A taxonomy of motion applications in data visualization

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ABSTRACT

We propose a new taxonomy that explains the roles of motion in data visualization, focusing especially on their communicative aspects. Our taxonomy clarifies the main axis in how visualization designers can employ motion in data portrayal.

CCS CONCEPTS

• **Human-centered computing → Visualization theory, concepts and paradigms**;

KEYWORDS

Visualization; information visualization; visualization theory

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1 INTRODUCTION

Motion is, with color, orientation, size, and stereoscopic depth, one of the feature types that attracts human visual attention, especially when it happens in the peripheral vision [Ware 2012]. This characteristic makes motion a good technique to alert to changes on the screen [Bartram 1997], and for selectively directing viewers' attention [WOODS 1995]. Studies in data visualization have led to claims that motion can distract and carry only a limited amount of information [Hong et al. 2004; Zhang 2000]; while other research infers that its implementation can lead to shorter cognitive workload and faster completion of comparative tasks [Hsueh et al. 2016]. Several studies have focused on how motion can be meaningful and useful for sending notifications and helping in visual searches [Bartram and Ware 2002], for detecting and identifying patterns [Ware and Bobrow 2006], groups [Nakayama and Silverman 1986], subsets through brushing and linking functions [Bartram and Ware 2002], links and nodes in network diagrams [Ware and Bobrow 2004], and for contributing to the transmission of emotions or aesthetic impressions [Bartram and Nakatani 2010].

Some of these studies address the implementation of motion in visual systems in general, while the others employ one technique in one type of data visualization. These two contexts can be either very broad or too specific to lay out a taxonomy that addresses motion in data visualization. Here, we propose a taxonomy that bridges these two contexts, explaining the roles of motion in data visualization, and how it can be used to represent the data itself. The taxonomy of Bartram [Bartram 2001] is the most comprehensive in this topic, classifying motion in information interfaces in eight categories: awareness, transition, functional description, emphasis, expression, representation of change, direct visualization, and association. Our taxonomy reorganizes these categories into three: data as motion, motion as a storytelling device, and motion as a captivator. Additionally, we expand Bartram's taxonomy including a category for motion as an interpolation of data values.

2 FOUR IMPLEMENTATIONS OF MOTION

2.1 Data as motion

When data attributes are mapped to visual variables that do not allow a quantitative decoding of information, such as color, texture, or orientation [Bertin 1983], viewers interpret the visualization by making comparisons between the visual forms. The same happens when data attributes are mapped into motion. In order for the viewers to understand what motion means, they must compare the behavior of the forms. Motion can carry information in three dimensions: flicker, direction, and velocity [Huber and Healey 2005]. However, the perception of motion can be richer since we see displacements when the relationship between a form and its surroundings changes [Wallach 1965]. The animation of forms in a visualization can illustrate the quantitative values of the data itself, and it can be done in a direct or indirect way.

2.1.1 Direct Data Encoding. The encoding is direct when the data has intrinsic movement or transformations. The data should be position and time-based, and if an attribute of a data entity varies in time, its visual attributes should vary at a consistent relative rate in the visualization space. For example, a dot that takes several geographic positions in a dataset is represented as a moving dot in the visualization projection, and a quantity that varies in time in the data translates into a form that grows and shrinks. Typical datasets that usually undergo this type of direct encoding are geographical flows of populations, geographical weather conditions, or transportation networks. Like Bartram's representation of change [Bartram 2001], this subcategory shows how behaviors in a system evolve over time in space.

2.1.2 Indirect Data Encoding. Data attributes that are not time-position based can also be mapped as motion. Through an indirect data encoding, a data attribute that is not position can be mapped to the rate of change of a visual variable or to the speed in which it moves in the visualization canvas. For example, in a series of politicians with varying corruption scores, the politicians can be

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represented as dots with a vibration motion that increases on par with their score, so that the more corrupt the politician, the more nervously they vibrate. The position of the dot is not data-related, but its instant velocity is proportional to a data attribute. Bartram identified this type of motion as a direct visualization [Bartram 2001] of unrepresented system variables. We consider this implementation to be indirect as those attributes do not have movement intrinsically in them. Therefore, data cannot be directly mapped to motion. It has to suffer a domain translation from a static data attribute to an animated visual variable in the visualization canvas. In this context, motion can be used as a metaphorical device, suggesting figurative cues that relate with the data's theme.

2.2 Motion as an interpolation of data values

Although data is discrete in its nature, the way of portraying it can be discrete or continuous. The difference between both depends on the rate of display of data attribute. If the rate of display is high, the changes in the data attributes may be perceived as continuous i.e., through data as motion. However, if the rate of display is low, intrinsically, data will appear as discrete. In this case, if data attributes are to appear as changing continuously, there may be the need of constructing interpolations between data states. The animation of a visual element that portrays the transition of one value of a data attribute to another, is constructed through an interpolation algorithm that conveys a higher data resolution in the data, as if these data states were continuously connected. This strategy is usually employed to illustrate trends in changes in the data [Robertson et al. 2008]. Motion as an interpolation of data values is usually seen in chronologies or time-series where historical moments are presented, and where motion is used to interpolate between them. This type of motion is what Heer and Robertson call a timestep, a transition that applies temporal changes to data values [Heer and Robertson 2007].

2.3 Motion as a storytelling device

Bartram differentiated several purposes in her taxonomy: awareness, transition, functional description, and emphasis [Bartram 2001]. We consider all of them part of a broader category that has the same aim: guiding viewers through the visualization. Transitions not only provide smooth shifts between views [Bartram 2001], but they also make users aware of all the changes that happen in the visual display. These transitions provide object constancy when there are changes in their color, shape, position, size, etc., and communicate cause-and-effect relationships [Heer and Robertson 2007]. This type of motion is close to film editing conventions and to the uses of time and transitions that are employed in cinematography. Some of them are used not only to transition between scenes but also to emphasize specific parts of the story and direct viewers' attention to it [Bartram 2001].

2.4 Motion as a captivator

While the other three categories were closely related to data and the data narrative, it is also important to consider the aesthetic and expressiveness aspects of motion in visualization [Bartram 2001]. Research claims that expressive icons and avatars enhance users' sense of engagement [Ware 1996]. As a visual component, motion can provide an aesthetic seduction to viewers but it can also undermine the final visualization. This type of motion can deliver interaction and content information to users, but it should be used in a way that enforces the visualization's message. Motion as a captivator should be used with care because it may confuse users and obscure information when over-explored.

3 CONCLUSIONS

Our taxonomy addresses how motion can have four communication roles in data visualization: portraying data, interpolating between data attributes, guiding viewers through the visualization, and attracting users' attention. These four categories bridge between general research about the use of animation in information systems and the studies about specific uses of motion in visualization in order to make these strategies clearer and more accessible for visualization designers to make conscious choices.

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