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Faculty of Computer Science
Department of Simulation and Graphics

Master Thesis

A Descriptive Characterization of Interactive Data-driven Visual Storytelling in a Spatio-temporal Context

Author:
Nastasja Steinhauer

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1. Reviewer
Prof. Dr. Bernhard Preim
Faculty of Computer Science
Department of Simulation and Graphics
Otto-von-Guericke University
Universitätsplatz 2
39106 Magdeburg, Germany

2. Reviewer
Stefan Bruckner
Faculty of Mathematics and Natural Sciences
Department of Informatics
University of Bergen
5020 Bergen, Norway

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Contents

Abstract

High-profile issues such as the COVID-19 pandemic and the Russia-Ukraine war have given Visual Storytelling with data a lot of attention in online journalism, confirming its high effectiveness and relevance for conveying stories. Thus, new ways have emerged that expand the space of Visual Storytelling techniques. In particular, visual data stories with spatio-temporal reference have not yet been holistically studied in research with respect to the current state of occurring genres, Visual Storytelling techniques, and visual space-time encodings. Thus, this thesis proposes a taxonomy based on related work by Roth [36], Stolper et al. [42], and Mayr & Windhager [30], which categorizes 130 collected web-based visual data stories with spatio-temporal reference (between 2018 and 2022) according to genre, Visual Storytelling techniques, and visual space-time encodings. An analysis of notable techniques, frequencies, trends, and similarities in the dataset summarizes key findings on the current state in a spatio-temporal context.

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1 Introduction

1.1 Motivation

The COVID-19 pandemic has brought data visualizations front and center. These proved to be a reliable and effective way to display the spread and extent of coronavirus in near real time [28]. Graphical concepts such as "flattening the curve" became common terms. Maps, in particular, were used as a standard tool to show the distribution of COVID-19 cases, deaths, and vaccinations [39], as we see, for example, in live-tracker posts of *The New York Times* [1]. Russia's invasion of Ukraine has also drawn the attention of many data teams [15]. *The Washington Post* showed "*Four maps that explain the Russia-Ukraine conflict"* [61]. The *Bloomberg* [71] journal focused on the impacts of the war, showing the banning of Russian aircraft and the changes in flight routes over Ukraine.

The COVID-19 pandemic and the Russia-Ukraine war highlight the relevance and effectiveness of data- and visualization-based online journalism, whose traditional form has always been concerned with communicating information in an understandable, interesting, and relevant way [34]. According to Gray et al. [17], "data can be used to create deeper insights into what is happening around us and how it might affect us" (p.5). Data is increasingly becoming an important part of storytelling, which formed the term *Visual Storytelling*, and the number and development of new corresponding techniques rises [42]. Segel & Heer [37] discovered that data stories "can also be interactive, inviting verification, new questions, and alternative explanations"(p.1).

As the field of Visual Storytelling brings new challenges, related work already exists [7, 37, 38, 42, 45] dealing with the exploration of the techniques of these new forms of communication. Storytellers of spatio-temporally bound events also make use of Visual Storytelling techniques, as they can help to relate the action to familiar places and to better understand the temporal sequence of events [30], as we can see with the COVID-19 and Russia-Ukraine war examples. However, related work, such as those mentioned above, has either given little attention to the particular structure and techniques of spatio-temporal data stories or focused mainly on broader map-based Visual Storytelling genres and design patterns [36], or only on selected visualization techniques [9, 26, 30]. Thus, it is of interest to explore which current Visual Storytelling techniques, genres, and visual space-time encodings are used in visual data stories with spatio-temporal reference and to integrate them in a taxonomy.

1.2 Aim of this Thesis

Based on a collection of recent data- and author-driven stories with spatio-temporal reference (from 2018 to 2022) in online journalism and on other visualization websites, this thesis aims to examine, categorize, and analyze the Visual Storytelling techniques used in the collected visual data stories. I based the resulting taxonomy on the genres presented by Roth [36], the Visual Storytelling techniques by Stolper et al. [42], and the design space of visual space-time encodings by Mayr & Windhager [30]. This taxonomy and analysis is intended to reveal how current storytellers realize the time component in combination with spatial information, and which genres and Visual Storytelling techniques are most represented, aiming to support the message of a spatio-temporal visual data story. Patterns in frequencies, trends, and similarities in the dataset are also examined. This may serve as guidance and inspiration for future storytellers to effectively present visual data stories with spatio-temporal reference and as a basis for future research. In summary, the following research questions are addressed:

- Which Visual Storytelling techniques are used by current visual data stories with a spatio-temporal reference?
- What conclusions can be drawn about frequencies of Visual Storytelling techniques used?
- What statements can be made about the change in genres, Visual Storytelling techniques, and space-time encodings in the spatio-temporal context and their use compared to four years ago?
- Are there characteristics shared among data stories using the same Visual Storytelling techniques?

1.3 Contributions of this Thesis

This thesis has the following contributions to the research:

- A comprehensive taxonomy that aims to provide an overview of genres, Visual Storytelling techniques and visual space-time encodings used in visual data stories with spatio-temporal reference.
- A set of 130 visual data stories with spatio-temporal reference collected from online journals and other websites from a time period between 2018 and 2022.
- An analysis of notable techniques, frequencies and trends of the techniques in spatio-temporal context and possible similarities among the visual data stories.

1.4 Structure of this Thesis

In the following, I provide a brief overview of the structure of the content of this thesis.

- **Chapter 2** describes basic concepts related to storytelling (2.1). Furthermore, terms concerning the underlying spatio-temporal data types and cartographic maps are clarified (2.2).
- **Chapter 3** provides an overview of related work concerning taxonomies and design spaces of Visual Storytelling techniques (3.1) and Visual Storytelling of spatio-temporal data (3.2).
- **Chapter 4** describes the research method and process for collecting the data (4.1), as well as the individual categories of the taxonomy of this thesis (4.3).
- **Chapter 5** presents the implementation approach (5.3) and the underlying dataset (5.1) of an interactive web-based notebook that supports the exploration of the taxonomy.
- **Chapter 6** examines the results that emerged from the analysis of the collection of spatio-temporal visual data stories. This chapter concludes with a discussion of possible factors influencing the results.
- **Chapter 8** summarizes this thesis (7.1) and concludes by addressing open questions and possibilities for further development of this work (7.2).

2
Theoretical Background

Narrative Visualizations, Visual Storytelling, and Data Journalism are concepts that all deal with supporting a data-based story visually. In this chapter, I introduce the definition of Narrative Visualizations based on information about *Narratives* and *Storytelling*. Furthermore, I discuss the relevance of Visual Storytelling in online journalism. At the end, I give a short insight into cartographic maps and the spatio-temporal context.

2.1 Narratives, Storytelling and Visualizations

Barthes & Duisit [8] define a narrative as "a prodigious variety of genres, themselves distributed amongst different substances – as though any material were fit to receive man's stories"(p.237). According to them, the narrative transcends cultures and "it is simply there, like life itself" [8](p.237). Tong et al. [43] add that "storytelling is a technique used to present dynamic relationships between story nodes through interaction"(p.2). Interaction lets the readers feel the joy of the moment of discovery that is typical of live storytelling [16]. Thus, according to Figueiras [16], technological progress helps modern storytelling to exhibit more of the characteristics that we value so much in traditional storytelling.
A narrative consists of a beginning, middle, and end [16]. Background information and a change or conflict are communicated in an initial situation at the beginning. This situation can develop into a fight, a complication, or something else in the middle part, which leads to a climax. The resolution of developments or even open endings conclude the narrative [16]. According to Figueiras [16], the computer and the internet as a new medium of storytelling give the possibility to create multimedia, complex and sophisticated narratives. Interactive storytelling techniques are also be-

coming more popular in news casting and documentaries, which were very much oriented towards traditional forms of storytelling.

2.1.1 Narrative Visualization and Visual Storytelling

The relationship between information visualization and storytelling got a name in 2010 by Segel & Heer [37] as *Narrative Visualization*, which shapes a new class of visualizations ever since. This new class includes visualizations that aim to communicate complex data in an effective and engaging way that promotes knowledge sharing [35]. Segel & Heer [37] identified the *Martini Glass Structure, Interactive Slideshow, and Drill-Down Story* as structures of story introduction in news media. These structures are based on the degree to which the story is author- or reader-based. Author-driven is an approach that follows a strictly linear path through the visualization and does not include interactivity. Reader-driven approaches have a high degree of interactivity and do not impose a sequence. Lee et al. [27] exclude web-based interactive visualizations that allow for completely free exploration without any guidance from their definition of a visual data story, which is akin to a reader-only driven approach. However, Segel & Heer [37] found that most examples of Narrative Visualization are flexible in balancing the use of both approaches, which they also emphasize as an important feature of Narrative Visualization. According to Figueiras [16], research also shows that flexible narratives with landmarks and spaces in between where the user can move freely are a good narrative strategy for different types of visualizations.
Lee et al. [27] identified further characteristics for defining a visual data story. A data story includes a set of story pieces, i.e., concrete facts supported by data (e.g., how energy consumption has changed over time), most of which are visualized to support one or more intended messages. To support the author's high-level communication goal, these pieces are presented in a meaningful order and connection to each other. Examples of story pieces linked to a plot can take the form of one or more visualizations compiled in a slide deck, a video with narration, an infographic presented on a poster, or a live demo with interactive elements [27].
Tong et al. [43] have also developed dimensions common to storytelling in visualization:

- **Authoring-tools** refer to the one who creates the story
- **User-engagement** refers to the audience and to the intention of the storytelling method

- **Narratives** refer to the narrative structures of a story (including events and the visualization of characters)
- **Transitions** refer to how a story can be told using transitions between events to support flow
- **Memorability** refers to the reason why data is presented in story form to increase the memorability of a story
- **Interpretation** includes determining the significance of important data and information and its critiquing

Using these dimensions, Tong et al. [43] provide a guideline to answer questions regarding effective storytelling with visualizations.
In the visualization research community, the term *Visual Storytelling* is also sometimes used as a synonym for the term *Narrative Visualization.* In the course of this thesis, I use the term of *Visual Storytelling.*

2.1.2 Visual Storytelling in Online Journalism

According to Riche et al. [34], "there has been a growing consciousness that some of today's most relevant stories are buried in data"(p.5). The complex raw structure of this data can be made more generally accessible through visualization. Interest in information visualization has increased significantly in areas such as business, education, art, and journalism [35].
Journalism has always been concerned with communicating primarily information that is understandable, interesting, and relevant [34]. Thus, it is also taking advantage of the new forms of communication, creating a new subcategory as *Data journalism.* Because with the help of visualizations, in addition to telling complex and compelling stories, readers are also given the opportunity to gain insights, make decisions [35], and interpret the underlying data [34]. Thus, according to Riche et al. [34], journalists are integrating standard techniques such as charts and maps and developing new ones that are adapted to the specific data types and messages of the story. The public's growing interest in data-driven news has been spurred by news sites such as *The New York Times, FiveThirtyEight, Bloomberg,* and *The Washington Post.* Since then, new data visualizations have been popping up in the media every day, driving progress in addressing the challenges of data-driven storytelling [34].
The inventor of the world wide web, Tim Berners-Lee, also thinks that the future lies in analyzing data and recommends that "journalists should be data-savvy" [4].

2.2 Cartographic Maps and Spatio-Temporal Data

If the goal is to show spatial patterns and provide insight into spatial relationships, then maps are known to be the ultimate graphical representation for this. In combination with the temporal component, maps can also be used to tell stories or explain events [24]. In the following, a definition of the underlying spatio-temporal data and a short introduction of cartographic map visualizations are given.

2.2.1 Spatio-Temporal Data

According to Rodrigues et al. [35], a story is usually located both temporally (when) and spatially (where), which ascribes a clear connection to storytelling and the dimensions of time and space. This thesis is based on a collection of visual data stories that have a spatio-temporal reference. Spatio-temporal visual data stories can have different goals, which may depend on the author's intent. For example, I have examined stories that seek to communicate the spread of wildfires [66] or infections over time [83] and thereby warn the population or allow them to prepare. On the other hand, there are stories that place a familiar setting in the context of globally related aspects, such as the climate [60], so that readers can identify with the content on a more global scale.
The goals may also depend on the underlying data. Spatio-temporal data types differ in the way space and time are used in the process of data acquisition and representation [5]. Atluri et al. [5] categorize four different spatio-temporal data types:

- **Event data**: refer to discrete events that occur at specific locations and times (e.g., frequencies of crime or disease). In addition to location and time, each event may also contain other variables with additional information (e.g., type of disease). Similarly, an event may be associated with a time period of occurrence instead of an immediate point in time.

- **Trajectory data**: refer to the measurement of paths (trajectories) traced by bodies moving in space over time (e.g., the route of a taxi from pick-up to drop-off location). Additional information about the moving body may also be included (e.g., a person's heart rate).

- **Point reference data**: refer to the measurement of a continuous spatio-temporal field, such as temperature or population, at moving spatio-temporal reference points (e.g., measurements of surface temperature with weather balloons)

- **Raster data**: refer to the acquisition of a continuous or discrete spatio-temporal field at fixed locations in space and at fixed points in time (e.g., fMRI scans of brain activity or the measurement of air quality). Unlike point reference data, the location and time points of measurement do not change.

The collected spatio-temporal visual data stories for this thesis are largely based on the first three types of spatio-temporal data: *Event data, Trajectory data*, and *Point reference data.* I did not notice the use of *Raster data* in any of the collected stories. Thus, a definition of spatio-temporal data in this thesis always refers to the first three categories.

2.2.2 Cartographic Map Visualization

According to Elzakker [14], maps are "an abstraction and simplification of geographic reality to scale, obtained by reducing the amount of information on geographic reality, translating it into graphic symbols and, usually, projecting it on a flat medium (e.g., paper or the display screen of a computer system)"(p.12). They are very effective for communicating, analyzing, synthesizing, and exploring geographic data and information. They are also very effective for providing an overview of spatial patterns, relationships, and trends [14].

Figure 2.1: Three different types of maps: Reference (topographic) map (A), Thematic map (B) and Special-purpose map (C). The figures were taken from the work by Brewer [12].

In general, there are three different types of maps [12]:

- **Reference (topographic) maps** (Fig. 2.1, A): represent several spatial data without specific emphasis. Generally, they contain only the various geographic features that provide a picture of the mapped area (e.g., political boundaries, cities, topographic features, and/or transportation routes).

- **Thematic maps** (Fig. 2.1, B): represent features or attributes of features (e.g., amount of precipitation). These maps have a specific theme or focus and may vary in topic, complexity, purpose, and method of presentation. They use visual variables (e.g., hue, brightness, pattern, shape) and symbols (e.g., dots, lines, areas) on which features of the data are mapped. An example of this type of map is *choropleths*, which encode data as colored regions [26].

- **Special-purpose maps** (Fig. 2.1, C): refer to a specific type of data or user types, but are like a reference map in their use. These maps are designed to guide map users with specific goals (e.g., navigation maps for hiking or biking).

A map showing the area to be viewed and the data with their coordinates is the most common form for the representation of geospatial data [32]. The information is generally represented by symbols, points, lines, and areas with different properties such as color or shape. Geospatial data can be decomposed into an abstract attribute space and a geographic space with two or three dimensions (latitude, longitude, and possibly altitude). Geospatial data can be defined as a point or an area [32].
In digital cartography, the components of a map can be differentiated by layers [40]. According to Kraak & Ormeling [25], reference (topographic) maps are composed of separate road and railway layers, settlement layers, hydrographic layers, a contour line layer, a geographic name layer, and a land cover layer, all of which have the same visual weight [25]. In addition, other symbols can be added to highlight specific points of interest, such as restaurants, hospitals, or hotels [12]. Thematic maps require topographic information as a base map, which is enhanced with thematic content [25, 40]. Through interaction or animation, the contents can be displayed individually or combined step by step by showing or hiding the relevant layers as required [41].
According to Nollenburg [32], dynamic and interactive representations are central to geovisualization. Animations can depict spatial features, such as flights over a terrain, or highlight elements by movement. However, the risk of users missing something while not having the opportunity to interact can be seen as a disadvantage of animations. This makes it difficult to compare data from different points in time [32]. According to Harrower [18], the creation of an animated map is justified only when the data is difficult or impossible to convey in static form. The strengths and limitations of animation as a tool and the impact of animation on map readers should be known, with which Harrower proposes solutions to some challenges. When animated maps are well designed, they can be very attractive and informative [18].

3 Related Work

This chapter is dedicated to related works, their contributions and also the areas they neglect, which serves as a starting point for this work. I mainly focus on taxonomies and design spaces of Visual Storytelling techniques and Visual Storytelling of spatio-temporal data.

3.1 Taxonomies and Design Spaces of Visual Storytelling Techniques

Segel & Heer [37] have developed a design space of different genres of Narrative Visualizations and thus laid a starting point for much research in the field of Visual Storytelling. Lee et al. [27] defined the characteristics a story must have to be called a visual data story and identified the roles in Narrative Visualizations. In the last decade, further work has followed, dedicated to advancing the study of Visual Storytelling. Stolper et al. [42] have developed a taxonomy that classifies web-based, data-driven stories according to Visual Storytelling techniques such as *Communicating Narrative and Explaining Data, Linking Separated Story Elements, Enhancing Structure and Navigation* and *Providing Controlled Exploration.* Tong et al. [43] examined important elements of storytelling visualizations and created a novel classification of the literature on the topic. Besides, Bach et al. [7] categorized 18 design patterns of data-driven narratives guided by the storyteller's intentions and the audience to be addressed. Yang et al.[45] proposed a design space for creating structured data stories based on the narrative structure of *Freytag's Pyramid.*

From a more specific view, I found further work on the contribution of different design spaces in Visual Storytelling techniques, such as for:

- **Transitions between common statistical data graphs** [19]. It illustrates effective design principles for transitions in the tool DynaVis.

- **Effective sequences in a series of linearly presented visualizations** [22]. It automatically identifies effective sequences in a series of linearly presented visualizations.
- **Chart annotations** [33]. It provides *ChartAccent* tool to enhance diagrams with annotation interactions.
- **Timelines** [11]. It provides different design options for storytelling in relation to timelines.
- **Different visual narrative flows** [31]. It shows the influence of seven *flow factors* to the reading experience.
- **Types of infographics in online long-form journalism** [38]. It focuses on the use of infographics in *Scrollytelling* and their integration into long-form articles.

Many of these works have provided me with much inspiration for the creation of the taxonomy. During my research, I realized that none of these extensive works mentioned above refer specifically to stories with a spatio-temporal reference. Nevertheless, there are already research approaches that aim to make the storytelling of spatio-temporal data more effective.

3.2 Visual Storytelling of Spatio-Temporal Data

Mayr & Windhager [30] created a visualization framework based on five standard techniques aiming to support the analysis of narrative spatio-temporal data. They also place particular emphasis on the cognitive effectiveness of the use of these techniques. They compiled these standard techniques from a variety of related works in the research area (e.g., [2, 3]), including static and animated maps, space-time cubes, and coordinated linked views. Besides this design space for the combined representation of temporal and spatial data by Mayr & Windhager [30], I came across the design space by Roth [36] related to spatio-temporal data in storytelling. Roth suggests three ways to articulate and organize the design space for map-based Visual Storytelling. He refers to:

- *Basic narrative elements* related to geographic phenomena and processes,
- *Visual narrative genres* that describe different narratives and

- *Visual narrative tropes* used to advance narratives across text, maps, images, and other multimedia.

Moreover, I could find one classification by Biriukov [9], focusing on interactive storytelling maps. This classification comes along with helpful tools and libraries as development guidance. However, maps are considered exclusively on their own, rather than as embedded in a textual narrative. Latif et al. [26] recently published a work in which they examine the interplay of visualizations and textual narratives in geographic data-driven stories. While their analysis goes more into detail by focusing on strategies for the interplay of visualization and text in 22 visual data stories, my analysis goes more into the broad and aims to reveal more general insights about the use of Visual Storytelling techniques in a spatio-temporal context.

Furthermore, I found work that relied more on the creation of specific storytelling tools or the addition of storytelling elements, rather than formulating general design spaces. For example, Hsu et al. [21] provide a web-based timelapse editor, with which guided video tours and interactive slideshows of spatial and temporal images can be created and embedded in web pages to support multimodal and interactive storytelling. Eccles et al. [13] added a story system to the space-time cube based *GeoTime* visualization tool for geo-temporal events, which is intended to support the identification, extraction, arrangement, and presentation of stories in the data. According to Kraak & Kveladze [24], the space-time cube is a visual representation that inherently links space and time. The horizontal plane of the cube represents space, the vertical axis represents time (for more details see Section 4.3.3). Kraak & Kveladze [24] added annotations to the space-time cube at the paths and stations of the cube, increasing the expressiveness of the representation. Lundblad & Jern [29] have developed the toolkit GAV Flash and the user application "World eXplorer" to create and share stories of spatio-temporal data.

3.3 Summary and Relevance for this Thesis

The use of visualizations for storytelling has become more established in recent years [42], bringing the field of Visual Storytelling more into research. With the work by Segel & Heer [37] from 2010, a first design space and genres within Narrative Visualization were proposed. This was followed by other more current or specific taxonomies and design spaces. Also, insights from research were applied to develop tools that make Visual Storytelling more effective and easier, which in my case was primarily geared towards spatio-temporal data stories. While there are already a variety of design spaces for Visual Storytelling techniques, they often focus less specifically on spatio-temporal data stories [7, 37, 38, 42, 45]. The few works dedicated to this type of data focus either only on general genres and design patterns for this data [36], or only on specific techniques, such as combined space-time encodings [30], the interplay of visualizations and textual narratives [26] or interactive maps [9]. I aim to follow this up with a comprehensive taxonomy that integrates genres, Visual Storytelling techniques, and visual space-time encodings, and examines them in the context of current web-based stories with spatio-temporal reference.

4

Descriptive Characterization Approach

In this chapter I present the research method and process, including the criteria, references and inspirations. In order to categorize the collected visual data stories according to techniques used, I formulated a taxonomy. I present this taxonomy with its categories in detail and my rationale for choosing these categories.

4.1 Research Method and Process

The aim of this thesis is to identify and understand the current status of techniques used for Visual Storytelling based on spatio-temporal data. In this sense, I conducted an analysis of selected current web-based data- and author-driven visual stories with spatio-temporal reference. Inspired by related works [11, 22, 31, 33, 42], the source of the visual data stories came mostly from online journals: *The New York Times, The Guardian, The Washington Post, The Economist, FiveThirtyAight, Bloomberg, National Geographics, The Pudding, Reuters, ProPublica, Berliner Morgenpost*, and *Zeit online*. According to Stolper et al. [42], most of them are commonly used sources for visual data journalism. Since Roth [36] used the journal *National Geographics* as a representative source for spatio-temporal stories, I decided to also include it in my research. Furthermore, I used the interactive *Manhattan Population Explorer* website and the *EcoWest* website, which tracks, analyzes, and visualizes environmental trends.

To give direction to and narrow the research, I first set a time period of 2018 to 2022 to begin after the research of related work but still include a period before the COVID-19 pandemic so that this topic does not dominate the stories too much. In the frame of this period, I then looked at the top-rated stories of these years, which were listed by the community in popular blog lists of *FlowingData* and *Vi-*

sualisingData as "*Best Data Visualization Projects of...*"[1] or "*Best of the Visualisation Web...*"[2]. To look more specifically for stories with spatio-temporal data, I searched for specific technique-related keywords ("Maps", "Timeline", "Interactive", "Graphics" or "Animation") or topic-related keywords ("War", "Climate change", "Wildfires", "Elections", "Protests", "Education", "Health" or "COVID-19") on the journal websites, the community blogs listed above or via Google Advanced Search. To search for stories that fit the characteristics of the *"Real-Time" Extension* of Roth's [36] *Visual Story Compilation* genre (see Sec. 4.2), I searched via Google Advanced Search for frequently used keywords in the texts, titles, or URL's of these stories (allinurl: "live"; allintitle: "Maps:Tracking", "Live Updates"; allintext: "Updated", "Reporting was contributed by"). Often, other articles at the end of one article also led to new interesting articles that covered, among other things, spatio-temporal techniques, which did not always necessarily have to include a map.

Figure 4.1: Example stories from the collected dataset representing the temporal-related criteria: Time is encoded as a color-coded value on the map (A) [52], juxtaposed changes of spatial-related information compared between two time intervals (B) [79], and both cases, encoding time on the map showing the number of fire weather days in California's regions as well as juxtaposed changes of these values over time (C)[74].

The selection of stories was based on the following criteria: the stories had to contain a spatial and temporal visual component, such as a map with temporal information or a line chart with spatial and temporal information (these components were also allowed to appear separately from each other in the story). Furthermore, they had to be data- and author-driven, and thus exclude exploratory, reader-driven and interactive visualiza-

[1] https://flowingdata.com/tag/best-of/
[2] https://www.visualisingdata.com/2022/02/best-of-the-visualisation-web-october-2021/

tions without author guidance as described by Lee et al. [27]. However, I considered visual stories that integrate at least one interactive component that goes beyond clicking the play button in an animation or video (e.g., scrolling). Hence, I excluded data videos. By considering interactive possibilities, the advantages of interaction–as we can see for example in the narrative design patterns from Bach et al. [7], such as *Familiarization*, *Make-a-guess* or *Users-find-themselves*, that stimulate curiosity and engagement and make abstract data personally relatable–can be taken into account and support the message of the story. The temporal aspect in this context includes, on the one hand, as with Mayr & Windhager [30], the change of spatial-related information over time (such as changes in birthrate over time, see Fig. 4.1, B). On the other hand, it also includes time information that was mapped directly as a value to the spatial information (such as the time of delivery of mail in days for different regions, see Fig. 4.1, A). Figure 4.1, C shows an example story from the journal *ProPublica*, which fulfills both time-related criteria.

Similar to Stolper et al. [42], I would like to emphasize that such research does not have the claim to be perfect and thus completely representative. Nevertheless, the examples used are intended to provide a representative overview of the techniques used.

4.2 Taxonomy

With the criteria in mind, for the analysis I was guided by the following Visual Storytelling genres (for an explanation of the genres see 4.3.1) by Roth [36]:

- *Longform Infographic*
- *Dynamic Slideshow* and
- *Multimedia Visual Experience.*

I excluded the

- *Personalized Story Map,*
- *Static Visual Story* and
- *Narrated Animation*

genres, since they either allow unguided, personalized navigation or they do contain too little or no interaction. Furthermore, I excluded the *Visual Story Compilation* as a genre, since its original form consists of a string of several linked stories where the author has little influence on the narrative element composition. However, I have integrated the compilation characteristic of real-time extension as an extended form with the help of a subcategory (see Section 4.3.2). In addition to the genres, Roth [36] suggests two other ways to organize the design space, as introduced in Section 3.2: *basic narrative elements* and *visual narrative tropes*. However, I have decided to exclude these other two suggestions from the taxonomy of this work, as they go beyond the focus on Visual Storytelling techniques. Despite the fact that I excluded half of the genres, the categories I included for the taxonomy are very extensive and still offered a large number of stories.

Since Stolper et al. [42] already provide a clear taxonomy of the operations and mechanisms of Visual Storytelling, I have applied appropriate techniques from their work to my case of spatio-temporal data. Additionally, I added further techniques like *"Real-Time" Extension* or replaced *Scrolling* by *Basic Scrolling* and *Scrollytelling*, which I will discuss in more detail later in this section. In order to integrate techniques for the visual encoding of space-time, I oriented on the design space by Mayr & Windhager [30]. However, they refer to visualizations that must contain a map. Since I also found spatio-temporal data stories without maps, I included an additional technique, which I call *Map-Independent Time Visualization*, that covers all encodings that are neither based on nor linked to a map.

4.3 Categories

Based on the categories described above, I formulated a taxonomy (see Fig. 4.2), that represents each of these categories with its subcategories. In the following, I describe these categories in more detail.

4.3.1 Genre

Roth's work [36] lists limitations of the genres of Segel & Heer [37]–*magazine style, annotated chart, partitioned poster, flow chart, comic strip, slide show, and film/video/animation*–that limit their practical use for design. The genres of Segel & Heer are delineated by the number and order of individual frames or individual sections, panels, slides, etc. [36]. Roth's genres, however, assume that the number of frames can

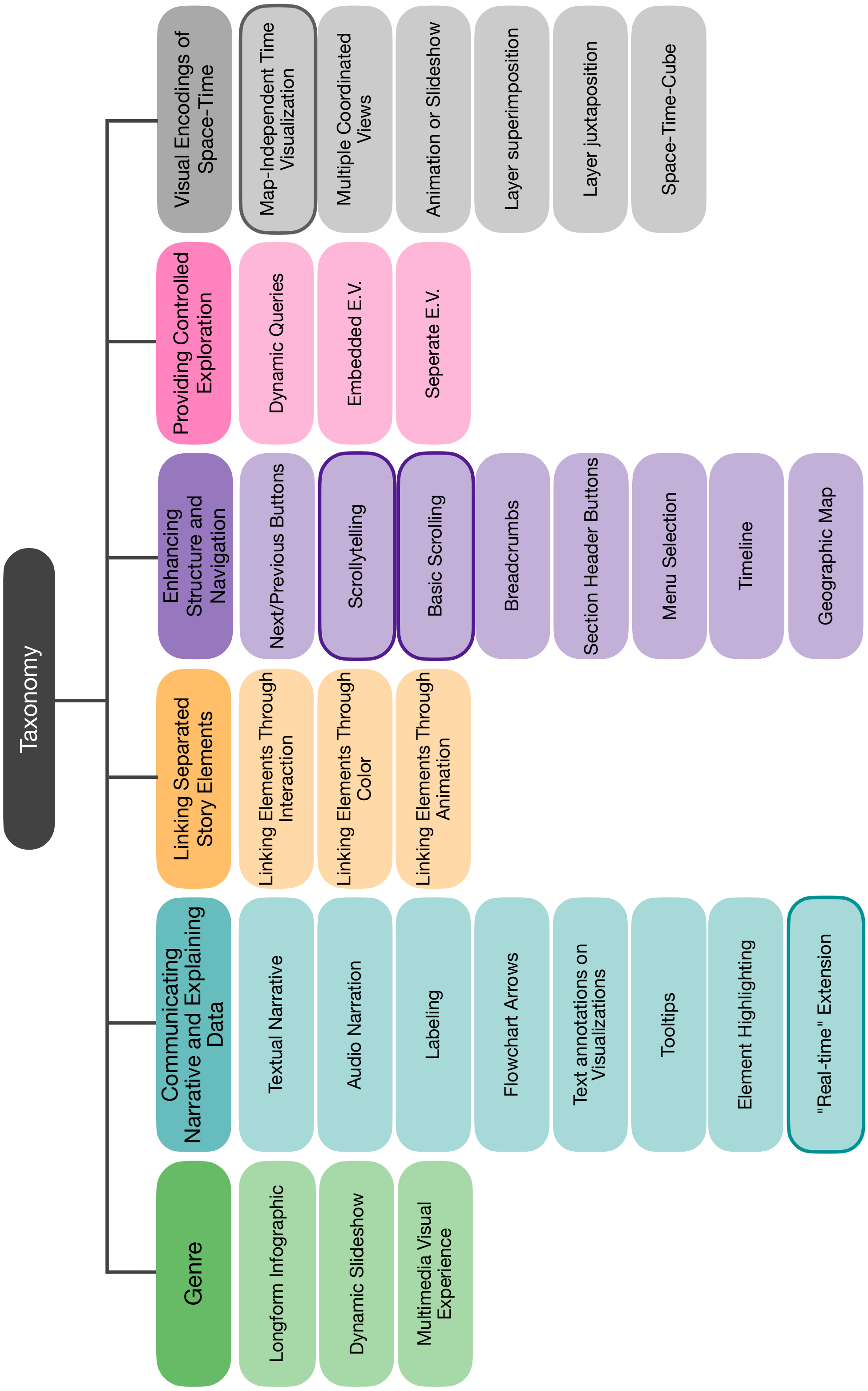

Figure 4.2: Information structure of the categories for the taxonomy of this thesis. The categories combine genres by Roth [36], Visual Storytelling techniques by Stolper et al. [42], and visual space-time encodings by Mayr & Windhager [30]. The categories that I have added are highlighted by a frame.

only distinguish between one or many frames, i.e., a flowing or fragmented layout, and since the genres of Segel & Heer potentially have a similar number of frames, the genres cannot be uniquely defined by the number of frames [36]. In addition, for stories with spatial references, a more important question for Roth is the role of the map as central or supportive to the narrative. Furthermore, Roth has expanded the genres to take advantage of the interactive and mobile possibilities of the Web. To recognize the enforcement of linearity in the narrative sequence of a story, Roth proposes seven genres that are defined only by their visual or interactive technique [36]. As previously mentioned, I focused on only three of Roth's seven genres, since interaction, as well as author-guidance, were relevant to my analysis. In the following, I will discuss these three genres in more detail.

Longform Infographic

According to Roth [36], the genre of *Longform Infographic* is often referred to by data journalists as *Scrollytelling* because text, graphics, and multimedia are layered with a limited width, and vertical reading and scrolling in the browser give the story linearity. Maps, timelines, or other graphics can either flow smoothly across the entire visual story or be fragmented by transitions in the narrative.
For stories with spatial references, this genre can resemble *strip maps* (see Fig. 4.3), which follow a single linear corridor that excludes information outside the corridor and where the storytelling is intimately dictated by the sequential order of locations on the map. *Longform Infographics* using a central strip map are also suitable for so-called "quest" plotlines, where a character moves from a starting point to a destination (such as the adventure of Frodo Baggins in *The Lord of the Rings*) [10]. In addition, the reader can interactively control the narrative tempo by continuously scrolling and is thus drawn into the story, which, on the other hand, according to Roth, can also lead to skimming and ignoring important plot points [36].

Figure 4.3: *Strip Map* example by *Bloomberg* [65] showing the annual tree loss around a Brazilian highway.

Dynamic Slideshow

Dynamic Slideshows create linearity through a series of slides or discrete visual panels of uniform size and format. Unlike *Longform Infographics*, navigation is characterized by conceptual horizontal scrolling rather than vertical scrolling, which is however extremely fragmented since there is no conventional lateral scrolling in modern web design [36]. As a result, the narrative in *Dynamic Slideshows* progresses through discrete clicks, taps, presses, or swipes, which limits the reader's skimming of important plot points. However, *Dynamic Slideshows* make it difficult to fast-forward or rewind multiple images at once [36]. For stories with spatial references, according to Roth, *Dynamic Slideshows* can resemble bound atlases, where you move page by page through a series of maps that follow a specific order and level of detail [36].

Multimedia Visual Experience

According to Roth [36], linearity in *Multimedia Visual Experience* is created through anchor tags and hyperlinks and is a relatively new, web-enabled genre of Visual Storytelling. Dynamic hyperlinks divide the visual story into chapters on multiple web pages and activate images, graphics, audio, and video files that accompany a central text narrative. However, since the criterion of anchor tags and hyperlinking would severely limit this genre to have any meaningfulness at all, I slightly opened up this criterion. In my case, a story was multimedia if it contained at least one video or audio, in addition to the visualizations and images, but which had to be supportive for the transformation of the story's message (however the video could also be without audio). This excludes stories with only one video running automatically in a loop at the beginning. In addition, it was not an exclusion criterion if the story did not span multiple web pages.

According to Roth [36], this genre can be easily combined with other genres, and just like *Longform Infographics*, the reader controls the story by scrolling. In addition, the story can include the author's voice or the perspectives of the people in the visual story, and along with a rich integration of images, maps, videos, and/or sounds, this creates a deep sense of place. In spatial narratives, maps in this genre are used to support the narrative and not as the centerpiece of it [36].

4.3.2 Visual Storytelling Techniques

Stolper et al. [42] grouped various techniques for Visual Storytelling under four broad categories in their analysis: *Communicating Narrative and Explaining Data; Linking Separated Story Elements; Enhancing Structure and Navigation*; and *Providing Controlled Exploration*. These categories often overlap in the techniques used but differ in the dominance of certain techniques. By comparing Roth's [36] selected genres with the ones used by Stolper et al. (which were based on the genres by Segel & Heer [37]), I accordingly selected the appropriate techniques for the taxonomy. Below, I describe the four categories in more detail based on the definition by Stolper et al. [42].

Communicating Narrative and Explaining Data

For conveying the message of a story, Stolper et al. [42] identified in their analysis various techniques that allow authors to combine storytelling methods (such as writing) with data. The technique in this category that occurred very often in Stolper et al.'s dataset is **Textual Narrative**. Here, the main points are conveyed through long texts, with supporting visualizations embedded at intervals. However, long texts can also accompany a visualization on a slide. In my case, this technique is accordingly represented in all three genres. In addition to Textual Narrative, **Audio Narration** can also be used, allowing elements of the story to be more closely linked. While Stolper et al. often refer to videos here, I have also integrated audio sequences that only play sounds or tones to make the story more immersive, such as the songs of certain bird species in "*Billions of Birds Migrate. Where Do They Go?*" [59] from *National Geographic*.

Narrative and data presentation are also often supported by textual **Labeling** above or below a visualization or as headings for a slide or section. The author's intended narrative structure and sequence can further be guided by **Flowchart Arrows**. The Labeling and Arrows can be distinguished from **Text annotations on Visualizations**, which direct the reader's attention to relevant aspects and which, according to Stolper et al., is also a fairly common technique. In general, Stolper et al. assign captioning as an important aspect of storytelling with data and list **Tooltips** for interactive explanations as another technique [42]. Here, details are displayed to the readers when they move the mouse over an element of the visualization. These details can be individual values, detailed information, or zoomed views of the visualizations. In addition to text, attention can also be drawn by graphical features that **Highlight Elements**. The highlighting can be done by shapes or by softening colors or selectively coloring elements. This can also be supported by text annotations and arrows [42]. In my case, this category also extends to the highlighting of territorial boundaries on maps or of specific locations on maps by symbols, such as dots or rectangles, combined with numbers.

Figure 4.4: Three selected stories within the story "*Maps: Tracking the Russian Invasion of Ukraine*", that includes the *"Real-Time" Extension* technique, based on Roth's genres [36]. The beginning of each embedded story is highlighted by an orange frame. The first story on the left is the most recent (10.10.2022), the last one on the right is the first published story on this topic (15.02.2022).

I have added the technique **"Real-Time" Extension** to this category. In his work, Roth refers to the genre of *Visual Story Compilation*, whereby events on a given topic are stacked vertically or in a grid in the form of visual summaries, and new ones are added in near real time [36]. One example is "*Maps: Tracking the Russian Invasion of Ukraine*" by *The New York Times* (See Fig. 4.4), whose first story was published on February 15, 2022, and has since been regularly expanded with new stories. During my research, I came across stories that extend the characteristics of Roth's compilation genre in which they do not link to other articles externally but are updated repeatedly (in almost real-time) to integrate multiple smaller articles concerning the same topic in the order of their release. I think that such compilations can be treated as *Longform Infographics* or sometimes as *Multimedia Visual Experience*, which have the feature of continuous *"Real-time" Extension*. Thus, I decided to integrate this characteristic not as a separate genre but as a single technique.

Linking Separated Story Elements

Stolper et al. [42] have identified three basic types of techniques authors use to connect different elements of a story, generally included in data-driven stories. According to them, such story elements include text in various forms and one or more visualizations or charts. Such linking is especially relevant when the story is explained with the help of the data used in the visualizations.
The first form is **Linking Elements Through Interaction**, which was surprisingly the least used in their analyzed stories, although they are very common as "brushing and linking" in visualization systems that help people explore data. One explanation for this might come from the deputy graphics director of *The New York Times*, Archie Tse [44], in which he attributes the reduction of interactions in articles to the fact that "Readers just want to scroll!" [44](p.6). However, this form of linking can exist not only between visualizations but also between the narrative text and visualization. Another type of linking is **Linking Elements Through Color**, which is achieved by consistent color mapping between attributes in multiple visualizations or between text and visualizations. Lastly, when transitions between diagrams are triggered or glyphs are animated to new positions by e.g., the reader's scrolling, Stolper et al. speak of **Linking Elements Through Animation** [42].

Enhancing Structure and Navigation

Although I assume some interaction for the readers, I follow the criterion that the authors provide structure, order, and navigational aids to the story.
To promote the structure of the story, **Next/Previous Buttons** are used, especially in connection with slideshows. According to Stolper et al. [42], the buttons and the ordering of the slides enforce a strong linearity. I have also integrated stories in this category that contain *Next/Previous Buttons* to navigate embedded mini slideshows but belong to the genres *Longform Infographic* or *Multimedia Visual Experience*.
Linearity can also appear in vertical high stories, where the appearance of visualizations or changes to the visualization itself is triggered by scrolling. In some cases, visualizations are overlaid with associated text that moves across the screen as the user scrolls. This technique of *Scrollytelling*, formulated by Seyser & Zeiller [38], is very common according to Stolper et al. and is often used. However, I also wanted to know where the differences lie in the technique of basic scrolling, i.e., that the elements are only moved up and down, and scrollytelling, i.e., changing the visualization. That's why I integrated both types of scrolling as **Basic Scrolling** and **Scrollytelling**.

To let the readers know where they are in the story, or to provide direct access to the appropriate places in the story, **Breadcrumbs** can be used. Here, single dots represent the individual slides or scenes and lead the reader to the corresponding slide. Structure and navigation can also be conveyed in the form of **Section Header Buttons**. For this, each scene is titled, and navigation through the story is enabled by using these titles at the beginning of the story. However, sometimes the author has a lot of sections that cannot all be represented by a *Breadcrumb* or a *Section Header Button*. In this case, a **Menu Selection** is often considered appropriate, allowing each section to be accessed individually and directly. The menu itself and the story can have a different order. Hence, this technique provides flexibility for authors to better tell their story while still staying in context for the reader [42]. Since navigation by *Menu Selection* is very underrepresented, I have also counted stories under this category when the menu selection updates the visualizations throughout the whole story, creating a "new section" rather than jumping to it.
Furthermore, Stolper et al. identified non-linear navigation techniques that do not have to follow a predefined order, such as a **Timeline** or a **Geographic Map**. For *Timelines*, each slide can be represented by glyphs, for example, either a flag (for points) or a bar (for duration), which highlight according to the position in the story or lead to the appearance of the corresponding position in the story when they are clicked. For **Geographic Maps** as navigation, the reader can click on specific locations on them, whereupon the story will adjust to that location [42]. Stolper et al.'s definition of *Breadcrumbs*, *Section Header Buttons*, *Timelines*, and *Geographic Maps* integrates examples that can be used interactively for navigation. However, it does not clearly state whether examples also fall into the category if they provide story context in a non-interactive way. According to my definition, I have assigned both cases to this category, so that the relation between them is not always interactive.

Providing Controlled Exploration

According to Stolper et al. [42], Narrative Visualizations have, unlike purely Exploratory Visualizations (E.V.), limited interaction possibilities. They have also found stories in their analysis that nevertheless integrate flexible and exploratory elements. However, they talked about risks that can arise when the visualization is changed too much, so that the data displayed is no longer consistent with the story. That's why they found that the exploratory portion in data-driven storytelling is often very limited or controlled.
For example, in some cases, the reader can change the components of a visualiza-

tion via **Dynamic Queries**. This can be done by filtering for certain information, or changing the color scheme, or certain attributes. Other ways to provide controlled exploration, Stolper et al. describe as **Embedded Exploratory Visualizations**, or **Separate Exploratory Visualizations**. Often, such E.V.s allow for a large amount of user interaction and therefore serve more as an add-on to the story. E.V.s (or a reference to it) are usually inserted at the beginning or at the end of a story.

4.3.3 Visual Encodings of Space-Time

Mayr & Windhager dedicate their work to the question of how the visual analysis and understanding of stories can be supported by different methods of spatio-temporal information visualization and thus, provide a visualization framework as guidance. In doing so, they focus primarily on techniques for representing individual motion data, which are also referred to, for example, as the "space-time path" or the "spatial history". For this, they are guided by five of the many techniques introduced by cartographers to represent motion, dynamics, and change, which are available in various visualization tools and geospatial analysis packages. As described in Section 2.2.1, the spatio-temporal data in the dataset of this work includes event data and point reference data in addition to trajectory data. Although Mayr & Windhager's design space refers to trajectory data, it is sufficient to cover all visual space-time encodings–except for those without map reference–in the stories. That is why I chose this design space for my taxonomy.
In the following, I would like to elaborate on the five corresponding techniques introduced in Section 3.2 (see Fig. 4.5). The relations encoded therein between the spatial and temporal data include techniques from Stolper et al.'s category [42] *Linking Separated Story Elements*, for example, using interaction, color, and animation. However, as mentioned before, I also found stories with a spatio-temporal context whose temporal information is represented in a map-independent manner, which is why in my case I added the category *Map-Independent Time Visualization* to Mayr & Windhager's design space [30].

Map-Independent Time Visualization

In some stories, the temporal data is coded independently of the map representation in diagrams, texts, or with the help of pictures or videos. In this case, either additional maps were used for the spatial reference or it was also presented completely without maps, in which case the spatial information was also depicted in the diagram, texts,

Figure 4.5: Adapted representation of visual encodings of spatial (blue) and temporal (orange) data based on the work by Mayr & Windhager [30]: the added category *Map-Independent Time Visualization* (A), *Multiple Coordinated Views* (B), *Animation or Slideshow* (C), *Layer Superimposition* (D), *Layer Juxtaposition* (E), *Space-Time-Cube* (F).

or pictures/videos. Since Mayr & Windhager do not consider this form, but only refer to the technique of *Multiple Coordinated Views*, I added this *Map-Independent Time Visualization* (see Fig. 4.5, A) encoding in the taxonomy. The role of the map in this case, if present, is more of a supportive nature.

Multiple Coordinated Views

With *Multiple Coordinated Views* (see Fig. 4.5, B), spatial and temporal data aspects are visualized in parallel by combining a standard map with a time chart. The spatial and temporal distribution of events in a story are represented separately and often coordinated via linked interaction methods, such as through linked brushing [30]. In my case, I have included in this category stories whose views are also linked by color or animation.

Animation or Slideshow

Animations or Slideshows (see Fig. 4.5, C) represent the change of information over time as a flowing animation or as a discrete sequence of steps in slideshows, mapping the narrative time orientation to the temporal dimension of the visual representation. If readers want to go back and forth, these representations can be interactive. However, slideshows can also be implemented as non-interactive. While animations are well suited for conveying changes, according to Mayr & Windhager, if there is too much information, a slideshow might be more appropriate to give readers more control over the temporal continuum of the information. However, comparisons with slideshows are also associated with high cognitive and interactive effort [30].

Layer Superimposition

With *Layer Superimposition* (see Fig. 4.5, D), multiple temporal positions–or temporal layers–are merged into an integrated representation while adjusting the transparency. Colors, time values, or vectorial references encode the temporal information and indicate a temporal sequence of positions in space. Thus, a spatio-temporally integrated internal representation of the story can be built up. According to Mayr & Windhager [30], a problem besides visual clutter and occlusion could be the visual conspicuousness of time in geographic space [30].

Layer Juxtaposition

Layer Juxtaposition (see Fig. 4.5, E) splits spatio-temporal data into multiple temporal layers, often arranging them in parallel along a spatial reading dimension. Examples include "small multiple" maps or the genre of "data comics". Unlike the slideshow, readers do not have to memorize the views because they are arranged side by side, and they can read and compare them sequentially to understand how the story unfolds over time [30].

Space-Time-Cube

In *Space-Time-Cubes* (see Fig. 4.5, F), maps and timelines are orthogonally combined in a cubic space. Here, the space-time paths are mapped as a three-dimensional trajectory using space-time coordinates. However, three-dimensional visualizations are fraught with problems of visual clutter, occlusion, and increased interaction costs. According to Mayr & Windhager [30], evaluations confirm the suitability of the *Space-Time-Cube* for the exploration of spatio-temporal patterns.

Mayr & Windhager [30] emphasize that each of these five techniques brings analytical advantages that come with certain costs. They declare that there is not one ideal view, but different techniques that complement each other and present narrative data in a spatio-temporal hybrid way, depending on the data and the intention.

4.4 Summary

The listed categories serve as a basis for the taxonomy of this thesis. As the field of Visual Storytelling is gaining momentum in information visualization research, I was able to build on studies of related work and apply it to the case of spatio-temporal visual stories. Only minor adjustments to the criteria and categories were made for the appropriateness of this work. In the following, I present an interactive web-based notebook to explore the taxonomy, which serves as the basis for the analysis of this work.

5

Implementation Approach

To analyse the collected visual data stories with spatio-temporal reference, I developed an interactive web-based notebook supporting the exploration of the taxonomy of this work. As such, it serves as the basis for the results section of this thesis, where I discuss the findings of the analysis. This chapter presents the dataset, the software, the visual encodings, and the operations of the interactive visualizations on the notebook.

5.1 Dataset

The analysis is based on my collection of web-based visual data stories with spatio-temporal reference from mainly online journals introduced in Section 4.1. Hence, I collected 130 different visual data stories, stored them in a table, and examined them. These stories form the entries in the dataset (I have attached a list of all 130 stories in appendix B). The categories I decided to use for the analysis (see Section 4.3), along with detailed information about the story (i.e., Title, Year, Journal, Theme, Authors, and Link), form the columns of the dataset. Thus, I was dealing with data of categorical and boolean character. The boolean values describe whether a certain technique is used in a story or not. The entry "1" is shown if the technique is used, otherwise the cell remains empty. In total, the dataset consists of 130 rows and 43 columns, of which 6 are story information columns.
While I was able to extract most of the information from the stories themselves, I added the *Theme* information to allow the analysis to provide further interesting insights and a better overview. Although many journals already have head categories, these are often different for similar themes from journal to journal, so I grouped them into corresponding broader themes. Four themes have emerged from the stories: *Life and Health* (such as COVID-19, Population and other Demographics, Business, Tech-

nology, Infrastructure, Travel), *Climate Change* (such as Temperature Changes, Natural Disasters, Drought, Emissions, Pollution, Biodiversity), *Election* (Votes, Shifts), and *Conflicts* (such as Attacks, Wars, Protests, Conflicts). I felt that this classification was the clearest in terms of the dominance of the topics. However, it did not make sense for me to separate the COVID-19 pandemic from other health topics, so I did not give it its own theme.

5.2 Software

For the exploration of the taxonomy of this work, I developed an interactive web-based notebook[1] in *Observable*[2]. *Observable* is a platform where data can be explored, analyzed, explained, and shared using notebooks. In a notebook, text in natural language can be combined with code-based cells. For clarity, the code-based cells can be hidden so that only their output is visible. This allows to create interactive visualizations together with descriptive texts. The texts and the linear arrangement can guide the readers through the information and give them the structure. These notebooks can be accessed and edited by anyone in a team, making it easier to discuss and collaborate. Furthermore, a variety of examples of techniques and general discussions about data science, visualization, and programming is provided in *Observable*. The programming of the visualizations is based on the Javascript library *D3.js–Data-Driven Documents*[3].

5.3 Visual Approach

This work contributes a taxonomy that aims to convey the current status of the genres, Visual Storytelling techniques, and visual space-time encodings used for spatio-temporal visual data stories. I aim to use the interactive taxonomy and other additional visualizations in the notebook to explore frequencies, trends, as well as possible similarities among stories, based on representative examples from online journalism. This may offer inspiration and guidance for techniques which support storytelling with a spatio-temporal context.

[1] `https://observablehq.com/d/da23466a9c2aab34`
[2] `https://observablehq.com`
[3] `https://d3js.org/`

5.3.1 Interactive Exploration of the Taxonomy

After a short introduction about the goal of the analysis in the *Observable* notebook as well as the dataset, the taxonomy is revealed to the readers, which in its initial state shows all 130 stories with their techniques and properties. The stories are sorted by themes. Here, the bar charts above each column (see Fig. 5.1, B) provide initial information about the frequencies of occurrence of the techniques in the displayed dataset. This simplifies and speeds up the assessment for the readers, since they do not have to scroll through the entire taxonomy to get a rough overview of the distribution of entries. Using the bar charts was inspired by *Summary Charts* [4] that *Observable* offers in connection with the exploration of database tables.

In addition to the techniques, further detailed information about the story is also displayed (see Fig. 5.1, D), which may be relevant for filtering (Year, Source, Theme). If the reader hovers over a box, a tooltip containing additional information about the story itself is revealed (see Fig. 5.1, C1), which may not be crucial for the analysis per se (Authors, Title, Link). For the color scheme of the categories, I used the colors from Stolper et al. [42]. I have chosen the colors for the categories not coming from Stolper et al., i.e., the genres and visual encodings of space-time, such that they stand out as well as possible from the ones used by Stolper et al. [42]. Figure 5.1 shows the interactive visualization of the taxonomy with an adjusted number of stories.

Sorting

For the analysis, it is useful to sort the stories in the taxonomy according to a certain category or property. For this purpose, a simple selection menu was integrated above the taxonomy (see Fig. 5.2, at the top). The sorting is always aligned to one selection only.

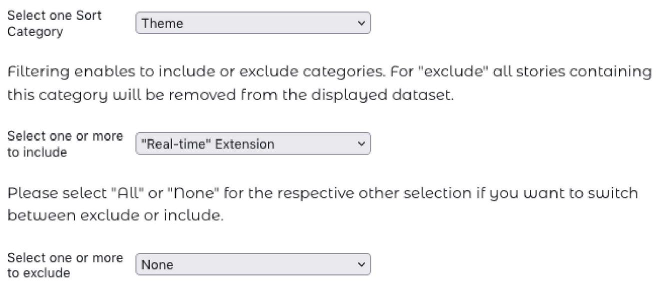

Figure 5.2: Selection menus for exploring the taxonomy. They allow for sorting by a certain category (here *Theme*), or for inclusive (here *"Real-Time" Extension*) or exclusive filtering of several categories.

[4] `https://observablehq.com/@observablehq/sql-cell#summaryCharts`

Figure 5.1: Interactive visualization supporting the exploration of the taxonomy. It consists of 37 categories (A), additional properties of the story *Theme, Year* and *Source* (D), a bar chart (B) that shows the frequencies of Visual Storytelling techniques in the whole dataset, and boxes (C) that indicate which techniques a story uses. Hovering over a box provides additional details about the title and authors; clicking opens the story's URL link. Due to space limitations, only 15 stories out of 130 are displayed.

Filter Option

I have offered the possibility to filter the dataset by certain categories of interest (see Fig. 5.2, at the bottom). This can be one or more categories. In the case of multiple categories, filtering is done according to a logical AND, where all selected conditions must be fulfilled so that certain techniques can be investigated. On the one hand, I allow *included filtering*, where only the stories containing the selected techniques are displayed in the taxonomy. On the other hand, I also give the option of *excluded filtering*, which can be used if, for example, it is clear that certain techniques are not relevant to the underlying question.

I have added further linked visualizations in addition to the taxonomy table in order to be able to specify the analysis. This information is provided when scrolling further down in the notebook.

5.3.2 Techniques Used per Theme

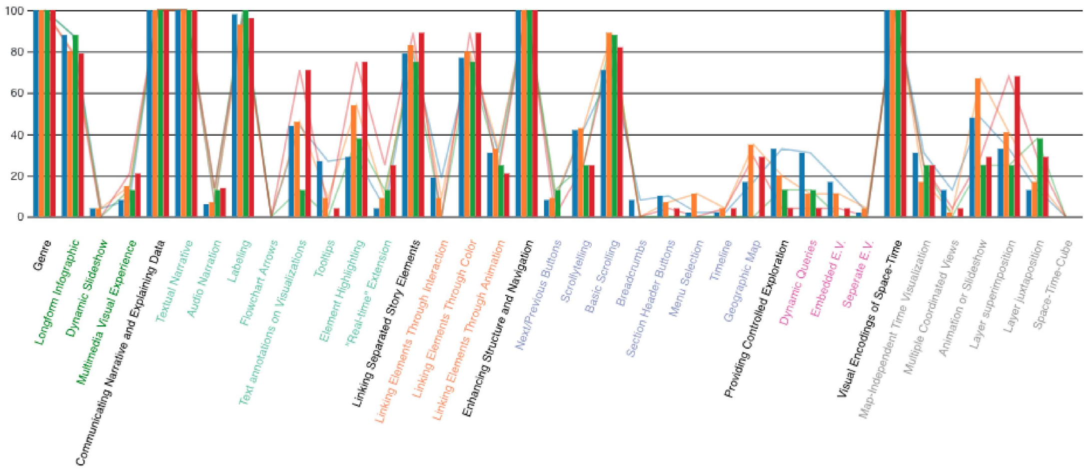

Figure 5.3: Grouped Bar Charts showing the proportion of the techniques in the stories according to their theme.

In this visualization, I wanted to use the themes I added to the story information: **Life and Health**, **Climate Change**, **Election**, and **Conflicts**. The bar chart is useful in this case to examine the proportion of a certain technique of a certain theme. However, since I have a relatively large number of techniques, I decided to offer the user the option to filter only by specific themes to get a better overview. However, the option to compare the proportions in all themes as side-by-side bars per technique is still included. To better compare the heights of the themes' proportions, I added a line chart in the background. The viewed data can be selected via checkboxes. Moreover, I present the findings from the views below the visualization. Thus, information about the most and least used technique per theme is provided (for a detailed discussion of the findings, see section 6).

5.3.3 Evolution of Technique Use

Visualizing the evolution of the use of certain techniques over time can provide insights into their usefulness and appropriateness. To show the evolution of the proportions over time for the large number of techniques, I used small multiple line charts. It should be noted that I only have a time span of four years, which is a relatively small sample size for a trend analysis. Nevertheless, I felt that this visualization allows for an impression of the changes over time. For a better understanding of the visualization, a short introductory text summarizes the number of each of the techniques used either more, the same, or less compared between 2018 and 2022. These statements are supported by small color-coded bars at the end of the trendline indicating a decrease ↗, unchange →, or increase ↘ by their slope. The intensity of the change is encoded by the saturation of their color. Furthermore, hovering displays information about the exact values for each year.

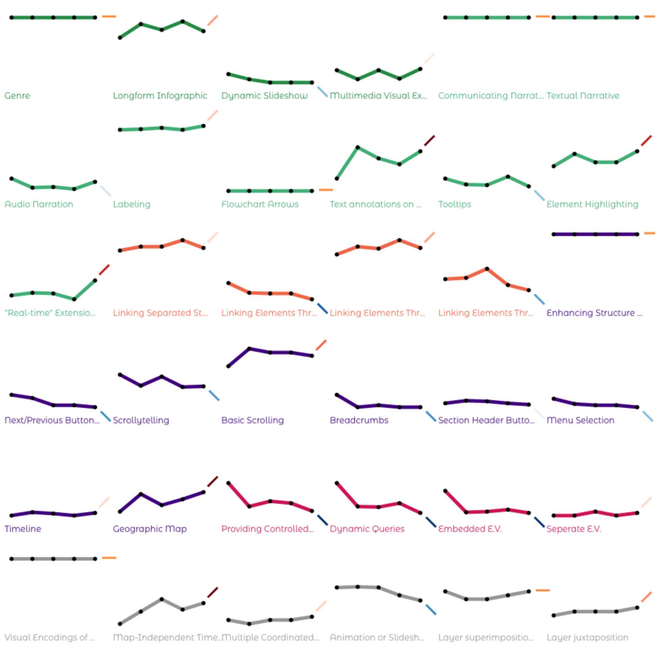

Figure 5.4: Small Multiple Line Charts showing the changes of the use of the genres, Visual Storytelling techniques and visual space-time encodings over the past four years from 2018 to 2022.

5.3.4 Similarities among Stories

For the analysis, it might also be interesting to provide visualizations that highlight stories that are similar or dissimilar in terms of their combination of techniques. This further aims to help gain insight into whether stories with the same combinations of

techniques also share the same properties, i.e., *Theme*, *Year*, and *Source*.
According to Hout [20], Multidimensional Scaling (MDS) is a tool to quantify the assessment of similarities, referring to statistical techniques (such as a distance metric) used for exploratory data analysis and dimension reduction. As a result, MDS provides a spatial representation of the relationships between the elements in terms of distance coordinates. For the calculation and visualization of the MDS, I followed the approach of Ben Frederickson [5], which is based on the classical version of MDS. According to this approach, a minimization of the squared error between the Euclidean distances of the coordinates themselves and the entries in the distance matrix for the choice of coordinates is intended. As a basis for the MDS calculation, similarity estimates between each pair of the elements are required. In my case, these estimates are obtained from the number of matching techniques of the stories and are stored in a similarity matrix. Hence, the similarity matrix is calculated based on a similarity score. For two stories, s and s', the similarity score between them is calculated as $sim(s,s') = 1 - \frac{\sum_{i=1}^{n} \|s_i - s'_i\|}{n}$, where n is the number of different techniques in the taxonomy and the classification of a story is represented as $s \in \{0,1\}^n$, where $s_i = 0$ means that the story does not use technique i and $s_i = 1$ means that the story uses technique i. With this definition, the similarity score sim has a maximum value of 1 if two stories are classified in exactly the same way, and a minimum value of 0 if their classifications differ for every single technique.

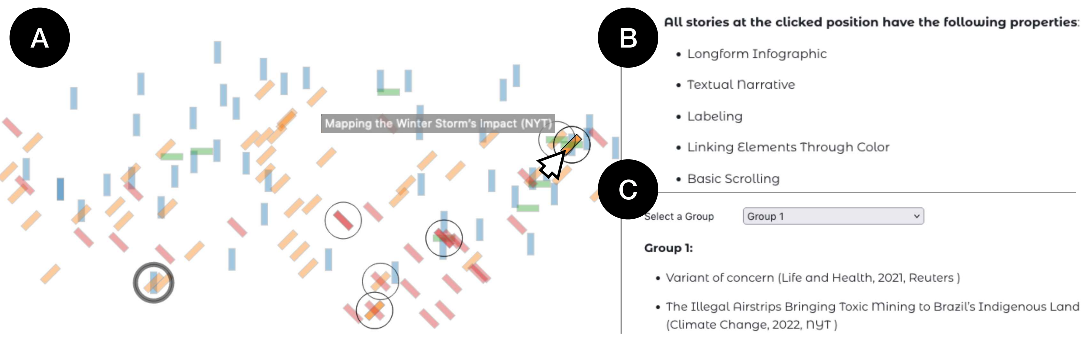

Figure 5.5: Representation of the MDS result. Each rectangle represents a story (A) color-coded with a certain theme, which can be filtered. To avoid occlusion, the opacity values were adjusted, which increase with the number of overlapping rectangles. Furthermore, the orientation angles of the rectangles are based on the grouping. When users hover over the rectangle, the title and source of the story appears. When they click, the techniques used by the stories are displayed below the visualizations (B). Stories with the same techniques are highlighted with a circle and form a group. A selected group (C) is marked with a thick stroke (A).

5 `https://www.benfrederickson.com/multidimensional-scaling/`

Figure 5.5 (A) shows the visualization of the MDS result for the dataset with 130 stories. Each rectangle represents a story. It allows to color the rectangles according to certain groups (Theme, Year, Source) and thus examine them in terms of their similarities in the techniques used. In Figure 5.5 (A), they are colored according to the themes (*Life and Health* |, *Climate Change* /, *Election* —, and *Conflicts* \). I will discuss the other two groups in Section 6.
Stories that are 100% the same in the combination of the techniques used have been marked with a circle, as they form a group of stories. In these cases, the rectangles overlap, so I have assigned different orientation angles to each group element (in this case, for the different themes) so that the information still remains visible. The groups can be further examined by selection (Fig. 5.5, C), with the selected group highlighted by a thick stroke of the circle (Fig. 5.5, A). For a detailed examination, the circles can also be zoomed in. The rectangles are proportionally closer to each other the more similar and further apart the more dissimilar they are. This representation allows a visual estimation of the relationships based on the simplification of complex datasets to primary dimensions for dissimilarity information of the elements [20]. Checkboxes above the visualization allow to show or hide certain group elements (of Theme, Year, or Source) and to remove possible overlaps. The techniques below the visualization update by clicking on a rectangle, indicating the techniques used by the stories (see Fig. 5.5, B). To get a more detailed overview of the clicked stories, the taxonomy can be updated by checking the *Apply* checkbox.

5.4 Summary

Although the creation of the interactive notebook for exploring the taxonomy in *Observable* is intended more as a helpful byproduct for the analysis, this chapter should serve to describe the notebook as basis for the analysis so that findings can be better illustrated and understood. To do this, I felt it was important to have interaction with the taxonomy for filtering and sorting by specific stories, as well as more detailed visualizations to more effectively examine for similarities, trends, and frequencies. In the next chapter, these interactive visualizations are used to facilitate the disclosure of findings from the data.

6 Results and Discussion

This chapter uses the foundations, the dataset of spatio-temporal data stories, and the interactive notebook described in this thesis to gain insights into specific questions regarding the frequencies and trends of the techniques and possible similarities among the stories. This chapter closes with a summary of the most notable findings and a discussion of the validity of the results.

6.1 Objectives of the Analysis

To give a direction for the analysis, I first formulated analysis questions based on a general overview, frequencies, trends, and similarities in the data. I have assigned each of these points of investigation to a developed visualization from Section 5.3 that supports me in gaining insights. In the following, I will list specific questions per visualization, which will form the basis of the analysis.

6.1.1 General Overview

The interactive taxonomy in the notebook serves to create an overview of the data. This can be done by free exploration, or by filtering and examining according to certain categories, if one has certain questions in mind. With the help of this visualization, I answer the following general questions:

Q1.1 Which genres, Visual Storytelling techniques and visual space-time encodings are more/less common?

Q1.2 Which techniques are (not) represented in a specific genre?

Q1.3 What are some striking manifestations within each genre and technique?

6.1.2 Frequencies of Techniques grouped per Theme

Stories that stand alone offer limited insights from the dataset for my analysis. Therefore, I use groupings to be able to make more general statements. In this case, I am interested in the frequency of the use of techniques according to certain themes in comparison. The grouped bars and line graphs provide insights for the following questions:

Q2.1 Which of the themes uses which technique the least/most?

Q2.2 Which techniques are never/always used by which theme?

Q2.3 Is there a technique that is used a lot overall but very little by one theme (or vice versa)?

Q2.4 In which theme occurs *"Real-Time" Extension* the most?

6.1.3 Showing Trends

I have implemented Small Multiple Line Charts to look at the evolution of the use of each technique side by side from 2018 to 2022. In the following, I list questions that give direction to this investigation:

Q3.1 How many of the techniques have increased/decreased over time?

Q3.2 In which years did the majority of techniques have their low point/peak in their use.

Q3.3 Which of the techniques have made the biggest change?

Q3.4 How was the trend for the *"Real-Time" Extension* technique?

6.1.4 Finding Similarities

To investigate similarities among stories, I reduced the stories to their similarity values and then mapped them into a two-dimensional space using MDS. This space offers me the possibility to answer the following similarity-related questions:

Q4.1 Are there stories that are unique/exactly the same in their combination of techniques used?

Q4.2 Can common properties (Theme, Year, Source) be found among stories that contain similar or the same techniques?

Q4.3 Are there stories with different properties that use the same techniques?

Q4.4 Which of the property groups has the most similar stories?

6.2 Taxonomy-based Analysis Results

In this section, I discuss the analysis questions introduced in Section 6.1. The sections are organized according to the visualizations used to answer the questions. The first section, *General Overview with the Taxonomy Visualization* is further divided into the individual categories (Genre, Communicating Narrative and Explaining Data, Linking Separated Story Elements, Enhancing Structure and Navigation, Providing Controlled Exploration, Visual Encodings of Space-Time) so that the overview questions can be answered according to the category.

6.2.1 General Overview

Each category has certain genres or techniques that are least or most common. In the following, I will examine these along with particularly prominent manifestations of the techniques (the references to the stories to which I refer in the following are deposited in a second library D at the end of this thesis).

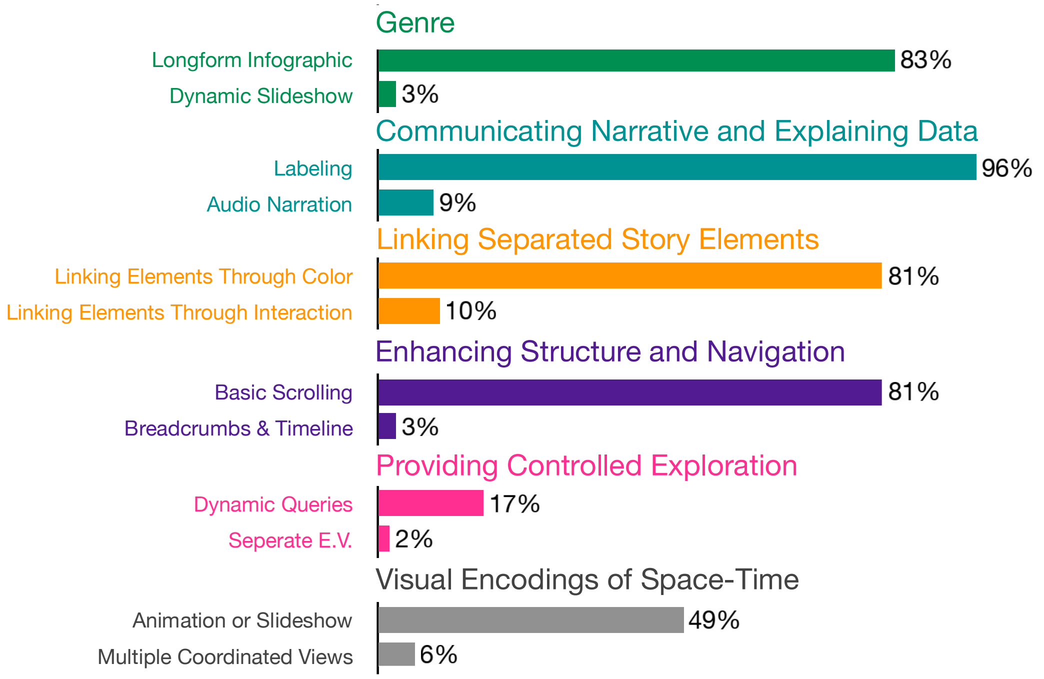

Figure 6.1: Overview of the most and least frequently used techniques and genres per category in the analyzed dataset. Here, the techniques that were never (0%) or always (100%) used were excluded and mentioned separately in the text.

Genre

Stolper et al. [42] observed in their analysis that scrolling has become a common practice for visualization stories and a distinct addition to the authors' interaction toolbox. They saw one reason for this development in the creation of compatibility of stories with cell phones and tablets. Furthermore, they cite the advantage of scrolling in giving the author greater control over how the story is consumed. The deputy graphics director of *The New York Times*, Archie Tse [44], even cites scrolling as one of the reasons they create fewer interactive stories at *The New York Times*. He talks about how interaction techniques like *sliders* or *steppers* were not used very often, even though they provided the opportunity for readers to get more information. Because, according to him, "Readers just want to scroll!" [44](p.6).
I can also confirm this development of the popular use of scrolling for visual data stories with spatio-temporal reference by looking at the distribution of the occurring **Genres** in the taxonomy. *Longform Infographic* is far ahead among the collected stories with a share of 83% (108/130), followed by the *Multimedia Visual Experience* genre with 14% (18/130), which is also based on scrolling as a navigation technique, and 3% (4/130) for the *Dynamic Slideshow* (**Q1.1**). Even in cases where *Longform Infographics*–as also mentioned by Stolper et al. [42]–integrate a *Dynamic Slideshow*, readers are in some cases guided through the slides with the help of scrolling, such as in "*Streetscapes*" [51] by *Zeit online*. Figure 6.1 shows an overview of the most and least frequently used techniques and genres in the analyzed dataset.

Notable examples of two *Dynamic Slideshows* are "*Human Terrain*" [54] by *The Pudding* and the "*Manhattan Population Explorer*" [57] (see Fig. 6.2). The stories take readers to different locations, showing population counts of different cities or the dynamic population of Manhattan at different time points by clicking the Next/Previous buttons. In doing so, the readers "fly through space" and the text is pushed one slide further. In "*Human Terrain*", readers can also navigate the story using *Section Header Buttons* (Fig. 6.2, bottom).

Figure 6.2: Two notable examples of a *Dynamic Slideshow* (Top: "*Manhattan Population Explorer*" [57], Bottom: "*Human Terrain*" [54]).

Figure 6.3: Example stories for the genre *Multimedia Visual Experience*, integrating personal stories (A) [70], TikTok videos (B) [76], or private chat histories (C) [50].

Multimedia Visual Experience often include personal stories of individuals or groups, such as personal experiences with the riots in Washington following the assassination of Reverend Martin Luther King Jr. in 1968, in the story "*The four Days in 1968 that reshaped D.C.*" [70] by *The Washington Post* (see Fig. 6.3, A). In some cases, private chat histories are used, as in "*Die Schlacht um Mariupol*" [50] by *Zeit online* (see Fig. 6.3, C), or TikTok videos, as in "*The TikTok buildup: Videos reveal Russian forces closing in on Ukraine*" [76] by *The Washington Post* (see Fig. 6.3, B), to recount events up close. This shows that social media is increasingly being combined with data stories.

The technique *Labeling* from the category *Communicating Narrative and Explaining Data* is used most often with 96% across the dataset (see Fig. 6.1). *Separate E.V.* from *Providing Controlled Exploration* is used least with 2% (**Q1.1**). This could be related to the fact that visualizations often occur in combination with headings or captions to increase their comprehension. Additionally, Latif et al. [26] suggest adding labels next to or on top of visualizations because informative labels reduce the mental effort required to process a data visualization. Less *Separate E.V.* confirm Stolper et al.'s [42] finding that components are embedded in the story rather than a part being linked externally (perhaps this is again an effect of the scrolling technique, which–as Tse [44] described–drives readers to less interaction). While *Labeling* is present in all three genres, I can observe that the three stories that integrate *Separate E.V.* are distributed among the genre *Longform Infographic* and *Multimedia Visual Experience* (**Q1.2**).

Communicating Narrative and Explaining Data

Linked to my criteria and definition of a visual data story, it might not be surprising that the *Textual Narrative* technique occurs in all stories in the dataset in some form (**Q1.1**). In connection with the *Scrollytelling* technique, the *Textual Narrative* mostly moves across the visualization when the readers scroll, as in "*How the Virus Won*" [83]

by *The New York Times*. In "*How coronavirus grounded the airline industry*" [56] by *The Washington Post*, a kind of this form in combination with the *Basic Scrolling* technique is used, where the text remains fixed in front of the visualization and an animation of the visualization runs in the background.
The storytelling technique *Flowchart Arrows* is not used once (**Q1.1**). I assume that *Flowchart Arrows* are more common in static infographics, which I have excluded from my analysis.

In the *Communicating Narrative and Explaining Data* category itself, the technique *Audio Narration* technique is the least represented with 9% (see Fig. 6.1). While embedded videos often include audio, there are also two stories in the category that use only audio to convey bird songs, as in "*Billions of Birds Migrate. Where Do They Go?*" [59] by *National Geographic*, or to convey the sounds of cannon thunder, as in "*Sieben Alltagsbegriffe, die aus dem Ersten Weltkrieg stammen*" [81] by *Berliner Morgenpost* (**Q1.3**). The most represented technique is also *Labeling* (**Q1.1**). Stolper et al. [42] said that half of their stories contained *Text annotations on Visualizations* and that this is a very common technique. I can also confirm this for my dataset of spatio-temporal visual data stories, where this technique occurs in 49% of the stories. One notable form is from the story "*How the Virus Won*" [83] by *The New York Times*, where the text annotation moves with the moving element on the map as the readers scroll further in the story (**Q1.3**).

One technique that has not been discussed much in research is that of *"Real-Time" Extension*. Roth [36] first formulated it in the form of the *Visual Story Compilation* genre, but did not explore its manifestations in more detail. I have noticed this technique especially in stories that occur over a period of time. Moreover, the updated and expanded description of the event seems to be of importance in assessing its development and significance in context. Thus, they often serve as a summary or provide an overview of the event. In the following, I will discuss the different ways in which this technique is implemented (see Fig. 6.4).
Some stories include a lot of text, images, videos, and occasionally data visualizations that link to other articles, as in "*Russian forces now control more than two-thirds of Sievierodonetsk - as it happened*" [64] by *The Guardian* (Fig. 6.4, A), or just summarize current events without specifically addressing other articles, such as "*Confirmed cases pass 1 million - as it happened*" [73] by *The Guardian* (Fig. 6.4, B). In other stories, only data visualizations and text are compiled. In some cases, these also link to other stories, such as "*Maps of Russia's invasion of Ukraine*" [78] by *The Washington Post* (Fig. 6.4, C). Another form I could observe is the *"Real-Time" Extension* of maps

Figure 6.4: Four different ways of integrating the *"Real-Time" Extension* technique: Few visualizations alongside many images, videos, and text with links to other articles (A) [64] or without linking (B) [73], exclusively visualizations such as maps with text and links to other articles (C) [78], or embedded map representations that extend in "real-time" (D1 [72] & D2 [48]). The orange boxes mark links to other articles or maps that extend.

within the story itself. Here, maps at the time the story was published are shown alongside maps that were added later. Examples include "*Russia's war in Ukraine: complete guide in maps, video and pictures*" [72] by *The Guardian* (Fig. 6.4, D1) and "*Ukraine-Karte aktuell*" [48] by *Zeit online* (Fig. 6.4, D2). For the latter, even the title updates to adapt to the effects of the events on the maps (**Q1.3**). Although the *"Real-Time" Extension* technique accounts for only 11% (14/130) of the dataset, it seems to be a popular technique for current issues such as the Russia-Ukraine war.
Also worth mentioning is a story that seems to sum up another story that contains the *"Real-Time" Extension* technique. For example, the story "*Russia's Shrinking War*" [58] by *The New York Times* presents Russia's invasion goals in Ukraine from March to May 2022, using maps from "*Maps: Tracking the Russian Invasion of Ukraine*" [77] by *The New York Times* (**Q1.3**).

Linking Separated Story Elements

Figure 6.5: Example stories of *Linking Elements Through Animation* (A [63], B [84]), where maps transform into other charts or vice versa. Figure C shows an example of *Linking Elements Through Interaction*, where a bar chart appears by hovering over an area [62].

As Stolper et al. [42] could observe in their dataset, elements are also linked very rarely by *Interaction* in my dataset for spatio-temporal data stories. In fact, *Linking Elements Through Color* is, with 81%, the most common form (see Fig. 6.1)(**Q1.1**). However, an interesting way to link two visualizations through interaction is that of "*Almost Everywhere, Fewer Children Are Dying*" [62] by *The New York Times* (see Fig. 6.5, C), where hovering over an area opens a Tooltip with a bar chart showing the child mortality rate for that area over time (**Q1.3**). Furthermore, there are stories that highlight the same elements at the same time in different visualizations, but not through interaction but through animation [80]. In total, there are 29% (38/130) of stories that integrate *Linking Elements Through Animation*. Particularly striking examples of this technique are "*Why Budapest, Warsaw, and Lithuania split themselves into two*" [63] by *The Pudding* (see Fig. 6.5, A) and "*How America Lost One Million People*" [84] (see Fig. 6.5, B) by *The New York Times* (**Q1.3**). Here, the *Scrollytelling* technique triggers visualizations to have their elements transformed into other elements through animation, such as the countries on a map becoming points or areas in a diagram. This seems to be a well-considered technique, as Heer & Robertson [19] showed in their work that animations are very effective for displaying transitions between data graphics.

There are 23 stories that have no form of linking at all, and ten of them are stories with *"Real-Time" Extension*. Furthermore, only four of the 14 stories with *"Real-Time" Extension* use some form of linking. This leads me to the assumption that stories with *"Real-Time" Extension* integrate fewer elements that need to be linked.

Enhancing Structure and Navigation

For the *Enhancing Structure and Navigation* category, I observed two techniques that are the least used, with the same percentage of 3%, i.e., only in four stories (see Fig. 6.1): *Breadcrumbs* and *Timeline*. The most common is *Basic Scrolling*, with 81% (**Q1.1**). As mentioned earlier, *Longform Infographics* are the most common in my dataset with 83%. The remaining 2% (83-81%) that are not based on *Basic Scrolling* are navigated using advanced *Scrollytelling*. In the definition in Section 4.3.2, I have not only counted slideshows for the technique *Next/Previous Buttons*, but also stories that integrate these buttons in other ways. This can be, for example, navigating through time on a map presentation (see Fig. 6.6, B), as with "*The Millions Who Left*" [47] from *Zeit online*. Or it can be navigating through the headings of the *"Real-Time" Extensions* of a story to get to the respective section (see Fig. 6.6, A), as in "*Aerial footage reveals extent of storm devastation in Bahamas – as it happened*" [68] by *The Guardian*.

Figure 6.6: Examples of *Next/Previous Buttons* (A: [68], B: [47]).

Stolper et al. [42] also noticed that the *scroll technique* occurred very often in their analyzed stories. This is the same case in my dataset. *Scrollytelling*, in the context of spatio-temporal stories, allows readers to "travel through space", flying from one place to the next by scrolling and tracing the event very vividly. The story "*How Kyiv Has Withstood Russia's Attacks*" [75] by *The New York Times* (see Fig. 6.7, A) is an example of this, with the immersion into the story enhanced even more by videos and images. Another form of vertical *Scrollytelling* allows horizontal movement through a line chart while the locations in the line chart are highlighted by animation on a map (**Q1.3**). This can be seen in the story "*The high price of heat*" [82] by *National Geographic* (see Fig. 6.7, B).

The techniques *Breadcrumbs* (3 non-interactive, 1 interactive) and *Geographic Map* (31 non-interactive, 1 interactive) are techniques that can be used both interactively for navigating and at the same time there are examples where they are considered non-interactive for providing story context (**Q1.3**). The *Geographic Map* is particularly striking, as maps are used more as a non-interactive overview of the area in which the story is currently taking place. Stolper et al. [42] had found only one example for an interactive example in this regard. The story "*Tracking U.S. Drought Severity*" [55] from *EcoWest* is one further example in which the location of the event is updated by clicking on a map. For *Timeline* (4 interactive) and *Section Header Buttons* (9 interactive), I found only interactive examples.

Figure 6.7: *Scrollytelling* stories that "fly through space" (A) [75] or trigger horizontal movement through a line chart (B) [82].

Another technique that is very little used is that of *Menu Selection*. Just six out of 130 stories integrate this technique. Worth mentioning is the story "*Your Climate, Changed*" [60] from *National Geographic*, where the location of the event is updated by a menu selection in the text for the entire story (**Q1.3**).

Providing Controlled Exploration

In the category *Providing Controlled Exploration*, 17% (22/130) of the stories contain *Dynamic Queries* (see Fig. 6.1). On the other hand, there are only three stories linking to *Separate E.V.* (**Q1.1**). It is worth mentioning that the *Separate E.V.* in these three stories is represented by a thumbnail image and a title, and is often the only or one of the few visualizations besides text, images, and sometimes videos. Thus, it also appears in some stories that have the property of *"Real-Time" Extension*, for example, to refer to current tracking maps and charts, as in "*Protesters Weigh Virus Risks on Crowded Streets*" [46] by *The New York Times*.

Visual Encodings of Space-Time

Visualizations of some of the stories are not based solely on maps, which is why the temporal and spatial components are mapped with the help of other *Map-Independent Time Visualization* methods. Latif et al. [26] named some visualization methods they identified for communicating spatio-temporal data. These include small multiples of line plots at specific locations and times, or a side-by-side map and line plot, which I could also observe. Furthermore, they mention a rather unusual form of an (overlapped) area plot for the presentation of a temporal overview. I could identify a similar visualization in the story "*Attacks by White Extremists Are Growing. So Are Their Connections.*" [53] by *The New York Times*. A timeline maps the number of people killed in deadly attacks. A difference to the one identified by Latif et al. [26] is that in the visualization I identified, the attacks are connected with lines that have influenced each other, which adds another dimension for relations. Another way, that was not explicitly mentioned by Latif et al. [26], is the use of radial time plots, as in "*Europe's COVID-19 divide*" [67] by *Reuters*.

Figure 6.8: Area plot as visual encoding of space-time [53].

Map-Independent Time Visualization is a 25% (32/130) used form in my dataset. The most commonly used form to encode time in combination with spatial information is *Animation or Slideshow*, with 49% (64/130), the least is *Multiple Coordinated Views*, with 6%, i.e., only in eight stories (**Q1.1**). I could observe that the *Animation* in the stories is sometimes triggered automatically and sometimes by scrolling. Scrolling also allowed, in some cases, the temporal information of events on a map to be communicated through the text flying over the visualization.

Figure 6.9: Example of *Layer Juxtaposition* [60] using a wiper to adjust the views at specific times.

A special form of *Layer Juxtaposition* is the one used in the story "*Your Climate, Changed*" [60] by *National Geographic* and in two other stories. The values at two specific time points on the same map can be changed back and forth by a kind of wiper (see Fig. 6.9). The visual space-time encoding *Space-Time-Cube* is not used a single time in the entire dataset, nor could I find any examples of it during my research (for further discussion see Sec. 6.4). According to Mayr and Windhager [30], evaluations confirm that *Space-Time-Cube* visualizations are particularly suitable for the exploration of spatio-temporal patterns. One reason it is never used could be its complex and not quite intuitive 3D structure, which often brings the problem of occlusion and might be unsuitable for the general audience (see Section 4.3.3). However, there are ten stories that integrate the spatial component in 3D, such as a sphere of the earth [49], a 3D animation of wildfires [69], or 3D animated landscapes and buildings on a map [75].

6.2.2 Frequencies of Techniques grouped per Theme

When looking at figure 6.10, I can see at first glance that the frequencies of the techniques are relatively similar for the themes. Techniques from the category *Communicating Narrative and Explaining Data* were used rather frequently, those from the category *Enhancing Structure and Navigation* rather less. The categories that were always used by each theme (see Fig. 6.10, circles-top) relate to four of the six main categories: *Genre*, *Communicating Narrative and Explaining Data*, *Enhancing Structure and Navigation*, and *Visual Encodings of Space-Time* (**Q.2.2**). In the case of the **Election** theme, the technique *Labeling* is added, which has always been used by these stories (see Fig. 6.10, green, circles-top). Techniques from the other two main categories, *Linking Separated Story Elements* and *Providing Controlled Exploration*, were not used by all stories. It is also noticeable that for the theme **Conflicts** a total of eight and for **Election** a total of thirteen techniques were not used at all (see Fig. 6.10, green & red, circles-bottom) (**Q.2.2**).

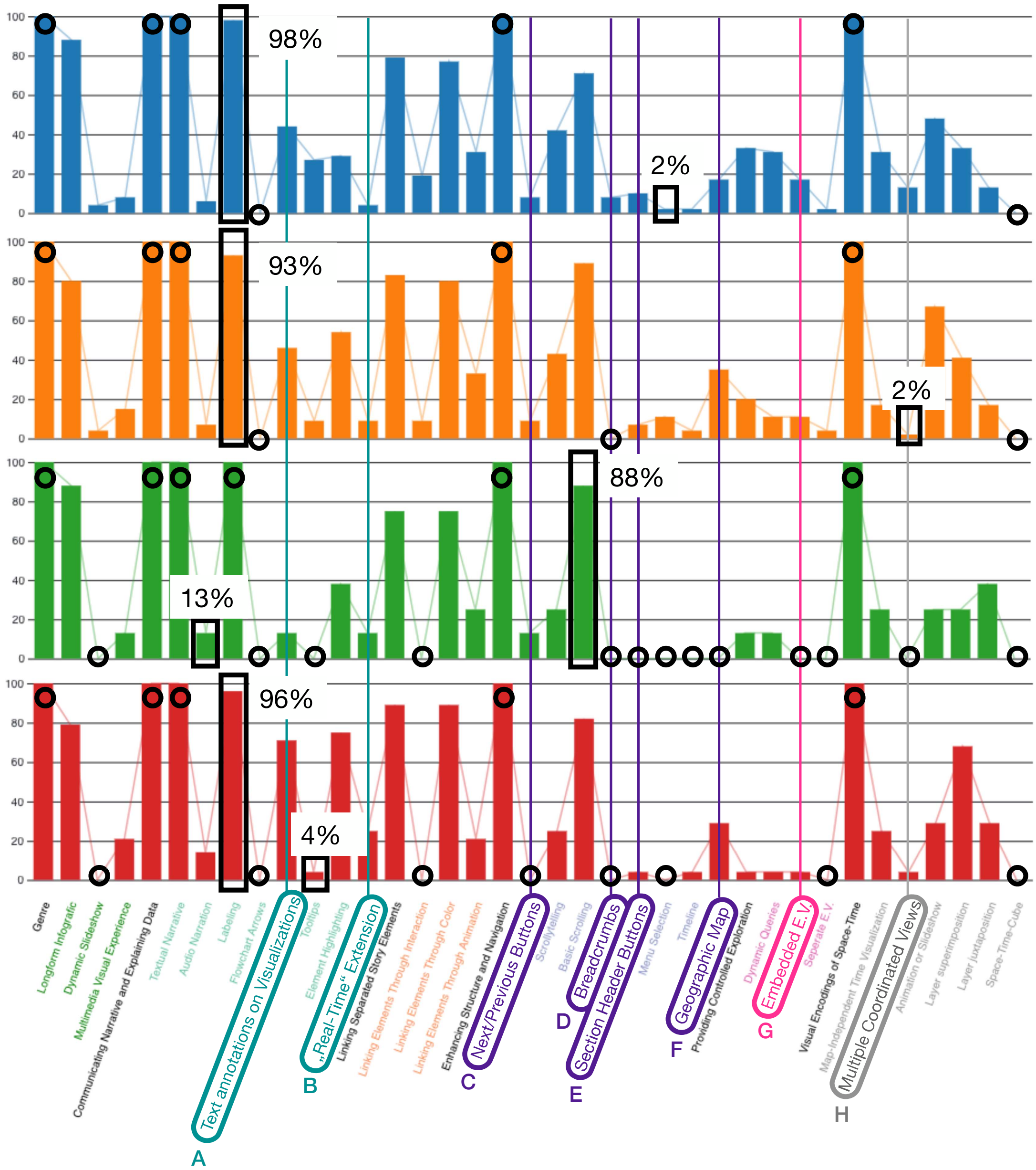

Figure 6.10: Overview of the frequencies of the techniques per theme: Life and Health (blue), Climate Change (orange), Election (green), Conflicts (red). Highlighted are the most/least used techniques (rectangles), the never/always used techniques (circles), and striking techniques (A-H).

Furthermore, it is noteworthy that there are techniques that are low for one theme and high for the other three, or vice versa (**Q.2.3**). For example, *Next/Previous Buttons* are not present at all in stories with the theme **Conflicts**, while *Text annotations on Visualizations* are particularly high in such stories (see Fig. 6.10, A & C). On the other hand, *Breadcrumbs* are only present in stories with the theme **Life and Health** (see Fig. 6.10, D), and only stories with the theme **Election** have never used *Section Header Buttons*, *Geographic Maps*, *Embedded E.V.* or *Multiple Coordinated Views* (see Fig. 6.10, E,F,G,H). One could speculate that, on the one hand, these correlations can be explained by the years of publication (e.g., stories with the *Conflicts* theme are mostly from the years 2021 to 2022 and the *Next/Previous Buttons* technique is decreasing in its use). On the other hand, it could also be related to the specific style of a dominant journal (e.g., stories from *The Economist* and *FiveThirtyEight* dominate in my dataset in the *Election* theme, which rather use very simple and non-interactive *Longform Infographics*) or other reasons.
Most stories that use the technique *"Real-Time" Extension* (see Fig. 6.10, B) are associated with the theme **Conflicts**, although they are also present in all other themes (**Q.2.4**).
In general, *Labeling* is the most used technique in the three themes **Life and Health** (98%), **Climate Change** (93%), and **Conflicts** (96%), see Fig. 6.10, the large rectangles. For **Election**, it is Basic Scrolling (88%). The least used techniques for the different themes are *Menu Selection* for the theme **Life and Health** with 2% (1/48), *Multiple Coordinated Views* for the theme **Climate Change** with 2% (1/46), *Audio Narration* for the theme **Election** with 13% (1/8), and *Tooltips* for the theme **Conflicts** with 4% (1/28), see Fig. 6.10, the small rectangles (**Q2.1**).

6.2.3 Showing Trends

There are 15 techniques that have decreased in their use over the period of four years, eight have not changed, and 14 techniques have increased in their use (**Q3.1**). In 2018, ten of these techniques reached their peak in the proportion of their use. Hence, this was a year where almost half of the techniques appeared in many stories, if I include the five techniques that were always used. Most of the techniques had their low point in their use in 2022 (**Q3.2**). That's when 12 techniques were used the least (plus those two that have never been used). This could confirm Tse's statement [44] that readers mainly want to scroll and there is less cause for interaction. For example, *Basic Scrolling* has increased by 16% (63 to 79%). I could further interpret Tse's statement to mean that the desire for readers to scroll can be extended to the more general de-

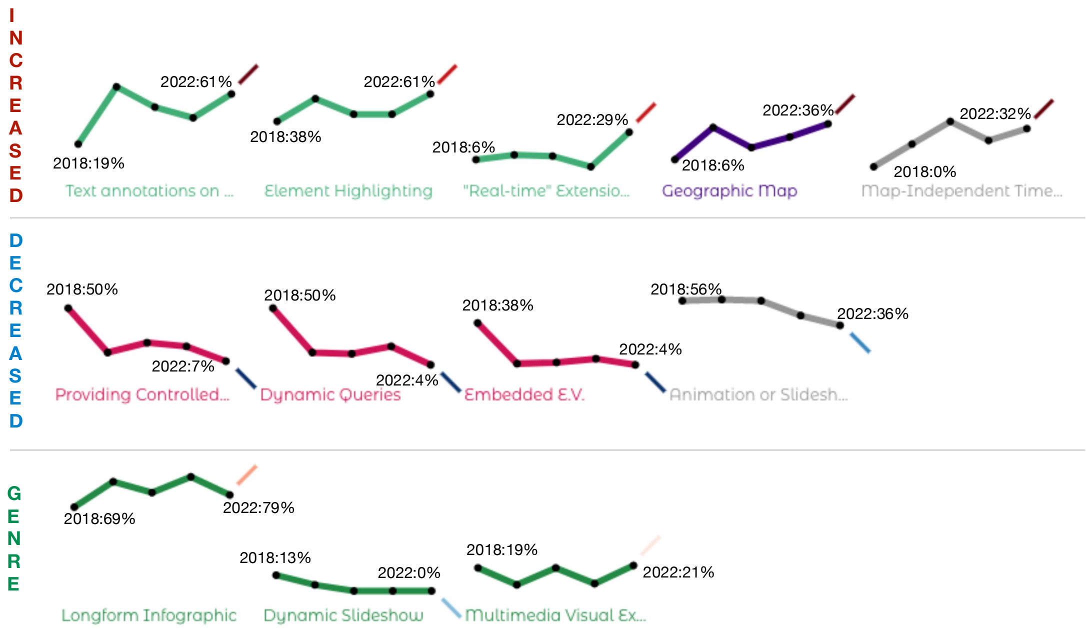

Figure 6.11: Trends of the techniques that have had the greatest change in an increase in their use (INCREASED, red), or in a decrease in their use (DECREASED, blue). Below, the trends of the genres are shown (GENRE, green).

sire to "have a reading experience that is as easy as possible." This would explain the 18% (50 to 32%) decrease in the *Scrollytelling* technique, as I would consider *Basic Scrolling* to be a simpler form. With *Scrollytelling*, the information can sometimes not be quite intuitively accessible and fly uncontrollably across the screen.

Particularly striking in the increase of their use in my dataset are the five techniques (**Q3.3**): *Text annotations on visualizations* (42%), *Element Highlighting* (23%), *"Real-time" Extension* (29%), *Geographic Map* (30%), and *Map-Independent Time Visualization* (32%). They all show an increase of at least 20% between 2018 and 2022 (see Fig. 6.11, INCREASED). The increase in the *"Real-time" Extension* technique could be related to the topicality of large-scale issues, such as global crises (**Q3.4**). The Russia-Ukraine war in 2022 is current and (unfortunately) ongoing, so adding "real-time" posts is an effective way to keep readers up-to-date on this topic.
On the other hand, there are techniques that show a drastic drop in their usage of at least 20% (**Q3.3**): *Providing Controlled Exploration* (43%), *Dynamic Queries* (46%), *Embedded E.V.* (34%), and *Animation or Slideshow* (20%), see Fig. 6.11, DECREASED. This might also show that the proportion of exploration in the stories is decreasing. In fact, there are nine stories in the dataset that use all of these techniques. Of these, five are from 2018 and none from 2022. It is also interesting to note that none of these

stories use the *"Real-time" Extension*, which might speak to its novelty.
As for genres, I can clearly see that *Longform Infographic* is always the most represented genre over the years (see Fig. 6.11, GENRE). *Multimedia Visual Experience* rises and falls from year to year until it finally rises again in 2022 and has increased by 2% compared to 2018. For *Dynamic Slideshow*, a steady decline can be seen until 2022.

6.2.4 Finding Similarities

In the dataset, there are 111 stories that are unique in their combination of techniques used (**Q4.1**). To be precise, that's 85% of all stories, which might show that Visual Storytelling in a spatio-temporal context also thrives on diversity. Each of these stories is different in a certain way, even if only in one technique. It also confirms the statement of Stolper et al. [42] that data-driven storytelling techniques do not exist in isolation, but rather occur in a rich combination with other techniques in the stories. The remaining 19 stories form seven story groups, each containing between two and five stories that are 100% the same in the combination of techniques used (**Q4.1**).
In the following, I use the term "matching stories" to refer to stories that have exactly the same combination of techniques used and that form a "matching story group". The expression "properties" refers to the information *Theme, Year* and *Source*. For matching story groups that contain only two stories (i.e., four out of seven groups), I could observe that three of these four groups do not share any properties. Thus, I can assume that there are stories with completely different properties that use exactly the same techniques, although it is not the majority (**Q4.3**).
On the other hand, I observed that matching story groups containing more than two stories (3/7) always contain stories that share a common property. If the common property was the same theme, then it was either **Climate Change** or **Conflicts**. If it was the same year, it was *2021*, and if it was the same source, it was *The New York Times*. So I could assume that matching stories with the exact same combination of techniques in the majority also share some properties (**Q4.2**).
However, if stories differ already in just a few techniques (I assume a similarity of between 80% and 99%), then the majority of these stories share no properties. For example, in this case, there are two times more stories that do not have the same *Theme* than those that do. For *Years* and *Sources* it is even three times more. However, there are a small number of stories that do not have exactly the same techniques but nevertheless share common properties. What is interesting here is that these common properties are related to the themes **Climate Change** (42%) and **Life and Health**

(36%), the year *2021* (34%), and the source *The New York Times* with 80% (**Q4.2**; **Q4.4**). Perhaps these extrema could be related to other, more specific topics, such as the COVID-19 pandemic, but this is only an assumption.
It is also worth mentioning that there are no stories that are 0% similar (i.e., they share no common techniques at all). There are only five groups that contain stories, which are similar by only 40%. These also mostly differ in their properties.

6.3 Most Notable Findings

In the following, I summarize the most notable findings from my analysis. I would like to emphasize that my findings are based only on my observations (for further discussion on the validity of my analysis, see Sec. 6.4).

For the findings, I would like to refer again to the deputy graphics director of *The New York Times*, Archie Tse [44]. He lists three rules for Visual Storytelling (2016 edition).

1. The first rule refers to the need for something spectacular to happen when readers click or do something other than scroll.
2. The second rule states that content that is important for readers to see should not be hidden. So one can assume that tooltips or rollovers will never be seen.
3. In the third rule, he points out that it is very expensive to make something interactive work on all platforms and that this should be taken into account.

I include the first two rules in my conclusions and examine the extent to which these rules can be applied to my underlying dataset. I cannot directly refer to the third rule, as I have not examined the stories on multiple platforms.

- **Linearity through scrolling and occasional interaction**. Linearity is most often created by scrolling in my dataset. Other techniques that *Enhance Structure and Navigation*, such as *Breadcrumbs, Timelines, Section Header Buttons*, or *Geographic Maps*, are rarely used, and when they are, they are partially non-interactive. Explorations inside and outside the story have become very rare. Thus, it seems that–as Tse [44] suggests for Visual Storytelling–interaction in stories with spatio-temporal reference is also decreasing. Nevertheless, he also points out that the team at *The New York Times* still incorporates interactives, but the bar is set very high. As Bach et al. [7] describe, interaction can, for example, help people identify with the content by creating a familiar setting. In doing so, they can filter according to their own region and follow the story from this perspective. This would also correspond to rule 1 of Tse [44], that something spectacular has to happen when readers do something other than scroll. Moreover, scroll-based stories, especially those belonging to the genre *Multimedia Visual Experience*, are increasingly supplemented by social media content.

- **Animation and color to connect important information**. *Scrollytelling* allows to link images, videos, visualizations, and text without needing much interaction. The *Linking of Separated Story Elements* by *Animation* or *Color* plays a special role in explaining the elements and their connections in a comprehensible way [42]. Instead of interactive *Tooltips*, animated *Text annotations on Visualizations* are used, which move and change with the scrolling. This is a way to consider rule 2 of Tse [44], which recommends that important content should not be hidden. For spatio-temporal stories, *Scrollytelling* provides an exciting way to "fly through 3D space" and track events over time in a very vivid way. Also, animations can be used to transform from maps to, e.g., line charts, and thus get an accurate referencing of elements. Also, Tse [44] suggests, if animation or movement is needed, to trigger it when the readers scroll.

- **"Real-time" Extensions are increasing, and so are their potential occasions**. Stories integrating the technique *Real-Time Extension* seem to increase. I observed that most stories with this technique were assigned to the themes *Climate Change* (4/14) and *Conflicts* (7/14). One could speculate that the increase might be related to an increasing number of crises that extend over a long period of time, such as wildfires as a result of climate change or pandemics and conflicts. In the wake of climate change, according to the IPCC's Climate Change 2014 Synthesis Report, [23] diseases and violent conflicts on a larger scale may become more frequent. Accordingly, it might be worthwhile to further explore the challenges and types of Visual Storytelling techniques for "real-time" extending stories. In my work, I have observed that these stories often serve to summarize or provide an overview by linking multiple articles or extending embedded visualizations such as maps.

- **Animation, Slideshow, or Layer Superimposition as Space-Time Encoding**. Time combined with spatial information is most often presented as *Animation or Slideshow*, followed by *Layer Superimposition*. According to Mayr & Windhager [30], these techniques do not take up much space on the screen. *Animations* can enhance the perception of even subtle changes or display dynamics, *Slideshows* especially when the visualization is more complex. *Layer Superimpositions* can promote the creation of a spatially and temporally integrated internal representation of the story. These forms of space-time encoding can also be very well combined with the *Scrollytelling* technique. However, the complexity of *Animations*, the difficulty of comparison in *Slideshows*, and the possibility of occlusion and visual salience of time in *Layer Superimpositions* are drawbacks that have to be considered. Harrower [18], for example, proposes some solutions to the four major challenges associated with watching and learning from animated graphics (disappearance, attention, confidence, and complexity).

- **Certain techniques for certain themes**. The frequencies of techniques used are relatively similar for all four themes (i.e., *Life and Health, Climate Change, Election, and Conflicts*). However, there are individual techniques that are used more or less often in some themes. For example, the *"Real-Time" Extension* technique occurred in all themes but most often in stories with the *Conflicts* theme. Also, *Breadcrumbs* are only present in stories with the theme *Life and Health*.

- **Explorations in stories tend to decrease**. Techniques for *Communicating Narratives and Explaining Data* have increased strongly over time. Techniques for *Providing Controlled Exploration* have decreased strongly. This might suggest that explorations in stories tend to decrease, but accurate labeling and highlighting of elements become all the more important. As the decreasing techniques tend to be more complex, it seems that the visual data stories with spatio-temporal reference are generally becoming "more easily consumable".

- **Stories with the same combinations of techniques mostly share some properties**. Stories with exactly the same techniques share in the majority some properties (*Theme, Year, Source*). In particular, the themes *Life and Health* and *Climate Change*, the year *2021* and the journal *The New York Times* have the most similar stories.

6.4 Discussion of Validity

For an empirical analysis, it is particularly important to create transparency for the analysis and data collection process in order to assess its validity. This also includes considering possible factors that may have an influence on the results of the analysis. In the following, I examine these factors in more detail.

- **The selection of stories**. According to Latif et al. [26], the selection of stories has a significant impact on the results. As Stolper et al. [42] already admit, no collection that does not include all examples can be comprehensive or representative of the entire field. However, in order to reflect a relatively representative space for the current state of Visual Storytelling techniques with spatio-temporal reference, my sources are based on a variety of different journals, most of which have been referenced by other related research that also addresses the topic of Visual Storytelling. Certainly, the choice of journals and time span also has an impact on the analysis results.
  Although most related work examines a rather small dataset (e.g., 45 [42], 22 [26]), I chose to examine 130 stories because my analysis also seeks to examine, to a large extent, quantitative issues such as frequencies. This sample size may still not be comprehensive enough, but it is sufficient enough to determine trends and frequencies of certain techniques.
- **The number of stories per category**. In collecting the stories, I didn't focus too strongly on finding an equal number of examples from each year, theme, and source. *The New York Times* is by far the most frequently referenced source (51/130), whose style may have influenced the results. I also collected slightly more stories in the more recent years than in the earlier ones (2018:16, 2019:21, 2020:32, 2021:32, 2022:28), despite trying to cover the different years equally with the help of the community or advanced searches. Normalizing the individual ranges allows me to maintain the validity of the statements for the most part. Nevertheless, there is a possibility that I covered more stories with different techniques in much-represented categories than in little-represented ones, thereby influencing the use of techniques within categories.
- **The number of analysts**. The selection of stories may also be determined by my personal, unconscious preferences. Also, the categorization of the techniques may have been done according to my subjective understanding, since I use categories from other work and may categorize those stories differently than they would. For a more objective examination, it probably requires the eyes of at least one other person to verify the categorization of the stories in the taxonomy. However, this also makes it a challenge because of the sample size of 130 examples.

- **The analysis method**. Since the analysis was based on a mainly manual method, the sample size could not be too large. If, on the other hand, advanced exploration methods were used, the sample size–also with regard to the time period–and the possibility to find further/different patterns might be increased. Besides the non-linear projection technique of MDS, one could also apply clustering methods or a regression analysis. This would allow to examine stories with similar characteristics, the distribution of the data and their relationships in more detail, or to identify outliers. A more comprehensive trend analysis (e.g., mean or variance) could be performed for a larger period of e.g., ten years containing days, months, and years.

- **The definition of "Real-Time" Extension stories**. Some stories that use the *Real-Time Extension* technique may be on the borderline between the definition of a visual data story and a traditional story since they contain only one visualization in addition to images and videos, which in some cases is a thumbnail to another article. I still included them in the category because the story refers to this visualization in one section. The increase in stories using the *"Real-Time" Extension* technique may also be influenced by the fact that the Russia-Ukraine war is very recent in 2022 and uses a relatively large number of these stories. Nevertheless, I could actually find very few of these types of stories in the earlier years. I found most of these stories at *The New York Times* (6/14) and *The Guardian* (4/14), which also give the style a certain direction. If the field should develop and more of these kinds of visual data stories emerge, these open questions might be explored more deeply.

- **Technical limitations and paywalls**. As Latif et al. [26] describe in their case, my collection of stories could also be limited by technical constraints such as browser performance, cross-platform compatibility, or choice of visualizations. In particular, visualizations with many data points had very slow and delayed rendering when loading and scrolling. Also, some journal paywalls may have had an impact on story selection (although these were paid for the main journals when necessary).

- **Space-Time-Cube modifications**. The *Space-Time-Cube* encoding was not used once in the collected stories. Bach et al. [6], however, discuss various operations of the *Space-Time-Cube* that represent possible variations that might expand the design space for visual space-time encodings. The two operations, *discrete time flattening* or *time juxtaposing*, have already been integrated by

Mayr & Windhager [30] as *Layer Superimposition* and *Layer Juxtaposition*. In addition, there are further operations, for example, concerning the drilling of a subset of a space-time object, the flattening, or also the scaling, coloring, or labeling of a space-time object. Possibly two stories [62, 81] could be assigned in a modified form to the *repeated drilling operation*, where temporal information was encoded in line or bar charts in a *Tooltip* above the areas on the map. However, to investigate how representative these other encodings are, a deeper analysis would be needed.

7 Conclusion

In the context of this work, I formulated a taxonomy aimed at determining the current state of Visual Storytelling techniques in visual data stories with a spatio-temporal reference. For the analysis, 130 visual data stories were examined in this context. With the help of a developed interactive web-based notebook, the results of the analysis could be evaluated and insights could be formulated. A concluding discussion on the validity of the results is intended to draw attention to possible influencing factors.

7.1 Summary

This work is a contribution to all storytellers to support the creation of compelling data-driven stories with spatio-temporal reference and the potential of visualization for storytelling. While related work focuses on genres [36], or very specific techniques [9, 26, 30], I wanted to take a comprehensive look at the current state, trends, similarities, and frequencies of storytelling techniques for stories with spatio-temporal reference. To do this, I collected 130 such author-driven, interactive visual data stories from popular online journals and other websites and examined and categorized them by *Genre*, *Visual Storytelling Technique*, and *Visual Space-Time Encoding*. For the categorization, I formulated a taxonomy based on related work by Roth [36], Stolper et al. [42], and Mayr & Windhager [30]. Using an interactive data-driven notebook I developed on the *Observable* platform, I analyzed the dataset of stories. Filters and sorting operations on the taxonomy, grouped bar charts, small multiple line charts, and MDS supported me in finding frequencies, trends, and similarities in the data.

This work integrates a list of the most notable findings, which may serve as an orientation for storytellers of spatio-temporal visual data stories or as a basis for future research. During the analysis, it was particularly noticeable that exploration parts seem to decrease, and communication and explanation parts seem to increase. Moreover, scrolling continues to play an increasingly important role as navigation, often using *Animation or Slideshow* as visual space-time encoding or *Animation* or *Color* as linking important story elements. Special properties of a story with a spatio-temporal reference, such as the theme, year of publication, or source, I could observe in the majority in connection with the techniques used, since stories with the same combinations of techniques often shared some properties. My analysis pays special attention to stories that integrate a relatively unexplored technique of *"Real-Time" Extension*, which seems to be relatively new. I observed that these stories often serve to summarize or provide an overview by linking multiple articles or extending embedded visualizations such as maps. Investigating the suitability and relevance of this technique for Visual Storytelling may be the subject of future research. To ensure the validity and transparency of the results, I discussed possible factors that might influence the results at the end.

7.2 Future Work

Some of the points mentioned in Section 6.4 and other aspects could be explored more deeply in future work. In the following, I will discuss possible starting points.

- **Investigate Visual Space-Time Encodings based on the Space-Time-Cube**. One possibility would be to investigate further *Visual Encodings of Space-Time* in web-based visual data stories based on the *Space-Time-Cube* operations described by Bach et al. [6].
- **Examine techniques of "Real-Time" Extension**. If the space of *"Real-Time" Extension* techniques expands and new ways of implementation are added, an investigation of only these techniques and their challenges, as well as the suitability for Visual Storytelling, might be of interest. Likewise, the occurrence of this technique could also be compared between stories with spatio-temporal reference and stories from other contexts to identify further patterns.
- **Implement appropriate advanced analysis methods**. As mentioned above, another analysis method can be applied to investigate a more comprehensive dataset and draw conclusions on a larger scale. For this purpose, it is advised to consider suitable advanced analysis methods and visualization methods.

- **Expand the taxonomy or apply it to other contexts**. In addition, certainly, the categories of the taxonomy could be extended or exchanged. For example, it could also be interesting to investigate the *Narrative design patterns for data-driven storytelling* according to Bach et al. [7] for visual data stories with spatio-temporal reference. Furthermore, the taxonomy could be extended to include techniques for opening or ending a story. Yang et al. [45], for example, propose a design space for creating data stories with Freytag's Pyramid, addressing techniques of *setting* and *resolution* of a story. Furthermore, the taxonomy could also be applied to other types of data or time periods.

A
Abbreviations

MDS Multidimensional Scaling 37

E.V. Exploratory Visualizations 25

B

List of 130 Stories

You can click on the title to open the hyperlink to the story.

1 **Manhattan Population Explorer**. Manpopex, 2018

2 **America is more diverse than ever — but still segregated**. The Washington Post, 2018

3 **Human Terrain**. The Pudding, 2018

4 **Streetscapes**. Zeit online, 2018

5 **Sieben Alltagsbegriffe, die aus dem Ersten Weltkrieg stammen**. Berliner Morgenpost, 2018

6 **Alt- oder Neubau? So wohnt Berlin**. Berliner Morgenpost, 2018

7 **The daily commute: travel times to cities around the world – mapped**. The Guardian, 2018

8 **Out of 54,868 homicides in 55 cities over the past decade, 50 percent did not result in an arrest.**. The Washington Post, 2018

9 **How Much Hotter Is Your Hometown Than When You Were Born?**. The New York Times, 2018

10 **See Flood Waters Rise Across the Carolinas After Hurricane Florence**. The New York Times, 2018

11 **Billions of Birds Migrate.Where Do They Go?**. National Geographic, 2018

12 **What Happens to the Plastic We Throw Out**. National Geographic, 2018

13 **Sizing Up the 2018 Blue Wave**. The New York Times, 2018

14 **Imperial borders still shape politics in Poland and Romania**. The Economist, 2018

15 **Why Is the Syrian Civil War Still Raging?**. The New York Times, 2018

16 **The four Days in 1968 that reshaped D.C.**. The Washington Post, 2018

17 **Almost Everywhere, Fewer Children Are Dying**. The New York Times, 2019

18 **The Millions Who Left**. Zeit online, 2019

19 **How the Internet Travels Across Oceans**. The New York Times, 2019

20 **From 8,600 Flights to Zero: Grounding the Boeing 737 Max 8**. The New York Times, 2019

21 **NASA's Opportunity Rover Dies on Mars**. The New York Times, 2019

22 **See How the World's Most Polluted Air Compares With Your City's**. The New York Times, 2019

23 **Those Hurricane Maps Don't Mean What You Think They Mean**. The New York Times, 2019

24 **Here's Where the Amazon Is Burning and Why It's Going to Get Worse**. Bloomberg, 2019

25 **What Satellite Imagery Tells Us About the Amazon Rain Forest Fires**. The New York Times, 2019

26 **How Two Big Earthquakes Triggered 16,000 More in Southern California**. The New York Times, 2019

27 **Mapping America's wicked weather and deadly disasters** . The Washington Post, 2019

28 **A Quarter of Humanity Faces Looming Water Crises**. The New York Times, 2019

29 **In a Notoriously Polluted Area of the Country, Massive New Chemical Plants Are Still Moving In**. ProPublica, 2019

30 **Live Maps: Tracking Hurricane Dorian's Path**. The New York Times, 2019

31 **Aerial footage reveals extent of storm devastation in Bahamas – as it happened**. The Guardian, 2019

32 **A Tale Of Two Suburbs** . FiveThirtyEight, 2019

33 **Joe Biden's Greatest Strength Is His Greatest Vulnerability** . FiveThirtyEight, 2019

34 **The Movement To Skip The Electoral College Is Picking Up Steam** . FiveThirtyEight, 2019

35 **Attacks by White Extremists Are Growing. So Are Their Connections.**. The New York Times, 2019

36 **ISIS Lost Its Last Territory in Syria. But the Attacks Continue.**. The New York Times, 2019

37 **Why Budapest, Warsaw, and Lithuania split themselves in two**. The Pudding, 2019

38 **Corona-Zahlen in Deutschland**. Zeit online, 2020

39 **How the Virus Won**. The New York Times, 2020

40 **There Has Been an Increase in Other Causes of Deaths, Not Just Coronavirus**. The New York Times, 2020

41 **How coronavirus spread across the globe - visualised**. The Guardian, 2020
42 **13,000 Missing Flights: The Global Consequences of the Coronavirus**. The New York Times, 2020
43 **How the Virus Got Out**. The New York Times, 2020
44 **The virus that shut down the world**. The Washington Post, 2020
45 **A deadly 'checkerboard': Covid-19's new surge across rural America**. The Washington Post, 2020
46 **America's cautious comeback**. Reuters, 2020
47 **See How the Coronavirus Death Toll Grew Across the U.S.**. The New York Times, 2020
48 **How coronavirus grounded the airline industry**. The Washington Post, 2020
49 **Tracking coronavirus vaccinations and outbreaks in the U.S.**. Reuters, 2020
50 **Confirmed cases pass 1 million – as it happened**. The Guardian, 2020
51 **Protesters Weigh Virus Risks on Crowded Streets**. The New York Times, 2020
52 **New York City Reopening Splits Along Lines of Wealth and Race**. Bloomberg, 2020
53 **Record Wildfires on the West Coast Are Capping a Disastrous Decade**. The New York Times, 2020
54 **Isaias Reaches Canada as a Dwindling Storm**. The New York Times, 2020
55 **Every Place Under Threat**. The New York Times, 2020
56 **Air attack**. Reuters, 2020
57 **World's biggest iceberg heads for disaster**. Reuters, 2020
58 **This is what fuels the West's infernos**. The Washington Post, 2020
59 **New Maps Show How Climate Change is Making California's "Fire Weather" Worse**. ProPublica, 2020
60 **Shifting smoke**. Reuters, 2020
61 **Time Is Running Out to Save the Last of the World's Rainforest**. Bloomberg, 2020
62 **Safe passages**. The Washington Post, 2020
63 **Your Climate, Changed**. National Geographic, 2020
64 **Life and Death in Our Hot Future Will Be Shaped by Today's Income Inequality**. Bloomberg, 2020
65 **The political winds in the U.S. are swirling**. The Washington Post, 2020
66 **Election 2020**. Reuters, 2020
67 **Why Afghanistan Became an Invisible War**. The New York Times, 2020
68 **Flush With Cash, Biden Eclipses Trump in War for the Airwaves**. The New York Times, 2020
69 **See maps of nine key moments that defined WWII**. National Geographic, 2020
70 **Tracking the coronavirus across Europe**. The Economist, 2021
71 **Variant of concern**. Reuters, 2021
72 **Where the Racial Makeup of the U.S. Shifted in the Last Decade**. The New York Times, 2021
73 **Inside the Diverse and Growing Asian Population in the U.S.**. The New York Times, 2021
74 **'Cultural genocide': the shameful history of Canada's residential schools – mapped**. The Guardian, 2021
75 **How the racial makeup of where you live has changed since 1990**. The Washington Post, 2021
76 **Where America's developed areas are growing: 'Way off into the horizon'** . The Washington Post, 2021
77 **DeJoy's USPS slowdown plan will delay the mail. What's it mean for your Zip code?**. The Washington Post, 2021
78 **Why American Women Everywhere Are Delaying Motherhood**. The New York Times, 2021
79 **Europe's COVID-19 divide**. Reuters, 2021
80 **Sorrow and stamina, defiance and despair. It's been a year.**. The Washington Post, 2021
81 **Stimulus payments will cover seven months of rent for some, less than one for others**. The Washington Post, 2021
82 **Mass cremations, day and night**. Reuters, 2021
83 **Charging Ahead**. National Geographic, 2021
84 **How Severe Is the Western Drought? See For Yourself.**. The New York Times, 2021
85 **A world ablaze: These maps show the devastating paths of wildfires**. National Geographic, 2021
86 **How Haiti Was Devastated by Two Natural Disasters in Three Days**. The New York Times, 2021
87 **How Much Are Countries Pledging to Reduce Emissions?**. The New York Times, 2021
88 **The climate disaster is here**. The Guardian, 2021
89 **See How the Dixie Fire Created Its Own Weather**. The New York Times, 2021
90 **Cold, heat, fires, hurricanes and tornadoes: The year in weather disasters**. The Washington Post, 2021

91 **Visualised: glaciers then and now**. The Guardian, 2021

92 **In the Atlantic Ocean, Subtle Shifts Hint at Dramatic Dangers**. The New York Times, 2021

93 **Mapping the Winter Storm's Impact**. The New York Times, 2021

94 **Wo Atomkraftwerke abgeschaltet werden – und wo neue ans Netz gehen**. Berliner Morgenpost, 2021

95 **The high price of heat**. National Geographic, 2021

96 **How Maps Reshape American Politics** . The New York Times, 2021

97 **They Stormed the Capitol. Their Apps Tracked Them.**. The New York Times, 2021

98 **20 Years of Defense, Erased by the Taliban in a Few Months**. The New York Times, 2021

99 **The Toll of Eight Days of Conflict in Gaza and Israel**. The New York Times, 2021

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101 **Russian military movements near Ukraine: What satellite images show**. The Washington Post, 2021

102 **Why the Global Oil Market Hinges on Five U.S. Counties**. Bloomberg, 2022

103 **Visualizing the omicron wave striking and rolling across the country**. The Washington Post, 2022

104 **Mapping the Coolest Spots Inside the World's Sweltering Cities**. Bloomberg, 2022

105 **One London Borough Is Continuing to Boom as Housing Market Slows**. Bloomberg, 2022

106 **A visual guide of NASA's plan to get back to the moon**. National Geographic, 2022

107 **How America Lost One Million People**. The New York Times, 2022

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109 **'It's Super Spectacular.' See How the Tonga Volcano Unleashed a Once-in-a-Century Shockwave.**. The New York Times, 2022

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