Animation and data visualization: an analysis protocol proposal

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Data visualization, animation, interactivity, animated transitions

Animation can have a range of purposes when applied to data visualization. It can be used to enhance a chart's readability, make it more appealing, or aid the narrative storytelling. The objective of this paper is to understand the different ways researchers have found to describe the use of animation as a tool for data visualization, and how these approaches interact with one another. Thus, an analysis protocol was established — based on definitions by Munzner, Heer & Robertson, Schwabish, and other researchers in the field — and it was applied to real examples in order to test its ability to identify and categorize types of animation and their uses. It is expected that this analysis protocol could be used as a resource for data visualization professionals and enthusiasts, students, and other interested parties who could benefit from a deeper examination of the theme.

1 Introduction

Data visualization is "the use of computer-supported, interactive, visual representations of data to amplify cognition" (Card et al., 1999). The choice to visualize data in any form is usually guided by particular objectives, the most common of which is to gain insight. The aims of this insight are discovery, decision-making, and explanation (Card et al., 1999), and any tools or elements added to data visualization should contribute to this.

Animation, which originally was only seen in the film industry and animated cartoons, is the technique of creating the illusion of movement in still images or characters. In web-based interactive data visualizations, which are this paper's objects of analysis, the use of animation is not related to video output. The use of animation is influenced by different intentions, among which are enhancing a graph's readability (by drawing attention to the shifting of information along certain criteria), making storytelling more efficient, making a visualization more attractive and engaging to the public, or simply expressing the feedback of a user's input (e.g., when showing selections or filtering data). Animation is an attractive but complex resource, and its use in graphics should be preceded by the understanding of its objectives and possibilities.

The first section of this paper defines and describes how animation can be used as a resource to improve data visualization, as well as some concerns one must keep in mind when developing animated visualizations. The second section is the prescriptive part, in which we discuss practical recommendations for applying animation to data visualization. In section three, an analysis protocol is presented, discussed, and applied to published animated visualizations. This resulted in a resource aimed at future works on the topic, to be used as an online archive of animated visualizations.

2 Animation and how it relates to data visualization

This section covers how animation can be used in the context of data visualization and its basic components. We based our discussion on previous research done by Heer & Robertson, Munzner, and Schwabish.

Animation has properties that can enhance comprehension, aid interaction, and bring more appeal to data visualization. In particular, movement differentiates itself from other visual features due to it being easily perceived through peripheral vision and highly effective at drawing attention. Animation conveys object constancy and, therefore, it is a natural way of depicting transformation, whether in size, shape, color, position, or other features. Animated graphs can also make causality and intentionality relations easier to perceive, which helps to establish narratives. Lastly, animation can make it easier for an audience to be emotionally engaged with or interested in something (Heer & Robertson, 2007). For the negatives associated with these properties, the researchers add the following:

> Animation's ability to grab attention can be a powerful force for distraction. Object constancy can be abused if an object is transformed into a completely unrelated object, establishing a false relation. Similarly, incorrect interpretations of causality may mislead more than inform. Engagement may facilitate interest, but can be used to make misleading information more attractive or may be frivolous—a form of temporal "chart junk"[1] (Heer & Robertson, 2007).

1 "Chart junk" is defined as elements in a graph that do not codify data and can be eliminated without loss of meaning (Tufte, 1983).

These are some of the concerns that have led a number of researchers and practitioners to favor static graphs over animated ones. Still, even with known risks and the additional labor required for its production, animation remains a valuable and versatile resource. Animation should explore the possibilities of its use according to the objectives of the visualization, its public, and place of publication.

Animation offers potential for engagement beyond what static formats can achieve. According to Schwabish (2019a), some of its uses are related to helping the public to perceive data transitions from one state to the next, and tracking the movement of data between states. The author also argues that the use of animation (and not the content itself) helps with communicating the message to the public. Like some elements that are part of a chart but do not make its meaning clearer, some animations enhance the presentation without improving the content.

These ideas relate to the thoughts of Nigel Holmes', who believes that data visualization should capture the interest of the audience, and that "the purpose for making a chart is to clarify or make visible the facts that otherwise would lie buried in a mass of written materials" (Holmes, 1984). Along the same line of thought, animations can support data and their narrative, creating empathy and providing meaning that would not otherwise be there.

Animation can also help in making data visualization easier to understand. Kirmer (2019) argues that a static graph with four or more dimensions can be difficult to understand. In this case, animation can represent one of the variables. Usually, it represents time, though not exclusively. Thus, we can say that animation is a powerful resource for graphs with a high density of information and many dimensions that can be presented separately. In this situation, the use of transitions must be carefully observed — sudden changes can lead to the audience losing track and having to reexamine the graph. Even considering its limitations, "animation is extremely powerful when used for transitions between two dataset configurations because it helps the user maintain context" (Munzner, 2014).

In explaining how audiences react to different types of movement, Kirmer (2019) affirms that fast movement in visualization elements may lead to the assumption that there is a meaning in the movement and that the speed is linked to the trend observed. Similarly, if a point transforms into the subsequent one, the audience will understand that there is a link between them, so it is important to avoid using this transition if such a relationship does not exist.

Challenges and problems may arise when opting for animation rather than static visualization, but Schwabish (2019a) argues that they give us the opportunity to create more engaging and detailed content. In the next sections, the basic elements and common uses for animation in data visualization will be presented.

2.1 Data types and levels of analysis

Before starting on the theme of animation in data visualization, we will examine some fundamental knowledge about data visualization that will help with understanding the next section.

Data attributes are usually divided into the following three types: categorical, ordinal, and quantitative (Munzner, 2014).

Categorical variables (also called nominal or qualitative data) do not have implicit ordering. Categorical data can be grouped according to the variables presented (e.g., sex/gender, city, etc.).

Quantitative variables are those that can be measured on a numerical scale. They are ordered and support arithmetic comparison and calculation.

Ordinal variables are also ordered and can be divided into ranges (small, medium, or large) or rankings. However, they cannot support mathematical operations.

Like two different axes, an attribute's type crosscuts its semantics and syntax — one does not rule the other.

Kosslyn (1989) analysed data visualization through its syntax, semantics, and pragmatics. In linguistics, syntax relates to how grammar elements are organized to form structures, while semantics is the study of meaning and interpretation. It is ultimately a matter of determining which elements refer to information external to the text, and which elements organize the information contained within it, following structures. The third level of analysis is pragmatics, which expresses meaning above and beyond the literal semantic interpretation (e.g., intention). In this text, we focus only on the first two concepts, which may be useful to data visualization researchers. We do not consider pragmatics to be applicable to data visualization.

Syntax involves the visual marks of a graph, their composition, and how they relate to one another. Syntactic elements include framing markers (substrates) like axes and grids, identifying marks such as labels, and data-representative marks like points and lines (Heer & Robertson, 2007). Syntactic analysis involves the recognition of visual properties, such as position, shape, and color, which visually translate the semantics.

Semantics focuses on the meaning of the graph and its underlying data. Semantic analysis associates the graph's syntax with what it represents. This includes dimensions, the ordering and filtering conditions, and the visual markers representing them (Heer & Robertson, 2007).

2.2 Types of animation in data visualization

In this subsection we will discuss the three main uses of animation in data visualization. According to Munzner (2014), they are: narrative storytelling, transitions from one state to another, and playback of a multiframe sequence. They are not mutually exclusive categories.

Animation as **narrative storytelling** is, as the name suggests, a way to support the story being told by the data. In this case, the integration between text and chart in the visualization is essential for understanding the narrative. Currently, one of the most frequent uses of this type of animation is the scrollytelling of data narratives. Scrollytelling, which is a combination of the word "storytelling" and "scrolling", refers to a digital story that unfolds as one scrolls. In this situation, animation can unravel cause and effect relations, as described by Heer & Robertson (2007).

Figure 1 Animation in data visualization as narrative storytelling. Source: author.

Animation as a **multiframe sequence** acts as the playback of a video or movie, which the audience is expected to watch in its entirety in order to make sense of the information. In its best manifestations, controls are given to the user to pause, advance, or replay the animation. According to John Burn-Murdoch in the PolicyViz podcast (2019), the act of sitting down and watching gives the audience the chance to naturally immerse themselves in the subject matter.

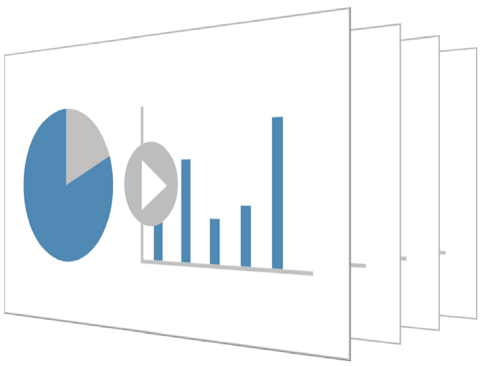

Figure 2 Animation as a multiframe sequence. Source: author.

Transitions between states are the simplest and most popular uses of animation in data visualization. They serve primarily to make changes between states smooth and comprehendible, so the audience can track what happens without additional effort. This use also has the benefit of demonstrating a constancy of data in different states for the same graph, making use of the property described by Heer and Robertson (2007).

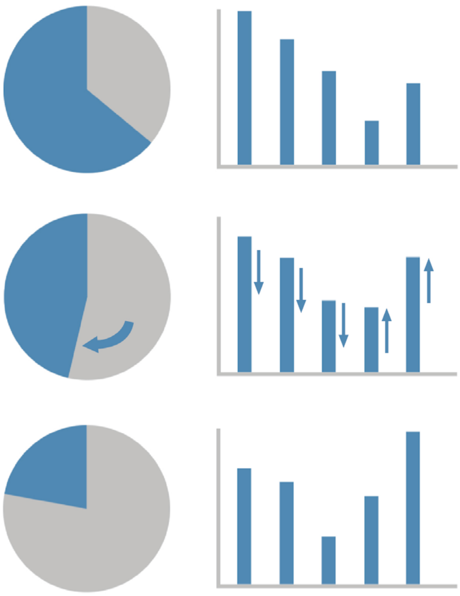

Figure 3 Animation as transition between states. Source: author.

The use of animated transitions can take a variety of forms and it can even be a resource for simpler charts. The variety of transition types will be described in the next subsection.

2.3 Types of animated transitions

There is a great variety of animated transitions between chart states or between different charts. Heer & Robertson (2007) created a taxonomy of transition types for the design of animated data visualization. Seven types of animated transitions were established:

- View transformation (Figure 4A) represents a camera movement through a virtual space. Examples include pans (lateral movement) and zooms. It is a syntactic transition, as data and their codifiers are not affected.
- Substrate transformation (Figure 4B) happens when there is a spatial change in the substrate, where data-representative marks, such as grids and axes, are anchored.
- Filtering (Figure 4C) is the addition or removal of elements from a visualization, following certain criteria and making specific visual marks visible or invisible. It does not tend to affect the visual encodings or data schemas, but may require a transformation such as an axis rescaling.

- Ordering transitions (Figure 4D) serve to rearrange visual marks that encode ordinal values.
- Timestep transitions (Figure 4E) apply time-based changes to data, in which each point in time is a state. They do not require changes to codifiers or to the data schema, but may need substrate transformations, similar to filtering.
- Visualization change (Figure 4F) occurs when the visual mappings applied to data are changed. This may happen as one type of chart (e.g., a bar chart) transitions into another (e.g., a scatter plot). It can also refer to changes in the meaning of elements such as colors, shapes, and sizes.
- Data schema changes (Figure 4G) alter the data dimensions being visualized. This can happen to facilitate comparison or change the way data or their narratives are perceived by the audience. Entire charts can be added on top of existing ones, and in various ways.

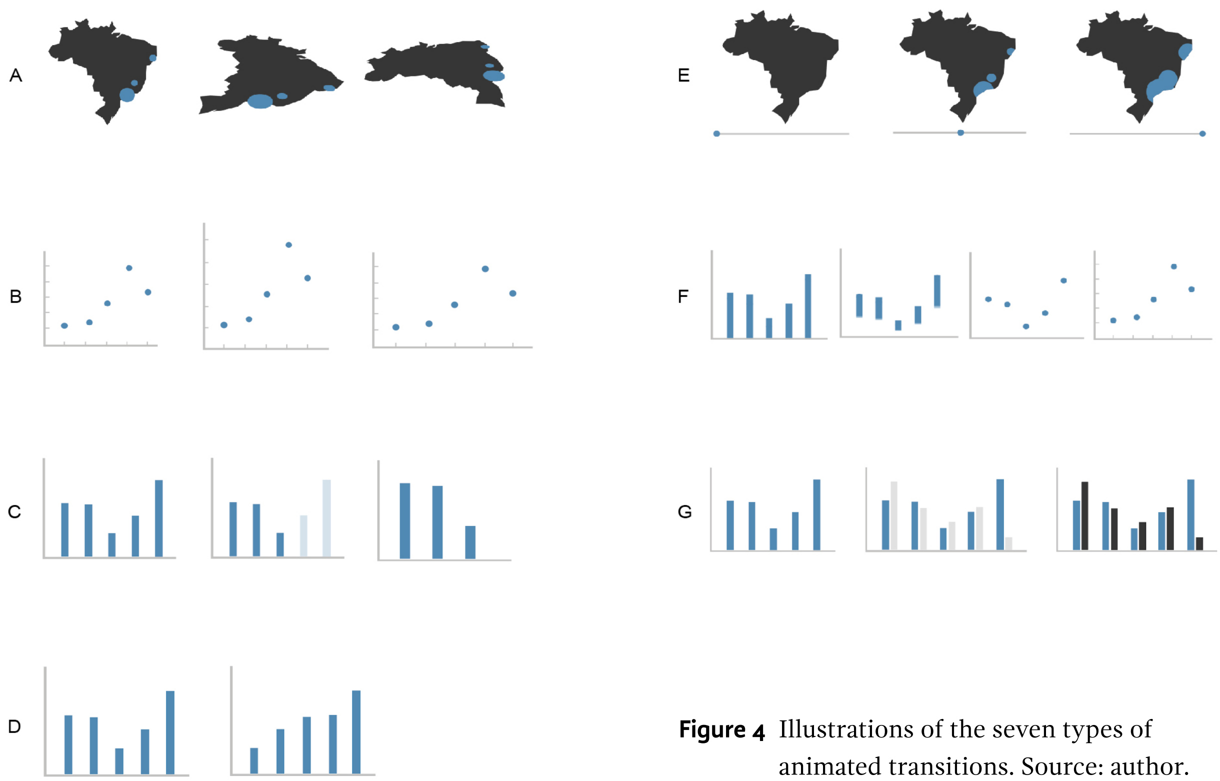

Figure 4 Illustrations of the seven types of animated transitions. Source: author.

The types of animated transitions presented in this subsection — which can help enhance the animation knowledge of information designers — will be used for later analysis. The figures shown above are printed screens of the *Guide for Animated Visualizations*,[2] which was developed during this research. This subsection ends the descriptive part of the paper — the next section focuses on recommendations for practical applications.

2 Guide for Animated Visualizations, available at http://animadatavis.animaapp.io/

3 Principles for applying animation to data visualization

After understanding the "whys" of animation use, it is time to explore the "hows". This section will present recommendations for best practices in the use of animation for data visualization, based on the research of Heer & Robertson (2007), Zongker & Salesin (2003), and Tversky et al. (2002).

3.1 The role of classic animation principles

The 12 classic principles, formulated and proposed by the Disney animators Ollie Johnston and Frank Thomas in 1981, are the primary guides for the production of character animation. However, not all of these principles are useful in data visualization, because of the different context and intentions observed in this technique and in animated cartoons and movies.

In classic animations, most of the principles are dedicated to creating the illusion of life in characters. In data visualization, transforming items from a graph into characters runs the risk of distracting the public from the data being presented (Zongker & Salesin, 2003). Thus, most of the useful animation principles in character animation are detrimental to the comprehension of the data. They might create movements that neither code information nor help make transitions clearer.

Nevertheless, some of the classic principles may be useful for data visualization. When animating data, ideally, the animation should not distract from the data: it should contribute to the absorbing and comprehending of the content. In accordance with this objective, Zongker & Salesin (2003) analysed which of those principles are applicable to animating visualizations. The three principles that were found to be useful in this context will be detailed in this paper: slow ins and slow outs, anticipation, and staging.

Slow in and slow out (Figure 5), also known as smoothing, aims to make movement more natural and easier to understand. As will be detailed in the next subsection, smoothing movements makes their trajectories more predictable and reduces the cognitive load on the audience.

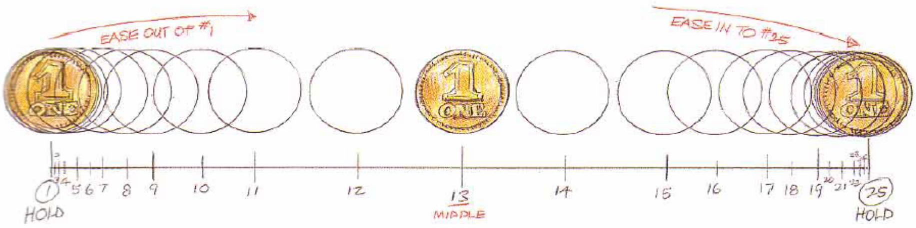

Figure 5 Example of slow in and slow out. Source: Williams (2001).

The logic of **anticipation** — preparing or directing attention to movement before it happens — can be useful for guiding the audience to relevant points in a graph. This does not necessarily need to be done with movement — examples of anticipation also include an object changing color or flashing before an important movement.

The logic of **staging** or making movement as clear as possible is aimed at reducing ambiguity and giving impact to certain animations. It can also be used to split complex movements into smaller, clearer ones (Heer & Robertson, 2007).

3.2 Adhering to Congruence and Apprehension principles

After investigating the low efficacy of animated graphics compared to static ones, psychologists Tversky, Morrison & Betrancout (2002) presented two guiding principles: the Congruence Principle and the Apprehension Principle.

The **Congruence Principle** establishes a correspondence between the real world and its representation. The authors assert that the structure and the content of an external representation should correspond to the structure and content of the internal representation. This principle is displayed, for example, in a map, in which the space represented on paper corresponds to the real space to which the map makes reference. In animation, this principle is demonstrated through the change over time that is intrinsic to its execution, which corresponds well to real change in the data over time, especially when it comes to chronological and cause-and-effect relations.

The **Apprehension Principle** establishes that the content and the structure of an external representation should be "readily and accurately perceived and comprehended" (Tversky, Morrison & Betrancout, 2002). This means that a graph should not include elements that make the visualization harder to understand or add unnecessary complexity to the reading process for little or no benefit. Animation resources are frequently seen as elements that make understanding harder, especially when they do not allow observation steps or cannot be controlled by the user. In most cases, animation can be replaced by clever use of annotations or other schematic elements.

To overcome this possible weakness indicated by Tversky, Morrison & Betrancout (2002), and to facilitate animation implementation in accordance with their principles, Heer & Robertson (2007) formulated 10 recommendations for the creation of animated data visualization. Four of them are related to the first principle, and six are related to the second. The design considerations related to the Congruence Principle are as follows:

- **Maintain valid data graphics during transitions**. This principle aims to reduce deformation during transitions by discouraging the use of non-essential movement in the

animations. Following this recommendation, one should keep the relationship between axes and data graphics consistent. The objective of this principle is to ensure that viewers' mental models are congruent with the semantics of the data and to prevent possible misinterpretations.
- **Use consistent semantic-syntactic mappings**. For better understanding, elements of a similar type should be represented in similar ways in the same chart or across different charts of a group. Using this rule helps with consistency and, therefore, learnability.
- **Respect semantic correspondence**. Abiding by this rule means keeping marks consistent before and after transitions, and that marks used for a type of data should not be reused for another type after a transition.
- **Avoid ambiguity**. Using different types of animated transition for distinct types of change is recommended for maintaining the relations between elements as clear as possible.

The design principles related to the Apprehension Principle are as follows:

- **Group similar transitions**. Objects that undergo similar changes can be better understood if they are visually part of a group. This principle takes advantage of Gestalt's principle of common fate.
- **Minimize occlusion**. Preventing an object from obscuring another during transitions, where possible, improves readability.
- **Maximize predictability**. This can be done through the use of smoothing (slow in and slow out). Making movements smoother makes the animation easier to understand and reduces cognitive load on the reader by reinforcing the start and end of the trajectory.
- **Use simple transitions**. These reduce cognitive load, reduce the user's dependence on memory, and improve predictability.
- **Use staging for complex transitions**. When an animated transition is inherently complex, dividing it into shorter, clearer steps may be a good way to facilitate its comprehension.
- **Make transitions as long as needed, but no longer**. As indicated by Schwabish (2019b), transition durations should be as long as necessary for the audience to grasp what the chart has to show, but lingering on slow animations may diminish the reading or viewing experience.

This subsection concludes the recommendations section of this paper. The principles described were the second pillar of the research.

4 Analysis protocol and its application

Following the literature review and the analysis of the principles for the use of animation in data visualization, we summarized the theoretical basis in the following table (Table 1).

The table content was used in the analysis of a number of web-based data visualizations. This process involved going through each concept and definition individually and identifying if and how it is present in each example. This process will be described in the following subsections.

Table 1 First version of the analysis protocol. Source: author.

Data types and levels of analysis	**Data types** Munzner (2014)		Quantitative
			Categorical
			Ordinal
	Levels of analysis Heer & Robertson (2007)		Syntactic
			Semantic
Types or Objectives of animation Munzner (2014)	Narrative storytelling		
	Multiframe sequence		
	Transition between states	**Types of animated transition** Heer & Robertson (2007)	View transformation
			Substrate transformation
			Filtering
			Ordering
			Timestep
			Visualization change
			Data schema change
Principles for application	**Design considerations** Heer & Robertson (2007)	**Congruence Principle** Tversky, Morrison, & Betrancourt (2002)	Maintain valid data on transitions
			Use consistent mappings
			Keep semantic correspondence
			Avoid ambiguity
		Apprehension Principle Tversky, Morrison, & Betrancourt (2002)	Group similar transitions
			Minimize occlusion
			Maximize predictability
			Use simple transitions
			Divide complex transitions
			Optimize transitions' durations
	Classic animation principles by Johnston & Thomas, 1981 Zongker & Salesin (2003)		Anticipation
			Staging
			Slow ins and slow outs

4.1 Examples of animation applied to data visualization

In this subsection, we will describe examples of animation applied to data visualization that were selected to test the analysis protocol. The objective of this analysis is to observe the effectiveness of the protocol and the presence of the concepts described in the previous sections. The examples were categorized according to the three types of animation presented in subsection 1.2 (Types of animation in data visualization), defined by Munzner (2014). The examples of each category consider the chart's predominant characteristics.

4.1.1 Animation as narrative storytelling

This first example uses animation not only as a visual aid to enhance narrative but also to enhance the data presented. Published by the fact-checking agency *Lupa* in 2020, "*No Epicentro*" (At the Epicenter)[3] showcases a simulation in which all the Brazilian Covid-19 deaths up to a certain date are distributed in a circular area around the user's location. The change is gradual, starting with the first reported death, and dots are added for each new death whenever the advance button is pressed.

The narrative unfolds as the animation illustrates what is being described in the textbox. The slow zoom out after each expansion of the circular area uses the staging principle to emphasize the severity of the numbers.

3 Available at https://piaui.folha.uol.com.br/lupa/epicentro/en/, accessed in May 2021.

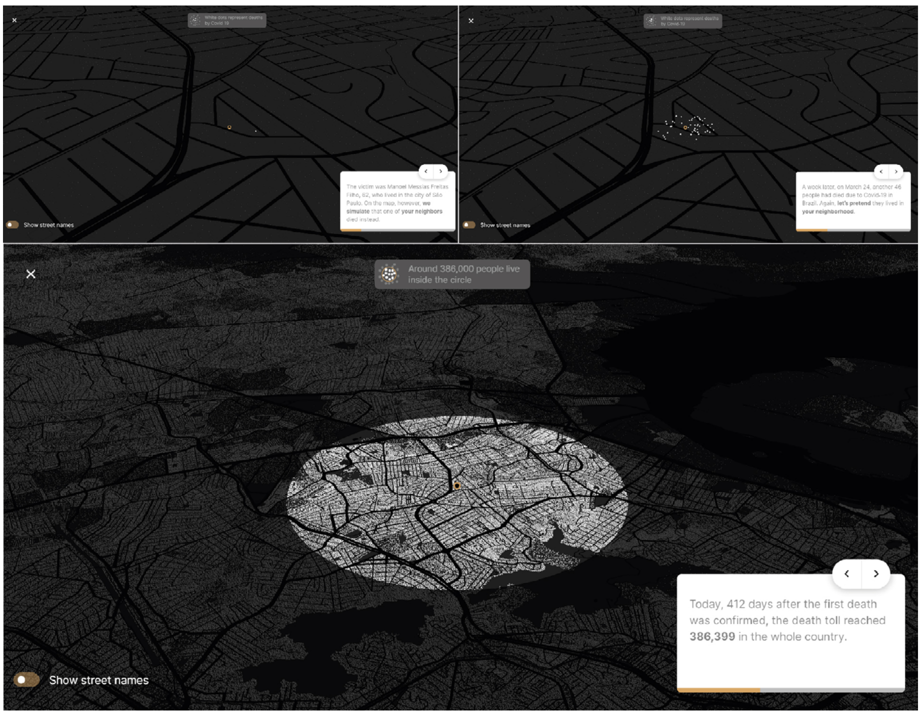

Figure 6 "At the Epicenter", in three states. Source: Lupa (2020).

The transitions smoothen the changes between areas and states of the map. The two main movements (the movement of the camera and the addition of new dots in fade in) are animated. In accordance with the types of animated transition described by Heer & Robertson (2007), we identified View Transformations and Timesteps.

Two other visualizations with a narrative focus that followed the same criteria were analysed: "Why outbreaks like coronavirus spread exponentially, and how to 'flatten the curve'",[4] published in the *Washington Post*; and "U.S. Gun Deaths",[5] created by Periscopic.

4 Available at https://washingtonpost.com/graphics/2020/world/corona-simulator/, accessed in December 2020.

5 Available at https://guns.periscopic.com/, accessed in December 2020.

4.1.2 *Animation as transition between states*

This category includes visualizations that make extensive use of animated transitions to keep the context of information through the constancy of data, make changes smoother and easier to track, and transform the spatial substrate where the data and its graphic markers are placed. The main example of this category is a data visualization from *The New York Times* called "Four Ways to Slice Obama's 2013 Budget Proposal",[6] which is presented in four different charts.

6 Available at archive.nytimes.com/www.nytimes.com/interactive/2012/02/13/us/politics/2013-budget-proposal-graphic.html, accessed in December 2020.

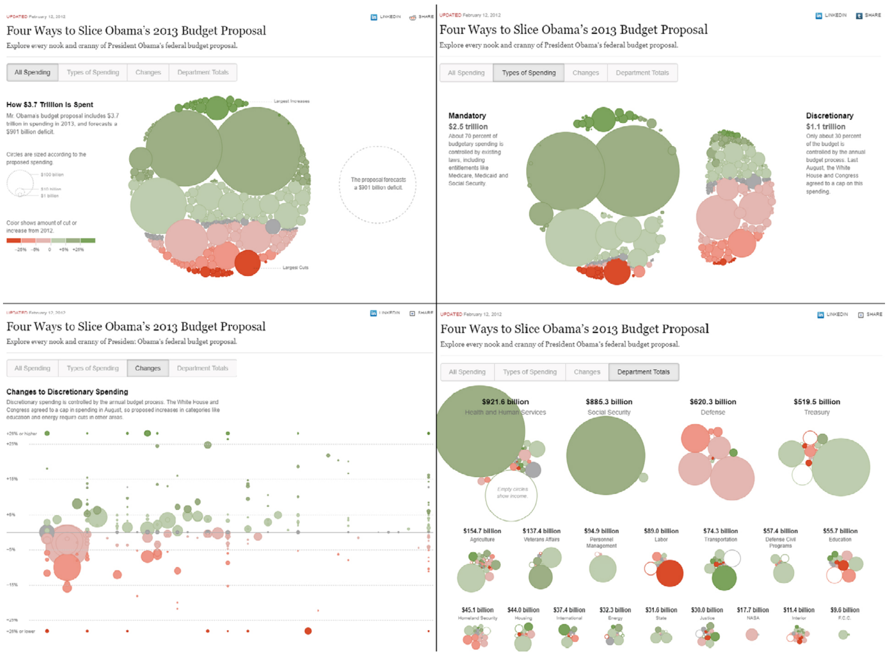

Figure 7 "Four Ways to Slice Obama's 2013 Budget Proposal", in four states. Source: The New York Times (2012).

The group of charts shows four ways to organize and visualize the budget, beginning with a spatially uncategorized view, followed by views divided by type, by degree of change, and by department. The animation used highlights the consistency of the data points and their sizes in relation to each other. The animated transition types (Heer & Robertson, 2007) used were Substrate Change, Filtering, View Transformation, and Data Schema Change. The animation seems exaggerated, which contradicts the recommendation of not deforming the data during transitions, but that potential flaw is compensated by the use of slow ins and outs, as well as staging, which makes the chart clear.

Two other visualizations in which animation is used to smooth transitions were also analysed: "Mountains out of Molehills",[7] published in Information is Beautiful; and "The most populous cities in the world from 1500 to 2018",[8] published by John Burn-Murdoch on Twitter.

7 Available at https://informationisbeautiful.net/visualizations/mountains-out-of-molehills/, accessed in December 2020.

8 Available at https://twitter.com/jburnmurdoch/status/1107552367795412992, accessed in December 2020.

4.1.3 Animation as a multiframe sequence

Visualizations in this category are built as a video to be watched. The animation usually represents time and, when properly implemented, allows the user to pause, play, and rewind to reexamine elements. The chart created by the Gapminder team, called "Gapminder Tools",[9] is a good example of this application.

Below is the updated version of the chart presented in 2006 by Hans Rosling. It shows data from many countries as an animated scatter plot. As time is represented by animation, both the axes can be used to represent other variables in a flexible and customizable way. In Figure 8, the X axis shows income and the Y axis shows life expectancy, for each country. The circle represents a country, and its

9 Available at https://www.gapminder.org/tools/#$chart-type=bubbles, accessed in December 2020.

Figure 8 Gapminder Tools, in three states. Source: Gapminder (2020).

size represents population. By default, colors show the continent in which the country is located, but that can also be customized by the user. It is possible to click on certain countries to highlight them or show their trajectories over time.

The animated transitions (Heer & Robertson, 2007) in this chart are: Timesteps, which are normally present in animations as multiframe sequences; and View Transformations, caused by zooming in or out. The number of items shown on screen makes the visualization more useful in identifying general tendencies and counter tendencies, which are highlighted by Gestalt's principle of common fate.

Two other visualizations that use multiframe sequences were analysed: "The Fall and Rise of U.S. Inequality",[10] published as a supplement to the NPR Planet Money podcast; and "A Day in the Life of Americans",[11] published by Nathan Yau in his blog, Flowing Data.

10 Available at https://www.npr.org/sections/money/2015/02/11/384988128/the-fall-and-rise-of-u-s-inequality-in-2-graphs?platform=hootsuite, accessed in December 2020.

11 Available at https://flowingdata.com/2015/12/15/a-day-in-the-life-of-americans/?platform=hootsuite, accessed in December 2020.

4.2 Analysis of results

After the analysis of the nine examples, we revised the table presented at the beginning of section 3 and expanded it to give Table 2, which lists the animation concepts observed in each example analyzed. This version of the table does not include the concepts of semantics and syntax. We made this modification because those concepts could be applied to all examples but in a specific manner, which would require further discussion. Some recommendations were not applicable for every example and type of animation, in which case we marked with "N/A".

The first section of the table covers data types. Most of the examples include quantitative variables. However, this does not mean that there is any correlation between data types and the kind of animation used. The only exception is ordinal data, which was only found in ordering animation.

The second section of the table examines types or objectives of animation (Munzner, 2019) and transitions between states (Heer & Robertson, 2007) that were applied to the examples. The main correlations found in this section were in substrate transformations and in timesteps. Substrate transformations were only found in visualizations where the animation was used to show change between states, whereas timestep transitions were predominant in animations as a multiframe sequence and as narrative storytelling.

The final section, about principles for application, shows us that the majority of the design considerations described by Heer & Robertson (2007) were being used and were applicable to most of the data visualizations. The use of simple transitions was observed in all examples. Classic animation principles (Zongker & Salesin, 2003) were observed unequally. Slow ins and slow outs were consistently used in more than half of the examples. One of the most prominent examples was "Four Ways to Slice Obama's 2013 Budget Proposal",

Table 2 Analysis protocol, expanded with examples.
Source: author.

				Example 1	Example 2	Example 3	Example 4	Example 5	Example 6	Example 7	Example 8	Example 9
Data types Munzner (2014)	Quantitative			■	■	■	■	■	■	■	■	□
	Categorical			■	■	□	□	■	□	□	■	■
	Ordinal			□	□	□	□	□	■	□	□	□
Types or Objectives of animation Munzner (2014)	Narrative storytelling			■	■	■	□	□	■	■	□	□
	Multiframe sequence			□	■	□	□	□	■	■	■	■
	Transition between states	**Types of animated transition** Heer & Robertson (2007)	View transformation	■	□	□	□	□	□	■	□	□
			Substrate transformation	□	□	□	■	■	■	□	□	□
			Filtering	□	□	■	□	■	□	□	□	□
			Ordering	□	□	□	□	□	■	□	□	□
			Timestep	■	■	□	□	□	■	■	■	■
			Visualization change	□	□	□	□	■	□	□	□	□
			Data schema change	□	□	□	■	□	□	□	□	□
Principles for application	**Design considerations** Heer & Robertson (2007)	**Congruence Principle** Tversky, Morrison, & Betrancourt (2002)	Maintain valid data on transitions	□	■	■	■	□	■	■	■	■
			Use consistent mappings	■	■	■	■	N/A	■	■	N/A	N/A
			Keep semantic correspondence	■	■	■	■	■	N/A	■	■	■
			Avoid ambiguity	■	N/A	■	□	■	■	■	■	■
		Apprehension Principle Tversky, Morrison, & Betrancourt (2002)	Group similar transitions	N/A	□	■	□	■	N/A	■	■	□
			Minimize occlusion	■	N/A	□	□	■	N/A	□	N/A	□
			Maximize predictability	■	□	■	■	■	■	□	■	■
			Use simple transitions	■	■	■	■	■	■	■	■	■
			Divide complex transitions	N/A	N/A	N/A	N/A	■	N/A	N/A	N/A	N/A
			Optimize transitions' durations	□	■	□	■	□	■	■	■	□
	Classic animation principles by Johnston & Thomas, 1981 Zongker & Salesin (2003)		Anticipation	□	□	□	□	□	■	□	□	□
			Staging	■	□	■	□	■	□	□	□	□
			Slow ins and slow outs	■	□	■	■	■	□	□	□	■

published in *The New York Times* (example 5), which uses slow ins and slow outs to help the flow and readability of the chart. The anticipation principle, on the other hand, is applicable but was only observed in one of the examples: "The most populous cities in the world from 1500 to 2018" — the bar chart race by John Burn-Murdoch (example 6). Staging was used across different types of visualization, but only in situations where timing was important for the animation.

The resulting table attests the use of concepts and categories already discussed in published examples. Some correlations between the types of animations (Munzner, 2019), types of transitions, and principles for application (Heer & Robertson, 2007) were highlighted. The type of variable did not indicate any influence in the analysis, except for ordinal values and ordering animation. The table was not intended to determine to which degree the concepts were observed in each visualization.

5 Conclusions

In this paper, we presented the development of a protocol to analyse animations as a resource for enhancing interactive web-based data visualizations. We developed a Guide for Animated Visualizations[12] (with animated examples), which is freely available online.

To determine the effectiveness of each type of animation, more studies are necessary, including the analysis of a larger number of examples. We used only nine objects of analysis, which limited the observation of the relationship between the product and the theory discussed. Tests with users would be necessary to determine the influence that each concept has on achieving better animated visualizations, which is beyond the scope of this paper. Still, as noted before, the second table was useful for validating the concepts discussed. This research can help enhance the animation knowledge and vocabulary of information designers, and its results can be used as a resource for future works on animation applied to data visualization.

12 Guide for Animated Visualizations, available at http://animadatavis.animaapp.io/

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