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A Characterization of Interactive Visual Data Stories With a Spatio-Temporal Context

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Abstract

Large-scale issues with a spatial and temporal context such as the COVID-19 pandemic, the war against Ukraine, and climate change 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. However, interactive visual data stories with a spatio-temporal context have not been extensively studied yet. Particularly quantitative information about the used layout and media, the visual storytelling techniques, and the visual encoding of space-time is relevant to get a deeper understanding of how such stories are commonly built to convey complex information in a comprehensible way. Covering these three aspects, we propose a design space derived by merging and adjusting existing approaches, which we used to categorize 130 collected web-based visual data stories with a spatio-temporal context from between 2018 and 2022. An analyzis of the collected data reveals the power of large-scale issues to shape the landscape of storytelling techniques and a trend towards a simplified consumability of stories. Taken together, our findings can serve story authors as inspiration regarding which storytelling techniques to include in their own spatio-temporal data stories.

Keywords: geographic visualization, information visualization, visualization

CCS Concepts: • Human-centered computing → Information visualization; Geographic visualization; Empirical studies in visualization

1. Introduction

The COVID-19 pandemic has brought interactive data visualizations front and center. These proved to be an effective way to display the spread of the virus in near real-time [LR20]. 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 [AAA*20]. Russia's invasion of the Ukraine has also drawn the attention of many data teams [Eun22]. For instance, *The Washington Post* created 'Four maps that explain the Russia-Ukraine conflict' [KM22]. Moreover, reporting on climate change makes considerable use of visualizations to convey the urgency of its messages, like in 'A Quarter of Humanity Faces Looming Water Crises' [SC19].

These examples 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 [RHDC18]. By providing interaction, such as navigating via scrolling, the reader may perceive the story according to their own preferences.

Existing work in visual storytelling is dealing with the exploration of these new forms of communication [BSB*18, SZ18, SH10]. However, little attention has been paid to data stories with a spatio-temporal context [Rot21, LCB21, MW18]. To better understand how such stories are built, we aim to contribute to their systematic characterization in the following way:

- We collected 130 web-based interactive visual data stories published between 2018 and 2022 with a spatio-temporal context.
- We derived a combined design space from three existing design spaces [SLHRS16, Rot21, MW18] and adapted it based on our collected data to characterize the 130 stories.
- We analyzed patterns and trends regarding the characteristics that the stories have shown, for example which techniques were frequently used and how similar the stories are to each other.

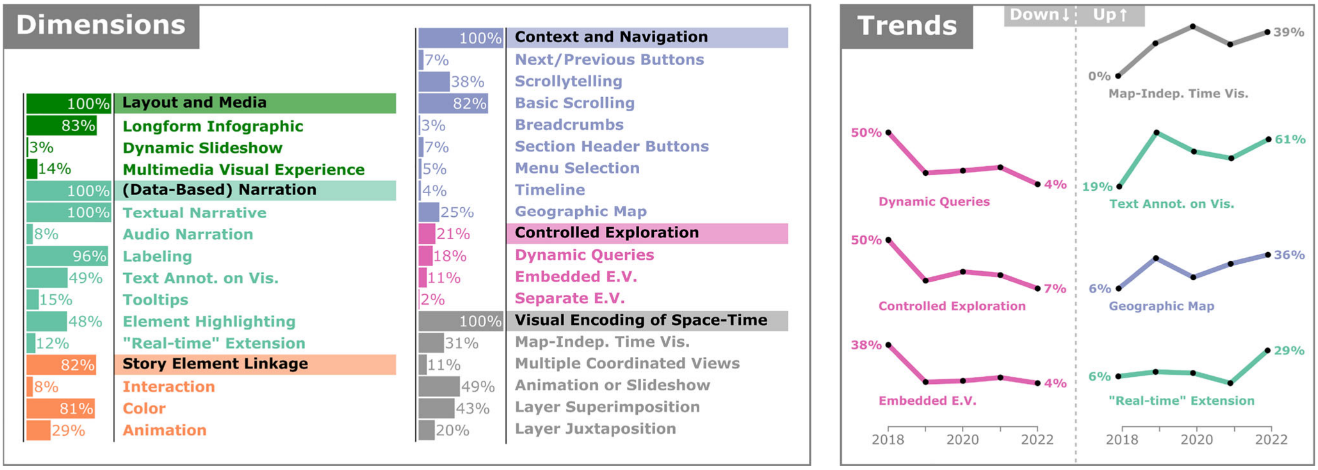

Figure 1: *On the left, we display the summarized distribution of 130 collected stories after classifying them with our design space, which we derived from existing approaches [Rot21, SLHRS16, MW18]. On the right, the strongest trends from the collected data set are displayed.*

The results of our analyzis can serve story authors as a source of inspiration for which techniques might work well for their story. We also summarized the results in an interactive story notebook [obsb]. Our collected data set is not exhaustive and, thus, cannot represent the entire corpus of spatio-temporal visual data stories. Yet, we think that the analyzis results provide valuable insights into the general trends in modern-day spatio-temporal storytelling.

2. Related Work

We present existing design spaces for visual storytelling, first from a general point of view and then with a focus on spatio-temporal data. Afterwards, we briefly discuss authoring tools for spatio-temporal data stories.

2.1. Design spaces for visual storytelling

With their design space for *narrative visualizations*, Segel and Heer created a milestone in the research field of *visual storytelling* [SH10]. Their approach was quite broad, proposing also genres with little to no interactivity like films, partitioned posters, or comic strips. We excluded such stories from the scope of our work as we required a certain degree of interactivity.

Lee et al. [LRIC15] expanded upon Segel and Heer's work [SH10] by abstracting the process of telling a visual story and discussing different roles people may have in the creation of a data story. In this context, our work benefits mostly the *scripter* and the *editor* who plot the story and prepare its visual presentation.

While Segel and Heer [SH10] already identified techniques to convey the narrative of a story, their focus was on analyzing broader structures. However, investigating the usage of concrete techniques can give authors a more practical idea of how to craft stories. Therefore, Stolper et al. [SLHRS16] distilled a list of 20 *storytelling techniques* from 45 visual data stories. Only few of the techniques directly consider a spatio-temporal context. Yet, after adjustments, we used them as a foundation for our design space as many of these basic techniques are also useful for crafting spatio-temporal stories. In addition, our work differs from Stolper et al.'s as we performed our analyzis in a more quantitative way and considered how the technique usages differ for certain subsets of our collected stories.

The state of visual storytelling up until 2018 was summarized in a survey by Tong et al. [TRB*18]. After that, Bach et al. presented a set of 18 *narrative design patterns* [BSB*18]. They can be used to shape a story based on the author's intents and the audience to be addressed, however, usually on a higher level than Stolper et al.'s [SLHRS16] concrete storytelling techniques. For creating stories, these patterns are intended as a starting point to assist the creative process. In contrast, Chen et al. proposed an approach to systematically synthesize stories directly from visual analytics systems [CLA*20]. However, in many cases, a fully-fledged visual analytics system is not available for each story that an author would like to tell. In addition, certain aspects are not covered in the approach, for example how to provide an arc to structure the story that engages the readers. For instance, the popular Freytag's Pyramid arc begins with some initial exposition, then rising the tension up to a climax and delivering a resolution afterwards. Yang et al. proposed a design space for creating data stories based on Freytag's Pyramid [YXL*21]. When relying on a story arc to structure a data story, it would be classified as *leading narrative* or *integrated narrative* according to the three trajectories that Edmond and Bednarz identified for narrative visualizations [EB21]. The third trajectory is *supporting narrative*, where traditional narratives are almost entirely replaced by pure data visualizations. The techniques we discuss in our design space focus on supporting the first two classes. However, they are independent of the underlying story arc.

Beyond story arcs, to engage readers, it can help to first make them reflect on what kind of patterns they believe to be underlying a certain issue before revealing the actual patterns to them. For this concept of *belief elicitation*, Mahajan et al. proposed a design space [MCK*22]. In the terminology of Bach et al., the concept is most closely related to the *make-a-guess* narrative pattern [BSB*18]. We did not incorporate the design space into our approach as only very few stories used such belief elicitation.

2.2. Visual storytelling with spatio-temporal data

None of the previously mentioned works refer specifically to stories with a spatio-temporal context. More recently, however, there have been corresponding approaches.

Accordingly, Mayr and Windhager [MW18] identified five techniques appropriate for visualizing spatio-temporal data in a storytelling context, factoring in their cognitive effectiveness. They focused on stories based on trajectory data, like the movement of historical figures through space and time, while the data used in our collected stories go beyond trajectory information. Still, we adopted the techniques for our design space as, with some modifications, it was a suitable classification scheme to represent all the different kinds of visual encoding used across our stories.

Moreover, we adapted the *visual narrative genres* from Roth's design space for map-based visual storytelling [Rot21]. However, not all of his proposed genres were relevant for our story collection. For instance, we excluded *static visual stories* and *narrated animations* as the corresponding stories involved too little interaction. Roth also proposed other dimensions, such as how traditional narrative elements can be adapted in a geographical context. While these other aspects are important for cartographic storytelling, they deal with more high-level structural aspects than the aspects we focused on in our work.

Based on Roth's design space, Song et al. [SRH*22] performed an empirical study to compare the influence of selected design decisions on the reader's retention, comprehension, and reaction. Moreover, Biriukov proposed a classification of maps in the context of interactive storytelling, along with recommended tools and libraries as development guidance [Bir21]. However, he considers maps on their own, independent of how they are embedded in a textual narrative, while texts were a key component of our collected stories. In contrast, Latif et al. examined the interplay of visualizations and textual narratives in geographic data-driven stories [LCB21]. In a qualitative manner, their analyzis focused on corresponding strategies that they observed in 22 visual data stories. In comparison, our work aims to reveal insights about the use of visual storytelling techniques in a larger set of space- and time-dependent stories. In addition, Nagel et al. demonstrated that breaking up complex animations into a sequence of staged transitions is beneficial when working with spatio-temporal data [NPD17].

The three approaches we selected as foundation for our work are well-established and, taken together, provide an extensive overview of concrete design decisions for creating stories of various styles. Yet, none of them was applied to analyze such an extensive and recent set of stories as in our collection. That is why we hope to find more generalized and current insights, along with carving out relations between the different design spaces.

2.3. Authoring tools

While authoring tools are not the focus of this work, we still expect that our findings can be of use to their future development. There already exist plenty of tools. This includes, for example enhancing diagrams with annotations [RBL*17], and automatically generating stories from spreadsheets [SXS*21] or from static infographics by adding animations [WGH*21]. It also covers the incorporation of natural language processing [WHS*23] or interpolation between key frames [SCC*23] to create stories. However, only few tools are tailored to spatio-temporal data. And those which are, either produce quite complex linked views [LJ12] or are restricted to specific visual encodings like the space-time cube [KK17] or to narrow application scenarios, like the creation of video tours or slideshows from satellite images [HDS*18]. Therefore, we think that our findings can support the development of a more diverse set of authoring tools for spatio-temporal stories by helping developers to identify which techniques might be relevant to be provided in such tools.

3. Data Collection Process

We present the sources from which we collected the stories and the criteria they had to fulfill to be included in our data set.

3.1. Story sources

Inspired by related approaches [BLB*16, HDR*13, MHRL*17, SLHRS16], we relied primarily on online journals: *The New York Times*, *The Guardian*, *The Washington Post*, *The Economist*, *FiveThirtyAight*, *Bloomberg*, *The Pudding*, *Reuters*, *ProPublica*, *Berliner Morgenpost*, and *Zeit online*. Most of them are commonly used sources for visual data journalism [SLHRS16]. In addition, we included the *National Geographic*, which Roth [Rot21] used as a representative source for spatio-temporal stories, along with the interactive *Manhattan Population Explorer* website [Fun18] and the *EcoWest* website [Econa] tracking environmental trends. As a time period, we selected the years from 2018 to 2022, thereby including a period before the COVID-19 pandemic and, hence, more diverse stories than the ones primarily related to the pandemic.

Among others, we considered the top-rated stories of these years listed by the community in popular blog lists of *FlowingData* and *VisualisingData* as 'Best Data Visualization Projects of…' [flo] or 'Best of the Visualisation Web…' [vis]. Moreover, to also look more specifically for stories with spatio-temporal data, we searched for 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, and via advanced Google searches. In addition, the links to related articles at the end of a story sometimes also led to other relevant stories.

3.2. Criteria for including a story

Each story had to contain at least one space- and one time-dependent visual component, for example a map with temporal information or a timeline visualization with spatial information in it. These components were allowed to appear in the same view or separated from each other. We did not require the presence of an actual map if spatial information was visually encoded in other ways, like via multiple area charts for different regions as in 'There Has Been an Increase in Other Causes of Deaths, Not Just Coronavirus' [Lu20].

Moreover, the stories had to be data-driven and were required to integrate at least one interactive component that goes beyond clicking the play button in a video, leading to the exclusion of data videos. In contrast, we considered the interactivity sufficient if a story could be navigated by scrolling up and down. This is arguable, but as scrolling allows readers to consume stories at their own speed and easily navigate back and forth, we considered it justified. Moreover, we wanted to investigate the assumption sparked by Tse that the use of more elaborate means of interactivity was declining since around 2016 because 'readers just want to scroll' [Tse16]. To allow for a corresponding analyzis, our data also had to contain stories that use scrolling as their only form of interaction.

This way, we collected 16 stories from 2018, 21 from 2019, 32 from 2020, 32 from 2021, 28 from 2022, and one continuously updating story without definite year information [Econa]. For the example stories we refer to in this work, we also added the citation identifier in Figure 2 next to the row in which the story is classified. For a combined overview of all story titles and their classifications, please refer to the supplementary material or our accompanying web-based story notebook [obsb].

4. A Design Space for Interactive Visual Data Stories With a Spatio-temporal Context

We created our design space by leveraging three related approaches [SLHRS16, Rot21, MW18] and adjusting them based on the stories we had collected. In this section, we describe the classification process and the final design space.

4.1. Story characterization process

For the coding process, we took inspiration from existing approaches [SH10, HDR*13]. After having created an initial design space consisting only of the dimensions of the previous approaches, three coders (all authors of this paper) participated in the classification of the stories. First, one coder classified the collected stories. Throughout the first round of classification, potential issues and ambiguities with the design space were resolved through discussions of the three coders until a mutual decision was found. This also led to the modification of the design space by redefining, adding, or removing dimensions. Once the classification by the first coder was done, the second coder went over all classifications, compared them to the original stories, and highlighted all classifications they did not agree with. Then, the third coder assisted to mediate discussions between the other coders, again, until a mutual decision was found. This resulted in the final design space and classifications. By relying on three coders, we aimed at reducing subjectivity but, of course, we cannot fully avoid it.

4.2. The design space

Below, we present the final dimensions of our design space, see also Figure 2. Throughout the classification, some border cases occurred. For full reproducibility, we wanted to draw a clear line in such cases. To do so, we referred to the original definitions as far as they seemed appropriate. However, they were sometimes not clear enough. In these cases, we drew the line as we considered it most reasonable. We include these cases in the descriptions below.

4.2.1. *Layout and media*

To classify the techniques used for structuring the overall story layout and media selection, we took inspiration from the visual narrative genres proposed by Roth [Rot21]. Since we focused on interactive and author-driven stories, only three of them were relevant in our case. In longform infographics, the main story flows linearly in a vertical reading direction, usually navigated via scrolling. Text, graphics, and multimedia usually only have a limited width optimized for mobile devices. Maps, timelines, or other graphics can either flow smoothly along the entire story or be fragmented across different sections of the narrative. Despite the vertical arrangement of the stories, individual visualizations may allow to explore developments over time by scrolling in a horizontal direction [TFCE21] or through animations [GY20]. **Dynamic slideshows** create linearity through a series of slides or discrete visual panels of uniform size and format. The information is usually moved across the screen in a horizontal direction rather than in a vertical direction like in longform infographics. To count as **multimedia visual experience**, a story had to contain at least one video or audio that is supportive for the transformation of the story's message. Such stories may include the perspectives of the people involved, along with a rich integration of images, maps, videos, or sounds, to create a deep sense of place. So, a single teaser video at the beginning of a story did not suffice, as it increases immersion only marginally. Deviating from Roth's original definition, we did not require the linearity of a story to be created through anchor tags or hyperlinks as this constraint restricted the definition quite heavily.

The next four categories are based on Stolper et al. [SLHRS16]. We incorporated 18 of the 20 techniques that they proposed in our design space and added two new techniques into the appropriate categories. We also renamed one category to refine its scope.

4.2.2. *(Data-based) narration*

We adapted this category from Stolper et al.'s category *Communicating Narrative and Explaining Data* [SLHRS16]. It contains techniques that facilitate the narration of the story, either based on data or by advancing the overall story without directly relying on data. In a **textual narrative**, the main points are conveyed through a text body. The text can either accompany a visualization on a slide or just have supporting visualizations embedded at intervals. **Audio narrations** allow elements of the story to be tied more closely. We also included audio sequences that make the story more immersive, such as the songs of certain bird species [Ili18]. With **labeling**, we refer to textual support above or below a visualization or as headings for a slide or section. In contrast, **text annotations on visualizations** are part of a visualization and direct the reader's attention, for example to where on a map an attack took place. **Tooltips** also provide additional details. However, the reader needs to hover over the visualization to reveal them. With **element highlighting**, attention is drawn to elements of a visualization, for example by coloring them or by adding new elements, like a frame around an important region on a map. However, we required the highlighting to be author-driven

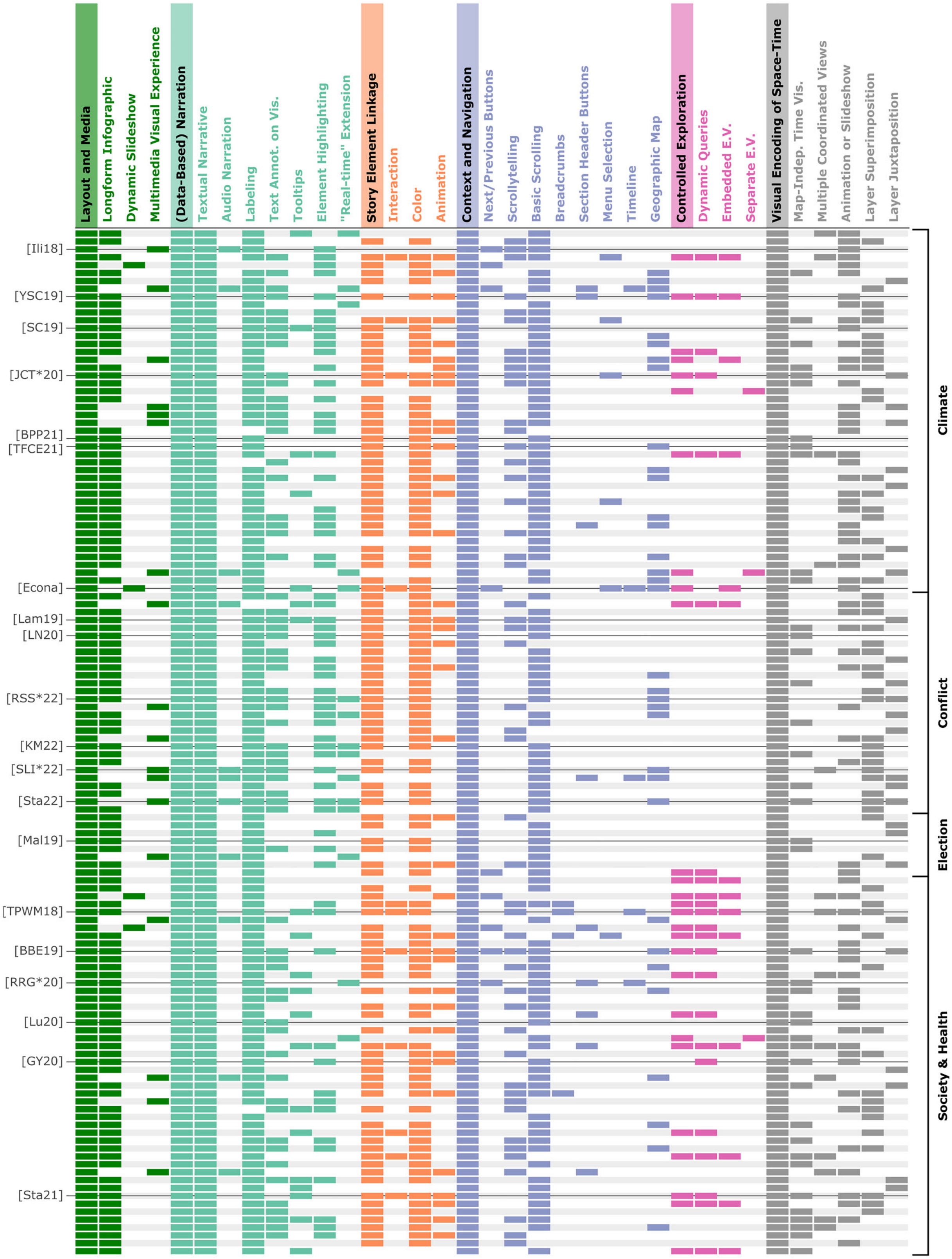

Figure 2: *Our design space and the story classifications with selected stories highlighted. Each row represents a story and the rows are grouped by theme. In each theme group, the stories are ordered according to their publication year, the earlier the further up.*

to support the narrative, so simply highlighting a territorial border when the reader hovers over it did not suffice.

We added the technique of **'real-time' extension** to cover a special case of how the narrative can be communicated over time: Some stories were repeatedly extended or updated, therefore, conveying their narrative in almost real-time. This can be done, for example by adding new sections to a story [Sta22] or updating maps [RSS*22] to extend the narrative as new events unfold. The technique was inspired by Roth's genre of *Visual Story Compilation* [Rot21], in which different events on a given topic are presented as a set of visual summaries that link to separate, more detailed pages. This set of summaries is updated in near real-time as new events unfold. However, we rather witnessed such extensions within full articles and not as links from a summary page to external pages, so we included it as an individual narrative technique.

Lastly, Stolper et al. also identified the technique *Flowchart Arrows* [SLHRS16] to connect parts of the story when the intended ordering may be unclear. However, as we never saw it used in our stories, we excluded it from the design space.

4.2.3. *Story element linkage*

In their category *Linking Separate Story Elements* , Stolper et al. identified three basic techniques to explicitly connect elements of a story, like text in various forms and visualizations [SLHRS16]. The first technique is through **interaction**. This can be done by synchronizing a point in time across multiple timelines when hovering [Sta21], or via dropdown menus that adjust the entire story based on a selected location [JCT*20]. Elements can also be linked through **color**, using a consistent color mapping between elements in multiple visualizations or between text and visualizations. For instance, text referring to certain regions can be colored like the corresponding regions on a map [Lam19]. In addition, **animation** can be used to maintain the connection between elements that are used in multiple consecutive views, smoothly transitioning between the views, for example by transforming region glyphs from a map view into circle glyphs in an abstract 2D view [Lam19]. Scrolling is a common cue to trigger such transitions.

4.2.4. *Context and Navigation*

We renamed Stolper et al.'s category *Enhancing Structure and Navigation* [SLHRS16] to *Context and Navigation*. In this context, *enhancing the structure* of a story usually meant informing the reader about *where in the story* the part is located that they are currently reading. However, we found that the techniques from this category were also used to inform the reader about *where in space and time* a certain part of the story took place. So, in the first case, *context* regarding the position inside the story was provided, and in the second case, *context* regarding the position in space and time. To capture both of these cases, we exchanged *structure* for *context*. In addition, we do not require a technique from this category that provides context to also be usable for interactive navigation.

The first technique, though, is interactive in its nature: With **next/previous buttons**, the reader can navigate between discrete parts of a story, sometimes embedded in a continuous longform infographic [BBE*19]. Next, we split up Stolper et al.'s technique of *scrollytelling* into two separate techniques: First, **basic scrolling** describes the linear navigation through a story through scrolling, where the different text blocks and visualizations of the story stay in the same relative position to each other. Second, **scrollytelling** describes the case when scrolling is also used to trigger changes to visualizations or to move texts and visualizations across the screen at different speeds relative to each other, for example sliding text over a visualization or at its side. Sometimes, also both techniques are used in the same story [Ili18]. **Breadcrumbs** are used to let the readers know where in the story they are and, if interactive, to provide direct access to different parts of it. Traditionally, they are represented as small dots, but they were also integrated more creatively, for example functioning at the same time as the temporal legend of a visualization [TPWM18]. Context and navigation can also be provided through **section header buttons**. For this, different sections of the story are titled and navigation is enabled by listing these titles at the beginning of the story. However, if too many options need to be listed, **menu selection** becomes more appropriate. We also included menu selections that update the entire story instead of just jumping to a specific section.

To represent at which time a certain part of a story took place, a **timeline** can be used, highlighting the corresponding time point or interval. Likewise to communicate the location at which a certain part of the story took place, a **geographic map** can be used. However, to be included in this definition, a map's main purpose had to be to provide context, and not to display additional data. Such maps were often small, displaying only territorial boundaries and the current location of the story [SLI*22]. The other option for a map to be included here was if it provided means for navigation. However, only one map allowed such navigational aid, transporting the reader to different parts of the story when clicking on the corresponding regions [Econa].

4.2.5. *Controlled exploration*

The last category, adopted one-to-one from Stolper et al. [SLHRS16], covers different ways in which readers are allowed to explore visualizations in a constrained way that maintains the linearity of the story. They include **dynamic queries**, for example for filtering or adjusting parameters of a visualization, like the displayed attributes, or by flying to selected locations on a map [YSC19]. In addition, **embedded exploratory visualizations (e. v.)** provide more than the usual interaction options in a less restrained way, like panning and zooming in a map [YSC19]. Such a visualization can also be extracted as a **separate exploratory visualization (e. v.)** on a separate web page.

4.2.6. *Visual encoding of space-time*

To characterize the encoding of space and time, we referred to Mayr and Windhager's visualization framework [MW18] after removing one of their proposed techniques and adding a new one. Example sketches for our set of techniques are displayed in Figure 3.

The first technique in this category, **map-independent time visualization**, was not part of Mayr and Windhager's framework. We

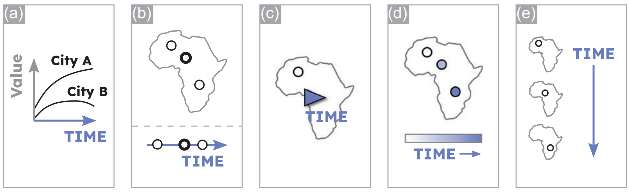

Figure 3: *Our techniques for encoding space-time encompass* (a) Map-Independent Time Visualization *with some additional value on the y-axis,* (b) Multiple Coordinated Views, (c) Animation or Slideshow *with a blue triangle representing a play button,* (d) Layer Superimposition*, and* (e) Layer Juxtaposition.

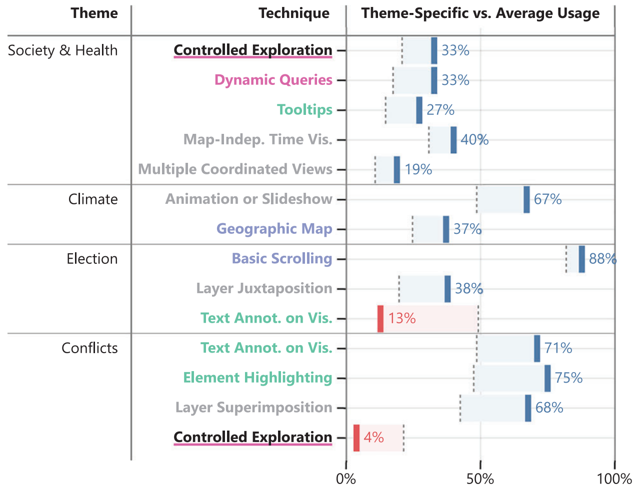

Figure 4: *For selected cases, we depict how strongly the usage of certain techniques deviated from the respective overall average (represented as dotted lines) for the different themes.*

added it as we found multiple stories in which time visualizations were not connected to a map but still included spatial information, for example in the form of a line chart where the lines are labelled with the names of corresponding cities. With **multiple coordinated views** we refer to multiple visualizations that are linked through interaction, consistent use of color, or animation. These visualizations usually separate the spatial and temporal information into different views. **Animations or slideshows** represent the change of information over time as a smooth animation or a discrete sequence of steps in a slideshow. These representations can also be interactive to allow the readers to navigate back and forth. As an individual view, this technique can be used with any type of story layout.

In **layer superimposition**, multiple time-dependent information layers referring to the same spatial region are merged into an integrated view. At that, readers need to be able to recognize the temporal sequence of the events. This can be achieved, for example by using a time-dependent color coding, or trajectory glyphs indicating movement. In contrast, a choropleth map aggregating the temporal information for a region into an average value would not suffice. With **layer juxtaposition**, the spatio-temporal data is split into temporal slices referring to the same region. The slices are arranged side-by-side, often in reading direction. Examples include *small multiples*.

Mayr and Windhager included the *space-time cube* as an additional encoding option [MW18]. Since we did not encounter it in any of the stories, probably due to too high complexity for a broad audience, we excluded it from the design space. Moreover, we did not include a column for the case when no map representation was used at all; but for completeness, we list the five corresponding stories here [BPP21, LN20, Mal19, RRG*20, Lu20].

Meta information

All of the mentioned techniques can be encoded as binary values: Either a story uses a certain technique or not. We also collected further information. First, the story **theme**, which is either *society & health*, *election*, *climate*, or *conflict*. We kept *society & health* as one theme as we encountered a lot of COVID-related stories where the transition between the impacts on health and on society was fluid. Moreover, we covered in which **year** a story was published and by which **source**, for example *The New York Times* or *The Guardian*.

5. Analyzis of the Collected Data Set

To analyze the data set, we pursued the following questions:

- **Q1**: General usage: Which techniques are used the most overall? Are there theme-specific differences?
- **Q2**: Similarity: How similar are the stories to each other? And how similar are the stories from different themes and sources?
- **Q3**: Trends: How did the usage of the different techniques evolve from 2018 to 2022?

To answer these questions, we relied on interactive visualizations that we implemented using the notebook-based platform *Observable* [obsa]. We summarized the findings in an interactive story notebook [obsb]. In this section, we present our findings regarding the analyzis questions and a summary of the key takeaway messages for story authors creating their own stories.

5.1. Q1: General usage

We provide an overview of the most-used techniques, grouped by the main categories. Afterwards, we report on noteworthy theme-based deviations from these patterns. The deviations are summarized in Figure 4 in the same order in which they are presented in the text.

Most-used techniques. Regarding **layout and media**, **longform infographics** are by far used most frequently (83%), probably as they have a straightforward layout for online and mobile-based journalism [Rot21, SZ18]. For **(data-based) narration**, most authors used **textual narrative** (100%) and **labeling** (96%), compared to **audio narration** with 8%. Possible reasons might be that textual elements are both easier to produce and more efficient to consume than audio narrations. The **story element linkage** was most often implemented using **color** (81%) and least often using **interaction** (8%), which can be cumbersome to implement, especially across multiple platforms. **Context and navigation** was most commonly provided through the familiar interaction of scrolling, with 82% of the stories using **basic scrolling** and 38% the more advanced **scrollytelling**, sometimes both mixed in the same story (23%). In contrast, techniques for **controlled exploration** were overall rarely used (21%) while, among them, **dynamic queries** were the most common choice (18%). The reason could again be the increased implementation effort, but also that exploration is more complex for readers than linear consumption. The technique usage for the **visual encoding of space-time** was quite evenly distributed, with more easy-to-consume **animations and slideshows** taking the lead (49%) and the more cognitively demanding **multiple coordinated views** coming in last (11%).

Theme-based deviations. When considering only stories with the theme *society & health* (48 of 130), we found that they provided **controlled exploration** more often than average (+13%), particularly **dynamic queries** (+16%). Stories from the corresponding theme often cover regions in which the readers of the stories actually live, compared to reports on, for example climate disasters or violent conflicts. Hence, it is more meaningful to allow personalization of the story to the reader's home region. The most obvious examples of this are COVID dashboards, which also often include **tooltips** for more detailed regional information (+12%). They also use **map-independent time visualizations** (+9%) to depict infection trends and **multiple coordinated views** (+8%).

Climate stories (46 of 130), on the other hand, focus strongly on **encoding space-time** as **animation or slideshow** (+18%). According to Harrower, 'animated maps are better suited to depicting geographic patterns (and changes in those patterns) rather than specific rates' [Har03]. And illustrating a change in patterns is often a goal in climate stories. In addition, in some stories, larger parts play in a specific region particularly affected by climate phenomena. In those cases, providing **context** via **geographic maps** can be beneficial, especially if the regions are not generally well known. This was also done more frequently (+12%).

Election stories (8 out of 130) focused almost exclusively on **basic scrolling** (+5%) for providing **navigation and context**. Regarding the **encoding of space-time**, they used primarily **layer juxtaposition** (+18%). This can be convenient to compare election results from different years. A technique that was used a lot less is **text annotations on visualizations** (-37%). Usually, the information that is conveyed in such stories is not as distinguished and location-specific as, for example movements of troops. Thus, detailed annotations are not often required.

Conflict stories (28 out of 130), on the other hand, used a lot of **text annotations on visualizations** (+22%) along with **element highlighting** (+27%). This way, information like territory gains and losses, or troop movements can be conveyed more clearly. To visualize such rather spatially limited data, authors most often used **layer superimposition** (+25%), which allows to merge all information into a single view. In contrast, barely any **controlled exploration** was provided (-17%). In stories about conflicts, often very specific messages should be conveyed. In this context, allowing users to explore the data would be detrimental.

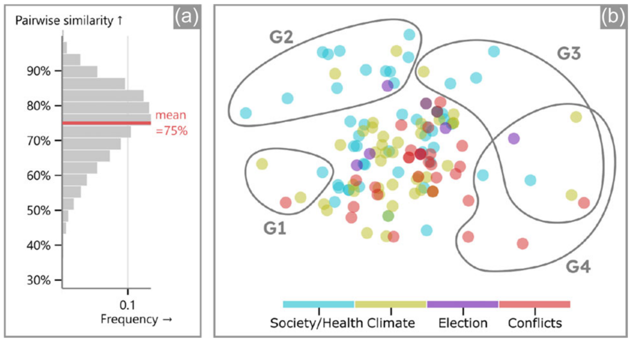

Figure 5: *(a) Displays the overall distribution of the pairwise similarities between all stories and the resulting mean value. (b) Depicts the stories as points after projecting them into 2D using MDS. The closer two points are, the more similar the corresponding stories are. The color of a point depicts the theme of the story.*

5.2. Q2: Similarity

We defined a *similarity score* to quantitatively compare the stories with each other. For two stories, s and s', it is defined as $sim(s, s') := 1 - \frac{\sum_{i=1}^{n} \|s_i - s'_i\|}{n}$, where $n = 29$ is the number of different techniques in the design space (excluding the six main category titles) and the classification of a story is represented as $s \in \{0, 1\}^n$. At that, $s_i = 0$ means that story s does not use technique i and $s_i = 1$ means that story s 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 technique.

Overall similarity. Figure 5a displays the distribution of the pairwise similarities between all stories. They range from a minimum of 28% (one story pair) to a maximum of 100% (18 pairs) around a mean of 75%. This means that any two stories share at least 28% of the techniques and that 18 pairs of stories use exactly the same techniques. Together with the bell-shaped distribution, this suggests that the majority of the similarities is homogeneously distributed. This is also conveyed by Figure 5b. To produce it, we used the dimension reduction method *Multi-dimensional Scaling* [HPG13] (MDS) as it only requires a distance measure and no exploration of appropriate hyperparameters, contrary to other dimensionality reduction techniques like t-SNE [vdMH08] or UMAP [MHM20]. MDS takes the pairwise distances between high-dimensional elements as an input to produce a low-dimensional (here 2D) representation of the elements. At that, the coordinates of the projected points are optimized to reflect the distances between the original high-dimensional points as well as possible. In our example, we used $dist(s, s') := 1 - sim(s, s') \in [0, 1]$ as the distance measure between two stories, s and s'.

The resulting projection in Figure 5b shows that the majority of the stories form a dense group of similar stories in the center. The other stories can be roughly characterized as follows. **G1** gives examples for animation-based stories as all of them use **animation or slideshow** to encode space-time and **animation** to link story elements. Moreover, all of them refer to **scrollytelling** for navigation

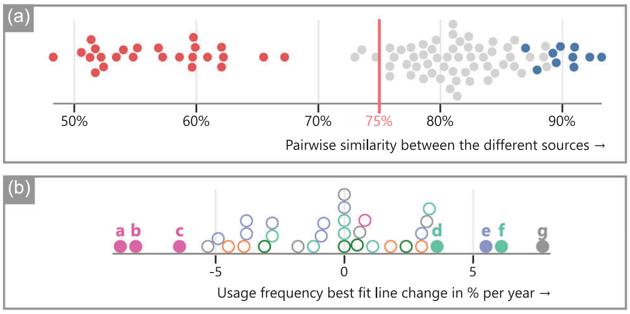

Figure 6: *The beeswarm plots display distributions in a non-aggregated way. In (a), the pairwise comparisons of all sources are displayed. A group with very high similarity is colored blue and a group with very low similarity is colored red. The red line indicates the overall average similarity between all stories (75%). (b) Shows for each technique the slope of the best fit line regarding the usage trend of the technique from 2018 to 2022.*

and **element highlighting** for communicating the narrative. **G2** consists, among others, of COVID dashboards. 12 of the 15 stories are about *society & health* and all of them provide **controlled exploration**, along with **tooltips** in 10 of the 15 cases. **G3** represents stories that employ little to no advanced combination of text and visualization. None of its stories uses any **story element linkage** and the only form of exploration is provided in **separate e.v.'s**. Moreover, all of the stories use **basic scrolling** for navigation and none of them **scrollytelling**. **G4** seems to consist of stories that should draw the reader in more deeply, as all of them are **multimedia visual experiences** and use **audio narration**, among others.

Between-group similarity. To get a better understanding of the themes and sources present in the data set, we summarized the average usage statistics for each theme and source to compare how similar they are to each other. The average technique usage for the different themes turned out to be quite similar, with *society & health* and *conflicts* being least alike (86%), and *society & health* and *climate* being most alike (92%). These high similarities are also conveyed by the strong overlap of points representing stories from different themes in Figure 5b. In contrast, the differences between the sources are stronger. The most significant patterns are highlighted in Figure 6a. There, the blue points represent all pairwise comparisons between the following sources: *The New York Times*, *Bloomberg*, *National Geographic*, *The Washington Post*, and *Reuters*. As they have similarities between each other of around 90%, these sources are most similar to each other. In addition, in Figure 6a, we have colored the points red that represent all comparisons between sources of which at least one was either the website *EcoWest* or the *Manhattan Population Explorer*. This reveals that these two sources were very dissimilar from the rest, reflected through the lowest pairwise similarity scores.

5.3. Q3: Trends

To compare the trends, we calculated the best fit line for each technique regarding its year-wise usage frequencies from 2018 to 2022 and ordered the techniques accordingly. The strongest *decrease* in usage over the years occurred for **dynamic queries**, **controlled exploration**, and **embedded e.v.**. In Figure 6b, these correspond to the points **a**, **b** and **c**. The R^2 of the estimations was 63%, 61% and 49%. The underlying trends are shown in Figure 1. The techniques whose usage *increased* the most are **map-independent time visualization**, **text annotations on visualizations**, and **geographic maps** for context and navigation. The corresponding points in Figure 6b are **g**, **f** and **e**, and Figure 1 shows the entire trends. The R^2 of the estimations was 51%, 27% and 48%. *Map-independent time visualizations* are often used in COVID-related stories, for example for comparing infection rates in different regions. The role that *text annotations on visualizations* play in depicting troop movements and territory changes in *conflict* stories was already discussed, as was the role that *geographic maps* play for *climate* stories to convey which specific regions are affected by climate phenomena. As all these issues have become more severe over the recent years, the corresponding techniques show a strong upward trend.

Another noteworthy trend occurred for **'real-time' extensions**. While its increase is lower than the last-mentioned techniques, it is still striking that it has the fourth-strongest increase (with $R^2 = 27\%$), see point **d** in Figure 6b. Naturally, fewer stories using this technique are created since such stories are usually extended when new events occur instead of creating an entirely new story. Therefore, this increase is more meaningful.

5.4. Takeaway messages for creating stories

When searching for inspiration to create a story, the previous sections can help as follows. In Section 5.1, for each technique category, we list the most-used techniques in addition to the entire distribution in Figure 1. This serves as a starting point for which techniques might be suitable. The information about theme-specific deviations can help to narrow down the technique selection even further. However, Section 5.2 showed that the theme alone does not automatically suffice to tell which techniques would be best to combine. In it, we presented exemplary groups of stories belonging to different themes but sharing key characteristics. Accordingly, it would be helpful for authors to not only get technique recommendations based on the theme but also based on the techniques they already know they want to use. Going into detail about all possible technique combinations goes beyond this paper, but we provide a corresponding section 'Inspiration for your new story' in our story notebook. There, authors may choose a theme and iteratively select techniques they want to use. After each selection, a view displays how often the other techniques were used in combination with the ones selected so far. In addition, a table lists all stories using the selected techniques so the author can get hands-on inspiration for how the techniques were combined in practice.

Example scenario. Ayla wants to write a story about the deforestation taking place near her hometown. She has collected the data for the past four years about which areas were deforested in each year. Now, she wants to decide which techniques to use to tell her story. In the corresponding notebook section, she filters for the theme *climate* to find that, in such stories, the spatio-temporal data is often visually encoded as an animation or slideshow. She selects the technique to filter for all stories that used it. She finds that, more often than usual, it is combined with scrollytelling for navigation. As she thinks that this would be an engaging way to navigate, she also selects that technique. This leads her to find that she should consider linking the separate story elements via animations and color. This way, she continues until she has decided on all the techniques she wants to use. She then refers to the table below and clicks on one of the stories that fulfill all her requirements to get a real-world example, for example an article by *ProPublica* discussing pollution [YSC19]. She likes how the article animates between different areas and decides to use it as an inspiration for her own story.

Aside from the steps described above, it can also help to consider the trends explored in Section 5.3 when deciding which techniques to use, even though they were only roughly estimated. It should also be noted that just because certain technique combinations were used often, they are not automatically the best. They might also just be, for example the most economical options for a company. Yet, we think that this can serve as a helpful source of inspiration and reflection.

6. Summary and Reflections

In this section, we summarize and reflect on the key findings from the analyzis and discuss potential shortcomings of our approach.

Large-scale struggles shape storytelling techniques. The increasing trends discussed regarding **Q3** show that global issues like COVID-19, the Ukraine War, and climate change drive the use of corresponding storytelling techniques. They also lead to the development of new techniques, like ‘real-time’ extensions, which are particularly applicable for providing a more comprehensive picture of longer-lasting crises. While it is arguable that the occurrence of these events might have skewed the picture conveyed by our data set, it is not unlikely for such trends to continue as diseases and violent conflicts on a larger scale may become more frequent due to climate change [IPC14]. Accordingly, the strength of the discussed trends in modern-day data-driven storytelling also reflects the urgency of the associated issues.

Stories are becoming easier to consume. In parallel with what Tse announced in 2016 regarding visual storytelling at *The New York Times* [Tse16], also stories with spatio-temporal context are on average becoming easier to consume. This comes with a reduced use of controlled exploration, interaction (aside from scrolling), and cognitively demanding design choices like multiple coordinated views. Yet, this has not always been the case. Stolper et al. had still encountered a number of exploratory stories [SLHRS16] and the trend for controlled exploration techniques in our data had started out much higher in 2018 with 50%. As Tse expressed, potential reasons for the decline could be that making interactivity work cross-platform is very time-consuming but also the overall preference that ‘readers just want to scroll’ [Tse16]. A potential reason for this preference could also be that the audience for data-driven stories has become broader, including also less technophile readers who are not very keen on interactive exploration.

Techniques that have, in contrast, become more relevant are non-interactive means to link separate story elements, like color, and ways to control animations, for example through scrollytelling. In such scenarios, scrollytelling is often restricted to animation-based sections embedded in a larger story that is otherwise navigated via basic scrolling. Basic scrolling is even simpler to control and was by far the most-used technique for navigation. This is also reflected in the fact that barely any slideshows were created, which, due to their nature, use the only layout not prone to scrolling. However, exploratory techniques are still in use, for example for creating a familiar setting for the reader [BSB*18], and more research could help to clarify in which cases such interactivity is worth the cost of creation [HCHC20].

Storytellers combine techniques creatively. The similarity analyzis showed that storytelling techniques are combined in a variety of ways across the collected stories. We identified key differences between the themes but also provided theme-independent examples in Figure 5, where we identified four groups that relied on quite different and sometimes even opposing technique selections. This variety across the stories aligns with Stolper et al., who also emphasized how creatively different storytelling techniques were combined in their analyzed stories [SLHRS16]. By allowing authors to explore this space of design decisions in our paper and our story notebook, we provide them with a source of inspiration for meaningful technique combinations. We plan to deepen the analyzis in the future, for example using biclustering [TSS05]. We also want to consider in the similarity measure the hierarchy introduced by the different technique categories to prevent potential imbalances. This way, we expect to detect even more patterns in the data set as to which techniques work well together.

Aside from representing a creativity input for authors and a potential foundation for storytelling guidelines, this diversity of technique combinations also implies an important consideration for the development of authoring tools. Together with the changing technique usage trends discussed before, it shows that, ideally, authoring tools should be flexible if they are designed for a broad application: Not only should they provide a diverse set of techniques to combine, but they should also be able to adapt to changing demands over time, like the inclusion of new techniques.

Authors and tool developers could be supported even more by collecting information about further aspects. Particularly, knowing which precise visualization techniques are used to encode what kind of data types in space and time can provide strong guidance. We observed quite divergent and creative techniques in that regard.

Limitations. Follow-up studies are necessary to investigate whether a high usage frequency of certain techniques also means that they were actually the best options for the respective stories. Moreover, the theme *election* contained comparatively few stories (8/130). A possible explanation is that, while a lot of stories reporting on elections exist, most of them do not compare the behavior between both different regions and different years. In addition, the theme is more narrow than, for example *society & health* and the events that *election* stories report on, that is elections, take place more rarely than events that lead to a story about *society & health*.

As the data set is not exhaustive, the detected trends and patterns should not be taken down to individual percentage values. Rather, the overall directions and their implications are relevant. Accordingly, when comparing the usage trends of the techniques, some estimations yielded a relatively low R^2. Yet, we think that the approach is useful to give a general idea, as we also provide the underlying year-wise developments in Figure 1 for reference. An issue that remains with collections such as ours is that some sources put up pay walls for their stories. While we paid for them in the context of our research, other people trying to access them might not be able to afford the costs. Still, neglecting stories entirely that are not freely accessible would likely skew the analyzis results.

Lastly, our design space is only able to represent a subset of the characteristics that spatio-temporal visual data stories can show. Considering other aspects like narrative design patterns [BSB*18], the interplay of visualizations and textual narratives [LCB21], or more detailed distinctions regarding the visual encoding of space-time [BDA*17] would certainly yield additional insights. Similarly, describing the aesthetics of the visualizations in the stories, that is their characteristic style, in a generalizable way might be fruitful. It would allow investigating to which extent different sources have a characteristic visual style that they follow throughout their stories and what impact a certain style has on the reading experience. This style might also differ between the themes, for example regarding what level of terrain details are displayed on maps.

7. Conclusion

We collected a set of 130 interactive visual data stories with a spatio-temporal context and characterized them based on a combined design space derived from three existing approaches. With this, we could get a deeper understanding of how such stories are commonly built: We analyzed how frequently the different visual storytelling techniques have been used over the past five years and in which direction the corresponding trends go.

Struggles with a global impact, like the COVID-19 pandemic, the war against Ukraine, and climate change, have a strong influence on which techniques are used for visual storytelling, even resulting in the development of new techniques tailored to the corresponding needs, like 'real-time' extensions. It also became apparent that interactivity and exploration are decreasing in modern-day storytelling, resulting in stories that primarily revolve around the scrolling interaction. However, exceptions exist when advanced interaction can be used to provide the reader with a personalized perspective on the story. Taken together with the more fine-grained patterns that can be explored in our data set, for example via the accompanying story notebook, our results can support authors in crafting successful stories and allow developers of authoring tools to identify which techniques their tools might be expected to provide.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supporting Information