Communicating with Motion: A Design Space for Animated Visual Narratives in Data Videos

Yang Shi
iDVX Lab, Tongji University
yangshi.idvx@tongji.edu.cn

Xingyu Lan
iDVX Lab, Tongji University
xingyulan@tongji.edu.cn

Jingwen Li
iDVX Lab, Tongji University
jinwere@tongji.edu.cn

Zhaorui Li
iDVX Lab, Tongji University
zhaorayli@tongji.edu.cn

Nan Cao
iDVX Lab, Tongji University
nan.cao@gmail.com

ABSTRACT

Data videos are a genre of narrative visualization that communicates stories by combining data visualization and motion graphics. While data videos are increasingly gaining popularity, few systematic reviews or structured analyses exist for their design. In this work, we introduce a design space for animated visual narratives in data videos. The design space combines a dimension for animation techniques that are frequently used to facilitate data communication with one for visual narrative strategies served by such animation techniques to support story presentation. We derived our design space from the analysis of 82 high-quality data videos collected from online sources. We conducted a workshop with 20 participants to evaluate the effectiveness of our design space. Qualitative and quantitative feedback suggested that our design space is inspirational and useful for designing and creating data videos.

CCS CONCEPTS

• **Human-centered computing → Visualization design and evaluation methods**.

KEYWORDS

Data Videos; Animation; Visual Narratives; Narrative Visualization

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1 INTRODUCTION

Data videos, as a genre of narrative visualization [41], combine visualization with motion graphics to tell data-driven stories [3]. When creating data videos, designers often use *animation* to encode data attributes such as revealing relationships, showing uncertainties, or conveying emotions [16, 27, 40]. Such animated representations can facilitate data communication and increase viewer engagement [2]. With the growing popularity of data videos among journalists, government agencies, and marketers, an increased demand for methodologies to support integrating animation into data-driven storytelling has emerged [1].

Prior research on animation in the visualization community has focused on estimating its effect on data transitions [14, 15, 18, 19, 24, 39]. In contrast, exploring animation through the lens of data-driven storytelling has received limited attention. In one case, Amini et al. [1] decomposed data videos into temporal sequences and coded these sequences based on their narrative structures, including establisher, initial, peak, and release. Following their previous work, Amini et al. [3] categorized animation in data videos by elemental units such as creation, annotation, and destruction. The aforementioned work analyzed the structures and components of data videos and has laid a solid foundation for understanding them. However, the role of animation that serves *visual narratives* [41] in data videos has been largely overlooked. Visual narratives are often adopted by designers to construct an expressive story that touches the audience. For example, when presenting *200 Countries, 200 Years, 4 Minutes* [9], Hans Rosling occasionally slows it down to *emphasize* key facts or speeds it up to *leave out* unnecessary explanation by manipulating the timeline. Such animated visual narratives help transfer complex data facts to an engaging story liked and shared by people over years [10, 29].

While animated visual narratives can support articulating the idea of a data video and enhancing its expressiveness, few structured analyses or systematic reviews exist for understanding their design and application. To bridge such a gap, our work explores the design space for animated visual narratives in data videos through three complementary methods. First, we collected a corpus of 82 data videos from a range of online sources and identified common design patterns of animated visual narratives that we found useful when analyzing these videos. Second, we constructed a design space that systematically describes these patterns, which is informed by coding 1) animation techniques frequently used to support data communication, combined with 2) visual narrative strategies served by such animation techniques to facilitate story presentation. Third, we evaluated the effectiveness of the design space by conducting a workshop with 20 participants. We also developed a data video explorer as teaching material for the workshop. The explorer shows a set of 43 animation cards derived from our design space and the participants were encouraged to apply these cards to designing and crafting data videos. Qualitative and quantitative feedback

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from the workshop suggested that our design space can assist the formulation of ideas when creating animated visual narratives in data videos. We also discuss design implications on extending our design space and developing future data video authoring tools.

In summary, the main contributions of this work include:

- We constructed a design space for animated visual narratives in data videos through the analysis of 82 data videos. Our design space integrates disparate threads of prior research on visual narratives across different fields and applies them to data videos for the first time.
- We conducted a workshop with 20 participants and instructed them to apply the design space to the creation of data videos. The results of the workshop indicated that our design space can support ideation and increase the likelihood of creating expressive data videos.
- We developed an interactive data video explorer[1] showing a set of method cards derived from our design space. It can provide researchers and practitioners with inspirational and useful design suggestions while creating and crafting data videos.

2 RELATED WORK

Our work builds on prior research on animation in data visualization, narrative visualization and data videos, and techniques augmenting visual narratives.

2.1 Animation in Data Visualization

The role of animation has been increasingly addressed in the visualization community recently [16]. As defined by Munzner [36], animation in data visualization can carry three different meanings: it is (1) a transition between two dataset configurations, (2) a video-style playback that the viewers can control, and (3) a medium for data-driven storytelling. Based on the taxonomy proposed by Munzner, most prior research falls into the first two categories. For example, Thompson et al. [30] characterized animated transitions based on four dimensions (object, graphic, data, and timing) and proposed 10 transition types such as enter/exist, visual alteration, and data encoding alteration. Heer and Robertson [24] proposed that a properly designed animation can significantly improve the chance of accurate perception of the transitions between statistical charts. Similarly, empirical studies [14, 15, 18] examined the effectiveness of applying certain animation strategies or principles to facilitate data transitions. Grammars and tools [20] were also developed to support animating transitions between visualization charts. In terms of a video-style playback, Mckenna et al. [35] identified three levels of control in animated transitions of story components, including discrete, continuous, and hybrid control.

When acting as a device for storytelling, animation conveys messages by constructing narratives and delivering an appropriate amount of data with a planned narrative rhythm. Compared to the aforementioned work, our work explores how to design animation with the goal of telling an expressive data-driven story. Consequently, we identified and categorizes animation techniques in data videos by narrative strategies such as emphasis and ellipsis.

[1] https://videoexplorer.idvxlab.com

2.2 Narrative Visualization and Data Videos

Narrative visualization, as an emerging form of storytelling, presents messages and arguments supported by data [41]. Being one of the common genres of narrative visualization, data videos integrate visualizations with animations, pictographic representations, and narrations [1, 3] to support storytelling. In comparison with other genres such as magazine style and annotated chart [41], data videos are entirely author-driven and have a linear path of narration. Thus, the audience can easily follow the narration and consume morsels of high-value information in a short time.

As annotated by Segel and Heer [41], narrative visualization can be viewed as the combination of *narrative structures* (strategies that organize plots or contents) and *visual narratives* (visual methods that shape narrative experience and communicate intended messages). Prior research on data video has been focused on the analysis of its narrative structures. For example, Amini et al. [1] initiated a first step towards understanding data videos by analyzing the structure of 50 data videos through the following narrative categories from cinematography: establisher, initial, peak, and release. As a subsequent effort, Amini et al. [3] analyzed the composition of over 70 data videos and proposed a taxonomy of elemental units in data videos. The taxonomy is the function of visualizations types and animation types. Based on the taxonomy, they developed an authoring tool called DataClips to support assembling data clips as a data video. On the other hand, visual narratives, as a strategic visual approach adopted to make a story more expressive, persuasive, or mind-blowing, is largely missing in existing studies about data videos. Therefore, our work complements previous research by investigating data videos specifically from the perspective of storytelling. We are in particular interested in what animated techniques reoccurred across data videos and how they serve certain narrative strategies.

2.3 Techniques Augmenting Visual Narratives

In narrative visualization, various techniques such as animation [41], interaction [43, 45], and narration [32, 42] can be used to augment visual narratives. For example, by examining 58 narrative visualizations, Segel and Heer [41] identified three approaches to supporting visual narratives, including visual structuring (e.g., a progress bar), highlighting (e.g., feature distinction), and transition guidance (e.g., animated transition). Hullman et al. [26] took a further look at story transitions by analyzing 42 narrative visualizations. They proposed six between-visualization transition types (e.g., dialogue, temporal, and causal) according to the logical relationships between frames. Such transitions can help build a smooth and meaningful story flow. Stolper et al. [45] analyzed 45 author-driven data stories and assigned storytelling techniques into four categories, including communicating narrative and explaining data, linking separated story elements, enhancing structure and navigation, and providing controlled exploration. Calliope designed by Shi et al. [42] can be used to automatically generate data stories using a sequence of expressive charts, accompanied by annotations and text narrations. Bach et al. [4] described a set of narrative design patterns such as argument and flow for data-driven stories. Our work is influenced by techniques that augment visual narratives described above. Specifically, we focus on assisting visual narratives through animation design. To do this, our work extends former research by building a

design space for animated visual narratives and allows designers to effectively apply the design space to data video creation.

3 CASE EXAMPLES

To identify common design patterns that shape visual narratives with animation, we collected a corpus of data videos of high quality. Our primary source for data collection was data video lists generated by previous studies [1, 26, 45]. These data videos were collected from reputable sources, recommended by domain experts, or popular among viewers. By merging these lists and removing duplicates, we obtained 58 data videos produced from 2008 to 2015. We successfully retrieved 45 out of 58 data videos from the Internet and these data videos constitute our initial corpus. Then, we complemented the initial corpus with data videos produced after 2015 to reflect recent developments in the field. Following the methodology by [1, 3], we collected data videos from news agencies famous for data video production (e.g., The Economist, Vox), well-known visualization communities, and opinionated lists of best visualizations. We also used search keywords such as "animated infographic", "data video", and "motion infographic" on online video platforms including YouTube.com and Vimeo.com, and processed the top videos with most views. As a result, we collected 52 more high-quality videos from these online sources. To ensure that these videos are data-driven [1], we mandated that the data videos (1) present messages and arguments supported by data, (2) include at least one visualization, and (3) follow the form of storytelling. In accordance with the three inclusion criteria, we identified 37 out of 52 data videos to be included in our corpus. In total, our corpus contains 82 data videos produced from 2008 to 2020. For the list of data videos included in our corpus, see *Appendix*.

In this section, we present three data videos selected from our corpus to introduce recurrent design patterns and animation techniques (marked in boldface in the following). The three videos were selected as they were produced by well-known news agencies and are popular among the audience. More importantly, they provide a diverse sample of data video exemplars in the design space of animated visual narratives and reveal how specific animation techniques can be integrated into different storylines.

3.1 Case 1: 200 Countries, 200 Years, 4 Minutes

200 Countries, 200 Years, 4 Minutes [9] is a data video presented by Hans Rosling, who has long been acknowledged as one of the most successful practitioners of narrative visualization [33, 41]. While this video is well-known for incorporating animation into visualization to engage the audience and sustain their attention [16, 39], its narrative strategies regarding capturing the excitement for data are also outstanding but under-explored.

In the video, Rosling first decodes a scatterplot by presenting its two dimensions: income (x-axis) and lifespan (y-axis). The axes **blink** to grab the audience's attention and a set of bubbles representing different countries **gradually reveal**. Rosling then explains the visual encoding of a single bubble. Meanwhile, the bubble **glows** to call attention while **an annotation is added** to explain which country it represents. After that, the bubbles start to move with time. During this process, Rosling sometimes **pauses** or **slows down** to elaborate on certain countries. The corresponding bubbles

Figure 1: 200 Countries, 200 Years, 4 Minutes [9].

glow while being **annotated**, as shown in Fig. 1. When pausing to talk about China, he **splits** the bubble representing China into smaller ones to show the information of individual provinces, explaining that some parts of the country are already as healthy as western countries. Meanwhile, other bubbles **fade** to make this bubble stand out. As the audience is getting to understand the visual encoding, Rosling then **speeds up** the bubble movement to leave out redundant information. The acceleration also metaphorically aligns with the core message Rosling attempts to deliver, that is, the fast progress of the world's health condition. Towards the end of the video, **an arrow is added** to the scatterplot, showing a global trend in health and wealth. A **ripple** spreading out along the orientation of the arrow is also drawn to emphasize the main idea of the story.

3.2 Case 2: Electric Cars Could Wreak Havoc on Oil Markets Within a Decade

Electric Cars Could Wreak Havoc on Oil Markets Within a Decade [11] was produced by Bloomberg to introduce how electric cars will undermine the oil industry. At the start of the video, a line chart showcasing the Peak Oil hypothesis is presented to the audience. To emphasize the peak, **an annotation is added** to call attention. However, the Peak Oil hypothesis is not occurring due to the availability of oil reserves. The narrator argues that, rather than exhausting oil reserves, the actual threat to the oil industry is that consumers stop purchasing oil due to the emergence of electric vehicles (EVs). Interestingly, the narrator supports his arguments by first illustrating two "contradictory" data facts. First, a number **counts up** to reveal that there are one billion gas-guzzling cars worldwide today and an ISOTYPE chart is presented to show that only one thousandth of these cars have a plug. Second, the camera **zooms in** to the year 2040 while the data of other years **fades out**, suggesting that EVs will only account for 1% of the car industry by 2040, as shown in Fig. 2.

"*But don't be so sure*" states the narrator. S Curves representing the spread of refrigerator, color television, computer, and cellphone **gradually reveal**, indicating that the growth of new technologies starts off slowly before increasing rapidly thereafter, as will be the case with EVs. Following this, a **swinging** balance is used to compare the supply and demand sides of the oil industry: as the demand side continues to fall, the supply side will experience a crash. The narrator then uses a bar chart to visualize the number

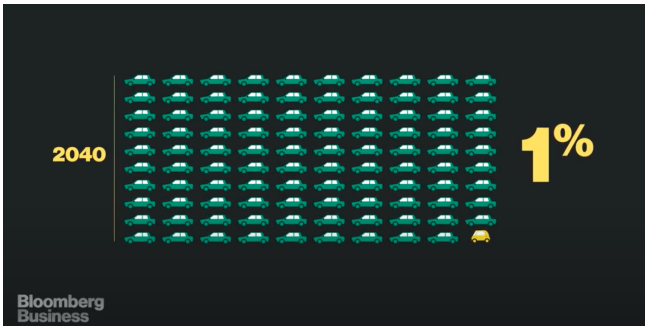


Figure 2: Electric Cars Could Wreak Havoc on Oil Markets Within a Decade [11].

of barrels of oil that will be replaced by EVs between 2010 and 2040. As the bars **gradually reveal** year by year, the camera **tracks** the rising level. When it reaches 2023, a **shake** effect is added to emphasize that an oil crisis will ultimately occur at this turning point. Subsequently, the camera **zooms out** from the screen and the growth of the bars **speeds up** to provide a quick summary of the data argument.

3.3 Case 3: One Race, Every Medalist Ever

One Race, Every Medalist Ever [46] was created by the New York Times to reveal how much faster Olympic men's 100-meter sprinters have become. In the video, all the medalists between 1896 and 2012 are put in an imaginary race. In the race, each medalist is placed on a lane representing the Olympic year he won the medal while his position on the lane encodes his average speed, as shown in Fig. 3.

The video starts with Usain Bolt, the winner of the London 2012 Olympics, appearing on his lane and running across the finish line. Then, the medalists of other years **gradually appear** and the camera moves horizontally to **track** them. Then, a **crane shot** is used to show a bird-view panorama of all the sprinters. The camera lens also **tilts** to look down vertically; each sprinter looks like a dot on a scatterplot. To further explain the speed of individual sprinters, **navigate** combining with **zoom in** is used. When introducing a specific sprinter, his lane is **filled with color** blue for highlighting while other sprinters and their lanes are **desaturated**. When the camera reaches the last sprinter, the winner of the Athens 1896 Olympics, the camera **zooms out** from the screen to compare the

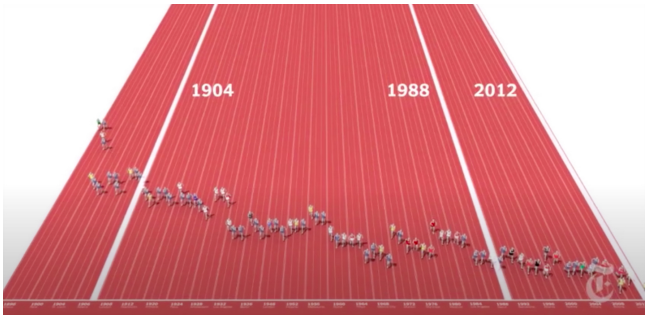


Figure 3: One Race, Every Medalist Ever [46].

speed of 1896's winner with that of 2012's winner by **highlighting a range**. As the narrator describes the contextual information such as the nationality of the sprinters, the camera, again, **cranes** to show the overview. After that, the narrator compares the speeds of these sprinters with that of America's best young sprinters. Similarly, **crane** and **zoom in** shots are used to support data explanation. Finally, the camera **zooms out** to show the front view to echo with the beginning of the video and the story moves to its end.

4 DESIGN SPACE

In this section, we first describe our methodology for analyzing the corpus of 82 data videos to identify common design patterns. Then, we introduce a design space derived from the analysis. The design space combines a dimension for *animation techniques* that are frequently used to facilitate data communication with one for *visual narrative strategies* served by such animation techniques to support story presentation.

4.1 Methodology

We analyzed the corpus in a two-step process: first, we coded the data videos to construct an initial design space; second, we validated and refined the design space by creating two data videos with a group of professionals.

Coding. Two researchers with design-related backgrounds were in charge of analyzing and coding the 82 data videos using thematic analysis [13]. We adopted an integrated approach combining the inductive development of codes and a deductive organizing framework for code types. Specifically, we coded the data videos independently by asking ourselves about (1) what animation techniques are used (codes) and (2) what narrative strategies are served by these animation techniques (code types). To identifying narrative strategies, we conducted a literature review from cross-domain fields including narrative visualization [4, 31], cinematic storytelling [12, 47], narratology [7, 49], and animation design [6, 23]. After the literature review, we extracted a set of key narrative strategies as code type candidates. For example, prior work suggested that Emphasis with motion can help convey critical information in a story [31] while Tension plays an important role in attracting the audience's attention [12, 47]. We then classified animation techniques into these narrative strategies by determining the object and intent of each animation technique in the context of the corresponding data video. For example, although *fill color* and *desaturate* can be similar in presentation, the former one serves Emphasis by highlighting the leading roles of the story while the latter one serves Ellipsis by making the supporting roles disappear. The two techniques are applied to two different objects and thus serve two different strategies related to the corresponding objects. We also found certain animation techniques that can serve multiple narrative strategies, e.g., *zoom out* can be used to serve both Comparison and Cohering.

During the coding process, we met for three sessions to compare our codes, merge similar codes, and discuss disagreements. Through multiple iterations, we identified 47 animation techniques categorized by 7 narrative strategies, which constitute our initial design space.

Validation. We validated and refined the design space by creating two data videos with a team from our data journalism partner organization. The team consists of three graphic designers, one data journalist, and one visualization researcher. We first introduced our design space to the team and encouraged them to apply it to their design. During the process, we observed how they used the design space and recorded their comments and questions. When finished, they presented the data videos and explained what design patterns from our design space were used. Finally, we conducted informal interviews with the team to collect feedback and the questions are as follows,

(1) What parts of the design space do you use the most? Why?
(2) What parts of the design space do you use the least? Why?
(3) What do you think of narrative strategies? How easy is it to understand? Any suggestions?
(4) What do you think about how animation techniques are organized? How easy is it to use? Any suggestions?
(5) Overall, what's your experience been with the design space?

By analyzing the results of the interviews, we found that the animation techniques related to Emphasis were more frequently used by the team, as "*it's a straightforward way to help explain data facts and sensitize the audience to their existence.*" In contrast, animation techniques regarding Focalization received less attention. One of the designers said, "*the implementation of 'crane' and 'pan & tilt' requires a variety of skills and involves a lot of effort.*" We also identified opportunities for dividing the narrative strategy of Tension into Suspense and Twist, as the data journalist implied that these two categories are mutually exclusive while both lead to tension. Related or redundant animation techniques were also merged. For example, the initial design space included *fade in* and *fly in* to describe the creation of a new annotation. However, the designers suggested that these techniques are designed at a low level of granularity and are of similar semantics. Thus, we merged the two techniques into one called *add annotation.* Also, the original presentation of our design space used one frame to depict each animation technique and the visualization researcher noted, "*it's difficult to imagine exactly what it looks like, especially for designers who are not skilled at creating animation.*" Thus, we decided to use a sequence of keyframes to depict each technique and tested several interactions of our design with the team until a satisfactory result was reached.

The validation process resulted in 43 animation techniques grouped into 8 narrative strategies. These codes and code types were then cross-checked and discussed to ensure that all of them are interpreted similarly. Last, we coded the 82 data videos using the final coding scheme and reached a Cohen's Kappa of 0.81. We then discussed the mismatches and reached a 100% consensus. In the next two subsections, we will introduce the animation techniques and narrative strategies in detail, respectively.

4.2 Animation Techniques

Animation techniques in data videos are used to capture changes in visual content (e.g., color, texture) and geometric properties (e.g., scale, rotation) of visualizations, as well as to indirectly manipulate visualizations over time (e.g., camera movements). To better describe the animation techniques that reoccurred across the data videos, we introduce the concept of *editorial layers*, which refers to composable primitives of data videos where editorial judgments can be applied. The idea was derived from the informal interviews with the three designers when validating our design space. We found that designers usually seek design suggestions that align well with their editing behaviors in video editing tools. For example, one designer noted, "*this technique (ripple) looks confusing to me, especially when I have multiple elements to animate in the video... It didn't tell me who's the subject*". Thus, we observed how the designers implemented the animation techniques in video editing tools and distinguished between four different editorial layers, namely, *the elements of visualization, elements added to visualization, camera*, and *timeline*. Next, we describe the four editorial layers where animation techniques can be applied.

The elements of visualization. The elements of visualization such as visual marks (e.g., bar, point, line), axes, grids, and legends constitute a common editorial layer where animation techniques can be applied (Fig. 4). For example, visual channels such as color, shape, size, and position can be transformed from one state to another using animation, e.g., filling bars with color in a bar chart (Fig. 4 No.3).

Elements added to visualization. Animation techniques on another layer manipulate textual or graphical elements added to visualization, such as embellishments and annotations (Fig. 4). Examples include adding a border around a bar in a bar chart (Fig. 4 No.6) and drawing a benchmark line on a bar chart (Fig. 4 No.23).

Camera. In this layer, camera movements and shot angles are used to set the performance space for a data video and thus change the audience's feelings towards a scene (Fig. 4). For example, zooming in (Fig. 4 No.10) and zooming out (Fig. 4 No.21) determine the proportion of the objects being included in the scene, whilst a tilt & pan shot (Fig. 4 No.37) decides the perspective from which to view them.

Timeline. Last, the timeline of a data video can be manipulated to control the pace and rhythm of storytelling (Fig. 4). By editing the keyframes, one can control the duration, speed, or sequence of animation. Examples include pausing (Fig. 4 No.11) or speeding up (Fig. 4 No.35) the emergence of bars in a bar chart.

4.3 Visual Narrative Strategies

Visual narrative strategies such as emphasis and suspense have been extensively used in various storytelling mediums including films, comics, and video games to create a storytelling experience that engages the audience. In data videos, such strategies are also prevalent and can be served by animation techniques to help assemble a set of separate data facts into an expressive and memorable data-driven story. By analyzing the 43 animation techniques through the lens of narrative visualization, we identified 8 categories of narrative strategies, namely, Emphasis, Suspense, Comparison, Cohering, Ellipsis, Focalization, Concretization, and Twist, as shown in Fig. 4. In Fig. 4, only the primary strategy of each technique is presented. Note that our design space is neither exclusive nor representative of the field. Alternatively, our design space sought to integrate concepts that are spread over a range of different areas of research and open up

Figure 4: Our design space for animated visual narratives in data videos.

the possibility of building upon existing research. These narrative strategies will now be described in descending order according to their frequencies found in our corpus.

Emphasis. Emphasis is one of the most supported narrative strategies in data videos, as shown in Fig. 4 No.1-13. It communicates core messages by creating "look here" signals with visual hierarchy, i.e., visual contrast between two different colors, shapes, sizes, or movements [31]. For example, animation techniques such as *pulse* and *glow* can highlight the key elements of a visualization via movement and luminance, respectively. In Case 1, *blink* is added to the axes of the scatterplot to emphasize that the position of the bubbles can encode "*poor and sick*" or "*rich and healthy*". Furthermore, adding textual or graphical elements to a visualization such as *drawing a(n) border/circle/arrow* and *adding annotation* can direct the audience's attention to areas of interest in a visualization. Specifically, *adding a magnifier* achieves the effect of searching and highlighting data insights. Camera effects such as *zoom in* focus on the "leading roles" of a visualization such as outliers and extreme values by adjusting the focal length. Manipulating the timeline, including *pause* and *slow down*, achieves emphasis by allotting more time for the audience to observe and digest key facts. For instance, *rewind* uses repetition, a typical visualization rhetoric [25], to recap the information previously presented, thereby cementing the information deep into the audience's memory.

Suspense. Suspense uses retardation to create tension and anticipation. It is used extensively in filmmaking and is regarded as one of the primary features of cinematic storytelling [12]. In data videos, several animation techniques are observed to create suspense, as shown in Fig. 4 No.14-18. For example, *count* is frequently used for numerical data by animating numbers counting up instead of simply presenting the final value. In Case 2, *count* is used multiple times to animate the number of gas guzzling cars worldwide or the amount of money invested in oil, thus achieving retardation. Another technique is referred to as *flip*, which is a game-like animation that makes viewers guess and anticipate the data before revealing the truth. Similarly, *unveil* achieves suspense by first hiding the visualization with a mask and then moving the mask away. In terms of camera effects, *track* is the most widely used animation technique for building suspense and is often combined with a close-up shot. As the camera moves laterally, objects from one side leave the scene while newcomers enter from the other side, thereby revealing the data gradually and raising anticipation. Last, *gradually reveal* is a timing effect where the elements of a visualization reveal themselves sequentially, leaving time for the audience to predict the upcoming content.

Comparison. Comparison facilitates the explanation of similarities and differences by analyzing two or more datasets/data points. As a common means of presenting visualizations [21], comparison is also effective for data-driven storytelling [4], as shown in Fig. 4 No.19-27. For example, when comparing two or more visualizations, designers usually use *move aside*, *shrink*, and *zoom out* to reframe current visualizations on the scene and leave space for newcomers. We also observed another frequently used animation technique called *swing*, which is a symbolic means of comparing visualizations by mimicking weighting them on a balance or seesaw. For example, Case 2 uses *swing* to compare the supply and demand sides of the oil industry, suggesting that a crash will occur when demand exceeds supply. In terms of within-visualization comparison, examples include *add a benchmark line*, *highlight a range*, and *rescale*, and these animation techniques are used to support analyzing the difference between values. For multi-series visualization, designers can *detach* a grouped visualization to individual charts, or vice versa, *assemble* multiple charts into a grouped one to facilitate comparison [21].

Cohering. Cohering is a visual narrative strategy that increases the continuity of a story by building smooth transitions between individual components, as shown in Fig. 4 No.28-31. It is commonly used in filmmaking to create an engaging viewing experience without sudden scene changes. In data videos, designers can *morph* the shape of marks in a visualization (e.g., from a bar to a bubble) to achieve a seamless transition where no object needs to enter or depart the scene. It is also observed that camera effects such as *navigate* and *spin* can be used to take the audience from one scene to another smoothly. In Case 3, *navigate* is applied to smoothly introduce the fastest sprinters in history one by one, instead of cutting from one shot to another. *Infinite zoom* is a special form of zoom where the camera moves into or away from a subframe. For example, designers can frame a visualization as an object in a scene in a television show and then enter the scene to take a closer look at it. In addition to shaping the continuity of a story, this technique also provides a sense of depth [10, 34] where the audience can enjoy an embodied travel experience between story chapters.

Ellipsis. Ellipsis is used to compact the narratives of a story and deliver the appropriate amount of information to prevent overwhelming the audience. In narratology, subnarratable content [49], i.e., something not worthy of being told as it is too obvious or not interesting, is often left out by the narrator. In terms of data videos, we also found that several animation techniques are applied for the same purpose, as shown in Fig. 4 No.32-35. *Fade* and *desaturate* are often adopted to eliminate trivial information in visualization, avoiding distraction and achieving visual ellipsis. In Case 3, when presenting the information of specific sprinters on the track, the details of other sprinters are irrelevant and their figures are thus be desaturated. *Rack focus* is a camera effect that shifts the focus of the lens from one object to another and then blurs objects of lower priorities. Last, timing effects such as *speed up* are also used for ellipsis when designers assume that a certain data fact is self-evident and does not require further explanation.

Focalization. Focalization is a concept in narratology that refers to selecting the perspective through which a narrative is presented [7]. In visual narratives, focalization can be achieved by manipulating the camera angle and scale. Traditionally, visualizations are presented in a two-dimensional (2D) space with a neutral shot, that is, the camera is level and looking straight. One of the reasons for using neutral shots is that adding angles to visualization may hinder accurate data perception [36]. However, in data videos, we found that designers occasionally utilize

focalization to enrich narratives, as shown in Fig. 4 No.36-37. Examples include *crane*, where the camera moves up and away from the visualization. Using a high-angle crane can create an omniscient quality, triggering a sense of dominance or empathy [7, 12, 47]. For example, Case 3 uses *crane* multiple times to provide an overview of the performance of all the medalists. A *tilt & pan* shot changes the angle of a camera that is pointing horizontally or vertically while maintaining the camera base stationary. When shooting from a low angle using *tilt & pan*, a three-dimensional (3D) bar chart is perceived taller and more likely to elicit a sense of awe. In data videos, the aforementioned animation techniques are often used in combination with 3D visualizations to support focalization.

Concretization. Concretization is a narrative strategy that illustrates abstract concepts with concrete objects. In visualization, concretization implies representing data with visual objects such as points and ISOTYPE charts [4, 17]. Concretization helps explain how data is aggregated and thus increases perception and engagement [22]. Animation can serve this strategy in several ways, as shown in Fig. 4 No.38-40. For example, a visualization can *split* into several pieces to show how it is composed, or vice versa, *merge* individual data points into an aggregated form. In Case 1, Hans Rosling splits the bubble representing China into provinces and further splits Guizhou into urban and rural parts. In doing so, the audience has a better understanding of the components of each visual mark. Designers also use *motion blur* to create an illusion for the eyes and thus achieve a smooth transformation from ISOTYPE representations to visualization charts or vice versa. Occasionally, designers further anthropomorphize ISOTYPE charts using animation, such as making a visual mark walk or jump, to embody data points. However, given that ISOTYPE-related animations have an infinite design space, as well as our motivation is to build a design space that applies to all visualizations, we choose not to include such animations in our design space.

Twist. Twist refers to an unexpected change in the narrative direction and usually acts as the turning point of a story [44]. In narratology, a twist is often accompanied by an intense conflict or denarration [38], namely, the narrator updates the story by denying his previously presented narration. Similarly, in data videos, creating a twist often means reversing or rejecting previous data arguments, as shown in Fig. 4 No.41-43. We observed that this strategy can be supported by the following animation techniques. *Shatter* simulates striking the screen and breaks the presented visualization into pieces. *Shake* breaks the peacefulness of a scene by making a visualization tremble or vibrate. *Cross* draws an "X" mark on a visualization, which conventionally denotes negation. One common feature of these techniques is that they use metaphorical movements to animate the screen which can be imagined as glass or paper, and then trigger an embodied feeling of twist among the audience.

5 WORKSHOP

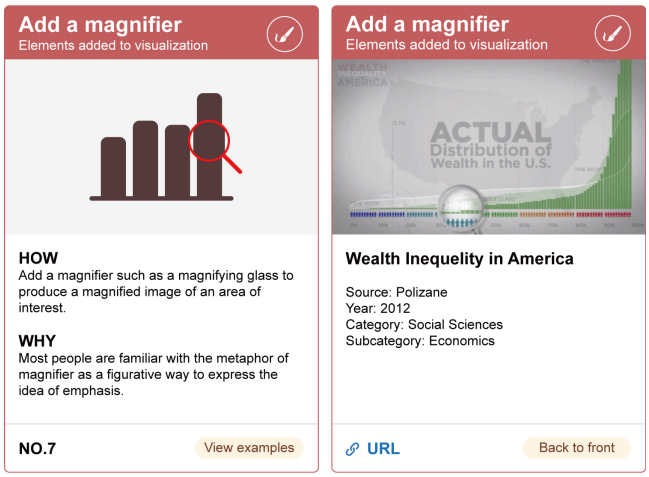
To evaluate the effectiveness of our design space on designing and crafting data videos, we conducted a workshop with 20 participants. To direct the analysis of results, we posed three research questions: RQ1) whether the design space is useful, RQ2) whether the design space is easy to use, and RQ3) how the design space was used by the participants.

5.1 Participants

We recruited participants via an event app and the social media platforms of our lab. Our recruitment material indicated that we were looking for designers experienced in visualization and animation design. 20 participants (13 females) aged between 20 and 40 (M = 25.30, SD = 4.94) were involved in our workshop. The participants consist of college students, researchers, and professionals from art and design, linguistics, computer science, psychology, and journalism backgrounds. The breakdown of their expertise in visualization is as follows: novice (50%), advanced beginner (25%), competent (10%), proficient (10%), expert (5%). All of the participants reported that they have checked at least one data video before. More than half of the participants (15 out of 20) reported that they have experience in making videos and their experience level varies: within 1 year (50%), 1-2 years (15%), 2-5 years (5%), more than 5 years (5%).

5.2 Data

We provided the participants with two datasets, whose topics include *the persona of football fans* and *global trends in obesity*. These datasets were extracted from the data videos in our corpus and their topics are of general interest. In alignment with previous studies [1, 5], we also provided the participants with extracted data facts [48] (e.g., trend, proportion, rank) for each dataset rather than raw data to keep the focus of the workshop on design. Examples of data facts include "*worldwide obesity has increased since 1980*", "*12% of the world's population were obese by 2008*", and "*top ten countries that are most interested in football is...*". To help illustrate each of the data facts, we also presented a set of applicable visualizations, all of which were amongst the most common types found in data videos [1]. Each participant was allowed to decide himself or herself



(a) (b)

Figure 5: Example of a method card from our data video explorer: (a) front and (b) back.

on a dataset, create a storyline based on the corresponding data facts, and was free to use the visualizations that we presented.

5.3 Teaching Material

We also developed a data video explorer as teaching material for the workshop and the participants were encouraged to use it as a reference when designing and crafting data videos. The explorer is available at https://videoexplorer.idvxlab.com and its design was inspired by the Napa Cards [8] and IDEO Method Cards [28]. In the explorer, the design space is presented as 43 method cards, each of which describes one animation technique. Fig. 5 shows an example card with its name, a GIF demo, and a brief description (how to use it and why it is useful) on its front and an exemplar data video on its back. The color of each card encodes the category of its narrative strategy while the icon beside the card name denotes the corresponding editorial layer. If a certain animation technique is categorized into multiple narrative strategies, its card will be encoded in a multiple-color blend. We also add an index number to each card at the bottom left corner. When browsing these cards in the explorer, users can hover on a card to play its GIF demo or click the "view examples" button to check its exemplar data video on the back.

5.4 Procedure

The workshop consisted of two phases: (1) a *design* phase for the participants to create storyboards for data videos and (2) a *craft* phase to craft data videos based on the storyboard they have drawn.

Design Phase. In the design phase, we began with a 30-minute introduction explaining the concepts of narrative visualization, data videos, and storyboards, and then showing examples of data videos. Then, the participants were asked to make a self-introduction to each other and formed groups based on individual backgrounds and skillsets, resulting in 10 groups. Next, the participants were given a 30-minute tutorial about the key ideas of narrative strategies, editorial layers, and animation techniques in our design space, as well as how to use the data video explorer. After the tutorial, we presented an example dataset entitled *the origin of kiwi fruits* and instructed each group to perform a 15-minute warm-up storyboarding exercise. In their storyboards, the participants were asked to label the animation techniques they had used and draw the expected effects they would like to achieve. The exercise was designed to familiarize the participants with the theoretical concepts, storyboarding techniques, and method cards introduced earlier. Next, we introduced the two datasets in detail and instructed each group to start sketching a storyboard based on the dataset of interest, as shown in Fig. 6. They could browse and discuss the cards in their groups. Each group was given 1.5 hours to finish the formal storyboarding process. When finished, each group had the opportunity to present their story using their storyboard, with emphasis on animation. At the end of the design phase, each participant was asked to complete a questionnaire regarding the usefulness, ease of use, and helpfulness of the design space using a 7-point Likert scale. The design phase ran for about 4 hours.

Crafting Phase. The participants were encouraged to create data videos based on their storyboards using video editing tools such as

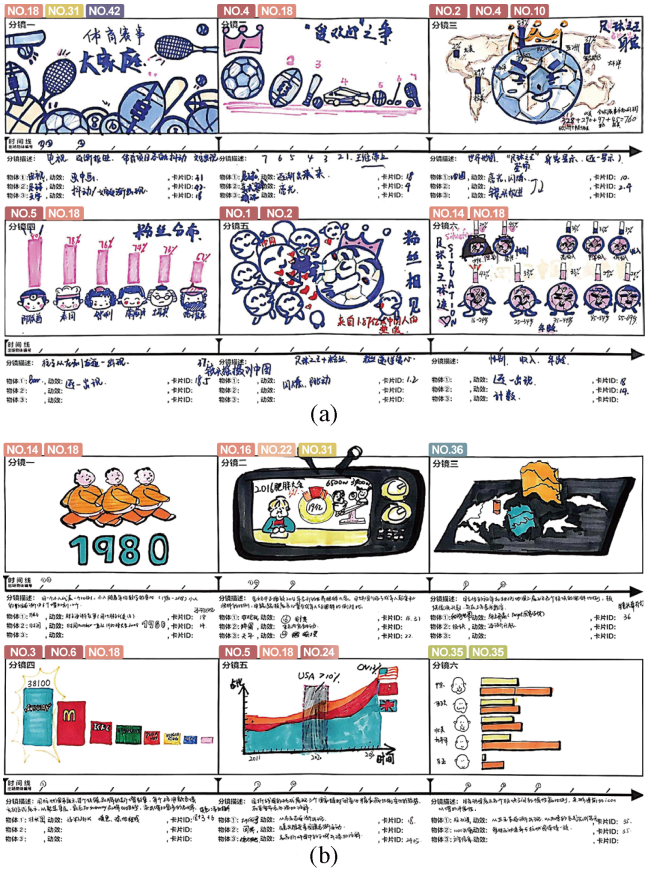


Figure 6: Storyboards from the workshop: (a) the persona of football fans (©Lin Wu, Quan Yuan), (b) global trends in obesity (©Mingxue Ma, Hanlin Yu). The animation cards used by the participants in their storyboards are highlighted on the top of each frame.

Adobe After Effects and DataClips [3]. As a result, 7 out of 20 participants with 2-5 years of video making experience showed interest and participated in the crafting phase. They were given a week to finish the task individually and each of them was compensated $25 for crafting a data video.

After each phase, we conducted a semi-structured interview with the participants. For both phases, audio and video were recorded for subsequent analysis. We also recorded the actions and strategies adopted by the participants and assisted when they raised questions about the material.

5.5 Results

During the workshop, we collected 10 storyboards, one per group from the design phase. We also obtained 7 data videos from the craft phase. The length of the videos ranged from 17 seconds to 1 minute and 3 seconds, with an average of 37.75 seconds.

Two researchers independently coded all the storyboards to investigate the animation techniques and narrative strategies used in these storyboards. Overall, each group used 12 animation cards

on average and 32 out of 43 cards were used in total. We found that *emphasis* is the most popular strategy served: 9 out of 13 cards (50 times) were used, where *glow* (10 times), *add annotation* (9 times), *fill color* (8 times), and *zoom in* (7 times) were used more frequently. In terms of other visual narrative strategies, cards such as *gradually reveal* (15 times) and *count* (7 times) were used more often than other cards. To better explain the qualitative and quantitative results, we now discuss the findings and feedback regarding the three posed research questions (RQ1-RQ3).

RQ1) Usefulness. Overall, the participants indicated that our design space is useful 1 7 (M = 6.00, SD = 1.08). Specifically, the usefulness of *editorial layers* was rated 1 7 (M = 6.20, SD = .83) while that of *visual narrative strategies* was rated 1 7 (M = 6.20, SD = .77). The participants appreciated its effectiveness and practicability, *"it's a systematic and comprehensive summary of animations for charts"* (G3P5), *"it greatly helps data-driven storytelling, especially for beginners"* (G5P8). During the interview, we also asked the participants who have experience in making animation (15 out of 20) about the benefits that the design space can bring compared to their previous animation-making experience. We found that the design space and its corresponding method cards can provide several benefits. First, the design space introduces novel animation techniques that can add diversity to the animation, "*the cards are lovely and 'add a magnifier' is a great visual metaphor that can focus viewers' attention on specific data points*" (G01P01), "*it's really cool that I've added 'infinite zoom' in my video, it makes the transition much smoother and I never thought of it in that way*" (G10P20). Second, the design space summarizes common narrative strategies that can augment the expressiveness of the story, "*when animating charts, I often borrow ideas from PowerPoint such as 'enter' or 'exit' effects... I tried 'shatter' and found it can create dramatic tension and keep the audience hooked to the story. It's a good way to increase their curiosity*" (G04P06). Third, the design space inspires additional design patterns that can increase the creativity of the design. For example, to present the maximum value in a 3D bar chart, Group 7 used a combination of four different cards: (1) *rescaling* (Fig. 4 No.25) the x-axis and moving the camera horizontally to *track* (Fig. 4 No.17) each bar, (2) *tilting and panning* (Fig. 4 No.37) the camera to introduce the bar with the maximum value, and (3) *zooming out* (Fig. 4 No.21) to provide an overview of comparison.

RQ2) Ease of use. All participants agreed that our design space is easy to use 1 7 (M = 6.05, SD = 1.10). One participant commented, *"it's well-categorized and user-friendly"* (G9P18). The participants were also impressed by the novelty and expressiveness of our design space, *"it's my first time to use such cards, full of creativity"* (G9P17), *"the cards introduce animation techniques with how, why, and examples... It can be a handy toolkit in class and workshop scenarios"* (G4P6), *"it's well-designed and the layout is clean. The color and ID make it easy for me to retrieve the one I'm looking for"* (G5P8). One participant thought that it could be served as a portable template: *"I used to find editable video templates when making videos... I think your cards open more possibilities for me to explore, think, and create videos"* (G2P3).

RQ3) How it helped. Satisfaction of design space was rated very positive among the participants 1 7 (M = 6.25, SD = .97) and all of the participants noted that they would apply it to their future work. We observed that the participants referred to the explorer quite often to browse instructions and examples during the ideation process. They suggested that the design space helps increases the *"coherence"* and *"expressiveness"* of data videos: *"I really like the animation technique called 'navigate' as it makes perfect transitions and augments the coherence of the story"* (G4P7), *"it helps establish the hierarchy and structure of stories. I can use techniques such as slow down or pause to emphasize the key plots of the story"* (G8P14). However, the participants also expressed their concern about the gap between the ideation and realization of data videos. One participant noted, "*although these cards helped sketch the storyboard and saved time from ideation, transferring it into a video took far more effort than I expected*" (G2P2).

6 DISCUSSION

In this section, we discuss the design implications and research opportunities from our study and limitations in our current work.

6.1 Data Videos as an Emerging Storytelling Medium

Our design space for animated visual narratives was derived from the analysis of our corpus containing 82 data videos. When complementing the corpus by collecting data videos produced after 2015, we found a few emerging trends in the design of data videos in recent years. Specifically, the visual representations of data are getting more diverse than before; customized visualizations such as ISOTYPE charts are increasingly being used [1]. Regarding types of animation, while motion graphics remains the most adopted visual form, whiteboard, live action, and stop motion are emerging and constituting alternative options. We also observed a trend of incorporating multimedia storytelling into data videos such as photographs, animated handwriting, and interview video clips to tell data stories.

As we have seen in qualitative feedback from the workshop, the participants found that data videos can be helpful in various scenarios. For example, one participant suggested that data videos can be used as *"teaching materials for the public"* while another participant said *"using data videos in explanatory news articles is of great help"*. Two participants suggested that data videos can be a substitute for traditional data reports and serve as their new choice for business presentations; a well-designed data video can help tell an expressive story on business performance. Given that data videos act as an emerging and promising storytelling medium, more research efforts can be made towards the in-depth understanding of data videos. For example, as data videos inherit design traits from both graphic design and cinematic storytelling [47], their audio narration, camera movement, and soundtrack are interesting research directions to explore. Also, more empirical studies can be conducted to evaluate and understand user experiences such as engagement, memorability, and data perception.

6.2 Opportunities for Exploring Animated Visual Narratives

Our design space highlights the well- and under-explored areas of animated visual narratives in data videos. We found that most

efforts have been made to *emphasize* the interesting data facets, whereas less attention has been paid to *focalization*, *concretization*, and *twist*. As suggested by our workshop, one possible reason for such unbalanced usage is a lack of guidelines for applying animated narratives to visualization.

We also found that when effectively applied, animated narratives can benefit data presentation to a great extent. In several data videos in our corpus, we observed a strong focus on explaining the process of data analysis, which allows the audience to understand the data in further depth and thus form judgments. For example, when explaining wealth inequality in America [37], the designer uses *concretization* to articulate how a wealth distribution histogram is derived from raw data by letting the data points fly to their bins and merge into bars. A data video is more than a combination of low-level functions such as transition guides or visual cues [1, 24], it also relates to high-level objectives in storytelling such as clarifying data explanation, augmenting story developments, and shaping viewing experience. Thus, our future work includes investigating how to support high-level objectives such as data reasoning through animated narratives, which can help present a sequence of data facts in an expressive and effective manner.

6.3 Design Requirements for Authoring Tools

The feedback and suggestions from our workshop shed light on the development of future data video authoring tools. When asked about the supports provided by existing data video authoring tools such as DataClips [3], the participants noted that while these tools lower the barriers to crafting data videos, selecting appropriate animation techniques for storytelling is challenging. Thus, we propose that future data video authoring tools can be improved from a task-oriented perspective. For example, these tools can suggest different animation techniques based on narrative strategies such as Emphasis or Suspense.

During the workshop, we observed several behavioral patterns of designers that can also inform the design of authoring tools. First, designers frequently decide the personality or characteristics of a data video at the very beginning based on its topic or the platform it will be published. Such decisions (e.g., "I'd use a realistic film-like style") will influence the animation techniques to be applied to the video. Thus, a successful authoring tool should provide characteristics- or topic-based templates and recommend animation techniques accordingly. Second, after deciding on a certain narrative strategy, designers often experiment with different animation techniques until they feel satisfied with the resulting effect. They would also combine multiple techniques to make the animation more informative and unique. Thus, future authoring tools should recommend possible alternatives and combinatorial techniques for designers throughout their ideation process. Third, we observed that designers would strengthen narrative strategies by adding "props" to a visualization. For example, some designers *add a magnifier* to address key facts while some use *swing* to simulate comparing data on a set of scales. Thus, future work includes exploring frequently used icons of "props" and incorporating such design assets into authoring tools.

6.4 Limitations and Future Work

The design space was derived from the analysis of our corpus of 82 data video. As our corpus is not exhaustive nor representative of the field, the design space is considered as an initial step toward animated understanding visual narratives in data videos. Further study includes collecting more high-quality data videos to expand our design space by involving additional dimensions and design patterns such as color palette, layout, and storyline. Also, our current design space provides suggestions and inspirations for designing lower-level components of data videos. In our future work, we plan to investigate the trajectory of a data story which can help assemble these lower-level components into higher-level concepts. In doing so, we can flesh out narrative linearity with animation in data-driven stories. Last, the results of our workshop suggested the design space can inform data video creation. However, a more rigorous assessment of the design space can be conducted to better understand the effectiveness of different design patterns. Future work includes deploying our design space in long-term data video-making work.

7 CONCLUSION

In this work, we introduced a design space for a cinematographically-inspired approach to animation in data videos, an emerging yet popular medium for data-driven storytelling. All of the 82 data videos in our corpus can be described along the two dimensions of our design space: animation techniques and visual narrative strategies. Quantitative and qualitative feedback from our workshop showed that the design space can be used as a tool that stimulates creativity and supports ideation for designing expressive data videos. We considered that our design space helps build out a language that describes how data videos are made and what the components of them are. Also, the design space can lower the barrier to crafting data videos that appeal to a broader audience and allow them to explores new methods to communicate data. We hope that our work can inspire the development of data video authoring tools from a task-oriented perspective.

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A APPENDIX

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