Examining the affordances for multi-dimensional data videos

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***Abstract*—To make the communication of data and information convenient and effective, people today are increasingly using videos. Data videos, one of seven genres of narrative visualisation, are considered a highly impactful method of communication. When compared with other types of narrative visualisation, data videos can provide a more engaging user experience, as they combine both visual and auditory elements to tell a story from within a dataset. While the majority of existing data videos utilise 2D content, 3D videos present advantages in being able to render immersive full scenes, giving the user control of their field of view to explore the 3D video individually. Extending these advances in technologies such as virtual reality allows us to present these same narratives in an immersive sense, putting users within the data they seek to understand. In this positional paper, we define what constitutes a data video, and discuss the current state of data videos utilising different formats, beginning with a discussion of existing videos utilising 2D and 2.5D format, through to what is now possible with 3D and virtual reality. While the use of data videos to communicate information should always come down to the right tool for the right jobs, based on recent technological developments, we argue for the strong consideration of the immersive 3D videos as a method putting users within the data, including the use of virtual reality.**

Keywords—data video; narrative visualisation; 3D; Virtual Reality

I. Introduction

Data videos, defined as videos aiming to present and communicate data, present an engaging method of conveying information to users. In this positional paper, we argue for the investigation and consideration of novel 3D data videos that may be viewed on traditional displays or in a Virtual Reality (VR) environment. Our investigations began as a collaboration between the Data to Decisions Cooperative Research Centre (D2D CRC) and the Australia Federal Police (AFP), exploring how to enable AFP agents to quickly gain an understanding of criminal cases. In such cases, the AFP is required to process large amounts of complex, interrelated data to generate status reports and legal briefings. Currently, almost all the information is manually processed by agents when trying to understand a case, which costs the AFP a significant amount of both time and money to read, analyse, and organise. As such, one of the difficulties faced by the AFP is ostensibly a big data problem.

Often described using five Vs: Volume, Velocity, Variety, Veracity, and Value [1], big data can present itself as an expansive black box of data. Unfortunately, the AFP's use of big data in reports and legal briefs requires that it is explained in a short, concise manner to varying stakeholders, with differing focuses (e.g. an AFP agent versus a criminal prosecutor). This means that we require efficient methods for disseminating this data to analyse, understand and present a case. Information visualisation supports this process of understanding by transforming data into a form that leverages the human visual system to perceive the embedded information [2] and is a natural approach to understand big data. Narrative visualisation allows this understanding to be conveyed to a wider audience of stakeholders.

As one of the world's oldest vocations [3], storytelling is well positioned to support information visualisation in the law enforcement scenarios. Kosara and Mackinlay [3] stated storytelling is the next step for information visualisation. However, effectively telling a story is not an easy task, which requires skills and knowledge of finding insights (data analysis), structure this data into a narrative (make a story), and communicating this narrative to the user in an appropriate method (tell a story). As such, the aim of narrative visualisation is to help people understand data in a more compelling and empathetic way. Such an approach works since by telling stories; people can not only consume and disseminate discrete facts but also provide the cognitive glue between facts to make them memorable [4].

In 2010, Segel and Heer [5] presented seven genres of narrative visualisation (Fig. 1). Data videos, as one of these seven genres of narrative visualisation, combine visual and auditory elements to tell a data story, which can provide diverse forms of narrative structures and an engaging user experience. Thus, it is considered to be a highly impactful method of narrative visualisation [6].

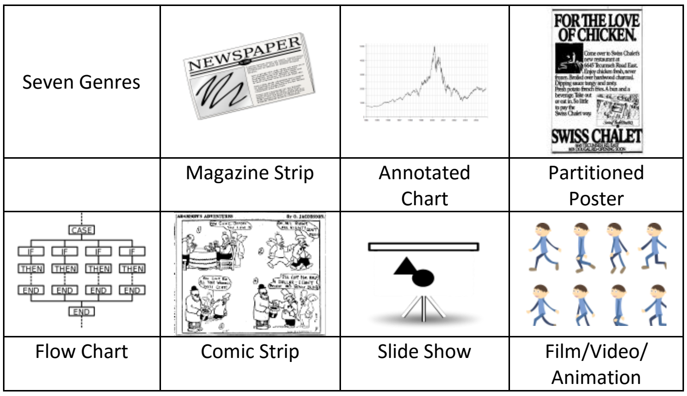


Fig. 1. Seven Genres of Narrative Visualization

The data videos being generated today are primarily two-dimensional, similar in appearance to slide presentations with animations, transitions, and voice-overs. Given the increasing availability of 3D data, authors are looking at methods to leverage 3D content within their data videos. This has inspired the development of 2.5D data videos, which incorporate fixed-perspective renders of 3D data, and 3D data videos, which incorporate 3D viewpoints 3D scenes and data. Building upon this, there are also recent attempts at using virtual reality technology to generate, show, and immerse the user within the data videos [7]. However, despite the increasing prevalence of data videos, there is little to no research regarding their authoring and consumption. Indeed, within the narrative visualisation community, there is no strongly accepted definition of a "data video". Based on the work of Amini, Riche et al. [6], we define a data video as a video meeting the following inclusion criteria:

- It contains at least one core message and presents arguments supported by data.
- It follows a narrative format.

Whilst we believe 2D data videos are clearly suited to specific types of applications, the advantages offered by 3D data videos, such as free point-of-view and added immersion, could potentially provide data video authors with a compelling medium to convey their narratives.

In this paper, after reviewing related research in information visualisation and data videos, we provide an overview of the current state of data videos containing different content of dimension (i.e. 2D, 2.5D, or 3D), discussing their features, advantages, and disadvantages. Based on that analysis, we then discuss the value of 3D content in data videos and the potential of VR for supporting data videos. Finally, we conclude the paper by discussing the opportunity data videos present to potential "data analysts as storytellers", and the need to evaluate their requirements against the available forms of data videos, while also advocating further research into using 3D and VR data videos.

II. Literature Review

Big data is an abstract concept used to describe enormous datasets. Compared to traditional datasets, big data typically includes massive amounts of unstructured data that needs real-time analysis [8]. Big data is proving to have a significant and increasing potential in creating value for businesses and consumers. For example, in 2008, Microsoft purchased Farecast, an airline ticket forecast system used for predicting the trends and airline ticket price. By 2012, the system helped to save almost 50 dollars for each ticket per passenger, and the forecasting accuracy was as high as 75%. Given the opportunities that exist for the industry, big data also brings new opportunities for research.

The ability to convey the information hidden in big data to a wide array of stakeholders is critical for big data's effectiveness. Narrative visualisation is one method of conveying this information, and we provide a brief overview of the concept of narrative visualisation. We go on to describe the research domain of data videos, the main topic of this paper.

A. Narrative Visualization

With the rise of narrative visualisation, the recent research behind the supporting theory has been increasingly studied, with Herman [9] noting that there are four basic elements of a narrative:

- Situatedness: A narrative representation should be situated in the specific discourse context.
- Event sequencing: A narrative representation should follow a specific path/order (temporal profile) to describe events.
- Worldmaking/World disruption: A narrative representation should base on a richly detailed story world.
- What it is like: A narrative representation should make people's feel/experience what it is like to undergo events in a story.

Hullman and Diakopoulos [10] studied the role of rhetoric in narrative visualisation and how it frames the presented data. Specifically, they described techniques involved in Information Access Rhetoric, Provenance Rhetoric, Mapping Rhetoric, Linguistic-based Rhetoric, and Procedural Rhetoric. Interestingly, they also introduced the concept of viewing codes: Cultural codes, Individual-level codes, Perceptual codes, Textual code, and Aesthetic codes, which are used for capturing how attributes of a receiver of a visualisation influence the interpretation of it. The structure of narrative was introduced in 2013 [11], which was considered as a further step toward understanding visual narrative. In Cohn's work, the core categories of the visual narrative are as follows:

- Establisher (E) – sets up an interaction without acting upon it;
- Initial (I) – initiate the tension of narrative arc;
- Prolongation (L) – marks a medial state of extension, often the trajectory of a path;

- Peak (P) – marks the height of narrative tension and point of maximal event structure;
- Release (R) releases the tension of the interaction.

According to the previous work, it is clear that the narrative visualisation theory can be utilised for data videos.

B. *Data Video*

Despite data videos' power of presenting data, currently we can find very little related research. Amini et al. [6] studied the constituent characteristics of data videos. After defining data videos, they studied 50 data videos and found that the most common pattern of videos is the "E+I+PR+" structure (as defined by Cohn's work on narrative visualisation). The "+" sign indicates repetition of the preceding element (one of E, I, P, and R). Fig. 2 shows the coding of an example data video.

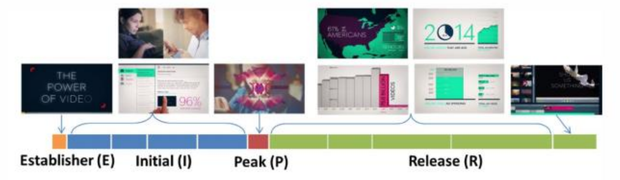


Fig. 2. Coding of an example data video [6]

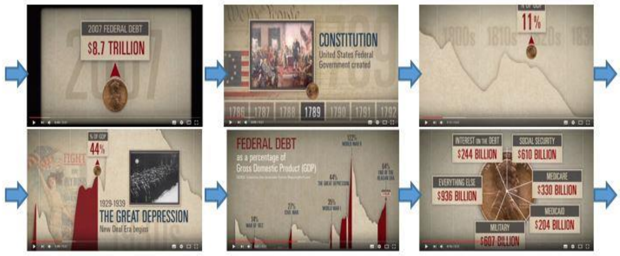
Another project, Amini, et al. [12] created a web-based tool, DataClips, which allows users to import data and generates graph automatically, a large component of what has been known as infographics.

III. Overview of Data Videos

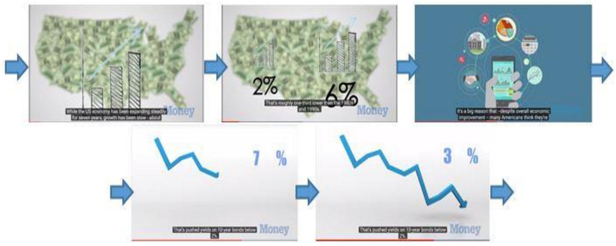
We have witnessed the progression of computer image rendering techniques from 2D to 3D, and more recently to VR. In utilising these techniques, data videos can also have many forms. In this section, we will describe and compare data videos in different forms, including 2D, 2.5D, 3D, and VR. Their definition, advantages, and disadvantages will be described. We will use "the four basic elements of a narrative" from Herman's work [9] as an important standard.

A. *2D Data Videos*

In our research, we define 2D data videos as animated data videos that present all content on a 2D plane. In this kind of data video, graphics is primarily iconographic in style, manifesting as flat graphs, images, and animations. Some examples of 2D data videos are shown in Fig. 3. Fig. 3(a) is a data video telling the history of the U.S. economy. This video uses 2D animation to combine bar charts, text, and real pictures to describe the process of American economic development. Similarly, Fig. 3(b) is a 2D data video introducing the trend of U.S. economy.



(a) The History of The American Economy, Debt And Inflation [13]



(b) What will the U.S. Economy Actually Look Like in 2017 [14]

Fig. 3. Examples of 2D data videos

Given their ease of authoring and the widespread adoption of the authoring tools, the majority of data videos available today are 2D. This trend is supported by the following motivations:

- Traditional 2D graphs and charts are easily understood visualisations for the average person.
- 2D transitions (e.g. wipes or fades) and animations (e.g. scroll in or scale in) are easy to create and comprehend.

However, 2D data videos have the following problems which can limit their effectiveness for certain scenarios:

- 2D data videos cannot make people fully feel/experience what it is like to undergo events in a story:

  2D representations of certain information are different from people's natural perception of that same information. People cannot easily link the information or animations to the real objects which they are familiar with.

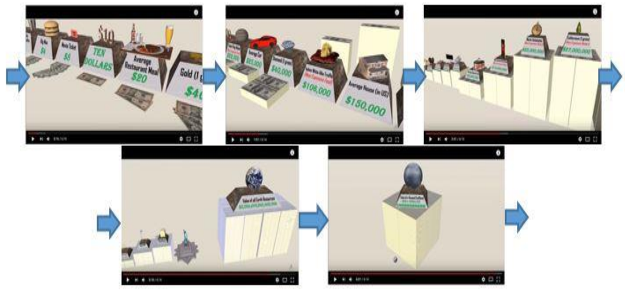
- 2D data videos cannot provide viewers with a richly detailed storyworld:

  2D data videos lack the ability to intuitively introduce certain aspects of 3D spatial information in any detail. For example, when describing a building in a crime scene, 2D technology cannot show every side of this building, not to mention showing the possible viewports from various viewpoints inside and around the building.

Therefore, we believe in some use cases, 3D techniques are needed to support data videos.

B. 2.5D Data Videos

Since 3D content can be a powerful means for presenting information, recent advances in authoring tools mean people are beginning to design and create data videos using 3D content. But many of recent attempts are just using renders of 3D models without any 3D techniques such as multiple camera angles or movement. We call these kinds of videos 2.5D data videos, examples of which are shown in Fig. 4.



(a) Price Comparison (World Most Expensive Things) [15]

(b) $17 Trillion U.S.DEBT - A Visual Perspective [16]

Fig. 4. Examples 2.5D data videos

Given the use of perspective, 2.5D data videos can allow certain elements to resemble their real-world equivalent or present a more evocative representation of an abstract concept (e.g. using 3D model of money to describe the price in Fig. 4). Compared with 2D data videos, 2.5D data videos provide viewers with a relatively richly detailed story world by the use of 3D models. Viewers can easily link the abstract data to real-world 3D objects, which they are familiar with, without doing too much association or mapping, which they usually do a lot when watching 2D data videos. However, 2D data visualisation methods are still the main means in 2.5D data videos. Normally, 3D models are simply placed in the videos and voices are added to introduce the data. 2D pictures, graphs, and text are still frequently used.

Although 2.5D data videos have some benefits compared with 2D data videos, 2.5D does not utilise the full potential of 3D content. Thus, full 3D data videos offer the next level of realism.

C. 3D Data Videos

We define 3D data videos as data videos which contain 3D computer generated content, apply 3D video techniques and can be displayed on traditional screens.

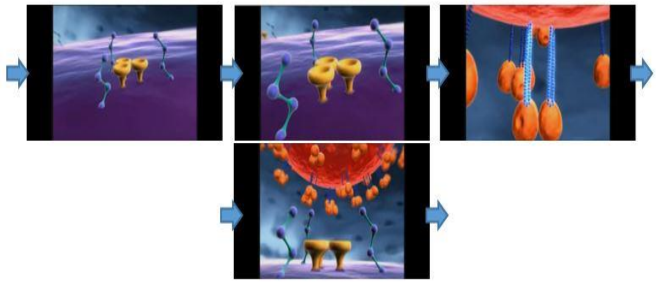


Fig. 5. HIV Replication 3D Medical Animation [17]

An example of 3D data videos is shown in Fig. 5. In this 3D data video, designers not only use voice and 3D models to introduce the process of HIV replication but also apply many 3D video-making skills and 3D animations. With the help of camera-movement, viewers can watch the process of virus replication from multiple perspectives. This introduces the potential to convey more information to viewers. For example, viewers can see the appearance of virus RNA via the first shot in “HIV Replication 3D Medical Animation”. Then, with the movement of the camera, viewers can also observe each component of this virus RNA.

Compared with 2D and 2.5D data videos, 3D data videos have the following merits:

- 3D data videos are very good at worldmaking/ world disruption:

  The higher dimension can embed and show more information.

  3D techniques can readily represent inherently 3D data. For example, in a criminal case, police might need to know the relative position between evidence. Traditionally, to describe this relation clearly, police might have to describe the scene or utilise multiple 2D photos. The results of this might be suboptimal since viewers have to imagine the real scene. 3D technology can intuitively show these spatial relations and help people to understand it.

- 3D data videos are better at supporting “what it is like” compared with 2D data videos:

  The way 3D data videos show information reflects human perception. Specifically, because of the use of 3D technology, the content of 3D data videos are like what people see in their life. This feature makes it easier for viewers to understand and memorise the data itself and the relationship between different data shown in 3D videos.

However, as with all formats, 3D data videos also have their respective problems:

- Higher dimension can be confusing, especially in simple use cases. For example, if a video just includes some graphs, introducing 3D perspective for no reason can obviously introduce perspective issues that affect reading accuracy.

- Authoring 3D videos are more difficult compared to 2D, often requiring designers to have professional skills and spend more time authoring the videos. Thus, for some cases in which data needs to be manually visualised very quickly, making 3D data videos not be ideal.
- Despite the use of 3D technology, people still lack the real feeling/experience of the story.

This is not a definitive list of limitations, and such, it demonstrates the need for more research focusing on 3D data videos is needed in we can find methods to overcome the 3D technology's deficiencies and make the best use of its merits.

D. VR Data Videos

VR as technology is currently experiencing an elevated level of interest, both inside and outside the research community given the following benefits:

- It provides users with a natural method of interaction.
- It provides immersion that can encourage a user's presence.

These features of VR can significantly enhance people's experiences. As such, we believe VR technology has potential to support immersive data videos, placing users within the data, giving them a free view to explore. In our research, VR data videos are defined as data videos which viewers can watch and experience using VR technology.

One of the current data videos applying VR technology is "The JFK Assassination in 4K 360° VR" [18] (Fig. 6).

Fig. 6. The JFK Assassination in 4K 360° VR [18]

In this VR video (Fig. 6), viewers are allowed to control their field-of-view and observe the whole environment of the scene from multiple angles, which enhance the ability to understand the position of the shooter. This requirement to understand 3D spatial relationships makes 3D videos, and immersive VR (especially in emotive contexts), very attractive. Supporting this, public comments on the assassination video were positive, commenting that they "[felt] like [they] time travelled". From this, we believe VR data videos are superior at supporting "worldmaking/ world disruption" and "what it is like" compared to 2D, 2.5D, and 3D data videos.

Despite its exciting opportunities, VR, like other technology, also has its limits. Normally, users are allowed, and even strongly encouraged, to explore the virtual world freely. But for videos, viewers should see what narrative's authors want them to see. The problem is that freely exploring the virtual environment may cause viewers to miss what the data video intended to illustrate–the user's focus cannot be guaranteed. As a result, the efficiency of data video would decrease. For example, in the video "The JFK Assassination in 4K 360° VR", people might watch some other sides of the environment and miss the assassination when it happens. As such, we consider VR data videos might not be good at supporting "event sequencing". However, the ability to re-watch the videos reduces this limitation, as does removing the user's ability to have free control of their view, at the cost of immersiveness.

IV. DISCUSSION AND CONCLUSION

Data videos, because of their diverse forms of narrative structures and engaging user experience, can be more effective than many other methods of data visualisation when used appropriately. As a result, there has been a significant number of data videos generated across a diverse range of domains and use cases. The forms are also various.

Aside for the types mentioned above, there are also other kinds of data videos which are also engaging and compelling, but do not fit our classification well. For example, a data video named "Hans Rosling's 200 Countries, 200 Years, 4 Minutes - The Joy of Stats - BBC Four [19]" is combining an animated 2D graph and a narrator from the real video to present the information. Such classification of such a video remains as future work. In this positional paper, we are only referring to typical 2D, 2.5D, 3D, and VR data videos.

With the exception of VR, each higher dimension of expression (2D, 2.5D, 3D) gains the benefits of the previous one while negating some of the problems. As shown in TABLE I. , data videos with a higher dimension of content are better at supporting the basic elements of narrative.

TABLE I. COMPARISION OF DATA VIDEOS (2D, 2.5D, AND 3D)

Supporting levels for narrative's four basic elements	**Data videos in different dimension**		
	2D data videos	***2.5D data videos***	***3D data videos***
Situatedness	High	High	High
Event sequencing	High	High	High
Worldmaking/word disruption	Low	Middle	High
What it is like	Very Low	Low	Middle

Although 3D technology has many problems when being applied to data videos (compared with 2D and 2.5D data videos), 3D data videos offer unique advantages, such as a higher dimension and natural way of presenting information. These merits are self-evident in some specific use cases, such as showing inherently 3D data. Thus, we believe 3D data videos are more powerful for presenting certain information. However, there is very little research applying 3D technology to enhance data videos (and indeed, data videos in general). What kinds of use cases would suitable for creating 3D data videos? How can we create an effective 3D data video? How can we make the best use of the merits of 3D content? All those questions need to be answered. To overcome 3D technology's problems and make the best use of its merits, we believe it is worth to conduct more and deeper research about 3D data videos.

Furthermore, VR as an emerging technology is attractive. We believe VR technology has the potential for presenting data videos immersive, and it will give people a unique perspective of the data not offered through other medium experiences, for example, the use of spatial relationship conveyed in the JFK video. By using VR technology, viewers would be allowed to explore the "world" of video, and experience what is happening in the video. However, there is currently little-to-no knowledge about how we can create and display a data video or even a regular video in a VR environment. In supporting Ribarsky and Bolter [20], we still cannot say whether VR is better than other visualisation and analysis approaches, and if so, by how much. The opportunity to study VR data videos presents a great research opportunity.

In conclusion, we believe 3D and VR technology can be powerful for supporting data videos. Therefore, research about applying 3D and VR technology into data videos should be actively investigated.

V. Acknowledgement

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