Animation for Time-Oriented Data: An Overview of Empirical Research

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Abstract

The usage of visualizations to aid the analysis of time-oriented data plays an important role in various fields of applications. The need to visualize such data was decisive for the development of different visualization techniques over the last years. One of the frequently applied techniques is animation in order to illustrate the movements in such a way to make changes in the data transparent. However, evaluation studies of such animated interfaces for time-oriented data with potential users are still difficult to find. In this paper, we present our observations based on a systematic literature review with the motivation to support researchers and designers to identify future directions for their research. The literature review is split in two parts: (1) research on animation from the field of psychology, and (2) evaluation studies with the focus on animation of time-oriented data.

Keywords— **Animation, Time-Oriented Data, Psychological Aspects, Evaluation**

1 Introduction

Animation is a technique that provides the illusion of movement to make changes between objects transparent in presentation tasks (see e.g., [13, 34]) and analysis tasks (e.g., [26, 27]). It has become more and more popular in the last years. The reason for this increased interest is that human vision is very sensitive to movement. Therefore it is an effective way to communicate temporal information [10]. Animation techniques are used in different fields of applications, such as simulating the real behavior of objects or for supporting users to understand complex structures (e.g., [6, 7, 16]), making changes over time for users more comprehensible (see e.g., [23, 26, 27]), and displaying transitions of one view or state to another (e.g., [2, 5, 29]).

Animation seems to be especially appropriate for time-oriented data. In the last years, a considerable amount of research concerning development of animation as an approach to visualize time-oriented data was accumulated. However, user studies with focus on the evaluation of animated interfaces with potential users are still difficult to find. In many cases, authors of evaluation studies mention that a more detailed investigation of animation will be a next step of their research. We could also observe that scenarios/case studies were often chosen to highlight the design and the usability of the animated visualization approaches (see e.g., [3, 14, 17]). A lot of research work has been done in measuring of system performance (see e.g., [19]) or on user performance (e.g., task completion time, error rates, accuracy rates).

Based on these observations we conducted a systematic literature review of evaluation studies regarding animation as an approach to make time-oriented data more comprehensible to users in information visualization systems. This paper should give researchers and designers a more systematic overview of existing studies to inform the design of approaches and future research.

This paper is structured as follows. The literature review used in this work is discussed in Section 2. In Section 3, we give an overview how the development of animation in information visualization is influenced by research from psychology. Evaluation studies concerning the usage of animation for time-oriented visualizations is presented in Section 4. In Section 5, we discuss different interesting observations based on our literature review. Finally, we give a short conclusion and an outlook on future work.

2 Literature Review

Although in the last 10 years, a considerable amount of research concerning the evaluation of animation as approach to visualize time-oriented data was published, it is often difficult to detect all or most of the relevant results and to find out what conclusions might be drawn from this research. Therefore, a literature review is used to get an overview which can support researchers to get a more systematic outlook on this research area. The literature review consists of two parts. The first part is a brief overview of empirical and theoretical research on animation from the field of psychology. We also discuss how this research has influenced the development of animation over the last few years. The second part of the literature review is concerned with animation of time-oriented data. For this part of the literature review, we concentrate on evaluation studies of information visualizations with empirical results which were published in proceedings or journal databases (e.g., IEEE Computer Society, ACM Digital Library, ScienceDirect, and SpringerLink). The presented collection of literature includes several interesting evaluation studies about visualization approaches which introduce animation as an approach to make time-oriented data more understandable.

3 Psychological Studies

Investigations about animation in information visualization are influenced by research from psychology, especially from educational psychology. There is a large amount of research in educational psychology on whether animation is beneficial for learning or not, and, if yes, under what conditions. This discussion has also been very important for information visualization. The influence of Tversky's well-known paper "Animation: Can It Facilitate?" [32] is a good example for this. In this article, we can only give a very brief overview of the most important investigations in that area, in order to show that results from other disciplines are highly relevant for research in information visualization in that context.

There is a considerable amount of research in cognitive psychology on the perception of movement and change. Specifically, the phenomenon of change blindness has been discussed in information visualization [25]. The identification of changes in scenes is very difficult because human beings usually concentrate only on restricted areas in their field of vision. There are possibilities to design animated information visualizations in a way that insights into the data are supported by the characteristics of the visualization (e.g., by drawing users' attention to specific changes). Another line of research concerns the ability of humans to track several moving targets. Pylyshyn argues in [24] that humans can track around four similar targets (e.g., dots) easily. This is, for example, relevant for animated scatter plots.

Tversky's overview article [32] on animation has already been mentioned. In this paper, she argues that, based on the educational literature available at that time, no positive effects of animation could be found. She also indicates that interactivity might be a possibility to overcome the problems with animations. When users are allowed to control the animations actively, they might be able to form more coherent mental models than when they can only watch animations passively. Lowe addressed this problem in a detailed study [18]. He found out that users did take advantage of the user control, but this was not always done effectively. He argues that additional design measurements have to be applied to make user control beneficial.

Mayer gives an overview of empirical research in [20] concerning design principles for an effective design of animations for learning. He argues, for example, that cues should be added to highlight relevant elements of the animation or that animations should be presented in learner-paced segments rather than as continuous movie-like presentation. Animations apparently only work in some contexts and when designed properly. A study by Kehoe et al. [15] also indicates this. The result of this study is that animations are probably more advantageous in open, interactive learning situations and that they are more valuable for the presentation of procedural aspects of the topic at hand.

4 Animation of Time-Oriented Data

In this section we will present interesting findings from the literature review regarding the evaluation of animation approaches with time-oriented data in information visualization. There are more papers on information visualization systems representing time-oriented data, but evaluations of such approaches occasionally do not address animation specifically, but rather investigate more general questions. We only found very few evaluations which had the goal to investigate animation with time-oriented data. The findings of the literature review showed us that animation was primarily used: (a) to improve the perception and handling of changes in data (e.g., [4, 8, 12, 28]) and (b) to support users in analyzing trends in data or data that evolves over time (e.g., [1, 26, 27, 30]). We chose 15 papers for a detailed analysis of their evaluation studies and the following interesting observations were made.

4.1 General Impressions

Although it was noted that animation was sometimes confusing and not an appropriate technique for every user [11, 33], the analysis of the results of the evaluation studies showed that the animation was often described as enjoyable, exciting and very helpful for understanding time-oriented data to see what was happening in the data [11, 23, 27, 30]. For example, McGrath and Blythe [21] found out that motion helped the participants to better grasp changes of data.

Generally, we noticed that the size of the represented data often played an important role how well an animated visualization supports users in their tasks. For example, Robertson et al. [27] pointed out that the participants were more successful with small datasets. A reason was that animation and traces tended to become cluttered with larger datasets and therefore static representations appeared to be more effective.

4.2 Aim of Evaluation

We noticed that most of the evaluation studies (60% of the papers) compared primarily their animation approach with static representations, like small multiples. The goal of the comparison studies was to find out if the usage of animation is more effective than a static representation (see e.g., [1, 11, 12, 23, 27]). McGrath and Blythe [21] conducted a user study to explore the effects of motion with different graph layouts on viewers' perception of changes in graphs. In contrast, Midtbø et al. [22] compared different animation types to identify which animation type users preferred depending on different time scales. Especially for comparison studies, the evaluation of user performance (e.g., task completion time, error rates, accuracy rates) played an important role and is often combined with user preferences. Furthermore, we found evaluation studies (27% of the papers) which only tested their visualization approach and how the user interacted with the animation (e.g., [4, 9, 26, 30]). Although the animation speed was often named as challenge, the literature review showed us that the animation speed often played no role in the evaluation studies. Often default animation speed was chosen which the user could change during the test sessions. The evaluation studies by Griffin et al. [12] and Tekušová et al. [31] are examples which also considered the speed of the animation in their evaluation.

4.3 Results of Comparison Studies

In comparison with static representation, animation seems to increase positive reactions to track changes, because the corresponding static graph was often perceived as overloaded [8, 23]. Furthermore, it was noted that animation better reflected how the data changed over a period of time [30]. Griffin et al. [12] found out that the participants of their study identified patterns more correctly and faster with the usage of animation than they did with small multiples. However, how well the participants identified patterns or groups depended on how strong the moving clusters and patterns were. The results of the comparison study concerning the different animation types by Midtbø et al. [22] pointed out that the participants had clear preferences in combination with specific time spans. For example, circular animation was preferred by most participants if the time was perceived as a repeating pattern (e.g., 24-hour period) and a linear animation was more attractive for the participants for more common linear models which had non-cyclic character. It was also mentioned that animation caused participants to get lost, especially if too many data points are moving across the screen which possibly distracts the viewers' attention [11, 23, 27]. In that case, Farrugia and Quigley [11] suggested to use animation sparingly. Selective animating parts could be helpful so that users will concentrate on a limited aspect of the visualization to support them in understanding the changes [11, 23]. In the evaluation study by Nakakoji et al. [23], a participant noticed that it would be helpful to annotate the time for a better orientation in the animation (e.g., as memory aid which time-span was interesting). Furthermore, we noticed that it also played a significant role if the participants had the possibility to control the animation or not. For example, Robertson et al. [27] pointed out that participants noted that they had to find the data very rapidly which they wanted to observe if they had no control over the animation. In comparison if the animation or small multiples are more effective for analysis tasks, Robertson et al. [27] found out that their animation approach to show trends in data was valuable especially for presenting data. For tasks of data analysis the usage of small multiples appeared more effective.

4.4 Animation Speed

The results of the evaluation studies [12, 31] showed that the speed has to be taken in account in order to how well participants identified changes in the animation. For example, they found out that the participants did not have sufficient time to realize changes if the speed of the animation was too fast. However if the speed was too slow, the visual system had problems to maintain the Gestalt grouping. Griffin et al. [12] concluded their findings that the interplay was an important role between (1) the distance that the objects moved, (2) the duration of the stimulus (e.g., length of time of the displayed frame) and (3) the interstimulus interval (e.g., frame rate).

4.5 Interactivity

In 73.3% of the evaluation studies, the participants had the possibility to interact with the animation like play, pause, control the speed and jump back or forth between keyframes. In addition to buttons for play, pause or stop, the play controller often included a slider to play the animation back or forward in order to regulate the desired speed. Although Archambault et al. [1] found out that many of their participants did not use the slider (because they felt pressed for time), it was noted that the usage was useful to answer the questions of the tasks faster. The results of the evaluation studies showed us that the participants first scanned the whole animation to get a comprehensive impression and for detailed analysis they used the play controller to go to a position of the animation or to influence the animation speed. It was observed that especially for the analysis of changes in data the participants went back and forth in the time lines to compare the frames and played the animation often extremely slowly (see e.g., [1, 4, 11, 23, 27]). This was also the reason why participants needed more time to analyze data with animation than with a static representation [8, 11, 27]. Therefore, Archambault et al. [1] noted that animation is preferable if accuracy is more important than response time. Tekušová and Kohlhammer [30] pointed out that features like a selection, filter, and search function can be useful for users to highlight specific data which they would like to observe during the animation. Furthermore, they noted that zoom or detail on demand function would support users to get more information about the observed data.

4.6 Additional Features

It was often recommended that the animation should be combined with additional indicators (e.g., traces, color or sound) to lead users' attention to the animation or to follow the changes in data over time more easily (see e.g., [4, 8, 21, 22, 26, 28, 30, 33]). For example, Schlienger et al. [28] found out that the combination of animation with sound would be an effective way to improve the perception of changes. Sound can be useful to lead the users' attention to a change (especially for changes outside of the user's field of view), whereas the animation would be helpful to track the changes in data. Often traces were used to support users to analyze changes in data over a period of time either during the animation or on static pictures. For example, Robertson et al. [27] found out that the participants were faster to analyze trends with traces than with animations which showed no path information. However, it was mentioned that the usage of traces was often described as confusing for the participants, especially if too many datasets were shown (see e.g., [26, 27, 30]).

5 Discussion

In the previous sections we present different observations from evaluation studies with the focus on the usage of animation for making time-oriented data more understandable. Based on this research we would like to outline several important areas where tentative conclusions can be drawn.

- **General Impressions:** It is still not easy to answer the question whether animation is advantageous for the visual representation of time-dependent data. Some of the researchers in educational research are still skeptical (see e.g., [32, 18]). Research results in education are still contradictory. Evaluation in information visualization yields more positive results (e.g., see [11, 21, 23, 27, 30]). Users usually enjoy animation and find it exciting. Under some conditions, animation can help users to understand patterns in the data better than from static displays (see e.g., [12]), especially when users are supposed to track changes. Static graphs were frequently described as overloaded. However, animation sometimes confuses the users when too many data points move across the screen (e.g., see [11, 23, 27]) and when the dataset becomes too large to see patterns at a glance.

- **Interactivity:** In her paper [32], Tversky argued that interactivity might be beneficial for understanding animations. Lowe made in [18] an extensive test of this assumption . He argues that interactivity exerts a positive influence on the subjects' performance, but this also depends on the design of the system and other context variables. In information visualization, interactivity helps users to get more accurate results (see e.g., [1]), especially when they are enabled to control the speed of the animation with sliders. For the analysis of changes in the data, animation seems to be very helpful (see e.g., [1, 4, 11, 23, 27])

- **Speed:** Speed of presentation is a difficult issue. For example, Lowe [18] describes that the subjects in his study preferred a slow, stepwise presentation to a movie-like, continuous presentation. This agrees with research from information visualization which also indicates that slower speeds are preferred to form consistent mental models. It seems to be beneficial when users can influence the animation speed of the presentation (see e.g., [1, 4, 23, 27]).

- **Context and Design:** As stated above, the advantages of animation depend on the design of the system and the context of use. Mayer [20] formulated principles for the design of animations. Tekušová and Kohlhammer [30] point out that additional features like selection and filter might help users to understand animations. Additional indicators (e.g., traces, color or sound) can be used to attract the users' attention and help them focus on important elements on the screen (see e.g., [4, 8, 21, 22, 26, 28, 30, 33]).

Conclusions

An overview of empirical research on animation indicates that animation might be beneficial for the presentation of time-oriented data, especially when the users are supposed to analyze changes in the data. It should be mentioned, however, that information visualization systems should be designed appropriately and that there are contexts in which animation might be confusing.

Future research should clarify in more detail when animation is useful for time-oriented data and when it is harmful. A more comprehensive overview should also include studies from other sources (as e.g., HCI journals and conference proceedings). Such research results could be very valuable to inform the design of efficient and advantageous animations for information visualization systems that have to deal with time-oriented data.

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