Information Sciences 330 (2016) 495–509

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Can animation support the visualisation of dynamic graphs?

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ARTICLE INFO

Article history:
Received 1 November 2014
Revised 2 March 2015
Accepted 9 April 2015
Available online 17 April 2015

Keywords:
Graph drawing
Dynamic graphs
Mental map
Drawing stability
Animation
Small multiples

ABSTRACT

Animation and small multiples are methods for visualising dynamically evolving graphs. Animations present an interactive movie of the data where positions of nodes are smoothly interpolated as the graph evolves. Nodes fade in/out as they are added/removed from the data set. Small multiples presents the data like a comic book with the graph at various states in separate windows. The user scans these windows to see how the data evolves. In a recent experiment, drawing stability (known more widely as *the "mental map"*) was shown to help users follow specific nodes or long paths in dynamically evolving data. However, no significant difference between animation and small multiples presentations was found. In this paper, we look at data where the nodes in the graph have low drawing stability and analyse it with new error metrics: measuring how close the given answer is from the correct answer on a continuous scale. We find evidence that when the stability of the drawing is low and important nodes in the task cannot be highlighted throughout the time series, animation can improve task performance when compared to the use of small multiples.

1. Introduction

Dynamic graph drawing deals with the depiction of graphs that evolve over time in terms of their structure. Nodes and edges can be added and removed. Dynamic graphs are usually represented using a series of **timeslices** or **time steps** whereby snapshots of the graph are taken over given time intervals. For graphs with this representation, dynamic graph drawing algorithms assign coordinates to the nodes in the timeslices in order to depict the structural evolution of the graph over time. Dynamic graphs exist in many application areas including: software engineering [17], computer networks [12], distributed systems [47], sociology and social networks [57,14], systems biology [9], financial networks [58] and many others. Understanding the perceptual factors related to visualising dynamic graphs is important for these fields.

An important factor to consider when visualising a dynamic graph is how the information is presented. Animation and small multiples are the two most common, basic methods for the visualisation of dynamic graphs. An **animation** of the dynamic graph presents the data like an interactive movie whereby the user has complete control of the animation through the use of a slider and a play/pause button. Smooth linear interpolations transition node positions between timeslices and nodes and edges are faded in/faded out if they are inserted/removed from the data. A **small multiples** presentation of the graph depicts each timeslice of the data in its own window [55]. The windows are arranged in chronological order like a

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http://dx.doi.org/10.1016/j.ins.2015.04.017

comic book to depict the evolving data. This presentation method has been shown to be more effective than an animation for dynamic graphs on a variety of tasks [6,25]. More specifically, small multiples is faster with no statistically significant difference in terms of error rate when linked highlighting between timeslices is used.

Animations have the advantage that the full screen can be devoted to a single timeslice at a given time. However, interaction is required and the user must rely on memory to understand how the graph evolves. Small multiples has the advantage that all timeslices are visible on the screen simultaneously and the user does not need to rely on memory. However, the number of pixels devoted to each timeslice is much less and could potentially make the graph more difficult to read.

In dynamic graph drawing, there is always a compromise between the drawing quality of the graph in each timeslice and the stability of the node positions in the drawing as the graph evolves through time. Preserving the mental map [23,41], or *drawing stability*, is a property of the dynamic graph that does not allow nodes to move too far in the plane between consecutive timeslices when a change is made to the graph. Thus, stable parts of the graph structure remain in similar positions in the plane during graph evolution. Recent experiments have shown that drawing stability can help with tasks that involve determining the insertion order of specific nodes [29], revisitation to specific nodes in a graph at later times [3], and following long paths through the data [3].

For tasks where drawing stability is important and the positions of nodes remain relatively stable throughout graph evolution, animation can provide little benefit as the identity of each node is disambiguated through its position. However, if the nodes of the drawing move substantially as the graph evolves, animated transitions might provide a larger benefit when compared to small multiples. Situations where the structure of the graph changes substantially due to node insertions/deletions can be the cause of such movement. In many areas of the graph visualisation and information visualisation literature [10,46,8], animated transitions have been shown to be helpful when there are significant changes to the data and/or how it is arranged on the screen.

Tversky et al. [56], strong critics of the usefulness of animation for many tasks in several disciplines, admit that animated transitions can be useful for very specific purposes. Specifically:

- *"At this point then, the most promising uses of animation seem to be to convey real-time changes and reorientations in time and space."* [56].

In terms of dynamic graph drawing, animated transitions have been found to be useful when compared to no transitions (like flipping through the slides of a Powerpoint presentation) [10,8]. Animated transitions have also been explored in the context of encoding changes with colour [5,46,8]. However, when comparing animation to small multiples directly on tasks where drawing stability has been shown to help, the question as to whether or not animated transitions provide a benefit when drawing stability is low remains unanswered.

We have previously shown that drawing stability has a positive effect on complex task performance, for both animation and small multiples [3]. In this paper, we investigate a question arising from this result:

- *For diagrams which have low drawing stability, can animation provide better support for complex task performance than small multiples?*

In addressing this question, we analyse the data for dynamic graphs with low drawing stability–graphs with a high degree of node movement between timeslices. We consider task performance not only in terms of response time and error rate, but we also measure the distance between the answer entered by the participant and the correct solution. We therefore apply the following error metrics: euclidean distance, graph theoretic distance, piecewise angle error, and geodesic error. These error measures allow for a continuous measure of error severity rather than discrete correctness values. We find that animation, when compared to small multiples, on low stability drawings can reduce error rates as measured by these metrics.

2. Definitions

In this section, we define what is meant by animation, small multiples, and the mental map. Most of these definitions are consistent across a wide range of experiments that test these factors for a variety of tasks [4].

In this paper, unless otherwise specified, **animation** means *interactive animation*. Empirical evaluations have been run where the animations were not interactive, and participants were shown the animation a set number of times [31]. For the experimental data that is analysed in this paper, participants could interactively view the evolving graph series over time using a slider to see how it changed. **Small multiples** [55] presents each timeslice in its own window, and the participant reads the timeslices left to right and top to bottom to see the evolution of the dynamic graph. As small multiples showed the entire graph series at once, no interaction was necessary for this presentation method.

For the remainder of this paper, **preserving the mental map** [23,41] is referred to using the term **drawing stability**. Preserving the mental map is a common term used throughout the dynamic graph drawing literature. As the *mental map* or *cognitive map* in psychology corresponds to the *internal representation* of the data inside the human mind, we advocate the use of the term *drawing stability* for this concept to avoid confusion between our disciplines. Drawing stability excludes the perception of the dynamic graph by the human and refers solely to the positions of the nodes on the external representation of the dynamic graph (usually the computer screen).