it here

It is worth mentioning that Flowmap.blue enables users to generate flow maps by visualizing their own origin-destination data, which can be conveniently sourced from Google Sheets. There is an example of a flow map titled 'Internal Migration in Greenland' created by Ilya Boyandin in 2020 using Flowmap.blue and presents the volume of migrating people by utilizing varying width and tail brightness.

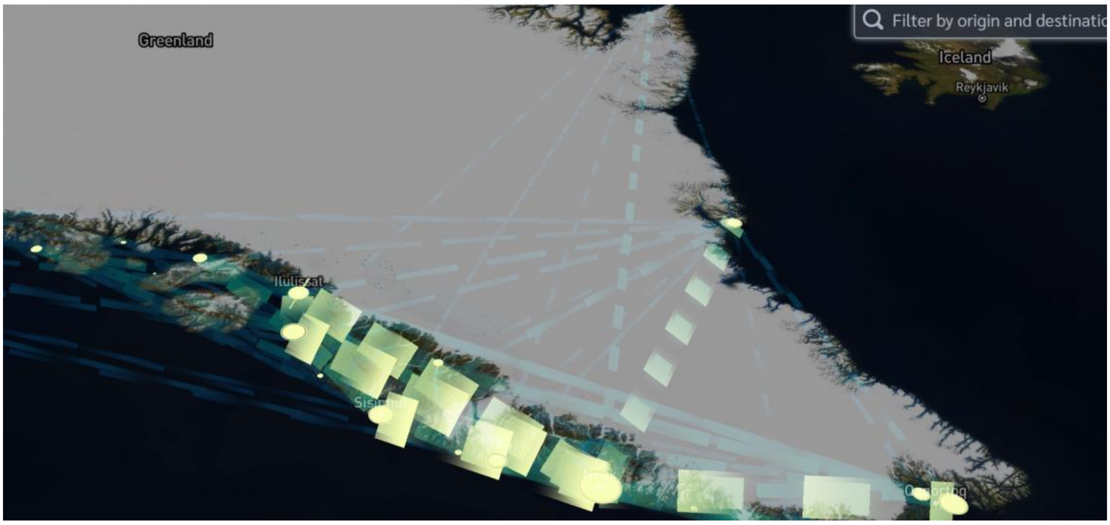


Figure 33. Migration in Greenland 1993-2018 (Boyandin, 2020)
Available at:
https://flowmap.blue/1XrvJF4AGdmY2JYu_F8BD7c_hktyY7eoLEBkRIBIc4Ls?v=67.389007%2C-51.247878%2C4.08%2C49%2C48&a=1&as=1&b=1&bo=60&c=1&ca=1&d=1&fe=1&lt=1&lfm=ALL&t=20190101T000000%2C20200101T000000&col=BluYl&f=35

2.4.2 Techniques for Trajectory-based Maps

The selection of tools for creating animated trajectory-based flow maps typically involves a combination of animation software and external plugins. This decision is based on the need to accurately depict the actual movement of study objects while also meeting the aesthetic requirements of animated trajectory-based flow maps. In the following section, I will introduce two demos of animated trajectory-based flow maps:

Method 1: Using GEOlayers 3 plugin for Adobe After Effects

GEOlayers 3 is a program that allows cartographers design and animate maps directly in After Effects (Blake, 2020). It renders custom maps from different online data sources and provides direct access to extensive databases of geospatial features of the world. Here are the steps to create an animated flow map using GEOlayers 3 (Markus Bergelt, 2023):

1. Install GEOlayers 3 in After Effects.

2. Use the online search feature to find geographical features such as countries, cities, famous buildings, points of interest.

3. Style your maps directly inside After Effects by choosing colors, adjusting line width, swapping fonts, adding hill-shading to your maps and even showing and hiding certain groups of features.

4. Animate your map by scrolling, zooming, pitching, and rotating it inside After Effects.

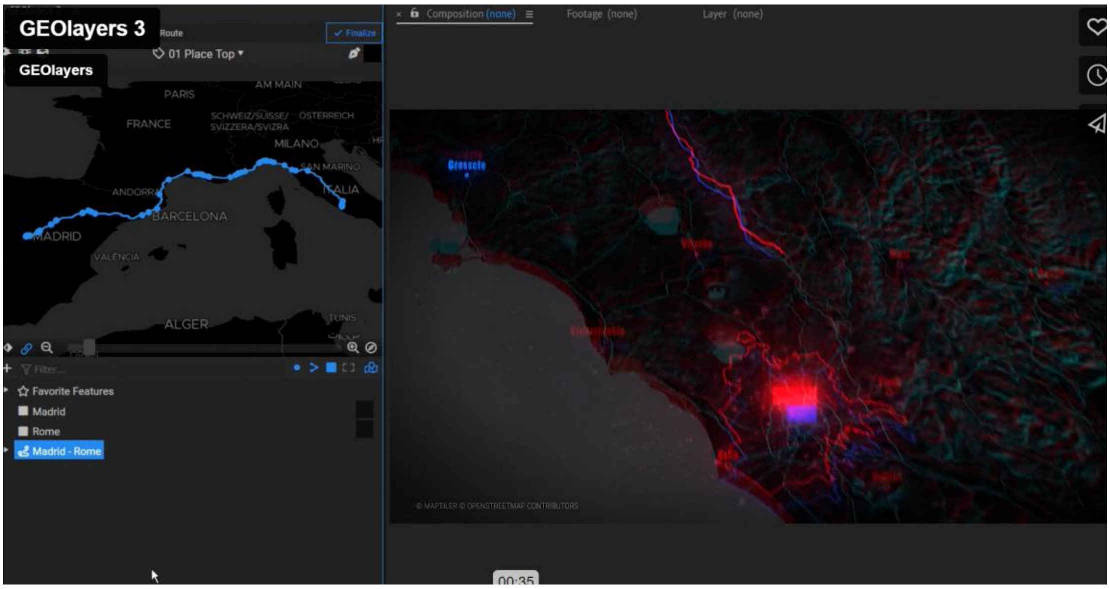


Figure 34. Animate driving routes by GEOlayers 3 (Blake, 2020 & Bergelt, 2023) Available at: https://aescripts.com/geolayers/

Method 2: Using Adobe Illustrator and After Effects

Creating a very simple trajectory map in Adobe Illustrator involves a series of steps that can be outlined as follows (YakobchukOlena et al, 2019):

1. Prepare the background map: Obtain or create a map image that serves as the base for your trajectory map. This can be a vector file or a high-resolution raster image. Import the map into Adobe Illustrator by selecting "File" > "Place" and choose the appropriate file.

2. Import trajectory data: such as GPS coordinates or spatial points, import the data into Adobe Illustrator. Convert the data into a compatible format, such as a CSV or Excel file. To import the data, select "File" > "Place" and select the trajectory data file.

3. Plot trajectory points: Use the Pen tool or the Line Segment tool to plot the trajectory points on the map. Ensure that the points are accurately placed according to the coordinates from your trajectory data.

4. Connect trajectory points: Use the Pen tool or the Line Segment tool to draw lines connecting the trajectory points in chronological order. This creates a visual representation of the trajectory path. Adjust the stroke settings, such as line thickness and color, to enhance visibility and aesthetics.

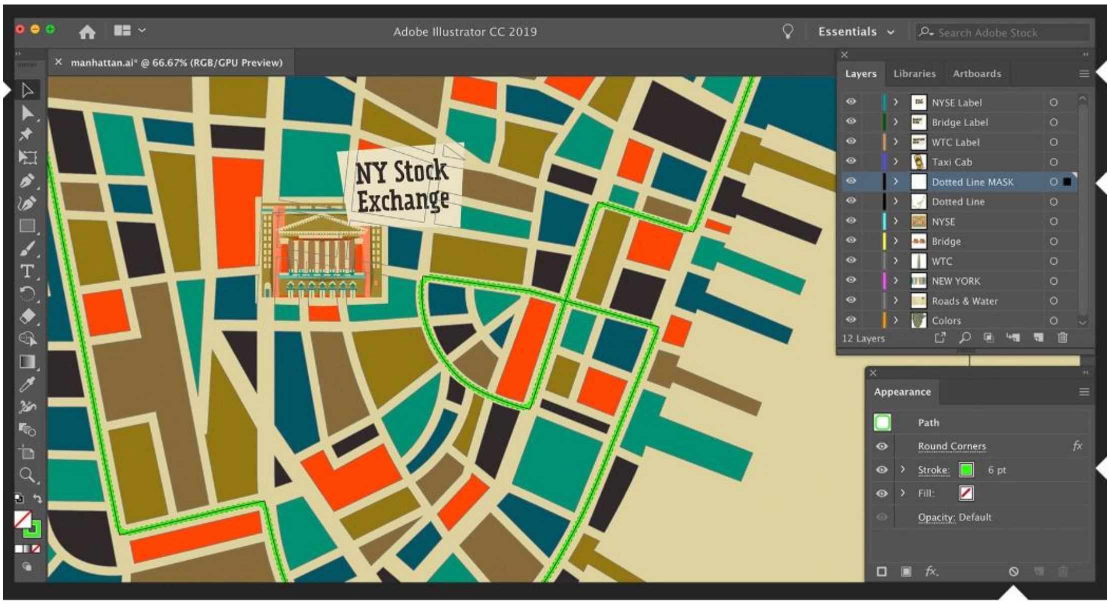


Figure 35. [Map animation in After Effects - Adobe Inc.]
(Available at: https://helpx.adobe.com/after-effects/how-to/map-animation.html) .

2.4.3 Techniques for Continuous Maps

Continuous flow maps serve a specific purpose in the realm of data visualization, primarily employed for visually representing wind patterns and ocean currents (Slocum et al., 2022). Different from the other two types, continuous flow maps emphasize the dynamic nature of wind and ocean currents. Below, I will introduce two methods that utilize the ArcGIS API for JavaScript and Echarts.js.

Method 1: Using ArcGIS API for JavaScript

Version 4.23 of the ArcGIS API for JavaScript brings the official release of a new renderer, the FlowRenderer, that can visualize raster data (e.g., UV or MagDir raster data) with animated streamlines. Here are the steps to create a continuous flow map using ArcGIS API for JavaScript (Fitz, 2022):

1. First, users need to publish their raster data as a hosted layer in ArcGIS Online or ArcGIS Enterprise.

2. Once the data is published, an ImageryLayer or ImageryTileLayer can be created from the service and rendered using the FlowRenderer. By customizing the properties of the FlowRenderer, such as color, density, flow representation, flow speed (See Figure 36).

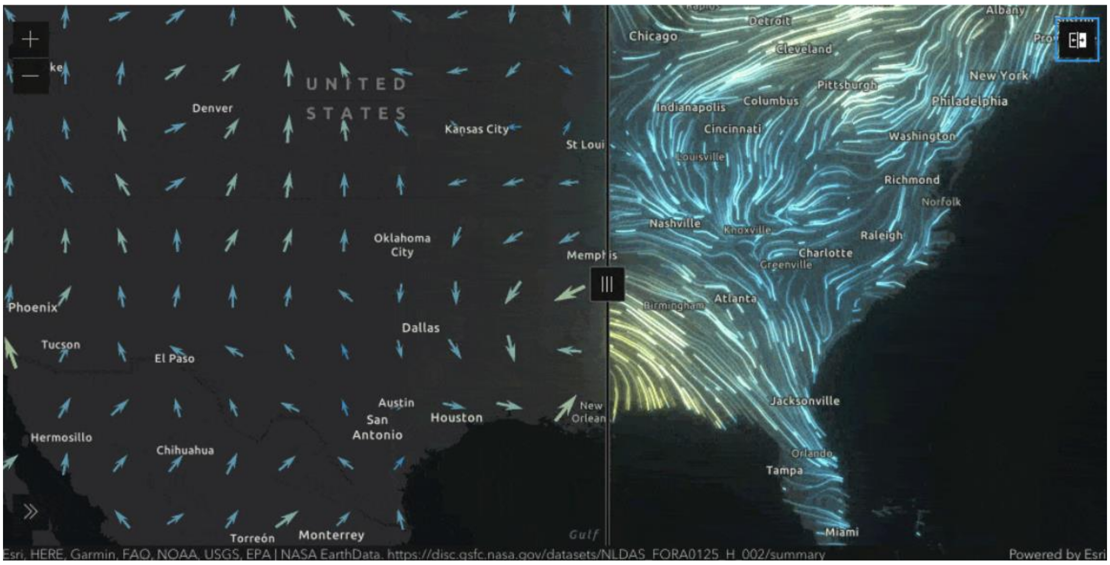


Figure 36. wind speeds during Hurricane Ida. (Fitz, 2022)
Available at:
https://www.esri.com/arcgis-blog/products/js-api-arcgis/mapping/create-an-animated-flow-visualization-with-the-arcgis-api-for-javascript/

Another presentation of using ArcGIS API for JavaScript is from Harrower (2022) from his online tutorial "Map Viewer introduces animated Flow renderer" (See Figure 37 below).

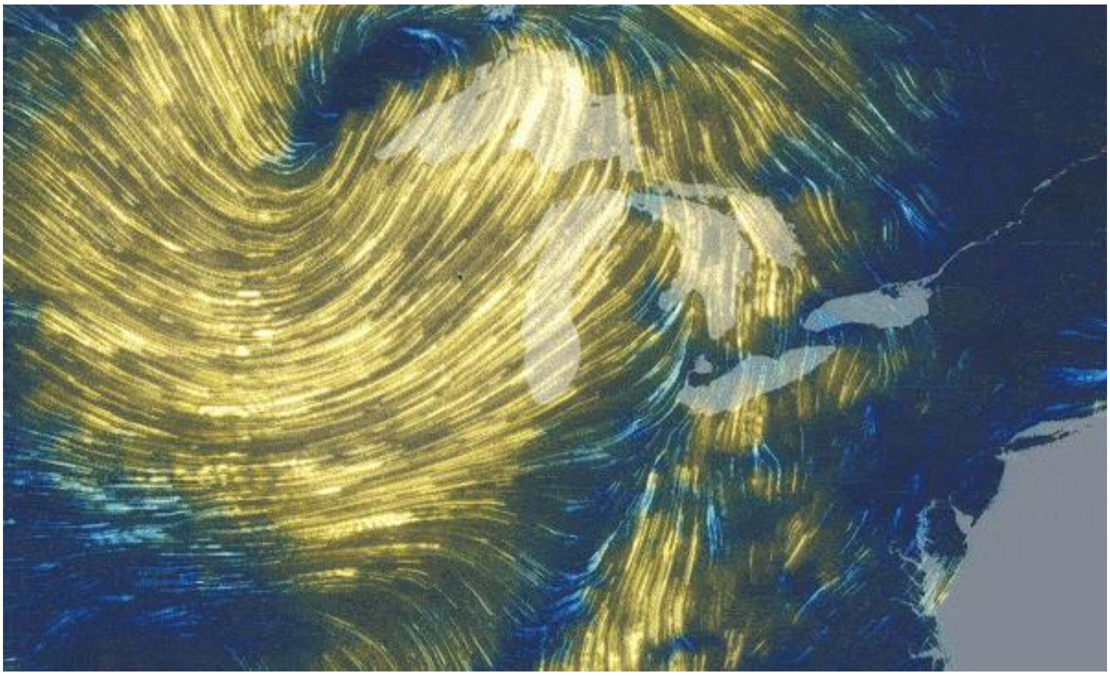


Figure 37. Wind Speed Map: Flowlines (Harrower, 2022)
Available at: https://www.esri.com/arcgis-blog/products/arcgis-online/mapping/flow-renderer/

Method 2: Echarts.js

ECharts.js is a JavaScript data visualization library that can be used to create animated flow maps. It provides a wide range of chart types, including maps, lines, and scatter plots, making it suitable for visualizing various types of data, including flow data (Apache ECharts, 2022). ECharts.js also offers various animation effects, such as smooth transitions and animated updates, allowing developers to create visually appealing and engaging flow maps. The library provides APIs for controlling the animation process, such as starting, pausing, and stopping animations. Below is an example from the Echarts gallery.

```json
// Full code can be found at
https://echarts.apache.org/examples/en/editor.html?c=global-wind-visualization&gl=1
$.getJSON(ROOT_PATH + '/data-gl/asset/data/winds.json', function (windData) {
  var data = [];
  var p = 0;
  var maxMag = 0;
  var minMag = Infinity;
  for (var j = 0; j < windData.ny; j++) {
    for (var i = 0; i <= windData.nx; i++) {
      // Continuous data.
      var p = (i % windData.nx) + j * windData.nx;
      var vx = windData.data[p][0];
      var vy = windData.data[p][1];
      var mag = Math.sqrt(vx * vx + vy * vy);

      data.push([
        (i / windData.nx) * 360 - 180,
        (j / windData.ny) * 180 - 90,
        vx,
        vy,
        mag
      ]);
      maxMag = Math.max(mag, maxMag);
      minMag = Math.min(mag, minMag);
    }
  }
```

Source code: https://echarts.apache.org/examples/en/editor.html?c=global-wind-visualization&gl=1

There is a code snippet written in JavaScript sourced from the official Apache ECharts documentation website *(more details can be seen at https://echarts.apache.org/)*. The retrieved data is stored in the windData variable and it iterates over the windData to process the wind data and populate the data array containing the longitude, latitude, velocity components, and magnitude of each wind data point (Apache ECharts, 2022). The wind map utilizes tail lightness and tail length to represent the magnitude of the wind. Figure 38. provides a visual example of this wind map, showcasing a representation of wind magnitude through tail lightness and tail length.

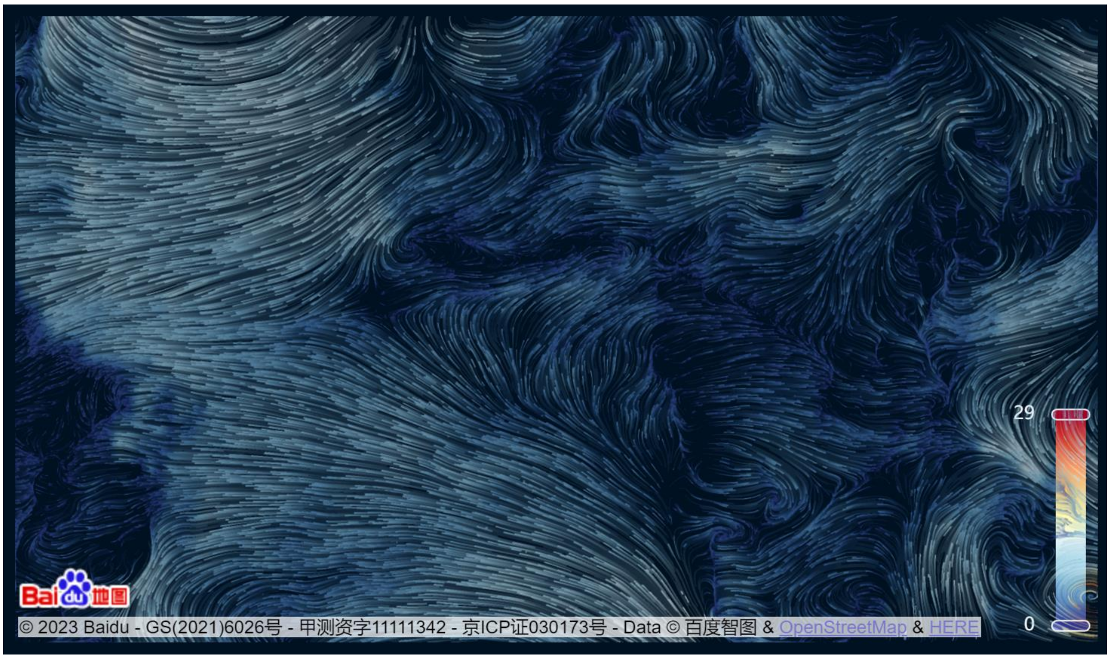


Figure 38. Global wind visualization (Apache ECharts, 2022)
Available at: https://echarts.apache.org/examples/en/editor.html?c=global-wind-visualization&gl=1&version=5.5.0-dev.20230705&theme=dark

2.4.4 Database for Making Animated Flow Maps

Due to the fact that flow maps are typically used to demonstrate the movement of various phenomena between geographic locations, there are some open data sources available that can be utilized for creating animated flow maps:

1. **OpenFlights** is a data source that offers comprehensive information on global flight routes, airlines, and airports. They provide downloadable datasets in various formats, which include detailed information such as airport codes, routes, and airline details. It is recommended because of its large amount of airline data, including over 10,000 airports, and the convenience of downloading the data in CSV format (OpenFlights, 2006) (available at: https://openflights.org/data.html).

2. **The Bureau of Transportation Statistics** (BTS), a part of the U.S. Department of Transportation, provides a wide range of transportation-related data, including flight statistics for domestic and international flights in the United States. Their website offers access to datasets and interactive tools for exploring flight data. The reason for recommending this data source is that it provides detailed information in the US, and apart from airline data, it also includes Enplaned Passengers data (BTS, 2023) (available at: https://www.transtats.bts.gov/).

3. **Movebank** is a platform that offers animal movement data from various species across the globe, enabling researchers to study the migratory patterns, behaviors,

and movements of animals. The reason for recommending this database is that it provides a diverse range of animal tracking datasets, offering detailed coordinates that are convenient for portraying the paths and behaviors of tracked animals over time, especially for animated trajectory flow maps (Movebank, 2023) (available at: https://www.movebank.org/cms/movebank-main).

III. Methodology

In this chapter, the focus is on presenting the methodology that was utilized to accomplish the research objectives of creating animated flow maps and evaluating their design rules. The primary aim is to provide insights into the techniques employed in developing online animated flow maps and to outline the evaluation process, which involves conducting a user study. The chapter begins by defining the dynamic visual variables and data preparation for animated flow maps. Furthermore, it will discuss flow map designs using various design techniques by analyzing existing animated flow maps. Then, the techniques employed in generating animated flow maps will be introduced, explaining the methods and codes used to create these visual representations of data. Next, the chapter delves into the evaluation process. It describes the methodology adopted for conducting a user study, which involves collecting information from participants to assess the effectiveness and usability of the animated flow maps. The chapter explains the study's design, including the selection of participants, the questions assigned to them, and the metrics used to measure their performance and feedback. Figure 39. below displays the workflow of the methodology and also explains the relationships between the methodology and Research Questions (RQs)."

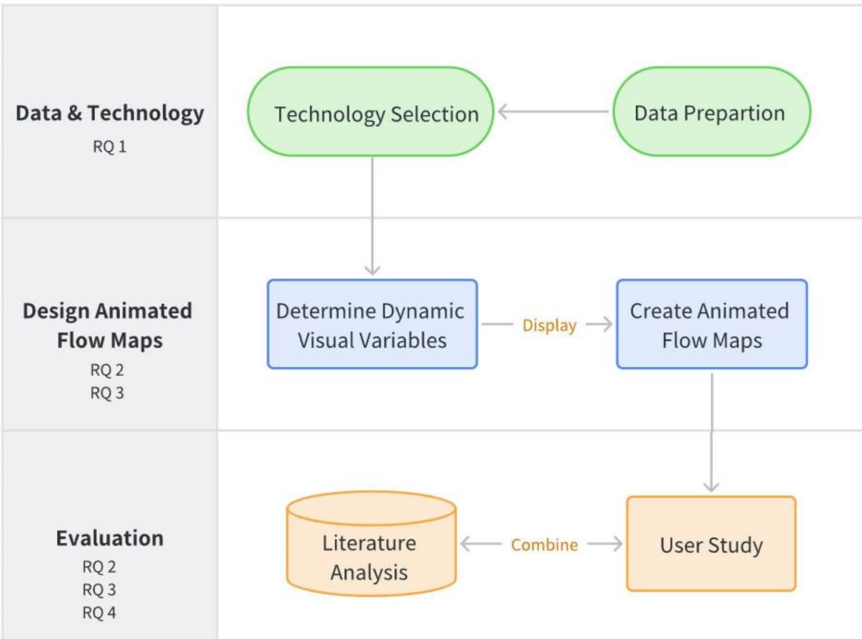


Figure 39. Workflow of methodology

3.1 Design Animated Flow Map

The design of animated flow maps in this thesis is seeking to be best suited for the user test and therefore, for resolution of Research Questions 2, 3, and 4 (RQ-2, RQ-3, and RQ-4).

For example, o answer RQ-2, it is important to analyze the existing guidelines derived from static flow maps. The approach to addressing this question is by using animated maps that do not adhere to some fundamental strategies derived from static flow maps. The goal is to test whether this kind of map (without some traditional design guidelines) can still work effectively for map users.

Furthermore, the use of dynamic visual variables on animated maps and the comparison between dynamic visual variables and static variables are also crucial in determining which dynamic visual variables effectively convey information to map users.

3.1.1 Data preparation and process

As stated before, animated flow maps offer a dynamic way to visualize the movement of data across geographic locations and often utilize diverse data sets, ranging from transportation and migration patterns to trade and social interactions. In particular, two data sources that will be used in this thesis are flight data and exports between countries. The reason is the massive volume of flight and export information they provide, encompassing not only departure and arrival points/cities but also other relevant details. Moreover, flight data and exports data are relatively open-source data that can be freely downloaded from public websites. This accessibility makes them valuable resources for conducting research and analysis in this study.

The actual number of flights used in this study was sourced from the official website of the General Administration of Civil Aviation of China (CAAC) (Available at: http://www.caacnews.com.cn/). The CAAC website provides data on civil aviation activities in China, including flight statistics and other relevant information. Additionally, the exports data was obtained from the tradingeconomics website, specifically from the page dedicated to exports by many countries (Available at: https://tradingeconomics.com/country-list/exports)

When creating animated flow maps, a crucial aspect is to incorporate nodes and links along with their corresponding attributes. While the links (lines) are typically generated automatically on the map, the data in animated flow maps refers to the information associated with the nodes, specifically the starting and ending points. To create a basic animated flow map, a minimum of three properties must be included: NAME, LATITUDE, and LONGITUDE. Below is an example of the data format as csv form (Table 2.):

Name	Lat	Lon
Point A	37.803379	-122,271843
Point B	37.765009	-122.419685
Point C	37.807807	-122.268595
Point D	37.751992	-122.41872
Point E	37.996448	-121.780665
Point F	37.852932	-122.268903

Table 2. Example of the data format

In the actual application of data, it is also common to represent the data in JSON format for mapping. JSON (JavaScript Object Notation) is a lightweight data interchange format that is easy to read and write for both humans and machines (JavaScript Object Notation, 1999). It provides a structured way to organize and store data and is convenient because it can be utilized with many different languages (JavaScript Object Notation, 1999). Therefore, geographic data for animated flow maps also uses this data interchange format.

For example, in the context of a flight map, each flight route is represented as an object with properties such as origin, destination, and flight count. This flexibility allows us to modify the properties of each individual route, such as visual variables like width and speed. Here is an example of how flight data can be structured in JSON format:

```
JSON
var data = {
  citys: [
    {
      name: "A",
      value: [116.27030, 41.03916],
    },
    {
      name: "B",
      value: [121.473701, 31.310416],
    },
    {
      name: "C",
      value: [90.76628, 41.6502],
    },
  ],
  moveLines: [
    {
      fromName: 'A',
      toName: 'B',
      coords: [
```

```
            [116.27030, 41.03916],
            [121.473701, 31.310416],
          ],
        },
        {
          fromName: 'B',
          toName: 'C',
          coords: [
            [121.473701, 31.310416],
            [90.76628, 41.6502],
          ],
        },
      ],
};
```

3.1.2 Determine visual variables

In the preliminary phase, the foremost consideration revolves around selecting the most suitable dynamic and static visual variables. These variables serve as the fundamentals for the later map-making and user test. As introduced in 2.1 and 2.1, dynamic visual variables involve moment, duration, frequency order, rate of change, and synchronization. Which of them will be selected in the later user study needs to be decided firstly.

3.1.2.1 Dynamic variables

According to a study conducted by Köbben & Yaman in 1995, they examined two dynamic visual variables that are relatively effective in displaying quantitative information (See Table 3). For this reason, these two dynamic visual variables will be integrated into the user test animated flow maps. In the following section, further details will be introduced on these selected variables, explaining their characteristics:

	perceptual property			
dynamic visual variable	association	order	quantity	selection
moment	○			
duration		●	✪	
frequency	✪	✪		○
order	✪	✪		○
rate of change		●	○	
synchronisation	*not tested*			

● – strong ✪ – fair ○ – weak

Table 3. Perceptual property of dynamic visual variables (Köbben & Yaman, 1995)

- **Rate of Change (Speed)** - it represents how dynamic the movement is on an animated flow map; in other words, the 'rate of change' is influenced by the degree of dynamism exhibited by the phenomenon and the rate of animation, expressed in frames per minute. (Köbben & Yaman, 1995). Therefore, the attribute "**Speed** (Rate of how dynamic the object is)" will be utilized in the user study of animated flow maps as the variation of movement speed of flow lines. By manipulating the speed at which the flow lines move across the map to convey different levels of volumes, they represent the flows. This animated visual variable allows viewers to perceive the speed at which the flows occur and gain insights into their potential volumes. For example, in animated flow maps (see Figure 40), flows with a large volume can be represented with faster movement speed, while flows with a shorter volume can be depicted with slower movement speed. This differentiation in speed helps visually distinguish between flows of varying magnitudes.

Figure 40. Maps using speed (rate of change) to represent volume (Han et al., (2017)

- **Duration (Tail Length)** - refers to the real-time period during which an element remains in the user's view in an animation. In simpler words, Köbben & Yaman (1995) provide an example stating that "if province A receives twice the amount of annual sunshine compared to province B, province A would be highlighted for twice the duration during the animation." Hence, the **Tail Length** attribute will be employed in representing the dynamic visual variable of 'duration,' as the length of "moving visual attributes" can be seen as a form of "real-time period" on the animated maps. For the user study maps in this thesis, the tail length of the small lines positioned above the entire flow lines will be utilized. An example demonstrating the use of different tail lengths for different flights can be observed in the kepler.gl demo of animated flight flow maps (see figure 41).

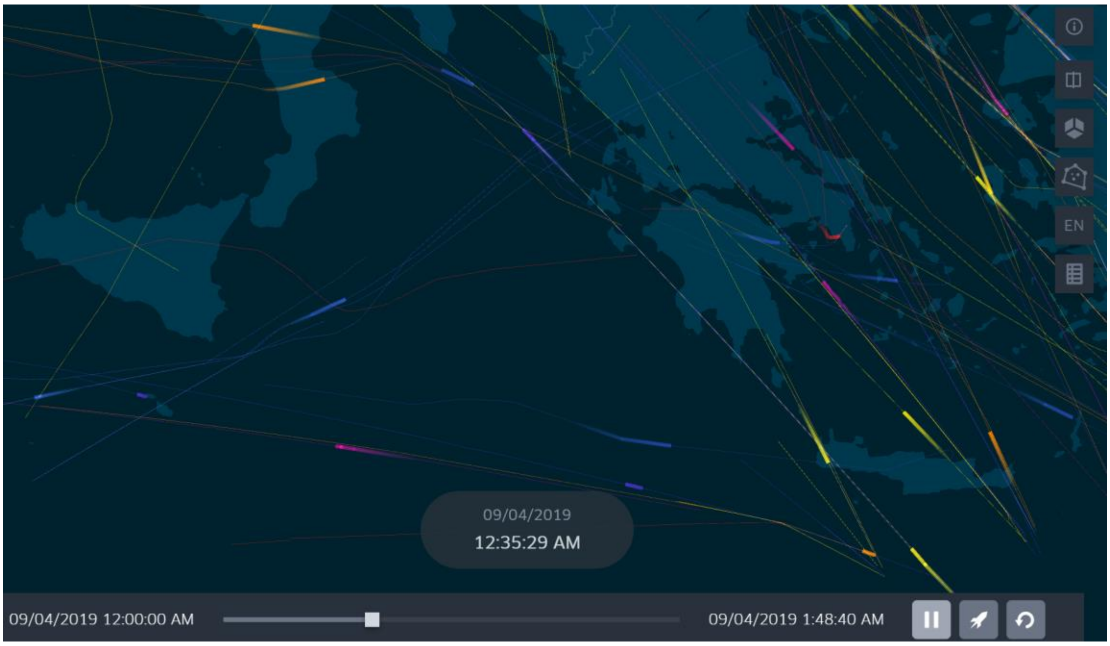


Figure 41. World Flights Animated Flow Maps (Kepler, 2023)
(Available at: https://kepler.gl/demo/world_flights)

3.1.2.2 Static variables

- **Size -** As introduced in the previous chapter, the size of a symbol plays a crucial role in conveying its dimensions, allowing for control over the size of individual points or the thickness of lines (Roth, 2017). Additionally, size is a highly recommended visual variable for representing quantitative information on maps, particularly when dealing with flow maps (Roth, 2017). However, this visual variable also has weaknesses, especially when attempting to represent a substantial volume of flow lines on a single map, particularly when these lines vary based on different volume data, as discussed above (Guo, 2009; Buchin et al., 2011). Therefore, it is worth analyzing this important static visual variable in a user test map and comparing it with dynamic visual variables.

In a short summary, the first step involves deciding on dynamic and static visual variables for map-making and user testing. The chosen dynamic variables are "Rate of Change (Speed)" and "Duration (Tail Length)," while the static variable is "Size." It is necessary to emphasize the definition and importance of these variables and their application in representing quantitative information on maps, particularly in animated flow maps for later user study.

3.1.2.3 Design Flows

The design inspiration for the flows comes from Han et al. (2017), who used "speed" as an attribute, and is also based on Köbben & Yaman's (1995) contributions on six dynamic visual variables, as well as the properties of dynamic visual variables. As mentioned above in 3.1.2, it is noted that 'rate of change' and 'duration' convey quantitative information more effectively than other attributes. Consequently, the flows in this thesis will utilize attributes related to these two visual variables.

For instance, the code below defines an object allData with a property moveLines which is an array of objects representing different move lines. Each move line object has properties fromName, toName, and coords which represent the starting point, ending point, and coordinates of the line, respectively.

```JSON
allData.moveLines.forEach((item) => {
  var fromName = item.fromName;
  var toName = item.toName;

  if (fromName === 'GroupA') {
    item.lineStyle = {
      width: 2,
      color: 'hsl(181 100% 79% / 1)',
    };
    item.effect = {
      constantSpeed: 150,
      symbolSize: 12,
    };
  } else if (fromName === 'GroupB') {
    item.lineStyle = {
      width: 2,
      color: 'hsl(181 60% 79% / 1)',
    };
    item.effect = {
      constantSpeed: 70,
      symbolSize: 12,
    };
  } else if (fromName === 'GroupC') {
    item.lineStyle = {
      width: 2,
      color: 'hsl(181 100% 79% / 1)',
    };
    item.effect = {
      constantSpeed: 40,
      symbolSize: 12,
    };
```

Therefore, in the dynamic flight map, the properties of each movement line are determined by the value of the name attribute of different groups. From Figure 42., Flight routes with a lower number of flights are assigned a lower speed (related to 'rate of change') or a shorter tail length (related to 'duration').

Figure 42. 'Speed & Tail length' differentiate number of flights

On the other hand, for the static maps used in the user test, the visual variable 'width' will be employed to represent the number of flights per route.

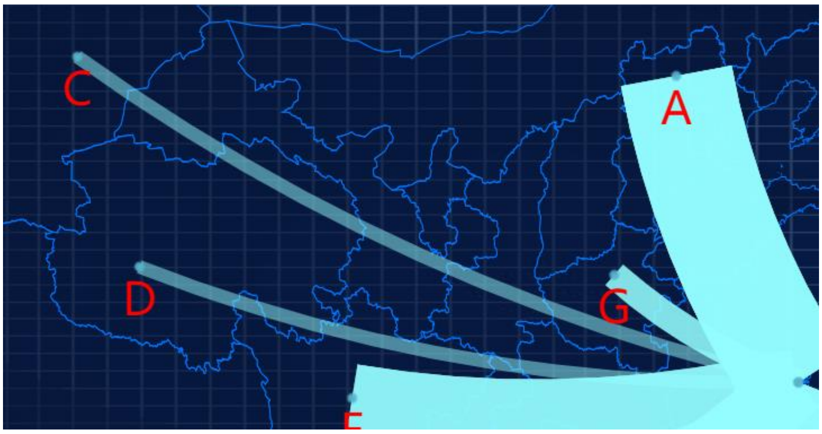


Figure 43. 'Width' differentiate number of flights

3.2 User Study

A user study could evaluate how people perceive different variations of a flow map, such as using a geographic and non-geographic layout (Steiner, 2019). This information can then be used to improve the design of map visualization too, making it more effective at communicating the underlying geographic information (Tory, 2013). In this thesis, the user test will analyze whether animated flow maps can effectively convey information to users using dynamic visual variables. Additionally, it will examine which dynamic visual variable is more efficient in representing volume of information. The results from the user tests can contribute to our exploration of the best research questions and design principles for creating animated flow maps.

The user study will be conducted through questionnaire surveys, where participants will be asked to interpret different maps and provide feedback on their understanding and perception. By gathering insights from user responses, to gain understanding of how users interact with animated flow maps.

3.2.1 Usability Criteria

Usability is about effectiveness, efficiency and the overall satisfaction of the user is a measure of how well a user can interact with a map (Nassar, 2012). It is an important aspect of design, as it determines how easily and effectively a user can accomplish their goals (Nassar, 2012). Usability is not just about making things easy to use, but also about creating a positive user experience. There are some well-developed common criteria that will be used for usability tests such as ease of learning, error management and subjective satisfaction (Scapin & Bastien, 1997).

Ease of learning/Efficiency : This concept refers to how quickly and easily a user can learn to use a map, meaning the time it takes for one to acquire the required information from the animated map (Wang, 2012). The results suggest that it is an important aspect of usability, as it determines how much time and effort a user must invest to become proficient with maps. Therefore, during the user test, participants will also be asked about the time it takes for them to understand the map information and to rate the difficulty of learning to use the maps (Jemstedt et al., 2017)

Error management: This refers to how well a map helps users avoid, detect, and recover from errors. It is an important aspect of usability, as errors can cause frustration, confusion, and delays for users. Error management is often assessed by measuring the frequency and severity of errors that occur during use, as well as the ease with which users can recover from those errors (Shneiderman et al., 2017).

Subjective satisfaction: This refers to the user's personal level of satisfaction with a map. It is a measure of how well the maps meets the user's needs and expectations, and how much the user enjoys using it. Subjective satisfaction is often assessed through surveys or interviews, where users are asked to rate their level of satisfaction with various aspects of the maps (Nielsen, 1994).

3.2.2 User Test Objectives

The objectives for conducting the user study of animated flow maps consisted of several key steps. This involves identifying the goals of investigating animated flow maps and the insights sought from user feedback. There are two research objectives for the user test part:

Objectives1: Which design rules from static flow maps may not be suitable for animated flow maps?

Objectives2 Which design guidelines from static flow maps can be adapted, and what new design suggestions can be incorporated to create animated flow maps?

Objectives3 Which variables are the most efficient for showing the volume of flows on animated flow maps?

User Test Methods:

- Conduct user studies where participants are invited to assess different visual variables used between animated flow maps and static maps.

- Assess participants' understanding of flow volume and direction information, record the difficulties it takes for them to understand and interpret the flow volume and direction.
- Observe participants' reactions and correctness when identifying the volume of information on different maps.
- Evaluate participants' subjective comprehension and understanding of flow volume using different visual variables.
- Ask users to identify satisfaction and preferences across different maps (animated vs static maps).

3.2.3 Questionnaire Design

Introduction and Consent

The purpose and procedures of the user study will be introduced and also obtain informed consent from participants, ensuring they understand the study's objectives, potential risks, and their rights as participants.

Task Explanation

Each question will be explained to participants during the study with examples or detailed information. For example, when asking participants to rank the volume of flows on the maps, an example will be provided below the question to ensure participants understand the instructions.

General Information

In order to gather essential background information, participants were asked a series of general information questions. The questions aim to capture demographic details, experience level with maps, and familiarity with animated maps. The specific questions and response options are outlined below:

1. How old are you?

   This question aims to ascertain the age range of participants. The goal is to include participants from as many different age groups as possible because, in real life, map users vary across nearly all age groups.

2. What is your gender?

   The purpose of this question is to understand the gender distribution among participants and attempt to achieve balance if possible.

3. Please rate your respective level of experience with maps.

   This question aims to assess participants' overall familiarity and proficiency with maps and aims to include more people who do not have much familiarity or proficiency with maps. This is because in reality, most users are not cartographers or map professionals.

4. Are you familiar with animated maps before?

This question sought to determine the extent to which participants had prior exposure to animated maps. The number of people who do not have experience with animated maps could represent a large group of people in daily life.

User Cognition of Volume Information

The section will be a "Comparison between static and animated maps" aims to assess participants' understanding of volume differences in two maps (air traffic flows and exports) in both static and animated presentations. The following questions were presented to two different groups of participants for different maps:

Airlines Map

5. Look at the map, can you see different volumes of air traffic flows?

This question aims to assess participants' visual perception and ability to identify varying volumes of air traffic flows on the map. It aims to determine if participants could differentiate areas with higher and lower flow volumes.

6. Look at the map, please rank the air traffic flows from the highest to lowest.

This question aims to evaluate participants' ability to compare and rank the air traffic flows on the map based on their perceived volume. It aims to capture participants' understanding and interpretation of the relative magnitudes of flow volumes.

7. Please estimate the volume ratio between Flight-A and Flight-D.

This question aims to assess participants' estimation skills in determining the ratio between the volume of air traffic flows for Flight-A and Flight-D. It aims to measure participants' ability to estimate the relative differences in flow volumes.

8. Please estimate the volume ratio between Flight-D and Flight-E.

Similar to the previous question, this question aims to evaluate participants' estimation skills in determining the ratio between the volume of air traffic flows for Flight-F and Flight-J. It aims to measure participants' ability to estimate the relative differences in flow volumes for different flights.

9. How confident are you in your ability to rank the flow volumes accurately?

This question aims to analyse participants' confidence in their ability to accurately rank the flow volumes on the map. It aims to capture participants' self-assessment of their accuracy in understanding and ranking the magnitudes of flow volumes (refer to Ease of learning/Efficiency mentioned in 3.2.1).

10. How long did it take you, on average, to answer the above three 'estimation' questions?
The aim of this question is to inquire about the response time for users to understand the volume of information. This response time could be used to compare the effectiveness between static and animated maps.

Exports Map

The same set of questions was presented for the Exports Map, with the relevant information tailored to the context of exports between countries.

11. Look at the map, can you see different volumes of exports between countries?

12. Look at the map, please rank the exports between countries from the highest to lowest.

13. Please estimate the volume ratio between Exports-C and Exports-F.

14. Please estimate the volume ratio between Exports-E and Exports-A.

15. How confident are you in your ability to rank the flow volumes accurately?
16. How long did it take you, on average, to answer the above three 'estimation' questions?

User Experience

The section "User Experience" aims to gather insights into participants' perceptions and opinions regarding the visual aspects, readability, interpretability, and overall helpfulness of dynamic flow maps. The following questions were presented to participants:

17. Did you find the flow lines on the map to be visually crowded or congested?

This question aims to assess participants' perception of the visual density of flow lines on the map. It aims to capture their observations and opinions regarding whether the flow lines appeared crowded or congested.

18. How would you rate the readability (ease of learning) of the flow lines on the map?

This question aims to evaluate participants' assessment of the flow lines' readability and interpretability. It aims to gauge their overall opinion on the clarity and ease of understanding the flow lines. Participants selected one of the provided rating options that best reflected their experience.

19. Now, we are presenting the static version of the map for the flight routes you just saw. Please compare them and select the map that you believe provides a better visual experience.

This question aims to understand participants' preference between the static and dynamic versions of the flight route map. By asking them to compare and select the map with a better visual experience

20. Now, we are showing you the static/dynamic version of the map for the trade data you just viewed. Please compare them and choose the map that you think offers a better visual experience.

This question focuses on participants' preference between the dynamic and static versions of the trade map. It seeks to uncover which map type participants find more visually engaging and effective for comprehending trade data.

21. Based on the comparison between the static and static/dynamic versions of the two maps mentioned above, which method do you think allows you to efficiently judge or perceive volume information represented by the lines on the map?

This question addresses the effectiveness of both static and animated map formats for conveying the volume information represented by lines on the map. By directly asking participants which method they believe enables them to better judge or perceive the quantity represented by the lines

22. [Only for animated map test] The following two animated maps use "two methods" to display the quantity of flight routes. Which one do you think allows you to more quickly and precisely perceive the differences in quantity between different lines?

Participants were asked to view two animated maps that used different visual attributes designs (speed vs. tail length) and provide their opinions on which one they found easier to understand volume of information. This question is designed to compare which visual attributes (speed or tail length) is more suitable for representing quantitative information on animated maps, corresponding to the 'rate of change' and 'duration,' which are two dynamic visual variables.

3.3 Summary

The methodology chapter firstly defines the dynamic visual variables that will be examined for the user test. Secondly, it introduces how to build up the animated maps, including data preparation and design details. The third section, the User

Study, focuses on evaluating the usability and user experience of these techniques. It incorporates specific usability criteria to assess factors such as ease of use, efficiency, learnability, and error prevention. By following this structured methodology, the study aims to understand the techniques for creating online animated flows and evaluate their user experience through a conducted user study.

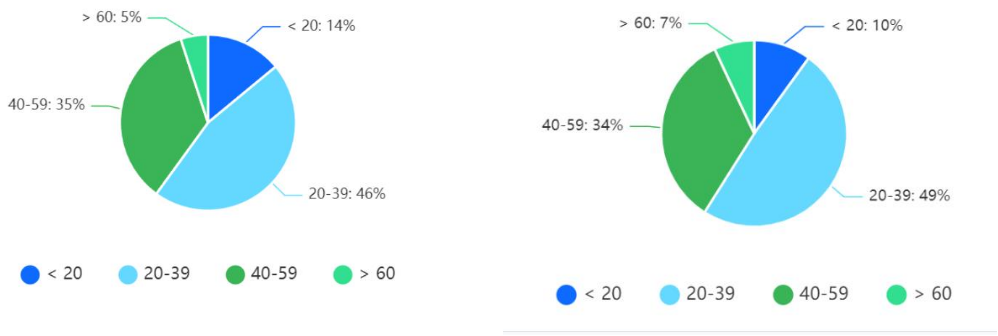
IV. Results

This chapter demonstrates the outcomes derived from the user study conducted with two distinct groups: Group-A for the static map test and Group-B for the animated map test. Two hundred people were invited to join the test and were divided into two different groups (Group-A & Group-B). The primary focus of this study is to evaluate the difference in conveying volume information using static and animated maps. The user study was conducted with these two diverse groups, testing efficiency, user satisfaction, and quality based on various visual variables. A detailed analysis of the user study results will be presented below.

4.1 General Information

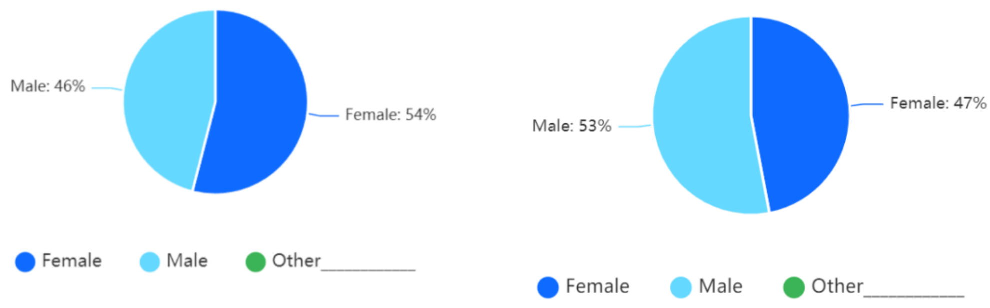
The general information, which includes age, gender, level of map experience, and familiarity with animated maps, will be introduced first (Q1-Q4). The group using static maps will be referred to as 'Group-A', while the users who view animated maps will be referred to as 'Group-B' (this will be applied in later analysis).

To better match the real daily usage context of maps, in other words, for mainstream users of flow maps, the selection of ages was designed to encompass a wide range of age groups. Therefore, a total of 200 participants were included, with roughly 50% falling within the 20 to 39-year-old age bracket. Approximately 34% of the participants fell within the age range of 40 to 59 years, effectively representing middle-aged users. Furthermore, there were about 10 participants who were older than 60 years, and 24 participants who were younger than 20 years. As a result, this user test also partly reflects both the younger and older age groups of users. Additionally, the user study included 99 male and 101 female participants.



Group-A Group-B

Figure 44. Answers for Q1, age



Group-A Group-B

Figure 45. Answers for Q2, gender

In terms of map experience, both groups exhibited similar patterns, with nearly 40% having a moderate level of experience, approximately 45% having limited experience, almost 10% possessing substantial experience, and about 3% being at the expert level. These results underline the diversity and representation of varying degrees of map experiences.

Similarly, the familiarity with dynamic maps also demonstrates a rich diversity, with a significant portion of participants being unfamiliar with them. Specifically, 38% (Group-A) and 31% (Group-B) expressed 'not very' level of familiarity, while 29% (Group-A) and 39% (Group-B) indicated being somewhat familiar. About 10% (in average) of participants claimed to be 'very familiar,' while a similar percentage stated 'Not at all' familiarity."

Group-A Group-B

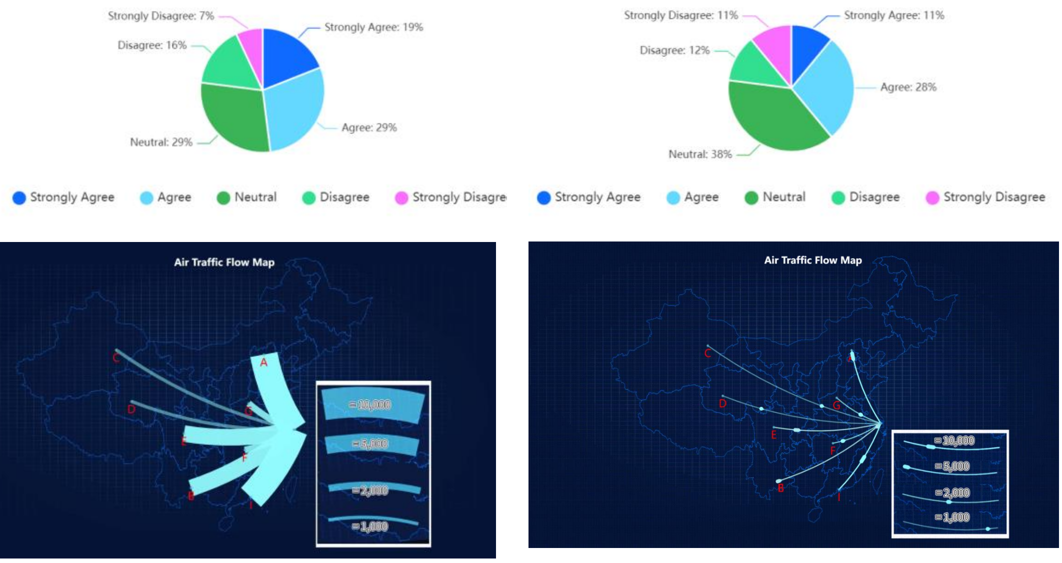
Figure 46. Answers for Q3, level of map experience

Group-A Group-B

Figure 47. Answers for Q4, familiarity with animated maps

4.2.1 Volume visual estimation - Flight maps

The initial question (Q5) regarding user cognition involved asking participants whether they could differentiate between various volumes of air traffic flows. The results from Group-A (static maps) revealed a slight advantage when compared to Group-B (animated maps). In Group-A, a total of 48% of participants chose responses indicating 'strongly agree' or 'agree,' while in Group-B, this percentage was 39%. The result shows that static flight maps utilizing the 'width' feature to represent volume information might offer a more intuitive demonstration to map users and make it easier for them to perceive differences. Conversely, the combined percentage of participants selecting 'strongly disagree' or 'disagree' was consistent at 23% in both Group-A and Group-B. This parity can be attributed to a significant number of participants (38%) opting for a 'neutral' response within Group-B.

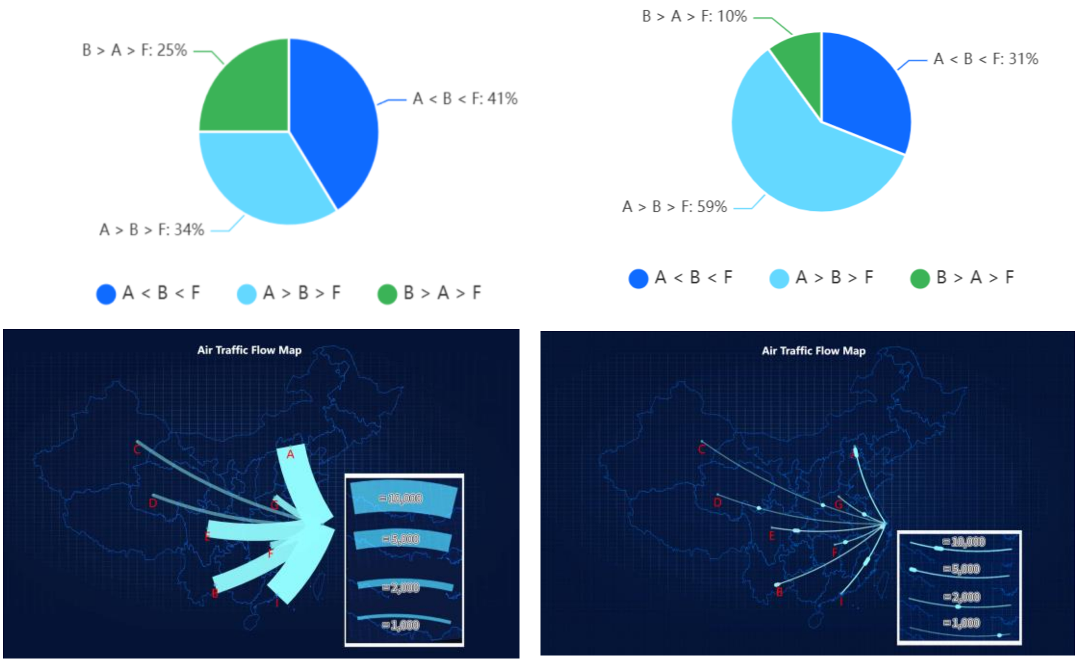


Group-A

Group-B

Figure 48. Answers for Q5, perception of different volumes

Figure 49. illustrates the results of a question (Q6) where participants were asked to rank the flow lines based on the volume they represent. Group-A represents the static map results, while Group-B depicts the dynamic map outcomes. The correct ranking is 'A > B > F,' with 34 individuals selecting the accurate sequence in Group-A. Conversely, the accuracy in Group-B is much higher, as 59 participants correctly identified the volume ranking order. Two additional volume estimation questions follow (Q7-Q8).



Group-A Group-B

Figure 49. Answers for Q6, ranking flow lines volumes

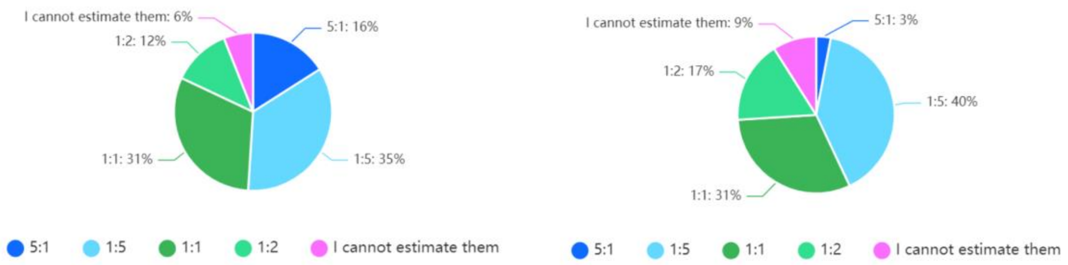
Figures 50. and 51. depict the results of questions that asked participants to estimate the ratio of specific flow lines based on their perception of volume ratios. In Figure 50., participants were tasked with comparing line-A and line-F, where line-A represents 10,000 flights and line-F represents 2,000 flights, resulting in a correct ratio of 5:1. The accuracy rate in Group-A stands at 38%, surpassing Group-B's rate of 29%. Interestingly, it's worth noting that 24 participants selected the inverse ratio of 1:5, and a higher number of participants in Group-B chose 'I cannot estimate them' compared to Group-A. This phenomenon might be attributed to the potential complexity of understanding the animated map, making it more challenging for these participants compared to the static map in this flight map.

Group-A Group-B

Figure 50. Answers for Q7, ratio of flow lines

Figure 51. presents the same question but regarding a comparison between the other

two lines, namely line-D and line-E. In this case, the accurate ratio comparison between D and E is '1:5,' as line-D represents 1,000 flights while line-E corresponds to 5,000 flights. Group-B demonstrated a slightly higher accuracy rate than Group-A (40% versus 35%). However, it's worth highlighting that, akin to the results in Figure 50., still more participants in Group-B selected 'I cannot estimate them' compared to Group-A. In this animated flight map, the animated demonstration might pose a higher accessibility level or learning cost for a portion of participants.



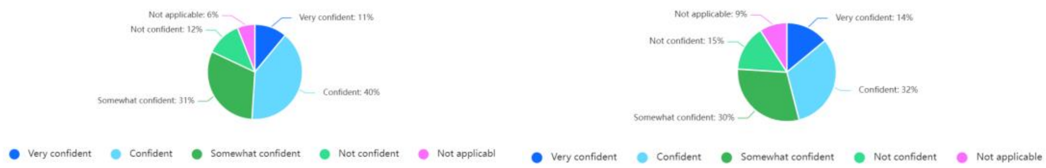
Group-A Group-B

Figure 51. Answers for Q8, ratio of flow lines

4.2.2 Efficiency estimation - Flight maps

In order to assess both efficiency and user confidence in the correctness of their answers to the three volume estimation questions mentioned earlier, Figure 52 and Figure 53 present the results. Figure 52 focuses on users' confidence levels when making their choices, while Figure 53 addresses the approximate time cost associated with answering each question.

Figure 52 illustrates the distribution of participants across categories such as 'very confident,' 'confident,' 'somewhat confident,' 'not confident,' and 'not applicable.' Notably, the percentage differences between the two groups are relatively minor, particularly in the categories of 'very confident,' 'confident,' and 'somewhat confident.' In total, 41 participants in Group-A reported feeling 'very confident' or 'confident,' while the corresponding number in Group-B was 43 participants. However, it is worth highlighting that the 'not applicable' category had a higher count in Group-B (dynamic map), echoing the earlier result where more participants in Group-B selected 'I cannot estimate them' compared to Group-A.



Group-A Group-B

Figure 52. Answers for Q9, confidence in making the right choice

Figure 53 provides an overview of the average approximate time that participants allocated to each of the three volume estimation questions mentioned earlier (Q6-Q8). The distribution of time spent between 1 to 3 minutes is comparable, with Group-A at 77% and Group-B at 75%. The noteworthy difference emerges with responses indicating 'above 3 minutes,' where a greater number of participants in Group-B reported spending more than 3 minutes compared to Group-A.

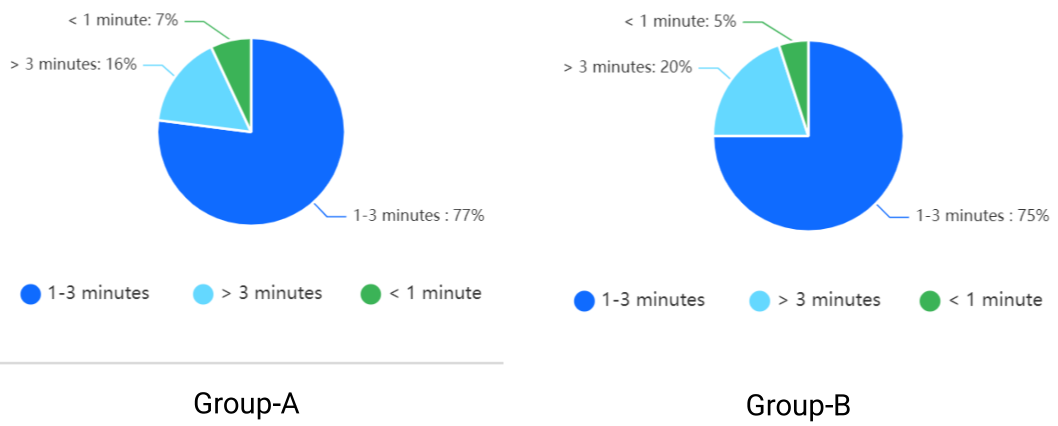
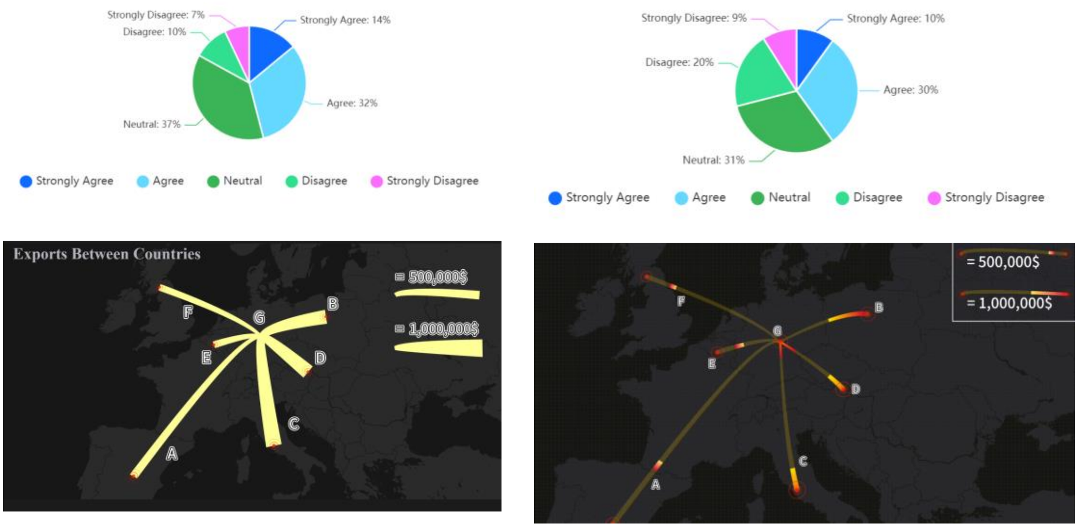


Figure 53. Answers for Q10, time cost for estimation question

4.2.3 Volume visual estimation - Exports maps

Figures 54 to 57 depict the results from questions Q11-Q14, following a similar approach as before (similar to Q5-Q8). These questions employed different maps to inquire about participants' perceptions of volume differences and their ability to estimate rankings and ratios of flow lines based on distinct visual variables.

In Group-A, 45% of participants chose responses indicating 'strongly agree' or 'agree,' a percentage higher than the 40% observed in Group-B. Additionally, a larger proportion of participants (29% in total, reflecting 'strongly disagree' and 'disagree') in Group-B did not perceive a significant difference in volume information compared to Group-A, where only 17% provided similar responses. This outcome closely mirrors the previous map case, demonstrating that the static map group (Group-A) consistently had a higher number of participants selecting 'strongly agree' and 'agree.' This suggests that, for both cases, static maps might be more easier in facilitating users' perception of volume differences in flow lines based on the 'width' visual variable.

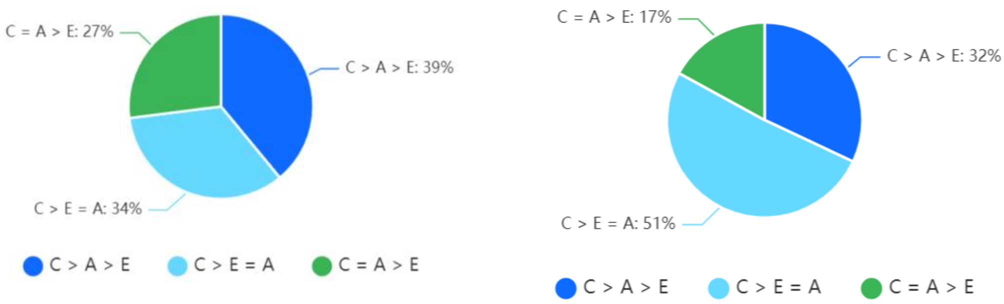


Group-A

Group-B

Figure 54. Answers for Q11, perception of different volumes

Figures 54 to 56 continue the evaluation of users' specific cognition of volume information, presenting the outcomes of three volume estimation questions (Q12-Q14). The correct answer for these questions is 'C > E = A'. Interestingly, the results parallel the findings of the 'ranking question' in the previous case (Q6). Group-B, representing the dynamic maps group, exhibits higher accuracy compared to Group-A, with rates of 51% and 34%, respectively.



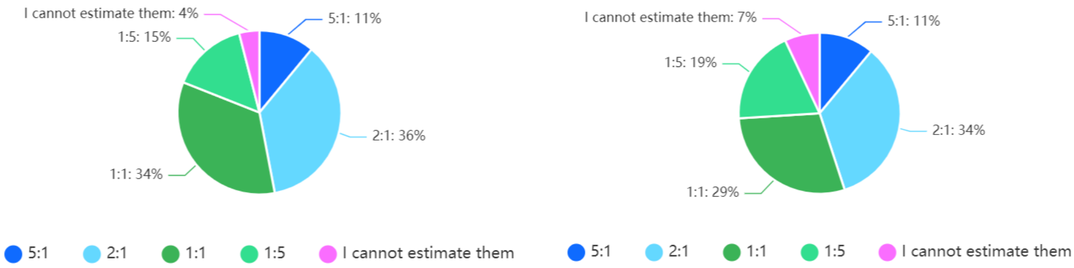
Group-A

Group-B

Figure 55. Answers for Q12, ranking flow lines volumes

Figures 56 and 57 provide the outcomes of Q13 and Q14, which involved comparing C:F and E:A, respectively. The correct answers should be 2:1 and 1:1, considering that C represents $1,000,000 and F, C, and A represent $500,000. In terms of accuracy, the results reveal some interesting patterns.

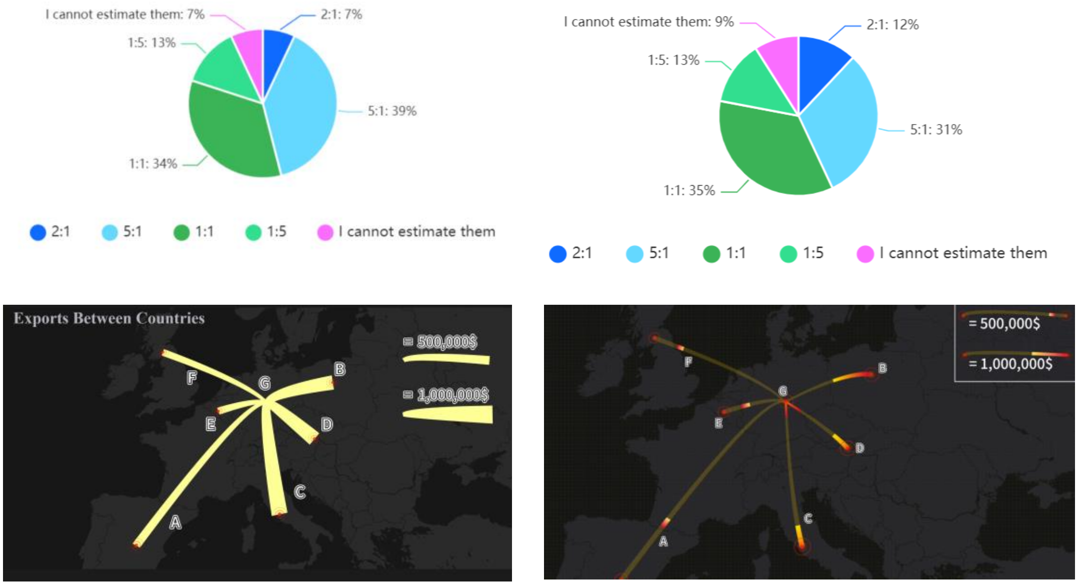
In Q13 (refer to Figure 56), Group-A demonstrates a slightly higher accuracy rate than Group-B. Similar to the earlier cases (Q7-Q8), Group-B shows a higher count of participants who selected 'I cannot estimate.'



Group-A Group-B

Figure 56. Answers for Q13, ratio of flow lines

Moving to Q14, Figure 57 shows that Group-B has a slightly higher accuracy than Group-A (35% versus 34%). Again, Group-B has a larger number of participants who did not provide an answer.



Group-A Group-B

Figure 57. Answers for Q14, ratio of flow lines

To conclude, the results closely mirror the outcomes of the ratio questions from the preceding scenario (Q7-Q8) involving the static and animated map groups. Similarly, as seen in the earlier flight map analysis, both groups displayed a higher accuracy rate in at least one question (with Q7 showing greater accuracy in the static map group, and Q8 showing higher accuracy in the animated map group). Additionally, it remains consistent that the animated map group consistently had a larger number of participants selecting 'I cannot estimate.

4.2.4 Efficiency estimation - Exports maps

Figures 58 and 59 shed light on participants' confidence levels while making estimations and the time expenditure in the exports map scenario. Notably, Group-B demonstrates a higher percentage (44% in total) of participants feeling 'very confident' or 'confident' in their estimations, in comparison to Group-A's 35%. Conversely, the count of participants who reported feeling 'not confident' or 'not applicable' was also greater in Group-B, constituting 24% of responses compared to Group-A's 17%.

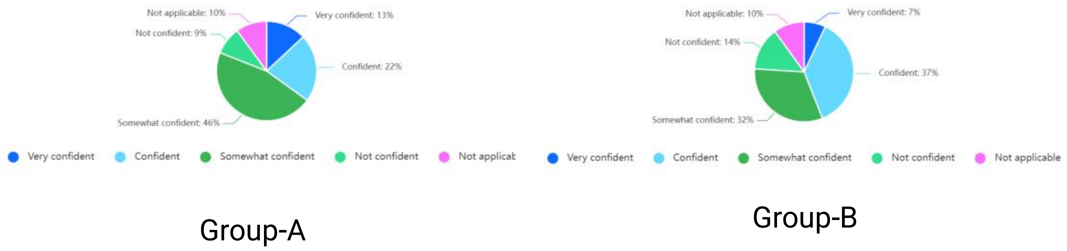


Figure 58. Answers for Q15, confidence in making the right choice

Moving on to Figure 59, the distinction between Group-A and Group-B is not substantial. However, the cumulative data indicates that participants in Group-B allocated more time for estimations across the questions. This is evident from the higher proportion of participants selecting both the 1-3 minutes and >3 minutes time ranges.

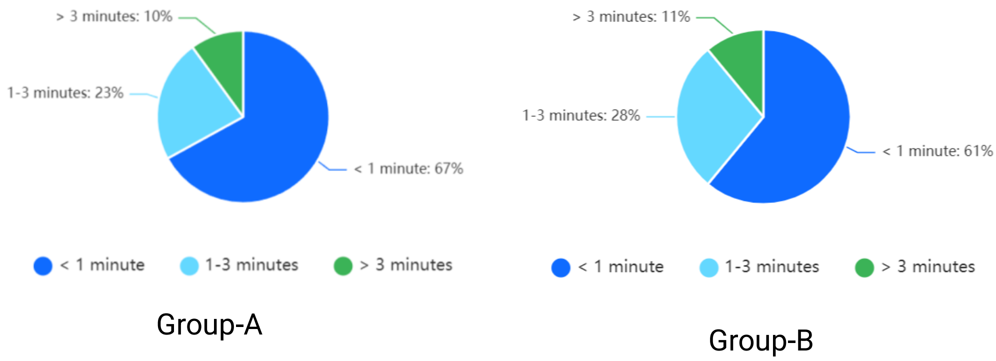


Figure 59. Answers for Q16, time cost for estimation question

In a concise summary, the findings here closely resemble those of the previous case (flight map, Q9-Q10), where more participants in Group-B, associated with animated maps, reported being 'not confident' or 'not applicable' in making estimations. Additionally, participants in Group-B spent more time on average for the estimation process.

4.3 User Experience

Figures 60-64 present the outcomes of the assessment of participants' subjective satisfaction and their perceptions concerning animated and static maps. This evaluation is grounded in aspects such as readability and overall helpfulness of animated flow maps. In a parallel vein, participants who initially interacted with static maps were subsequently prompted to view animated maps. This allowed them to choose which type of map they deemed better for distinguishing volume information. Likewise, animated map users were asked to look at static maps towards the end of the questionnaire. These results collectively showcase participants' preferences regarding which map type they find more efficient and satisfying.

The findings derived from Figure 60 are from the question 'Did you find the flow lines on the map to be visually crowded or congested?' In Group-A, a combined 47% of participants chose 'strongly agree' or 'agree.' Conversely, in Group-B, the corresponding percentage was slightly lower at 43%. Additionally, 25% of participants in Group-A expressed disagreement or strong disagreement with the notion that the dynamic maps in the questionnaire appeared visually crowded or congested. This number exceeded Group-B's 19%.

Group-A

Group-B

Figure 60. Answers for Q17, visually crowded or congested test

Figure 61 presents the results obtained from the question: 'How would you rate the readability (easy to understand) of the flow lines on the map?' In Group-A, positive responses accounted for 51% (Excellent & Good), 29% indicated fair, and a total of 20% gave negative responses (Poor & I cannot estimate). Meanwhile, in Group-B, the distribution was 42% (Excellent & Good), 31% (fair), and 27% (Poor & I cannot estimate). Comparing the data, static map users (Group-A) reported a more favorable ease of learning and visual experience.

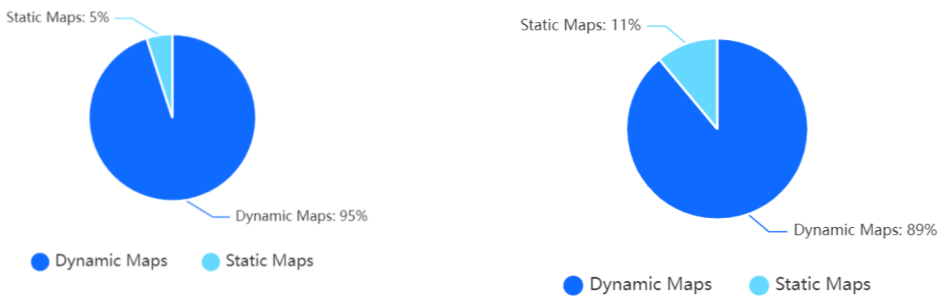
Group-A

Group-B

Figure 61. *Answers for Q18, ease of learning rating*

Figures 62 and 63 depict the results obtained from asking participants to compare animated and static maps. Participants were tasked with evaluating the static/dynamic versions of the map (Q19 for flight map, Q20 for exports map) compared to what they had seen earlier. They were then prompted to select the map that they believe offers a superior visual experience.

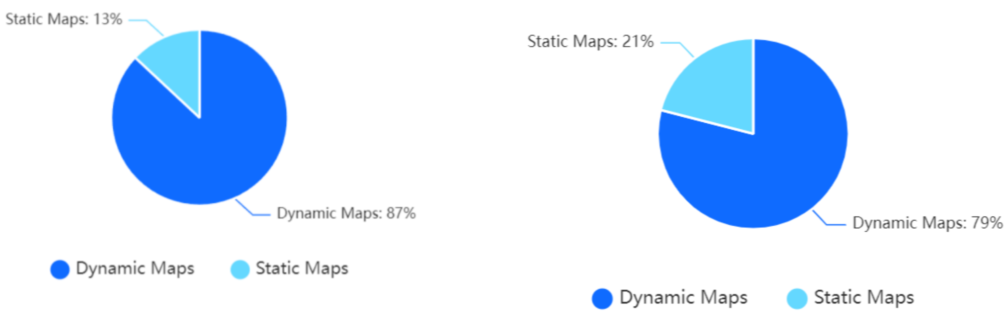
In Group-A, consisting of participants who previously answered questions based on static maps, a substantial 95% preferred the animated map's visual experience. This proportion exceeded Group-B's result of 89%, which represents participants who had answered questions based on animated maps. After viewing the animated maps, 89% of Group-B participants still believed that animated maps provided a better visual experience.



Group-A Group-B

Figure 62. *Answers for Q19, compare flights map static & animated*

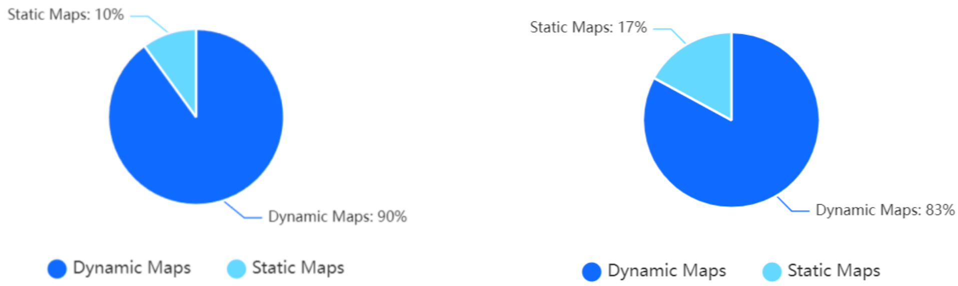
The similar trend continued in Figure 63, focusing on the exports map scenario. In Group-A, 87% of participants favored animated maps, while in Group-B, 79% persisted in selecting animated maps for a better visual experience.



Group-A Group-B

Figure 63. *Answers for Q20, compare exports map static & animated*

Figure 64 presents the outcomes obtained from the question: 'Based on the comparison between the static and animated versions of the two maps mentioned above, which method do you think allows you to efficiently judge or perceive volume information represented by the lines on the map?'. Notably, 90% of participants expressed that the animated map enabled them to more efficiently perceive volume information. This percentage surpasses Group-B's result of 83%.



Group-A

Group-B

Figure 64. Answers for Q21, compare static & animated map efficiency

Map-A used 'tail length' as a dynamic visual variable representing 'duration', while Map-B employed 'speed' as a dynamic visual variable representing 'the rate of change' to depict the volume of flights. Question 22, aimed at Group-B participants, inquired about their preference between these two methods for efficiently and precisely perceiving the differences in quantity between different lines on the map. Among Group-B participants, 54% opted for 'tail length' as the preferred method, which employs duration as a dynamic visual variable, while 46% favored 'speed,' which uses the rate of change as a dynamic visual variable.

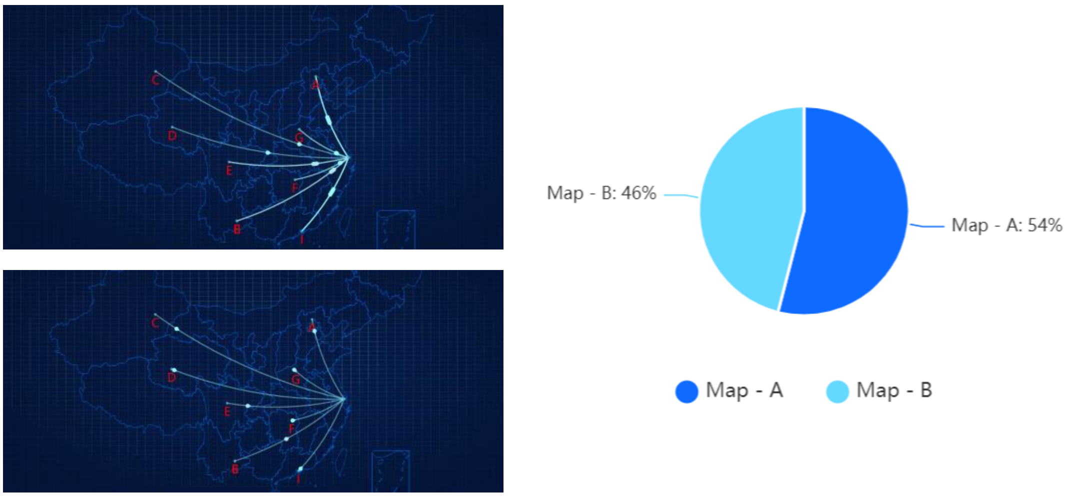


Figure 65. Answers for Q22, compare different dynamic visual attributes

4.4 Summary

This chapter presents the outcomes of a user study that aimed to compare the effectiveness of conveying volume information through static and animated maps. The study involved two groups, 200 participants: Group-A, which interacted with static maps, and Group-B, which interacted with animated maps and received the responses whithin three weeks. The user cognition of volume information was evaluated through various questions related to flight and exports maps. In terms of volume visual estimation for flight maps, Group-A showed a slightly higher percentage of participants agreeing that they could differentiate between various air traffic flow volumes compared to Group-B. Similar trends were observed in the estimation of volume ratios. However, Group-B demonstrated higher accuracy in some instances, particularly in comparing volume rankings and ratios of flow lines. Efficiency estimation analyses indicated that participants in Group-B spent more time on average making estimations and reported higher confidence levels in their estimations, but also showed a greater tendency to feel "not confident" or "not applicable."

Regarding the last part, user experience, Group-A participants reported a higher preference for animated maps after experiencing both static and dynamic versions, while participants in Group-B maintained their preference for animated maps. Additionally, animated maps were considered more efficient for judging and perceiving the volume of information. In summary, the user study suggests that while animated maps may require more time to grasp for some participants, they tend to be more efficient and visually preferable for conveying volume information compared to static maps.

V. Discussion

This chapter serves as the platform for an exploration and analysis of the findings obtained through the user study and literature findings discussed earlier. The research objectives will be addressed based on the analysis of participants' responses in the animated and static maps user test. The preceding section that discussed design rules from the literature will also be integrated with the findings in the user test section. Furthermore, this part will address the limitations that have emerged, along with their potential impacts. Through this analysis, future development and research directions will be presented

5.1 Summary of the findings

5.1.1 Animated maps technologies

The exploration of techniques for creating online animated flow maps forms a fundamental aspect of this research, directly addressing the Research Question 1 (RQ-1): "Which techniques can be used for making online animated flow maps and how they can be used?" In a digital landscape characterized by an increasing demand for complex and animated data representation, the significance of effectively conveying information through animated maps has gained paramount importance (Koussoulakou & Kraak, 1992; Han et al., 2017). As evidenced in the previous literature review, animated visualizations facilitate a comprehensive understanding of data movement across geographical spaces, offering viewers insights into intricate patterns and interdependencies (Buchin et al., 2011).

The investigation into available techniques for crafting animated flow maps commences with the examination of methods employed in contemporary practices, catering to different types of animated flow maps. These methods encompass a spectrum of possibilities, including Animation Software, Geographic Information System (GIS) software, and Programming and Data Visualization Libraries. Notably, while these methods can be employed individually, synergistic combinations often yield the most potent results, as exemplified by Jacobs' (2018) study on Bird Migration in the Americas. This study merged After Effects, ArcGIS, and the D3 library, resulting in a sophisticated and insightful animated flow map.

Through the confluence of scholarly insights from the literature review and the user study on map creation, a comprehensive understanding of techniques for crafting animated flow maps emerges. This examination, tailored to the types of animated flow maps delineated in Chapter 2.4, attests to the applicability of Animation Software, GIS software, and Programming and Data Visualization Libraries. By strategically matching different techniques with the specific requirements of datasets, cartographers can create dynamic flow maps that cater to diverse types of flows and data, as well as the intended audiences.

5.1.2 Design principles for animated maps

Static flow maps have long been guided by a set of design principles according to contributions from numerous cartographers. However, as the field continues to evolve, the emergence of animated flow maps introduces a new dimension of complexity and challenges in terms of design. Therefore, the adaptation of existing static map design rules for animated flow maps has been discussed, addressing the question of which design rules from static flow maps may not be suitable for animated flow maps.

5.1.2.1 Review of static map design rules

Drawing from the review of static map design principles provided by Borden Dent and colleagues (2009), several of these design rules might need careful consideration when transitioning from static to animated flow maps. The following exploration sheds light on the rules that may undergo modification or may not be suitable in the context of animated maps, addressing Research Question 2 (RQ-2) – "Which design rules from static flow maps may not be suitable for animated flow maps?"

1. Managing Line Overlaps: While the guideline to position smaller intersecting flow lines on top of larger ones might be relevant, animated maps usually do not have overlaps because the 'width' visual variable is not commonly used in animated maps. Additionally, since all flow lines are animated, overlaps can often be avoided by adjusting the occurrence order of flow lines. Therefore, this design principle might not be of high priority for animated map design.

2. Directional Arrows & Arrowhead Scaling: Arrows are crucial for indicating flow direction in static maps, but their role might not be essential in animated maps. Flow lines in animated maps usually have starting and ending points; the movement from one point to another along the line might replace the need for directional arrows.

3. Line Placement and Balance: Achieving a balanced composition might not be the top concern in animated flow maps. As Dent and colleagues (2009) mentioned, this placement is to 'avoid top-heavy or bottom-heavy arrangements'. However, the flow lines on animated flow maps are usually created automatically and do not overlap with each other.

4. Distributive Flow Lines: The concept of distributive flow lines, maintaining proportional widths, may not be well suited for animated maps. The reason is similar to 'overlaps'; animated maps often don't use widths to represent flow quantity.

5.1.2.2 Adaption to animated maps

As illuminated by the work of Hannah (2021), the integration of static and dynamic visual variables presents an innovative approach to map design. The simultaneous use of static visual variables (e.g., size) and animated visual variables (e.g., animation) offers an opportunity to enhance comprehension of complex patterns, such as migration flows. The findings align with Köbben and Yaman's (1995) insights on the combination of dynamic and static visual variables, emphasizing the value of integrating these approaches for improved map comprehension. Addressing

Research Question 3 (RQ-3) – "Which design guidelines from static flow maps can be adapted, and what new design suggestions can be incorporated to create animated flow maps?"

1. Simplicity and Information Presentation: The principle of simplicity remains essential in animated maps, but the challenge lies in presenting changing information coherently. Simplification techniques that adapt to varying flow patterns can enhance user understanding. The user test in Group B from Chapter 4.2 shows that many participants might need more time to understand the animated map information or cannot estimate differences in some flow lines. This number is higher than that for static maps for every question. Therefore, simplicity and information presentation should be one of the highest design focuses in animated maps.

2. Flow Line Priority: The principle of assigning the highest visual importance to flow lines remains pertinent in animated maps. In the context of animated maps, due to the dynamic nature of animated maps, considerations must be given to how flow lines evolve over time and how their hierarchy may change during animation transitions. In the user test (Chapter 4.2), the average accuracy of volume difference estimation questions is approximately between 30% and 40%, which means that most participants cannot precisely understand some important information from the maps. In other words, there is a gap between the design of flow lines and what can still be enhanced based on flow line priority or other design rules.

3. Visual Balance: Balancing the placement of new lines is essential, especially as animations involve the introduction of new elements over time. Visual equilibrium must be maintained throughout the animation sequence. As Köbben and Yaman (1995) summarized, animated maps have temporal and non-temporal representations. The user test maps belong to the non-temporal representation, therefore, they might not obviously reflect visual balance. However, for temporal representations, this might be a more important and considerable design consideration.

5.1.3 Visual variable efficiency

The investigation into the efficiency of dynamic visual variables for representing the volume of flows on animated flow maps constitutes a pivotal aspect of this research. In pursuit of answering Research Question 4 (RQ-4) – "Which variables are the most efficient for showing the volume of flows on animated flow maps?" – 100 participants were tasked with selecting the two dynamic visual variables that they perceived as more efficient for this purpose. The two dynamic visual variables put to the user test were 'tail length,' chosen to represent 'duration,' and 'speed,' selected as a representation of 'the rate of change' dynamic visual variables. Upon analyzing the participants' responses, although there was no significant gap between 'tail length' and 'speed', a slightly higher percentage of participants favored 'tail length' (which reflects the 'duration' dynamic visual variable) as the more efficient dynamic visual variable for depicting the volume of flows on animated flow maps. This preference was observed across various demographics and user profiles, suggesting the potential value of the dynamic visual variable 'duration' in conveying information about duration.

Additionally, the outcomes of the user study find similarity in existing literature, particularly in the seminal work of Köbben and Yaman (1995). Their study on the properties of dynamic visual variables offers valuable insights into the efficiency of different variables for representing quantitative information. Notably, Köbben and Yaman (1995) highlight that 'Duration' and 'rate of change' stand out as the only two dynamic visual variables that exhibit the potential to efficiently represent quantitative data. In the context of this thesis, 'tail length' serves as a manifestation of the 'Duration' variable. The user study findings reinforce Köbben and Yaman's observation that 'Duration' is a highly capable dynamic visual variable for conveying quantitative information, as evidenced by the participants' preference for 'tail length' in the user study. Conversely, Köbben and Yaman (1995) also determined that 'rate of change' (represented using 'speed' in this study) has limitations in its ability to effectively communicate quantitative data. The 'speed' variable received less favor among participants in the user study, aligning with the 'poor' categorization for 'rate of change' proposed by Köbben and Yaman. Collectively, the user studies results and the insights from Köbben and Yaman's (1995) research harmonize to underscore the preeminence of 'Duration' (represented through 'tail length') as the most efficient dynamic visual variable for depicting the volume of flows on animated flow maps. This serves to address RQ-4 by establishing the relatively superiority of 'duration' visual variables through both empirical user test and literature-based support.

5.2 Limitations and challenges

5.2.1 Deisgn guidelines

The design principles discussed in the previous chapters offer adaptation of certain design guidelines from static maps to animated flow maps. However, while this thesis covered several design guidelines, some principles were not explored in depth. Notably, the role of legends in animated maps requires nuanced examination.

The principle of creating separate lines for branching and trunk flows, as well as employing techniques to distinguish overlapping flows, remains relevant in animated flow maps. However, the transition from static to dynamic introduces complexities. The animated flow maps presented above do not include the distributive flow map type. This is because they were not found during the period of this thesis study. However, this does not mean there is no need for this kind of animated flow map. Therefore, the specific design guidelines for such cases might also be important. Additionally, techniques such as shadows or borders for distinguishing overlapping flows, which require adaptation to the dynamic environment, were also not studied here. Another design guideline mentioned by Dent (2009) is the choice of projection and its center, which significantly influence attention and focus in both static and animated maps. In animations, this choice should also be pivotal. Moreover, the consideration of contrasting elements, particularly land and water areas, was not analyzed in this thesis due to space constraints in the user test.

In conclusion, while this thesis provides insights into how design principles can be adapted and transitioned from static flow maps to animated flow maps, certain design guidelines pose challenges that were not fully addressed. These limitations underscore the need for further research and exploration in these areas to refine our understanding of effective design strategies for animated flow maps.

5.2.2 User study

The user study conducted in this research offers insights into the design and exploration of visual variables through static and animated flow maps. However, several limitations emerge in terms of 'participants' and 'study design', which should be acknowledged to contextualize the findings accurately.

The study attempted to achieve a balanced distribution across different age groups. However, a predominant portion of participants fell within the younger age brackets or did not belong to the older age group. Consequently, the study's conclusions may be more representative of the cognitive processes of younger individuals, potentially overlooking the perspectives of older age groups. This limitation arises from the nature of the study's focus on comparing static and animated maps, rendering it inadequate for capturing the cognitive aspects of older participants. To address this, future studies might consider implementing research designs that specifically target older age groups to obtain a more comprehensive understanding of cognitive variations across different demographics.

Moreover, while efforts were made to ensure demographic diversity, the generalizability of the findings may be limited by the sample size. Enlarging the sample size could enhance the study's external validity, offering a broader spectrum of perspectives that better reflect the diverse user base of flow maps. Furthermore, the survey's online nature introduced subjectivity into responses, as 60% of participants from each group completed the questions without strict supervision (due to time cost). This lack of control over survey conditions might have impacted the quality of responses, potentially introducing bias and variability. Addressing this limitation could involve implementing more controlled environments for data collection, thereby enhancing the reliability of participants' responses.

The user study employed specific maps using flight and exports data to assess the efficacy of conveying volume information through animated maps. However, the generalizability of the findings to other types of animated flow maps, particularly those with different data characteristics, remains uncertain. Additionally, the study cases focused on non-temporal animated flow maps, raising questions about the applicability of the results to users' cognition of temporal animated flow maps. Furthermore, participants' feedback highlighted the potential challenge of survey fatigue due to the number and complexity of questions presented. This limitation suggests that participants' attention and response quality could be affected as they navigate through a sizable questionnaire. To address this, future studies could consider refining the questionnaire structure, reducing redundancy, and balancing question complexity to ensure participants remain engaged and provide accurate responses.

VI. Conclusion

The overall research objective of this study is to evaluate techniques for creating animated flow maps and explore differences in design principles between animated and static flow maps. The investigation of techniques for crafting online animated flow maps addressed the use of various techniques, examining methods employed in contemporary practices for different types of animated flow maps. The integration of Animation Software, GIS software, and Programming and Data Visualization Libraries emerges as a potent strategy, exemplified by a variety of cases. A user study was conducted to explore differences in efficiency of visual variables. Based on the user study and literature analysis, the adaptation of design principles from static to animated flow maps was pursued in order to identify gaps between static and animated maps. The examination of these principles revealed that certain guidelines related to line overlaps, directional arrows, and line placement might not be entirely suitable for animated maps. Furthermore, the innovative integration of static and dynamic visual variables to enhance map design was also mentioned and might be a focus of future studies (Hannah, 2021). The user study indicated that 'duration,' represented by 'tail length,' emerged as the most efficient dynamic visual variable for conveying volume information, aligning with Köbben and Yaman's (1995) insights. Overall, this study's findings provide a summary of techniques and design principles for animated flow maps, offering insights into their efficacy and challenges in dynamically conveying complex spatial data.

This study has elaborated on the adaptation of design principles from static to animated flow maps, albeit with certain principles left underexplored. For example, the significance of legends in animated maps demands nuanced investigation. While concepts like distinct lines for branching and trunk flows and techniques for handling overlapping flows persist in animated flow maps, the shift from static to animated introduces complexities. In conclusion, while this thesis provides insights into transitioning design principles to animated flow maps, certain guidelines pose challenges warranting further research. The subsequent user study offers insights into visual variable exploration in static and animated flow maps. However, limitations in participant distribution across age groups and study design necessitate acknowledgement. The focus on younger participants may overlook older individuals' cognitive processes, prompting future research targeting broader demographics. Generalizability is constrained by the sample size and online survey conditions, implying potential bias. Survey fatigue emerged as a challenge, advocating for streamlined questionnaires in subsequent studies to maintain participant engagement and response quality.

To summarize, this study explores the adaptation of design principles from static to animated flow maps, identifying challenges and potential areas for further research, including additional investigation into static map rules and the integration of static and dynamic visual variables. As technologies continue to develop, studying animated flow maps holds increasing value and significance.

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VIII. Appendices

8.1 User study questionnaire

Questionnaire links:

- Group-A (Static map): https://wj.qq.com/s2/13118815/1a71/
- Group-B (Animated map): https://wj.qq.com/s2/13119031/4c05

8.1.1 Introduction and Consent

Hi,

many thanks for taking part in this online survey on the evaluation of dynamic maps. This survey is part of my Master's Thesis, conducted by Zhiheng Jiao, pursuing "The Principles of Quantitative Design in Animated Flow Maps" at Technische Universität München (TUM).

Consent

By selecting 'yes', I agree and affirm that:

- I have read and understood the purpose of the information stated above
- I am submitting this form and participating in the project voluntarily and that I was not coerced, forced, threatened, or intimidated.

1. How old are you?

○ < 20

○ 20-39

○ 40-59

○ > 60

2. What is your gender?

○ Female

○ Male

○ Other ______________

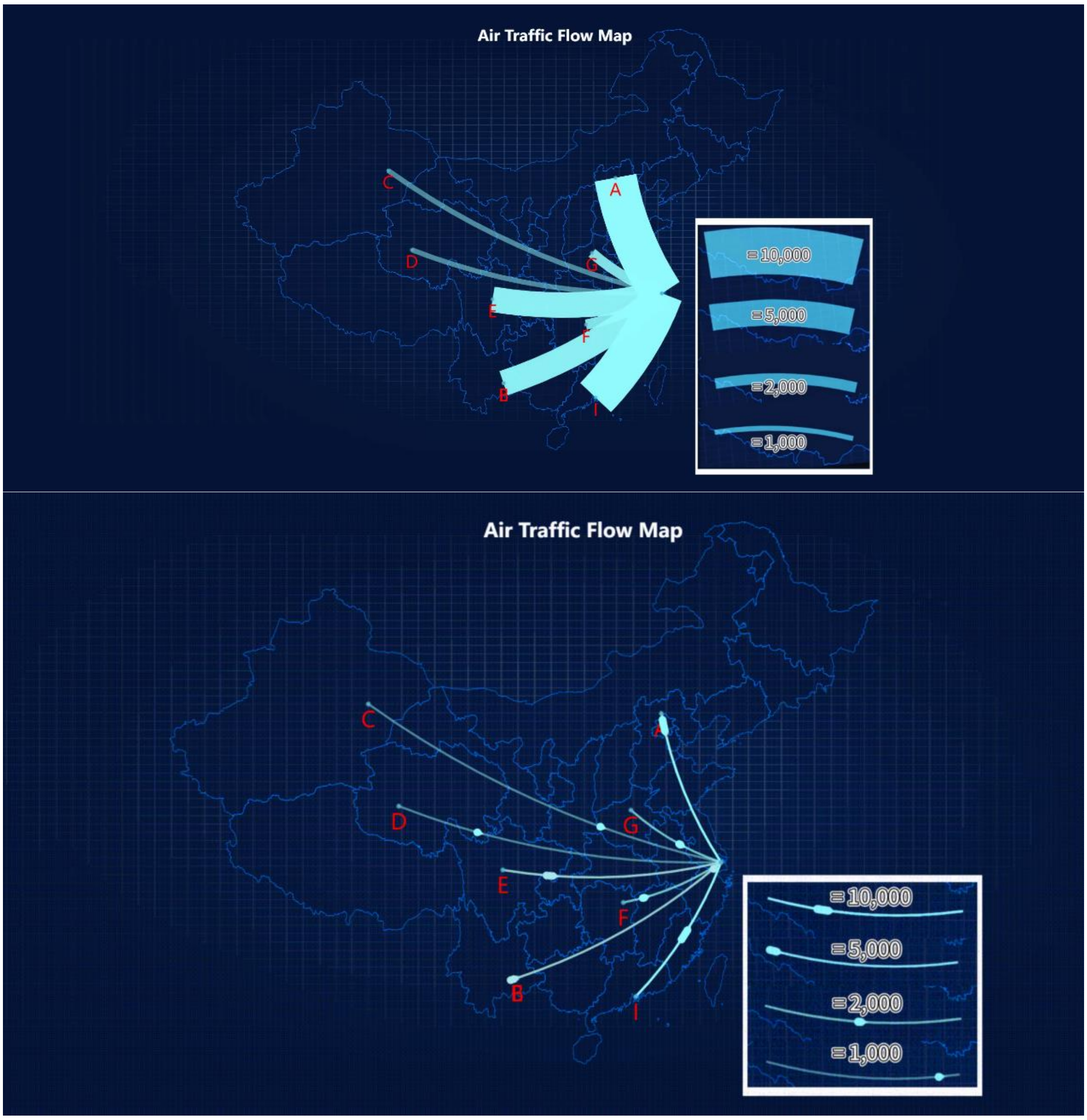
3. Please rate your respective level of experience with maps.

- None
- Little
- Moderate
- Much
- Expert

4. Are you familiar with animated maps before?

- Not at all
- Not very familiar
- Somewhat familiar
- Familiar
- Very familiar

5. Look at the map, can you see different volumes of air traffic flows?



- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

6. Look at the map, please rank the air traffic flows from the highest to lowest.

- A < B < F
- A > B > F
- B > A > F

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7. Please estimate the volume ratio between Flight-A and Flight-D.

- 2:1
- 5:1
- 1:1
- 1:5
- I cannot estimate them

8. Please estimate the volume ratio between Flight-D and Flight-E.

- 5:1
- 1:5
- 1:1
- 1:2
- I cannot estimate them

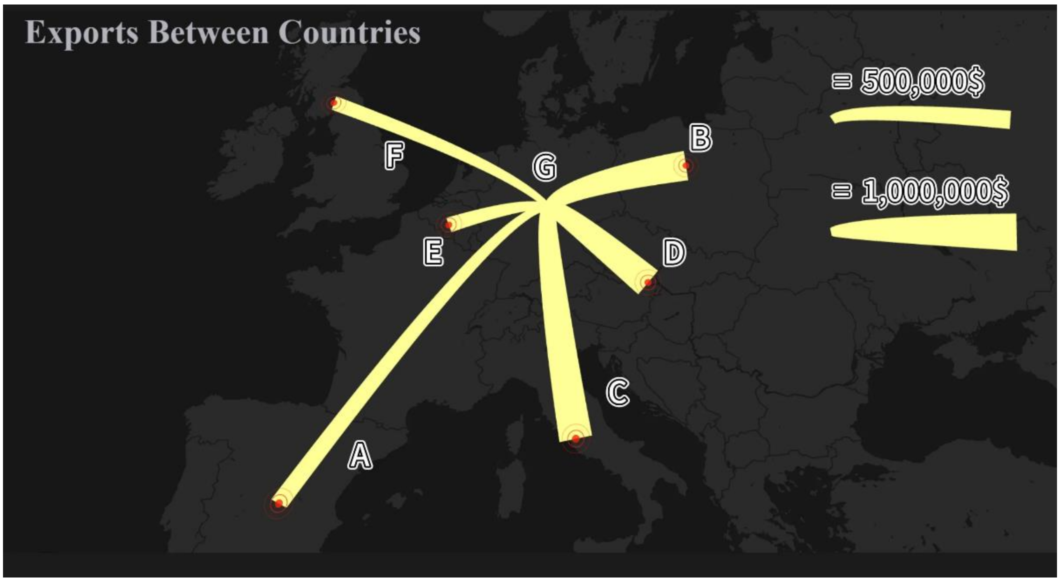
9. How confident are you in your ability to rank the flow volumes accurately?

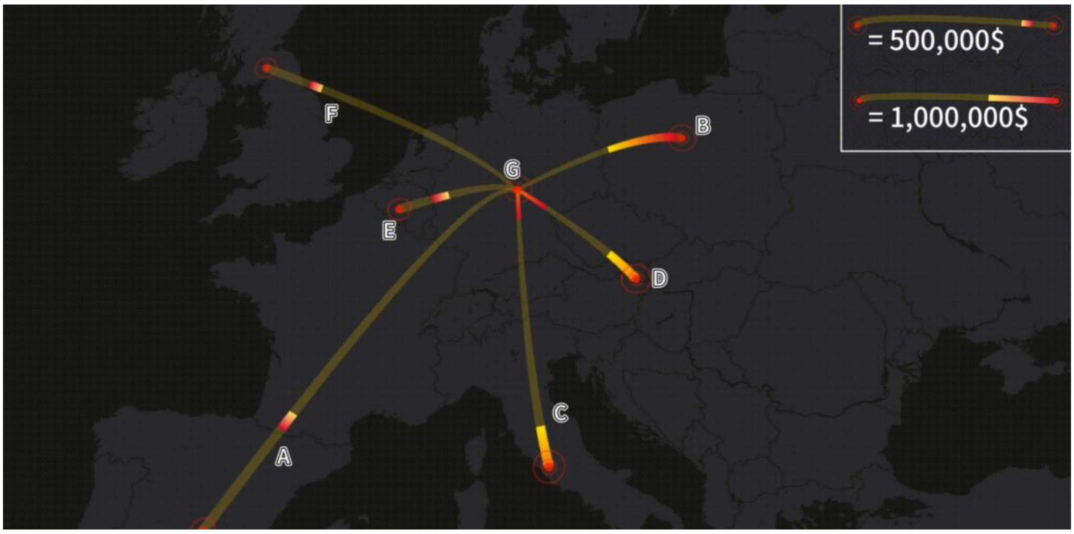
- Very confident
- Confident
- Somewhat confident
- Not confident
- Not applicable

10. How long did it take you, on average, to answer the above three 'estimation' questions?

- 1-3 minutes
- > 3 minutes
- < 1 minute

11. Look at the map, can you see different volumes of exports between countries?





○ Strongly Agree

○ Agree

○ Neutral

○ Disagree

○ Strongly Disagree

12. Look at the map, please rank the exports between countries from the highest to lowest.

○ C > A > E

○ C > E = A

○ C = A > E

13. Please estimate the volume ratio between Exports-C and Exports-F.

- ◯ 5:1
- ◯ 2:1
- ◯ 1:1
- ◯ 1:5
- ◯ I cannot estimate them

14. Please estimate the volume ratio between Exports-E and Exports-A.

- ◯ 2:1
- ◯ 5:1
- ◯ 1:1
- ◯ 1:5
- ◯ I cannot estimate them

15. How confident are you in your ability to rank the flow volumes accurately?

- ◯ Very confident
- ◯ Confident
- ◯ Somewhat confident
- ◯ Not confident
- ◯ Not applicable

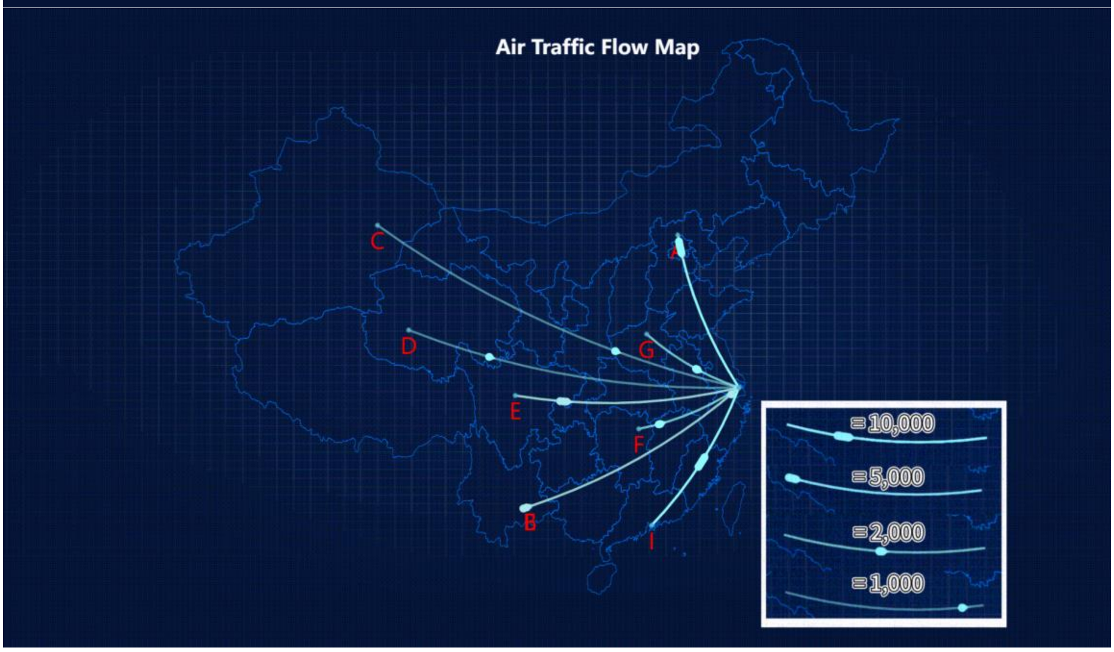
16. How long did it take you, on average, to answer the above three 'estimation' questions?

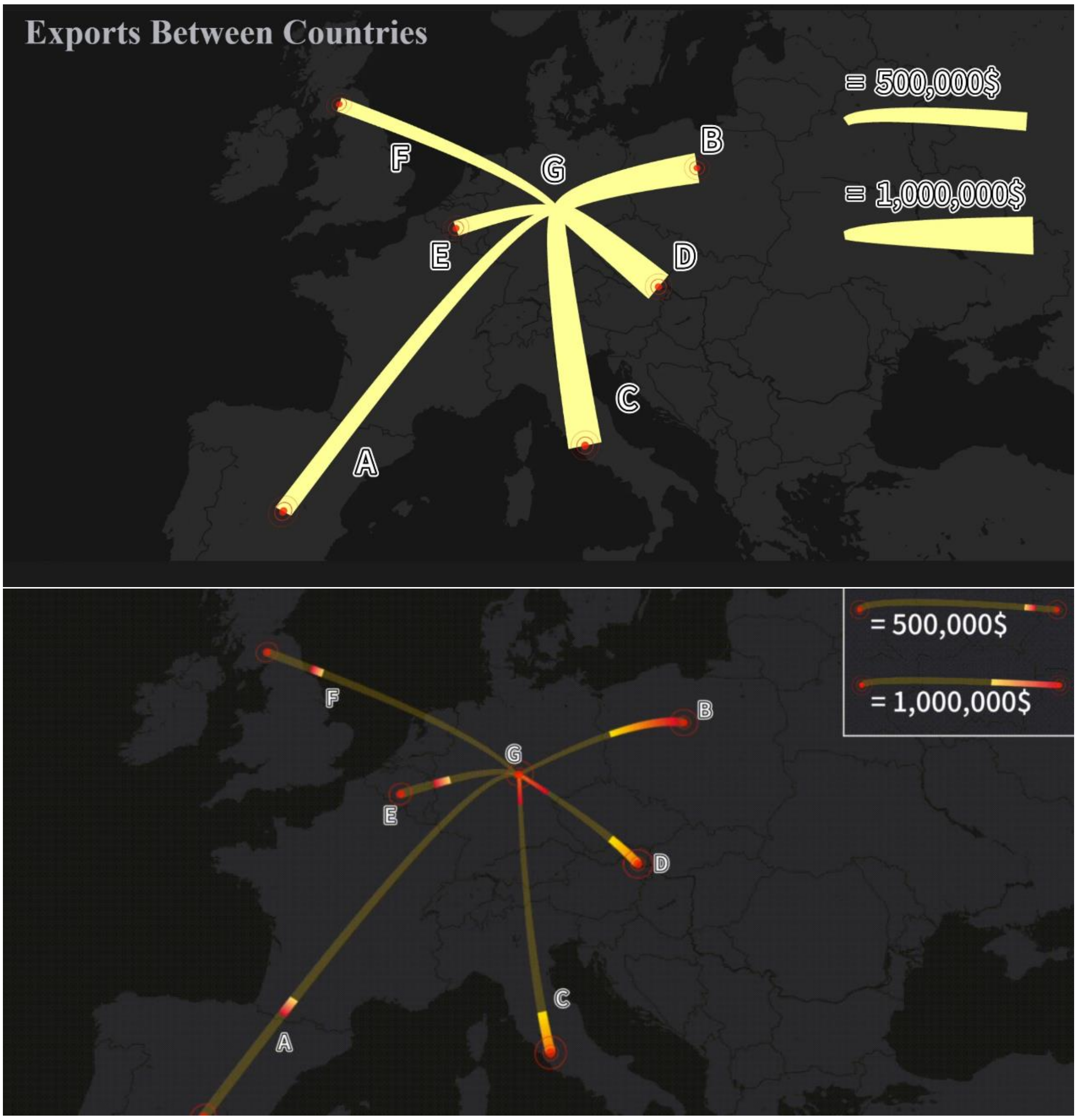
◯ < 1 minute

◯ 1-3 minutes

◯ > 3 minutes

17. Did you find the flow lines on the map to be visually crowded or congested?





◯ Strongly Agree

◯ Agree

◯ Neutral

◯ Disagree

◯ Strongly Disagree

18. How would you rate the readability (ease of learning) of the flow lines on the map?

○ Excellent

○ Good

○ Fair

○ Poor

○ I cannot estimate them

19. Now, we are presenting the static version of the map for the flight routes you just saw.

○ Dynamic Maps

○ Static Maps

20. Now, we are showing you the static/dynamic version of the map for the trade data you just viewed. Please compare them and choose the map that you think offers a better visual experience.

○ Dynamic Maps

○ Static Maps

21. Based on the comparison between the static and static/dynamic versions of the two maps mentioned above, which method do you think allows you to efficiently judge or perceive volume information represented by the lines on the map?

○ Dynamic Maps

○ Static Maps

22. [Only for animated map test] The following two animated maps use "two methods" to display the quantity of flight routes. Which one do you think allows you to more quickly and precisely perceive the differences in quantity between different lines?


Air Traffic Flow Map
A
C
G
D
E
F
B
I


Air Traffic Flow Map
A
C
G
D
E
F
B
I

◯ Map - A

◯ Map - B